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Colonization and primary mangrove forest development in riverine islet of Indian Sundarbans

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Sundarbans estuary is characterized by dynamic depositional and erosional processes of sediments. The change in species composition and diversity–dominance are deduced by two studies carried out in the year 2006 (1st Study) and 2014 (2nd Study). There are 13 species in the 1st Study which was dominated by the early colonizing species. It is marked by high stem density but low basal area. The diversity index is 1.59 and the total biomass 65.5472 t ha^{-1}. In the 2nd Study, 20 species are recorded – where the dominance has shifted to the intermediate colonizers. While the stem density reduced by two and half times, the basal area tripled. The diversity value is 3.86 and the total biomass 269.6691 t ha^{-1}. Initally, the islet measured 49.78 ha with 50% vegetation cover, which later expanded to 61.15 ha with 89% forest cover.

[Keywords: Basal area, Biomass, Diversity, Mangrove forest, Stem density, Sundarbans]

Introduction

Across the world, mangrove forest areas have been estimated to be only 137,760 km^2 - a mere 0.7% of the total tropical forests[1]. Mangroves however, are important coastal resource that provide vast array of goods and services to mankind. But they are declining rapidly and that has been assigned to heavy population pressure in the coastal areas leading to encroachment, reclamation, over exploitation, unsustainable fishery practices, waste-water effluents and diversion of freshwaters[2,3]. In this context, Sundarbans – the largest single block of mangrove ecosystem in the world[4] assumes importance. The Sundarbans has witnessed 56% reclamation in the last two hundred years and presently occupies only 4267 Km^2 area. The region is remarkable for its high biodiversity, wide tidal amplitude and temporal - spatial variations in salinity regime[5,6]. There is also continuous erosion of banks, land subsidence and sediment accumulation, so much so, that more areas are eroded than accreted[7]. At the same time, there is prediction of relative sea level rise leading to partial drowning of land mass[8].

In this scenario, formation of a riverine islet offers an opportunity to record the gradual vegetal colonization of the newly formed landmass over a period of time. Studies were thus carried out to record the change in species composition, dominance-diversity shift and the development of a primary forest. Tree biomass were also estimated (by allometric method) to deduce the carbon stock, especially because mangroves are efficient carbon sink and allocation of the former in plant parts is essential for regional C-accounting[9].

Materials and Methods

The entire study was carried out in the islet ($22^0$09’17” N – $22^0$08’40”N Lat. and $88^0$51’32” E – $88^0$50’32” E Long.) – shaped as a reverse ‘D’ in the Gomor tidal river. It was adjacent to the large inhabited island of Gosaba, Sundarbans (Figures 1a, 1b, 1c). Presently covering an area of 61.15 ha, this riverine mudflat came into existence some decade and half ago (according to local EDC personnel) and was inundated during high tide.

The region experienced subtropical, maritime climate with distinct seasonality – showing three major seasons among others. While summer (April-May) is hot-humid with occasional thunder storm (mean monthly average, Max. -35.7^{0}C, Min. - 24.2^{0}C); monsoon (June - September) is marked by heavy shower. During that time it received 77% of total annual rainfall of 2150 mm and the relative humidity remained consistently high (100% - 68%). However, the winter (December - February) is rather cool and dry (mean monthly average, Max. - 24.2^{0}C, Min. - 11.8^{0}C).

The initial study was made in 2006 and the next in 2014 – from hence forth these are to be called 1st

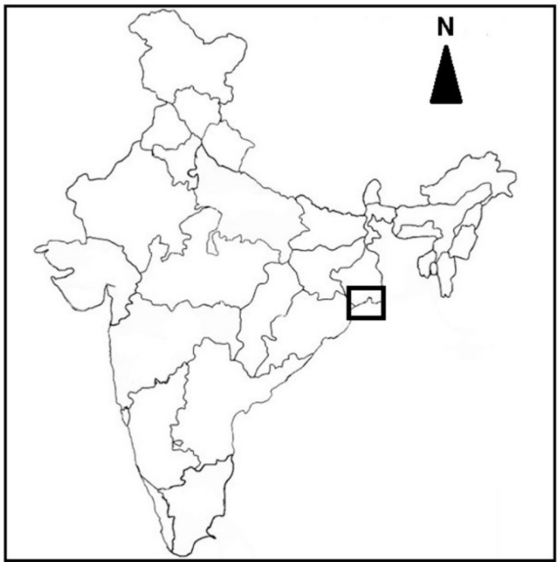

Fig.1a — Map of India showing the location of Sundarbans (in box).

