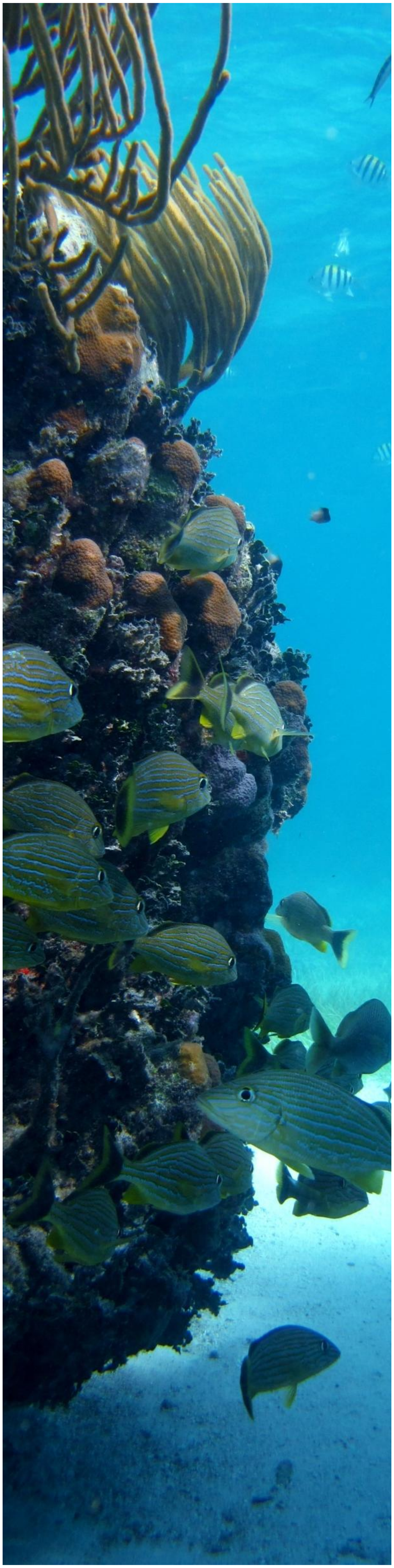

Jennifer K. Chapman

Status of marine resources in Bacalar Chico Marine Reserve 2011

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Keywords: Belize, Bacalar Chico Marine Reserve

Acknowledgements: The author would like to thank Fran Humber, Jo Hudson and Mebhratu Ateweberhan for undertaking thorough reviews of this report. Also to Klavdija Jenko, for providing invaluable input towards the megafauna data analysis and interpretation - this report would not be the same without your help. An enormous thank you to Sarah Beach, Sam Hope and Nikkita Lawton, who led the data collection in the field, and to all Blue Ventures' staff and volunteers who support and assist with the reef monitoring programme. Finally, thank you to the Belize Fisheries Department for your support and advice.

Recommended citation: Chapman, J.K. 2011. Status of marine resources in Bacalar Chico Marine Reserve 2011**.** Blue Ventures Conservation Report, Blue Ventures, London.

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Acronyms

BBRS	Belize Barrier Reef System
BCMR	Bacalar Chico Marine Reserve and National Park
CZ	Conservation Zone
GUZ	General Use Zone
HCC	Hard Coral Cover
IUCN	International Union for the Conservation of Nature
MBRS	Mesoamerican Barrier Reef System
MPA	Marine Protected Area
NTZ	No Take Zone
PIT	Point Intercept Transect
PZ	Preservation Zone
UNESCO	United Nations Educational, Scientific and Cultural Organisation

Abstract

Bacalar Chico Marine Reserve and National Park ('Bacalar Chico') forms part of the Belize Barrier Reef Reserve System, a UNESCO World Heritage Site. Coastal development, primarily the extensive clearing of mangrove forest, combined with direct over-extraction of marine resources and increased frequency of coral bleaching, diseases and hurricane events have caused dramatic decline in reef health, leading to its inclusion on the *List of World Heritage Sites in Danger*.

In March 2010, Blue Ventures embarked upon a long-term coral reef monitoring project within Bacalar Chico. In 2010, the majority of sites were found to be in poor condition, with no evidence of management-related difference between the four zones.

Results of monitoring in 2011 show continued decline in reef health, with the average Simplified Integrated Reef Health Index score of 2.16 in 2010 dropping to 1.90 in 2011. Average hard coral cover is 10%, and remains unchanged from 2010, with fleshy macroalgae and turf algae occupying the majority of the benthos. Commercial fish biomass is extremely low (536.89 ± 94.51 to 8996.70 ± 3010.30 g 100 m^{-2}), with no observed differences between management zones.

Despite thriving herbivorous fish populations, some portions of the reef exhibit critically high levels of fleshy macroalgae, possibly linked to the loss of potential key phase-shift reversing species such as the rainbow parrotfish, *Scarus guacamaia*. Identification and intensification of conservation efforts for recovery of such species is of critical importance for any future recovery of reef health and function. As the threshold for phase-shift reversal from an algae-dominated reef to hard coral dominance is high and compounded by multiple factors, protection of reefs which have yet to undergo phase-shift should be prioritised. One section of the forereef system, located in the General Use Zone, has been identified as the healthiest site and maintaining reef health at this site is essential.

1. Introduction

1.1 History of Blue Ventures' Belize Coral Reef Monitoring Programme

Established in March 2010, Blue Ventures' Belize long-term coral reef monitoring programme aims to provide information on the status of the reefs and associated ecosystems in Bacalar Chico Marine Reserve (BCMR), Ambergris Caye, Belize. Through monitoring and analysis of reef health, the effectiveness of the marine reserve in maintaining ecological processes and sustainable fish stocks is assessed.

Key findings of the 2010 monitoring were:

- Simplified Integrated Reef Health Index (SIRHI) score for all sites combined was 2.16 ("Poor"); with the highest score of 2.75 ("Fair") for a site located in the Preservation Zone (PZ).
- Average hard coral cover was 10.5% and fleshy macroalgal cover was 23.1%.
- Total average biomass of fish recorded along fish belts (26 g/m^2) was near the lower range of the regional national averages (14 to 263 g/m^2) (Newman *et al*., 2006).
- No patterns in biomass of ecologically or commercially significant species were evident.
- Scarid abundance and diversity were positively associated with hard coral cover.
- Sightings of invasive lionfish (*Pterois volitans*) increased throughout the duration of the study period.
- Taking into account that Bacalar Chico had thus far experienced 14 years of management, full benefit had not yet been achieved.

1.2 The Belize Barrier Reef

The Belize Barrier Reef Reserve System is a UNESCO World Heritage Site and forms the core region of the world's second largest barrier reef, the Mesoamerican Barrier Reef System (MBRS). The entire reef system encompasses barrier, atoll, faro and fringing reef types, supporting a large diversity of coral and fish species.

A deep offshore continental shelf provides characteristic environmental conditions (promontories with nearby reefs and drop-offs to deep water, with cyclic currents) for the assembly of spawning aggregations of fish in numerous locations along the stretch of the Belize Barrier Reef System (BBRS) (Shcherbina *et al*., 2008). Fourteen multi-species spawning aggregation sites have been identified (Heyman and Kobara, 2011), with the critically endangered Nassau grouper (*Epinephelus striatus*), as well as commercially important dog snapper

(*Lutjanus jocu*) and black grouper (*Mycteroperca bonaci*), among other species, recorded (Heyman, 2001; Heyman and Requena, 2002).

Major threats to the BBR include storm damage, coastal development and overexploitation of resources (Gibson *et al*., 1998; Healthy Reefs Initiative 2010; McField, 2000; Mumby, 1999). To address these concerns, the Belizean government has designated approximately 13% of its waters as marine protected areas (MPA) (Belize MNREI, 2005). The fishing of parrotfish (scarids) was made illegal in 2009 (NERC, 2012) and in January 2010, bottom trawling was banned within Belizean waters (Oceana, 2010). Furthermore, rapid response and monitoring programmes for marine mammal and turtle strandings, coral bleaching events, storm damage to reefs and the management of invasive lionfish are operational throughout Belize.

Despite conservation efforts, Belizean coral reef health is in decline (Healthy Reefs Initiative, 2010). Overall reef health is variable across the country, though the majority of reefs are considered to be in a poor or critical state (Healthy Reefs Initiative, 2010). The declining health of the BBR has led to its inclusion on the *List of World Heritage Sites in Danger* in 2009 (UNESCO World Heritage Committee – Decision – 33 COM 7B:33).

In the early 1990s, hard coral cover (HCC) was reported to be between 20 and 84% at barrier and patch reef sites, dropping to an average of 11% in 2005 for all reef types (Garcia-Salgado *et al*., 2008a). Such decline in HCC has been attributed to a multitude of factors, including:

- Outbreak of white band disease in 1981, affecting *Acropora* corals (Schutte *et al*., 2010).
- A severe bleaching event in 1998 (Aronson *et al*., 2002), which acted synergistically with category 5 Hurricane Mitch causing mass coral mortality throughout the MBRS (McField, 2000).
- Reduction in herbivory[1], hence an increase in the relative contribution of macroalgae to reef benthic assemblage (Garcia-Salgado *et al*., 2008b), outcompeting coral recruits for space (Carpenter and Edumunds, 2006; Mumby, 2006) and thereby exacerbating decline in coral cover.

Overexploitation and habitat degradation has led to an overall decline in commercial fish biomass (Healthy Reefs Initiative, 2010), though recovery of commercially important fish and invertebrate populations has been

[1] The combined effect of region-wide overexploitation of herbivorous fish (Paddack *et al.*, 2009) and a disease epidemic which caused mass mortality to herbivorous *Diadema* sea urchins between 1983 and 1984 (Lessios, 1988), from which only limited, patchy recovery has been observed (Carpenter and Edmunds, 2006).

documented within some Belizean MPAs (Huntington *et al*., 2011; Shank and Kaufman, 2009; Wildtracks, 2010). Nevertheless, lobster and conch stocks, which comprise over 90% of capture fisheries in Belize (Wildtracks, 2010), are considered to be fully exploited to overexploited (Pomeroy and Goetze, 2003).

1.3 Bacalar Chico Marine Reserve and National Park

Bacalar Chico Marine Reserve and National Park ('Bacalar Chico') is located at the north of Ambergris Caye, sharing a border with the Mexican MPA, Arrecife de Xcalak. Covering 15,529 acres of coastal waters, the reserve encompasses a variety of marine ecosystems, including coral reefs, seagrass beds, mangroves and lagoons.

The marine reserve is divided into five zones, characterised by four different management schemes (Figure 2.1). The Preservation Zone (PZ) is completely protected, with no commercial or recreational activities permitted. Recreational activities such as snorkelling and SCUBA diving are permitted within Conservation Zone (CZ) 1, though all forms of fishing are banned. Recreational activities, including non-extractive sport fishing, are permitted within CZ 2. Two General Use Zones (GUZ) are located on either side of CZ 2. Extractive fishing is permitted within the GUZ, with some fishing gear prohibited (e.g. gill nets and long lines) and special licence required for fishermen.

