

# Post tsunami mangrove evaluation in coastal vicinity of Andaman Islands, India

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**Abstract** The present study was carried out to determine the mangrove area water quality, mangrove diversity and density at Minnie Bay, Lalaji Bay and Aerial Bay (Andaman Islands, India). The physicochemical parameters such as salinity, nitrate, inorganic phosphate and total phosphorus varied significantly. Mangrove diversity was high at Minnie Bay while density at Aerial Bay. *Rhizophora mucronata* dominated at all three sites during the study period. Shannon-Wiener diversity index ( $H' = 2.261$ ) and Pielou's evenness ( $J' = 0.8348$ ) were high at Minnie Bay. The higher species density cover ( $5.679 \text{ Nos./m}^2$ ) was recorded at Aerial Bay. Bray-Curtis cluster analysis showed 63.35 % similarity and formed two clusters. Though uplift and subsidence of coastal land due to the  $M_w$  9.3 Sumatra earthquake in 2004 has affected the mangrove vegetation, its rejuvenation was observed in the newly formed inter-tidal areas due to changes in coastal geomorphology. The comparative study on physicochemical parameters, mangrove coverage and conservation are discussed in detail.

**Keywords** Diversity · Density · Mangrove · Physicochemical parameters · Andaman

## Introduction

Mangrove forests are one among the world's most productive tropical ecosystem and act as interface between land and sea in tropical and subtropical environment. It constitutes a dynamic ecosystem in association with flora and fauna of terrestrial as well as coastal environment. It survives in sheltered coast line in the tropical and subtropical inter-tidal regions such as bays, estuaries, lagoons and creeks (Qasim 1998). The mangrove forests act as valuable guard and save lives and properties against destructive cyclones, violent storm surges and tsunami (Danielsen et al. 2005; Selvam 2005). The mangroves of Andaman and Nicobar (A & N) Islands are probably the best in India in terms of its density and growth (Dagar et al. 1991). According to the latest estimate by the Forest Survey of India (Anonymous 2011), the total mangrove area is about  $4,662.56 \text{ km}^2$  in India, out of which,  $617 \text{ km}^2$  (13.23 %) occurs in A & N Islands. Out of that,  $614 \text{ km}^2$  is in Andaman with only  $3 \text{ km}^2$  spreads in Nicobar Islands. About 39 mangrove species were reported from India (Kathiresan 2000), of which 35 species belonging to 17 genera and 14 families are found in A & N Islands (<http://forest.and.nic.in>). The earthquake and subsequent tsunami of 2004 caused considerable damage to the mangrove stands (Roy and Krishnan 2005; Chaudhuri et al. 2009) of these islands reducing the stands by  $20 \text{ km}^2$  with a small revival of  $2 \text{ km}^2$  after 2009 (Anonymous 2011). In South Andaman Islands, 30–80 % of mangrove stands got affected due to tsunami (2004) at some locations whereas it was negligible in Middle Andaman Islands. On the other hand, sea water is not reaching to mangrove stands at some locations in North Andaman Islands due to land uplift (Roy and Krishnan 2005). The mangrove vegetation requires suitable water quality condition for its

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optimum growth (Kathiresan 2002). In the recent past, the mangrove vegetations rejuvenating and establishing its stands in newly developed inter-tidal zone. Thus it is better to calculate the diversity index for better understanding, conservation and utilization of living resources by creating a single annotated index of biological collections (Kulkarni et al. 2010).

This study is novel than the other studies carried out in other coastal and estuarine environment (Tripathy et al. 2005; Chauhan and Ramanathan 2008; Mitra et al. 2009; Prasad 2011). The novelty in this study is the usage of Bray-Curtis cluster analysis, (one way) analysis of variance (ANOVA), Shannon-Wiener diversity index and application of Geographical Information System (GIS). The objectives of present study are : (1) to analyses mangrove species density and diversity in selected coastal areas, (2) investigation of water quality parameters in mangrove environment and (3) to propose integration of statistics with landuse data as a effective method for visual assessment of mangrove coverage.

