

CAN MANGROVES HELP COMBAT SEA LEVEL RISE THROUGH SEDIMENT ACCRETION AND ACCUMULATION?

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ABSTRACT Mangroves have substantial roles to induce sedimentation in the vulnerable coastal regions, which subsequently helps to combat climate change induced impacts like sea level rise. Although Sarawak has numerous pristine estuarine mangroves, studies on the roles of these mangroves in regards to sediment deposition are scanty. Therefore, this study was carried out to determine the sediment accretion and accumulation pattern of pristine Sibuti mangrove using tiles and sediment traps from January to December 2013. Monthly average accretion and accumulation rate of sediments of this mangrove were 0.55 mm and 0.08 g cm⁻², respectively. A total of 6.56 mm and 0.93 g cm⁻² sediments were accreted and accumulated annually. Significantly positive correlation ($r=0.794$) was found for the monthly accretion of sediments with accumulation. Accretion and accumulation of sediments were also positively correlated with rainfall. Comparatively higher rate of accretion and accumulation of sediments were estimated in the months of wet season when the rainfall and tidal inundation duration were high. Erosion was found higher in the months of dry season when the rainfall was low. Seasonal variations were not found for sediment accretion as well as accumulation in the study area. The findings of the study suggest that the roles of this forest in regards to sediment accretion through retention is compatible with the predicted annual rate of sea level rise of 1.8 to 5.9 mm within 21st century by IPCC.

(Keywords: Sediment accretion, Sediment accumulation, Sea level rise, Sibuti mangrove, Sarawak)

INTRODUCTION

There are numerous evidence that mangroves are one of the most productive and valuable ecosystem lying between land and sea especially in the tropical and sub-tropical region [1, 2]. Out of numerous functions, the most remarkable function of this ecosystem to coastal environment is to provide a suitable technique for trapping sediments, and due to aforementioned reason it is a recognized ecosystem that retains and accumulate suspended sediments [3-6]. Sediment accretion means the accumulation of suspended sediments rich in organic and inorganic materials borne by tidal water during high tide [2, 7]. These suspended materials settle down in the forest floor during low tide, while the velocity of water-flow is very low [2, 6]. Besides, the unique and complex structure of mangrove trees having prop roots, knee roots and pneumatophore reduces the velocity of tidal flow and thus trap sediments which eventually plays key role in land building process [2, 8-11]. Pristine and undisturbed mangroves are able to trap and retain more than 80% of tidal sediments [6]. In most of the studies, the annual rate of sedimentation in mangrove areas were found within 1-8 mm [12].

Global warming is the important issue at present

throughout the world and has strong relation to sea level rise (SLR) [13, 14]. Besides, sea level rise is a severe threat for the existence of many mangroves in the coming decades [15, 16]. The existence of mangroves in future will mostly depend on their accretion and retention/deposition capability of sediments to combat upcoming prediction of sea level rise [8, 15, 17, 18]. Due to global warming, the projected rate of global sea level rise (GSLR) is expected to be 1.8 to 5.9 mm yr⁻¹ by 2100 [19]. However, this projection is completely based on global perspective, the local or regional changes of sea level may vary from this projection [20, 21]. National Hydraulic Research Institute of Malaysia (NAHRIM) reported that due to local climate and topographical conditions, the regional sea level rise in Malaysia is expected to be higher [22]. They predicted the observed mean SLR rate along the Malaysian coast (based on satellite altimetry data from 1993-2010) is within 2.7-7.0 mm yr⁻¹. However, in Miri, Sarawak the projected SLR for the year of 2100 is 5.23 mm yr⁻¹.

In Malaysia, there are about 5,77,500 ha of mangroves forest reserves and Sarawak is the second largest estate that covers 23% of the total mangrove forests [23]. The mangroves of Sarawak are mostly found

along the coastlines [24, 25]. The studies conducted on Malaysian mangroves were mostly on standing biomass, productivity, litter dynamics, nutrient flux [26-30] and few studies were on sedimentation [31, 32] that focused completely on mangroves of Peninsular Malaysia. Although Sarawak mangroves are mostly found in coastlines, very few researches have yet been conducted to explore the geomorphological roles of these mangroves considering the GSLR. This leads to incomplete understanding of mangroves function in Sarawak. Therefore, this study was carried out to determine the sediment accretion and accumulation pattern of *Rhizophora apiculata* dominated mangrove [33] of Sibuti, an important and undisturbed mangrove [34] of Sarawak, Malaysia. The outcome of this study would be helpful to quantify the land building pattern of Sarawak mangroves in regards to projected estimation of GSLR.

