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Role of edaphic factors on the growth of dominant mangrove species in Indian Sundarbans

[*] Mahua Roy Chowdhury, Tarun Kumar De, Santosh Kumar Sarkar
Department of Marine Science, University of Calcutta, Kolkata, West Bengal, India

Abstract
We evaluated the above-ground biomass (AGB) of five even aged dominant mangrove species (*Avicennia officinalis, Avicennia marina, Avicennia alba, Sonneratia apetala and Excoecaria agallocha*) in the western and central sectors of Indian Sundarbans during 2012 to 2014. Among the studied species, *Avicennia officinalis* showed maximum above-ground biomass followed by *A. alba*, *A. marina*, *S. apetala* and *E. agallocha*. The Biomass of above-ground structures (stem, branch and leaf) of the species vary significantly with spatial location ($p<0.05$), the values being more in western sector on account of higher stem biomass. Salinity and availability of nutrients posed significant impact on the biomass and growth of studied mangrove species. The *Avicennia spp.* has extreme salt tolerance capacity with unique morphological characteristics such as salt secreting salt glands in leaves as well as efficient salt filtration capacity at the roots, reflecting considerable resilience of the species to sea level rise.

Keywords: Indian Sundarbans, above-ground biomass, growth, mangroves, salinity, nutrients

1. Introduction

Mangroves are diverse and highly productive ecological communities [13], which provide important ecosystem functions [25]. They protect coastal areas against natural hazards such as cyclones and tsunamis [9, 10, 16, 33], they serve as an important habitat such as breeding, spawning and nursery ground for commercial fish species and support enormous biodiversity [25]. The Sundarbans Mangrove Forest is particularly critical and a highly fragile ecosystem because of its complex geo-morphological and environmental settings, enormous population density and gradual shrinking of the islands under the rising Sea level [11]. The mangrove ecosystem of Indian Sundarbans has lost a considerable proportion of vegetation due to shrimp farming, unplanned tourism, urbanization and several anthropogenic pressures [4, 21]. Realizing the role of the vegetation in defending natural calamities like cyclones, tidal surges and tsunami, thrust has been given to restore the system. Massive afforestation has been initiated by government agencies, NGOs and several eco-clubs as a part of the ecorestoration programme. Now-a-days afforestation of several mangrove species in the river flats, river slopes and the intertidal deltaic lands of the Sundarbans area have been noticed as a common eco-developmental practice [1]. However, a critical field survey revealed that each and every major elements of the mangrove require some specific sediment nutrient status and tidal inundation behaviour. Till date no study has yet been undertaken to know the role of the nutrients (whether synergistic or antagonistic) on the growth of the mangroves in the frame work of Indian Sundarbans. On this background, the present paper is trying to establish a baseline of the role of edaphic factors on the growth of dominant mangroves and to assess the above-ground biomass production of five dominant mangrove species (*Avicennia alba*, *Avicennia marina*, *Avicennia officinalis*, *Sonneratia apetala* and *Excoecaria agallocha*) in the Indian Sundarbans.

2. Materials and methods

2.1 Study Area

The Indian Sundarbans (21˚13' to 22˚ 40' N and 88˚ 03' to 89˚ 07' E) is the largest delta in the estuarine phase of the River Ganges, situated in the low lying, meso-macrotidal, humid and tropical belt. The Indian Sundarbans falls within the geographical limits of the Dampier and Hodges line in the north, Bangladesh in the east, the Hooghly River (a continuation of the River Ganga) in the west and the Bay of Bengal in the south [4]. The deltaic complex has an area of 9,630 sq. km comprising of 102 islands, out of which 48 are inhabited and 54 are uninhabited [24]. The flow of Ganges (Bhagirathi) River through Hugli estuary in the western sector of Indian Sundarbans to end up at Bay of Bengal has made the geographical situation totally different from the central sector, where five major rivers have lost their root with Ganga – Bhagirathi system due to heavy siltation [23]. Enormous load of sediments carried by the Rivers contribute to its expansion and dynamics.

