# Coral mortality in the Gulf of Mannar, southeastern India, due to bleaching caused by elevated sea temperature in 2016

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**Intensive underwater surveys have been conducted to assess the extent of coral bleaching and subsequent mortality in the Gulf of Mannar between March and October 2016. The extent of bleaching was 23.92% ± 10.55% during the period between March and June 2016, and the live coral cover was drastically reduced to 22.69 ± 9.07% during October 2016 with a mortality of 16.17 ± 8.46%. Fast-growing coral forms, including the genera *Acropora*, *Montipora* and *Pocillopora* were most affected, not only by bleaching but also by severe mortality. Boulders, including the genera *Porites*, *Favia* and *Favites* were found to be resistant to bleaching. During the bleaching period, water temperature was between 31.2°C and 32.6°C. The current bleaching is in alignment with the third global coral bleaching event which occurred between 2014 and 2017. Management interventions, including protection and rehabilitation using the native resistant coral species will not only help in the recovery process, but also increase the live coral cover.**

**Keywords:** Bleaching, climate change, coral reefs, mortality, sea surface temperature.

CORAL reefs have the highest biodiversity in any marine ecosystem; they provide important ecosystem services and direct economic benefits to the large and growing human population[1]. In spite of their intrinsic value, coral reefs around the world have undergone dramatic degradation in the past 20–50 years, because of various anthropogenic factors such as coral mining, destructive fishing practices, coastal development and pollution, along with natural factors such as coral bleaching[2]. Since coral reefs occur near the junction of land, sea and atmosphere, their natural habitats experience the effects of any climatic change in both the marine and terrestrial realms; they are also vulnerable to human activities[3].

Corals are animals which respond to variation in the environmental parameters, especially temperature fluctuations. Coral bleaching is a general response of corals to increased sea surface temperature (SST). Coral bleaching refers to the loss of symbiotic unicellular algae called zooxanthellae by the corals. Since zooxanthellae give their corals their colour, their absence makes the latter look white or bleached. Bleaching can happen when corals experience increased SST of even 1°–2°C. Corals would recover if the normal temperature returns within a short period; but if the temperature stress continues for a long time, they will eventually die[4]. Currently, the longest global coral bleaching driven by climate change is underway in many countries[4]. The current bleaching was first observed in Guam[5] during June 2014 and it spread to many other reef regions[6]. By October 2015, the phenomenon was witnessed in all the three ocean basins – Indian, Pacific and Atlantic[7,8]. Hence, the US National Oceanic and Atmospheric Administration (NOAA) declared it as the third global coral bleaching event in October 2015, but the event continued until June 2017. Global coral bleaching has been declared only twice before, in 1998 and 2010, when significant coral mortality was witnessed globally[7,9].

The Gulf of Mannar (GoM) (Figure 1) is located along the southeast coast of India. It is one of the four major coral reef areas in the country with 117 corals species[10]. The reefs in GoM are formed mainly around the 21 uninhabited islands situated between Rameswaram and Tuticorin, Tamil Nadu (TN) and the area has been declared as the Gulf of Mannar Marine National Park in 1986 by the TN government. For management purposes, the 21 islands have been placed under three groups: Tuticorin group, Keelakarai group and Mandapam group. Each group encompasses seven islands. The islands lie at an average distance of 8–10 km from the mainland. Narrow fringing reefs are mostly located at a distance of 100–350 m from the islands; patchy reefs rise from depths of 2.5–8 m, extend for 1–4 km in length and are up to 50 m wide[10]. The reef areas are comparatively shallow, with the depth ranging between 0.5 and 3 m. A temperature range of around 28°–29°C prevails throughout the year; the corals seem to be acclimatized to such conditions. During summer (April–June), the temperature varies between 31.0°C and 33.5°C (refs 11, 12).

