BELIZE BEACH CONSERVATION, MARINE CONSERVATION AND DIVING PROGRAMME

Caye Caulker, Belize

BZM Phase 172 Science Report

April 2017 – June 2017

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2. Acknowledgements

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3. Introduction

3.1 Project Background and Location

Belize, formerly known as British Honduras, is a Central American country on the Eastern coast. Belize is bordered by Guatemala from the West and Mexico from the North with the Caribbean Sea to the East. The small mainland area is roughly 290 km long and 110 km wide. The Mesoamerican Reef is the largest barrier reef in the Northern Hemisphere and the second largest barrier reef in the world. Large areas of the barrier reef are protected by the Belize Barrier Reef Reserve System (BBRRS) and have been designated a world heritage site by UNESCO for the past 20 years. Included in the BBRRS are seven marine reserves, 450 cayes and three of the four atolls present: Turneffe Atoll, Glover's Reef Atoll and Lighthouse Reef Atoll (Home to the Great Blue Hole dive site made famous by Jacques Cousteau) (Gibson *et al.* 1998). The Belize Barrier Reef (BBR) is the largest single section of the Mesoamerican Barrier Reef System (MBRS), which extends 998 km from Cancun on the tip of the Yucatan Peninsula up to Honduras making it the second largest barrier reef in the world. Due to its size and multiple areas of marine protection the BBR provides a wealth of biological and geological diversity (Sedburry *et al.* 1996).

The Frontier Belize Marine project (BZM) was established in April 2014 within the Caye Caulker Forest and Marne Reserve (Figure 1). The Frontier Belize camp is located on the North island of Caye Caulker (CC) and hosts Marine Conservation and Diving and Beach Conservation volunteers. CC is a small limestone island located approximately 20 miles North-Northeast of Belize City at 17°44'33N 88°1'30W.

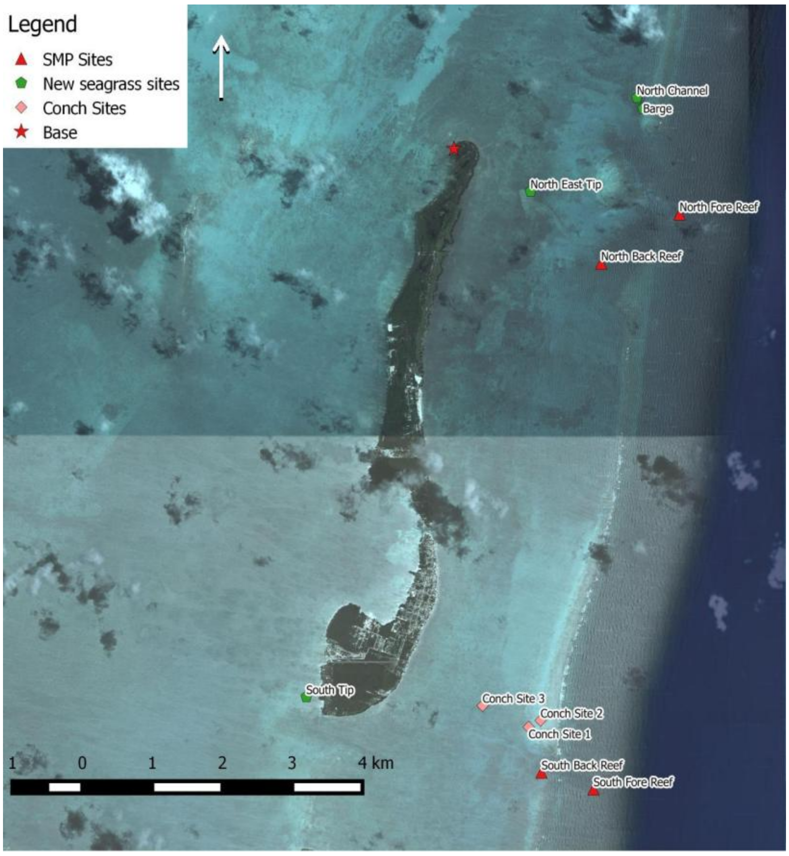

Figure 1: Caye Caulker Island with seagrass survey, conch survey and synoptic monitoring program site locations. The location of the Frontier Belize camp is also noted.

The project aims to conduct long term monitoring of key habitats and species through the assistance of international volunteers and in collaboration with the governmental Belize Forestries Department (BFD) and the non-governmental NGO FAMRACC who co-manage CC's forest and marine reserve. CC spans approximately 8km from North to South and approximately 1.5km East to West at its widest part. The island is separated by a narrow man-made waterway known as the 'Split' creating a North and South divide of the island. A popular myth is that the divide was created by Hurricane Hattie in 1961 (www.cayecaulker.org). The majority of infrastructure is located on the smaller South island which holds a population of approximately 1700 residents and many transient visitors (CZMAI 2016). Many tourists visit the island due to the abundance of exotic flora and fauna, which provides excellent snorkelling, diving and nature trail opportunities. The island is particularly popular for backpackers due to its easy-going reputation, a result of the strong Creole presence and community of Rastafarians.

Unfortunately, as with much of our natural world, the marine life around CC is under threat from many anthropogenic activities (CZMAI 2016), such as climate change, overfishing, tourism and coastal development. Of the many species affected, several are listed as critically endangered such as the Staghorn (*Acropora cerviconis)* and Elkhorn (*Acropora palmata)* corals, and the Hawksbill turtle (*Eretmochelys imbricata).* The Green turtle (*Chelonia mydas)* and Loggerhead turtle (*Caretta caretta)* are also at risk of extinction, currently listed as endangered (IUCN 2014). The West Indian Manatee (*Trichechus manatus),* listed as vulnerable and the common bottlenose dolphin (*Tursiops truncates*), currently listed as least concern can also be found in the waters around CC. While not currently endangered manatees and dolphins are still threatened by many anthropogenic factors (Belize Fisheries 2010, IUCN 2014).

The coastal waters around CC provide rich fishery grounds for two of the most important commercial fisheries in Belize: the Caribbean spiny lobster (*Panulirus argus)* and the queen conch (*Strombus gigas).* Currently there is a strict management regime in place to regulate the fishing seasons for each species which includes catch size and gear restrictions (CZMAI 2016). The hope is that these regulations will maintain healthy and sustainable populations within the area. Size (length and weight) is a useful parameter to control and manage overfishing of conch and lobster populations since the shell of the queen conch and the carapace of the spiny lobster allows for estimation of sexual maturity (Huitric2005).

3.2 Caye Caulker Marine Reserve

A large portion of the waters around CC are under marine spatial management. The Caye Caulker Marine Reserve (CCMR) is 11km long extending to the Belize Barrier Reef from the Northern tip of CC. The CCMR was established in the early 1990s but did not become completely recognised as a marine reserve until 1998 at which point it was included alongside the Caye Caulker Forest Reserve (CCFR) as part of a single management unit. CCMR and CCFR encompass an area of 40 km² and 0.5 km² respectively (CZMAI 2016). This unit was set up with the aim of ensuring protection of the littoral forest, reef lagoon, reef crest and fore reef areas.

CCMR encompasses five ecologically-related but distinct habitats: mangrove forest, littoral forests, lagoon marshlands, seagrass beds and coral reefs. The marine reserve is managed via three regulated zones: The General Use Zone (GUZ) comprises 25 km², the Conservation Zone (CZ) 8.2 km² and the Preservation Zone (PZ) 5.8 km² (Belize Fisheries Department 2010). Both the CZ and PZ are non-extractive and do not allow fishing. However, CZ allows recreational use which primarily consists of snorkelling and diving. PZ does not allow boat traffic or recreational use and is principally set aside for the recovery of overexploited populations of marine life. The GZ permits commercial and sport fishing alongside recreational use. Use of the CCMR is charged at 20 Belize dollars per tourist, locals may use the reserve for free. Outside of CCMR there are no charges to marine users and it is less monitored by the BFD. Despite the strict fishery management practices that are in place, overfishing and illegal fishing is still a major issue in CC and across Belize. As a result many fishermen have reported that their catch per unit effort has decreased noticeably in recent years (CZMAI 2016).

The CCMR is important to the country's economy through the money it generates from tourism, evident by residents of CC being almost entirely dependent upon tourism as a source of income. Furthermore, all users of the marine reserve are charged for the privilege which helps subsidise management of the area. The reserve provides essential ecosystem services, through the reserves protection the habitats of commercially important species are protected, additionally the coral reef and mangroves provide a natural protection for CC from storm damage and wave erosion (Belize Fisheries Department 2010).

Research into the sustainability and effectiveness of the reserve's current management plan is essential for stakeholders involved and currently understudied (Williams and Polunin 1993). Management of the Belize Barrier Reef was originally envisioned through the creation of marine protected areas (MPA); however the influence from land-based activities was not accounted for within these programs. As a result the focus was shifted towards the previously described integrated, multi-sectoral approach currently used in Belize marine reserves (Cho 2005).

The research conducted by Frontier within the CCMR lies within the MBRS and therefore involves methods adapted from the MBRS Synoptic Monitoring Program (SMP), a multi-level methodology designed to monitor changes in ecosystem health for research and management purposes. Standard Frontier methodology is also incorporated to provide an effective and yet reliable way of utilising volunteers as a resource for data collection during surveys.

Surveys carried out as part of BZM include MBRS SMP surveys (fish, benthic, coral colony characterization and invertebrates), conch, lobster, mangrove, seagrass and beach clean surveys. It is important to note that some surveys are seasonally and volunteer dependent.

3.3 Aims of the project

1. To establish new fixed survey sites in addition to the sites suggested and used by the BFD and FAMRACC.
2. Continue to collect data on the health of the coral reef via the MBRS SMP methodology. This currently includes the benthic point intercept transect surveys, coral colony characterisation surveys and the adult/juvenile reef fish surveys.
3. Continue to collect data on the abundance, sex ratios, maturity and size-frequency distributions of the commercially important Caribbean spiny lobster throughout the year, in order to supplement the biannual data collection by the BFD and FAMRACC.
4. Reinstate and establish sites for data collection on the abundance, sex ratios and size-frequency distributions of the commercially important queen conch alongside the BFD and FAMRACC.
5. To continue and improve the current seagrass surveys on species composition, percentage coverage, abundance and health across the four established survey sites.
6. Reinstate the manatee monitoring project during manatee observation season.

7. Continue to build upon new connections with the local community, including local NGO Oceana and the local private school Ocean Academy.

3.4 Training

3.4.1 Science training and volunteer briefings

To achieve the above aims, all volunteers and staff members receive a combination of briefings, science presentations and lectures and practical field training (Table 1) before conducting any marine surveys. For all tests a 95% pass mark is required and in case of any failures, those individuals will have to re-sit a different version of the test. All marine conservation and diving volunteers are PADI scuba trained to at least Advanced Open Water level.

Table 1. Complete list of science lectures, field training lectures, briefings and staff member responsible for training. All training was conducted by both PM, DG and DA.

Lecture/ Presentation/ Test	**Lecturer**
Health and safety and medical presentations and tests	PM/DG
Dangers of the reef presentation	PM
Introductory science presentation for Frontier Belize Project	PM/DG
Introduction to coral reefs presentation	PM
Benthic identification and survey methodology presentation	PM
Coral health presentation	PM
Coral flash, revision slides	PM/DA
Benthic test	PM/DA
In water, practical benthic test	PM/DA
Fish identification presentation	PM/DA
Fish flash, revision slides	PM/DA
Fish families test	PM/DA
Fish ID test	PM/DA
Juveniles and recruits fish ID test	PM/DA
In water, practical fish test	PM/DA
Practice mock survey	PM/DA
Queen conch presentation	PM
Caribbean spiny lobster presentation	PM
Seagrass presentation	PM

3.4.2 Dive Training

All diving volunteers receive training up to PADI Advanced Open Water. PADI dive training is currently outsourced to a local dive company on the South island. This will continue until Frontier is able to offer this training ‘in-house’.

3.4.3 BTEC

No BTECs were conducted during this phase.

