Status of Earthquake and Tsunami Affected Coral Reefs in the Andaman and Nicobar Islands, India

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INTRODUCTION

The Andaman and Nicobar Islands, located in the south eastern part of the Bay of Bengal between latitudes 6° 45' and 13° 41' S and longitudes 92° 12' and 93° 57' E, are host to a rich biodiversity. The archipelago is one of the few key biodiversity regions in the world surrounded by fringing coral reefs characteristic of the Southeast Asian region, and is the most diverse among Indian subcontinent reef areas (Pillai, 1983, Davidar *et al.*, 1994).

On 26th December 2004, an earthquake measuring 9.3 on the Richter scale hit the region. As a result of tectonic activity, low lying areas from South Andaman to the Nicobar Group of Islands were submerged by 1-2 meters, while large areas, including coral reefs, were uplifted in the northern group of the Andaman islands. The uplift resulted in permanent damage to shallow reefs in the northern group of the Andaman Islands (Kulkarni, 2005). The earthquake also generated tsunamis, the effect of which ranged from a temporary rise in sea level such as in South Andaman, and up to 15 m high waves in parts of the Nicobar Islands. This caused loss of human lives and destruction to infrastructure in the islands (Sankaran et. al., 2005). The environmental impacts of the tsunami were diverse, with damage to coral reefs and

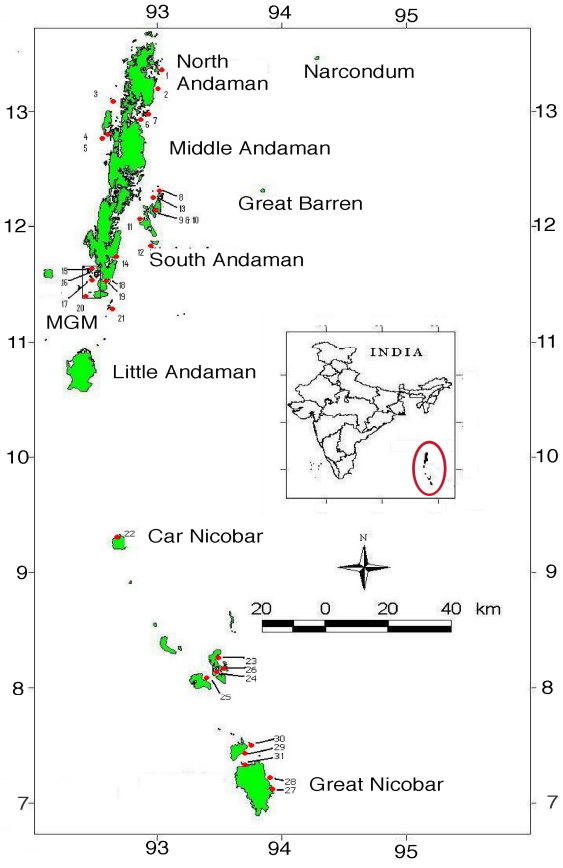

Figure 1. The Andaman and Nicobar Islands. Numbered dots indicate survey sites. See also Table 1.

Obura, D.O., Tamelander, J., & Linden, O. (Eds) (2008). Ten years after bleaching - facing the consequences of climate change in the Indian Ocean.CORDIO Status Report 2008. Coastal Oceans Research and Development in the Indian Ocean/Sida-SAREC. Mombasa. http//:www.cordioea.org

Table 1. Sites where benthic assessment was carried out. Site numbers correspond to numbers in Figure 1.

Nr.	Site
North Andaman	
1	Smith Island
2	Lamia Bay
3	North Reef Island
Middle Andaman	
4	Interview Island
5	South Reef Island
6	Aves Island
7	South Island
Ritchie's Archipelago	
8	Outram Island
9	Henry Lawrence
10	John Lawrence
11	Havelock Island
12	Neil Island
13	South Button Island
South Andaman	
14	North Bay
15	Grub Island
16	Redskin Island
17	Jolly Buoy Island
18	Chidiyatapu
19	Rutland Island
20	Twins Islands
21	Cinque Island
Nicobar Group	
22	Car Nicobar
23	Camorta Island (northeastern)
24	Camorta Island (southeastern)
25	Katchall Island
26	Trinket Island
27	Great Nicobar
28	Pigeon Island
29	Little Nicobar
30	Menchal Island
31	Kondul Island

other coastal habitats in the entire region (Malik and Murti 2005).

This study gives a detailed account of the impact and long-term implications of the earthquake and the tsunami on the reefs of the Andaman and Nicobar Islands.