The coast of GoM is densely populated and the traditional fisherfolk numbering over 100,000 mainly depend on the reef-associated fishery resources for their livelihood. Though GoM was once considered a biological paradise, decades of exploitation has caused the destruction of reef areas in an unprecedented manner. Coral mining coupled with destructive fishing practices has caused severe damages. Inshore trawling, shore seine operation and pollution are the major factors. However, following the Indian Ocean tsunami of 2004, coral mining was stopped completely from 2005 due to increased awareness and strict enforcement. Since then, successful coral reproduction and subsequent coral recruitment have

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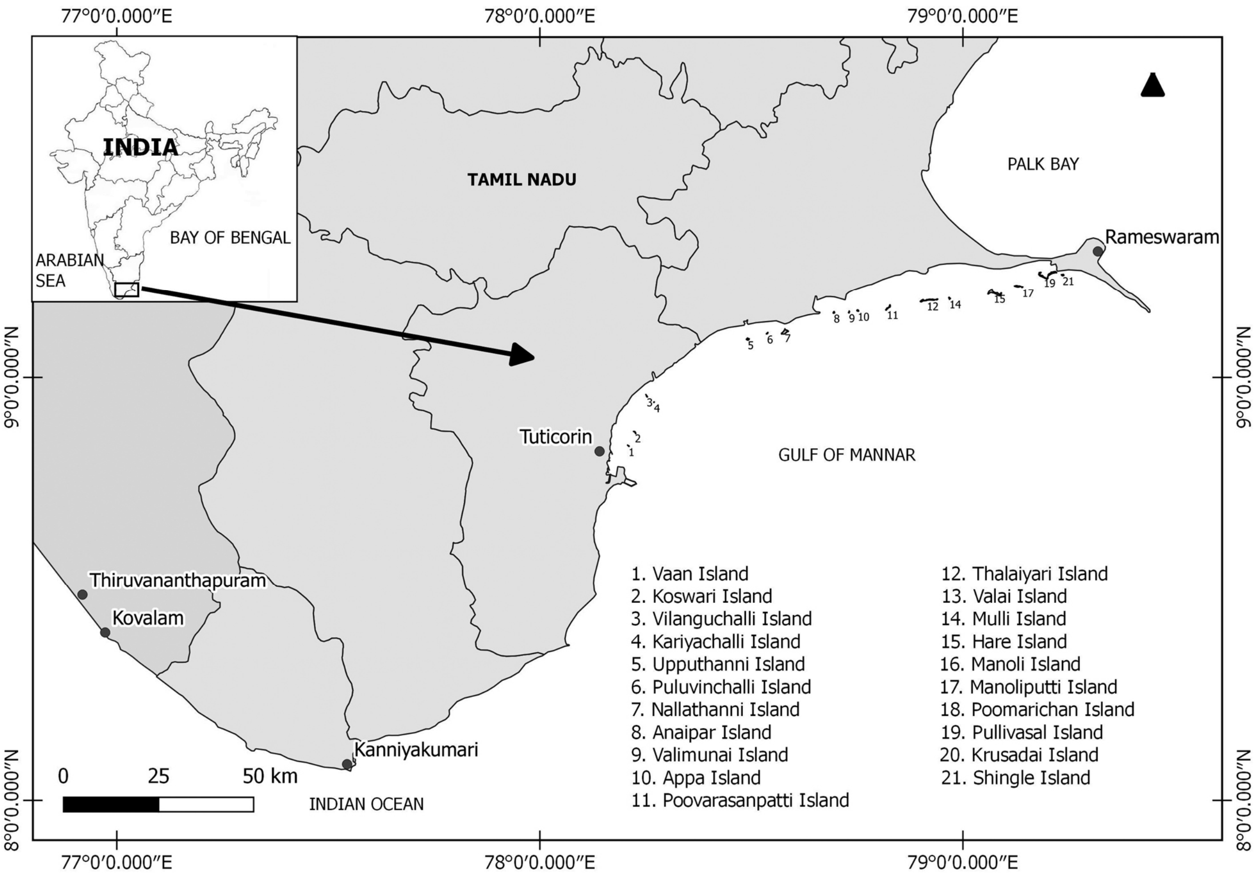


**Figure 1.** Map showing the study area, 21 islands in the Gulf of Mannar, southeastern India.

brought about significant positive changes in the live coral cover[13]. At present, several new threats such as bio-invasion of exotic seaweed, trap fishing and elevated SST are making the recovery difficult. The reef areas of GoM have encountered elevated SST annually, and have suffered the resultant coral bleaching during summer since 2005; significant coral mortality was recorded in 2010, when the second global coral bleaching event occurred[14]. The present work was carried out to study the intensity of coral bleaching and the subsequent mortality in GoM in 2016.

