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Five Years in Bacalar Chico Marine Reserve:
an evaluation of reef health and reserve effectiveness between 2011-2015.

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This report is dedicated to Mr. Isaias Majil.

Cover image: A Blue Ventures volunteer diving in the backreef of Bacalar Chico Marine Reserve. Credit: Emma Muench.

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Acronyms

AGRRA	Atlantic and Gulf Rapid Reef Assessment
BBRRS	Belize Barrier Reef Reserve System
BCMR	Bacalar Chico Marine Reserve and National Park
CZ	Conservation Zone
DHW	Degree Heating Week
EDGE	Evolutionary Distinct and Globally Endangered
FMA	Fleshy Macroalgae
GUZ	General Use Zone
HC	Hard Coral
HRI	Healthy Reef Initiative
IUCN	International Union for Conservation of Nature
MBRS	Mesoamerican Barrier Reef System
MBRS-SMP	Mesoamerican Barrier Reef Synoptic Monitoring Program
MPA	Marine Protected Area
NBCC	Northern Belize Coastal Complex
NGO	Non-governmental organization
NTZ	No take zone
PIT	Point Intercept Transect
PZ	Preservation Zone
REEF	Reef Environmental Education Foundation
SIRHI	Simplified Integrated Reef Health Index
SST	Sea Surface Temperature

Abstract

The increase in negative impacts due to unsustainable tourism practices, overfishing, marine pollution and global climate change has made coral reefs one of the world's most threatened ecosystems. In order to improve the resilience of reefs to global changes, local stressors need to be managed. Historically, marine protected areas (MPAs) have been one of the most commonly applied tools for coral reef conservation, with variable success in restoring fisheries or benefitting reef health. Bacalar Chico Marine Reserve (BCMR) was established in northern Belize in 1996 as a small multiple-use MPA. In order to evaluate the management effectiveness of BCMR, dive surveys following the Mesoamerican Barrier Reef System Synoptic Monitoring Program (MBRS-SMP) protocol were conducted at ten sites within the reserve and two control sites outside the reserve over a five-year period (2011–15). Additional surveys were conducted on queen conch (*Lobatus gigas*) and Caribbean spiny lobster (*Panulirus argus*), both important commercial species in Belize, along with opportunistic sightings of megafauna recorded during routine activities. Results show that coral reef health in BCMR is ranked at Poor to Critical status under the Simplified Integrated Reef Health Index (SIRHI) scale. This ranking was based on several factors, including a significant decline in fish biomass between 2011–15, with Critical commercial fish biomass and herbivorous fish biomass in 2015. Although hard coral cover increased from Poor in 2011 to Fair in 2015 it was lower than the 2015 national average (15%), and fleshy macroalgae cover was higher than the 2015 national average (24%). The abundance of lobster and queen conch varied across management zones but with no significant difference between the years. Five species of ray, two species of shark and three species of marine turtle were sighted in BCMR between 2011–15; there was no significant difference per zone for elasmobranch sightings, and turtle sightings only differed significantly between reef types. There was minimal or no measurable influence of the different management zones on coral reef condition or the populations of commercial and endangered species. On the basis of these results, a reassessment of the management approach for BCMR is strongly recommended, including a review of the location of management zones, the implementation of an updated management plan, strengthening the enforcement of reserve regulations, and improving ridge-to-reef management focusing on land-based pollution within the Northern Belize Coastal Complex.

Executive summary

Background

Over the last 50 years, coral reefs have been declining rapidly in terms of health and global reef area, which has been attributed to increasing human activities and climate change (Wilkinson, 2006). This decline has resulted in reduced reef fish density, biodiversity, and coral coverage, affecting the resilience of reef ecosystems to global climatic stressors. To help arrest this decline, local impacts such as unsustainable tourism practices, overfishing and marine pollution must be managed and mitigated where possible. The use of marine protected areas (MPAs) has been one of the most commonly applied tools for coral reef conservation, with variable success in restoring fisheries or recovering coral reef health (Armfield, 2008).

Situated in northern Belize within the Belize Barrier Reserve System, a UNESCO World Heritage Site, Bacalar Chico Marine Reserve (BCMR) was established in 1996 as a small multiple use MPA, with levels of protection ranging from General Use Zones (fishing activities permitted) to Conservation and Preservation Zones (only recreational activity and scientific diving permitted, respectively). In the past, coral reef health in BCMR has been negatively impacted due to overfishing and hurricanes, and is presently being further affected by elevated nutrient input from land-based activities (Healthy Reef Initiative, 2015) as well as ineffective protection (Dahlgren, 2014).

Chapman (2012) assessed the coral reefs within BCMR, and concluded that the reefs were in Poor condition under the Simplified Integrated Reef Health Index (SIRHI, Appendix 1). The reefs exhibited low hard coral (HC) cover, high fleshy macroalgae (FMA) cover and low fish density.

Evaluating BCMR status

Blue Ventures established a monitoring programme in BCMR in 2010. The programme includes surveys of habitat composition, coral bleaching and disease, mobile invertebrates, fish biomass and megafauna. It provides a comprehensive evaluation of the effectiveness of management measures within BCMR. This report analyses the results of the programme over five years, between 2011 and 2015.

SCUBA-based surveys were conducted at ten sites representing different reef habitats within each management zone of the reserve. In addition, two control sites outside the MPA boundaries were also surveyed, thus facilitating spatial and temporal comparisons over a five-year period (2011–15). Protocols for dive surveys of fish and benthic communities followed the Mesoamerican Barrier Reef System Synoptic Monitoring Program (MBRS-SMP). This ensured national and regional comparability (Sale et al., 2003). Dedicated surveys were conducted for coral bleaching and disease incidence, and for the abundance of key fishery invertebrates (conch and lobster). Opportunistic sightings of megafauna were also recorded during routine activities.

Results

Coral reef health (SIRHI)

The results in this study echo those obtained by Chapman (2012), with most surveyed sites displaying a reef health ranking between Poor and Critical condition on the SIRHI scale. The study also found that the coral reef benthic community has shifted from HC to FMA dominance; the density of important herbivorous fish families such as parrotfish (*Scaridae*) and surgeonfish (*Acanthuridae*) are low; groupers (*Serranidae*) and snappers (*Lutjanidae*), both important commercial species, are critically low; and coral bleaching and disease prevalence has increased over the years.

Overall, the existing management zones exert minimal influence on reef health within BCMR. In 2011, the majority (66%) of the sites were scored in Critical condition and 33% in Poor condition; this did not significantly differ or improve across the study period. Only one site within BCMR scored in Good condition during this time; this site is located in the General Use Zone, and achieved the score in 2013. The predominantly low SIRHI index scores across all sites and years is attributed to depleted herbivorous and commercial fish biomass, high FMA cover and low HC cover.

Reef health indicators: fish biomass, FMA and HC cover

Mean fish biomass inside the reserve declined significantly between 2011 and 2015, with commercial fish and herbivorous fish biomass at their lowest levels of 267.13 ± 62.36 g/100 m^2 (mean ± SE) and 937.88 ± 144.61 g/100 m^2 respectively in 2015. Mean FMA cover remained consistently high, with the reef scoring in Poor condition on this metric from 2011 to 2014 followed by a decline into Critical (27.00 ± 1.36%) condition in 2015. Mean HC cover showed an increase from Poor (11.26 ± 1.06%) in 2011 to Fair (13.16 ± 0.86%) in 2015, with fluctuations in mean percentage cover across the period. Nonetheless, HC cover (13.16 ± 0.86%) for BCMR in 2015 remains lower than the 2015 national average (15%) and FMA cover (27.00 ± 1.36%) is higher than the 2015 national average (24%) (Healthy Reef Initiative, 2015).

Fish community

A total of 140 fish species from 38 families were observed within BCMR during 218 fish species richness surveys. New species were observed throughout the five-year surveying period and the cumulative species curve has yet to level out, suggesting that more surveys are needed before all species within BCMR have been observed. Based on survey results to date, it is unlikely that the total richness of the area will exceed 145 species.

Blue tang (*Acanthurus coerulus*) and French grunt (*Haemulon flavolineatum*) were the most frequently observed species, recorded on 98.55% and 98.48% of all fish rover surveys, respectively. Almost as frequently observed were striped parrotfish (*Scarus iseri*) at 97.85%, redband parrotfish (*Sparisoma aurofrenatum*) at 97.16% and white grunt (*Haemulon plumierii*) at 95.29%.

Overall fish abundance and biomass within BCMR decreased significantly during the period between 2011–2015. In 2015, the mean fish abundance for all species was 36.47 ind/100 m^2 and the mean biomass was 1933 g/100 m^2.

Recruit abundance remained consistently around 27 ind/100 m^2 between 2012 and 2015 with no significant difference over time in any management zones. The year 2011 was not included in the recruit abundance analysis as no data were available from the Preservation Zone for this period; only sites with recruit data available in every year were used.

Reef type did not influence total abundance of juveniles in any management zone, although reef type was a predictor of difference in juvenile community structure, with forereefs having a significantly higher abundance of yellowhead wrasse (*Halichoeres garnoti*) and backreefs having a higher abundance of blue tang and slippery dick (*Halichoeres bivittatus*).

Benthic community

The reef benthic community of BCMR is primarily dominated by FMA, a situation which might be due to high nutrient input from nearby land-based activities, combined with low herbivorous fish density within the reserve. Conversely, the important invertebrate reef herbivore *Diadema antillarum* or the long-spined sea urchin, a key grazer of algae, is extremely low in number, with mean abundance averaging 0.0032 ± 0.0019 ind/m^2 per year. The highest mean FMA percentage cover across BCMR during the study period was at 27.00% in 2015.

Hard coral cover changed significantly over the study period, from the lowest level of 8.83% in 2012 to the highest of 14.77% in 2014. There was no significant difference in HC cover between management zones across all years. Mean HC cover was found to be significantly higher on forereef sites (16.84%) in comparison to backreef sites (8.24%). Coral community structure also differed between reef types; in 2015, for example, 11 coral species were recorded solely on forereef sites.

Coral bleaching and disease

Throughout the study there was a significant increase in the proportion of coral colonies with evidence of bleaching, rising from 14% in 2011 to 32% in 2015. Although poor coral health can be attributed to large scale natural forces, such as hurricanes and climate change (Hinrichen, 1997; Mumby et al, 2014b), the proportion of bleached corals was not found to correlate with either the presence of a High Degree Heating Week (DHW), or the intensity of DHW. There was a significant difference in disease prevalence among coral colonies between years, rising from 4.5% in 2011 to 8.5% in 2014 before falling again in 2015 to 6.6%.

In 2015, nine out of thirty-six species of coral identified in BCMR were either listed as EDGE (Evolutionarily Distinct and Globally Endangered) priorities or on the International Union for Conservation of Nature (IUCN) Red List as threatened.

Queen conch and Caribbean spiny lobster

Belize's important commercial invertebrate species, the queen conch and the Caribbean spiny lobster, showed variable spatial abundance with a higher number recorded in the no take zone (NTZ) of the reserve compared to zones permitting extractive fishing. However, there was no difference in annual abundance for any management zone. There was also no difference in the abundance of either species between the open and closed fishing seasons, regardless of management regime.

Megafauna sightings

The most commonly sighted elasmobranch was the southern stingray (*Dasyatis americana*) (53% of sightings), followed by nurse shark (*Ginglymostoma cirratum*) (21%) and spotted eagle ray (*Aetobatis narinari*) (17%). Yellow stingray (*Urolophus jamaicensis*) and lesser electric ray (*Narcina brasiliensis*) were the least frequently spotted (< 4%). No difference was detected in overall elasmobranch sightings between years or management zones. However, ray species did show a significant difference between management zones across the study period, with more rays sighted in the Preservation Zone (PZ).

BCMR supports several species of globally threatened sea turtle. The most frequently sighted were hawksbill turtles (*Eretmochelys imbricata*) (44% of sightings) followed by loggerhead (*Caretta caretta*) (32%) and green turtles (*Chelonia mydas*) (14%). There was no significant difference in sea turtle sightings between management zones, seasons or years. As West Indian manatee (*Trichechus manatus*) sightings were extremely rare, this species was excluded from the analysis.

Conclusion and recommendations

Bacalar Chico Marine Reserve has been protected and managed since 1996, reef health has been observed to be in poor condition, and according to our analysis, its condition continues to deteriorate. Between 2011 and 2015, fish biomass has decreased, incidence of coral bleaching and disease has increased, and FMA cover has remained consistently high. Nonetheless, the increase in HC cover during the study period is an important positive trend, and moreover the BCMR represents a refuge for several threatened coral species present on the EDGE and IUCN Red lists. BCMR also supports a diverse suite of megafauna species including the endangered West Indian manatee and three species of threatened sea turtles.

It is believed that the decline in coral reef health in BCMR is due to a combination of historical factors that have reduced the health of the reef ecosystem (overfishing, past coral bleaching, disease events and hurricanes), and ongoing factors that continue to impact the reef today, such as watershed pollution, unsustainable coastal development, and the acceleration of global climate change. The results also indicate that the existing management zonations implemented in BCMR are not positively influencing fish populations, the benthic community or overall reef health.

Based on these results it is strongly recommended that the reserve design be reviewed and an updated management plan developed for BCMR; to include recommendations to reduce and mitigate impacts on the reef and improve land-based pollution monitoring and management. These recommendations should include the involvement of all local stakeholders and relevant actors.

Tables 1 and 2 below present a summary of recommendations for the reduction of land-based pollution impacts for the reef and management effectiveness of BCMR

Table 1. Summary of recommendations to reduce land-based pollution impact on reefs.

Pollutant reduction target	Establish a National Water Quality Programme for the scientific community, public and Government. Include all parameter analyses regarding pollution runoff.
Partner collaboration	Review target source of pollutant and recommend actions with agricultural experts. Plan the implementation of best farming practice with agricultural experts to reduce land-based pollution, e.g. organic or integrated farming.
Education and outreach	Educate land users about the impact of herbicides and pesticides on coral reefs. Carry out workshops to encourage farmers to implement new farming practices based on expert advice.
Support for farming innovation	Ensure that NGOs and Government support the process of learning, adapting and implementing new farming practices. Provide low interest loans or insurance to assist with the upfront cost of improved practices. Ensure that NGOs and Government are carrying out research and development of new pollution reduction practices in the agricultural sector. Implement National Water Quality Programme that legislates to ensure reef safe standards and hold polluters accountable for infringements of these standards. Introduce product certification for sustainable farming methods.

Table 2. Summary of recommendations to improve MPA effectiveness.

Coral reef status	Continuously evaluate BCMR coral reef health indicators.
MPA design	Consult with stakeholders to review survey results, and invite input into reserve design, as data shows that the current design is ineffective
Staff training	Ensure rangers are able to successfully carry out surveillance and enforcement through providing capacity building and necessary equipment. Build capacity with relevant staff in order to continue research and monitoring activities. Work with local users to establish a coordinated network of rangers. Involve coastal community participation to increase surveillance and enforcement for Northern Belize Coastal Complex (NBCC).
Funding	Review the reserve management plan to determine financial gaps. Address financial gaps through diversifying funding base. Improve internal financial system to reduce cost of operations and facilities. Partner with NGOs and share the reserve operations and costs.
Education and awareness	Strengthen communication and collaboration with current and potential partners to increase education and outreach amongst stakeholder communities and the general public. Disseminate results from research on MPAs to stakeholders. Ensure fisheries users, tour guides and visitors are aware of rules and regulations of the reserve. Encourage local communities and schools to visit the reserve. Involve local communities in education activities and outreach events.
Stakeholder involvement	Management plan reassessment should follow a bottom up process. All local stakeholders and authorities should be involved.

1 Introduction

1.1 Blue Ventures' Coral Reef Monitoring Programme

Blue Ventures is an international marine conservation organisation that works in collaboration with coastal communities for whom the sea is culturally and economically important. The organisation works with these communities to develop effective, adaptive and locally appropriate conservation strategies, designed to sustain their small-scale fisheries. In 2010, Blue Ventures established a coral reef monitoring programme in Bacalar Chico Marine Reserve (BCMR), located at the far north of Ambergris Caye, Belize. The aim of this programme is to provide information concerning the health of the reserve's coral reefs and associated ecosystems. The data, collected through a volunteer programme, are used to assess the health of the reefs throughout BCMR and, working in collaboration with the Belize Fisheries Department, to evaluate how well the reserve is contributing to long-term fishery sustainability.

1.2 The Mesoamerican Barrier Reef System and the Belize Barrier Reef

The Belize Barrier Reef forms part of the Mesoamerican Barrier Reef System (MBRS), which is the second longest barrier reef system in the world (Healthy Reef Initiative, 2010). It extends for 1,000 km from the Yucatan Peninsula, Mexico (18°50 N, 89°07 W) to the Bay Islands in Honduras (16°17 N, 86°24 W) (Figure 1), and is home to a range of habitats, such as mangroves, seagrass beds, lagoons, estuaries and coral reefs. The MBRS is environmentally important as it helps to stabilise and protect the coastal landscape from wave erosion (Perkins et al., 1985; Kramer and Kramer, 2002), sustains species of commercial and ecological importance (Healthy Reef Initiative, 2010), and provides breeding and feeding grounds for marine mammals, reptiles, fish and invertebrates.

Furthermore, the MBRS is socially important as it generates employment through tourism and fisheries for approximately one million people living in coastal zones adjacent to the reef system (Sale et al., 2003). Fisheries within the Belize Barrier Reef have become increasingly important to the Belizean economy since the 1970s, contributing to the employment of around 3,000 fishers (Pomeroy et al., 2003). Queen conch and Caribbean spiny lobster are the primary target species for Belizean fisheries due to the high value (Heyman et al., 2000). Finfish such as snapper, grouper, and barracuda (*Sphyraena barracuda*) are also widely targeted by fishers, both for subsistence and to be sold locally in markets or to restaurants and resorts.

Figure 1. Map of The Mesoamerican Barrier Reef System, reproduced from Healthy Reefs Initiative, 2015.

Despite the environmental and social importance of the MBRS, it is declining in health. A recent study of the MBRS by Kramer et al. (2015) found that only 9% of reefs were rated in Good to Very Good condition (according to the SIRHI system, Appendix 1), while the majority of reefs surveyed (57%) were in Poor to Critical condition. Compared with the MBRS overall, the Belize Barrier Reef appears to be in slightly worse health, as no reefs were found to be in Very Good condition, only 4% were in Good condition and 96% were in Poor to Critical condition (Healthy Reefs Initiative, 2015). This decline in reef health in Belize has been attributed to poor tourism practices, overfishing, marine pollution and unsustainable coastal development (Mumby et al., 2014a; Williams et al., 2015), as well as the damaging effects of global climate change, including increasing sea surface temperatures (SST) leading to increased prevalence of coral disease and bleaching (Aronson et al., 2001), and an increase in the frequency and intensity of storms (Hinrichsen, 1997; Jones et al., 2011).

1.3 Marine protected areas and the Bacalar Chico Marine Reserve

Marine protected areas (MPAs) can be an effective tool for protecting biodiversity, reef health and populations of key fisheries species (Dahlgren, 2014) for the benefit of local communities who rely on these reefs for their livelihoods (Healthy Reef Initiative, 2012). In Belize, 13 MPAs have been established and are managed either by the Belize Fisheries Department or in co-management initiatives between the department and communities or NGOs. The aims of MPAs in the region focus on sustainable fishing, tourism, research and education (Wildtracks, 2012). These MPAs are divided into usage zones, ranging from those that allow certain degrees of extractive or non-extractive use, to those given full protection from all activities.

Bacalar Chico Marine Reserve (BCMR), established in 1996 under the Fisheries Act (Laws of Belize, chapter 210, revised 2000), is located on the northern tip of Ambergris Caye (San Pedro) and shares a border with Mexico. The MPA covers 6,303 hectares of marine area encompassing seagrass beds, coral reef patches, lagoon and mangrove habitats (Dahlgren, 2009), and is located in an area with high terrestrial and marine biodiversity (Grimshaw & Paz, 2004). The east-facing beaches are important nesting sites for three species of sea turtles (loggerhead, green, and hawksbill). The MPA also encompasses spawning aggregation sites for species such as black grouper (*Mycteroperca bonaci*), dog snapper (*Lutjanus jocu*) and horse-eye jacks (*Caranx latus*). In addition, BCMR is recognised as an important conch nursery for both Belizean and Mexican conch fisheries (Wildtracks, 2009).

The MPA is divided into several zones (Figure 2), each with different management strategies; two General Use Zones, two Conservation Zones and one Preservation Zone. The latter is completely protected, with no commercial or recreational activities permitted. Recreational activities such as SCUBA diving and snorkelling are allowed in Conservation Zone 1 (CZ1), though no fishing is permitted. Conservation Zone 2 (CZ2) allows non-extractive sport fishing in addition to the aforementioned activities. The two General Use Zones (GUZs) allow extractive fishing; however, gear restrictions are in place in the form of a ban on gill nets and long lines, and fishers are required to possess fishing licenses. BCMR was established as a site for monitoring and research, ecotourism and job opportunities for local guides (Wildtracks, 2009).

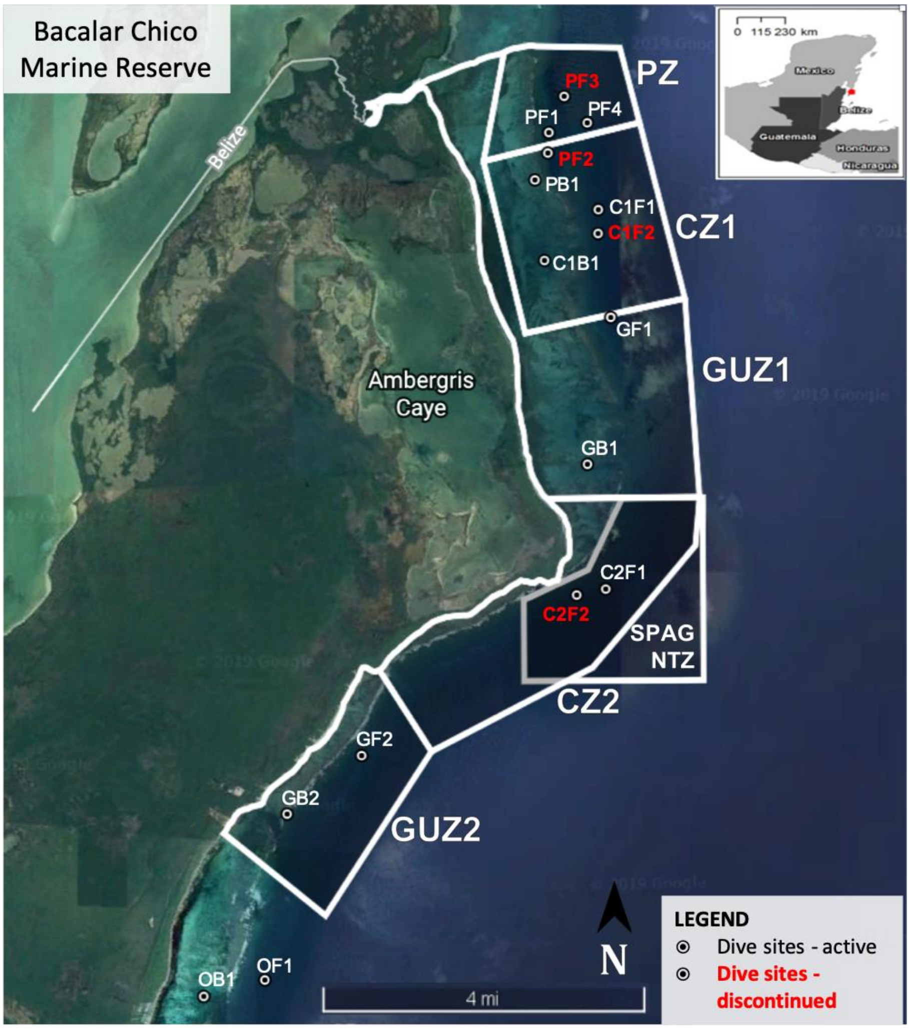


Figure 2. Map of Bacalar Chico Marine Reserve with different management zones and dive sites highlighted. (PZ – Preservation Zone; CZ – Conservation Zone; GUZ – General Use Zone; SPAG NTZ – Spawning Aggregation No Take Zone).

1.4 Coral reef ecology

1.4.1 Reef habitat

Global studies have indicated that a high level of biodiversity on coral reefs is strongly related to coral reef structural complexity (Alvarez et al., 2011), which creates a heterogeneous environment that provides shelter for other marine life, leading to an increase in fish and invertebrate populations (Graham et al., 2012). The Belize Barrier Reef is a complex ecosystem which supports a high diversity of organisms (Dumas, 2009), including commercially targeted species such as Caribbean spiny lobster and queen conch.

However, over recent decades, coral reef health in Belize has declined considerably (Schutte et al., 2010), resulting in a reduction in live coral cover and a phase shift from coral to macroalgae dominated reef systems (Suchley et al., 2016).

Marine protected areas have been shown to counteract the decline of habitat health on reefs (Halpern et al., 2002; Lester et al., 2009). Reefs isolated from human impact through reserve protection are more likely to recover from natural disturbance events such as coral bleaching (Mumby et al., 2010), have healthier benthic communities through the effects of trophic cascading (Soler et al., 2015), and can benefit unprotected coral communities through the export of larvae (Gaines et al., 2010; Russ et al., 2011).

1.4.2 Coral community health

Despite the relatively isolated location of BCMR, it is still subject to human-induced local and regional stressors, in addition to global stressors such as an increase in SST and ocean acidification due to climate change. With the rise in SST, the number of bleaching events both in the Caribbean and globally has been increasing along with increased spread of pathogens and disease (Table 3; The Nature Conservancy, 2016). During a recent major bleaching event in the Caribbean in 2005, 27.9% of Belize's coral colonies were bleached and 6.5% were killed (McField et al., 2008). Another threat affecting corals in BCMR is hurricanes, as the strength of waves produced by Category 4 and 5 hurricanes can have a devastating effect on reefs by destroying fragile coral colonies, such as elkhorn coral (*Acropora palmata*) and staghorn coral (*Acropora cervicornis*) (Kleypas & Hoegh-Guldberg, 2008). However, tropical storms or hurricanes can sometimes have a beneficial influence by reducing thermal stress and SST through three mechanisms: (1) absorbing thermal energy from surface waters; (2) inducing local upwelling and bringing deeper, cooler water to the surface; (3) hurricane clouds shading the ocean surface from solar heating (Heron et al., 2008).

Table 3. List of diseases which may affect coral species of concern in Bacalar Chico Marine Reserve.

Disease	Acronym	Pathogens	Number of species affected	Species of concern
White Plague	WP	Bacterium	42	*Orbicella* spp., *Mycetophyllia* spp., *Dendrogyra* spp.
Caribbean Ciliate Infection	CCI	Foliculinid ciliates	22	*Orbicella* spp., *Acropora* spp., *Dichocoenia* spp.
Black Band Disease	BBD	Bacteria	19	*Obicella* spp.
Dark Spot Disease	DSD	Unknown	16	*Orbicella* spp.
Caribbean Yellow Band Disease	CYBD	Bacteria	11	*Orbicellaa* spp.
Red Band Disease	RBD	Cyanobacteria	9	*Mycetophyllia* spp., *Orbicella* spp.
White Band Disease	WBD	Bacterium	2	*Acropora* spp.

White Patch	WPA	Bacterium	1	*Acropora palmata*

Ocean warming, land-based pollution, sedimentation and overfishing are all key contributing factors to coral disease outbreaks (The Nature Conservancy, 2016). Even though there is no major coastal development adjacent to BCMR, the dominant current patterns bring human land-based pollution from the south which can contaminate the coral communities of the MPA. The town of San Pedro has an inefficient sewage treatment system (Belize Water System, 2013), and is located only 21 km south of the border of BCMR General Use Zone 2 (GUZ2). There are also several hotel resorts located adjacent to GUZ2 that could be producing land-based pollution.

The waters of BCMR are affected by river-runoff from the Rio Hondo, New River, and coastal lagoons of the mainland which flow through the Corozal Bay Wildlife Sanctuary (SACD, 2015). Both of these rivers run through areas with intensive agriculture and are considered to be heavily polluted (Marisol & Rojas, 2014; Noren, 2007) (Figure 3).

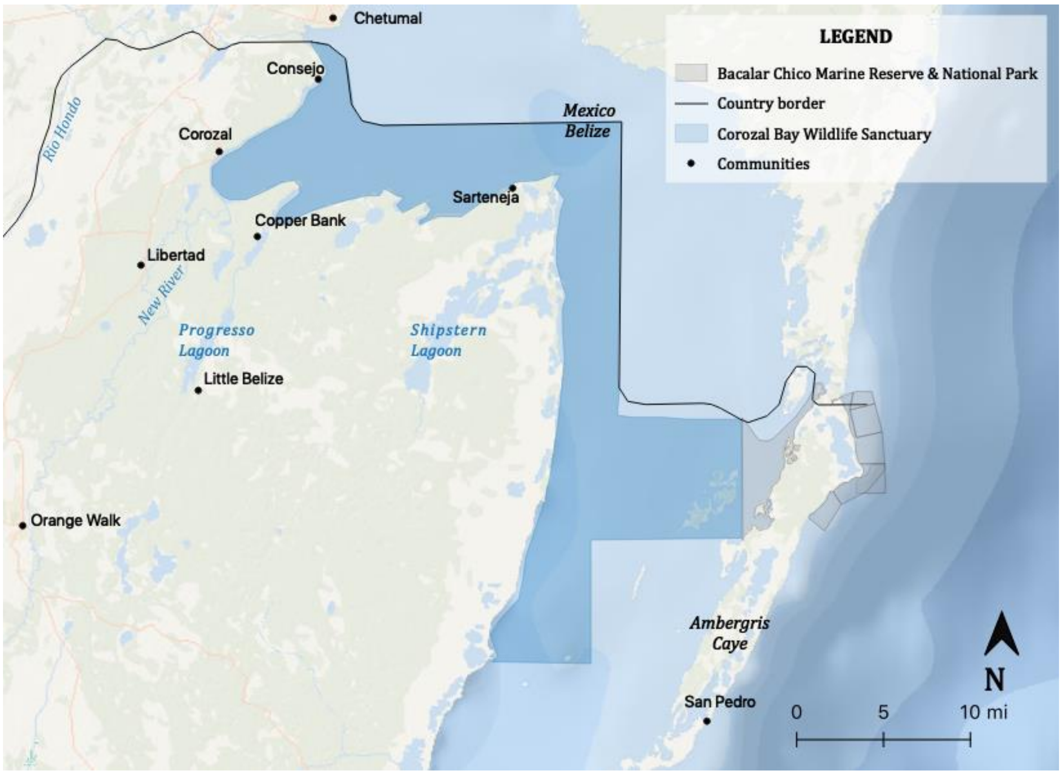


Figure 3. River-to-reef map of the Northern Belize Coastal Complex with local rivers and lagoons featured.

