PORT HONDURAS MARINE RESERVE: CORAL REEF ECOSYSTEM HEALTH REPORT

2020

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TABLE OF CONTENTS

1.0 INTRODUCTION

The Port Honduras Marine Reserve (PHMR) is a unique coastal protected area that spans estuarine areas where watersheds exit into the coast, to lagoonal coral reef communities inside the main barrier reef. This marine protected area was established in 2000 with an area of 40,468 Ha and co-managed by the Toledo Institute for Development and Environment (TIDE). It extends approximately 8 km out to sea in the southern barrier lagoon. The PHMR includes a range of ecosystems from coastal wetlands to mid lagoonal reefs (a unique reef type along the Belize Barrier Reef). It also contains extensive seagrass beds and surrounds over 100 mangrove cayes (Wildtracks 2017). It supports important artisanal commercial fisheries for spiny lobster and queen conch, in southern Belize. It serves as an important buffer between the southern mainland and the main barrier reef, with five majors watersheds exiting in the area.

The PHMR includes approximately 380 hectares of coral reefs (TIDE 2016) with varying coral community composition. Coral reefs within the inner lagoon consist of patch reefs or algal dominated hard bottom communities, while near the Snake Cayes, more diverse coral reefs can be found (Foley 2016). Previous reef surveys of the marine reserve have identified over 118 species of fish, of which six were found only within the Snake Cayes area (Sullivan et al. 1995, Harborne 2000, Robinson et al. 2004). While the coral reefs of the PHMR are located within a coastal area subject to major anthropogenic influences from land-based runoff, they have shown remarkable resilience having survived and recovered from the 1998 and 2010 bleaching events (Wildtracks 2017).

The focus of the marine protected area is fisheries management with the majority of this marine reserve a general use zone (95%), open to fishing, where commercial, subsistence and recreational fishing are allowed. Four replenishment or no-take zones are designated (4%) around West, East and South Snake Cayes and West Cane Cayes, where non-extractive recreational activities are allowed. There is a preservation zone (1%), 0.8 km radius around Middle Snake Cayes, where only research activities are allowed (Figure 1) (Wildtracks 2017).

One of the main management goals of the PHMR in relation to ecosystem health is to promote sustainable marine resource use for the continued benefit of all users. The primary conservation target related coral reefs is to return coral reef ecosystems in PHMR to a healthy state, providing the full range of functions and services. In order to achieve this target one of the important management strategies is to have an established and sustained research and monitoring program, that can provide the scientific data needed on the status and health of PHMR coral reefs to inform adaptive management and decision making.

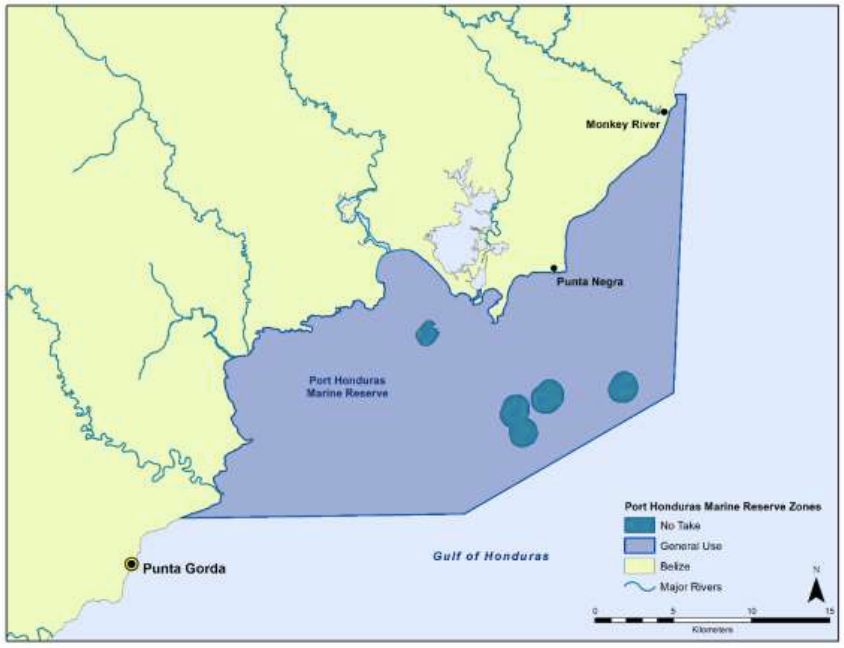

Figure 1 PHMR Zones, from the PHMR Management Plan 2017-2021 (Wildtracks 2017)

2.0 METHODOLOGY

Since 2003 TIDE has been monitoring coral reef health from across eight sites within the management zones of the marine reserve with two more sites added in 2011 (Figure 2). This long-term monitoring has produced information on coral community structure, coral health and reef fish abundance and community structure. This data up to 2016 has been incorporated into the PHMR Management Plan 2017-2021.

This current report gives the coral reef community structure and health status for 2020 comparing with previous years data to highlight trends in health. Data for 2020 was collected in October 2020 and followed the previous, standard and nationally recommended methodology using the Mesoamerican Barrier Reef System Synoptic Monitoring Program coral reef protocol. Ten coral reef sites were surveyed, 4 within the replenishment zones (RZ), 4 in the general use zone (GUZ) and 2 outside the reserve (OUT) (Figure 2).

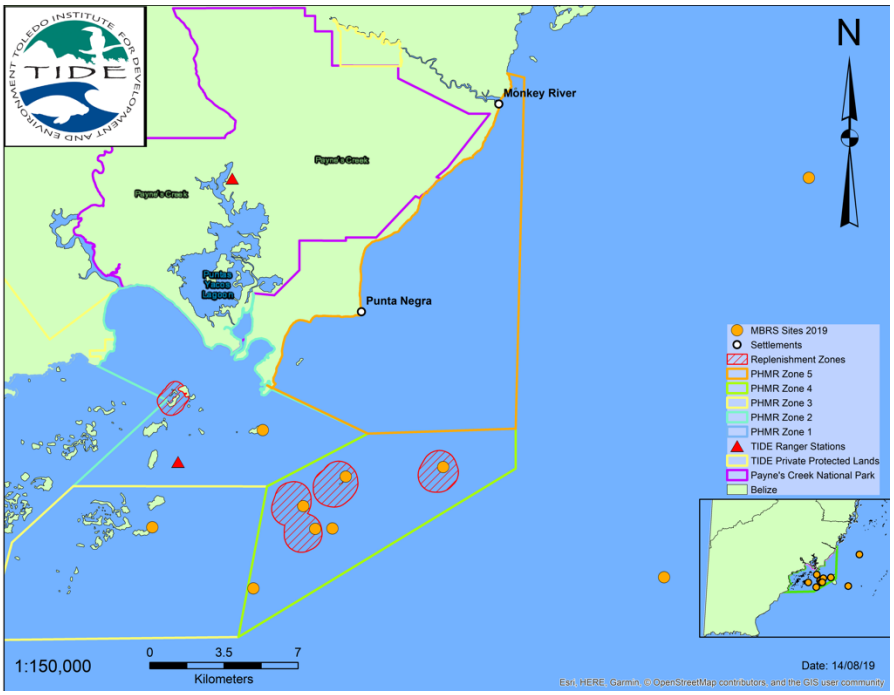

Figure 2 Coral reef monitoring sites within the PHMR and adjacent buffer area (TIDE 2019)

3.0 RESULTS

In 2020, TIDE conducted its annual coral reef ecosystem surveys across ten (10) long-term monitoring sites during October 2020. These results provide information on the status of the coral reef ecosystems in PHMR and any changes in coral reef health. Coral reef ecosystem health assessment looks at reef community structure using a variety of indicators including coral species abundance, coral health - mortality, disease and bleaching, reef fish abundance and population structure - in particular herbivores and commercial species, and *Diadema* abundance. All these indicators are incorporated in an overall reef health score using the HRI Reef index (HRI 2008). The results of these are presented below.

CORAL REEF COMMUNITY STRUCTURE

The reefs of Port Honduras Marine Reserve have a mean live coral cover of 19% (±2.1) ranging between 8.9% at Wilson Caye to 30.4% at East Snake Caye, with East Snake, West Snake and South Snake Cayes having live coral cover above 20%. Mean fleshy macroalgae cover was 10.5% (±2.2) ranging from 4.3% at East Snake Caye to 27.4% at Bank 3 (Figure

3, Appendix 1). Mean gorgonian abundance was 8.9% (±1.1) with West Snake Caye having the highest abundance, sponge was 3.2% (±0.6) with the highest abundance at Bank 3, Middle Snake Caye and Frenchman Caye, calcareous macroalgae was 6.6% (±1.1), with South Snake Caye having the highest, and turf algae having a mean cover of 3.2% (±0.6) with the reef sites comprised of a majority of sand (42.8%±2.4) (Figure 3, Appendix 1). Coral reef sites of the PHMR have very low cover of crustose coralline algae (CCA) with a mean of 0.1% (±0.0). They also have low cover by other invertebrates such as zooanthids, corallimorphs and other cnidarians, 2.6% (±0.6) and low abundance of cyanobacteria, 1.8% (±0.4) (Figure 3).

When reef community structure was analyzed across management zones, the replenishment zone (RZ) had the highest mean live coral cover (24.9%±3.0), followed by sites outside the marine reserve (OUT) (18.8%±0.0), with the general use zone (GUZ) having the lowest mean live coral cover of 13.3% (±1.8) (Figure 4, Appendix 2). Conversely, fleshy macroalgae was highest in the general use zone (13.4%±4.8) followed by outside the reserve (10.3±5.9) and least in the replenishment zone (7.8%±1.6). Gorgonian abundance was also greatest in the replenishment zone (10.2%±1.8), but next highest in abundance in the general use zone (8.4%±2.1) and finally outside the reserve (7.2%±0.1) (Figure 4). Sponge abundance was greatest outside the reserve (5.4%±1.8), then the general use zone (3.0%±0.9) and least within the replenishment zone (2.4%±0.5) Calcareous macroalgae was similar between the three zones, ranging from 5.3-7.8%. Turf algae was greatest in the GZ (3.9%±1.1), followed by the replenishment zone (3.5%±0.9) and then outside the marine reserve (1.3%±0.6). Across all management zones, crustose coralline algae (CCA) was similar and very minimal, with a cover of <0.2%. (Figure 4, Appendix 2).

CORAL SPECIES ABUNDANCE

Individual coral species abundance was examined from across the sites surveyed with a total of 25 coral species encountered from the point intercept transect surveys (Table 1). The top six most abundant coral species were *Porites astreoides* (PAST), *Siderastrea siderea* (SSID), *Millepora alcicornis* (MALC), *Orbicella faveolata* (OFAV), *Undaria tenuifolia* (UTEN) and *Millepora complanata* (MCOM), in that order (Figure 5). The Acroporid corals (*Acropora cervicornis* (ACER) and *Acropora palmata* (APAL)) were rare, with ACER occurring at Daly Bank and South Snake Caye (0.6% and 0.1% respectively) and APAL at South Snake Caye only with 1.7%, (Figure 5). *Orbicella annularis*, another major reef builder was also rare, occurring at only two sites (Frenchman Caye and East Snake Caye) with cumulative cover of 1.4%. Across the management zones, the six most abundant species were greatest in the replenishment zone with the exception of MALC which was more abundant outside the marine reserve

(Figure 6). The endangered Acroporids were found both in the replenishment zone and outside the marine reserve. As noted, coral abundance was greatest in the replenishment zone, followed by outside the marine reserve and then the general use zone (Figure 6).

