GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

STATUS OF STORED CARBON IN MANGROVES OF LOWER GANGETIC DELTA

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ABSTRACT

Mangrove forests, mostly concentrated at the land-sea interface and estuarine delta naturally sequester carbon dioxide during photosynthesis. Over time carbon accumulates in the trees, forest-floor (in form of litter) and soil. Approximately 39% - 43% of the dry above ground biomass of 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. Here we provide a comprehensive synthesis of the available data on carbon stock in two forest patches distributed in the western and central sectors of Indian Sundarbans, a Gangetic delta at the apex of Bay of Bengal. The sampling stations were selected considering contrasting physiographic variability. The two patches are significantly different with respect to above ground biomass, carbon stock and carbon dioxide equivalent per hectare. The organic carbon and mangrove litter production rate also showed spatial variation. This may be attributed to drastically different environmental conditions to which these forest patches are exposed to, on account of massive siltation that prevent the flow of Gangetic fresh water to the central sector of the study area. The carbon stock in the above ground biomass varied as per the order Sonneratia apetala > Avicennia alba > Avicennia marina > Avicennia officinalis > Excoecaria agallocha in the western sector, but the mangroves thriving along the tide fed Matla River in the central sector exhibited stored carbon as per the sequence Sonneratia apetala > Avicennia alba > Avicennia marina > Excoecaria agallocha > Avicennia officinalis.

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Keywords- *Carbon stock; Mangroves; Above Ground Biomass; Carbon dioxide equivalent.*

I. INTRODUCTION

The general consensus among climate researchers and environmentalists is that increased levels 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. Carbon dioxide (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 of carbon was released into the air just for land-use changes [1]. Most of the increase has been since 1940 [2]. The atmospheric CO_2 concentration is currently rising by 4% per decade [3]. Worldwide concern about climate change has created increasing interest in trees to help reduce the level of atmospheric CO_2 [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 [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 [6]. Although the area covered by mangrove ecosystems represent only a small fraction of tropical forests, their position at the terrestrial-ocean interface and potential exchange with coastal water suggests these forests make a unique contribution to carbon biogeochemistry in coastal ocean [7]. Mangrove ecosystems thrive along coastlines throughout most of the tropics and subtropics. About 75% of tropical and sub-tropical countries of the world comprise of mangrove forests [8]. These intertidal forests play important ecological and socioeconomic roles by acting as a nutrient filter between land and sea [9], contributing to coastline protection [10], providing commercial fisheries resources [11] and nursery grounds for coastal fishes and crustaceans. The coastal zone (<200 m depth), covering ~7% of the ocean surface [12] 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 [12, 13]. 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 [14] and Odum and Heald [15] suggested 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 have indicated that 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 [16], 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 in 1987 and 1989 respectively by UNESCO owing to its unique biological productivity, taxonomic diversity and aesthetic beauty. To preserve the ecosystem in its pristine form, mangrove plantation is carried out on regular basis in the entire Gangetic delta complex. 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 [17,18]. 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 [19]. 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 four major compartments. 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.

In this study, the above ground stem, branch, and leaf biomass, litter and soil were analyzed for carbon content in two different physiographic sets of Indian Sundarbans. The difference is caused by freshwater supply from Himalayan glaciers (largest glacial coverage ~ 34,660 km^2) through Farakka barrage in the western part of Gangetic delta. The barrage was constructed in 1975 to ensure availability of water to the riverine ports. The Ganga-Bhagirathi-Hooghly river system in the western part of Indian Sundarbans is therefore appropriately diluted in relation to mangrove growth. In contrast, the Matla River in the central sector is disconnected to the Himalayan glaciers' freshwater 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 climatic signals in salinity profile and mangrove growth leading to variation in carbon pool under different environmental conditions.