1.4.3 Mobile invertebrates

Long-spined sea urchin (Diadema antillarum)

The long-spined sea urchin (*Diadema antillarum*) is one of the most important grazers and bioeroders on Caribbean reefs (Carpenter, 1981; Ogden & Lobel, 1978; Sammarco et al., 1974). Historically, long-spined sea urchin was abundant on Caribbean coral reefs, seagrass beds, mangrove and sand habitats, often attaining very high population densities (Bauer, 1980; Randall et al., 1964). In 1983–84, a still unidentified pathogen caused a mass mortality of this species in the Caribbean, depleting most populations by more than 93% (Carpenter, 1990; Lessios et al., 1984). As an immediate response to the reduced grazing pressure of long-spined sea urchin, macroalgal cover dramatically increased on shallow water reefs throughout the Caribbean (Carpenter, 1990; Levitan, 1988; Liddell & Ohlhorst, 1986).

The increase in macroalgae resulted in reduced rates of coral recruitment and contributed to a phase shift from coral to macroalgae on shallow reefs (Hughes et al., 1987; Sammarco, 1980). The dramatic impact of the removal of long-spined sea urchin from the ecosystem shows its importance as a keystone species in structuring reef communities (Lessios et al., 1984; Pinnegar et al., 2000) (Figure 4). Reefs that have recovered to pre-1984 urchin densities (1.7–12 urchins m^{-2}) have seen a decrease in macroalgal cover and an increase in coral recruitment (Carpenter & Edmunds, 2006; Edmunds & Carpenter, 2001). McField and Kramer (2007) and Healthy Reef (2008) suggest that a density < 1 urchin m^{-2} to be considered too low and indicate that a density between 1.1 – 7 urchins m^{-2} would help to support the health of a reef community. However, urchin densities throughout the Mesoamerican Barrier Reef region generally remain lower than 1 urchin m^{-2}, particularly on forereefs (Kramer, 2003).

The role of marine reserves in the recovery of long-spined sea urchin is controversial. On the one hand, healthy long-spined sea urchin populations promote high coral cover as grazing decreases fleshy macroalgae cover and increases coral recruit settlement on healthy reefs which in theory are found inside marine reserves (Mumby and Harborne, 2010). On the other hand, reduced fishing pressure in marine reserves has been shown to result in higher numbers of urchin.

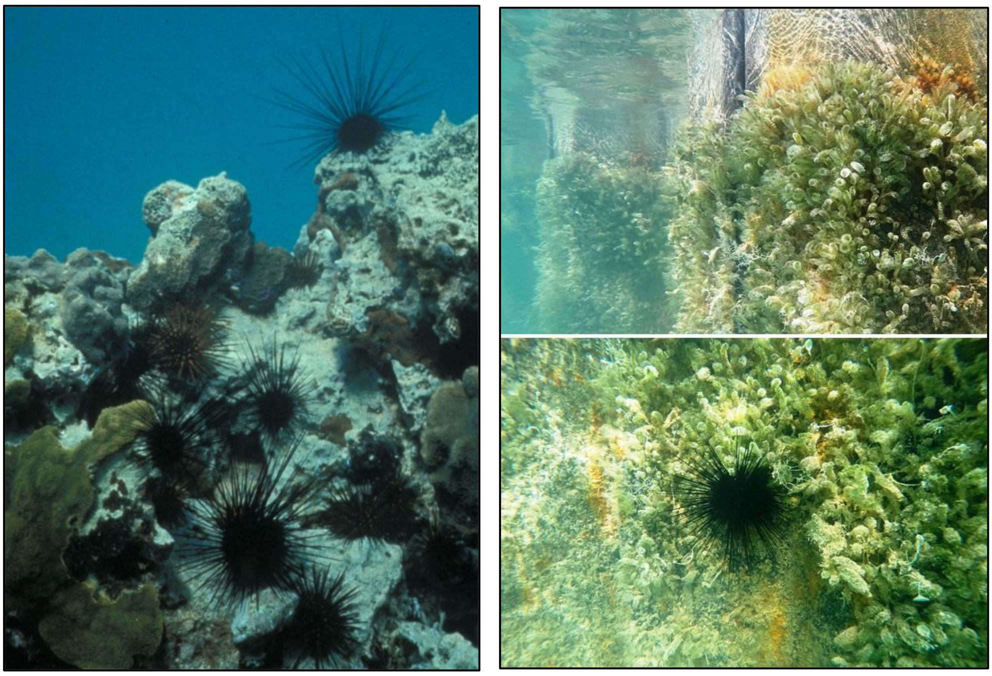


Figure 4. Examples of environments with a healthy density of long-spined sea urchin (left) and the results of herbivorous activity of a transplanted urchin before (above) and after (below), photos reproduced from Precht & Cordy (2015).Caribbean spiny lobster and queen conch

Caribbean spiny lobster (hereafter 'lobster') and queen conch (Figure 5) are Belize's primary fishing targets; lobster is the most important commercial fishery in Belize with exports totalled at 193 tons in 2011, valued at 36 USD per kilogram. Queen conch exports totalled 240 tons, valued at 13 USD per kilogram (Zeller et al., 2011).

Since the 1980s, total national landings have been relatively stable, although catch per unit effort has decreased (Fisheries Department, 2016; Huitric, 2005). Consequently, there is concern that national stocks are declining due to unsustainable fishing pressure and threatening fishers' livelihoods. For this reason, effective management of national fisheries stocks is crucial (Berkes, 2001).

In addition to their commercial importance, queen conch and lobster play ecologically important roles. Lobster has been shown to be important in structuring communities via predation (Acosta, 1999) and queen conch is an important herbivorous grazer. Juvenile conch also provide an important food source for a wide variety of predators (Iversen et al., 1986; Stoner, 1989; Stoner & Glazer, 1998; Stoner & Ray, 1993; Stoner et al., 1995).

Figure 5. Caribbean spiny lobster (left) and queen conch (right).

In the 1970s, the Belize Government introduced conservation measures, which aim to allow these species to mature and reproduce before entering the fishery. Fishery closures run from February 14th to June 13th for lobster and from July 1st to September 30th for conch, and size limits (a minimum carapace length (8 cm) and tail weight (113 g) for lobster, and a minimum shell length (18 cm) and market clean weight (85 g) for conch are in effect throughout the open season. In lobster fisheries, it is also prohibited to catch egg-carrying 'berried' females or recently-moulted 'soft-shelled' lobster (Theile, 2001).

Marine protected areas have been shown to be an effective conch and lobster fisheries management tool by providing refuge areas in the form of NTZs, which allow these species to reproduce and ultimately replenish populations in adjacent fished areas (Acosta, 2001; Eggleston & Parsons, 2008). Studies in Belize, Bahamas, Turks and Caicos and Florida found densities of queen conch and lobster to be several times higher in NTZs than in general use zones (GUZs), demonstrating the potential effectiveness of MPAs in benefiting conch and lobster stocks (Acosta, 2006; Bene & Tewfik, 2003; Chicas & Williams, 2012; Hagen, 2010; Stoner et al., 2012). Furthermore, some studies found that individuals were larger in NTZs than in GUZs (Acosta, 2006).

For queen conch, studies conducted in the Bahamas on mating and egg-laying are directly related to density of mature adults, requiring a minimum abundance of at least 50 mature individuals per ha^{-1} (Stoner & Ray-Culp, 2000). In fished zones, densities were mostly below this minimum threshold (Stoner et al., 2012). Although less is known about the effectiveness of closed seasons in replenishing populations in BCMR, Brown (2012) reported higher conch densities in the replenishment zones (the Preservation Zone and Conservation Zones 1 & 2 of BCMR, see section 4.4) in both the closed and open season compared to the other zones.

Flamingo Tongue

According to the Lamar University (2018), Flamingo tongues (*Cyphona gibbosum*) are marine gastropods that are commonly found on coral reefs in the Caribbean as well as the tropical western Atlantic. These gastropods average size ranges from 1.8 to 3 centimetres and are commonly found at depths of 2 to 15 metres. Flamingo tongues are common predators of soft corals such as; sea rods, sea plumes, sea fans and sea whips.

1.4.4 Fish community

Abundance, biomass and richness

Loss of total abundance, biomass or diversity of reef fish leads to declines in ecosystem functionality and reef resilience (Guillemot et al., 2014; Pratchett et al., 2011), and negatively impacts local, commercial and artisanal fisheries (Daskalov et al., 2007; Pinnegar et al., 2000).

Measuring the biomass of commercially important fish species helps to understand changes in coral reef communities, such as trophic structure and reproductive output, and to identify anthropogenic impacts such as overfishing (McField & Kramer, 2007). Overfishing directly impacts fish assemblages through removing individual fish, especially large individuals, in addition to reducing the reproductive potential and larval recruitment of fish (McField & Kramer, 2007).

Herbivorous fish populations represent another key factor influencing coral reef health, vital in controlling the benthic composition of algae and corals (Burkepile & Hay, 2008). Macroalgae directly competes with corals for space by inhibiting the outward growth of coral, inhibiting the recruitment of coral larvae by overgrowing space for settlement (pre-empting space), or by overgrowing coral directly (McField & Kramer, 2007; Williams & Polunin, 2001). A high abundance of grazing fish species, especially members of the parrotfish and surgeonfish families, is required to maintain low macroalgae cover on reefs, with large-bodied parrotfish being especially effective at cropping macroalgae (McField & Kramer, 2007; Williams & Polunin, 2001). Changes in herbivorous fish biomass result in significant changes in coral reef community structure, and low abundance of grazer species populations results in rapid macroalgae growth (Kopp et al., 2010; Smith et al., 2001). With long-spined sea urchin populations still recovering from the 1980s disease outbreak, the burden of algal control falls on herbivorous fish species, making the sustainable management of such populations essential for coral recovery in the Caribbean (McField & Kramer, 2007; Newman et al., 2006).

Fish diversity is the measurement of different fish species inhabiting a certain spatial region, and represents a further important indicator in determining reef health (McField & Kramer, 2007). The greater the fish diversity, the healthier and more resilient the reef (Hiddink et al., 2008). Decreases in fish diversity and abundance, particularly rare or range-specific species, are indicators of declining reef health (McField & Kramer, 2007). High biodiversity and abundance of fish species also enhances the success of water-based tourism (Hiddink et al., 2008). Marine protected areas are frequently employed as a tool to maintain the biomass, abundance and species richness of fish communities, as they provide a refuge for populations to increase in abundance, size, and reproductive potential (Gell & Roberts, 2003). Through strict protection, previously impacted fish assemblages can recover to healthy levels of biomass and diversity, leading to the reassembly of trophic structure and ecosystem functionality in the long term (Newman et al., 2006).

Juvenile Fish

The mechanism of fish recruitment is defined as the addition of new individuals to populations, or to successive life-stages within populations (Caley et al., 1996). Understanding how, when and where juvenile fish recruit on coral reefs can provide insight into the population dynamics and community structures of adult coral reef fish.

Protected areas that are effective at improving fish populations can become sources of larvae (Almany et al., 2009), potentially benefitting fisheries on near or distant reefs through larval dispersal (Harrison et al., 2012). However, there has been little research investigating whether the establishment of protected areas encourages reef fish recruitment within the protected areas themselves. Instead, juvenile fish have been known to preferentially recruit to areas of good habitat health (Dixson et al., 2014; Lecchini et al., 2013). By pinpointing the drivers behind the recruitment of reef fish on a local scale, we can adapt management strategies to best encourage reef fish population growth, thus benefitting both fisheries and reef ecosystem health as a whole.

1.4.5 Megafauna

Sharks and rays (Elasmobranchs)

Sharks and rays play important ecological roles in coral reef ecosystems, and reductions in their abundances can lead to changes in community structure through trophic cascading (Ferretti et al., 2010; Heithaus et al., 2007; Stevens et al., 2000). These species are particularly impacted by fishing due to low growth rates, late sexual maturity and low fecundity (Frisk et al., 2001; Myers & Worm, 2005). Commercial fishing, by-catch and artisanal fishing are the primary threats to sharks and rays followed by habitat destruction and pollution (Dulvy et al., 2014).

Belizean waters are known to support several species of sharks and rays (Walker and Walker, 2009), including several threatened species such as the whale shark (*Rhincodon typus*; Endangered) and the great hammerhead (*Sphyrna mokarran*; Endangered). Chapman (2013) reported the most commonly sighted species in the BCMR include nurse sharks, southern stingrays and spotted eagle rays.

Sea turtles

Sea turtles are iconic species used in marine conservation efforts in the Caribbean, and their magnetism has been used as a means to garner public support for contemporary conservation issues and marine environmental management (Eckert & Hemphill, 2005). They are also keystone species in coral reef and seagrass communities (Bjorndal & Jackson, 2003). However, they are threatened by: coastal development damaging their nesting sites (Harrison, 2005), reef habitat change (Lal et al., 2010), pollution (Schuyler et al., 2014) and commercial and artisanal fishing (Bräutigam & Eckert, 2006; Gray & Kennelly, 2018). As highly migratory animals with complex life histories, local impacts, on nesting beaches for example, can affect turtle populations over large geographic scales (Carreras et al., 2013; Lohmann et al., 1997). For example, green turtles tagged in Costa Rica were found to migrate to Belize (Troeng et al., 2005) and juvenile hawksbill turtles from Belize have been found to travel to foraging grounds in West Africa (Monzon-Arguello et al., 2011), underlining the need for local and global understanding of turtle populations.

Five species of marine turtle occur in Belize, the most common being hawksbill, green and loggerhead turtles, all of which have nesting sites along the Belizean coastline and are considered either Endangered or Critically Endangered by the IUCN Red List (Seminoff & Shanker, 2008). Leatherback (*Dermochelys coriacea,* Endangered) and olive ridley (*Lepidochelys olivacea,* Vulnerable) turtles have also been sighted in Belizean waters.

1.5 Objectives

1.5.1 Reef ecology

- Assess whether BCMR has delivered any benefits to coral reefs in the area, identify spatial variations in habitat health within the reserve, and assess whether reef health has changed over time.

1.5.2 Coral community

- Assess the health, diversity and percentage cover of Scleractinian corals.
- Analyse coral bleaching and sea surface temperature monitoring data to assess species-specific sensitivity, reef resilience and recovery potential, and examine whether the protection of coral species can improve their resilience to the effects of human disturbance.
- Examine the health of the coral communities inside and outside BCMR by looking at the incidence of bleaching, disease and other afflictions, to the coral community in general and highlighting impacts to EDGE/IUCN Red Listed species.
- Identify any patterns in coral distribution as well as how coral health changes over space and time so that we can better understand how to protect these keystone species in the future.

1.5.3 Mobile invertebrates

- Long-spined sea urchin Assess long-spined sea urchin density in different management zones within BCMR and at control forereef and backreef sites beyond the reserve over time, therefore assessing the impact of the reserve on their populations.

Caribbean spiny lobster and queen conch

- Determine the current status and trends in abundances of queen conch and lobster.
- Compare queen conch and lobster populations in take and NTZs in BCMR during open and closed fishing seasons, to determine if the BCMR or seasonal fishery closures have impacted populations.

1.5.4 Fish community

Abundance, biomass and richness

- Assess the health of reef fish populations in BCMR by examining how total biomass and abundance changes over time.
- Evaluate spatial and temporal trends in populations of key herbivorous (parrotfish and surgeonfish) and commercial (snappers and groupers) fish families.
- Determine the total species richness of BCMR and evaluate the impact of BCMR on fish populations.

Juvenile fish

- Assess juvenile fish abundance over time across management zones and reef types in the BCMR.
- Investigate the relationship between juvenile fish abundance and hard coral coverage.

1.5.5 Megafauna

- Assess whether management of the BCMR is having an effect on shark and ray populations, whether the frequency of sightings has changed over time, and determine which elasmobranchs are sighted most often.
- Determine whether turtle sightings have changed over time, which turtles are sighted most frequently, and whether there is a difference in turtle sightings between forereefs and backreefs or between management zones.

2 Methodology

2.1 Site description

Bacalar Chico Marine Reserve is divided into five management zones (Figure 2), each with its own management approach. Bordering Mexico at the northern end of the reserve is the Preservation Zone (PZ) which is an NTZ where no recreational activities are permitted. Researchers with special permission granted by the Belize Fisheries Department are allowed to visit this zone. On the backreef, the zone is characterised by coral reef patches, sea grass meadows and sand patches. The forereef encompasses a double reef system which is separated by a sandy channel that runs from Mexico and into the PZ.

Adjacent to the PZ is Conservation Zone 1 (CZ1) which is also a NTZ, but recreational activities are allowed such as scuba diving and snorkelling. Areas of seagrass meadow, coral reef, and deep sand can be found at the backreef while the forereef is predominantly composed of a spur and groove system which faces eastwards and extends into the deep.

In Conservation Zone 2 (CZ2), catch and release fishing is regulated along with the aforementioned recreational activities. The north of CZ2 is unique as it contains the only area within Belize where the barrier reef meets with the land creating a fringing reef system. In the south the forereef consists of further spur and groove sites while the backreef consists of coral reef patches and large sandy patches.

Fishing is permitted by licensed fishers in General Use Zones 1 and 2 (GUZ1 and GUZ2), which are located on the northern and southern sides of CZ2. The forereef consists of both spur and groove reef and flat reef sites, while the backreef is relatively shallow with reef patches and extensive seagrass beds. Also considered within the GUZ1 is the mangrove survey site. Monitoring of the mangrove site is conducted in a selected location in a mangrove channel which connects Lovers Tunnel and Cantena Creek.

In order to select sites within BCMR which fulfilled the criteria for surveys, field scientists from Blue Ventures obtained a general description of reef locations and topography of the different management zones using the manta tow technique, a technique used to provide a general description of large areas of reef and to gauge broad changes in abundance and distribution of organisms on coral reefs (Caroline et al., 1994). In 2011, 12 sites were selected within the management zones to be surveyed; in 2012, four of the original sites were discontinued and were replaced by four new sites, two of which were control sites representing unprotected areas outside the marine reserve. Sites were selected in both the backreef and the forereef, and within each management zone of the BCMR.

2.2 Reef monitoring programme

Prior to 2011, Blue Ventures' reef monitoring programme in BCMR followed a simplified version of the MBRS-Synoptic Monitoring Program (MBRS-SMP) methodology (Sale et al., 2003); from 2011, the monitoring programme followed the MBRS-SMP method accurately, ensuring comparable data and enabling detailed analysis of the reef's ecological status (Chapman, 2013). The BCMR monitoring programme includes surveys of habitat composition, coral bleaching and disease, mobile invertebrates, and fish biomass, as well as a dedicated log for opportunistic sightings of megafauna.

Sites were scheduled to be surveyed during different months throughout the year (Table 4), driven by site accessibility due to weather conditions: the southern portion of the reserve is difficult to access during the

Norte season[1] due to large swell. Therefore, most of the sites located in the southern portion of the reserve were surveyed during the dry (March to June) and rainy (July to October) seasons, while sites in the northern portion of the reserve were surveyed during the *Norte* season (November to February).

Table 4. Months in which sites were surveyed in 2011–2015.

Zone	Site name	Site code	Reef type	2011	2012	2013	2014	2015
Preservation Zone	Tarpon Patch	PB1	Backreef	Feb	Jan	Mar/Aug	Mar/Aug	Feb/Sep
	Garden Wall	PF1	Forereef	Feb	Jan	Mar/Aug	Mar/Aug	Feb/Aug
	Moose Country	PF2	Forereef	Sep	Discontinued			
	Hot Point	PF3	Forereef	May	Discontinued			
	Pig Sty	PF4	Forereef	Oct	Oct	May/Oct	May/Oct	May/Oct-Dec
Conservation Zone 1	Last Resort	C1B1	Backreef	Oct	Dec	Jun/Dec	Jun/Dec	
	Alleys	C1F1	Forereef	Nov	Nov	Jun/Dec	Jun/Dec	Jun/Dec
	Canyons	C1F2	Forereef	Jun	Discontinued			
General Use Zone 1	Peccary Patch	G1B1	Backreef	Mar	Feb	Mar/Aug	Mar/Aug	May/Sep
	Goliath	G1F1	Forereef	Sep	Oct	May/Oct	May/Oct	Apr/Oct-Dec
Conservation Zone 2	Rocky Point North	C2F1	Forereef	Dec	Oct	May/Sep	May/Oct	May/Oct
	Rocky Point South	C2F2	Forereef	Jul	Discontinued			
General Use Zone 2	Rainbow Reef	G2B1	Backreef	-	Jun	Jun	Aug	Aug
	The Anchor	G2F1	Forereef	-	Jul	Aug	Aug	Oct
Outside	Palm Springs	OB1	Backreef	-	Jul	Aug	Aug	Aug
	Control	OF1	Forereef	-	Jul	Jul	Jul	Aug

The survey sites, as described by Chapman (2012), are as follows:

Tarpon Patch – PB1

Location: North section of BCMR

Zone: Preservation Zone (PZ)

Reef type: Backreef

Description: There is scattered patch reef close to the reef crest with a few large colonies of thin leaf lettuce coral (*Undaria tenuifolia*) and lobed star coral (*Orbicella annularis*), though predominantly comprised of

[1] The *Norte* (northern) season runs from late November to mid-January, when the jet stream dips far south and creates northerly winds and showers in areas of Belize and Mexico.

smaller colonies of lesser starlet coral (*Siderastrea radians*), massive starlet coral (*Siderastrea siderea*), knobby brain coral (*Pseudodiploria clivosa*) and symmetrical brain coral (*Pseudodiploria strigosa*). Large aggregations of grunts (*Haemulids*) are frequently observed. Between coral colonies, large numbers of queen conch are found scattered on the sandy seabed. Depth of 1–2 m.

Hot Point – PF3 (discontinued in 2012)

Location: North section of BCMR

Zone: Preservation Zone (PZ)

Reef type: Forereef

Description: A reef flat on the eastern ridge of the double-reef system, with a gentle slope along the west of the site to a sandy bottom at approximately 20 m deep. Large colonies of elkhorn coral are located at approximately 6 m at the rocky pinnacle of the site, and a large colony of pillar coral (*Dendrogyra cylindrus*) located on the north-western corner at approximately 12 m. Depth of 8–12 m.

Pig Sty – PF4

Location: North section of BCMR

Zone: Preservation Zone (PZ)

Reef type: Forereef

Description: A reef flat on the eastern ridge of the double-reef system, with a gentle slope along the west of the site to a sandy bottom at approximately 20 m deep. Large colonies of elkhorn coral are located at approximately 6 m at the rocky pinnacle of the site, where lobster is frequently observed. Depth of 8–12 m.

Garden Wall – PF1

Location: North section of BCMR

Zone: Preservation Zone (PZ)

Reef type: Forereef

Description: A reef flat on the western ridge of the double-reef system, with a steep wall along the east of the site to a sandy bottom at approximately 20 m deep. Large colonies of elkhorn coral, lobed star coral and mountainous star coral (*Orbicella faveolata*) are scattered throughout the area, providing crevices which shelter lobster as well as a great diversity of fish. Depth of 7–12 m.

Moose Country – PF2 (discontinued in 2012)

Location: North section of BCMR

Zone: Preservation Zone (PZ)

Reef type: Forereef

Description: On the western ridge of the double-reef system, south of PF1, the reef flat is shallower and closer to the crest of the barrier reef. Large colonies of elkhorn coral are abundant, providing crevices in which long-spined sea urchin are frequently observed. Depth of 5–8 m.

Canyons – C1F2 (discontinued in 2012)

Location: North section of BCMR

Zone: Conservation Zone 1 (CZ1)

Reef type: Forereef

Description: The reef tops are separated by deep sandy channels, which become increasingly deeper eastwards until eventually the reef structure breaks up deeper than 30 m. There is a relatively high diversity of coral species throughout the site, with large mountainous star coral colonies on the reef tops and knobby cactus (*Mycetophyllia aliciae),* ridged cactus *(Mycetophyllia lamarckiana)*, Fragile Saucer (*Agaricia fragilis)* and white star sheet lettuce (*Aaricia lamarcki)* coral colonies on the reef walls. Depth of 10–15 m.

Alleys – C1F1

Location: North section of BCMR

Zone: Conservation Zone 1 (CZ1)

Reef type: Forereef

Description: The reef tops are separated every 10–20 m by thin sandy channels 16–18 m deep. Large sheets of mountainous star coral are present on the reef tops, lobed star coral colonies also occur. The channels open up on the eastern edge of the site as the reef gets deeper. Depth of 10–15 m.

Peccary Patch – GB1

Location: North section of BCMR

Zone: General Use Zone 1 (GUZ1)

Reef type: Backreef

Description: Large long-dead coral colonies of elkhorn coral protrude above the surface of the water at the centre of the patch reef, with newer coral colonies attached to the dead sections and successive colonies expanding outwards from this central coherent section. Large colonies of living elkhorn coral are present at the south of the reef and a gorgonian bed is present to the west. Crevices amongst their dead colonies provide habitat for lobster. Large aggregations of grunts are frequently observed. Depth of 1–2 m.

Goliath – GF1

Location: North section of BCMR

Zone: General Use Zone 1 (GUZ1)

Reef type: Forereef

Description: Spur and groove formation reef with consistently high diversity in coral and fish sightings. Deep grooves provide habitat for many large groupers, including goliath grouper (*Epinephelus itajara*), Nassau grouper (*Epinephelus striatus*), black grouper and yellowfin grouper (*Myctoperca venenosa*). Depth of 12–15 m.

Last Resort – C1B1

Location: North section of BCMR

Zone: General Use Zone 1 (GUZ1)

Reef type: Backreef

Description: Coherent patch reef close to a large channel, which often affects current and water clarity. Two large colonies of thin lettuce leaf coral (*Undaria tenuifolia*) cover the south-eastern side of the reef, and high reef rugosity has facilitated the formation of a large number of crevices, which shelter lobster. Large aggregations of grunt and snapper are frequently observed. Depth of 3–5 m.

Rock Point North – C2F1

Location: South section of BCMR

Zone: Conservation Zone 2 (CZ2)

Reef type: Forereef

Description: Fringing reef with a steep wall which drops to a gorgonian bed at approximately 20 m. The wall is characterised by the presence of numerous caves and overhangs, which provide shelter for a wide variety of fish species, including large black grouper, Nassau grouper and cubera snapper (*Lutjanus cyanopterus*) as well as many lionfish (*Pterois volitans).* Large mixed aggregations of surgeonfish are typically observed on top of the reef flat at approximately 10 m deep. Surveys take place on the reef flat, where a large colony of pillar coral is distinctive. Depth of 10–15 m.

Rocky Point South – C2F2 – (discontinued in 2012)

Location: South section of BCMR

Zone: Conservation Zone 2 (CZ2)

Reef type: Forereef

Description: Fringing reef with a steep wall which drops to a gorgonian bed at approximately 20 m. The wall is characterised by the presence of numerous caves and overhangs, within which large numbers of lionfish can be found. Surveys take place on the reef flat, where a large coral colony of pillar coral is distinctive. Depth of 8–10 m.

The Anchor - GF2

Location: South section of BCMR

Zone: General Use Zone 2 (GUZ2)

Reef type: Forereef

Description: Low spur and groove formation with high abundance of gorgonians such as sea plumes and sea rods on the surface of the spur. Spur and groove formations are widespread with large sand valleys between spurs and small crevasse formations along the spurs. Fleshy macroalgae dominate most of the substrate. Coral cover is poor. Depth of 14–16 m

Rainbow Reef - GB2

Location: South section of BCMR

Zone: General Use Zone 2 (GUZ2)

Reef type: Backreef

Description: A patch reef that is divided by a deep channel with a depth of 20–25 m. On the north side of the channel; patch reef is formed of mainly lobed star coral and on the south side of the channel the patch reef formation is a long dead colony of elkhorn coral which has a steep fall towards the channel that affects current and visibility. Depth of 6–8 m.

Outside Marine Reserve

Palm Spring – OB1

Location: South section of BCMR

Zone: Outside Marine Reserve

Reef type: Backreef

Description: Long dead colonies of elkhorn coral extending to the surface of a huge shallow reef patch. Large congregations of gorgonians are abundant along the reef bed. Very few live coral species such as symmetrical brain coral can be found on the edge of the reef patch. Depth of 3–4 m.

Control – OF1

Location: South section of BCMR

Zone: Outside Marine Reserve

Reef type: Forereef

Description: Spur and groove formations follow from a gorgonian flat plain and are steeper and narrower compared to GF2, with small crevasses along spur. Sandy grooves between the high-relief spurs contain isolated soft corals (sea fans) and macroalgae with occasional hard corals on boulders. Gorgonians are abundant on spur surface. Depth of 14–16 m.

Mangrove

Location: Bacalar Chico Marine Reserve and National Park

Zone: General Use Zone 1

Reef Type: N/A

Description: The mangrove site is a swim through area connecting Lovers Tunnel and Cantena Creek within the mangrove channels. This area connects Bacalar Chico Marine Reserve to the Bacalar Chico National Park located inside of Corozal Bay. Generally, a few species of snapper, mojarra and needlefish are found within the water way or nestled in the water around the root system of the mangroves. Depth 1-2 m.

2.3 Reef benthic communities

Habitat composition surveys are used in coral reef monitoring programmes to assess temporal fluctuations and trends in reef state in response to natural forces or management action (Hill et al., 2004).

Blue Ventures used the point intercept transect (PIT) method to assess the percentage cover of the different benthic organisms as illustrated in Appendix 2. Surveys consisted of five PITs that were laid arbitrarily, at least 2 m apart, at depths between 1 and 5 m on backreef sites, and between 8 and 15 m on forereef sites. Transects were 30 m in length, and followed the contours of the reef. The observer recorded any coral, algae or other substrate type located directly beneath the transect point at every 25 cm, totalling 120 points per transect. This data was used to calculate the proportion of cover for each benthic category. Further, following the Healthy Reef Initiative’s (HRI) Simplified Integrated Reef Health Index (SIRHI) system two of the main indicator's, HC and FMA, mean values of the proportion of cover were calculated to determine overall scores (Appendix 1).

Binomial generalised mixed effects models (GLMs) that include both fixed and random effects were run using PIT data to determine the drivers behind changes in algae and hard coral cover. The fixed variables included management zone, reef type and location (north/south), and the year was used as the random factor. These spatial models tested for differences between years. Models were repeated for each algal type as well as for hard coral as a whole.

Binomial GLMs were run on percentage cover of algae and hard coral to compare benthic composition six months before the impact of hurricane Ernesto (1–10 August, 2012) and in the six months afterwards; data from all sites in BCMR were used in these models.

2.4 Coral bleaching and disease

Fifty hard coral colonies were systematically selected from PITs for further assessment. To be selected, the colony had to exceed 10 cm in diameter and cross the transect line. The total distance travelled to encounter fifty coral colonies was recorded.

For each of these fifty hard coral colonies, data were collected on: morphometrics (diameter at widest point and the maximum height); mortality (visual estimation of percent of coral colony from plan view, with differentiation between recently killed and long dead coral); bleaching (visual estimation of percent of coral colony from plain view, with differentiation between pale and full bleaching); the incidence of disease, and any other additional information that may affect the health of a coral colony (e.g. presence of orange icing sponge, encrusting mat tunicate, brown encrusting sponge, fish bites, etc.).

These data were used to draw conclusions concerning coral community structure, i.e. which coral species were most abundant in different management zones or at different sites. It was also used to calculate the proportion of corals that showed signs of bleaching or disease. Binomial GLMs were run to test whether the prevalence of disease and prevalence of bleaching varied significantly over time, between management zones, between the northern and southern parts of BCMR, and between the forereef and backreef.