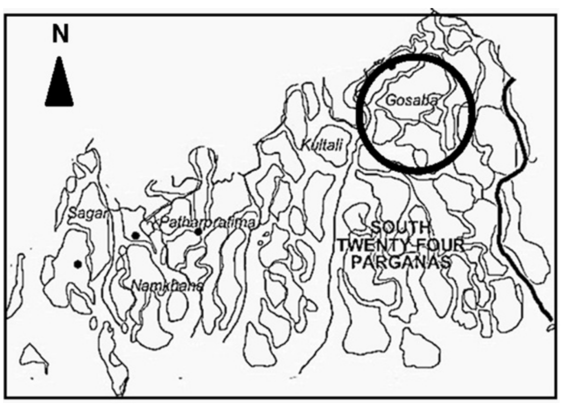

Fig.1b — Outline map of a portion of Sundarbans showing the location of the study area (in circle).

Fig.1c —Satellite image of the islet under study in 2014.

Study and 2nd Study, respectively. Samplings for vegetation analyses were carried out by laying a total of twenty quadrates of 10m x 10 m dimensions during each study. With the aid of GPS, quadrates were laid from the water edge towards the centre of the islet with a gap of 60-70 m. They were laid along five lines drawn randomly from different directions, with four quadrates in each line. All the plant species in the sampling area were identified, listed and individuals counted. For correct identification, standard literatures were consulted[10,11]. Stem circumference for tree species were measured at breast height. The diameter of herb, shrub, climber species and *Nypa* were taken at the ground level. Frequency, density, abundance of species was determined by following[12] while the importance value index (IVI) was calculated by following[13]. The ratio of abundance to frequency was used to interpret the distribution pattern of species[14]. Species evenness was evaluated following[15] and species diversity and concentration of dominance were determined by following[16,17], respectively. The similarity coefficient between the vegetation of 1st and 2nd Studies was calculated with respect to[18].

The tree species Above Ground Biomass (AGB) and Below Ground Biomass (BGB) were deduced by using the common allometric equations for mangroves[19].They were given as -

$W_{top} = 0.251\text{þ}D^{2.46}$…Above ground tree weight (W_{top} in kg);

$W_R = 0.199\text{þ}^{0.899}D^{2.22}$…Below ground tree weight (W_R in kg);

where, D stood for stem diameter in cm and þ for wood density in t m^{-3}. The þ for tree species was determined by taking wood samples of every species and then deduced by placing oven dried wood blocks over fresh volume (Table 1).

The area of the islet and the total vegetation cover for the 1st and 2nd Studies were done by the application of RS & GIS. Data were availed from Landsat IV satellite imagery for research purpose having 28.5m x 28.5m spatial resolution for the year 2006. Digital Globe images from Google Earth Imagery (Snapshot) were used for analyzing the major changes for the years 2010 and 2014. Snapshots of the images were referenced with respect to control points from earlier multi-spectral image using TNTmips Pro software from MicroImages, USA. The study area has been passed through hybrid classification technique, where the unsupervised classification is followed by supervised classification method. Digital image processing were applied in terms of contrast

Table 1 — The wood density (N=5), species density, basal area (BA) and importance value index (IVI) of the species in the study area.

