Report on the Systematic Surveying of Bar Reef Sanctuary 2017

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Report on the Systematic Survey of the Status of Coral and Fish Communities in Bar Reef Marine Sanctuary

2017

Acknowledgement

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List of Abbreviations

AL	Algae/Fleshy algae/ Sea weeds
BRMS	Bar Reef Marine Sanctuary
CR	Coral rubbles/Loose, unconsolidated accumulations of coral
DC	Dead coral/Recently dead coral
ENSO	El Nino Southern Oscillation
LC	Live coral
RK	Rock/Hard substrate including old dead coral
SA	Sand/Fine sand including small bits of rubble and shell fragments
SC	Soft coral
DWC	Department of Wildlife Conservation

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Introduction

Reefs in Sri Lanka can be categorized into three habitat types as true coral reefs, sandstone reefs and rocky habitats (Swan 1983; Rajasuriya & De Silva 1988; Rajasuriya et al., 1995; Rajasuriya & White 1995). True coral reefs are composed of corals growing on a limestone and coralline substrate of dead and living coral and are characterized by a high live coral cover. In Sri Lanka, coral reefs occur either as fringing reefs or continental shelf patch reefs from shallow near shore waters to offshore areas. True coral reefs are found mainly in the Gulf of Mannar between Kalpitiya Peninsula and Mannar Island as fringing and offshore patch reefs, and as fringing reefs in the east coast around Trincomalee and Batticaloa Districts, the southern coast from Akurala to Tangalle, and around the Jaffna Peninsula in the north (Swan 1983; Rajasuriya & De Silva 1988; Rajasuriya et al., 1995; Rajasuriya et al., 1998). In addition, there are isolated patch reefs of coral on consolidated hard substrate along the seabed, mainly on the western and eastern sides of the island within a depth range of 15 to 25 m and vary in extent from about a hectare to several hectares. Sandstone reefs are common around the island and can be found within the continental shelf. Many sandstone reefs occur as ridges running parallel to the shoreline, and according to Swan (1983) these may represent former coastlines that have been submerged due to sea level changes in the past. Rocky shorelines and submarine structures based on geological formations are found along most coastal areas of the island (Cooray 1984). Live coral cover is low in these habitats, and is often less than 5% of total benthic cover.

Reef and reef-associated fisheries are the main economic use of coral reefs in Sri Lanka. Major reef associated fisheries are demersal and semi-demersal fisheries, spiny lobster fishery and the marine ornamental fishery. In addition, sea cucumbers and chanks (*Turbinella pyrum*) are harvested in soft bottom areas around reefs. Ornamental fish, sea cucumber and chanks are harvested exclusively for export, while most of the spiny lobster catch is also exported. The marine ornamental fishery depends on more than 250 species of marine fish and about 50 species of marine invertebrates (Reviewed by Rajasuriya & Perera 2004) and accounts for annual export earnings of around $6 million (Wijesekara & Yakupitiyage 2001).

Bar Reef Marine Sanctuary

Bar Reef Marine Sanctuary (BRMS) is located northwest of the Kalpitiya peninsular, and covers an area of 306.7 km^2, encompasses coral reefs, sandstone reefs, sea grass communities and soft bottom habitats. The shallow coral habitat within Bar Reef was considered one of the healthiest and relatively undisturbed coral reef areas in Sri Lanka with live coral cover of around 80% of the substrate (Rajasuriya et al., 1998). The reef was severely affected by coral bleaching due to increased sea temperatures in 1998 resulting in live coral cover decreasing to less than 1%. However the reef has shown significant recovery with extensive coral recruitment and a high live coral cover within 10 years of the bleaching event. The shallow coral reef area of the Bar Reef consists of extensive coral patches interspaced by sand and rubble. The depth ranges from around 1m to around 8m in the deeper sand patches. Reef recovery after the 1998 bleaching event has been patchy with some areas recovering well while other sections of the reef continued to have low coral cover. The reef is dominated by branching, tabulate, foliose and digitate coral forms, and dominant genera include *Acropora, Montipora, Echinopora* and *Pocillopora*. Sea anemones, particularly the giant sea anemone (*Heteractis magnifica*) with associated anemonefish are common on the reef.

Scope of the Surveys

This survey was undertaken for the purpose of developing a data base with the following objectives:

1. Develop maps of marine debris accumulation in the reef
2. Identify the areas that can be subsequently cleaned with minimal invasion to the reef
3. Identify the types of debris
4. Develop a video data base on current status of coral reef (areas of dead coral and live coral) and identify GPS locations of Reef
5. Determine the types of corals and marine associates

Methodology

Survey Sites

A combination of both qualitative and quantitative methods was used to survey the reef. Initially, rapid snorkel surveys were conducted to cover a larger area of the reef and understand the current state of the reef as well as assessing the level of marine debris accumulation on the reef. Thereafter, seven sites (Site 01 to 08) were identified within the Bar Reef for quantitative monitoring (Figure 1). Coordinates of the study sites and depth range are given in the table 01. Sites were selected in close proximity to previous survey areas and in order to provide a representative coverage of coral areas within the reef.

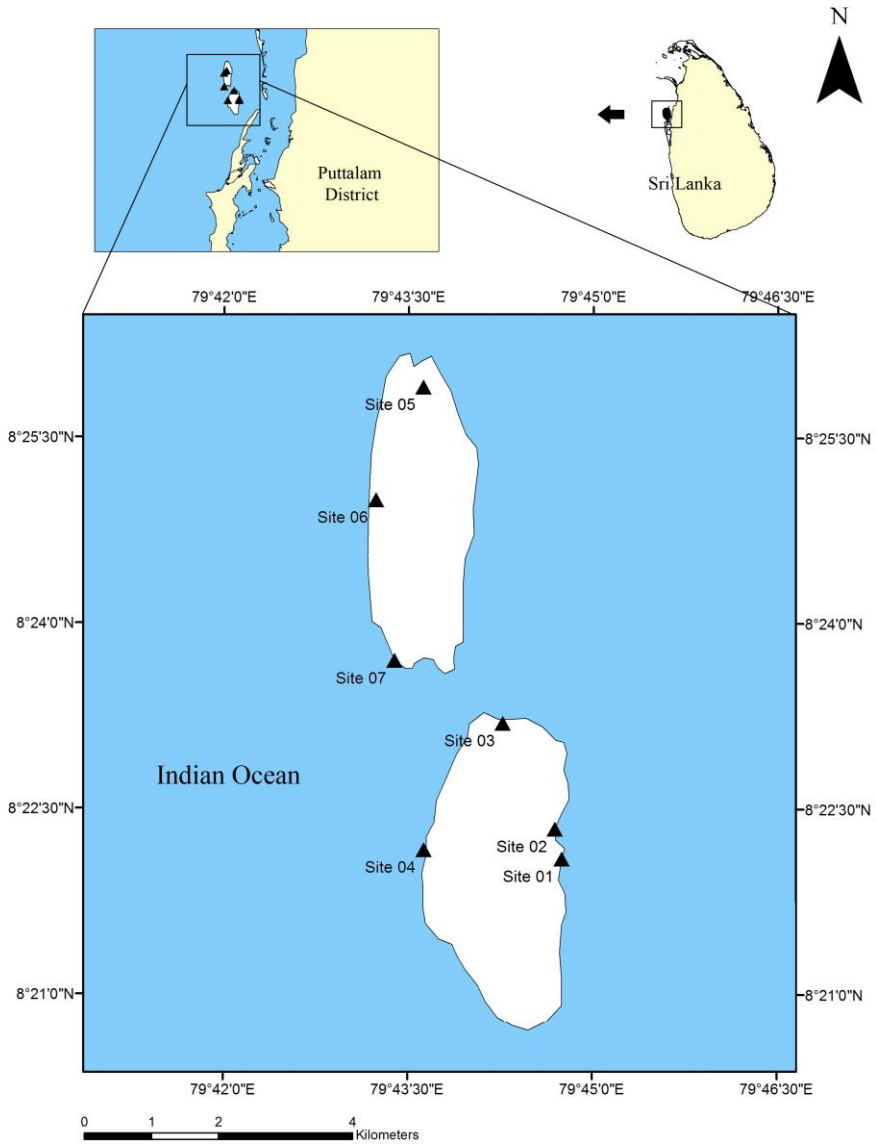

Figure 1. Map of survey area showing survey sites within the Bar reef.

In addition limited surveying was carried out at a deeper reef off Kandakuliya (Site 08) in order to compare coral health and fish abundance outside the Bar Reef. This reef consists of an extensive hard bottom habitat with scattered hard corals, soft coral and sponges. Hard corals are primarily of the genus *Turbinaria*. The depth of the reef ranged from 12-14m.

