Coral bleaching: causes, consequences and mitigation

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The coral reefs are distributed in the tropical regions and cover less than one percent of the earth's surface, but provide habitat for many species in the marine realm. The majority of reef building corals are found in tropical and subtropical waters and typically occur between 30° N and 30° S latitudes (Fig. 1). Coral reefs are greatly valued due for their beauty, biodiversity it encompasses and the products and services they provide to human society. The coral reefs are made of calcium carbonate secreted as skeletal material by the coral polyp. Coral polyps live in association with intracellular algae (zooxanthellae), which provide additional nutrition to the coral in its life processes. The association of coral polyp with zooxanthellae, restrict its distribution in waters up to the depth of 100 meters where sunlight would be available for the photosynthetic zooxanthellae. The worldwide of zooxanthellate corals in the different distribution eco-regions is a unique underwater ecosystem and provides annual net economic benefit around 30 billion dollars (Buddemeier *et al.*, 2004 Pew Center on Global Climate Change, 44p). However, coral reefs are most vulnerable to Climate Change due to the stenothermic nature of coral polyps. Coral reef stressors are multitude (climate to non-climate

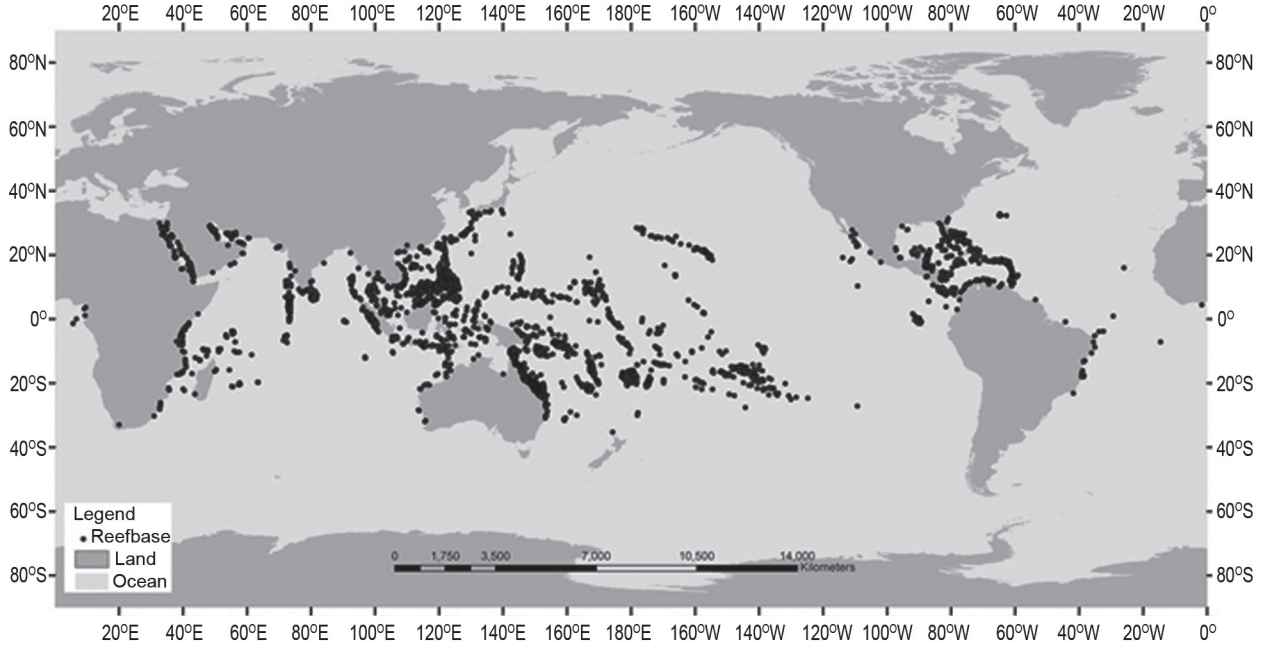


Fig. 1. Distribution of major coral reefs of the world (NOAA Ocean Service Education portal: https://oceanservice.noaa.gov/education/kits/corals/media/supp_coral05a.html)