The Reef Research Team (RRT) of Suganthi Devadason Marine Research Institute (SDMRI), Tuticorin has been observing coral bleaching in GoM from late March in 2016. Assessment of the intensity of coral bleaching and extent of the resultant mortality was done in the 21 islands of GoM between March and October 2016, in the wake of the third global coral bleaching event across the world. The assessment protocol involved scuba diving, and the initial assessment was made by underwater visual observations. Coral bleaching can be easily observed visually because of the discolouration of coral colonies. Bleached corals appear white, exposing the calcium carbonate skeleton. Four permanent sites were marked in each island and 20 m belt transects[15] were laid for the assessment. Transects were laid parallel to the islands to assess the specific prevalence of coral bleaching in each site. Three transects were laid in each reef site and a distance of 20 m was allowed between each transect.

Benthic community structure in the reef areas of GoM like live coral cover, coral growth forms and other benthic forms are being regularly assessed by RRT since 2003 with the application of the line intercept transect method[15]. Coral life forms were categorized according to English *et al.*[15] and the percentage cover of each category was calculated. Using SPSS software, the independent *t* test was applied for analysing two variables, namely coral cover of 2015 and 2016.

The quantum of bleaching during April–June 2016 was $23.92 \pm 10.55\%$ (Figure 2). The intensity of bleaching was higher in Mandapam group of islands ($26.5 \pm 8.09\%$). This was followed by Keelakarai group ($23.87 \pm 9.5\%$) and Tuticorin group ($21.38 \pm 14.13\%$). The average live coral cover was $38.86 \pm 10.2\%$ during 2015 in GoM and the live coral cover of Mandapam, Keelakarai and Tuticorin groups was $37.2 \pm 7\%$, $43.39 \pm 7.9\%$ and $36.01 \pm 14.1\%$ respectively. Live coral cover had drastically decreased from $38.86 \pm 10.2\%$ to $22.69 \pm 9.07\%$ during October 2016, with a mortality of $16.17 \pm 8.46\%$. Mandapam group of islands was most affected by the current bleaching