CORAL HEALTH

Coral health was assessed from surveys of coral colonies greater than 10 cm (n=500). Based on analysis of the data, recent coral mortality was low with 1.9% mortality rate while old mortality (greater than 6 months) was 12.2%. Coral diseases were also recorded for the surveyed coral colonies with five diseases affecting a total of 4.8% of the coral colonies (Figure 7). These were dark spot, black band, yellow blotch, white spot and white band in that order. Eight out of the ten sites were affected by disease, with only Wilson Caye and Frenchman Caye not showing any signs of disease on the corals surveyed. The sites with the highest disease incidence were Bank 3 with 2.4% of colonies affected, followed by South Snake Caye and West Snake Caye with 0.6% each (Figure 8). The most commonly affected coral species were massive corals such as *Siderastrea siderea, Colpophyllia natans, Diploria labyrinthiformis, Orbicella faveolata* and *Orbicella franksi* (Table 2). Coral colonies were also assessed for bleaching with up to 65% of colonies (n=500) recorded with some level of bleaching (Pale (P), Partially Bleached (PB), Fully Bleached (PB)). Most corals were suffering paling (P, 35%). Thirteen (13%) percent of coral colonies were partially bleached and 17% were fully bleached (Figure 9). All ten sites were affected by bleaching of some form and the sites outside the reserve had the lowest level of bleaching. The replenishment zone was the zone with the highest level of fully bleached and pale colonies (Figure 10). In terms of individual species, SSID showed the highest percentage of bleaching (three levels cumulatively: P, PB, BL) with the next most bleached corals being *Pseudodiploria strigosa* (PSTR), *Colpohyllia natans* (CNAT), and *Stephanocoenia intersepta* (SINT) (Figure 11).

REEF FISH ABUNDANCE AND POPULATION STRUCTURE

Reef fish populations were assessed based on the major fish groups used to indicate reef health: herbivores and commercially fished species (commercial species). These include the acanthurid family comprised of doctorfishes, surgeonfishes and tangs, and the parrotfish family, along with the various snapper and grouper species. In total there were 12 herbivore species and 12 commercial species observed from the fish surveys of the PHMR (Table 3).

Abundance of these families was measured using density (# fish per hectare) and biomass (g of fish per 100 m^{-2}). In terms of fish density, herbivores were far more abundant than

the commercial species, more than six times the abundance, with herbivore density ranging from 3021 to 10250 ha^{-1} (Figure 12) and parrotfish density exceeded the other families by an order of about 6, with Bank 3, Daly bank, Spanish Bank and West Snake Caye having some of the highest densities of acanthurids, parrotfishes and snappers (Appendix 3). Mean densities of herbivores and commercial species were 6,665 and 996 ha^{-1}. Density varied across the management zones of the PHMR. The general trend was an increase in density of herbivores from the general use zone through the replenishment zone and to the outside of the marine reserve. Commercial species had a less pronounced trend with the highest abundance of snappers and groupers found outside the marine reserve (Figure 13).

Herbivore biomass was greater than commercial species biomass. Mean herbivore biomass within the PHMR was 1316 g/100 m^{-2} and mean commercial species biomass was 662 g/100 m^{-2}, with herbivores ranging from 377 - 2937 g/100 m^{-2}, and commercial species ranging from 116 - 1674 g/100 m^{-2} (Figure 14). Parrotfishes had the greatest biomass of the four families with groupers being the least abundant, occurring in very few numbers (Appendix 4). South Snake and West Snake Cayes had the greatest abundance of fish (Appendix 4). Across management zones, herbivore biomass was greatest in the replenishment zone followed by outside the marine reserve and lowest in the general use zone. Biomass of commercial species showed a similar trend to density, with sites outside the marine reserve having the highest biomass (Figure 15).

Fish within the PHMR were mostly small fish occurring in the lower size classes of 6-10 cm and 11-20 cm with a large number of juveniles (<5 cm), particularly among the herbivorous species. The snappers and groupers surveyed were small, with a majority also falling in the 6-10 cm and 11-20 cm size classes and only 1 occurrence of a snapper in the 31-40 size class (Figure 16). As noted, the number of groupers was extremely low. There was a marked absence of the large grouper species from the genus Mycteroperca.

DIADEMA ABUNDANCE

Diadema antillarum, the long-spined black sea urchin, and an important herbivore, was rare on the reefs of the PHMR. Densities of urchins ranged from 0.01 to 0.10 urchins m^{-2} (Figure 17) and the mean was 0.04 urchins m^{-2}. The replenishment zone had the highest mean density followed by sites outside the marine reserve and then the general use zone (Figure 18).

4.0 DISCUSSIONS AND RECOMMENDATIONS

CORAL REEF COMMUNITY STRUCTURE

The coral reefs of PHMR have FAIR coral cover (mean of 19%) (Figure 19a) based on the Healthy Reefs Index (HRI) coral cover indicator ranking. This means that the coral reefs in the marine reserve are in a fair condition or doing ok based on the HRI's live coral cover rank of between 10-19.9%. Mean fleshy macroalgal cover of 10.5% ranked as FAIR, indicating that in regards to macroalgal health these reefs are doing ok also. In terms of calcareous macroalgae and turf algae, these were low in abundance, which indicate a fairly healthy balance. However, crustose coralline algae (CCA), an important reef building group, was very low in abundance on these reefs. This may be due to the location of these reefs in inshore coastal waters, heavily influenced by land-based runoff. Sites closest to the mainland (Wilson, Frenchman Caye and Bank 3) had the lowest coral cover which may be due to their proximity to impacts from pulses of sediments and poor water quality.

When coral reef community composition data was compared with data from previous years for the PHMR, there seems to be a trend of increased coral cover, suggesting these reefs are resilient considering their exposure to land-based runoff, particularly sedimentation, and previous episodes of coral bleaching from which they have recovered (Foley 2016, Wildtracks 2017). However, the long-term data set shows a major decrease in gorgonian cover in 2014 that seems to have continued into the present day, with only 8.9% in 2020 and as the 2003-2014 dataset shows (Appendix 5), there has been a two-fold increase in sand on these reefs indicating sedimentation impacts.

In regards to management zones and their functions, it is apparent that the replenishment zones are working as refugia of resilient or healthier coral reefs, as the live coral cover was much higher in these zones than in the general use zone, with a ranking of GOOD (HRI 2018, Figure 19a). However, the sites outside the marine reserve seem to also be faring better than the general use zone of the marine reserve in terms of coral cover, with a ranking of FAIR. The coral cover in the general use zone was still FAIR but lower. Overall, in relation to other benthic groups such as fleshy macroalgae and gorgonians, their abundance was healthiest in the replenishment zones. Hence the replenishment zones have the healthiest coral reefs within the PHMR, most likely due to their location further away from shore.

CORAL SPECIES ABUNDANCE

Based on the most abundant coral species encountered, the coral reefs of PHMR are mostly populated by smaller, faster growing mound corals, such as *Porites astreoides* and *Siderastrea siderea* with the larger, slower and/or major reef building corals in low abundance. Historically *Acropora* spp. and *Orbicella* spp. were the dominant and most abundant corals on reefs of Belize and the Caribbean (McField 2000, Mumby et al. 2007, Bruno et al. 2009, Huntington et al. 2011) and the primary reef builders, but these have been severely impacted by a variety of anthropogenic threats including overfishing, nutrient enrichment and climate change (Carilli et al. 2009, Roff and Mumby 2012). The end result is a significant reduction in their cover and populations, placing them on the endangered species list. Currently the PHMR reefs have a low abundance of these dominant species and may most likely be slower growing reefs with less accretion or reef building, signaled through the loss of these species. This shift in coral species dominance has also been a factor contributing to the continued trend in a shift from coral dominated to algal dominated reefs.

CORAL HEALTH

On analysis of the coral health data collected on mortality, disease and bleaching and based on the HRI coral disease indicator, the coral reefs of PHMR rank as POOR in regards to coral disease prevalence with 4.8% (Figure 19b, HRI 2008). This suggests that the reefs are suffering from stressors that are causing a variety of coral diseases targeting mainly mound or massive corals such as *Siderastrea siderea*, *Colpophyllia natans* and *Orbicella faveolata* (Table 2). Fortunately, the Stony Coral Tissue Loss Disease (SCTLD) has not extended to the PHMR. The coral disease levels need further monitoring to keep track of this and to try to establish causal relationships.

In terms of coral bleaching, the coral reefs of PHMR suffered mild to moderate bleaching in 2020 based on the levels of fully bleached, partially bleached and pale corals. Sea surface temperatures (SST) are increasing yearly and 2020 was a year with major coral bleaching forecasted due to elevated temperature. Once again, the most affected corals were the massive or mound corals. It is noteworthy that corals within the replenishment zones suffered the most bleaching and partial bleaching although these sites are further offshore, however it may be due to them being at fairly shallow depths. While temperature data exists for five of these sites, the data have not been analyzed to indicate the trends. For future monitoring efforts, this temperature data should be analyzed and presented especially in relation to bleaching trends. Despite the higher bleaching however, the coral reefs in these zones display resilience since they have maintained GOOD live coral cover. Further monitoring in subsequent years will determine the extent of this resilience. Sites

outside the marine reserve, were deeper sites and may have therefore suffered less bleaching from the elevated sea surface temperatures. They were also further from shore. Continued monitoring of coral bleaching during periods of forecasted bleaching is important to track the response of corals to elevated SST combined with establishing permanently marked transects and/or tagged corals at the annual coral reef monitoring sites. Any additional sites that are monitored for bleaching during the predicated peak bleaching season should also have the corals tagged. Based on this, a subset of these sites can be selected and monitored using the bar drop method during the peak bleaching period, depending on funding and logistics.

REEF FISH ABUNDANCE AND COMMUNITY STRUCTURE

The fish populations of the PHMR have been determined to be in POOR health. The herbivore populations are ranked as POOR using the HRI Index (Figure 19b), with a mean biomass of 1316 g/100 m^{-2}, and the commercial species populations also ranked as POOR with mean biomass of 662 g/100 m^{-2} based. While the density of herbivorous fishes is high, this abundance is comprised of primarily juvenile fish hence the low biomass. Most of the herbivores and commercial species mature within the higher end of the size class 11-20 cm (above 16 cm). The snappers mature at larger lengths in size class 21-30 cm. The replenishment zones indicate that they act as a refuge for these fish species as more herbivores and commercial species were found within these zones that the general use zone. There is a trend of more abundant commercial species at the sites outside the marine reserve, which requires some further investigation to identify the causes for this.

DIADEMA ABUNDANCE

While *Diadema* was found at all the ten sites surveyed, its numbers were still significantly low occurring well below 0.05 m^{-2}. This level of abundance is considered CRITICAL using the *Diadema* indicator from the HRI Reef Index, 2008 (Figure 19b). Given the importance of this herbivorous urchin to maintaining reef health, it is important to keep monitoring its populations to look for any increases over time. Similar to abundance for other important coral reef health indicators, the replenishment zones are the areas of highest abundance with regard to these urchins, reinforcing the importance of this zone(s) to maintaining the health of the coral reefs of the PHMR.