Sl. No.	Species	Average Wood Density ($t\ m^{-3} \pm SD$)	1st Study Density (ha^{-1})	1st Study Basal Area ($m^2\ ha^{-1}$)[Av.BA/tree (cm^2)]	1st Study IVI	2nd Study Density (ha^{-1})	2nd Study Basal Area ($m^2\ ha^{-1}$) [Av.BA/tree (cm^2)]	2nd Study IVI
1.	*Aegialitis rotundifolia* (Aegialitidaceae)	0.461 ± .093	2280	0.59 [2.59]	12.85	470	1.95 [41.42]	22.84
2.	*Aegiceras corniculatum* (Myrsinaceae)	0.744 ± .141	2360	0.39 [1.22]	13.84	520	0.87 [16.74]	20.07
3.	*Avicennia alba* (Avicenniaceae)	0.631 ± .101	3120	3.12 [10.01]	50.51	310	1.76 [56.67]	18.61
4.	*Avicennia officinalis* (Avicenniaceae)	0.696 ± .080	1360	0.61 [4.52]	20.23	510	4.81 [94.23]	32.35
5.	*Avicennia marina* (Avicenniaceae)	0.807 ± .071	2680	1.7 [6.18]	36.70	420	1.85 [44.09]	20.84
6.	*Bruguiera cylindrica* (Rhizophoraceae)	0.755 ± .047	760	0.86 [11.30]	20.06			
7.	*Bruguiera gymnorhiza* (Rhizophoraceae)	0.744 ± .089				450	1.21 [26.80]	18.70
8.	*Ceriops decandra* (Rhizophoraceae)	0.835 ± .101	1520	0.25 [1.62]	8.38	480	0.84 [17.49]	18.47
9.	*Ceriops tagal* (Rhizophoraceae)	0.821 ± .066				60	0.33 [54.56]	3.77
10.	*Excoecaria agallocha* (Euphorbiaceae)	0.753 ± 0.063	440	0.67 [15.18]	13.62	1110	7.99 [72.07]	54.31
11.	*Heritiera fomes* (Sterculiaceae)	0.827 ± 0.047				250	1.07 [42.61]	12.80
12.	*Nypa fruticans* (Arecaceae)					130	2.05 [157.85]	11.60
13.	*Rhizophora apiculata* (Rhizophoraceae)	0.927 ± 0.050				140	0.46 [33.02]	9.68
14.	*Rhizophora mucronata* (Rhizophoraceae)	0.848 ± 0.032	120	0.21 [17.51]	8.46	260	0.77 [29.79]	14.44
15.	*Sonneratia apetala* (Sonneratiaceae)	0.704 ± 0.065	120	1.21 [101.24]	16.95	250	1.78 [71.19]	14.39
16.	*Sonneratia griffithii* (Sonneratiaceae)	0.523 ± 0.078				60	1.01 [167.86]	6.87
17.	*Xylocarpus granatum* (Meliaceae)	0.750 ± 0.068				50	0.24 [48.04]	4.12
18.	*Xylocarpus mekongensis* (Meliaceae)	0.899 ± 0.075				100	0.29 [28.81]	6.77
			Σ14760	Σ 9.61		Σ5570	Σ 29.28	
19.	*Acanthus ilicifolius* (Acanthaceae)					70		2.97
20.	*Derris trifoliata* (Fabaceae)		320		4.46	110		5.17
21.	*Porteresia coarctata* (Poaceae)		$728/100m^2$	2.50	91.42			
22.	*Suaeda maritime* (Chenopodiaceae)		400		2.50	20		1.28

Note : Sl. No. 1-18 are Tree species, while Sl. 19,20,21,22 are shrub, climber, grass and herb, respectively

enhancement and spatial filtering on the selected bands to increase the correlation for better judgment of training set, prior to supervised classification.

Four soil monoliths of $20x20x20cm^3$ dimensions were extracted from different parts of the islet during each study. Thereafter, the samples were air dried, Table — 2 The above ground, below ground and total biomass of tree species in the study area. A, B and C represent the above ground, below ground and total biomass per tree respectively.