1.4 Ecological Monitoring

1.4.1 Overall Reef Health

As foundation species, the diversity, health and relative cover of scleractinian corals influences reef biodiversity and resilience through the provision of habitat, food resources and structural complexity (Alvarez-Filip *et al*., 2011; Paddack *et al*., 2009). Whilst not providing insight into architectural complexity (Alvarez-Filip *et al*., 2011), percentage cover of scleractinian corals is used as a fundamental indicator of reef health (Healthy Reefs, 2007; Healthy Reefs, 2010). Monitoring of incidence and severity of bleaching and disease, the two major drivers for decline in scleractinian coral cover, facilitates the understanding of species-specific sensitivity, reef resilience and recovery potential (Rogers, 2011; Healthy Reefs, 2007; McField 2000).

As key competitors for space on coral reefs, diversity and cover of algal functional groups influence coral recruitment and habitat structure, thereby affecting reef fish and invertebrate populations (Done, 1992; Edmunds and Carpenter, 2001; Healthy Reefs, 2007; McClanahan *et al*., 2001). Increasing algal cover has been shown to be driven by changes in water quality (McClanahan *et al*., 2002, Lapointe *et al*., 2004) and decreases in scleractinian coral cover (Williams *et al*., 2001), though the abundance, diversity and biomass of herbivore populations have been identified as the primary drivers of change in algal cover in the Caribbean (Burkepile and Hay, 2010; Kopp *et al*., 2010; Macia *et al*., 2007; Myhre and Acevedo-Gutierrez, 2007).

Therefore, describing the population structure of key herbivorous fish, such as acanthurids and scarids, enables identification of factors influencing local reef benthic assemblage (Mumby, 2006, 2009; Burkepile and Hay, 2010; Healthy Reefs, 2007, 2010). Characterisation of general fish population composition may assist in the identification of less abundant or unrecognised phase-shift reversing species (Bellwood *et al*., 2006).

1.4.2 Invertebrates as Early Indicators of Changes in Reef Dynamics

Indicator species are selected due to their sensitivity in response to changes in environmental conditions, therefore acting as early warnings for changes in ecosystem health. Additionally, some environmental variables or populations have complex monitoring requirements; indicator species are therefore selected to enable rapid and straightforward assessment of specific variables or target species populations.

Diadema antillarum sea urchins are key reef herbivores and an outbreak of disease in 1983 resulted in mass mortality of these ecologically significant invertebrates throughout the Caribbean (Lessios, 1988). As herbivores, the loss of this species has been linked to increases in macroalgal cover as well as an associated decrease in hard coral cover (Aronson and Precht, 2000; Idjadi *et al*., 2006; Lessios, 1988). The recovery of *Diadema* populations is of critical importance and monitored throughout the Caribbean. Prior to the disease epidemic, populations of *Diadema* ranged between 4 and 25 urchins/m^{-2} of reef throughout the MBRS. Post-epidemic populations had dropped to less than 0.3 urchins m^{-2}. Population sizes below one urchin per m^2 are considered critically low (McField and Kramer, 2007).

The flamingo tongue snail (*Cyphoma gibbosum*) is a predator of gorgonians, with an expansive distribution on reefs throughout the Caribbean. Its density is influenced by the abundance of predators, with reefs protected from fishing exhibiting lower densities of *C. gibbosum* than heavily fished reefs (Burkepile and Hay, 2007; Chiappone *et al*., 2003). Known predators of *C. gibbosum* include the commercially significant hogfish (*Lachnolaimus maximus*), listed as vulnerable on the IUCN Red List, and Caribbean spiny lobsters (*Panulirus argus*), one of Belize’s primary fisheries (Wildtracks, 2010).

1.4.3 Megafauna

The West-Indian manatee, *Trichechus manatus*, is classified as Vulnerable by the IUCN Red List of Threatened Species (Hilton-Taylor, 2001). The declining population trend is attributed to human activities, with coastal development leading to the removal of critical resting and feeding grounds, as well as increased injury and mortality via boat traffic (CZMAI, 2000; UNESCO, 1996; Waring *et al.*, 2006). There are two sub-species of the West-Indian manatee (Waring *et al.*, 2006), the Floridian (*T. m. latirostris*) and Antillean (*T. m. manatus*) manatee, of which the latter is found in the Caribbean. The largest number of Antillean manatees, are found in the coastal waters of northern Belize, forming an integral part of the discrete Mexican and Belizean population of the sub-species (O'Shea and Salisbury, 1991; UNESCO, 1996). Two species of dolphin, bottlenose (*Tursiops truncatus*) and the Atlantic spotted dolphin (*Stenella frontalis*) have been sighted in the BCMR (Jones *et al.*, 2011).

There have been five species of marine turtle documented in Belize, with loggerhead (*Caretta caretta*), hawksbill (*Eretmochelys imbricata*) and green (*Chelonia mydas*) being the most common, with known nesting beaches and foraging grounds (Bonham, 2011; Walker and Walker, 2009; UNESCO, 1996). In addition, leatherbacks (*Dermochelys coriacea*) have been sighted in Belizean waters (UNESCO, 1996; Jones *et al.*, 2011), and there has been one confirmed sighting of an olive ridley (*Lepidochelys olivacea*) in 2011 (Belize Fisheries Department, pers comms.).

Many species of sharks and rays are known to inhabit the waters of Belize (UNESCO, 1996; Walker and Walker, 2009), including several IUCN red-listed species such as the great hammerhead (*Sphyrna mokarran*; EN) and whale shark (*Rhincodon typus*; VU). In Bacalar Chico, southern stingrays (*Dasyatis americana*), spotted eagle rays (*Aetobatus narinari*) and nurse sharks (*Ginglymostoma cirratum*) are the most commonly sighted elasmobranchs (Jones *et al.*, 2011).

1.4.4 Invasive Species

Lionfish (*Pterois volitans*) [2] were introduced to the Atlantic in the 1980s, initially in the waters surrounding Florida, USA, though their population has now spread throughout the Caribbean (Ruttenberg *et al.*, 2012). The

[2] A second species, *P. miles*, was simultaneously introduced; however the invasion of this morphologically similar species did not expand beyond Bermuda and the eastern coast of the USA (Bentacur-R. *et al.*, 2011).

first confirmed sighting of a lionfish in Belize was in 2008 (Schofield, 2009), and the species are now well established throughout the country (Jones *et al.*, 2010; Walker, 2009).

Voracious predators, lionfish predate on over 40 different species of fish and crustacean (Morris and Atkins, 2009), and have been documented to consume up to ca. 8.5 g of prey items per day, (Fishelson, 1997). Lionfish also have the ability to consume large meals, expanding their stomach sizes to 30 times the original volume, following which the fish undergoes a fasting period (Fishelson, 1997). Due to the presence of venomous spines located on the dorsal, ventral and anal fins, lionfish have few natural predators (Morris, 2009). Coupled with fast recruitment rates, ca. 24 fish ha^{-1} day^{-1} (Fishelson, 1997), lionfish exhibit several characteristics of successful invasive species. Both visible and potential impacts of the establishment of lionfish populations on coral reefs in the Atlantic include a reduction in fish recruitment (Albins and Hixon, 2008) and competition with native predators (Morris and Whitfield, 2009). Such effects disrupt reef community structures and food web interactions, ultimately exacerbating concerns for already threatened fish stocks and overall coral reef health.

1.4.5 Birds

Birds are often used as indicator species of ecosystem health due to their diversity and the range of ecosystem services they perform, such as pollination and predation. Furthermore, birds are often conspicuous and relatively easy to identify. Bacalar Chico is a known bird nesting site for species such as the roseate spoonbill (*Ajaia ajaja*) and white ibis (*Eudocimus albus*) (Brown, 2011); a stopover for migratory species such as the reddish egret, (*Egretta rufescens*) and the wood stork (*Mycteria americana*) (Meadows, 1995); as well as providing a habitat for Yucatan endemics such as the black catbird (*Melanoptilla glabrirostris*) and the red-vented woodpecker (*Centurus pygmaeus*) (Grimshaw and Paz, 2004).

Regular monitoring of bird species will provide information on annual fluctuations in bird populations, long term data on population trends as well as assist in the identification crucial sites for local and migratory populations.

2. Monitoring

2.1 Coral Reef Monitoring

The reef monitoring programme in Bacalar Chico has been appraised and some changes instigated from 2010 to align methods with the Mesoamerican Barrier Reef System Synoptic Monitoring Program (MBRS-SMP) methodology, as well as to provide a more detailed view of reef ecology and population distribution of commercially significant species. These changes were introduced in July 2012, and therefore any sites surveys prior to that date followed methods used in 2010. For detailed description of corrected 2011 survey methods see Appendix 1.

Key changes to the methods used in 2010 were:

1. In spur-and-groove formation reefs, transects were laid along the top of spurs, with no transects crossing grooves. In 2010, all transects were laid in a north-south direction, regardless of reef formation.

2. All transects were laid shallower than 15 m. In 2010, transects at Firing Range North and Firing Range South were deeper than 15 m; these sites were excluded from surveys in 2011.

3. During fish belt surveys the tape was unreeled whilst the diver collected data, preventing survey area disturbance prior to data collection. This change was implemented in July 2011, prior to which the transect tapes were laid and divers then swam away from the survey area for two minutes to allow fish to settle before returning to collect data.

4. As in 2010, the priority fish species list included all those outlined by MBRS-SMP methods, as well as a list of additional arbitrary species. As they are so numerous, their inclusion in analysis of fish abundance along transects would lead to an overestimation of average fish abundance, preventing direct comparison with data reported by other organisations in the region. Although included in the 2010 annual report, the following species were omitted from fish belt data analysis for this report:
    - Bicolour damselfish (*Stegastes partitus*)
    - Sergeant major (*Abudefduf saxatilis*)
    - Blue chromis (*Chromis cyanea*)
    - Unidentified damselfish (pomacentrid spp.)

- Creole wrasse (*Clepticus parrae)*
- Unidentified wrasse (labrid spp.)
- Unidentified squirrelfish (holocentrid spp.)

5. The priority fish species list was expanded in 2011 to include three relatively uncommon species due to their commercial significance. As their abundance is so low, they do not interfere with fish counting, nor do they influence mean fish abundance along belts significantly. Whilst their abundance was not recorded in 2010, the following species are included in fish belt data analysis for this report:
    - Tarpon (*Megalops atlanticus*)
    - Cero (*Scomberomorus regalis*)
    - Permit (*Trachinotus falcatus*)

6. A sighting log for a defined list of target species was introduced in January 2011, providing continuous monitoring for some commercially significant or endangered species with low population densities. The list of species (Appendix 6) was produced based on anecdotal fisheries targets, IUCN categorisation and/or population trends of the species in other parts of the MBRS. Lionfish are an invasive species in the Caribbean, with sightings being recorded in Bacalar Chico since August 2010. On every dive, the location, size, depth and abundance of target species and lionfish were recorded, as well as any additional information such as sex, behaviour, etc. Cape length is used for lobster size estimation and total length for fish.

