Parana Journal of Science and Education (PJSE) – v.4, n.4, (7-29) June 17, 2018
ISSN: 2447-6153 *https://sites.google.com/site/pjsciencea*

Indian Sundarban Mangroves: A potential Carbon Scrubbing System

Abhijit Mitra[1◊], Sufia Zaman[2#] and Ricardo Gobato[3☼]

[1]Department of Marine Science, University of Calcutta, 35 B. C Road, Kolkata, 700019, West Bengal, India.

[2]Department of Oceanography, Techno India University, Salt Lake Campus, Sector V, Kolkata 700091, West Bengal, India.

[3]Laboratory of Biophysics and Molecular Modeling Genesis, State Secretariat for Education of Paraná, CEJC, St. Rocha Pombo, 953, Center, Bela Vista do Paraíso, Paraná, 86130-000, Brazil.

Abstract

The stored carbon in dominant mangrove species namely *Avicennia alba*, *A. marina*, *A. officinalis*, *Sonneratia apetala* and *Excoecaria agallocha* were monitored during December 2009 to March 2010 through seasons in ten selected stations (5 in the western and 5 in the central sectors) of Indian Sundarbans. The species-wise carbon stored in the Above Ground Biomass (in t/ha) followed almost a similar order in both the sectors throughout the study period. The soil and litter carbon were also simultaneously analysed. The annual litter fall in the western and central sectors has been extrapolated to 8.05 t ha^{-1} yr^{-1} and 5.22 t ha^{-1} yr^{-1} respectively. In the present study, the highest litter fall during September, 2009 may be related to heavy rainfall and wind action in the region that accelerates the litter fall in this unique mangrove system of the tropics. The organic carbon in the study area showed a distinct seasonal pattern with highest value in monsoon (September, 2009), followed by postmonsoon (December, 2009) and premonsoon (March, 2010). In the western sector, the mean values were 1.182%, 1.010% and 0.882% in the monsoon, postmonsoon and premonsoon respectively. In the central sector, the mean values were 0.936%, 0.820% and 0.650% in the monsoon, postmonsoon and premonsoon respectively. The surface soil pH in the study area showed a distinct seasonal pattern with highest value in premonsoon (March, 2010), followed by postmonsoon (December, 2009) and monsoon (September, 2009). In the western sector, the mean values were 7.24, 7.30 and 7.36 in the monsoon, postmonsoon and premonsoon respectively. In the central sector, the mean values were 7.32, 7.37 and 7.39 in the monsoon, postmonsoon and premonsoon respectively. The overall results confirm the potential of carbon scrubbing vegetation in Indian Sundarbans.

Keywords: Above Ground Biomass, Carbon scrubbing vegetation, Litter, Indian Sundarbans, Mangroves, Soil Organic Carbon.

◊E-mail: abhijit_mitra@hotmail.com
#E-mail: zamansufia123@gmail.com
☼E-mail: ricardogobato@seed.pr.gov.br

Parana Journal of Science and Education (PJSE) – v.4, n.4, (7-29) June 17, 2018
ISSN: 2447-6153 https://sites.google.com/site/pjsciencea

1. Introduction

The general consensus among climate researchers and environmentalists is that increased emissions of greenhouse gases (GHGs) from human activities and luxurious life styles, burning fossil fuels, and massive deforestation in many regions of the world are changing the climate of the planet Earth. CO_2 plays the major role in absorbing outgoing terrestrial radiation and contributes about half of the total green house effect. Between 1850 and 1900, around 100 gigatons (GT) of carbon was released into the air just for land-use changes (Pandey, 2002) [1]. Most of the increase has been since 1940 (Hair and Sampson, 1992) [2]. The atmospheric CO_2 concentration is currently rising by 4% per decade (Jo and McPherson, 2001) [3]. Worldwide concern about climate change has created increasing interest in trees to help reduce the level of atmospheric CO_2 (Dwyer et al., 1992) [4]. Forests are most critical components for taking carbon out of circulation for long periods of time. Of the total amount of carbon tied up in earthbound forms, an estimated 90% is contained in the world's forests, which includes trees, forest floor (litter) and forest soil. For each cubic foot of merchantable wood produced in a tree, about 33 lb. (14.9 kg) of carbon is stored in total tree biomass (Sampson et al., 1992) [5]. Tropical forests in general are a disproportionately important component in the global carbon cycle, and are thought to represent 30-40% of the terrestrial net primary production (Clark et al., 2001a) [6]. Although the area covered by mangrove ecosystems represents only a small fraction of tropical forests, their position at the terrestrial-ocean interface and potential exchange with coastal water suggest these forests make a unique contribution to carbon biogeochemistry in coastal ocean (Twilley et al., 1992) [7].

Mangrove ecosystems thrive along coastlines throughout most of the tropics and subtropics. These intertidal forests play important ecological and socioeconomic roles by acting as a nutrient filter between land and sea (Robertson and Phillips, 1995) [8], contributing to coastline protection (Vermatt and Thampanya, 2006) [9], providing commercial fisheries resources (Constanza et al., 1997) [10] and nursery grounds for coastal fishes and crustaceans. The coastal zone (<200 m depth), covering ~7% of the ocean surface (Gattuso et al., 1998) [11] has an important role in the oceanic carbon cycle, and various estimates indicate that the majority of mineralization and burial of organic carbon, as well as carbonate production and accumulation takes place in the coastal ocean (Gattuso et al., 1998; Mackenzie et al., 2004) [11, 12]. The potential impact of mangrove on coastal zone carbon dynamics has been a topic of intense debate during the past decades. The "outwelling" hypothesis, first proposed for mangroves by Odum (1968) [13] and Odum and Heald (1972) [14] suggests that a large fraction of the organic matter produced by mangrove trees is exported to the coastal ocean, where it forms the basis of a detritus food chain and thereby supports coastal fisheries. A number of recent studies, however, have indicated a direct trophic link between mangrove forest production and offshore secondary production is unlikely for many mangrove systems. Despite the large number of case studies dealing with various aspects of organic matter cycling in mangrove systems (Kristensen et al., 2008) [15], there is very limited consensus on the carbon sequestering potential of mangroves.

The present study is an attempt to establish a baseline data set of the carbon content in the mangrove ecosystem of Indian Sundarbans that has received the crown of World Heritage site and Biosphere Reserve owing to its unique biological productivity, taxonomic diversity and aesthetic beauty. An accurate estimate of carbon storage and sequestration is essential for any project related to plantation particularly in the sector of social forestry. In context to mangrove dominated Gangetic delta region, this is extremely important as several Government, Non-Government Organizations and even foreign donors are participating in the mangrove afforestation programme owing to extreme vulnerability of the system to sea level rise, erosion and tidal surges (Hazra et al, 2002; Mitra and Banerjee, 2004) [16, 17]. The ability of these plantations to sequester carbon has generated a lot of interest, since carbon sequestration projects in developing nations could receive investments from companies and governments wishing to offset their emissions of green house gases through the Kyoto Protocol's Clean Development Mechanism (Fearnside, 1999). [18] Carbon registries typically segregate a number of carbon pools within a mangrove forests that can be identified and quantified. These carbon pools are categorized in a variety of ways, but typically include many of the same components. The total carbon in a mangrove system is the summation of above ground biomass, below ground biomass, litter, and soil. The mangrove ecosystem is unique in terms of carbon dynamics as the litters and detritus contributed by the floral species are exported to adjacent water bodies in every tidal cycle.

Figure 1. Mangrove tree typical of East Bengal region. **Source:** (Mitra and Zaman, 2014) [19].

In this study, the carbon content in five distinct mangrove components (above ground stem biomass, branch biomass, leaf biomass, litter and surface soil) were analyzed in two different physiographic set-ups of Indian Sundarbans. The difference is caused due to variation in freshwater supply from Himalayan glaciers (largest glacial coverage ~ 34,660 km^2) after being regulated through several barrages on the way. The Ganga-Bhagirathi-Hugli river system in the western part of Indian Sundarbans is appropriately diluted in relation to mangrove growth as the system receives the freshwater input after being regulated through Farakka barrage. In contrast, the Matla River in the central sector is disconnected to the Himalayan glaciers' freshwater supply due to heavy siltation of the Bidyadhari River since late 15th century and is now primarily tide-fed. This difference created a contrasting natural laboratory for identifying signals of climate change in the salinity profile and mangrove growth leading to variation in carbon pool under different environmental conditions. (Mitra et al., 2014) [20].

2. Study Objectives

- Monitoring the carbon sequestering pattern in the above ground biomass of common mangrove species (*Avicennia alba*, *A. marina*, *A. officinalis*, *Sonneratia apetala*, and *Excoecaria agallocha*) in Indian Sundarbans through seasons.
- Monitoring the soil organic carbon of the substratum in the sampling sites through seasons.
- Monitoring the carbon content in mangrove litter (species-wise) through space (different salinity zone) and time (different seasons).
- Monitoring the trend of carbon load in the mangrove system with changing salinity profile (along with soil pH).

3. Description of the Study Sites

Two sampling zones were selected each in the western and central sectors of Indian Sundarbans, a Gangetic delta at the apex of the Bay of Bengal. The deltaic complex has an area of 9,630 sq. Km and houses 102 islands.

Table 1. Location of the sampling stations

Station Name	* Stn	Geographical Location	
		Longitude	Latitude
Mandirtala	1	88°10'44.55"	21°43'08.58"
Chemaguri	2	88°10'07.03"	21°39'58.15"
Harinbari	3	88°04'02.98"	21°47'01.36"
Sagar South	4	88°03'06.17"	21°38'54.37"
Lothian island	5	88°22'13.99"	21°39'01.58"
Canning	6	88°41'16.20"	22°18'40.25"
Sajnekhali	7	88°48'17.60"	22°16'33.79"
Chotomollakhali	8	88°54'26.71"	22°10'40.00"
Satjelia	9	88°52'49.51"	22°05'17.86"
Pakhiralaya	10	88°48'29.00"	22°07'07.23"

* Station Code (Stn). **Source:** (Mitra et al., 2009) [22].

The western sector of the deltaic lobe receives the snowmelt water of mighty Himalayan glaciers after being regulated through several barrages on the way. The central sector on the other hand, is fully deprived from such supply due to heavy siltation and clogging of the Bidyadhari channel in the late 15th century (Chaudhuri and Choudhury, 1994) [21]. During the 1st year of the project 10 stations were selected (5 each in the western and central Indian Sundarbans) on the basis of physicochemical variables arising from different geomorphologic features (**Figure 1A and Table 1**).

