

# Climate Change and Other Impacts on Coral Reefs in India's Islands

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## Introduction

Coral reefs world over are facing severe ecological decline, as indicated by the decrease in coral cover over the years. The causes could be attributed to the impacts of climate change and direct human pressures. In the case of well managed reefs the direct human pressures may be low (e.g. Great Barrier Reef, Sweatman *et al.*, 2011), the picture is different for the reefs and islands in developing countries where the economy of the people is dependent on resources from the reefs and the development in those areas; and the impact is both from climatic and local-scale factors which may also act synergistically. The management of these reefs to aiming sustenance of resources, conservation of biodiversity and protection of environment is utmost difficult, in view of the lack of scientific information, little or no coordination between different sectors involved in management as well enforcement and the lack of awareness among people regarding conservation. Given this scenario, it could be easily discerned that the reefs in India fall in the latter category. It is anyone's guess that the islands in the continental shelf and closer the mainland coast of India could be more prone to local stressors where the same could be minimal in offshore Island reefs. What are the possible causes and impacts to the reefs, reef-wise? Do the impacts vary between reefs, and if so what may be the reasons? These are some of the several questions to which one needs answers.

An analysis of reef status to understand the changes over the years could be one tool to answering these questions mentioned above. *Scleractinian* (hard coral) species diversity data could be another. Although these may be simplistic and not comprehensive observations, studies other than these (except a few) are lacking for the island reefs in India. Given this, in this article an overview of the island reefs in India are presented first, followed by a discussion on their current status and changes over the years – based on coral cover and diversity – to the understanding of the reader the impacts of climate change and other local scale factors in the island reefs.

## Island reefs in India

The total reef area in India, estimated based on 2004-07 satellite data in India is 2383.87 km<sup>2</sup> (SAC, 2010). Leaving Palk Bay and Malvan reefs, the remaining constitute island reefs, and are Gulf of Kachchh, Lakshadweep, Gulf of Mannar and Andaman and Nicobar. The total area in these reefs forms 2376.69 km<sup>2</sup>. The reef area estimated for each Island area are 352.5, 933.7, 69.03, and 1021.46 km<sup>2</sup> for Gulf of Kachchh, Lakshadweep, Gulf of Mannar and Andaman and Nicobar Islands respectively. These reefs differ from each other in structure, geomorphology, species composition and diversity, water quality, resource harvesting patterns, and the amount of local pressures contributing to pollution. Some basic characteristics of each reef are as below.

### 1. Gulf of Kachchh

The coral reefs in are found in thirty four of the forty two islands of the Gulf of Kachchh located between 21° 15'-24° 40' N and 68° 20' - 70° 40' E. The reefs are generally restricted to the areas exposed to strongest tidal currents and hence living corals are confined to the northern and western side of the islands (Pillai and Patel, 1988). The conspicuous feature of the fauna is the total absence of any living ramose forms, though *Acropora* thrived to exist in the recent past as is evident from the dead and semi fossilized pieces at several sites (Pillai, 1987). The reasons cited for the disappearance of this species are the characteristic long exposures due to tidal fluctuation, excessive siltation and extreme variation in temperature. The dominant genera reported presently in these reefs are *Montipora*, *Favia*, *Goniopora*, *Tubastrea* and *Turbinaria*, which are also stress tolerant.

Despite the islands being declared as a Marine Sanctuary, and 32 islands covering 162.89 km<sup>2</sup> as Marine National Park in the year 1982(Singh, 2002), there are heavy local pressures. These reefs

have been subjected to large-scale coral mining in the past (Patel, 1985). According to Rao & Sastry (2005) the area may have retained luxuriant biota till early seventies, and periodical observations thereafter by them suggested gradual deterioration of faunal wealth. Rao & Sastry (2005) summarized the activities caused degradation, some of which still exist, as: i) commercial fishing in the vicinity and subsistence fishing in the core area, ii) coral collection for industrial and domestic use – resulted in habitat destruction and heavy siltation iii) Commercial shell collection – continued illegal exploitation, iv) felling and gracing of mangroves – siltation in reefs, v) developmental activities – discharge of domestic and industrial effluents, dredging for port activities, and vi) un-guided educational and recreational activities.