	Above Ground Biomass (t ha^{-1}) [A(kg Tree^{-1})]		Below Ground Biomass(t ha^{-1}) [B(kg Tree^{-1})]		Total Biomass (t ha^{-1}) [C(kg Tree^{-1})]	
Tree Species	1st Study	2nd Study	1st Study	2nd Study	1st Study	2nd Study
Aegialitis rotundifolia	1.1996 [0.53]	7.86570 [16.74]	0. 8716 [0.38]	4.08680 [8.69]	2.0712 [0.91]	11.9525 [25.43]
Aegiceras corniculatum	0. 9572 [0.41]	4.65500 [8.95]	0.6528 [0.28]	2.47940 [4.77]	1.61 [0.69]	7.1344 [13.72]
Avicennia alba	12.4952 [4.00]	10.36000 [33.42]	7.094 [2.27]	4.90020 [15.81]	19.5892 [6.27]	15.2602 [49.23]
Avicennia officinalis	2.1628 [1.59]	35.21680 [69.05]	1.3952 [1.03]	15.53630 [30.46]	3.558 [2.62]	50.7531 [99.52]
Avicennia marina	7.7512 [2.89]	13.1125 [31.22]	4.5576 [1.70]	6.23200 14.84]	12.3088 [4.59]	19.3445 [46.06]
Bruguiera cylindrica	3.7796 [4.97]		2.2668 [2.98]		6.0464 [7.95]	
Bruguiera gymnorhiza		6.78990 [15.09]		3.43390 [7.63]		10.2238 [22.72]
Ceriops decandra	0.7836 [0.52]	4.51950 [9.41]	0.5736 [0.38]	2.41200 [5.03]	1.3572 [0.90]	6.9315 [14.44]
Ceriops tagal		2.32520 [38.75]		1.11800 [18.63]		3.4432 [57.38]
Excoecaria agallocha	3.2068 [7.29]	61.26470 [55.19]	1.8252 [4.15]	27.1976 [24.50]	5.032 [11.44]	88.4623 [79.69]
Heritiera fomes		7.76360 [31.05]		3.68390 [14.74]		11.4475 [45.79]
Rhizophora apiculata		3.3442 [23.89]		1.62100 [11.58]		4.9642 [35.47]
Rhizophora mucronata	1.1668 [9.72]	5.43420 [20.90]	0.6476 [5.40]	2.70570 [10.41]	1.8144 [15.12]	8.1399 [31.31]
Sonneratia apetala	8.3652 [69.71]	12.18580 [48.75]	3.7948 [31.62]	5.58860 [22.35]	12.160 [101.33]	17.7744 [71.10]
Sonneratia griffithii		5.84160 [97.36]		2.58290 [43.05]		8.4245 [140.41]
Xylocarpus granatum		1.53480 [30.70]		0.75000 [15.00]		2.2848 [45.70]
Xylocarpus mekongensis		2.09650 [20.97]		1.03080 [10.31]		3.1273 [31.28]
Total	41.868	184.310	23.6792	85.3591	65.5472	269.6691

Table 3 — Properties of soil in the study area.

	1st Study	2nd Study
Soil Texture (%)	Sand – 17.84 Silt – 24.00 Clay – 58.16	
pH	8.53 ± 0.125	8.30±0.41
EC (mmhos cm^{-1})	4.15 ± 0.16	8.75±0.79
Organic C%	0.48±0.11	1.04 ± 0.075
Available N (kg ha^{-1})	69.20 ± 4.73	188.2±13.82
Available P (kg ha^{-1})	86.46 ±4.76	66.5±10.04
Available K (kg ha^{-1})	1286.56 ± 105.77	1305.0±64.52

sieved, mixed together and stored for analyses in the laboratory. Soil pH was determined by digital pH meter and Electric conductivity (EC) was analysed by EI Deluxe Water and Soil Analysing Kit. Soil texture was determined by Hydrometer method[20]. The organic C was estimated by[21], while the available nitrogen, phosphorus and potassium were determined by following[22,23,24], respectively.