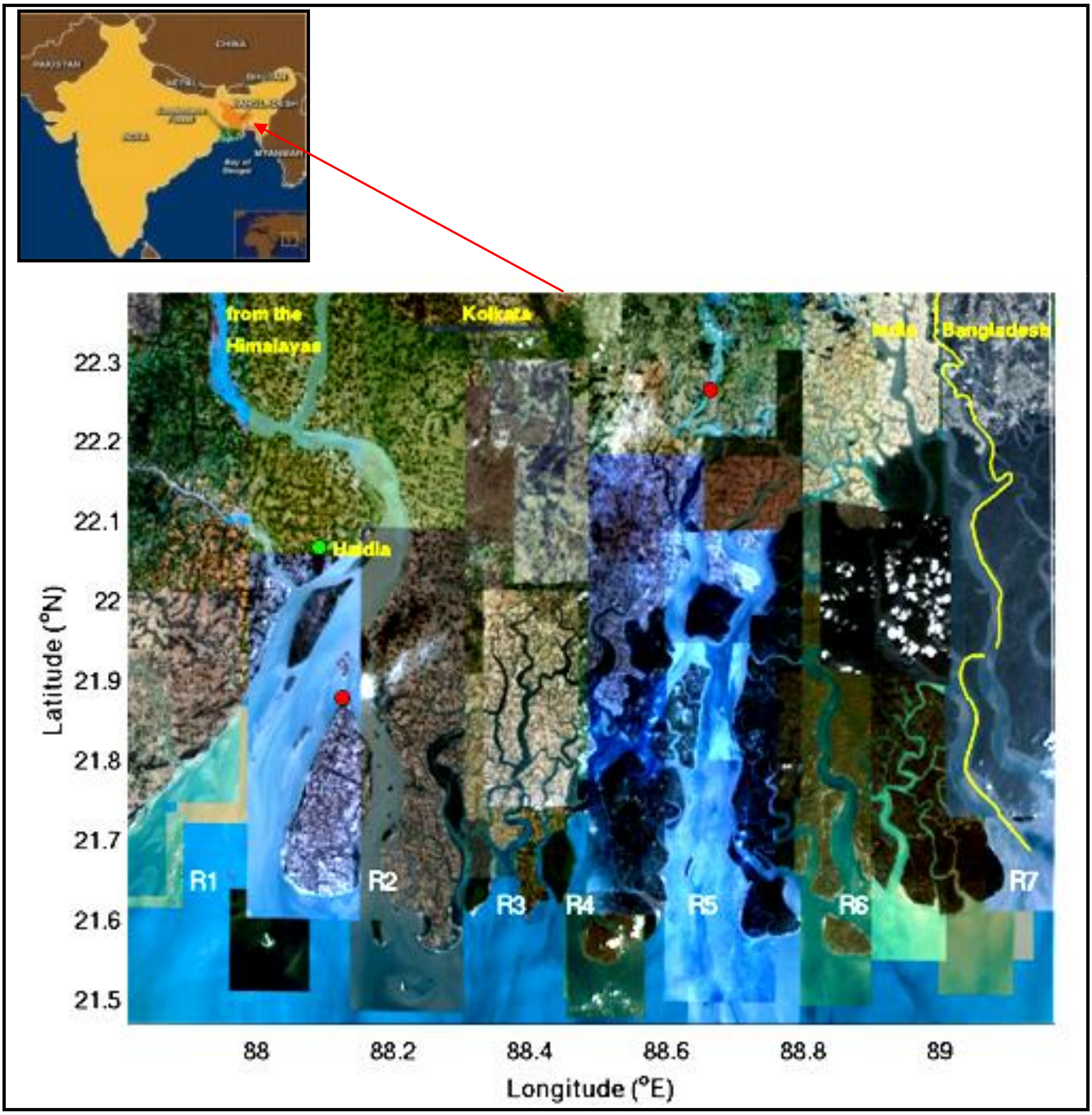

Figure 1A. Map of the study region. The seven rivers marked by R1 through R7 from west to east are: Hugli, Muriganga, Saptamukhi, Thakuran, Matla, Gosaba and Harinbhanga. The discharge system of the two metropolises of Haldia and Kolkata (Calcutta) are connected to the two western rivers, which are also fed by the meltwater from the Himalayas after being regulated through barrages. The central sector is connected to the rivers R4 and R5 which do not have any freshwater input. **Source**: (Mitra et al., 2009) [22].

4. Methodology

The entire network of the present study initiated with the selection of 10 stations - 5 each in western and central sectors of Indian Sundarbans. In each station, plot size of 10 m × 10 m was selected for the study and the average readings were documented from 15 such plots. The mean relative abundance of each species of true mangrove flora was evaluated for the order of dominance in the study area.

The above ground biomass (comprising of stem, branch and leaf) of individual trees of five dominant species in each plot was estimated as per the standard procedure stated here and the average biomass values of 15 plots (of each station) were finally expressed as tonnes per hectare. Litter production studies were carried out in all the stations through net collection method. Organic carbon in the soil substratum was analyzed as par the modified method of Walkley and Black (1934) [23]. Surface water salinity was instantly measured in the field by refractometer and cross-checked in the laboratory by argentometric method. Soil pH of the respective stations were measured with a pH meter (sensitivity = ± 0.02) after appropriate dilution of 10 mg of dried soil with 100 cc double distilled water.

The methodologies adopted for assessing different biotic and abiotic parameters in the present study are explained in details in 7 sections (4.1 to 4.7).

4.1. Stem biomass estimation

The stem biomass for each mangrove species in every plot was estimated using non-destructive method in which the diameter at the breast height (DBH) was measured with a measuring tape and height with laser beam (BOSCH DLE 70 Professional model). Form factor was determined with Spiegel relascope as per the method outlined by Koul and Panwar (2008) [24]. The stem volume (*V*) was then calculated using the expression $FH\Pi R^2$, where *F* is the form factor, *Π* is a mathematical constant ~ 3.1415926535, *R* is the radius of the tree derived from its DBH and *H* is the height of the target tree. Specific gravity (*G*) of the wood was estimated taking the stem cores, which was further converted into stem biomass (B_S) as per the expression $B_S = G.V.$ (Koul and Panwar, 2008); Mitra et al., 2017. [24, 25]

4.2. Branch biomass estimation

The total number of branches irrespective of size was counted on each of the sample trees. These branches were categorized on the basis of basal diameter into three groups, ***viz***. <6 cm, 6–10 cm and >10 cm. Fresh weight of two branches from each size group was recorded separately using the equation of Chidumaya (1990). [26]

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

$$B_{db} = n_1 bw_1 + n_2 bw_2 + n_3 bw_3 = \sum_{i=1}^{3} n_i bw_i \tag{1}$$

Where, B_{db} is the dry branch biomass per tree, n_i the number of branches in the *i*th branch group, b_{wi} the average weight of branches in the *i*th group and $i = 1, 2, 3, \ldots, n$ are the branch groups. This procedure was followed for all the dominant mangrove species separately in both the sectors of the study area.

4.3. Leaf biomass estimation

Leaves from nine branches (three of each size group as stated in section 2) of individual trees of each species were removed. One tree of each species per plot was considered for estimation. The leaves were weighed and oven dried separately (species wise) to a constant weight at 80 ± 5°C. The leaf biomass was then estimated by multiplying the average biomass of the leaves per branch with the number of branches in a single tree and the average number of trees per plot as per the expression:

$$L_{db} = n_1 LwN_1 + n_2 Lw_2 N_2 + \cdots + n_i Lw_i N_i \tag{2}$$

where, L_{db} is the dry leaf biomass of dominant mangrove species per plot, $n_1, \ldots, n_i$ are the number of branches of each tree of five dominant species, $Lw_1, \ldots, Lw_i$ are the average dry weight of leaves removed from the branches and $N_1, \ldots, \ldots N_i$ are the number of trees per species in the plot.

4.4. Litter fall estimation

Litter fall was determined by setting 5 rectangular traps (3m × 3m) in each of the 15 plots per station. The traps were made of 1mm mesh size nylon screen, through which rainwater can pass (Brown, 1984). [27] The traps were positioned above the high tide level (Jeffrie and Tokuyama, 1998) [28] and contents of all the 5 traps per plot (total 75 traps per station) were collected and brought to the laboratory after duration of one month, where it was dried to a constant weight at 80°C. Finally the mean weight per station was estimated and expressed in **$gm.m^{-2}.d^{-1}$** unit (considering the number of days in a month).

4.5. Carbon estimation

Direct estimation of percent carbon was done by a CHN analyzer. For this, a portion of fresh sample of stem, branch and leaf from thirty trees (two trees/species/plot) of individual species (covering all the 15 plots) was oven dried at 70^0C, randomly mixed and ground to pass through a 0.5 mm screen (1.0 mm screen for leaves). The carbon content (in %) was finally analyzed on a ***Vario MACRO elementar CHN*** analyzer. For litter, the same procedure was followed after oven drying the net collection at 70^0C.

4.6. Soil pH & organic carbon analysis

Soil samples from the upper 5 cm were collected from all the 15 plots and dried at 60°C for 48 hrs. For analysis, visible plant particles were hand picked and removed from the soil. After sieving the soil through a 2 mm sieve, we ground the samples of the bulk soil (50 gm from each plot) finely in a ball – mill. The fine dried sample was randomly mixed to get a representative picture of the study site. Modified version of Walkley and Black method (1934) [23] was then followed to determine the organic carbon of the soil in %.

Surface soil from each plot of the sampling stations were collected, dried and mixed with double distilled water (1:10). After vigorous stirring the beaker containing the sample was allowed to stand for few hours till a clear supernatant was obtained. The pH of the supernatant was measured with a pH meter (sensitivity = ±0.02).

4.7. Analysis of surface water salinity

Surface water salinity was measured by refractometer and cross-checked in the laboratory by argentometric method. The salinity of the standard seawater was analyzed by the same method and a deviation of 0.2% was obtained.

5. Results and Discussions

The biomass and productivity of mangrove forests have been studied mainly in terms of wood production, forest conservation, and ecosystem management (Putz and Chan, 1986; Tamai et al., 1986; Komiyama et al., 1987; Clough and Scott, 1989; McKee, 1995; Ong et al., 1995). [29, 30, 31, 32, 33, 34] The contemporary understanding of the global warming phenomenon, however, has generated interest in the carbon-stocking ability of mangroves. The carbon sequestration in this unique producer community is a function of biomass production capacity, which in turn depends upon interaction between edaphic, climate, and topographic factors of an area. Hence, results obtained at one place may not be applicable to another. Therefore region based potential of different land types needs to be worked out. In the present study, the results obtained have been compared with other regions of the world to evaluate the potential of Indian Sundarbans mangrove as carbon sink on the background of changing scenario of the climate.