## 2. Lakshadweep

Lakshadweep island reefs are the only atoll reefs in Indian waters. These are the northernmost of the Laccadive-Chagos ridge, extending between 12° – 8° N and 71° – 74° E in the Arabian Sea. There are 14 atolls (Baliyapaniyam, Cheriyanapaniyam, Chetlet, Bitra, Kiltan, Kadmat, Amini, Perumal Par, Bangaram, Agatti, Kavaratti, Suheli Par, Kalpeni and Minicoy), 1 platform reef (Androth Island, where the reef extends right from the island as a platform, and lacks a clear cut lagoon and a reef flat), and 2 prominent submerged banks (Pitti and Elikalpeni); situated within these atolls and reefs are 12 inhabited islands and 12 islets (Venkataraman *et al.*, 2012). A depth of 1870 to 2100 m of surrounding Ocean separate the Lakshadweep from India (Kinsey, 1977). The atolls have NE-SW orientations, and except Baliyapaniyam and Cheriyanapaniyam, have low-lying islands on the east (leeward side) and a lagoon on the west connected to the open ocean by one or two channels. The width of the lagoons varies from 1–4 km and most of the lagoons have coral knolls arising from the lagoon floor (Wafar, 1986). The islands are small, vary from 0.1 – to 4.4 km<sup>2</sup> in size and together with the islets cover a total land area of 32 km<sup>2</sup>. The lagoons support a rich growth of benthic macro algae and seagrass and hitherto, more than 100 species of flora have been recorded (Rao, 1991). Coral diversity is high and the islands share much of their fauna with the reefs of the

Maldives, with some faunal affinity to the reefs of mainland India (Sheppard, 1987). Pillai and Jasmine (1990) reported 107 species of hard corals under 37 genera with species *Acropora* and *Porites* occurring commonly and species of *Montipora*, *Seriatopora*, *Cyphastrea* and *Echinopora* being few. An account of 152 species of meiofauna, 69 species of polychaeta, 17 species of sipuncula, 7 species of Echiura, 13 species of Stomatopoda, 79 species of Insecta, 168 species of Mollusca, and 72 species of Echinodermata have been so far reported, along with 4 species of marine turtles such as *Erethmochelys imbricata*, *Lepidochelys olivacea*, *Chelonia mydas*, *Dermochelys coriacea* of which the first three listed in the endangered category of the IUCN Red list of threatened animals (Ghosh, 1991).

The island waters provide optimal conditions for coral growth, with narrow ranges in salinity (34 to 39.4 ppt) and temperature (28° – 31°C). Total population of these islands is around 70000 (60595 in the year 2001) and the density highest in the country with 1922 people/km<sup>2</sup> (Thangal, 1994). Fisheries, coconut cultivation and tourism are the major economic activities in these islands. There are about 6200 fishermen engaged in fishing using 900 boats. The total fish landings in these islands per year are about 15000 tonnes (Rajan *et al.*, 2011). The island people are dependent on the mainland for all essential supplies including fuel, vegetables, packaged foods, and infrastructure. The existing tourist infrastructure in government sector extends to 5 islands (Kavaratti, Kalpeni, Kadmat, Agatti and Minicoy), and one Island (Bangaram) leased to private sector, with the annual average tourist arrivals of about 3000 domestic and 1500 foreigners (Rajan *et al.*, 2011). Pitti Island, which has been declared as the Bird Sanctuary is the only PA in these islands.

These coral reefs were severely affected during the bleaching event in the year 1998, with the record of post-bleaching mortality of more than 80%. Though recovery has been observed, the studies also noted increased population pressures on coral colonization (Jeyabaskaran, 2004; Arthur, 2008). Increased developmental activities in the islands is also a concern for coral recovery and survival in these reefs.





A healthy reef-scape in Andman Islands



Bleaching of coral in Lakshadweep Islands in 2010



Algal smothering of corals in Gulf of Mannar

### 3. Gulf of Mannar

The reefs in Gulf of Mannar are found around the 21 islands situated between 8° 48' N, 78° 9' E and 9° 14' N, 79° 14' E aligned parallel to the shoreline at an average of 8 km from the shore. The reef flat of these reefs could be found at 50–500 m from the shore of the islands. Seagrass beds are available on the western side of the islands and near the coast and the area estimated is 85.5 sq km (Ramaswamy *et al.*, 2009). There are also patches of mangroves within the shoreline in some of the islands. The GOM is the first Marine Biosphere in India (declared in the year 1989), with the core area comprising the islands and the surrounding reefs (560 km<sup>2</sup>, declared as Gulf of Mannar Marine National Park in 1980) and surrounded by 10 km wide, 160 km long buffer zone of shallow marine habitats. The biosphere reserve is deemed a priority area under the authoritative reference work published by the World Bank, the Great Barrier Reef Marine Park authority and World Conservation Union (Venkataraman *et al.*, 2002).