## Materials and methods

### Description of the study areas

The study sites (Fig. 1) were selected in such a way to represent the areas from South, Middle and North Andaman Islands. Minnie Bay (MB) and Aerial Bay (AB) are tsunami affected areas of South Andaman (land subsidence) and North Andaman (land uplift), respectively, surrounded by human settlements; whereas Lalaji Bay (LB) is situated on the western side of Long Island (Middle Andaman) not affected much by tsunami; having negligible settlement around the study area. These were chosen as study sites, due to earthquake ( $M_w$  9.3) induced uplift and subsidence with occurrence of a good mangrove prior to the tsunami event.

### Sampling and analysis

Sampling was carried out between December 2010 and July 2011, to study the density, diversity and physicochemical parameters in the selected areas. The mangrove density and diversity cover were studied using quadrat method (Pound and Clements 1898). Quadrates ( $15 \times 15$  m) were plotted randomly to estimate the density and diversity at each study area. Totally, 45 quadrates were plotted within the sampling sites. Species were identified with the help of available literature (Dagar et al. 1991; Kathiresan and Bingham 2001; Rajendran and Baskara 2004). Further species were confirmed with the help of specimens of Botanical Survey of India (BSI), Andaman & Nicobar Regional Centre, Port Blair.

The seawater samples were collected from each study area (low and high tides) and transferred to laboratory. During the sampling, *in situ* measurement was made for the parameters

like water temperature (WT) and pH. Dissolved oxygen (DO) in the samples were fixed immediately and analyzed by Winkler's titration method (1888). Salinity was analysed by argentometric titration method (Strickland and Parsons 1972). Nutrients such as nitrite, nitrate, ammonia, inorganic phosphate (IP), silicate, total nitrogen (TN) and total phosphorus (TP) were analyzed by following methods of Grasshoff et al. (1999). Sampling positions were recorded by GPS (Garmin eTrex Vista H,  $\pm 3$  m). Sediment pH was recorded using a soil pH meter (Takemura DM-15) during low tide.

### Data analysis

The site-wise variation between the physicochemical parameters at MB, LB and AB were analysed using one way analysis of variance (ANOVA) using Microsoft Excel 2007. Bray-Curtis cluster analysis was employed using PRIMER v.6 (Clarke and Gorley 2006). Apart from this, univariate measures [Shannon-Wiener diversity index ( $H'$ ), Margalef's species richness ( $d$ ) and Pielou's evenness ( $J'$ ), Simpson dominance ( $D$ )] were analysed using Microsoft Excel 2007. The land-use/land-cover classification was done through supervised classification using Maximum Likelihood Algorithm and output was processed in ArcGIS® 9.3.1 (ESRI 2009).

