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Salinity: A Primary Growth Driver of Mangrove Forest

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ABSTRACT

The biomass of three dominant mangrove species (*Sonneratia apetala, Avicennia alba and Excoecaria agallocha*) in the Indian Sundarbans, the designated World Heritage Site was evaluated to understand whether the biomass vary with spatial locations (western region vs. central region) and with seasons (pre-monsoon, monsoon and post-monsoon). The reasons for selecting these two regions and seasons are the contrasting variation in salinity. Among the three studied species, *Sonneratia apetala* showed the maximum biomass followed by *Avicennia alba* and *Excoecaria agallocha*. We also observed that the biomass varied significantly with spatial locations ($p < 0.05$), but not with seasons. The variation may be attributed to different environmental conditions to which these forest patches are exposed to.

***Keywords*:** Mangroves; Indian Sundarbans; Salinity; *Sonneratia apetala*; *Avicennia alba*; *Excoecaria agallocha*

1. Introduction

Salinity of the brackish water ecosystem is the consequence of the interaction among the frequency of tidal inundation, evaporation and supply of fresh water (Clarke and Hannon, 1969). Other factors contributing towards the development of salinity include soil type and topography, depth of impervious subsoil, amount and seasonality of rainfall, freshwater discharge in rivers, and run off from adjacent landmasses (Hutchings and Saenger, 1987). Increased temperature enhances evaporation and thereby causes increased salinity. Rainfall through adding freshwater in the ecosystem reduces salinity and makes the environment suitable for mangrove growth and survival. Humidity regulates the evapo-transpiration in the mangrove and thus in turn regulates salt movement in the soil. High salinity accompanied with high temperature and wind causes accumulation of salt at the surface of the soil that makes the site unsuitable for mangroves. The extent of plant cover also has a significant influence on evaporative losses from the mangrove community (Hutchings and Saenger, 1987). Presence of salt is a critical factor for the development of mangrove ecosystems. At lower intensities it favors the development of mangroves eliminating more vigorous terrestrial plants which other wise could compete with. On the contrary at increased level it might cause overall degradation of mangroves. Salinity affects plant growth in a variety of ways: 1) by limiting the availability of water against the osmotic gradient, 2) by reducing nutrient availability, 3) by causing accumulation of Na^+ and Cl^- in toxic concentration causing water stress conditions enhancing closure of stomata, reduced photosynthesis (Jalil, 2002). Salinity is also a controlling factor for mangrove seedling recruitment and the relation is negatively proportional. Siddiqi (2001) noted reduced recruitment of Heritiera fomes and Excoecaria agallocha seedling in the Sundarbans mangrove forest with increased salinity. Ball and Pidsley (1995) observed adverse impact of increased salinity on canopy development, leaf initiation, and leaf area expansion in Sonneratia alba and Sonneratia lanceolata. In Indian coastal region, the adverse impact of salinity on the growth of mangrove species has been documented (Mitra *et al*, 2004). Salinity, therefore, greatly influences the overall growth and productivity of the mangroves (Das and Siddiqi, 1985). In this section, the effect of salinity on the biomass of selected mangrove species (*Sonneratia apetala, Avicennia marina and Excoecaria agallocha*) has been analyzed considering the data of 10 stations of Indian Sundarbans with variable salinity.

The present study is relevant from the point of adaptation of the species to sea level rise and subsequent saline water intrusion (from the Bay of Bengal) into the islands of Indian Sundarbans. The delta is vulnerable to climate change related effects owing to its location below the mean sea level and experiencing a sea level rise of 3.14 mm/yr.

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2. Materials and methods

2.1 Study areas

The mighty River Ganga emerges from the Himalayas and flows down to the Bay of Bengal covering a distance of 2525 km. At the apex of Bay of Bengal a delta has been formed which is recognized as one of the most diversified and productive ecosystems of the tropics and is referred to as Indian Sundarbans. The deltaic complex has a Biosphere Reserve area of 9630 sq. km and houses some 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 (Chaudhuri and Choudhury 1994). Such variation cause sharp difference in salinity between the two sectors (Mitra *et al*. 2009). Ten sampling sites were selected in this geographical locale (**Table 1**). The stations in the western part (stations 1 to 5) lie at the confluence of the River Hooghly (a continuation of Ganga-Bhagirathi system) and Bay of Bengal. In the central sector, the sampling stations (stations 6 to 10) were selected adjacent to tide fed Matla River. Study was undertaken in both these sectors during low tide period through three seasons (pre-monsoon, monsoon and post-monsoon) in 2017.

