

Community structure and coral status across reef fishing intensity gradients in Palk bay reef, Southeast coast of India

Manikandan B¹, Ravindran J^{2*}, Shrinivaasu S³, Marimuthu N⁴, Paramasivam K³

¹ CSIR-National Institute of Oceanography, Regional centre, Dr. Salim Ali Road, PB. No. 1913, Kochi-682018, Kerala, India

² CSIR-National Institute of Oceanography, Biological Oceanography Division, Dona Paula, Goa – 403 004, India

³ Marine Biology Regional Center, Zoological survey of India, Santhome High Road, Chennai- 600028, India

⁴ Gujarat Ecology Commission, Gandhinagar- 382001, India

***Corresponding Author:** Dr. J. Ravindran, jravi@nio.org, Telephone No: +91-832-2450218, Fax No: +91-832- 2450602

Abstract

Coral reef fishes are exploited without the knowledge of their sustainability and their possible effect in altering the community structure of a coral reef ecosystem. Alteration of the community structure could cause a decline in the health of coral reefs and its services. We documented the coral community structure, status of live corals and reef fish assemblages in Palk Bay at the reef fishing hotspots and its nearby reef area with minimum fishing pressure and compared it with a control reef area where reef fishing was banned for more than two decades. The comparison was based on the percent cover of different forms of live corals, their diversity and the density and diversity of reef fishes. The reef fish stock in the reef fishing hotspots and its neighbouring reef was lower by 61% and 38% respectively compared to the control reef. The herbivore fish *Scarus ghobban* and *Siganus javus* were exploited at a rate of 250kg and 105kg month⁻¹fishermen⁻¹ respectively, relatively high comparing the small reef area. Live and dead corals colonized by turf algae were predominant in both the reef fishing hotspots and its nearby coral ecosystems. The percent cover of healthy live corals and live corals colonized by turf algae was <10% and >80% respectively in the intensively fished coral ecosystems. The corals were less diverse and the massive *Porites* and *Favia* colonies were abundant in the intensive reef fishing sites. Results of this study suggest the impact of reef fish exploitation were not solely restricted to the intensively fished reefs, but also to the nearby reefs which play a critical role in the resilience of degraded reef ecosystems.

Keywords: Palk bay, Coral, Community structure, Reef fish, Exploitation

1. Introduction

Coral reef ecosystems host numerous resources that benefit over billion people worldwide (Moberg and Folke 1999; Done et al. 1996; Peterson and Lubchenco 1997). In spite of their importance, coral reefs are under degradation globally at a faster rate due to the impacts of the processes generated by climate change and human activities (Wilkinson and Salvat 2012; Wilkinson 2008; Burke et al. 2011). Global factors like climate change and ocean acidification has gained maximum attention among researchers that made them evolve specific management practices for its conservation (Strong et al. 2012; Rau et al. 2012). Marine Protected Areas (MPAs) exist all around the globe and they offer different level of protection to the reefs (McClanahan et al. 2006). However, majority of the MPAs lack effective enforcement of laws leading to reef damage and over exploitation (Mora et al. 2006). Climate change and Ocean acidification are chronic processes that exert their effects at a slower pace than the anthropogenic threats that evoke a quick response in coral reefs. Recent studies shed light on the adaptive nature of corals to the impacts of climate change, specifically to temperature through shuffling of symbiotic zooxanthellae (Buddemier and Fautin 1993; Buddemeir et al. 2004; Kinzie et al. 2001; Berkelmans et al. 2006; Hughes et al. 2003). In contrast, the corals are non-adaptive and highly sensitive to any imbalance in the ecosystem due to over exploitation, pollution and other anthropogenic manipulations which lead to their death and permanent loss.

Coral reef fishes serve as a major source of protein for at least 85% of the people living in the coastal areas (UNEP 2004). More than 80% of the worlds shallow reefs were severely exploited (Wilkinson 2002) to meet the growing demand for reef fish. Herbivory is an important reef process that maintains equilibrium between the corals and macro algae (Mumby 2006). Herbivore reef fish exploitation strengthens the algal competition with corals leading to their mortality, which subsequently turns a coral dominant reef into an algal reef (Hughes et al. 2007; Diaz-Pullido et al. 2009). Other factors like mechanical destruction and outbreak of coral eaters that facilitate the substrate availability for macroalgal attachment and nutrient enrichment will enhance the algal population in the coral ecosystems (McManus and Polsenberg 2004). Algal domination in a coral ecosystem has severe ecological implications including coral bleaching (Hughes 1989), reduced coral growth (Lirman 2001), and coral mortality (Smith et al. 2006). The algae, based on their functional properties differ on their effect on corals (Jompa and Mc Cook 2003). Recent studies showed that the algae secreted toxic chemicals that killed the live coral tissue (Rasher et al. 2011). The corals are capable of recovering to

their normal state after a major stress event and it has been the key for reef resilience. Macro algae and algal turfs in combination with sediment affect the coral resilience by preventing the settlement of new coral recruits (Birrell et al. 2005) and the recovery of corals after a stress event.

Palk bay reef in southeast coast of India was a potential fishing ground for small-scale fishermen throughout the year except during the period of northeast monsoon that falls between October and December every year. The peak fishing season in Palk bay is between January and September and the fishing effort ranges between 30 days boat⁻¹ month⁻¹ in the intensive reef fishing sites and 15±4 days boat⁻¹ month⁻¹ in lightly fished reef sites. The percent cover of different benthic forms, their diversity and the abundance of healthy live corals, live corals smothered by turf algae and macro algae were observed across the reef fishing sites of Palkbay with varying fishing intensity and it was compared with the control reef where reef fishing was banned for more than two decades. In addition, the standing stock of reef fish, quantity of reef fish exploited (defined by wet weight) and their diversity were recorded from the study sites. The consequences of removing the reef fish from the coral ecosystem were widely understood. Impact of reef fish exploitation in their hotspots and on the coral ecosystems in their neighbourhood with minimal fishing effort was evaluated.