5.1. Relative abundance

We present here the mean of five stations each for western and central Indian Sundarbans.

Nine species of true mangroves were documented in the selected plots in the western sector, but in the central sector only six species were recorded. The mean order of abundance of these species was *Sonneratia apetala* (27.08) > *Excoecaria agallocha* (18.75) > *Avicennia alba* (14.58%) > *Avicennia marina* (12.5%) = *Avicennia officinalis* (12.5%) > *Acanthus ilicifolius* (6.25%) > *Aegiceros corniculatum* (4.17%) > *Bruguiera gymnorhiza* (2.08%) = *Xylocarpous molluscensis* (2.08%) in the western sector, but the order in the central sector was *Excoecaria agallocha* (23.68%) > *Avicennia alba* (21.05%) > *Avicennia marina* (15.79%) = *Avicennia officinalis* (15.79%) > *Sonneratia apetala* (13.16%) > *Acanthus ilicifolius* (10.53%) **(Table 1)**. Few mangrove associate floral species (like *Porteresia coarctata*, *Suaeda* sp. etc.) were also documented in the plots. On the basis of relative abundance of the true mangrove species, five dominant species namely *Avicennia alba*, *Avicennia marina*, *Excoecaria agallocha*, *Sonneratia apetala* and

Parana Journal of Science and Education (PJSE) – v.4, n.4, (7-29) June 17, 2018
ISSN: 2447-6153 https://sites.google.com/site/pjsciencea

Avicennia officinalis were considered for carbon stock estimation in their respective above ground biomass. In both these sectors, the forests were ~12 years old, but high salinity in the central sector probably created a stress to the growth of the floral species.

5.2. Stem biomass

The stem biomass temporally varied as per the order March, 2010 > December, 2009 > September, 2009, which is a reflection of the growth with time. However, the growth rate was more in all the species during the phase of September, 2009 to December, 2009 in comparison to duration from December, 2009 to March, 2010. The monsoonal effect (during August/September in the present geographical locale) might be the reason for higher growth between September, 2009 and December, 2009. Growth also slowed down during postmonsoon (December, 2009) onward and the biomass reduces considerably during the phase of December, 2009 to March, 2010 **(Table 3A to 3E; *vide* the % decrease/increase column)**. The maximum litter fall during March is also a significant factor behind the lowering of branch and leaf biomass in mangroves.

There was also significant difference in the stem biomass between the western and central sectors of Indian Sundarbans. In the western sector, the above ground stem biomass of the dominant mangrove trees in the monsoon season (September, 2009) were 104.09 t ha^{-1}, 14.09 t ha^{-1}, 27.20 t ha^{-1}, 21.37 t ha^{-1}, and 21.46 t ha^{-1} for *Sonneratia apetala*, *Excoecaria agallocha*, *Avicennia alba*, *Avicennia marina*, and *Avicennia officinalis* respectively, but in the central sector, these values were much lower exhibiting 21.68 t ha^{-1}, 9.27 t ha^{-1}, 15.56 t ha^{-1}, 11.93 t ha^{-1}, and 6.18 t ha^{-1} for *Sonneratia apetala*, *Excoecaria agallocha*, *Avicennia alba*, *Avicennia marina*, and *Avicennia officinalis* respectively **(Table 2A)**.

The picture is similar in the postmonsoon season (December, 2009) as per the order of the biomass of the species is concerned. In the western sector, the above ground stem biomass of the dominant mangrove trees were 113.35 t ha^{-1}, 15.25 t ha^{-1}, 29.18 t ha^{-1}, 22.48 t ha^{-1}, and 22.18 t ha^{-1} for *Sonneratia apetala*, *Excoecaria agallocha*, *Avicennia alba*, *Avicennia marina*, and *Avicennia officinalis* respectively, but in the central sector, these values were much lower exhibiting 22.18 t ha^{-1}, 9.98 t ha^{-1}, 16.65 t ha^{-1}, 12.88 t ha^{-1}, and 6.42 t ha^{-1} for *Sonneratia apetala*, *Excoecaria agallocha*, *Avicennia alba*, *Avicennia marina*, and *Avicennia officinalis* respectively **(Table 2B)**.

Similar sequence was also observed during premonsoon (March, 2010). In the western sector, the above ground stem biomass of the dominant mangrove trees were 116.74 t ha^{-1}, 15.55 t ha^{-1}, 30.34 t ha^{-1}, 23.13 t ha^{-1}, and 22.73 t ha^{-1} for *Sonneratia apetala*, *Excoecaria agallocha*, *Avicennia alba*, *Avicennia marina*, and *Avicennia officinalis* respectively, but in the central sector, these values were much lower exhibiting 22.45 t ha^{-1}, 10.12 t ha^{-1}, 17.14 t ha^{-1}, 17.35 t ha^{-1}, and 7.17 t ha^{-1} for *Sonneratia apetala*, *Excoecaria agallocha*, *Avicennia alba*, *Avicennia marina*, and *Avicennia officinalis* respectively **(Table 2C)**.

For all the species, the stem biomass in the western sector is higher than the central sector **(Figures 2A to 2E)**.

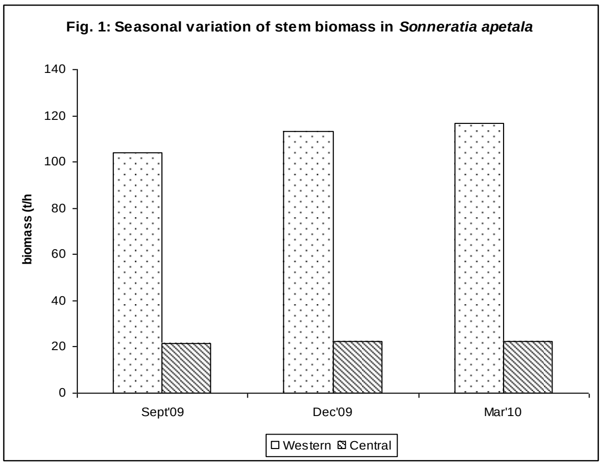

Figure 2A.

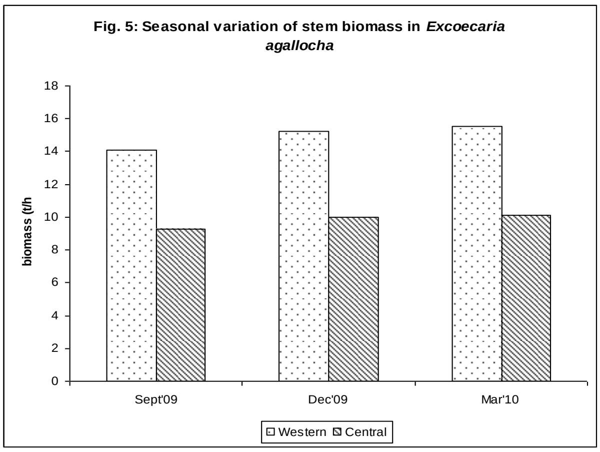

Figure 2B.

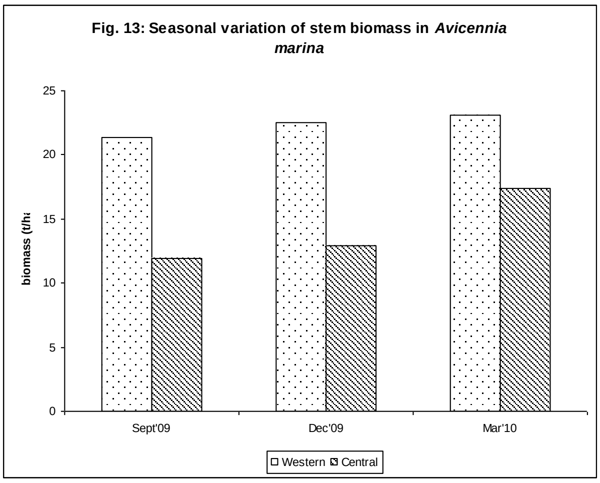

Figure 2C.

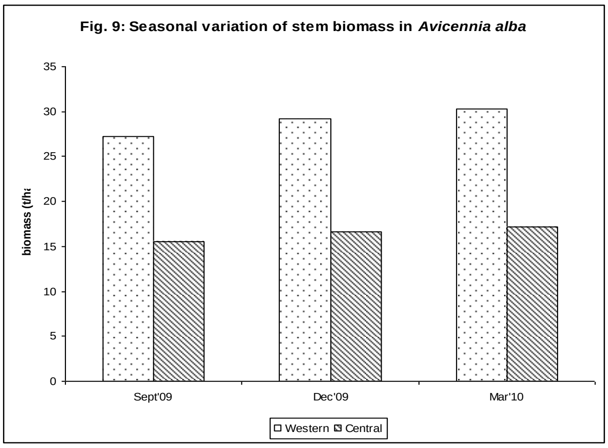

Figure 2D.

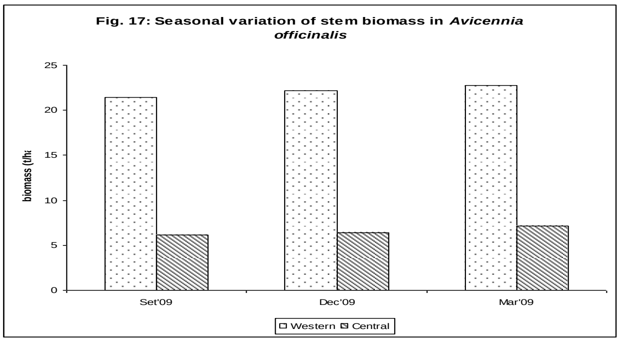

Figure 2E.

The values of mangrove stem biomass in the western sector are similar to the data of Komiyama et al. (2000) [35] in a secondary mangrove (*Ceriops tagal*) forest at Southern Thailand. The relatively higher stem biomass of similar aged trees in western sector may be attributed to optimum hydrological and soil characteristics contributed by the River Ganga-Bhagirathi system. Mangroves, in general, prefer brackish water environment and in extreme saline condition stunted growth is observed (Mitra et al., 2004). [36] The western sector of Indian Sundarbans provides a congenial environment for mangrove sustenance due to fresh water input from the Himalayan Glaciers after being regulated by the Farakka barrage. Five-year surveys (1999 to 2003) on water discharge from Farakka barrage revealed an average discharge of (3.4 ± 1.2) X 10^3 m^3s^{-1}. Higher discharge values were observed during the monsoon with an average of (3.2 ± 1.2) X 10^3 m^3s^{-1}, and the maximum of the order 4200 m^3s^{-1} during freshet (September). Considerably lower discharge values were recorded during premonsoon with an average of (1.2 ± 0.09) ×10^3 m^3s^{-1}, and the minimum of the order 860 m^3s^{-1} during May. During postmonsoon discharge values were moderate with an average of (2.1 ± 0.98) ×10^3 m^3s^{-1}. The lower Gangetic deltaic lobe also experiences considerable rainfall (1400 mm average rainfall). This causes a considerable volume of surface runoff from the 60000 km^2 catchment areas of Ganga-Bhagirathi-Hugli system and their tributaries. All these factors (dam discharge + precipitation + run-off) increase the dilution factor of the Hugli estuary in the western part of Indian Sundarbans – a condition for better growth and increase of mangrove biomass. The central sector, on contrary, does not receive the freshwater input on account of siltation of the Bidyadhari River which may be attributed to low stem biomass of the selected mangrove species inhabiting the zone.

