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Original Article

Mangroves of Indian Sunderban: Nature Based Buffer Against Estuarine Acidification

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Abstract

The ecosystem services of mangroves are well known and can be subdivided into provisioning, regulating, cultural, and supporting. The regulating services of mangroves are extremely crucial to combating the effect of climate change on the estuarine ecosystem. The present study reveals that there are five widely available species of mangroves that are found to be dominant in the study area, namely *Sonneratia apetala*, *Avicennia marina*, *Avicennia alba*, *Avicennia officinalis*, and *Excoecaria agallocha,* that are present in all 24 selected stations to assess the impact of mangrove Above Ground Biomass (AGB) on the pH level of the surrounding estuarine water. It is evident from the investigation that the biomass of mangroves has a potential to retard the rate of acidification in the estuaries of the Indian Sunderban. The present study was therefore conducted during the pre-monsoon season of 2023 based on the ground-level pH and Above Ground Bionmss (AGB) of dominant mangrove species obtained from 24 stations along the estuaries of the Sunderban Delta Complex. The significant positive correlation found between these two variables ($r = 0.9588$; $p<0.01$) reveals that mangroves effectively buffer and mitigate the adverse impact of acidification.

Keywords: *Above Ground Biomass (AGB), Aquatic pH, Estuary, Indian Sunderban, Mangroves*.

Introduction

The damaging effects of climate change that include broadly, amongst other, weather anomalies, acidification etc. were recognized decades ago, leading to have negative impact on the overall changing of the climate. This situation, in turn, poses significant negative impacts on agriculture, pisciculture, human health, livelihood, and thus, on the economy of the respective region. Several efforts have been undertaken to reduce the quantity of carbon dioxide and other GHG emissions in the atmosphere because it is established that CO_2 in the lower atmosphere leads to reduce the pH of the surface water of marine and estuarine ecosystems, often called *ocean acidification*.

Because of the fact that Indian Sunderban provide plenty of fish and fishery products on a daily basis, organizing and targeting this zone to be labeled as the blue economy zone would be the best option for local economic growth, and the advancement of scientific research in studying ocean acidification is inevitably required. The present investigation has therefore been planned towards the procurement of data (goal); however, for the advancement of understanding of the state of ocean acidification (OA) in Indian Sunderban, where mangrove-dominated ecosystems prevail, and to study such mangrove

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species and their apparent roles in mitigating the ocean acidification of Sunderban estuarine water (objectives).

Chaudhuri and Choudhury, (1994) carried out a detailed study on the Indian Sunderban ecology, which lies between $21^0$13'N and $22^0$40'N latitude and $88^0$03'E and $89^0$07'E longitude. The delta complex has the rivers Hooghly and Harinbhanga as the western and eastern boundaries, respectively. The Dampier-Hodges line is the northern boundary, while the Bay of Bengal, with an average salinity of 34 psu, lies in the southern part of the delta complex. Aquatic pH varies in the estuaries of Sunderban, with seasons being pre-monsoon > post-monsoon > monsoon, although within a narrow range, but with a significant impact (Mitra, 2013). The highest dilution of the Sunderban estuaries is generally caused by precipitation and subsequent water flow, which is the primary reason of the lowest pH value during the monsoon season.

Mangrove forests are noted for their significant ability to store carbon in their above- and below-ground biomass and also in the underlying soil substratum. These halophytes are mostly evergreen in nature and can accumulate a substantial amount of carbon in their above-ground and below-ground biomass (de Jong Cleyndert *et al*., 2020; Lamont *et al*., 2020). The carbon-storing ability of mangroves is associated with the enzyme RuBisCO, which is the major actor behind the absorption and accumulation of carbon dioxide from the surrounding environment through the process of photosynthesis.

Keeping this scenario in view, an attempt has been made in the present investigation to study the impact of reducing pH scale or '*acidification*' in the mangrove dominated areas of Sunderban as the marine and estuarine ecosystems have received special focus in this context because of the ability of the coastal vegetation, mainly covered by the mangroves referred to as ''blue carbon" to combat the negative impact of climate change through carbon sequestration (Mitra *et al*., 2011; Mitra *et al*., 2012; Sengupta *et al*., 2013; Bhattacharyya *et al*., 2015; Mitra and Roberto, 2015; Mitra *et al*., 2016; *Ahmad et al.*, 2018; Jiao *et al*, 2018; Macreadie *et al*., 2021).