METHODOLOGY

The study was carried out at 31 sites around 29 islands in the Andaman and Nicobar Islands (Table 1, Fig. 1), between February 2005 and June 2006. The extent of uplift was estimated based on the difference between the new and the old water level as indicated by high-water marks on rocks and structures. The presence of full-grown barnacles at deeper levels of jetties served as an indication of the submergence level. The height of the tsunami was estimated by newly formed high water marks on trees and structures along the coast, referred against previous indications.

Benthic cover was assessed using randomly laid Line Intercept Transects (LIT) (Loya, 1972). Five transects 20 meters long were run parallel to depth contours at each site at depths between 4 and 9 meters. Transects were separated by at least 10 to 30 meters, to cover approximately 150 to 250 m along the reefs. Benthic cover categories recorded were live coral, dead coral, broken corals and rubble, sand, algae, soft coral and other. Relative abundance of coral genera was recorded in permanent LIT and is presented by genera as percentage of total coral cover.

In addition, general visual observation of reefs and associated biota were made using SCUBA down to depths of 30 meters. Damage to the reef was categorized based on type/cause of the damage, and GPS readings of the damaged area were recorded. The areas were then demarcated on high-resolution post-tsunami satellite images (scale 1:2000) obtained from Google Earth Pro Inc. and areas of destruction were approximated by constructing polygons connecting the coordinates, and using Google Earth software for area calculations.

Table 2: Estimated reef damage in North Andaman group of islands. The cause of damage is shown as uplift (UL) and/or tsunami (TS).

Island	Cause	Damaged Area (km^2)
Landfall	UL	5.82
West	UL	2.07
White cliff	UL	0.16
Reef	UL	1.08
Paget	UL	1.86
Point	UL	2.61
Snark	UL	0.16
Kwang Tung	UL	0.25
North Reef	UL/TS	13.27
Latuche	UL/TS	0.21
North Andaman	UL/TS	21.8
Thornhill	UL	0.24
Total		49.53

RESULTS

North Andaman

The earthquake resulted in uplift of the west coast of North Andaman, which led to mortality of corals and associated life-forms in shallow waters due to aerial exposure and direct sunlight. Signs of sand deposition were also observed on these exposed reefs. Middle Andaman, including small islands from Landfall Island to South Reef was uplifted by more than one meter and the areas on the eastern coast such as Diglipur, Smith and Ross Islands, by less than one meter. Table 2 summarizes reef damage in the archipelago, including areas not surveyed with LIT. Almost 50 km^2 of reef was destroyed or severely damaged.

Smith island (1 in Fig. 1) has a length of 8.6 km and a width of 5.1 km. It has extensive mangroves on the northwestern side and narrow fringing reefs all around the island. The reef flat contains mainly rocks, sand and dead coral heads. Extensive coral growth starts at a depth of 4 meters and extends along a gradual slope down to 10 meters. The western reef is sheltered and dominated by *Porites* spp. while the eastern reef is dominated by *Acropora* spp.

The island appears to have been raised by half a meter, resulting in exposure of the reef flat on the eastern side. As coral growth on the reef flat was very moderate prior to the Tsunami, the impact, if any, has not been significant. The tsunami was not violent in this area and water only rose by around 2.5 meters. No physical damage, such as broken coral colonies, were seen.

In 2003, prior to the tsunami, live coral cover on the eastern side of the island was 54.0%, dominated by *Acropora* (44.6%) followed by *Porites* (16.1 %), *Favia* (9.3%) and *Montipora* (8.3%). Coral cover in 2006 was 50.5%, with the relative abundance of most major coral genera unchanged (*Acropora* 41.5%; *Porites* 18.3%; encrusting *Montipora* 11.5%).

Lamia Bay (2 in Fig. 1) is situated on the east coast of North Andaman and at the base of Saddle Peak (the highest point in the Andaman and Nicobar Islands). The site is dominated by patch reefs. Eyewitness reports confirm that the tsunami came in the form of a rise in sea water of around 1.9m and did not cause any physical destruction on land. There are also no signs of reef damage. Live coral cover was 41.1% before the tsunami and 39% after. Since 2003 rubble cover has been reduced from 11.8% to 1.3% while the soft coral cover has increased from 0.5 to 9.8%.

Prior to the tsunami, North Reef island (3 in Fig. 1) had luxuriant coral growth all around, and was considered one of the most diverse reefs in the Andaman and Nicobar Islands. The northern side of the island had an inter-tidal reef flat dominated by mono-specific stands of *Acropora formosa*. The reef on the western side of the island was dominated by *Acropora* spp. and *Montipora aequituberculata*. *Millepora dichotoma, Porites lutea* and *Acropora robusta* dominated the southeastern bay.