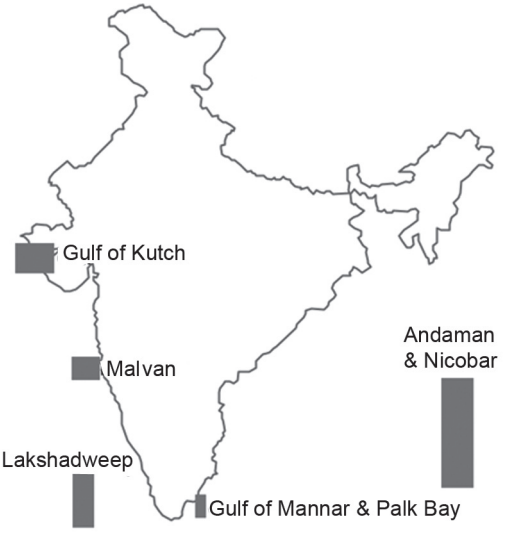


Fig. 2. Major coral reef areas of India

stressors) some are acute in nature like tropical storms and others are chronic like sediment loading (Table 1).

Coral reef areas of India comprise of two reef types viz., fringing reef and atolls. The major reef formations around India are found in Gulf of Mannar, Palk Bay, Gulf of Kutch, Malvan, Lakshadweep and Andaman & Nicobar others. While the Lakshadweep reefs are atolls, the remaining reefs are fringing reefs (Fig. 2). There are also patches of reef in the inter-tidal areas of the central west coast of the country off Ratnagiri and Malvan (Maharashtra) and Gaveshani Bank off Mangaluru, Karnataka. Along the Kerala coast, patch reefs are recorded from Quilon to Enayam. Recent surveys of ICAR-CMFRI reveal the occurrence of reefs between Cuddalore and Puducherry.

Coral bleaching

The turquoise blue colour of the lagoons in coral Islands is primarily contributed by the zooxanthellae associated with the coral polyps. Under extreme environmental conditions like alteration in the sea surface temperature the intracellular zooxanthellae is expelled by the coral polyp as a stress response which makes it appear white. The white, unhealthy corals called bleached corals are weak and susceptible to diseases. Some coral species are hardy and able to recover after bleaching, but in most cases these die and the entire ecosystem is affected. Coral polyps are highly dependent on the nutrition provided by the zooxanthellae, and it is estimated that up to 90 percent of their energy requirement is fulfilled by zooxanthellae (Muscatine, 1990 *Coral Reefs*, 25:75–87), hence any breakup in this association is catastrophic to coral polyps and its ecosystem. Bleached corals are still living and if stressful conditions subside soon enough, the zooxanthellae can repopulate their tissues and the corals survives the bleaching event. However this depends on many factors like light, duration of the high temperature regime, etc. Sea surface temperature (SST) increases of 1 to 2°C above the long term average maximum can trigger mass bleaching (Hoegh-Guldberg, 1999 *Marine and Freshwater Research,* 50 (8):839–866). However, the threshold temperature for coral bleaching varies from place to place and species to species; hence it is highly difficult to have control over this natural process, once it is started. There are two forms of corals, branching and massive forms. The former one suffers more due to bleaching than the massive forms, which is a slow grower and more resilient. However, in many areas of the world this general phenomenon was altered and massive forms became more prone to bleaching than the branching form. This was noticed during the surveys in the Palk Bay coral reefs around the islands of Pamban.