Results

In 2006, when the 1st Study was made, the islet had an area of 49.78 ha, of which the vegetation cover was 25.31 ha. A total of 13 mangrove species under 11 genera and 9 Family were recorded. There were 10 tree species (small statured 'True Mangroves') and

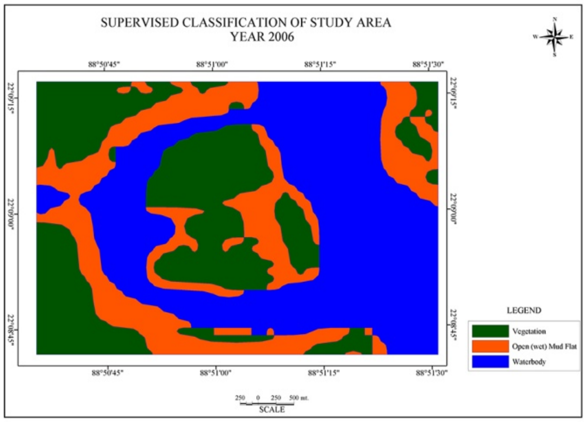

Fig. 2a — Satellite image of the islet in 2006, after supervised classification.

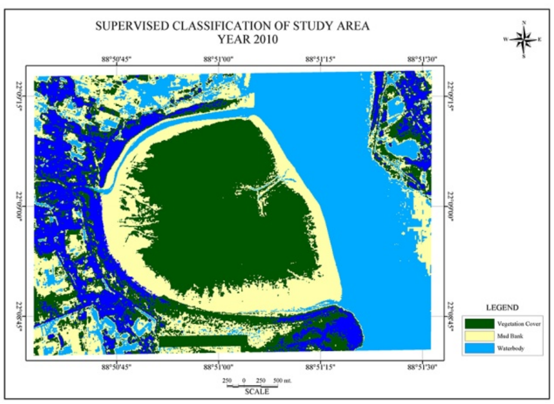

Fig. 2b — Satellite image of the islet in 2010, after supervised classification.

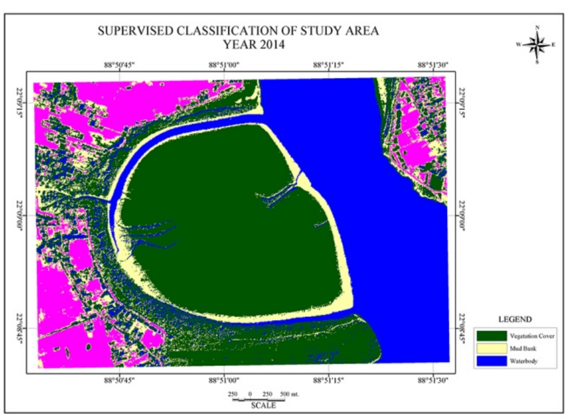

Fig. 2c — Satellite image of the islet in 2014, after supervised classification.

one species each of climber (*Derris trifoliata*), saline-soil grass (*Porteresia coarctata*) and herb (*Suaeda maritima*) – considered as 'Mangrove Associates' (Table 1). The total stem density was extremely high (14,760 stems ha^{-1}) though the total basal area was rather low (9.61 m^2 ha^{-1}) - suggesting immature trees. Such high stem density but lower basal area was typical of vegetation in formative islands. While, *Porteresia* had the highest importance value individually (91.42), the three species of *Avicennia* collectively showed greater importance among the trees (107.44). All the species were contagiously distributed. The species diversity index was a modest 1.590, the concentration of dominance 0.684 and evenness 1.427.

During the 2nd Study in 2014, the land area had increased to 61.15 ha, while the forest cover had more than doubled to 54.50 ha. A total of 20 species were recorded, who were placed under 14 genera and 12 Family (Table 1). Of these, there were 17 tree species (medium sized 'True Mangroves') along with the previously mentioned herb, climber and the saline-bank shrub (*Acanthus ilicifolius*). While the stem density had reduced by two and half times (5570 stems ha^{-1}), the total basal area had tripled (29.28 m^2 ha^{-1}). This was typical of a developing forest. Then again, none of the species showed absolute high importance value and there was a significant reduction in the importance of the three *Avicennia* species (collectively 71.8). But *Excoecaria* had improved remarkably both in number (1110 ha^{-1}), basal area (7.99 m^2 ha^{-1}) and in importance value (54.31). All the species were contagiously distributed except for *Rhizophora* and *Xylocarpus*, which were random in distribution. Species diversity had increased to 3.860 with the consequent reduction in concentration of dominance value to 0.089. The evenness had doubled to 2.970. All these were reflected in 45.65% similarly index, thus showing greater dissimilarity between the vegetations of the two Studies.