The tectonic activity caused North Reef to be raised by more than 1.5 meters. This has resulted in exposure of the reef flat on the northern and western sides, resulting in increased turbulence in the sub-tidal reefs and deposition of sand. Destruction of coastal

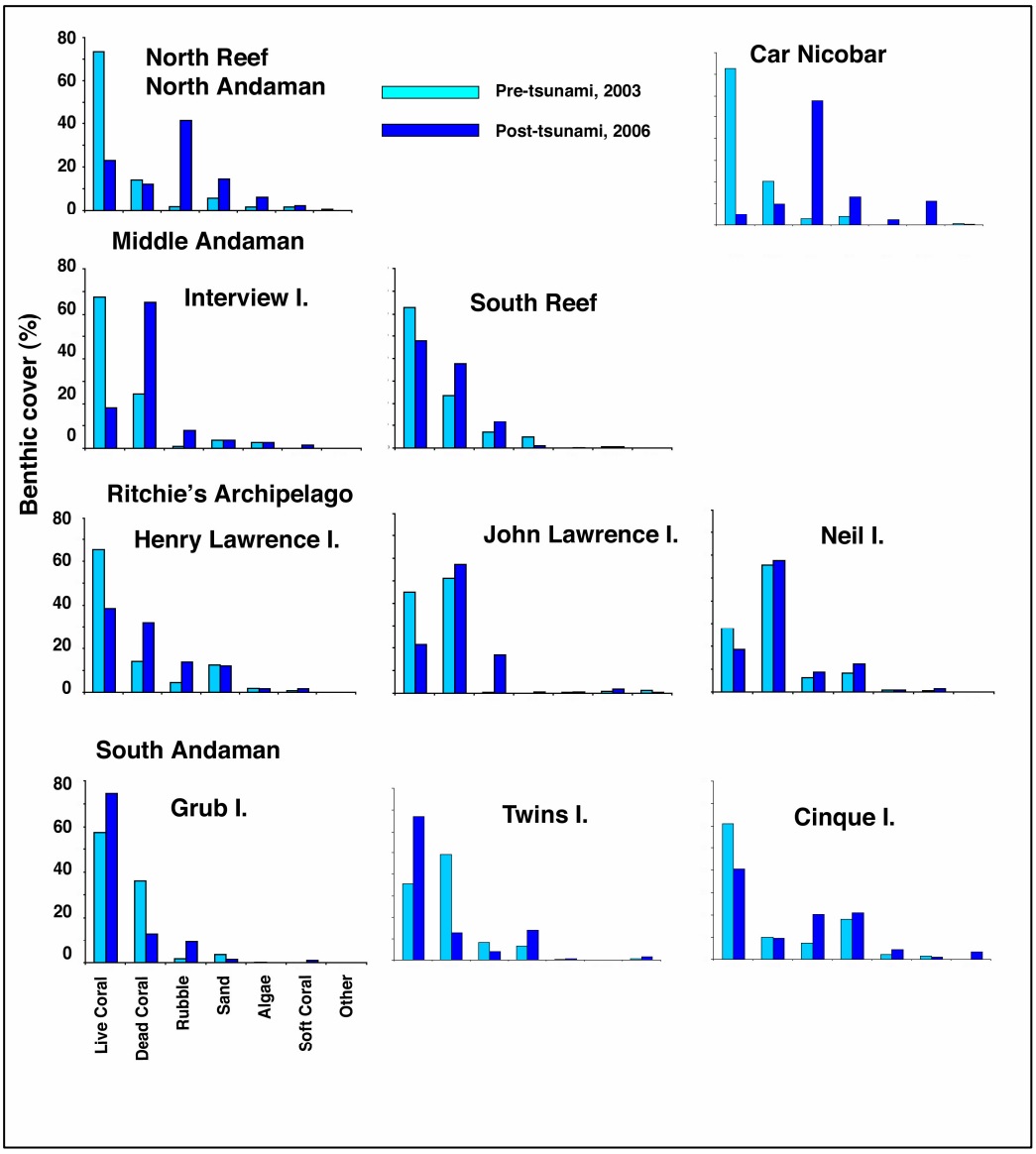

Figure 2. Benthic cover at study sites in the Andaman and Nicobar Islands: North Andaman - North Reef; Middle Andaman - Interview Island, South Reef; Ritchie's Archipelago - Henry Lawrence, John Lawrence, Neil Island; South Andaman - Grub Island, Twins Island, Cinque Island; Car Nicobar.

vegetation indicates that the tsunami was severe with a height of about 3.5 meters on the eastern side of the island.

At the monitoring site (south-eastern), the average live coral cover pre-tsunami was 73.5%, dominated by large colonies of *Acropora* spp. at a relative abundance of 31.7%, followed by *Porites* (21.8%) and *Millepora* (10.7%). By 2006 the live coral cover had been reduced to 23%. The relative abundance of *Acropora* and *Millepora* was reduced to 8.8% and 2.3%

Table 3: Estimated reef damage in Middle Andaman group of islands. The cause of damage is shown as uplift (UL) and/or tsunami (TS).