Eight sampling stations were selected in each of the western (S_1 to S_4) and central sectors (S_5 to S_8) of Sundarbans (Table 1 and Fig. 1). The sampling stations in the western sector lie at the confluence of the River Hugli (a continuation of Ganga-Bhagirathi system) and Bay of Bengal. In the central sector of Sundarbans, the sampling stations were selected adjacent to the tide fed Matla River. Samplings in both sectors were carried out in low tide period covering three seasons (pre-monsoon, monsoon and post-monsoon) during 2012 to 2014.

In each station, selected forest patches were ~ 14 years old. 15 sampling plots (10m × 10m) at an interval of 100 m were established (in the river bank) through random sampling in the various qualitatively classified biomass levels for each stations. The mean of 15 sampling plots (relative abundance) of each mangrove species was evaluated for the order of dominance in the study area.

AGB of individual trees of the species in each sampling plot were estimated and the average values of 15 sampling plots from each station were finally converted into biomass (tha^{-1}) in the study area. AGB is the sum total of stem, branch and leaves of the tree. Hence the above-ground biomass of the vegetative parts was estimated separately.

2.2 Above-Ground Biomass (AGB) estimation

The biomass of above-ground structures were estimated as per the procedure outlined by Husch *et al.* [14] for stem, Chidumaya [7] for branch and Mitra *et al.* [24] for leaf.

2.3 Analysis of sediment quality parameters

In the study area 5 m × 5 m were considered for sediment sampling. Sediment samples were collected seasonally (pre-monsoon, monsoon and post-monsoon) during low tide period. In the laboratory, the collected samples were carefully sieved and homogenized to remove roots and other plant and animal debris prior to oven-drying to constant weight at 105^0C. Salinity was determined in supernatant of 1:10 soil-double distilled water mixtures using refractometer. The pH value was measured in the field with a micro pH meter (Systronics, Model No, 362) with glass – calomel electrode (sensitivity ± 0.01) and standardized with buffer 7.0. The total organic carbon (C_{org}) was analysed by rapid dichromate oxidation method of Walkley and Black [32]. The concentration of nitrate-nitrogen and phosphate-phosphorus in the sediment sample were measured by standard spectrophotometric methods [12]. Potassium content was analysed by flame photometry as per the standard procedure outlined by Prasad [27]**.** Texture was analysed by mechanical method of sieving in a Ro-Tap Shaker [18].

2.4 Statistical analysis

To assess whether above-ground biomass and edaphic factors were varied significantly between stations and seasons, Analysis of Variance (ANOVA) was performed considering the data collected during the study period. Possibilities less than 0.05 ($p<0.05$) was considered statistically significant. Correlation coefficients (r) were performed to find the inter-relationship between edaphic factors and above-ground biomass for each species in Indian Sundarbans. All statistical calculations were performed with SPSS 9.0 for Windows.