Material and Methods

Site selection

The Sunderban mangrove delta of Indian Sunderban: The part of whole Sunderban is shared between Bangladesh (62%) and India (38%). The contributions of sediments carried by the rivers Ganga, Brahmaputra, and Meghna have resulted in the formation of this unique ecosystem.

Field studies were carried out during the month of April 2023 at 24 different locations in the Indian Sunderban that are identified as stations with their geographical coordinates expressed in latitude and longitude given in Table 1 and also in Figure. 1. The sampling seasonal period is generally characterized by high temperatures, minimum rainfall, and high salinity of the estuarine water.

Table 1: Sampling stations in Indian Sunderban

Station No.	Sampling station	Longitude	Latitude
1	Muriganga	$88^0$08'53.55" E	$21^0$38'25.86"N
2	Saptamukhi	$88^0$23'47.18"E	$21^0$36'02.49"N
3	Thakuran	$88^0$33'21.57"E	$21^0$49'43.17"N
4	Herobhanga	$88^0$41'46.52"E	$21^0$59'34.32"N
5	Ajmalmari	$88^0$39'00.68"E	$21^0$51'34.72"N
6	Dhulibasani	$88^0$33'48.20"E	$21^0$47'06.62"N
7	Chulkathi	$88^0$34'10.31"E	$21^0$41'53.62"N
8	Arbesi	$89^0$01'09.04"E	$22^0$11'43.14"N

9	Jhilla	88°57'57.07"E	22°09'51.53"N
10	Pirkhali	88°51'06.04"E	22°06'00.97"N
11	Panchmukhani	88°54'14.71"E	21°59'41.58"N
12	Harinbhanga	88°59'33.24"E	21°57'17.85"N
13	Khatuajhuri	89°01'05.33"E	22°03'06.55"N
14	Chamta	88°57'11.40"E	21°53'18.56"N
15	Matla	88°44'08.74"E	21°53'15.30"N
16	Chandkhali	89°00'44.68"E	21°51'13.59"N
17	Goasaba	88°46'41.44"E	21°43'50.64"N
18	Gona	88°54'31.09"E	21°41'15.44"N
19	Chhotahardi	88°44'17.79"E	21°44'42.24"N
20	Baghmara	89°04'40.59"E	21°39'04.45"N
21	Mayadwip	88°47'09.95"E	21°35'50.23"N
22	Jambu Island	88°10'22.76"E	21°35'42.03"N
23	Lothian	88°20'29.32"E	21°38'21.20"N
24	Sagar Island	88°02'20.97"E	21°38'51.55"N"

