Chapter 25
Studies on the Recovery of Bleached Corals in Andaman: Fishes as Indicators of Reef Health

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Abstract The corals in Andaman and Nicobar Islands suffered extensive bleaching during April 2010 to the extent of 60–70 % due to elevated sea surface temperature (SST) and a significant portion of that is hitherto dead. This study evaluates the degree of recovery of the coral reefs and reef fishes, a year after the event. Line intercept transect (LIT) surveys were conducted in three sites, namely, North Bay, Tarmugli and Chidiyatapu for assessing coral cover together with visual census of reef fishes along the same transects. It was observed that all sites were quite badly affected during the bleaching period with more than 95 % of the corals being fully or partially bleached. Out of the bleached corals, only 54 % recovered at North Bay, whereas Tarmugli and Chidiyatapu exhibited 81 and 86 % recovery, respectively. The collapse of coral reef systems affected the abundance and diversity among fish species. Due to recovery and new recruitment of corals, live coral cover has increased, and consequently,, abundance of fishes seems to have increased. Understanding the associations of fishes and corals could possibly lead to selection of certain species of fishes as indicators of reef health. The results of the study lead to the hypothesis that fishes, especially those belong to the families, Chaetodontidae, Pomacentridae, Acanthuridae and Scaridae can be potential indicators of reef health.

Keywords Andaman · Coral bleaching · Indicator species · Recovery · Reef fishes

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25.1 Introduction

Coral reefs are some of the most diverse and productive ecosystems on earth (Connell 1978; Jackson 1991). They are associated with a variety of micro-organisms, algae, invertebrates and vertebrates. Reef ecosystems are highly diverse and rich but are subjected to disturbances like tropical storms (Done 1992), freshwater plumes (Ostrander et al. 2008), rise in temperature (Brown and Ogden 1993), microbial diseases (Ravindran et al. 1999) and crown-of-thorn starfish blooms (Hughes 1994). Climate-induced coral bleaching represents one of the most significant and increasingly prevalent disturbances to coral reef ecosystems (Pratchett et al. 2008). Changes in the physical and biological structure of benthic reef habitats are likely to have detrimental effects on reef-associated organisms particularly coral reef fishes that depend on corals for food, shelter or recruitment (Wilson et al. 2006; Pratchett et al. 2008). Mass bleaching of corals occurred in April 2010 in Andaman and Nicobar islands due to rise in sea surface temperature (SST) (Krishnan et al. 2011). Following this event, a study was carried out for assessing the recovery of reef areas in three sites, North Bay, Tarmugli and Chidiyatapu. The reef fish estimates were done to verify if they can be used as coral reef health indicators.

25.2 Methods

25.2.1 Study Area

Andaman and Nicobar group of islands are located in the Bay of Bengal (6°45′ to 13°41′ N and 92°12′ to 93°57′ E) in the Indian Ocean. It consist of 572 islands, islets and rocky outcrops with a coastline of around 1,912 km. Most of the islands (about 550) are in the Andaman group of islands of which 28 are inhabited. Three study sites with significant reefs were selected in South Andaman (Fig. 25.1).

25.2.2 North Bay: [11°42′09.11″N; 92°45′12.80″E]

North Bay beach is located 5 km from Phoenix Bay, and represents the closest coral reefs to the capital city of Port Blair. Water enters the Bay area approximately 1 km^2 through the open sea on the south-eastern side. Massive corals (*Porites* sp.) dominate the biota here.