A second reef off Kandakuliya (Site 09) was investigated but no quantitative sampling was conducted as it was found to be a sandstone reef with very low coral cover. This reef consisted of extensive sandstone habitat with a few encrusting and submissive corals.

Table 1. Coordinates and depth records of the survey sites.

Site Name	Latitude	Longitude	Average depth (m)	Maximum depth (m)
Site 01	8° 22.205′	79° 44.797′	2.7	4
Site 02	8° 22.357′	79° 44.788′	2.7	5.2
Site 03	8° 23.200′	79° 44.269′	4.6	6.7
Site 04	8° 22.178′	79° 43.627′	7.0	7.9
Site 05	8° 25.910′	79° 43.532′	8.2	9.8
Site 06	8° 25.000′	79° 43.232′	8.8	9.5
Site 07	8° 23.600′	79° 44.250′	7.9	9.1
Site 08	8° 14.819′	79° 41.324′	11.6	13.4
Site 09	8° 15.116′	79° 41.972′	6.4	7.6

Selection of Survey Methods

Survey methods were selected in accordance with globally used protocols. Point transects and belt transects (English et al., 1997) were selected in order to provide a rapid quantitative assessment of the coral reef. In every survey site, two transects were carried out to gather quantitative data. Finally, average of the data was calculated for each and every survey site. The sampling methods were designed to identify and monitor bio-indicators that could be easily monitored in the future to assess the changes in the reef from its current status. All surveys were carried out between 9am and 2pm in order to provide a standardized data collection protocol and make us of the best seas conditions.

Substrate Survey

Substrate surveys were carried out using the point transect method. A 50 m fiberglass tape was laid across the reef and the substrate category at 50 cm intervals were recorded on an underwater slate by a scuba diver (Figure 02). Then, the percentage cover of the substrate categories were calculated. The substrate categories used for the surveys are presented below.

Live Coral (LC) – Live hard coral
Soft coral (SC) – Soft coral
Dead Coral (DC) – Recently dead coral
Algae (AL) – Fleshy algae/ Sea weeds
Rock (RK) – Hard substrate including old dead coral
Sand (SA) – Fine sand including small bits of rubble and shell fragments
Coral Rubble (CR) – Loose, unconsolidated accumulations of coral

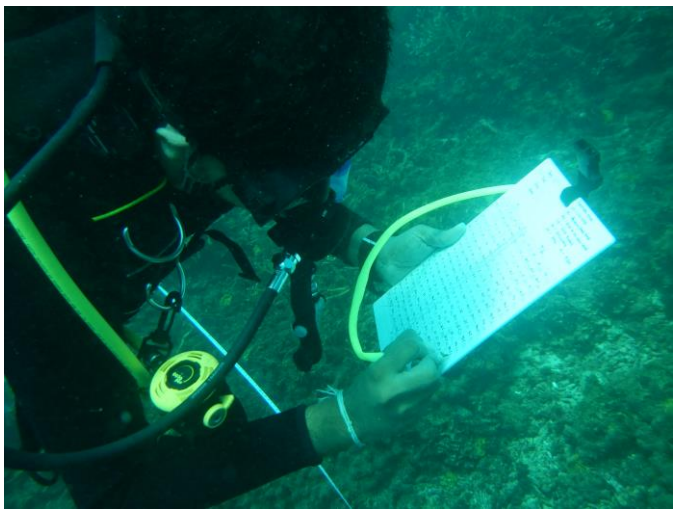

Figure 2. Scuba diver recording the substrate data.

In appendix I to VIII show substrate information of the survey sites at Bar Reef and Kandakuliya deep reef.

Reef Fish Survey

Fish surveys were carried out using the belt transect method. Two belt transects were conducted in every sampling site. A diver swimming along a 50 m tape at a speed of 10 m per second recorded selected fish species and groups on 2.5m on either side of the transect covering a total area of 250m^2. Average densities (individual/m^2) of the recorded fish species within transects were calculated for each survey site. The following fish groups were selected for monitoring.

Butterflyfish, Angelfish, Snappers, Grouper >30cm, Grouper <30cm, Parrotfish >30cm, Parrotfish <30cm, Rabbitfish, Surgeonfish.

In addition, a list of all reef fish species observed at Bar Reef during the survey period was compiled.

Survey on large Invertebrates and Debris

Large invertebrates (starfish, Crown of Thorns starfish, sea cucumbers, sea urchins and large shells) were recorded along a belt transect of 50 m length and 1 m width for a total area of 50m^2 per transect, along a 50 m fiberglass tape laid across the reef. All marine debris within the belt transect (5 m × 50 m) was also recorded.

In addition, video recordings were taken along transects apart from the notes prepared *in situ* (Figure 03).

Figure 3. Scuba diver making video record along a transect.

Results and Discussion

Marine Debris

Marine debris accumulation on the reef

No marine debris was recorded in transects (5 m × 50 m). However, parts of old discarded fishing nets, gunny bags, a carpet and plastic bags were noted during initial exploration of Bar Reef. Overall, marine debris levels within the reef can be considered negligible at the time of sampling. According to local divers around the Kandakuliya, marine debris on the bar reef has been cleaned in 2015 with the support of scuba divers and snorkelers.

Since limited data are available on origin, floating and floating directions of debris with seasonal changes, it is important to conduct routine survey after each monsoon to identify new debris. Once debris become entangled and gradually when biofilms form over them turning them into part of substrate, it is difficult to remove them without damaging the reef. Hence, it is important to conduct routine clearance operations with the assistance of local divers.

There is no solution to solid waste in Kalpitiya and Gangewadiya area. Additionally, both Kala Oya and Mee Oya drain to this area, thus brings along with them substantial amount of debris originated at upper courses of these rivers. Hence, creating awareness among coastal communities as well as inland communities are important. So it can be concluded that a reef cleaning process in the Bar reef is not required at the moment.

Type of debris found during the survey

The following debris were observed in the survey sites,

- Discorded fishing nets
- Sinkers made using gunny bags and plastic bottles
- Discarded fabric materials

The observed marine debris around the survey sites are shown in figure 04.