II. MATERIALS AND METHODS

A. Study site description

Two sampling sites were selected each in the western and central sectors in and around Indian Sundarbans, a Gangetic delta at the apex of the Bay of Bengal (Fig. 1). The deltaic complex has an area of 9630 sq. km and houses 102 islands. 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 [20]. The station in the western part lies at the confluence of the river Hooghly (a continuation of Ganga-Bhagirathi system) and Bay of Bengal. The site is locally known as Sagar South (88°01'47.28" N latitude and 21°31'4.68" E longitude). In the central sector, the sampling station was selected at Canning (88°40'36.84" N latitude and 22°18'37.44" E longitude), adjacent to tide fed Matla River. Samplings in both these sectors were carried out in low tide period during January 2016.

In each sector, 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 was evaluated for the order of dominance of mangrove species at the study sites.

The above ground biomass (AGB) of individual trees of five dominant species namely *Sonneratia apetala, Avicennia alba, Avicennia marina, Avicennia officinalis* and *Excoecaria agallocha* in each plot was estimated as per the standard procedure stated here and the average values of 15 plots were finally converted into biomass (in tonnes) per hectare in the study area. Litter production studies were carried out in both the sectors through net collection method and organic carbon in the soil substratum was analyzed following the modified method of Walkley and Black [21].

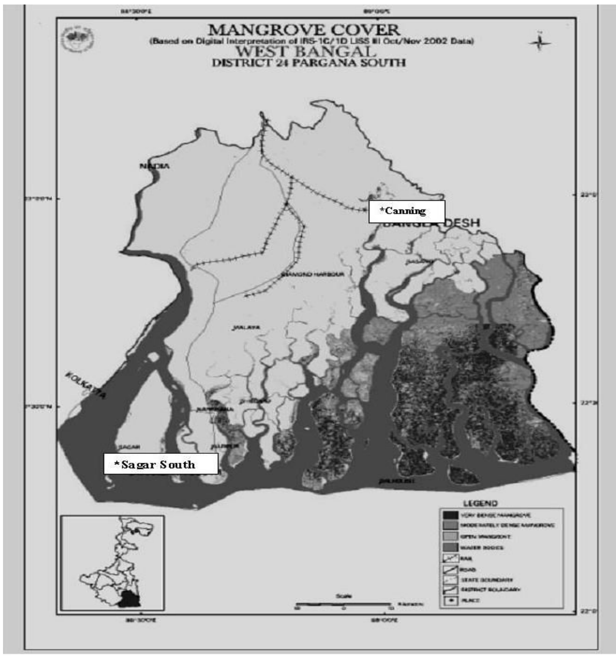

Fig. 1 Location of sampling stations in the western and central sectors of Indian Sundarbans

B. Above ground stem biomass estimation

The above ground (stem) biomass of individual trees of each species in every plot was estimated using non-destructive method in which the diameter at the breast height (DBH) was measured with a caliper and height with Ravi's multimeter. Form factor was determined as per the standard expression [22] with Spiegel relascope to find out the tree volume (V) using the standard formula given [23, 24]. Specific gravity (G) was estimated taking the stem cores, which was further converted into stem biomass (B_S) as per the expression $B_S = GV$. The expression for V is $FH\Pi R^2$, where F is the form factor, R is the radius of the tree derived from its DBH and H is the height of the target tree.

C. Above ground 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. <5 cm, 5–10 cm and >10 cm. Fresh weight of two branches from each size group was recorded separately. Dry weight of branches was estimated using the standard equation [25].

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

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

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, . . .the branch groups (i = 3 in the present study). This procedure was followed for all the dominant mangrove species separately in both the sectors of the study area.

D. Above ground leaf biomass estimation

Leaves from ten branches (of all the three size groups) 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 to a constant weight at 80 ± 5^0C. The species-wise 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:

$$L_{db} = n_1Lw_1N_1 + n_2Lw_2N_2 + \ldots\ldots\ldots n_5Lw_5N_5$$

Where, L_{db} is the dry leaf biomass of dominant mangrove species per plot, n_i ….n_5 are the number of branches of each tree of five dominant species, Lw_1 …..Lw_5 are the average dry weight of leaves removed from ten branches of each of the five species and N_1 to N_5 are the number of trees per species in the plot.