3. Results and Discussion

3.1 Sediment quality parameters

In Indian Sundarbans, spatial variation of physicochemical parameters (salinity, pH, C_{org}, nutrients) of sediment is shown in Table 2. Salinity (considering of three seasons) of sediment in this mangrove environment was ranged from 6.27±1.38 at Harinbari (S_4) to 16.89±2.79 at Bonnie Camp (S_8). Relatively low salinity in the western sector (S_1 to S_4) is the effect of Farakka barrage discharge that release fresh water through the main Hooghly channel. The pH value (mean of three seasons) was ranged from 8.10±0.24 at Bonnie Camp (S_8) to 8.22±0.22 at Chemaguri (S_1). In this mangrove ecosystem, organic carbon content (mean of three seasons) value was ranged from 0.47±0.06% at Bonnie Camp (S_8) to 0.82±0.22% at Chemaguri (S_1). Nitrate-nitrogen and phosphate-phosphorus content (considering of three seasons) were ranged from 0.15±0.01 μg g^{-1} at Dhulibasani (S_7) to 0.23±0.01 μg g^{-1} at Chemaguri (S_1) and 0.30±0.03 μg g^{-1} at Chulkathi (S_5) to 0.49±0.06 μg g^{-1} at Harinbari (S_4) respectively. Potassium content (mean of three seasons) was ranged from 454.47±3.56 μg g^{-1} at Bonnie Camp (S_8) to 476.12±10.39 μg g^{-1} at Lothian Island (S_2). Results of ANOVA confirmed significant spatial and seasonal variations ($p < 0.05$) of salinity and pH (Table 3).The significant variation ($p < 0.05$) of C_{org} and nutrients content of sediment (Table 3) between anthropogenically stressed western sector (Chemaguri and Harinbari) and less-disturbed central sector may be attributed to a large extent by human activities and associate physical factors like accretion and erosion. Both the stations, Chemaguri and Harinbari are under severe stress due to intense industrialization, rapid urbanization, unplanned tourism and aquaculture activities [4, 19, 20] which contribute appreciable load of organic carbon and nutrients in the sediment. According to the texture, sand content was minimum ranging from 4.27±3.74% at Dhulibasani (S_6) to 16.90±4.15% at Lothian Island (S_2), whereas silt from 46.64± 2.90% at Chemaguri (S_1) to 66.31±2.87% at Dhulibasani (S_6) and clay from 27.88±2.85% at Chulkathi (S_5) to 38.45±2.52% at Chemaguri (S_1) respectively (Fig. 2). Textural properties further revealed an overall dominance of mud (silt and clay) varying from fine silty to clayey very fine. It is suggested that this high mud content was due to the low fluvial discharge and a better mixing of saline and fresh water, which could have facilitated flocculation and subsequent settling of suspended particles [26].

3.2 Relative abundance

On the basis of relative abundance, the mean order of five studied species were *Avicennia officinalis* (20.00%)> *Avicennia marina* (18.60%)> *Avicennia alba* (16.36%)> *Excoecaria agallocha* (17.24%)> *Sonneratia apetala* (13.72%) in the western sector and *Avicennia officinalis* (22.91%)> *Avicennia alba* (20.83%)> *Avicennia marina* (18.51%)> *Excoecaria agallocha* (16.67%)> *Sonneratia apetala* (8.33%) in the central sector of Sundarbans.

3.3 Above-Ground Biomass (AGB)

The above-ground biomass in this mangrove forest ranged from 103.40±5.56 tha^{-1} (*E. agallocha*) to 244.70±10.98 tha^{-1} (*A. officinalis*) in the western sector and 70.00±5.25 tha^{-1} (*E. agallocha*) to 212.58±7.32 tha^{-1} (*A. officinalis*) in the central sector respectively. The AGB value for *S. apetala* and *E. agallocha* were ranged from 27.44 tha^{-1} at S_8 (Bonnie Camp) to 54.06 tha^{-1} at S_4 (Harinbari) and 8.56 tha^{-1} at S_5 (Chulkathi) to 36.53 tha^{-1} at S_4 (Harinbari) respectively. In case of *A. alba*, the value was ranged from 33.12 tha^{-1} at S_5 (Chulkathi) to 75.67 tha^{-1} at S_1 (Chemaguri). The value of AGB in *A. marina* and *A. officinalis* were ranged from 17.86 tha^{-1} at S_7 (Jharkhali) to 72.49 tha^{-1} at S_1 (Chemaguri) and 35.45 tha^{-1} at S_5 (Chulkathi) to 80.12 tha^{-1} at S_1 (Chemaguri) respectively (Fig. 3). ANOVA results also confirmed significant spatial and seasonal variations in AGB ($p<0.05$) of the five species (Table 4).