2. Materials and Methods

2.1 Study site

Palk bay was a part of Gulf of Mannar Marine Biosphere Reserve (GOMBR) and it comprises a narrow reef that runs parallel to the land between longitudes 79° 17' 40" E and 79° 8' E and at latitude of 9° 17' N in east-west direction (Fig. 1). The width of the reef varies between 200m - 600m away from the shore at different places. The reef occurs at a depth of 1m to 4m. A narrow channel, almost at the mid-length of the reef that permits the entry of the fishing boats into the lagoon, separates the reef into an eastern and a western sector. The western sector of the Palk bay reef further divided as Vedhalai reef and Mandapam reef based on the near shore area. Similarly the eastern sector of the Palk Bay reef divided into Pamban reef and Rameswaram reef. In a snorkelling and SCUBA diving survey, two sites were observed each in Vedhalai reef (VDRF1 and VDRF2) and Mandapam reef (MDRF1 and MDRF2) where the reef fishing effort was higher. Another two sites were observed, in the Pamban reef (PBRF1 and PBRF 2) where the reef fishing effort was minimal. The reef fishing effort in the Vedhalai, Mandapam and Pamban reefs were summarized in Table 1. A reef (MRC) near Manoli Island in the Gulf of Mannar was observed as a control site where reef fishing was banned for the more than two

decades. The Gulf of Mannar reef encompasses 21 islands fringed with coral reefs and it was the first Marine National Park in Southeast Asia..

2.2 Coral Community assessment

The community structure of the corals was analyzed following the photo quadrat method described by English et al. (1997) with slight modifications. A square shaped area of 100m² consisting of 100 grids of 1m² each was demarcated using a 5mm thick polypropylene rope in each of the observation site. Each of the 1m² quadrat was photographed using Olympus μ tough 8000 camera in underwater macro mode. The quadrat images were processed manually by classifying different benthic forms including the abiotic forms like sand and measuring their area coverage using a graph paper with the factor of simple proportion. The corals were identified using the keys described by Veron (2000).

Status of the live coral colonies in the observation sites was estimated following the belt transect method. A 50m transect line was laid parallel to the shore and the observations were made following the belt transect survey, with a swath of 2.5m on either side of the transect making the effective observed width as 5m. The coral colonies, either live or partially live that falls within the transect were taken into consideration and categorized using a three point scale namely Healthy live coral (LC/H), Live coral colonized by turf algae (LC/TA) and Live coral colonized by macro algae (LC/MA).

2.3 Reef fish survey

The diversity and the quantity of commercially exploited reef fishes in the Palk bay reef was surveyed through questionnaire with fishermen, under water observations in the fish traps and at the fish landings in Palk bay on daily basis during the active fishing season (January–September) in 2012. The reef fishes caught were identified following the standard identification keys (Allen et al. 2003; Rao 2004). The standing stock of the reef fishes was estimated following the reef fish visual census method described by English et al. (1997). The visual census has been made on a 50m transect line with a width of 2m on either side covering an area of 200m².

2.4. Statistical analysis

The coral community data were compiled to form a matrix showcasing the percent cover of different life-forms in the observed sites. The data was subjected to the multivariate analyses to understand the present status of coral community structure. Principal component analyses (PCA) was done for different life-form categories observed in order to determine the most important benthic form

contributing to the changes in the community structure and to understand the contribution of each benthic form to the changes observed in the study sites. Bray-Curtis cluster analysis under the paired linkage was made to test the similarity between the intensive reef fishing sites, minimal reef fishing sites and control site. Principal Coordinate Analysis (PCoA) was done for segregating the study sites based on their similarity in community structure. The relationship between the herbivore fish density and abundance of the healthy live corals was delineated using correlation analysis. All the statistical analysis was performed using the software PAST, version 2.15.

3. Results

3.1 Coral community structure

The corals in the intensively fished Vedhalai and Mandapam reefs of Palk bay were severely degraded owing to the mechanical damage, algal turf and macro algal colonization. Community structure analysis revealed majority of the corals were dead and the existing live corals exhibit partial mortality due to the colonization of algal turf and macro algae. The proportion of different community forms in the study sites were presented in Fig. 2. There were no significant differences in the live coral cover among the four study sites in Vedhalai and Mandapam reef (ANOVA, $df = 3$, $F = 0.38$, $p \text{ value} > 0.05$). Dead corals colonized by turf algae (DC/TA) predominates VDRF 2 and MDRF 1 accounting for 56.2% and 33.1% respectively. Whereas, VDRF 1 and MDRF 2 was dominated by LC/TA which contributes 26.7% and 30.4% respectively. The rubbles cover was noteworthy in the intensive reef fishing sites compared to the control site MRC, as they provide direct evidence for the mechanical damage that arose due to the drifting activities of the fishermen in the reef fishing sites. The percent cover of LC/H was less than 3% in the intensive reef fishing sites except VDRF 1 (7.8 %). Algal competition by macro and turf algal assemblages on live corals were noticed more in intensively fished Mandapam reef sites than the other sites. More than 8% of live corals were colonized by the macro algal species like *Caluerpa racemosa*, *Padina* sp and *Sargassum* sp in the intensive reef fishing sites. Diversity of the live corals were restricted to massive colonies of *Porites*, *Favites* and *Favia* sp, whereas other forms of corals were dead due to turf algal colonization. Six species of corals belonging to four genera were recorded in the intensively fished Vedhalai and Mandapam reefs.

The impacts of intensive reef fishing in Vedhalai and Mandapam reefs spreads out to the Pamban reef (PBRF 1 and PBRF 2) despite the minimal fishing pressure. Live corals of 12.8% and 18.4% exhibit partial mortality due to turf and macro algal colonization in PBRF 1 and PBRF 2 respectively. Similar to

the intensive reef fishing sites, DC/TA was dominant in both PBRF 1 (39.3%) and PBRF 2 (29.6%) reducing the availability of bare substrate for coral recruitment. The impacts of reef fishing were low in PBRF 2 compared to PBRF 1. It can be attributed to the level of proximity of these sites from the intensive fishing sites. The live coral cover was high in PBRF 2 (17.9%) compared to PBRF 1 (7.1%). The taxonomic composition of corals was higher in the Pamban reef compared to the Vedhalai and Mandapam reefs. Ten species of corals of six genera were recorded in PBRF 1 and PBRF 2. Massive *Porites* sp was abundant followed by *Favia* and *Favites* sp in these sites. The Principal component analysis (PCA) revealed that the MRC and PBRF 2 contributed more live corals, according to the observation made in this study (Fig. 3). The percent cover of LC/H was high in MRC accounts for 24%. However, LC/TA and LC/MA together contributes 12% and DC/TA contributes 17.3% to the total community composition. Ten species of corals from seven genera has been recorded in MRC, comparatively higher than the sites influenced by reef fishing.. The diversity of corals present in the study sites were summarized in the Table 2.

As per the results of Bray-Curtis cluster analysis under paired linkage the study sites were grouped into three major groups with more than 60% similarity, based on the benthic categories observed in this study (Fig. 4). The Mandapam reef site (MDRF-1) was merged with Vedhalai reef sites (VDRF-1 and VDRF-2) due to similar composition of benthic life-form categories. Similarly, the Mandapam reef site (MDRF-2) was merged with Pamban reef site (PBRF-1). Due to similar composition of LC/H and LC/MA, PBRF 2 and MRC were merged in one single group. Hence, these two sites were separated from other sites in the Principal Coordinate analysis (PCoA) (Fig. 5). It also showed a clear difference between intensive fishing reef and Non-fishing reef sites.

