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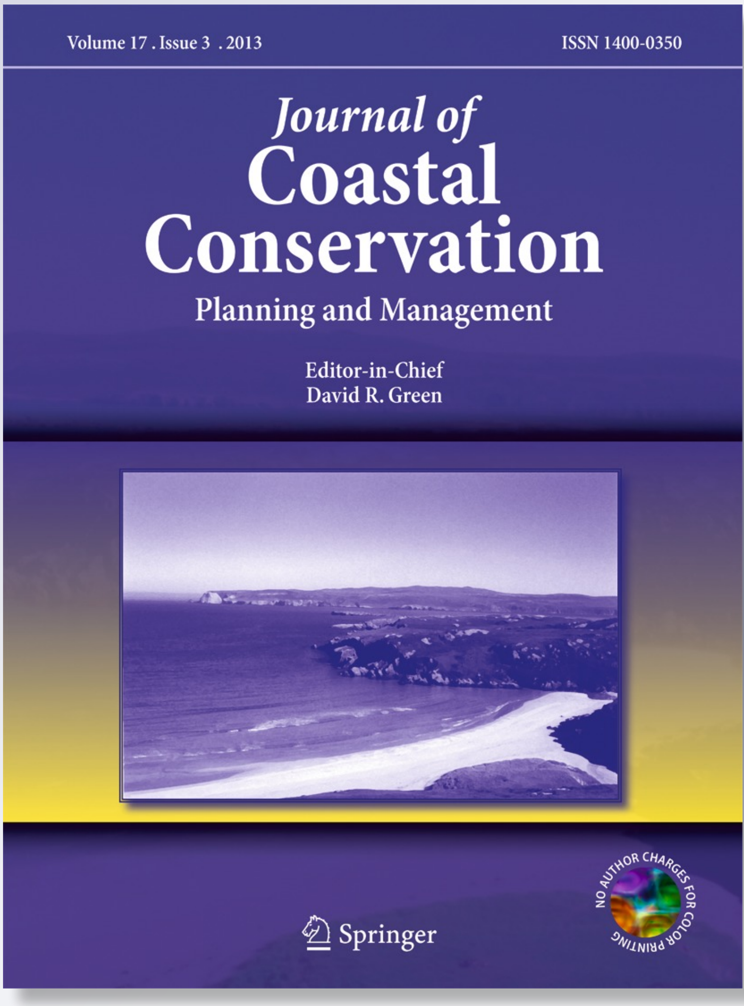

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Abstract The Aerial Bay group of Islands are one of the diverse environments of Andaman & Nicobar Islands, where the coral reefs degraded much due to the natural calamity of tsunami on 26 December 2004. After this event, the entire North Andaman Islands got elevated, which resulted in the exposure of coral reefs during low tide, causing mass mortalities and destructions to this pristine environment. In order to understand the current status, bio-physical monitoring of coral reefs was carried out and compared with classified coral map of pre-tsunami period. A decline from 411.14 to 68.25 hectares (ha) of live coral area was observed in the Aerial Bay group of Islands. The dead corals and other abiotic factors (sand, mud and rubble) were observed to be 317.33 and 25.56 ha respectively, based on comparisons between ground truthed and classified pre-tsunami coral map (2004) processed in ArcGIS®. The detrended correspondence analysis of coral life form categories showed maximum cover of dead coral with algae, in comparison with the live corals. Bray-curtis cluster analysis revealed three different groups of study sites with 60 % similarity based on life-form categories within the coral reef environment.

Keywords Coral reef assessment · Post-tsunami · GIS · Andaman Sea

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Introduction

Coral reefs are one of the vital components of coastal ecosystem as it protects shores as well as provides breeding grounds for diverse groups of marine organisms. In India, the estimated coral coverage is 2,374.9 km^2 of which 959.3 km^2 are in the Andaman and Nicobar (A&N) Islands (DOD, SAC 1997). Many studies have shown the importance of field based monitoring of coral reef (Al-Sofyani et al. 2013; Tamelander and Rajasuriya 2008; Edward et al. 2006; Kumaraguru et al. 2005) and the application of Geographical Information System (GIS) (Jha et al. 2011; Snow and Snow 2008) to gather information on coral reefs. The 26 December 2004 earthquake (Mw 9.1) followed by tsunami in and around the A&N Islands generated co-seismic deformation features that affected varieties of coastal ecosystems especially coral reefs (Javed and Murty 2005). They also reported that vertical uplift of the land by 1.2 m from the pre-earthquake levels observed in Diglipur and Mayabunder jetties, confirming the catastrophic damage to this region. Due to this event, the reef environments of A&N Islands have lost about 50,000 ha and about 11,300 ha around these Islands have been covered with sediments, mud and detritus (Nayak and Bahuguna 2008). The ground truthing work carried out in the South Andaman Islands (Jha et al. 2011) and mainland Indian coast (Marimuthu et al. 2010; Edward et al. 2006; Kumaraguru et al.