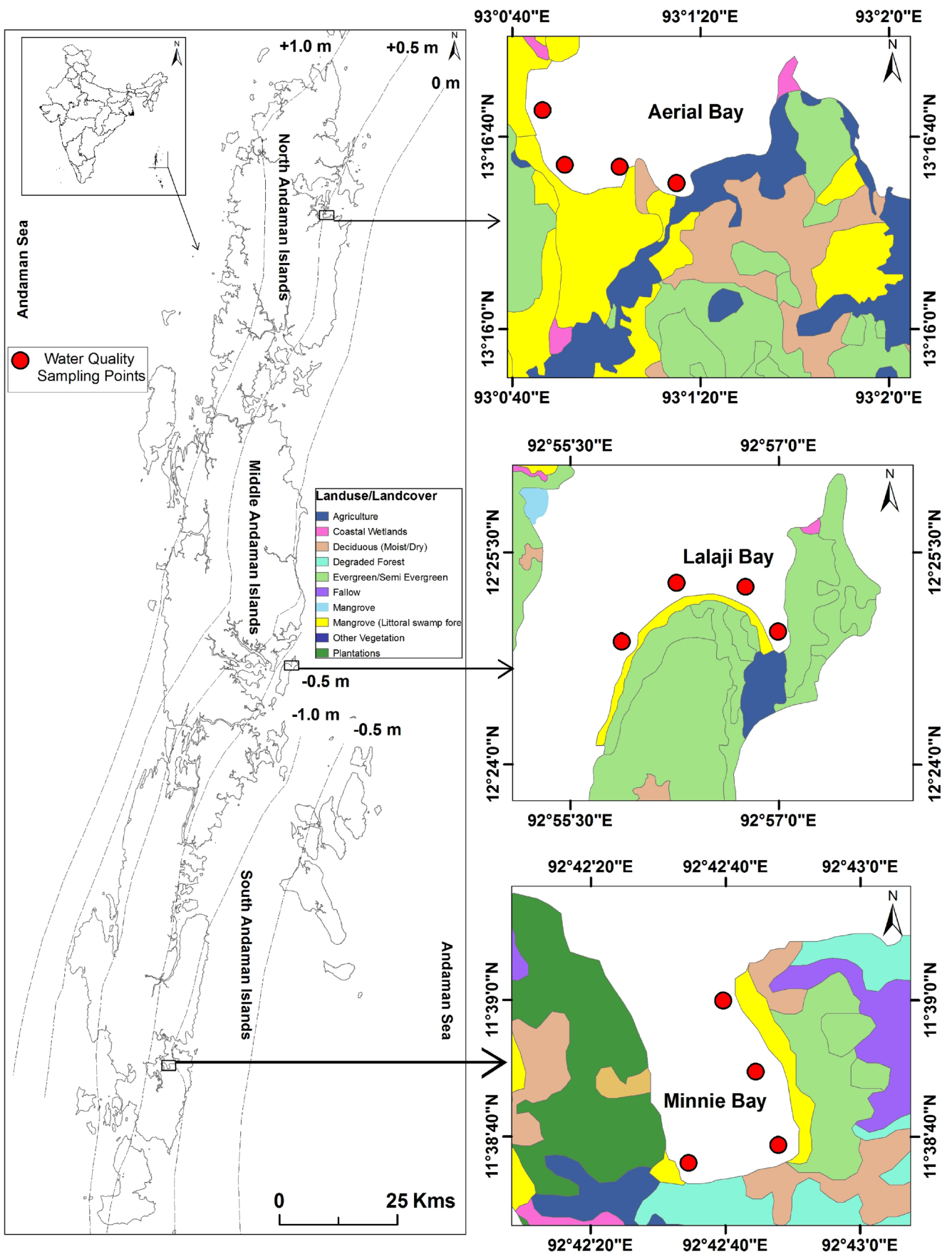
## Results

### Mangrove study

The results of mangrove density and relative abundance are presented in Table 1. Totally, 12 true and 5 associated mangrove species were recorded. Among them, *Rhizophora mucronata* and *R. apiculata* are dominant followed by *Avicennia marina* at all study sites. The mangrove density at MB, LB and AB were found 3.075, 3.113 and 5.679 Nos./m<sup>2</sup>, respectively. The higher mangrove density was recorded at AB.

*Rhizophora mucronata* (26.4 %) dominated at MB, followed by *Avicennia marina* (16.3 %), *R. apiculata* (12.2 %) and *Nypa fruticans* (12.2 %). Similarly, *R. mucronata* (38.2%) dominated at LB, followed by *R. apiculata* (29.3%), *Bruguiera cylindrica* (7.2%) and *Sonneratia alba* (6.4%). Similarly, *R. mucronata* (56.6 %) dominated at AB, followed by *Avicennia marina* (35.2 %), *R. apiculata* (6.3 %) and *Excoecaria agallocha* (1.9 %). The higher diversity with 15 species, belonging to 14 genera and 12 families were recorded at MB. Totally, 11 species, belonging to 9 genera and 7 families were recorded at LB. Lower species diversity with