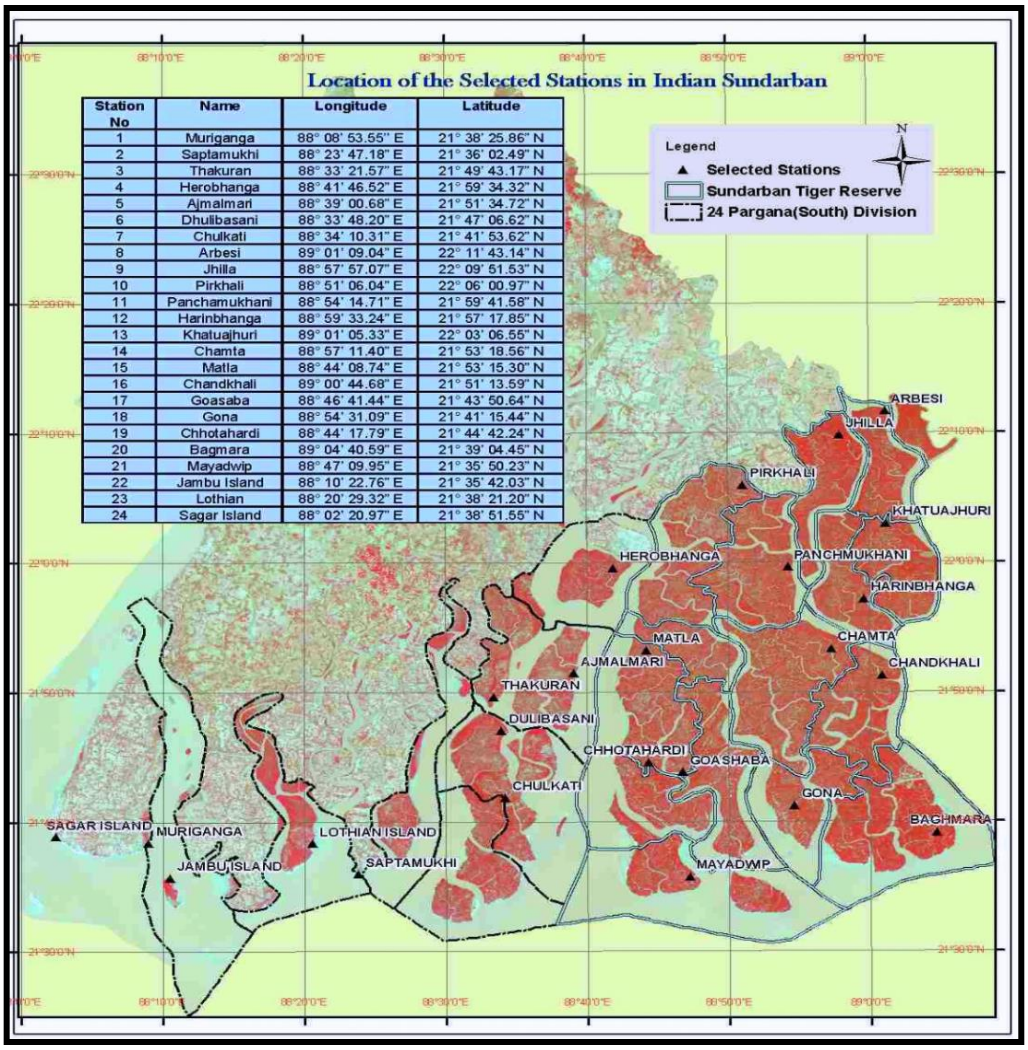

Figure 1 Selected stations in the Indian Sunderban

Measurement of pH

pH was determined from each sample taken from the respective ambient estuarine water of the 24 stations considered for the present study during high tide by a portable digital pH meter (manufactured by Hanna Instrument, Italy) with an accuracy of ± 0.01.

Estimation of AGB of the dominant mangroves of the study area

Above Ground Biomass (AGB) of tree species refers to the sum of the biomass of the stem, branch, and leaf of the species that lie above the soil or sediment. For each of the selected stations, the AGB of each species was estimated using the standard formula as outlined by Mitra and Sundaresan (2016).

The AGB of the selected mangrove species was evaluated through the following steps:

Step 1: A species-wise population count in the 10 m x 10 m quadrat was carried out at each station from 15 selected plots during the low tide phase. The mean value of each species was considered for AGB estimation.

Step 2: Species-wise diameter at breast height (DBH) was estimated in the selected plots at all the stations from which radius (r) was measured. The basal diameter of each species was estimated, and again, the basal radius (R) was calculated.

Step 3: The form factor expressed as r^2/R^2 was calculated to provide the data as a correction factor. The heights of the trees were estimated using a laser beam for each species in all 24 stations.

Step 4: Wood density (WD) was measured based on a cube cut from 4.5 depth inside the stem, followed by oven drying.

Step 5: Stem biomass was finally computed as per the expression -- $\pi r^2 h$x WDx (r^2/R^2)

Step 6: Three branches of each species were weighed after drying, and the mean weight of the dried branches was multiplied by the number of branches in the tree for each species.

Step 7: The leaf biomass of the species was calculated after manually plucking the leaves from three branches (stated in step 6) and drying them at 60 °C overnight to remove the moisture. The mean weight of the leaf was multiplied by the number of branches to get the mean biomass of leaves for each species.

Step 8: In the final step, the AGB was calculated by adding the sum of Above Ground Stem Biomass (AGSB), Above Ground Branch Biomass (AGBB) and Above Ground Leaf Biomass (AGLB).

Thus, AGB= AGSB + AGBB + AGLB.