2005) reported that the loss of coral reefs was mainly due to this event. Further, the impact of bleaching on coral reef ecosystems (Sarkar and Ghosh 2013; Vinoth et al. 2012; Dharani et al. 2012; Krishnan et al. 2011; Kumaraguru et al. 2003) and their considerable recovery (Marimuthu et al. 2013) and its associated fauna (Marimuthu et al. 2011) were also reported.

Methodology

The present study is aimed to assess the present status of coral reef resource at Aerial Bay coast, covering an area of 411.14 ha where mostly live coral existed prior to the 2004 tsunami event. Aerial Bay is located about 350 km north of Port Blair (Fig. 1) 13°14′N–13°22′N latitudes & 92°56′E–93°06′E longitudes. The depth varies between 0.4 and 25 m whereas tidal amplitude recorded was about 2.5 m during the study period. It was chosen as a study site, due to tsunami induced land uplift, and occurrence of a coral reef prior to the tsunami.

The land use and land cover classification of the Aerial Bay group of Islands was delineated using high-resolution satellite image (P6 LISS4-MX) from the Indian Space Research Organization (ISRO) and National Natural Resources Management System (NNRMS) for baseline information. The classification was processed through ERDAS Imagine 8.7 (ERDAS 1993) image processing software using unsupervised classification technique (Bahuguna and Nayak 1998). The geo-database generated using ArcGIS® 9.3.1 (ESRI 2009) was used as baseline data for the comparative study.

For ground truthing of coral reef cover in the Aerial Bay group of Islands, two methods were used. In the first