**Fig. 1** Site map of the study areas (Minnie Bay, Lalaji Bay and Aerial Bay) [The dashed line indicating the contours of vertical ground movement. The '+' and '-' signs indicate ground uplift and subsidence respectively in Andaman Islands (Ray and Acharyya 2011). The '0' value contour represents the neutral line (Ray and Acharyya 2007)]



**Table 1** Density and relative abundance of mangrove

Mangrove species	Family	MB		LB		AB	
		Den (Nos./m <sup>2</sup> )	RA (%)	Den (Nos./m <sup>2</sup> )	RA (%)	Den (Nos./m <sup>2</sup> )	RA (%)
<i>Rhizophora mucronata</i> Lam.	Rhizophoraceae	0.813	26.4	1.188	38.2	3.214	56.6
<i>Rhizophora apiculata</i> Blume.	Rhizophoraceae	0.375	12.2	0.913	29.3	0.357	6.3
<i>Bruguiera cylindrica</i> (L.) Bl.	Rhizophoraceae	0.250	8.1	0.225	7.2	–	–
<i>Bruguiera gymnorrhiza</i> (L.) Lam.	Rhizophoraceae	–	–	0.150	4.8	–	–
<i>Ceriops tagal</i> (Perr.) Robin.	Rhizophoraceae	0.100	3.3	0.100	3.2	–	–
<i>Avicennia marina</i> (Forsk.) Vierh.	Avicenniaceae	0.500	16.3	0.038	1.2	2.000	35.2
<i>Scyphiphora hydrophyllacea</i> C.F. Gaertn.	Rubiaceae	0.125	4.1	–	–	–	–
<i>Sonneratia alba</i> J. Smith.	Sonneratiaceae	0.038	1.2	0.200	6.4	–	–
<i>Lumnitzera littorea</i> (Jack) Voigt.	Combretaceae	0.050	1.6	–	–	–	–
<i>Xylocarpus granatum</i> Koen.	Meliaceae	0.025	0.8	–	–	–	–
<i>Nypa fruticans</i> Wurm.	Arecaceae	0.375	12.2	–	–	–	–
<i>Excoecaria agallocha</i> Linn.	Euphorbiaceae	0.088	2.9	0.075	2.4	0.107	1.9
Mangrove associates							
<i>Clerodendrum inerme</i> (L.) Gaertn.	Verbenaceae	0.150	4.9	–	–	–	–
<i>Finlaysonia obovata</i> Wall.	Asclepiadacea	0.063	2.0	–	–	–	–
<i>Hibiscus tiliaceus</i> Linn.	Malvaceae	0.050	1.6	0.125	4.0	–	–
<i>Heritiera littoralis</i> Dryand.	Sterculiaceae	0.075	2.4	0.075	2.4	–	–
<i>Pandanus tectorius</i> Parkinson ex Du Roi	Pandanaceae	–	–	0.025	0.8	–	–
Total		3.075	100	3.113	100	5.679	100

Den density, RA relative abundance

only 4 species belonging to 3 genera and 3 families were recorded at AB.

Univariate diversity indices were applied to study species abundance and the results are presented in Table 2. Margalef's species richness (d) was found high at MB followed by LB and AB. The Shannon Wiener's diversity index was high at MB ( $H' = 2.261$ ) compared to LB ( $H' = 1.767$ ) and AB ( $H' = 0.9413$ ). The greater number of species diversity was observed at MB which showed that the individuals in the community are distributed more equitably ( $J' = 0.8348$ ) which might be due to stable and enclosed bay environment. The percentage cover of *Rhizophora mucronata* was 56.6 % at AB, thus the Simpson's dominance (D) showed higher value (0.449).