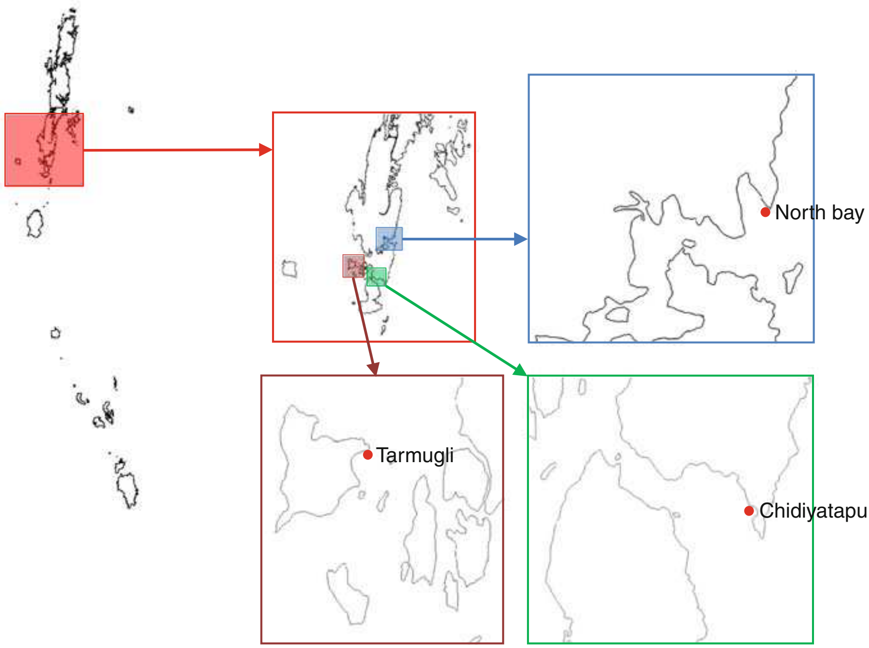

Fig. 25.1 Map showing the study sites, North Bay, Tarmugli and Chidiyatapu in Andaman and Nicobar Islands

25.2.3 Tarmugli Island: [11°34′35.78″N; 92°33′29.21″E]

Tarmugli Island is one of the islands of the Mahatma Gandhi Marine National Park (MGMNP) at Wandoor. It covers an area of 281.5 km^2 consisting of 15 differently sized islands. Tarmugli Island is well -known for its coral diversity and other reef-associated fauna.

25.2.4 Chidiyatapu: [11°29′11.50″N; 92°42′33.46″E]

A popular tourist destination located 25 km from Port Blair, Chidiyatapu is the southern-most tip of South Andaman. It is also known for its diversity of corals and other reef-associated fauna. The reef here is situated 500–600 m from the shore.

The study was conducted during two time periods, during the mass bleaching event [April–June 2010; bleaching period (BP)] and a year after the event [April–June 2011; recovery period (RP)]. Two surveys were carried out in both the periods at each of the sites to estimate the abundance and diversity of corals and reef fishes.

25.2.5 Transect Survey and Analysis

Underwater surveys were carried out using SCUBA equipments at depths ranging from 5 to 18 m. Line intercept transect (LIT) survey (Halford and Thompson 1994) was carried out to determine the abundance of corals and other benthic components present in the reef. Three parallel transects, each 30 m long and separated by a distance of 7–10 m, were laid over the reef parallel to the shore. The different benthic components were classified into live coral, dead coral, sand, rubble, algae and other sessile invertebrate fauna and their extent of occurrence in centimetres along the transect was noted in the underwater notepad and subsequently, expressed as mean percentage of the three transects that were laid. During the BP, two additional components were added to the transect survey, namely, partially bleached and fully bleached corals.

The corals that were fully bleached and partially bleached out of the total coral cover were added up and were considered as the percentage of damage caused by the bleaching event. Out of the bleached corals, the percentage of corals that were restored to good health as well as the increase due to new recruits were considered as the percentage of coral recovery.

25.2.6 Coral Reef Fish Visual Census

The visual census surveys were carried out following English et al. (1997) in order to ascertain the diversity and abundance of reef fishes. The diversity and abundance of fishes occurring within 2.5 m on either side of the transect line were noted. An area of 150 m^2 (30 m $\times$ 5 m) was therefore covered in each transect. Transects were also videographed using an underwater camera (Model—SEA & SEA, DSC) for subsequent analysis and validation.