Gulf of Mannar is home to **flagship species such as Dugong dugong, 3 species of dolphins, 2 species of whales, at least 5 species of turtles and 68 species of elasmobranchs, and an Hemi-chordate (*Phychodera fluva*)**. A total of 1097 species of fauna under 254 families and 567 genera, which included 85 species of corals, 15 gorgonids, 16 sea anemones, 24 prawns, 3 lobsters, 21 crabs, 88 molluscs, 108 Echinodermates, 2, Hemichordates, 2 Cephalo-chordates, 78 Tunicates, 553 fishes, 6 reptiles, 63 birds, 6 Mammals have been reported (Venkataraman *et al.*, 2002). Acropora was the most diverse coral genera in these reefs, represented by 24 species (Pillai, 1971; 1972).

Extensive damages were caused to these reefs by coral quarrying until 2002. Areas of live corals could be only observed in the eastern side of the islands, since quarrying was mostly on the western side and the coral growth being restricted in the northern side due to hydro-logical conditions (Rajendran and David, 1972). Unlimited resources exploitation is one serious threat to these coral reefs. 50,000+ people involve about 850 trawlers, 7400 small-scale fishing vessels (SFV), and 300 catamarans for fishing and allied fisheries (Gopakumar, *et al.*, 2011). About 5000 women are

also involved in harvesting seaweeds, ~4500 divers are collecting sea cucumbers, of which ~1000 are also involved in chank (*Turbinella pyrum*) collection in GOM (Rajagopalan, 2011). Venkataraman *et al.*, (2002) report the exploitation of large volume of gorgonids (106 Tons exported from 1975-1992); brachyuran crabs; chanks (landing of 1 – 1.5 millions / year); and the trading of large numbers of sea urchins, brittle stars, sea lilies, sea anemones and 60 species of ornamental fishes as aquarium animals. Recent estimates show that there is severe depletion on valuable fisheries due to excessive demand, thereby causing the non-target biomass dominating the total catch (ZSI, 2012). Department of Forests identified the use of prohibited fishing gear and techniques near the islands—including dynamite or blast fishing, pair trawling, purse-seining, use of roller nets and drag-nets and seaweed collection—as major threats to the sustenance of the reefs. The degradation in these reefs is also due to developmental activities in the shore, industrial pollution, sewage disposal, waste dumping etc., which is evidenced by heavy sedimentation, excessive algal growth, and the occurrence of coral diseases.

### 4. Andaman Nicobar Islands

Andaman Nicobar Islands lie at 13° 40' - 6° 45' N and 92° 12' - 93° 57' E in southeast Bay of Bengal, where the islands located north of 10° N Latitude are called Andaman islands and those located south of 10° N Latitude are called Nicobar islands. There are a total of 350 islands, including the exposed islets and rocky outcrops, in this chain. Human habitation is in 25 Andaman islands and in 13 islands Nicobar islands, and the total population as per 2001 census is 3,56,265 people. A total of 106 PAs (96 wildlife sanctuaries, 9 National Parks and 1 Biosphere reserve), located in these islands, of which Mahatma Gandhi Marine National Park, Rani Jhansi Marine National Park and Lohabarrack Wildlife Sanctuary are designated as Marine Protected Areas – the former two for the conservation of coral reefs and the later for conservation of saltwater crocodiles.

The reefs are fringing, barrier and patch types, and fringing reefs occur intermittently around these islands. Reef platforms extend about 500 m from the shore in Andaman Islands to ~1000 m from



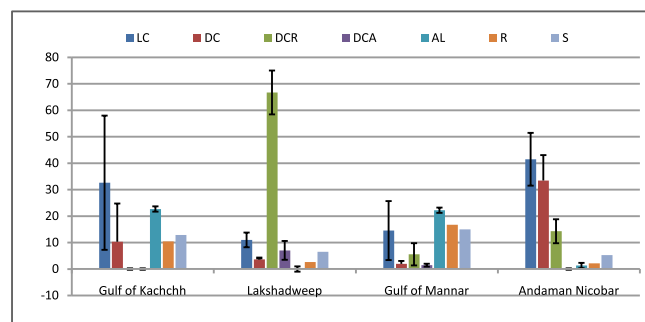
shore in the Nicobar Islands, the latter having small surge channels (Reddiah, 1977). The barrier formation is found on the western side of Andaman islands between 10° 26' N and 13° 40' N Latitude, for a distance of approximately 200 miles. These reefs harbor good species diversity with 235 species of corals, 111 soft corals, 112 sponges, 411 crustaceans, 1422 molluscs, 430 echinoderms, 750 fishes, 4 mammals, 14 reptiles, 50 marine birds and 64 algae (Rajan *et al.*, 2011). The islands are also nesting sites and habitats for Leatherback, Hawksbill, Olive Ridley and Green turtles and the mammal Dugong. The dominant coral fauna observed had been *Porites*, *Favia*, *Acropora*, *Pocillopora*, *Heliopora*, and *Montipora* (Pillai, 1983).