3.2 Status of Live corals

The percent cover of different forms of live corals describing its state in the intensive and minimal reef fishing sites and control site was presented in the Fig. 6. There was a greater variation in the percent composition of LC/H compared to LC/TA and LC/MA across the study sites which are free and influenced by reef fishing pressure. The percent cover of LC/TA ranges between a maximum of 96% to a minimum of 84% and LC/H accounts for <10% in the intensively fished Vedhalai and Mandapam reefs. *Porites* sp was largely affected by turf algae compared to the other coral species. The percent cover of LC/H to that of LC/TA in two sites of Pamban reef varied with their proximity to the intensively fished Vedhalai and Mandapam reef. PBRF 1 lies in close proximity to the intensive reef

fishing sites and hosts 63% and 36% of LC/TA and LC/H respectively. Whereas PBRF 2 lies far from the Vedhalai and Mandapam reef and encompass 31% and 49% of LC/TA and LC/H respectively. The control site hosts high LC/H (77%) compared to those sites influenced by reef fishing. However the percent composition of LC/MA was high in MRC (21%) and PBRF 2 (20%) compared to the intensively fished Vedhalai and Mandapam reef.

3.3 Reef fish assessment

The density of the reef fishes ranged from 15-33 fish/200m² in the intensively fished Vedhalai and Mandapam reef. Whereas it ranges between 25-39 fish/200m² in the slightly fished Pamban reef (Fig. 7). The density of reef fish was higher in the MRC compared to the intensive and slightly fished reefs by 61% and 38% respectively. Carnivore fishes were abundant in the MRC and Pamban reefs than the herbivore fishes. Though herbivore fishes were abundant than other reef fishes in the Vedhalai and Mandapam reefs, their density was low compared to the MRC and Pamban reefs. Based on the coefficient of determination value ($r^2=0.840$), it was evident that almost 84% of the variance in the dependent variable (i.e. Herbivore fish count) is explained by the derived regression equation, and mere 16% is unexplained (Fig. 8). A significant positive correlation exists between the herbivore fish density and the percent cover of healthy live corals. A total of 49 species of reef fishes belonging to 36 genera were recorded in the MRC. On the other hand, a total of 13 species of 10 genera and 18 species of 15 genera were recorded in VDRF 1 and VDRF 2 respectively. Similarly, MDRF 1 and MDRF 2 host 18 species of 13 genera and 16 species of 12 genera respectively. PBRF 1 which lies at close proximity to intensive fishing sites hosts 19 species belonging to 11 genera. Whereas, PBRF 2 far from the intensive fishing sites hosts 22 species belonging to 11 genera (Table 3).

Commercially exploited reef fishes in Palk bay and their catch rate were presented in the Table 4. The commercially exploited reef fishes include scrapers, grazers and carnivores which are functionally important in a reef ecosystem. An average of 414 kg of herbivore fish and 135 kg of carnivore fish were exploited per month by a single fisherman. The herbivore fishes including *Scarus ghobban*, *Scarus gibbus*, *Siganus javus* and *Siganus canaliculatus* and the carnivore fish including *Epinephalus* sp, *Lutjanus* sp and *Lethrinus* sp are targeted foremost by fishermen and exploited in large quantity.

4. Discussion

It is obvious from the results that turf algal and macroalgal colonization that arises out of the existing fishing practices was the major factor driving the degradation of corals in the reef fishing sites of Palk bay. The competition between the corals and algal communities was seen as a vital process in structuring the reef community (McCook et al. 2001). However, the dominance of one form over the other due to external stress results in severe catastrophes that will be felt in the entire ecosystem. Current fishing practices such as deployment of trap nets and cages around the healthy coral colonies results in mechanical damage of corals. All these practices created the dead patches on the surface of the healthy coral colonies which facilitated the settlement of borers and algal spores and their subsequent colonization over corals (Fig. 9). These actions coupled with removal of herbivore reef fishes exacerbated the development of algae over the corals. It was noticed that >90% of the live corals existing in the intensive reef fishing sites were mechanically damaged, either partly or wholly, and colonized by the algal turf and macro algae. The impacts of reef fish exploitation were not solely restricted to the intensive fishing sites, but also to its neighbouring coral ecosystems despite the minimal fishing pressure. Of the 100m² area analyzed in the Pamban reef (PBRF 1 and PBRF 2), >40m² of area spanning live corals and dead corals were colonized by algal turfs. Added to this, the abundance of herbivore and other reef fishes were comparatively low in the Pamban reef.

The impact of algal communities over corals has been widely described (Tanner 1995; McCook et al. 2001; Kuffner et al. 2006). The reefs with high terrestrial inputs are often dominated by algal turfs. Birrell et al. (2005) proved that algal turfs in combination with sediments prevent the settlement of coral recruits. In addition, the filamentous turf algae upon interaction with corals results in a chronic stress, overgrowth and mortality (Cetz-Navvaro et al. 2013). The macro algae can negatively influence the corals by smothering, shading, overgrowth, enhancing the coral microbial activity (Smith et al. 2006), being a vector harbouring potential pathogens and affecting the regeneration of tissues (Bender et al. 2012). The calcium carbonate deposition during an incidence of high algal biomass is solely attributable to the algal deposition and the so formed reef structure is inappropriate for fish habitat and shore line protection (McClanahan 1995). Nutrient enrichment due to pollution and reduction in herbivory fish has been considered as prime factors triggering the algal dominance in reefs. Experimental evidence indicate that exploitation of large herbivory fish have profound impacts in a coral ecosystem than nutrient

enrichment (Miller et al. 1999). The exploitation of reef herbivory fish may exacerbate the effects of turf algal assemblage over the corals by affecting their recruitment and resilience potential.

The western sector of the Palk bay that includes Vedhalai and Mandapam reefs spans a reef area of 4.85 km². Observations revealed that the diversity and density of the herbivore reef fishes within this area was low than the reef fishes of other functional groups. The herbivore reef fishes are classified as scrapers, grazers and browsers (Bellwood 1994). Scrapers remove algae, sediment and other material by taking non-excavating bites and create a substrate for the settlement of new recruits. Similarly, the grazers feed on the epilithic turf algae which in turn limit the growth of macro algae (Bellwood and Choat 1990). High diversity of the herbivore fishes in a coral reef ecosystem provides numerous benefits that help in maintaining the community and functional structure of the reef (Burkepile and Hay 2008). Fishermen in Palk bay with traditional fishing gears such as dingy or canoes solely depend on reef fishing for their income and livelihood and the ever-growing demand increased the exploitation of the reef fishes. The ratio of exploitation of functionally important herbivore fish was high compared to the carnivore fish owing to their commercial value. With a little diversity of the large herbivore fishes in Palk bay, the *Scarus* and *Siganus* species plays an important role in regulating the algal population. However these fishes are the primary targets of fishermen and were exploited in larger quantities compared to other carnivore fishes.