25.2.7 Determination of Environmental Parameters

Physico-chemical parameters, namely, salinity, air temperature, water temperature, pH, dissolved oxygen (DO) and water transparency were regularly monitored during the surveys. DO content of the water was estimated following Winkler's Method (Drew and Robertson 1974). Salinity was measured using a handheld refractometer; water transparency using a Secchi disc; air and water temperatures using mercury thermometer and pH using a handheld digital pH meter.

Monthly averaged Chlorophyll-a (Chl-a) datasets of NASA (http://oceancolor.gsfc.nasa.gov/) derived from observations of MODIS sensor on board the Aqua satellite, with a spatial resolution of 4 km were downloaded from the NASA Earth Observations (NEO) portal (http://neo.sci.gsfc.nasa.gov/). The

Chl-a datasets in HDF format were taken to ARC GIS platform for display and analysis. The Chl-a values (mg m^{-3}) over 4 × 4 pixels were averaged for the locations closest to the coral reef study sites. Limited observations during the March–June period due to cloudy conditions over the Andaman and Nicobar Islands necessitated the use of monthly averaged Chl-a datasets.

25.2.8 Data Analysis

The live coral abundance and the benthic components from the transect surveys were compared against a series of statistics derived from fish assemblage data viz., species richness, species evenness and Shannon-Wiener diversity index. Species richness was calculated using Margalef's species richness: $d = (S - 1)/\mathrm{Log}(N)$, where $S =$ the number of species present and $N =$ the number of individuals. Species evenness was calculated using Pielou's Evenness Index: $J = H/\mathrm{Log}(S)$, where H is the Shannon-Wiener diversity index. Shannon-Wiener index was calculated using the formula $H = -\sum p_i \log(p_i)$, where p_i is the relative abundance of each species.

Present live coral cover was compared against the abundance of Butterflyfishes (Chaetodontidae), Damselfishes (Pomacentridae), Surgeonfishes (Acanthuridae) and Parrotfishes (Scaridae). Surgeonfishes and Parrotfishes are key grazers on reefs, reducing the abundances of macroalgae affecting the corals (Burkepile and Hay 2008). Many of the Butterfly-fishes are obligate or facultative coral feeders and are dependent on live coral cover. Damsel fishes depend to a great extent on the structural complexities of the reef for protection.

25.3 Results and Discussion

The average air and water temperatures during April–June 2010 were significantly ($P < 0.05$) higher than the temperature noted for the same period in 2011 in all the sites. The mean increase in air and water temperatures was 1.7 ± 0.03 °C and 2.0 ± 0.03 °C, respectively during the BP. There was no significant ($P > 0.01$) difference in the other parameters between the two periods of observation (Table 25.1).

Prolonged increase in SST has been the primary cause of most mass bleaching events around the world (Middlebrook et al. 2008). During the mass bleaching event in 2010, both air and water temperatures were higher in Andaman (Krishnan et al. 2011). The rainfall during April–June 2010 (483.6 mm) was significantly ($P < 0.001$) less compared to mean rainfall through these months for the past 25 years (892.6 ± 0.03 mm) (Fig. 25.2). The reduction in the number of rainy days and significant reduction in the rainfall in 2010 contributed to the increase in SST and the resultant mass bleaching of corals. In the corresponding period in

Table 25.1 Hydrographical parameters of the study area

Parameter	North bay		Tarmugli		Chidiyatapu	
	BP	RP	BP	RP	BP	RP
Salinity (‰)	33.83	33.16	33.83	34.00	33.00	33.50
Air temp (°C)	32.00	30.83	31.50	28.02	31.16	30.66
Water temp (°C)	31.16	29.33	30.66	28.31	31.16	29.33
pH	7.83	7.86	7.90	7.90	7.70	7.76
DO (ml/L)	5.06	4.90	4.63	5.00	4.86	4.73
Transparency (m)	7.00	7.66	9.66	11.33	7.66	8.50