OVERALL CORAL REEF HEALTH

The Healthy Reefs Index is a standardized, regional index used for assessing coral reef health within the Mesoamerican Reef. Based on the index using the various indicators presented below in Figure 20, the overall reef health as determined by the HRI reef index is POOR, the reefs are ranked at a 2.3. Coral cover and fleshy macroalgae cover are both FAIR but herbivorous and commercial fish abundance are POOR and *Diadema* abundance is CRITICAL.

RECOMMENDATIONS

The coral reefs of Port Honduras Marine Reserve are in poor health. While coral cover is fairly healthy fish populations are poor, and declines in health have been identified from previous years. Given the range of anthropogenic impacts to these coral reefs such as land-based runoff including nutrients and pesticides from Belize and the Gulf of Honduras, along with overfishing and the overlying threat of global climate change, evidenced through annual coral bleaching events, there needs to be an expansion of annual coral reef monitoring efforts. Since these reefs are near shore and subject to runoff from land including sedimentation and nutrients, reef health monitoring needs to include water quality parameters, especially at these long-term sites and other strategic areas from shore and across the PHMR. Parameters such as water temperature, dissolved oxygen, turbidity, nutrients, sedimentation and pH should be regularly monitored. In addition, given the ever-present threat of coral bleaching, sea surface temperatures must also be monitored throughout the year using in situ temperature loggers at established coral monitoring sites to detect elevated heating periods. Lastly in order to effectively assess the recovery and resilience of the PHMR coral reefs to coral bleaching, permanent transects including tagged corals must be established on the existing ten monitoring sites to be able to conclusively track the health of the corals.

In terms of management strategies to help improve reef resilience, programs that focus on developing sustainable practices for the use of fertilizers, pesticides and farming techniques should be established with organizations in the area to help reduce land-based runoff and sedimentation, which negatively affect coral health and reduce resilience. Also reducing fishing pressure by ensuring effective enforcement of existing fisheries laws, promoting sustainable fishing practices, setting size limits for commercial species and establishing an effective fishery catch monitoring program to provide comprehensive data on fishing effort to guide management actions, will be important to help reduce fishing pressure and build resilience of these coral reefs.

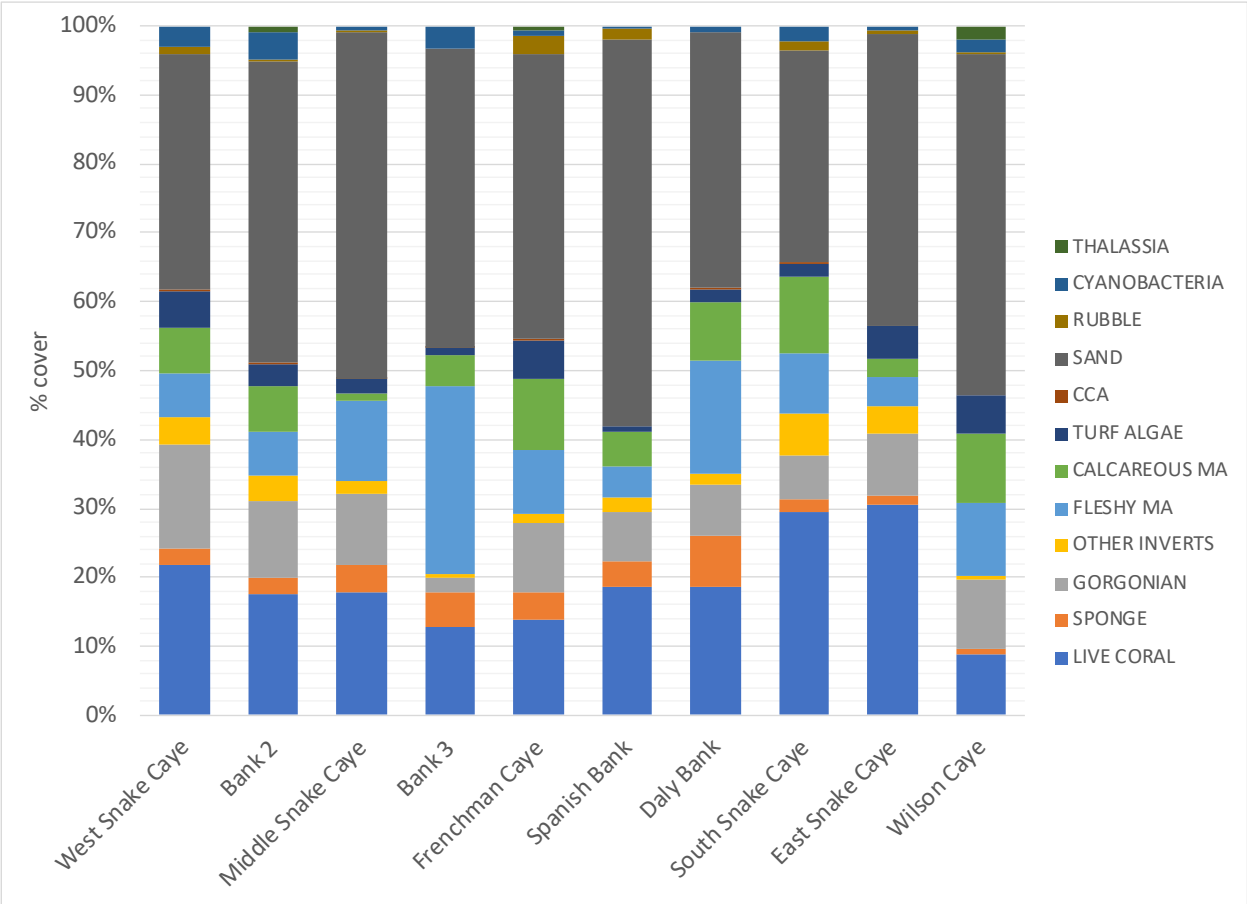

Figure 3 Percent cover of the major benthic groups from ten coral reef sites within the PHMR

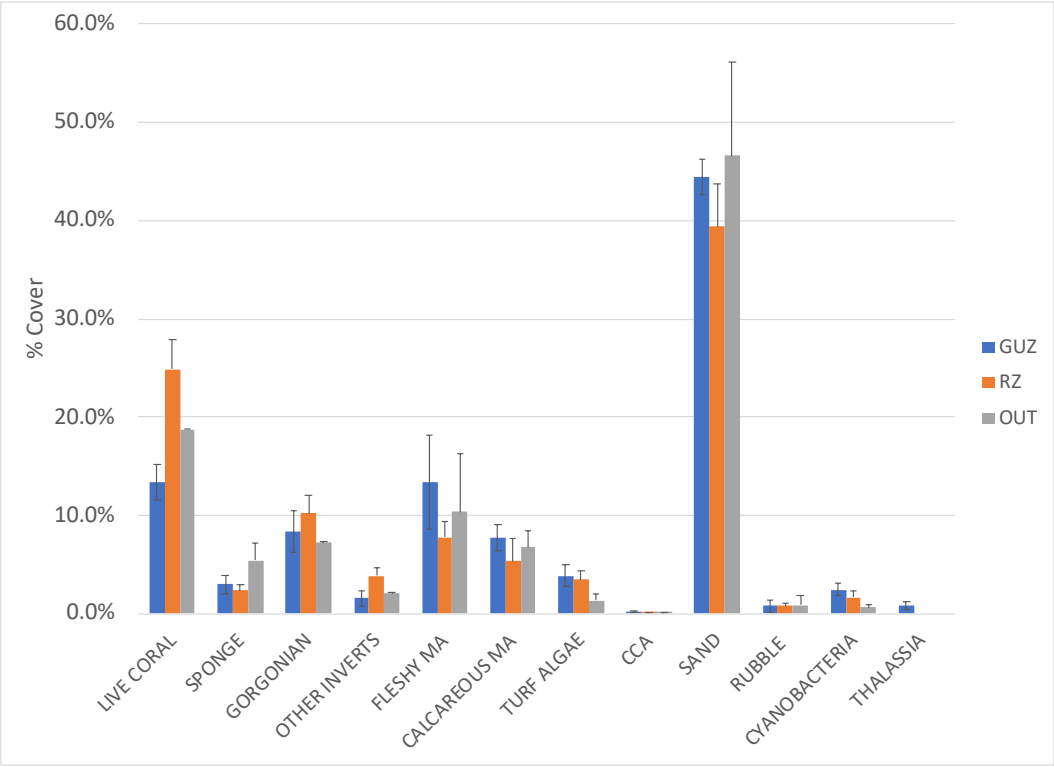

Figure 4 Mean percent cover of the major benthic groups by management zones within the PHMR (GUZ-General Use Zone, RZ-Replenishment Zone, OUT-Outside Reserve) (±Standard Error Bars, S.E)

Table 1 List of coral species encountered from surveys at ten sites within the PHMR

NUMBER	SPECIES	CODE
1	*Acropora cervicornis*	ACER
2	*Agaricia fragilis*	AFRA
3	*Acropora palmata*	APAL
4	*Colpophyllia natans*	CNAT
5	*Dendrogyrus cylindrus*	DCYL
6	*Diploria labyrinthiformis*	DLAB
7	*Dichoenia stokesi*	DSTO
8	*Eusmilia fastigiata*	EFAS
9	*Helioseris cucullata*	HCUC
10	*Millepora alcicornis*	MALC
11	*Montastrea cavernosa*	MCAV
12	*Millepora complanata*	MCOM
13	*Orbicella annularis*	OANN
14	*Orbicella faveolata*	OFAV
15	*Orbicella franksi*	OFRA
16	*Porites astreoides*	PAST
17	*Pseudodiploria clivosa*	PCLI
18	*Porites spp*	PDIG
19	*Porites porites*	PPOR
20	*Pseudodiploria strigosa*	PSTR
21	*Solenastrea buornoni*	SBOU
22	*Stephanocoenia intersepta*	SINT
23	*Siderastrea siderea*	SSID
24	*Undaria tenuifolia*	UTEN
25	*Undaria agaricites*	UAGA