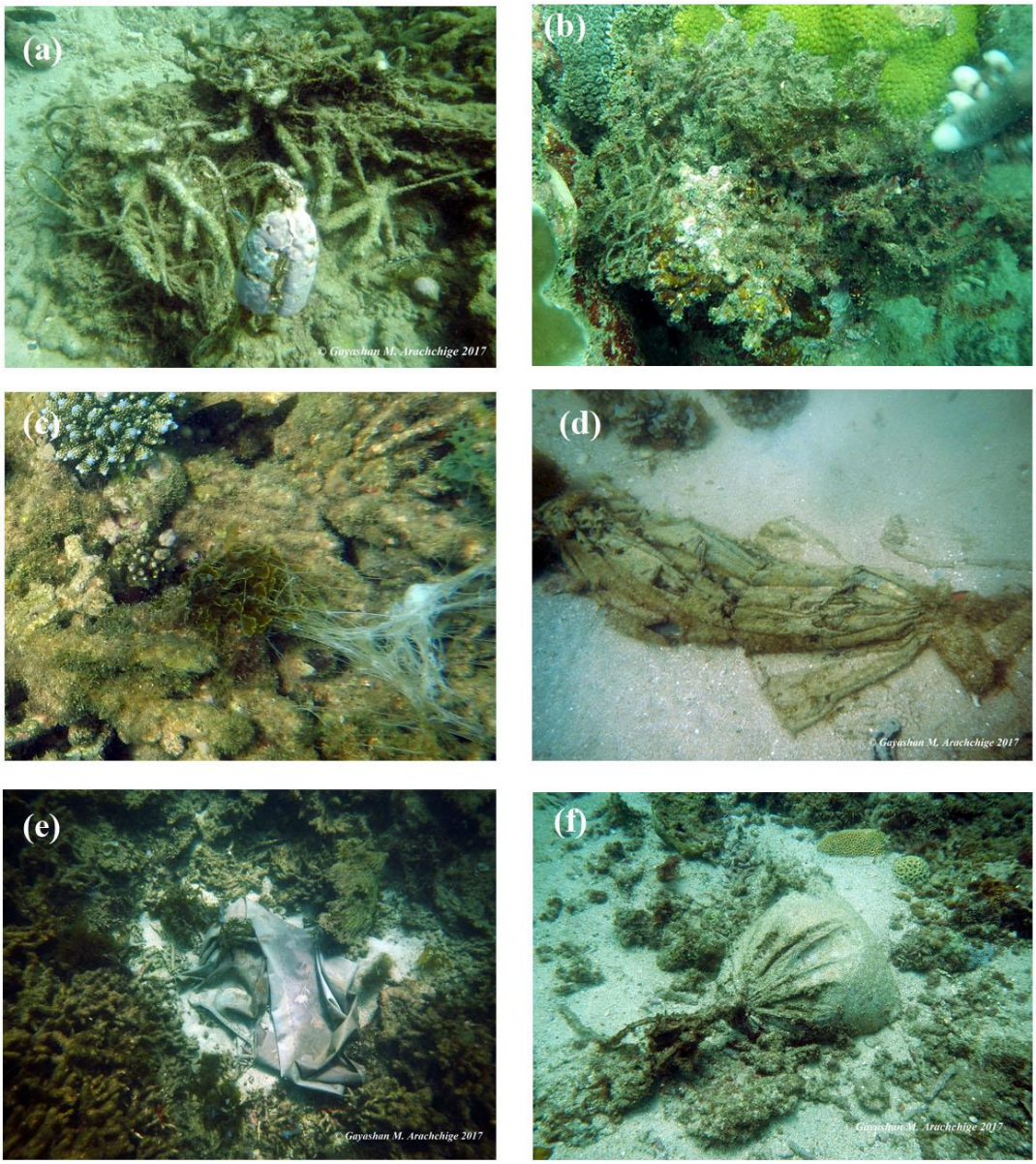

Figure 4. The observed marine debris around the survey sites; a, b and c, discarded fishing nets; d and e, discarded fabric materials; f, sinkers made from gunny bags.

Substrate

Among the seven sites within Bar Reef, the highest live hard coral cover was recorded at Site 4 with a live hard coral cover of 26.7% (Fig 5 and 6). The overall distribution of substrate categories recorded on transects was different across the sampling sites. Shallow water sites (site 01, site 02 and site 03) were dominant with branching corals (*Acropora* sp.). These shallow reefs contained a live coral percentage less than 2% (Fig 5). Although,

site 05 in deep water was also dominant with branching corals (*Acropora* sp.), the live coral percentage was higher (13.4%) (Figure 6).

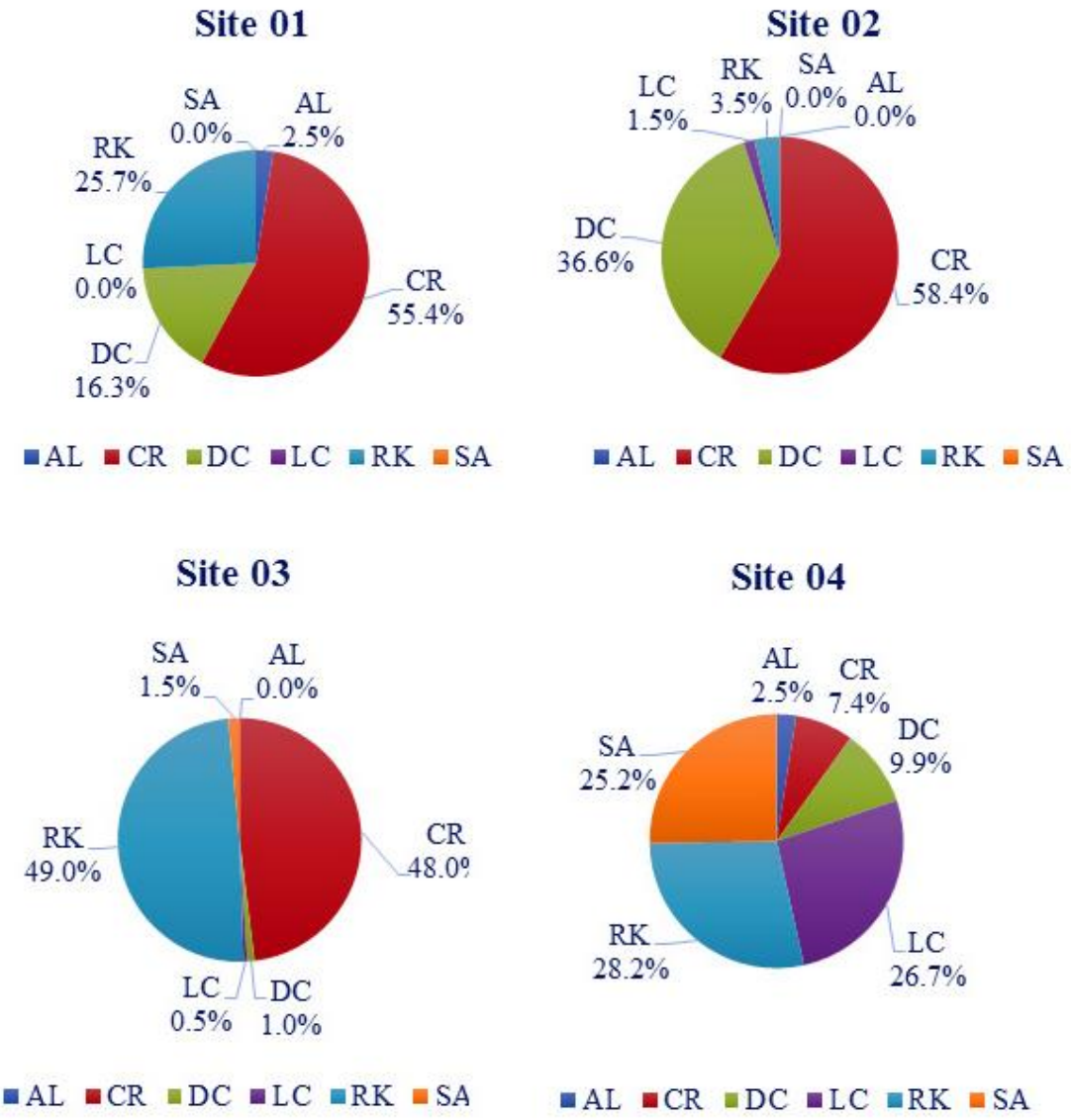

Figure 5. Percentage substrate cover among sampling sites 01, 02, 03 and 04 at Bar Reef (AL=Algae; CR=Coral Rubble; DC=Dead Coral; LC=Live Hard Coral; RK=Rock; SA=Sand).

The highest live coral percentage (26.7%) was observed at site 04 among the survey site. This site was dominant with stony corals belonging to genera of *Favites, Leptoria Platygyra* and *Porites* and distribution of branching corals (*Acropora* sp.) lower.

Site 2 had the highest amount of coral rubble and live hard coral. Site 3 had a lower percent cover of dead coral and a higher percent cover of rock recorded on transects compared to the other sampling sites within Bar Reef (Fig 5). A list of coral species recorded during the surveys is listed in Appendix IX.