As the ocean temperature is on the rising trend more long lasting coral bleaching effect are expected in the form of disease outbreak in corals viz., black band disease, white band disease, white plague, and white pox, all of which can lead to mass mortality of coral, which endanger the entire ecosystem. Coral bleaching is a relatively recent phenomenon and before 1980 it was hardly noticeable in the wild. The first global corals bleaching event was in 1997-1998, during a strong *El Niño* that was followed by an equally strong *La Niña* phenomenon. Prior to this mass bleaching event coral bleaching was considered to be a localized problem due to local stressers. The second event occurred in 2006. The third global bleaching event

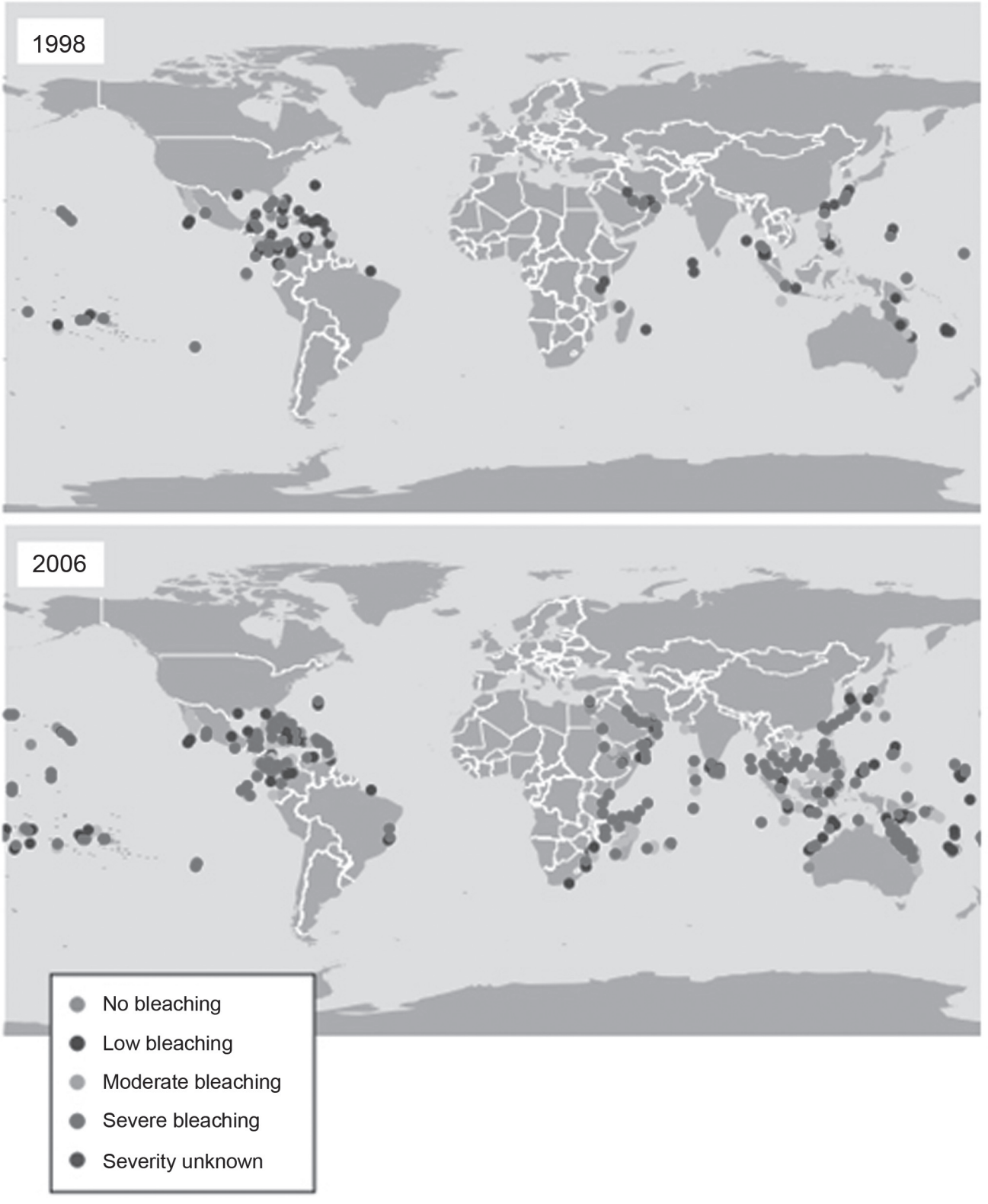


Fig. 3. Comparision of global mass bleaching event of 1998 and 2006 (NOAA CORIS https://www.coris.noaa.gov/activities/reef_managers_guide))