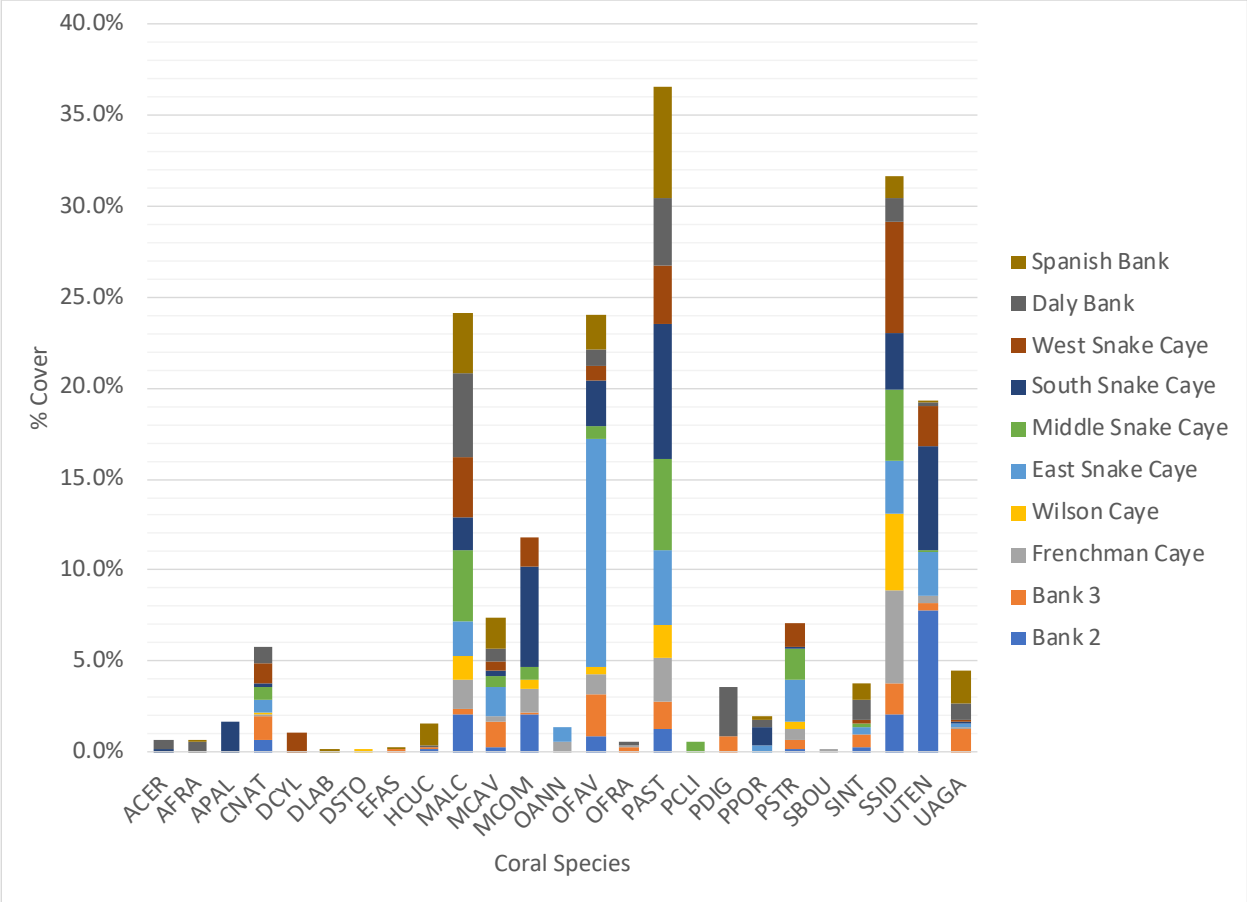

Figure 5 Percent cover of different coral species found from ten sites within the PHMR (±Standard Error Bars, S.E.)

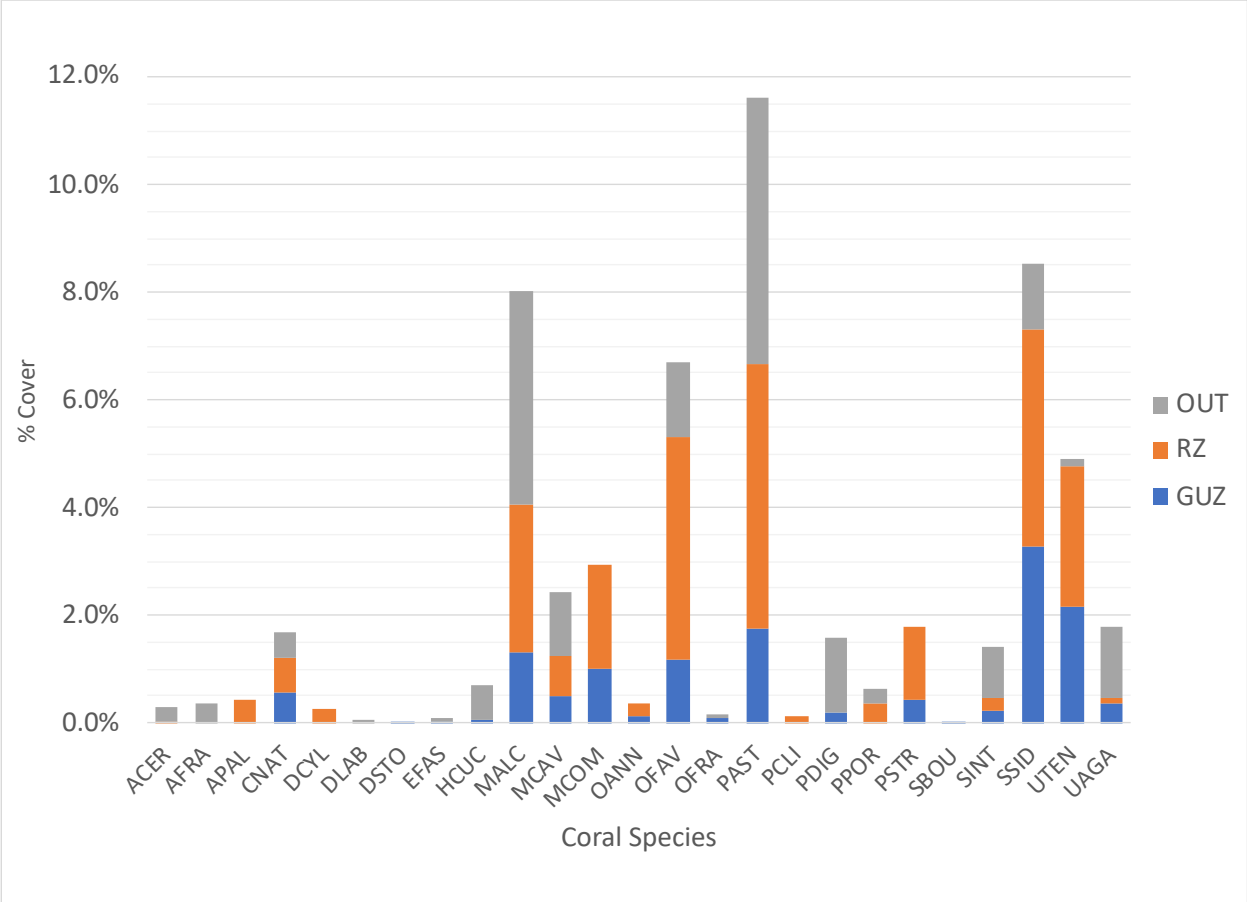

Figure 6 Percent cover of different coral species found across the management zones within the PHMR (GUZ-General Use Zone, RZ-Replenishment Zone, OUT-Outside Reserve) (±Standard Error Bars, S.E.)

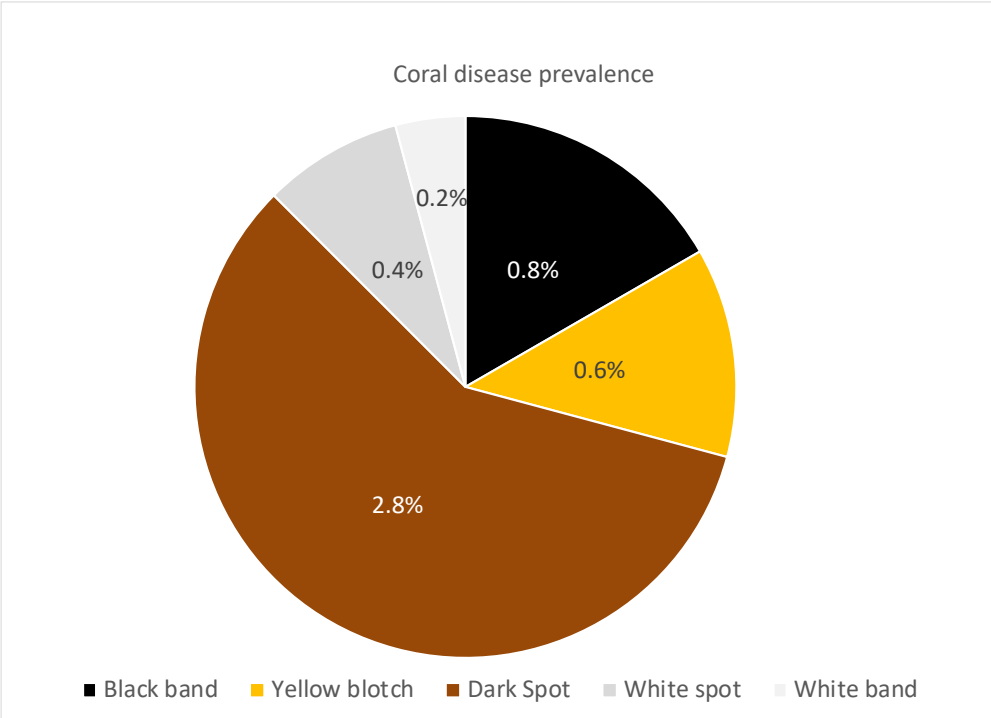

Figure 7 Coral disease prevalence from colonies assessed for coral health at 10 sites within the PHMR, (n=500).

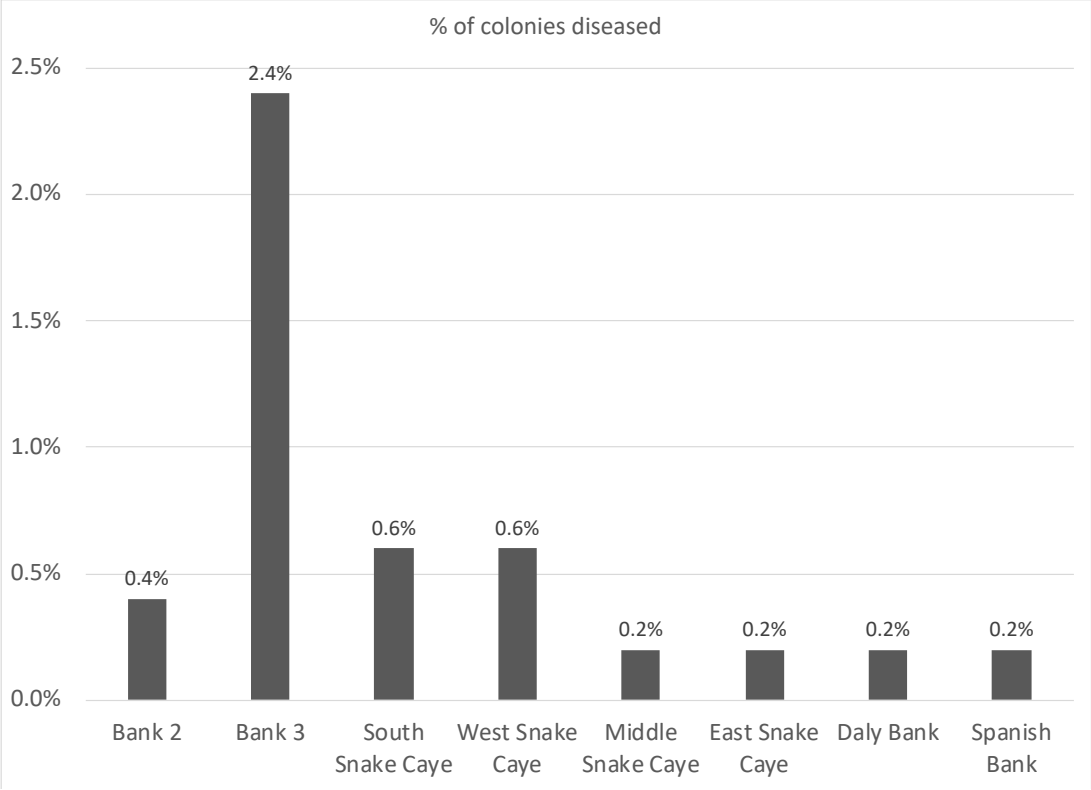

Figure 8 Percent of colonies affected by coral diseases from each site surveyed within the PHMR, (n=500)