4. Research Projects

4.1 SMP Coral Reef Diving Surveys

4.1.1 Introduction

Coral reefs are highly valuable and productive marine ecosystems. They provide essential habitats and feeding grounds for a diverse array of marine fauna such as fin-fish, elasmobranchs, turtles, sea-birds and numerous invertebrates. Coral reefs also provide an array of important ecosystem services, most crucially fish production, but they also generate revenue through tourism and medicinal discoveries and are especially vital to human survival in developing countries (Bryant *et al.* 1998, Costanza *et al.* 2007, Hughes *et al.* 2010). Despite this, coral reefs remain one of the world's most heavily impacted marine ecosystems, due largely to overfishing, habitat destruction, increase in sea surface temperature (SST), coral disease, invasive species and poor land use-practices leading to coastal eutrophication and heavy sediment loading (Harvell *et al.* 2007, Hughes *et al.* 2010). These mostly anthropogenic issues result in the reef ecology being dramatically altered. Coral reefs are affected by both indirect anthropogenic issues such as climate change and directly affected by activities that result in nutrient pollution and sedimentation which enhances algal growth, reducing zooxanthellae photosynthesis efficiency which in turn stresses the mutualistic relationship between the coral and the zooxanthellae (Shutte *et al.* 2010).

In recent years Caribbean coral reefs have experienced more frequent and severe ecological changes due to coral disease, coral bleaching, extreme weather events and human disturbances which result in significant coral damage and death. The region was devastated by hurricanes in 2000, 2001, 2002, destroying many coral formations with recorded losses of up to 75% in some parts of Belize (Almada-Villela *et al*. 2002). A point of note is that these smaller hurricanes all occurred soon after Hurricane Mitch, a category 5 storm, and the 1998 extreme bleaching event which exacerbated the destruction caused by Hurricane Mitch. Many observations of widespread bleaching within reefs of the tropics were documented in the summer and autumn of 1998, which was caused by unprecedented elevations in SST due primarily to a severe El Nino Southern Oscillation (ENSO) and likely enhanced by global warming resulting in a 48% reduction in live coral coverage (Goreau *et al.* 2001). All habitats along the BBR experience bleaching as a result of these thermal anomalies (Mumby 1999). By 1999 some fore-reef habitats demonstrated signs of recovery, while coral populations amongst the sheltered lagoons of the back reef displayed reduced coral cover, low coral recruitment and little indication of recovery (Aronson *et al*. 2002). Aronson *et al.* (2002) determined that during this prolonged period of elevated sea surface temperatures, anomalies peaked at 4°C above the local hotspot threshold, which is an extraordinary increase compared to previous years sea surface temperature anomaly spike of 1°C.

Currently coastal and marine activities in the CC area are relatively minor; however this is changing with the rapidly growing tourism industry (Almada-Villela *et al.* 2002, CZMAI 2016). An increase in tourist numbers has caused an increase in waste, plastic pollution, boat traffic, coastal development and greater human interaction with the marine wildlife. These activities have promoted algal growth on the reefs leading to a decline in coral cover (McClanahan *et al.* 2001, Schutte *et al.* 2010). This has resulted in negative implications for fish assemblages which are directly associated with coral reef health. Promisingly Belize has the highest fish species richness in the MBRS region, with over 320 recognised fish species but with fishing efforts in the region intensifying this richness is under threat. This is largely due to changes to spawning aggregations; spawning location depends on the recognisable characteristics of cayes and reefs, characteristics which may be lost with overfishing and other human activities (FAO 2003). A documented example of this is the Nassau grouper (*Epinephalus striatus)* which during the full moons of December and January forms spawning aggregations annually in the same location (GREI 2002). This allows fishermen to become very familiar with these cycles, leading to overfishing of this species. This species is currently listed as endangered on the IUCN Red List of Threatened Species, despite its protected status in Belize it is seldom observed within the reefs of the CCMR (Almada-Villela *et al*. 2002). Hughes *et al.* (2007) observed that the exclusion of large predatory and herbivorous fish, such as the Nassau grouper, led to a dramatic explosion of macro-algae which in turn suppressed the fecundity, recruitment and survival of coral and ultimately reduced total coral cover within the reef systems. Consequently, the coordination and control of fish stocks is one of the primary components in preventing phase shifts and managing reef resilience.

Disturbances to the invertebrate community have also profoundly influenced reef health on the BBR. Diseases, potentially caused by water-borne pathogens, have dramatically reduced populations of the herbivorous sea urchin *Diadema antillarum* in the Caribbean which resulted in the increased abundance of macro-algae and reduced coral cover (Harbone *et al.* 2009). Many other invertebrate species play important roles in reducing macro-algae cover by grazing on the biofilms on substrate suitable for hard cover (Klumpp & Pulfrich 1989). Furthermore, it is important to monitor the abundance and diversity of invertebrates which are prone to overfishing, such as the commercially important queen conch (*Strombus* gigas) and Caribbean spiny lobster (*Panulirus argus*) (Theile 2002; Perez & Garcia 2012).

The MBRS SMP was designed to standardise data collection and management for ecosystem monitoring. It aims to monitor changes in ecosystem health within priority protected areas, enabling quicker and more effective responses to changes in reef health (Gomez 2004). Ultimately the utilisation of this protocol coupled with the long-term monitoring work conducted by Frontier will provide much needed baseline data on the health of the BBR marine ecosystem. Frontier currently conducts SMP surveys in 4 locations within the CCMR; however due to weather conditions the Fore-reef sites are rarely sampled. The back-reef survey sites are both shallow patch-reefs located approximately 3.2 km apart. Due to the shallowness of the survey sites coral is likely to experience relatively higher wave action and well as strong currents from the nearby channels: South Channel and North Channel (Komyakova *et al.* 2013). In areas of high water movement the slower growing massive corals such as *Orbicella annularis* thrive particularly well as they are able to withstand moderate wave action, the larger they grow the more stable they become. In contrast branching colonies such as *Acropora cervicornis* and *Acropora palmata* grow much faster but as result become increasingly unstable as the small area attached to the substratum has a heavier load to support. In areas such as the back-reef survey sites where wave action is higher this structural instability is put under greater pressure often resulting in branches snapping off (Barnes & Hughes. 1999). In the very high wave action areas the community diversity should be low as few species are able to tolerate extreme conditions. Additionally, low wave action areas also exhibit lower species diversity but this is due to competitive dominants excluding other species. Ideally surveys should take place in an area of intermediate wave action where neither excess disturbance nor competition exerts a dominating influence on species diversity (Cornell 1978).

4.1.3 Methodology

4.1.3.1 Survey Area

Site 1: North Back-Reef (NB): (16Q 0393822 UTM 1966284) a shallow patch reef on the inside of the MBRS located between the reef crest and a lagoon, with a maximum depth of approximately 5m and within the General Use Zone of CCMR. Current flow and wave energy are generally moderate to high on days with greater wind force.

Site 2: South Back Border (SBB): A relatively shallow patch reef with a maximum depth of 6m, located just south of the conservation buoy this site marks the start of the General Use Zone.

Site 3: South Back-reef (SB): (16Q 0392922 UTM 1959724) a shallow patch reef on the inside of the MBRS which is situated between the reef crest and the lagoon, with a maximum depth of approximately 5m and located in the Conservation Zone of CCMR. Due to moderately low current flow this site is frequented regularly by tour operators and dive companies. Nicknamed ‘the island’.

Site 4: South Back Shark and Ray (SBSR): A shallow, 1-2m, tourist hotspot on the reef. The site is located within in the Conservation Zone but is heavily visited by tour boats daily. The shallowness of the reef makes it an easy target for careless snorkelers.

Site 5: North Fore-reef (NF): (16Q 0394839 UTM 1966980) a barrier reef on the inside of the MBRS with a maximum depth of approximately 15m in the General Use Zone of CCMR. This site is only accessible on very calm days, when the wind force and sea state is low.

Site 6: South Fore-reef (SF): (16Q 0393628 UTM 1959502) A relatively deep reef on the outside of the MBRS with a maximum depth of approximately 20m in the General Use Zone of CCMR. This reef is subject to moderate levels of tourist activity, predominantly in the form of PADI dive training and recreational scuba diving. This site is only accessible on very calm days, when the wind force and sea state is low.

4.1.3.2 Experiments and Survey Protocol

The protocol for SMP surveys is adopted from the MBRS SMP as the standard methodology used to monitor coral reefs at established sites (Almada-Villela et al., 2003). Survey methods were adapted for the BFD, FAMRACC and FRONTIER. For each survey a minimum of three divers was required and each had a specific role for which they had undergone the required training. At each survey site 5 replicates were conducted, roughly 5m apart.

4.1.3.3 Physical Surveyor

A physical surveyor collected coral community characterisation data. Prior to each transect the following information was recorded: date and site name and/or GPS coordinates. A 30m transect line was laid haphazardly within the general confines of the site to avoid choosing places due to any sort of bias. The transect line was weighted at one end with a 2lb dive weight so it remained in place. With the aid of an underwater compass the transect line was laid parallel to the reef in a straight line. Coral measurements began at the first colony located directly beneath the transect line which was at least 10cm in diameter. For each colony surveyed the following information was recorded, the species of coral, diameter and maximum height of the colony. Percentage of dead coral along with the presence of any diseases and/or bleached tissues was also estimated (Table 2). These measurements were repeated for the rest of the transect until at least 10 coral colonies had been sampled at each site.

Table 2: Definitions of the codes used by the physical surveyor when identifying coral diseases or bleaching.

Disease Codes	**Bleaching Codes**
BB= Black Band	PB= Partially bleached
WB= White Band	BL= Bleached, fully-bleached
RB= Red Band	P= Pale, signs of colour loss
YB= Yellow Band	
WP= White Plague	
DS= Darkspot	

4.1.3.4 Fish Surveyor

The Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol for coral reef fishes has been adopted by the MBRS SMP as the standard methodology for assessing overall fish community composition. The first method involved belt transects, it is designed to measure the density and sizes of fish species. A fish surveyor swam alongside the physical surveyor whilst the transect line was reeled out, so as to minimise any changes in depth. While the full 30m transect line was laid out the surveyor counted and recorded the fish species observed within a 2m wide visual estimate (1m either side of the line), counting while deploying minimizes disturbance to the fishes prior to their being counted. The size of each fish was estimated by assigning them to the following size categories (<5, 5-15, 16-30, 31-40, >40cm). A two minute pause was taken once the surveyor reached the end of the transect line before the surveyor returned along the line looking for any additional recruits (only during summer months) (Almada-Villela *et al.* 2003). On the return journey the surveyor swam along the 30m transect recording only selected juvenile fish, fish species <5cm and *Diadema sp.* Sea urchins. The latter was recorded as part of the fish survey whenever an Invertebrate surveyor was not present.

4.1.3.5 Benthic Surveyor

A benthic surveyor swam the 30m transect line to identify and count the benthos every 25cm, providing 120 records of data. Substratum percentage coverage was calculated from the data as (#records/120) * 100. SMP target benthos includes coralline algae (code=COR), turf algae (TURF), target macro algae species, sponges (SPN), gorgonians (GG) and target stony corals (see appendix for full species list). Any abiotic substrate including sand (SN), bare rock (BR) and dead coral (DC) was also recorded.

4.1.3.6 Roving Diver Surveys

The Roving Diver Survey technique is the second AGRRA fish surveying method, it does not involve transects and is designed to give information on species composition and diversity with crude information on abundance. The roving diver survey is visual survey method; divers swam for 30 minutes at each survey site (within the same general area as the belt transects) and recorded every observed fish or coral species. The objective is to find the maximum number of species within 30 minutes, an estimation of the fish or coral abundance and diversity was estimated from the data collected which provided a good idea of the species richness of each survey site.

4.1.3.7 Coral Abbreviations

All target coral species are abbreviated from their scientific names as per Atlantic and Gulf Rapid Reef Assessment (AGRRA), where the first letter of the genus is the first letter in the abbreviation and the last three letters of the abbreviation are from the first three letters of the species. For example: lettuce coral, *Agaricia agaricites*= AAGA. For a full list of target corals and their abbreviations see appendix 1.

4.1.4 Results

4.1.4.1 Coral Results

For South Back (SB) survey site there are currently 2 full PIT surveys, 1 completed in Phase 171 and 1 from 172. SB PIT provided n = 1200 points of data, 600 during each survey.

The North Back (NB) has been 1 full PIT conducted during phase 172. NB PIT provided n = 600 points of data. In addition 1 PIT survey was conducted at South Back Shark and Ray (SBSR) during phase 172 providing n= 600 PIT of data and 2 PIT surveys were conducted at the South Back Border, within the General Use Zone, providing n=1200 PIT of data. CZ and GUZ therefore have 1800 PIT of data each. Fore Reef surveys are incomplete due to adverse weather conditions and limited volunteer's numbers during the beginning of BZM 172. Coral community composition surveys were not completed in BZM 172 but should be reintroduced in BZM 173.

4.1.4.2 Hermatypic (hard corals)

Across the two survey zones, general use and conservation a total of 1618 hard corals were counted. The CZ boasted considerably more hard corals, 987 than the GUZ, 631.