Island	Cause	Damaged Area (km^2)
Middle Andaman	UL/TS	12.32
Spike	UL/TS	0.58
South reef	UL	0.37
Anderson	UL	2.11
Flat	UL	6.67
Total		22.05

respectively. The percentage cover of rubble increased from 2% to 41% (Fig. 2). The area of coral reef destroyed by exposure from the uplift of the landmass and due to the tsunami is estimated to be about 13 km^2.

Middle Andaman

Reef damage in Middle Andaman is summarized in Table 3, including areas not surveyed with LIT. Over 22 km^2 of reef was destroyed or severely damaged.

Interview Island is situated to the south of North Reef Island and to the west of Middle Andaman. Prior to the earthquake and tsunami the western, northern and southern areas of this island had extensive reef flats mainly dominated by *Porites* micro-atolls. The sheltered eastern side showed patchy coral reefs and high turbidity.

Due to uplift caused by the earthquake, reef flats on the northern and western side have become exposed. Waves are breaking directly on the edge of reef flat, resulting in low visibility and deposition of sand mainly along the sub-tidal reefs on the western side.

Live coral cover in the sub-tidal region of the southern reef (4 in Fig. 1) has been reduced from 67.7% (dominated by *Porites* and *Acropora*) to 18.4%. The percentage cover of dead intact coral has increased from 25% to 65.5%, and that of rubble has increased from 1% to 8% (Fig. 2). High water temperature was also observed in the southern reef areas during the surveys in 2006. This is possibly due to localized warming of stagnant seawater in sub-tidal zones of the southern reef during low tide, causing coral mortality.

South Reef Island lies to the south of Interview Island. It is surrounded by a 30 to 70 meter wide reef flat, wider on the western than on the eastern side. This island was raised by 1 meter as a result of the earthquake, causing damage to coral reefs mainly on the western reef flat. The pre-tsunami coral cover on the eastern side (5 in Fig. 1) of the island, 63.2%, was reduced to 48% in 2006 (Fig. 2). The mortality cased a shift in the coral community with the dominance of *Acropora sp.* reduced from a relative abundance of 46.6% to 31.4% in 2006. An increase in relative abundance was recorded in *Porites sp.* (16.8% prior to the tsunami to 21.6% after), *Echinopora* (9.5% to 13.7%) and *Millepora* (7.1% to 9.3%).

Aves Island is situated on the eastern side of Mayabundar. Coral reefs occur all around the island from a depth of 4 meters to 14 meters, except at the southern end, where the seabed is covered mainly by rocks. On the eastern and northern sides, *Acropora* and *Porites* dominate the coral reefs while on the western side coral reefs are dominated by *Porites*. No significant change in live coral cover was recorded at the study site on the eastern side of the island (6 in Fig. 1.) between 2003 (61%) and 2006 (58 %). *Acropora* (40.2%) dominated the live coral cover followed by *Porites* (23.1%), *Hydnophora* (8.9%) and *Echinopora* (6.4%).

Sound Island is situated to the northeast of Mayabundar and Aves Island. Coral reefs were surveyed on the eastern side (7 in Fig. 1.) of the island. Live coral cover was 47% in 2003 and 45% in 2006. *Porites* dominated the live coral cover with a relative abundance of 44.4% followed by *Montipora* (17.3%) and *Acropora* (12.6%).

Ritchie's Archipelago

Ritchie's Archipelago comprises 4 large islands, 7 small islands and several islets, extending in a roughly north-south chain, parallel to the main Great

Table 4: Estimated reef damage in Ritchie's Archipelago, South Andaman and Little Andaman. The cause of damage is shown as uplift (UL) and/or tsunami (TS).

Island	Cause	Damaged Area (km^2)
North Sentinel	UL	12.59
South Andaman group	TS	1.00
Ritchies Archipelago	TS	1.11
Little Andaman	UL/TS	12.85
Total		27.55

Andaman Group. Corals reefs at six islands were surveyed. Reef damage is summarized in Table 4.

Outram Island lies to the north of Henry Lawrence. Mangroves are present on the northern and southern side of the island. The island is surrounded by fringing reefs. The western reef flats are narrow, with widths ranging from 50-80 meters, and mainly dominated by *Acropora*. *Porites* and *Acropora* dominated the live coral cover on the southern and eastern sides with a relative abundance of 42.4 % and 31.9 % respectively. The maximum coral growth occurs down to 12 meters, beyond which sea fans, soft corals and some Faviids dominated the rocky bottom.

Coral cover and community composition appear unchanged by the tsunami, with live coral cover on the western side of the island (8 in Fig. 1.) recorded as 67% in 2004 and 64.7% in 2006. A marginal increase in dead intact coral cover was seen, with no increase in rubble.