Table 2 Percent disease prevalence by disease type for the coral species affected from the PHMR, (n=500)

Disease	Corals	% Disease
Black Band	Siderastrea siderea	0.8%
Dark Spot	Siderastrea siderea	0.4%
	Colpophyllia natans	1.8%
	Diploria labyrinthiformis	0.2%
	Stephanocoenia intercepta	0.4%
White Band	Acropora cervicornis	0.2%
White Spot	Orbicella faveolata	0.4%
Yellow Blotch	Orbicella faveolata	0.4%
	Orbicella franski	0.2%

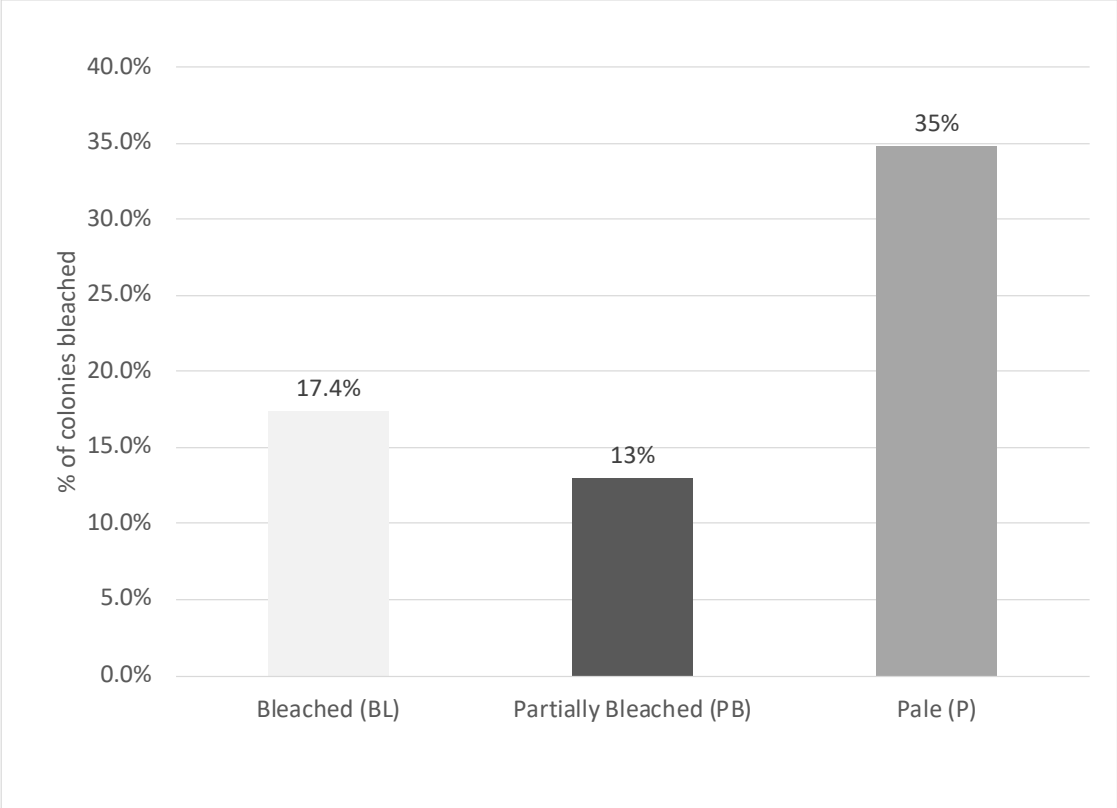

Figure 9 Level of bleaching occurring on colonies surveyed at the ten coral reef sites within the PHMR, (n=500)

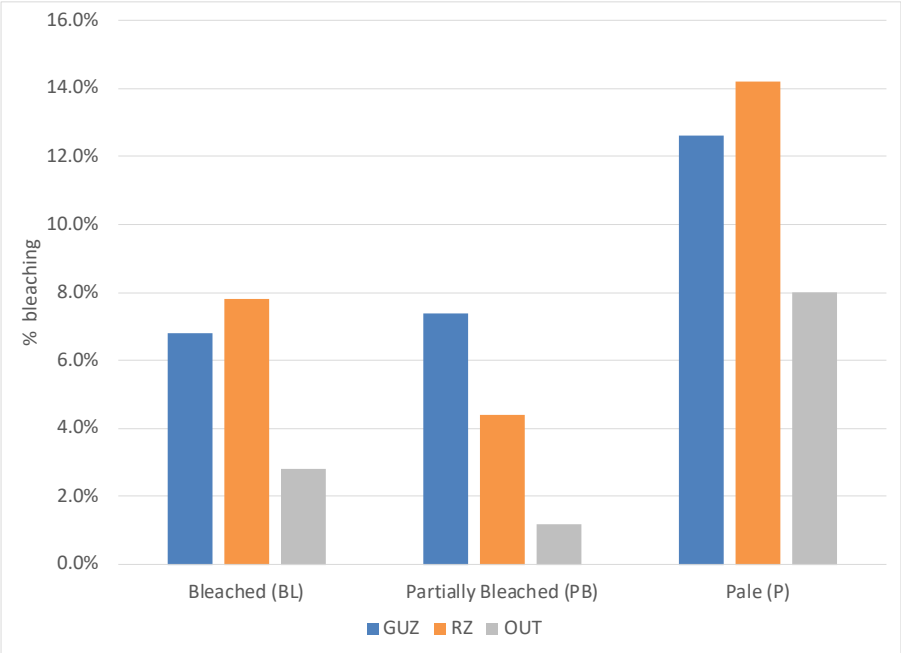

Figure 10 Total bleaching levels across the management zones (GUZ-General Use Zone, RZ-Replenishment Zone, OUT-Outside Reserve) from ten sites within the PHMR, (n=500)

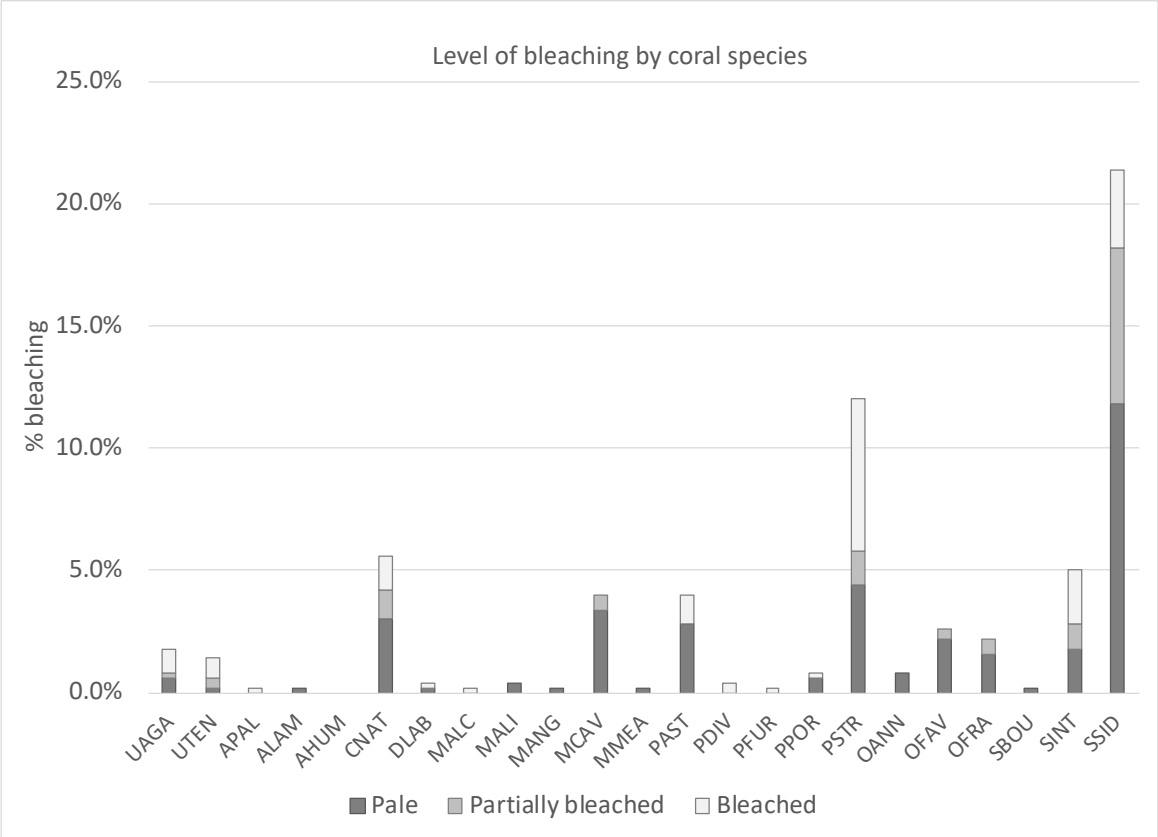

Figure 11 Coral species affected by bleaching: Pale (P), Partially Bleached (PB), Fully Bleached (PB) from ten sites within the PHMR, (n=500)

Table 3 List of fish species belonging to the acanthurid, parrotfish, snapper and grouper families encountered from PHMR coral reef sites

NUMBER	Acanthurids
1	Blue Tang (*Acanthurus coeruleus*)
2	Doctorfish (*Acanthurus chirurgus*)
3	Ocean Surgeonfish (*Acanthurus bahianus*)
	Parrotfishes
4	Greenblotch Parrotfish (*Sparisoma atomarium)*
5	Princess Parrotfish (*Scarus taeniopterus*)
6	Queen Parrotfish (*Scarus vetula*)
7	Rainbow Parrotfish (*Scarus guacamaia*)
8	Redband Parrotfish (*Sparisoma aurofrenatum*)
9	Redtail Parrotfish (*Sparisoma chrysopterum*)
10	Stoplight Parrotfish (*Sparisoma viride*)
11	Striped Parrotfish (*Scarus inserti*)
12	Yellowtail Parrotfish (Redfin Parrotfish) (*Sparisoma rubripinne)*
	Snappers
13	Cubera Snapper (*Lutjanus cyanopterus*)
14	Dog Snapper (*Lutjanus jocu*)
15	Gray Snapper (*Lutjanus griseus*)
16	Lane Snapper (*Lutjanus synagris*)
17	Mahogany Snapper (*Lutjanus mahogani*)
18	Mutton Snapper (*Lutjanus analis)*
19	Schoolmaster (*Lutjanus apodus*)
20	Yellowtail Snapper (*Ocyurus chrysurus*)
	Groupers
21	Graysby (*Cephalopholis cruentata*)
22	Nassau Grouper (*Epinephelus striatus*)
23	Red Hind (*Epinephelus guttatus*)
24	Rock Hind (*Epinephelus adscensionis*)