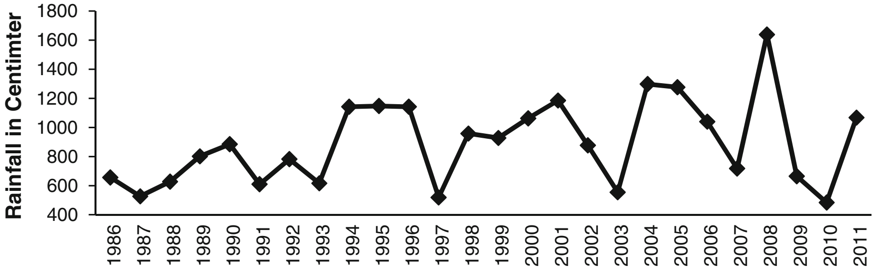

Fig. 25.2 Rainfall during April–June in the last 25 years

2011, there was no significant ($P < 0.05$) increase in temperature from the decadal average while the rainfall increased significantly ($P < 0.01$) which together contributed to the recovery of reefs in Andaman. The present cover of healthy live coral has increased during the RP in all the sites when compared to BP, thus increasing the reef fish abundance and diversity in most of the sites.

The status of different components of the reefs during and after bleaching is summarised in Table 25.2. The live coral cover was maximum at North Bay prior to bleaching and was the worst affected among the three sites probably because of the higher percentage of branching corals (*Acropora* sp.). Chidiyatapu exhibited significantly lesser effect to bleaching owing to the higher percentage of boulder corals (*Porites* sp.). It was also the reef with the lowest amount of live coral cover prior to bleaching. North Bay had 54 % of coral recovery from bleaching which is the lowest, whereas Tarmugli and Chidiyatapu show 81 and 86 %, respectively (Table 25.2).

Phytoplankton biomass (expressed as chlorophyll-a concentration; Chl-a) is considered as one of the indicators of water quality in coral reef systems and the fluctuation in the phytoplankton biomass is usually due to factors like light and temperature regime, natural and anthropogenic nutrient sources, grazing and water residence time (Otero and Carbery 2005).

Chlorophyll-a concentration has been found to range from 0.16 to 0.7 $\mu g\ l^{-1}$ in the Great Barrier Reef (GBR) (Liston et al. 1992; Furnas et al. 1990); from 0.26 to 1.1 $\mu g\ l^{-1}$ in Curacao with the higher values found at the mouth of the local

Table 25.2 Percentage cover of corals: bleaching vis-à-vis recovery period

Components	North bay		Tarmugli		Chidiyatapu	
	BP	RP	BP	RP	BP	RP
Live coral	1.11	40.45	2.55	43.30	1.09	32.73
Fully bleached	30.48		17.80		13.82	
Partially bleached	41.59		32.05		22.91	
Dead coral	13.65	40.00	22.50	40.10	19.82	33.85
Others[a]	13.17	19.55	25.10	16.60	42.36	33.42

[a] Include algae, sand, rubble and other sessile invertebrate fauna

harbour and in sewage-contaminated reef waters (Van-Duyl et al. 2002); from 0.171 to 0.489 in Puerto Rico over the reefs with a higher value of 1.1 found over reefs in the vicinity of Town of La Perguera which was a result of anthropogenic induced eutrophication (Otero and Carbery 2005). An eutrophication threshold of 0.3 μg l^{-1} Chl-a was suggested as indicator of detrimental nitrification effects, that could have led to the death of acroporid species in the GBR (Bell et al. 1993).

Studies of degraded reefs have shown that algal biomass increases as the dead coral substrate and coralline algae are overgrown by fleshy foliose and corticated foliose macrophytes that can take advantage of increased nutrient availability due to anthropogenic nutrient inputs (Szmant 2005).