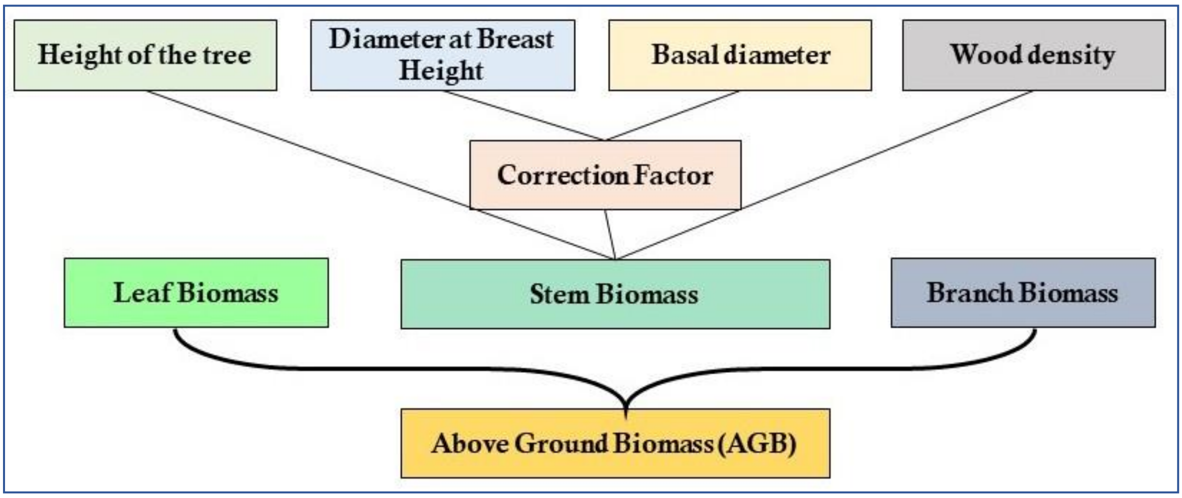

Figure 2 Schematic representation of AGB estimation

Results

Surface water pH

The pH of the surface water exhibited significant variations, falling into a range between 8.22 and 8.33. The spatial order of pH is Chulkathi (Station 7) = Jhilla (Station 9) = Chamta (Station 14) = Baghmara (Station 20) = Mayadip (Station 21) >Dhulibasani (Station 6) = Arbesi (Station 8) = Khatuajhuri (Station 13) = Gona (Station 18) = Lothian (Station 23) >Ajmalmari (Station 5) = Chotahardi (Station 19) >Herobhanga (Station 4) = Panchmukhani (Station 11) = Harinbhanga (Station 12) = Chandkhali (Station 16) >Muriganga (Station 1) = Thakuran (Station 3) = Pirkhali (Station 10) = Goshaba (Station 17) = Jammu Island (Station 22) >Saptamukhi (Station 2) > Matla (Station 15) > Sagar Island (Station 24) (Fig. 3).