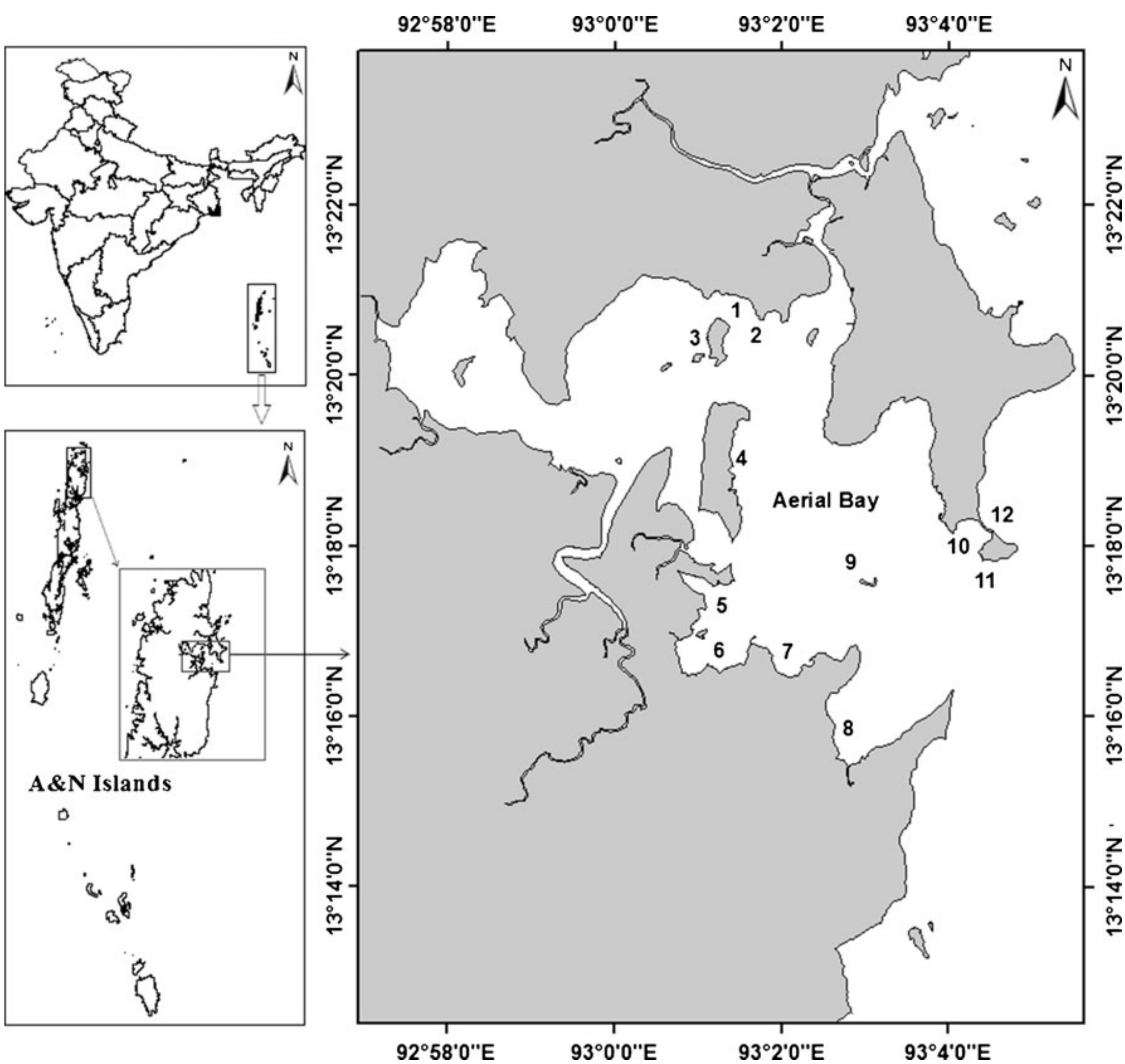

Fig. 1 Map showing the study area

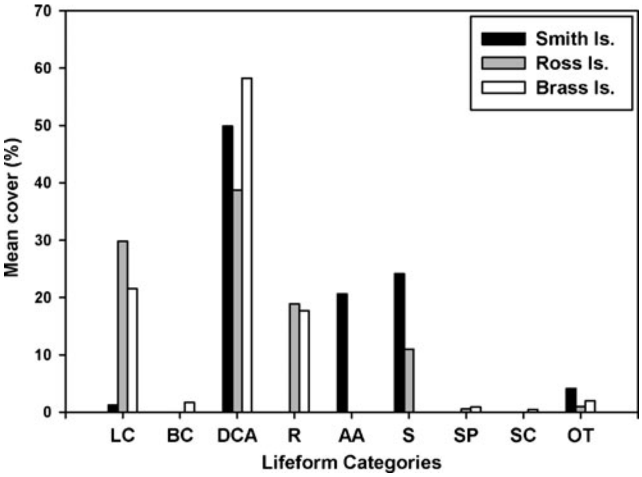

Fig. 2 Life form categories observed in the Aerial Bay group of Islands after the tsunami event of 2004. *LC* live coral, *BC* bleached coral, *DCA* dead coral with algae, *R* rubble, *AA* algal assemblage, *S* sand, *SP* sponge, *SC* soft coral, *OT* other associated organisms

method, seven sites (Fig. 1) were selected in and around the Aerial Bay group of Islands and live coral cover were estimated using Line Intercept Transect (English et al. 1997). A 20 m long flexible underwater tape was laid on the reefs roughly parallel to the shore with five replicates at each site. Coral life forms (eg. massive, submassive, encrusting etc.) encountered under the transition points were recorded whereas associated life form categories were noted based on standard designated codes. The collected raw data were sorted using AIMS Reef Monitoring Data Entry System version 1.6 (ARMDES 1996) to calculate the percentage cover of life form composition. The cumulative percentage of live coral cover and abiotic forms were also estimated using this package. Multivariate analyses were carried out using PAST version 2.15 (Hammer 2012).

In the second method, 12 sites (Fig. 1) were selected in and around the Aerial Bay group of Islands and the coral reef boundaries were precisely determined with the help of a glass-bottom boat fitted with a RTK-GPS, by sailing the boat along the reef boundaries (Jha et al. 2011). This survey was carried out during lowest low tide conditions for better clarity of underwater features. Further, the transition points of destroyed and exposed dead coral reefs were also marked with GPS for updating the geo-database of coral reef in the Aerial Bay group of Islands. The survey was conducted for three categories of coral reef features *viz*., presence of live coral, dead coral and other abiotic forms in the areas where coral reefs existed prior to the tsunami. The positional error was minimized by repeating the survey three times during the lowest low tide condition. The collected data were processed in MS-Excel with its geo-coordinates and it was linked to the earlier created geo-database. The new polygons were formed as 'live coral', 'dead coral' and 'other abiotic form' categories. The areas of extent of each category were computed and compared with the coral map (2004). The satellite image (P6 LISS4-