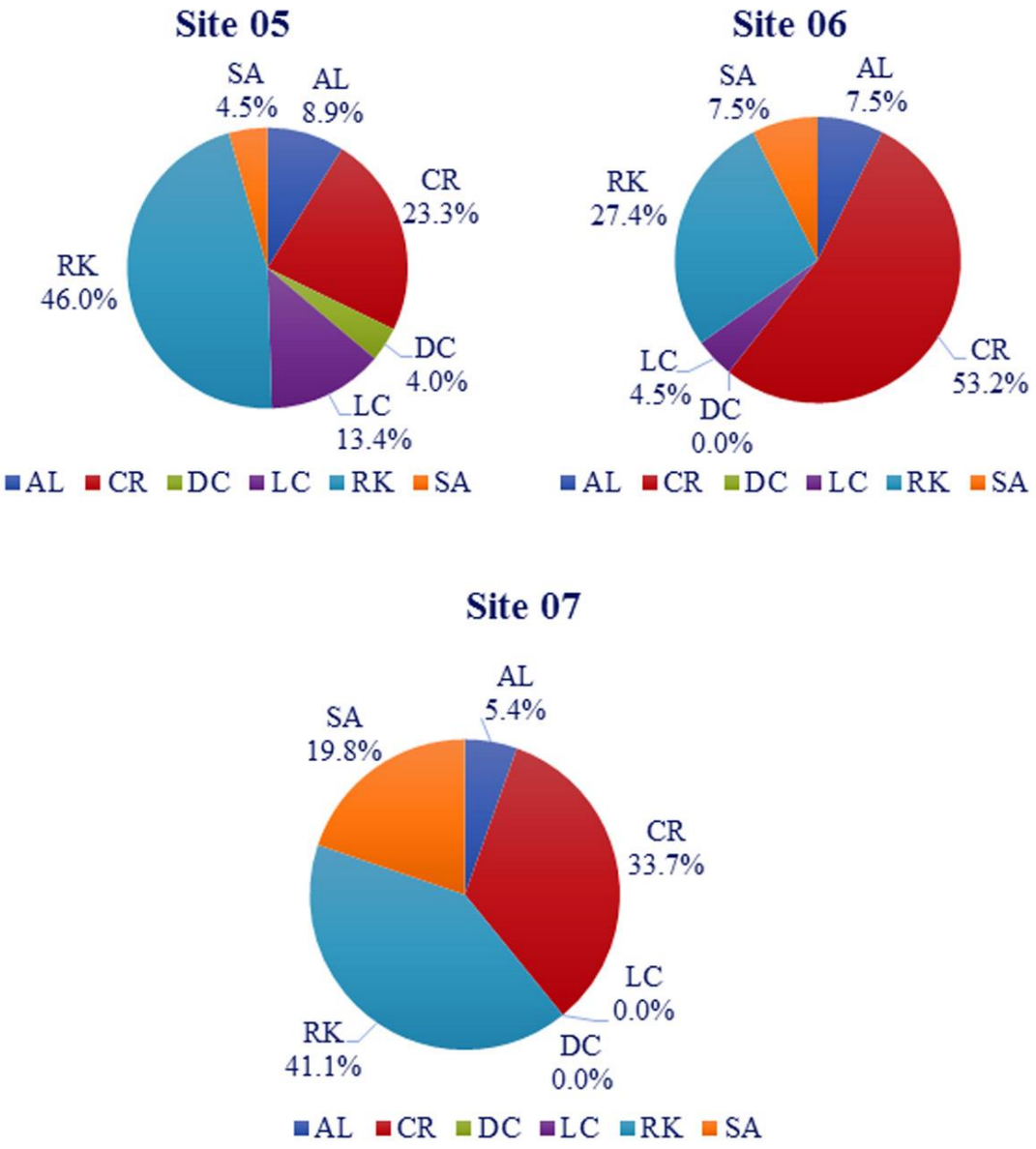

Figure 6. Percentage substrate cover among sampling sites 05, 06 and 07 at Bar Reef (AL=Algae; CR=Coral Rubble; DC=Dead Coral; LC=Live Hard Coral; RK=Rock; SA=Sand).

Average live hard coral cover recorded on transects across all sampling sites within Bar Reef was 6.7% (Fig 7). Coral rubble (39.9%), rock, (31.6%) and dead coral (9.7%) were the dominant substrate categories recorded on transects within Bar Reef (Fig 7).

The results indicate the effects of surface sea water anomalies brought in by El Nino and mild La Nina conditions experienced by the reef in 2016 and 2017. The destruction to live coral cover is compatible with the observations in other reefs of Indian Ocean. In addition to bleaching, the gradual transformation into coral rubble can take this reef to the tipping point. Hence immediate management measures are required to mitigate any human induced negative activates that could concurrently affect the reef. Though ENSO is a natural event, reef resilience is also weakened by human activities and such activities require to be minimized at times like this.

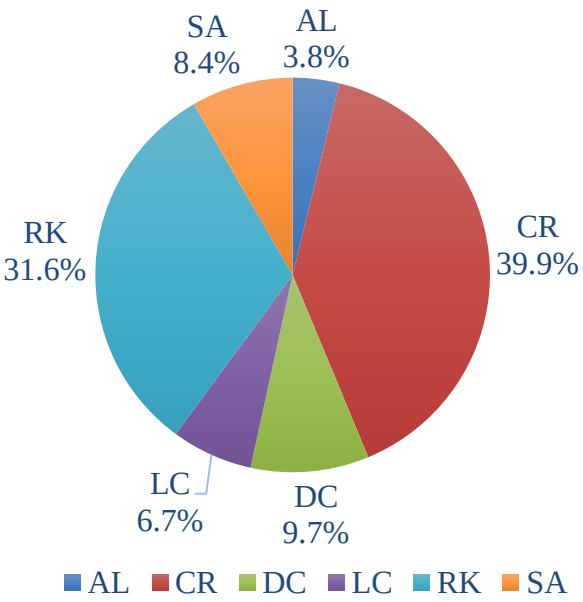

Figure 7. Average percentage substrate cover at Bar Reef (AL=Algae; CR=Coral Rubble; DC=Dead Coral; LC=Live Hard Coral; RK=Rock; SA=Sand).

Comparison of Bar Reef with Kandakuliya deep reef

In comparison with Bar Reef, the Kandakuliya deep reef had a much higher live hard coral coverage with of 31.7% live coral recorded on the single transect conducted at the site (Fig 8 and 9). This site is dominant with cup coral (*Turbinaria* spp.). Hence, it is evident that live coral coverage varies from site to site and factors for such differences are important to be known.

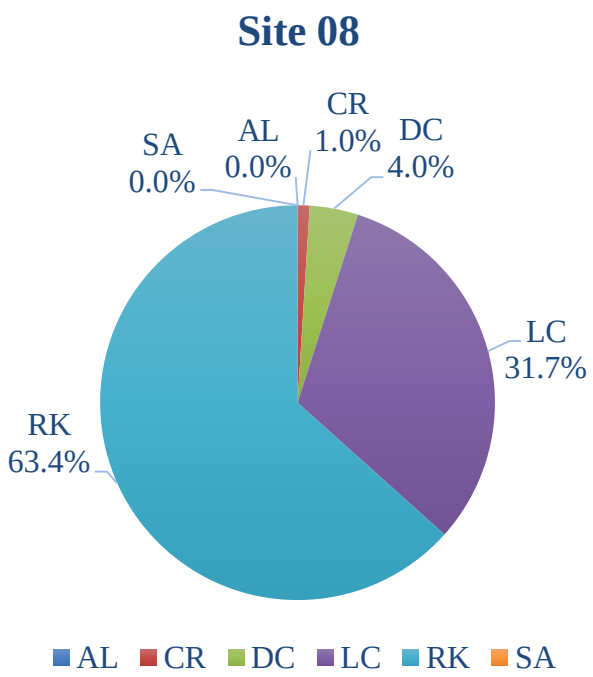

Figure 8. Average percentage substrate cover at sampling site of Kandakuliya deep reef.

AL=Algae; CR=Coral Rubble; DC=Dead Coral; LC=Live Hard Coral; RK=Rock; SA=Sand.

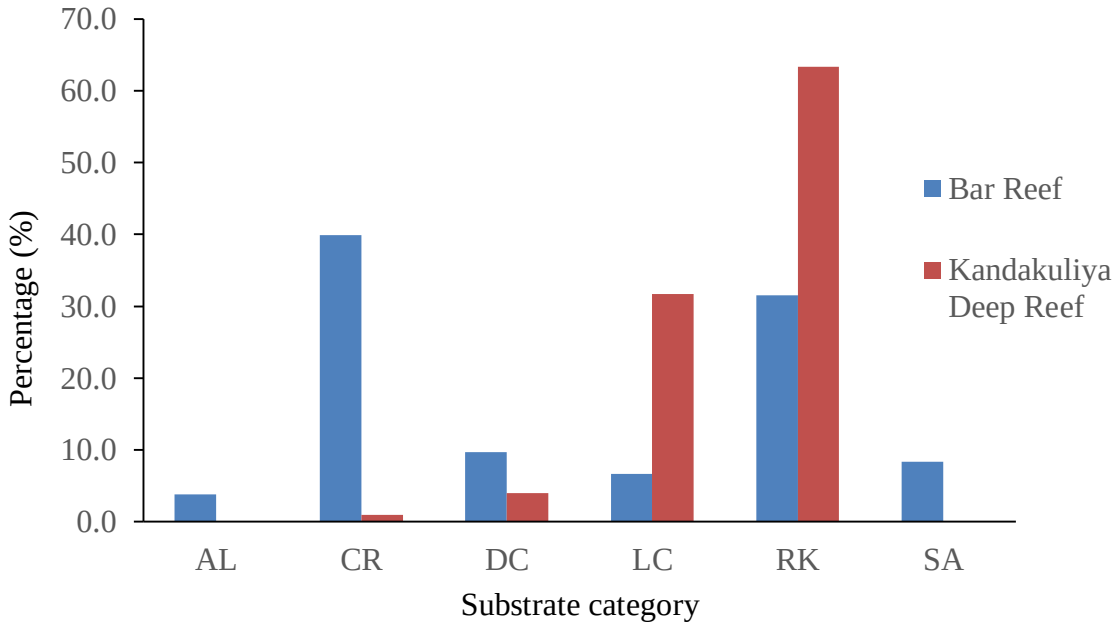

Figure 9. Comparison of substrate cover between Bar Reef and Kandakuliya Deep Reef (AL=Algae; CR=Coral Rubble; DC=Dead Coral; LC=Live Hard Coral; RK=Rock; SA=Sand).