5.3 Branch biomass

The branch biomass of mangroves showed marked differences between the trees of western and central sectors in all the three seasons. During monsoon (September, 2009) the values in the western sector were 42.64 t ha^{-1}, 6.30 t ha^{-1}, 12.42 t ha^{-1}, 10.08 t ha^{-1}, and 9.23 t ha^{-1} and in the central sector the values were 9.03 t ha^{-1}, 3.81 t ha^{-1}, 6.30 t ha^{-1}, 5.25 t ha^{-1}, and 2.59 t ha^{-1} for *Sonneratia apetala*, *Excoecaria agallocha*, *Avicennia alba*, *Avicennia marina*, and *Avicennia officinalis* respectively **(Table 2A)**.

During postmonsoon (December, 2009) the values in the western sector were 43.07 t ha^{-1}, 6.48 t ha^{-1}, 12.98 t ha^{-1}, 9.99 t ha^{-1}, and 9.09 t ha^{-1} and in the central sector the values were 9.09 t ha^{-1}, 3.90 t ha^{-1}, 6.33 t ha^{-1}, 5.19 t ha^{-1}, and 2.70 t ha^{-1} for *Sonneratia apetala*, *Excoecaria agallocha*, *Avicennia alba*, *Avicennia marina*, and *Avicennia officinalis* respectively **(Table 2B)**.

During premonsoon period of highest salinity (March, 2010) the values in the western sector were 43.43 t ha^{-1}, 6.03 t ha^{-1}, 11.91 t ha^{-1}, 9.64 t ha^{-1}, and 8.45 t ha^{-1} and in the central sector the values were 7.77 t ha^{-1}, 3.60 t ha^{-1}, 5.79 t ha^{-1}, 4.96 t ha^{-1}, and 2.79 t ha^{-1} for *Sonneratia apetala*, *Excoecaria agallocha*, *Avicennia alba*, *Avicennia marina*, and *Avicennia officinalis* respectively **(Table 2C)**.

The branch biomass in the western sector is almost similar to the values in a secondary mangrove (*Ceriops tagal*) forest at Southern Thailand as documented by Komiyama et al. (2000). [35] Stunted branches of mangroves in the central sector **(Figures 3A - 3E)** may again be related to high salinity in this sector (Mitra et al., 2009) [37].

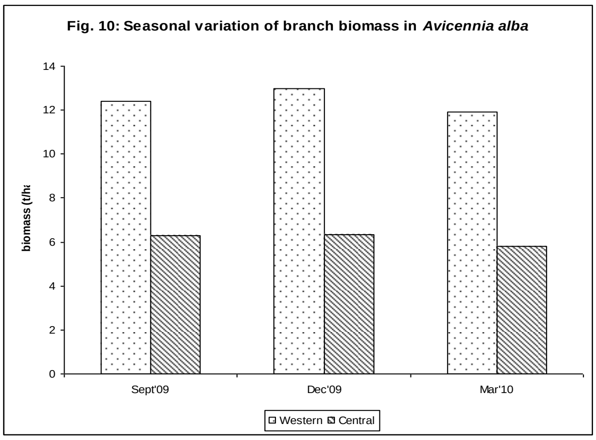

Figure 3C.

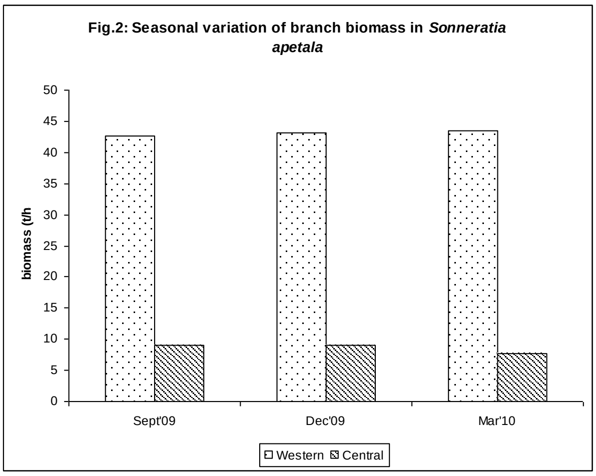

Figure 3A.

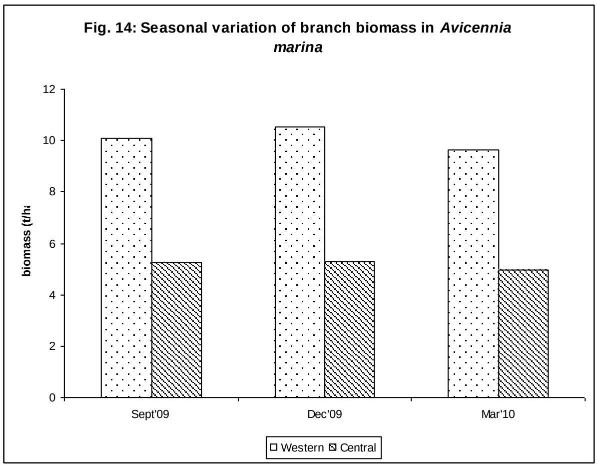

Figure 3D.

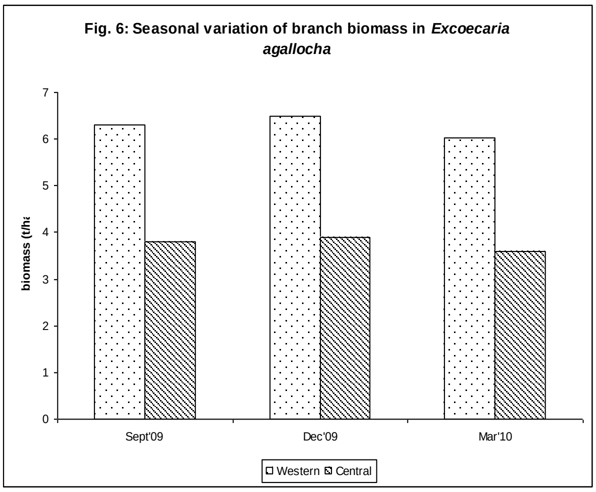

Figure 3B.

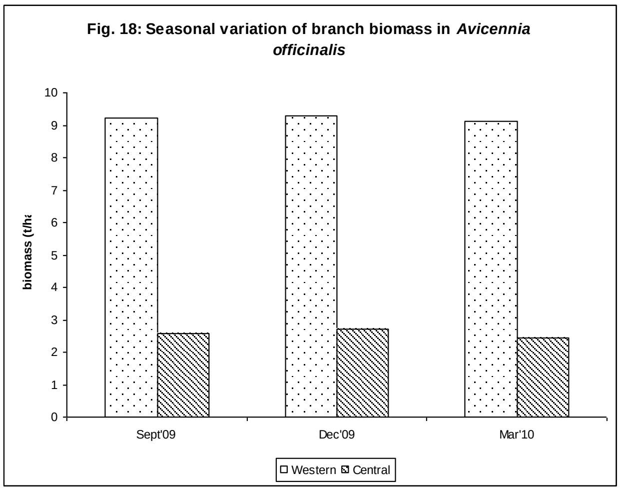

Figure 3E.

5.4. Leaf biomass

The leaf biomass of the trees in the western and central sectors were 22.88 t ha^{-1} and 4.33 t ha^{-1} respectively for *Sonneratia apetala*, 3.22 t ha^{-1} and 1.85 t ha^{-1} respectively for *Excoecaria agallocha*, 7.07 t ha^{-1} and 2.96 t ha^{-1} respectively for *Avicennia alba*, 4.83 t ha^{-1} and 2.20 t ha^{-1} respectively for *Avicennia marina*, and 5.46 t ha^{-1} and 1.24 t ha^{-1} respectively for *Avicennia officinalis* during monsoon (September, 2009) **(Table 2A)**.

During postmonsoon (December, 2009) the values in the western sector were 23.97 t ha^{-1}, 3.25 t ha^{-1}, 7.10 t ha^{-1}, 4.62 t ha^{-1}, and 5.05 t ha^{-1} and in the central sector the values were 4.41 t ha^{-1}, 1.87 t ha^{-1}, 3.05 t ha^{-1}, 2.18 t ha^{-1}, and 1.15 t ha^{-1} for *Sonneratia apetala*, *Excoecaria agallocha*, *Avicennia alba*, *Avicennia marina*, and *Avicennia officinalis* respectively **(Table 2B)**.

During premonsoon (March, 2010) the values in the western sector were 22.85 t ha^{-1}, 3.21 t ha^{-1}, 6.90 t ha^{-1}, 4.39 t ha^{-1}, and 4.44 t ha^{-1} and in the central sector the values were 4.15 t ha^{-1}, 1.80 t ha^{-1}, 2.99 t ha^{-1}, 2.16 t ha^{-1}, and 1.13 t ha^{-1} for *Sonneratia apetala*, *Excoecaria agallocha*, *Avicennia alba*, *Avicennia marina*, and *Avicennia officinalis* respectively **(Table 2C)**.

The leaf biomass in the western sector also exhibited higher values than the respective species in the central sector **(Figures 4A - 4E)**.

Comparing the results of the present study area with other regions of the world, the leaf biomass exhibited considerable similarity with the data of western sector of Indian Sundarbans *e.g.*, 2.1 - 15.0 t ha^{-1} in *Avicennia* forests of Australia (Briggs, 1977) [38], 6.2 – 20.2 t ha^{-1} in *Rhizophora apiculata* young plantations of Thailand (Aksomkoae, 1975) [39], 13.3 t ha^{-1} in *Rhizophora* patch in **Matabungkay Beach Batangas Province** (De La Cruz and Banaag, 1967) [40] and 8.1 t ha^{-1} in a matured *Rhizophora* forest of southern Thailand (Tamai et al., 1986) [30].