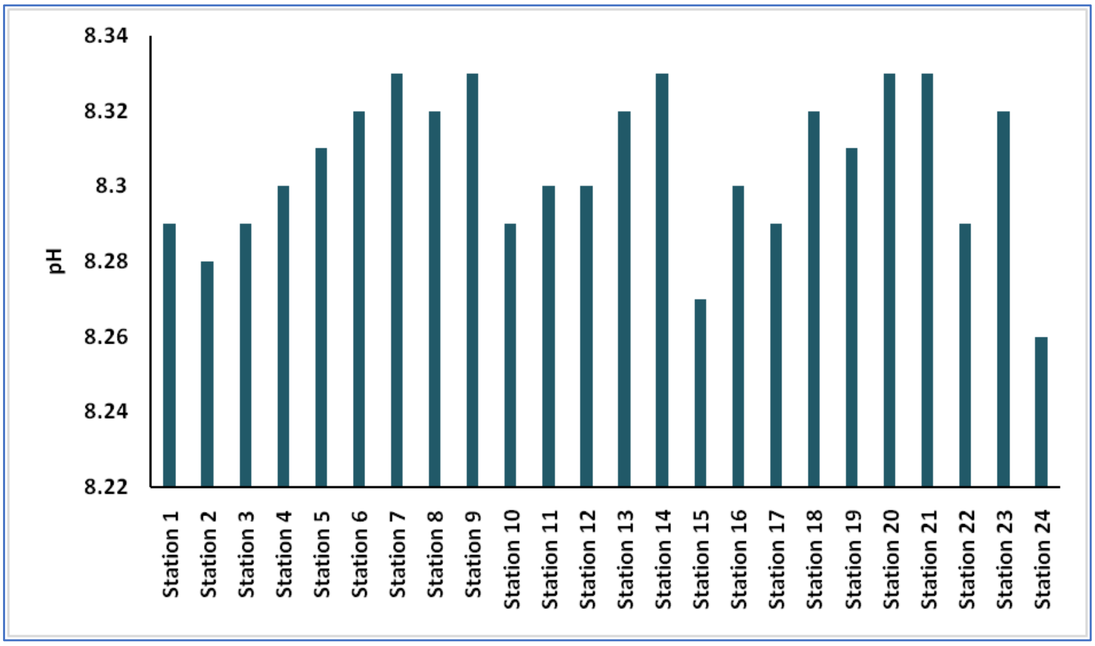

Figure 3 Mean surface water pH of the ambient water of the stations under survey

AGB of dominant mangroves

The total AGB values of all five dominant species ranged from 29 tonnes ha^{-1}(at Sagar Island) to 87 tonnes ha^{-1}(at Mayadip). The values varied as per the sequence Mayadip (Station 21) > Jhilla (Station 9) > Chulkathi (Station 7) = Baghmara (Station 20) > Chamta (Station 14) > Goshaba (Station 17) > Arbesi (Station 8) = Chhotahardi (Station 19) = Lothian (Station 23) > Dhulibasani (Station 6) > Khatuajhuri (Station 13) > Ajmalmari (Station 5) = Panchmukhani (Station 11) > Harinbhanga (Station 12) > Herobhanga (Station 4) > Chandkhali (Station 16) > Goshaba (Station 17) > Thakuran (Station 3) > Muriganga (Station 1) > Saptamukhi (Station 2) = Pirkhali (Station 10) > Jambu Island (Station 22) > Matla (Station 15) > Sagar Island (Station 24) (Fig. 4).