Reef Fish

Chromis ternatensis had the highest population density with 2.49 indiviual/m^2 at site 5 compared to other reef fish species recorded in transects (Table 2). *Abudefduf vaigiensis, Chaetodon collare, Chaetodon decussatus, Chaetodon trifasciatus, Chromis ternatensis, Chromis viridis, Ctenochaetus striatus, Dascyllus carneus, Dascyllus trimaculatus, Halichoeres nebulosus, Plectorhinchus* spp, *Pomacentrus similis, Thalassoma lunare* had average population densities above 0.02 indiviual/m^2 in survey site at Bar reef. A higher number of species were recorded at site 03, 04 and 05 (23-24 species) where live hard corals coverage was also higher. Table 2 shows average population densities of reef fish species recorded in survey sites at Bar Reef and Kandakuliya deep reef.

Table 2. Average population densities (individual/m^2) of reef fish species in survey sites at Bar Reef and Kandakuliya deep reef.

Fish species	Density (Individual/m^2)							
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Abudefduf vaigiensis	0	0	0	0	0.028	0	0	0
Acantharus leucosternon	0	0	0	0.004	0	0	0	0
Acanthurus lineatus	0	0	0.004	0.004	0.002	0	0	0
Apolemichthys xanthurus	0	0	0	0.014	0	0	0.004	0.024
Centropyge multispinis	0.004	0	0	0	0	0	0	0
Cephalopholis formosa	0	0	0	0.012	0.004	0	0	0
Chaetodon collare	0	0	0	0.034	0.006	0	0	0
Chaetodon decussatus	0.002	0	0	0.026	0.004	0	0	0.016
Chaetodon melannotus	0	0	0	0	0	0	0	0
Chaetodon octofasciatus	0.002	0	0.002	0	0	0	0	0
Chaetodon trifascialis	0	0	0	0	0.01	0	0	0
Chaetodon trifasciatus	0.002	0.004	0	0.004	0.022	0.012	0	0
Cheilinus chlorourus	0	0	0	0.002	0	0	0	0
Chromis ternatensis	0	0	0	0	2.49	0.008	0	0
Chromis viridis	0	0	0	0.078	0.032	0.13	0.044	0
Coris formosa	0	0	0.006	0.006	0	0	0	0
Ctenochaetus striatus	0	0	0	0.02	0	0	0	0
Dascyllus carneus	0	0	0	0	0.226	0.2	0	0
Dascyllus trimaculatus	0	0	0	0.006	0	0.048	0.02	0
Epinephelus merra	0	0	0	0	0	0	0	0
Gnathanodon speciosus	0	0	0.002	0	0	0	0	0
Gomphosus caeruleus	0	0	0	0	0.004	0	0	0
Gymnothorax javanicus	0	0	0	0	0	0	0	0
Gymnothorax javanicus	0.01	0.01	0	0	0	0	0	0
Halichoeres hortulanus	0	0	0	0.01	0.006	0	0.004	0
Halichoeres nebulosus	0	0	0	0.104	0.026	0	0	0
Heniochus acuminatus	0	0	0	0	0	0	0	0
Labroides dimidiatus	0	0	0	0.014	0.004	0.016	0.012	0
Lutjanus decussatus	0.004	0.006	0	0.006	0.006	0.012	0.008	0
Lutjanus kasmira	0	0	0	0.004	0	0	0	0
Lutjanus monostigma	0	0.002	0	0	0	0	0	0
Lutjanus sp	0	0	0	0	0	0	0	0.136
Parapercis clathrata	0	0	0	0.01	0.002	0	0.004	0
Parupeneus indicus	0	0	0	0	0.002	0.008	0.004	0
Plectorhinchus ceylonensis	0	0	0	0	0	0.008	0	0

Plectorhinchus schotaf	0	0	0	0	0	0.028	0	0.012
Plectorhinchus spp	0.002	0.002	0	0.02	0	0	0	0
Plectorhinchus vittatus	0.002	0.002	0.002	0	0	0	0	0.004
Pomacanthus annularis	0	0	0.002	0	0	0	0	0
Pomacanthus imperator	0	0	0	0.002	0	0	0	0
Pomacanthus semicirculatus	0.004	0.002	0	0	0	0	0.004	0
Pomacentrus chrysurus	0	0	0.002	0	0.006	0	0	0
Pomacentrus philippinus	0	0	0	0	0.01	0	0	0
Pomacentrus similis	0	0	0	0.018	0	0.028	0.052	0
Sargocentron diadema	0	0	0	0.006	0	0	0.008	0
Siganus sp	0	0	0	0	0.008	0	0	0
Stegastes nigricans	0	0	0	0	0.006	0	0	0
Thalassoma lunare	0	0	0	0.034	0.006	0.012	0	0
Zanclus cornutus	0	0	0	0	0.016	0	0	0
Zebrasoma desjardinii	0	0	0	0	0.002	0	0	0

According to the studies conducted at shallow reef (site 01, 02 and 03) for fish groups that were selected for monitoring, surgeonfish were the most dominant group of reef fish on transects at Bar Reef with an average of around 42 fish per transect (Fig 10). This was followed by small parrotfish below 30cm in length (Fig 10). However, large parrotfish were extremely rare at Bar Reef but they used to be a major coral reef inhabitant in the past. Most other fish groups selected for monitoring also recorded low numbers on transects. Small groupers and moray eels were frequently encountered on transects but very few large groupers, sweetlips, snappers and other food fish were seen during surveys. The number of butterflyfish recorded on transects at Bar Reef was less than 2 individuals per transect and only 5 species of butterflyfish were observed during the survey period at Bar Reef (Appendix II).

In comparison, the Kandakuliya Deep Reef had a healthier fish population with most major groups except surgeonfish recording higher numbers of individuals on the transect. Most notably, food fish such as snappers were more common at Kandakuliya Deep Reef than at Bar Reef.

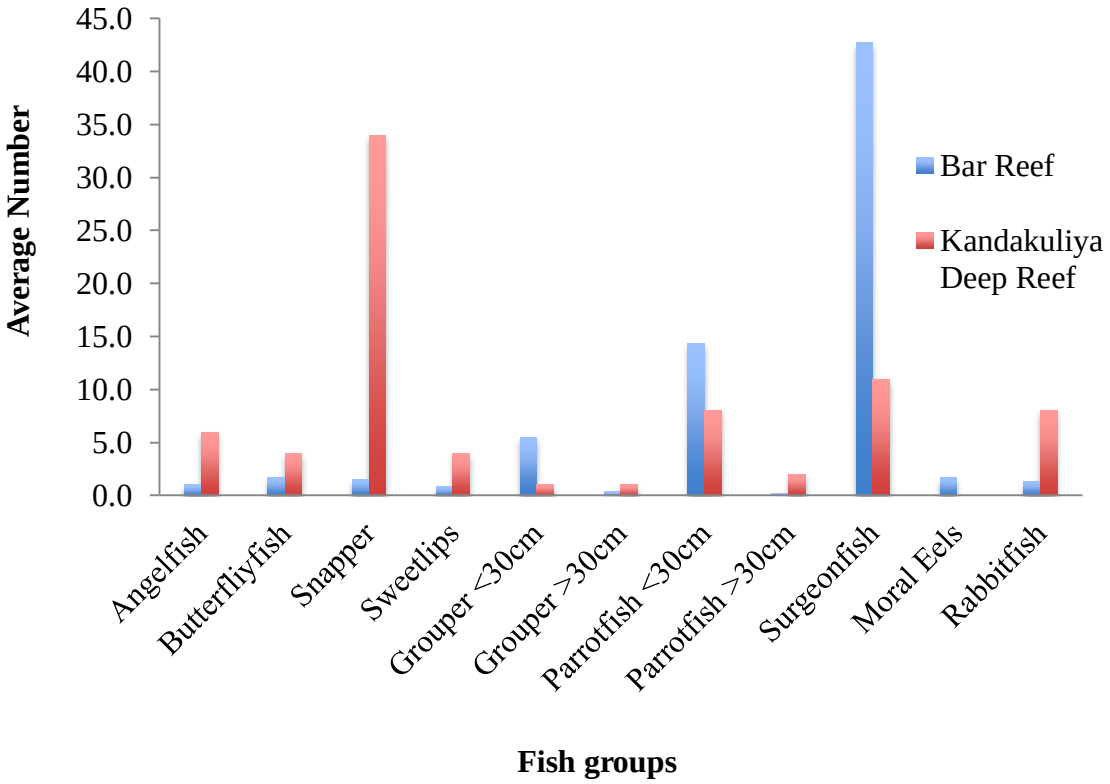

Figure 10. Comparison of major reef fish groups between Bar Reef and Kandakuliya Deep Reef (only data of site 01, 02 and 03 at Bar Reef and site 08 at Kandakuliya deep reef are used).

