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An assessment of the ecological integrity of Bacalar Chico Marine Reserve and National Park: Recommendations for a renewed, science-based management plan.

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1. Abstract

Declines in global coral reef health are primarily attributed to direct, tangible, and, most importantly, manageable human activities. The Belize Barrier Reef Reserve System was declared a UNESCO World Heritage Site due to its exceptional biodiversity and direct contribution to Belize's economy through tourism and fisheries. It forms the heart of the Mesoamerican Reef (MAR), the largest continuous reef system in the western hemisphere. In the MAR region, reef health is threatened by invasive species, coastal development, overfishing, pollution and climate change. As one of seven marine protected areas comprising the UNESCO World Heritage Site, the management and reef health of Bacalar Chico Marine Reserve and National Park (BCMR and NP) is of particular relevance at local, national and international scales. In March 2010, Blue Ventures implemented a long-term coral reef monitoring plan. Results show that the majority of reefs within BCMR are in 'poor' or 'critical' condition when interpreted using the Simplified Integrated Reef Health Index (SIRHI), with depleted commercial fish populations and high fleshy macroalgal cover the primary cause for low site scores. There was no significant difference between management zones or outside the reserve for any of the key indicators (hard coral, fleshy macroalgae, commercial fish biomass and herbivorous fish biomass). As the management plan for BCMR was last revised in 2004, it is strongly recommended to the Belize Fisheries Department to prioritise reviewing and updating a management plan for BCMR and NP. Such a plan should reconsider the location of management zones, as they appear to be ineffective in maintaining ecological integrity of the reefs.

2. Introduction

Coral Reefs in Global Crisis

Direct and indirect human impacts have caused declines in coral cover and reef health globally (Gardner *et al*. 2003; Côté *et al*. 2005; Bruno & Selig 2007). However, over 60% of the world's coral reefs are threatened by manageable activities, including overfishing, destructive fishing techniques, land-based sources of pollution (e.g. runoff), marine-based sources of pollution (e.g. offshore oil and gas drilling) and coastal development (Burke *et al*. 2011).

In the Caribbean, wide scale decline in reef health is primarily attributed to the loss of reef herbivores and the outbreak of white-band disease in the 1980s (Jackson *et al*. 2013). Important reef herbivores include the sea urchin *Diadema* (Idjadi *et al*. 2010), which was almost entirely wiped-out by a disease outbreak in 1983 (Lessios *et al*. 1984), and parrotfish (Mumby 2009), targeted by fishers regionally, and frequently caught as bycatch in fish traps.

Secondary factors driving Caribbean coral reef decline include land-based/watershed pollution (agricultural runoff, sewage disposal) and coastal development, leading to the loss of key coastal ecosystems, reducing fish nursery habitat availability and increasing sedimentation rates on reefs (Burke *et al*. 2011; Jackson *et al*. 2013).

The relatively recent introduction of red lionfish (*Pterois volitans*) presents a new stress to Caribbean reefs (Morris Jr & Whitfield 2009). Invasive species have been highlighted as one of the greatest threats to global ecosystems (Mooney & Cleland 2001; Wilcove *et al*. 1998), leading to a loss of biodiversity, food web disruption and alterations in ecosystem structure and species dominance (Jackson 2008). The presence of numerous venomous spines make lionfish an unsavoury prey item, with few species recorded to successfully predate upon them (Morris Jr & Whitfield 2009; Bernadsky & Goulet 1991). This lack of predatory pressure, in combination with a generalist diet (Green *et al*. 2011; Green *et al*. 2012) and high annual fecundity in the their invaded ranges (Morris Jr & Whitfield 2009), have enabled the establishment of rapidly growing populations of lionfish throughout the Caribbean (Schofield 2009; Healthy Reefs Initiative 2010; Ruttenberg *et al*. 2012).

Furthermore, overpopulation and high-density tourism in coastal areas are correlated with declines in reef health throughout the Caribbean, except in Bermuda, where strong enforcement of environmental regulations has been effective in maintaining good coral reef health (Jackson *et al*. 2013).

Effective management of these local threats increases reef resilience to the long-term, unmanageable threat of global climate change (Jackson *et al*. 2013; Hughes *et al*. 2007)

Belize: A Country Dependent on Healthy Reefs

It is estimated that 2,700 people currently actively work as fishers in Belize (J. Azueta pers. comm.), with the total direct revenue of the fishing industry in 2011 estimated to be USD 22 million (Harper *et al*. 2011) – 1.8% of national Gross Domestic Product (Statistical Institute of Belize 2013). The Belize fishing industry is dominated by conch and lobster, comprising almost half of total catch (Zeller *et al*. 2011). The conch fishery is estimated to generate over USD 3 million annually through domestic and international export markets, with higher-value lobster generating over USD 8 million per year (Harper *et al*. 2011).

Both fisheries are considered to be fully- or over-exploited, with total reported landings steadily declining since the 1980s, despite increased fishing efforts (Gillet 2003; Finch *et al*. 2008; Pomeroy & Goetze 2003; Zeller *et al*. 2011). Populations within protected areas show declining trends, and are unlikely to recover without significant human intervention (Walker & Walker 2009; Foley 2011; Pomeroy & Goetze 2003). Subsistence and artisanal fisheries for finfish, such as Nassau grouper (*Epinephelus striatus*) and mutton snapper (*Lutjanus analis*), are also recognised as being in decline (Graham *et al*. 2008). Local and international management interventions, with recorded localised successes (e.g., Carne 2009), include size limits, seasonal closures, managed access and quotas.