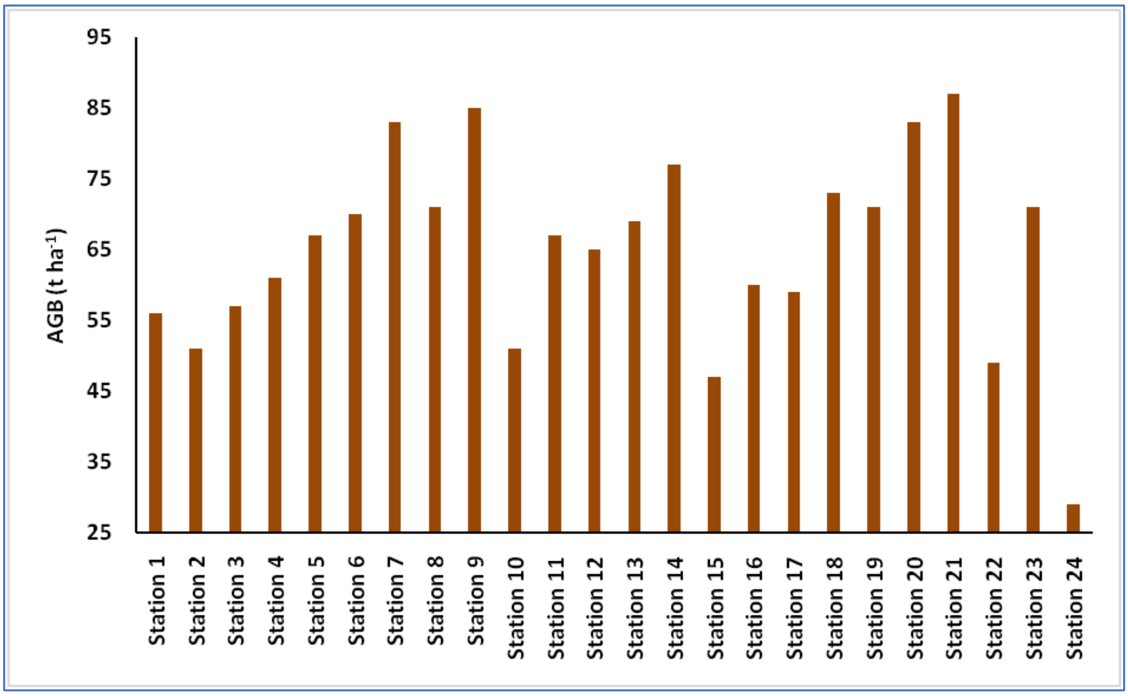

Figure 4. AGB of dominant mangrove species in the study area

The first order analysis of the data sets reveals a positive correlation between AGB and ambient water pH ($r= 0.9588$; $p<0.01$), which means the region with the high values of AGB of dominant mangrove species is associated with surrounding water with relatively high pH (Fig. 5).

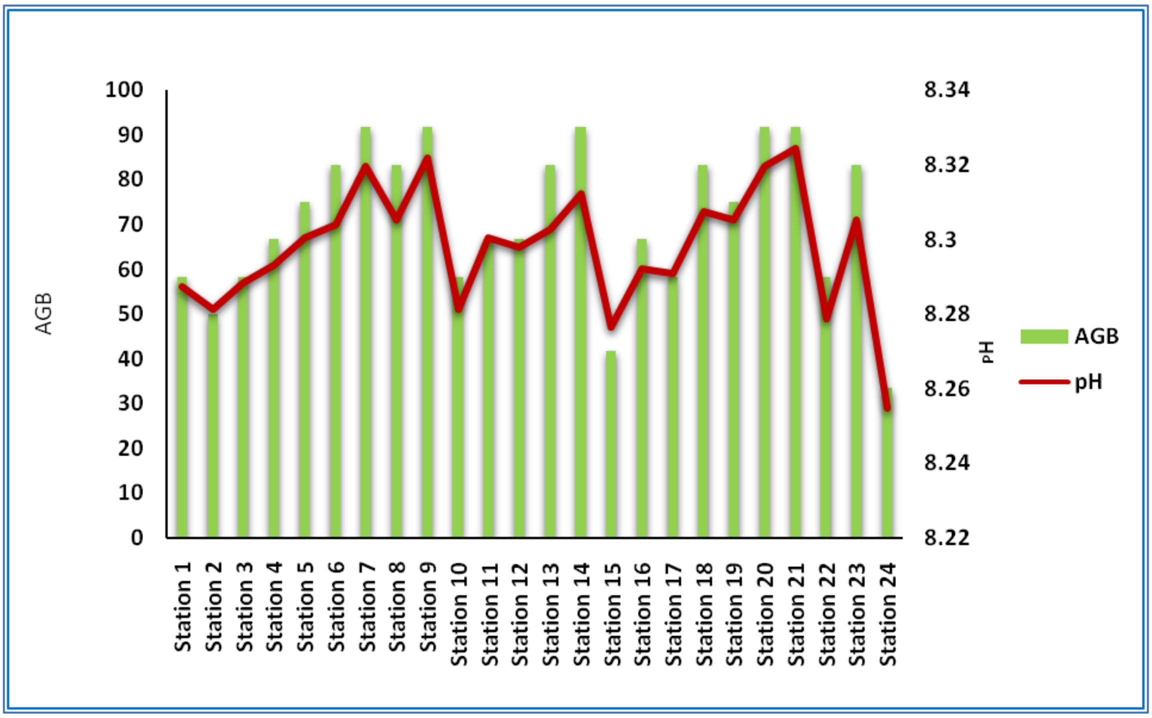

Figure 5 Inter-relationship between AGB of the dominant mangroves and the pH of the ambient estuarine water

Discussion

As stated earlier, the present investigation was planned to study the state of lowering pH in Sunderban estuarine water, which supports the growth of fish and fishery products by strengthening 'blue economy' for the area under the influence of versatile species of mangrove vegetation available. In order to fulfill the objective of this investigation by studying the influence of various mangrove species in 24 locations of the Indian Sunderban, the procurement of data on the pH of the estuarine surface water at the field of each location was set out as the goal of the present investigation. It was felt important, however, for the advancement of understanding of the state of ocean acidification (OA) under the influence of mangrove-dominated ecosystems in the Indian Sunderban and their roles in mitigating the ocean acidification of Sunderban estuarine water.