7. 60 m^2 invertebrate belts were introduced in February 2011 to determine population density of:
    - Long-spine sea urchin (*Diadema antillarum)*
    - Caribbean spiny lobster (*Panulirus argus)*
    - Spotted spiny lobster (*Panulirus guttatus)*
    - Spanish lobster (*Scyllarides aequinoctialis)*
    - Flamingo tongue snail (*Cyphoma gibossum)*
    - Queen conch (*Strombus gigas)*
    - Sea cucumbers (Holothuroidea)

8. Fish recruit belts, following MBRS-SMP methodology, were introduced in July 2011.

2.1.1 Study Area (Figure 2.1)

With the exception of Firing Range North and Firing Range South, all sites surveyed in 2010 were repeatedly surveyed in 2011. A new forereef site within GUZ 1 (Goliath) was included in the 2011 surveys. No backreef site within CZ 2 has yet been located, nor has a forereef or backreef site within GUZ 2. In total, three backreef and nine forereef sites were surveyed.

2.1.1a Survey Site Nomenclature

A standardised system for defining and naming reef survey sites in Bacalar Chico was introduced in 2011. The coding system is as follows: *Zone* (G = General Use Zone; C1 = Conservation Zone 1; C2 = Conservation Zone 2; P = Preservation Zone), *Reef Type* (B = backreef; F = forereef) and a number to differentiate between multiple survey sites within each location. For example, *PF1* and *PF2* are located on the forereef (F) of the Preservation Zone (P), whereas *C1B1* is a backreef (B) site in Conservation Zone 1 (C1).

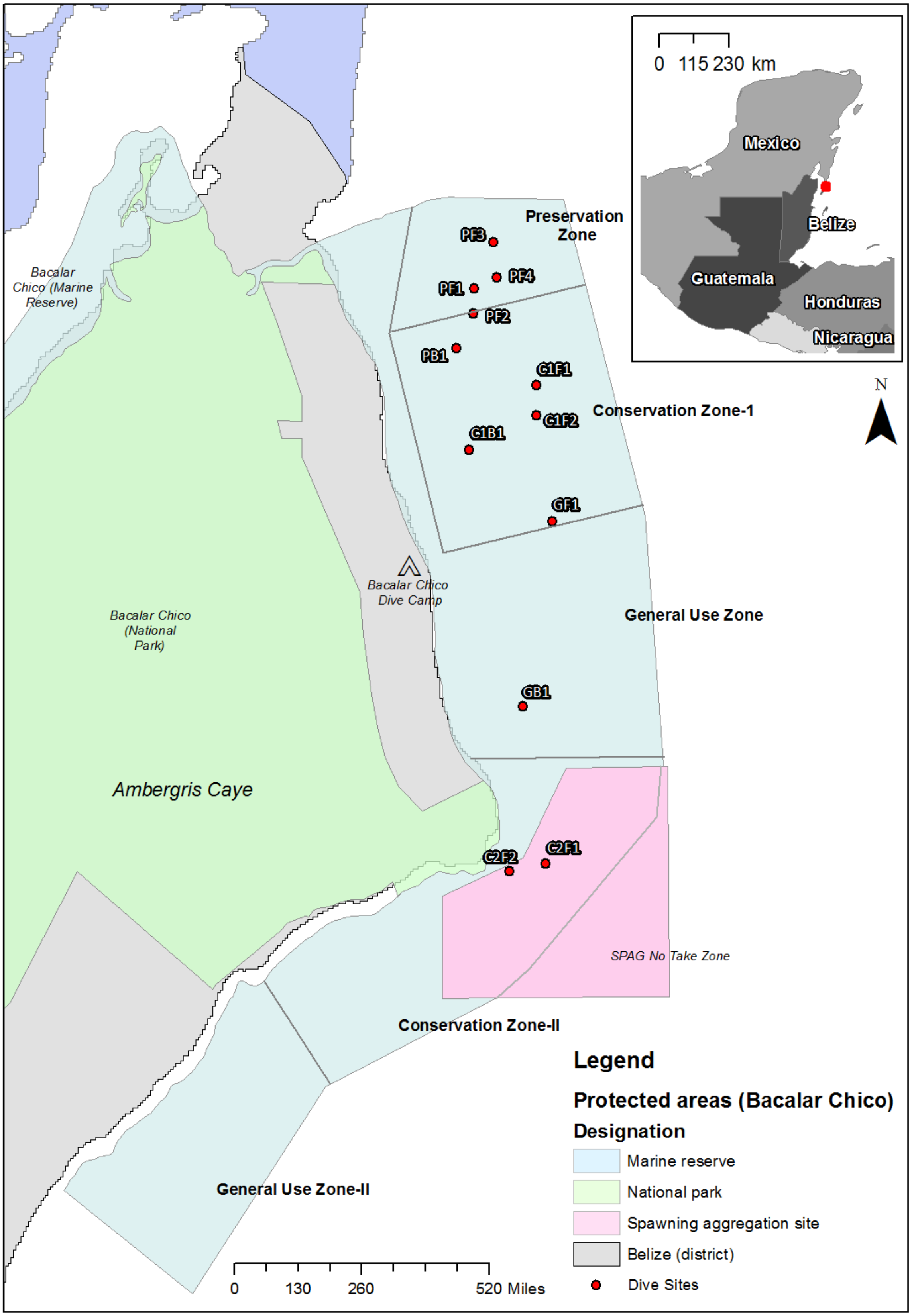


Figure 2.1: Management zones and location of monitoring sites in Bacalar Chico Marine Reserve

Backreef Survey Sites

The backreef sites are shallow patch reefs within close proximity to coastal mangroves and surrounded by seagrass beds.

GB1 – Peccary Patch

Location: General Use Zone 1

Depth: 1-2 m

Description: Large long-dead coral colonies of *Acropora palmata* protrude above the surface of the water at the centre of the patch reef, with newer coral colonies attached to the dead *A. palmata* and successive colonies expanding outwards from this central coherent section. Large colonies of living *A. palmata* are present at the south of the reef and a gorgonian bed is present to the west. Crevices amongst dead *A. palmata* provide habitat for lobster. Large aggregations of haemulids are frequently observed.

2010 Surveys: 6-8 fish belts, 4 PITs, coral community health characterisation and fish rover.
Surveys performed in March and October.

2011 Surveys: 8 fish belts, 4 PITs, 4 invertebrate belts, coral community health characterisation and fish rover.
Surveys performed in March.

Comments: Surveys in 2011 took place before changes to survey methodology were implemented, and therefore fish belts were laid prior to data collection.

C1B1 – Last Resort

Location: Conservation Zone 1

Depth: 3-5 m

Description: Coherent patch reef close to a large channel, which often affects current and water clarity. Two large colonies of *Agaricia tenuifolia* cover the south eastern side of the reef, and high reef rugosity has facilitated the formation of a large number of crevices, which shelter all three species of lobster. Large aggregations of haemulids and lutjanids are frequently observed.

2010 Surveys: 8 fish belts, 4 PITs, coral community health characterisation and fish rover.
Surveys performed in May and November.

2011 Surveys: 7 fish belts, 5 PITs, 7 invertebrate belts, 7 fish recruit belts, coral community health characterisation and fish rover.

Surveys performed in October.

Comments: The size of survey site does not enable the placement of more than 7 transects whilst maintaining an interval distance of 5 m. Fish belts in 2010 were laid closer together than specified by the MBRS-SMP.

PB1 – Tarpon Patch

Location: Preservation Zone

Depth: 1-2 m

Description: Scattered patch reef close to the reef crest with a few large colonies of *Agaricia tenuifolia* and *Montastrea annularis*, though predominantly smaller colonies of *Siderastrea siderea, S. radians, Diploria strigosa* and *D. clivosa*. Large aggregations of haemulids are frequently observed. Between coral colonies, large numbers of queen conch are found scattered on sandy bottoms.

2010 Surveys: 8 fish belts, 4 point intercept transects (PITs), coral community health characterisation and fish rover.

Surveys performed in May.

2011 Surveys: 8 fish belts, 5 PITs, 5 invertebrate belts, coral community health characterisation and fish rover.

Surveys performed in February.

Comments: No data was collected on abundance of *C. gibbosum* along invertebrate belts.

Surveys in 2011 took place before changes to survey methodology were implemented, and therefore fish belts were laid prior to data collection.

Forereef Survey Sites

Within the Preservation Zone, the forereef is comprised of a double reef system, separated by a deep sandy valley approximately 500 m wide. The forereef in CZ 1 and GUZ 1 is predominantly spur-and-groove formation, with deep channels providing habitat for large serranids and lutjanids. The forereef in CZ 2 is comprised primarily of fringing reef, where the barrier reef meets the land at Rocky Point. To the south of Rocky Point, the reef reverts to a deep spur-and-groove formation.

GF1 – Goliath

Location: General Use Zone 1

Depth: 12-15 m

Description: Spur-and-groove formation reef with consistently high diversity in coral and fish sightings. Deep grooves provide habitat to many large serranids, including goliath grouper (*Epinephelus itajara*), Nassau grouper (*E. striatus*), black grouper (*Mycteroperca bonaci*) and yellowfin grouper (*M. venenosa*).

2010 Surveys: N/A

2011 Surveys: 8 fish belts, 5 PITs, 8 invertebrate belts, 8 fish recruit belts, coral community health characterisation and fish rover.
Surveys performed in September.

Comments: *None.*

C1F1 – Alleys

Location: Conservation Zone 1

Depth: 10-15 m

Description: Spur-and-groove reef exhibiting a high diversity in coral species, with *Scolymia* and *Mycetophyllia* species frequently observed. Located close to a channel through the barrier reef, the site often is affected by strong surge and current.

2010 Surveys: 4-8 fish belts, 4 PITs, coral community health characterisation and fish rover.
Surveys performed in March and November.

2011 Surveys: 8 fish belts, 5 PITs, 8 invertebrate belts, 8 fish recruit belts, coral community health characterisation and fish rover.
Surveys performed in November.

Comments: *None.*

C1F2 – Canyons

Location: Conservation Zone 1

Depth: 10-15 m

Description: Spur-and-groove reef with deep valleys and extensive interconnected swim-throughs providing habitat to large dog snapper (*Lutjanus jocu*) and tiger grouper (*Mycteroperca tigris*). Midnight parrotfish (*Scarus coelestinus*) are occasionally seen grazing on algae covering dead *M. annularis* colonies.

2010 Surveys: 8 fish belts, 4 PITs, coral community health characterisation and fish rover.
Surveys performed in August.

2011 Surveys: 8 fish belts, 4 PITs, coral community health characterisation and fish rover.
Surveys performed in June.

Comments: Surveys in 2011 took place before changes to survey methodology were implemented, and therefore fish belts were laid prior to data collection.

C2F1 – Rocky Point North

Location: Conservation Zone 2

Depth: 10-15 m

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

2010 Surveys: 8 fish belts, 4 PITs, coral community health characterisation and fish rover.
Surveys performed in June and November.

2011 Surveys: 8 fish belts, 5 PITs, 8 invertebrate belts, 8 fish recruit belts, coral community health characterisation and fish rover.
Surveys performed in November.

Comments: *None.*

C2F2 – Rocky Point South

Location: Conservation Zone 2

Depth: 8-12 m

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

2010 Surveys: 8 fish belts, 4 PITs, coral community health characterisation and fish rover.
Surveys performed in August.

2011 Surveys: 8 fish belts, 5 PITs, 8 invertebrate belts, 8 fish recruit belts, coral community health characterisation and fish rover.
Surveys performed in July.