E. Litter fall estimation

Litter fall was determined by setting 15 rectangular traps (3m × 3m) in all the 15 plots in each sector. The traps were made of 1mm mesh size nylon screen, through which rainwater can pass [26]. The traps were positioned above the high tide level [27] and contents of all the 15 traps per sector were collected and brought to the laboratory after duration of one month. The collected materials were segregated into leaves and miscellaneous fraction that comprised of fruits, twigs, stipules, flowers etc. The materials were dried separately to a constant weight 80±5° C. Finally the mean weight per plot was estimated for both the western and central sectors in the study area and transformed into gm^{-2} day^{-1} unit.

F. Carbon estimation in trees

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 LECO® CHN-600 analyzer. For litter, the same procedure was followed after oven drying the net collection at 70ºC.

G. Organic Carbon analysis in soil

Soil samples from the upper 5 cm were collected from all the 15 plots and dried at 60^0C for 48 hrs. For analysis, visible plant particles and other organisms (like mollusks, crabs, decaying bodies of fishes *etc*.) 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 sector-wise representative picture of the study site. Modified version of Walkley and Black method [21] was then followed to determine the organic carbon of the soil in %.

III. RESULTS & DISCUSSION

The biomass and productivity of mangrove forests have been studied mainly in terms of wood production, forest conservation, and ecosystem management [28-33]. 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. The present sectorial case study has also been undertaken with the aim to visualize the impact of salinity on the biomass and carbon budget of mangrove system.

H. Relative abundance

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 order in 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, only five dominant species namely, *Avicennia alba*, *Avicennia marina*, *Excoecaria agallocha* *Sonneratia apetala*, and *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.

I. Above ground stem biomass

In the western sector, the above ground stem biomass of the dominant mangrove trees 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 2). The values in the western sector are similar to the earlier study [34] in a secondary mangrove (*Ceriops tagal*) forest at Southern Thailand.

Table 1 Relative abundance of mangrove species (mean of 15 plots) in the study area

Species	No./100m²		Relative abundance (%)	
	Western sector	*Central sector*	*Western sector*	*Central sector*
Sonneratia apetala	13	5	27.08	13.16
EXCOECARIA AGALLOCHA	9	9	18.75	23.68
AVICENNIA ALBA	7	8	14.58	21.05
Avicennia marina	6	6	12.5	15.79
Avicennia officinalis	6	6	12.5	15.79
Acanthus ilicifolius	3	4	6.25	10.53
Aegiceros corniculatum	2	ab[a]	4.17	-
Bruguiera gymnorrhiza	1	ab[a]	2.08	-
Xylocarpous molluscensis	1	ab[a]	2.08	-

[a] 'ab' means absence of the selected species in the selected plots of the study site

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 Ganges. Mangroves, in general, prefer brackish water environment and in extreme saline condition stunted growth is observed [35]. The western sector of Indian Sundarbans provides a congenial environment for mangrove sustenance due to fresh water discharge from Farakka barrage in the Hooghly estuarine system. Five-year surveys (1999 to 2003) on water discharge from Farakka barrage revealed an average discharge of $(3.4 \pm 1.2) \times 10^3$ m^3s^{-1}. Higher discharge values were observed during the monsoon with an average of $(3.2 \pm 1.2) \times 10^3$ 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 $(1.2 \pm 0.09) \times 10^3$ 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 $2.1 \pm 0.98) \times 10^3$ 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-Hooghly system and their tributaries. All these factors (dam discharge + precipitation + runoff) increase the dilution factor of the Hooghly 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 discharge on account of siltation of Bidyadhari River which may be accounted for low above ground stem biomass of the selected mangrove species inhabiting the zone.

J. Above ground branch biomass

The branch biomass of mangroves showed marked differences between the trees of western and central sectors. In western sector, the values 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 central sectors 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 2). 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 in earlier study [36]. Stunted branches of mangroves of central sector may again be related to high salinity in this sector [37].