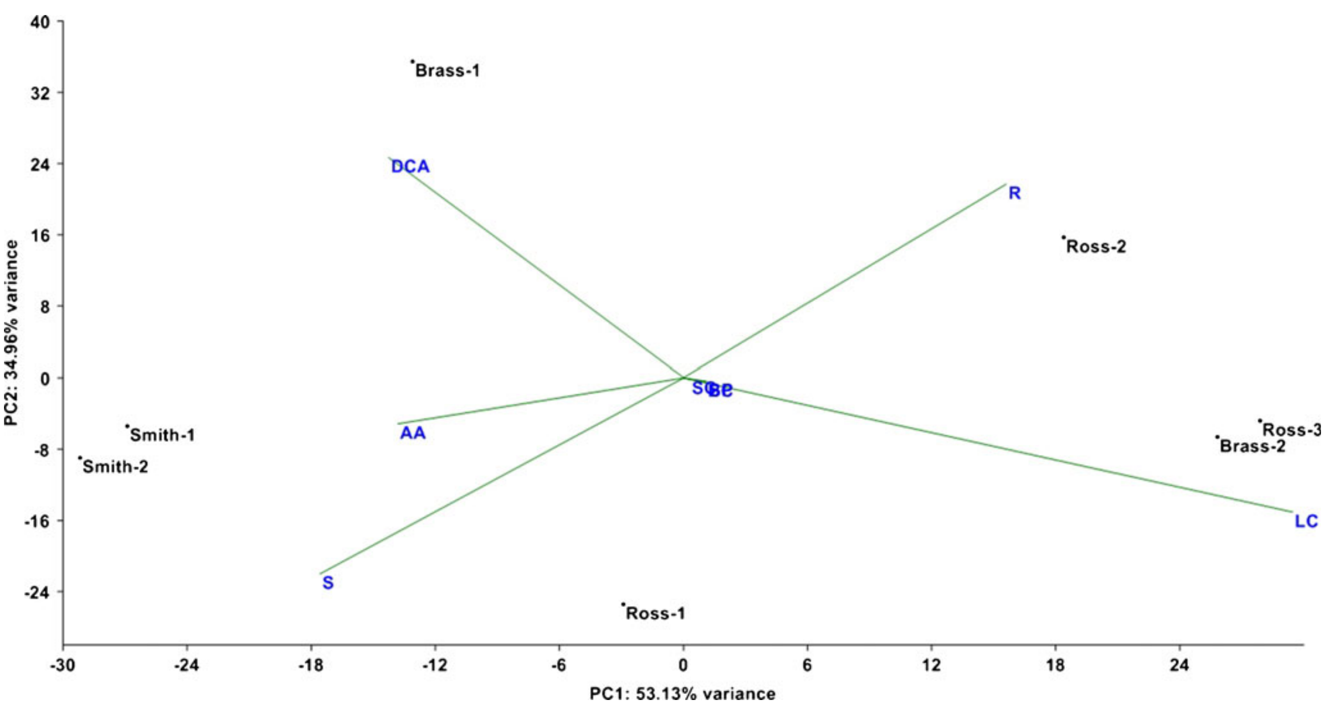

Fig. 3 Principal Component Analyses (PCA) of life-form categories in the Aerial Bay group of Islands. *LC* live coral, *BC* bleached coral, *DCA* dead coral with algae, *R* rubble, *AA* algal assemblage, *S* sand, *SP* sponge, *SC* soft coral