Local anthropogenic disturbances on coral reefs are low in these islands. However, there are siltation and nutrient runoff due to deforestation, clearing of mangroves, coastal erosion and agricultural practices in these islands. There is also uncontrolled exploitation of resources such as shells (*Trochus niloticus* and *Turbo* sp, etc.), and high value export fished (groupers and snappers). Uncontrolled tourism growth is another major threat to the reefs, by means of solid waste accumulation, construction of tourism infrastructures, and damages to the corals through boat anchoring, diving, and snorkelling activities.

Bleaching in these reefs was reported in the year 1998 and again in 2010 (Krishnan *et al.*, 2011). Severe damages to these reefs were caused by Earthquake and Tsunami in December 2004: ~30% of reef area has been lost in the North Andaman due to landmass uplift (Rajan *et al.*, 2008), and coral damages were observed in Nicobar Islands due to Tsunami onslaught.

## Current status and trend

Gulf of Kachchh reefs hosts an average live coral cover ( $32.62 \pm 25.37$  %) (Fig. 1), which is fair in terms of health assessment and shows an increase from the past. However, many reefs here are dominated with algae, it forming the next high cover category. Though diversity of scleractinians has been reported low and consisted of stress tolerators in the previous assessments (Arthur, 1995 and 2000; Patel, 1985), attributed to the chronic sedimentation and other local stressors, majority of the



**Figure 1.** Percentage cover of benthic categories [LC – Live coral, DC– Dead coral, DCR – Dead coral rock, DCA - Dead coral with algae, AL- Algae, R – Rubble, S- sand]

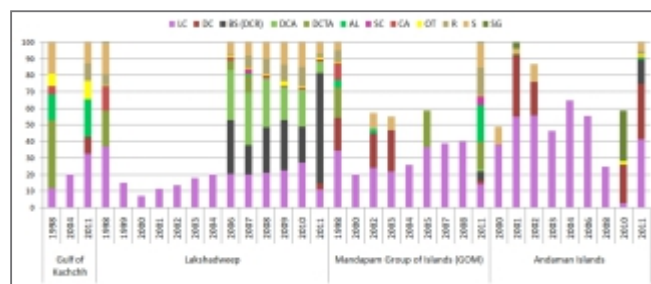
reefs are now dominated with species categorized as stress tolerators such as *Favia favius*, *Porites compressa* and *Goniastrea pectinata*, thereby exhibiting dominance of species with low diversity and evenness indices. Siltation and eutrophication are identified as the major stressors so are coastal developments and polluting industries (Ravindran *et al.*, 1999; Arthur, 2000). Bleaching was not considered as a major cause of coral decline here, as no bleaching related mortality was observed in May 1998, with only 1.92% of the coral being bleached severely, though the total bleached coral was 11% (Arthur, 2000).

Lakshadweep reefs, dead coral rock formed the dominant benthic cover ( $66.74 \pm 8.29$  %) and the average live coral cover is  $11.0 \pm 2.78$  % (Fig. 1). A review of previous studies' data (Fig. 2) shows a clear reduction in live coral cover as a result of the bleaching in 1998. The recovery was observed from the year 2000 to 2010 which was also marked by the reduction in algal cover, helped apparently by the healthy populations of herbivorous fishes. The reduction in live coral cover in the latest observation in these reefs is due to the result of the bleaching in 2010. The major die-off of corals can cause increase in macro algal benthic cover (Endean, 1976), and can be catalysed by environmental conditions that favour algal growth, such as elevated nutrient concentrations, or reduction in herbivores due to overfishing (Hughes, 1994). However, the high cover of bare substrate (the dead coral rock benthic cover, which is not over grown by algae) reported in the latest observation shows that the phase shift to high algae cover has not taken place, similar to the status after the bleaching in 1998 (Arthur, 2006). This points to the absence of impacts from regional-scale stressors. Further, the steady increase in coral cover until 2010, in

the absence of a major bleaching event in these years post the 1998 event, point to the vulnerability of these reefs more to bleaching than any regional-scale stressors.

All the reefs studied in Lakshadweep sported good diversity and evenness indices ( $H' \geq 2.0$ ;  $E \geq 0.7$ ) with low dominance ( $D \leq 0.1$ ) of species. *Acropora* was a dominant form in Lakshadweep prior to bleaching and were severely affected by the bleaching in 1998 (Arthur, 2000; McClanahan, 2000; Sheppard, 2002). Three genera, *Acropora*, *Goniastrea* and *Porites*, dominated the recovery from 2001-03 (Arthur, 2006). It is a concern the stress tolerant genus *Porites* is dominant at present. However, given the short time between the bleaching event and the estimation of species cover, it could be assumed that *Acropora* being suffered high mortality than the stress tolerators could not have recovered the benthic cover in the given duration.