MATERIALS AND METHODS

Study Area

Sibuti mangrove forest ($3^{\circ}59'25.76''$ N and $113^{\circ}43'51.6''$ E) is located at the edge of South China Sea, approximately 45 km West of Miri town, Sarawak, Malaysia (Figure 1). The forest is bounded by Bungai farmlands on the North and Sibuti river at the South and East. This is an undisturbed tropical mangrove forest dominated by *R. apiculata* [33] followed by *Xylocarpus granatum* and *Nypa fruticans*. The forest is regularly inundated by normal high tide and was found to be inundated averagely 34 times per month [35]. Therefore, the forest is under classification-3 [36]. The estuary is semi-diurnal and tidal range varied between 0.2 to 2 m during neap and spring tide [35]. From the river bank to inner side, the whole forest is almost flat with modest increase of elevation at the edge of the forest.



Figure 1. Location of the study area showing sample plots in the Sibuti mangrove forest, Miri, Sarawak.

Collection of Sample

Three sampling plots, each $100\text{ m} \times 100\text{ m}$ (river estuary, middle and last part of the forest) were purposively selected considering the structure, density and topography of the forest to gather overall information about the forest. A total of nine solid tiles (30 cm^2 ; three replicates in each sampling plot)

were placed horizontally at 5 cm depth from the sediment surface and marked by flags following the methods of Mahmood *et al.* [32] and Christiansen *et al.* [37]. Initial sediment height (mm) on each tile was recorded monthly from January to December 2013. Monthly accretion and erosion were estimated by deducting the sediment height on the same tile base of preceding month.

Similarly nine sets (each set attached with three traps) of sediment traps (three replicates in each sampling plot) were set up 10 cm above the forest floor [38] and the sediment traps were collected and replaced by new sets monthly and brought back to laboratory for further processing. The traps sediments were filtered by Oil-less Vacuum Pumps (Model: Rocker 300; Rocker Scientific Co., Limited, Taiwan) and oven dried at 60°C until the constant weight of the samples were attained. The dried samples were then weighed to nearest gram and then calculated to $g\ cm^{-2}$.

Statistical Analysis

Monthly mean values of sediment accretion as well as accumulation were calculated considering the three seasons [39] namely, Intermediate (January-April), Dry (May-August), and Wet (September-December). Seasonal variation of total accreted and accumulated sediments were compared by one way analysis of variance (ANOVA) followed by Tukey’s test using SAS 9.2 version. Pearson correlation coefficient was performed to determine the influence of climatic and hydro parameters (temperature, rainfall, tidal frequency and inundation duration) on monthly sediment accretion and accumulation.

RESULTS

Climatic and Hydro Parameters

The monthly temperature, rainfall, tidal frequency and inundation duration that influence sediment accretion/erosion and accumulation are shown in Table 1. Significant seasonal variations were not found in monthly mean temperature, monthly total rainfall, tidal frequency and inundation duration throughout the year. The highest tidal frequency was calculated in intermediate season especially in March (41 times) and April (40 times), whereas the lowest frequency was observed in the months of dry season especially in June (30 times) and May (31 times). The tidal inundation duration that flooded the study area was recorded highest in May (263 hrs) followed by December (261 hrs), April (238 hrs) and October (236 hrs), whereas, the lowest tidal inundation duration was found in February (200 hrs) followed by August (217 hrs), September (217 hrs) and March (219 hrs). The lowest rainfall was recorded in August (101.3 mm) of dry season and highest rainfall was recorded in December (691.2 mm) of wet season (Figure 2).

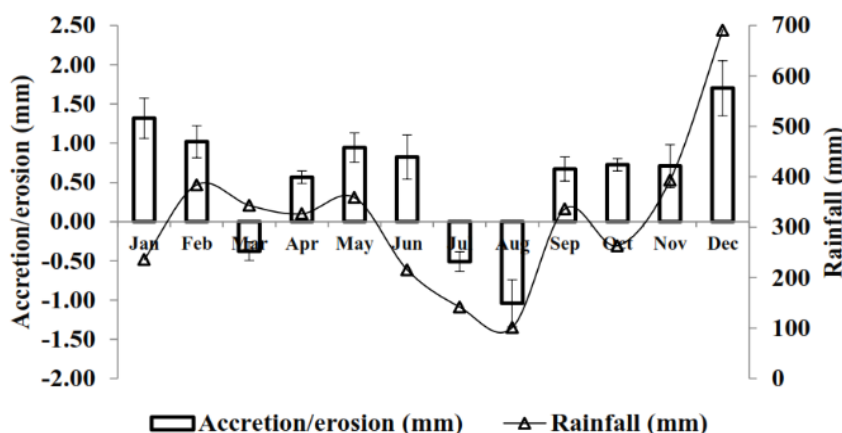


Figure 2.Relation between month wise sediment accretion/erosion and rainfall of Sibuti Mangrove, Sarawak.