While exploitation of functionally important herbivore fishes can have direct impact on corals, exploitation of non functional groups and predatory fishes may exert unpredicted catastrophes affecting the ecosystem function (Dulvy et al. 2004). Most fishing techniques and fishermen target the larger individuals in populations to yield maximum biomass and this reduces the proportion of large and matured individuals in a population. Reef fish exploitation has severe ecological implications affecting the inorganic carbon cycle in reef ecosystems (Jennings and Wilson 2009), collapse the food web (Wilson et al. 2008) and outbreak of non reef building taxa such as sea urchin (McClanahan and Shafir 1990) and crown of thorns star fish (Dulvy et al. 2004). The consequences of reef fishing were restricted to the loss of corals and no such outbreaks of non reef building taxa were observed in Palk bay reef.

Minimum fishing pressure has no role in maintaining the community structure of the reef, as both the LC/H cover and reef fish stock were low in the lightly fished Pamban reef. Reef fishes migrate between ecosystems and habitats, often between their feeding and resting grounds which are parted by long distances (Ogden and Quinn 1984). Such migrating fishes from neighbouring ecosystems visiting

an intensively fished reef for food could be trapped and exploited by the existing fishing practices. It eventually leads to the depletion of fish stock in the neighbouring coral ecosystems and further degradation of corals. It is important to protect the neighbouring coral ecosystems through effective management in order to enhance the resilience potential of the disturbed reef ecosystems (Olds et al. 2012). Though excessive sedimentation affects the corals of Palk bay other than the fishing practices (Wilson et al. 2005; Ravindran et al. 2012), there are no reports on the impact of excessive sedimentation over the distribution and abundance of reef fish communities except that it triggers behavioral changes in reef fish (Wenger and McCormick 2013; Wenger et al. 2013). Any decline in reef fish communities is often related to the deterioration of live corals due to excessive sedimentation (Rogers 1990)

The herbivore fishes are highly susceptible to the gears used in artisanal fishing practice (McClanahan and Cinner 2008). The reef fishing practices that exist in Palk bay include deploying underwater cages, shore seine, trap nets, bait fishing and throw nets. Reef fishing using these artisanal fishing gears is largely seen as a harmless and effective method while their indirect effects have been ignored. Of these practices, trap net fishing and cage fishing methods are followed by majority of the fishermen in Palk bay which incur mechanical damage to the corals. In addition, the other activities associated with reef fishing such as drifting of boat over the reef to locate the cages, anchoring of boats over corals and beating up of corals using large wooden logs to disturb the fishes that hides under the holes and crevices thereby luring them into the traps adds up to the mechanical destruction of corals affecting their structural complexity. Structural complexity of a reef is critical to the biomass and species richness of the reef fish (Wilson et al. 2012). Mechanical damage to the corals during the reef fishing activities could reduce the structural heterogeneity of the reef thereby decreasing the shelter available for non-targeted herbivory fishes making them vulnerable to predation (Dayton et al. 1995).

Connectivity between the coral ecosystems plays a critical role in the resilience of degraded reef ecosystems by means of larvae and nutrients supply (Mumby and Hastings 2008). Connectivity between the coral ecosystems was affected by the reduction in the density of reef fishes. The mobile organisms like fishes play an important role in connecting the ecosystems (Nystorm and Folke 2001; Lundberg and Moberg 2003) by transferring the essential and limiting nutrients and minerals from the adjacent ecosystems to the other coral ecosystems under stress (Geesey et al. 1984; Meyer and Schultz 1985) thereby enhancing the resilience potential of the reef. In addition, they also prevent the phase shifts in the disturbed coral ecosystems through grazing (Hughes 1994). Apart from the neighbouring

coral ecosystems, the mangroves and sea grass also plays a vital role in maintaining the reef resilience as these ecosystems were used as nursery habitats by the herbivory fishes. However these ecosystems are also threatened to a greater extent due to reef fish exploitation (Waycott et al. 2009; Alongi 2008).

Palk bay, being an area of biological significance and species richness was less conserved compared to the adjacent Gulf of Mannar Marine National Park (GOMNP). Establishment of a Marine Protected Area (MPAs) similar to GOMNP ensures the conservation of Palk bay. However, the profound impacts of human activities inside an ecosystem have diluted the conservation efforts of the MPAs. Fishing activities inside a protected area is regulated by imposing strict fish catch regulations and encouraging the use of traditional fishing gears. However, there are no standards describing the threshold limit of fishing intensity that may disrupt the reef resilience (Mumby et al. 2007). Knowledge on the abundance of herbivory fish populations in an ecosystem of concern and a long term data on the amount of reef fish being exploited is important, as it can help the managers to avoid ecosystem catastrophes (Lokrantz et al. 2009; Nystrom et al. 2008) by devising a resilience based management strategy (Graham et al. 2011) . At present there is no resilience based management system limiting the exploitation of reef fish in Palk bay. It is important to devise a local management strategy that focuses on the fisheries management, limitations of terrestrial input and offering protection to the core and adjacent ecosystems (Adam et al. 2011) in order to maintain their connectivity and achieve the coral reef resilience in the face of global climate change.

5. Conclusion

In conclusion, removal of the herbivore reef fish exert severe impact over reef building corals leading to their mortality mainly due to lack of control over macro algal and turf algal propagation over live corals. Moreover, continuous exploitation of the reef fish in the adjacent reefs also rules out the replenishment of the reef fish stock in the study area. Reef fish being a connector between communities makes their absence, a delink of trophic dynamics in the reef environment and makes the communities especially the coral vulnerable for various stressors. Since the resilience potential of an affected reef largely depends on the supply of new recruits of the depleted communities from the neighbouring reefs, it becomes important to maintain a no fishing zones of reef fish in the neighbourhood of reef fishing hotspots. In addition, long term data on diversity, quantity, age, size structure and sex of the reef fishes exploited and the associated changes with the coral community is essential to develop standards that aids in evolving an effective management practice. In order to minimize the damages caused by current

fishing practices, refined methods involving fish luring devices (FLDs) or fish aggregating devices (FADs) has to be used. In a long term, as the demand for reef fish increases, the exploitation also will increase. So, it is essential to promote alternative livelihood for the fishermen in Palk Bay in the cultivation of seaweeds of nutraceutical and pharmaceutical interests. This not only conserves the natural resources but also minimizes or prevents the damages to the reef.

