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Effect of salinity on the above-ground biomass and growth of dominant mangrove plants in Indian sundarbans

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ABSTRACT

Depending on the geographic locale of the Indian Sundarbans was diversified in terms of salinity which directly reduced the growth of mangrove vegetation. Above-ground biomass estimation was carried out for five even–aged dominant mangrove species (Sonneratia apetala, Excoecaria agallocha, Avicennia alba, Avicennia officinalis and Avicennia marina) in western and central sectors of Indian Sundarbans during 2011 to 2013. Among the selected species, A. marina (60.15 tha^{-1}) showed maximum above-ground biomass in western sector followed by A. officinalis (55.88 tha^{-1}), S. apetala (52.85 tha^{-1}), A. alba (51.55 tha^{-1}) and E. agallocha (26.41 tha^{-1}). In central sector, the maximum above-ground biomass was observed in A. marina (49.74 tha^{-1}) followed by A. officinalis (44.46 tha^{-1}), S. apetala (42.52 tha^{-1}), A. alba (36.96 tha^{-1}), and E. agallocha (17.94 tha^{-1}). The growth was more in the species of western Indian Sundarbans compared to the central Indian Sundarbans. The relatively higher values of AGB in the western sector compared to the central sector are reflections of salinity.

Keywords: Indian Sundarbans, Above-Ground Biomass, Salinity

INTRODUCTION

The Sundarbans, a UNESCO World Heritage Site (for rich flora and fauna) covering parts of Bangladesh and Indian state of West Bengal, is the largest single block of tidal halophytic mangrove forest in the world [14]. Mangroves are a taxonomically diverse group of salt-tolerant, mainly arboreal, flowering plants that grow primarily in tropical and subtropical regions [13]. The biomass and productivity of mangrove forests have been studied mainly in terms of wood production, forest conservation, and ecosystem management [11, 17, 21, 24, 25, 28]. Being host for a number of threatened and endangered species, with different animals, mammals, amphibians, reptiles and bird species, they play crucial role for protecting environment from the fury of cyclones and storms and also protect coral reefs, sea-grass bed, shipping lines from siltation. Mangrove communities often exhibit distinct patterns of species distribution [5, 18, 29]. Waring and Major [32] reported that a complex of environmental factors determines the actual distribution of plants in nature, although each plant has a certain tolerance for each factor. Since the mangrove habitat is basically saline, several studies have attempted to correlate salinity with the standing crop of vegetation and productivity [6, 7, 20, 30]. The distribution of mangrove species, in many cases, can be explained primarily by salinity gradients [2, 31]. The Indian Sundarbans is one of the most biologically productive, taxonomically diverse and aesthetically celebrated ecotones of the tropics, where few works on growth of mangroves have been carried out in a sporadic manner, although the deltaic zone offers a unique test bed for such study owing to presence of two significantly distinct sectors in terms of salinity caused by anthropogenic coupled with geo-physical factors.

In this paper, we evaluate a site specific variation of the above-ground biomass production and growth of five dominant mangrove species (*S. apetala, E. agallocha, A. alba, A. officinalis and A. marina)* in the Indian Sundarbans with respect to salinity gradient.

MATERIALS AND METHODS

Study area

The Sundarban mangrove ecosystem covering about one million ha in the deltaic complex of the Rivers Ganga, Brahmaputra and Meghna is shared between Bangladesh (62%) and India (38%) and is the world's largest coastal wetland. Enormous load of sediments carried by the rivers contribute to its expansion and dynamics.

Eight sampling stations in the Indian Sundarbans deltaic complex were considered in this study. The sampling stations in western sector (S_1 to S_4) lie at the confluence of the River Hugli (a continuation of Ganga-Bhagirathi system) and Bay of Bengal. In the central sector, the sampling stations (S_5 to S_8) were selected adjacent to the tide fed Matla River (Table 1 and Fig 1). Study was undertaken in both these sectors through three seasons (pre-monsoon, monsoon and post-monsoon) during 2011 to 2013. The two sectors are significantly different with respect to salinity, anthropogenic pressure and mangrove floral richness.

In both sectors, selected forest patches were ~ 12 years old. In each sector, 15 sampling plots (10m × 10m) were established (in the river bank) through random sampling in the various qualitatively classified biomass levels for each sector (n=30). Seasonal sampling in both sectors was carried out in the low tide period.