Many coastal communities are directly dependent upon healthy reefs as their primary source of income – San Pedro Town and Placencia, Belize's tourism hubs, attract divers and sport fishers. Sarteneja Village, in Corozal District, is the largest fishing community in Belize, where over 80% of households are directly dependent upon fishing as their primary source of income (SACD 2009). Sartenejan fishing boats are active throughout the Belize Barrier Reef System (BBRS) (Walker & Walker 2011), and the community's fishers are key stakeholders of six of Belize's nine marine reserves, as well as the Lighthouse Reef Atoll Management Unit (encompassing Half Moon Caye and Blue Hole Natural Monuments) and Corozal Bay Wildlife Sanctuary (Fedler 2011; Walker & Walker 2011; Wildtracks 2009, 2010). With such a large footprint across the entire BBRS and high dependency upon fishing, Sarteneja is particularly affected by depleted fish stocks.

Bacalar Chico: A Key Part of the MPA Puzzle

Located in the north of Ambergris Caye, Bacalar Chico (Figure 1) is uninhabited except for two hotels, the Belize Fisheries Department's San Juan Ranger Station, and Blue Ventures' Bacalar Chico Dive Camp (BCDC). Bacalar Chico Marine Reserve (BCMR), established in 1996 following lobbying from Sartenejan fishers, forms part of the Belize Barrier Reef Reserve System UNESCO World Heritage Site (UNESCO 1996). BCMR meets three of UNESCO's Natural Criteria[1] and is therefore considered to be a site of 'Outstanding Universal Value'. The Mayan site, *Chac Balam*, near to the San Juan Ranger Station, additionally demonstrates Bacalar Chico's historical and cultural value.
Despite conservation efforts, Belizean coral reef health is in decline (Healthy Reefs Initiative 2012). Overall reef health is variable across the country, though the majority of reefs are considered to be in a poor or critical state (Healthy Reefs Initiative 2012). The declining health of the BBR led to its inclusion on the List of World Heritage Sites in Danger in 2009 (UNESCO World Heritage Committee – Decision – 33 COM 7B:33).

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[1] Natural Criteria

(vii) contains "areas of exceptional natural beauty and aesthetic importance".

(ix) represents "significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals".

(x) contains "the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of Outstanding Universal Value from the point of view of science or conservation".

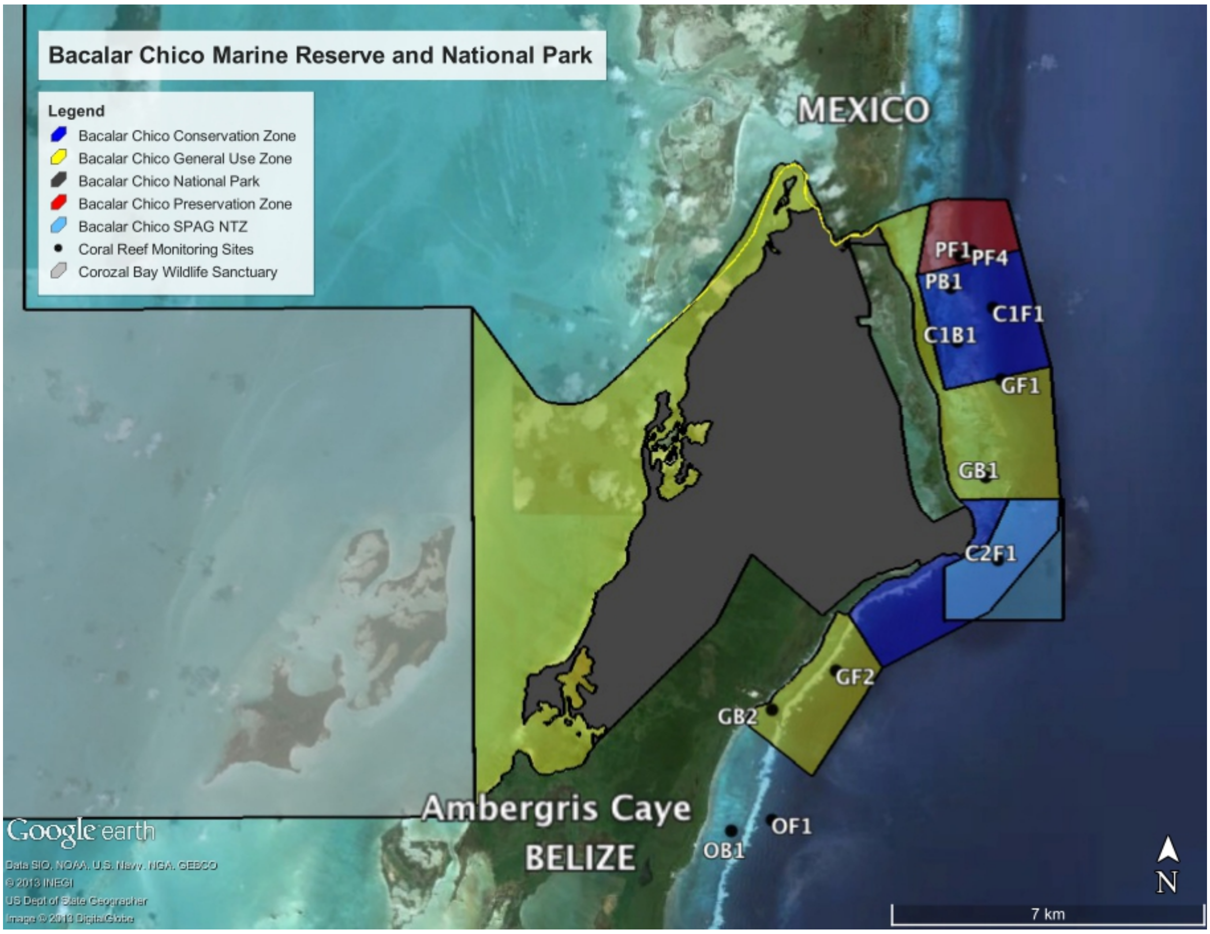

Figure 1 Zonation scheme for Bacalar Chico Marine Reserve and National Park with Blue Ventures' coral reef monitoring sites.