Comments: *None.*

PF1 – Garden Wall

Location: Preservation Zone

Depth: 7-12 m

Description: Reef flat on the western ridge of the double-reef system, with a steep wall along the east of the site to a sandy bottom at approximately 20 m deep. Large colonies of *A. palmata*, *Montastrea faveolata* and *M. annularis* are scattered throughout the area, providing crevices which support all three species of lobster as well as a great diversity of fish families and species.

2010 Surveys: 8 fish belts, 4 PITs, coral community health characterisation and fish rover.
Surveys performed in June.

2011 Surveys: 8 fish belts, 4 PITs, 4 invertebrate belts, coral community health characterisation and fish rover.
Surveys performed in February.

Comments: No data was collected on abundance of *C. gibbosum* along invertebrate belts.
Surveys in 2011 took place before changes to survey methodology were implemented, and therefore fish belts were laid prior to data collection.

PF2 – Moose Country

Location: Preservation Zone

Depth: 5-8 m

Description: On the western ridge of the double-reef system, south of PF1 (Garden Wall), the reef flat is shallower and closer to the crest of the barrier reef. Large colonies of *A. palmata* are abundant, providing crevices in which *Diadema* sea urchins are frequently observed.

2010 Surveys: 8 fish belts, 4 PITs, coral community health characterisation and fish rover.
Surveys performed in August.

2011 Surveys: 8 fish belts, 5 PITs, 8 invertebrate belts, 8 fish recruit belts, coral community health characterisation and fish rover.
Surveys performed in September.

Comments: *None*.

PF3 – Hot Point

Location: Preservation Zone

Depth: 8-12 m

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

2010 Surveys: 8 fish belts, 4 PITs, coral community health characterisation and fish rover.
Surveys performed in July.

2011 Surveys: 8 fish belts, 4 PITs, 4 invertebrate belts, coral community health characterisation and fish rover.
Surveys performed in April.

Comments: Surveys in 2011 took place before changes to survey methodology were implemented, and therefore fish belts were laid prior to data collection.

PF4 – Pig Sty

Location: Preservation Zone

Depth: 8-12 m

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

2010 Surveys: 8 fish belts, 4 PITs, coral community health characterisation and fish rover.
Surveys performed in July.

2011 Surveys: 8 fish belts, 5 PITs, 8 invertebrate belts, 8 fish recruit belts coral community health characterisation and fish rover.
Surveys performed in October.

Comments: *None*.

2.2 Lionfish Culls and Stomach Content Analysis

Data collected on abundance and location of lionfish is used to decide locations for targeted lionfish-culling dives. Hawaiian slings are used to spear lionfish, which are then placed into a bucket. The size and depth of these lionfish are still recorded in the target and invasive species monitoring log.

Equipment

- Ruler
- Scissors
- Fillet Knife

Method

1. Using scissors, the venomous spines are removed. These are located on the dorsal fin, ventral fins and anal fin.
2. With the mouth closed, the total length (to end of tail) and body length (to end of caudal peduncle) of the fish are measured.
3. Using a fillet knife, an incision is made along the belly of the fish, exposing the internal organs.
4. Presence or absence of roe is recorded.
5. Stomach is exposed and a small incision made to remove contents and all stomach contents are removed by inserting a finger into the fish’s mouth and pushing prey trapped in the oesophagus out through the incision in the stomach.
6. All prey is identified as accurately as possible and measured.

2.3 Mangrove Fish Population Monitoring

Mangroves are an important habitat and nursery area for a number of fish species. All mangrove areas in Bacalar Chico are within the GUZ, and as such extractive activities and sport fishing are permitted.

Fish population monitoring in the mangroves takes place as a thirty minute 'fish rover' counting in Cantena Creek, a natural channel leading from a shallow lagoon (Crocodile Lagoon), undertaken by snorkel. The objective is to identify and count the maximum number of species possible during the search time to the best of the data collector's ability, and so maximum effort was made to search within and underneath mangrove roots as well as along the centre of the channel.

2.4 Bird Monitoring Programme

Monitoring sites were selected to encompass different habitats and to capture a variety of different species. Mangroves, coastal and lagoon areas were explored by boat and foot and all birds encountered were recorded.

Four monitoring sites were selected and each surveyed at least once every six weeks. Cantena Lagoon and Crocodile Lagoon are both shallow lagoons within the mangrove system. Belize Island is located adjacent to a cenote and the final survey was conducted along the coastline.

Cantena Lagoon is very large and has many small mangrove islands within it. These islands are known to be bird nesting sites during the winter months (December to March), and as such bird sightings are particularly relevant during these months. Surveys took place as stationary point counts.

Crocodile Lagoon is much smaller and surrounded by dense mangroves, providing insight into mangrove bird populations. Surveys took place as stationary point counts.

Belize Island is a small island at the mouth of the main mangrove channel exiting Bacalar Chico, near to San Juan Ranger Station. Adjacent to Belize Island is a cenote with a great number of fish. During pilot studies many pelicans were observed feeding at the surface of the cenote. Surveys took place as stationary point counts.

The fourth survey location is the **Coastline** survey. Many waders use the littoral zone to feed, and may not move for over half an hour. Therefore, a more accurate description of the birds feeding in the littoral zone is attained through the 'walking rover' technique, covering a distance of approximately 500 m following the contours of the coast. The survey also allows data collectors to observe birds living along the forest edge.

Equipment

- Slate and pencil

- Binoculars
- Bird Identification Guides

Method

1. A minimum two observers are involved – one observer with binoculars, one observer with bird identification guides and slate.
2. All surveys are conducted shortly after sunrise (approximately 30 minutes).
3. For stationary point counts, observers sat quietly for two minutes upon arrival at the site to allow birds to settle before beginning records. For walking rovers, observers moved slowly and quietly, without approaching the birds, so as to not disturb the survey area.
4. Start time of survey is recorded and observation made for thirty minutes.
5. Every bird observed during the 30 minute time period is tallied. Birds are identified to the greatest degree of precision possible (e.g. species, sex, maturity). If unsure, observations are recorded to a more general category (e.g. family). Unidentified species are recorded as “Unid. Sp. 1”, “Unid. Sp. 2”, etc.
6. If bird calls are recognised, they are recorded as “Heard”. This data is used to build the species list for each area. As bird calls are not consistently identified (depending on the experience of the survey team), this data is not used for further analysis.

2.5 Megafauna Sightings

All sightings of marine mammals, marine reptiles and elasmobranchs (sharks and rays) are recorded in the megafauna logbook. Sighting records included as much information as possible, including species, size, sex, depth, time of sighting and location. When possible, the GPS position of the sighting is recorded for population mapping.

2.6 Data Analysis

2.6.1 The Simplified Integrated Reef Health Index

The use of indicators to evaluate and interpret reef health translates numerical data into distinct, comprehensible categories. By monitoring these indicators over time the progress of the reef can be assessed and reefs are placed in one of the following five categories: Very Good, Good, Poor, Fair or Critical. This allows trends or spatial comparisons to be made, gaining insights into the most important aspects of an individual site or over an entire area.

Healthy Reefs for Healthy People developed an index in 2008 ranking criteria for indicators of reef health with the view to map reef health giving a comprehensive view of the region (Healthy Reefs Initiative, 2008). This was reviewed and the Simplified Integrated Reef Health Index (SIRHI) was created to monitor 4 specific areas;

- **Hard coral cover (%)**
- **Fleshy macroalgal cover (%)**
- **Biomass of key herbivorous fish** (acanthurids and scarids; g 100 m^{-2})
- **Biomass of key commercial fish** (lutjanids and serranids; g 100 m^{-2})

The data collected on these four indicators are then graded to give an indication of reef health. The mean data value of each indicator is converted into a grade or condition from one ("Critical") to five ("Very Good") depending upon specific data ranges (Table 2.1).

Table 2.1 Threshold values by indicator used to determine the SIRHI

SIRHI Indicators (Score)	**Very Good (5)**	**Good (4)**	**Fair (3)**	**Poor (2)**	**Critical (1)**
Hard Coral Cover (%)	≥40	20.0-39.9	10.0-19.9	5.0-9.9	<5
Fleshy Macroalgal Cover (%)	0-0.9	1.0-5.0	5.1-12.0	12.1-25	>25.0
Key Herbivorous Fish (g 100 m^{-2})	≥3480	2880-3479	1920-2879	960-1919	<960
Key Commercial Fish (g 100 m^{-2})	≥1680	1260-1679	840-1259	420-839	<420
Overall Reef Health (Average Score)	4.2-5.0	3.4-4.2	2.6-3.4	1.8-2.6	1.0-1.8

2.6.2 Detailed Reef Health Analysis

Benthic, fish and invertebrate data were grouped according to ecological function and/or taxonomy, with comparisons made for percentage contribution, abundance, size (estimated length, target species only) and biomass by site and management zone. Biomass was calculated from published length-weight conversions (Marks and Klomp, 2003; Froese and Pauly, 2011), using the middle value for fish length in each size class and 50 cm as the fish length for fish recorded as >40 cm, according to standard calculations used by the Atlantic and Gulf Rapid Reef Assessment (Marks and Klomp, 2003). Biomass is reported in g/100 m^2, to align with regional standards. Hard coral species, fish species, and algal genera, were compared by percentage contribution, abundance and biomass by site and management zone.

Community diversity for hard coral and fish species was determined from PIT and fish belt occurrence and abundance data. The species richness and Simpson's Diversity Index (SDI) was determined for each transect, following which the mean for each site with standard error of the mean was calculated. The SDI was calculated for each transect using the following formula:

$$1-\lambda = 1-\frac{\sum n(n-1)}{N(N-1)}$$

Where $(1-\lambda)$ is SDI, n is the abundance of a single species, and N is the total abundance for all species along that transect. This index integrates the total species richness as well as the relative contribution of each species to total abundance. Therefore, a large SDI value (maximum of 1) indicates a high diversity, with species composition evenly spread in the community, whereas a low SDI value (minimum of 0) indicates that one or few species is dominant.

Hard coral community health was compared for the frequency of disease, hyperplasm/neoplasm, competition and overgrowth by tunicates, sponges, gorgonians, fire corals and other species of hard coral by site and year.

An index was developed to compare coral mortality by site and year, and was calculated for each site from all sampled scleractinian coral colonies using the following formula:

$$Mortality\ Index = \frac{p_{(1-25\%)} + 2p_{(26-50\%)} + 3p_{(51-75\%)} + 4p_{(>75\%)}}{5}$$

Where p is the percentage frequency of colonies recorded to have $x\%$ mortality. The index for each site in 2010 and 2011 was transformed using the arcsine transformation before comparison to account for the truncation of the normal distribution curve at 0 and 80 due to the theoretical minimum and maximum values for the index. Transformed mortality indices for each site were compared from 2010 to 2011 using the non-parametric Wilcoxon Matched Pairs t. Encounter frequency of mortality (presence or absence) was also compared for sites between years using the *G*-test.

Bleaching was categorised according to the degree of tissue discolouration as well as the percentage of the colony affected. Any instance of tissue paler than what is considered to be typical colour variation, was classified as “Pale”. For instances where the less than 75% of the colony exhibited white, fully bleached tissue, the colony was classified as “Partially Bleached”, and for instances where greater than 75% of the colony exhibited white, fully bleached tissue, the colony was classified as “Fully Bleached”.