Table 1. Climatic and hydro-parameters of Sibuti mangrove during the study period.

Climatic/hydro-parameters	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Total rainfall (mm)†	236.4	384.4	343.5	326.8	359.0	215.8	141.8	101.3	336.5	263.6	393.7	691.2
Mean Temp (°C)†	27.9	28.5	28.7	28.8	28.8	28.9	28.4	28.5	28.2	28.0	28.2	28.2
Tidal frequency (times)#	34	32	41	40	31	30	33	33	34	41	32	32
Total tidal inundation (hr)#	229	200	219	238	263	243	222	217	217	236	235	261

Source: † stands for source: Meteorological Department, Niah Forest Research Station, Miri, Sarawak, Malaysia, and # stands for source: The Director of Marine Sarawak, Malaysia (DOMSM), 2013. Sarawak Hourly High and Low Tide Tables (Including Standard Ports of Sabah). The Sarawak Marine Department (SMD), Malaysia.

Sediment Accretion and Erosion

Monthly sediment erosion and accretion of Sibuti mangrove were within -1.04 and 1.72 mm. The highest accretion rate was recorded in December (1.72 mm) followed by January (1.32 mm), February (1.02 mm), May (0.94 mm), June (0.83 mm), October (0.73 mm), September (0.67 mm) and April (0.57 mm). The erosion rate was recorded highest in August (-1.04 mm) followed by July (-0.51 mm) and March (-0.38 mm; Figure 2). A total of 6.56 mm sediment was accreted annually with monthly average of 0.55 mm in this mangrove forest during the study period. The rate of accretion was comparatively higher in wet season than that of dry and intermediate seasons, whereas, the rate of erosion was found vice-versa, although no significant variations were found ($df=2$, $f=1.47$, $p=0.28$) among the seasons. Monthly accretion and accumulation rate of sediments was positively correlated ($r=0.79$, $p<0.05$) and related to the rainfall ($r=0.67$, $p<0.05$). The sediment accretion rate was not related to the temperature, monthly tidal frequency as well as inundation duration that flooded the mangrove ecosystem (Table 2).

Sediment Accumulation

Monthly sediment accumulation rate in Sibuti mangrove ranged from 0.02 to 0.18 g cm⁻². The highest accumulation was recorded in December (0.18 g cm⁻²) followed by January (0.13 g cm⁻²), November (0.10 g cm⁻²), June and September (0.08 g cm⁻²), February, May, October (0.07 g cm⁻²), April, July (0.06 g cm⁻²), March (0.03 g cm⁻²) and August (0.02 g cm⁻²). The lowest accumulation was recorded in August (0.02 g cm⁻²) followed by March (0.03 g cm⁻²), April, July (0.06 g cm⁻²), and February, May, October (0.07 g cm⁻²) (Figure 3). Annually, 0.93 g cm⁻² sediments were accumulated with the monthly average of 0.08 g cm⁻² in this mangrove forest. Sediments accumulated in the wet season was higher than the intermediate and dry seasons, however the seasonal changes of accumulation was not significant ($df=2$, $f=1.60$, $p=0.25$). Similar to sediment accretion, monthly sediment accumulation rate was also positively related ($r=0.69$, $p<0.05$) with monthly rainfall (Table 2).