3. Methods

Volunteer-Assisted Data Collection

Blue Ventures' coral reef monitoring programme in BCMR is supported and assisted by volunteers, who undergo a rigorous scientific training programme prior to data collection. Volunteers are trained in species identification for benthic taxa and fish species in order to collect fish belt and point intercept transect data. Training involves a series of detailed lectures, in-water point-outs, and in-water methods training. Before participating in data collection, each volunteer must achieve at least 98% in both computer and in-water unassisted species identification tests. All training and surveys are led by Blue Ventures' qualified and experienced field scientists.

Monitoring in 2012

Mesoamerican Barrier Reef System Synoptic Monitoring Programme

In 2012, twelve sites were surveyed using the Mesoamerican Barrier Reef System Synoptic Monitoring Programme (MBRS-SMP) Category 1 methods for coral reefs (Sale *et al*. 2003). In addition to the baseline Category 1 monitoring outlined in the MBRS-SMP, eight 30 m x 2 m invertebrate belts were conducted at each site, monitoring abundance of three species of lobster (Caribbean spiny, *Panulirus argus*, spotted spiny, *P. guttatus* and Spanish, *Scyllarides aequinoctialis*), queen conch (*Strombus gigas*), long-spined sea urchin (*Diadema antillarum*) and flamingo tongue snails (*Cyphoma gibbosum*).

Additional, Simplified Coral Reef Monitoring

A method for rapid assessment was trialled at eight sites, collecting data for:

1. Fish family abundance and size class frequency.
2. Fish recruit species abundance.
3. Scleractinian coral, turf algae, crustose coralline algae and fleshy macroalgae cover.
4. Ratio of colonies exhibiting full bleaching (>75% bleached tissue), partial bleaching (<75% bleached tissue), paling (noticeable difference from typical colouration) and no bleaching.

Data at these sites were collected at different times of year to MBRS-SMP surveys, to complement more comprehensive monitoring.

Target Species and Megafauna Monitoring

All megafauna sightings (marine mammals, marine turtles and elasmobranchs) were recorded, including, when possible, species, size, sex, depth, time of sighting and location.

The presence and size of 'target species'[2] (Table 1) were recorded for every dive performed by Blue Ventures in BCMR, in order to provide a proxy of population trends for commercially significant and/or endangered species known to exist locally, but with low population densities. For lobster species, size estimation was based on cape length, and for fish, total length (mouth to tip of tail).

[2] The list of 'target species' was produced in 2011 based upon anecdotal fisheries targets, IUCN categorisation and/or population trends of the species in other parts of the Mesoamerican Barrier Reef.

Table 1: Target species list

Family	Common Name	Latin Name
Lutjanidae	Mutton Snapper	*Lutjanus analis*
Lutjanidae	Cubera Snapper	*Lutjanus cyanopterus*
Lutjanidae	Dog Snapper	*Lutjanus jocu*
Serranidae	Black Grouper	*Mycteroperca bonaci*
Serranidae	Tiger Grouper	*Mycteroperca tigris*
Serranidae	Nassau Grouper	*Epinephelus striatus*
Carangidae	Permit	*Trachinotus falcatus*
Scombridae	Cero	*Scomberomorus regalis*
Elopidae	Tarpon	*Megalops atlanticus*
Sphyraenidae	Great Barracuda	*Sphyraena barracuda*
Palinuridae	Caribbean Spiny Lobster	*Panulirus argus*
Palinuridae	Spotted Spiny Lobster	*Panulirus guttatus*
Scyllaridae	Spanish Lobster	*Scyllarides aequinoctialis*
Strombidae	Queen Conch	*Strombus gigas*

Invasive Lionfish

Sightings if the invasive lionfish (*Pterois volitans*) have been recorded in BCMR since August 2010.

On every dive, including survey dives, the location, size, depth and abundance of lionfish are recorded as well as any additional comments such as sex and behaviour.

4. Results

Overall Reef Health

A complete set of 12 sites, including representatives of backreef and forereef from within each management zone of BCMR, as well as outside of BCMR, were surveyed in 2012. For the majority of sites, hard coral cover, fleshy macroalgae cover and herbivorous fish populations were in poor condition, and commercial fish populations were critically low.

Average Simplified Integrated Reef Health Index (SIRHI) score within BCMR in 2012 was 2.08 (*n*=10), falling within the category 'Poor'. This categorical ranking is unchanged from previous years (2010 SIRHI=2.22, *n*=8; and 2011 SIRHI=2.10, *n*=7). No sites ranked as 'Good' or 'Very Good'. The highest-ranking site in 2012 was *C1B1*, which was the only site to rank as 'Fair' (Figure 1). 'Very Good' herbivorous and commercial fish biomass at this site influenced the overall site ranking, despite 'Poor' hard coral cover and 'Critical' fleshy macroalgal cover (Table 1).