The changes in the Chl-a values in the selected sites between the two periods are depicted in Table 25.3. The maximum values in each of the sites do not show much difference during the two study periods, though the minimum value 0.06 can be attributed to the effect of averaging of limited observations and rainfall during the period. The chlorophyll values at this study site of Andaman and Nicobar Islands do not indicate a threat of effluent-induced eutrophication and agree well with the values at other healthy and unaffected reef sites (Fig. 25.3). The values observed in March–June 2010 are similar to those recorded for the same period in 2011 indicating no effect of increased water temperatures on chl-a and hence the phytoplankton productivity. Presence of these nominal environmental conditions favours the revival of the normal coral community structure with time (Burt et al. 2008). Increased phytoplankton productivity or nutrient availability would threaten the revival of the coral reefs and their community structure by tilting in favour of macrophytes.

A total of 94 species of fishes were recorded from the three sites during both the periods of study, with North Bay, Tarmugli and Chidyatapu contributing to 60, 55

Table 25.3 Monthly Chlorophyll-a concentrations from March to June of 2010 and 2011

Site	Chlorophyll-a in mg m^{-3}							
	Mar-10	Apr-10	May-10	Jun-10	Mar-11	Apr-11	May-11	Jun-11
North Bay	0.163	0.191	0.167	0.06	0.060	0.220	0.222	0.06
Chidiyatapu	0.174	0.182	0.151	0.316	0.409	0.191	0.152	0.06
Tarmugli	0.201	0.268	0.223	0.178	0.222	0.229	0.125	0.06

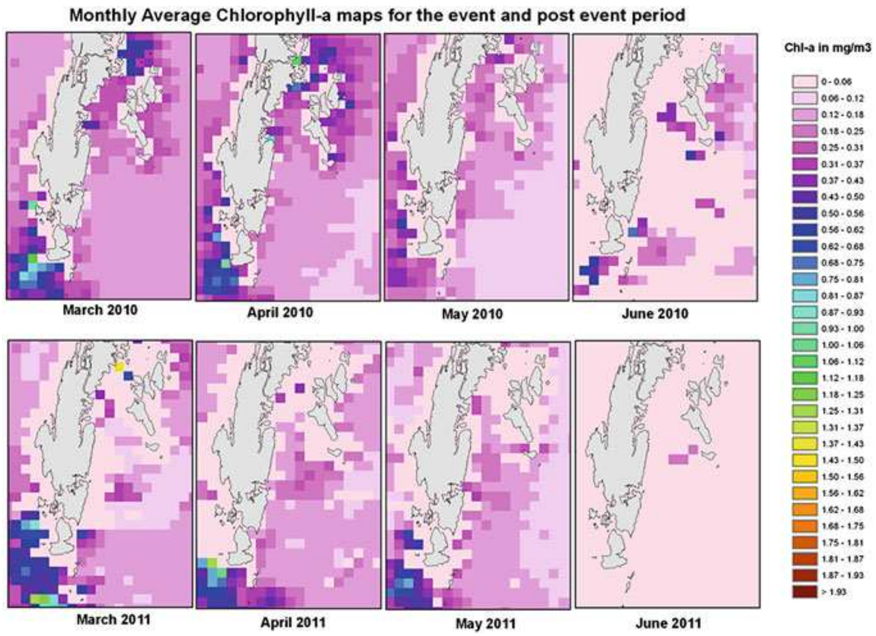

Fig. 25.3 Monthly average Chlorophyll-a concentrations from March to June of 2010 and 2011

and 40 species, respectively (Table 25.4). The diversity as well as the abundance of reef fishes were lesser in North Bay and Tarmugli during bleaching when compared to recovery period. The diversity and abundance were observed to be getting closer to the normal pre-bleaching status. North Bay recorded the highest diversity both in BP (2.48) and RP (2.63) while Chidiyatapu had the least diversity in the corresponding periods [BP: 0.98; RP: 1.45]. Species richness (d) showed similar trend as North Bay had higher indices and Chidiyatapu with the least both during bleaching and a year later (Table 25.4).