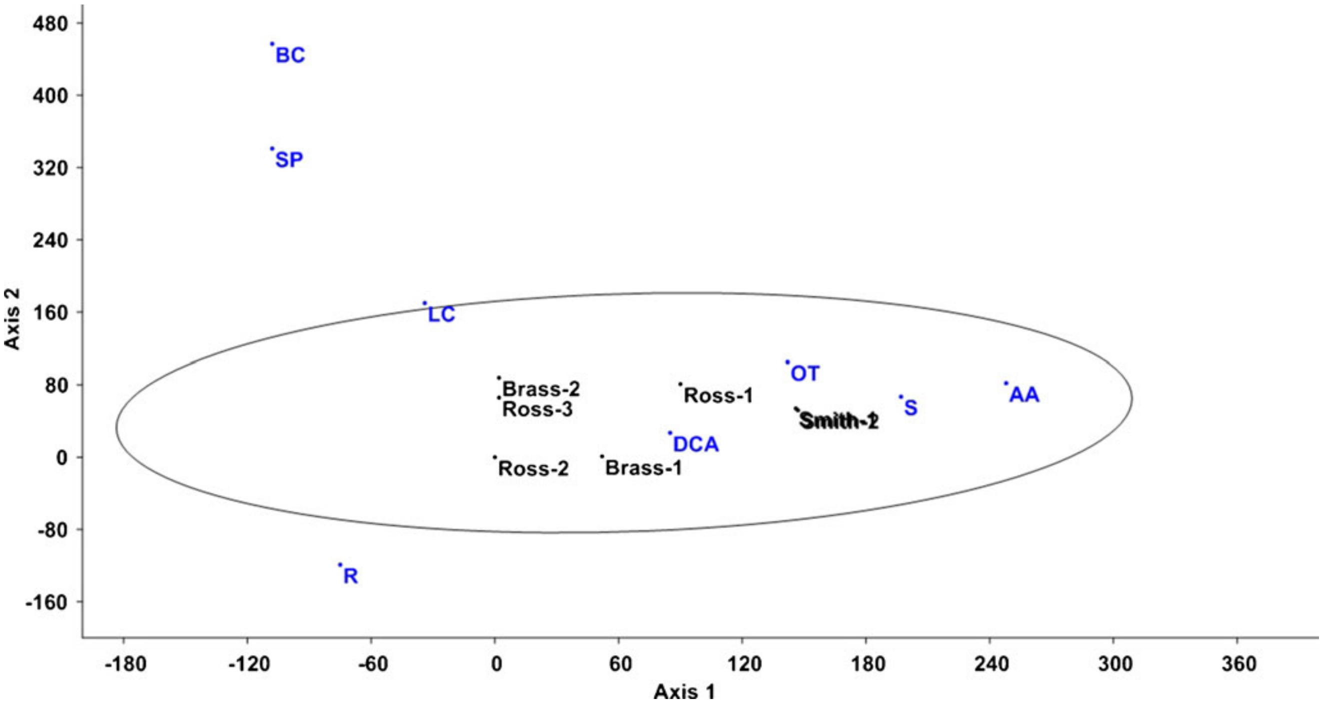

Fig. 4 Detrended correspondence analysis of life-form categories in the Aerial Bay group of Islands. *LC* live coral, *BC* bleached coral, *DCA* dead coral with algae, *R* rubble, *AA* algal assemblage, *S* sand, *SP* sponge

MX) was enhanced in ERDAS Imagine 8.7 with respect to multiple bands. The visual interpretation was made on the satellite image to delineate the coral coverage based on the ground truthing. Thus, the created polygon was transferred to ArcGIS®, and detailed map was prepared with sufficient field checks.