In both zones the most dominant single hard coral species was OANN (*Orbicella annularis*) which exhibited similar abundances in both the conservation and general use zone, making up almost 18% of coral coverage in the GUZ and almost 17% in the CZ. Throughout the other species abundance was relatively low with higher abundances of AAGA and PPOR compared to other species. However the CZ exhibited far higher abundances of CNAT than the General Use Zone, with CNAT making up 13% of all species in the CZ while in the GUZ only 1% of species were CNAT (Fig.2).

As only one data set has been collected for BZM 172 it would be unreliable to make statistical comparisons at this time, further repeats of the transects are required, statistical analysis may be possible in BZM 173 or BZM 174 when a complete data set has been collected.

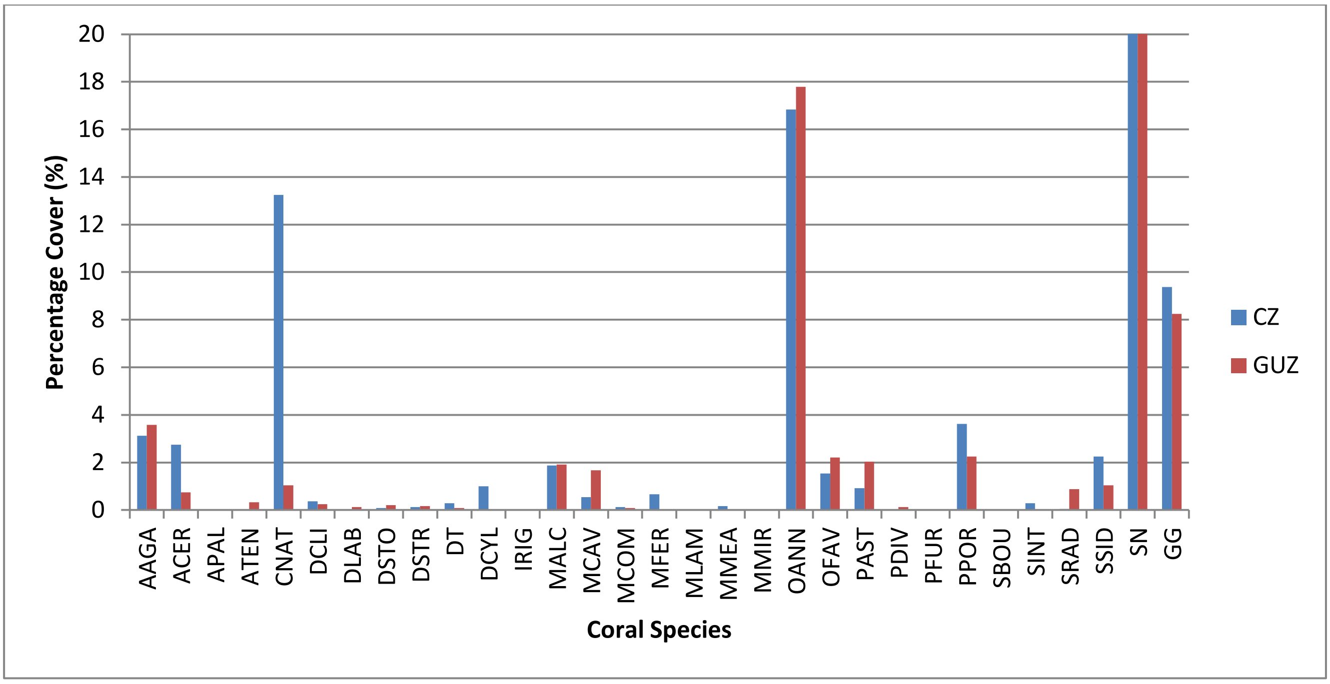

Figure 2: The frequency data from the Conservation Zone (SB and SBSR) (n= 1800 points) and the frequency data from the General Use Zone (NB and SBB) (n= 1800 points).

4.1.4.3 Acropora sp. Abundance

One of the most threatened and important hermatypic corals in the Caribbean belong to the genus *Acropora*. *Acropora cervicornis* and *Acropora palmata* (codes: ACER; APAL), which were once the dominant reef-building corals in the Caribbean (Young *et al.* 2012). In all, ACER only counted for 3% of coral coverage in the CZ, while in the GUZ ACER made up an abundance of less than 1%. APAL was counted 0 times at CZ site and 0 times at the GUZ site, giving a coverage of 0%.

4.1.4.4 Fish Results

South Back, located in the Conservation zone had the higher abundance of fish of the two sites studied with 257 fish counted in the CZ and 118 counted in the GUZ, however more species were counted at the GUZ with a total of 51 species compared to 46 at the CZ.

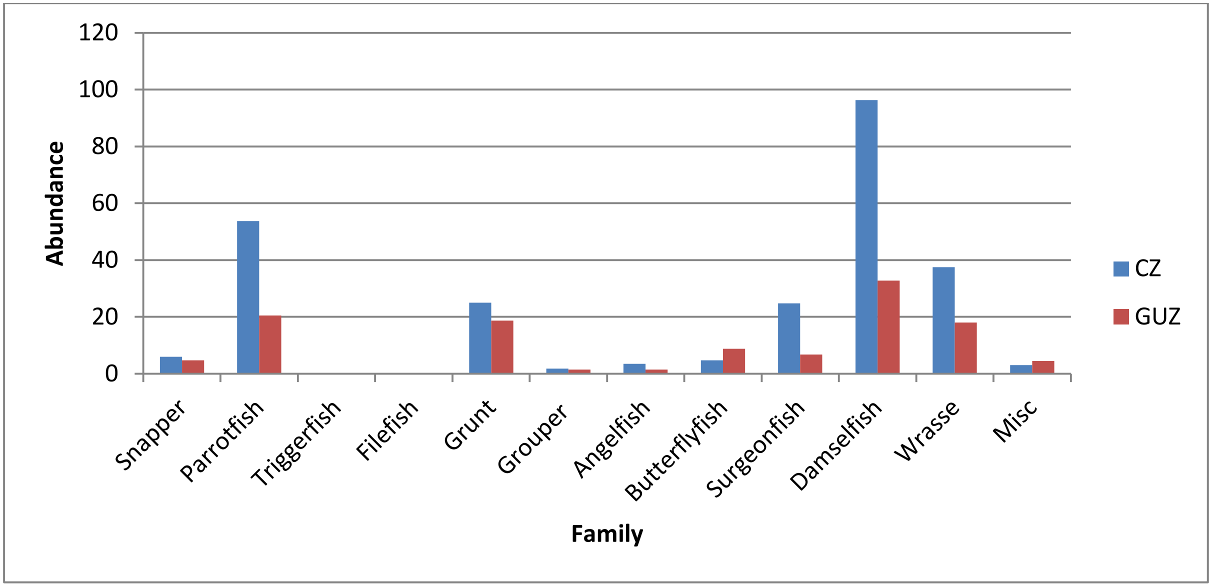

Figure 3: The total abundance of each fish family in the Conservation Zone (SB and SBSR) and the total abundance of each fish family at in the General Use Zone (SBB and NB)

Damselfish made up the highest percentage of fish for both sites with 96 counts (38%) in the CZ and 33 counts (27%) in the GUZ zone. Parrotfish were the second most dominant family for both sites comprising 21% of fish count in the CZ and 17% in the GUZ, the most abundant single species at both sites was the striped parrotfish.

4.1.4.5 Fish Roving Diver Survey Results

The results of a t-test on the number of fish in the conservation zone and the general use zone showed there to be a significant difference between the number of fish present ($t= 4.93$, $df = 161$, $p<0.01$) with 111 fish observed in the conservation zone and only 52 in the General Use Zone. Statistical analysis of species richness was not possible because this is the first time the roving diver survey has been used thus previous data is non-existent. Despite this, 22 fish species were observed in the conservation zone whereas 15 were observed in the general use zone which may indicate the conservation zone has higher species richness than the general use zone. The fish most observed was the sharpnose pufferfish (*Cathigaster valentini*) which during the months of July to October was seen on every dive in all locations, additionally due to the poisonous nature of the pufferfish they have no known predators and do not swim away from surveyors unlike other fish which may be missed because of this, the high abundance of the sharpnose pufferfish meant the most observed fish family was pufferfish, the second most abundant fish family was the parrotfish.

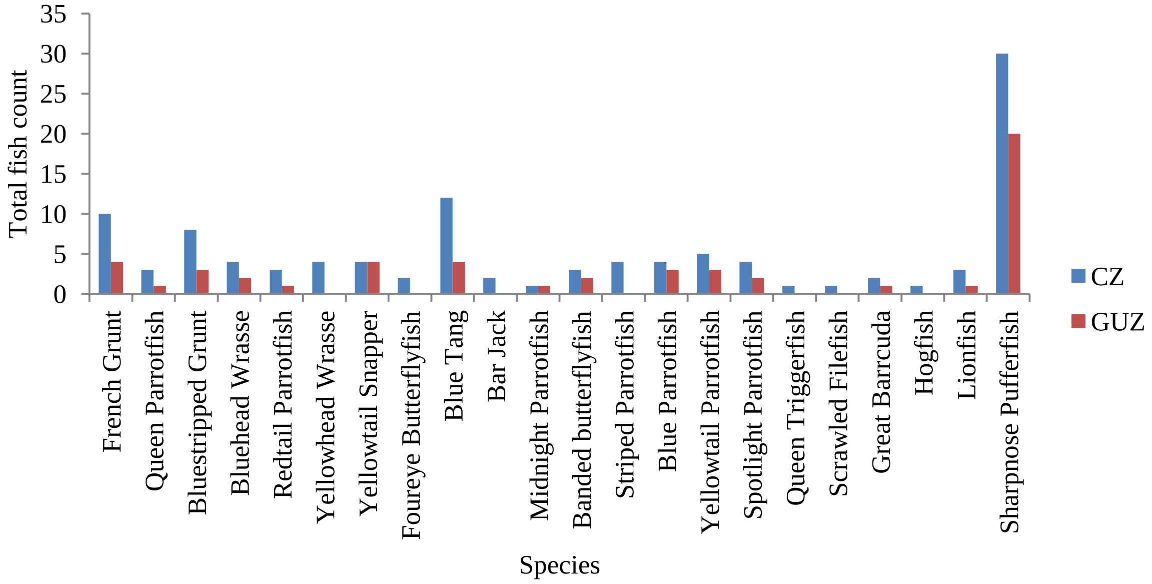

Figure 4: Total fish count during the roving diver surveys within the conservation and general use zone, 111 fish were observed in the CZ and 52 in the GUZ. The sharpnose pufferfish was the most abundant fish recorded.

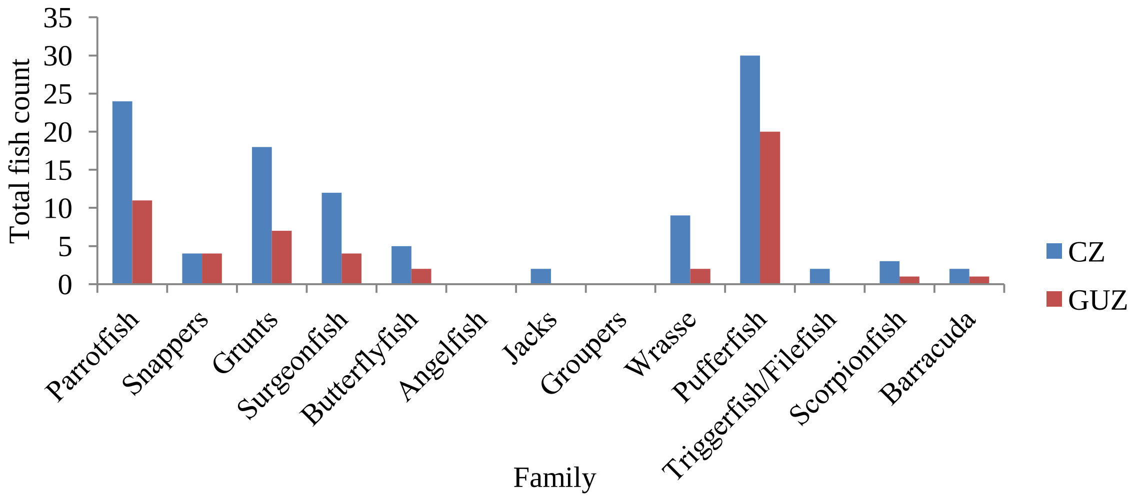

Figure5: Fish family comparison between the CZ and GUZ, the pufferfish family was the most abundant in both zones with parrotfish the second most abundant.