A total of nine acanthurids were recorded from the three sites. The abundance of Acanthuridae is 2.4 times (North Bay) and 1.4 times (Tarmugli) from BP to 2011 (Fig. 25.4). In Chidyatapu, there is no significant change in abundance of acanthurids. The abundance of Scaridae was clearly observed to increase in 2011

Table 25.4 Status of reef fishes: bleaching vis-à-vis recovery period

Parameters	North bay		Tarmugli		Chidyatapu	
	BP	RP	BP	RP	BP	RP
No. of species	57	60	50	55	40	39
Total no. of individuals	1547	3510	2305	3407	1678	1719
Diversity index (H)	2.48	2.63	1.22	1.95	0.98	1.45
Species richness (d)	7.63	7.23	6.33	6.64	5.25	5.1
Species eveness	0.61	0.64	0.31	0.48	0.26	0.39

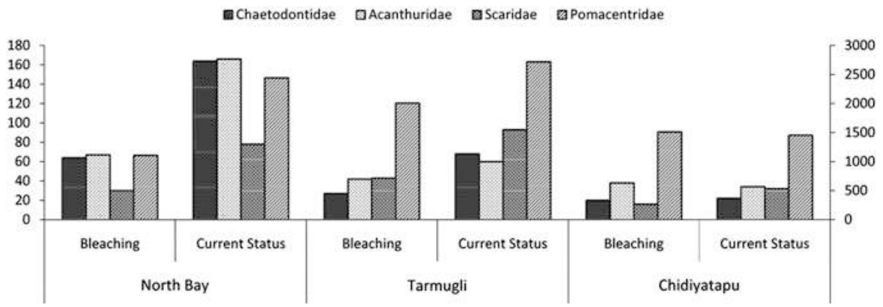

Fig. 25.4 Reef fish abundance through both the periods

in all the sites with the numbers doubling compared to that in the year of bleaching (Fig. 25.4). A total of nine species of Scaridae were recorded from the three sites.

Herbivory is an important structuring factor in coral reefs, influencing seaweed abundance, competitive interactions between seaweeds and corals, and coral reef resilience (Korzen et al. 2011). The main group of Grazers and Scrapers that feed on the algal turf are Acanthuridae, Scaridae and Siganidae (Korzen et al. 2011). Parrotfishes and surgeonfishes usually move in large schools grazing and scraping epilithic algal turf off the substratum facilitating the space for settlement of coralline algae and new corals (Green and Bellwood 2009). Both in North Bay and Tarmugli, there is a considerable increase in the abundance of Acanthuridae and Scaridae. Groups of scarid and Acanthurid juveniles have been observed to be grazing on the algae in mixed schools often joined by siganid juveniles.

A total of 23 species of Pomacentridae were recorded from the threesites. The most dominant family throughout the survey was the Pomacentridae with Chidyatapu, Tarmugli and North Bay accounted for 90.1, 87 and 71.5 % in 2010 and 84.58, 79.8 and 69.6 % in 2011, respectively. *Neopomacentrus azysron* was the dominant species of Pomacentridae, which of the total number of pomacentrids, accounted for 92.5, 92.1 and 67.7 % during 2010 and 85.6, 79 and 63.8 % during 2011 in Chidyatapu, Tarmugli and North Bay, respectively (Fig. 25.4).