2.4.1 Degree Heating Week

Corals experience thermal stress, the main cause of bleaching, when SST exceeds 1°C (1.8°F) above the maximum summertime mean. This stress worsens as the heat anomaly persists. The thermal stress index called Coral Bleaching Degree Heating Weeks (DHW) is a cumulative measurement of the duration and intensity of heat stress that has accumulated in an area over 12 weeks, by summing temperature records that exceeded the bleaching threshold during that time period. When DHW reaches 4° C-weeks (7.2 °F-weeks), significant coral bleaching is likely, especially in more sensitive species. When DHW is 8°C-weeks (14.4 °F-weeks) or higher, widespread bleaching and mortality from thermal stress may occur. A binomial GLM was run to test the correlation between bleaching prevalence and DHW, examining both the number of DHWs exceeding 4° C week^{-1} and the intensity of DHWs (the monthly mean DHW). Degree heating weeks were calculated as per the methods used in McClanahan (2007).

2.5 Mobile invertebrates

Invertebrate belts were used to identify spatial and temporal trends in the abundance of queen conch, lobster, the long-spined sea urchin and the flamingo tongue. Transects were 30 m in length and laid haphazardly at least 5 m apart, at depths between 1 and 5 m on backreef sites, and between 8 and 15 m on forereef sites, with eight transects per site conducted before 2013 and 10 transects per site conducted after 2013. As fish community data were collected along the same transect, in order to not disturb the survey area, the invertebrate surveyor completed the invertebrate belt whilst swimming a minimum of two metres behind the fish surveyor. The invertebrate surveyor swam along a 30 m transect searching for invertebrates within a 2 m belt (1 m each side of the transect tape). There was no time limit for this transect because invertebrates are often cryptic and/or hidden, making them difficult to spot. Flamingo tongue abundance was also surveyed, as lobster, hogfish (*Lachnolaimus maximus*) and pufferfish (*Tetraodontidae)* are major predators of this mollusc. Consequently, the abundance of flamingo tongue has been identified as a potential indicator for these species, especially the lobster (Burkepile & Hay, 2007; Chiappone et al., 2003).

In order to compare the effect of management zones on the abundance of queen conch and Caribbean spiny lobster in BCMR, only data from sites surveyed annually were analysed and tested for differences in the abundance of lobster and queen conch between years, open and closed seasons, and GUZ and NTZ using non-parametric Kruskal Wallis tests, taking into account the fact that data on abundance of lobster and queen conch were not normally distributed.

We ran a GLM model with Poisson errors and year included as the random factor to test whether there is a correlation between flamingo tongue and lobster abundance between GUZ and NTZ.

The changes in abundance of long-spined sea urchin over time and between management zones were tested using ANOVA. Any significant results were followed by post hoc Tukey HSD tests to identify the source of the difference.

Between November 2012 and May 2013, additional sea urchin surveys were conducted to create a snapshot of the drivers behind urchin abundance change over spatial scales. Surveys were conducted using SCUBA underwater visual census at nine sites representing the different management zones in BCMR and unmanaged sites outside the reserve, and covering both forereef and backreef areas. Sea urchin density was calculated using data from nine 10 m^2 circular quadrats at each site. The densities of long-spined sea urchin, rock boring urchin *(Echinometra lucunter)*, reef urchin (*Echinometra Viridis)*, slate pencil urchin (*Eucidaris tribuloides)* and green sea urchin *(Lytechinus variegatus)* were recorded, using flashlights to find any urchins hidden in holes and crevices. The rugosity of each site was calculated using the chain link method (McCormick, 1994). Abundances of herbivorous fishes (those of trophic levels 2.9 or below, fish whose diet is either herbivorous or omnivorous but consists mainly of plant matter; Froese and Pauly, 2000) and those that prey on urchins (black margate (*Anisotremus surinamensis)*, queen triggerfish (*Balistes vetula)*, Spanish hogfish (*Bodianus rufus)*, saucereye porgy (*Calamus calamus)*, ocean triggerfish (*Canthidermis sufflamen)*, spot-fin porcupinefish *(Diodontidae hystrix)*, Caeser grunt (*Haemulon carbonarium)*, Spanish grunt (*Haemulon Macrostomum)*, white grunt, bluestriped grunt (*Haemulon sciurus)*, puddingwife wrasse (*Halichoeres radiatus)*, spotted trunkfish (*Lactophrys bicaudalis)* and permit (*Trachinotus falcatus);* (Randall et al., 1964)) were also recorded using eight 30 m x 2 m fish belts per site (see fish belt methods 2.6.1).

The correlations between urchin abundances, rugosity and the abundances of herbivorous and predatory fish were tested using a GLM model (Poisson error), with month included as a random factor to account for potential seasonality throughout the sampling period.

2.6 Fish

2.6.1 Fish abundance and biomass

Priority fish species (**Error! Reference source not found.**3) were identified and counted by a diver swimming along a bearing, whilst unrolling a 30 m transect and recording species observed within a 2 m wide belt and up to 2 m ahead. The size of priority species observed was estimated and assigned to one of the following size categories: < 5 cm, 5–10 cm, 11–20 cm, 21–30 cm, 31–40 cm, > 40 cm (as per Almada-Villeal et al., 2003). Belts were spaced a minimum of 5 m apart, with eight transects per site conducted before 2013 and 10 transects per site conducted after 2013. At the end of each fish belt the end depth and time were recorded, ensuring that surveys were conducted within depth and time limits of 8–15 m and 6–8 minutes, respectively. The surveys for fish recruits and invertebrates were conducted on the same belt, with a two-minute delay between surveys.

Following the Healthy Reef Initiative's (HRI) Simplified Integrated Reef Health Index (SIRHI) system two of the main indicator's, commercial fish and herbivorous fish, mean values of the biomass (g/100m^2) were calculated to determine overall scores (Appendix 1).

Two-way ANOVA was used to test for differences in fish abundance and biomass between years, between management zones and between forereef and backreef sites. Any significant differences were followed up with post hoc Tukey HSD tests to identify the specific sources of difference.

Non-parametric Kruskal Wallis tests were used to identify any changes in the abundance of herbivorous (parrotfish and surgeonfish) and commercial (grouper and snapper) fish families over time (2011–2015) and between management zone.

2.6.2 Fish recruitment

Fish species listed in Table 5 were identified and counted within a belt of 1 m wide x 30 m long, using the same transect line as the fish belt. Only those up to the maximum size listed were counted. Any other juvenile fish not on the target list but occurring within the belt transect were also recorded.

Table 5. Species of juvenile fish identified in recruitment surveys and the maximum size before they are no longer considered 'juveniles'.

Family	Common name	Species name	Maximum size (cm)
Acanthuridae	Blue tang	*Acanthus coeruleus*	5
	Ocean surgeon	*Acanthurus bahianus*	5
Chaetodontidae	Banded butterfly	*Chaetodon striatus*	2
	Four-eye butterfly	*Chaetodon capistratus*	2
Grammatidae	Fairy basslet	*Grammatidae spp.*	3
Labridae	Bluehead wrasse	*Thalassoma bifasciatum*	3
	Clown wrasse	*Coris aygula*	3
	Puddingwife wrasse	*Halichoeres radiatus*	3
	Rainbow wrasse	*Thalassoma lucasanum*	3
	Slippery dick wrasse	*Halichoeres bivittatus*	3
	Spanish hogfish	*Bodianus rufus*	3.5
	Yellowhead wrasse	*Halichoeres garnoti*	3
Pomacanthidae	Rock beauty	*Holacanthus tricolour*	5
Pomacentridae	Beaugregory	*Stegastes leucostictus*	2.5
	Bicolour damselfish	*Stegastes partitus*	2.5
	Blue chromis	*Chromis viridis*	3.5
	Cocoa damselfish	*Stegastes variabilis*	2.5
	Dusky damselfish	*Stegastes adustus*	2.5
	Longfin damselfish	*Stegastes diencaeus*	2.5
	Sergeant major	*Abedefduf saxatilis*	3
	Three-spot damselfish	*Stegastes planifrons*	2.5
	Yellowtail damselfish	*Chrysiptera parasema*	2.5
Scaridae	Princess parrotfish	*Scarus taeniopterus*	3.5
	Bucktooth parrotfish	*Sparisoma radians*	3.5
	Greenblotch parrotfish	*Sparisoma atomarium*	3.5
	Redband parrotfish	*Sparisoma aurofrenatum*	3.5

	Stoplight parrotfish	*Sparisoma viride*	3.5
	Striped parrotfish	*Scarus iseri*	3.5
Pomacanthidae	Blue angelfish	*Holacanthus isabelita*	5
	Queen angelfish	*Holacanthus ciliaris*	5
	Grey angelfish	*Pomacanthus arcuatus*	5
	French angelfish	*Pomacanthus paru*	5
Serranidae	Coney grouper	*Cephalopholis fulva*	~5
	Graysby grouper	*Cephalopholis cruentata*	~5

Five sites from four management zones were used in the analysis to ensure that the dataset was balanced. These were C1B1 (Last Resort), C2F1 (Rocky Point North), GF1 (Goliath), PF1 (Garden Wall) and PB1 (Tarpon Patch) between 2012 and 2015. Other management zones were not included due to insufficient data.

Two-way ANOVA without replication was conducted on the log transformed total abundance of recruits after testing for normality using the Kolmogorov Smirnov test and homogeneity of variance with the F-test. Several two-way ANOVAs were conducted with mean total juvenile abundance as the dependent variable using the following independent variables:

1. Management zone and year
2. Management zone and season (wet, dry or *Norte*)
3. Management zone and reef type

Spearman's rank test was conducted to assess any correlation between hard coral cover and total recruit abundance. Hard coral cover and juvenile abundance in this analysis were taken from sites where surveys of both variables were conducted in the same season. When two surveys of the same type at the same location were conducted in one season, the mean of the two surveys was taken to avoid pseudo-replication.

Finally, community analysis was carried out in PRIMER 6 in order to identify any differences in juvenile community structure between management zones and reef types. A Nonmetric multidimensional scaling (nMDS) plot was created from a Bray-Curtis similarity matrix of fourth-root transformed species level abundance per site per season. Factors showing separation of juvenile assemblages in this nMDS plot were tested for significance using PERMANOVA. Species contributing towards the differences in assemblage structure were identified using one-way SIMPER.

2.6.3 Fish species richness

Reef Environmental Education Foundation (REEF) developed the fish rover survey (FRS) methodology, which enables the collection of fish biodiversity and abundance data across large spatial areas in a consistent and rapid manner (McField & Kramer, 2007; REEF, 2007). Divers searched sites extensively for thirty minutes, with the goal of recording the maximum number of species in the timed dive. The relative abundance of each species was also classified into one of four categories: Single (1), Few (2-10), Many (11-100), and Abundant (> 100) (Almada-Villeal, et al., 2003; REEF, 2012). One FRS was conducted at each site as part of the MBRS-SMP survey. This survey was also conducted in the mangroves frequently but not systematically (when time allowed), with a thorough search conducted in and under the mangrove roots. Fish rover surveys provide a holistic view of the fish biodiversity found in BCMR because all encountered species are recorded, not only those which are identified as priority species for fish belt surveys (Error! Reference source not found.3,4).

Data obtained from FRSs were used to generate a species list of all fish sighted in BCMR over five years (2011–2015), and to identify which species were recorded most frequently. A cumulative species richness curve was created to assess how much effort was required to observe additional new species and to estimate the total species richness of BCMR. The cumulative number of new fish species observed is plotted over the cumulative number of surveys completed (Park & Tonkyn, 2015).

In addition, the FRS data were analysed following the Reef Environmental Education Foundation Protocol (REEF, 2012). The four abundance categories, Single (S), Few (F), Many (M), and Abundant (A) were used to determine the sighting frequency (SF) and density (Den) of fish species observed, using the following formulae:

$$\%SF = \frac{S + F + M + A}{n} \times 100$$

$$Den = \frac{1S + 2F + 3M + 4A}{n}$$

SF measures the frequency with which a species was sighted on all FRS dives, whereas Den is a weighted average index based on the frequency a species was observed in each category. An average SF and Den was calculated for each species per year, management zone, reef type (forereef/backreef), and location within and outside BCMR. An SF of > 50 and a Den of > 3.00 were considered as thresholds for high species abundance (REEF, 2007).

2.7 Megafauna

Opportunistic sightings of sea turtles, sharks and rays were recorded on SCUBA dives between 2011 and 2015. These sightings were converted to sightings per unit effort by accounting for the number of SCUBA divers on each dive and the length of each dive. No data were available from 2014 because the number of people per dive was not recorded. Data were analysed from 10 sites in BCMR across four management zones covering forereef and backreef areas (Table). Note that backreef data in CZ2 were unavailable.

Table 6. Survey sites in each management zone, their reef types and the total effort per person (minutes snorkelling or diving) on each site per year.

			Total Effort (min person^{-1})			
Management Zone	**Reef Type**	**Site**	**2011**	**2012**	**2013**	**2015**
Conservation Zone 1	Backreef	Last Resort	443	807	295	66
	Forereef	Alleys	179	486	504	72
	Forereef	Canyons	359	308	147	123
Conservation Zone 2	Forereef	Rocky Point North	187	339	309	98
	Forereef	Rocky Point South	152	75	93	40
General Use Zone	Backreef	Peccary Patch	94	175	131	83
	Forereef	Goliath	131	560	962	275
Preservation Zone	Backreef	Tarpon Patch	156	220	103	86
	Forereef	Garden Wall	479	682	1038	341
	Forereef	Pig Sty	69	96	101	62

Two-way ANOVAs were used to analyse the significance of management zones, years and reef types (forereef and backreef) on turtle and elasmobranch sightings. Any significant results were followed by post-hoc Tukey tests to identify the sources of the differences.

2.8 Data validation

To ensure the quality of the data collected at BCMR by Blue Ventures staff and volunteers are of high quality, all individuals involved undergo rigorous training on fish and coral species identification and the associated survey methods. Volunteers are assigned to either the fish group or the benthic group so that they can focus their studies. Before participating in any data collection, volunteers must pass both computer and in-water tests with 95% of answers correct, and must also pass a sizing test for fish with 90% accuracy. Volunteers only collect data on fish belts or PITs under the direct supervision of a Blue Ventures field scientist to ensure that survey standards are upheld. More complex work such as fish recruits and coral bleaching and disease surveys are only carried out by staff. Data collected by volunteers are verified by a field scientist before data entry, and if the raw data contain errors or inaccuracies then the survey will be re-done. As part of quality assurance all the data are then entered into a database twice, with the two datasets then checked against each other by a staff member. This means that any mistakes made during data entry are detected and corrected before analysis.

3 Results

3.1 Overall Reef health

According to the Simplified Integrated Reef Health Index (SIRHI) scores (Appendix 1), BCMR's habitat health has varied between Poor and Critical condition during the study period (Figure 6). In 2011, more than 66% of sites were found to be in Critical condition compared to an average of 36% in the years 2012-14, while in 2015, the percentage of sites in Critical condition increased to 50%. During the survey period, only one site (PF1) was found to be in Good condition (2013), while in 2014, the healthiest site was in Fair condition. The reserve's overall SIRHI score in 2015 was 1.8 (±0.1), which is lower than the 2015 overall SIRHI score for Belize and the MBRS, which had scores of 2.5 and 2.8, respectively.

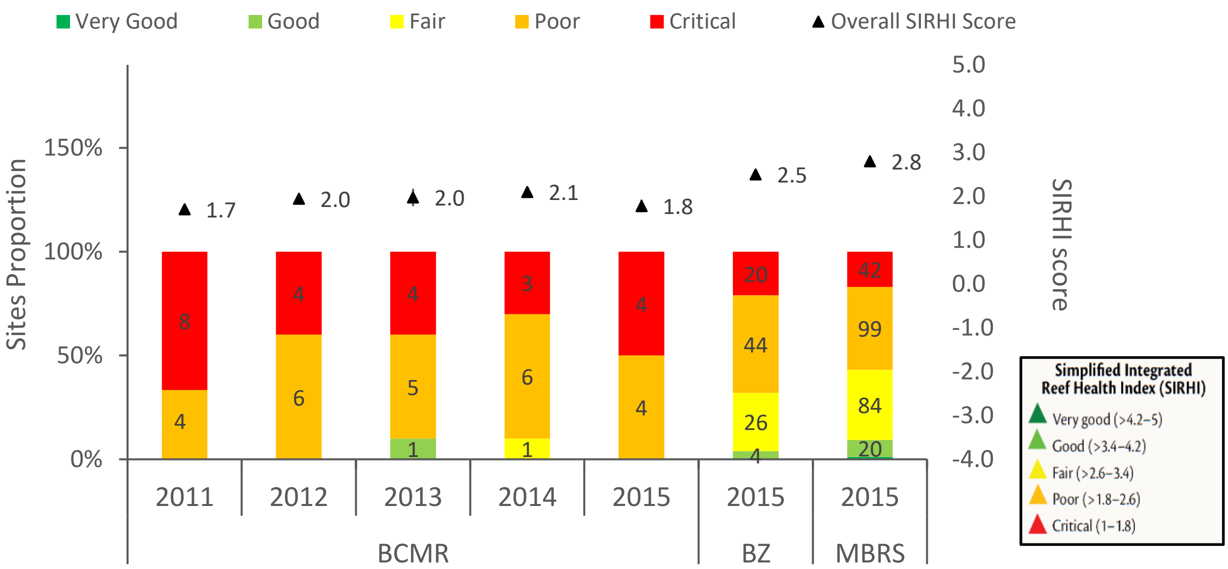


Figure 6. Health of sites monitored per year at: Bacalar Chico Marine Reserve (BCMR), Belize (BZ) and the entire Mesoamerican Barrier Reef System (MBRS) for 2015.

The highest overall SIRHI score experienced in BCMR for any one year was in 2014 at 2.1 (±0.1), but there was no significant change in reef health over the survey period ($F=_{1.073,9}$, p=0.41). Although SIRHI scores ranged from a low of 1.25 in CZ2 in 2015, to a high of 2.75 in the GUZ2 in 2014 (Figure 7), there was no significant difference between management zones ($F=_{2.003,9}$, p=0.18).

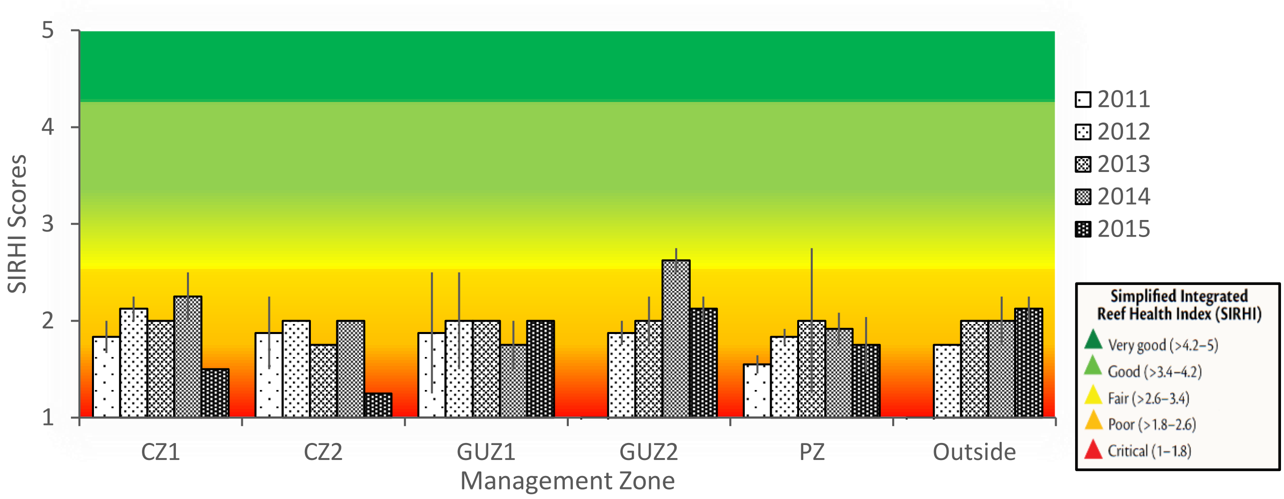


Figure 7. Reef health of each management zone inside BCMR and outside BCMR over time, measured with the SIRHI. Error bar showing standard error of mean.

Overall hard coral cover ranged from Poor to Fair with the lowest score of 8.83 ± 0.70% in 2012 and the highest 14.77 ± 1.14% in 2014. Overall FMA has been at Critical levels throughout the study period with highest cover at 27 ±1.36% in 2015, dominating most of the substrate. In 2015, herbivorous fish biomass was Poor at 1179.35 ± 253.94 g/100 m^2, only slightly greater than the biomass in 2011 at 996.42 ± 231.93 g/100 m^2 and lower than 2014 levels of 1506.12 ± 183.40 g/100 m^2 (**Error! Reference source not found.**8). Commercial fish biomass was even lower than their herbivorous counterparts in 2015, with biomass of 254.2 ± 90.81 g/100 m^2 ranking in Critical condition. The highest commercial fish biomass was 502.13 ± 150.23 g/100 m^2 ranking as Poor for 2013. Both herbivorous and commercial fish biomass had a slight improvement from Critical to Poor condition from 2012 to 2014.

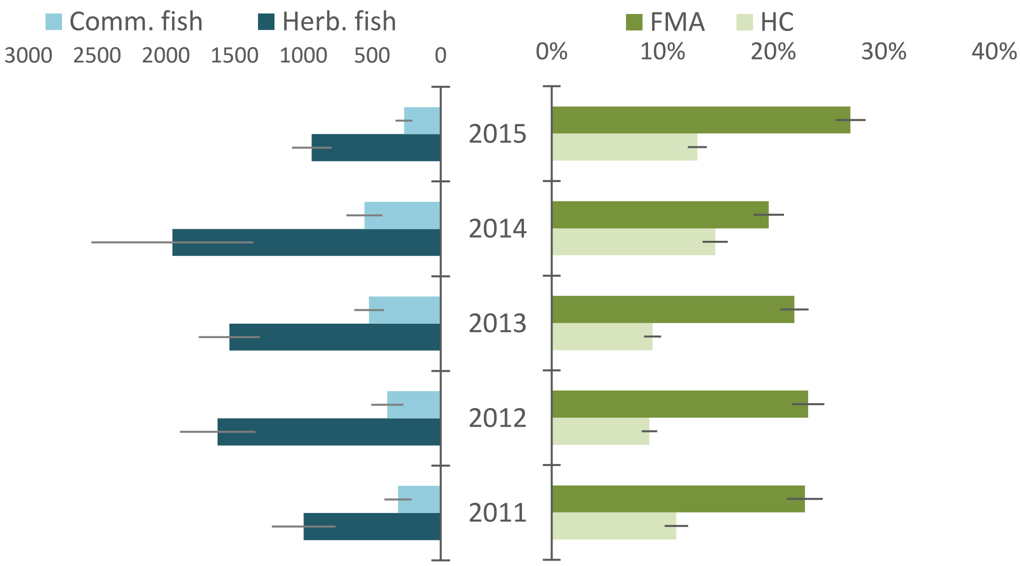


Figure 8. Annual average of commercial (Comm.) and herbivorous (Herb.) fish biomass g/100m^2 and percentage cover of hard coral (HC) and fleshy macroalgae (FMA) in BCMR. Error bars show standard error of mean.

3.2 Fleshy macroalgae cover

Mean FMA (including y-branch algae (*Dictyota* sp.), encrusting fan-leaf algae (*Lobophora* sp.) and other fleshy macroalgae) cover remained high across all years with the highest cover in 2015 at 27 ± 1.36% and the lowest in 2014 at 19.62 ± 1.37% (Figure 9). A binomial GLM model revealed that there was no significant change in FMA cover over time in BCMR (Estimate = -0.14 (0.10), z=-1.44, p=0.15).

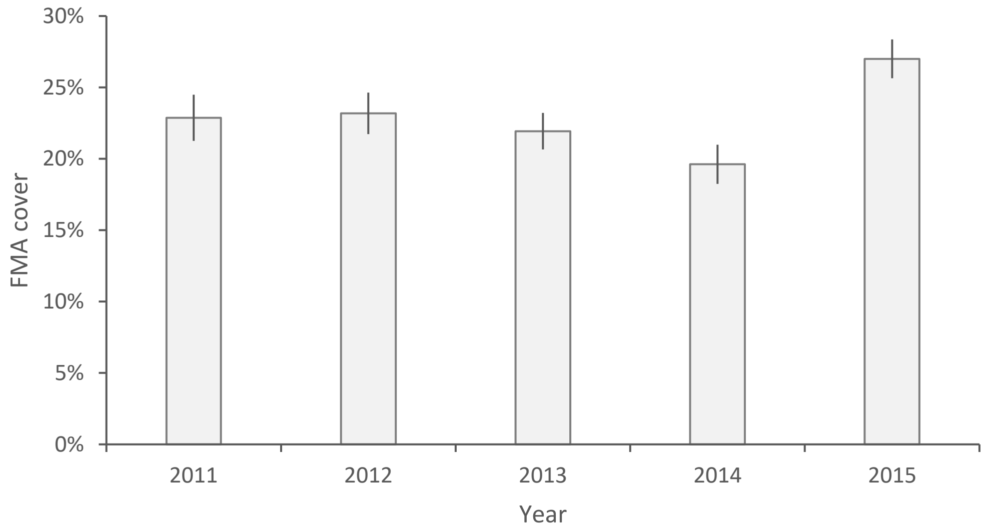


Figure 9. Mean FMA cover of the years (2011-2015) for each management zone. Error bars represent standard error.

A second binomial GLM model was run to determine whether the location on the reef (north/south), reef type (fore/back), management zone (CZ, PZ, GU, control) had an influence on FMA cover. Year was included as a random factor. Of the three spatial variables, only management zone was a significant predictor of FMA coverage (Table 7).

Table 7. Binomial GLM with FMA cover as the dependent variable, management zone, location of reef (north/south) and reef type (forereef/backreef) are included as fixed factors with reef as a random factor.

Variable	Estimate (SE)	Z	P
(Intercept)	*-0.76 (0.59)*	*-1.29*	*0.197*
North/south	0.37 (0.36)	1.05	0.293
Forereef/backreef	-0.40 (0.39)	-1.04	0.297
Management zone	**-0.16 (0.08)**	**-1.93**	**0.05**

We found that the source of variation in FMA cover between management zone was due to the low FMA cover in PZ (17.38%) relative to the cover in CZ2 (31.17%) (Figure 10). Between the years of 2012–2014, the PZ presented the minimum mean FMA cover at 17.38 ± 1.17%, while CZ2 presented the highest mean FMA cover at 31.17 ± 1.97%. Sites outside the reserve (control) had a mean cover of 26.85 ± 1.66%.

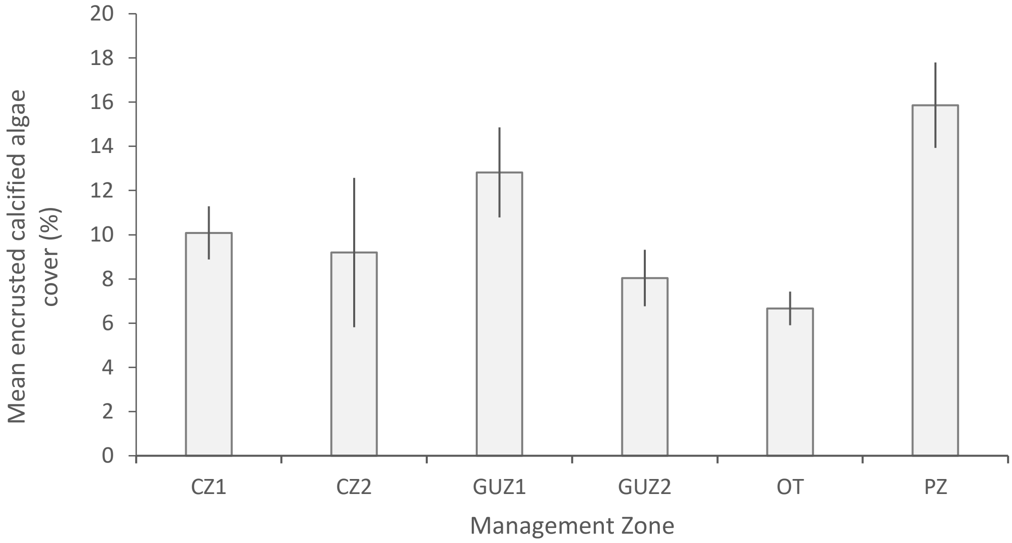


Figure 10. Mean cover of encrusted calcified algae between 2012 and 2015 in each management zone. Data for 2011 were not included due to a lack of data from outside BCMR (OT). Error bars show standard error of the mean.

Time had no effect on any algal type (Table 8); however, the cover of encrusted calcified algae (which includes crustose coralline algae (CCA) and other encrusting calcified algae) differed between the northern (12.48%) and southern (7.75%) parts of BCMR, as well as between management zones. The difference between management zones mostly originates from the high CCA cover in the PZ (15.86%), compared with reefs outside BCMR (OT, 6.67%) and in GUZ2 (8.04%) (Figure 9).

The cover of y-branched algae (*Dictyota sp.*) also changed when moving from the north to south within the BCMR, with more encrusting fan-leaf algae (*Lobophora sp.*) cover in the south (15.29%) compared to the north (12.71%). No other algal types differed significantly over spatial scales (Table 8).

Table 8. Results of mixed effects binomial GLM models, showing the effect of spatial variables ('management zone' and 'north/south') on algae cover, with 'year' as a random factor, and the effect of time (years) on algae cover.

SPATIAL	**Common Name**	**Variable**	**Estimate (SE)**	**Z**	**P**
Crustose coralline algae	CCA	Intercept	-1.38 (1.24)	-1.11	0.26
		Management zone*	0.34 (0.12)	2.91	**< 0.01**
		North/south*	-2.29 (1.03)	-2.23	**< 0.05**
Articulated coralline algae	ARTIC	Intercept	26.75 (130.45)	0.21	0.84
		Management zone	0.36 (0.30)	1.22	0.22

		North/south	-32.47 (130.45)	-0.25	0.80
Lobophora sp.	Encrusting fan-leaf algae	Intercept	-2.66 (0.97)	-2.74	< 0.01
		Management zone	-0.30 (0.19)	-1.54	0.12
		North/south	0.22 (0.78)	0.28	0.77
Halimeda sp.		**Intercept**	**65.93 (165.57)**	**0.39**	**0.69**
	Halimeda	Management zone	0.29 (0.20)	1.45	0.15
		North/south	-70.56 (165.57)	-0.43	0.67
Dictyota sp.	Y-branched algae	Intercept	-3.24 (0.58)	-5.58	< 0.001
		Management zone	0.10 (0.09)	1.052	0.29
		North/south*	0.81 (0.33)	2.50	**< 0.05**
TEMPORAL		**Variable**	**Estimate (SE)**	**Z**	**P**
Crustose coralline algae	CCA	Time (years)	0.01 (0.10)	0.109	0.913
Articulated coralline algae	ARTIC		0.28 (0.17)	1.71	0.08
Lobophora	Encrusting fan-leaf algae		-0.05 (0.22)	-2.05	0.84
Halimeda	Halimeda		0.01 (0.10)	0.09	0.93
Dictyota	Y-branched algae		0.05 (0.09)	0.58	0.56

*Variables with a significant influence on the cover of a specific algal type are marked with asterisks, their p values are in bold.