Mangroves are the most widespread tree communities of the Gangetic delta and their physiology is considerably influenced by salinity [34]. Therefore, salinity alteration is clearly visualized in the mangrove community by way of differential growth of above-ground biomass (AGB) of selected mangrove species [17]. A critical analysis of the results obtained from edaphic factors of the host sediments and dominated mangrove species indicated that considerable variations exist in stem biomass, branch biomass, leaf biomass, AGB, salinity, pH, C_{org} and nutrients between the stations and seasons (Table 3 and 4). The correlation coefficient (r) values showed a significant negative impact of salinity on AGB for *S. apetala* and *E. agallocha* but in case of *Avicennia spp.* did not exhibit any relationships with salinity indicating its wide range of salinity tolerance level (Table 5). The significant positive correlation between pH, C_{org}, nitrate-nitrogen, phosphate-phosphorus and AGB of all the five selected species clearly reflects a close inter-relationship between these variables (Table 5). These findings confirmed that the AGB values of *Avicennia spp, S. apetala* and *E. agallocha* are primarily regulated by salinity and other variables are pH, C_{org}, nitrate-nitrogen and phosphate-phosphorus in the present geographical locale. The role of potassium on the AGB of the five mangrove species was not at all evident in contrast to the finding of Kathiresan *et al*. [15] (Table 5). Previous workers confirmed the role of salinity, pH, C_{org}, nitrate-nitrogen and phosphate-phosphorus on the growth of mangroves [15, 24, 28, 31]. The above results confirmed the relatively higher growth rate of mangrove species in the western sector rather than the central one (Figure 3) due to the different trends of salinity, which increased in the central sector and decreased in the western one. Different causes (discharge, precipitation, run-off) increase the dilution factor of the Hooghly estuary in the western sector—a condition for the better growth of the mangroves biomass. On the contrary, the Matla estuary, in the central sector of the Gangetic delta, does not receive the freshwater discharge on account of siltation of the Bidyadhari River, which may be the cause for stunted growth of the mangroves in an environment of increasing salinity [3]. Majority of the mangrove species grow best in low to moderate salinities (25), although there appear to be marked differences in the ability of species to tolerate very high salinities [15]. The mangroves are salt tolerant species but under hypersaline condition they exhibit stunted growth [5, 24, 31]. High salinity result to physiological responses, as highly saline sediment has low osmotic potential that constrain water relation of mangroves [2]. Saintilan also found substratum salinity as a major controlling factor for the variation of above-ground biomass of *Avicennia marina* and *Aegiceras corniculatum* [29]. Increased salinity caused reduced growth in *S. apetala* and *E. agallocha* compared to other mangrove species like *A. alba*, *A. officinalis* and *A. marina*. Such differential adaptability of mangrove species to salinity was also reported from Bangladesh Sundarbans [8]. C_{org} is an important factor on the growth of mangrove forest [6, 22]. The C_{org} in the mangrove ecosystem is contributed by the vegetative and reproductive parts of the halophytes, although the contributions of riverine inputs pose a regulatory effect on organic carbon budget of the mangrove sediment [4]. In mangrove ecosystem nutrients are considered as the most important parameters that influence growth, reproduction and metabolic activities of biotic components. The distribution of nutrients is mainly based on season, tidal conditions and fresh water influx from land [30]. The above results also exhibited relatively (from the statistical point of view) higher values of C_{org}, nitrate-nitrogen and phosphate-phosphorus of sediments are also major drivers for the growth and above-ground biomass production of five studied mangrove species in the western sector [4]. This may be attributed to agricultural run-off, pollution load and other anthropogenic factors such as fish-landing stations, several shrimp farms which are extremely high in Hugli estuarine system encircling the western sector of Sundarbans [4, 20]. The significantly high correlation coefficient values of C_{org}, nitrate-nitrogen and phosphate-phosphorus of sediment with AGB of five mangrove species support the dependency of these variables on mangrove growth and biomass (Table 15 and 16). This study also indicates the need of optimum salinity, pH, C_{org}, nitrate-nitrogen and phosphate-phosphorus are important factors for the growth of mangroves. The above result affirms comparatively congenial environment for the growth of mangrove species in the western sector and also indicates the necessity of comparatively more freshwater supply and resource availability (nutrients) to accelerate the growth and AGB of mangrove species thriving in Indian Sundarbans region in the lower gangetic delta complex.