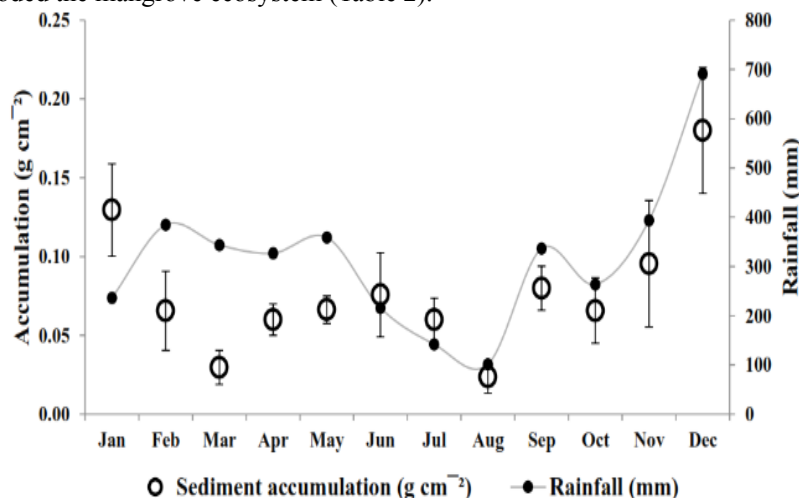


Figure 3. Relation between month wise sediment accumulation and rainfall of Sibuti Mangrove, Sarawak.

Table 2. Pearson correlation coefficients among sediment accretion and accumulation with climatic and hydro-parameters of Sibuti mangrove, Sarawak.

	Accretion (mm)	Accumulation (g cm ⁻²)	Tidal Frequency (times)	Tidal inundation (hr)	Rainfall (mm)	Mean Temp (°C)
Accretion (mm)	-					
Accumulation (g cm ⁻²)	0.79**	-				
Tidal Frequency (times)	-0.17 ^{ns}	-0.35 ^{ns}				
Tidal inundation (hr)	0.49 ^{ns}	0.51 ^{ns}	-0.17 ^{ns}	-		
Rainfall (mm)	0.67*	0.69*	-0.08 ^{ns}	0.44 ^{ns}	-	
Mean temp (°C)	-0.19 ^{ns}	-0.49 ^{ns}	-0.09 ^{ns}	0.16 ^{ns}	-0.15 ^{ns}	-

** Significant at P<0.01; ns; not significant at P>0.05; *significant at P<0.05; n=12.

DISCUSSION

A significant relation was found between monthly sediment accretion and accumulation. The highest accretion (1.72 mm) was recorded in December, followed by January, February, and May when the monthly rainfall was comparatively higher along with higher tidal inundation duration that flooded the mangrove ecosystem. In contrast, the erosion rate was higher in dryer months especially in August (-1.04 mm) when the rainfall and tidal inundation duration were relatively low (Figure 2; Table 1). This indicates that rainfall has profound influence on sediment accretion in mangrove ecosystems. The finding of the present study showed the similar pattern of accretion that was observed in other tropical mangrove ecosystems [32]. Besides, the topography of the forest floor is almost flat with very little variation at the edge of the forest. Moreover, the canopy of the forest is almost closed. So the raindrops can not directly hit the forest floor. The higher accretion during the aforementioned months when maximum sediments were accumulated may also be due to the flat topography of the forest floor and canopy closure. Accretion/erosion rate of sediment in this mangrove ecosystem followed the monthly trend of sediment accumulation, which indicates that nature itself maintains a balance and logical pattern in regards to sediment accretion through accumulation in a mangrove ecosystem (Figure 4). The relationship between accretion and sedimentation in the present study is in agreement with the findings of Hedges and Keil [40]. Acceleration of land building process through elevated sedimentation in mangroves was reported by Mahmood et al. [32] in a protected mangrove forest of Kuala Selangor, Malaysia. Due to successive sedimentation in a mangrove ecosystem, land surface increases through sediment retention and the complex structure and root system of mangroves accelerate this process by enhancing the friction along with the reduction of tidal current speed [4, 41].

Generally, the rate of sediment deposition depends on the tidal frequency and its duration that flooded the mangrove ecosystem [42, 43]. In the present study, monthly tidal frequency and inundation duration that flooded the study area were not remarkably varied throughout the year. During the study period, it was hypothesized that the most relevant and influencing hydro-parameters especially tidal frequency and its duration of

flooding might have significant influence on the rate of sediment accretion and accumulation. But after correlating the variables with the monthly rate of sediment accretion and accumulation, it was not found as important as speculated at the beginning (Table 2). Similar results were also reported by Cahoon and Lynch [44] from the three forest types of southwestern Florida, U.S.A. They did not find any influence of tidal duration that flooded the area on sediment accretion. The insignificant correlation may be due to the negligible and less fluctuation of hydro parameters of the study area. Sediment accretion and accumulation vary from mangroves to mangroves especially due to variation of species composition and tree density [2, 32]. *Avicennia* and *Rhizophora* dominated mangroves have the higher rate of sediment accreting and accumulating capacity due to their unique criteria of root systems i.e. pneumatophore, knee roots and prop/stilt roots that induce sedimentation process by creating physical barrier as well as reducing the velocity of tidal current [2]. *Rhizophora* experiences higher tidal velocity along with higher tidal duration due to the growing nature in the river bank areas [2]. The accretion and accumulation of sediments in this study area may be influenced by the dominance of *R. apiculata* rather than hydro parameters influences.