Bray-Curtis cluster analysis under group average (Fig. 2) showed that the study sites were grouped into one major group with 63.35 % similarity, based on the species density

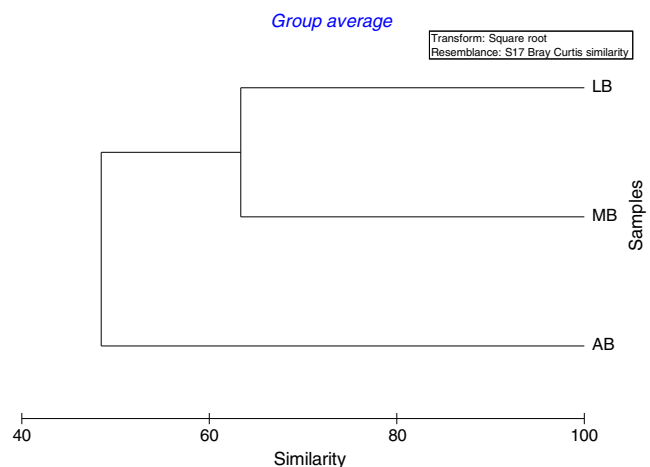
**Table 2** Diversity indices of mangrove

Univariate diversity indices	MB	LB	AB
Margalef's species richness (d)	2.44	1.739	0.473
Shannon Wiener diversity index ( $H'$ )	2.261	1.767	0.9413
Pielou's evenness ( $J'$ )	0.8348	0.7371	0.679
Simpson's dominance (D)	0.140	0.247	0.449

observed. The outlier AB might be due to the occurrence of higher species density cover (5.679 Nos./m<sup>2</sup>) compared to other two sites.

#### Physicochemical parameters

The mean values ( $\pm$ SD) and ANOVA result of physicochemical parameters in mangrove environment are presented in

**Fig. 2** Bray-Curtis cluster analysis of plant density of three study areas under group average linkage



**Table 3** Mean ( $\pm$ SD) and ANOVA result of physicochemical and sediment parameters

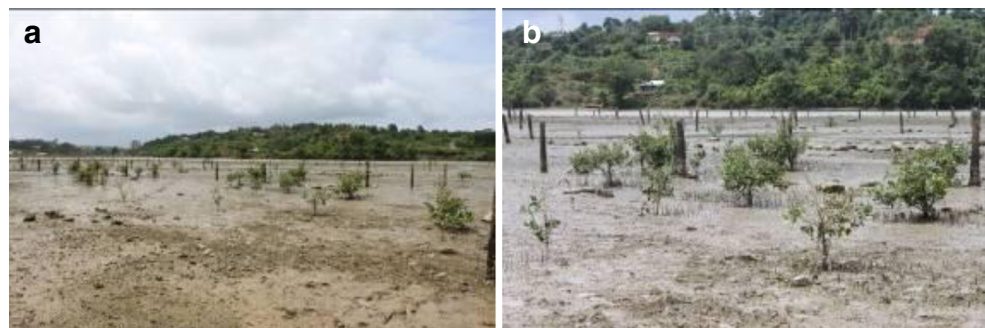
Locations	MB	LB	AB	ANOVA result	
				F value	P value
Parameters	Mean ( $\pm$ SD)	Mean ( $\pm$ SD)	Mean ( $\pm$ SD)		
WT ( $^{\circ}$ C)	30.20 $\pm$ 1.13	28.75 $\pm$ 1.33	29.50 $\pm$ 0.71	1.7164	0.2336
Salinity (PSU)	31.00 $\pm$ 1.66	33.75 $\pm$ 0.50	31.57 $\pm$ 0.85	6.8031	<b>0.0159</b>
pH	8.10 $\pm$ 0.08	8.19 $\pm$ 0.07	8.16 $\pm$ 0.04	1.2730	0.3259
DO (mg/L)	6.00 $\pm$ 0.63	7.00 $\pm$ 1.12	6.66 $\pm$ 0.31	1.7669	0.2253
Nitrite ( $\mu$ mol/L)	0.10 $\pm$ 0.10	0.04 $\pm$ 0.08	0.06 $\pm$ 0.04	0.3144	0.7380
Nitrate ( $\mu$ mol/L)	0.80 $\pm$ 0.70	1.49 $\pm$ 0.20	0.48 $\pm$ 0.28	5.4371	<b>0.0283</b>
Ammonia ( $\mu$ mol/L)	0.30 $\pm$ 0.26	0.79 $\pm$ 0.61	1.17 $\pm$ 0.31	3.7513	0.0653
IP ( $\mu$ mol/L)	0.10 $\pm$ 0.09	0.68 $\pm$ 0.43	0.30 $\pm$ 0.14	4.8351	<b>0.0375</b>
Silicate ( $\mu$ mol/L)	4.90 $\pm$ 1.35	1.75 $\pm$ 1.03	4.42 $\pm$ 2.41	4.0060	0.0570
TN ( $\mu$ mol/L)	16.70 $\pm$ 7.31	25.39 $\pm$ 17.56	13.10 $\pm$ 4.88	1.2413	0.3341
TP ( $\mu$ mol/L)	0.70 $\pm$ 0.16	0.91 $\pm$ 0.28	0.36 $\pm$ 0.21	6.0164	<b>0.0219</b>
Sediment parameter					
pH	5.05 $\pm$ 0.64	5.00 $\pm$ 0.53	4.72 $\pm$ 0.18	0.6402	0.5429