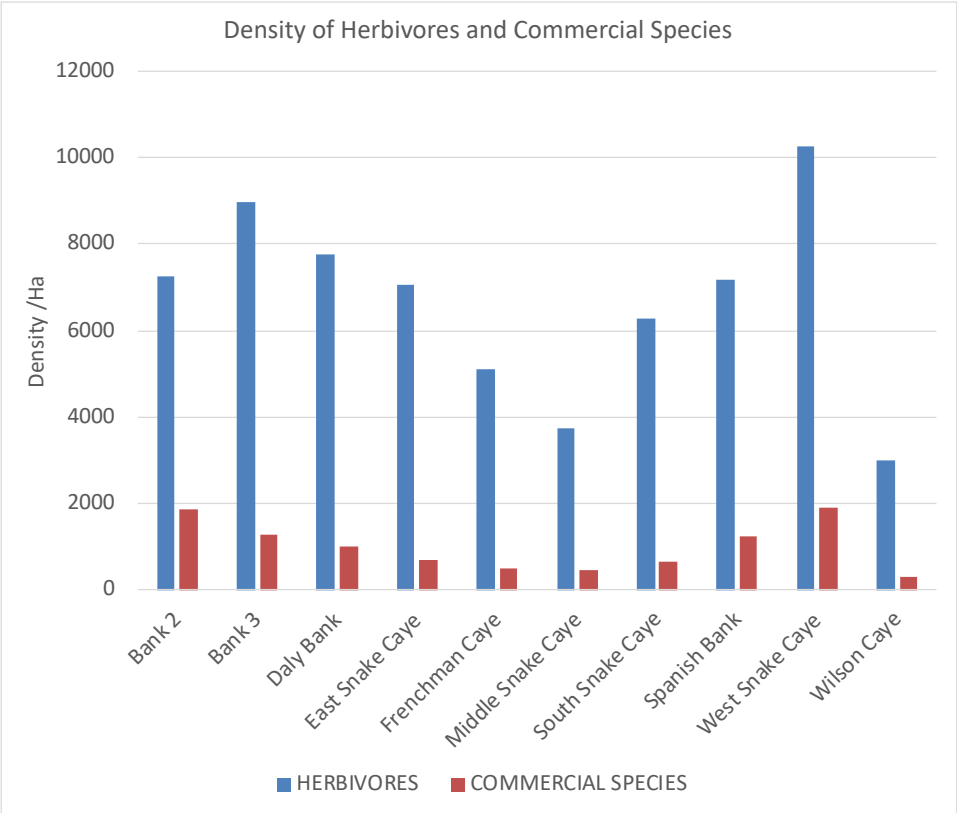

Figure 12 Density (fish per Hectare, Ha) of herbivores (acanthurids and parrotfishes) and commercial species (snappers and groupers) from ten sites within the PHMR

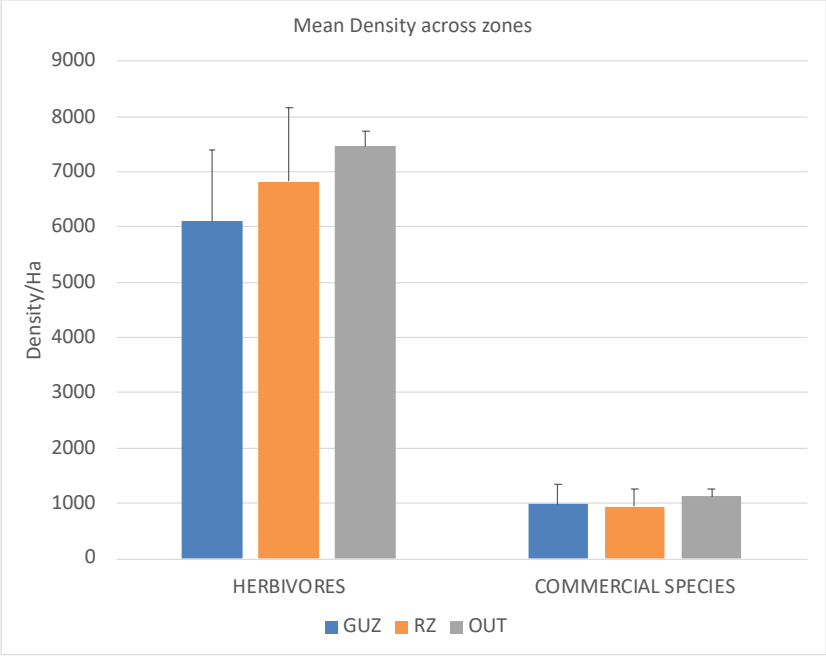

Figure 13 Mean density (fish per hectare, Ha) of herbivores (acanthurids and parrotfishes) and commercial species (snappers and groupers) among the management zones of the PHMR (±Standard Error bars)

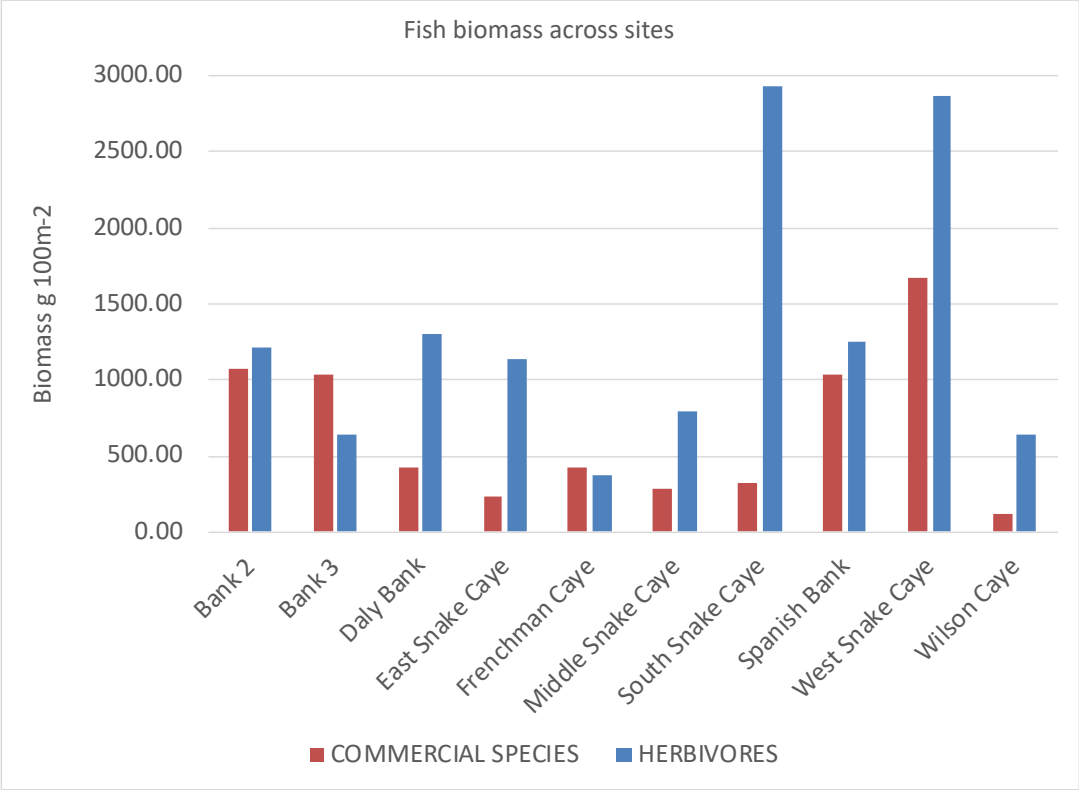

Figure 14 Biomass (g per 100 m^{-2}) of herbivores (acanthurids and parrotfishes) and commercial species (snappers and groupers) from ten sites within the PHMR

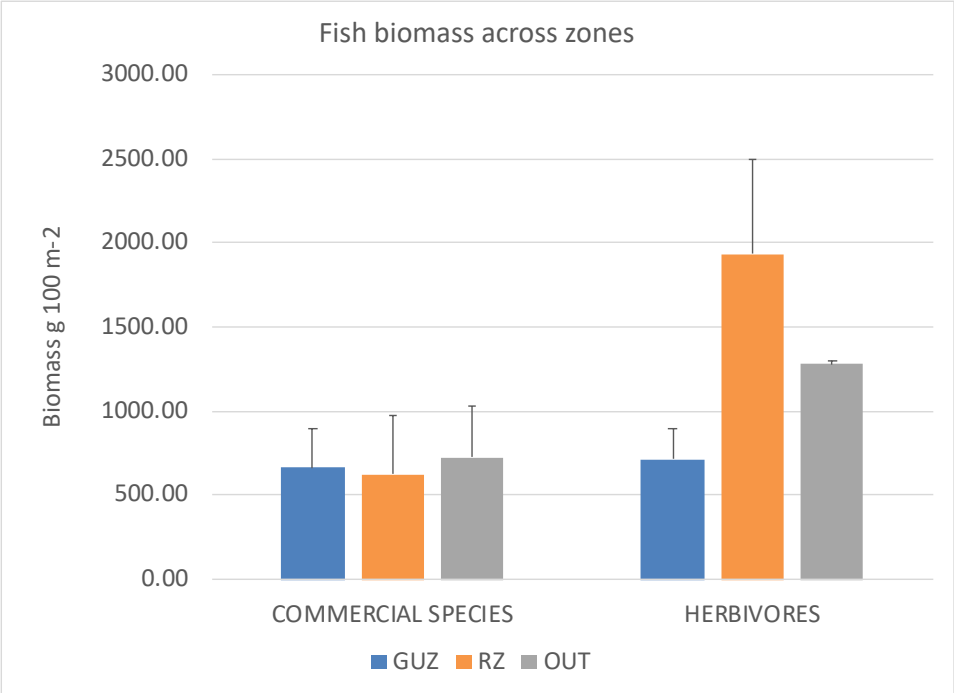

Figure 15 Biomass (g per 100 m^{-2}) of herbivores (acanthurids and parrotfishes) and commercial species (snappers and groupers) among the management zones of the PHMR (±Standard Error bars)

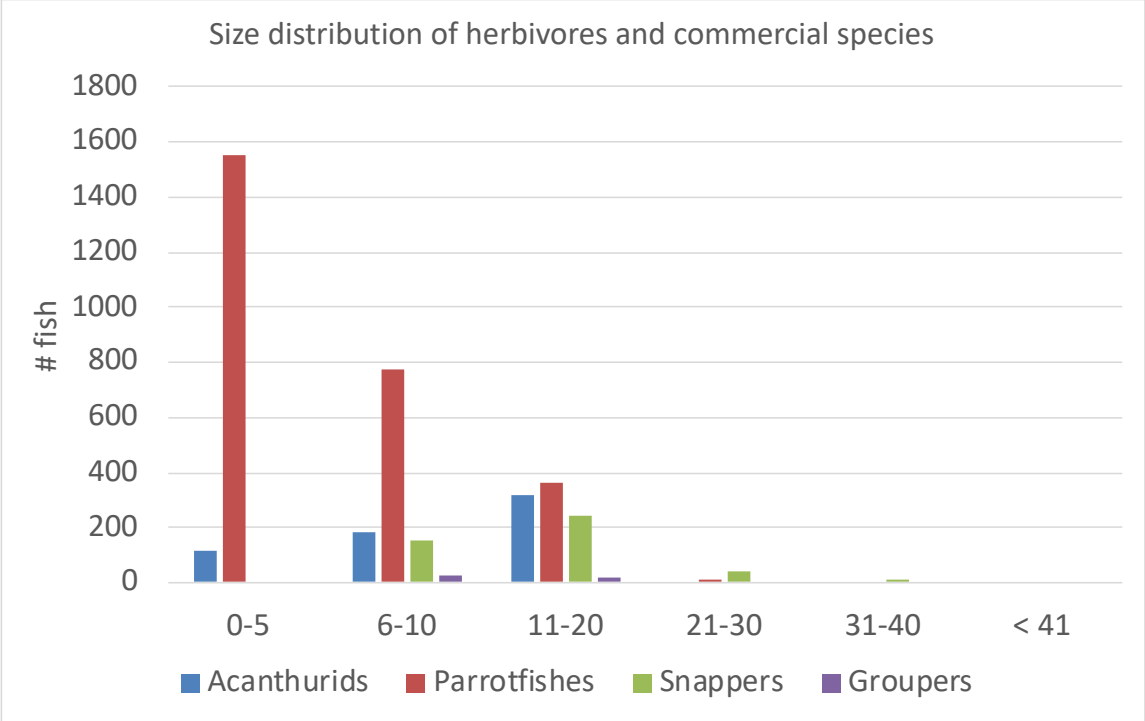

Figure 16 Size distribution of the four major families: acanthurids, parrotfishes, snappers and groupers within the PHMR