Henry Lawrence Island is part of the Rani Jhansi Marine National Park. Coral reefs occur all around the island except on the western coast, where mangroves are found. The coral communities are mainly dominated by *Porites lutea* and *P. nigrescens*. On the eastern coast, reef flats range from 50 – 100 meters in width, with gentle reef slopes down to about 13 meters, beyond which the bottom is sandy. The western side of Henry Lawrence and the eastern side of John Lawrence form a narrow channel from south to north.

The tsunami wave's kinetic energy increased in the narrow channels causing high-velocity currents. This caused damage to corals along the edges of reef flats. Large colonies of *Porites lutea* on reef edges were uprooted and some stretches of mangroves were destroyed. Accumulation of rubble was observed on the central-western side of the reef. Qualitative assessment carried out in the monitoring site on the western side (9 in Fig. 1.) revealed that live coral cover was reduced to 21.5% compared to 45.1% in 2003. The percentage cover of rubble has increased to more than 16% in 2006 compared to 2003 (Fig. 2). *Porites* is still the dominant genus, making up more than half of the live coral cover. Dense clusters of *Turbinaria* algae have occupied dead parts of *Porites* colonies.

John Lawrence Island is also part of Rani Jhansi Marine National Park. The entire north-western region is surrounded by extensive mangrove forests. Coral reefs are mainly patchy with narrow reef flats that slope steeply to a maximum depth of 12 meters. The reefs are dominated by large colonies of *Porites*.

The concentrated energy of the tsunami in the channels between John Lawrence, Wilson and Nicholson islands caused mangrove and coral reef destruction. Large patches of mangroves alongside the channel were destroyed, and boulders of *Porites* were uprooted and scattered all over the channel making navigation for dinghies difficult. Coral reefs were studied on the eastern side (10 in Fig. 1.) of the island. Large colonies of *Porites* were tilted and smaller ones were uprooted and smothered. Live coral cover declined from 65.5% in 2003 to 38.5% in 2006, and cover of rubble doubled (Fig. 2). The coral community structure suggests that *Porites* sustained damage with a reduction in relative abundance from 59.9% to 43.2%, with encrusting *Montipora* and foliose *Echinopora* increasing in relative abundance. Large clusters of *Turbinaria* algae were found on dead coral boulders.

Havelock Island is surrounded by fringing reefs with wide reef flats on the western side and narrow on the eastern side. Reef flats are dominated by large colonies of *Porites,* the top portions of which are mostly dead. This island experienced the tsunami mainly in the form of a rise in sea water level. Along

the north and north-west coasts the rise in sea water level was about one meter accompanied by strong currents. Corals, mainly in the channel and at the mouth of the channel sustained most of the damage. However, the damage was restricted to smaller colonies of *Porites* and *Acropora*.

The monitoring site, located on the north-western reef (11 in Fig. 1), close to the lighthouse, has a steep reef slope extending down to 21 meters, with a sandy bottom beyond. The average live coral cover at this site declined from 59.7 % in 2003 to 43.2% in 2006. Change in cover of intact dead coral was minimal but rubble cover increased somewhat.

Neil Island is situated to the south of Havelock Island. Fringing reefs occur on the eastern and western side of the island, with patch reefs to the north and south. Reefs studied on the northwestern side of the island (12 in Fig. 1) were *Porites* dominated, making up over two thirds of the live coral cover. A reduction in live coral from 27.8% to 18.6% in 2006 was observed, while the cover of dead standing coral remained unchanged and comparatively high (Fig. 2).

Coral reefs around South Button Island (13 in Fig. 1) studied in 2006 were healthy, with a live coral cover of 80% and high fish diversity and abundance.

South Andaman

In South Andaman, coral reefs around North Bay, Chidiyatapu and some of the islands of the Mahatma Gandhi Marine National Park were studied. Coral reef mortality due to the tsunami was visible in channels and edges of reef slopes. In recent years solar radiation has caused coral mortality in shallow areas (Kulkarni, 2004). The increase in depth due to subsidence may have a positive effect in promoting coral growth. Reef damage is summarized in Table 4.

North Bay is located near Port Blair Harbour, with fringing reefs to the north and south. The tsunami reached a height of around 2.5 meters in this area. Corals on the northern side of the bay were not affected as the community is dominated by massive boulders of *Porites*. The southern side (14 in Fig. 1) sustained around 10% damage that was restricted to primarily *Acropora* colonies, and an increase in coral rubble. *Porites* species, such as *P. solida* and *P. nigrescens,* remain dominant at the site with a relative abundance of 91.4%.