Significant at  $p < 0.05$  (marked in bold)

Table 3. The mean water temperature was 30.20 $\pm$ 1.13, 28.75 $\pm$ 1.33 and 29.50 $\pm$ 0.71  $^{\circ}$ C at MB, LB and AB, respectively. There was no significant site wise variation observed for water temperature. The mean salinity was 31.00 $\pm$ 1.66, 33.75 $\pm$ 0.50 and 31.57 $\pm$ 0.85 PSU at MB, LB and AB, respectively. A significant site wise variation in salinity ( $p < 0.05$ ) was observed. The mean pH was 8.10 $\pm$ 0.08 at MB; lower than the other two areas LB (8.19 $\pm$ 0.07) and AB (8.16 $\pm$ 0.04). This might be due to enrichment of organic matter through mangroves degradation in the enclosed bay environment. The sediment pH at MB, LB and AB were 5.05 $\pm$ 0.64, 5.00 $\pm$ 0.53 and 4.72 $\pm$ 0.18, respectively. The concentration of nitrate (1.49 $\pm$ 0.20  $\mu$ mol/L) and inorganic phosphate (0.68 $\pm$ 0.43  $\mu$ mol/L) were comparatively higher at LB. The concentration of nitrate and inorganic phosphate showed significant site wise ( $p < 0.05$ ) variation. Agriculture is being practiced (Fig. 1) in the nearby areas; increase the phosphorus input into the coastal waters. Further, variation might be due to ready use of nutrients by

phytoplankton in the semi-enclosed bays (MB and AB) as compared to LB where open ocean water prevails. Nitrite (0.10 $\pm$ 0.10  $\mu$ mol/L) and silicate (4.90 $\pm$ 1.35  $\mu$ mol/L) concentration were high at MB, which might be due to untreated sewage input from the surrounding areas. Ammonia concentration (1.17 $\pm$ 0.31  $\mu$ mol/L) was found high at AB. The concentration of TN and TP were high at MB and LB. The site wise variation of TP was significant ( $p < 0.05$ ). The values of total nitrogen and inorganic nitrogen ( $\text{NO}_2$ ,  $\text{NO}_3$  and  $\text{NH}_4$ ) were used to estimate the percentage of organic nitrogen in the study area. The percentage composition of organic nitrogen at MB, LB and AB were 92.9 %, 90.9 % and 86.9 %, respectively. This indicates that the source of nitrogen is organic matter mostly enriched from mangrove litters. The percentage of organic phosphorous at MB, LB and AB were 84.4 %, 24.6 % and 16.8 %, respectively. The organic loadings from litters falling from mangroves have more residence time in enclosed bays. This was also reflected in the present study.