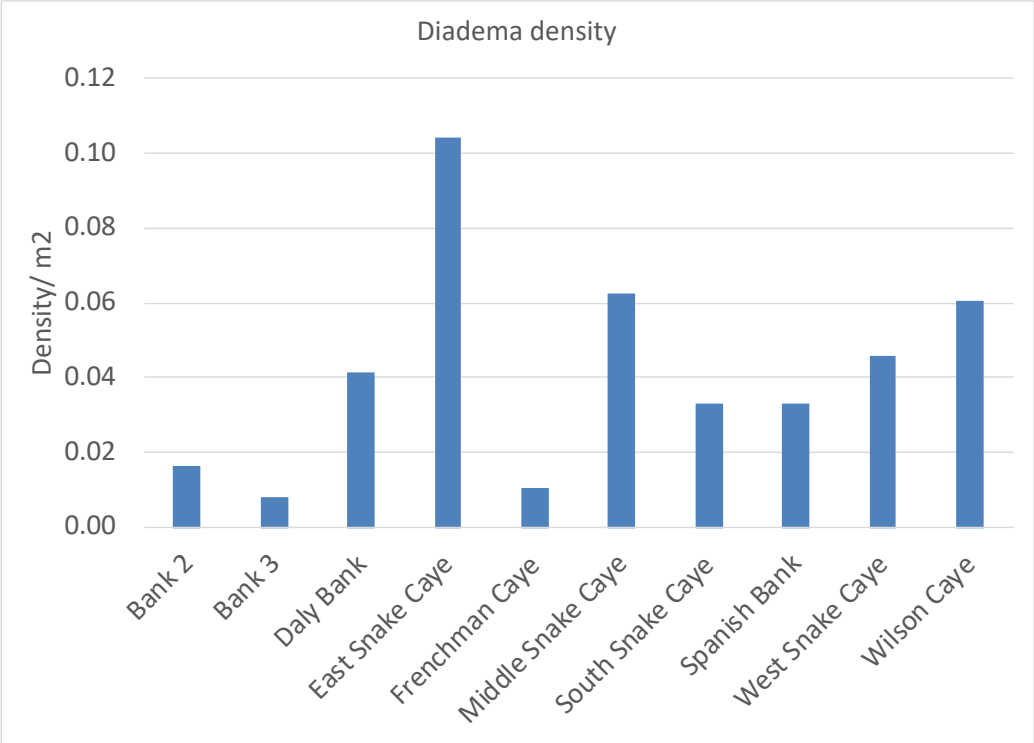

Figure 17 *Diadema antillarum* density (per m^2) from ten sites within the PHMR

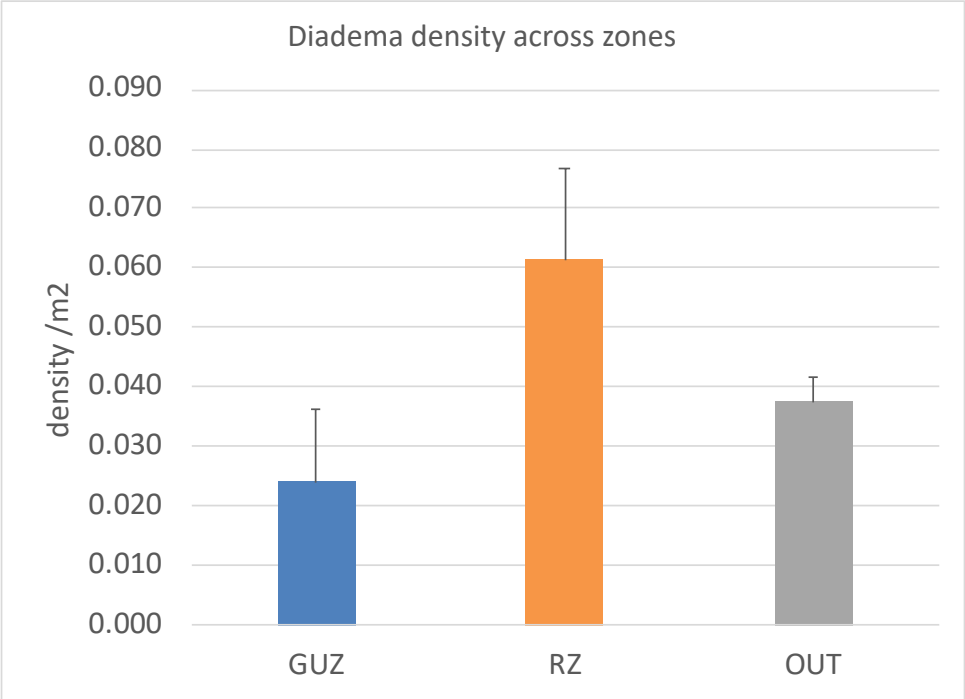

Figure 18 *Diadema antillarum* density (per m^2) across management zones of the PHMR

Threshold Values for Indicators
(ASSIGNED THE HIGHEST RANK MEETING THESE MINIMUM VALUES)

Grade	Coral Cover	Fleshy Macroalgae Cover	Herbivorous Fish Biomass	Commercial Fish Biomass
Very Good	40%	1%	3,290	1,620
Good	20%	5%	2,740	1,210
Fair	10%	12%	1,860	800
Poor	5%	25%	990	390
Critical	<5%	>25%	<990	<390

Biomass in g/100m^2; Cover in percent benthic cover
Fish biomass modifications based on new a and b values; and adjustments for total vs fork length as described in the online supplement (healthyreefs.org)
Grades assigned to the class meeting these minimum values (maximums for macro algae)

Figure 19a Reef Health index for coral and fleshy macroalgae cover, herbivorous and commercial fish biomass (HRI 2018)

INDEX/ INDICATOR	VERY GOOD (5)	GOOD (4)	FAIR(3)	POOR (2)	CRITICAL (1)
Coral Index					
Coral cover (%)	≥40	20.0–39.9	10.0–19.9	5.0–9.9	<5
Coral disease prevalence(%)	<1	1.1–1.9	2.0–3.9	4.0–6.0	>6
Coral recruitment (m^{-2})	≥10	5.0–9.9	3.0–4.9	2–2.9	<2
Reef Biota Index					
Fleshy Macroalgal Index	<10	10–19	20–39	40–59	≥60
Herbivorous fish abundance ($g{\cdot}100m^{-2}$)	≥4800	3600–4799	2400–3599	1200–2399	<1200
Commercial fish abundance ($g{\cdot}100m^{-2}$)	≥2800	2100–2799	1400–2099	700–1399	<700
Diadema abundance (m^{-2})	>2.5 (and <~7)	1.1–2.5	0.5–1.0	0.25–0.49	<0.25

Figure 19b Reef Health index for coral and fleshy macroalgae cover, herbivorous and commercial fish biomass and *Diadema* abundance (HRI 2008)

Table 4 List of Reef Health Indicators and the scores for the PHMR adapted from HRI Reef Index (2018)

PHMR Reef Health Indicators	2020	Rank
Coral Cover	19%	FAIR
Fleshy Macroalgae Cover	10.5%	FAIR
Key Herbivorous Fish (only parrotfish and surgeons)	1316 g 100 m^2	POOR
Key Commercial Fish (only groupers and snappers)	662 g 100 m^2	POOR
Diadema abundance	0.04 m^{-2}	CRITICAL
REEF HEALTH INDEX (RHI)	**2.3**	**POOR**

HRI Index Key	Rank
1 - 1.8	Critical
>1.8 - 2.6	Poor
>2.6 - 3.4	Fair
>3.4 - 4.2	Good
>4.2 – 5.0	V. Good

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6.0 REFERENCES

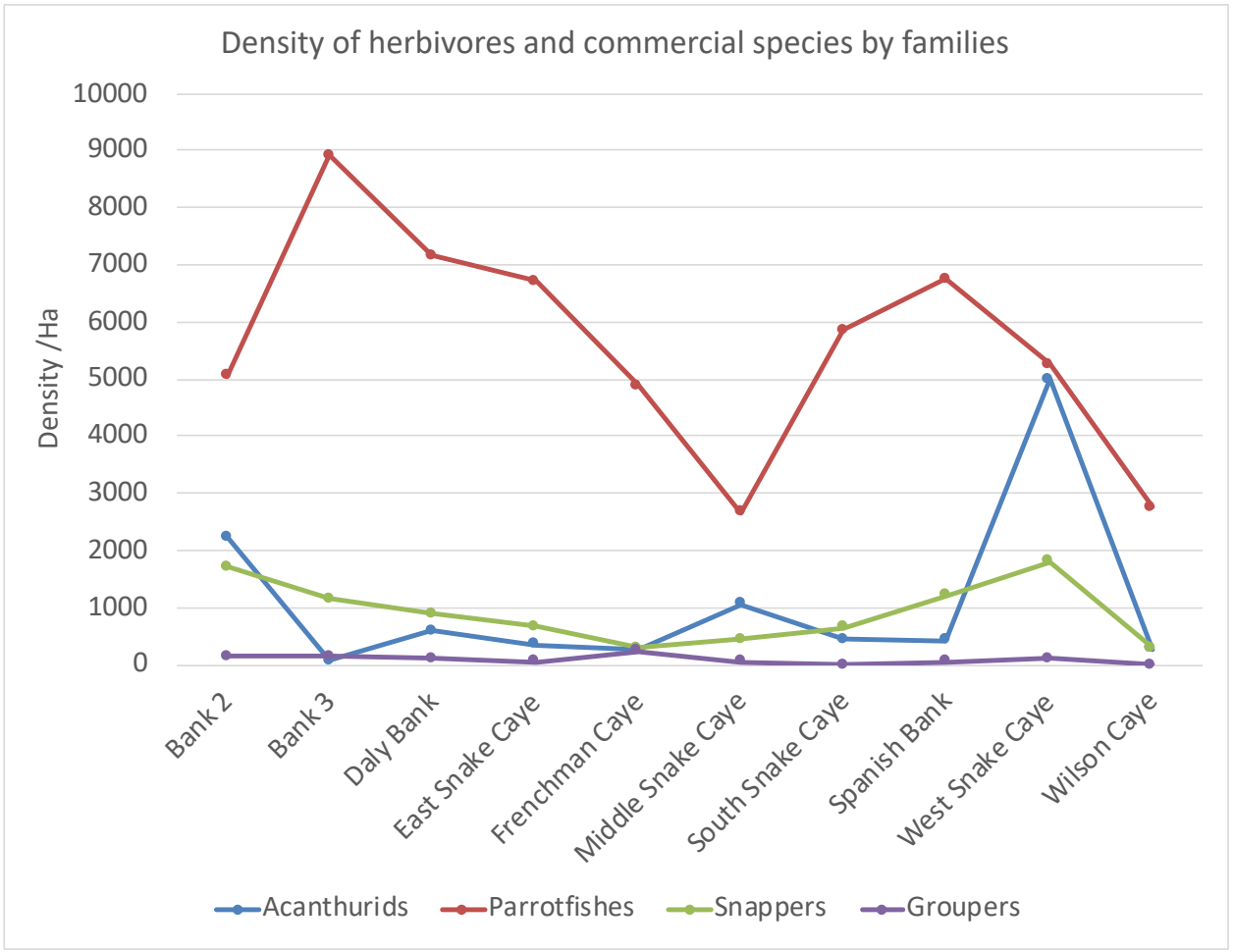
Appendix 1 Percent cover of twelve benthic groups across ten sites, showing mean cover within the PHMR (±Standard Error Bars, S.E)