Grub Island is part of M. G. Marine National Park. The reef around this island has a gentle slope and coral growth occurs to a depth of 6 meters, with a higher live coral cover on the eastern than on the western side. The coral community is dominated by *Acropora,* followed by *Porites* and *Echinopora lamellose*; further north, where the reef stretches up to 300 m from the shoreline, by *Porites* and *Millepora dichotoma,* Other common coral genera include *Montipora* and *Hydnophora*. The southern part of this island is sandy with no coral growth.

On reefs studied in 2003 on the eastern side (15 in Fig. 1) the coral cover was about 57.7%, dominated by *Porites* (46%), *Acropora* (22.3 %) and *Echinopora* (22.3 %, mainly *E. lamellosa*). By 2006 coral cover had increased by 17 percentage points (Fig. 2), due to an increase especially in *Acropora,* apparently with aggressive competition from *Echinopora*. A reduction in intact dead coral suggests that new coral growth is covering dead standing reef structure. *Acropora* and *Porites* now dominate the reef, followed by *Echinopora*.

Redskin Island is surrounded by fringing reefs. Reefs to the north have a gentle slope with diverse coral growth that is comparatively healthier in deeper than in shallow water. The dominant species is *Acropora formosa*, unlike the other parts of the island which are dominated by *Porites*. The reef flat on the northeastern side of the island, protected from strong wave action, is wide, while in the rest of the area it is narrow and extends about 30 m from the shore. Reefs to the southeast are patchy and composed of *Porites, Favia, Favites, Acropora* and *Pectinia*. The southwestern and southern areas are mainly rocky with patchy coral growth. The depth of reef areas decreases towards the south. The western reef is narrow with a steep slope to a depth of 15 meters where the seabed is covered by calcareous sand.

Observations made in 2003 on coral reefs in the north, west and eastern sides of the island (16 in Fig.

1) showed an average coral cover 32.6 %, dominated by *Porites* (56.4%), followed by *Echinopora, Acropora, Montipora, Hydnophora, Favia, Lobophyllia, Turbinaria, Pocillopora, Galaxea, Pectinia, Montastrea* and *Symphillia,* with relative abundance ranging from 1 to 8%. Though there was an impact of the tsunami on corals, it is restricted to the outer edge of the reef crest, where some large colonies of *Porites* have been toppled and some of those on the edge of the steep reef slope have slid down into deeper waters. However, many of these colonies have survived in spite of the change in habitat. A moderate reduction in percentage cover was recorded, from 32.6% in 2003 to 25.6% in 2006.

On Jolly Buoy Island coral reefs were surveyed on the north, west and eastern sides of the island in 2003. The average coral cover was 37.4%, with *Porites* dominating the reef (62.3%), followed by *Hydnophora rigida* (11.8%) and *Echinopora* (5.9%). Other genera ranged from 1 to 4% of the coral cover. Post-tsunami surveys revealed an impact only on the eastern side of the island (17 in Fig. 1), with a reduction in coral cover to 28.67% in 2006. The percentage of rubble has increased to 12.8% in 2006 compared to 4.1% in 2003.

Chidiyatapu (18 in Fig. 1) is the southern end of South Andaman Islands. Fringing coral reefs occur mainly in the bay, from about 300m from the shore. The reef ends at Munda Pahad (barren hillock), after which the habitat becomes rocky. The width of the fringing reefs is about 20-30m, followed by a gradual slope down to a depth of 10m and sandy substrate. In 2003 the average coral cover in the area was 51.3%, mainly due to dominance of *Porites solida* and *Porites rus,* and growth of encrusting *Montipora* over dead *Porites* and *Acropora*. The relative abundance of *Porites* was 40.4 %, followed by *Montipora* (28.8%). The relative abundance of *Acropora* was 1.0 %. The survey in 2006 suggests that the tsunami and earthquake had minimal impact on the reefs, recording a coral cover of 47%.

Rutland Island is one of the largest islands in this archipelago. This island has extensive coral reefs, mangroves and turtle nesting beaches. The monitoring site lies on the eastern side of Rutland (19 in Fig. 1). Here, coral growth starts 50m from the shore, the reef slope is gentle and coral growth continues to a depth of 8m, beyond which the bottom is sandy. The coral cover was 26.9% in 2003, dominated by *Porites solida* and *P. lutea* (48.2%) followed by encrusting *Montipora* (10.2%), *Hydnophora rigida and H. microconos* (8.3%) and *Acropora* (7.8%). The tsunami had minimal impact at this site, with the coral cover of 23.2% recorded in 2006.

Table 5 Estimated reef damage in the Nicobar Group of islands. The cause of damage is shown as tsunami (TS) and/or sedimentation (sed).