Table 1: Sampling stations in Indian Sundarbans

Sectors	Sampling stations	Longitude	Latitude
Western Sector	Chemaguri (S_1)	$88^0$08'53.55" E	$21^0$38'25.86"N
	Lothian Island(S_2)	$88^0$20'29.32"E	$21^0$38'21.20"N
	Prentice Island(S_3)	$88^0$17'55.05"E	$21^0$42'47.88"N
	Harinbari (S_4)	$88^0$04'10.83"E	$21^0$44'22.16"N
Central Sector	Chulkathi (S_5)	$88^0$34'10.31"E	$21^0$41'53.62"N
	Dhulibasani(S_6)	$88^0$33'48.20"E	$21^0$47'06.62"N
	Jharkhali (S_7)	$88^0$38'56.22"E	$21^0$59'40.88"N
	Bonnie Camp (S_8)	$88^0$37'21.50"E	$21^0$49'48.80"N

Table 2: Spatial variation of sediment quality parameters in Indian Sundarbans

Stations	Salinity	pH	Organic carbon (%)	Nitrate-nitrogen (µg g^{-1})	Phosphate-phosphorus (µg g^{-1})	Potassium (µg g^{-1})
(S_1)	9.73±3.07	8.22±0.22	0.82±0.18	0.23±0.01	0.42±0.06	468.18±15.93
(S_2)	15.78±3.59	8.17±0.19	0.76±0.15	0.22±0.02	0.43±0.04	476.12±10.39
(S_3)	15.42±2.21	8.15±0.20	0.64±0.16	0.19±0.01	0.39±0.07	463.85±3.34
(S_4)	6.27±2.38	8.14±0.25	0.72±0.10	0.22±0.02	0.49±0.06	469.45±3.95

(S_5)	16.58±1.78	8.12±0.35	0.44±0.09	0.17±0.01	0.30±0.03	479.48±4.66
(S_6)	16.19±2.88	8.14±0.28	0.52±0.07	0.15±0.01	0.32±0.03	472.42±5.22
(S_7)	15.47±1.90	8.14±0.32	0.59±0.13	0.18±0.02	0.35±0.01	459.22±7.54
(S_8)	16.89±2.79	8.10±0.24	0.47±0.06	0.16±0.01	0.31±0.02	454.47±3.56

Table 3: ANOVA results showing spatial and seasonal variations of sediment quality parameters in Indian Sundarbans

Variable		F_{cal}	P-value	F_{crit}
Salinity	Between stations	170.64	4.3E-37	1.76
	Between seasons	159.36	2.08E-21	3.19
pH	Between stations	4.67	4.22E-31	1.76
	Between seasons	626.11	4.33E-34	3.19
Organic Carbon	Between stations	36.67	2.49E-22	1.76
	Between seasons	161.02	1.69E-21	3.19
Nitrate-nitrogen	Between stations	23.66	2.34E-18	1.76
	Between seasons	145.63	1.26E-20	3.19
Phosphate-phosphorus	Between stations	21.66	1.41E-17	1.76
	Between seasons	419.27	2.94E-30	3.19
Potassium	Between stations	5.01	1.76E-06	1.76
	Between seasons	4585.63	1.14E-53	3.19

Table 4: ANOVA results showing spatial and seasonal variations in stem, branch, leaf and Above-Ground Biomass (AGB) of five mangrove species in Indian Sundarbans

Variable	Species	Stem	Branch	Leaf	AGB	F_{cri}
Between stations	*A. alba*	1904.31	255.28	111.25	2588.36	1.76
	A. marina	2199.77	830.19	209.86	2759.61	1.76
	A. officinalis	1262.27	572.80	178.02	1501.86	1.76
	S. apetala	598.92	288.27	107.10	789.26	1.76
	E. agallocha	1151.33	337.35	122.02	1141.86	1.76
Between seasons	*A. alba*	353.49	80.81	21.74	611.35	3.19
	A. marina	266.48	123.35	29.14	362.55	3.19
	A. officinalis	282.06	274.64	72.09	465.21	3.19
	S. apetala	317.02	174.93	14.62	387.00	3.19
	E. agallocha	219.63	58.86	11.29	194.08	3.19

Table 5: Correlation between sediment quality parameters and Above-Ground Biomass (AGB) of five mangrove species in Indian Sundarbans