4.1.4.6 Coral Roving Diver Survey Results

The t-test results showed no significant difference (t= 0.97, df = 542, p= 0.169) between the number of coral colonies seen within the conservation zone (289) and the general use zone (255). There was also little difference in the number of species seen with 18 observed within the conservation zone and 16 observed within the general use zone. A statistical analysis of species richness is not possible until further surveys have been completed. The most abundant coral species at both sites was OANN with the second most abundant being UTEN. ACER and UAGA were also in high abundance at both sites. UHUM and DLAB were only observed within the conservation zone giving this zone a slightly higher number of species observed than the general use zone, however very few of these species were observed (<10 colonies). It is possible they were simply missed during the general use zone surveys.

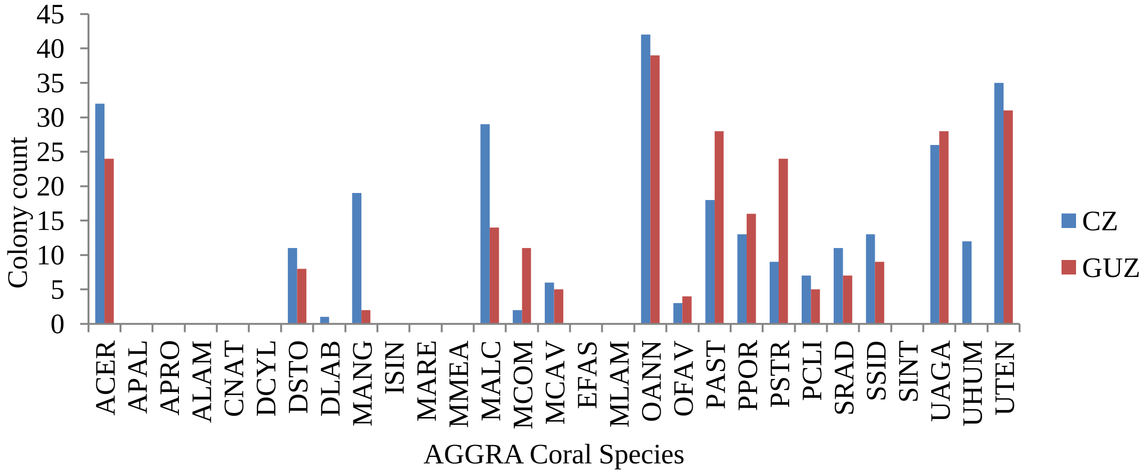

Figure 6: Coral species comparison between the CZ and GUZ, the most abundant coral in both zones was OANN with two more species of coral found in the CZ. There was little difference in overall colony count between both zones.

4.1.5 Discussion

4.1.5.1 Coral SMP

4.1.5.2 Hard coral coverage

Hard corals (hermatypic) are the cornerstone of tropical coral reefs. Conservation Zone and General Use survey zones had coral coverages of 50% and 36% respectively, which is relatively good when compared to previous datasets: for example, during a collaborative MBRS monitoring effort in 2001, researchers found that MBRS reefs had an average live coral cover of 15.2% (with a range 2.6% to 39.7%) (Almada-Villela *et al*. 2002). In all, a live coral coverage of more than 20% is considered to be good while less than 10% is considered to be poor (Neal et al. 2007). The difference in hard coral coverage between the two sites is interesting, considering they are only a small distance apart and have similar physical characteristics; SB and NB are both by channels while SBSR and SBB are more sheltered. It is possible that proximity to the channel and prevailing currents make the NB reef site less favourable for coral settlement, due to higher levels of mechanical forcing from stronger currents and waves (Almada-Villela *et al.* 2002; McField *et al.* 2005;Chollett & Mumby 2012) Furthermore, NB also had higher algal abundance which may also explain why hard coral coverage at NB survey site is less (McField *et al.* 2005; Hughes *et al.* 2007). Such conditions impede or prevent growth of corals, especially some hard coral species as the macroalgae leave little substrate free for coral recruitment. In areas of high wave action the recovery period and settlement of coral onto free substrate is very important and areas such as NB suffer more from the effects of macro algae presence. This may also be due to different wave and current regimes, which has been observed to have an effect on back-reef macroalgal communities (Lillieskӧld Sjӧӧ *et al.* 2011). NB also likely had more algae than SB due to its location within the Caye Caulker Marine Reserve (CCMR): SB is located in the Conservation Zone, where no commercial fishing is permitted. Whereas NB is located in the General Use Zone, where commercial and recreational fishing is permitted. Due to this it is likely that there are less herbivorous fish, such as the current primary reef grazer parrotfish (family:

Scaridae) at NB, leading to less herbivorous activity and thus an increase in macroalgae coverage (Mumby 2006; Hughes et al. 2007; Sotka & Hay 2009; Edmunds 2013). The fish survey data supports this to an extent; parrotfish were less prevalent in the GUZ compared to the CZ with almost 3 times as many parrotfish seen in the CZ. None the less, a further level of protection for the NB reef site is likely to protect the herbivorous fish population, reducing the abundance of algae and increasing the coverage of hard coral (Mumby 2006; Hughes *et al.* 2007; Komyakova *et al.* 2013). It is important to mention that this difference in species diversity was slight with 19 different coral species identified at the CZ and 18 at the GUZ. One would have expected the GUZ to have slightly higher diversity due to the frequency of disturbances such as wave action which aid to prevent single coral species dominance such as *Orbicella annularis* which appears to dominate in both the GUZ and the CZ, perhaps the disturbance strength and frequency is too strong for more novel non-framework coral assemblages to prosper (Perry *et al.* 2015).

4.1.5.3 Acropora sp. abundance

Of the two survey zones the CZ had the higher abundance of ACER, likely due to the lesser wave action seen in the CZ. ACER corals break apart in strong wave action therefore areas such as NB are highly unsuitable for growth. Both sites showed no sign of APAL, APAL is often harder to record because the tape measure cannot go over the coral, APAL often sticks out the top of the water preventing surveying through SMP means.

4.1.4.4 Fish SMP

No statistical difference in fish abundance and diversity is possible to determine at this point with only one set of data collected. It is expected that even though the South Back site is located in the marine reserve, it is right on the south border, and hence is likely to act as a buffer zone between the middle of the reserve and the general use zone. In order to gain more accurate results we would need to survey more sites, particularly on the fore reef as well as within the preservation zone of the reserve as any differences in abundance of economically valuable reef fishes and community structure between the reserve and unprotected areas may indicate ecosystem overfishing. Previous studies by Sedberry *et al.* (1996) found that observations of individuals and species were greater in protected areas with the most dominant species being snappers. The decline in snappers seen within our results and dominance of the protected parrotfish may reflect the impacts of overfishing since Sedberry *et al.* (1996). The high abundance of Damselfish in the GUZ and CZ survey sites is likely due to reduced predation as a result of fishing of species higher in the food chain such as a snappers. The dominance of parrotfish in both the conservation zone and general use zone is likely due their protected status and the reduced numbers of predators such as large snappers and groupers (Randall 1967). The abundance of herbivorous pre-species such as parrotfish is impacted by reserve designation and the protection of their predators. The effects of overfishing on the Belize reef system are evident at a community level; complete protection is needed to restore the reef to previous trophic structure of fish communities.

4.1.4.5 Fish roving diver survey

The results of the roving diver survey show a significant difference between the numbers of fish in the conservation zone compared to the general use zone which is unsurprising considering the general use zone is heavily fished whereas the conservation zone has very limited legal fishing, both survey sites have similar habitats thus any differences in fish abundance is due to overfishing (Sedberry 1996). The results would indicate that the conservation zone has a significant and positive impact on the health of the reef by protecting the fish population, over double the number of fish were observed in the conservation zone compared to the general use zone, additionally 7 more species of fish were recorded in the conservation zone. The high abundance of parrotfish is a good sign that the reef is healthy as parrotfish help to keep macroalgae growth low preventing a species shift from coral to macroalgae. The high abundance of sharpnose pufferfish is a result of their poisonous bodies preventing predation, high numbers of pufferfish were observed in both the conservation zone and the general use zone indicating that they are not commercially fished, again due to their poisonous nature. Similar studies in the Chico Marine Reserve have indicated a similar high abundance of herbivorous species such as surgeonfish and parrotfish, the higher abundances of herbivores fish indicates overfishing in non-reserve areas impacting recruitment in protected areas (Chapman 2011).

The low abundance of lionfish on the reef suggests that the CC lionfish hunting and fishing program is a success. The lionfish season is all year round and fishermen are encouraged to kill lionfish whenever they can, the immediate benefit to the fishermen is that lionfish can be sold to local restaurants on the island too. Additionally CC hosts a lionfish hunting tournament once a year where hundreds of lionfish are removed from the reef keeping the local population very low and preventing the negative effects of lionfish on the reef. If lionfish become a successful alternative fishery product the fishing pressure on the already overburdened native fish stocks could be lessened (Searle *et al.* 2012). The lionfish population in Belize was slow to increase with only 13 confirmed sightings by 2009 with the first sighting being in 2008, this gave the Belize Fisheries Department and ECOMAR a chance to prepare fishermen and start their “lionfish: wanted dead or alive” poster campaign. This may be the reason Belize has for the moment managed to mitigate the damage the lionfish could have caused if left unchecked (*Searle et al.*2012).

Only one roving diver survey was completed for fish during BZM163 so these initial results may not give a clear indication of the fish populations and abundance in the general use zone and conservation zone. More surveys are needed to allow for a species richness comparison between the two zones. Due to lack of volunteers during BZM 171 roving surveys could not be completed.

4.1.5.6 Coral Roving Survey

The results of the roving diver coral surveys suggest that the conservation zone has no statistically significant effect on the number of coral colonies and little effect on the coral species present with only two more coral species observed in the conservation zone compared to the general use zone. While the lack of difference between the conservation zone and the general use zone may imply the conservation zone is ineffective the lack of difference is actually a good sign of the overall health of the local reefs regardless of location, as both sites showed high abundances of coral colonies and a good diversity of coral species. Similar studies between the Bacalar Chico reserve and non-protected areas also showed no significant difference, studies in the same area found that there was a high abundance of opportunistic and fast growing corals tolerant to relatively stressful conditions (Huntington *et al* 2011). This may indicate the Bacalar Chico reserve is experiencing new stressors or the amplification of existing stressors (Chapman 2011), the CC survey sites still show high numbers of slower growing species such as OANN and ACER with lower abundances of the opportunistic coral species such as SSID and PPOR. For the moment this would indicate the overall health of the CCMR is good in both the protected and unprotected areas. However as only one roving diver survey was conducted in BZM163 due to Hurricane Earl and boat captain licencing delays there is not enough data to make a confident conclusion on the health of the local reef at this time.

4.2 Caribbean Spiny Lobster Surveys

4.2.1 Introduction

The Caribbean Spiny Lobster (*Panulirus argus*) is the most important commercial marine species into the Caribbean due to its economic value, both as a source of income and employment for the local population, as well as foreign exchange for national government (Acosta & Robertson 2003). Furthermore, due to the high unit prices, the international trade of lobster provides improvements to the livelihoods of fisheries-dependent populations (Monnereau & Pollnac 2012). Ecologically, Caribbean spiny lobsters are keystone species that serve as prey for a wide range of marine animals, such as sharks, rays, turtles and moray eels (Seudeal 2013). They are also important predators; their primary diet consists of molluscs (gastropods, chitons and bivalves) and arthropods (Cox *et al*. 1997). Caribbean spiny lobsters are found in a wide range of habitats including sand, seagrass, coral reefs and coral rubble. Due to lack of abundance data, their threatened status is currently assessed as 'data deficient' on the IUCN Red List. This is likely due to their cryptic nature (Butler *et al*, 2013). Unsustainable fishing of this species could lead to population declines and ultimately collapse of the industry, particularly in Belize, where a decline of 28% in catch per unit effort is being noticed by fishermen from 2.7kg/fishing day in 1999 to 1.94 kg/fishing day in 2009 (Gongora 2010; Butler *et al.* 2013; CZMAI 2016).

Caribbean spiny lobsters are social, and when there is an abundance of food they are known to form high population densities, similar to that of the American lobster (*Homarus americanus*) (Behringer & Butler 2006). This suggests healthy, sustainable local lobster populations can be maintained through effective fishery management. Protected areas, similar to the Conservation Zones found within CCMR can function as refuge for the Caribbean lobster. In these protected areas lobsters are often found in higher populations, have a larger mean size and thus are often more reproductively successful due to increased fecundity (Acosta & Robertson 2003). These protections should result in increased regional larval supply and net movements of adult individuals from the reserve to adjacent fishing grounds. In addition to the protection granted by marine reserves, the Belize lobster fishery is seasonal. The fishery is closed on February 14th until June 15th country-wide; this protects the lobster populations throughout their reproductive season. Furthermore, Caribbean spiny lobster landings must adhere to a minimum size limit/carapace length of 7.6 cm and tail weight of 4 ounces (113 g), which is applied throughout the year. There is also a ban on the use of SCUBA for catching lobsters and other gear restrictions and license limitations. Despite this there is no current total allowable catch quota for lobsters (Babcock 2012).