BENTHIC GROUPS	West Snake Caye	Bank 2	Middle Snak	Bank 3	Frenchman Caye	Spanish Bank	Daly Bank	South Snake Caye	East Snake Caye	Wilson Caye	Means	Standard Error
LIVE CORAL	21.8%	17.6%	17.9%	12.9%	13.9%	18.8%	18.8%	29.4%	30.4%	8.9%	**19.0%**	**2.1%**
SPONGE	2.4%	2.4%	3.9%	4.9%	3.9%	3.6%	7.2%	1.8%	1.4%	0.7%	**3.2%**	**0.6%**
GORGONIAN	15.0%	11.1%	10.4%	2.2%	10.1%	7.1%	7.4%	6.4%	9.2%	10.0%	**8.9%**	**1.1%**
OTHER INVERTS	4.0%	3.8%	1.8%	0.4%	1.4%	2.2%	1.8%	6.0%	3.8%	0.7%	**2.6%**	**0.6%**
FLESHY MA	6.5%	6.3%	11.7%	27.4%	9.3%	4.4%	16.3%	8.8%	4.3%	10.6%	**10.5%**	**2.2%**
CALCAREOUS MA	6.4%	6.7%	1.1%	4.4%	10.1%	5.0%	8.5%	11.3%	2.6%	9.9%	**6.6%**	**1.1%**
TURF ALGAE	5.4%	3.2%	1.9%	1.0%	5.7%	0.7%	1.9%	1.8%	4.7%	5.6%	**3.2%**	**0.6%**
CCA	0.1%	0.3%	0.1%	0.1%	0.3%	0.0%	0.1%	0.1%	0.0%	0.0%	**0.1%**	**0.0%**
SAND	34.2%	43.6%	50.3%	43.5%	41.1%	56.1%	37.1%	30.7%	42.4%	49.6%	**42.8%**	**2.4%**
RUBBLE	1.1%	0.3%	0.1%	0.0%	2.8%	1.8%	0.0%	1.4%	0.6%	0.1%	**0.8%**	**0.3%**
CYANOBACTERIA	3.1%	3.9%	0.7%	3.2%	0.8%	0.3%	1.0%	2.2%	0.7%	1.9%	**1.8%**	**0.4%**
THALASSIA	0.0%	1.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%	1.9%	**0.3%**	**0.2%**

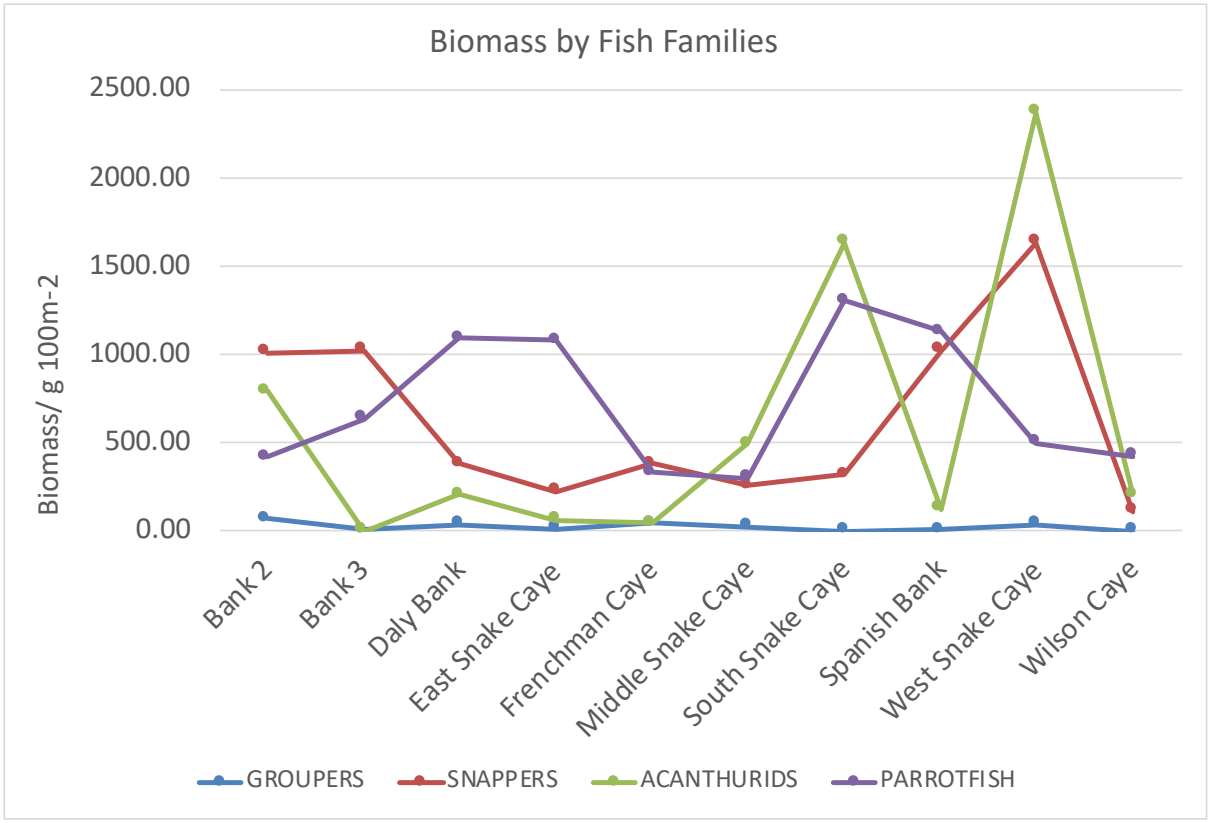
Appendix 2 Percent cover of twelve benthic groups across management zones of the PHMR (GUZ-General Use Zone, RZ-Replenishment Zone, OUT-Outside Reserve) (±Standard Error Bars, S.E)

Mean Cover	LIVE CORAL	SPONGE	GORGONIAN	OTHER INVERTS	FLESHY MA	CALCAREOUS MA	TURF ALGAE	CCA	SAND	RUBBLE	CYANOBACTERIA	THALASSIA
GUZ	13.3%	3.0%	8.4%	1.6%	13.4%	7.8%	3.9%	0.2%	44.4%	0.8%	2.5%	0.9%
RZ	24.9%	2.4%	10.2%	3.9%	7.8%	5.3%	3.5%	0.1%	39.4%	0.8%	1.7%	0.0%
OUT	18.8%	5.4%	7.2%	2.0%	10.3%	6.7%	1.3%	0.1%	46.6%	0.9%	0.6%	0.0%
Standard Error	**LIVE CORAL**	**SPONGE**	**GORGONIAN**	**OTHER INVERTS**	**FLESHY MA**	**CALCAREOUS MA**	**TURF ALGAE**	**CCA**	**SAND**	**RUBBLE**	**CYANOBACTERIA**	**THALASSIA**
GUZ	1.8%	0.9%	2.1%	0.8%	4.8%	1.4%	1.1%	0.1%	1.8%	0.7%	0.7%	0.4%
RZ	3.0%	0.5%	1.8%	0.9%	1.6%	2.3%	0.9%	0.0%	4.4%	0.3%	0.6%	0.0%
OUT	0.0%	1.8%	0.1%	0.2%	5.9%	1.7%	0.6%	0.1%	9.5%	0.9%	0.3%	0.0%

Appendix 3 Density (fish per hectare, Ha) of four major fish groups: acanthurids, parrotfishes, snappers and groupers from ten sites within the PHMR



Appendix 4 Biomass (g per 100 m^{-2}) of four major fish groups: acanthurids, parrotfishes, snappers and groupers from ten sites within the PHMR



Appendix 5 Percent Cover data for major benthic species for 2003-2014 from PHMR (Foley 2016)

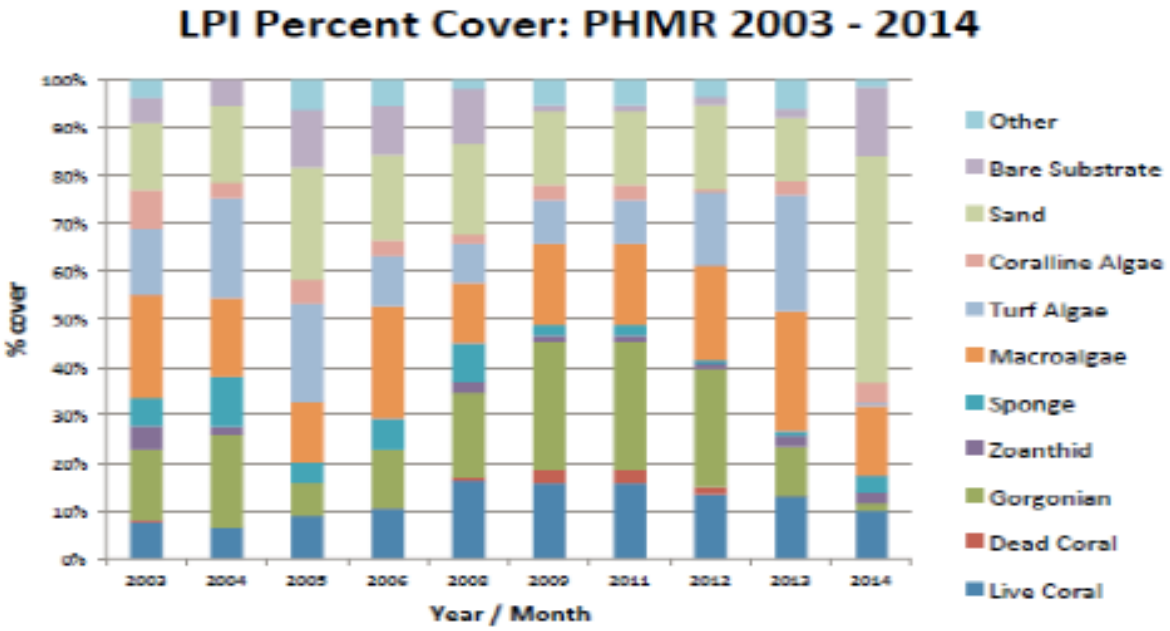


Figure 28: Percentage benthic cover in PHMR monitoring sites, 2003 – 2014 (TIDE data)