3.2.1 Coral cover

Bacalar Chico Marine Reserve had a mean hard coral (HC) cover that differed significantly between years ($F_{3,15} = 3.29$, $p = 0.002$), with the highest cover in 2014 at 14.77 ± 1.14% and the lowest in 2012 at 8.83 ± 0.70% (Figure 11). In 2015, mean HC cover was at 13.16 ± 0.86%.

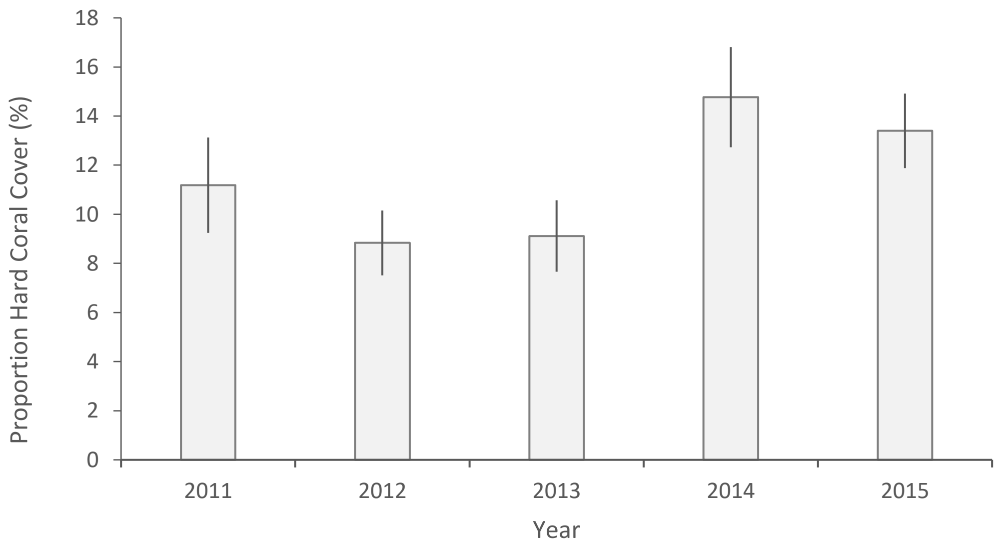


Figure 11. Mean hard coral cover (%) over time in BCMR. Error bars show standard error of the mean.

There was no significant difference in HC cover between management zones across all years ($F_{5,15}$ = 2.90, p = 0.07), although HC cover was significantly higher on forereefs (16.84%) than backreefs (8.24%) ($F_{1,8}$ = 5.32, p = 0.009). No difference in coral cover exists between northern and southern parts of the BCMR ($F_{1,8}$ = 5.32, p = 0.70).

The species-level coral community differs significantly between management zones (PERMANOVA $F_{4,101}$ = 1.99, p = 0.001). Principal Component Analysis (PCA) shows that CZ2 is dissimilar from all other management zones (Figure 12), as the PZ, GZ1 and GZ2 all possess similar species-level coral communities. The variation in coral community between management zones is mostly due to differences in the proportion of lettuce coral (*Undaria agaricites*), staghorn coral and low relief lettuce coral (*Agaricia humilis*), with more lettuce coral and low relief lettuce coral in CZ2, and all other management zones possessing higher proportions of staghorn coral (the PZ and GUZ2 had the highest proportions of this species).

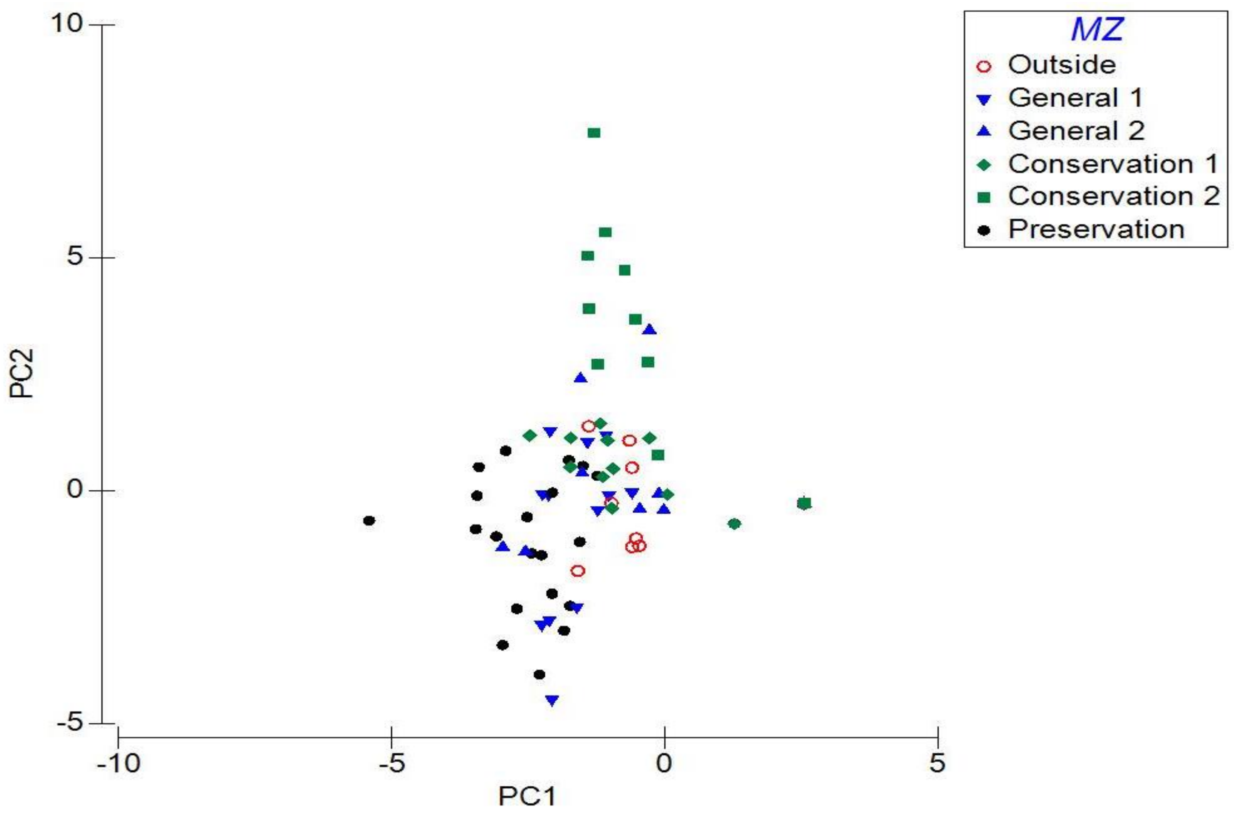


Figure 12. Principal component analysis of coral species community structure. The key in the top left shows the colours of each management zone.

Coral community structure also differed significantly between forereefs and backreefs (PERMANOVA F_{1101} = 1.6, p = 0.05). In 2015, 11 species of corals were only found on forereefs and not backreefs. These included staghorn coral, elliptical star coral (*Dichocoenia stokesii*), boulder star coral (*Orbicella franksi*) and rough cactus coral (*Mycetophyllia ferox*), all of which are either EDGE or IUCN red list species (Appendix 5).

The largest differences between forereefs and backreefs in 2015 were due to the difference in coverage of two coral species, lettuce coral and mustard hill coral (*Porites astreoides*). Lettuce coral made up on average 28% of coral colonies on forereefs, but only 13% on backreefs whereas mustard hill coral made up 13% of coral colonies on forereefs, and 23% of colonies on backreefs.

PERMANOVA showed that species-level coral communities did not differ between years ($F_{4,95}$ = 1.10, p = 0.25) nor seasons ($F_{2,95}$ = 0.90, p = 0.63) throughout BCMR.

3.2.2 Coral Disease

Between 2011 and 2015, there was a significant difference in disease in coral colonies between years (binomial GLM; estimate = 0.20 (± 0.06), z = 3.50, p < 0.001). The prevalence of coral disease rose from 4.5% in 2011 to 8.5% in 2014 before falling again in 2015 to 6.6% (Figure 13). In 2015, elkhorn coral, massive starlet coral and lobed star coral had the highest prevalence of disease, with 50.0%, 19.2% and 8.3% respectively. The colonies showed signs of disease including: white patch, black spot and yellow band disease.

There was a significant difference in coral disease prevalence between reef type (binomial GLM; estimate = -0.682 (± 0.20), z = 3.41, p < 0.001). Disease prevalence on forereefs was higher at 7% compared with the 5% prevalence seen on backreefs. However, no significant difference existed in disease prevalence between management zones (binomial GLM; estimate = -0.061 (± 0.04), z = -1.43, p = 0.152), nor between the north (5.5%) and south (5.2%) of BCMR (binomial GLMER; estimate = -0.2832 (± 0.17), z = -1.62, p = 0.105).

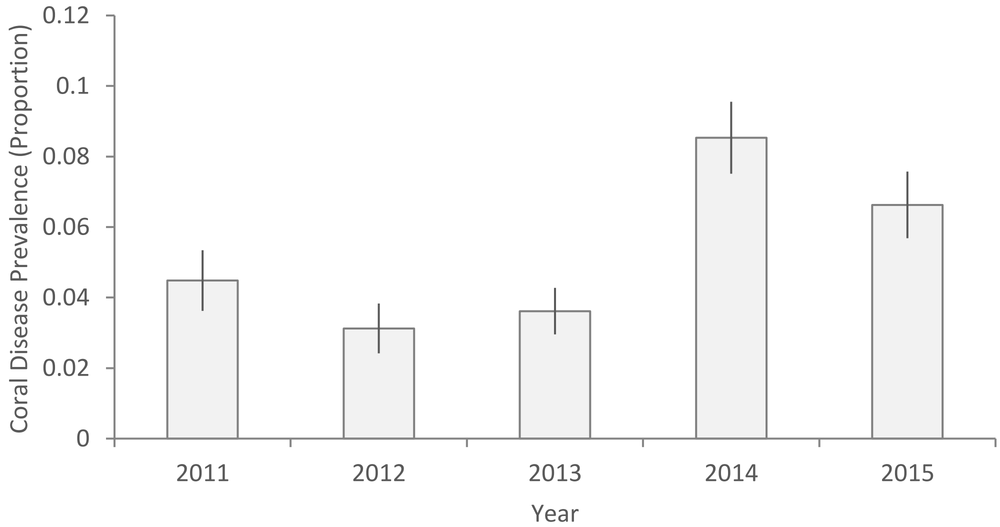


Figure 13. Mean proportion of coral colonies with signs of disease over time. Error bars represent standard error of mean.

3.2.3 Coral Bleaching

Between 2011 and 2015, there was a significant increase in the proportion of coral colonies with evidence of bleaching (binomial GLM; estimate = 0.16 (± 0.03), z = 5.52, p < 0.0001), rising from 14% in 2011 to 32% in 2015 (Figure 14). The species most vulnerable to bleaching were lobed star coral, lettuce coral and maze coral (*Meandrina meandrites*), with 40.5%, 40.4% and 33.3% (respectively) of all colonies showing some signs of bleaching in 2015.

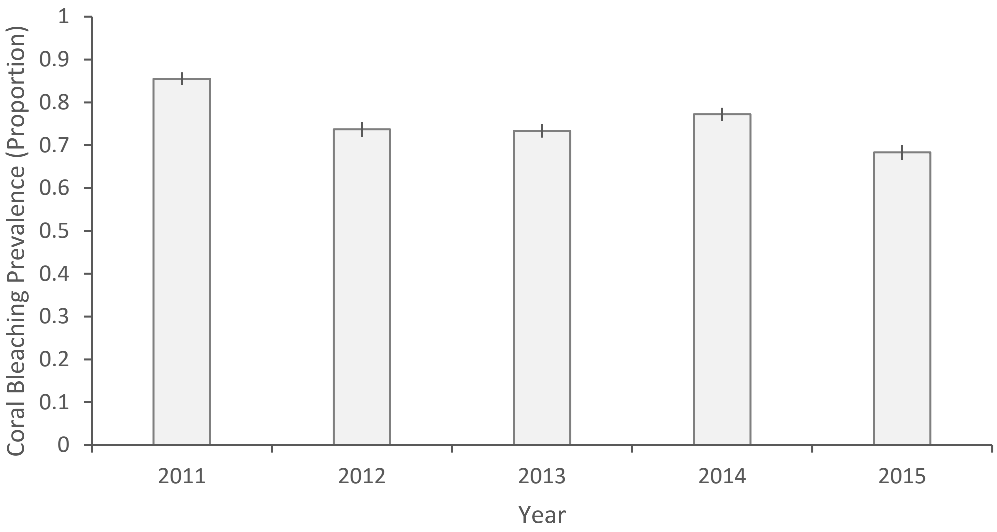


Figure 14. Proportion of coral colonies with some signs of bleaching. Error bars represent standard error of mean.

However, the proportion of bleached corals was not found to correlate with either the presence of a high DHW, nor the intensity of DHW (Table 9). The months with the highest bleaching prevalence across all years were October, December and January, with mean at 33.5%, 34.4% and 33.3, respectively.

Table 9. Results of binomial GLM model. The dependent variable was the proportion of bleached corals; fixed variables included the presence of degree heating weeks (DHW) exceeding 4°C-week^{-1} and the intensity of DHW (only positive values used).

Variable	Estimate (SE)	Z	P
Intercept	1.19945 (0.15)	-7.77	< 0.0001
Presence of DHW (i.e. DHW > 4.0° C)	0.28 (0.15)	1.84	0.07
Intensity of DHW (value of DHW using monthly mean)	-0.02 (0.01)	-1.25	0.21

Despite the 17.8% difference in bleached corals between outside the reserve and inside GUZ2 (Figure 15), the presence of bleaching did not differ significantly between management zones (binomial GLM; estimate = -0.06 (± 0.04), z = -1.43, p = 0.152). Bleaching also did not differ significantly over other spatial scales.

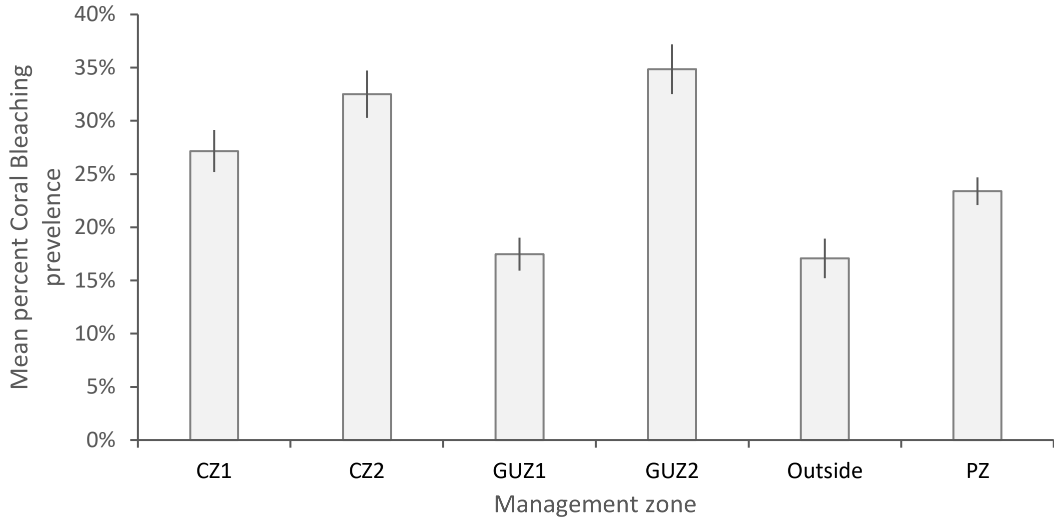


Figure 15. The mean proportion of coral colonies with some evidence of bleaching per management zone over five years from 2011 to 2015. Error bars show standard error of the mean.

3.2.4 Current status of EDGE and IUCN coral species

In 2015, seven out of 33 species of corals identified were included in either the EDGE list or IUCN red list (Table 10). Only one colony of staghorn coral and rough cactus coral were recorded on surveys; the former species was long dead and the latter completely healthy with no signs of bleaching nor disease.

Table 10. Summary of conservation priority coral species affected by bleaching or disease in 2015.

Common name	Scientific name	Number of colonies	Colonies with signs of bleaching (%)	Diseased colonies (%)	Diseases/other conditions	Dead colonies (%)
Staghorn	*Acropora cervicornis*	1	0	0	---	100
Elkhorn	*Acropora palmata*	4	25	75	WPA, BES	75
Elliptical Star	*Dichocoenia stokesii*	11	9	0	---	36
Lobed Star	*Orbicella annularis*	15	40	33	YB, OIS, FB	93
Mountainous Star	*Orbicella faveolata*	16	31	19	RB, OIS, FB	81
Boulder Star	*Orbicella franksi*	4	100	0	---	0
Rough Cactus	*Mycetophyllia ferox*	1	0	0	---	0

- Abbreviations of diseases and other conditions: BES – brown encrusting sponge, FB – fish bites, OIS – orange icing sponge, RB – red band, WPA – white patch, YB – yellow blotch.

Five of the seven coral species of importance showed evidence of bleaching, with only two (boulder star coral and elliptical star coral) lacking signs of disease. Three species showed evidence of disease: elkhorn coral, lobed star coral and mountainous star coral, which exhibited colonies with white patch, yellow blotch and red band disease respectively. These three species also showed evidence of mortality and encroaching encrusting sponge. Elliptical star coral also showed evidence of mortality.

3.2.5 Hurricane Ernesto's impact on habitat

Despite the total macroalgae (including both fleshy and calcareous macroalgae) cover decline and hard coral cover increase following Hurricane Ernesto, neither change was significant (Table 11). Furthermore, no significant change was observed in the cover of different algal types at any site in BCMR following Hurricane Ernesto.

Table 11. Proportion cover of algae and hard coral in the six months before and after the impact of Hurricane Ernesto. GLM testing was carried out before and after impact. Reef site was used as the random factor.

Category	*Mean % cover before*	*Mean % cover after*	*Direction of change*	*GLM result*		
				Estimate (SE)	*Z*	*P*
Total Macroalgae	78	65	↓	-0.65 (0.65)	-1.00	0.32
Total Hard Coral	9	13	↑	0.41 (0.93)	0.44	0.66
CCA	0.32	0.27	↓	-0.22 (0.61)	-0.37	0.71
LOBO	0.06	0.02	↓	-1.06 (SE 1.45)	-0.73	0.46
DICT	0.39	0.30	↓	-0.43 (0.58)	-0.73	0.46
HALI	0.19	0.22	↑	0.16 (0.70)	0.24	0.81
ARTIC	0.00	0.02	↑	1.52 (3.5)	0.43	0.67

- See Appendix 2 for affiliated common and scientific names.

3.3 Invertebrates

3.3.1 Long-spined sea urchin population

Analysis of the invertebrate data collected using fish belt surveys shows that mean long-spined sea urchin abundance across BCMR did not change during the study period (ANOVA; $F_{4,905} = 1.5$, $p = 0.33$) and did not differ significantly between any pair of years when post hoc Tukey HSD tests were conducted (Figure 16).

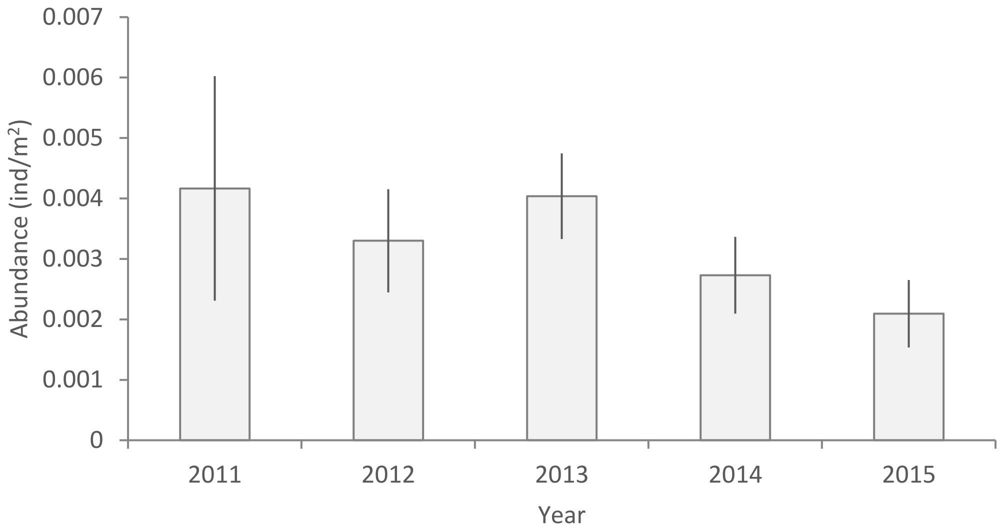


Figure 16. Long-spined sea urchin density per m^2 in BCMR over time. Error bars show standard error of the mean.

Data collected during the long-spined sea urchin survey for 2013 relating to spatial distribution of long-spined sea urchin populations shows a hotspot of abundance at the site PF2 (Moose County) at 6.6 ind/m^2 (Figure 17). On the other hand, long-spined sea urchin abundances were extremely low in site C1B1 (Last Resort) and C2F1 (Rocky Point North). When comparing abundance between zone types, the PZ had the highest mean abundance at 3.26 ind/m^2; however, long-spined sea urchin abundance did not differ significantly between management zones ($F_{5,29} = 2.23$, $p = 0.08$).

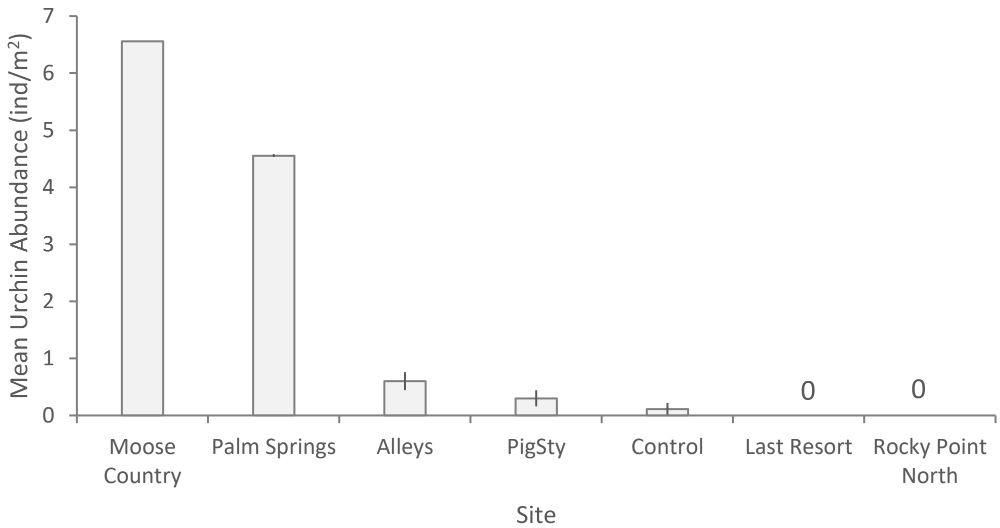


Figure 17. Mean long-spined sea urchin abundance (ind/m^2) at a selection of sites, displaying the range of abundances that can be observed in BCMR.

Results of a GLM model on data from these surveys showed that rugosity, herbivore abundance and urchin predator abundance all significantly influenced long-spined sea urchin abundance (Table 12). Rugosity and predators both negatively influenced abundance, whereas the presence of other herbivorous species was positively associated with the presence of long-spined sea urchin.

Table 12. Generalised linear mixed model of long-spined sea urchin abundance. Reef rugosity, herbivorous fish abundance and predator abundance as fixed factors, and month as a random factor.

Variable	Estimate (SE)	Z	P
(Intercept)	*23.34 (9.93)*	*2.35*	*< 0.05*
Rugosity	-41.83 (15.26)	-2.74	< 0.01
Mean herbivore abundance	1.25 (0.62)	2.00	< 0.05
Mean predator abundance	-3.53 (1.59)	-2.21	< 0.05

3.3.2 Caribbean spiny lobster

During open fishing season CZ1 displayed the highest densities of Caribbean spiny lobster among all management zones from 2012 to 2014 (p = < 0.001; Figure 18). Density did not significantly differ between zones. There was no significant difference between the years 2012 to 2014 (P = 0.839).

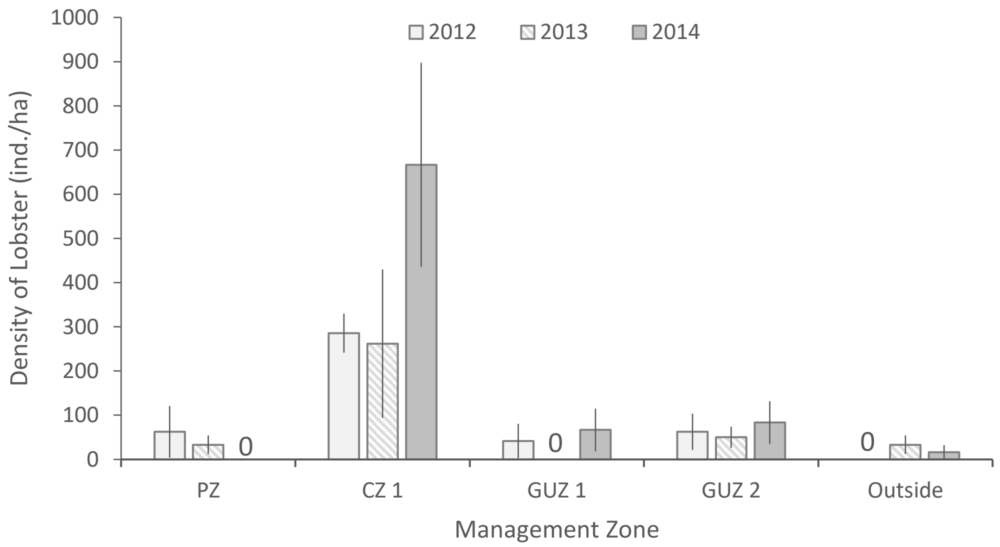


Figure 18. Caribbean spiny lobster density per hectare at backreef sites in BCMR during open fishing season between the years 2012 to 2014. Five sites in five management zones were surveyed. Error bar shows the standard error of mean. Insufficient data were collected for respective sites in 2011 and 2015.

There was no significant difference between open and closed season in the GUZ, nor was there a difference between open and closed season in the NTZ (P = 0.414). There was no significant difference between the years 2012 to 2015 (P = 0.482) (Figure 19).

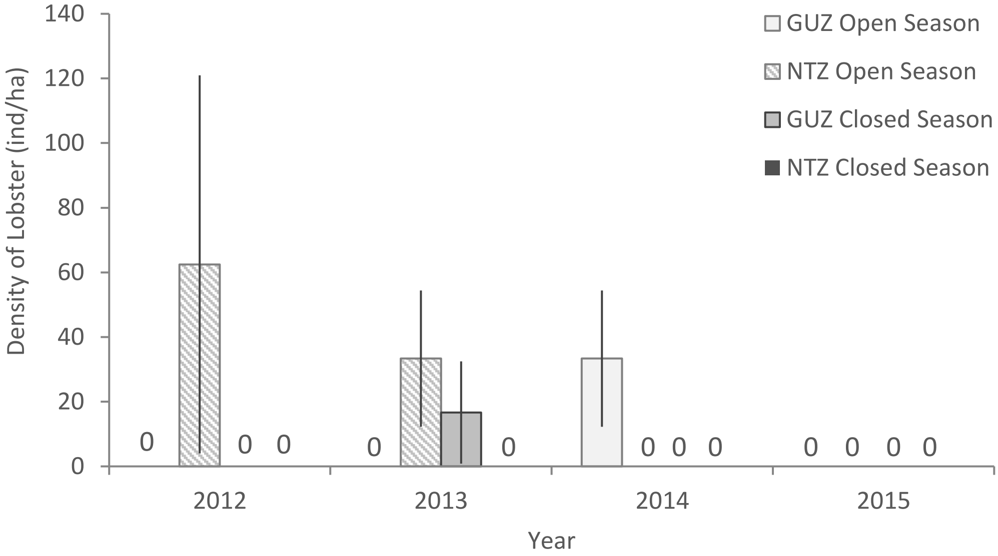


Figure 19. Caribbean spiny lobster density per hectare at two backreef sites in BCMR between the years of 2012 to 2015, during open and closed season. One site lies in a take zone (GUZ1), the other one lies in a no take zone (PZ). Error bar shows the standard error of mean. Insufficient data were collected for respective sites in 2011.

During the open season, lobster density was found to be higher in NTZs compared to GUZs across all years, with the highest density in 2013 at 121.79 ± 42.23 ind/ha. Outside had lower lobster density compared to the GUZs in the reserve except in 2013 where the outside had a mean average of 33.33 ± 21.08 ind/ha compared to the GUZs at 12.5 ± 6.94 ind/ha (Figure 20).

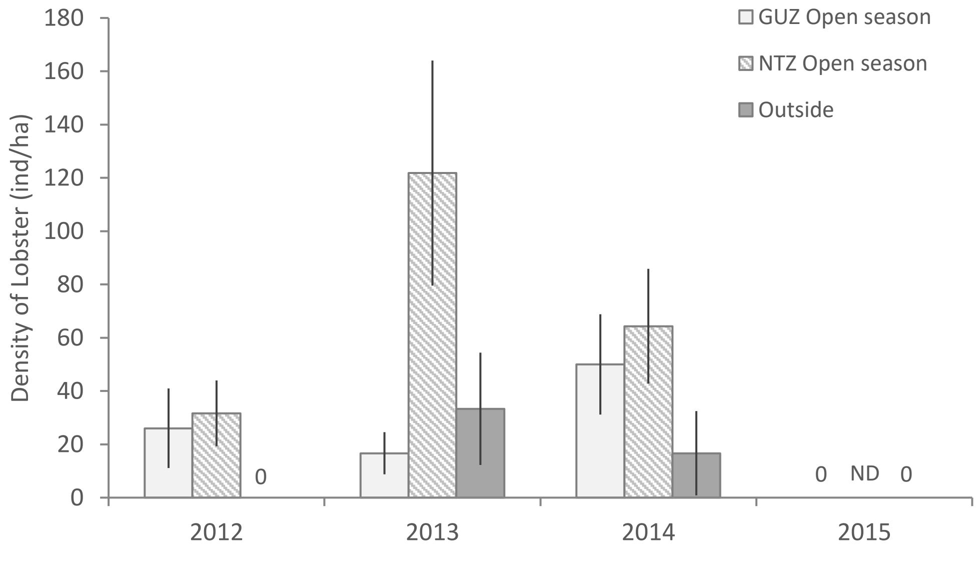


Figure 20. Caribbean spiny lobster density per hectare at backreef sites in BCMR between the years of 2012 to 2015 during open fishing season. GUZs include two sites, one in GUZ1 and one in GUZ2; NTZs include two sites, one in CZ

and one in PZ. Outside includes one site outside of BCMR. Insufficient data were collected for respective sites in 2011. Error bar show the standard error of mean. No data was collected in the NTZ during open season in 2015.