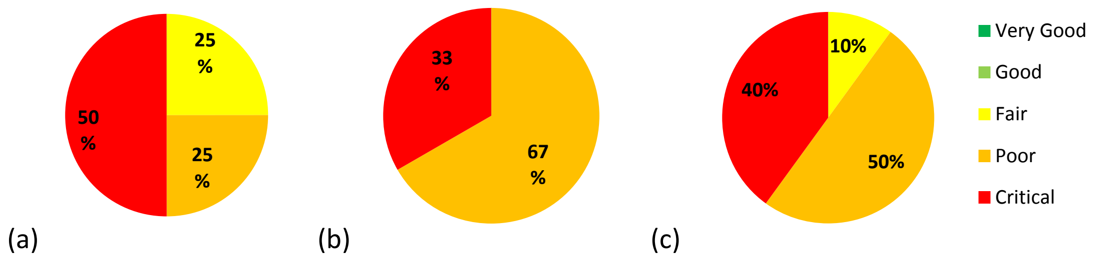

Figure 2: Coral reef condition in 2012 in (a) backreef, (b) forereef and (c) throughout BCMR.

The average SIRHI score outside of BCMR in 2012 was 2.00 (*n*=2, 'Poor'), with the backreef site (*OB1*) 'Critical' overall, and the forereef site (*OF1*) 'Poor' (Table 1).

Table 2: SIRHI Scores for each indicator and overall coral reef condition of sites in and around BCMR.

Reef Location	Zone	Site	Hard Coral Cover	Fleshy Macroalgae Cover	Herbivorous Fish Biomass	Commercial Fish Biomass	Overall SIRHI Score
Back reef	GUZ1	**GB1**	Poor	Critical	Poor	Critical	Critical
	GUZ2	**GB2**	Poor	Poor	Poor	Critical	Critical
	CZ1	**C1B1**	Poor	Critical	Very Good	Very Good	Fair
	PZ	**PB1**	Poor	Good	Critical	Poor	Poor
Fore reef	GUZ1	**GF1**	Fair	Critical	Poor	Critical	Critical
	GUZ2	**GF2**	Poor	Poor	Poor	Critical	Critical
	CZ1	**C1F1**	Fair	Critical	Good	Poor	Poor
	CZ2	**C2F1**	Poor	Poor	Fair	Critical	Poor
	PZ	**PF1**	Fair	Poor	Poor	Critical	Poor
	PZ	**PF4**	Critical	Poor	Fair	Fair	Poor
Back reef	None (Outside Reserve)	**OB1**	Poor	Poor	Poor	Critical	Critical
Fore reef	None (Outside Reserve)	**OF1**	Fair	Critical	Fair	Poor	Poor

Analysis showed that there were no trends by year, nor within and outside of the reserve (Figure 3). The highest overall reef health score for the entire survey period was in CZ1 in 2012 (2.88 ± 2.27; Fair).

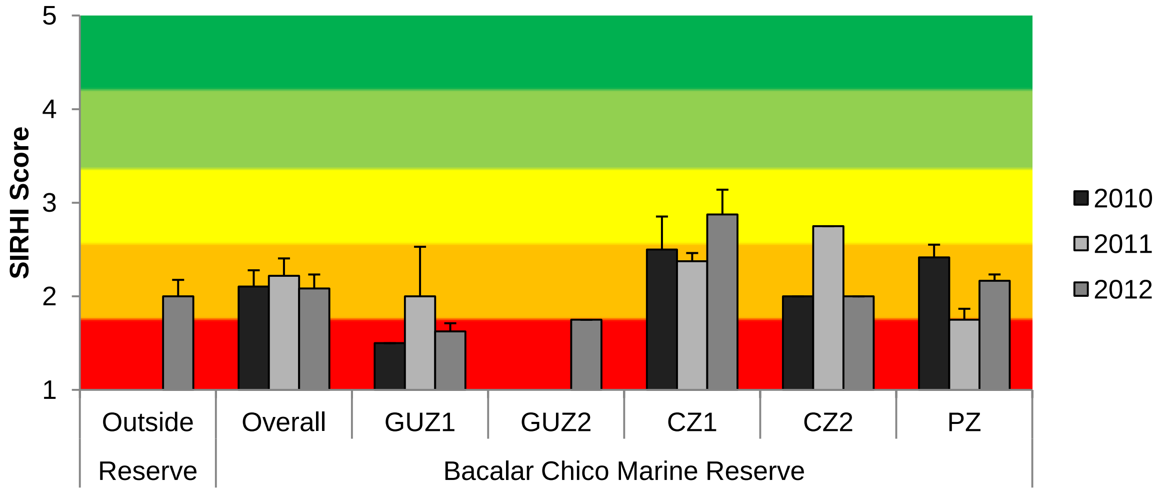

Figure 3: Average Simplified Integrated Reef Health Index (SIRHI) scores for sites surveyed within each management zone and outside of the reserve, with Standard Error bars displayed. Background is colour coded to indicate interpretation – "Critical" (1-1.8; Red), "Poor" (>1.8-2.6; Orange), "Fair" (>2.6-3.4; Yellow), "Good" (>3.4-4.2; Light Green) and "Very Good" (>4,2-5; Dark Green).