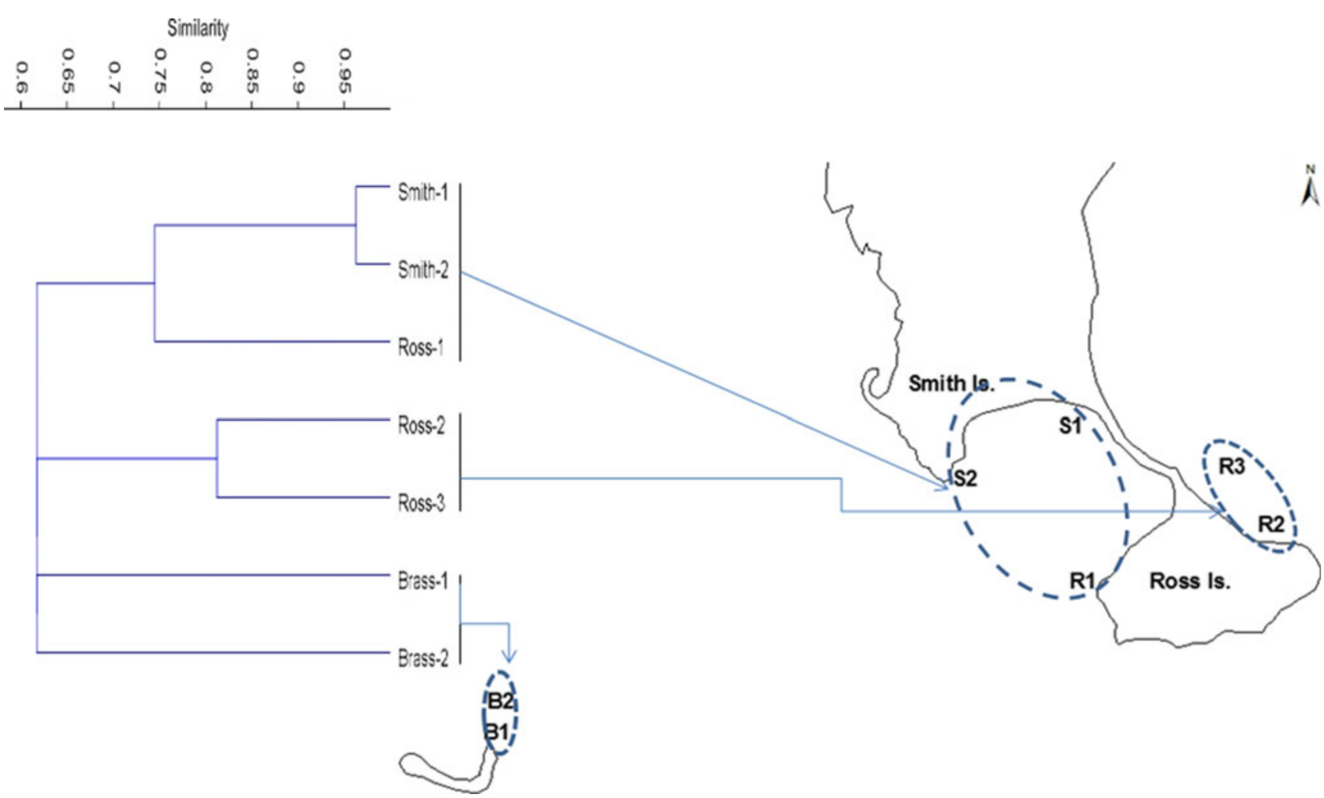

Fig. 5 Bray-Curtis Cluster analysis of the Aerial Bay group of Islands under single linkage

Table 1 Pre and post-tsunami live coral cover comparison in the Aerial Bay group of Islands using ArcGIS® technique based on ground verified observation.

Pre-tsunami (2004)		Post-tsunami (2011)		
Category	Area (Hectare)	Category	Area (Hectare)	Total area surveyed (%)
Live coral	411.14	Live coral	68.25	16.60
		Dead coral	317.33	77.18
		Abiotic	25.56	6.22
Total	411.14	Total	411.14	100.00

Results

In the first method of ground truthing, among seven sites studied in the Aerial Bay group of Islands, Ross Island (R1, R2 & R3) had live coral cover (29.82 %) followed by Brass Island (B1 & B2) with a cover of 21.53 % at a depth between 15 and 18 m. The highest mean cover of Dead coral with algae (DCA) (58.25 %) was observed in the Brass Island near the ship route, followed by the Smith Island (S1 & S2) (49.88 %). Algal cover in the form of Turf and Macro-algae (20.63 %) was commonly observed in the Smith Island and were absent in Ross and Brass Island (Fig. 2).

Multivariate analyses were also performed to understand the present status of coral reef environment. Principal Component Analyses (PCA) (Fig. 3) was conducted for different life-form categories observed in order to determine the most important benthic substrate. The reef flat region of the Brass Island contributed more DCA, as per the observation made in this study. This is mainly due to erosion of coastal land, resulting in settlement of sediment over the coral reef area. The erosion is found to be a recent phenomenon after the uplift and submergence of land at many places in A&N Islands. The detrended correspondence analysis of different life-form categories are shown with their site descriptions (Fig. 4). Dead coral with algae dominated all the study sites than the other life-forms. Bray-curtis cluster analysis under single linkage (Fig. 5) showed that the study sites were grouped into three major groups with 60 % similarity, based on the life-form categories observed in this study. Among them, the Brass Island was separated from the other study sites, owing to the occurrence of maximum DCA cover (58.25 %) rather than the other life forms.

In the second method of ground verification, among 12 study sites, site no. 9–12 had good coral covers whereas live coral was in declining phase at site no. 1. The other sites from 2 to 8 were completely dead and categorised as DCA. Other abiotic forms such as coral rubble, sand and muddy bottom were also studied.