Lobster abundance did not correlate with the abundance of flamingo tongue. There were significantly fewer flamingo tongue individuals inside the no take zone than outside (Table 13) and no difference in the abundance of flamingo tongue between the open and closed seasons of the lobster fishery (estimate = -0.03 (SE 0.14), z = -0.22, p = 0.92).

Table 13. GLM model of flamingo tongue abundance, with lobster fishery closure (NTZ) status and the abundance of lobster as fixed variables, and year as a random variable.

Variable	Estimate (SE)	Z	p
Intercept	-0.58 (0.14)	-4.16	< 0.001
NTZ (yes/no)	-0.44 (0.10)	-4.41	< 0.001
Abundance of Caribbean spiny lobster	0.02 (0.04)	0.45	0.65

3.3.3 Queen Conch

During open fishing season queen conch densities were higher in the PZ than in CZ1 and GUZ1 ($P < 0.001$) (Figure 21). There were no significant differences between the years 2012 to 2015 ($P = 0.228$).

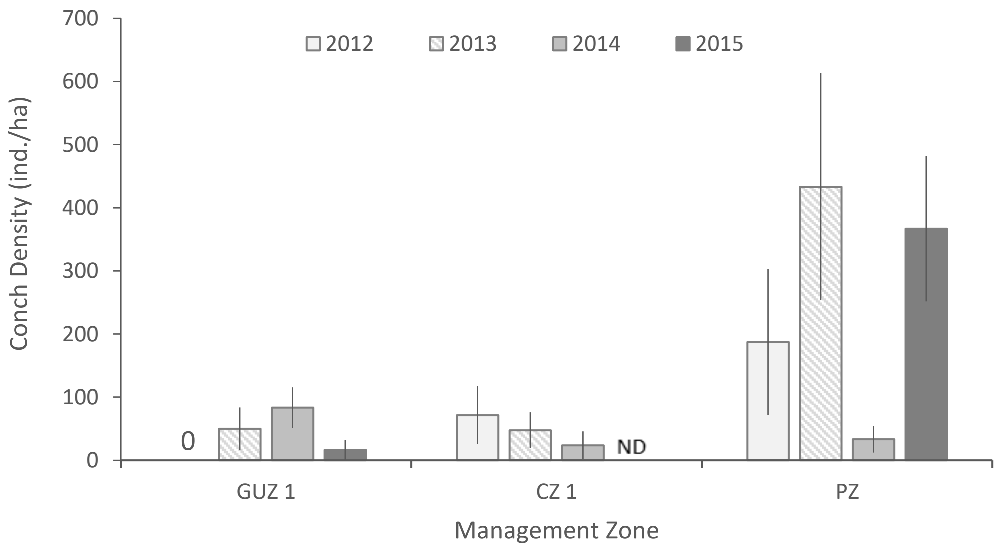


Figure 21. Queen conch density per hectare at backreef sites in BCMR over the years 2012 to 2015 during open season. Three sites in three management zones have been surveyed (PZ, CZ1, GUZ1). No data (ND) has been collected at GUZ1 in 2012 or CZ1 in 2015. Insufficient data were collected for respective sites in 2011. Error bar shows standard error of mean. No data was collected in 2015 in CZ1.

During open fishing season densities at the site in the NTZ (PB1) were higher between the years of 2012 to 2015 than in the GUZ (GB1) ($P < 0.001$, Figure 22). There was no significant difference between the years of 2011 to 2015 at the GUZ ($P = 0.232$) and NTZ ($P = 0.061$).

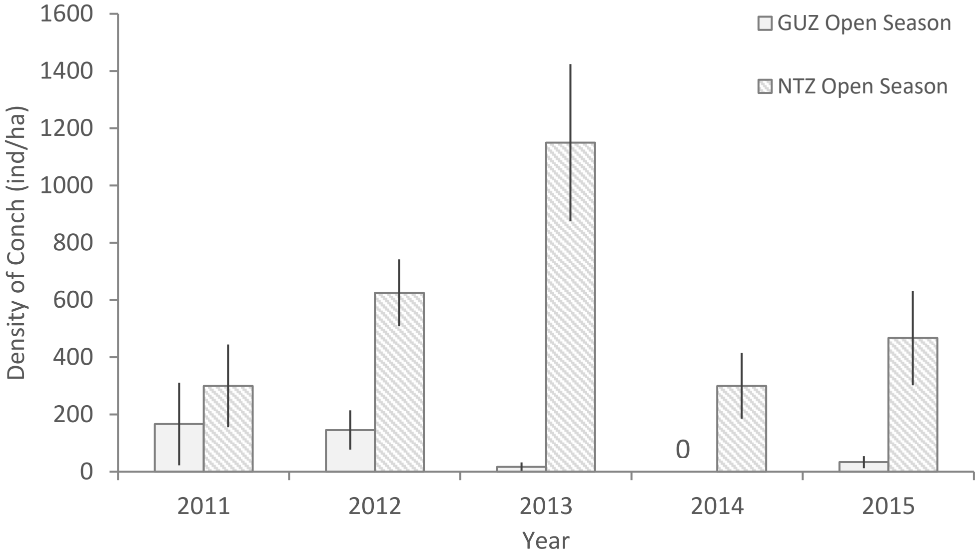


Figure 22. Queen conch density per hectare at two backreef sites in BCMR over the years 2011 to 2015 during open season. One site lies in a GUZ (GB1), the other one lies in the NTZ (PB1). Error bar show the standard error of mean.

No significant difference in queen conch density was detected between open and closed season at a backreef site in a GUZ (Figure 23). Densities at sites outside the BCMR during closed season were significantly higher than at sites in the GUZ (GUZ1) during closed and open season ($P < 0.001$), except for year 2012 ($P = 0.146$). Densities varied significantly between the years at the site in the GUZ during closed season ($P = 0.015$).

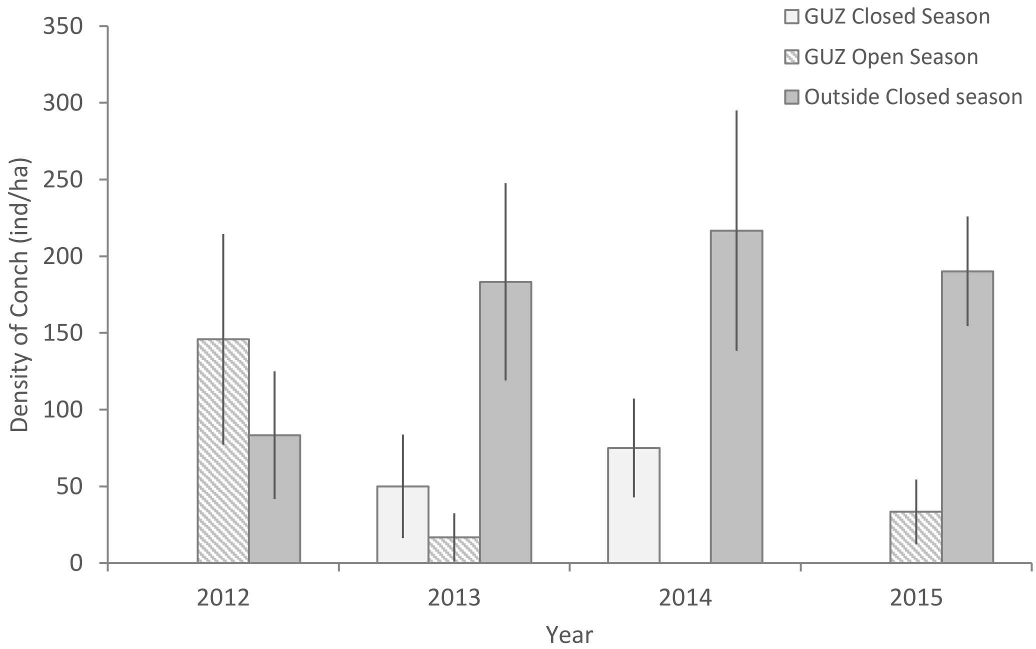


Figure 23. Queen conch density per hectare at one backreef site in the GUZ in BCMR during open and closed season, and one site outside of the reserve during closed season. Insufficient data were collected for respective sites in 2011. Error bar shows the standard error of mean.

3.4 Fish

3.4.1 Richness

A total of 140 species (38 families) were observed within BCMR over 218 survey dives (Figure 24). Outside the reserve, 83 species (32 families) were observed at two control sites. As for the FRS conducted in the mangroves, 50 species were identified at the site with grey snapper (*Lutjanus griseus*) being the most common species.

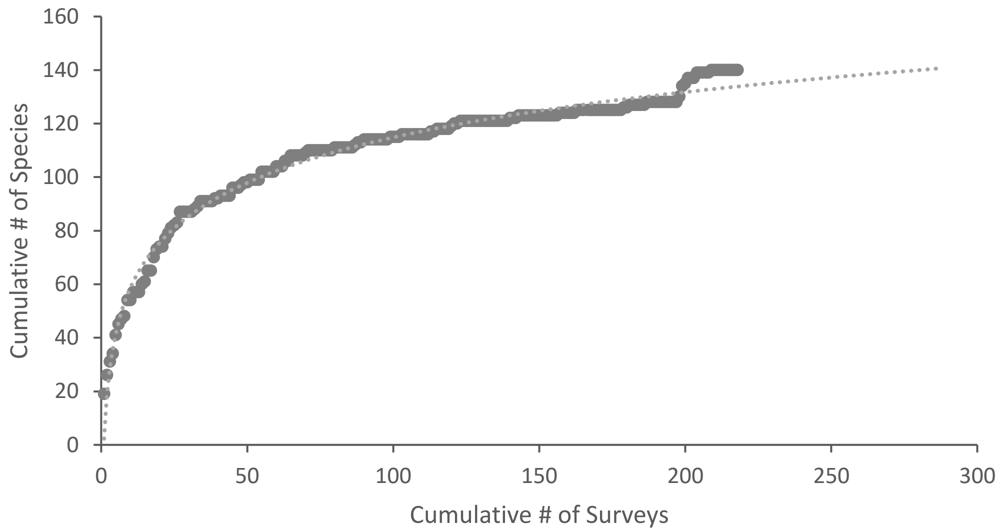


Figure 24. Species richness curve of BCMR with cumulative number of species sighted plotted against cumulative number of survey dives.

Eleven new species were identified in BCMR throughout the five-year surveying period which were previously unknown to the reserve. These include Atlantic lizardfish (*Synodus saurus*), yellowfin mojarra (*Gerres cinereus*), lightning wrasse (*Halichoeres cyanocephalus*) and green razorfish (*Xyrichtys splendens*). For a full list of species, see **Error! Reference source not found.**4.

Cumulative species richness increased by 11 species between surveys 198 and 204. Several new species such as blennie (*Chaenopsidae)*, gobie (*Gobiidae)*, wrasse (*Labridae)*, moray eel (*Muraenidae)*, porcupinefish (*Didontidae)* and grouper were identified following a fish identification workshop for field staff.

The cumulative species curve has yet to level off suggesting that more surveys are needed before all species within BCMR have been observed. However, by looking at the logarithmic curve fitted to our data, it is unlikely that the total richness of the region will exceed 145 species.

3.4.2 Sighting frequency

Common species

Inside BCMR

Within the BCMR, there were eight common species observed > 95% SF throughout the years 2011-2015 (Table 14). Blue tang, striped parrotfish, and French grunt were observed at 100% SF in three of the five years. Redband parrotfish, white grunt and ocean surgeonfish (*Acanthurus bahianus*) were observed at 100% SF only in one year out of five. Regarding the weighted average index (Den), blue tang and striped parrotfish were the two species with highest average Den values over the study period at 2.69 and 2.67, respectively.

Outside BCMR

Outside the reserve, blue tang, French grunt, redband parrotfish and striped parrotfish were observed at 100% SF for all years 2012-2015 (Table 14). Ocean surgeonfish was only sighted below 95% SF in 2013, while stoplight parrotfish (*Sparisoma viride*) and white grunt were sighted below 95% SF in 2014-2015. Bluestriped grunt was only sighted below 95% SF in 2015.

Mangrove habitat

In Cantena Creek, grey snapper was the most common species, observed at 100% SF on all surveys carried out between 2011-2015. Yellowfin mojarra was the second most common species, observed at 100% SF from 2011-2013, but decreased to 70.83% SF for 2015. Other commonly observed species were bluestriped grunt (100% SF in 2011 and 2014) and schoolmaster snapper (*Lutjanus apodus*) (100% SF in 2011 and 2015). Mollies (Poeciliidae) were only observed > 70% SF in 2011 and 2012 and were not observed on surveys in 2015. For flagfin mojarra (*Gerres filamentosus*), the highest sighting > 70% was in 2012 (73.52% SF, Den 1.58) and 2013 (82.35% SF, Den 1.9). Additional species observed above 50% SF in Cantena Creek were hound needlefish (*Tylosurus crocodilus)* (51.72% SF, 2011), unidentified wrasse species (64.7% SF, 2012), bar jack (*Caranx ruber*) (54.16% SF, 2015) and great barracuda (62.50% SF, 2014). For weighted average index, grey snapper was the only species observed in Cantena Creek with value > 3.00 Den (Table 14).

Table 14. Common fish species observed at reef sites >95% sighting frequency (%SF) with their corresponding weighted average index (Den) within and outside BCMR and the most common species observed in the mangrove habitat.

Location	Scientific name		2011		2012		2013		2014		2015	
		Common name	%SF	Den	%SF	Den	%SF	Den	%SF	Den	%SF	Den
BCMR	*Acanthurus coeruleus*	Blue tang	100.0	2.8	100.0	2.7	99.0	2.7	100.0	2.7	97.9	2.4
	Haemulon flavolineatus	French grunt	100.0	2.5	100.0	2.5	100.0	2.4	*	*	*	*
	Acanthurus bahianus	Ocean surgeonfish	95.8	2.5	100.0	2.5	*	*	*	*	96.4	2.4

	Sparisoma aurofrenatum	Redband parrotfish	100.0	2.6	98.0	2.7	*	*	97.8	2.6	*	*
	Sparisoma viride	Stoplight parrotfish	*	*	100.0	2.1	96.8	2.0	*	*	*	*
	Scarus iseri	Striped parrotfish	100.0	2.7	100.0	2.7	100.0	2.8	97.8	2.5	95.6	2.6
	Haemulon plumierii	White grunt	*	*	95.5	2.0	98.0	2.0	98.1	2.0	*	*
	Microspathodon chrysurus	Yellowtail damselfish	*	*	97.5	2.0	*	*	*	*	*	*
Outside	*Acanthurus coeruleus*	Blue Tang	-	-	100.0	2.5	100.0	2.5	100.0	2.6	100.0	2.7
	Haemulon flavolineatus	French grunt	-	-	100.0	2.2	100.0	2.4	100.0	2.2	100.0	2.6
	Acanthurus bahianus	Ocean surgeonfish	-	-	100.0	3.0	*	*	100.0	2.9	100.0	3.0
	Sparisoma aurofrenatum	Redband parrotfish	-	-	100.0	2.8	100.0	2.7	100.0	2.7	100.0	2.7
	Sparisoma viride	Stoplight parrotfish	-	-	100.0	1.8	100.0	2.5	*	*	*	*
	Scarus iseri	Striped parrotfish	-	-	100.0	2.8	100.0	2.9	100.0	2.7	100.0	3.0
	Haemulon plumierii	White grunt	-	-	100.0	1.7	100.0	1.8	*	*	*	*
	Haemulon sciurus	Blue striped grunt	-	-	100.0	1.8	100.0	2.0	100.0	1.8	*	*
Mangrove	*Haemulon sciurus*	Blue striped grunt	100.0	2.9	*	2.1	*	1.6	100.0	2.4	-	-
	Gerres filamentosus	Flagfin mojarra	-	-	*	1.6	*	1.9	-	-	-	-
	Lutjanus griseus	Grey snapper	100.0	3.7	100.0	3.2	100.0	3.0	100.0	3.8	100.0	3.6
	Lutjanus apodus	Schoolmaster snapper	100.0	2.8	94.1	2.4	*	1.9	*	2.5	100.0	2.4
	Gerres cinereus	Yellowfin mojarra	100.0	2.9	100.0	2.9	100.0	2.9	*	1.9	*	1.9

(-) no data available and (*) sighting frequency lower than 95%

Commercially important species in BCMR

Twelve species of grouper were observed within BCMR, with 91.6% being sighted in the forereef. Coney grouper (*Cephalopholis fulva*) and graysby grouper (*Cephalopholis cruentatus*) were the most commonly observed species throughout 2011-2015 with the highest sighting frequency at 91.67% in 2012 and 73.59% in 2013, respectively. Fished target species such as Nassau grouper, red hind (*Epinephelus guttatus*), black grouper and tiger grouper (*Mycteroperca tigris*) were observed in low abundance with Den value < 0.5 on all surveys with the exception in 2015 where Nassau grouper was sighted at 75% with Den value at 0.75 in CZ1. Black grouper was observed in all zones, with the highest sighting frequency of 50% in both the GUZ1 in 2012 and GUZ2 in 2013. Tiger grouper was only observed at 50% in the GUZ1 in 2012, while red hind was recorded in all zones except CZ1, with a peak sighting frequency of 33.33% in CZ2 for 2012.

Data on the snapper family determined that yellowtail snapper (*Ocyurus chrysurus*) was the most frequently observed species with the highest SF of 76.66% in 2012, followed by mahogany snapper (*Lutajanus mahogoni*) with a 69.16% SF in 2012. Grey snapper was observed at higher frequency on backreef sites (12% SF, Den 0.19) compared to forereef sites (3.41% SF, Den 0.03), with the highest SF at 33.33% in GUZ2. Cubera snapper was only sighted on the forereef with the highest at 100% SF and Den 2.66 in the CZ2 in 2012. In addition, cubera snapper was only sighted in the PZ once in 2012 at 22.22% SF and Den 0.33. Mutton snapper (*Lutjanus analis)* and dog snapper were sighted < 50% SF and Den < 0.5 throughout the years, except in 2012. Mutton snapper was sighted at 66.7% SF in CZ1 and in 2015 dog snapper was sighted at 50.00% SF.

Hogfish from the wrasse family is a highly fished species in Belize, its highest sighting frequency in BCMR of 66.66% SF was recorded in the CZ2 in 2012. Hogfish is more frequently sighted on the forereef (21.79%) than the backreef (10.81% SF). Cero mackerel (*Scomberomorus regalis*) and great barracuda are other fished species and their highest sighting frequency (20.83% SF and 18.75% SF, respectively) was in 2011. In 2012, both cero mackerel and great barracuda were sighted at 66.66% with Den 0.66 in CZ2.

Ecologically important species in BCMR

Both the parrotfish and surgeonfish families are important ecological species that play an important role in controlling FMA cover in coral reefs. Thirteen species of parrotfish were observed in BCMR in 2011-2015 (Table 15).

Table 15. Parrotfish and surgeonfish species sighting frequency (%SF) with their corresponding weighted average index (Den) within BCMR.

Family name	Scientific name	Common name	2011		2012		2013		2014		2015	
			%SF	Den	%SF	Den	%SF	Den	%SF	Den	%SF	Den
Parrotifsh Scaridae	*Sparisoma viride*	Stoplight	86.8	1.8	100.0	2.1	96.8	2.0	92.5	2.1	92.5	0.01
	Scarus iseri	Striped	100.0	2.7	100.0	2.7	100.0	2.8	97.8	2.5	95.6	2.6
	Sparisoma aurofrenatum	*Redband*	100.0	2.6	98.0	2.7	90.0	2.2	97.7	2.6	100.0	2.8
	Sparisoma chrysopterum	*Redtail*	<50.0	0.7	75.2	1.4	53.0	0.9	<50.0	0.7	<50.0	0.5
	Scarus taeniopterus	*Princess*	<50.0	0.6	<50.0	0.7	58.8	1.1	<50.0	0.8	58.3	1.1
	Sparisoma rubripinne	*Yellowtail*	68.9	1.2	70.0	1.2	64.5	1.2	59.1	1.1	63.6	1.1
	Cryptotomus roseus	*Bluelip*	-	-	-	-	<50.0	0.1	-	-	-	-
	Sparisoma radian	*Bucktooth*	-	-	-	-	-	-	-	-	<50.0	0.1
	Scarus vetula	*Queen*	<50.0	0.1	<50.0	0.4	<50.0	0.2	<50.0	0.3	<50.0	0.4
	Nichosina usta	*Emerald*	-	-	-	-	-	-	<50.0	0.1	-	-
	Scarus guacamaia	*Rainbow*	-	-	-	-	<50.0	0.1	-	-	-	-
	Scarus coelestinus	*Midnight*	<50.0	0.04	<50.0	0.03	<50.0	0.03	-	-	-	-

Surgeonfish Acanthuridae	*Acanthurus coeruleus*	*Blue tang*	100.0	2.8	100.0	2.7	100.0	2.7	100.0	2.7	97.9	2.7
	Acanthurus bahianus	Ocean surgeon	95.8	2.5	100.0	2.5	93.8	2.4	85.0	2.2	96.4	2.4
	Acanthurus chirurgus	Doctorfish tang	67.4	1.3	79.7	1.5	94.1	1.8	75.1	1.7	65.5	1.1

(-) *insufficient data*

Striped parrotfish and stoplight parrotfish were the most sighted species at > 85% SF. Yellowtail parrotfish (*Sparisoma rubripinne*) was sighted at 100% SF in the GUZ1 from 2011-2012 and 2015 and in the GUZ2 in 2012 which varied from their overall %SF and Den averages. Other species observed were the bluelip parrotfish (*Cryptotomus roseus*), bucktooth parrotfish (*Sparisoma radian*), queen parrotfish (*Scarus vetula*) and emerald parrotfish (*Nichosina usta*) but all abundances and densities were below the high threshold for sighting frequency and density (< 50% SF, Den < 3.00) or there was insufficient data. Target fished species within the parrotfish family include the rainbow parrotfish (*Scarus guacamaia*) and midnight parrotfish (*Scarus coelestinus*), which were both observed in CZ1, however both were under the threshold overall. Midnight parrotfish was observed in 2011 (SF 16.67%, Den 0.17) and 2012 (SF 12.5%, Den 0.125) in low abundances.

Blue tang was the most commonly sighted species of the surgeonfish family sighted at > 95% SF on surveys throughout 2011-2015, followed by ocean surgeonfish with the highest sighting frequency of 100% in 2012. The highest sighting frequency of doctorfish (*Acanthurus chirurgus*) was in 2013 at 94.07%. All three species of surgeonfish were sighted > 90% in both forereef and backreef in all zones (Table 15).

Other species in BCMR

General coral reef fish species were observed with some recorded above the high threshold, this included 15 individual species from the angelfish (*Pomacanthidae*), grunt, damselfish (*Pomacentridae*), and butterflyfish (*Chaetodontidae*) families (Table 16).

Table 16. Other fish species sighting frequency (%SF) with their corresponding weighted average index (Den) above the high threshold (< 50% SF and Den < 3.00) within BCMR.

Common family name	Scientific name	Common name	2011 %SF	2011 Den	2012 %SF	2012 Den	2013 %SF	2013 Den	2014 %SF	2014 Den	2015 %SF	2015 Den
Angelfish	*Holacanthus tricolor*	Rock beauty	60.8	1.1	50.0	0.9	<50.0	0.9	<50.0	0.8	65.8	1.1
	Pomacanthus paru	French angel	<50.0	0.3	<50.0	0.1	<50.0	0.2	<50.0	0.3	<50.0	0.1
	Pomacanthus arcuatus	Grey angel	<50.0	0.3	<50.0	0.3	<50.0	0.5	<50.0	0.4	<50.0	0.5
	Holacanthus ciliaris	*Queen angel*	<50.0	0.2	-	-	<50.0	0.1	<50.0	0.1	<50.0	0.2
Grunt	*Haemulon flavolineatus*	French grunt	100.0	2.5	100.0	2.5	100.0	2.4	92.4	2.2	100.0	2.4
	Haemulon sciurus	Blue striped	83.3	1.8	87.5	2.1	89.5	1.95	81.2	1.9	76.98	1.7
	Haemulon plumierii	White	82.4	1.7	95.5	1.97	98.0	2.0	98.1	1.96	93.7	1.8

	Haemulon carbonarium	Caesar	58.2	1.2	52.7	1.05	<50.0	0.7	57.3	1.01	57.9	1.02
Damselfish	*Microspathodon chrysurus*	Yellowtail	92.4	1.9	97.5	1.95	85.7	1.9	90.5	1.89	79.7	1.6
	Stegastes partitus	Bicolor	95.0	2.5	62.0	1.6	55.4	1.5	55.4	1.46	88.4	2.4
	Abudefduf saxatilis	Sergeant major	54.6	1.3	62.5	1.5	53.4	1.3	<50.0	1.1	<50.0	1.3
	Chromis viridis	Blue chromis	68.75	1.9	53.3	1.4	64.4	1.7	<50.0	0.9	53.1	0.2
Butterfly	*Chaetodon capistratus*	Foureye	73.9	1.2	55.8	1.0	65.1	1.1	<50.0	0.99	51.1	0.89
	Chaetodon striattus	Banded	58.6	0.9	60.2	0.88	50.9	0.9	<50.0	0.8	<50.0	0.7
	Chaetodon acellaus	Spotfin	<50.0	0.2	<50.0	0.4	<50.0	0.46	<50.0	0.4	<50.0	0.3

(-) *insufficient data*

Rock beauty angelfish (*Holacanthus tricolor*) was the most frequently recorded species of the angelfish family. Rock beauty were observed in high frequency in 2011 (60.8% SF, Den 1.1) and 2015 (65.8% SF, Den 1.1). The French angelfish (*Pomacanthus paru*) was most frequently observed in CZ1 in 2011 (58.33% SF, Den 0.89) along with the grey angelfish (*Pomacanthus arcuatus*) in 2012 (77.5% SF, Den 0.9) and 2015 (100% SF, Den 1.75). Queen angelfish (*Holacanthus ciliaris*) sightings were determined higher on the forereef (26.19% SF, Den 0.29, 2015) than on the backreef (11.11% SF, Den 0.11, 2011).

A total of thirteen species of grunt were observed however the French, bluestriped, white, and ceasar grunts were the most common. French grunt was observed at 100% SF within BCMR. Bluestriped grunt was sighted at 100% SF on the backreef, which only differed slightly from the overall %SF. Caesar grunt had high sighting frequencies in the PZ with the highest in 2012 (SF 77.78%, Den 1.72).

Eleven species of damselfish were observed in total. Yellowtail damselfish (*Microspathodon chrysurus*), bicolor damselfish (*Stegastes partitus*), sergeant major (*Abudefduf saxatilis*) and blue chromis (*Chromis viridis*) were most commonly observed throughout the years 2011-2015. Blue chromis had a higher sighting frequency on the forereef (96.78% SF, Den 2.6, 2013) than the backreef (16.66% SF, Den 0.16, 2015).

Three species from the butterflyfish family were observed. Foureye butterflyfish (*Chaetodon capistratus)* was the most commonly observed species followed by the banded butterflyfish. On the forereef the foureye butterflyfish had a higher sighting frequency than its overall average within BCMR: 2011 (78.52% SF, Den 1.38), 2012 (58.33% SF, Den 1.13), 2013 (78.47% SF, Den 1.32), and 2014 (73.31% SF, Den 1.49). On the backreef, the banded butterflyfish was the most commonly observed with high SF values for each year: 2011 (75% SF, Den 1.31), 2012 (75.42% SF, Den 1.12), 2013 (58.33% SF, Den 1.03), 2014 (56.67% SF, Den 0.9), and 2015 (87.5% SF, Den 1.5). Spotfin butterflyfish (*Chaetodon acellaus*) was recorded with high frequencies in CZ2 (2012 (100% SF, Den 1.33) and 2014 (57.14% SF, Den 0.86)) and in GUZ1 (2011 (73.33% SF, Den 1.07), 2012 (87.5% SF, Den 1.5), 2013 (90% SF, 1.49), and 2015 (87.5% SF, Den 1.63)).

The Bermuda/yellow chub (*Kyphosus* sectatrix) was sighted in forereef and backreef sites, but in abundance and densities below the high threshold for sighting frequency and density (< 50% SF, Den < 3.00). This species was only observed in great abundance and density in CZ2 in 2012 (100% SF, Den 3.00) and GUZ2 in 2012 (66.67% SF, Den 1.33). Bar jack were the most common of the five species of jack (family Carangidae) observed in the reserve with the species highest sighting value at 80.56% SF with Den 1.19 in 2013. Permit was sighted at 75% SF and Den 1.63 in 2015.

Seven species of gobies were observed at low abundance and densities (SF < 50%, Den < 3.0). Broadstripe goby (*Elacatinus procilos*) was the only goby species positively identified in backreef sites in 2015. Five species of blennie belonging to the *Labrisomidae, Chaenopsidae,* and *Blenniidae* families were observed at low threshold (50% SF, Den 3.00). Four species of filefish (*Monacanthidae*) were observed in forereef sites in low abundance < 50%, Den < 3.00. Orangespotted filefish (*Cantherhines pullus*) was the only species observed in backreef habitats in 2012 and 2013. Three species of the moray eel were observed at low abundance in the reserve with green moray (*Gymnothorax funebris*) being the only species sighted in the backreef. No moray species were observed in GUZ2 in 2011 and 2014.

Families with one or two species observed below threshold (50% SF and Den 3.00) in BCMR included hawkfish (*Cirrhitidae*), needlefish (*Belonidae*), goatfish (*Mullidae*), eagle rays (*Myliobatidae*), drums/croakers (*Sciaenidae*).

3.4.3 Abundance and biomass

In 2015, the mean fish abundance was 36.47 ind/100 m^2 and the mean biomass was 1933 g/100 m^2. The abundance and biomass of fish differed significantly between years (abundance $F_{4,710} = 4.787$, $p < 0.001$; biomass $F_{4,710} = 4.786$, $p < 0.001$) (Figure 25). For both abundance and biomass, post-hoc Tukey tests showed that this is due to the differences between 2011 and 2015. Abundance dropped from 104.7 ind/100 m^2 to 40.73 ind/100 m^2 ($p = 0.005$) and biomass dropped from 5966 g/100 m^2 to 2252 g/100 m^2 ($p = 0.02$; Figure 25).

Management zone had no effect on abundance ($F_{5,709} = 0.23$, $p = 0.95$) or biomass ($F_{5,709} = 1.73$, $p = 0.13$). However, abundance was significantly lower on forereefs ($T_{407,76} = 2.143$, $p = 0.033$) at 37.72 ind/100 m^2 in 2015 compared to backreefs at 44.93 ind/100 m^2 in the same year. There was no significant difference in biomass between reef types ($T_{713} = 0.74$, $p = 0.46$).