Published trophic level data (Froese and Pauly, 2011) what used to calculate the contribution of fish trophic levels to biomass at each site, with a trophic level ≤ 2 equivalent to a herbivorous diet, 2.1-2.9 equivalent to an omnivorous diet dominated by vegetal matter, 2.9-3.7 equivalent to an omnivorous diet dominated by animal matter, 3.7-4.0 equivalent to a carnivorous diet dominated by invertebrates, and a trophic level > 4.0 equivalent to a carnivorous diet dominated by fish.

Fish rover surveys were analysed following the Reef Environmental Education Foundation’s protocol (REEF, 2007). Abundance data were classified into four categories, “Single” (1), “Few” (2-10), “Many” (11-100) and “Abundant” (>100), allowing the calculation of sighting frequency ($\%SF$) and a density index (Den) to be calculated for each species and family using the following formulae:

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

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

Where S, F, M and A are the number of times the species/family is recorded into the categories Single, Few, Many and Abundant, and n is the number of sampling occasions. $\%SF$ greater than 50 and Den values greater than 3.00 are considered to be high (REEF, 2007). The product of $\%SF$ and Den was calculated to portray an overview of fish family composition by site, with the maximum value of 400 indicating that the family is observed as “Abundant” on every sampling occasion.

2.6.3 Megafauna

Marine turtle size was estimated as Standard Carapace Length (SCL), the straight line measurement from the middle anterior of the carapace to the posterior-most marginal scute (Wyneken, 2001). Sex was determined only in adults, when a male is recognised by an elongated tail (Wyneken, 2001). As there is no obvious external sexual dimorphism in juveniles (Wyneken, 2001), to prevent an over-estimation of the adult female population the upper limits for local records of size of maturity were used for each species where they were available (Table 2.2).

Table 2.2: SCL for each species used to classify turtle sightings as immature or adult

Species Common Name	Species Latin Name	SCL at First Maturity	Reference
Hawksbill	*Eretmochelys imbricata*	80 cm	Moncada *et al.*, 1999
Loggerhead	*Caretta caretta*	92 cm	Parham and Zug, 1997
Green	*Chelonia mydas*	99 cm	Goshe, 2009

Average adult size for the Floridian manatee is 350 cm and the minimum size at sexual maturity is 275 cm (U.S. Fish and Wildlife Service, 1999). However, mother measuring 260 cm with calf (200 cm in length) was observed in Belize (Caryn Self-Sullivan, personal communication), suggesting that Antillean manatees mature at smaller lengths relative to the Floridian sub-species. Given the lack of specific information for the Antillean manatee, data was not interpreted in terms of maturity.

Dolphins are considered to reach sexual maturity at 85-95% of mean adult body length (Whitehead and Mann, 1999). Stolen *et al.*, 2006, found that bottlenose dolphins reach asymptotic length at 250 cm, and Whitehead and Mann (1999) reported that mean adult body length of Atlantic spotted dolphins was 200 cm. Based upon this information, size of first maturity was conservatively estimated at 238 cm for bottlenose dolphins and 190 cm for Atlantic spotted dolphins.

A correction factor was calculated for each zone to account for bias due to unequal diving effort throughout the reserve, using the following formula:

$$Correction\ Factor = \frac{n_{Observed}}{n_{Expected}}$$

Where $n_{Observed}$ is the number of dives conducted in that zone, and $n_{Expected}$ is the total number of dives that would have been conducted in that zone had diving effort been equal, that is:

$$n_{Expected} = \frac{Total\ Number\ of\ Dives}{Number\ of\ Zones\ Visited}$$

The corrected sighting frequency is therefore actual sighting frequency divided by the correction factor.

3. Results

3.1 Coral Reef Monitoring

3.1.1 Simplified Integrated Reef Health Indices (SIRHI)

In 2011 hard coral percentage cover (HCC) was lower at nine sites (range -0.33% to -10.83%) and greater at two (range 1.00 to 5.67) than in 2010. Conversely, percentage contribution of fleshy macroalgae to benthos was greater at nine sites (range 0.42% to 20.42%) and lower at two (range -0.95 to -10.30). The overall difference was that in 2011 hard coral contributed 3.12% less and fleshy macroalgae 3.79% more to the benthos than in 2010 (Table 3.1).

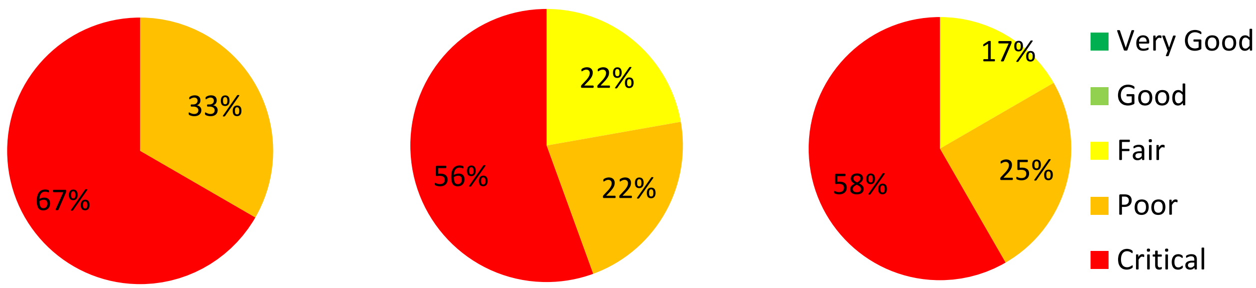
Similarly, in 2011 biomass of key herbivorous was lower in nine sites (range -537.24 to -2209.69) and greater in two sites (range 166.87 to 2530.90), representing an overall change of -844.31 g/100m^{-2}. Key commercial fish biomass was lower in five sites (range -83.75 to -1076.02) and greater in six sites (range 150.57 to 1093.63), representing an overall change of 13.35 g/100m^{-2} (Table 3.1).

Site GF1 was not surveyed in 2010.

Table 3.1. Change in reef indicators from 2010 to 2011. NA denotes no data available from 2010

Reef Type	Zone	Site Code	Hard Coral Cover (%)	Fleshy Macroalgae Cover (%)	Key Herbivorous Fish Biomass (g.100m^{-2})	Key Commercial Fish Biomass (g.100m^{-2})
Back-reef	General Use 1	GB1	-2.06	-10.30	-1638.98	-281.36
	Conservation 1	C1B1	-2.44	5.64	-1600.90	1093.63
	Preservation	PB1	-5.97	1.70	166.87	-83.75
Forereef	General Use 1	GF1	*NA*	*NA*	*NA*	*NA*
	Conservation 1	C1F1	5.67	4.23	-2114.95	763.96
		C1F2	-1.46	8.75	-2209.69	-1076.02
	Conservation 2	C2F1	1.00	2.23	2530.90	481.09
		C2F2	-3.08	-0.95	-703.35	504.21
	Preservation	PF1	-8.75	11.04	-1223.24	150.57
		PF2	-6.04	0.42	-598.87	175.17
		PF3	-10.83	20.42	-537.24	-709.31
		PF4	-0.33	-1.52	-1357.94	-871.33
Overall Difference			**-3.12**	**3.79**	**-844.31**	**13.35**

Average SIRHI score for Bacalar Chico was 1.90, ranking as 'Poor'. Over half of coral reefs at Bacalar Chico were in 'Critical' condition (Figure 3.1), with the majority of reef benthos exhibiting 'Poor' or 'Critical' fleshy macroalgal levels and key commercial fish biomass generally low (Table 3.2).



(a) (b) (c)

Figure 3.1. Coral reef condition: (a) backreef, (b) forereef and (c) throughout Bacalar Chico

Table 3.2. SIRHI scores for each indicator and overall coral reef condition of sites in Bacalar Chico

Reef Type	Zone	Site Code	Hard Coral Cover	Fleshy Macroalgae Cover	Key Herbivorous Fish Biomass	Key Commercial Fish Biomass	Overall Reef Condition
Back-reef	General Use 1	GB1	Critical	Poor	Critical	Critical	Critical
	Conservation 1	C1B1	Poor	Critical	Poor	Good	Poor
	Preservation	PB1	Poor	Fair	Critical	Critical	Critical
Forereef	General Use 1	GF1	Good	Poor	Fair	Poor	Fair
	Conservation 1	C1F1	Good	Critical	Poor	Fair	Poor
		C1F2	Fair	Critical	Critical	Critical	Critical
	Conservation 2	C2F1	Fair	Critical	Very Good	Poor	Fair
		C2F2	Poor	Critical	Critical	Poor	Critical
	Preservation	PF1	Fair	Poor	Poor	Critical	Poor
		PF2	Fair	Poor	Critical	Critical	Critical
		PF3	Critical	Critical	Poor	Critical	Critical
		PF4	Critical	Poor	Poor	Critical	Critical

Three sites had critically low HCC – GB1, in the backreef of the GUZ, as well as PF3 and PF4, both located on the eastern ridge of the forereef in the PZ. These sites also score as 'Poor' or 'Critical' for all other indicators, and were 'Critical' in terms of overall reef condition (Table 3.2).

Only PB1, the backreef site in the PZ, was 'Fair' in terms of macroalgal coverage, with all other sites scoring as 'Poor' or 'Critical' (Table 3.2). However, PB1 had 'Poor' HCC and critically low fish biomass.

Key herbivorous fish (acanthurid and scarid) biomass was generally low throughout Bacalar Chico (Table 3.2). GF1, in the forereef of the GUZ, had 'Fair' herbivorous fish biomass. This site was one of only two sites found to have 'Fair' overall coral reef health. One of the forereef sites in CZ 2, C2F1, had 'Very Good' herbivorous fish biomass, whilst the neighbouring survey location, C2F2, was found to have critically low herbivorous fish biomass. Acanthurids were frequently observed in large schools at C2F1, and were the greatest contributor to key herbivorous fish biomass at this site.

Biomass of key commercial species (lutjanids and serranids) was critically low at all sites in the PZ (Table 3.2). Only one site, C1B1, located in the backreef of CZ1, had 'Good' commercial fish biomass, predominantly composed of lutjanids. C1F1, within the forereef of CZ 1, had 'Fair' key commercial fish biomass; all remaining sites were either 'Poor' or 'Critical'.

3.1.2 Benthic Composition

Overall HCC at Bacalar Chico was 10.12% ± 1.02, varying greatly across reef location and management zone (Figure 3.2). There was no significant difference between HCC in 2010 (10.46% ± 0.76) and 2011 (Mann-Whitney U = 2111.0, P = 0.215).

HCC was greatest on the forereef (11.65% ± 1.25), though the two sites on the eastern ridge of the PZ had extremely low HCC (PF3, 3.96% ± 0.52 and PF4, 2.17% ± 1.01 (Figure 3.3).

The forereef of the GUZ had the greatest overall HCC (20.33% ± 1.53; Figure 3.2), followed closely by CZ 1 (19.72% ± 2.10; Figure 3.2). The site with the greatest HCC was C1F1, located on the forereef of CZ 1 (22.33% ± 2.96; Figure 3.3).