K. Above ground 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* (Table. 2). The values in the western sector are comparatively similar to the records of other workers like 12.1 -15.0 t ha^{-1} in *Avicennia* forests (Briggs, 1977), 6.2 – 20.2 t ha^{-1} in *Rhizophora apiculata* young plantations (Aksomkoae, 1975), 13.3 t ha^{-1} in *Rhizophora* patch [38] and 8.1 t ha^{-1} in a matured *Rhizophora* forest [39].

Table 2 Above ground biomass (t/ha) of five dominant mangrove species in the intertidal

Mangrove vegetative part	***Sonneratia apetala***		***Excoecaria agallocha***		***Avicennia alba***		***Avicennia marina***		***Avicennia officinalis***	
	Western sector	***Central sector***	***Western sector***	***Central sector***	***Western sector***	***Central sector***	***Western sector***	***Central sector***	***Western sector***	***Central sector***
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

L. Litter production

Average values of total litter, leaf litter and miscellaneous litter fall (comprised of twigs, stipules, flowers and fruits) are shown in Fig. 2. The biomass of total litter is more in the western sector in comparison to central part of Indian Sundarbans. The leaf litter accounted for nearly 70% and 64% of the total litter in the western and central sectors respectively.

Although we have not studied the litter fall throughout the year but a significant difference was observed between western and central sectors of the study area with respect to quantum and rate of litter production. The value in the western sector is comparable to the data of several workers. According to Twilley *et al.* [39] 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 [40] reported the total annual litter fall of mangrove forest in the Mgeni estuary was 8.61 t ha^{-1} yr^{-1}. According to earlier study [41] the litter fall 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} [39, 42-47]. In context to Indian mangrove system, the mangrove litter production was recorded as 7.50 tonnes/ha/yr in Pichavaram at Tamil Nadu [48], in which leaf biomass amounts to about 80-90% [49]. Assuming hypothetical situation of uniformity in litter fall through seasons, our data may be interpolated to yield an annual litter production of 3.19 t ha^{-1} in the western sector and 1.33 t ha^{-1} in the central sector respectively. The lower value of litter production in the central Indian Sundarbans may be attributed to the trend of rising salinity due to siltation of Bidyadhari River in the present geographical locale [20]. The growth, survival, and biomass of mangroves depend on appropriate dilution of the brackish water system with fresh water. The central sector of Indian Sundarbans hardly witness such dilution as the freshwater discharge of the Ganga-Bhagirathi system cannot reach the area due to clogging of the Bidyadhari River by silt and solid wastes [38]. The rivers in the study area are noted for their silt carrying potential. It has been reported that each year Ganga and Brahmaputra bring around 166.70 crore tonnes of silt that has created the present Gangetic delta and the building process is still ongoing.

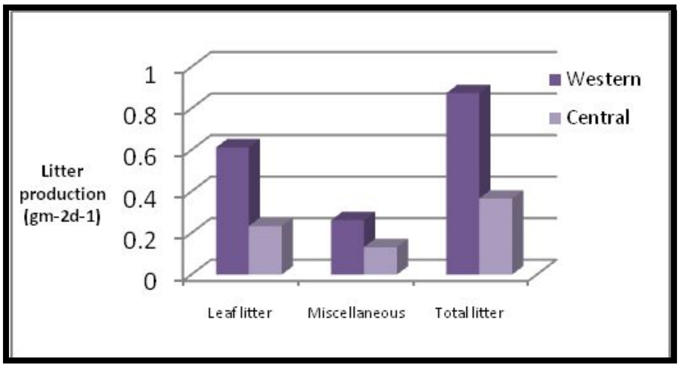

Fig. 2 Variation in leaf litter, miscellaneous litter and total litter in the western and central sectors of Indian Sundarbans.