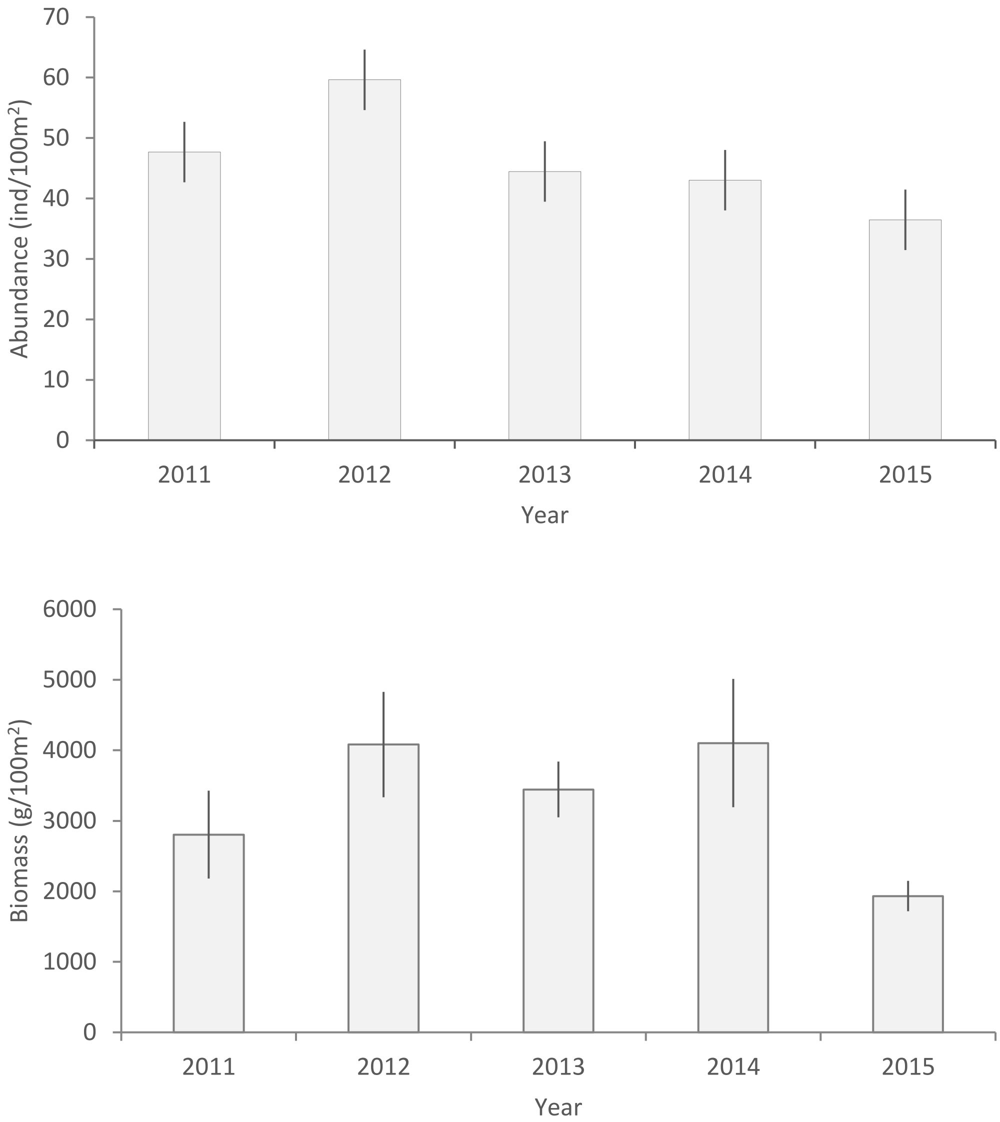


Figure 25. Mean fish abundance (above) and biomass (below) of reef fish for each year.

Commercial fish – snappers and groupers

Very few groupers were recorded on surveys within BCMR between 2011 and 2015, with all years possessing a median of zero ind/ha (Figure 26). There was no significant difference in the abundance of grouper between years (KW test; X^2 = 3.5324, df = 4, p-value = 0.473). However, there was a significant difference in grouper abundance between management zones (KW test; X2 = 36.9961, df = 5, p-value < 0.0001).

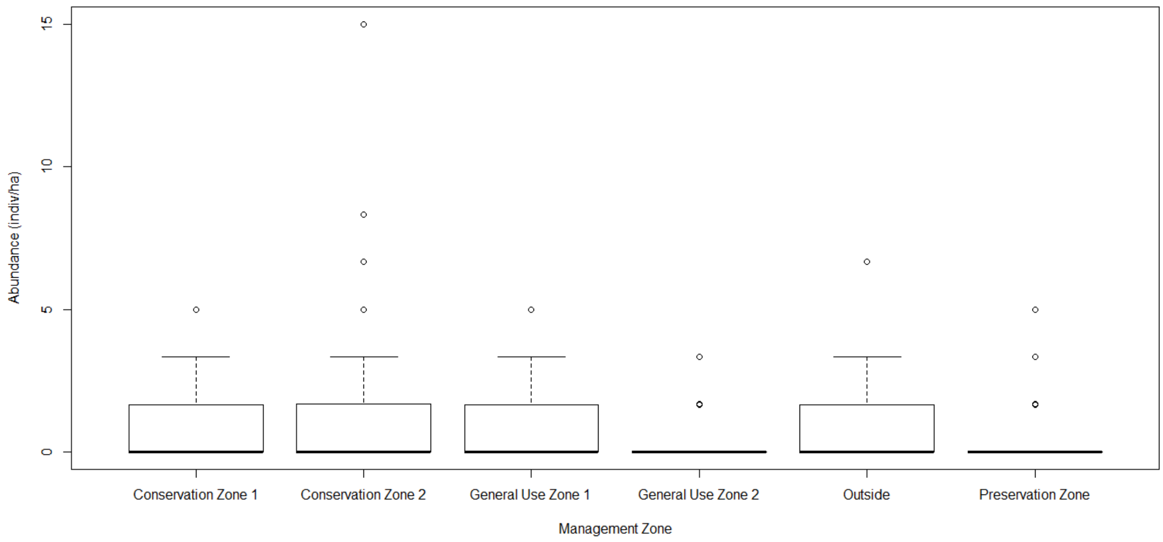


Figure 26. Median and interquartile range of grouper abundance in each management zone across BCMR between 2011 and 2015.

For snapper, abundance differed between years (KW test; X2 = 23.5709, df = 4, p-value < 0.001). The abundance of snappers was at its highest in 2012 at 13.33 ind/ha and it lowest in 2011 at 6.67 ind/ha. There was also a significant difference in snapper abundance between management zones (KW test; X2 = 60.2881, df = 5, p-value < 0.0001). Median abundance was highest at 1.67 ind/ha in CZ1, GUZ2, PZ and outside the reserve (control sites). It was at its lowest at 0.83 ind/ha in GUZ1 and zero in CZ2 (Figure 27).

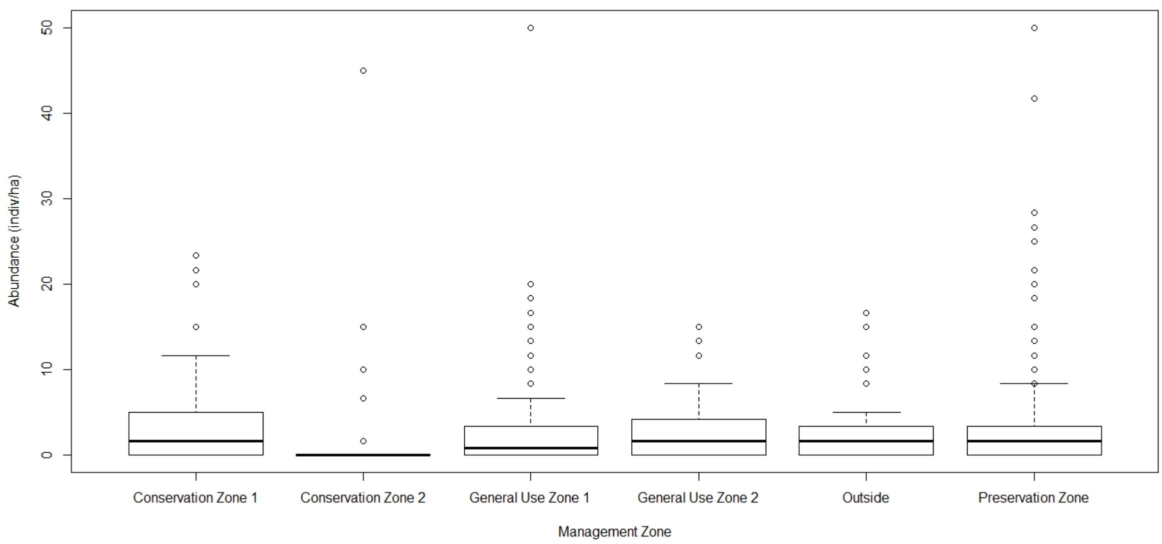
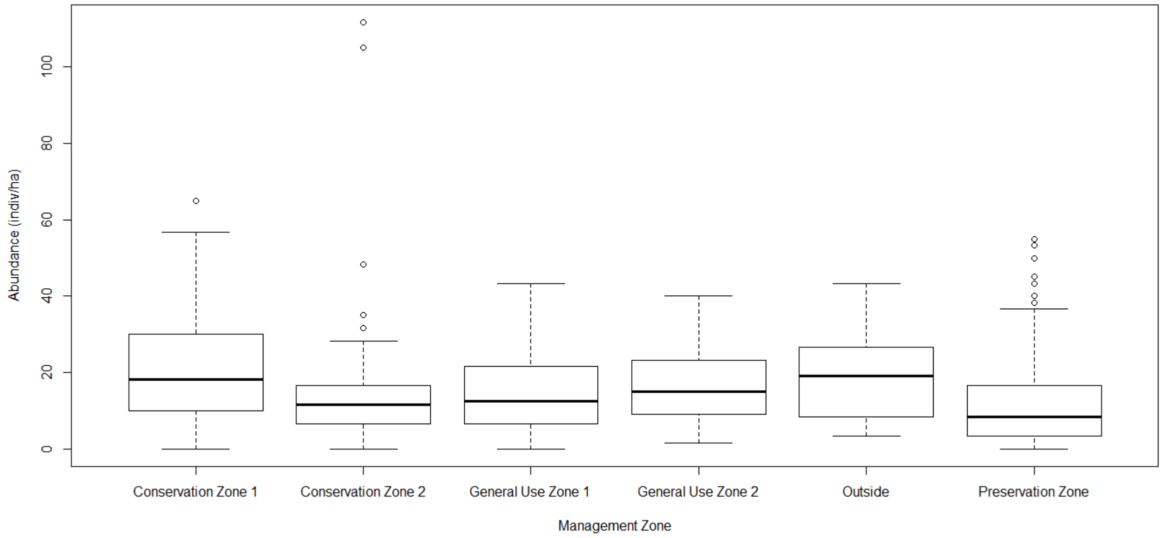


Figure 27. Median and interquartile range of Snapper abundance in each management zone across BCMR between 2011 and 2015.

Herbivorous fish – parrotfish and surgeonfish

The abundance of both parrotfish and surgeonfish differed significantly between management zones (parrotfish KW test; X2 = 76.2403, df = 5, p-value < 0.0001; surgeonfish KW test; X2 = 18.1381, df = 5, p-value < 0.01), with each having their highest abundance outside BCMR at 8.33 ind/ha and 11.6 ind/ha, respectively (Figure 28). The abundance of parrotfish fluctuated significantly between 2011 and 2015 (KW test; X2 = 14.7289, df = 4, p-value < 0.01), with the highest abundance in 2012 at 16.67 ind/ha.



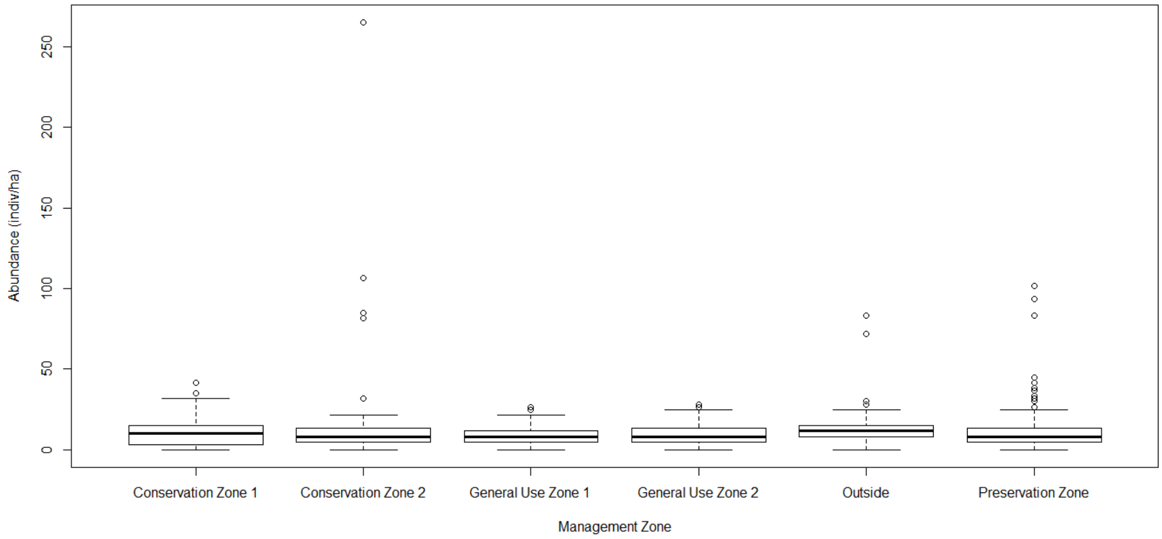


Figure 28. Median and interquartile range of parrotfish (above) and surgeonfish (below) abundance in each management zone across BCMR between 2011 and 2015.

3.4.4 Fish Recruitment

There was no significant difference in the abundance of juveniles over time in all management zones ($F_{3,9}$ = 0.70, p = 0.58), at a mean of ~27 juveniles/100 m^2 in both 2012 (27.4 ±2.8) and 2015 (27.1 ±2.4) (Figure 29).

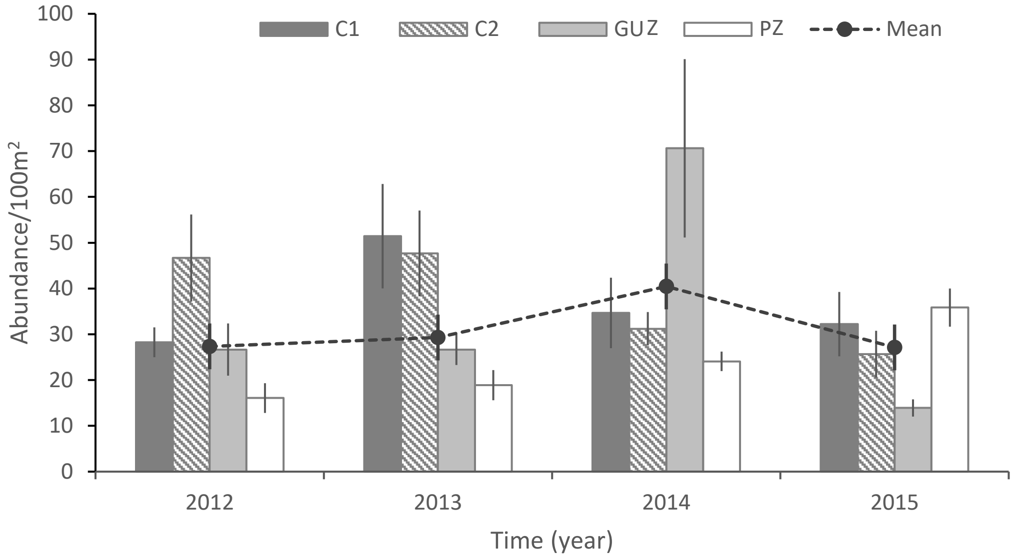


Figure 29. Total abundance of juvenile fish over time in different management zones.C1=Conservation Zone 1, C2=Conservation Zone 2, GUZ =General Use Zone, PZ=Preservation Zone. Black dots indicate annual mean, all error bars are standard error of the mean. Data from 2011 wasn't included as none was available in the preservation zone for this year. Only sites with data available in every year were used.

The mean abundance of fish recruits did not significantly differ between management zones across all years ($F_{3,9}$ = 0.61, p = 0.63) and seasons ($F_{3,6}$ = 0.29, p = 0.83) (Figure 30).

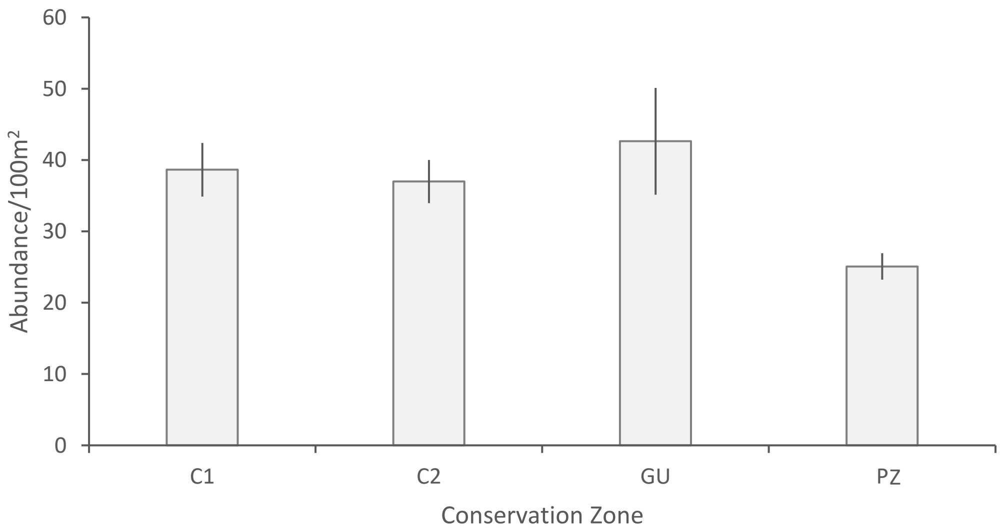


Figure 30. Mean total abundance of juveniles per 100 m^2 in each management zone across all years and seasons. Error bar shows standard error of the mean. C=Conservation Zone 1, C2=Conservation Zone 2, GU=General Use Zone, PZ= Preservation Zone.

There is little correlation between total fish recruit abundance and hard coral cover (Spearman Rank; R = 0.011, t_{15} = 0.04, p = 0.48; Figure 31).

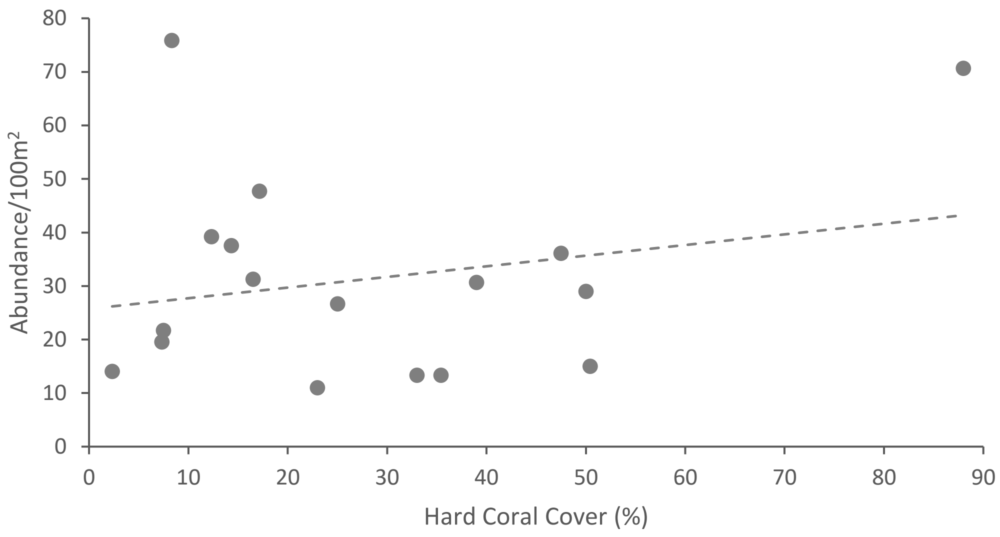


Figure 31. Proportion of hard coral cover against total abundance of juvenile fish. Data is from mean hard coral and fish recruit abundances per site per season where available. Dotted line shows the line of best fit.

Although reef type (forereef or backreef) had no significant influence on the total abundance of juveniles in each management zone ($F_{1,3}$ = 0.38, p = 0.60), reef type was a significant predictor of differences in juvenile community structure (PERMANOVA $F_{1,54}$ = 9.12, p = 0.001; Figure 32). SIMPER analysis shows more yellowhead wrasse on forereefs while backreefs are characterised by higher abundances of Blue tang and slippery dick. Little separation in community structure was observed between different management zones (Figure 32).

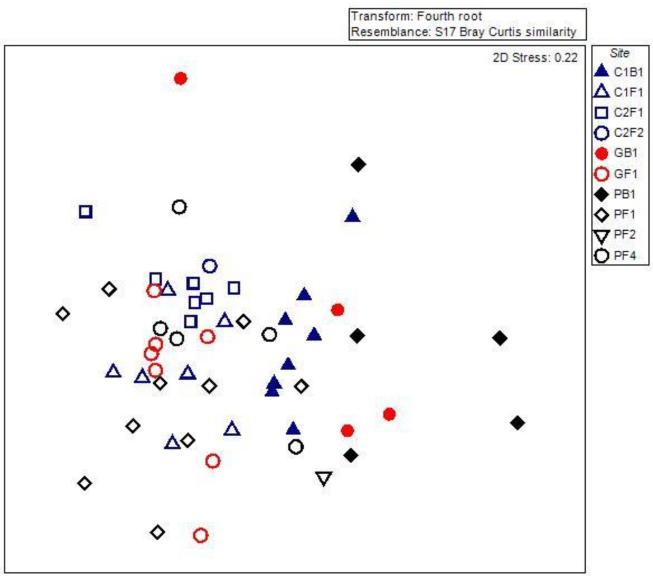


Figure 32. nMDS plot of fourth-root transformed species-level juvenile assemblages, using a Bray-Curtis resemblance matrix of mean seasonal abundances per 100 m². Empty symbols show forereef communities, filled symbols indicate backreefs. Red = GUZ, Blue = CZ, Black = PZ.

3.5 Megafauna

3.5.1 Elasmobranchs

Out of all elasmobranch sightings, 53% were southern stingray, followed by nurse shark (21%), spotted eagle ray (17%), Caribbean round stingray (*Himantura schmardae*) (5%) and Caribbean reef shark (*Carcharhinus perezii*) (3%). Less than 1% of all sightings were yellow stingray, lesser electric ray or unidentified sharks and rays.

The mean number of elasmobranch sightings did not differ significantly between forereefs and backreefs throughout the sampling period (ANOVA; $F_{1,3}$= 0.04, p = 0.85), with backreefs having 0.050 sightings (person^{-1} minute^{-1}) and forereefs with 0.053 sightings (person^{-1} minute^{-1}) (Figure 33).

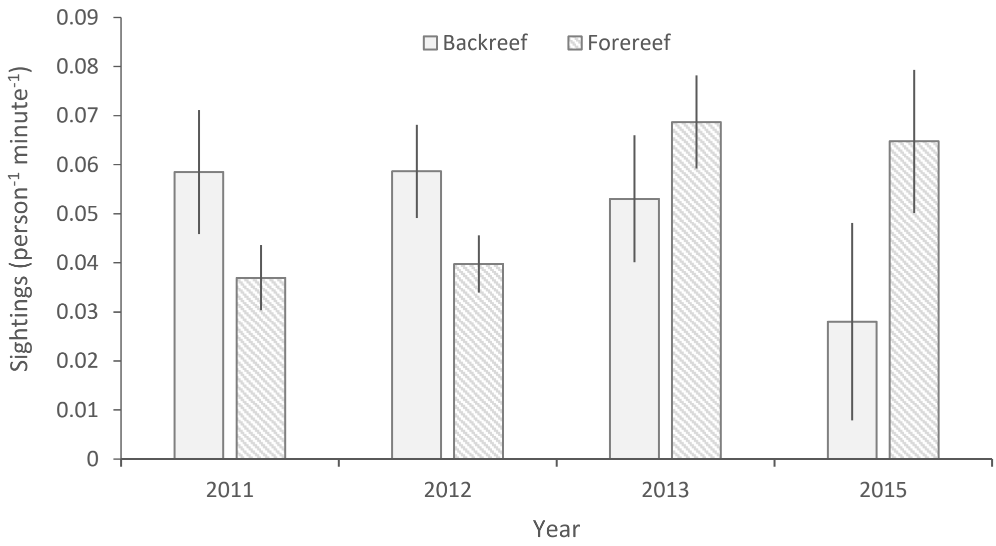


Figure 32. Mean sightings (person^{-1} minute^{-1}) of all elasmobranchs over time in both forereef and backreef. Error bar shows standard error of the mean. Data collected in 2014 would have biased results and therefore was not included.

Although total sightings (person^{-1} minute^{-1}) of elasmobranchs were at their highest in the PZ zone in 2013 and 2015 at 0.067 sightings (person^{-1} minute^{-1}) (± 0.043) and 0.026 sightings (person^{-1} minute^{-1}) (± 0.015) (Figure 34), there was no difference detected in the sightings of elasmobranchs between years (ANOVA; $F_{3,9}$= 0.53, p = 0.68) nor between management zones (ANOVA; $F_{3,9}$ = 2.52, p = 0.12).

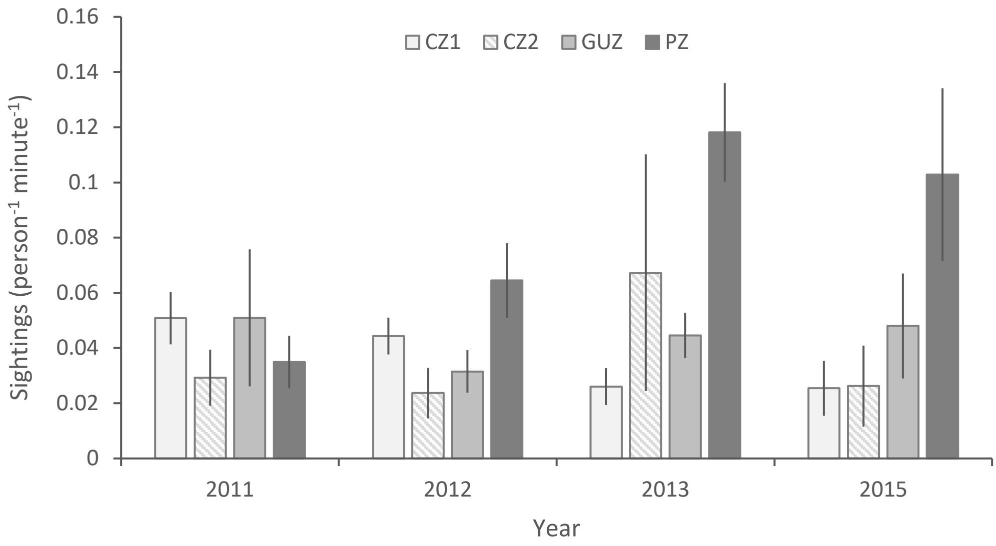


Figure 34. Mean sightings (person^{-1} minute^{-1}) of all elasmobranchs over time in each management zone. Error bar shows standard error of the mean. Data collected in 2014 would have biased results and therefore was not included.

When we break these sightings down into sharks and rays, different trends emerge. Shark sightings did not differ between years (ANOVA; $F_{3,9} = 1.59$, $p = 0.26$); however, they did differ significantly between management zones (ANOVA; $F_{3,9} = 5.17$, $p = 0.02$). Post hoc Tukey HSD tests show that the source of the difference between management zones is one anomalously high frequency of sightings in CZ2 in 2013 at 0.061 sightings (person^{-1} minute^{-1}) (± 0.039).

Ray sightings showed a significant difference between management zones across all years (ANOVA; $F_{3,9} = 7.23$, $p = 0.01$), Tukey HSD tests indicate that this difference is due to a higher abundance of rays inside the PZ relative to other sites (Figure 35). However, the difference in ray sightings between management zones did not change significantly over time ($F_{3,11} = 0.28$, $p = 0.84$), despite sightings in the PZ increasing from 0.026 sightings (person^{-1} minute^{-1}) (±0.009) in 2011 to 0.092 sightings (person-1 minute-1) (± 0.029) in 2015.

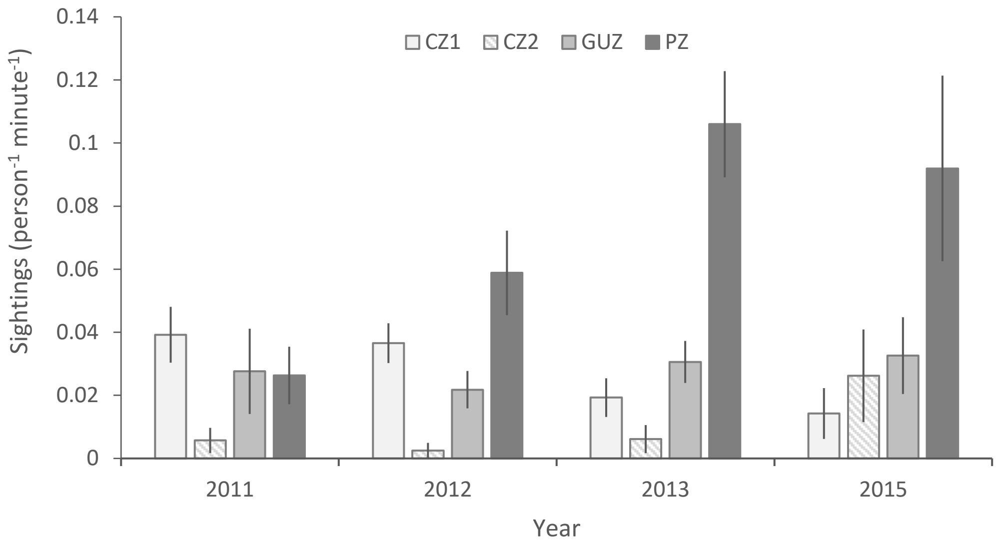


Figure 35. Mean sightings (person^{-1} minute^{-1}) of rays in each management zone over time. Error bar shows standard error of the mean. Data collected in 2014 would have biased results and therefore was not included.

3.5.2 Sea turtles

Hawksbill turtles accounted for 44% of the sea turtle sightings in BCMR, followed by loggerhead turtles (32%) and green turtles (14%). Ten percent of sea turtle sightings were not identified to species level. There was no significant difference in sea turtle sightings between seasons ($F_{2,11} = 4.26$, $p = 0.52$), nor years ($F_{3,9} = 1.40$, $p = 0.30$).There was a significant difference in sea turtle sightings between management zones in every year of surveying with fewer sightings in CZ1 compared with CZ2 across all years (Figure 36).