Above-ground biomass estimation

The biomass of above ground structures were estimated as per the procedure outlined by Husch *et al* [15] for stem, Chidumayo [8] for branch and Mitra *et al* [22] for leaf.

Salinity

The surface water salinity was recorded by means of an optical refractometer (Atago, Japan) in the field and cross-checked in laboratory by employing Mohr- Knudsen method. The correction factor was found out by titrating the silver nitrate solution against standard seawater (IAPO standard seawater service Charlottenlund, Slot Denmark, chlorinity = 19.376‰).

Statistical analysis

To assess whether above-ground biomass and salinity varied significantly among stations and seasons, analysis of variance (ANOVA) was performed considering the data collected for 3 years. Possibilities less than 0.05 ($p<0.05$) were considered statistically significant. The inter-relationships between aquatic salinity and above-ground biomass were assessed by correlation coefficient (r) values computed separately for each species. All statistical calculations were performed with SPSS 9.0 for Windows.

RESULTS

Relative abundance

A total of seventeen species of mangroves were recorded in the selected stations of the study area. It was observed that S_2 (Lothian Island) and S_3 (Prentice Island) exhibited relatively more species diversity compared to other stations. On the basis of relative abundance, the species *A. marina*, *E. agallocha*, *A. alba*, *A .officinalis and S. apetala* were found dominant in the study site constituting 42.59% of the total species. *Avicennia* is the pioneering mangrove followed by other mangrove species like *Excoecaria sp*., *Sonneratia sp*. etc.

Above-ground biomass (AGB)

Total above ground biomass in Indian Sundarban mangrove forest ranged from 12.37±1.93 t/ha (*E. agallocha*) to 73.09±6.88 t/ha (*A. marina*). The above-ground biomass recorded was species-specific, which may be due to different adaptability of the concerned species to different salinity range and other abiotic variables. In Indian Sundarbans, the values of AGB for *S. apetala* and *E. agallocha,* ranged from 34.67±3.21 tha^{-1} at S_8 (Bonnie Camp) to 64.69±7.30 tha^{-1} at S_1 (Chemaguri) and 12.37±1.93 tha^{-1} at S_6 (Dhulibasani) to 32.51±3.00 tha^{-1} at S_4 (Harinbari) respectively. In case of *A. alba,* the AGB value ranged from 24.68±4.22 tha^{-1} at S_7 (Jharkhali) to 65.78±4.54 tha^{-1} at S_2 (Lothian Island). The value of AGB in *A. marina*, ranged from 34.70±5.74 tha^{-1} at S_5 (Chulkathi) to 73.09±6.88

tha^{-1} at S_4 (Harinbari). In case of *A. officinalis* the AGB value ranged from 30.84±4.43 tha^{-1} at S_5 (Chulkathi) to 69.60±5.55 tha^{-1} at S_1 (Chemaguri). The AGB value varied as per the order western sector (49.37 tha^{-1}) > central sector (38.32 tha^{-1}). In the present study, biomass production of stem was higher than branch and leaf biomass of five selected mangrove species. This is Worthwhile to mention that in AGB of selected species, the stem constitutes 61% to 64%, the branch constitutes 23% to 27% and 12% to 14% of AGB is allocated to leaf [23]. ANOVA results also confirm significant spatial and seasonal variations in stem, branch, leaf and AGB (p<0.05) of the selected species in Indian Sundarbans (Table 2). Spatial variation of above-ground biomass is shown in Fig 2.

The rate of growth in selected mangrove species was however not uniform in both the sectors of Indian Sundarbans. In western sector, the rate of above-ground biomass values for *A. marina*, *A. officinalis*, *A. alba*, *S. apetala* and *E. agallocha* were 5.84 tha^{-1}yr^{-1}, 4.56 tha^{-1}yr^{-1}, 4.45 tha^{-1}yr^{-1}, 5.47 tha^{-1}yr^{-1}, 2.58 tha^{-1}yr^{-1} respectively. In the central sector, the rate of above-ground biomass values for *A. marina*, *A. officinalis*, *A. alba*, *S. apetala* and *E. agallocha* were 5.38 tha^{-1}yr^{-1}, 4.02 tha^{-1}yr^{-1}, 4.66 tha^{-1}yr^{-1}, 3.63 tha^{-1}yr^{-1}, 1.98 tha^{-1}yr^{-1} respectively. In the mangrove forest, the annual increment in above-ground biomass ranges from 4 tha^{-1}yr^{-1} in an *Avicennia* mangrove forest in Mexico [12] to 26.7 tha^{-1}yr^{-1} in a *Rhizophora* forest in Thailand [9].