In each sector, plot size of 10m × 10m was selected and the average readings were documented from 15 such plots. The mean relative density of the selected species was evaluated for relative abundance of the species.

Station	**Longitude & Latitude**	**Site Description**
Harinbari (Stn. 1)	$88^{0}04^{/}22.88^{//}$ $21^{0}46^{/}53.07^{//}$	Situated in the western sector of Sundarbans almost in the middle of the Sagar Island; receives the water of the Hooghly River.
Chemaguri (Stn. 2)	$88^{0}08^{/}49.01^{//}$ $21^{0}39^{/}42.88^{//}$	Situated on the south-eastern side of Sagar Island and receives the water of the Mooriganga River.
Sagar South (Stn. 3)	$88^{0}04^{/}\ 0.51^{//}$ $21^{0}37^{/}49.90^{//}$	Situated on the south-western part of the Sagar Island at the confluence of the River Hooghly and the Bay of Bengal. Anthropogenically stressed zone due to presence of passenger jetties, fishing activities and pilgrimage.
Lothian island (Stn. 4)	$88^{0}19^{/}8.47^{//}$ $21^{0}39^{/}08.04^{//}$	Situated east of Bakkhali island; a Wildlife sanctuary; faces the River Saptamukhi.
Prentice island (Stn. 5)	$88^{0}17^{/}3.62^{//}$ $21^{0}42^{/}43.31^{//}$	Situated north of Lothian island; receives the water of the Saptamukhi River.
Canning (Stn. 6)	$88^{0}41^{/}04.43^{//}$ $22^{0}19^{/}03.20^{//}$	Situated in the central part of the Indian Sundarbans and faces the mighty River Matla, a tide-fed river. Due to presence of fish landing stations, passenger jetties and busy market, the area is anthropogenically stressed.
Sajnekhali (Stn. 7)	$88^{0}48^{/}15.78^{//}$ $22^{0}06^{/}34.19^{//}$	A Wildlife Sanctuary and a part of Sundarban Tiger Reserve; adjacent to River Bidhya and Gomor. Tourism pressure is extremely high in this station particularly during post monsoon.

Chotomollakhali (stn. 8)	$88^{0}54^{/}42.81^{//}$ $22^{0}10^{/}18.45^{//}$	Situated in the upper portion of Central Indian Sundarban adjacent to Jhila forest; receives the water of Rangabelia and Korankhali rivers.
Satjelia (Stn. 9)	$88^{0}52^{/}39.51^{//}$ $22^{0}05^{/}27.77^{//}$	Situated adjacent to river Duttar in the upper region of Central Indian Sundarban facing western part of Jhilla forest block.
Pakhiralaya (Stn. 10)	$88^{0}49^{/}11.09^{//}$ $22^{0}08^{/}29.89^{//}$	Situated adjacent to river Gomor; opposite to Sajnekhali Forest Complex.

Table 1. Coordinates of the stations

2.2 Above Ground Biomass (AGB) estimation

The above ground biomass of the dominant mangrove species was estimated as per the method outlined in a very recent study by Mitra *et al* (2011). The above ground biomass includes the biomass of stem, branches and leaves.

2.3 Below Ground Biomass (BGB) estimation

An excavation method (Bledsoe *et al*. 1999) was used to estimate root biomass of the same trees that were selected for AGB estimate. According to our observation, very few roots in our sampling plots were distributed deeper than 1 m in sediments. We also found canopy diameter of these trees was usually smaller than 2 m. Most roots of the selected species were distributed within the projected canopy zone. Therefore, for below-ground biomass (BGB, referring to root biomass in this study), we excavated all roots (of 2 trees/species) in 1 m depth within the radius of 1 m from the tree center, and then washed the roots. We excavated all the sediments within the sampling cylinder (2 m in diameter × 1 m in height) and washed them with a fine screen to collect all roots. The roots were sorted into four size classes: extreme fine roots (diameter <0.2 cm), fine roots (diameter 0.2–0.5 cm), small roots (diameter 0.5–1.0 cm), and coarse roots (diameter >1 cm). We did not separate live or dead roots. The roots after thorough washing were oven dried to a constant weight at 80 ± 5^{0}C and biomass was estimated for each species.