Island	Cause	Damaged Area (km^2)
Car Nicobar	TS	37.57
Nancowry Group	TS/Sed	88.88
Chowra	TS/Sed	3.37
Trak	TS	0.12
Treis	TS	0.34
Kondul	TS/Sed	0.85
Little Nicobar	TS/Sed	33.11
Great Nicobar	TS/Sed	46.39
Total		210.63

Twins Islands are the southernmost islands in M. G. Marine National Park. Corals occur at a depth of 2 to 12 m. Shallow areas mainly comprise of *Millepora* and *Heliopora,* with a live coral cover around 35-40%. *Porites* was found growing in patches off the southern rocky shoreline. *Acropora* colonies dominated the deeper (10-12m) parts of the reef, with a relative abundance of 10%. Reefs on the eastern side of West Twins Island (20 in Fig. 1) surveyed in 2003 had a coral cover of 35.6%, dominated by encrusting *Montipora* (relative abundance 38.2%), mainly growing over dead *Millepora*. Other major genera were *Millepora* (30.1 %) and *Porites* (19.5 %). Post-tsunami surveys indicated a significant increase in coral cover, to 67% in 2006 (Fig. 2). The reefs have also undergone a change in species composition, with *Acropora, Heliopora, Pocillopora* and *Porites* now

dominant. No major changes were evident in algae and soft coral cover.

Cinque Island is situated to the south of Rutland Island. The northern side has a rocky bottom and a steep slope down to 20 m, with sea fans, soft corals and some sporadic growth of sub-massive corals such as *Goniastrea, Lobophyllia, Coeloseris* and *Goniopora*. Currents are strong around the northern tip of the island. Towards the south the gradient of the slope decreases, with sandy bottoms, rubble and coral reefs in the southern portion of the island. Fish diversity is high in this area. Coral reefs were surveyed on the western side of this island (21 in Fig. 1). In 2003 the average coral cover was high (61.2 %), increasing with depth down to 15 m, and dominated by *Acropora* (relative abundance of 46.9%), followed by *Porites* (21.5 %), *Millepora* (5.3 %) and *Favia* (5.0 %).

The 2006 assessment suggests that the reef was affected by the tsunami, with coral cover reduced by a fifth at the monitoring site (Fig. 2). No substantial change in intact dead coral was noticed, but rubble had increased from 7.0 % in 2003 to 20.2 % in 2006, indicating a direct impact of the tsunami.

Nicobar Group

Of the Andaman and Nicobar archipelago, the Nicobar group of Islands was closest to the epicenter of the 2004 earthquake. The resultant displacement of water had a severe impact on these islands, with a tsunami wave height reported at around 12 meters (the seawater first receded to a great extent), causing the death of thousands of people and wiping out coastal habitats. Coral reef destruction was highest in this group of islands, with the submergence of the islands by more than two meters triggering sedimentation that continued for more than 8 months due to the monsoon that followed. Table 5 provides detail on reef area impacted in the archipelago, including sites not surveyed using LIT. Over 200km^2 of coral reef is believed to have been damaged or destroyed.

Car Nicobar Island is surrounded by fringing reefs. Prior to the tsunami the average coral cover in Sawai Bay (22 in Fig. 1) was 72.7%, dominated by *Acropora* spp. and with some large patches of *Millepora dichotoma* and *Porites nigrescens*. The reef profile was a drop to a depth of 4 meters and then a gradual slope to 8 meters over a distance of 60 meters, with the deeper sections dominated by *Porites* colonies.

The tsunami has all but wiped out the shallow reefs in Sawai Bay, with a reduction of coral cover to less than 5% and an increase in rubble to almost 60% of the benthic cover (Fig. 2). The impact was similar on shallow and deeper reefs on the east coast. The damage was restricted to 10 meters in the northern bay and to 25 meters on the east coast, with rubble observed in deeper waters on the eastern coast comprising mainly broken *Acropora* and *Porites* colonies. Debris deposited on the reef included wooden logs and tyres on the northern section, mainly of household materials, window panes and logs in the east.

Some shallow reefs on the eastern side of Car Nicobar survived the tsunami as the orientation of the bay sheltered them from the path of direct as well as refracted tsunami waves. These reefs are now showing signs of recovery from the damage sustained. However, the predominantly sub-massive and slow-growing corals such as Mussids, Faviids and *Porites* are now facing competition from soft corals. While Mussids and Faviids seem to be resisting this competition with some success, *Porites* appears not to be. However, a positive sign is the observation of settlement of juvenile corals on the reefs in Sawai Bay.

The islands of Central Nicobar comprise Nancowry, Camorta, Katchall and Trinket, while Southern Nicobar includes Great Nicobar, Little Nicobar and a few lesser islands. No pre-tsunami data was available for these areas, and due to cyclonic storms and turbulent seas during the post-tsunami surveys methods were limited to rapid assessment and visual estimates of the status of reefs. Results presented below are largely qualitative and indicative in nature and further quantitative studies of the area is recommended.