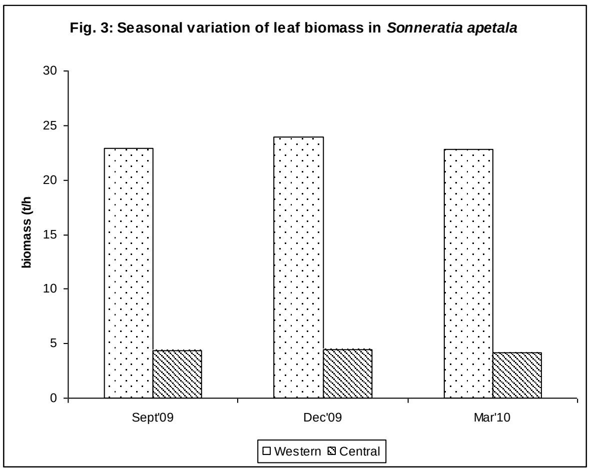

Figure 4A.

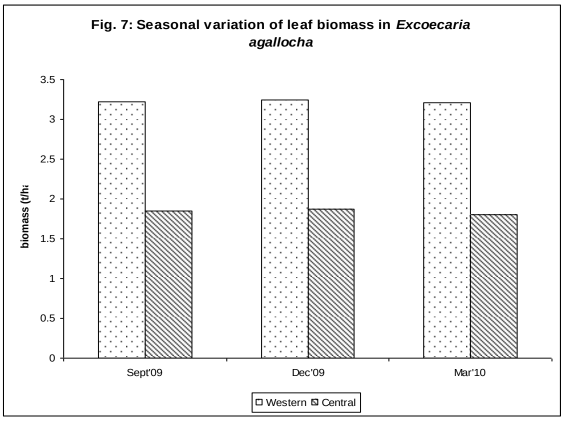

Figure 4B.

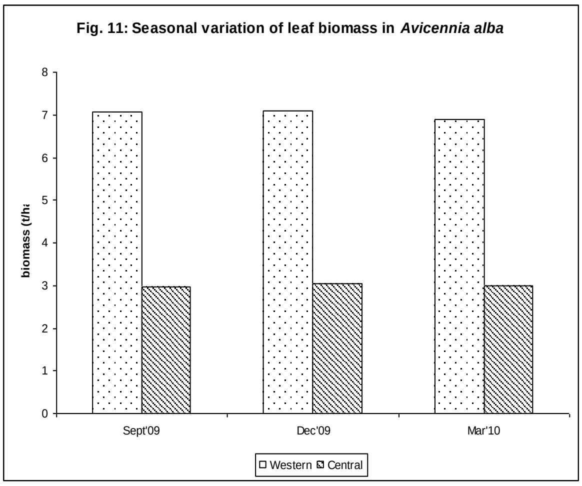

Figure 4C.

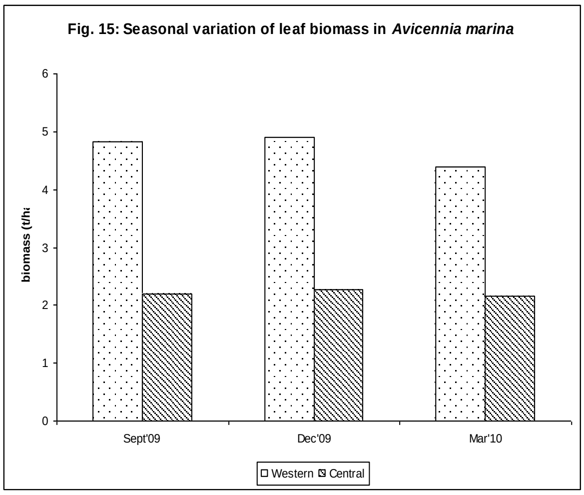

Figure 4D.

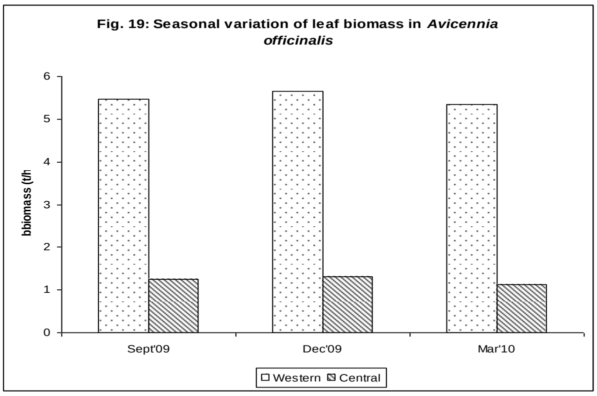

Figure 4E.

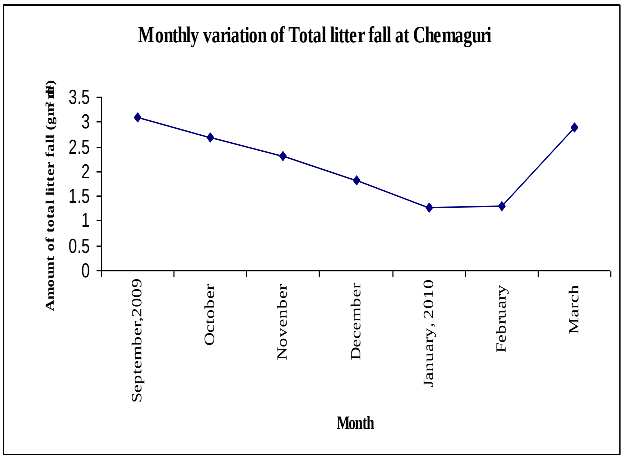

Figure 5A.

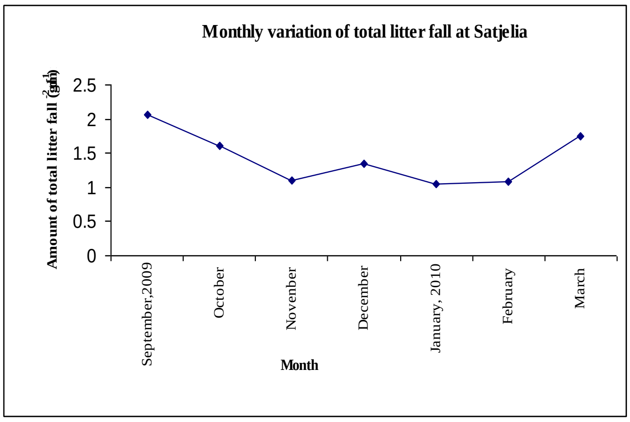

Figure 5B.

5.5. Litter production

Average values of total litter, leaf litter and miscellaneous litter fall (comprised of twigs, stipules, flowers and fruits) in western and central sectors of Indian Sundarbans are shown in **Tables 4A and 4B**. The biomass of total litter is more in the western sector in comparison to central part of Indian Sundarbans. The higher above ground biomass of the mangroves in the western sector may be the possible cause behind this significant variation. Our team members have studied the litter fall during September, 2009 to March, 2010 (~212 days). Considering the quantum of quantum of litter fall for this span of time, the annual litter fall in the western and central sectors may be extrapolated to 8.05 t ha^{-1} yr^{-1} and 5.22 t ha^{-1} yr^{-1} respectively. In the present study the highest litter fall during September, 2009 may be related to heavy rainfall and wind action in the region that accelerates the litter fall in mangrove system **(Figures 5A and 5B)**.

The value in the western sector is comparable to the data of several workers in other parts of the world. Twilley et al. (1986) [41] reported that the total annual litter fall of mixed mangrove forest of *Avicennia germinans*, *Rhizophora mangle* and *Laguncularia racemosa* in South Florida was 8.68 t ha^{-1} yr^{-1} (in Fort Myers) and 7.51 t ha^{-1} yr^{-1} (at Rookery Bay). Steinke and Charles (1984) [42] reported the total annual litterfall of mangrove forest in the Mgeni estuary was 8.61 t ha^{-1} yr^{-1}. Kishimoto et al. (1987) [43] reported that the litterfall of mangrove stands on Iriomote Island (Japan), was 7.5 and 8.8 t ha^{-1} yr^{-1} in *Rhizophora stylosa* and *Bruguiera gymnorrhiza* community, respectively. The annual litter fall across broad geographic boundaries are reported as 7 to 12 t dry weight ha^{-1} yr^{-1} (Duke et al., 1981; Twilley et al., 1986; Hardiwinoto et al., 1989; Lee, 1990; Gong and Ong, 1990; Mall et al., 1991 and Mmochi, 1993).[44, 41, 45, 46, 47, 48, 49] In context to Indian mangrove system, the mangrove litter production was recorded as 7.50 tonnes/ha/yr in Pichavaram at Tamil Nadu

(Krishnamurthy, 1985) [50], in which leaf biomass amounts to about 80 – 90% (Yadav and Choudhury, 1985) [51].

5.6. Surface soil pH and organic carbon

The surface soil pH in the study area showed a distinct seasonal pattern with highest value in premonsoon (March, 2010), followed by postmonsoon (December, 2009) and monsoon (September, 2009). In the western sector the mean values were 7.24, 7.30 and 7.36 in the monsoon, postmonsoon and premonsoon respectively. In the central sector the mean values were 7.32, 7.37 and 7.39 in the monsoon, postmonsoon and premonsoon respectively. Station-wise values of surface soil pH in both the sectors of Indian Sundarbans are shown in **Table 5A**.

The organic carbon in the study area showed a distinct season pattern with highest value in monsoon (September, 2009), followed by postmonsoon (December, 2009) and premonsoon (March, 2010). In the western sector the mean values were 1.182%, 1.010% and 0.882% in the monsoon, postmonsoon and premonsoon respectively. In the central sector the mean values were 0.936%, 0.820% and 0.650% in the monsoon, postmonsoon and premonsoon respectively. Station-wise seasonal variation of organic carbon in both the sectors of Indian Sundarbans are shown in **Figures 6A and 6B**.

The values of soil organic carbon are indicators of mangrove growth, biomass, decay and litter fall for a particular site. Carbon fixed within plant biomass ultimately enters within the soil, where it may reside for hundreds of years. The ability of soil to store this additional carbon, however, is highly controversial, because there are two contrasting ways in which the increased input of carbon may be processed in the soil. First, the extra-fixed carbon may become soil organic carbon. Second, this readily available source of carbon may stimulate soil microbial processes by providing substrates that enhance decomposition of the organic matter through the so-called 'priming effect' (Peterson et al., 1997) [52]. Strong evidence for a long-term sink for increased atmospheric CO_2 in soils is still lacking (Schlesinger, 1990; Schimel, 1995; Canadell et al., 1996) [53, 54, 55]. Our study indicate that high saline soil (as observed in case of central sector) are relatively poor sink of CO_2, which may be attributed to either poor growth of mangroves (Mitra et al, 2004) [36] or low fertility of the soil in terms of nitrogen that acts as retarding factor for plant growth.