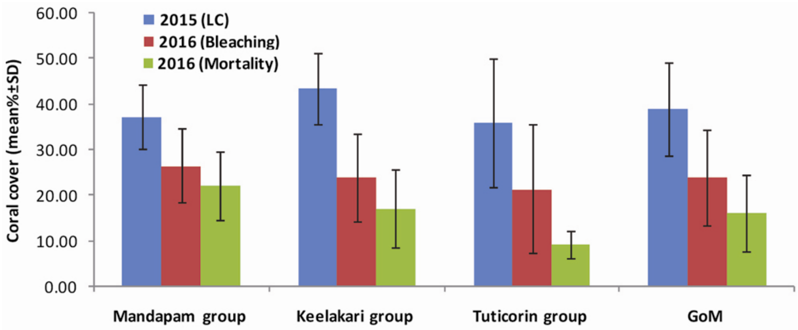


**Figure 2.** Intensity of coral bleaching in GoM during 2016 (LC, live coral).

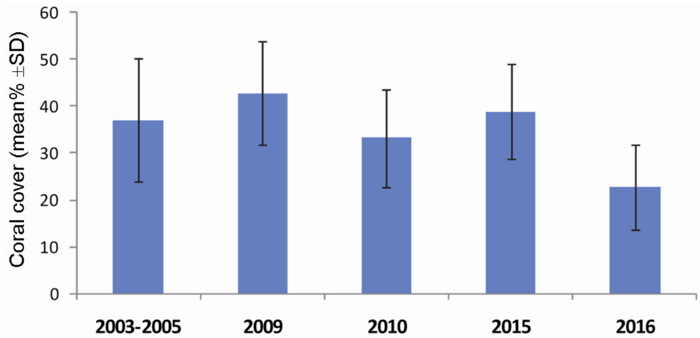


**Figure 3.** Mean live coral cover in GoM during 2003–2016.

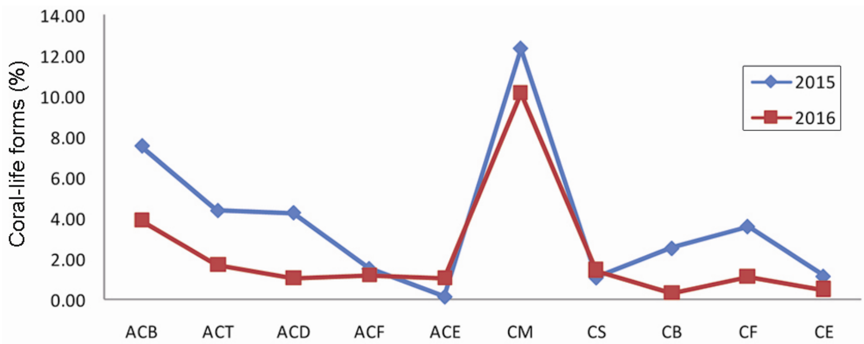


**Figure 4.** Change in coral life-form categories in GoM during 2015 and 2016. ACB, *Acropora* branching; ACT, *Acropora* table; ACD, *Acropora* digitate; ACF, *Acropora* foliose; ACE, *Acropora* encrusting; CM, Coral massive; CS, Coral submassive; CB, Coral branching; CF, Coral foliose; CE, Coral encrusting.

event (mortality 22.17 ± 7.51%) followed by Keelakarai (17.15 ± 8.52%) and Tuticorin (9.19 ± 3.03%).

The results of baseline data collected by RRT during 2003–05 show that the live coral cover in GoM was 36.98 ± 13.12% in that period. It increased to 42.85 ± 11% in 2009 and in 2010 it decreased to 33.2 ± 10.48% because of bleaching mortality (Figure 3). In 2015, corals started recovering and the live cover increased to 38.86 ± 10.20%. The current mortality has reduced the coral cover to 22.69 ± 9.07%. The results of the *t* test showed that the live coral cover during 2015 and that after the bleaching event in 2016 had a significant deviation ($t = 8.764$, DF = 20, $P < 0.05$).

As the mortality due to coral bleaching was severe, the structure of benthic community has changed significantly. Dead coral with algae (DCA) was the dominant category in all the islands, as the dead coral colonies are being immediately occupied by algae. In 2016, the overall DCA cover was 23.93% in GoM whereas it was 23.6%, 26% and 22.19% in Mandapam, Keelakarai and Tuticorin groups respectively. *Acropora* branching (ACB), *Acropora* table (ACT), *Acropora* digitate (ACD), *Acropora* foliose (ACF), *Acropora* encrusting (ACE) and coral branching (CB) are the fast-growing life-forms in GoM, which consist of the genera *Acropora*, *Montipora* and *Pocillopora* (Figures 4 and 5). The percentage cover of these life-forms ranged between 0.35 and 3.91 in GoM, as there was a huge mortality among these growth forms in 2016. Especially the cover of ACB was 7.59% during 2015, and it decreased to 3.91% after the mortality in 2016. *Acropora formosa*, *A. intermdeia*, *A. nobilis*, *A. cytherea*, *Montipora foliosa*, *M. digitata*, *M. divaricata*, *M. hispida* and *Pocillopora damicornis* were the species most affected by bleaching mortality. The cover of *P. damicornis*, the only representative of CB in GoM dwindled significantly from 2.55 ± 1.99% to 0.35 ± 0.38% because of the mortality. Among massive corals (CM), i.e. the boulders, mortality was significantly less. Hence, the cover of CM encompassing all the massive corals has become dominant (10.17%) in GoM. CM consists of the genera *Porites*, *Favia*, *Favites*, *Goniastrea*, *Goniopora*, *Platygyra*, *Symphyllia*, etc.

Water temperature ranged between 31.2°C and 32.6°C during March to June 2016; and it started decreasing in July 2016. It was around 27°C during October 2016. Figures 6–9 show the bleached, dead and recovering corals after the bleaching event in 2016 in GoM.

Coral reefs are vulnerable marine ecosystems; dramatic reversals in their health have been reported from every part of the world[16]. A diverse range of human-induced and natural threats endanger coral reefs. Coral bleaching and the ensuing mortality have been witnessed in almost all the reefs around the world. Hoegh-Guldberg[16] predicted that mass bleaching could become an annual occurrence in Southeast Asia and the Caribbean by 2020, in the Great Barrier Reef by 2030, and in the central Pacific by 2040. According to the prediction, annual coral bleaching during the summer months has been witnessed in GoM since 2005. During late April every year, corals in GoM are exposed to elevated temperature levels of 2°C to 3°C when coral bleaching takes place[11]. Generally, corals which are bleached during this annual phenomenon tend to recover within a period of three months when the normal temperature returns. This annual bleaching event is local; and it varies according to region and country. Annual coral bleaching may or may not cause mortality, which generally depends on the intensity and duration of temperature elevation. Climate change has aggravated the annual bleaching events, and has prompted mortality in many reef regions[16,17]. Certain coral species are resistant, while other species are susceptible to this annual coral bleaching[18].