Invertebrates

Sea stars and sea urchins were the most common large invertebrates both within the Bar Reef and at Kandakuliya deep reef (Table 3). *Linckia multifora* was the dominant starfish and observed in all survey sites. Crown of thorns starfish (*Acanthaster planci*) which is an invasive was recorded at site 05 at Bar Reef and Kandakuliya. *Culcita schmideliana* was only observed at site 01 and site 02. Similarly, *Protoreaster linckii* was recorded at site 03 and site 04. *Stomopneustes variolaris* was the only sea urchin species recorded within transects at site 01. However, *Echinostrephus molaris* and *Metalia sternalis* were observed

at Bar Reef. *Echinostrephus molaris* was only recorded at site 6. Likewise, *Metalia sternalis* was only observed at site 02.

Table 3. Average population densities of large invertebrate species recorded in survey sites at Bar Reef and Kandakuliya deep reef.

Class	Species name	Density (Individual/m^2)							
		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
Asteroidea	*Linckia multifora*	0.03	0.03	0	0.13	0.03	0.18	0.04	0.02
	Acanthaster planci	0	0	0	0	0.01	0	0	0.02
	Culcita schmideliana	0.04	0.01	0	0	0	0	0	0
	Protoreaster linckii	0	0	0.01	0.01	0	0	0	0
Echinoidea	*Stomopneustes variolaris*	0.01	0	0	0	0	0	0	0
Holothuroidea	*Holothuria atra*	0.02	0.01	0.07	0.3	0.19	0.13	0.12	0.04
	Holothuria edulis	0.01	0	0.04	0.18	0.1	0.08	0.06	0
	Stichopus chloronotus	0	0	0	0.06	0	0.02	0.04	0
Gastropoda	*Cypraea tigris*	0	0	0	0	0	0.02	0	0

Sea cucumbers, *Holothuria atra* and *Holothuria edulis* were recorded in all survey sites. *Holothuria atra* had the highest population densities throughout all sites compared to other sea cucumber species. *Stichopus chloronotus* was observed in site 04, 06 and 07 in Bar Reef. One mollusk species *Cypraea tigris* was recorded in transect of site 06.

Conclusions and recommendations

1. Bar Reef was extensive impacted by the 2016 coral bleaching event with extensive coral mortality of more than 92.3% of corals on the reef. As evident from the results, the percentage of live coral cover varies from place to place in the sanctuary and with shallow reefs showing the highest level of dead corals. However a few coral colonies appear to have survived and may be important catalyst for reef recovery.

2. Almost no new coral recruits were observed during the surveys. However coral recruitment tends to occur in episodic events and it is likely that recruitment will take place sometime in the future provided that good substrate is available. Coral recovery after the 1998 bleaching event also began to occur more than one year after the original bleaching event. Overall the current state of the reef can be considered similar to the immediate post bleaching status in 1998. However, reef recovery should be aided by reducing other stresses, especially human disturbances. Compared to reefs along the south coast, the Bar Reef showed healthy recovery after the 1998 bleaching event. However, at the time, Bar Reef remained in a relatively undisturbed state, mainly due to the civil unrest in the area that limited fishing and tourism activities. In contrast, the reef is now heavily impacted by human activities such as tourism and especially fishing.

3. Despite being a marine sanctuary there is almost no enforcement of fishing regulations. Illegal fishing occurs on a large scale on a daily basis (Figure …..) . Up to ten fishing boats were observed fishing on the reef every day during the surveys. Most fishing boats use encircling nets on the reef that result in damage to the reef structure. This fishing methods also result in the indiscriminate capture of all species resulting in a rapid decrease in fish biomass. The absence of large and mid-sized fish such targeted as food such as large parrotfish, rabbitfish, large groupers, snappers and sweetlips is an indicator of heavy fishing pressure.

4. The reduction of herbivores such as parrotfish and rabbitfish can have major impacts on the reef by reducing the cropping rate and thus the ability to control algal

growth. High algal cover is known to inhibit coral recruitment and therefore impact the ability of the reef to recover. Therefore reducing the fishing pressure inside the reef and strict monitoring of fishing activities is urgently required.

5. Setting aside the key coral reefs to recover at least for five years with community and all other stakeholder participation, creating greater awareness among all public to obtain their support is required.

6. Sri Lanka Navy with its resources could be a potential partner in reef monitoring. Floating buoys can be erected with the support of SL Navy and Sri Lanka Coast Guards thus, DWC can effectively manage the sanctuary.

7. Current study indicated minimal presence of marine debris entangled in the reef. However this was due to a recent cleaning conducted in the site. Developing a protocol for reef cleaning and adoption of scientific methods for cleaning is essential. Periodic monitoring is also recommended to determine the impact of ocean currents, wind direction and other factors on arrival of debris to reef.

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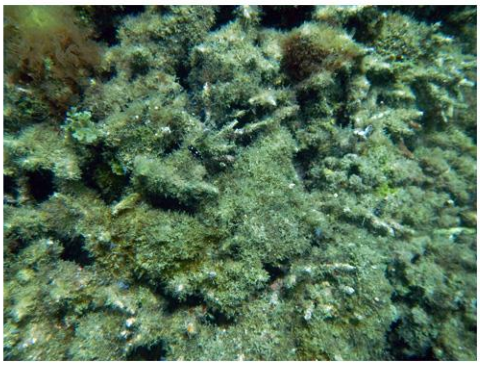
Appendixes

Appendix I. Photos showing substrate cover with dead corals and coral rubbles at site 01.

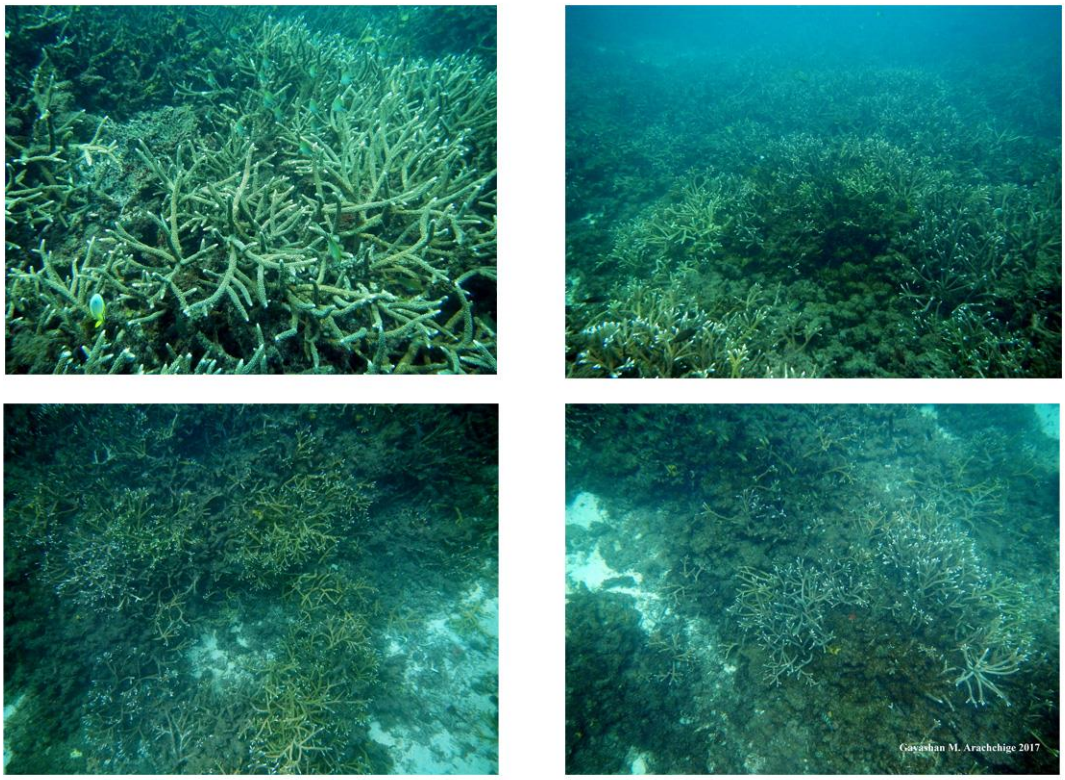
Appendix II. Photos showing substrate cover with dead corals and coral rubbles at site 02.

Appendix III. Photos showing substrate cover with dead corals at site 03.



Appendix IV. Photos showing substrate cover with dead corals and live hard corals at site 04.

Appendix V. Photos showing substrate cover with dead corals and live hard corals at site 05.



Appendix VI. Photos showing substrate cover with dead corals and coral rubbles at site 06.

Appendix VII. Photos showing substrate cover with dead corals and coral rubbles at site 07.