Given the importance of the Caribbean spiny lobster at both an economic and ecosystem level, it is essential to assess the effectiveness of the conservation efforts mentioned above, in order to gain an insight into the sustainability of the lobster fishery. Frontier aims to carry out long-term monitoring and assessment of the local population size structure and sex ratios of the Caribbean spiny lobster. Surveys are conducted and compared between each zone of CCMR (where possible), in order to provide data on the effectiveness of spatial management on the local lobster population.

In addition to vital information on the sustainability of the lobster fishery, data on lobster distribution could potentially provide insight into the level of complexity and structure of the local coral reef systems. This is because higher densities of Caribbean spiny lobster have been associated with areas of higher habitat complexity, where the reef is intricate and creates crevices and hidden sites for lobsters (Rios-Lara *et al*. 2007). Higher lobster densities could therefore be a used as an indicator of reef habitat complexity and general health.

4.2.2 Methodology

In line with the aim of this study, surveys were carried out within the Caye Caulker Marine Reserve (CCMR). GPS location of the survey sites were recorded, to ensure the same sites were surveyed each time. Surveys were carried out using an active search approach, which consisted of a team of snorkelers actively searching for lobsters without the use of fixed transects. The rationale behind this method was to simulate local fishing practices and get an estimate of Catch Per Unit Effort (CPUE); the effort unit was time (minutes).

Each individual snorkelled for 30 minutes looking for lobsters. Each individual lobster found was measured using a ruler to approximate its total carapace length. Sex was also recorded, which was carried out by determining if two extra claws were present on the back legs, or if there was an extra pair of swimming legs underneath the tail in females. Despite best efforts it was often not possible to visually determine the lobster's sex, as they are usually found underneath rock crevices with their abdomen not visible to the surveyor. Lobsters were not handled in order to minimise disturbance. If lobsters escaped before measurements could be made, then their carapace length was estimated by sight.

4.2.3 Results

There were significantly (t-test = 5.099, df = 4, p = <0.05) more lobsters sighted in the Conservation Zone than the General Use Zone with 17 (mean = 3.4) lobsters observed in the months of July to October in the Conservation Zone and only 4 (mean = 0.8) observed in the General Use Zone with the same number of surveys conducted (5 in each zone). The lobsters in the conservation zone also exhibited a significantly higher (t-test = 2.70, df = 13, p = <0.05) carapace length with an average length of 26.47cm in the conservation and 21.25cm in the General Use Zone.

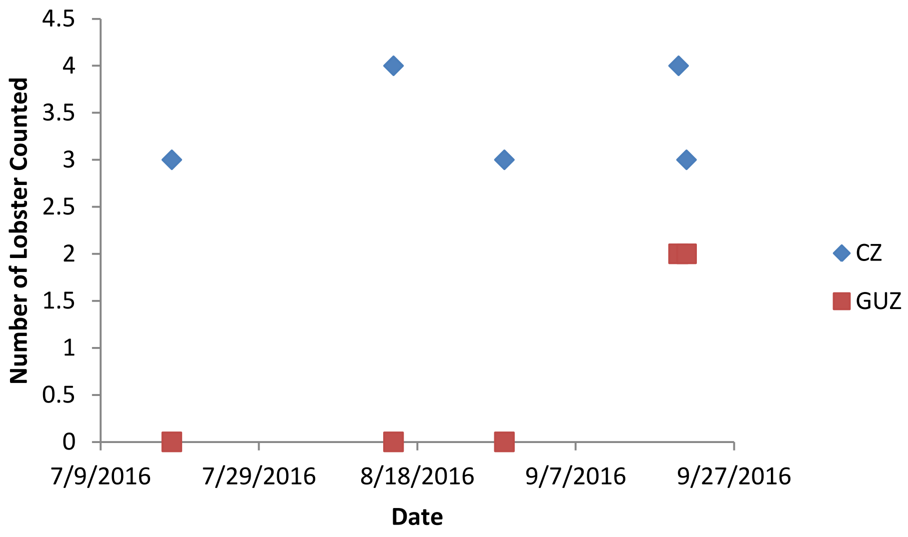

Figure 7: The number of lobster sightings from July to October 2016 in the Conservation Zone and General Use Zone.

4.2.4 Discussion

Although in total only 21 lobsters were observed during the 10 lobster surveys conducted it is promising to see that significantly more lobsters were sighted in the conservation zone, this represents the zones effectiveness at protecting the lobster population and decreasing the impact the lobster fishing season has on the population. The biggest issue with the lobster fishing season is that there is no catch limit, the limitation to lobster fishing comes from the size of the lobster and whether the lobster is 'berried' with eggs.

As such fishermen can catch as many lobsters as they are able to find of legal size in the general use zone devastating the local lobster population in this zone, however it is predicted that 2% of annual catches are undersized (Gongora 2010). The fisheries department of CC is currently understaffed compared to the size of the reef they have to patrol, this leads to significant amounts of illegal lobster fishing of undersized lobsters and even lobsters being removed from the conservation zone. The catch per unit effort has declined by 28.15%, stock size by 25% and recruitment levels by 36.1% during the period of 1999 to 2009 (Gongora 2010). In recent years the region has reported declines in lobster catches causing concern for the many livelihoods that could be affected (FAO 2007). At the current rate of lobster fishing the spiny Caribbean lobster will likely become endangered within the region, currently more data is needed to make an effective plan for mitigating the lobster fishery damage on the lobster population, if possible the off season may need to be extended or increased policing of illegal lobster fishing is needed. Additionally recommendations include increasing the minimum lobster tail weight to 4.5 ounces instead of 4 ounces, a deep-water lobster stock assessment should be carried out and the traditional licencing system which allows all fishermen to fish for lobsters needs to be revised (Gongora 2010).

4.3 Seagrass and Manatee Monitoring

4.3.1 Introduction

Seagrasses are primary producers and marine angiosperms that account for 0.1-0.2% coverage of ocean habitat worldwide (Duarte 2002). Seagrasses act as ecosystem engineers, profoundly influencing the physical, chemical and biological environments within coastal waters. They alter water flow, nutrient cycling and food web dynamics and stabilise sediments (Orth *et al*. 2006). They are also a vital food source for mega-herbivores in the Caribbean, including the green, loggerhead and hawksbill sea turtles (*Chelonia mydas*, *Caretta caretta* and *Eretmochelys imbricata* respectively) and West Indian Manatees (*Trichechus manatus*) all of which are of international conservation concern (Beck *et al*, 2001). Seagrasses provide a critical habitat for juveniles of both commercially and recreationally important fishery species that depend upon the habitat for nursery and refuge areas (Heck *et al*. 2003).

Seagrasses are common in shallow coastal waters across most continents; however, there has been a noticeable loss of seagrass coverage worldwide for many decades equating to a scale of hundreds of square kilometres (Heck *et al.* 2003). This is mostly due to rapid environmental changes as a consequence of increased coastal development and a growing global population (Lotze 2006). The most widely accepted disturbances include sediment and nutrient runoff, physical damage, invasive species, disease, commercial fishing practices, aquaculture, overgrazing, algal blooms and increased sea surface temperatures (Orth *et al*. 2006). Such disturbances have resulted in the recent decline of seagrass meadows in Belize, which has increased the necessity for the protection, as well as monitoring and management of seagrass beds.

Coastal ecosystems have the ability to sequester huge amounts of carbon. These ecosystems include mangroves, coral reefs, saltmarshes and seagrasses, with seagrasses having a disproportionately large carbon storage potential relative to their global area (Laffoley *et al*. 2009). These ecosystems cover <0.5% of the ocean floor and form part of the earth's blue carbon sink accounting for 10-16% of annual carbon storage in the ocean (Nellman *et al.* 2009). There has been a recent surge in interest of carbon sequestration due to increasing global pressure to mitigate the effects of climate change brought on by carbon emissions. The recent focus on carbon trading and carbon pricing has resulted in considerable interest in quantifying the capacity of the world's ecosystems to trap and store carbon (Lavery *et al.* 2013). Blue carbon is also the name of a new strategic approach to make use of the large carbon capture and storage potential of coastal ecosystems. If this carbon could be quantified and sold on international carbon trading markets then this could help fund preservation and restoration projects, which would also help capture more carbon and ease the effects of climate change (Emmett-Mattox & Crooks 2013). There are three species of seagrass found in Caribbean waters; Turtle grass (*Thalassia testudinum*), Manatee grass (*Syringodium filiforme*) and shoal grass (*Halodule wrightii*), with turtle grass being the most abundant in the waters around CC.

The implementation of weekly seagrass surveys in CC will allow monitoring of the health of the seagrass beds during the continued coastal development plans of CC (CZMAI 2016). This is a great opportunity to study anthropogenic effects on seagrass beds, and in particular, how coastal development affects this important habitat. By comparing seagrass coverage and health between north CC (non-developed) and south CC (developed/developing), we hope to provide data on the adverse effects of coastal development on seagrass communities. It is hypothesised that there will be a decrease in seagrass coverage in seagrass beds closest to coastal development.

Another prospective project is to conduct GIS mapping of the seagrass beds around CC. This habitat has never been mapped in this area and so a detailed survey to examine the extent of seagrass beds would prove extremely beneficial. It would provide key logistical information for the management of this habitat and also start baseline data which will enable monitoring of changes over time. In addition to mapping the seagrass beds finding a large area of seabed along the north coast of CC could allow for the farming of algae by FAMRACC. If a suitable area is found, this could be used as an incentive to allow the designation of an extended area of protection. This would continue north from the northern limit of the current MPA, which has already been proposed by FAMRACC. The proposed extension includes an area of reef which includes the critically endangered *Acropora sp.* and also an area which manatees are known to frequently inhabit. A suitable area of seabed, for example, within the general use area in the northern extent of the MPA could be proposed as an area of algae farming for the local fishermen in return for the extension of the protected zone area. The area allotted for algae farming will need to be where the seabed is barren substrate and not in close proximity to seagrasses or coral, which the algae could smother and kill through inhibiting photosynthesis. An extensive mapping survey would not only allow vital mapping of crucial habitats but would also allow GIS spatial analysis to present any potential sites for algae farming.

Manatee Ecology

The Antillean manatee (*Trichechus manatus manatus*) belongs to the order Sirenia - the only aquatic herbivorous order of mammals currently existing (Bertram and Bertram, 1973; Burn, 1985). Forming multispecies communities in marine environments, these mammals partition seagrass resources for their feeding (Domning, 2012). A combination of global cooling after the middle Miocene as well as human predation in the North Pacific has reduced their diversity to only two living genera and four species (Domning, 2012).

These two genera, or families of the Sirenia are the *Dugongidae* (Dugongs) and *Trichechidae* (Manatee) (Aketa *et al,* 2001). These can further be divided into four species through skull examination: the Dugong (*Dugong dungon)*, the Amazonian manatee (*Trichechus inunguis*), the West African manatee (*Trichechus senegulsensis*) and the West Indian manatee (*Trichechus manatus*) (Hatt, 1934). The West Indian manatee is finally subdivided into another two subspecies, the Florida manatee (*Trichechus manatus latirostris*) and the Antillean manatee (*Trichechus manatus manatus)* (Marsh *et al,* 1986), both of which reveal a diversity of aquatic herbivore feeding patterns (Aketa *et al,* 2001). The latter subspecies is the one examined in this project.

The West Indian manatees can be found in both freshwater and saltwater habitats (Campbell and Irvine, 1977). The Antillean manatee's habitat is along the coast of Mexico, Central America as well as South America, but can also be found in the Greater Antilles such as Cuba, Jamaica, Hispaniola and Puerto Rico (Alvarez-Aleman *et al,* 2007). Belize is believed to be one of the biggest strong-holds of the Antillean manatee (Morales-Vela *et al*. 2000). They are found in shallow coastal areas, slow moving rivers, estuaries, saltwater bays, and canals, with pregnant females seeking refuge in even more shallow waters (Bengston, 1981). The manatees exhibit elusive and secretive behavior, making them one of the hardest animals to study and observe directly (Bertram and Bertram, 1973). Importantly, they can stay submerged under water for relatively long periods of time, with a dive time between 16.3 to 24 minutes (Best, 1981). Several studies have contributed to the known feeding ecology such as Alvarez (2010) cited by Navarro (2012), Bengtson (1981), Hartman (1979), Ledder (1986), Lefebrve *et al*, (2000) and Reynolds (1981).