started in 2015 continues unabated. Comparison of the global bleaching events (Marshall and Schuttenberg, 2006, *A Reef Manager's Guide to Coral Bleaching,* 163p) is shown in Fig. 3.

Coral Bleaching Hotspot

Corals are vulnerable to bleaching when the SST exceeds the temperatures they would normally experience in the hottest month. Coral Bleaching Hotspot (HS) product measures the occurrence and magnitude of thermal stress potentially conducive to coral bleaching. HS regions highlights where the Sea Surface Comparative (SST) is currently warmer than the highest Monthly Maximum Mean (MMM) of SST. The HS value less than or equal to zero is categorized as 'No Stress' condition, HS value within the range of 0 to 1.0°C is categorized as 'watch' and values above 1.0°C are the threshold for thermal stress leading to coral bleaching.

Hotspot (°C) = SST – (Monthly Maximum Mean SST)

The HS anomaly is based on the climatological mean SST of the hottest month (Liu *et al*., 2003 *Earth & Space Science News (EOS), Transactions, American Geophysical Union* 84: 137–144).

Coral Bleaching Degree Heating Weeks (DHW)

Corals experience thermal stress, the main cause of coral bleaching, when sea surface temperatures exceed 1°C above the maximum summertime mean. If the heat anomaly persists the stress worsens and mass bleaching of coral occurs due prolonged periods of thermal stress. DHW is a cumulative measurement of the intensity and duration of thermal stress, and is expressed in the unit °C-weeks. The DHW shows any Hotspots greater than 1°C over a 12-weeks period, thus showing how stressful conditions have been for corals during the last three months. DHWs over 4 °C-weeks have been shown to cause significant coral bleaching to more sensitive species. DHW values over 8°C-weeks have caused higher, widespread bleaching and some mortality of corals may also occur.

Coral bleaching survey in Palk Bay

A coral bleaching survey was undertaken during summer months of 2016 along the northeastern part of Pamban Island off Olikuda fishing village in Palk Bay, where the fringing reefs locally known as Lighthouse Reef (located from 9°

Table 1. Scheme for assessing the local, regional and global stress on coral reefs

Chronic stresses	Global	Regional	Local
Carbonate ion decrease and reduced calcification	✓		
Temperature increase	✓		
Overharvesting	✓	✓	✓
Nutrient loading		✓	
Introduced/Invasive species		✓	
Ocean/atmospheric circulation change		✓	
Coastal and watershed alteration		✓	
Sedimentation		✓	
Acute stresses			
Temperature increase	✓	✓	
ENSO	✓	✓	
Diseases, Introduced/Invasive species		✓	✓
Storm frequency and intensity increase		✓	✓
Sedimentation		✓	✓
Urbanization and watershed modification		✓	✓
Commercial and incidental destruction		✓	✓

19' 27.17" E and 79° 19' 46.81" N to 9° 18' 20.7" E and 79° 20' 8.13"N) occur. Fishermen understand the bleaching event and reported that they can recover. During the survey more of massive forms were found to be bleached then the branching form which is contrary to the generalized hierarchy of coral susceptibility to bleaching. The bleaching event in the Lighthouse Reef has been classified as moderate bleaching; where bleached colonies are frequent but constitute less than half of all colonies (Table 2). Some of the most commonly seen bleached colonies belonged to species of *Pocillopora*, *Porites* and *Platygyra*.