Salinity

In Indian Sundarbans average salinity (average of three season) ranged from 15.58 ± 4.62 psu at Chemaguri (S_1) to 23.82 ± 4.90 psu at Dhulibasani (S_6). Results of ANOVA confirm significant spatial and seasonal variation ($p < 0.05$) of salinity in Indian Sundarbans (Table 3). Spatial and seasonal variations of salinity are shown in Fig 3.

Table 1. Sampling stations in Indian Sundarbans

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

Table 2. ANOVA showing Stem, Branch, Leaf and AGB of dominant mangrove species in Indian Sundarbans

Species	Variable	F_{cal}				F_{crit}
		Stem	Branch	Leaf	AGB	
Avicennia alba	Between station	1327.064	165.369	152.934	1947.776	2.203
	Between season	130.513	10.029	23.243	191.391	2.203
Avicennia officinalis	Between station	1387.643	39.897	32.945	1455.917	2.203
	Between season	172.997	9.220	4.443	224.031	2.203
Avicennia marina	Between station	215.182	76.387	16.639	1141.997	2.203
	Between season	103.922	5.578	2.675	314.509	2.203
Excoecaria agallocha	Between station	645.511	68.413	40.820	1038.138	2.203
	Between season	97.981	5.050	4.598	131.196	2.203
Sonneratia apetala	Between station	187.609	35.9523	31.071	331.397	2.203
	Between season	66.967	2.605	6.719	71.578	2.203

Table 3. ANOVA showing aquatic salinity in Indian Sundarbans

	Variable	F	P-value	F_{crit}
Salinity	Between season	444.442	4.75E-42	2.203
	Between station	160.365	1.61E-31	2.203

Table 4. Correlation between salinity and AGB of selected mangrove species in Indian Sundarbans

Species	Combination	r-value	p-value
Avicennia alba	Salinity × AGB	-0.4312	IS
Avicennia officinalis	Salinity × AGB	-0.3372	IS
Avicennia marina	Salinity × AGB	-0.4475	IS
Excoecaria agallocha	Salinity × AGB	-0.6806	<0.01
Sonneratia apetala	Salinity × AGB	-0.6472	<0.01

Fig 1. Location of sampling stations of Indian Sundarbans

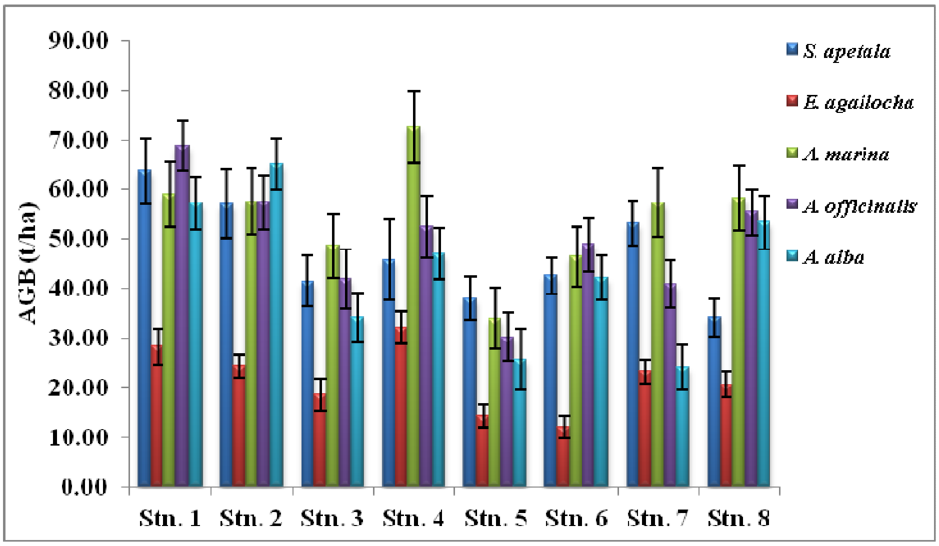

Fig 2. Spatial variation of above-ground biomass of mangrove species in Indian Sundarbans