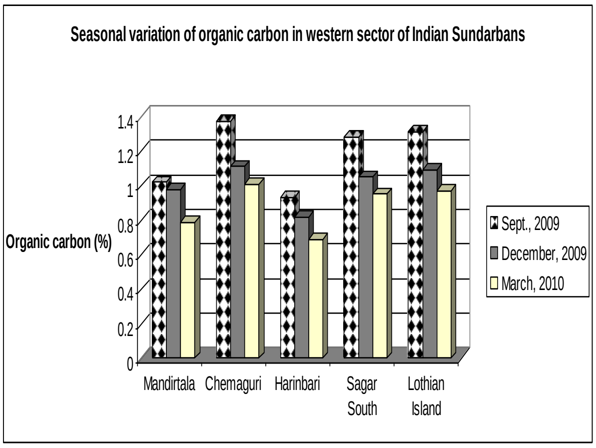

Figure 6A.

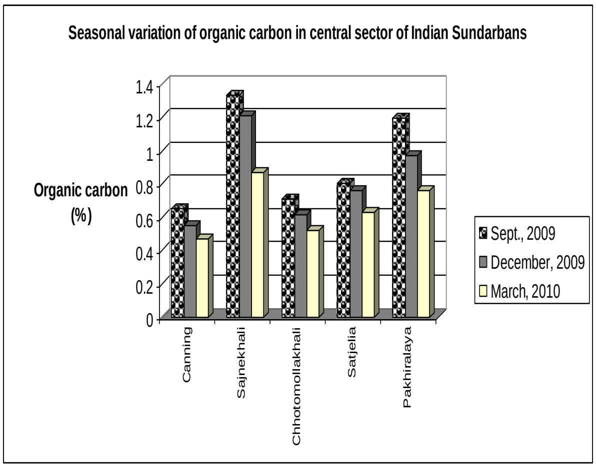

Figure 6B.

5.7. Comparison of carbon stocks

Mangroves are unique storehouse for carbon. The global storage of carbon in mangrove biomass is estimated to be 4.03 pg, 70% of which occurs in coastal margins from 0^0 to 10° latitude (Twilley et al., 1992). [7] For the present study, the results of carbon stock in the above ground biomass of the selected species are shown in **Tables 6A, 6B and 6C**. Species wise carbon content are in the order *Sonneratia apetala*> *Avicennia alba*> *Avicennia marina*> *Avicennia officinalis* > *Excoecaria agallocha* in the western sector and *Sonneratia apetala*> *Avicennia alba*> *Avicennia marina*> *Excoecaria agallocha*> *Avicennia officinalis* in the central sector. Approximately 40.9% - 49.9% of the dry above ground biomass of mangrove trees is made up of carbon (as revealed from direct %C analysis through CHN analyzer); thus as long as the tree is growing and accumulating biomass, it is accumulating carbon **(Table 6A to 6C)**.

The % of carbon in the mangrove litter (total) ranged from 32.8% to 36.5% and 35.3% to 38.1% in the western and central sectors respectively.

The data generated in the present geographical locale show significant variations between the two sectors. The hypersalinity of the central part of Indian Sundarbans may be considered as one of the important reason for such shortfall. Records show that surface water salinity has increased by 40.46% in central sector, and decreased by 46.21% in western sector of Indian Sundarbans over a period of 27 years (1980 to 2007), which is the result of the blockage of fresh water flow from western side of Indian Sundarbans to central sector (Mitra et al., 2009) [37]. During the present study period also higher aquatic salinity was recorded in the stations of central sectors **(Table 5B)**. Higher salinity has therefore reduced the floral growth, and subsequent litter production and organic carbon in soil of central sector of Indian Sundarbans.

6. Conclusions

Mangroves are unique sink of carbon. The data banks of stored carbon obtained from Indian Sundarbans during December 2009 to March 2010 confirm that species like *Sonneratia apetala, Avicennia alba, A. marina, A. officinalis* and *Excoecaria agallocha* have considerable scrubbing capacity of carbon, although it is salinity specific. The soil and mangrove litter act as reservoir of carbon in this designated World Heritage Site. Considering the exponential rise of atmospheric carbon dioxide, it is of utmost importance to conserve this natural carbon scrubber of the tropics.

References

[1] Pandey, D. N., 2002. Global climate change and carbon management in multifunctional forests. *Curr. Sci*. 83, 593-602.

[2] Hair, Dwight., Sampson, R. Neil., 1992. Climate Change - History, prospects, and possible impacts. In Forests and Global Change Volume One: Opportunities for Increasing Forest Cover (Dwight Hair and R. Neil Sampson, eds.) *American Forests*, Washington, DC. pp. 1-10.

[3] Hyun-Kil Jo., Gregory, McPherson. E., 2001. Carbon storage and flux in urban residential greenspace. *J. Env. Manage*. 61, 165-177.

[4] Dwyer, John F., Mcpherson, E., Gregory, Schroeder, Herbert W., and Rowan, A. Rowntree., 1992. Assessing the benefits and costs of the urban forest. *J. Arboricult*. 18, 227-234.

[5] Sampson, R. N., Moll., Gary, A., Kielbaso, James J. 1992. Opportunities to increase urban forests and the potential impacts on carbon storage and conservation. In Forests and Global Change Volume One: Opportunities for Increasing Forest Cover (Dwight Hair and R Neil Sampson, eds.). *American Forests*, Washington, DC. pp. 51-72.

[6] Clark, D. A., Brown, S., Kiicklighter, D. W., Chambers, J. Q., Thomlinson, J. R. J. Ni., Holland, E. A., 2001a. Measuring net primary production in forest: An evaluation and synthesis of existing field data. *Ecol. Appl*. 11, 371-384.

[7] Twilley, R. R., Chen, R. H., Hargis, T., 1992. Carbon sinks in mangrove forests and their implications to the carbon budget of tropical coastal ecosystems. *Water Air Soil Pollut*. 64, 265-288.

[8] Robertson, A. I., Phillips, M. J., 1995. Mangroves as filters of shrimp pond effluent-Prediction and biogeochemical research needs. *Hydrobiol*. 295, 311-321.

[9] Vermatt, J. E., Thampanya, U., 2006. Mangroves mitigate tsunami damage: A further response. *Estuar. Coast. Shelf. Sci*. 69, 1-3.

[10] Constanza, R *et al*., 1997. The value of the world's ecosystem service and natural capital. *Ecol. Econ*. 25, 3-15.

[11] Gattuso, J. P., Frankignoulle, M., Wollast, R., 1998. Carbon and carbonate metabolism in coastal ecosystems. *Annu. Rev. Ecol. Syst*. 29, 405-434.

[12] Mackenzie, F. T., Lerman, A., Andersson, A. J., 2004. Past and present of sediment of carbon biogeochemical cycling models. *Biogeosci*. 1, 11-32.

[13] Odum, E. P., 1968. A research challenge: Evaluating the productivity of coastal and estuarine waters. In Proceedings of the 2nd Sea Grant Conference, *Univ. of Rhode Island* Kingston. pp. 63-64.

[14] Odum, W. E., Heald, E. J., 1972. Trophic analysis of an estuarine mangrove community. *Bull. Mar. Sci*. 22, 671-738.

[15] Kristensen, E., Bouillon, S., Dittmar, T., Marchand, C., 2008. Organic matter dynamics in mangrove ecosystems. *Aqua. Bot*. DOI 10.1016/ J Aqua. Bot. 2007 15.05 (in press).

[16] Hazra, S., Ghosh, T., Dasgupta, R., Sen, G., 2002. Sea level and associated changes in the Sundarbans. *Science and Culture*, 68, 309-321.

[17] Mitra, A., Banerjee, K., 2004. In: Living Resources of the Sea: Focus Indian Sundarbans, Published by WWF India. (Ed: *Col S.R. Banerjee*), Canning Field Office, 24 Parganas (S), W.B. pp 96.

[18] Fearnside, P. M., 1999. Forests and global warming mitigation in Brazil opportunities in the Brazilian forest sector for responses to global warming under the "clean development mechanism.". *Biomass Bioenergy* 16, 171-189.

[19] Mitra, Abhijit and Zaman, Sufia. 2014. In: Carbon Sequestration by Coastal Floral Community; published by The Energy and Resources Institute (TERI) TERI Press, India; Copyright *The Energy and Resources Institute 2014*; pp. 1-412; ISBN- 978-81-7993-551-4.

[20] Mitra, A., Zaman, S., Pramanick, P., Banerjee, K., 2014. Adaptive efficiency of *Avicennia marina* Seedlings to Climate Change induced Salinity fluctuation. *Int. Sc. J.* 1(1), 126 – 132.

[21] Chaudhuri, A. B., Choudhury, A., 1994. Mangroves of the Sundarbans. India, IUCN- *The World Conservation Union*, 1.

[22] Mitra, A., Gangopadhyay, A., Dube, A., C.K. Schmidt, Andre., Banerjee, K.. 2009. Observed changes in water mass properties in the Indian Sundarbans (north-western Bay of Bengal) during 1980–2007. *Curr. Sc.* 97(10), 1445-1452.

[23] Walkley, A., Black, I. A., 1934. "An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method". *Soil Sci*. 37, 29-38.

[24] Koul, D. N., Panwar, P., 2008. Prioritizing Land-management options for carbon sequestration potential. *Curr. Sci*. 95, 5-10.

[25] Mitra, A., Chaudhuri, T. R., Pal, N., Zaman, Z. and Mitra, A., 2017. Oxygen Generation by Dominant Urban Trees: A Case Study from Konnagar Municipality, West Bengal, India. *Biomedical J. Sci. & Tec. Research*. May 31, doi: 10.26717/BJSTR.2017.01.000114.

[26] Chidumaya, E. N., 1990. Aboveground woody biomass structure and productivity in a Zambezian woodland. *For. Ecol. & Manage*. 36, 33-46.

[27] Brown, S., Lugo, A. E., 1984. Biomass of tropical forests: a new estimate based on forest volumes. *Science* 223, 1290-1293.

[28] Jeffrie, F. M., Tokuyama, A., 1998. Litter production of Mangrove Forests at the Gesashi River. *Bull. Coll. Sci. Univ. Ryukyus*. 65, 73-79.

[29] Putz, F. E., Chan, H. T., 1986. Tree growth Dynamics and productivity in a mature mangrove forest in Malaysia. *For. Ecol & Manage*. 17, 211-230.