The annual rate of sediment accretion of this study area is comparable with other *R. apiculata* dominated mangroves of the world especially of Malaysia (Table 3). This result also supports the sediment trapping capacity and pattern of *R. apiculata* dominated mangroves throughout the world. Bacon [49] and Snedaker *et al.* [50] reported that in most of the cases mangroves are keeping pace with the rate of sea level rise. However, long term and extensive research is essential for this kind of prediction and comparison.

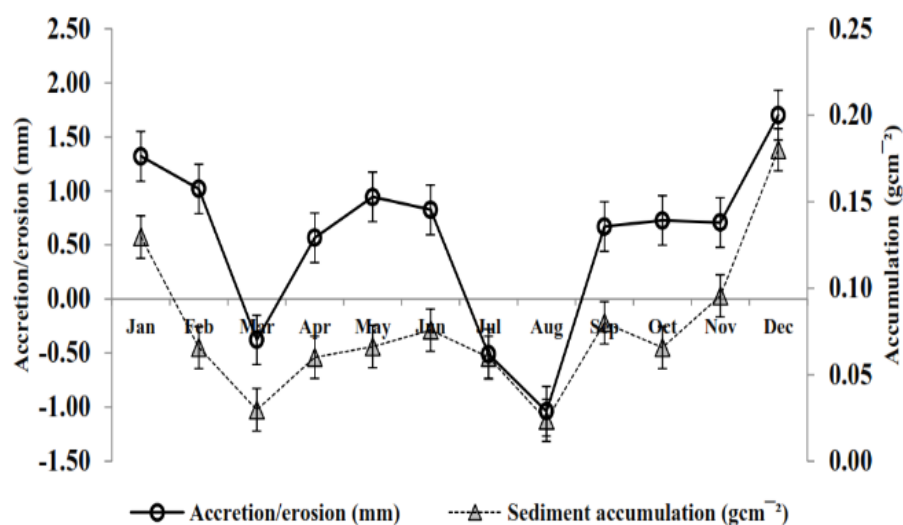


Figure 4. Relation between month wise sediment accretion/erosion and sediment accumulation of Sibuti Mangrove, Sarawak.

Table 3. Comparison of annual sediment accretion in various mangroves of the world.

Location	Dominant species	Accretion rate (mm yr ⁻¹)	Source
Mexico	<i>Rhizophora sp.</i>	3.00	[45]
Northern Australia	<i>Rhizophora sp.</i>	6.00	[46]
Kuala Kemaman, Terengganu , Malaysia	<i>Rhizophora sp.</i>	6.4 - 14.6	[47]
Bebar River Mangrove, Pahang, Malaysia	-	5.3 to 5.4	[48]
Setiu Mangrove, Malaysia	-	6.10	[31]
Kuala Selangor, Malaysia	<i>Bruquiere parviflora</i>	10.20	[32]
Sibuti Mangrove, Sarawak, Malaysia	<i>Rhizophora sp</i>	6.56	This study

CONCLUSION

Sibuti mangrove forest located at the mouth of South China Sea is possible to be affected by the consequences of global warming as well as sea level rise. Annual rate of sediment accretion of this mangrove forest is 6.56 mm. The projected annual rate of global sea level rise for the year 2100 by IPCC is 1.8-5.9 mm [19] and by National Hydraulic Research Institute of Malaysia (NAHRIM) for Miri, Sarawak is 5.23 mm [22]. So our study clearly suggests that Sibuti mangroves is quite capable to combat predicted sea level rise by IPCC and NAHRIM through sediment accretion and accumulation. This result will also provide baseline

information of a pristine mangrove in regards to sedimentation. Long term research including various influencing parameters may develop a model of sedimentation process for the coastal area of the tropical region. The information of sediment accreting and accumulating pattern of this pristine mangrove ecosystem of Sarawak would be useful to the national and international community for realizing the importance of mangroves to compare and combat future sea level rise (SLR).

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