Table 3 Above ground carbon stock (t/ha) of five dominant mangrove species in the intertidal

Mangrove vegetative part	***Sonneratia apetala***		***Excoecaria agallocha***		***Avicennia alba***		***Avicennia marina***		***Avicennia officinalis***	
	Western sector	***Central sector***	***Western sector***	***Central sector***	***Western sector***	***Central sector***	***Western sector***	***Central sector***	***Western sector***	***Central sector***
Stem	43.51	8.63	5.78	3.81	11.07	6.32	8.48	4.89	9.14	2.61
Branch	18.34	3.61	2.63	1.55	5.25	2.52	4.19	2.09	3.98	1.03
Leaf	9.38	1.69	1.29	0.73	2.80	1.16	2.02	0.88	2.38	0.50
Total (AG Carbon stock))	71.23	13.93	9.70	6.09	19.12	10.00	14.69	22.55	15.50	4.14

M. Soil organic carbon

The values of organic carbon were 2.78% in the western sector and 0.58% in the central sector. These values 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' [50]. Strong evidence for a long-term sink for increased atmospheric CO_2 in soils is still lacking [51-53]. Our study indicate that high saline soil are relatively poor sink of CO_2, which may be attributed to either poor growth of mangroves [35] or low fertility of the soil in terms of nitrogen that acts as retarding factor for plant growth. Canadell *et al.* [54] opined that soil quality may influence sequestration of carbon in response to increased atmospheric CO_2. Soil fertility may control the carbon inputs into the soil, since CO_2 enrichment can stimulate plant growth only in soils with adequate nutrients [53]. Absence of nutrient in the soil of central sector may therefore be considered as plausible cause of poor plant growth in the area as reflected through comparatively low soil organic carbon content.

N. 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 10^0 latitude [7]. For the present study, the results of carbon stock in the above ground biomass of the selected species are shown in Table 3. 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. The % of carbon in the mangrove litter was 31.8 and 29.3 in the western and central sectors respectively. On the basis of the % carbon and average daily production values, the carbon stock of the litter were 1.01 t ha^{-1} yr^{-1} and 0.39 t ha^{-1} yr^{-1} in the western and central sectors respectively (Table 4). The soil organic carbon also exhibited similar trend with higher value in the western sector (2.78%) than that of the central region (0.58%). Considering the carbon pool in the above ground biomass of the dominant mangrove species and total litter and assuming seasonal uniformity in carbon stock the corresponding CO_2 equivalents ha^{-1} yr^{-1} in western and central sectors of Indian Sundarbans were 477.55 t and 154.07 tonnes respectively (Table 4), which are effective figures when the present trend of atmospheric CO_2 rise is 4% per decade [55]. These figures can be manipulated through effective soil management, tidal interactions (through artificial canalization) and proper dilution of the system with freshwater, which are important requisites for accelerating the biomass of mangrove species. 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). Higher salinity has therefore reduced the floral growth, and subsequent litter production and organic carbon in soil of central sector of Indian Sundarbans. Interlinking of the tide fed rivers of the central portion with the Ganga-Bhagirathi-Hooghly river system in the western part might serve as an effective management strategy for accelerating the mangrove plant biomass and subsequent rate of carbon sequestration by the mangrove system in the central sector around the Matla River.

Table 4 Carbon stock and CO_2 equivalent in AGB of dominant mangrove species and litter in t ha^{-1} yr^{-1} in the western and central sectors of Indian Sundarbans

Sampling station	**Component**	**AGB**	**Litter**	**Interpretation**
Sagar south (88° 01' 47.28" N latitude and 21° 31' 4.68" E Longitude) in the western sector	C	130.24	1.01	Dilution of the Hooghly River by ice melt water from Himalaya through barrage regulation
	CO_2 equivalent	477.55	11.70	
Canning (88° 40' 36.84" N Latitude and 22° 18' 37.44" E Longitude) in the central sector	C	42.02	0.39	Disconnection of fresh water supply due to massive siltation in the Bidyadhari River leading to higher aquatic salinity
	CO_2 equivalent	154.07	4.91	

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