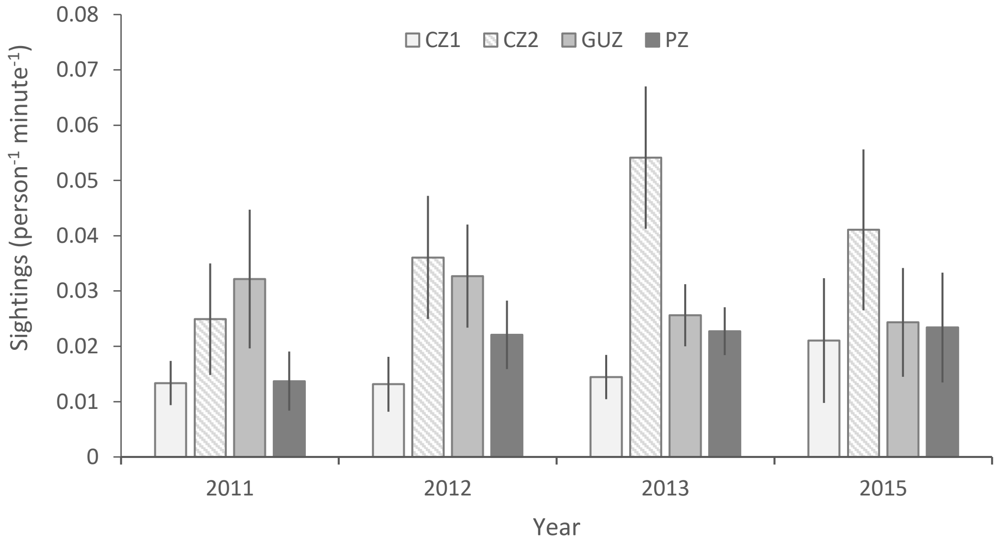


Figure 36. Mean sightings (person^{-1} minute^{-1}) of all sea turtles over time in each management zone. Error bars are standard error of the mean. Data collected in 2014 would have biased results and therefore was not included.

However, only forereefs were sampled in CZ2, which we have shown to experience a higher frequency of sea turtle sightings than backreefs (Figure 37). Therefore, the high number of sea turtle sightings in CZ2 may be solely due to the difference between the forereef and backreef.

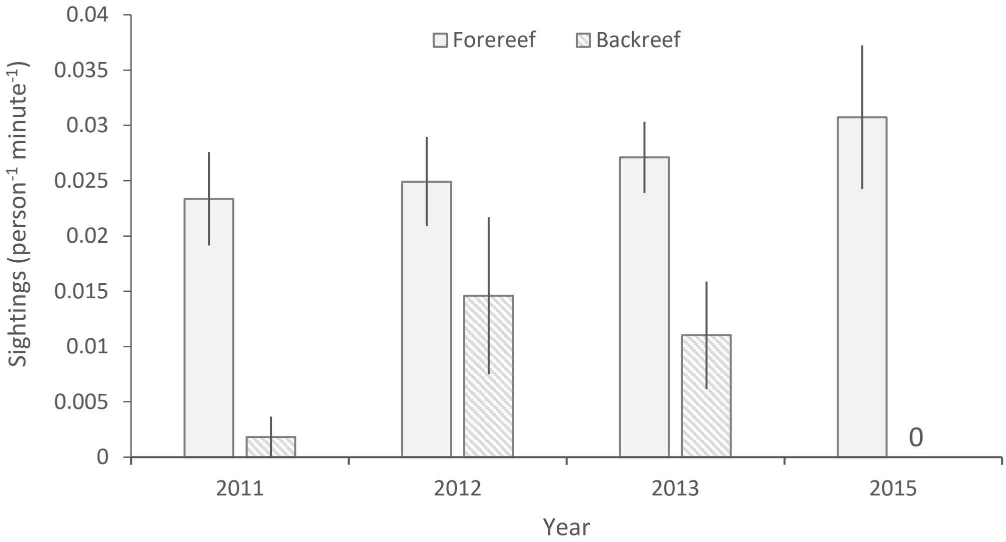


Figure 37. Mean number of sightings per person per minute of sea turtles over time, broken down into sightings on forereefs and backreefs. Error bar shows standard error of the mean. Data collected in 2014 would have biased results and therefore was not included.

The spatial distribution of sea turtles indicated a significant difference in sightings between forereefs and backreefs across all years (ANOVA; $F_{1,3}$ = 20.31, p = 0.02) with divers on forereefs seeing 0.027 turtles sightings (person-1 minute-1), compared with 0.007 sightings (person-1 minute-1) on backreefs. This difference between forereefs and backreefs did not change significantly over time (ANOVA; $F_{3,3}$=0.60, p=0.66).

4 Discussion

4.1 Bacalar Chico Marine Reserve's reef health

Bacalar Chico Marine Reserve was established in 1996 as a management tool to ensure the health of coral reefs and fisheries in the northern part of the Belize Barrier Reef by restoring fishery target species and coral reef habitat (Wildtracks, 2012). Previous evaluations had shown declines in reef health with the average Simplified Integrated Reef Health Index (SIRHI) score dropping from 2.2 in 2010 to 1.9 in 2011 (Chapman, 2012). This was attributed to the low hard coral cover (HC, 10%) and high fleshy macroalgae (FMA, 16% on backreef and 25% on forereef) dominance of the benthos. In addition, overall fish biomass was low across all zones with the highest biomass located in the PZ at 8996.7 g/100 m^2. Management zone had no influence on benthic community and fish community, or on overall reef health (Chapman, 2012).

The results of this five-year evaluation from 2011-2015 shows a similar outcome to the previous study, as BCMR's coral reef health still remains between Critical and Poor condition on the SIRHI scale with no reef sites within or outside the reserve scoring in Good or Very Good condition. In 2015, BCMR's average SIRHI score was 1.9, which was lower than the 2015 national and regional SIRHI score at 2.5 and 2.8, respectively (Healthy Reef Initiative, 2015). This is attributed to the low HC cover, high FMA cover and extremely low biomass of commercially important (groupers and snappers) and key herbivorous (parrotfish and surgeonfish) fish families.

4.2 Coral reef benthic community structure

Coral reef health has declined on a global scale over the decades with losses of 80% of coral cover on many Caribbean reefs, however, there have been some encouraging signs of coral cover recovery in recent years (Wilkinson, 2006). The Mesoamerican Barrier Reef System (MBRS) has shown an increase in coral cover from 10% in 2006 to 16% in 2015 (Healthy Reef Initiative, 2015). Coral cover within BCMR differed significantly between the years 2011-2015 with mean coral cover increasing from 11.26% in 2011 to 13.16% in 2015. However, it did not correlate with the MPA's structure, since management zone had no influence on coral cover over the years, nor did coral cover differ between the northern and southern sections of the reserve. The southern section of the reserve sees more human activities because of its close proximity to San Pedro and as coastal development continues to move north towards the border of the reserve this trend will most likely continue over the coming years. Coral cover only differed significantly between reef type, with the forereef presenting higher cover than the backreef. Therefore, the increasing coral cover in BCMR might be attributed to a regional coral reef recovery process, rather than factors specific to the MPA itself. Coral cover in BCMR still remains lower than the 2015 national average (15%). Other sites within Belize such as Glover's Reef and Turneffe Atoll have been reported to have coral cover slightly higher than 16% (Healthy Reef Initiative, 2015).

Another contributor to poor reef health in BCMR is the high FMA cover including; y-branch algae, encrusting fan-leaf algae and other algae species, which has not changed between 2011 and 2015. These algae compete with coral for space on the reef, and when FMA is dominant coral recruits are prevented from settling on the substrate, hindering hard coral recovery (Letters, 2006).

Management zones within BCMR had a slight influence on FMA cover; the PZ had the lowest FMA cover (17.38%) compared to the other zones. However; biomass of herbivorous fish in the PZ was also low, which could indicate that low FMA cover in this zone may be due to other factors. It is possible that there is low nutrient input in the north section of the reserve compared to the south section, or that the existing herbivorous fish population is exerting enough grazing pressure to control FMA cover.

In contrast, CZ2 had the highest FMA cover at 31.17%. This zone along with GUZ2 and our two control sites located outside the reserve are located on the south section of the reserve. The south section contained significantly higher FMA cover compared to the north section of the reserve with y-branch algae (*Dictyota)* found to be the dominant genus in the FMA community.

Some species of FMA such as *Dictyota cervicornis* and *Dictyota jamaicensis,* both y-branching algae, are fast-growing pollution indicators that rapidly overgrow even deep coral reefs on densely populated islands (Goldstein et al., 2007). The south section of the reserve has a higher risk of exposure to pollutant runoff originating from San Pedro town which is located south of the reserve and has undergone continuous coastal development over the last three decades (Clarke, C. & M. Canto, 2013).

Overall, the south section of the reserve contained the highest levels of FMA cover in the reserve which contribute to the high average FMA cover in BCMR (27 ± 1.36%) which exceeded the national average 24% (Healthy Reef Initiative, 2015).

4.3 Fish density within BCMR

BCMR has a wide variety of fish species, with 140 species (38 families) reported in this study and the most sighted species being herbivorous fish (striped parrotfish, stoplight parrotfish, and blue tang). This may be attributed to the Government of Belize banning any taking of parrotfish and surgeonfish in 2009. Both surgeonfish and parrotfish families, are considered important grazers that help in controlling FMA cover on coral reefs. However, overall fish abundance and biomass on the coral reefs of BCMR has decreased between 2011 and 2015 with no concrete evidence showing a positive influence by management zones. Fish recruitment has not varied per season or per zone. Average fish recruitment across all years was constant around 27 ind./100 m^2, which suggests that fish recruitment is not being strongly impacted by lionfish predation. Lionfish populations have remained low (27.1 ± 8.8 ind/ha in 2014) in BCMR (Chapman et al., 2016) as a result of intense year-round culling pressure by Blue Ventures staff and volunteers.

The biomass of herbivorous grazing fish such as surgeonfish and parrotfish did fluctuate across the years but remained consistently low. In 2015, BCMR was found to have herbivorous fish biomass of 1179.35 ± 253.94 g/100 m^2. This is lower than other sites within Belize such as Turneffe Atoll, which presented the highest herbivore biomass in 2015 with 2383 g/100 m^2 (Healthy Reef Initiative, 2015). The biomass of large predators such as grouper, snapper and barracuda were found to be low. Very few groupers were recorded on fish belt surveys within all zones of the reserve and outside, although it should be noted that groupers are cryptic species with a tendency to hide in crevices and overhangs making them difficult to spot with this method. This may mean that the number of groupers observed in BCMR is an underestimation. In 2015, the Healthy Reef Initiative reported 700 groupers counted at 149 reef sites within the entire Mesoamerican Barrier Reef System, of which 4% were > 40 cm. For BCMR, 47 groupers were counted at 11 sites in 2015 of which 2.13% were > 40 cm. The median abundance of grouper was zero ind/ha, due to many surveys recording no individual groupers. The low total abundance of groupers limits our conclusions in statistical terms, with a higher risk of type 1 error. Snapper abundance in BCMR did differ significantly between zones and over the years with a highest value in 2012 at 13.33 ind/ha. Both grouper and snapper are important commercial species in Belize, and these populations were found to be in poor condition within BCMR with no increase in biomass over the years.

Overall biomass of commercial fish species (both groupers and snappers) at 254.2 90.81 g/100 m^2 for BCMR in 2015, remains lower than the national average at 811 g/100 m^2 (Healthy Reef Initiative, 2015).

4.4 Belize's two main commercial species

MPAs have previously been shown to influence commercial species abundance (Armfield, 2008) and this phenomenon can be seen within BCMR where CZ1 and the PZ influenced Caribbean spiny lobster and queen conch abundance, respectively. Conch abundance was at its highest in 2015 at 366.67 ind/ha in the PZ, while in the GUZ1 it was at 16.67 ind/ha. In 2014 lobster abundance was highest at 666.67 ind/ha in CZ1 and the lowest in GUZ1 at 66.67 ind/ha. The invertebrates survey, which was carried out on the fish belt, is a rapid approach to estimating invertebrate density; however, it should be noted that this method differs from the standardised Belize national lobster and conch underwater survey methods (The Belize Fisheries Department, 2005).

CZ1 and the PZ presented the highest abundance compared to the other zones; however, there was no significant change in lobster or conch abundance over the years, which suggests that management zones had no effect over time. Another explanation might be insufficient adherence to and/or enforcement of reserve regulations, meaning that these species were being extracted from these NTZs. The PZ, CZ1 and CZ2 of BCMR are intended to be replenishment zones for conch and lobster populations with extraction prohibited; however, fishing incursions from Mexico as well as from within Belize have been common in the reserve (Fisheries Department, pers. comm.). These incursions target both lobster and conch, which are species of high price value, and have possibly contributed to the low abundance of these species over the years.

One of the enforcement issues in BCMR has been incursion fishing from Mexico within the PZ, due to the zone's proximity to the international border. For example in 2013, three Mexican fishers were fined for fishing in the PZ in BCMR (Longsworth, 2013). Belizean fishers primarily target the Conservation Zones, particularly CZ2 which is in the far south of the reserve and therefore difficult to monitor. Surveillance is essential for the success of MPAs, as intruders who violate the reserve can seriously damage the recovery process for target species' populations (Armfield, 2008; Cabigas et al., 2012).

4.5 Megafauna

Certain beaches within the BCMR are important nesting grounds for sea turtles (Grimshaw & Mito Paz, 2004), for this reason three species of sea turtle are regularly sighted within the reserve. The most frequently sighted species was the hawksbill turtle which prefers to live on coral reef habitats during adulthood (Harrison, 2005).

Nurse sharks were the most commonly sighted elasmobranch species; this shark is thought to be abundant throughout its range and is not yet considered threatened with extinction. The proximity of the nurse shark habitat to human activities is putting increased pressure on the species (Castro, 2000).

4.6 Management zones effectiveness

Zoning within an MPA is often used to regulate different extractive and non-extractive activities in the area, reduce conflicts among different user groups and provide increased levels of protection for key areas within the MPA (Dahlgren, 2014).

The PZ and CZs in BCMR are important as both designations are considered NTZs where protection should theoretically have a positive influence on biodiversity and fish stocks (Armfield, 2008). GUZs permit fishing offers users the benefit of the spill-over effect from increased fish populations in the NTZs. Although no significant influence was detected for any biological indicators between GUZs and NTZs areas in BCMR, the NTZ areas did appear to influence the abundance of certain commercial invertebrate species such as lobster and conch. Notably, conch abundance in GUZs dropped during open fishing seasons, but no significant change in abundance was detected year-round in the NTZs. However, no such change was observed in lobster abundance, suggesting that there is fishing pressure within the NTZ and highlighting a need for improved enforcement of this area.

For MPAs to be effective, the size and location of NTZs must be carefully considered prior to the establishment of the reserve. Larger NTZs help to increase the spill-over of populations into adjacent areas while limiting the proportion of stock exposed to fishing activities (Boeker, 2012).

Being a small multi-use MPA of 6,303 hectares of coastal waters, the reserve's NTZs are small in size which increases the potential for species to migrate into areas where fishing is permitted. This may prevent them from achieving larger size, greater abundance and increased reproductive output (Boeker, 2012).

The location of NTZs in relation to preferred habitat for target species is extremely important, as species may occur in or around specific features such as areas of high coral cover, seagrass or mangroves. If NTZs are created at random without taking habitat type into account, the benefits may be minimal (Boeker, 2012; Cabigas et al., 2012). The establishment of BCMR was the result of lobbying by fishers from Sarteneja village, using marine surveys conducted by a team of volunteers and project leaders from Coral Cay Conservation to provide the baseline data for the preparation of the reserve management zoning scheme (Grimshaw & Mito Paz, 2004) . GF1 is an important healthy site that has shown consistently high coral and fish biodiversity, and is located in GUZ1. Studies have found that the larger the abundance of a target species in a NTZ, the more the overall ecosystem will benefit (Dahlgren & Tewfik, 2015). Therefore, protecting a location such as GF1, could potentially lead to indirect effects through competitive and trophic interactions within the zone, further the effect of emigration or "spillover" of adult and juvenile fish species across the protected zone's border and would benefit the overall health of BCMR (Dahlgren & Tewfik, 2015; Forcada et al., 2008). Additionally, in order to enhance and maintain coral cover in BCMR, studies show that protecting areas which currently have high hard coral cover would best serve the ecosystem as it helps retain an overall healthy reef system (McClanahan et al., 2011). Based on the evidence presented in this report, it is strongly recommended that a reassessment of the BCMR reserve design and management plan be conducted.

4.7 Threats to Bacalar Chico Marine Reserve

Coral reef health in BCMR has been declining in recent decades with loss of coral cover, increase in FMA cover and decreases in fish biomass. These trends have also been seen at both regional and global scales (Hughes et al., 2007). The decline of coral reefs in BCMR can be attributed to similar problems experienced on other reefs around the world, with increasing coral bleaching and disease coinciding with global climate change and increasing human activities such as over-fishing, poor tourism practices and pollution by nutrients and sediments from agriculture and coastal development (Bank, 2000; Hernández et al., 2014).

In the early 1990s, the Belize Barrier Reef had coral cover ranging between 25-84% and was considered to be in good condition; however, in 1998, the reef suffered a severe impact through the combination of a mass bleaching event and the Category 5 hurricane Mitch (Jones et al., 2011; Wilkinson, 2006). These impacts contributed to a reduction of coral cover, thereby leading to a shift from coral to FMA dominance (Díaz et al., 2014).

Hurricanes and tropical storms are well known to reduce coral cover, which affects the structure and function of reef ecosystems (Gardner et al., 2005). Coral cover after hurricanes can be observed to recover as a result of the successful attachment and growth of coral fragments broken during the storm, or further decrease due to other stressors (Gardner et al., 2005).

Coral cover was at 11.26% in 2011 in BCMR and after category two Hurricane Ernesto passed through the region in 2012, coral cover in BCMR was at 13.16% in 2015. Coral cover was not significantly affected by Hurricane Ernesto, but there was a decline in FMA cover following the impact from 23.18% in 2012 to 21.94% in 2013. Hurricanes may cause high wave intensity which can wipe away masses of FMA from the reef, particularly from shallow reef sites (Mumby, Foster, & Fahy, 2005).

Coral bleaching prevalence has been increasing over the years 2011–2015 in BCMR. Globally, bleaching is mainly influenced by increasing Sea Surface Temperature (SST) caused by global climate change, where corals suffer a breakdown in their symbiosis with zooxanthellae in periods where temperatures are anomalously high. However, bleaching within BCMR did not correlate with the Degree Heating Week (DHW) data. This might be due to temperature data on the DHW covering a wider spatial area and not being sufficiently specific to the BCMR area.

Moreover, SST can be influenced by many factors such as reef topography and ocean currents which might affect the SST around BCMR in comparison to other areas in the region. Another potential explanation is that bleaching in BCMR might be influenced by other factors than temperature, such as stress from disease, sedimentation or chemicals from pollutant runoff (Díaz et al., 2014). Increased bleaching frequency can be observed throughout the Caribbean region. This area has experienced several large-scale bleaching events in 1995, 1998, 2005, and 2010, contributing to the long-term decline of coral cover in the region.

In the early 1980s, coral cover in the Caribbean suffered a sharp decline due to an outbreak of white band disease, which caused a massive mortality of the branching elkhorn and staghorn coral (Mumby et al., 2014a; Diaz et al., 2014). These fast growing corals once dominated most of the shallow water of the Caribbean, acting as reef-builders and providing vital habitat for many species. Since then, these species have been slowly recovering over the years throughout the region, and therefore it is a concern that coral disease prevalence has been increasing in BCMR during this report's study period, with elkhorn coral having the highest disease prevalence (primarily white band disease) at 50% for 2015. Conversely, no sign of white band disease was observed on staghorn coral colonies, which was found to have high coral coverage in the PZ and GUZ2.

BCMR has nine coral species that are listed on the IUCN Red list or EDGE. Five of these species have shown evidence of bleaching and disease in BCMR. This is concerning as these species are vulnerable or in danger of becoming extinct.

Nutrient enrichment from runoff may be contributing to the high FMA cover observed at BCMR. In addition, runoff may be increasing the prevalence of coral disease and making the corals more susceptible to bleaching. The closest communities are San Pedro Town (Belize) and Xcalak (Mexico). San Pedro is located about 25 km south and Xcalak is about 14 km north of BCMR. The high levels of development and pollution in particular from San Pedro Town could be associated with the eutrophication seen in BCMR, and potentially negatively impact coral coverage (Díaz et al., 2014).

Increased nutrient input, combined with declining herbivorous species within BCMR, would create conditions favouring FMA growth at the expense of coral cover. Herbivorous species such as the long-spined sea urchin, parrotfish and surgeonfish are main grazers on coral reefs (Hughes, 2003). These populations have remained at a low density between 2011 and 2015. Long-spined sea urchin populations within BCMR (0.033 ind/m^2) are below the recommended threshold of 2-6 ind/m^2 required to control FMA cover (Mcfield, 2007).

Before the ban on fishing for parrotfish (Fisheries Regulation 2009), they were a target commercial species along with grouper and snapper. This regulation should have led to a reduction in fishing pressure and an increase in parrotfish abundance; however, parrotfish abundance has remained low within BCMR. Fishers in Belize now target snappers and certain groupers, although, the Nassau grouper and the goliath grouper are also protected by Belize's law.

In BCMR, commercial species (groupers and snapper) are critically low with very few groupers sighted in the reserve being > 40 cm in size. Most groupers sighted are small-bodied species, such as graysby and coney. Snapper on the other hand were sighted at a higher abundance. Fishers tend to target bigger species which have more value, thus decreasing the biomass of these species in the region.

The recent invasion of lionfish within the Gulf of Mexico and Caribbean region has become another stress upon coral reef health. Lionfish predation significantly decreases the number of native fish (Green, 2014). Lionfish feed on a wide range of juvenile fish and crustaceans which include important ecological and commercial species. Lionfish have been sighted within BCMR since 2010 and diet studies have identified 25 families (fish and crustacean) which lionfish feed on (Chapman, 2016; Jones et al., 2010). Fish recruits in BCMR average at 27 ind/100 m^2. This hasn't differed over the years, which tells us that lionfish predation has had minimal impact on fish recruits. It is possible that the lionfish population in BCMR is below threshold as a result of the continuous culling by Blue Ventures staff. A continuous removal of lionfish helps to decrease the predation impact on native fish (Chapman et al., 2016; Valdez-Moreno et al., 2012).

5 Conclusions and recommendations

Reef decline in BCMR is attributed mainly to historical impacts similarly to other reefs in the Caribbean. These include: overfishing (Hughes, 2003); loss of key reef herbivores e.g. long-spined sea urchin (Hughes et al., 1987; Keller, 2011); and coral disease outbreak and bleaching events (Schutte et al., 2011); and global climate change (Pandolfi et al., 2010). Reefs are also currently facing increased local and regional threats, primarily due to land-based pollution that causes a decline in water quality (Healthy Reef Initiative, 2012).

Coral reef health in BCMR is in Poor to Critical condition. Key results from this study showed:

- Coral reef benthic community has shifted from coral to fleshy macroalgae dominance.
- Density of important herbivorous fish families such as parrotfish and surgeonfish are low.
- Grouper and snapper populations, both important commercial species, are critically low.
- Coral bleaching and disease prevalence have increased from 2011 to 2015.

A one-day workshop with the Belize Fisheries Department (BFD) marine biologist and rangers as well as Blue Ventures staff and volunteers was held in BCMR in 2017 to collectively review results and discuss root causes for problems and recommendations for possible solution (Figure 38).

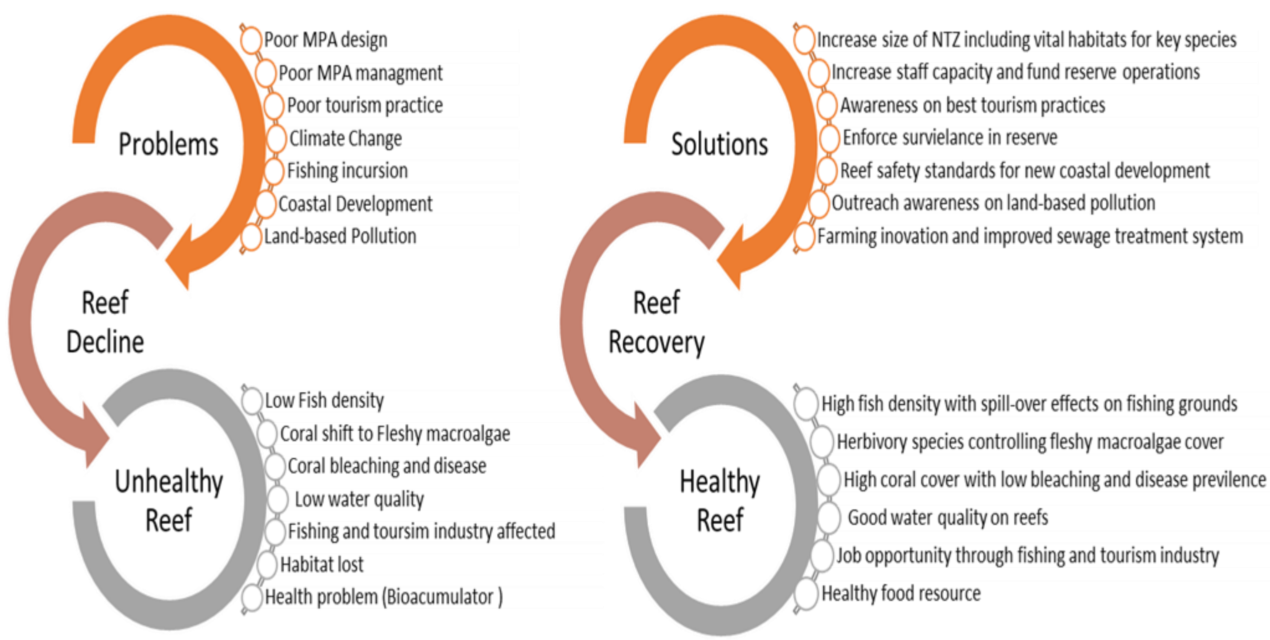


Figure 38. Problems and recommended solutions with outcome on reef health created collaboratively with Blue Ventures and Belize Fisheries Department staff working at BCMR.

Seven potential root causes for poor reef health were identified by the group (Table 18). Problems were divided into local stressors, i.e. those that occur within the boundaries of BCMR, and regional stressors, i.e. those that occur outside of BCMR but influence the condition of ecosystems or resources within the reserve.

Table 17. Local and regional stressors affecting reefs in Bacalar Chico Marine Reserve identified by BFD and BV workshop.

Stressors	Issue	Specific	Status
Local	MPA Design	Size	The NTZs are relatively small compared to the General Use Zones. NTZs are not large enough to protect species home ranges, allowing species to be exposed to fishing pressure.
		Location	Location of NTZs does not protect key habitats that are essential for marine species, e.g. mangrove and seagrass habitats that are important nursery grounds for commercial and ecological species. Further, healthier reef sites are not found within NTZs but in the GUZs which prevents proper protection for those sites.
	MPA Management	Enforcement of regulations	Poor enforcement of reserve regulations due to limited staff and resources. Staff are not fully trained in surveillance and enforcement. Lack of equipment for enforcement.
		Staff	Limited staff: usually 2-3 staff on a two-week rotation shift. New untrained staff as a result of high staff turn-over on an annual basis. Limited capacity to carry out the reserve operation (surveillance, enforcement, research, etc.).
		Finance	Limited finance support to sustain the reserve operations and facilities, which restricts surveillance, enforcement and research efforts.
	Recreational Users	Illegal extraction	Tour guides are extracting resources through sport fishing in CZ2 as there is a lack of surveillance and enforcement in the south section of the reserve.
		Tourism practice	Tour guides are carrying out poor snorkelling practices within CZ1.
	Fishing incursion	Mexican fishers	Mexican fishers are extracting resources in the PZ due to proximity of borders.
		Belizean fishers	Belizean fishers are extracting resources in the CZ1.
Regional	Land-based Pollution	Agriculture	Poor farm practices and deforestation upstream increase chemical input from herbicide and pesticide into rivers (i.e. New River, Rio Hondo) and then to Bacalar Chico, causing declining water quality and affecting surrounding coral reef.
		Sewage and grey water	Poor septic management in large settlements (e.g. Corozal Town and Chetumal City) increases nutrient content input to the bay and to the reef increasing algae blooms, coral bleaching and disease prevalence.
	Coastal Development	Mangrove clearance	Mangroves are key nursery grounds for important marine species such as snappers and lobsters. Mangrove clearance has been expanding up the San Pedro coastline, south of the reserve.

		Erosion/Sedimentation	Increased sedimentation from shore and boat activities are suffocating coral reef by altering water clarity which increase stress on coral, resulting in coral bleaching and disease.
	Climate Change	Storm and hurricanes	Increasing storm, hurricane intensity and frequency each year. Hurricanes have negative impacts on reef such as destroying reef complexity and decreasing coral cover.
		Sea Surface Temperature (SST)	SST increasing over the years, putting stress on corals which are already vulnerable from other stressors. This increases coral bleaching and disease prevalence.

Of the seven identified issues that contribute to BCMR's poor reef health, one regional threat (land-based pollution) and two local threats (MPA design and MPA management) were prioritised.

5.1 Land-based Pollution & the Impact on the Coral Reef

The reefs of BCMR form part of the Belize Barrier Reef Reserve System (BBRRS) which encompasses a variety of ecosystems of high biodiversity making it an economic asset generating money through tourism and fishing industry (Healthy Reef Initiative, 2015). However, the Belize Barrier Reef and its economic wealth are facing an increase in regional threats such as land based pollution (Díaz et al., 2014; Healthy Reef Initiative, 2012).

Land-based pollution within the Northern Belize Coastal Complex (NBCC) is mainly chemical runoff from intense agriculture activities in upstream communities (SACD, 2009, 2012a), combined with pollutants from sewage and storm water from Corozal Town and Chetumal City (Grimshaw & Mito Paz, 2004).

Agriculture contributes to high deforestation, where buffer zones along river banks are removed (Cherrington et al., 2012), increasing sediment and agro-chemical runoff from poor application of fertilisers and pesticides into river and reef (Díaz et al., 2014). Farmers may not be aware of the effects of poor farming practices on ecosystems or if they are, they have ignored it as a result of poor enforcement of best farming practice (Gibson, Mcfield, & Wells, 1998).

Improving farming practices can help reduce agrochemical runoff; however, innovative farming practices alone will not achieve reef-safe water quality. Pollution from sewage and grey water from the Corozal Town and Chetumal City needs to be addressed as well. If there is a broad scale agricultural expansion upstream, this pollution load would have a significant impact on the nearby reefs (WWF, 2017). Improving or implementing good sewage and grey water treatment systems will help to cut down these pollutant loads reducing land-based pollution impact on reefs (Degeorges et al., 2010).

Addressing land-based pollution within the NBCC will require collaboration between marine organisations, upstream NGOs and land holders to help understand the downstream implication from land-based pollution on coral reefs and to provide guidance on best practices. The following actions are recommended:

1. Research into water quality

Detailed research on land-based pollution impact on coral reefs should be carried out to identify the specific pollutants that are affecting reef health and the source of pollutant input. Water quality analysis will be essential for this. To date, this has been carried out within the NBCC largely by the Sarteneja Alliance for Conservation and Development (SACD, 2012b). However, there are some gaps in water quality analysis by SACD as it is limited to a few analysis parameters, including salinity, temperature, pH, dissolved oxygen and turbidity. To ensure a detailed analysis of pollutant runoff, other parameters need to be accounted for such as nitrogen, phosphorus, pathogens, metals and organic contaminants which are key pollutants from agriculture and sewage discharge (Degeorges et al., 2010; Díaz et al., 2014).