It has been suggested that in Sundarbans, salinity was the most important determinant for mangrove zonation[25]. During the 1st Study, this polyhaline, mudflat was dominated by the pioneering grass *Porteresia*, while the trees were the early colonizing species of *Avicennia* and *Sonneratia*. All these species together had 72% of the importance value. Although *Avicennia* spp. have wide range of salinity tolerance but they preferred open mudflats where their lighter propagules were easily carried by the tidal waters. Collectively, *Avicennia* and *Sonneratia* had 49% and

69% of total stem density and basal area, respectively. During the 2nd Study, the vegetation had changed in composition and diversity. Though the early colonizing trees still retained their importance (31%), density (28%) and basal area (38%), but *Porteresia* had ceased to exist. In fact, the thick maze of pneumatophores ensured plenty of heavier propagule trapping[26]. As a result, the shade loving, flood tolerant intermediate colonizers (*Aegialitis, Bruguiera, Ceriops, Rhizophora, Xylocarpus*) gained importance (32%), density (36%) and basal area (21%). These also promoted excellent growth of *Excoecaria*, who alone had 18% importance, 20% density and 27% of the basal area. Such positive correlation in the performance of *Excoecaria* with respect to salinity has been reported in Sundarbans[27]. There was also the presence of late colonizers like, *Heritiera, Nypa* and *Aegiceras* having collectively 15% importance value, 16% density and 13% basal area.

Biomass estimation is essential for assessing the carbon stock in tropical forests[28]. In the 1st Study, the total biomass was 65.5472 t ha^{-1} of which AGB contributed 64% and the BGB 36% (Table 2). The range for the proportion of AGB-BGB for these species were 69% - 31% (*Sonneratia*) and 58% - 42% (*Ceriops*), thereby showing consistently high BGB. *Sonneratia* individually had the highest biomass indicating comparatively older trees but collectively *Avicennia* spp. contributed 54% of the total biomass. Here, the four early colonizing species together contributed 72.5% (47.616 t ha^{-1}) of the total biomass while the balance 27.5% (17.9312 t ha^{-1}) were contributed by rest of the six tree species.

In the 2nd Study, the total biomass was 269.6691 t ha^{-1} of which AGB contributed 68% and the BGB 32% (Table 2). The range for the proportion of AGB-BGB for these species were 69% - 31% (*Sonneratia*) and 65% - 35% (*Ceriops*), thus showing somewhat greater allocation of biomass to the above ground parts. *Excoecaria* alone contributed 33% biomass - thereby stamping its dominance in the present vegetation. In this study, the five early colonizing species gave 41% (111.5567 t ha^{-1}) of the total biomass, while the intermediate colonizers contributed 52% (139.5295 t ha^{-1}) and the balance 7% (18.5819 t ha^{-1}) were provided by the late colonizers. Evidently, in between the two Studies, the total biomass had increased by four times (where the proportional increase for AGB was 4.4 times, the same for BGB was 3.6 times). The plants therefore invested more on stem than any other component with age.

For evaluating the vegetation carbon stock (t C ha^{-1}) it was assumed that 50% of total plant biomass (AGB+BGB) was carbon[29]. In the 1st Study, the above ground and below ground carbon stock were 20.934 t C ha^{-1} and 11.8396 t C ha^{-1}, respectively (total 32.7736 t C ha^{-1}). The same in the 2nd Study, were 92.155 t C ha^{-1} and 42.67955 t C ha^{-1}, respectively (total 134.83455 t C ha^{-1}). Of particular significance is the large C-stock in the subterranean portion. Average ratio of the AGB to BGB in the 1st Study was 1.67 (ranging from 2.20 in *Sonneratia* to 1.37 in *Ceriops)*. While in the 2nd Study, the same was 2.09 (ranging from 2.59 in *Sonneratia* to 1.87 in *Ceriops)*. Such low values were typical of mangroves, since they tend to allocate more to root biomass for adaptation to soft, water-logged sediments[9]. In comparison, the AGB: BGB for upland forests were between 3.96 and 4.52[30].