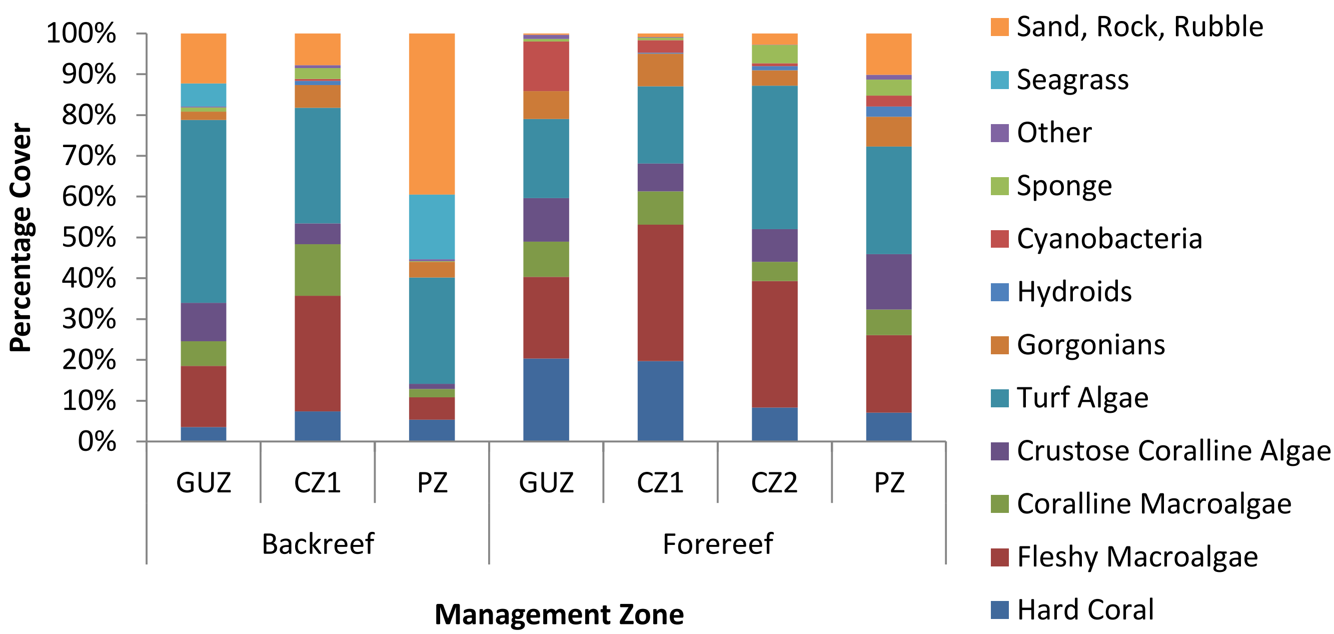


Figure 3.2. ***Benthic composition of coral reefs in each management zone of Bacalar Chico, separated by reef type***

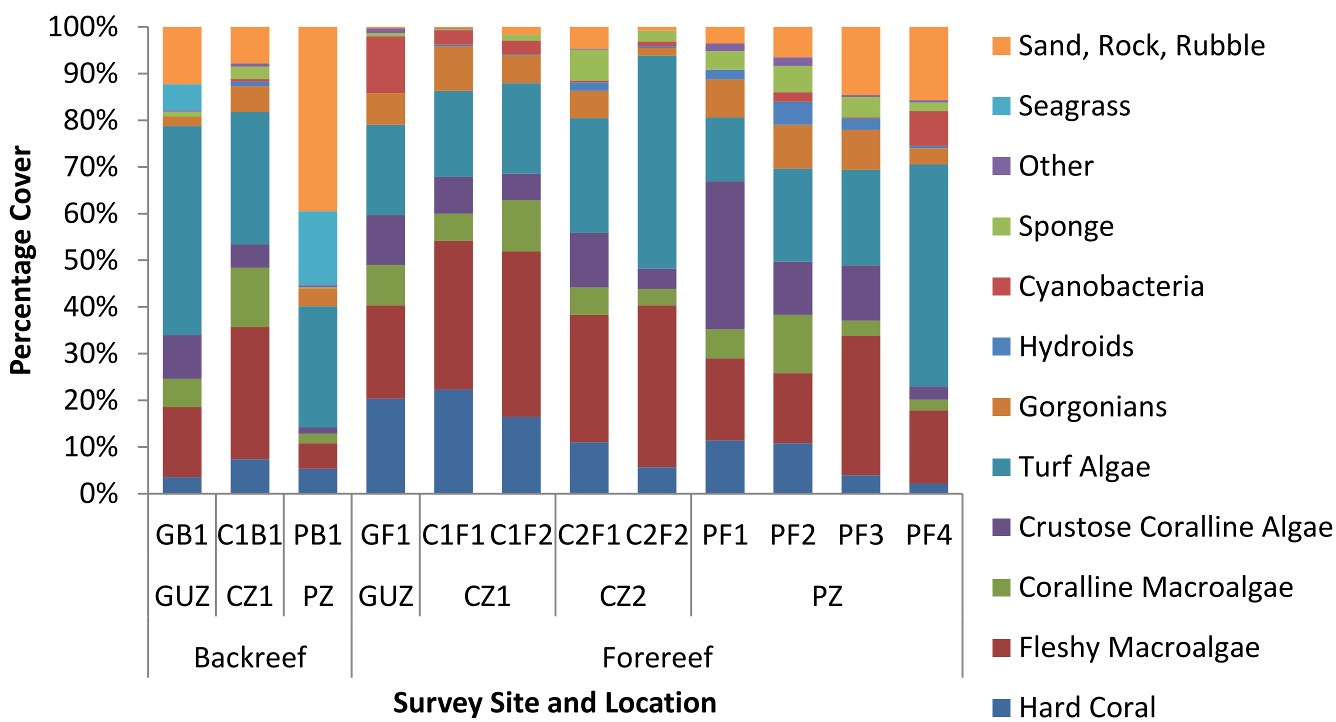


Figure 3.3. ***Benthic composition of coral reef survey sites in Bacalar Chico, separated by management zone and reef type***

Benthic macroalgae were dominant along all benthic transects (Figure 3.2 and Figure 3.3), with turf algae occupying the majority of the benthos (32.21% ± 5.03 in the backreef and 26.01% ± 2.25 in the forereef). Fleshy macroalgae were also common (16.37% ± 3.53 in the backreef and 25.08% ± 1.72 in the forereef), and crustose coralline algae occupied a large proportion of the benthos on the forereef (10.48% ± 1.33).

Backreef sites in the GUZ and PZ had patchy distribution of benthos, with a large proportion recorded as sand, rock or rubble (Figure 3.3). Both forereef sites on the eastern ridge of the PZ (PF3 and PF4) appeared to have been damaged by hurricanes, and exhibited a high proportion of sand, rock or rubble (14.58% ± 3.73 and 15.67% ± 6.19 respectively).

The most commonly encountered genus of macroalgae was *Dictyota* (11.60% ± 1.02, Figure 3.4), though macroalgal abundance and composition differed between zones and location (backreef or forereef). *Lobophora* was only recorded in the forereef at three sites, and never recorded within the PZ (Figure 3.4).

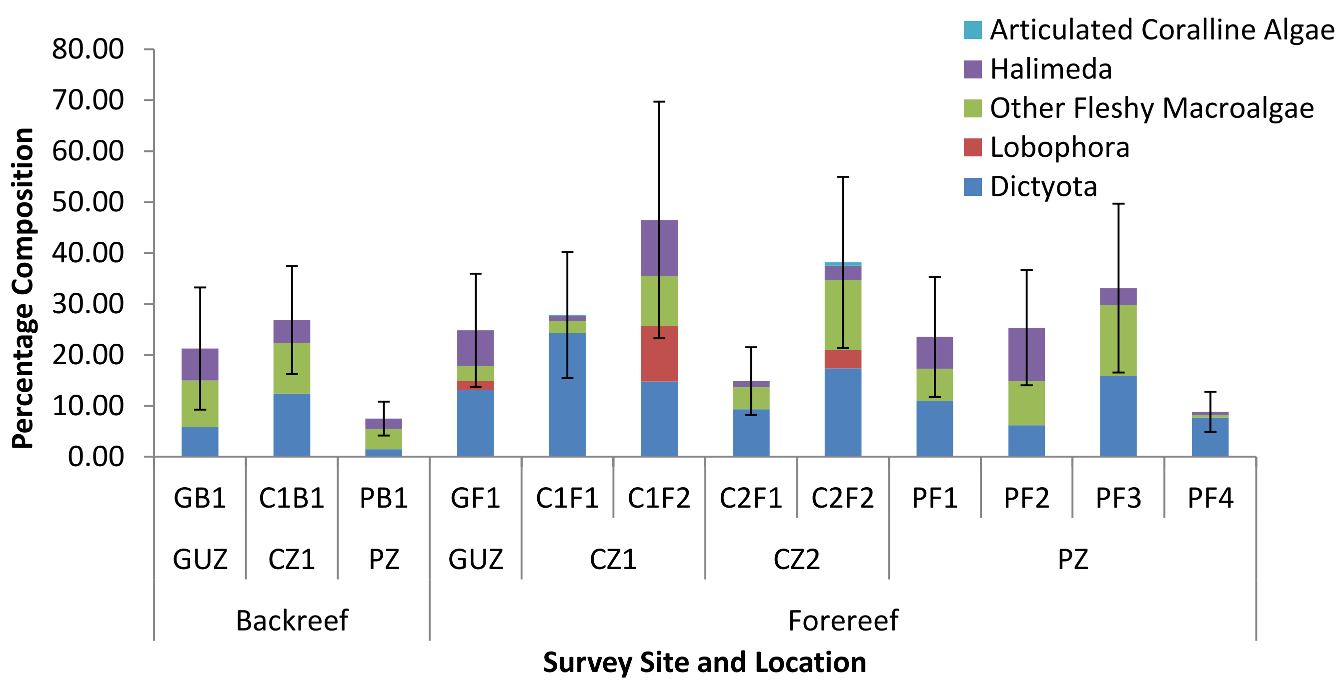


Figure 3.4. ***Fleshy and coralline macroalgal composition by management zone of Bacalar Chico, separated by reef type***

3.1.2a Hard Coral Community Diversity

Hard coral species richness and diversity was greatest in forereef sites of the GUZ and CZ 1 (Figure 3.5). At each of these sites, the most frequently encountered species was *Agaricia agaricites*. Diversity of coral species was also high at sites C1B1 (CZ 1, backreef) and PF3 (PZ 1, eastern ridge of the forereef).