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7. References

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8. Figure Captions

Fig. 1 Map showing the study locations in the Palk Bay and Gulf of Mannar Reef, Southeast coast of India. . (VDRF1- Vedhalai Reef 1; VDRF2- Vedhalai Reef 2; MDRF1- Mandapam reef 1; MDRF2- Mandapam reef 2; PBRF1 – Pamban Reef 1; PBRF2- Pamban reef 2; MRC- Manoli Reef Complex)

Fig. 2 Area cover of different reef community forms along the intensive reef fishing (VDRF1, VDRF2, MDRF1 and MDRF2) and mild reef fishing sites (PBRF1 and PBRF2) of Palk Bay and Control site (MRC). CCA- Crustose coralline algae; R/MA- Macroalgae attached to Rubbles; DC/MA- Dead coral colonized by macro algae; LC/MA- Live coral colonized by macro algae; DC/TA- Dead coral colonized by turf algal assemblage; LC/H- Healthy Live coral; LC/TA- Live coral colonized by turf algal assemblage).

Fig. 3 Principal component analysis (PCA) of reef communities at study sites

Fig. 4 Bray-curtis cluster analysis of studies sites under paired linkage. The study sites grouped together were highly similar in their community structure.

Fig. 5 Principal co-ordinate analysis of the study sites based on the similarity in community composition. The control site and PBRF 2 was segregated from other study sites due to their similarity in community composition.

Fig. 6 Percent cover of live corals of different states in the study sites. (LC/H- Healthy Live coral; LC/TA- Live coral colonized by turf algae, LC/MA- Live coral colonized by macro algae).

Fig. 7 Density of reef fishes in the study sites. The density of reef fishes in the control site (MRC) was several times higher than the reef fishing hotspots.

Fig. 8 Regression analysis of herbivore fish count with percent cover of healthy live corals in the study sites.

Fig. 9 Turf algal colonization over corals. (a) Dead patch on the coral *Favia pallida* formed due to the drifting activity of the boat; (b) turf algal colonization over the dead patch of the coral; (c) turf algae spreads to the healthy portion of coral thereby affecting the entire colony.

Table 1. Fishing effort in the intensive (Vedhalai and Mandapam reef) and lightly fished reef areas (Pamban reef) in Palk Bay

S. No	Details	Vedhalai and Mandapam reef	Pamban reef
1	Duration of Fishing	January-September	January- September
2	No. of Fishing days month ⁻¹	30±1	22±4
3	Fishing methods	Cages, Shore seine, hooks, Trap nets	Shore seine, Hooks, hand picking
4	Hours of Operation	5±2 hours	3±1 hours
5	No. of Boats	20±5	15±5
6	No. of Fishermen's	45±10	30±10

Table 2. Diversity of corals recorded in the study sites. ('+ 'indicates presence; '- 'indicates absence)

Coral sp	MRC	VDRF 1	VDRF 2	MDRF 1	MDRF 2	PBRF 1	PBRF 2
<i>Acropora cyatherea</i>	-	-	-	-	-	+	+
<i>Acropora formosa</i>	-	-	-	-	-	+	+
<i>Cyphastrea microphthalma</i>	-	+	+	-	-	-	-
<i>Echinopora lamellosa</i>	+		-	-	-	-	-
<i>Favia pallida</i>	+	+	+	+	+	+	+
<i>Favia speciosa</i>	+	+	+	+	+	+	+
<i>Favites halicora</i>	+	+	+	+	+	+	+
<i>Goniastrea sp</i>	+	-	-	-	-	-	-
<i>Montipora foliosa</i>	+	-	-	-	-	-	-
<i>Porites annae</i>	+	-	-	-	-	+	+
<i>Porites lobata</i>	+	+	+	+	+	+	+
<i>Porites lutea</i>	+	+	+	+	+	+	+
<i>Symphyllia radians</i>	-	-	-	-	-	+	+
<i>Turbinaria peltata</i>	+	-	-	-	-	-	-
<i>Platygyra sp</i>	-	-	-	-	-	+	+

Table 3. List of reef fishes observed in the study sites. ('+ 'indicates presence; '- 'indicates absence)

Fish sp	MRC	VDRF 1	VDRF 2	MDRF 1	MDRF 2	PBRF 1	PBRF 2
Herbivores							
<i>Abudefduf septemfasciatus</i>	+	-	+	-	+	-	-
<i>Abudefduf veagiensis</i>	+	+	-	-	-	-	-
<i>Acanthurus leucosternon</i>	+	-	-	+	-	+	+
<i>Acanthurus lineatus</i>	+	-	+	-	+	+	+
<i>Acanthurus mata</i>	-	-	+	+	+	+	+
<i>Acanthurus nigrofuscus</i>	+	+	-	-	-	+	+
<i>Canthigaster solandri</i>	-	+	-	-	+	-	-
<i>Chaetodon deccusatus</i>	+	-	-	-	+	+	+
<i>Chlorurus gibbus</i>	+	-	-	-	+	-	+
<i>Scarus ghobban</i>	+	+	+	+	-	+	+
<i>Scarus rubroviolaceus</i>	+	-	-	-	-	-	+
<i>Siganus canaliculatus</i>	-	+	+	+	+	+	+
<i>Siganus javus</i>	+	+	+	+	-	+	+
<i>Siganus lineatus</i>	+	-	-	-	+	-	+
<i>Zebrasoma veliferum</i>	+	-	-	-	-	-	-
Carnivores							
<i>Balistoides viridescens</i>	+	-	-	-	-	-	-
<i>Caranx heberi</i>	+	-	-	-	-	-	-
<i>Chaetodon collare</i>	+	-	+	+	+	+	+
<i>Chaetodon octofasciatus</i>	+	-	-	-	-	-	-
<i>Chaetodon pleubis</i>	+	-	-	+	+	-	+
<i>Chelinus undulates</i>	+	-	-	-	-	+	+
<i>Chilosecyllium griseum</i>	+	-	-	-	-	-	-
<i>Diagramma pictum</i>	+	-	-	+	+	-	-
<i>Diodon holocanthus</i>	+	-	-	-	-	-	-
<i>Epinephalus</i>	+	-	-	-	-	-	-