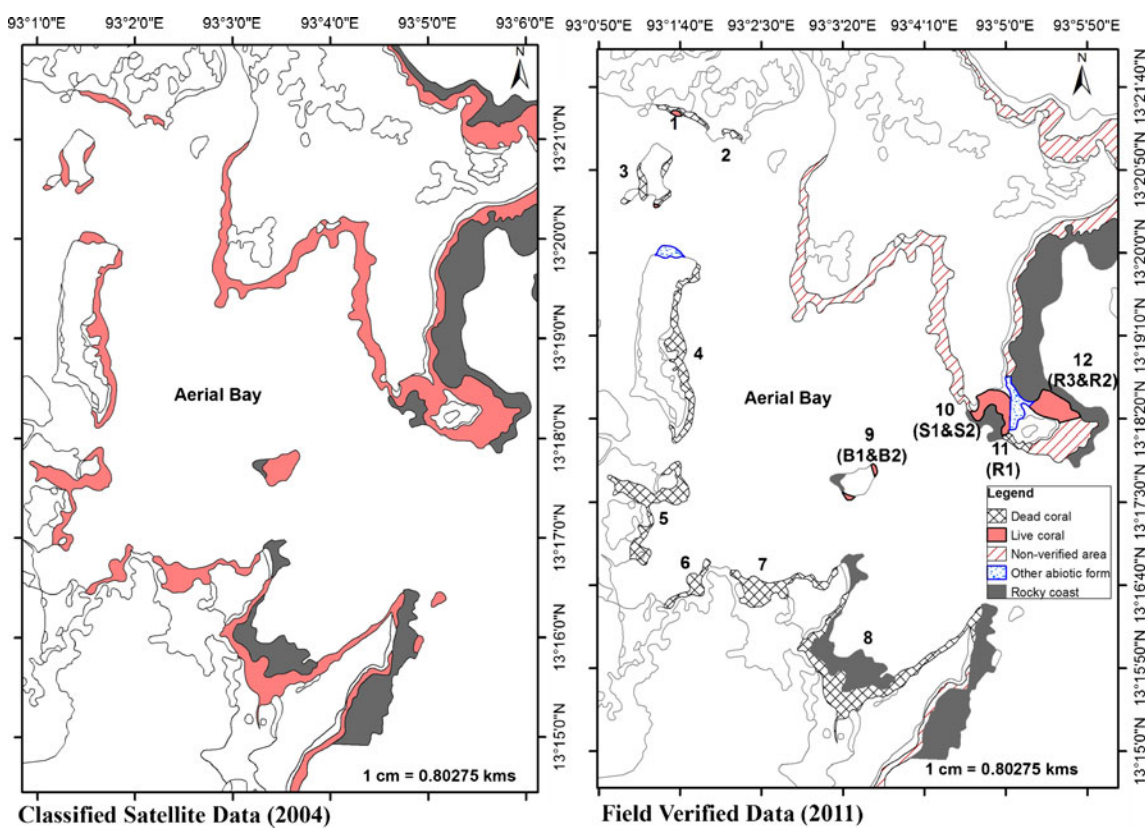

Fig. 6 Maps showing Pre-tsunami (2004) and Post-tsunami (2011) spatial coverage of coral reefs at the Aerial Bay coast

The ground verified data observed in these studies were compared with the changes in coral reef features from the pre-tsunami baseline data. The pre and post-tsunami coral reef characteristics and its area are presented in Table 1. Among 411.14 ha, only 68.25 ha (16.60 %) area remained as reef with live corals whereas 317.33 ha (77.18 %) of reef area was found to have DCA. The comparative results on spatial coverage of coral reefs between pre and post-tsunami are presented in Fig. 6. The exposed coral reef and coral boulders could be seen in the intertidal region along the Aerial Bay coast during low tide (Fig. 7). These are the areas where live corals got exposed due to vertical uplift of coastal land and subsequently declined. The areas were now invaded by turf and macro algae. Figure 7 shows the evidence of declined coral resources in the study area. The dead reef fragments in the form of Rubble (R) and some fragments with diseased condition (Pink-line syndrome) were observed in the intertidal region showed the destruction of coral reefs after the tsunami event (Fig. 7) at some sites.