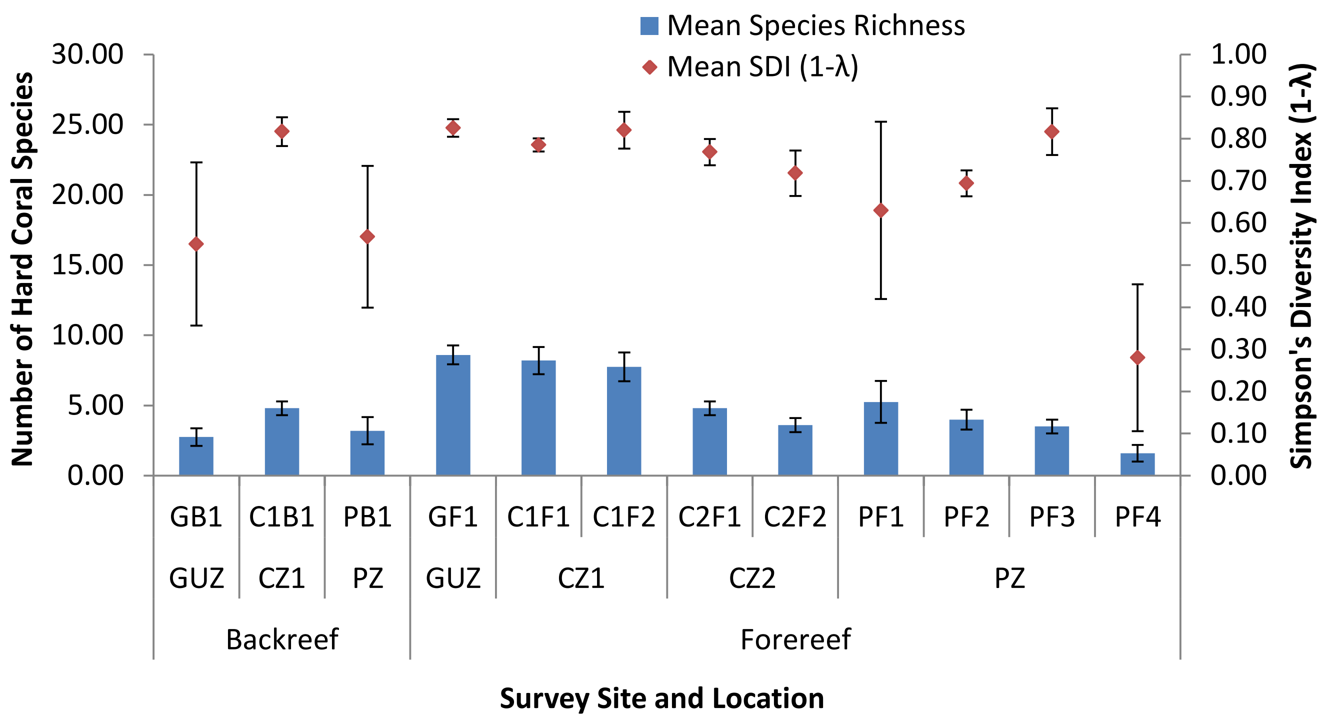


Figure 3.5. ***Hard coral species richness and Simpson's Diversity Index (SDI) for each site***

3.1.2b Coral Community Health

A total of 41 species of coral were encountered during coral community health surveys, with *A. agaricites* (24.67%), *Porites astreoides* (18.54%) and *Siderastrea siderea* (16.89%) as the most frequently encountered species. The next most frequently encountered species was *Montastraea cavernosa* (5.63%) and all other encountered species each contributed less than 5.00% to total encounters.

There was no significant change in overall scleractinian coral mortality between 2010 and 2011 (Matched Pairs $t = -0.947$, df = 10, P = 0.366; Figure 3.6), however there were significant site-specific changes in coral mortality between 2010 and 2011 at six of the eleven sites that were surveyed in both years.

The encounter frequency of coral mortality was significantly lower in 2011 at two backreef sites, C1B1 (G = 28.582, df = 2, P < 0.01) and PB1 (G = 5.145, df = 1, P < 0.05), whilst it was significantly higher in 2011 at three forereef sites, C1F1 (G = 14.031, df = 2, P < 0.01), C2F2 (G = 9.181, df = 1, P < 0.01), and PF3 (G = 15.417, df = 1, P < 0.01). Furthermore, there was as significant difference between encounter frequencies at site PF4 for surveys in 2010 and 2011 (G = 20.413, df = 2, P < 0.01), with a higher frequency of coral mortality in April 2010 (Series "2010 (Extra)") than in October 2010 or October 2011 (Figure 3.6).

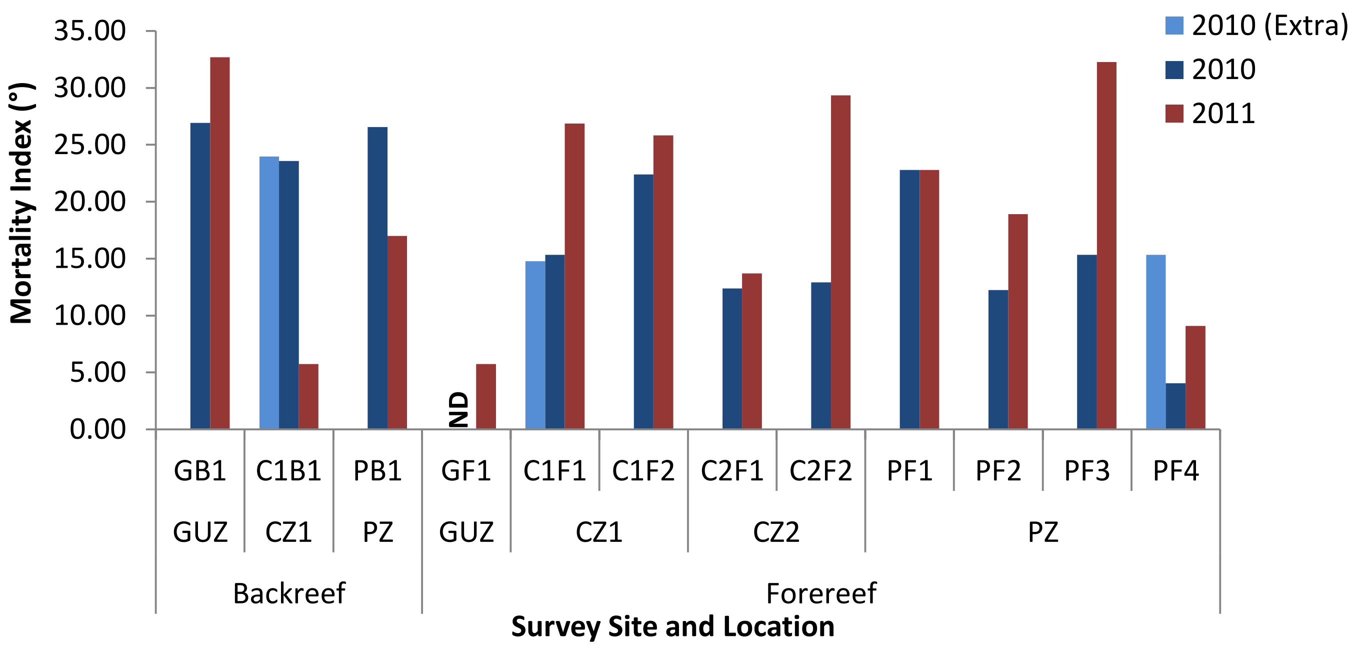


Figure 3.6. ***Comparison of mortality indices for scleractinian coral at sites in each management zone of Bacalar Chico between 2010 and 2011. Three sites, C1B1, C1F1 and PF4, were surveyed twice in 2010, depicted by an additional bar: Series "2010 (Extra)". No data is available for Site GF1 in 2010.***

Predation on corals existed predominantly as scars from scarids and algal farming by pomacentrids, occupying only small surfaces of the coral colonies. Predation was greatest at C1F2 (36.00%), on the forereef of CZ 1 (Figure 3.7). It was also high at PB1 (24.39%) and PF3 (32.56%).

Competition to scleractinian corals existed primarily in the form of macroalgal shading. In addition, scleractinian corals were occasionally found overgrown by hydrocorals or the tunicate *Trididemum solidum*, as well as one instance of overgrowth by a gorgonian. The greatest encounter frequencies of competition were recorded at PF2 (8.00%), PF3 (6.98%), C2F1 (6.12%) and C2F2 (6.00%) (Figure 3.7).

Orange icing sponge (*Mycale laevis*) was encountered at every site except PB1, C2F1, and PF4 (Figure 3.7). Encounter frequency of *M. laevis* was greatest at PF1 (22.00%), where it associated with *Montastraea annularis*, *M. franksi, Agaricia agaricites*, *A. tenuifolia*. and *P. astreoides*. At other sites, *M. laevis* also associated with *M. faveolata*, *S. siderea* and *Diploria strigosa*.

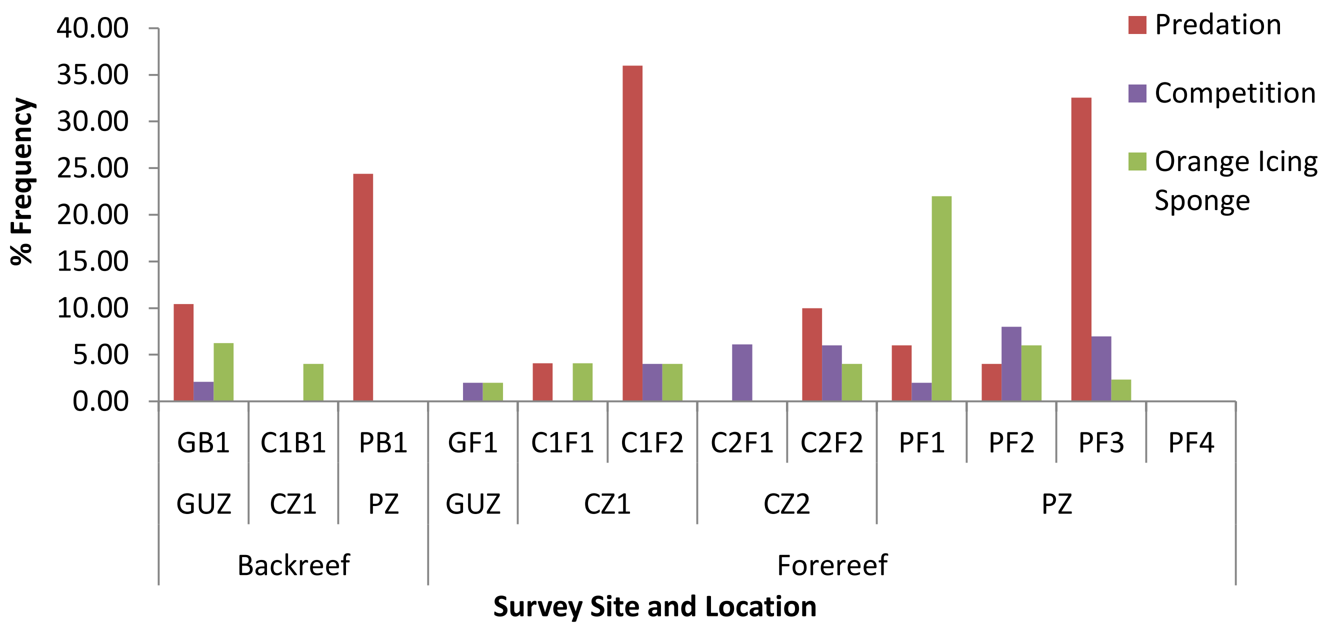


Figure 3.7. Percentage frequency of predation, competition and orange icing sponge by site and management zone at Bacalar Chico

In total 4.48% (n = 26) of hard coral colonies were recorded with disease (Figure 3.8), which was not significantly different from 2010 (1.88%, n = 15; Figure 3.8; Matched Pairs t = -1.369, df = 10, p = 0.201). The most frequently affected species in 2011 were *Meandrina meandrites* (20.00%, n = 1), *Acropora palmata* (16.67%, n = 2), *Diploria clivosa* (14.29%, n = 1), *S. siderea* (12.75%, n = 13) and *Montastraea faveolata* (11.76%, n = 2).