It is evident from the results (Figure 3) that the pH of surface estuarine water in 24 locations (Figure 1) of Sunderban is varying, although it appears to be in a narrow range but seems to be significant as the geographical coordinates vary. This is likely as the estuary is influenced by various factors including temperature, salinity, and residence time of the flowing water that has had varying solubility potential for CO_2 because of the variation in salinity gradient and nearby river water and their mixing variability leading to have resulted in low salinity of the estuarine water at the considered locations and provided greater accessibility of more CO_2 solubility into the estuarine water (Joesoef *et al.*, 2015) and emission pattern and quantity due to industrial and other developmental activities (Mitra and Zaman, 2021).

Figure 4 shows the results on the Above Ground Biomass (AGB) of dominant mangrove species obtained from 24 stations along the estuaries of the Sunderban delta region. It is evident that there are five widely available species of mangroves that are found to be dominant in the study area (24 selected stations), namely *Sonneratia apetala, Avicennia marina*, *Avicennia alba*, *Avicennia officinalis*, and *Excoecaria agallocha.* The result of the study shows (Figure 4) that the total AGB values of all five dominant species were found to range from 29 tonnes ha^{-1} (at Sagar Island Lat -21º38'51.55"N Long – 88º02'20.97") to 87 tonnes ha^{-1} (at Mayadip). The values of the AGB tonnes per ha were found to vary as per the sequence. Mayadip (Station 21) > Jhilla (Station 9) > Chulkathi (Station 7) = Baghmara (Station 20) > Chamta (Station 14) > Gosaba (Station 17) > Arbesi (Station 8) = Chhotahardi (Station 19) = Lothian (Station 23) > Dhulibasani (Station 6) > Khatuajhuri (Station 13) > Ajmalmari (Station 5) = Panchmukhani (Station 11) > Harinbhanga (Station 12) > Herobhanga (Station 4) > Chandkhali (Station 16) > Gosaba (Station 17) > Thakuran (Station 3) > Muriganga (Station 1) > Saptamukhi (Station 2) = Pirkhali (Station 10) > Jambu Island (Station 22) > Matla (Station 15) > Sagar Island (Station 24).

Figure 5 shows the interrelationship between the Above Ground Biomass (AGB) of the dominant species of mangrove and the lowering of the pH of the respective estuarine water. The graph shows that pH and AGB are positively correlated, the value of which was found to be $r = 0.9588$; ($p < 0.01$) in this study.

There are several scientific studies that have been reported increase in the rate of GHGs, mostly the carbon dioxide, into the atmosphere due to expansive and extensive emissions from industrial, urban, tourism, and several infrastructure developmental activities (Doney *et al*., 2020) at the expense of the blue carbon community, which in turn has resulted in the lowering of the pH of estuarine water. It has been documented that the average pH of the world's ocean surface water has already fallen by about 0.10 units from an average value of about 8.21 to 8.10 since the beginning of the industrial revolution (Feely *et al.,* 2008).

The assessment of the Intergovernmental Panel on Climate Change (IPCC), considering the target year of 2100, forecasts that there will be a rise of 150% lowering of pH of the ocean water (Chakraborty *et al.*, 2013), which can reduce the absorption potential of atmospheric carbon, keeping a high probability to accelerate the ongoing phenomenon of global warming through the lowering of pH in the estuarine system. Moreover, the acidification of the coastal and estuarine ecosystems poses significant negative impacts on biotic communities, preferably those with calcareous shell like molluscs (Mele *et al*., 2023)

The halophytes present in the coastal zone are the key players in buffering the pH of the aquatic ecosystem. The estuaries of the Indian Sunderban, sustaining a rich mangrove pool, are an ideal habitat to conduct such an in-depth study on acidification due to the presence of emission hotspots like the megacity of Kolkata in its vicinity (200 km from the heart of the city) and the Haldia industrial zone.