Seven sites were monitored over all three years (2010-2012), and eight in both 2011 and 2012 (Table 3). At these sites, there was no significant difference in hard coral (HC) cover between years (Kruskal-Wallis, X^2=1.30, df=2, p=0.52; Figure 4), but fleshy macroalgal (FMA) increased significantly from 18.30% ± 3.63 (*n*=7) in 2010 to 26.58% ± 4.64 (*n*=7) in 2012 (X^2=6.29, df=2, p=0.04). Wilcoxon pairwise comparison showed that the difference in FMA cover was not significant from 2010-2011 (*H*=0.35, df=1, p= 0.55) or 2011-2012 (*H*=2.81, df=1, p=0.09), but was significant for 2010-2012 (*H*=6.12, df=1, p=0.01).

Table 3: Changes in reef health indicators and overall SIRHI scores at sites surveyed in 2011 and 2012.

Reef Location	Zone	Site	Hard Coral Cover (%)	Fleshy Macroalgal Cover (%)	Herbivorous Fish Biomass (g/100m^2)	Commercial Fish Biomass (g/100m^2)	Overall SIRHI Score
Backreef	GUZ1	**GB1**	1.46	11.67	332.79	281.11	0.25
	CZ1	**C1B1**	-0.03	3.66	3540.04	435.96	1.00
	PZ	**PB1**	2.33	-0.50	-252.57	429.49	0.50
Forereef	GUZ1	**GF1**	-7.83	9.00	-649.73	-305.27	-1.00
	CZ1	**C1F1**	-8.31	7.74	1779.90	-432.17	0.00
	CZ2	**C2F1**	-3.67	-5.17	-1881.42	-319.33	-0.75
	PZ (West)	**PF1**	1.46	1.33	803.21	192.78	0.00
	PZ (East)	**PF4**	-1.17	3.17	1597.07	879.01	0.75
	TOTAL		-2.32	3.04	559.23	42.09	-0.14

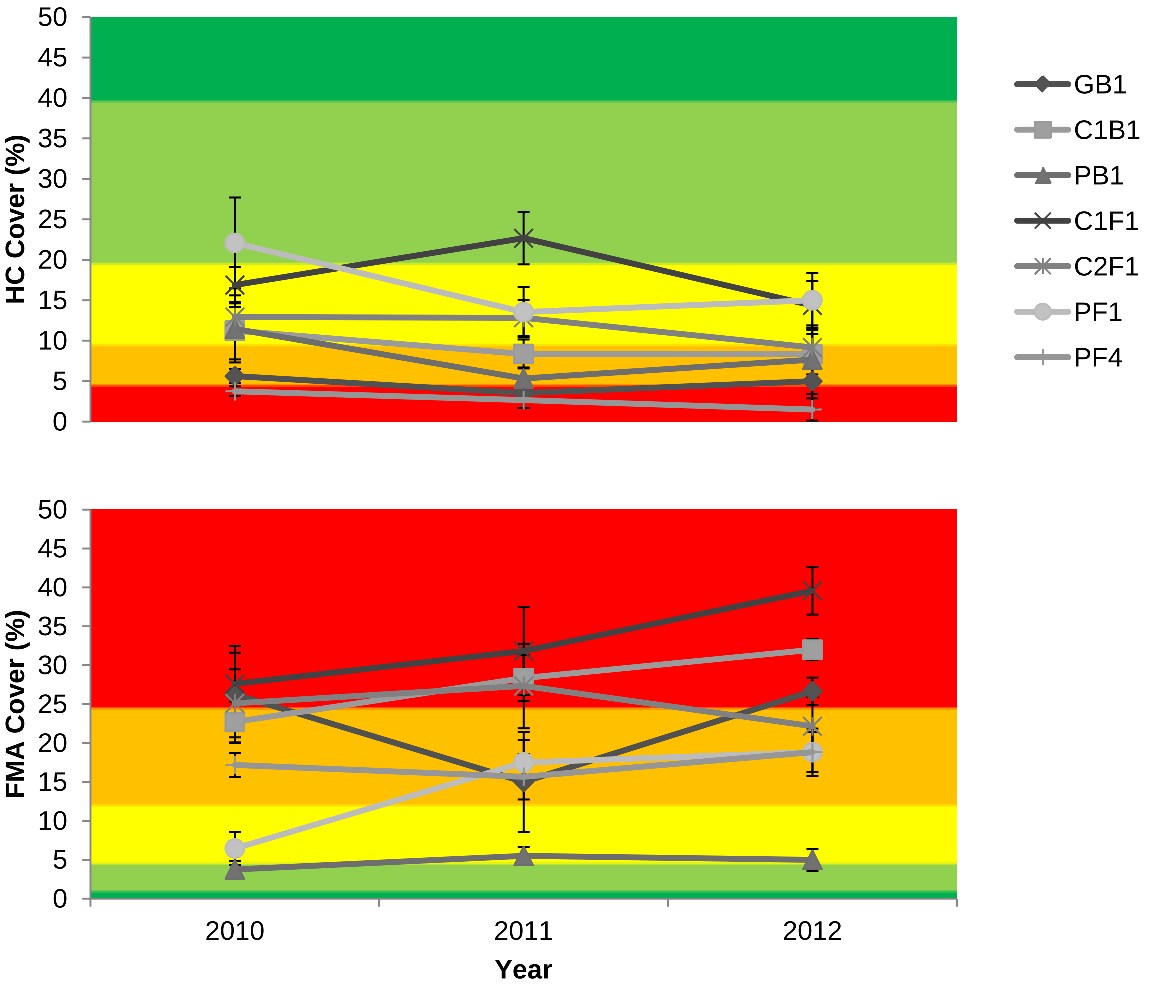

Figure 4: Average hard coral and fleshy macroalgae cover at core reef monitoring sites in Bacalar Chico Marine Reserve, 2010 to 2012, with Standard Error bars displayed. Background is colour coded to indicate interpretation using the SIRHI – "Critical" (red),"Poor" (orange), "Fair" (yellow), "Good" (light green) and "Very Good" (dark green).