This study evaluates the manatee population and their habitat around Caye Caulker in Belize, a necessary study due to Belize being a manatee stronghold as mentioned above.

Habitat & nutrition

The shallow waters in their habitat are essential for feeding, particularly as less shallow waters do not require such deep dives and therefore save more energy and time spent foraging and grazing (Anderson, 1994). The Seagrass communities in these shallow waters are thus found to be the most ideal depth for the manatee's dive time (Domning, 1982). The main species that comprise the diet of the manatees are marine angiosperms, *Division Angiospermae* - seagrass (Green and Short, 2003), leaves of *Rizophora mangle* - mangrove, and algae (Bengston, 1981). The manatees have one of the slowest consumption and passage rate of any mammalian herbivore (Lomolino and Ewel, 1984), allowing for a cellulose digestion coefficient of 80% (Burn, 1985). Using their pectorals, the *T.manatus* excavates rhizomes from the ground, which it then feeds on (Anderson, 2000; Packard, 1984). Both the dugong and manatees share a similar cellular digestion (Murrey *et al,* 1977), which ultimately allows for comparison between these two subspecies.

Opportunist feeders

Several studies indicate that manatees are opportunists at seagrass foraging, and specialise in the readily available species (Anderson, 2000; Anderson and Brittles 1978; Boyle and Khan, 1993; Domning, 1976). Foraging up to 6 to 8 hours per day (Bengston, 1981), they can have a potential daily consumption of 42-65kg per day (Lomolino, 1977). Most West Indian manatee habitats have access to both salt water and freshwater and so may choose to eat seagrass, despite this not being their preferred food. This is because it will be the most readily available food source, as seagrass meadows are found in the majority of the manatee's habitats (Domning, 1982). Importantly, the manatee loses and replace its teeth like elephants, which means it may choose less fibrous seagrass, as a lower fibre content requires less chewing (Domning and Hayek, 1984). The seagrass species preferred are thus *Thallassia, Halodule, Halophila* and *Syringodium* (Deutch *et al,* 2008).

The plants fed on by manatees

While there are 60 species of seagrass (Green and Short, 2003), manatees feed on a limited range of species. Hartman (1971) suggested that *Thalassia testudinum, Syringgodium filiforme, Halodule wrightii* and *Halophila engelmanni* are the main dietary preferences of the West Indian Manatee. *T. testudium* is the most dominant species in the Caribbean due to their regeneration speed (Dawes and Lawrence, 1979). However recent studies conducted in Cuba (Alvarez-German, 2010 and Martinez Navarro, 2012) show that the only species preferred by the *T.manatus* was the *H.wrightii, T. testudinum, S. filiforme,* - rhizomes and mangrove. Occasionally, the *caulerpa paspaloides* and *Halophila enegelmanni* were consumed. The seagrass species found in Belize, and specifically around Caye Caulker are *H.wrightii, T. testudinum, S. filiforme* with *T. testudinum* being the most abundant (Mudan *et al,* 2016).

The importance of the rhizomes

The rhizomes seem to play an important part in the manatee feeding ecology. Above the ground it may seem that seagrass are individual plants, but the rhizomes are the horizontally growing stems below ground connecting each plant to each other, and where the roots sprout. The species *Halophila spinulosa* has fleshy rhizomes, suggesting high abundance of starch and carbohydrates (Anderson, 1994). The leaf *Halodule univervis* is fragile and often lost to drift (Anderson, 1998), and so the rhizomes are chosen for the high concentration of digestible starch (Masini, 1982) and non-cellulose glucose allowing for maximum energy for foraging (Masini *et al,* 2001). Thayer stated in 1984 that fiber makes up a high percentage of the plant (Burn, 1986), also indicating why the rhizomes are favored. All the field experiments above indicate that the Sirenia feeding habits have the ability to change the seagrass communities, through composition alteration and nutrient modification. The experiments also conclude that the more favored seagrass is the *Halodule* and *Halophila* (Marsh *et al,* 2012). Anderson and Birtles (1978) discovered Dugongs moved on to new feeding grounds 5 or 6 days after grazing 30% of an area. A study by Adler *et al,* (2005) suggested that abiotic variables affect the ability of a seagrass ecosystem to tolerate grazing or not. Anderson (1994) investigated why Dugongs were diving deeper for *H.spinulosa,* and suggested the nutrient content compensated for the high cost of dive. Anderson (1998) further discovered the seagrass species *Halodule univervis* rhizomes were rich in carbohydrates and therefore selected and grazed by Dugongs, also corroborating with the study of Masini *et al,* (2001), who further discovered dugongs excluded the dominant seagrass and chose early growth *Halodule,* which were low in fiber and high in nitrogen. Ledder (1986). This characterized the feeding habits of the West Indian manatee *Trichechus manatus. latirostris.,* finding that *Halodule wrightii* was the dominant species in the diet in the summer and winter, but changed seasonally in spring to *Syringodium filiforme.* The above research may indicate why the manatees choose to migrate to new feeding areas between the seasons in Belize, also indicating that when looking at a feeding area the sediment type plays a key role in the site choice. If the rhizomes are unobtainable it would be unlikely that the manatee choose this area, allowing the expectation that the manatees will choose areas with a soft sediment type, with mainly *H.wrightii* or *S.filiforme* present.

The manatees' role in nutrient recycling

Examining the manatee feeding patterns allows an understanding of the composition and preference and role within their ecosystems. Seagrass meadows are highly overlooked but extremely important habitats for providing shelter for fish, shellfish, nursery areas for other animals. Unfortunately, these meadows are declining across the world (Green and Short, 2003). The manatees prove important nutrient cycling within seagrass meadows and communities. Their grazing may affect the plant traits, such as chemical and nutrient composition. Here, the nutrient content and palatability of the grass determines the plant response to grazing (Adler *et al,* 2005). While Nitrogen (N) is usually replenished into the terrestrial ecosystems through defecation, this is not possible in marine ecosystems due to the movement of water preventing any nutrient to settle on the ground and diffuse back into the ecosystem. The manatee and dugongs play a vital in regards to N recycling (Aragones *et al,* 1997)- through the dugong-grazing patterns the bacterial N fixation was found to be disturbed. Thus, due to the serpentine feeding behavior, (Anderson and Britles, 1978) the detritus aerated the sediment providing substrate for the bacterial N fixation (Aragones *et al,* 1997). Here, Adler *et al,* (2005) argue that the plant traits are the independent variable in grazing, however further study would be needed to find the cause for variation in plant traits. Overall the manatees are important in the N cycle within seagrass meadows.

The effect of grazing by manatees

Through examination of past studies, herbivores have been found to increase primary production through limiting nutrient recycling resulting in grazing optimization, occurring when the lost nutrient proportion is smaller than the lost nutrient proportion throughout the overall ecosystem (Mazancourt *et al,* 1998). Preen (1995) suggested grazing may alter the species composition within a community and act as cultivation for species, thereby preventing certain species growing. *Zostera Capricorni* grazed, for instance allowed the faster growing *Halophila* to take its place. Aragones *et al,* (1977) further found that nutrient levels in regrowth were affected by grazing.

Manatees and weed control

Manatees have been linked to important aquatic weed control (Campbell and Powell, 1976). Aragones *et al,* (1997) found that dugong grazing on seagrass communities in Australia increased the speed of seagrass species regrowth, such as *Halophila ovalis* and *Halodule inivervis,* by 25-35% in one year. The nutrient concentration such as Nitrogen (N) increased by 30% and reduced the fibre concentration too. Such finding are supported by Bryant (2003); Green and Delting, (2000); Hamilton *et al,* (1998); Hik *et al,* (1991).

Threats

Humans present the main threat to manatees (Bertram and Bertram, 1973), which were listed as protected under the Wildlife Protection Act 1981 (Morales-Vela *et al,* 2000). Historically, the mammals were also hunted in the US during the period of the two world wars for their meat due to their size and pose little threat to humans when hunted (Campbell and Powell, 1976). The ICUN assessed and concluded the Antillean manatee to be endangered (Deutch *et al,* 2008). This is due to mature population sizes believed to be lower than 2500 with a 20% expected decline over the next two generations, minimal conservation efforts and finally the increased threats to their environment. The main threats to their existence are hunting, habitat degradation, and entanglement in fishing gear, pollution, natural disasters, and incidental catch and watercraft collisions.

Examining the history of the *Hydrodamalis* gigas (Stellers sea cow) gives the perfect example of how important conservation of the manatee is. By protecting the individual species, their habitat will experience the umbrella effect of protection too. Stellers sea cow was the first aquatic mammal to go extinct due to threats posed by humans. Their size was described to be larger than the blue whale and was classified as extinct in 1756, supposedly only resisting a mere 27 years of human pressure (Marsh *et al,* 2012). The short existence of such mammals shows the strength of danger humans pose and should be taken as proof that human intervention is necessary for the survival of several marine mammals as their main threats are only due to humans.

In 1976, the Florida manatee population was estimated at 600-1200 mature individuals (Campbell and Powell, 1976), and only decline was expected (Marmontel *et al*, 1997) if no conservation efforts were implemented. The US took action and today it is discussed to down-list the Florida manatee (Erickson, 2016) from endangered down to threatened on the ICUN as the population size is estimated to be more than 6000.

4.3.2. Survey techniques

There are several survey techniques and methodologies used in manatee ecology discussed below, such as aerial surveys, direct observation, capture-release tagging, side sonar-scan, stomach content sampling and fecal sampling. Each of these survey techniques was considered, but due to lack of funding the basic survey techniques such as direct observation and habitat evaluations must be applied, a successful technique used in study on the manatee around San Pedro by Courtene-Jones *et al.* (2014).

The movement of the Florida manatee is highly affected by the water temperature, highlighting one of the first differences in manatee studies in the Caribbean to Florida, as the water temperature is steady all year round. In Florida, the manatees will aggregate in hot water springs due to seasonal temperature changes, allowing easy population counts and surveys (Campbell and Powell, 1976). Reported by Alvarez-Aleman *et al.* (2007), who further documented the first Florida manatee to have migrated to Cuba to a power plant effluent by the photo-identification data base created in Florida. Aerial surveys have been a successful and a popular technique in manatee research such as; Bengston and Magor (1979) and Morales-Vela *et al*, (2000) surveyed manatees in Belize; Craig and Reynolds (2004) surveyed manatees in Florida; Masini *et al*, (2001) study of *Halodule* in Australia. Gonzalez-Socoloske (2007) and Gonzalez-Socoloske, Olivera-Gomez and Ford, (2009) found the side-scan sonar technique, also suggested by Kenny *et al*, (2003) allowed for a better survey where unclear and turbid waters were most present.

In order to understand the feeding and digestive strategy of the manatees and dugongs, several studies (Andre and Lawler, 2003; Ledder, 1986 and Burn, 1986) have analyzed the stomach contents. This method however would prove difficult in Belize, due to the lack of resources available. Bengston (1983) studied the food consumption in manatees through recording of their chewing sounds using a hydrophone and tagged manatees with radio transmitters.

Underwater valuations allowed profiles to be created for different areas, consisting of abiotic and biotic factors. In order to compare the variety of angiosperm quality in understanding the manatees' choice a variable is needed. Past studies by Clergy (2003), Alvarez (2010) cited by Martinez Navarro (2012), use the Index Foliage Area (IFA) in order to give the seagrass species of *T.testudinum* and *H.wrightii* a comparable quality data set. The IFA for each species of a certain area is calculated from the equation below.

$$IFA = \Sigma D * AF * N_0 HD$$

D= average density
A= average number of leaves
N_0HD = average area m^2 (average area/10000)

The highest IFA results indicate the area with the highest density of plants with the highest average number of leaves per plant – therefore the plants will have the highest surface area per m^2. This means that areas with the highest IFA, will have the highest nutritional value and greatest abundance of the specific species. Manatees will therefore choose the areas with the highest IFA of the seagrass of their choice, as it will give them the largest yield for the least energy spent.

The underwater valuation will generate profiles of the sample areas, allowing comparison to each other. The IFA will be calculated to give the areas a quantitative comparison factor of seagrass in order to understand why the manatees choose a certain area or areas.

Deutch, Self-Sullivan and Mignucci, (2008) explain that the main forms of conservation for the Antillean manatee are:

- Policy-based actions
- Educational outreach programs
- Research actions, site-specific and country-wide surveys
- Protected areas
- Species-based actions (reintroductions, stranding networks.)