Appendix VIII. Photos showing substrate cover with hard rock, live hard corals, dead and bleached corals at site 08.

Appendix IX. List of coral species recorded at Bar Reef.

Family	**Species**
Acroporidae	*Acropora cytherea* (Dana, 1846)
Acroporidae	*Acropora muricata* (Dana, 1846)
Acroporidae	*Montipora aequituberculata* (Bernard, 1897)
Agariciidae	*Pavona clavus* (Dana, 1846)
Dendrophylliidae	*Turbinaria* spp.
Faviidae	*Echinopora lamellosa* (Esper, 1795)
Faviidae	*Favites abdita* (Ellis & Solander, 1786)
Faviidae	*Leptoria* sp.
Faviidae	*Platygyra lamellina* (Ehrenberg, 1834)
Pocilloporidae	*Pocillopora damicornis* (Linnaeus, 1758)
Pocilloporidae	*Pocillopra verrucosa* (Ellis and Solander, 1786)
Poritidae	*Porites rus* (Forskal, 1775)

Appendix X. List of reef fish species recorded at Bar Reef during survey period.

Family	Species	Common name
Acanthuridae	*Acanthurus blochii*	Ringtail surgeonfish
Acanthuridae	*Acanthurus leucosternon*	Powder blue surgeonfish
Acanthuridae	*Acanthurus lineatus*	Lined surgeonfish
Acanthuridae	*Acantharus triostegus*	Convict surgeonfish
Acanthuridae	*Acanthurus xanthopterus*	Yellowfin surgeonfish
Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish
Acanthuridae	*Ctenochaetus* spp.	
Acanthuridae	*Zebrasoma desjardinii*	Indian sailfin tang
Acanthuridae	*Zebrasoma scopas*	Two-tone tang
Apogonidae	*Apogon aureus*	Ring-tailed cardinalfish
Apogonidae	*Apogon nigrofasciatus*	Blackstripe cardinalfish
Apogonidae	*Cheilodipterus macrodon*	Large-toothed cardinalfish
Balistidae	*Balistapus undulatus*	Orange-lined triggerfish
Balistidae	*Rhinecanthus rectangulus*	Wedge-tail triggerfish
Balistidae	*Sufflamen chrysopterus*	Halfmoon triggerfish
Belonidae	*Strongylura incisa*	Reef needlefish
Blenniidae	*Aspidontus taeniatus*	False cleanerfish
Blenniidae	*Cirripectes* sp.	
Blenniidae	*Istiblennius* sp.	
Blenniidae	*Salarias* sp.	
Caesionidae	*Caesio caerulaurea*	Blue and gold fusilier
Caesionidae	*Pterocaesio tesselata*	One-stripe fusilier
Carangidae	*Caranx melampygus*	Bluefin trevally
Carangidae	*Gnathanodon speciosus*	Golden trevally
Chaetodontidae	*Chaetodon collare*	Redtail butterflyfish
Chaetodontidae	*Chaetodon decussatus*	Indian vagabond butterflyfish
Chaetodontidae	*Chaetodon lineolatus*	Lined butterflyfish
Chaetodontidae	*Chaetodon octofasciatus*	Eightband butterflyfish
Chaetodontidae	*Chaetodon plebeius*	Blueblotch butterflyfish
Chaetodontidae	*Chaetodon trifasciatus*	Melon butterflyfish
Chaetodontidae	*Heniochus acuminatus*	Pennant coralfish

Chaetodontidae	*Heniochus monoceros*	Masked bannerfish
Cirrhitidae	*Paracirrhites forsteri*	Blackside hawkfish
Gerridae	*Gerres* sp.	
Gobiidae	*Gobiodon* sp.	
Kyphosidae	*Kyphosus* sp.	
	Plectorhinchus ceylonensis	Sri Lanka sweetlips
Haemulidae	*Plectorhinchus schotaf*	Minstrel sweetlips
Haemulidae	*Plectorhinchus vittatus*	Indian Ocean oriental sweetlips
Haemulidae	*Pomadasys* sp.	
Hemiramphidae	*Hemiramphus* sp.	
Holocentridae	*Myripristis hexagona*	Doubletooth soldierfish
Holocentridae	*Myripristis* sp.	
Holocentridae	*Sargocentron caudimaculatum*	Silverspot squirrelfish
Holocentridae	*Sargocentron cornutum*	Threespot squirrelfish
Holocentridae	*Sargocentron spiniferum*	Long-jawed squirrelfish
Labridae	*Cheilinus chlorourus*	Floral wrasse
Labridae	*Coris Formosa*	Queen coris
Labridae	*Epibulus insidiator*	Sling-jaw wrasse
Labridae	*Gomphosus caeruleus*	Green birdmouth wrasse
Labridae	*Halichoeres hortulanus*	Checkerboard wrasse
Labridae	*Halichoeres marginatus*	Dusky wrasse
Labridae	*Halichoeres timorensis*	Timor wrasse
Labridae	*Halichoeres* sp.	
Labridae	*Hemigymnus fasciatus*	Barred thicklip
Labridae	*Labroides dimidiatus*	Bluestreak cleaner wrasse
Labridae	*Macropharyngodon ornatus*	False leopard
Labridae	*Thalassoma hardwicke*	Sixbar wrasse
Labridae	*Thalassoma janseni*	Jansen's wrasse
Labridae	*Thalassoma lunare*	Moon wrasse
Lethrinidae	*Lethrinus harak*	Thumbprint emperor
Lutjanidae	*Lutjanus decussatus*	Checkered snapper
Lutjanidae	*Lutjanus fulviflamma*	Dory snapper
Lutjanidae	*Lutjanus quinquelineatus*	Five-lined snapper

Monodactylidae	*Monodactylus argenteus*	Silver moony
Mullidae	*Parupeneus barberinus*	Dash-and-dot goatfish
Mullidae	*Parupeneus indicus*	Indian goatfish
Muraenidae	*Gymnothorax favagineus*	Laced moray
Muraenidae	*Gymnothorax javanicus*	Giant moray
Pempheridae	*Pempheris* sp.	
Pinguipedidae	*Parapercis* sp.	
Pomacanthidae	*Apolemichthys xanthurus*	Yellowtail angelfish
Pomacanthidae	*Centropyge multispinis*	Dusky angelfish
Pomacanthidae	*Pomacanthus imperator*	Emperor angelfish
Pomacanthidae	*Pomacanthus semicirculatus*	Semicircle angelfish
Pomacentridae	*Abudefduf vaigiensis*	Indo-Pacific sergeant
Pomacentridae	*Amphiprion nigripes*	Maldive anemonefish
Pomacentridae	*Amphiprion sebae*	Sebae anemonefish
Pomacentridae	*Chromis atripectoralis*	Black-axil chromis
Pomacentridae	*Chromis dimidiata*	Chocolatedip chromis
Pomacentridae	*Chromis ternatensis*	Ternate chromis
Pomacentridae	*Chromis viridis*	Blue green damselfish
Pomacentridae	*Chrysiptera unimaculata*	Onespot demoiselle
Pomacentridae	*Dascyllus trimaculatus*	Threespot dascyllus
Pomacentridae	*Neoglyphidodon bonang*	Ocellated damsel
Pomacentridae	*Neopomacentrus azysron*	Yellowtail demoiselle
Pomacentridae	*Plectroglyphidodon dickii*	Blackbar devil
Pomacentridae	*Plectroglyphidodon lacrymatus*	Whitespotted devil
Pomacentridae	*Plectroglyphidodon leucozonus*	Singlebar devil
Pomacentridae	*Pomacentrus chrysurus*	Whitetail damsel
Pomacentridae	*Pomacentrus indicus*	Indian damsel
Pomacentridae	*Pomacentrus philippinus*	Philippine damsel
Pomacentridae	*Pomacentrus similis*	Similar damsel
Pomacentridae	*Stegastes nigricans*	Dusky farmerfish
Scaridae	*Chlorurus rhakoura*	Raggedfin parrotfish

Scaridae	*Chlorurus sordidus*	
Scaridae	*Scarus* spp.	
Scorpaenidae	*Pterois volitans*	Red lionfish
Scorpaenidae	*Scorpaenopsis oxycephala*	Tassled scorpionfish
Serranidae	*Aethaloperca rogaa*	Redmouth grouper
Serranidae	*Cephalopholis argus*	Peacock hind
Serranidae	*Cephalopholis formosa*	Bluelined hind
Serranidae	*Epinephelus hexagonatus*	Starspotted grouper
Serranidae	*Epinephelus merra*	Honeycomb grouper
Siganidae	*Siganus argenteus*	Streamlined spinefoot
Siganidae	*Siganus javus*	Streaked spinefoot
Siganidae	*Siganus lineatus*	Golden-lined spinefoot
Zanclidae	*Zanclus cornutus*	Moorish idol

Appendix XI. List of invertebrate species recorded at Bar Reef during survey period.