[30] Tamai, S., Nakasuga, T., Tabuchi, R., Ogino, K., 1986. Standing biomass of mangrove forests in Southern Thailand. *J. Jpn. For. Soc*. 68, 384-388.

[31] Komiyama, A., Ogino, K., Aksomkoae, S., Sabhasri, S., 1987. Root biomass of a mangrove forest in southern Thailand 1. Estimation by the trench method and the zonal structure of root biomass. *J. Trop. Ecol*. 3, 97-108.

[32] Clough, B. F., Scott, K., 1989. Allometric relationship for estimating above ground biomass in six mangrove species. *For. Ecol. & Manage*. 27, 117-127.

[33] McKee, K. L., 1995. Inter-specific variation in growth biomass partitioning and defensive characteristics of neotropical mangrove seedlings response to light and nutrient availability. *Amer. J. Bot*. 82, 299-307.

[34] Ong, J. E., Gong, W. K., Clough, B. F., 1995. Structure and productivity of a 20-year old stand of *Rhizophora apiculata* BL mangrove forest. *J. Biogeogr*. 55, 417-424.

[35] Komiyama, A., Havanond, S., Srisawatt, W., Mochida, Y., Fujimoto, K., Ohnishi, T., 2000. Ishihara S and Miyagi T 2000 Top root biomass ratio of secondary mangrove (*Ceriops tagal* (Perr.) C.B Rob.) forest. *For. Ecol. Manage*. 139, 127-134.

[36] Mitra, A., Banerjee, K., Bhattacharyya, D.P. 2004. In The Other Face of Mangroves. Published by *Department of Environment, Govt. of West Bengal*, India.

[37] Mitra, A., Banerjee, K., Sengupta, K., Gangopadhyay, A., 2009. Pulse of climate change in Indian Sundarbans: A myth or reality? *Natl. Acad. Sci. Lett*. 32, 1-2.

[38] Briggs, S. V., 1977. Estimates of biomass in a temperate mangrove community. *J. Aust. Ecol*. 2, 369-373.

[39] Aksomkoae, S., 1975. Structure regeneration and productivity of mangroves in Thailand. Ph.D. Dissertation, *Michigan State University*, pp. 1-109.

[40] De La Cruz, A. A., Banaag, B. F., 1967. The ecology of a small mangrove patch in Matabungkay Beach Batangas Province. *Natur. Appl. Sci. Bull*. 20, 486-494.

[41] Twilley, R., Lugo, A.E., Zucca, C. P., 1986. Litter production and turnover in basin mangrove forest in South- West Florida, USA. *Ecology* 67, (3): 670-683.

[42] Steinke, T.D., Charles. L.M., 1984. Productivity and phenology of *Avicennia marina* and *Bruguiera gymnorrhiza* in Mgeni estuary, South Africa. In Physiology and management of mangroves (Teas, H. J. ed.). *Dr. W. Junk Publisher*, The Hague, 25-36.

[43] Kishimoto, T., Miyajima, H., Nakasuga, T., Baba, S., 1987. Zonation of mangrove forest (III) litterfall and its seasonal change. *Trans. Mtg. Jap. For. Soc*. 98, 301-302. (in Japanese)

[44] Duke, N. C., Bunt, J. S., Williams, W.T., 1981. Mangrove litterfall in north- eastern Australia, Annual totals by component in selected species. *Australian J. Bot*. 29, 547-553.

[45] Hardiwinoto, S., Nakasuga, T., Igarashi, T., 1989. Litter production and decomposition of mangrove forest at Ohura Bay, Okinawa Research bulletins of the college Experiment Forest, *Hokkaido University*. 46 (3), 577-594.

[46] Lee, Y. S., 1990. Primary productivity and particulate organic matter flow in an estuarine a mangrove wetland in Hongkong. Marine Ecol. 106, 453-463.

[47] Gong, W.K., Ong, J. E., 1990. Plant biomass and nutrient flux in a managed mangrove forest in Malayasia. *Estuar. Coast. Shelf. Sci*. 31, 519-530.

[48] Mall, L., Singh, V. P., Garge, A., 1991. Study of biomass, litterfall, litter decomposition and soil respiration monogeneric and mixed mangrove forest of Andaman Island. *Trop. Ecol*. 32, 235-249.

[49] Mmochi, A. J., 1993. Ecology of mangrove ecosystems: Role of mangrove in dissolved inorganic nutrient fluxes, sediment budgets and litter supplies to Gesashi Bay, Higashi Village, Okinawa, Japan, pp 82. Thesis Master of Science, *Coll. Sci. Univ of the Ryuykyus*.

[50] Krishnamurthy, K., 1985. The changing landscape of the Indian Mangroves, Proceedings Natural. Symposium Biology, Utilization and Conservation of Mangroves, *Tamil Nadu*. 119-126.

[51] Yadav, V. K., Choudhury, A., 1985. Litter production in mangrove forest of Lothian island in Sunderbans. In Proceedings Natural. *Symposium Biology, Utilization and Conservation of Mangroves, West Bengal*. 227-229.

[52] Paterson, E., Hall, J.M., Rattray, E.A.S., Griffiths, B.S., Ritz, K., Killham, K., 1997. Effect of elevated CO_2 on rhizosphere carbon flow and soil microbial processes. *Global Change Biology*, 3, 363 – 377.

[53] Schlesinger, W. H., 1990. Evidence from chronosequence studies for a low carbon storage potential of soils. *Nature* 348, 232-234.

[54] Schimel, D.S., 1995. Terrestrial ecosystems and the carbon cycle. Global Change Biology. 1, 77-91.

[55] Canadell, J.G., Pitelka, L.F., Ingram, J.S.I., 1996. The effects of elevated [CO_2] on plant-soil carbon below - ground: A summary and synthesis. *Plant soil*, 187, 391 – 400.

Tables

Table 1. Relative abundance of mangrove species (mean of 15 plots/station) in the study area; **(Average data of 5 sampling stations in the west and central sectors are presented);** Figures within bracket indicate the value in each station.

Species	**No./100m²**		**Relative abundance (%)**	
	Western	**Central**	**Western**	**Central**
Sonneratia apetala	13 (10, 12, 15, 15, 13)	5 (4, 6, 3, 10, 2)	27.08	13.16
Excoecaria agallocha	9 (8, 7, 10, 10, 10)	9 (13, 10, 3, 4, 15)	18.75	23.68
Avicennia alba	7 (9, 9, 6, 5, 6)	8 (10, 11, 9, 1, 9)	14.58	21.05
Avicennia marina	6 (5, 7, 7, 4, 7)	6 (7, 9, 4, 3, 7)	12.5	15.79
Avicennia officinalis	6 (8, 2, 4, 7, 9)	6 (12, 5, 3, 3, 7)	12.2	15.79
Acanthus ilicifolius	3 (5, 2, 1, 3, 4)	4 (5, 4, 3, 1, 7)	6.25	10.53
Aegiceros corniculatum	2	ab	4.17	-
Bruguiera gymnorrhiza	1	ab	2.08	-
Xylocarpous molluscensis	1	ab	2.08	-

'ab' means absence of the species in the selected plots.

Table 2A. Above ground biomass (t/ha) of five dominant mangrove species in the intertidal mudflats during **September, 2009** (average data of 5 sampling stations in the west and central sectors are presented)

Mangrove vegetative part	***Sonneratia apetala***		***Excoecaria agallocha***		***Avicennia alba***		***Avicennia marina***		***Avicennia officinalis***	
	Western	Central	Western	Central	Western	Central	Western	Central	Western	Central
Stem	104.09	21.68	14.09	9.27	27.20	15.56	21.37	11.93	21.46	6.18
Branch	42.64	9.03	6.30	3.81	12.42	6.30	10.08	5.25	9.23	2.59
Leaf	22.88	4.33	3.22	1.85	7.07	2.96	4.83	2.20	5.46	1.24
Total (AGB)	**169.61**	**35.04**	**23.61**	**14.93**	**46.69**	**24.82**	**36.28**	**19.38**	**36.15**	**10.01**

Table 2B. Above ground biomass (t/ha) of five dominant mangrove species in the intertidal mudflats during **December, 2009** (average data of 5 sampling stations in the west and central sectors are presented)

Mangrove vegetative part	*Sonneratia apetala*		*Excoecaria agallocha*		*Avicennia alba*		*Avicennia marina*		*Avicennia officinalis*	
	Western	Central	Western	Central	Western	Central	Western	Central	Western	Central
Stem	113.35	22.18	15.25	9.98	29.18	16.65	22.48	12.88	22.18	6.42
Branch	43.07	9.09	6.48	3.90	12.98	6.33	9.99	5.19	9.09	2.70
Leaf	23.97	4.41	3.25	1.87	7.10	3.05	4.62	2.18	5.05	1.15
Total (AGB)	**180.39**	**35.68**	**24.98**	**15.75**	**49.26**	**26.03**	**37.09**	**20.25**	**36.32**	**10.27**

Table 2C. Above ground biomass (t/ha) of five dominant mangrove species in the intertidal mudflats during **March, 2010** (average data of 5 sampling stations in the west and central sectors are presented)

Mangrove vegetative part	*Sonneratia apetala*		*Excoecaria agallocha*		*Avicennia alba*		*Avicennia marina*		*Avicennia officinalis*	
	Western	Central	Western	Central	Western	Central	Western	Central	Western	Central
Stem	116.74	22.45	15.55	10.12	30.34	17.14	23.13	17.35	22.73	7.17
Branch	43.43	7.77	6.03	3.60	11.91	5.79	9.64	4.96	8.45	2.79
Leaf	22.85	4.15	3.21	1.80	6.90	2.99	4.39	2.16	4.44	1.13
Total (AGB)	**183.02**	**34.37**	**24.79**	**15.52**	**49.15**	**25.92**	**37.16**	**24.47**	**35.62**	**11.09**

Parana Journal of Science and Education (PJSE) – v.4, n.4, (7-29) June 17, 2018
ISSN: 2447-6153 https://sites.google.com/site/pjsciencea

Table 3A. Seasonal variation of above ground biomass (t/ha) of ***Sonneratia apetala*** in the intertidal mudflats (average data of 5 sampling stations in each sector is presented)

	Western					Central				
Plants Part	Sep. 2009	Dec. 2009	Mar. 2010	(%) Increase/Decrease		Sep. 2009	Dec. 2009	Mar. 2010	(%) Increase/Decrease	
				Dec. over Sep.	Mar. over Dec.				Dec. over Sep.	Mar. over Dec.
Stem	104.09	113.35	116.74	8.90	2.99	21.68	22.18	22.45	2.31	1.22
Branch	42.64	43.07	43.43	1.01	0.84	9.03	9.09	7.77	0.66	-14.52
Leaf	22.88	23.97	22.85	4.76	-4.67	4.33	4.41	4.15	1.85	-5.90
Total (AGB)	**169.61**	**180.39**	**183.02**	**6.35**	**1.46**	**35.04**	**35.68**	**34.37**	**1.83**	**-3.67**