Palk Bay, which spans an area of 13,500km^2 with average depth around 9 m, has a narrow connection to the Bay of Bengal through Palk Strait in the north and through Adams Bridge in the south to the Gulf of Mannar. The coral reefs of Palk Bay distributed at a depth of 1 to 4 m runs parallel to the Pamban Island and off Pudumadam lagoon with a width ranging from 200 to 600m. This narrowness makes for poor water exchange and Palk Bay warmer than Gulf of Mannar. The period of warming is also longer in the Palk Bay. These factors invariably make the fringing reefs of the Palk Bay more susceptible to bleaching. Earlier observations on coral bleaching Palk Bay have reported on the slow recovery of corals after bleaching. However recent studies have indicated the reduction in the species richness, which may not be merely due to coral bleaching. The light house reef which was surveyed in the present study has not been widely studied and could become one of the possible eco-reserve. The fishermen of the Olikuda village take care of this reef and operate only minimally invasive fishing gears like bamboo traps in this reef. This area could be developed as a community managed reef. It can also be used for ecotourism activities due to the proximity of Rameswaram temple, in addition to their fishery based livelihood activities.

Mitigation measures

I. Management of local stressors

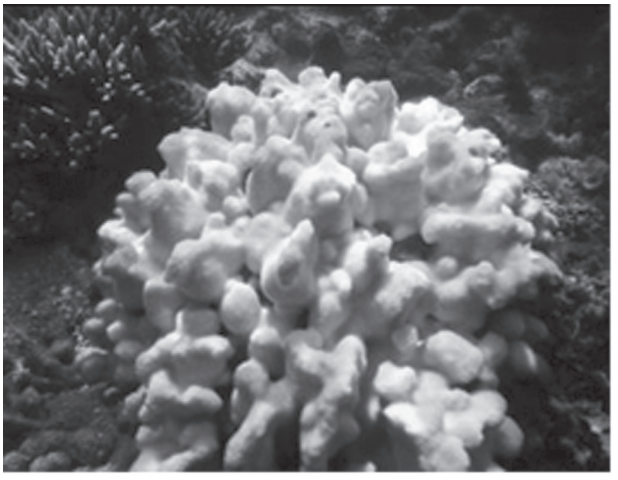
Local stressors includes physical damage due to diving, snorkeling and anchoring, water quality and fishing activity. In the present case, the Lighthouse Reef suffers from physical damage due to anchoring as well as effluent discharge from the adjacent shrimp farms. The local, regional and global stressors for the reef system should be analysed as indicated in Table 1. Monitoring light, temperature and water currents is important as Palk Bay is prone to quick and longer spells of seawater warming.

II. Identifying resilient coral reef areas

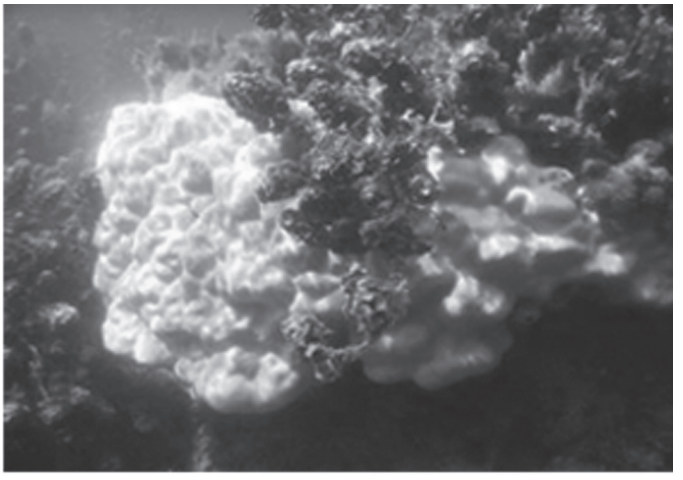
Identifying the healthy reef areas, which tolerate bleaching and protecting them for the reef recovery is required. A resilient coral community might suffer significant coral mortality from a bleaching event, but reorganize so that the community composition shifts toward different coral species that require similar habitat and are more tolerant to coral bleaching. Building long term reef resilience can be achieved by identifying the resilient coral community and incorporating the area into a management plan.