2.4 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‰). Our method was applied to estimate the salinity of standard seawater procured from NIO and a standard deviation of 0.02% was obtained for salinity.

2.5 Statistical analysis

The above - and under -ground biomasses were added to get the total biomass of the tree and finally correlation coefficients were performed to find the inter-relationship between biomass and salinity for each of the three species. ANOVA was performed to know the spatial and seasonal variations of mangrove biomass. All statistical calculations were performed with SPSS 9.0 for Windows.

3. Results and discussion

3.1 Relative abundance

A total of fourteen species of mangroves were recorded in the selected plots of the study area. On the basis of relative abundance the species Sonneratia apetala, Excoecaria agallocha and Avicennia alba were found dominant in the study site (**Table 2**) constituting 48.05% of the total species. The selected species were ~16 years old, but high salinity in the central sector probably stunted their growth.

Species	**No./100m^2**									
	Stn. 1	**Stn. 2**	**Stn. 3**	**Stn. 4**	**Stn. 5**	**Stn. 6**	**Stn. 7**	**Stn. 8**	**Stn. 9**	**Stn. 10**
Sonneratia apetala	9 (16.98)	11 (20.75)	13 (20.97)	15 (24.19)	17 (25.76)	7 (15.56)	6 (10.53)	6 (12.24)	6 (13.95)	6 (13.33)
Excoecaria agallocha	8 (15.09)	8 (15.09)	9 (14.52)	9 (14.52)	12 (18.18)	6 (13.33)	7 (12.28)	8 (16.33)	8 (18.60)	8 (17.78)
Avicennia alba	9 (16.98)	11 (20.75)	10 (16.13)	7 (11.29)	8 (12.12)	9 (20.0)	8 (14.04)	7 (14.29)	5 (11.63)	6 (13.33)
Avicennia marina	6 (11.32)	5 (9.43)	5 (8.06)	6 (9.68)	4 (6.06)	6 (13.33)	6 (10.53)	6 (12.24)	4 (9.30)	5 (11.11)
Avicennia officinalis	5 (9.43)	6 (11.32)	7 (11.29)	6 (9.68)	5 (7.58)	5 (11.11)	5 (8.77)	5 (10.20)	4 (9.30)	4 (8.89)
Aegiceros corniculatum	3 (5.66)	2 (3.77)	3 (4.84)	2 (3.23)	4 (6.06)	3 (6.67)	2 (3.51)	ab	ab	2 (4.44)
Bruguiera gymnorrhiza	4 (7.55)	5 (9.43)	3 (4.84)	1 (1.61)	2 (3.03)	2 (4.44)	2 (3.51)	1 (2.04)	ab	1 (2.22)
Xylocarpus granatum	2 (3.77)	2 (3.77)	1 (1.61)	1 (1.61)	1 (1.51)	ab	1 (1.75)	1 (2.04)	ab	2 (4.44)
Nypa fruticans	ab	ab	1 (1.61)	2 (3.23)	2 (3.03)	ab	2 (3.51)	1 (2.04)	ab	ab
Phoenix paludosa	ab	ab	ab	1 (1.61)	1 (1.51)	2 (4.44)	3 (5.26)	3 (6.12)	4 (9.30)	3 (6.67)

Ceriops decandra	ab	ab	ab	ab	ab	1 (2.22)	2 (3.51)	2 (4.08)	3 (6.98)	2 (4.44)
Rhizophora mucronata	ab	ab	2 (3.23)	1 (1.61)	1 (1.51)	ab	2 (3.51)	2 (4.08)	1 (2.33)	ab
Heritiera fomes	2 (3.77)	ab	ab	2 (3.23)	1 (1.51)	ab	2 (3.51)	ab	ab	1 (2.22)
Aegialitis rotundifolia	ab	ab	2 (3.23)	3 (4.84)	1 (1.51)	ab	3 (5.26)	2 (4.08)	3 (6.98)	1 (2.22)