<i>arolatus</i>							
<i>Epinephalus coioides</i>	+	+	+	+	-	+	+
<i>Epinephalus faveatus</i>	+	-	-	-	-	-	-
<i>Epinephalus malabaricus</i>	-	+	-	+	+	+	+
<i>Hemigymmus melapterus</i>	+	-	-	-	-	-	-
<i>Labyoides dimicliatus</i>	+	-	-	-	-	-	-
<i>Lutjanus deccusatus</i>	+	+	-	+	-	+	+
<i>Lutjanus fulviflamma</i>	+	+	+	-	-	+	+
<i>Lutjanus fulvus</i>	+	-	+	+	-	+	+
<i>Mulloidichthys vanicolensis</i>	+	-	-	-	-	-	-
<i>Paraupeneus macronema</i>	+	-	-	-	-	-	-
<i>Pempheris molucca</i>	+	-	-	-	-	-	-
<i>Plectoshinchus lineatus</i>	+	+	-	-	-	-	-
<i>Plotorus lineatus</i>	+	-	-	-	-	-	-
<i>Psammoperca waigiensis</i>	+	-	+	-	+	-	+
<i>Pterois lineatus</i>	+	-	-	-	-	-	-
<i>Sargocentron rubrum</i>	+	-	+	+	-	+	-
<i>Tearpon Jarbua</i>	+	+	+	+	+	+	+
<i>Upeneus vittatus</i>	+	-	-	-	-	-	-
Others							
<i>Apogon fasciatus</i>	+	-	+	-	+	+	-
<i>Apolemichthys xanthurus</i>	+	-	+	+	-	-	-
<i>Arothron immacualtus</i>	+	+	+	+	+	-	-
<i>Dascyllus reticulates</i>	+	-	-	-	-	-	-
<i>Ghathodon speciosus</i>	+	-	-	-	-	-	-
<i>Halichoeres nigriescens</i>	+	-	-	-	-	-	-

<i>Pomacentrus cacruleus</i>	+	-	+	+	-	+	+
<i>Synodus indicus</i>	+	-	+	+	-	-	-
<i>Pterocaesio chrysozona</i>	+	-	-	-	-	-	-
<i>Heniochus acuminatus</i>	+	-	-	-	-	-	-

Table 4. Commercially exploited reef fishes in Palk Bay

Species	Catch rate (kg \pm 10 month ⁻¹ fisherman ⁻¹)	Functional group
<i>Scarus ghobban</i>	240	Scraper
<i>Scarus gibbus</i>	15	Scraper
<i>Siganus javus</i>	105	Grazer
<i>Siganus canaliculatus</i>	54	Grazer
<i>Epinephalus sp</i>	45	Carnivores
<i>Acanthurus xanthopterus</i>	10	Grazer
<i>Acanthurus mata</i>	10	Grazer
<i>Acanthurus bleekeri</i>	10	Grazer
<i>Psammaoperca waigiensis</i>	10	Carnivores
<i>Lethrinus lentjan</i>	10	Carnivores
<i>Lutjanus decussatus</i>	10	Carnivores
<i>Lutjanus rivulatus</i>	10	Carnivores
<i>Lutjanus fulviflamma</i>	10	Carnivores
<i>Lutjanus malabaricus</i>	10	Carnivores