Table 3B. Seasonal variation of above ground biomass (t/ha) of ***Excoecaria agallocha*** in the intertidal mudflats (average data of 5 sampling stations in each sector is presented)

	Western					Central				
Plants Part	Sep. 2009	Dec. 2009	Mar. 2010	(%) Increase/Decrease		Sep. 2009	Dec. 2009	Mar. 2010	(%) Increase/Decrease	
				Dec. over Sep.	Mar. over Dec.				Dec. over Sep.	Mar. over Dec.
Stem	14.09	15.25	15.55	8.23	1.97	9.27	9.98	10.12	7.66	1.40
Branch	6.30	6.48	6.03	2.86	-6.94	3.81	3.90	3.60	2.36	-7.69
Leaf	3.22	3.25	3.21	0.93	-1.23	1.85	1.87	1.80	1.08	-3.74
Total (AGB)	**23.61**	**24.98**	**24.79**	**5.80**	**-0.76**	**14.93**	**15.75**	**15.52**	**5.49**	**-1.46**

Table 3C. Seasonal variation of above ground biomass (t/ha) of ***Avicennia alba*** in the intertidal mudflats (average data of 5 sampling stations in each sector is presented)

Western						Central				
Plants Part	Sep. 2009	Dec. 2009	Mar. 2010	(%) Increase/Decrease		Sep. 2009	Dec. 2009	Mar. 2010	(%) Increase/Decrease	
				Dec. over Sep.	Mar. over Dec.				Dec. over Sep.	Mar. over Dec.
Stem	27.20	29.18	30.34	7.28	3.98	15.56	16.65	17.14	7.01	2.94
Branch	12.42	12.98	11.91	4.51	-8.24	6.30	6.33	5.79	0.48	-8.53
Leaf	7.07	7.10	6.90	0.42	-2.82	2.96	3.05	2.99	3.04	-1.97
Total (AGB)	**46.69**	**49.26**	**49.15**	**5.50**	**-0.22**	**24.82**	**26.5**	**25.92**	**6.77**	**-2.19**

Table 3D. Seasonal variation of above ground biomass (t/ha) of ***Avicennia marina*** in the intertidal mudflats (average data of five sampling stations in each sector is presented)

Western						Central				
Plants Part	Sep. 2009	Dec. 2009	Mar. 2010	(%) Increase/Decrease		Sep. 2009	Dec. 2009	Mar. 2010	(%) Increase/Decrease	
				Dec. over Sep.	Mar. over Dec.				Dec. over Sep.	Mar. over Dec.
Stem	21.37	22.48	23.13	5.19	2.89	11.93	12.88	17.35	7.96	34.70
Branch	10.08	10.55	9.64	4.66	- 8.63	5.25	5.30	4.96	- 0.95	-6.42
Leaf	4.83	4.90	4.39	1.45	-10.41	2.20	2.28	2.16	3.64	-5.26
Total (AGB)	**36.28**	**36.55**	**37.43**	**0.74**	**2.41**	**19.38**	**20.25**	**24.88**	**4.49**	**22.86**

Table 3E. Seasonal variation of above ground biomass (t/ha) of ***Avicennia officinalis*** in the intertidal mudflats (average data of 5 sampling stations in each sector is presented)

	Western					Central				
Plants Part	**Sep. 2009**	**Dec. 2009**	**Mar. 2010**	**(%) Increase/Decrease**		**Sep. 2009**	**Dec. 2009**	**Mar. 2010**	**(%) Increase/Decrease**	
				Dec. over Sep.	**Mar. over Dec.**				**Dec. over Sep.**	**Mar. over Dec.**
Stem	21.46	22.18	22.73	3.36	2.48	6.18	6.42	7.17	3.88	11.68
Branch	9.23	9.29	9.11	0.65	-1.94	2.59	2.70	2.45	4.25	-9.26
Leaf	5.46	5.65	5.35	3.48	- 5.31	1.24	1.32	1.13	6.45	-14.39
Total (AGB)	**17.27**	**17.98**	**18.19**	**2.68**	**0.19**	**4.59**	**4.89**	**5.12**	**4.30**	**2.97**

Table 4A. Monthly variation of leaf litter fall, miscellaneous litter fall and total litter fall in a mangrove stand at Chemaguri (representative station of western Indian Sundarbans)

Months	**Leaf litter fall ($gm.m^{-2}d^{-1}$)**	**Miscellaneous litter fall ($gm.m^{-2}d^{-1}$)**	**Total litter fall ($gm.\ m^{-2}\ d^{-1}$)**
September, 2009	1.033	0.517	3.103
October	1.015	0.398	2.685
November	0.985	0.346	2.321
December	0.991	0.302	1.826
January, 2010	0.973	0.337	1.278
February	0.789	0.293	1.297
March	1.005	0.494	2.879
Total production ($t\ ha^{-1}\ y^{-1}$)	**3.54**	**1.40**	**8.05**

Table 4B. Monthly variation of leaf litter fall, miscellaneous litter fall and total litter fall in a mangrove stand at Satjelia Island (representative station of central Indian Sundarbans)

Months	Leaf litter fall ($gm.m^{-2}d^{-1}$)±SD	Miscellaneous litter fall ($gm.m^{-2}d^{-1}$)±SD	Total litter fall ($gm. m^{-2} d^{-1}$) ±SD
September, 2009	0.975 ± 0.048	0.295 ± 0.018	2.070 ± 0.061
October	0.815 ± 0.075	0.185 ± 0.011	1.600 ± 0.075
November	0.486 ± 0.053	0.119 ± 0.026	1.105 ± 0.032
December	0.273 ± 0.022	0.177 ± 0.016	1.350 ± 0.033
January, 2010	0.423± 0.230	0.321 ± 0.075	1.044 ± 0.031
February	0.448 ± 0.275	0.238 ± 0.376	1.086 ± 0.052
March	0.881 ± 0.358	0.366 ± 0.097	1.747 ± 0.073
Total production ($t\ ha^{-1}\ y^{-1}$)	**2.24**	**0.888**	**5.22**

Table 5A.Variation of soil pH in sampling site.

Station	Western Sector			Station	Central Sector		
	September 2009	December 2009	March 2010		September 2009	December 2009	March 2010
1	7.21	7.30	7.30	**6**	7.10	7.22	7.19
2	7.07	7.19	7.25	**7**	7.33	7.40	7.38
3	7.31	7.35	7.46	**8**	7.32	7.37	7.41
4	7.45	7.48	7.52	**9**	7.38	7.40	7.45
5	7.15	7.20	7.29	**10**	7.41	7.46	7.50
Average	**7.24**	**7.30**	**7.36**	**Average**	**7.32**	**7.37**	**7.39**

Table 5B. Variation of surface water salinity in sampling site.

Station	Western Sector			Station	Central Sector		
	September 2009	December 2009	March 2010		September 2009	December 2009	March 2010
1	3.18	8.32	15.65	**6**	4.39	10.85	20.10
2	6.05	13.78	21.54	**7**	7.15	22.30	28.75
3	3.37	12.88	16.09	**8**	6.90	20.83	27.12
4	9.02	19.86	26.22	**9**	7.83	21.77	29.39
5	10.15	20.78	27.95	**10**	6.99	21.93	28.82
Average	**6.35**	**15.12**	**21.49**	**Average**	**6.65**	**19.54**	**26.84**

Table 6A. Above ground carbon stock (t/ha) of five dominant mangrove species in the intertidal mudflats during Sept., 2009 (Average data of 5 sampling stations in each sector is presented)

Mangrove vegetative part	*Sonneratia apetala*		*Excoecaria agallocha*		*Avicennia alba*		*Avicennia marina*		*Avicennia officinalis*	
	Western	Central	Western	Central	Western	Central	Western	Central	Western	Central
Stem	44.65	9.69	5.88	3.77	12.26	6.98	10.21	5.48	10.30	2.85
Branch	17.90	3.76	2.58	1.53	5.46	2.64	4.67	2.34	4.32	1.16
Leaf	10.59	1.94	1.36	0.75	3.40	1.33	2.31	1.03	2.65	0.58
Total (AG Carbon stock)	**73.14**	**15.39**	**9.82**	**6.05**	**21.12**	**10.95**	**17.19**	**8.85**	**17.27**	**4.59**

Parana Journal of Science and Education (PJSE) – v.4, n.4, (7-29) June 17, 2018
ISSN: 2447-6153 https://sites.google.com/site/pjsciencea

Table 6B. Above ground carbon stock (t/ha) of five dominant mangrove species in the intertidal mudflats during December, 2009 (Average data of 5 sampling stations in each sector is presented)

Mangrove vegetative part	*Sonneratia apetala*		*Excoecaria agallocha*		*Avicennia alba*		*Avicennia marina*		*Avicennia officinalis*	
	Western	Central	Western	Central	Western	Central	Western	Central	Western	Central
Stem	51.34	9.98	6.60	4.16	13.68	7.65	10.90	6.01	10.77	3.04
Branch	18.47	3.82	2.71	1.59	5.87	2.79	4.95	2.39	4.42	1.22
Leaf	11.48	1.99	1.42	0.79	3.44	1.44	2.41	10.7	2.79	0.63
Total (AG Carbon stock)	**81.29**	**15.79**	**10.73**	**6.54**	**22.99**	**11.88**	**18.26**	**9.47**	**17.98**	**4.89**

Table 6C. Above ground carbon stock (t/ha) of five dominant mangrove species in the intertidal mudflats during March, 2010 (Average data of 5 sampling stations in each sector is presented)

Mangrove vegetative part	*Sonneratia apetala*		*Excoecaria agallocha*		*Avicennia alba*		*Avicennia marina*		*Avicennia officinalis*	
	Western	Central	Western	Central	Western	Central	Western	Central	Western	Central
Stem	53.93	10.34	6.98	4.33	14.44	8.02	11.28	8.18	11.16	3.44
Branch	19.76	3.40	2.55	1.50	5.49	2.61	4.55	2.28	4.37	1.13
Leaf	11.10	1.93	1.49	0.82	3.39	1.42	2.16	1.04	2.66	0.55
Total (AG Carbon stock)	**84.79**	**15.67**	**11.02**	**6.65**	**23.32**	**12.05**	**17.99**	**11.5**	**18.19**	**5.12**