At these same sites (Table 3), mean key herbivorous fish biomass was 'Fair' in in 2010 (2021±446 $g.100m^{-2}$, *n*=7), decreasing to 'Poor' in 2011 (1489±462 $g.100m^{-2}$, *n*=7). In 2012, mean herbivorous fish biomass was 'Fair' (2334±558 $g.100m^{-2}$, *n*=7).

Mean key commercial fish biomass was critical in all three years (2010: 438±162 $g.100m^{-2}$, *n*=7; 2011: 487±191 $g.100m^{-2}$, *n*=7; 2012: 697±211 $g.100m^{-2}$, *n*=7). At one of these sites (C1B1), mean key commercial fish biomass increased annually to 'Very Good' in 2012 (Figure 5).

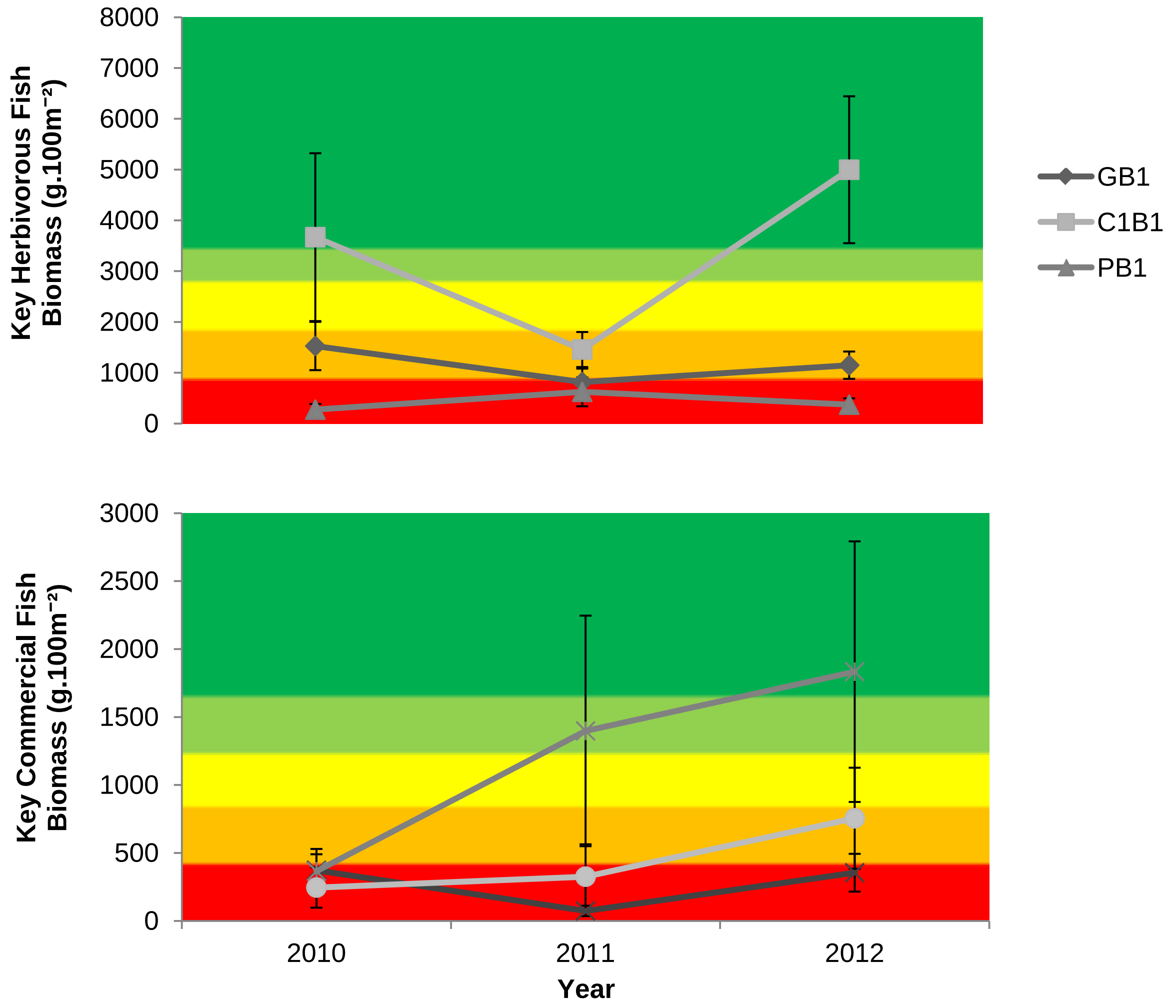

Figure 5: Average key herbivorous and commercial fish biomass at core backreef sites in Bacalar Chico Marine Reserve, 2010 to 2012, with Standard Error bars displayed. Background is colour coded to indicate interpretation using the SIRHI – "Critical" (red),"Poor" (orange), "Fair" (yellow), "Good" (light green) and "Very Good" (dark green).