Very few fish taxa are obligate corallivores (Hixon 1997), many preferentially settle on live corals (Booth and Beretta 1994; Munday et al. 1997). Degradation of coral reef habitat may therefore affect abundance of coral reef fishes, either by enhancing densities of herbivores, or reducing densities of obligate corallivores, but this is not the case always (Booth and Beretta 2002; Ohman et al. 1998). During bleaching, it was observed that the number of pomacentrids had drastically reduced though they are not exactly obligate corallivores. There was specially a huge reduction in numbers of the pomacentrids in North Bay probably because of the higher percentage of *Acropora* sp., which were affected badly by the bleaching. Acroporidae being mostly branching corals and providing shelter to large varieties of fishes are also the most vulnerable to bleaching effects compared to other coral species (Fisk and Done 1985; Williams and Bunkley-Williams 1990; Glynn et al. 1994; Drollet et al. 1995). In Chidiyatapu, the number of the pomacentrids during the BP is almost the same probably due to the reef not being severely damaged due to dominance of *Porites* spp. The increase in the abundance of pomacentrids in both North Bay and Tarmugli could also be due to the increase in algal cover on dead corals due to bleaching and pomacentrids mostly being algivores.

A total of 11 chaetodontid species were recorded from the three sites. The increase in the number of fishes from 2010 to 2011 is 2.5 times in both Tarmugli and North Bay (Fig. 25.3). In Chidyatapu, there is no significant change in the abundance of chaetodontidae. There is an increase in both obligate as well as facultative corallivores quite evenly.

Chaetodontidae consist of facultative and obligatory corallivores as well as omnivores where the obligatory corallivores are the most adversely affected due to deprivation of their food (Bouchon-Navaro et al. 1985; Williams 1986; Pratchett et al. 2006; Graham 2007). The Chaetodontidae have shown an increase of more than double the amount of fishes that were present in North Bay and Tarmugli, whereas in Chidiyatapu the numbers are almost the same. It is observed that the facultative corallivores and the omnivorous chaetodontids have increased in numbers compared to the BP, but there is not much increase in the number of obligatory corallivores. When compared with the data before bleaching some of the obligatory corallivores are missing after the bleaching event. Increase in the facultative corallivores suggests improving conditions of the reef but increase in abundance of obligatory corallivores would further strengthen this argument.

Coral reefs are under increasing stress in many parts of the world and dramatic declines in coral abundance and changes in coral community structure have been reported from numerous locations (Wilkinson 2000). Coral reef resilience and restoration are important topics that are being debated about around the world. The rapid recovery and increasing dominance of *Acropora* spp. in the aftermath of extensive coral bleaching suggests that climate forcing of coral communities may initially favour coral species with rapid recovery potential, rather than slow-growing corals that might otherwise have greater resistance to bleaching (Hughes et al. 2003; McClanahan et al. 2007). Fortunately, faster-growing corals (especially *Acropora*) contribute mostly to topographical complexity of reef habitats (Sheppard et al. 2002) and are also the major corals used by corallivorous and coral-dwelling fishes (Munday et al. 1997; Pratchett 2005). But the overall successful recovery from algal takeover and other disturbances in coral reefs largely depends on the ability of coral larvae to settle and recruit (West and Salm 2003; Jones et al. 2004; Birrell et al. 2008).

Fishes play a very important role as indicators of reef health and have a positive effect on the recruitment of corals. The increase in the abundance of obligate and facultative corallivorous indicates the adequate recovery of the reefs to house in such populations. Increase in herbivorous fishes should aid in the removal of epilithic algal mats off the reef substrates, which in turn increases the scope of coralline algae and coral settlement. This study shows that the status of reefs in Andaman is improving, since the damage it suffered during mass bleaching, as elucidated by the increase in the reef fish numbers, as well as live coral estimates.

25.4 Conclusion

The impact of coral bleaching on reef fishes is evident from this study. Increase in the live coral cover and associated facultative and omnivorous corallivores indicate a definite improvement in the health of the damaged reef ecosystem. Increase in the population of obligatory corallivores in the future would confirm the recovery of the reef, which is being monitored. The abundance and diversity of reef fishes as evidenced in this study can be an indirect monitoring index of coral reef health in Andaman and Nicobar Islands. Long-term monitoring of reef fishes along with the changing health of corals due to different factors like bleaching, siltation, etc. can help us in understanding the association of corals and reef fishes better.

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