Table 2. Standard methods of recording coral bleaching

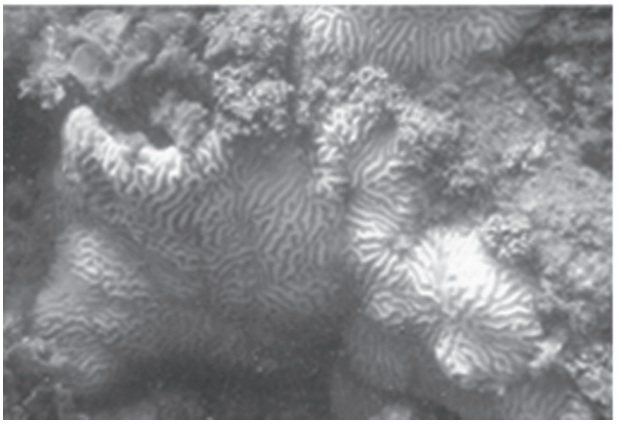
Category	Percent	Description	Visual assessment
0	<1	No bleaching	No bleaching observed, or only very occasional, scattered bleached colonies (one or two per dive).
1	1-10	Low or Mild bleaching	Conspicuous bleached colonies seen occasionally, butvast majority of colonies not bleached.
2	10-50	Moderate bleaching	Bleached colonies frequent but constitute less than half of all colonies.
3	50-90	High bleaching	Bleaching very frequent and conspicuous, most corals bleached.
4	>90	Extreme bleaching	Bleaching dominates the landscape, unbleached colonies not common. The whole reef looks white.



Bleached corals of *Pocillopora* sp.



Porites sp. showing bleaching



Colonies of *Platygyra* sp.

Close up view of bleached *Pocillopora* sp.

Underwater photographs of bleached corals of Light House Reef, Palk Bay

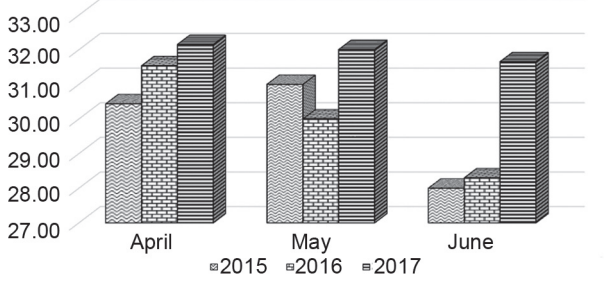


Fig. 4. SST of Palk Bay during summer months of 2015 - 2017 period

III. Fishermen involvement in reporting and monitoring coral bleaching events

Identifying the fishermen for reporting the bleaching events to the state and central government agencies and monitoring the bleached coral reef sites as community management is required.

Developing a forecast model for coral bleaching

The US National Oceanic and Atmospheric Administration (NOAA) developed a forecast system on global level for coral bleaching due to thermal stress. Operating on similar lines, the Coral Bleaching Alert System (CBAS) is a service initiated by Earth System Science Organisation – Indian National Centre for Ocean Information Services (ESSO-INCOIS) since February 2011 in India. This employs a model that assesses the thermal stress accumulated in the coral environs with the help of satellite derived SST.

In conclusion, as far as Palk Bay coral reefs are concerned, the damaging effect of anthropogenic stressors are more than the threat of coral bleaching. The growth and recruitment of corals is severely affected by many factors such as overfishing, land based pollution, usage patterns, habitat degradation, introduction of invasive species but can be controlled through appropriate management measures for this unique ecosystem. Coral reefs in Palk Bay are valuable from conservation and biodiversity point of view and could be termed as biodiversity banks where rich species and genetic diversity is stored. It warrants a shared responsibility by all stakeholders including fishermen, public, policy makers and scientists.