Live coral cover on the northeastern side of Camorta Island (23 in Fig. 1) was estimated to be

around 40%. Reefs in this area are dominated by *Porites, Millepora, Acropora, Pocillopora, Stylopora,* and *Hydnophora*. Physical damage to branching colonies of *Acropora* and *Pocillopora* was observed and evident in the coral rubble, and a few colonies of dead massive and sub-massive *Porites* were seen. This is likely to be an effect of the sedimentation that followed the earthquake and tsunami. An estimated 30% of live coral cover was seen on the southeastern side (24 in Fig. 1) of Camorta, with *Porites* dominating.

The reefs on the eastern side of Katchall Island (25 in Fig. 1) had a live coral cover of c. 40%, mainly comprising *Porites, Millepora, Heliopora Acropora* and *Seriatopora*. Dead massive *Porites* colonies and toppled sub-massive colonies were observed, implying a direct impact of the tsunami waves.

Trinket Island residents reported that 10-12 m high tsunami waves had covered this entire island, causing major damage to the surrounding coral reefs. This was evident from the widespread distribution of rubble on the western side (26 in Fig. 1) dominated by fragmented *Acropora,* interspersed with small patches of live coral.

On Great Nicobar Island, the southernmost island of the Nicobar Group, the western side of Campbell Bay (27 in Fig. 1) was surveyed. The average coral cover was 10% dominated by *Porites*.

Pigeon Island is situated on the north-eastern side of Great Nicobar Island. Surveys on the eastern side of the island (28 in Fig. 1) indicate an average coral cover of 20%. Toppled colonies of massive and sub-massive *Porites* were seen.

Little Nicobar Island has a mountainous terrain and few beaches. Tsunami waves have ploughed into the mountainous terrain destroying vegetation all along the shore. The island has subsided by 2-3 m and land up to 50 m from the previous high tide mark has been engulfed by the sea. Coral reefs have been destroyed by direct wave impact as evidenced by the large amounts of coral rubble under water. Sand and silt deposition on dead corals was observed. Surviving coral species include *Heliopora* and *Millepora*, and *Acropora* and *Heliopora* showed signs of regeneration. Coral cover of approximately 30% was seen on the southeastern side of the island (29 in Fig. 1).

Menchal Island, on the southeastern side of Little Nicobar, is uninhabited and is covered by coconut and banana plantations belonging to the Nicobarese of Little Nicobar. Surveys of the western side of the island (30 in Fig. 1) indicated a coral cover of 20%.

Kondul Island is situated to the north of Great Nicobar Island. The island was inhabited by Nicobarese prior to the tsunami, but as the entire coastline has been destroyed the island has become unsuitable for habitation and people of this island have now permanently shifted to Great Nicobar Island. On the southeastern side of the island (31 in Fig. 1) the average coral cover was 10%. Large colonies of dead *Acropora clathrata* were seen.

DISCUSSION AND CONCLUSIONS

The impact of the tsunami differed between the Andaman and Nicobar groups of island. In the Andaman group, coral reefs in channels between small islands were most affected, while in the Nicobar group reefs all around the islands except those sheltered between islands have been affected. As a result of the tectonic activity, the northern islands of the Andaman group have been raised, causing the death of shallow coral reefs due to permanent exposure. Where coral reefs have been uplifted, shallow water reefs have been affected due to altered wave action and localized warming of stagnant sea water. Coral reef destruction due to the tsunami was restricted to shallow areas (up to a 5-meter depth) in the Andaman Islands. In the Nicobar Islands, destruction of coral reefs occurred up to a depth of 20 meters. Severe damage was caused by the impact of the tsunami and in particular the increased sedimentation that followed. Due to the subsidence of the Islands, changed beach profiles and the monsoon, erosion and sedimentation continued for more than 8 months.

Regeneration patterns also differed between the Andaman and Nicobar Islands. New settlement of

corals were recorded at several sites in the Andaman Islands but was negligible in the southern group of the Nicobar Islands. In some parts of the Nicobar Islands, hard corals are facing competition from soft corals.

Coral reef research priorities in the archipelago include: resilience of coral communities to changes in habitats and environmental conditions, coral regeneration patterns. emerging coral community structure, and implications for resource species and dependent communities. There is also a need for documentation of regeneration patterns in coral reef communities that have been completely destroyed. Management and conservation initiatives need to mitigate sedimentation effects caused by altered land-use patterns, deforestation and post-tsunami rehabilitation activities, building on available scientific research. There is also a need to create awareness among local communities, including Nicobari tribes, about the destruction of coral reefs and implications for their livelihoods.

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