‘ab’ means absence of the species in the selected plots

Table 2. Density of mangrove species (mean of 15 plots/station) in the study area; Figures within bracket indicate the relative abundance in each station

3.2 AGB

The stem, branch, leaf constituting the AGB of the mangrove species was relatively higher in the stations of the western sector (stations 1 – 5) compared to the central sector (stations 6 – 10) (**Table 3**) ($p<0.01$). It is observed that AGB of the dominant species in the western sector are 359.99 t ha^{-1} during pre-monsoon, 402.54 t ha^{-1} during monsoon and 475.58 t ha^{-1} during post-monsoon, whereas in the central sector the values are 290.55 t ha^{-1} during pre-monsoon, 339.35 t ha^{-1} during monsoon and 413.63 t ha^{-1} during post-monsoon.

Our data on AGB (particularly in the western Indian Sundarbans) are higher than most of the global figures which may be attributed to favorable climatic conditions and appropriate dilution of the saline system with fresh water of the mighty River Ganga. The western sector continuously receives the fresh water input from the Himalayan Glaciers after being regulated by the Farakka barrage. The lower Gangetic deltaic lobe also experiences considerable rainfall (1400 mm average rainfall) and surface runoff from the 60000 km^2 catchments 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.

Location	**Salinity (psu)**			**Species**	**AGB (t/ha)**			**BGB (t/ha)**			**TB (t/ha)**		
	Prm	Mon	Pom		Prm	Mon	Pom	Prm	Mon	Pom	Prm	Mon	Pom
Harinbari (Stn. 1) $88^0 10^/ 44.55^{//}$ $21^0 43^/ 08.58^{//}$	14.20	2.09	9.65	A	37.91	41.98	49.90	10.24 (27.01)	11.67 (27.80)	13.97 (27.99)	48.15	53.65	63.87
				B	37.23	40.05	44.02	8.62 (23.15)	9.60 (23.96)	10.63 (24.14)	45.85	49.65	54.65

				C	7.55	10.58	12.20	1.7 (22.56)	2.47 (23.36)	2.87 (23.54)	9.25	13.05	15.07
Chemaguri (Stn.2) 88^{0}10$^{/}$07.03$^{//}$ 21^{0}39$^{/}$58.15$^{//}$	21.20	8.79	16.32	A	25.10	26.97	34.91	6.57 (26.19)	7.28 (26.99)	9.49 (27.19)	31.67	34.25	44.4
				B	39.12	41.07	45.05	9.14 (23.36)	9.23 (24.17)	10.97 (24.36)	48.26	50.30	56.02
				C	9.75	11.47	14.09	2.21 (22.62)	2.68 (23.39)	3.32 (23.59)	11.96	14.15	17.41
Sagar South (Stn.3) 88^{0}04$^{/}$ 52.98$^{//}$ 21^{0}47$^{/}$01.36$^{//}$	26.99	10.02	17.67	A	16.70	18.77	22.92	4.32 (25.89)	5.01 (26.68)	6.16 (26.88)	21.02	23.78	29.08
				B	41.48	45.16	51.82	9.69 (23.37)	10.92 (24.17)	12.63 (24.37)	51.17	56.08	64.45
				C	10.04	12.94	16.77	2.32 (23.14)	3.10 (23.94)	4.05 (24.14)	12.36	16.04	20.82
Lothian island (Stn.4) 88^{0}22$^{/}$ 13.99$^{//}$ 21^{0}39$^{/}$01.58$^{//}$	28.99	11.15	18.69	A	13.14	14.10	19.00	3.29 (25.03)	3.64 (25.83)	4.95 (26.03)	16.43	17.74	23.95
				B	46.13	48.60	53.03	10.81 (23.44)	11.78 (24.24)	12.96 (24.44)	94.73	60.38	65.99
				C	10.30	14.00	19.85	2.40 (23.28)	3.37 (24.08)	4.82 (24.28)	12.70	17.37	24.67
Prentice island (Stn.5) 88^{0}17$^{/}$ 10.04$^{//}$ 21^{0}42$^{/}$40.97$^{//}$	28.56	11.09	18.22	A	13.86	17.28	21.59	3.52 (25.40)	4.53 (26.20)	5.70 (26.40)	17.38	21.81	27.29
				B	43.19	47.34	52.22	10.11 (23.40)	11.46 (24.20)	12.74 (24.40)	53.3	58.8	64.96
				C	8.49	12.22	18.21	1.97 (23.18)	2.93 (23.98)	4.40 (24.18)	10.46	15.15	22.61
Canning (Stn. 6) 88^{0}41$^{/}$16.20$^{//}$	15.21	3.95	9.81	A	14.91	18.92	22.45	2.87 (19.24)	3.80 (20.10)	4.58 (20.42)	17.78	22.72	27.03