Figure 1

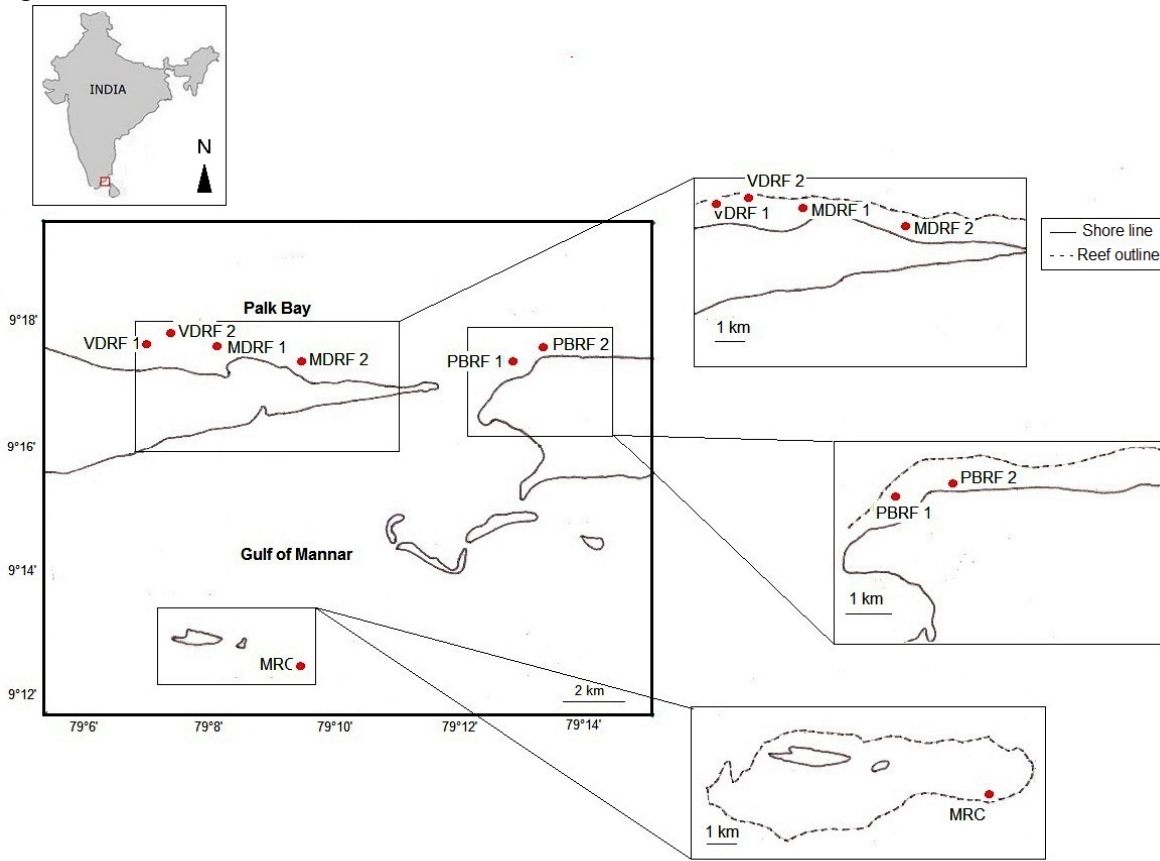


Figure 2

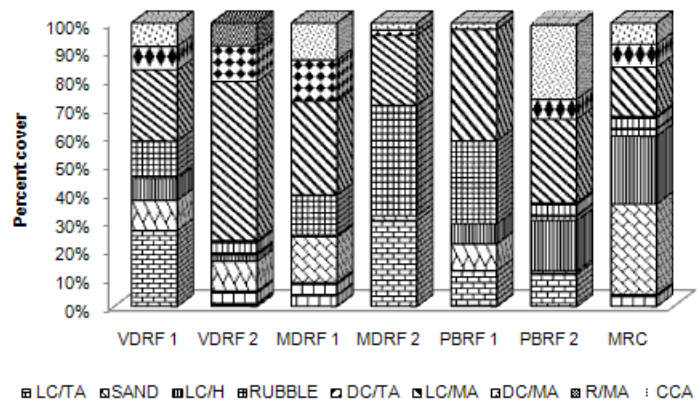


Figure 3

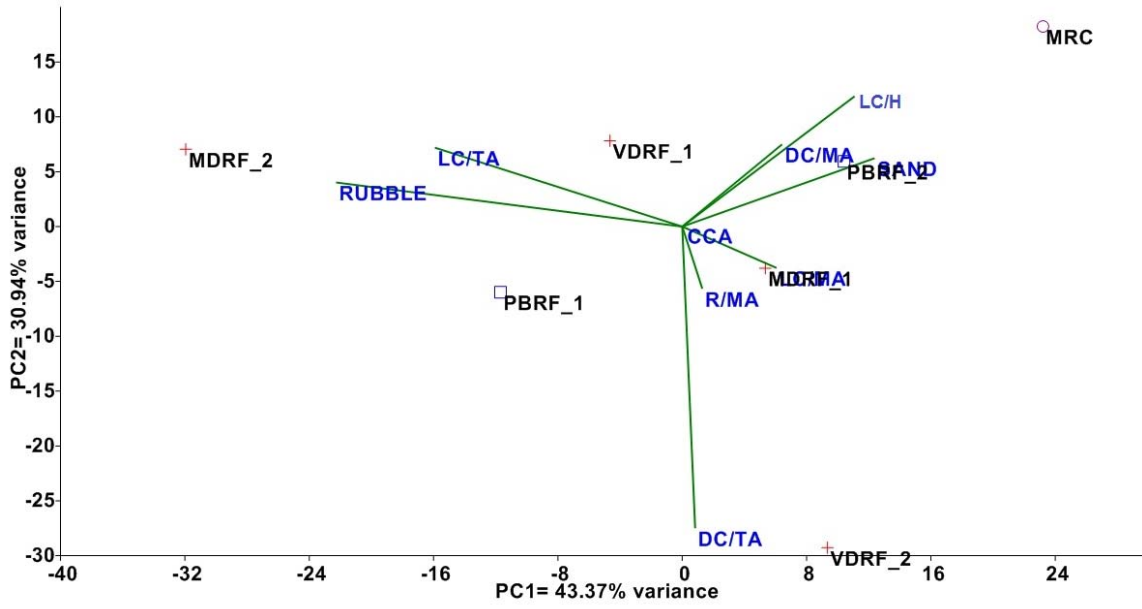


Figure 4

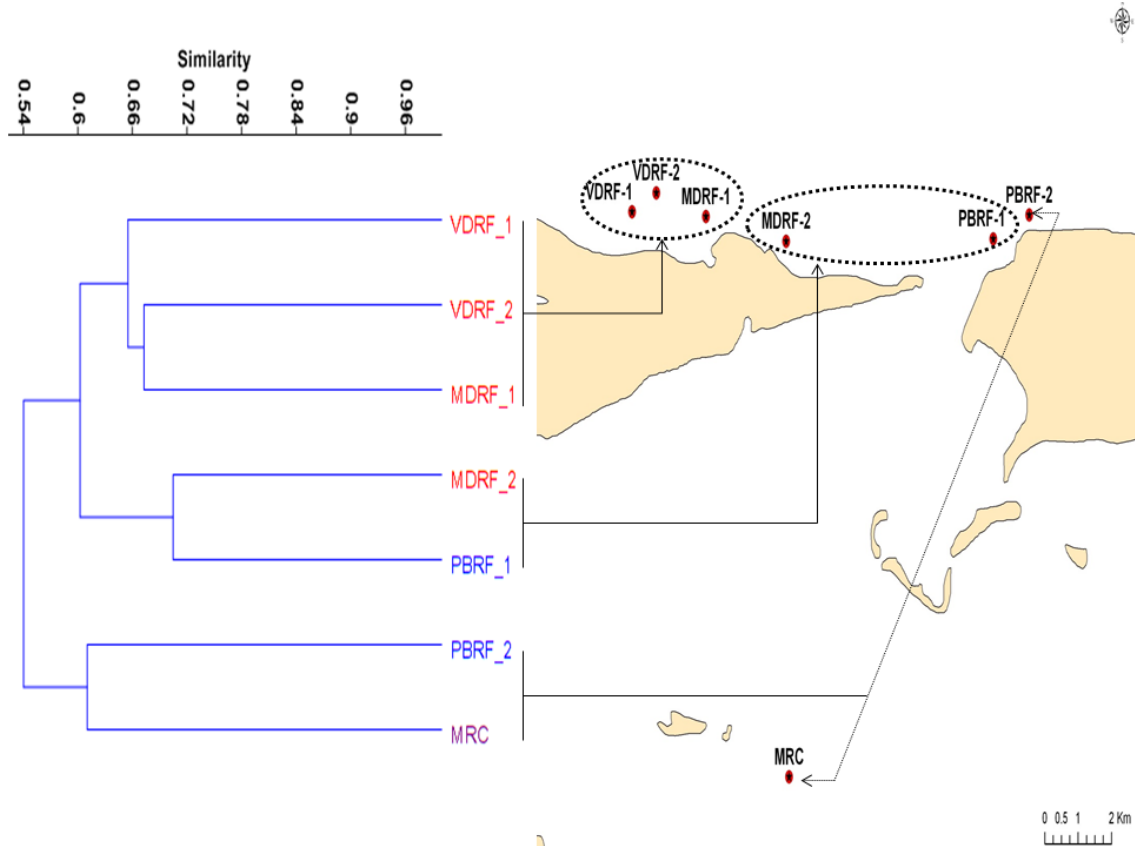