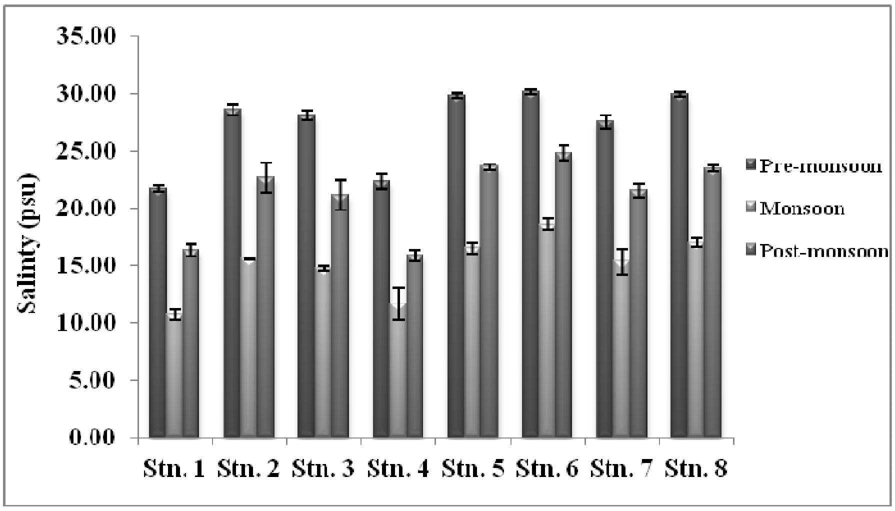

Fig 3. Spatial and seasonal variation of aquatic salinity in Indian Sundarbans

DISCUSSION

It is observed that AGB exhibit significant spatial variations with highest value in the western sector (246.89 tha^{-1}) compared to central sector (191.60 tha^{-1}) of Indian Sundarbans. Komiyama [17] reported 356.8 tha^{-1} of AGB for *Sonneratia* forest, 178.2 tha^{-1} for *Rhizophora*, and 406.0 tha^{-1} for *Bruguiera* in Indonesia. Our observed AGB (246.89 tha^{-1}) in western sector is around value of a *Rhizophora* stand (240.0 tha^{-1}) in Sri Lanka [1] and of Mackey [19] in a secondary mangrove forest (*A. marina*) of Australia (341.0 tha^{-1}).

Salinity is an important factor on the growth and zonation of mangrove forests. Majority of the mangrove species grow best in low to moderate salinities (25 ppt), although there appear to be marked differences in the ability of species to tolerate very high salinities [16]. The mangroves are salt tolerant species but under hypersaline condition they exhibit stunted growth [4, 22, 23, 27]. High salinity result to physiological responses, as highly saline sediment has low osmotic potential that constrain water relation of mangroves [3]. Saintilan [26] also found substratum salinity as a major controlling factor for the variation of above-ground biomass of *A. marina* and *Aegiceras corniculatum*. Critical analysis of the data on AGB and salinity profile of the study area exhibits the regulatory effect of salinity on the above-ground biomass of the *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 4).

The relatively higher AGB values in *S. apetala* and *E. agallocha* in western Indian Sundarbans (Chemaguri and Harinbari)provides ideal growing conditions for mangroves due to fresh water input from the Himalayan Glaciers after being regulated by the Farakka dam. Five-year surveys (1999 to 2003) on water discharge from Farakka dam revealed an average discharge of (3.4 ± 1.2) × 10^3 m^3s^{-1}. Higher discharge values were observed during the monsoon with an average of (3.2 ± 1.2) × 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 pre-monsoon 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 post-monsoon 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) and surface runoff from the 60000 km^2 catchment areas of Ganga-Bhagirathi-Hugli system and their tributaries. All these factors (dam discharge + precipitation + runoff) increase the dilution factor of the Hugli estuary in the western sector of Indian Sundarbans [23]. The central sector, on contrary, does not receive the freshwater input on account of siltation of the Bidyadhari River which may be attributed to lower AGB values of the *S. apetala* and *E. agallocha* inhabiting zone. 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 ([10].

CONCLUSION

The present study indicates that the regulatory role of salinity on the growth and above-ground biomass of mangrove species in Indian Sundarbans. Effective soil management, tidal interactions (through artificial canalization) and sufficient flow of freshwater into the mangrove system are important mediators for growth and biomass production in mangrove flora.

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