This project contributes to site-specific research action.

Photo-identification of manatees

This technique has been extremely successful in past studies in Florida, by Beck and Reid (1995), Langtimm *et al,* (2004) and O'Shea *et al,* (1995). Creating a database of the manatee population allows for resident manatees to be identified and migratory behavior to be assessed. As mentioned above a Florida manatee was identified in Cuba due to the photo-identification database (Alvarez-Aleman *et al,* 2007). Identification markers for the manatees will be distinctive scarring and unique features.

4.3.3. Knowledge gap and reasoning: future conservation and importance of the study.

By tagging a manatee you are able to observe their movement patterns, but if you want a reason as to why they move to specific areas further examination needs to be made. From the literature above it is clear that there are three things affecting the movement of the Antillean manatee; the temperature of the water they live in, their source of food and lastly their source of fresh drinking water. The water temperature varies slightly in Belize giving the manatee sightings a high season and low season. High season being May until September and low season being October to April (Morales-Vela *et al,* 2000).

The understanding of the feeding ecology of the manatee is very important to their future conservation, as lack of proper nutrients may result in health issues for the manatees as the *Hydrdamalis gigas* (sea cows) experienced when they were forced to switch feeding habits as the seagrass communities declined and resulted in the loss of molars and teeth in the seacow (Anderson, 2000). The manatees provide important grazing factors to the seagrass (Courtene-Jones *et al.* 2014), and therefore if manatee numbers reduce then negative effects may possibly be seen in the meadows (Aragones *et al,* 1997). (Morales-Furthermore, Vela *et al,* (2000) recommend that more manatee surveys need to be completed around the Cayes off Belize City. There is a known correlation between mangrove forests and seagrass meadows and a change in one will affect the other (Courtene-Jones *et al* 2014; Mudan, 2016). The south island of Caye Caulker is highly developed, thus a comparison of the seagrass meadows found around the south island and the north island will indicate the effects that development has had on the meadows, the results of the study may be used effectively by the Fisheries Department when managing the forest reserves and possible future development on the north island. According to local knowledge from tour guides the manatees are one of the main attractions to the island, and so if the manatee's feeding habitat is lost due to over-development then they may choose to migrate elsewhere severely affecting Caye Caulker and subsequently Belize's tourism.

Aims

1. Observe the distribution of the *Trichechus manatus* (Antillean manatee) around Caye Caulker, and their habitat
2. Test for a correlation between manatee distribution and habitat choice
3. Create a photo ID data base of the manatee population around Caye Caulker

4.3.4. Methodology

1. In order to meet the first aim above survey boat transects need to be completed.

Transect routes will be chosen based on local knowledge of manatee locations and based on incidental sighting data collected from tour shops and fishermen. Four transects will be designed, two on each side of the north island and two on each side of the south island (Approximately 4km each). The North Channel and South Channel will be included in these transects as they are known hotspots for manatees.

Once a manatee is sighted the data collected will be:

a. GPS location
b. Date
c. Time of day
d. Number of individuals,
e. Number of calves
f. Behavior of the manatees
    i. Moving/Travelling
    ii. Resting
    iii. Feeding
    iv. Sexual
    v. Socializing
    vi. Milling
    vii. Unspecified
g. Distance from boat
h. Reaction to boat

i. Avoidance: Manatee moves away from boat

ii. Attraction: Manatee moves towards the boat

iii. No response: Manatee behavior not affected by the presence of the boat.

i. Distance to urban areas

j. Distance to freshwater

k. Abiotic variables recorded on the surface of the water and bottom of the water:

i. Salinity

ii. Water temperature

iii. Turbidity

iv. Dissolved Oxygen (mg/l)

v. Sediment type

a. Silt (Deep or Shallow)

b. Mud (Deep or Shallow)

c. Sand (Deep or Shallow)

vi. Current

a. None

b. Mild

c. Medium

d. Strong

l. Biotic variable of the seagrass species present.

The abiotic variables will be collected at set intervals in order to give comparison of the areas used by manatees and those not used.

2. In order to meet the second aim a habitat evaluation needs to be conducted. Using the data collected from the boat survey transects the main hotspots for manatee sightings will be determined, 2-3 highly used areas and 2-3 low use areas will be used for comparison. Habitat evaluation will initially record the distance to freshwater at each area. The seagrass composition of each area will then be determined using a quadrate sampling technique (a); additionally the IFA (Index Foliage Area) of each area will be calculated (b).

   a. Underwater Valuation: Quadrate sampling will be conducted using a 50cm x50cm quadrate, variables collected will be:

i. % Cover of 3 main seagrass species (*H. wrightii*, *S. filiforme* & *T. testudinum*)

ii. % Cover of coral

iii. No. coral

iv. % Cover of sponges

v. No. sponges

vi. % Cover of gorgonian

vii. No. gorgonia

viii. % Cover of echninoderms

ix. No. echinoderms (starfish & sea urchins) present

x. % of algae present

xi. species of algae

b. Using a 25cm x 25cm quadrate, the variable collected will be:

i. Number of individual plant for each of the species.

ii. Average height of each species

c. The IFA is calculated using the equation:

$$IFA = \Sigma D * AF * N_0 HD$$

D= average density

A= average number of leaves

N_0HD = average area m^2 (average area/10000)

The IFA is calculated by collecting 30 samples of each seagrass, for each plant the variable recorded will be:

i. No. grass blades

ii. Height of each blade

iii. Width of each blade

d. The IFA calculation will be attempted for *Syringodium filiforme*, using the same equation, however the average will need to be calculated using $A = 2\pi rh + 2\pi r^2$, as the species has a cylindrical shape.

3. The habitat evaluation should be conducted during the dry season and also the low season allowing seasonal comparison in addition to the distribution comparison.

4. Lastly, to meet the third and final aim a photo identification database will be made of the current population. The data is recorded and collected by photographs and identifying their scarring and defining marks, also recording an estimate of their size where possible.

Equipment needed:

- Secchi disk
- Salinity meter
- 25cmx25cm quadrate
- 50cm x 50cm quadrate
- Underwater data collection slates
- Underwater camera
- Scuba gear for data collection too deep to snorkel
- GPS
- Watch
- Measuring Tape

The methodology of the project did not vary or change greatly. However, the hotspots for their feeding habitat evaluation were chosen mainly through local knowledge from tour guides and fishermen.

Three highly used areas, and three low use areas were chosen descried in the table below.

Table 3 Description of survey sites

Zone	No. sites	Description	Lat. Long	Manatee Use	Proximity to fresh water	Bottom Type	Average Depth	Current

1	3	Behind split	17^{o} 44’ 3 2.8 N 88^{o} 01' 5 7.6 W	High	To Be Confirmed		2 m	High
2	2	In front of split	17^{o}45’0 3.0”N 88^{o}01’2 4.2”W	Low			1 m	High
3	3	In front of base	17^{o} 47'4 2.8 "N 88^{o} 01'1 7.1 "W	Low			1 m	low
4	4	North Channel	17^{o} 47'2 9.1 "N 87^{o} 59' 4 6.1 "W	High			5 m	high
5		Behind Bahia	17^{o} 43'59.2 "N 88^{o} 02'28.1 "W	Low				low
6		South Channel	17^{o} 43'2 1.8 "N 88^{o} 00'30.8 "W	High			7 m	high

Within each site, 3 to 5 zones where chosen to sample. The quadrate samples were repeated 25 times each to give an average. Four zones have currently been completed successfully with the IFA of each of the seagrass species calculated using the IFA equation. The species that show to be the dominant species are the same as previous reports of this site have shown; *H. wrightii*, *T. testidium* and *S. filoforme*. Further mapping and profiling of each of the areas cannot be completed yet until more sites and zones are surveyed. Each profile of the areas will include the information shown in the table above, additionally they will include;

- Average canopy height of each species
- Average IFA of each species
- A breakdown of the average density of each species
- A breakdown of the average % cover of each species
- Presence of Epiphytes, Echinoderms, Gorgonia, Sponges, Macro Algae and Hard coral.

Once all the profiles can be constructed the data can then be tested for normality using the Shapiro Wilk test. The normally distributed data can then be further analysed using the One-Way ANOVA, and the variables not normally distributed will be analysed using the non-parametric Kruskal Wallis test. These tests should determine if there is a significant difference in any of the variables within each of the sites. Any variable which shows a significant difference the Mann-Whitney Test may be used to compare each of the areas to determine the specific areas where the differences existed.

Additionally to the seagrass surveys, a volunteer from the Tampa Bay Estuary Program has offered to map out the seagrass using satellite imagery, which may complement the surveys when final profiles are made.

4.3.5. Results

The Table below described the manatee sightings and variables collected with each sighting.

Table 4: Manatee Sightings

Description	**Sighting**	1	2	3	4	5
	Location	Behind Split	Behind Split	Behind Split	North Channel	North Channel
	Date	23/03/17	24/03/17	06/05/17	26/05/17	06/06/17
	Time	13:00	15:00	16:00	11:00	15:00
	No. Individuals	1	2	1	3	3
	No, Calves	0	0	0	0	0
	Behavior	Feeding	Milling	Moving	Sexual	Sexual
	Distance from Boat	1 m from canoe	10 m from canoe	40 m	10 m	10 m
	Reaction to boat	Avoidance	Avoidance	Avoidance	No Response	Attraction & No Response
	Distance to urban areas	very close	very close	very close	Far	Far
	Distance to fresh water	To be confirmed	To be confirmed	To be confirmed	To be confirmed	To be confirmed
Abiotic Variables	**Salinity**					
	Water temp.	29	29	30	30	30
	Turbidity	clear	clear	unclear	Clear	clear
	DO					

	Sediment Type	Deep silt	Deep silt	Deep silt	Shallow Sand	Shallow Sand
	Current	medium	medium	medium	None	None
	Seagrass species	TT	TT	TT	Sand	Sand

4.3.6. Discussion

At this time further study sites need to be completed before IFA analysis can be conducted.

The health of the seagrass can be directly linked to the health of the mangroves along the coastline. Therefore, it is suggested to analyse the health and distribution of the mangroves to investigate a possible correlation between the seagrass health to the mangroves. Furthermore, understanding the distribution and health of the mangroves around Caye Caulker may assist in further development on the island. Mangroves are directly linked to fisheries and lobster recruitment (Vaslet *et al.* 2012). This means that understanding the health and distribution of the mangrove forest around Caye Caulker is vital for the fisheries and lobster surveys. Lobster recruitment boxes may be placed along the Caye in areas of high and low current as well as close to and far from mangroves. In this project you may analyse the general recruitment rates of the lobsters in correlation to the current flows, as well as analyse a possible correlation of mangroves and lobster recruitment.

4.4 Queen Conch Surveys

4.4.1 Introduction

The Queen Conch (*Strombus gigas)* is a species of large edible marine gastropod, one of the largest species of conch native to the tropical North-western Atlantic, reaching up to 35cm in shell length (Toller & Lewis 2003). The Queen Conch is herbivorous and lives in seagrass beds. Conchs are slow moving with their shell being their only defence. The mortality of juveniles from predation is high as a consequence of having a less developed shell (Stoner 1997). As adults they have few natural predators, the main threat to their survival comes from fishing. The Queen Conch was first exported by Belize around 1950 but the fishery remained small until 1967 (Strasdine 1998). Exports then climbed dramatically from 174,000 kg in 1967 to 562, 634 kg in 1972. As with all exploited fishery populations, biomass decreased as the abundance of older reproductive adults decline and the size distribution shifted towards small sized often immature conchs By 1980 the conch fishery was essentially seasonal with a third of production taking place in October, the first month of the conch season which closes again in July. The closed conch season was implemented in 1978 alongside a catch size limit (Strasdine 1998). The current Belizean legal minimum for conch is 18cm, however the Queen Conch reaches sexual maturity at 21cm, therefore this length may not allow conch to reach sexual maturity before entering the fishery. Conch mating is density dependent, requiring 50 conch/ha (Stoner 1997). Mating occurs in the summer when adults aggregate in deeper seagrass beds. This mating season is protected by the closed season, between the 1st July to 30th September. Conch as a fishery resource is highly valued by the industry as a substitute to lobster income when the lobster season is closed (Aiken *et al.* 1999, Heyman and Graham 2000, Joyce 1997). In Belize, conch fisheries are still small scale characterised by skiffs owned or jointly owned by a senior operator with a middle income level (Berkes *et al.* 2001). The use of poisons, dynamite, SCUBA and hookah are illegal, conch fishing grounds are largely limited to waters less than 30m as this is the maximum depth for most skin divers. Skin diving is further limited by visibility which is better behind the barrier reef and on the atolls (Heyman and Kjferve 1999). Despite their size these fisheries share similarities to large-scale fisheries in that they depend upon fossil fuel, are commercial and mainly sell to organised and international markets. In 1998 the conch fishery accounted for 20% of earnings from marine produce, approximately BZ$ 3 million (Belize Fisheries Department 2001). Unlike large-fisheries the conch fishery are directly dependent on national stocks not pelagic stocks, as a result they cannot easily relocate if stocks decline. Even with this dependence on national stocks and being less capital intensive the conch fishery demonstrates a pathological resource use (Hughes 1994, McManus 1998, Smith and Berkes 1991). While the Queen Conch as a whole is not listed as endangered it is commercially threatened in many areas of the Caribbean due to overfishing and has been put on the watchlist by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Size is a useful parameter used to control and manage the fishing of conch as the shell and lip size represents sexual maturity (Avila-Poveda and Baqueiro-Cardenas 2006). Conservation and management of the Queen Conch requires ecological knowledge of the species, including population density, structure, maturity status and shell morphology (Peel and Aranda 2012). As size of the conch is both useful and easy to measure this is the main parameter used during Frontier's Queen Conch surveys here in Belize. The aims of the Queen Conch surveys are to identify differences in conch density, size and maturity status between three sites with different levels of protection within the CCMR, specifically the General Use Zone and the Conservation Zone. Long-term monitoring of these variables will provide insights on the sustainability of local conch fishing practices, and the effectiveness of the multi-zone management and closed fishing season which is currently in place in the CCMR.