These analysis parameters have been a challenge for organisations in the country as there is a lack of capacity, equipment and facilities for analysis of samples and proper storage and disposal of reagents. To overcome these gaps, a National Water Quality Monitoring Programme (which has already been drafted by the Environmental and Research Institute (ERI) of the University of Belize in 2014) should be established and operated by the scientific community, Department of Environment, Human Health Department and other governmental levels. Having functional water quality programmes will help to provide a better understanding of reef water quality and identify the actions and level of investment needed to achieve our goals of reducing pollutant input.

2. Collaboration with partners

Results of studies on coral reef status and threats need to be shared by marine organisations e.g. Fisheries Department, Blue Ventures, etc. with NGOs working upstream on terrestrial conservation issues, such as SACD and Corozal Sustainable Future Initiative (CSFI). The root sources of pollution within the NBCC, and possible solutions and recommendations, should be discussed and identified. Agro-chemical pollutants have been one of the main sources of land based pollution affecting the MBRS, followed by secondary pollutant sources such as sewage and grey water (Healthy Reef Initiative, 2010, 2012, 2015), thus making agriculture a focal target.

Planning and implementing best farming practices with agriculture experts should be prioritised to help reduce pollutant runoff. A study carried out in the Yakima River Basin of Washington State, USA compared the level of water pollution due to nitrogen resulting from organic, integrated, and conventional farming practices; results showed that the organic and integrated fertilisation practices presented the lowest nitrate pollution runoff (Kramer et al., 2006).

3. Education and awareness

Upstream communities and stakeholders with agriculture activities should be targeted for outreach events organised by Blue Ventures in collaboration with upstream NGOs to share information on coral reef status and land-based pollution impacts on reefs. Workshops should be arranged with farmers and agriculture experts to provide guidelines on best farming practices that can help reduce pollutant input into watersheds and secure cleaner water for healthier reef ecosystems.

4. Farming innovation

To successfully implement best farming practices, communities and stakeholders will need strong support from NGOs and governments to guide them through the process of implementing and adapting new farming practices. It will take time to bring all farmers up to best practice standards. Most importantly, financial support needs to exist either through funds or governments as farming innovation can be costly (WWF, 2017). Through financial support, farmers can benefit by obtaining low interest loans to assist with the upfront cost of improved practices, or insurance where farmers are insured for any total loss in production due to any failure in new farm practices.

NGOs and governments must support more research and development for the next generation of profitable pollution cutting practices in the agriculture sector as well as the National Water Quality Monitoring programme, which can help to hold polluters accountable to reef safe standards (Degeorges et al., 2010).

Product certification for sustainable farming should be set up. This would encourage farmers to comply, as they will be able to sell their products for a better price on the international market with reef safe practice credentials (WWF, 2017). Certification would encourage best farming practices and help reduce pollutant runoff, giving reefs a better chance of building up a resilience to climate change as well as recover from other diseases, bleaching, etc. (Mumby et al., 2014a).

5.2 Marine Protected Area Management & Effectiveness

Effectiveness is the degree to which management actions are achieving the goals and objectives of the MPA (Hockings et al., 2002). Bacalar Chico Marine Reserve is a small multiuse MPA, with few visits from fishers from Sarteneja village and tour operators of San Pedro and Ambergris Caye thus limiting the influence of direct human interaction on reef health.

Grimshaw & Paz (2004) found that the CZ and PZ at BCMR are ineffective as a result of poor enforcement and fishing incursions. This was corroborated by two studies conducted by Blue Ventures in 2011 and 2013, which also concluded the ineffectiveness of management and zonation on the reserve's overall reef health. The predominant problems were found to be poor enforcement, illegal fishing and illegal tourism practices within NTZs (Chapman, 2012; Chapman & Gough, 2013). A healthy reef with properly managed tourism and fishing industries will secure a future of revenue for the country (Healthy Reef Initiative, 2015).

Based on the results of this study, the reserve management plan should be reassessed, focusing primarily on reserve design, and management. According to Hockings et al., (2002), an evaluation of an MPA's effectiveness should take into account the assessment and monitoring of three broad components:

1. Design of the MPA (e.g. objectives, purposes of use, size, shape, buffers, linkages, location of boundaries)
2. Appropriateness of management systems and processes (e.g. planning approaches, management implementation, enforcement, relationships with local communities and private sector)
3. Delivery of the MPA's objectives (does the MPA achieve its stated goals and objectives?)

This will help to improve the reserve's effectiveness through learning, adapting, and addressing specific issues influencing the reserve.

The following are some recommendations to be considered when addressing the MPA's design and management:

MPA design

1. Size of NTZ

The NTZs (Preservation Zone and Conservation Zones) are currently too small to effectively protect key species and their home ranges (Green et al., 2015). Some small protected areas can provide benefits for more sedentary species, however, for biodiversity protection, larger areas are necessary, as certain species tend to have larger ranges than others so they pass beyond buffer zones and may be exposed to fishing pressures (Dahlgren, 2014).

2. Location of NTZ

Ecosystem based management principles recognize the importance of preserving an ecosystem in a healthy and productive state which are therefore capable of providing for local communities (McLeod et al., 2005). To do so under a multi-use managed marine area would call for a proportionate representation of key habitats in NTZs. NTZs provide refuge in an ecosystem allowing for fish and coral species to thrive which in turn enhances overall ecosystem health (Dahlgren & Tewfik, 2015; McClanahan et al., 2011). Healthy reefs are known to have a higher resilience to threats created by climate change (Mcleod et al., 2009). In addition, NTZs need to be spaced out correctly in order to allow safe movement of protected species between vital habitats (Green et al., 2015). Therefore, in order to protect key habitats that are ecologically important (e.g. home range, nursery areas, fish spawning area, etc.), and increase resiliency to climate change, the location of NTZs should be reconsidered.

MPA management

1. *Staff*

In the past, limited capacity of staff and resources has resulted in poor surveillance, enforcement and scientific research (Dahlgren, 2009) and high staff turn-over (Grimshaw & Mito Paz, 2004). Belize Fisheries Department performs its tasks as it can, however it is widely recognized that more effort is needed to support effective management of BCMR. To support ongoing efforts by Belize Fisheries Department to build staff capacity and improve monitoring and enforcement, Blue Ventures will continue to offer dive and science training to ensure staff members are aware of conservation targets and are trained to participate in research and monitoring.

Recruiting staff that are knowledgeable, enthusiastic, trained and committed in the protection of MPAs is critical. Therefore the possibility of working with local users through the establishment of a coordinated network of rangers from San Pedro and Sarteneja as part of a broader community empowerment programme should be considered as this will increase surveillance throughout the NBCC and reduce illegal activities (SEA Belize, 2016).

2. Funding

There is a need for sustainable financial support to maintain operations and facilities of the MPA in order to continue its planning, implementation, coordination, monitoring and enforcement. BCMR operations and facilities have been supported by funds from the Coastal Zone Management Authorities and Institute, visitor fees and minimal budget from the Belize Fisheries Department (Grimshaw & Mito Paz, 2004). Nevertheless, there are still financial gaps which limit the reserve's operation. These have resulted in reduced surveillance and enforcement, and insufficient facilities (no SCUBA gear, small boat and limited fuel). These financial gaps need to be addressed by reassessing the reserve management plan and seeking out sustainable funding sources. This should be an integral component of a reserve management plan (Upton, 2016). Diversifying the funding base, improving the internal financial systems and partnering with NGOs to share operational costs are options that could help improve the reserve's operation and infrastructure needs (SEA Belize, 2016) .

3. Education and outreach

Stakeholders are usually unaware of MPA objectives and benefits as a result of limited access to information (Leisher, Mangubhai, Hess, Widodo, & Soekirman, 2012). There is a need to strengthen communication and collaboration with current and future partners (Blue Ventures, Fisheries Department, CSFI, etc.). Improved education and outreach efforts in stakeholder communities would result in an increased awareness of the importance of MPAs. Results from data collected on coral reef health, density of fish, conch and lobster inside and outside the reserve should be disseminated.

It is important to ensure that all fisheries users and tour operators are fully aware of the zonation and regulations of the marine reserve. Visitors should be educated about rules and regulations when visiting the marine reserve through presentations, brochures, handouts or any other educational materials. Local communities or school groups should be encouraged to visit on well-organised and planned trips by NGOs. Local communities should be involved through participation in outreach activities and events.

5.3 Bacalar Chico Marine Reserve Objectives

Bacalar Chico Marine Reserve's management plan is ineffective in accomplishing the reserve's goals and objectives. A reassessment of the management plan is strongly recommended and should be done based on science-led advice and strong community involvement with linkage to all stakeholders (fishers, tour operators, private business, NGOs, Fisheries Department, Coastguard and other governmental organisations). Any agreement made between stakeholders and the authorities should be legalised, respected and fulfilled.

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7 Appendices

7.1 Appendix 1

Simplified Integrated Reef Health Index (SIRHI)

In 2008, the Healthy Reef Initiative (HRI) developed the Simplified Integrated Reef Health Index (SIRHI). This integrates four indicators (hard coral cover, fleshy macro algal cover, biomass of key herbivorous fish and key commercial fish) to rapidly and easily evaluate and interpret reef health by translating these data into distinct and comprehensible categories. Data on these indicators are usually collected with the Atlantic and Gulf Rapid Reef Assessment Method (AGRRA, 2017; Healthy Reef Initiative, 2010); however, Blue Ventures uses the Mesoamerican Barrier Reef System Synoptic Monitoring Program (MBRS-SMP) method (PITs and fish belts) which was agreed between Mexico, Belize, Guatemala and Honduras as a standardised survey method for the MBRS (Sale et al., 2003), so that data could be compared at regional scales. The mean data values of each indicator are converted into one of the following five categories: Very Good, Good, Poor, Fair or Critical (Table 18). This allowed temporal trends and spatial comparisons of reef condition in the BCMR to be examined between 2011 and 2015, gaining insight into the health of individual sites, different management zones and the marine reserve. This rapid assessment of reef health in the BCMR forms part of a larger initiative that monitors the management effectiveness of all protected areas in Belize and across the Mesoamerican Barrier Reef System (MBRS), identifying the strengths and weaknesses of the protected areas system (Healthy Reef Initiative, 2010).

Table 18. Simplified Integrated Reef Health Index (SIRHI) categories, indicators and threshold values.

SIRHI Indicator	Very Good (5)	Good (4)	Fair (3)	Poor (2)	Critical (1)
Coral Cover (%)	≥ 40.0	20.0 – 39.9	10.0 – 19.9	5.0 – 9.9	< 5.0
Fleshy Macroalgae Cover (%)	0.0 – 0.9	1.0 – 5.0	5.1 – 12.0	12.1 – 25.0	> 25.0
Herbivorous Fish* Biomass (g/100 m^2)	≥ 3480	2880 – 3479	1920 – 2879	960 – 1919	< 960
Commercial Fish* Biomass (g/100 m^2)	≥ 1680	1260 – 1679	840 – 1259	420 – 839	< 420
Overall Reef Health (Average)	4.2 – 5.0	3.4 – 4.2	2.6 – 3.4	1.8 – 2.6	0 – 1.8

*Herbivorous fish: Parrotfish and Surgeonfish, Commercial fish: Groupers and Snappers.

7.2 Appendix 2

Table 19. Priority coral species list.

HARD CORALS

Family	Genus	Species	Code	Common Name
Acroporidae	*Acropora*	*palmata*	APAL	Elkhorn
	Acropora	*cervicornis*	ACER	Staghorn
Poritidae	*Porites*	*porites*	PPOR	Finger
	Porites	*astreoides*	PAST	Mustard Hill
Siderastreidae	*Siderastrea*	*sidera*	SSID	Massive Starlet
	Siderastrea	*radians*	SRAD	Lesser Starlet
Agariciidae	*Undaria*	*agaricites*	UAGA	Lettuce
	Undaria	*tenuifolia*	UTEN	Thin Leaf Lettuce
	Undaria	*humilis*	UHUM	Low Relief Lettuce
	Agaricia	*lamarcki*	ALAM	White Star Sheet Lettuce
	Agaricia	*fragilis*	AFRA	Fragile Saucer
	Helioseris	*cucullata*	HCUC	Sunray Lettuce
Astrocoeniidae	*Madracis*	*decactis*	MDEC	10 Ray Star
	Madracis	*formosa*	MFOR	8-Ray Finger
	Madracis	*auretenra*	MAUR	Yellow Pencil
	Stephanocoenia	*intercepta*	SINT	Blushing Star
Faviidae	*Pseudodiploria*	*strigosa*	PSTR	Symmetrical Brain
	Pseudodiploria	*clivosa*	PCLI	Knobby Brain
	Diploria	*labrynthiformis*	DLAB	Grooved Brain
	Colpophyllia	*natans*	CNAT	Boulder Brain
	Montastrea	*cavernosa*	MCAV	Great Star
	Obicella	*annularis*	OANN	Lobed Star
	Orbicella	*faveolata*	OFAV	Mountainous Star
	Orbicella	*franksi*	OFRA	Boulder Star
	Favia	*fragum*	FFRA	Golfball
Meandrinidae	*Dichocoenia*	*stokesii*	DSTO	Elliptical Star
	Meandrina	*meandrites*	MMEA	Maze
	Dendrogyra	*cylindrus*	DCYL	Pillar
Caryophylliidae	*Eusmilia*	*fastigiata*	EFAS	Smooth Flower
Mussidae	*Isophyllia*	*sinuosa*	ISIN	Sinuous Cactus
	Isophyllastrea	*rigida*	IRIG	Rough Star
	Mycetophyllia	*lamarckiana*	MLAM	Ridged Cactus
	Mycetophyllia	*aliciae*	MALI	Knobby Cactus
	Mycetophyllia	*ferox*	MFER	Rough Cactus
	Mussa	*angulosa*	MANG	Spiny Flower
	Scolymia	*spp.*	SCOL	AtlanticMushroom/Artichoke/Solitary Disk
GORGONIANS				
Order Alcyonacea			SROD	Gorgonian Sea Rod
			SPLU	Gorgonian Sea Plume

			SFAN	Gorgonian Sea Fan
			EGOR	Encrusting Gorgonian
OTHER ANTHOZOANS				
Order Actiniaria			ANEM	Anemone
Order Corallimorpharia			CMORPH	Corallimorph
Order Zoanthidea			ZOAN	Zoanthid
ALGAE				
Phylum Phaeophyta	*Dictyota*	*spp.*	DICT	Y-Branched Algae
	Lobophora	*variegata*	LOBO	Encrusting Fan-Leaf Algae
Phylum Rhodophyta			CCA	Crustose Coralline Algae
			ARTIC	Articulated Coralline Algae
Phylum Chlorophyta	*Halimeda*	*spp.*	HALI	Halimeda
			TA	Turf Algae
			FMA	Fleshy Macro Algae
OTHERS				
Class Hydrozoa Phylym Cnidaria Family Milleporidae	*Millepora*	*alcicornis*	MALC	Branching Fire
	Millepora	*complanata*	MCOM	Blade Fire
Class Ascidiacea Phylum Porifera			TUNI	Tunicate
			ERSP	Erect Sponge
			ENSP	Encrusting Sponge
Class Angiospermae Phylum Cyanophyta Substrate			SG	Seagrass
			CYA	Cyanobacteria / Blue-Green Algae
			BR	Bare Rock
			SD	Sand
			RB	Rubble
			RKC	Recently Killed Coral

7.3 Appendix 3

Table 20. Priority fish species list.

Family - Common	Family - Latin	Common Name	Genus	Species
Surgeonfish	**Acanthuridae**	Blue Tang	*Acanthurus*	*coeruleus*
		Ocean Surgeonfish	*Acanthurus*	*bahianus*
		Doctorfish	*Acanthurus*	*chirurgus*
Parrotfish	**Scaridae**	Rainbow Parrotfish	*Scarus*	*guacamaia*
		Midnight Parrotfish	*Scarus*	*coelestinus*
		Blue Parrotfish	*Scarus*	*coeruleus*
		Queen Parrotfish	*Scarus*	*vetula*
		Princess Parrotfish	*Scarus*	*taeniopterus*
		Striped Parrotfish	*Scarus*	*iserti*

		Stoplight Parrotfish	*Sparisoma*	*viride*
		Redband Parrotfish	*Sparisoma*	*aurofrenatum*
		Redtail Parrotfish	*Sparisoma*	*chrysopterum*
		Yellowtail Parrotfish	*Sparisoma*	*rubripinne*
Wrasse	**Labridae**	Hogfish	*Lachnolaimus*	*maximus*
		Spanish Hogfish	*Bodianus*	*rufus*
Butterflyfish	**Chaetodontidae**	Foureye Butterflyfish	*Chaetodon*	*capistratus*
		Banded Butterflyfish	*Chaetodon*	*striatus*
		Spotfin Butterflyfish	*Chaetodon*	*ocellatus*
		Longsnout Butterflyfish	*Chaetodon*	*aculeatus*
Angelfish	**Pomacanthidae**	Grey Angelfish	*Pomacanthus*	*arcuatus*
		French Angelfish	*Pomacanthus*	*paru*
		Queen Angelfish	*Holacanthus*	*ciliaris*
		Rock Beauty	*Holacanthus*	*tricolor*
Damselfish	**Pomacentridae**	Yellowtail Damselfish	*Microspathodon*	*chrysurus*
Filefish	**Monacanthidae**	Scrawled Filefish	*Aluterus*	*scriptus*
		Whitespotted Filefish	*Cantherhines*	*macrocerus*
		Orangespotted Filefish	*Cantherhines*	*pullus*
Triggerfish	**Balistidae**	Black Durgon	*Melichthys*	*niger*
		Queen Triggerfish	*Balistes*	*vetula*
Mackerel	**Scombridae**	Cero	*Scomberomorus*	*regalis*
Tarpon	**Elopidae**	Tarpon	*Megalops*	*atlanticus*
Barracuda	**Sphyraenidae**	Great Barracuda	*Sphyraena*	*barracuda*
Grunt	**Haemulidae**	French Grunt	*Haemulon*	*flavolineatus*
		Cottonwick	*Haemulon*	*melanurum*
		Bluestriped Grunt	*Haemulon*	*sciurus*
		Caesar Grunt	*Haemulon*	*carbonarium*
		Spanish Grunt	*Haemulon*	*macrostomum*
		White Grunt	*Haemulon*	*plumierii*
		White Margate	*Haemulon*	*album*
		Black Margate	*Anisotremus*	*surinamensis*
		Sailor's Choice	*Haemulon*	*parra*
		Black Grunt	*Haemulon*	*bonariense*
		Tomtate	*Haemulon*	*aurolineatum*
		Smallmouth Grunt	*Haemulon*	*chrysargyreum*
		Porkfish	*Anisotremus*	*virginicus*
Snapper	**Lutjanidae**	Schoolmaster	*Lutjanus*	*apodus*
		Grey Snapper	*Lutjanus*	*griseus*
		Mahogany Snapper	*Lutjanus*	*mahogoni*
		Mutton Snapper	*Lutjanus*	*analis*
		Lane Snapper	*Lutjanus*	*synagris*
		Cubera Snapper	*Lutjanus*	*cyanopterus*
		Dog Snapper	*Lutjanus*	*jocu*
		Yellowtail Snapper	*Ocyurus*	*chrysurus*
Grouper	**Serranidae**	Black Grouper	*Mycteroperca*	*bonaci*
		Tiger Grouper	*Mycteroperca*	*tigris*

		Goliath Grouper	*Epinephelus*	*itajara*
		Yellowmouth Grouper	*Mycteroperca*	*interstitialis*
		Yellowfin Grouper	*Mycteroperca*	*venenosa*
		Marbled Grouper	*Epinephelus*	*inermis*
		Nassau Grouper	*Epinephelus*	*striatus*
		Red Grouper	*Epinephelus*	*morio*
		Graysby	*Cephalopholis*	*cruentatus*
		Coney	*Cephalopholis*	*fulva*
		Red Hind	*Epinephelus*	*guttatus*
Jack	**Carangidae**	Bar Jack	*Caranx*	*ruber*
		Permit	*Trachinotus*	*falcatus*
Scorpionfish	**Scorpaenidae**	Lionfish	*Pterois*	*volitans/miles*

7.4 Appendix 4

Table 21. Fish species list from fish rover surveys.

Family - Common	Family/Order - Latin	Common Name	Genus	Species
Angelfish	**Pomacanthidae**	Grey Angelfish	*Pomacanthus*	*arcuatus*
		French Angelfish	*Pomacanthus*	*paru*
		Queen Angelfish	*Holacanthus*	*ciliaris*
		Rock Beauty	*Holacanthus*	*tricolor*
Barracuda	**Sphyraenidae**	Great Barracuda	*Sphyraena*	*barracuda*
Basslet	**Grammatidae**	Fairy Basslet	*Gramma*	*loreto*
Bigeyes	**Pricanthidae**	Glasseye Snapper	*Heteropriacanthus*	*cruentatus*
Blenny	**Blenniiformes**	Redlip Blenny	*Ophioblennius*	*atlanticus*
		Roughhead Blenny	*Acanthemblemaria*	*aspera*
		Saddled Blenny	*Malacoctenus*	*triangulatus*
		Secretary Blenny	*Acanthemblemaria*	*maria*
		Spinyhead Blenny	*Acanthemblemaria*	*spinose*
Boxfish	**Ostraciidae**	Honeycomb Cowfish	*Acanthostracion*	*polygonius*
		Smooth Trunkfish	*Lactophrys*	*triqueter*
		Spotted Trunkfish	*Lactophrys*	*bicaudalis*
		Trunkfish	*Lactophrys*	*trigonus*
Butterflyfish	**Chaetodontidae**	Banded Butterflyfish	*Chaetodon*	*striatus*
		Foureye Butterflyfish	*Chaetodon*	*capistratus*
		Spotfin Butterflyfish	*Chaetodon*	*ocellatus*
Chubs	**Kyphosidae**	Bermuda/Yellow Chub	*Kyphosus*	*sectatrix*
Damselfish	**Pomacentridae**	Beaugregory	*Stegastes*	*leucostictus*
		Bicolor Damselfish	*Stegastes*	*partitus*
		Blue Chromis	*Chromis*	*cyanea*
		Brown Chromis	*Chromis*	*multilineata*
		Cocoa Damselfish	*Stegastes*	*variabilis*
		Dusky Damselfish	*Stegastes*	*adustus*
		Longfin Damselfish	*Stegastes*	*diencaeus*

		Sergeant Major	*Abudefduf*	*saxatilis*
		Sunshine Fish	*Chromis*	*insolata*
		Threespot Damselfish	*Stegastes*	*planifrons*
		Yellowtail Damselfish	*Microspathodon*	*chrysurus*
Drums & Croakers	**Sciaenidae**	High-hat	*Pareques*	*acuminatus*
		Spotted Drum	*Equetus*	*punctatus*
Eagle Ray	**Myliobatidae**	Spotted Eagle Ray	*Aetobatus*	*narinari*
Filefish	**Monacanthidae**	Orangespotted Filefish	*Cantherhines*	*pullus*
		Scrawled Filefish	*Aluterus*	*scriptus*
		Slender Filefish	*Monacanthus*	*tuckeri*
		Whitespotted Filefish	*Cantherhines*	*macrocerus*
Goatfish	**Mullidae**	Spotted Goatfish	*Pseudupeneus*	*maculatus*
		Yellow Goatfish	*Mulloidichthys*	*martinicus*
Gobies	**Gobiidae**	Bridled Goby	*Coryphopterus*	*glaucofraenum*
		Broadstripe Goby	*Elacatinus*	*prochilos*
		Colon Goby	*Coryphopterus*	*dicrus*
		Goldspot Goby	*Gnatholepis*	*thompsoni*
		Masked/Glass Goby	*Cryphopterus*	*hyalinus*
		Neon Goby	*Elacatinus*	*oceanops*
		Orangesided Goby	*Elacatinus*	*dilepis*
Grouper	**Serranidae**	Black Grouper	*Mycteroperca*	*bonaci*
		Black Hamlet	*Hypoplectrus*	*nigricans*
		Tiger Grouper	*Mycteroperca*	*tigris*
		Harlequin Bass	*Serranus*	*tigrinus*
		Indigo Hamlet	*Hypoplectrus*	*indigo*
		Marbled Grouper	*Epinephelus*	*inermis*
		Nassau Grouper	*Epinephelus*	*striatus*
		Lantern Bass	*Serranus*	*baldwini*
		Graysby	*Cephalopholis*	*cruentatus*
		Coney	*Cephalopholis*	*fulva*
		Red Hind	*Epinephelus*	*guttatus*
		Rock Hind	*Epinephelus*	*adscensionis*
Grunt	**Haemulidae**	French Grunt	*Haemulon*	*flavolineatus*
		Cottonwick	*Haemulon*	*melanurum*
		Bluestriped Grunt	*Haemulon*	*sciurus*
		Caesar Grunt	*Haemulon*	*carbonarium*
		Spanish Grunt	*Haemulon*	*macrostomum*
		White Grunt	*Haemulon*	*plumierii*
		White Margate	*Haemulon*	*album*
		Black Margate	*Anisotremus*	*surinamensis*
		Sailor's Choice	*Haemulon*	*parra*
		Black Grunt	*Haemulon*	*bonariense*
		Tomtate	*Haemulon*	*aurolineatum*
		Smallmouth Grunt	*Haemulon*	*chrysargyreum*
		Porkfish	*Anisotremus*	*virginicus*
Hawkfish	**Cirrhitidae**	Redspotted Hawkfish	*Amblycirrhitus*	*pinos*

Jack	**Carangidae**	Bar Jack	*Caranx*	*ruber*
		Blue Runner	*Caranx*	*crysos*
		Horse-eye Jack	*Caranx*	*latus*
		Permit	*Trachinotus*	*falcatus*
		Yellow Jack	*Caranx*	*bartholomaei*
Mackerel	**Scombridae**	Cero	*Scomberomorus*	*regalis*
		King Mackerel	*Scomberomorus*	*cavalla*
Moray Eels	**Muraenidae**	Goldentail Moray	*Gymnothorax*	*miliaris*
		Green Moray	*Gymnothorax*	*funebris*
		Spotted Moray	*Gymnothorax*	*moringa*
Needlefish	**Belonidae**	Houndfish	*Tylosurus*	*crocodilus*
Parrotfish	**Scaridae**	Bluelip Parrotfish	*Cryptotomus*	*roseus*
		Bucktooth Parrotfish	*Sparisoma*	*radians*
		Emerald Parrotfish	*Nicholsina*	*usta*
		Greenblotch Parrotfish	*Sparisoma*	*atomarium*
		Midnight Parrotfish	*Scarus*	*coelestinus*
		Princess Parrotfish	*Scarus*	*taeniopterus*
		Queen Parrotfish	*Scarus*	*vetula*
		Rainbow Parrotfish	*Scarus*	*guacamaia*
		Redband Parrotfish	*Sparisoma*	*aurofrenatum*
		Redtail Parrotfish	*Sparisoma*	*chrysopterum*
		Stoplight Parrotfish	*Sparisoma*	*viride*
		Striped Parrotfish	*Scarus*	*iserti*
		Yellowtail Parrotfish	*Sparisoma*	*rubripinne*
Porcupinefish	**Diodontidae**	Balloonfish	*Diodon*	*holocanthus*
		Porcupinefish	*Diodon*	*hystrix*
		Striped Burrfish	*Chilomycterus*	*schoepfi*
		Web Burrfish	*Chilomycterus*	*antillarum*
Porgies	**Sparidae**	Saucereye Porgy	*Calamus*	*calamus*
Pufferfish	**Tetraodontidae**	Sharpnose Puffer	*Canthigaster*	*rostrata*
Remoras	**Echeneidae**	Sharksucker	*Echeneis*	*naucrates*
Scorpionfish	**Sorpaenidae**	Lionfish	*Pterois*	*volitans*
Snapper	**Lutjanidae**	Schoolmaster	*Lutjanus*	*apodus*
		Grey Snapper	*Lutjanus*	*griseus*
		Mahogany Snapper	*Lutjanus*	*mahogoni*
		Mutton Snapper	*Lutjanus*	*analis*
		Lane Snapper	*Lutjanus*	*synagris*
		Cubera Snapper	*Lutjanus*	*cyanopterus*
		Dog Snapper	*Lutjanus*	*jocu*
		Yellowtail Snapper	*Ocyurus*	*chrysurus*
Spadefish	**Ephippidae**	Atlantic Spadefish	*Chaetodipterus*	*faber*
Squirrelfish	**Holocentridae**	Barred Soldierfish	*Sargocentron*	*long-spined sea urchin*
		Dusky Squirrelfish	*Sargocentron*	*vexillarium*
		Longspine Squirrelfish	*Holocentrus*	*rufus*
		Squirrelfish	*Holocentrus*	*adscensionis*

Stingray	**Dasyatidae**	Southern Stingray	*Dasyatis*	*americana*
Surgeonfish	**Acanthuridae**	Blue Tang	*Acanthurus*	*coeruleus*
		Doctorfish	*Acanthurus*	*chirurgus*
		Ocean Surgeonfish	*Acanthurus*	*bahianus*
Sweeper	**Pempheridae**	Glassy Sweeper	*Pempheris*	*schomburgki*
Tarpon	**Elopidae**	Tarpon	*Megalops*	*atlanticus*
Tilefish	**Malacanthidae**	Sand Tilefish	*Malacanthus*	*plumieri*
Triggerfish	**Balistidae**	Black Durgon	*Melichthys*	*niger*
		Ocean Triggerfish	*Canthidermis*	*sufflamen*
		Queen Triggerfish	*Balistes*	*vetula*
Trumpetfish	**Aulostomidae**	Trumpetfish	*Aulostomus*	*maculatus*
Wrasse	**Labridae**	Hogfish	*Lachnolaimus*	*maximus*
		Spanish Hogfish	*Bodianus*	*rufus*
		Blackear Wrasse	*Halichoeres*	*poeyi*
		Bluehead Wrasse	*Thalassoma*	*bifasciatum*
		Clown Wrasse	*Halichoeres*	*maculipinna*
		Creole Wrasse	*Clepticus*	*parrae*
		Green Razorfish	*Xyrichtys*	*splendens*
		Puddingwife	*Halichoeres*	*radiatus*
		Rainbow Wrasse	*Halichoeres*	*pictus*
		Slippery Dick	*Halichoeres*	*bivittatus*
		Yellowhead Wrasse	*Halichoeres*	*garnoti*

7.5 Appendix 5

Table 22. Endangered coral species of BCMR.

Common name	Species	List
Boulder Star Coral	*Orbicella annularis*	EDGE, IUCN Red List
Mountainous Star Coral	*Orbicella faveolata*	EDGE
Star Coral	*Orbicella franksi*	EDGE
Elliptical Star Cora	*Dichocoenia stokesii*	EDGE, IUCN Red List
Pillar Coral	*Dendrogyra cylindrus*	EDGE, IUCN Red List
Staghorn Coral	*Acropora cervicornis*	IUCN Red List
Elkhorn Coral	*Acropora palmata*	IUCN Red List
Lamarck's Sheet Coral	*Agaricia lamarcki*	IUCN Red List
Rough Cactus Coral	*Mycetophyllia ferox*	IUCN Red List