**Fig. 3** **a** House site became intertidal area. **b** Mangrove growth in new intertidal area



## Discussion

Mangrove plants were arranged according to Jayatissa et al. (2002). It was reported (Malik and Murty 2005) that subsidence of coastal land by 1.0 m damaged the mangroves severely due to permanent submergence of its roots at MB in South Andaman Islands. Similarly, estimated 0.3 to 1.5 m uplift and its easterly tilt in North Andaman Islands (Malik and Murty 2005; Ray and Acharyya 2011) also affected mangrove vegetation at few locations in North Andaman Islands. Forty percentage of *Rhizophora* spp. was affected due to inundation (Roy and Krishnan 2005) at MB. Varadachari and Kesava (1984) reported that mangroves prefer calm water with tidal influence (low-wave energy) for better survival and growth. Mangrove plants build up as forests and grow best in low wave energy areas; supports the deposition of fine sediments and subsequent establishment of mangrove propagules (Alongi 2009). Among the three areas studied, MB was found to be the better site because of less exposure to the open sea and hence higher species diversity was recorded. The mean salinity values were less at MB compared to other two areas. At MB, the areas are extended deep inside the land hence the salinity is affected by land run off. The mangrove like *Nypa fruticans* (Common) and *Lumnitzera littorea* (Critically endangered and occur in Odisha and A&N Islands) which mainly prefers to grow in low saline water (Rajendran and Baskara 2004), were observed at MB only.

The sediment pH at MB, LB and AB are comparable to pH values in Andaman Islands observed by Chaudhuri et al. (2009). The higher concentration of ammonia was found at AB which may attribute higher density of mangrove. Generally, the mangrove sediments are reducing in nature (Alongi et al. 2005) and contain high amount of organic matter and ammonia (Morell and Corredor 1993). The high productivity is often attributed to high litter degradation and efficient recycling of nutrients (Lee 1990; Kazungu et al. 1993; Bouillon et al. 2002). The higher percentage of phosphorous at MB, might be due to the degrading tsunami hit submerged mangroves and anthropogenically influenced untreated municipal sewages. In comparison with the reported nutrient values of Indian mangroves (Ramanathan et al. 1999; Tripathy et al. 2005; Prasad 2011), the concentration was found low in present study. The overall nutrient stoichiometry like N:P and Si:P ratios of all the three areas were 4.80 and 2.12, respectively. These ratios are found similar to (Mangalavan mangrove) the west coast of India, which is in pristine condition (Prasad 2011).

The mangrove vegetation is establishing its ecosystem after 2004 earthquake and tsunami in newly formed inter-tidal zone. It was reported by Roy and Krishnan (2005) that due to subsidence, there might be a change in the composition of mangrove stands. It was observed (Fig. 3a–b) in the present

study that the mangrove species are growing in newly formed inter-tidal area which was early a housing site at MB. Due to subsidence, the newly formed inter-tidal areas are more conducive for propagating mangrove propagules especially in South Andaman Islands. The present study suggests that considerable areas of the mangrove environment in these Islands are affected much by natural forces.

## Conclusion

High mangrove diversity was observed at MB. *Rhizophora mucronata* dominated at all the three sites in Andaman Islands. The physicochemical parameters played a significant role in the distribution of mangrove in different latitudes from South to North Andaman Islands. In the newly formed inter-tidal areas, mangroves are growing and this would significantly contribute to the total mangrove coverage in these Islands. Periodical monitoring of physicochemical parameters in mangrove environment with density and diversity studies of mangrove will help to develop better planning for sustainable conservation and management practices. The present study also suggests that visual map integrated with statistical analysis can help to develop and locate newly developing mangrove forest to conserve the present status and induce the rebuilding process for natural resources.

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