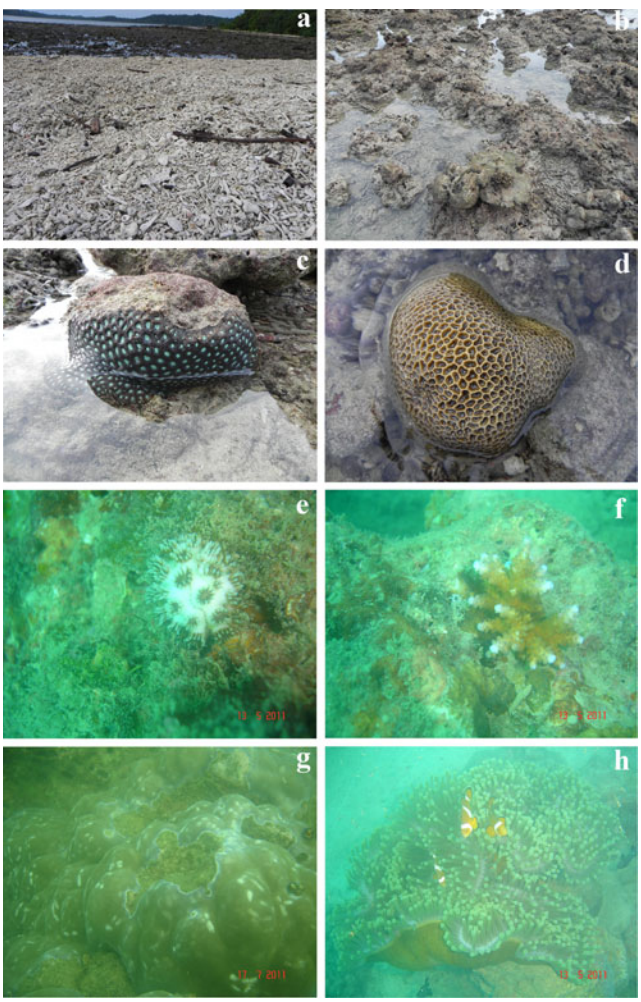

Fig. 7 Field photographs of Aerial Bay reef ecosystem. **a**, **b** Ecosystem showing evidence of coral degradation; **c** *Favia* sp.; **d** *Platygyra* sp.; **e**, **f** Coral rejuvenates of *Galaxea* sp. & *Acropora* sp.; **g** Pink-line syndrome on *Porites* sp.; **h** False clownfish, *Amphiprion ocellaris* on *Heteractis magnifica*

Discussion

Dead coral with algae dominated all the study sites compared to the other life-forms during bio-physical assessment (Fig. 4) which were similar to the results (77.18 % cover of DCA) obtained by GIS analysis (Table 1). This is mainly due to erosion of coastal land, resulting in settlement of sediment over the coral reef area. The erosion is found to be a recent phenomenon after the uplift and submergence of land at many places in A&N Islands. Similar observations were also recorded in the Pongi Balu coast, south Andaman Islands (Jha et al. 2011). Hence, this mass degradation may be due to the impact of tsunami and two bleaching events of 2005 (Dharani et al. 2012) and 2010 (Sarkar and Ghosh 2013; Marimuthu et al. 2011; Krishnan et al. 2011). It was reported (Pearson 1981) that bleached corals can recover to the previous state with appropriate light condition and less sedimentation. The coral recovery rate of South Andaman Islands was 13–21 % from the bleaching event of 2010 (Marimuthu et al. 2013). Kumaraguru et al. (2003) observed that the maximum recovery rate of 57 % at Palk bay within 3 months period. Suitable in-situ scientific management practices will also enhance better recovery rate. Wilson and Marimuthu (2012) observed complete recovery from bleaching in the transplanted nubbins by removing turf algal population during the recovery time. Similar technique may be adopted in order to protect reef ecosystem of the A&N Islands and mainland India.

The comparative results on spatial coverage of coral reefs between pre and post-tsunami (Fig. 6) will be useful to assess the risk zone in order to support integrated coastal zone management (Deshmukh et al. 2005; Vanderstraete and Goossens 2005; Bryant et al. 1998). Though the coral cover has declined after the tsunami event 2004, some sites noticed rejuvenation of the coral colonies, slightly in deeper part especially in the Brass Islands (Fig. 7). Other organisms (Octocorals, Star fish, Sea cucumber, Giant clam etc.) associated with reef ecosystem were also recorded in the range of 0.97–4.93 % (Fig. 2) from the study area which show the present biodiversity in this region.

The present study shows that there is considerable reduction in coral reef area from 2004 to 2011. The major degradation may be due to tsunami impact followed by two major bleaching events of 2005 and 2010. Live coral colonies existed prior to the tsunami event of 2004, is now reduced to a reef with dead corals and dead coral with algae. Signs of coral rejuvenation were observed at deeper areas due to changes in the coastal geomorphology and eventually will develop into coral reefs if undisturbed.

Hence, more protections are needed by minimizing sedimentation along the coast to conserve the present status and induce the rejuvenation process in the Aerial Bay group of Islands.

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