Benthic Composition

Mean HC (including *Millepora* spp.) cover for reefs within BCMR in 2012 was 8.84% ± 1.32 (*n*=10. Mean FMA cover at these sites was 26.74% ± 3.44 (*n*=10). Mean HC and FMA cover outside of BCMR was 11.58% ± 1.75 (*n*=2) and 32.58% ± 7.42 (*n*=2) respectively.

Cluster analysis and multidimensional scaling (MDS) of the eight core sites (Table 3, Figure 4) show relatively little separation between sites with no clustering at 60% similarity. Clustering occurs at 70% (2 groups), separating Tarpon Patch (PB1) from the other sites, and 80% for 5 groups which separate Tarpon Patch, Peccary Patch (GB1), Pig Sty (PF4, 2011 and 2012 only), Garden Wall (PF1) and Last Resort (C1B1, 2010 only)

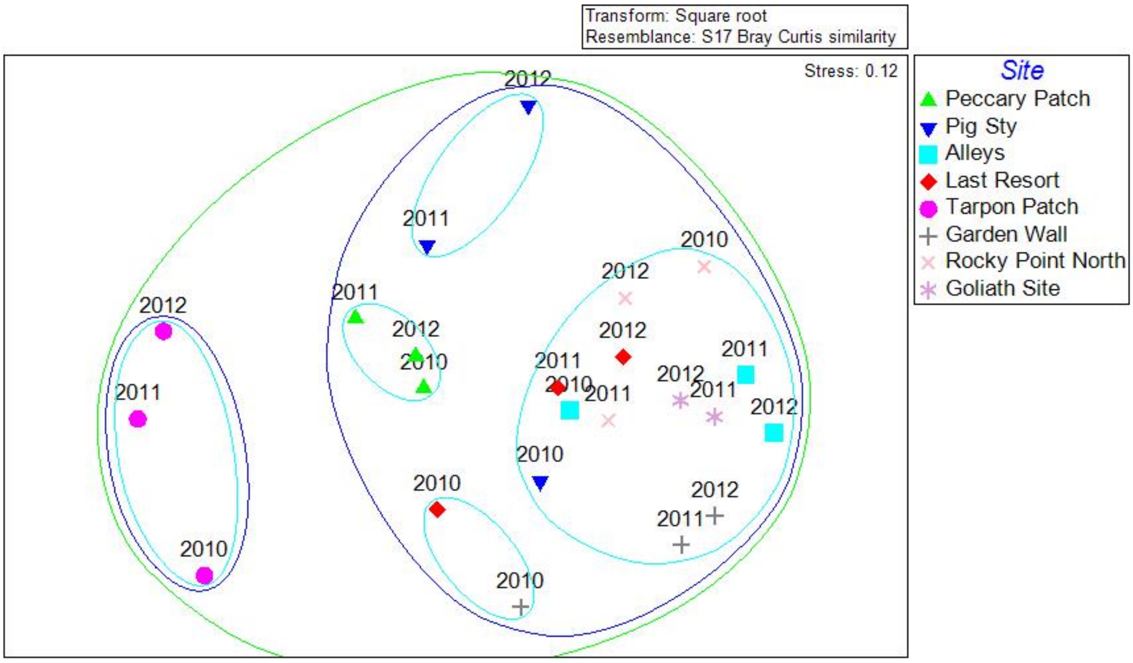

Figure 6: MDS of core monitoring sites in 2010, 2011 and 2012 for benthic community composition in Bacalar Chico Marine Reserve.

The 2-way crossed Anosim showed an overall significant (p = 0.001) but weak separation between years (R = 0.23) with a similarly significant (p = 0.001) but slightly stronger difference between sites (R = 0.56).

SIMPER (similarity percentages) analysis shows that the dissimilarities between years are strongest between 2010-2012 and 2010-2011, due to differences in crustose coralline algae (CCA), turf algae (TA), gorgonians (GORG) and sand/rock/rubble (SD,RK,RB), rather than FMA or HC.

Fish Composition

Mean key herbivorous fish (parrotfish and surgeonfish) biomass within BCMR in 2012 was 'Fair' (2334±558 g.100m^{-2}, *n*=10), and mean key commercial fish (grouper and snapper) biomass was 'Poor' (697±211 g.100m^{-2}, *n*=10). Mean key herbivorous and commercial fish biomass outside of the reserve in 2012 was 'Poor' (1791±307 g.100m^{-2}, *n*=2) and 'Critical' (380±221 g.100m^{-2}, *n*=2), respectively.

Site based analysis by year showed no difference between years (R = -0.143, p = 0.96), while there was some variation by site this was overall not very strong (R = 0.27, p = 0.001). There was no difference between management zones, or between fished and un-fished areas.

Location (fore and back reef) showed a significant but weak variation, (R = 0.07, p = 0.04). Zones also had weak but significant variation, with the strongest differences between CZ1 and CZ2 (R = 0.46, p = 0.001), and CZ2 and GUZ1 (R = 0.34, p = 0.001).

Cluster analysis and multidimensional scaling (MDS) show relatively little separation between the sites and none between years (Figure 6). One site, Rocky Point North (C2F1) separated from all sites for all years. SIMPER analysis of locations showed that many (n=26) fish species were responsible for the dissimilarity in fish biomass between fore reef and back reef locations. The largest contributor to dissimilarity was the bluestriped grunt (0.3%) and the french grunt (6.03%).