The soil in the islet was clayey, dark grayish-brown; heavy textured that showed poor drainage and tendency to super-saturated. They had hypothermic temperature and aqua-moisture regime. Soils for both the studies were alkaline and saline - since being inundated regularly by tidal waters. But salinity varied widely in time and space and interestingly, the salinity increased in the 2nd Study (Table 3). This was attributed to the upward capillary movement of water from the brackish ground water table and then following evaporation, the salts accumulated on the surface[31]. While organic C and available N values increased in the 2nd Study, but were rather low for forest soils. This was because, the litter were in continuous mode of movement as dissolved organic matter and particulate organic matter by the tidal waters. Added to these was the poor decomposability of mangrove litter due to high lignin and wax contents[32]. However, the P content was better, being more strongly bound with soil particles and also because fresh water discharge brought in P laden sediments. The quantity of available K was extremely high as the tidal water contained high proportion of soluble salts. This was expected in clayey soils and was a common feature of 2:1 type expanding lattice clay that cracked up when dry but stuck together when wet – thereby holding K^+ in between the particles.

Discussion

In Sundarbans over the years, several changes were discernible in species composition, high mortality, biodiversity loss and invasion of undesirable species[33]. Amongst the 84 mangrove species recognized in Sundarbans[11], 22 species were recorded from this islet alone (18 True Mangroves and 4 Mangrove Associates). More importantly, *Nypa, Heritiera* and *Xylocarpus* - all locally threatened species were also recorded. Although, the rate of natural regeneration is slow in mangroves, but the present state of the forest was rather healthy with seedling count of 7900-10800 ha^{-1}. Biomass estimates in this study were also comparable with those carried out elsewhere in Sundarbans[34], Kenya[35] and Indonesia[36]. The vegetation appeared to be in a transition zone from Riverine Flat to Mature Mangrove Ridge Forest. Then, the wood density which was considered to be a functional trait of plants providing information on their life history strategies - it is hypothesized that, early successional species showed less wood density, whereas the late successional ones have denser wood[37,38]. Average wood density for the 1^{st} Study was 0.708 t m^{-3} (0.605 – 0.779 t m^{-3} across all the plots), whereas in the 2^{nd} Study the same was 0.734 t m^{-3} (0.706 – 0.767 t m^{-3} across all the plots). Evidently, lighter wooded, short statured trees dominated the former which were later overshadowed by heavier wooded, trees with bigger (viviparous) propagules.

Mangroves, by virtue of their locations are predicted to be severely affected by the relative sea level rise. But with respect to Sundarbans, it has been argued that Hooghly River discharged between 328 and 616 million t sediment yr^{-1} and the major part of those were used up in filling the estuary. While the sediments were subjected to both depositional and erosional processes, the overall sediment sink would compensate for the effect of sea level rise in terms of land loss[39]. This islet, which was 49.78 ha in 2006 grew to 60.28 ha in 2010 (21% increase of land area) and then to 61.15 ha in 2014 (1.4% increase) (Figures 2a, 2b, 2c).

However, at the same time, vegetation cover grew more rapidly. There were only 50% cover (25.31 ha) in 2006 which increased to 70% cover in 2010 (42.08 ha *i.e.* 66% increment) and in 2014 the cover was 89% (54.50 ha *i.e.* 30% further increment). This showed that the mangroves actively aided in accretion of sediments that led to increase in land area. It was also evident from this study that with the forest cover expansion, the vegetation diversified simultaneously. All the species recorded in the islet have proven commercial values or were variously used for domestic purposes. In spite of that, during the entire study period there have been negligible sign of man induced disturbances (like grazing, fodder and fuel wood collection etc.). When mangroves are declining all over the world, formation of a new landmass and subsequent development of a mangrove forest is rather welcome. Now it would be interesting to observe in the next several years whether the islet would merge with the main island or dissipate naturally due to sediment realignment.

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