Global coral bleaching may be defined as the incidence of coral bleaching in all coral reefs throughout the world simultaneously, followed by significant coral mortality. Already two such global bleaching events with dire consequences have been recorded during 1998 and 2010 (ref. 9). This third global bleaching event has been severe and longer than the previous two events. Significant coral

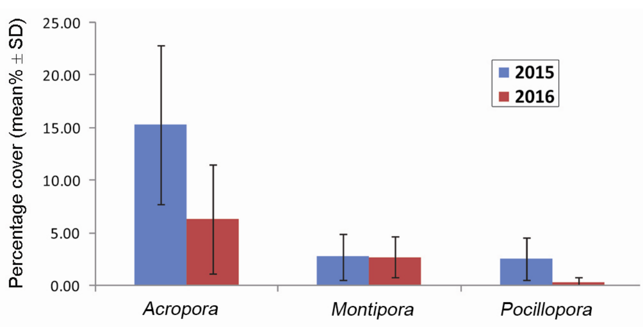


**Figure 5.** Percentage cover of *Acropora*, *Montipora* and *Pocillopora* during 2015 and 2016.

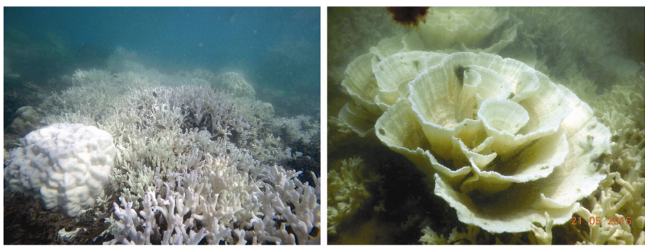

**Figure 6.** Bleached massive and fast-growing corals in GoM in 2016.

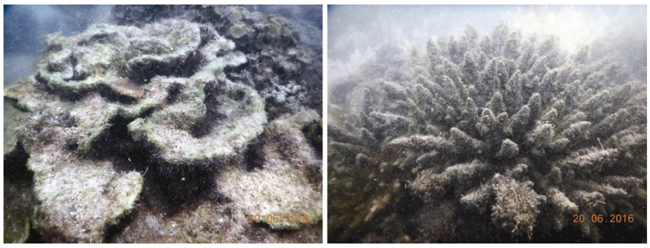

**Figure 7.** Dead, fast-growing corals invaded by turf algae in 2016.

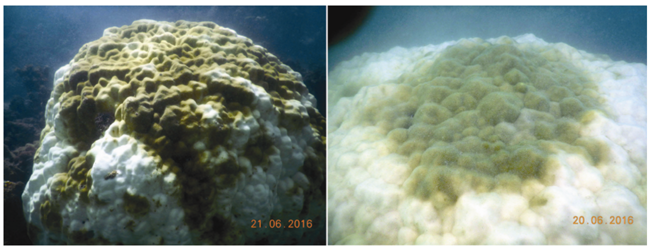

**Figure 8.** Recovering massive corals in the GoM after bleaching in 2016.

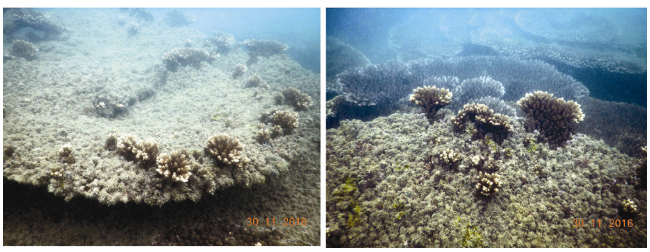

**Figure 9.** Recovering fast-growing corals in the Tuticorin group of islands in GoM.

mortality was witnessed during the second global bleaching event in GoM during 2010, when elevated temperature levels (32.2°C to 33.2°C) persisted for four months (April–July)[14]. The annual bleaching events during the other years between 2005 and 2009 as well as between 2011 and 2015 did not cause coral mortality in GoM. However, during 2016, simultaneous with the third global coral bleaching event, there has been significant coral mortality in GoM, as presented in this study.