$22^{0}18^{/}40.25^{//}$				B	28.91	31.86	37.01	7.11 (24.61)	7.72 (24.24)	9.47 (25.58)	36.02	39.58	46.48
				C	4.34	6.43	9.46	1.00 (23.11)	1.60 (24.81)	2.32 (24.54)	5.34	8.03	11.78
Sajnekhali (Stn. 7) $88^{0}48^{/}17.60^{//}$ $22^{0}16^{/}33.79^{//}$	29.16	12.00	19.67	A	2.79	4.00	5.98	0.57 (20.44)	0.83 (20.75)	1.24 (20.70)	3.36	4.83	7.22
				B	45.67	50.05	57.31	11.32 (24.78)	12.47 (24.91)	14.90 (26.00)	56.99	62.52	72.21
				C	13.58	19.45	25.95	3.20 (23.55)	4.85 (24.96)	6.40 (24.65)	16.78	24.30	32.35
Chotomollakhali (Stn.8) $88^{0}54^{/}26.71^{//}$ $22^{0}10^{/}40.00^{//}$	25.85	11.02	17.30	A	4.10	7.78	12.27	0.82 (20.12)	1.58 (20.36)	2.52 (20.51)	4.92	9.36	14.79
				B	40.43	42.87	48.9	9.98 (24.68)	10.62 (24.78)	12.67 (25.91)	50.41	53.49	61.57
				C	6.70	10.87	15.79	1.55 (23.12)	2.68 (24.62)	3.84 (24.33)	8.25	13.55	19.63
Satjelia (Stn. 9) $88^{0}52^{/}49.51^{//}$ $22^{0}05^{/}17.86^{//}$	29.83	12.35	19.99	A	1.05	2.89	3.36	0.21 (20.24)	0.59 (20.56)	0.70 (20.77)	1.26	3.48	4.06
				B	50.57	54.92	61.76	12.52 (24.76)	13.63 (24.81)	16.05 (25.99)	63.09	68.55	77.81
				C	20.77	25.66	32.75	4.90 (23.61)	6.38 (24.88)	8.18 (24.98)	25.67	32.04	40.93
Pakhiralaya (Stn10) $88^{0}48^{/}29.00^{//}$ $22^{0}07^{/}07.23^{//}$	28.72	12.20	18.00	A	4.10	5.82	7.61	0.83 (20.36)	1.21 (20.71)	1.57 (20.66)	4.93	7.03	9.18
				B	40.37	42.88	50.64	9.97 (24.70)	10.67 (24.88)	13.14 (25.95)	50.34	53.55	63.78
				C	12.26	14.95	22.39	2.86 (23.36)	3.72 (24.85)	5.50 (24.55)	15.12	18.67	27.89

A = *Sonneratia apetala*, B= *Avicennia marin*a, C= *Excoecaria agallocha*; Prm = Premonsoon, Mon = Monsoon, Pom = Post monsoon **Table 3.** Seasonal variations in AGB and BGB of selected mangrove species along with ambient salinity in the western and central sectors; the figures within bracket represents the percentage of BGB of AGB

3.3 BGB

The BGB comprising of the root portion of the mangrove was higher in the western sector compared to the central sector. The total BGB of the three dominant species in the western sector are 87.09 t ha^{-1} during pre-monsoon, 99.67 t ha^{-1} during monsoon and 119.66 t ha^{-1} during post-monsoon, whereas in the central sector the values are 69.71 t ha^{-1} during pre-monsoon, 82.35 t ha^{-1} during monsoon and 103.08 t ha^{-1} during post-monsoon. The BGB varies significantly between western and central sectors ($p<0.01$), but not between seasons.