Figure 5

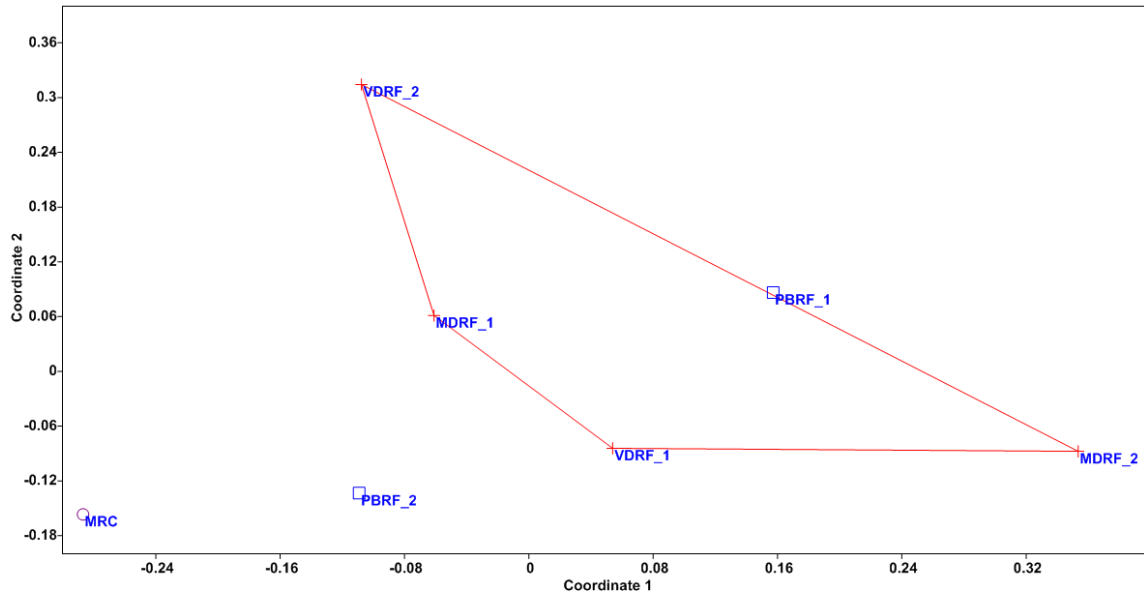


Figure 6

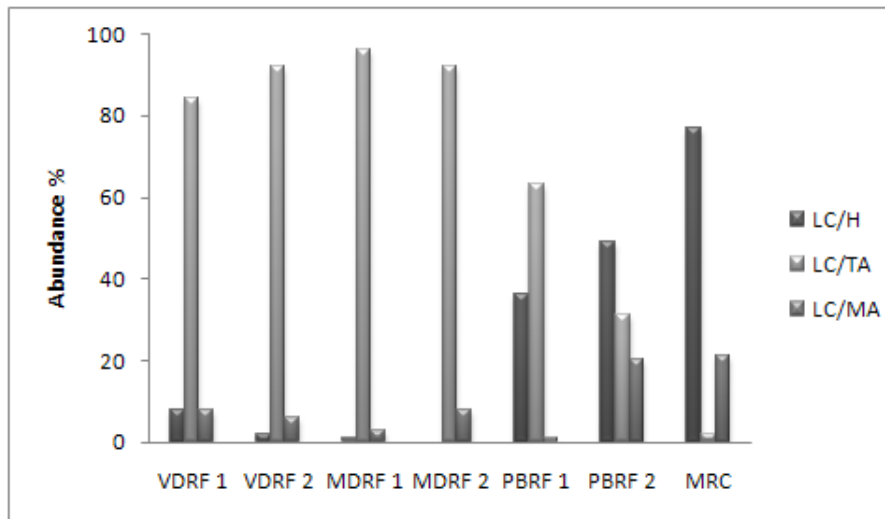


Figure 7

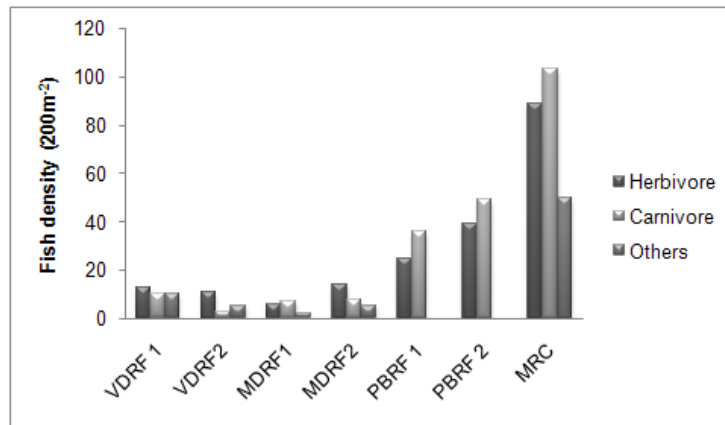


Figure 8

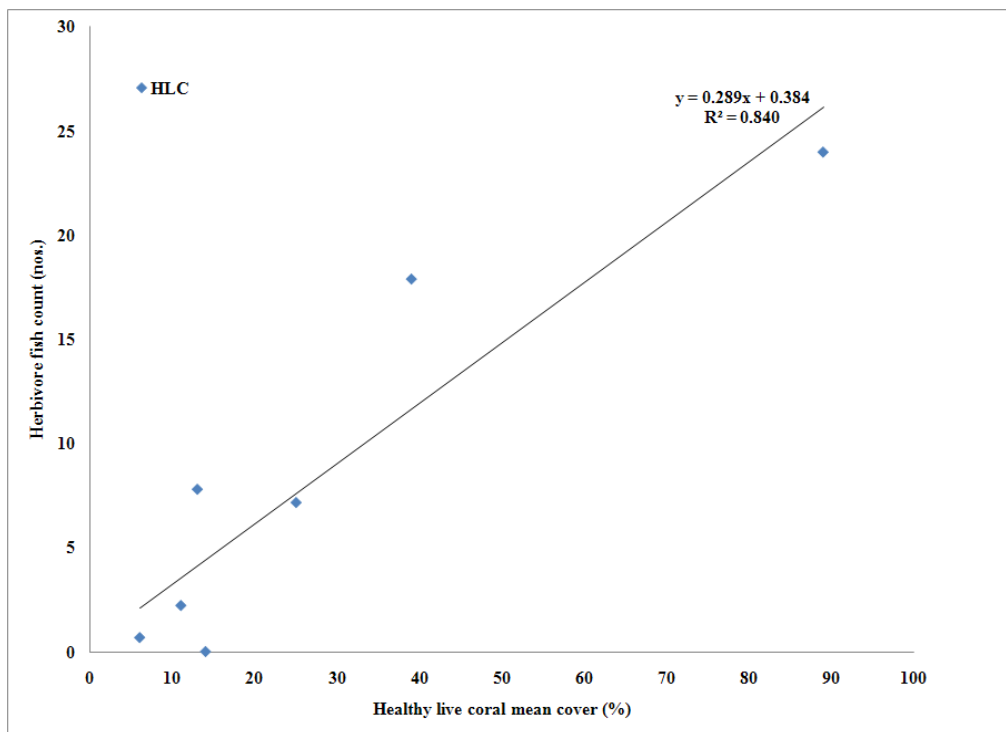


Figure 9