Class	Order	Family	Species
Asteroidea	Valvatida	Acanthasteridae	*Acanthaster planci*
	Valvatida	Ophidiasteridae	*Linckia guildingi*
	Valvatida	Ophidiasteridae	*Linckia multifora*
	Valvatida	Oreasteridae	*Culcita schmideliana*
	Valvatida	Oreasteridae	*Protoreaster lincki*
Echinoidea	Stomopneustoida	Stomopneustidae	*Stomopneustes variolaris*
Holothuroidea	Aspidochirotida	Holothuriidae	*Holothuria atra*
	Aspidochirotida	Holothuriidae	*Holothuria edulis*
	Aspidochirotida	Stichopodidae	*Stichopus chloronotus*
Gastropoda	Littorinimorpha	Cypraeidae	*Cypraea tigris*

Appendix XII. Photographs of some of the recorded coral species during the survey period.

Acropora spp.

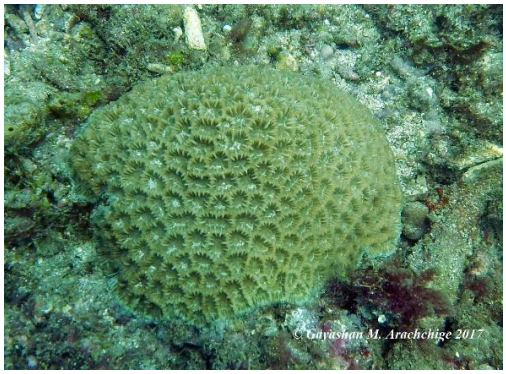
Acropora spp.

Acropora spp.

Acropora spp.

Turbinaria sp.

Dipsastrea sp.



Favites spp.

Favites spp.

Favites spp.

Leptoria sp.

Platygyra spp.

Platygyra spp.

Porites sp.

Symphilia sp.

Lobophytum spp.

Lobophytum spp.

Sinularia sp.

Appendix XIII. Photos of some of the reef fish species recorded from the Bar Reef during the survey period.

Acantharus leucosternon

Acanthurus lineatus

Acantharus triostegus

Ctenochaetus striatus

Zebrasoma desjardinii

Gnathanodon speciosus

Heniochus monoceros

Chaetodon collare

Chaetodon decussatus

Chaetodon plebeius

Chaetodon trifasciatus

Heniochus acuminatus

Plectorhinchus sp.

Plectorhinchus ceylonensis

Plectorhinchus vittatus

Myripristis hexagona

Sargocentron cornutum

Cheilinus chlorourus

Coris formosa

Halichoeres hortulanus

Labroides dimidiatus

Thalassoma jansenii

Thalassoma hardwicke

Lutjanus quinquelineatus

Lutjanus decussatus

Gymnothorax javanicus

Apolemichthys xanthurus

Pomacanthus semicirculatus

Pomacanthus imperator

Abudefduf vaigiensis

Chromis atripectoralis

Chromis ternatensis

Dascyllus trimaculatus

Pomacentrus chrysurus

Pomacentrus similis

Cephalopholis formosa

Plectroglyphidodon lacrymatus

Chlorurus sordidus

Epinephelus merra

Siganus javus

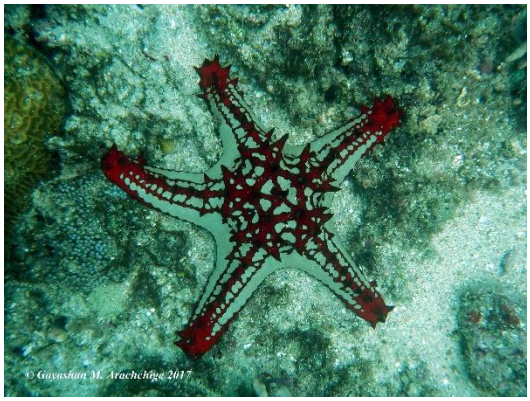
Siganus lineatus

Zanclus cornutus

Appendix XIV. Star fish species recorded during the survey.

Acanthaster planci

Culcita schmideliana



Protoreaster linckii

Linckia multifora

Linckia guildingi

Appendix XV. Sea urchins species recorded during the survey.

Stomopneustes variolaris

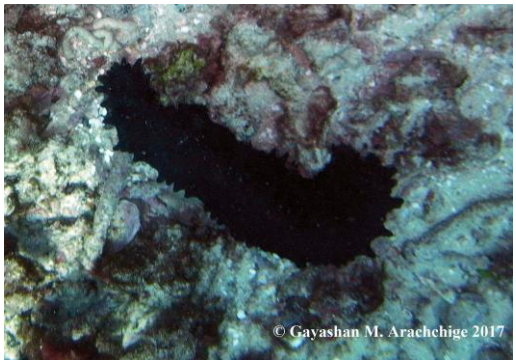
Echinostrephus molaris

Metalia sternalis

Appendix XVI. Sea cucumber species recorded during the survey.

Holothuria atra

Holothuria edulis



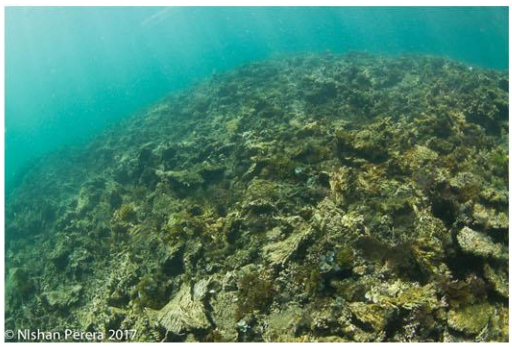
Stichopus chloronotus

Appendix XVII. Mollusk species recorded during the survey.

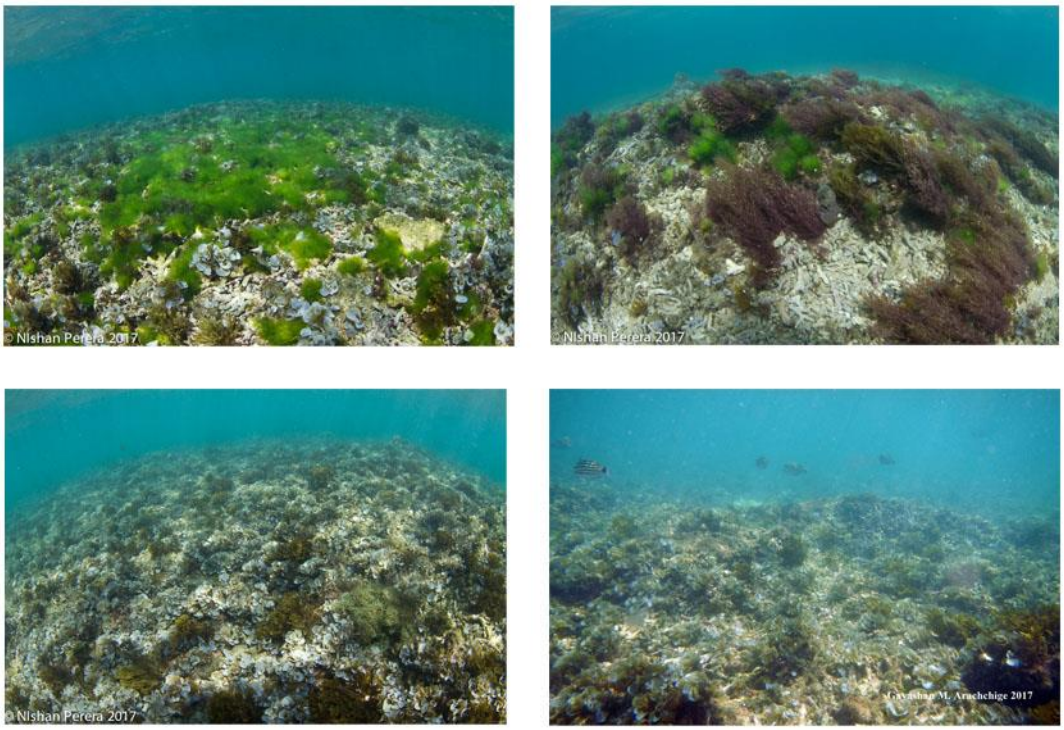
Cypraea tigris

Aplysia sp

Appendix XVIII. Collapsed, dead coral structures at Bar Reef.



Appendix XIX. Algae growing on rubble mound at shallow reef crest in Bar Reef.



Appendix XX. Live hard coral among extensive dead coral area at Bar Reef.