4.4.2 Methodology

The protocol for this methodology was adapted from the current methodology used by Belize Fisheries Department. Since one of the aims of the project was to identify the sustainability of local queen conch fishing practices, which involve the fishermen snorkelling and then free-diving to collect conchs, surveys were carried out as snorkel surveys to simulate these practices. There were three zones utilised for conch surveys, sites were surveyed multiple times the week before conch season opened. Below is a description of each of these conch survey zones.

Conch Site 1: (General Use Zone) No person is permitted to use long lines, spear guns or nets unless authorised by the Fisheries Department. Commercial fishing is allowed with a valid fisher folk licence, traps must be placed 100m from corals. Sport fishing is allowed under licence from the Fisheries Department, whereas spear fishing is not permitted. Catch and release tours can only remove fish for subsistence purposes.

Conch Site 2: (Preservation Zone) No fishing, sport fishing, diving or any other water activities are permitted within the preservation zone. Motor boats are not to be operated within the preservation zone except for emergencies or with permission from the Fisheries Department.

Conch Site 3: (Conservation Zone) No fishing or collection or marine items of any type. Only non-extractive recreational activities allowed in the conservation zone. No feeding of marine life except by licensed tour guides. Water skiing and jet skiing are not allowed.

For each survey a 100m transect line was laid out by the boat. Once the transect line was laid two surveyors surveyed a 4m wide belt transect (2m either side) searching for queen conchs. Each conch found inside the belt-transect was collected and carried to the boat, to avoid recording and measuring the same individual twice. Once every conch had been collected the transect line was reeled back in and the survey team measured the total length of each conch shell and the thickness of the lip if present, using callipers. Once all the conchs had been measured, they were placed carefully back on the sea floor at the same site where they were found.

Once the data had been collected, conchs were divided into three maturity status categories according to the measured lip thickness. Queen conchs with lip thickness >5mm were classified as adults, those with a <5mm lip were classified as sub-adults, and those where the lip was absent were classified as juveniles (Horsford, 2011).

4.4.3 Results

During BZM163 28 conch surveys were completed (2.8km), the surveys were completed in the last week of September before the opening of conch season to observe the current health and abundance of the queen conch at a point before fishing commences.

4.4.4 Discussion

The results of the conch survey are still being used by the Belize Fisheries Department. Another annual conch survey is expected to occur in June prior to the closing of the conch season. It is hoped that once both data sets are collected analysis of the data will be allowed.

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6.0 Appendices

6.1 Fish Species List

Angelfish - *Pomacanthidae*	
Blue Angelfish	*Holacanthus bermudensis*
French Angelfish	*Pomacanthus paru*
Gray Angelfish	*Pomacanthus arcuatus*
Queen Angelfish	*Holacanthus ciliaris*
Rock Beauty	*Holacanthus tricolor*
Butterflyfish - *Chaetodontidea*	
Banded Butterflyfish	*Chaetodon striatus*
Foureye Butterflyfish	*Chaetodon capistratus*
Longsnout Butterflyfish	*Prognathodes aculeatus*
Reef Butterflyfish	*Chaetodon sedentarius*
Spotfin Butterflyfish	*Chaetodon ocellatus*
Surgeonfish - *Acanthuridae*	
Blue Tang	*Acanthurus coeruleus*
Doctorfish	*Acanthurus chirurgus*
Ocean Surgeonfish	*Acanthurus tractus*
Jacks - *Carangidae*	
Bar Jack	*Caranx ruber*
Permit	*Trachinotus falcatus*
Grunts – *Haemulidae*	
Black Margate	*Anisotremus surinamensis*
Bluestriped grunt	*Haemulon sciurus*
Caesar Grunt	*Haemulon carbonarium*
Cottonwick	*Haemulon melanurum*
French Grunt	*Haemulon flavolineatum*
Porkfish	*Anisotremus virginicus*
Sailors Choice	*Haemulon parra*
Smallmouth Grunt	*Haemulon chrysargyreum*
Spanish Grunt	*Haemulon macrostomatum*
Striped Grunt	*Haemulon striatum*
Tomtate	*Haemulon aurolineatum*
White Grunt	*Haemulon plumierii*
White Margate	*Haemulon album*
Snappers - *Lutjanidae*	
Cubera Snapper	*Lutjanus cyanopterus*
Dog Snapper	*Lutjanus jocu*
Gray Snapper	*Lutjanus griseus*
Lane Snapper	*Lutjanus synagris*

Mahogany Snapper	*Lutjanus mahogoni*
Mutton Snapper	*Lutjanus analis*
Red Snapper	*Lutjanus campechanus*
Schoolmaster	*Lutjanus apodus*
Yellowtail Snapper	*Ocyurus chrysurus*

Groupers - Serranidae

Black Grouper	*Mycteroperca bonaci*
Coney	*Epinephelus fulvus*
Goliath Grouper	*Epinephelus itajara*
Graysby	*Cephalopholis cruentata*,
Nassau Grouper	*Epinephelus striatus*
Red Grouper	*Epinephelus morio*
Red Hind	*Epinephelus guttatus*
Rock Hind	*Epinephelus adscensionis*
Tiger Grouper	*Mycteroperca tigris*
Yellowfin Grouper	*Mycteroperca venenosa*
Yellowmouth Grouper	Mycteroperca *interstitialis*

Parrotfish - *Scaridae*

Blue Parrotfish	*Scarus coeruleus*
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	*Sparisome chrysopterum*
Stoplight Parrotfish	*Sparisoma viride*
Striped Parrotfish	*Scarus iseri*
Yellowtail Parrotfish	*Sparisoma rubripinne*

Trunkfish - *Ostraciidae*

Spotted Trunkfish	*Lactophrys bicaudalis*

Triggerfish & Filefish - *Balistidae*

Black Durgon	*Melicthys niger*
Ocean Triggerfish	*Canthidermis sufflamen*
Orangespotted Filefish	*Cantherhines pullus*
Queen Triggerfish	*Balistes vetula*
Scrawled Filefish	*Aluterus scriptus*
Whitespotted Filefish	*Cantherhines macrocerus*

Miscellaneous

Chub	*Kyphosus sectatrix/incisor*
Great Barracuda	*Sphyraena barracuda*
Hogfish	*Lachnolaimus maximus*

Lionfish	*Pterois volitans*
Spanish Hogfish	*Bodianus rufus*
Yellowtail Damselfish	*Microspathodon chrysurus*

6.2 Juveniles and Recruits Fish Species List

Damselfish (<3.5cm)

Bicolor Damselfish	*Stegastes partitus*
Blue Chromis	*Chromis cyanea*
Brown Chromis	*Chromis multilineata*
Cocoa Damselfish	*Stegastes variabilis*
Dusky Damselfish	*Stegastes adustus*
Longfin Damselfish	*Stegastes diencaues*
Threespot Damselfish	*Stegastes planifrons*

Surgeonfish (<5cm)

Blue Tang	*Acanthurus coeruleus*
Ocean Surgeonfish	*Acanthurus tractus*

Butterflyfish (<2.5cm)

Banded Butterflyfish	*Chaetodon striatus*
Foureye Butterflyfish	*Chaetodon capistratus*

Parrotfish

Greenblotch Parrotfish	*Sparisoma atomarium*
Princess Parrotfish	*Scarus taeniopterus*
Redband Parrotfish	*Sparisoma aurofrenatum*
Stoplight Parrotfish	*Sparisoma viride*
Striped Parrotfish	*Scarus iseri*

Others (<3.5cm)

Bluehead Wrasse	*Thalassoma bifasciatum*
Clown Wrasse	*Halichoeres maculipinna*
Fairy Basslet	*Gramma loreto*
Rainbow Wrasse	*Halichoeres pictus*
Slippery Dick	*Halichoeres bivittatus*
Spanish Hogfish	*Bodianus rufus*
Yellowhead Wrasses	*Halichoeres garnoti*

6.3 Benthos species list

Sponges		SPN

Corals

Branching Fire Coral	*Millepora cervicornis*	MALC

Blade Fire Coral	*Millepora complanata*	MCOM
Gorgonian		GG
Staghorn Coral	*Acropora cervicornis*	ACER
Fused Staghorn Coral	*Acropora prolifera*	APRO
Elkhorn Coral	*Acropora palmata*	APAL
Clubtip Finger Coral	*Porites porites*	PPOR
Pillar Coral	*Dendrogyra cylindrus*	DCYL
Blushing Star Coral	*Stephanocoenia intersepta*	SINT
Lobed Star Coral	*Orbicella annularis*	OANN
Mountainous Star Coral	*Orbicella faveolata*	OFAV
Great Star Coral	*Montastraea cavernosa*	MCAV
Elliptical Star Coral	*Dichocoenia stokesi*	DSTO
Massive Starlet Coral	*Siderastrea siderea*	SSID
Lesser Starlet Coral	*Siderastrea radians*	SRAD
Symmetrical Brain Coral	*Pseudodiploria strigosa*	PSTR (was *Diploria sp.)*
Knobby Brain Coral	*Pseudodiploria clivosa*	PCLI (was *Diploria sp.)*
Grooved Brain Coral	*Diploria labyrinthiformis*	DLAB
Maze Coral	*Meandrina meandrites*	MMEA
Rose Coral	*Mancina areolata*	MARE
Boulder Brain Coral	*Colpophyllia natans*	CNAT
Whitestar Sheet Coral	*Agaricia lamarcki*	ALAM
Lettuce Coral	*Undaria agaricites*	UAGA (was *Agaricia sp.*)
Low Relief Lettuce Coral	*Undaria humilis*	UHUM (was *Agaricia sp.*)
Thin Relief Lettuce Coral	*Undaria tenufoila*	UTEN (was *Agaricia sp.*)
Ridged Cactus Coral	*Mycetophyllia lamarckiana*	MLAM
Sinuous Cactus Coral	*Isophyllia sinuosa*	ISIN
Spiny Flower Coral	*Mussa angulosa*	MANG
Smooth Flower Coral	*Eusmilia fastigiata*	EFAS

Marine algae

Thalassia sp.	TH
Dictyota sp.	DT
Lobophora sp.	LOB
Halimeda sp.	HM
Blue/Green Algae	BGA
Turf Algae	TURF
Macro Algae	MAC
Coralline Algae	COR

Other Substrates

Sand	SN
Bare Rock	BR

7. Abbreviations

Atlantic and Gulf Rapid Reef Assessment	AGRRA
Belize Barrier Reef	BBR
Belize Barrier Reef Reserve System	BBRRS
Caye Caulker	CC
Caye Caulker Forest Reserve	CCFR
Caye Caulker Marine Reserve	CCMR
Conservation Zone	CZ
Convention on International Trade in Endangered Species of Wild Fauna and Flora	CITES
Forest and Marine Reserve Association of Caye Caulker	FAMRACC
General Use Zone	GUZ
Marine Protected Areas	MPA
Mesoamerican barrier reef system	MBRS
North Back reef	NB
Preservation Zone	PZ
Sea Surface Temperature	SST
South Back reef	SB
Synoptic Monitoring Program	SMP