The Indian Sunderban mangrove ecosystem comprising of 34 species of true mangroves is noted for their unique ability to sequester carbon (Agarwal *et al*., 2017; Dutta *et al.,* 2022; Khokher *et al*., 2023).

The buffering potential can be validated through mangrove patches along the estuaries (Sengupta *et al.*, 2013; Raha *et al.,* 2013). The acidification of the mangroves adjoining estuaries is attributed to the release of carbon dioxide from the mangove-sourced organic matter that finds its way into the pelagic and benthic zones (Borges *et al*., 2003; Alongi, 2014; Call *et al*., 2015). However, Sippo *et al.* (2016) have put forward the view that much of the carbon dioxide produced is outgassed within the mangrove creeks themselves, and mangrove forests can release alkalinity into the nearby coastal ocean.

From the result of the present investigation, it appears that this might be one of the reasons for the significant positive correlation between mangrove biomass, more precisely AGB, and the ambient aquatic pH scale ($r = 0.9588$; $p< 0.01$) in the present study. The ratio of Dissolved Inorganic Carbon (DIC) and alkalinity inputs to coastal waters (1:1.2) would result in an overall increase in pH and thus lead to a buffering effect (Sippo *et al*., 2016).

From that point of view, the result of the present investigation has thrown some important light on the nature-based buffer capacity of mangroves in reducing acidification in estuarine ecosystems (Seddon *et al*., 2020), inspiring further future studies considering all other parameters into consideration.

The majorly available species in the present delta complex are: *Sonneratia apetala*, *Avicennia marina*, *Avicennia alba*, *Avicennia officinalis*, and *Excoecaria agallocha."* and these species, which are common to all 24 stations selected for the present study, scrub carbon dioxide from the surrounding environment and store it in organic form through ribulose 1, 5-biphosphate carboxylase oxygenase (RuBisCO), which appears to be the primary enzyme for the fixation of atmospheric carbon (Bathellier *et al.*, 2020). The quantum of halophytic biomass (here AGB) thus poses a significant influence on the pH of the estuarine water as these halophytes absorb carbon dioxide for photosynthesis and push the value towards an alkaline condition. The atmospheric carbon dioxide fixed into organic matter by mangroves is mineralized *in situ* through anaerobic degradation, and subsequently exported as alkalinity to the coastal ocean through tidal action. Apart from this, mangroves increase the alkalinity of the ambient estuarine water *via* natural biogeochemical cycling. Furthermore, mangrove roots have evolved to metabolize organic matter from the surrounding oxygen – deficit soil, releasing alkalinity into the water. Mangroves and salt marshes releases inorganic carbon in the form of carbonate alkalinity and dissolved inorganic carbon that buffers the surrounding estuarine water. Figure 5 clearly shows the highly significant positive influence of AGB on the ambient aquatic pH.

Conclusion

To sum up, it can be advocated that the pH of the ambient water of Sunderban is regulated by the magnitude of AGB in mangroves (a major component of the blue carbon reservoir). Hence, conservation and expansion of mangroves in Sunderban should be prioritized to buffer the lowering of pH in the estuarine water. In context to the present study region, the AGB of mangroves can be increased through appropriate dilution of the estuarine water (*via* channelizing stocked rainwater through gravity flow), as many pockets in the Indian Sunderban have been silted, which has blocked the flow of fresh water from the upland riverine system. It is interesting to note that the survival and subsequent physiological growth (referred to as AGB herein) of mangroves are significantly salinity specific. Therefore, salinity-based plantations of mangroves might be considered a road map to effectively buffer the lowering of pH in the estuarine water of the Indian Sunderban.

It is evident from the investigation that the biomass of mangroves has the potential to retard the rate of acidification in the estuaries of the Indian Sunderban. The present study was conducted during the premonsoon season of 2023 based on the ground-level pH of the estuarine water system and the

Above Ground Biomass (AGB) of dominant mangrove species obtained from 24 stations along the estuaries of the Sunderban Delta Complex. The significant positive correlation found between these two variables ($r = 0.9588$; $p<0.01$) reveals that mangroves effectively buffer and mitigate the adverse impact of estuarine acidification.

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Conflict of Interest:

All the authors fully agree with the contents of the manuscript as to prevailing no conflict of interest of any kind.

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