Combination	Species	r-value	p-value
Salinity × AGB	*Avicennia alba*	-0.367	IS
	Avicennia officinalis	-0.334	IS
	Avicennia marina	-0.261	IS
	Excoecaria agallocha	-0.758	<0.01
	Sonneratia apetala	-0.684	<0.01
pH × AGB	*Avicennia alba*	0.663	<0.01
	Avicennia officinalis	0.716	<0.01
	Avicennia marina	0.576	<0.05
	Excoecaria agallocha	0.642	<0.01
	Sonneratia apetala	0.703	<0.01
C_{org}× AGB	*Avicennia alba*	0.613	<0.01
	Avicennia officinalis	0.693	<0.01
	Avicennia marina	0.588	<0.05
	Excoecaria agallocha	0.761	<0.01
	Sonneratia apetala	0.657	<0.01
Nitrate × AGB	*Avicennia alba*	0.614	<0.01
	Avicennia officinalis	0.682	<0.01
	Avicennia marina	0.628	<0.01
	Excoecaria agallocha	0.765	<0.01
	Sonneratia apetala	0.638	<0.01
Phosphate × AGB	*Avicennia alba*	0.572	<0.05
	Avicennia officinalis	0.635	<0.01
	Avicennia marina	0.602	<0.01

	Excoecaria agallocha	0.708	<0.01
	Sonneratia apetala	0.587	<0.05
Potassium × AGB	*Avicennia alba*	0.021	IS
	Avicennia officinalis	-0.015	IS
	Avicennia marina	-0.001	IS
	Excoecaria agallocha	-0.128	IS
	Sonneratia apetala	0.292	IS

Fig 1: Location of sampling stations in Indian Sundarbans

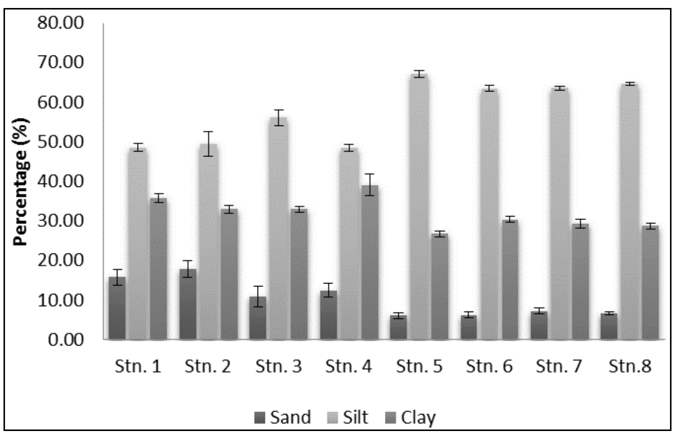

Fig 2: Spatial variation of sand, silt and clay (%) of sediment in Indian Sundarbans

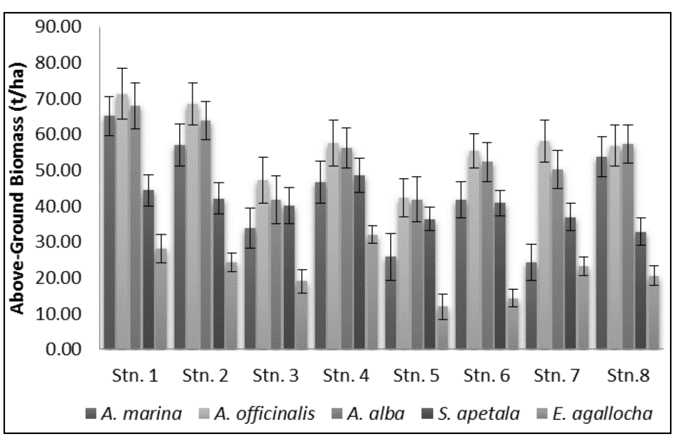

Fig 3: Spatial variation of Above-Ground Biomass (AGB) (tha^{-1}) of five mangrove species in Indian Sundarbans

4. Conclusions

This study found that the annual growth rate and above-ground biomass production of mangrove species is much higher in the western sector as compared to the central sector due to lack of fresh water supply and nutrients availability. Organic carbon and nutrients are also two major drivers for mangrove growth. High salinities impair nutrient acquisition in mangroves and relatively poor sink of CO_2, which is attributed to poor growth of mangroves. This can be achieved through channelization of freshwater in the central sector, rain-water harvesting and salinity based afforestation programme and policy level management through setting up of a State Level Mangrove Wetland Conservation and Management Authority.

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