In mangrove forests, the root biomass is higher, which could be an adaptation for living on soft sediments. Mangroves may be unable to mechanically support their above-ground weight without a heavy root system. In addition, soil moisture may cause increased allocation of biomass to the roots (Kramer and Kozlowski, 1979), with enhanced cambial activity induced by ethylene production under submerged conditions (Yamamoto *et al.*, 1995). It is interesting to note that the BGB in our study area constituted 24.75% and 24.45% of the AGB in the western and central sectors respectively. These values are higher than the usual 15% value of BGB compared to AGB (MacDicken, 1997). The high allocation of biomass in the root compartment of mangroves in the present geographical locale is probably an adaptation to cope with the unstable muddy substratum of the intertidal zone caused by high tidal amplitude (2-6 m), frequent inundation of the mudflats with the tidal waters and location of the region below the mean sea level.

3.4 Salinity

In the western sector the salinity of surface water ranged from 2.09 psu (at station 1 during monsoon) to 26.99 psu (at station 4 during premonsoon) and the average salinity was 14.45±3.55 psu. In the central sector the lowest salinity was recorded at station 6 (3.95 psu during monsoon) and the highest salinity was recorded at station 9 (29.83 psu during premonsoon) with an average value of 18.97±4.08 psu. The relatively lower salinity in the western sector may be attributed to Farakka barrage that release fresh water on regular basis through Ganga – Bhagirathi - Hooghly River system. The central sector, on contrary does not receive the riverine discharge due to massive siltation of the Bidyadhari River that blocks the fresh water flow in the region.

Critical analysis of the data on above ground biomass, below ground biomass, total biomass and salinity profile of the study area exhibits the regulatory effect of salinity on the biomass of the selected species. Correlation coefficient values reveal the adverse impact of salinity on Sonneratia apetala, but positive influence on the biomass of Avicennia alba and Excoecaria agallocha (**Table 4**).

The present study confirms the adaptability of Avicennia alba to higher salinity followed by Excoecaria agallocha. The significant negative correlation values between Sonneratia apetala biomass and ambient salinity reflects the sensitivity of the species to high salinity. There is a consensus of scientific opinion that the activities of man may cause a significant change in the global climate over the next hundred years due to which associated arms like rise of atmospheric carbon dioxide level, acidification and sea-level rise may be extended. This may have a far reaching impact on the coastal vegetation (blue carbon), which are potential sink of carbon dioxide. Hence, the present study is extremely relevant to establish the mangrove species as indicators of salinity fluctuation due to climate change. The present study also identified some better adapted mangrove species that can thrive luxuriantly in a hypersaline environment.

Species	**Combination**	**r-value**		
		Prm	Mon	Pom
A	Salinity × AGB	-0.7410	-0.7982	-0.7250
	Salinity × BGB	-0.6872	-0.7311	-0.6559
	Salinity × TB	-0.7301	-0.7842	-0.7103
B	Salinity × AGB	0.8215	0.8001	0.8738
	Salinity × BGB	0.8339	0.8081	0.8559
	Salinity × TB	0.5658	0.8037	0.8731

C	Salinity × AGB	0.6217	0.6808	0.7847
	Salinity × BGB	0.6291	0.6840	0.7757
	Salinity × TB	0.6231	0.6816	0.7829

A = *Sonneratia apetala*, B= *Avicennia alba*, C= *Excoecaria agallocha*; Prm = Premonsoon, Mon = Monsoon, Pom = Post monsoon; All values have p-values at 1% level ($p<0.01$)

Table 4. Correlation between salinity, AGB, BGB and TB of selected mangrove species in the selected stations

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