Gulf of Mannar (GOM), the AL cover dominates the benthic category (Fig. 1). The average live coral cover in the present estimation is lowest from the previous status reports (Fig. 2). A clear reduction in live coral cover as a result of the bleaching in 1998 as that of Lakshadweep was observed (Fig. 2). From the lower value in 2000 (Rajasuriya *et al.*, 2002), the live coral covers increased to 40% in 2008 (Fig. 2). The present values show >50% decline, and most of the reefs studied were dominated either by fleshy or turf algae (Fig. 2). These reefs may have experienced bleaching stressed coral mortality, simultaneous to the episode in May 2010 in Andaman and Nicobar reefs (Krishnan *et al.*, 2011) may be the reason for low cover in the latest assessment. Unlike Lakshadweep reefs, however, the local disturbances impeding recovery are evident by the immediate dominance of algae.



**Figure 2.** Average benthic cover values for the reef regions from the published data 1998-2011. [LC – Live coral cover, DC – Dead Coral Cover, BS (DCR) – Bare Substrate or Dead Coral Rock, DCTA – Dead Coral Covered with Turf Algae, AL – Algae, SC – Soft Coral, OT – Others, R- Rubbles, S-Sand, SG – Seagrass]

Majority of the reefs in Gulf of Mannar at present show dominance of species with low diversity and evenness indices (Table 2). The reefs which are represented with high coral cover (>20%) had usually one species dominating, either - as per conservation classes (Edinger and Risk, 2000), of competitors (*M. digitata*; % contribution.: 79.2), or ruderals (*A. hyacinthus*; % contr.: 73.3) or stress tolerators (*Porties lutea*; % contr.: 66.6), which may be indicating the reefs shifting to poor diversity status.

Andaman Nicobar reefs, the benthic cover values show the live corals dominating in majority of the reefs studied. Dead coral cover (DC) is observed as the second highest category in all the reefs. The data since 2000 show a declining live coral cover, notwithstanding some increased live cover values observed in between. There is a decrease in live coral cover in 2010 due to bleaching and the recovery of bleached corals has been observed with the increase in live coral cover (LC) in 2011. Damages on account of reef up-lift in North Andaman and tsunami disaster in Nicobar reefs had caused reduction in live coral cover (41% and 55% less cover for North Andaman and Nicobar reefs respectively, from the 2003 values (Kulkarni *et al.*, 2008; Rajan *et al.*, 2008; Saxena *et al.*, 2008). The long-term impacts of bleaching, reef up-lift and tsunami on coral health is clear from the declining trend in reef health of these reefs from status assessment data since 2000 and the latest assessment.

Majority of the reefs studied in Andaman sported good diversity and evenness indices ( $H' \geq 2.0$ ;  $E \geq 0.7$ ) with low dominance ( $D \leq 0.1$ ) of species. Though the stress tolerators such as *Porites solida*, *P. lobata* and *P. lutea* formed the highest cover in most of the reefs, species dominance was not observed - except for few reefs where siltation due to shore erosion is an issue. The dominance of stress tolerators in reefs severely affected by sedimentation, had been identified in some Andaman reefs (Kulkarni and Saxena, 2002), which could be the case in these reefs too.

## Conclusions

These observations clearly show the different levels of impact on the reef regions in India due to climate change and natural events to local activities. The present composition of coral species in these reefs may be the result of the severity and frequency of climate change events and natural calamities, the role of localized



stressors was found more critical. Siltation and eutrophication (Ravindran *et al.*, 1999) have been identified as major stressors in Gulf of Kachch reefs amplifying the impacts of long exposures (due to high tidal amplitude) and summer bleaching. Bleaching has been identified as the major factor determining reef health in Lakshadweep reefs. Gulf of Mannar reefs are stressed more in terms intense local activities besides the regular bleaching events. In Andaman and Nicobar there is siltation and eutrophication through: defores-

tation, sewage discharge and terrestrial runoff associated with the monsoons. Siltation due to erosion, associated with land subsidence in South Andaman is another major concern. These observations also show that the reefs with minimal local pressures (e.g. Lakshadweep and Andaman) have recovered steadily from major bleaching and other catastrophic events and to maintaining the good coral diversity, thus advising for measures to minimising local pressures in Indian reefs.

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