All zones showed between 50 and 70% dissimilarity, with contribution from 22-26 species. This was predominantly the bluestriped grunt (*Haemulon sciurus*), the black durgon (*Melichthys niger*), blue tang (*Acanthurus coeruleus*), the French grunt (*H. flavolineatum*) and the ocean surgeonfish (*A. bahianus*).

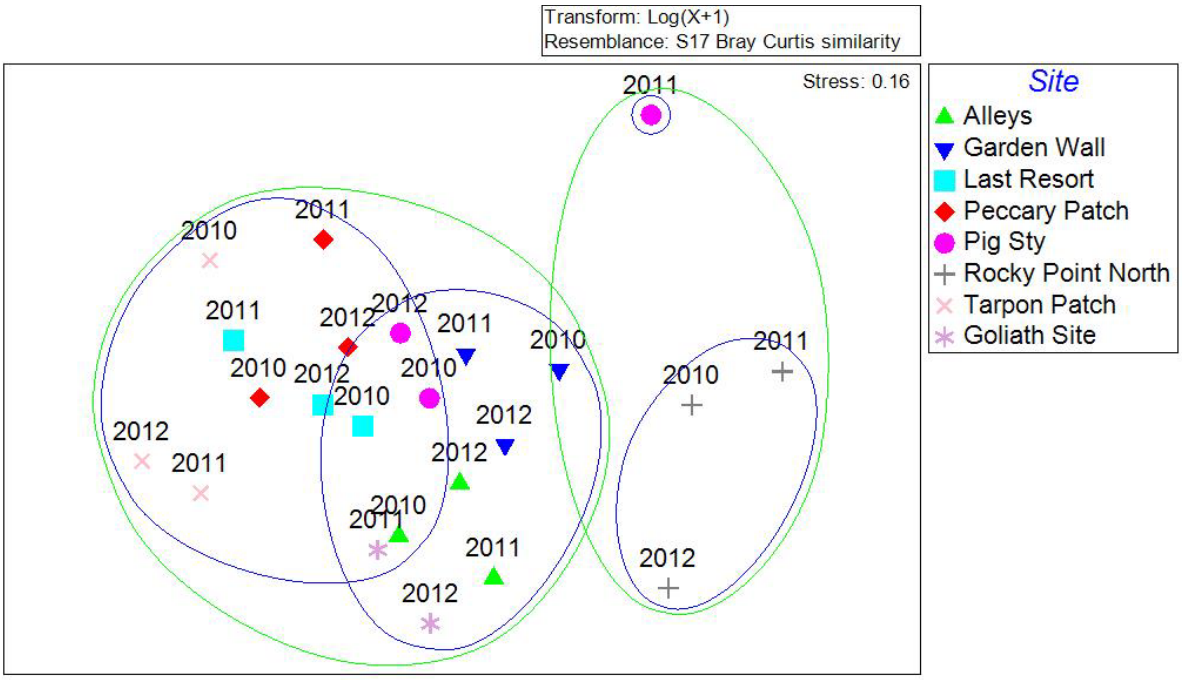

Figure 7: MDS for core monitoring sites in 2010, 2011 and 2012 for fish community composition in Bacalar Chico Marine Reserve.

5. Discussion

Coral reefs in BCMR are in extremely poor health, with HC cover (9%) dramatically lower than the 2012 national average (19%) and FMA cover (27%) higher than the 2012 national average (16%) (Healthy Reefs Initiative 2012).

Critically high levels of FMA persist in BCMR, with FMA cover increasing significantly over the three years of monitoring conducted by Blue Ventures, despite herbivorous fish biomass categorised as 'good' to 'very good' at some sites. Although diverse and abundant populations of parrotfish and surgeonfish can provide suitable grazing pressure to prevent macroalgal phase shift, phase-shift reversal is likely to be dependent upon the presence of certain key species, such as the rainbow parrotfish (*Scarus guacamaia*) and long-spined sea urchin (*Diadema antillarum*), that are able to graze upon tall stands of late-successional macroalgae (Mumby 2006; Mumby et al. 2007; Burkepile & Hay 2009; Burkepile & Hay 2010; McClanahan et al. 2011; Mumby 2009; Harborne et al. 2009).

Notably, between March 2010 and December 2012, no rainbow parrotfish were observed in BCMR, and *Diadema* sea urchin populations are critically low (Chapman 2012). Activities to aid the recovery of these species should be included in an updated management plan.

There was no observable effect of local nutrient enrichment due to coastal development; mean FMA in 2012 was 'poor' in GUZ2, in the south of BCMR and adjacent to two large hotels – significantly lower than the FMA levels in CZ1, located in the north of BCMR.

Biomass of key commercial and herbivorous fish populations are both marginally greater in BCMR (697 and 2334 $g.100m^{-2}$ respectively) than 2012 national averages (495 and 1870 $g.100m^{-2}$ respectively) (Healthy Reefs Initiative 2012), however dramatic fluctuations in fish abundance and biomass along transects make site averages unreliable, a result observed throughout Belize (National Coral Reef Monitoring Network, pers. comm.). In February 2013, consensus was reached amongst National Coral Reef Monitoring Network members to increase replication of MBRS-SMP fish belts at all sites to at least 10, and to conduct fish belt surveys at each site twice annually when possible, in an attempt to overcome this error.

With no influence of management zonation on coral reef condition, it is strongly recommended that the management plan for BCMR be assessed and revised, and enforcement of reserve regulations increased. Blue Ventures witnessed multiple incursions by tourism operators from both Mexico and Belize into the Preservation and Conservation zones throughout the course of 2012, likely contributing to the lack of management effectiveness.

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