Unprecedented increase in global average temperature has been witnessed during the past few decades. The year 2015 became the hottest ever on record, when it broke the previous record held in 2014 (ref. 19). It is estimated that about 36% of the world's coral reefs have been affected by this third major coral bleaching, and that nearly all the reefs around the world have experienced some thermal stress[4]. The current global bleaching started during June 2014 in Guam[5] and spread to Hawaii, Florida, Marshall Islands, Papua New Guinea, Solomon Islands, Fiji, American Samoa, Chagos Archipelago, Maldives, Indonesia, Red Sea, Panama, Kiribati, Cuba, Bahamas, Turks and Caicos, Cayman Islands, Dominican Republic, Haiti, Bonaire, Tanzania, New Caledonia and the Great Barrier Reef[6]. The world's biggest reef, the Great Barrier Reef in Australia, has been affected by a mammoth 93% coral bleaching[4]. It has been reported that 35% of the corals have already died[20]. Corals that are regularly exposed to stressful environmental conditions have, in some cases, been shown to acclimatize and exhibit physiological tolerance to elevated temperatures that exceed normal thresholds[21,22]. Optimum temperature level for reef-building corals has been reported to be between 23°C and 29°C, but thermal thresholds differ from region to region. Thermally induced coral mortality occurs in cooler regions like Rapa Nui at 27°C and in hotter regions like the Persian Gulf at 35°C (ref. 23).

Temperature range in GoM is comparatively higher as it has been reported to be between 26°C and 33.5°C (ref. 11). During annual bleaching periods, temperature level crosses 30°C when corals begin to bleach, and recover within three months (April–June) when the level comes down to less than 30°C. Thus the corals in GoM are exposed to a comparatively higher temperature level and are acclimatized to the same[11]. In the Malvan coast of Maharashtra in the Arabian Sea, temperature threshold of 29.8°C caused coral bleaching and subsequent mortality in December 2015 (ref. 24). In GoM, during this third global coral bleaching event, temperature level reached up to 32.6°C, which is within the limits of the annual bleaching event, but the difference here is the duration of temperature elevation. Current bleaching started in March 2016, which is earlier than normal, and persisted until June 2016. It is evident from the literature that corals can acclimatize to small-scale changes in the environment. However, they are unlikely to cope with increasing temperatures levels[25]. Therefore, more thermal stress and mortality are expected in the future. The recovering ability of the reefs depends on many factors, including the kind of species involved, the environmental cues, predation, disease outbreaks and other stresses.

It is interesting to note that in GoM mortality was severe among the fast-growing species such as *Acropora*, *Montipora* and *Pocillopora*. Massive corals such as *Porites*, *Favia* and *Favites* were found to be resistant to bleaching, and these slow-growing species escaped death. In GoM, coral recovery after the 2010 mortality was noticeable by significant increase in the live coral cover; a predominant additional contribution to this increase was by coral recruits (0–10 cm) and young adult colonies (11–40 cm), as they were relatively unaffected by bleaching[14]. However, in 2016, the recruits of fast-growing species also died in Mandapam and Keelakarai groups making recovery difficult. Due to lesser mortality and the consequent recovery in the Tuticorin group, corals are expected to recover in a couple of years if there is no further mortality due to bleaching and disease outbreaks. Also, corals from Tuticorin group of islands can supply larvae to the other groups, and a complete recovery is possible over the years if conducive environmental conditions prevail. The comparatively severe mortality in Mandapam group of islands could be attributed to the abundance of invasive organisms like coralline algae, turf algae and macroalgae, which invade the partially dead colonies and make recovery difficult.

After the halt of coral mining in 2005, live coral cover has increased considerably in GoM[14]. Successful coral reproduction along with coral recruitment is the key to coral recovery; both reproduction and recruitment have been recorded in GoM[13,26]. The natural recovery process was also supplemented by coral rehabilitation for the increase of live coral cover in GoM. In the Tuticorin group of islands, coral recovery has been observed in several, large, affected colonies, but recovery was comparatively slow in the Mandapam and Keelakarai groups. Coral rehabilitation with artificial structures using resistant native species is a well-proven option to enhance the recovery process in GoM. From earlier experience, the reefs in GoM are expected to show resilience in the coming days, if there is successful spawning and coral recruitment for increase of live coral cover, in which the coral colonies in the Tuticorin group of islands would play a major role. Further, recovering corals are prone to disease outbreaks, and hence continuous and proper monitoring is essential to take remedial actions, whenever necessary. Other threats that mainly cause disturbance to reef areas like fishing practices, exotic seaweed invasion and seaweed collection should be prevented to ensure a favourable environment for recovery.

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