Dark spot was the most frequently encountered disease in 2011 (2.24%, n = 13; Figure 3.8). This was equivalent to a frequency of 1.05% ± 1.05 for each survey site, which was not significantly different when sites were compared to data from 2010 (0.63%, n = 5, for all sampled colonies in Bacalar Chico; 4.91% ± 2.90 frequency for each survey site; Matched Pairs t = -1.483, df = 10, p = 0.169). Of the diseased colonies, 50.00% (n = 13) were *S. siderea* infected with dark spot disease. No other coral species displayed signs of dark spot disease infection, nor did any *S. siderea* show signs of infection with any other disease.

Only a single colony of *D. strigosa* was infected with black band disease; no other *D. strigosa* surveyed were infected with any other disease, nor was black band disease recorded on any other species. 23% (n = 6) of diseased colonies were infected with white plague, affecting *A. agaricites*, *Montastraea faveolata* and *D. clivosa*. Yellow blotch disease was observed in 11.54% of colonies (n = 3), affecting *M. faveolata* and *Montastraea cavernosa*. Patchy necrosis was observed on two colonies of *A. palmata*. One colony each of *M. meandrites* and *A. agaricites* displayed signs of disease in the form of atypical dark, patchy colouration.

PF3 exhibited the greatest percentage frequency of disease, with 23.26% (n = 10) of scleractinian coral colonies displaying signs of infection (Figure 3.8). No colonies were recorded with disease at this site the previous year.

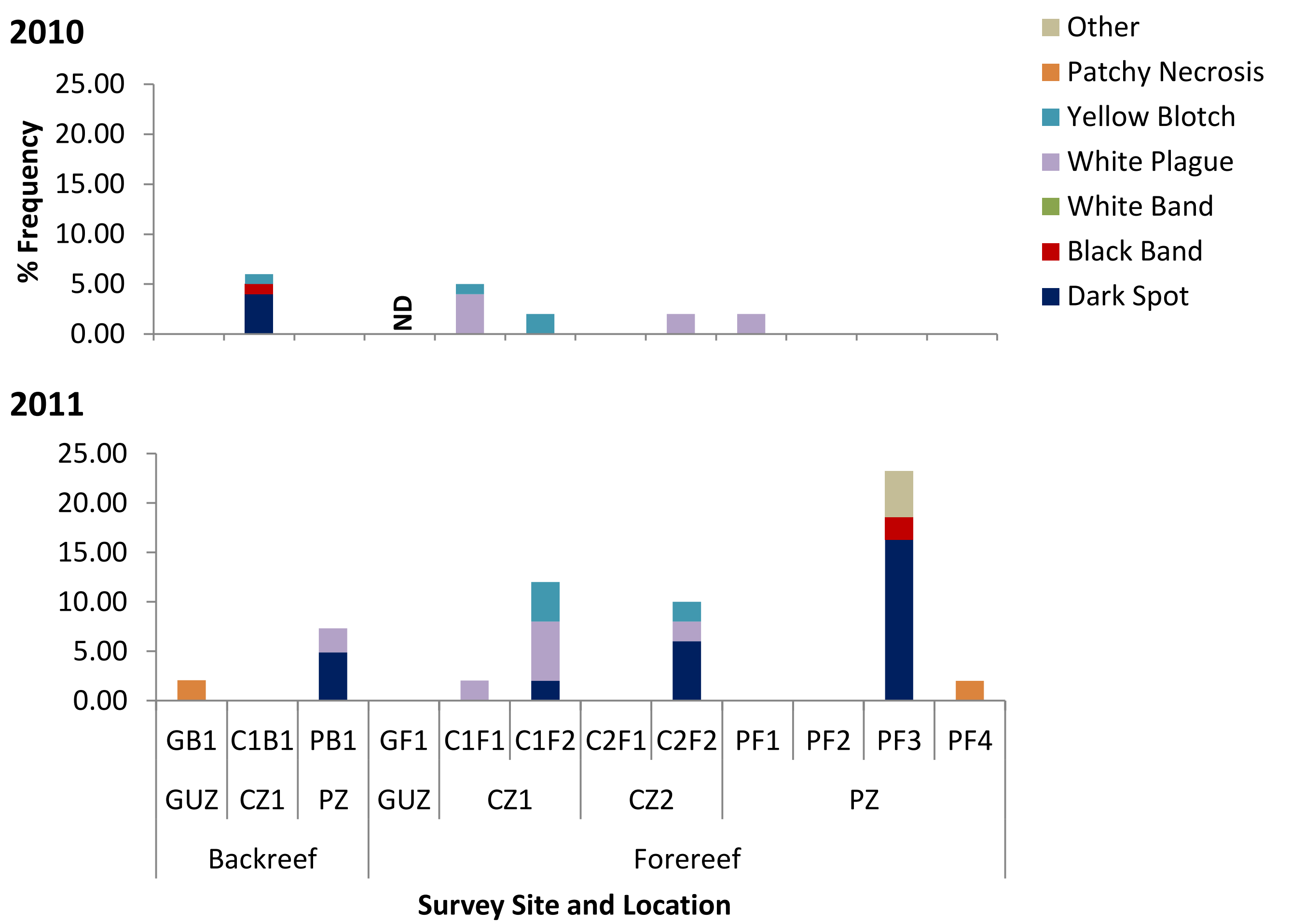


Figure 3.8. ***Percentage frequency of disease on scleractinian corals by site and management zone in Bacalar Chico, surveyed in 2010 and 2011. No data was available for Site GF1 in 2010 (ND).***

Three sites displayed 'red flag' levels of bleaching (Healthy Reefs, 2007), with greater than 10% of surveyed colonies at C1B1, C1F1 and C2F1 all exhibiting partial or full bleaching (Figure 3.9). The greatest incidence of bleaching was encountered in the backreef at C1B1 during October, where 20.00% (n = 10) of colonies displayed partial bleaching (less than 75% of bleached tissue). Full bleaching (greater than 75% of bleached tissue) was encountered in December at site C2F1, on the forereef, where 6.12% (n = 3) of colonies displayed full bleaching and 10.20% (n = 5) of colonies displayed partial bleaching.

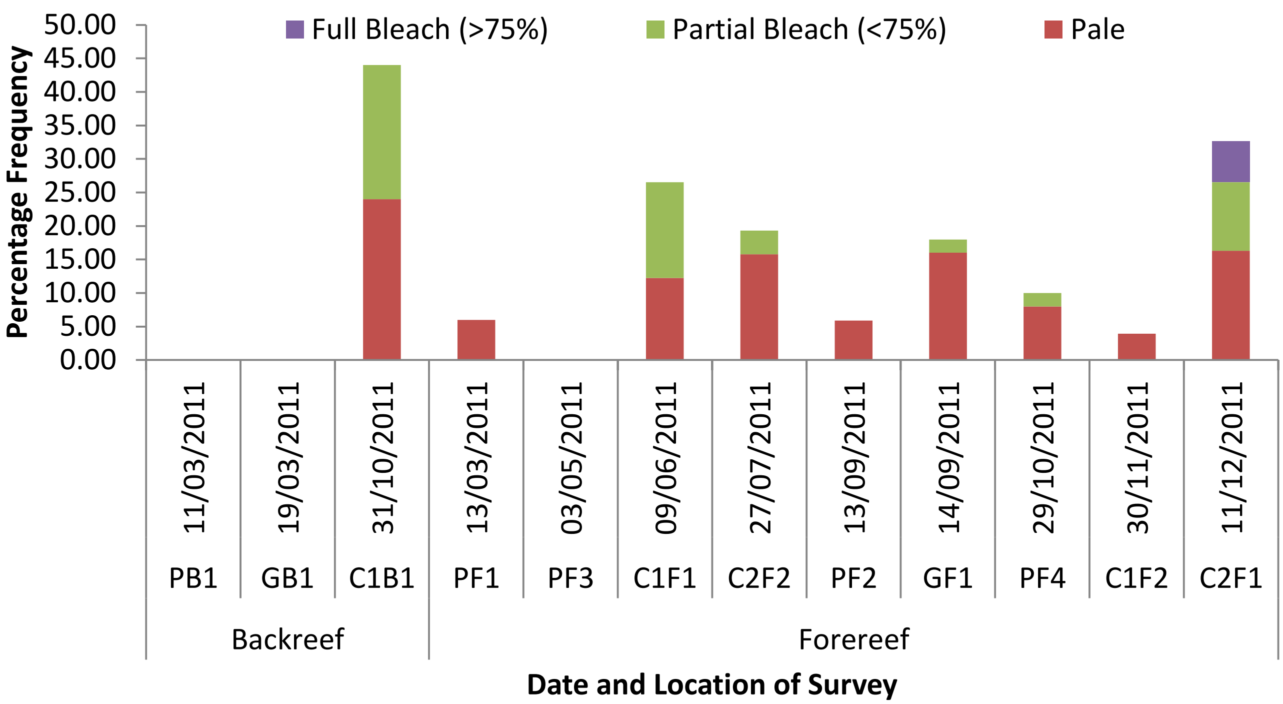


Figure 3.9. ***Percentage frequency of bleached colonies at survey sites, arranged by date of survey***

In total, eight species of scleractinian coral exhibited either paling or bleaching during the surveys (*Siderastrea siderea, Montastrea franksi, M. annularis, M. cavernosa, Porites porites, P. astreoides, Agaricia agaricites* and *Eusmilia fastigiata*). The most frequently bleached species was *Siderastrea siderea*, with over half (57.84%, n = 59) of sampled colonies exhibiting signs of bleaching.

3.1.3 Fish Community Composition

Fish abundance and biomass was variable across sites and zones (Figure 3.10 and Figure 3.11). The greatest fish abundance was recorded on the forereef in CZ 2 at C2F1 (total abundance 84.17 ± 45.17 fish 100 m^{-2}), the majority of which were acanthurids (48.33 ± 32.38 fish 100 m^{-2}), which were present in large schools on two of the transects. Lowest fish abundance was recorded on the eastern ridge of the forereef of the PZ, at PF3 and PF4 (22.71 ± 3.86 and 22.92 ± 5.73 fish 100 m^{-2} respectively). Abundance and biomass of priority fish were consistently low at all sites on the forereef within the PZ (Figure 3.10, Figure 3.11).

Fish biomass (Figure 3.11) was exceptionally low at site C1F2 (536.89 ± 94.51 g 100 m^{-2}), a forereef site within CZ 1. Fish abundance at this site was also low (29.17 ± 6.70 fish 100 m^{-2}).

Greatest fish biomass was recorded on the backreef of the PZ (8996.70 ± 3010.30 g 100 m^{-2}), though fish abundance at this site (41.46 ± 10.89 fish 100 m^{-2}) was approximately average for records at all sites in 2011. Over 80% of fish biomass was made up of haemulids (7313.13 ± 2473.44 g 100 m^{-2}), with the remaining biomass made predominantly of scarids (537.33 ± 280.33 g 100 m^{-2}) and balistids (669.42 ± 669.42 g 100 m^{-2}). Balistid biomass was entirely contributed by one large *Balistes vetula* recorded on one transect.

Scarid biomass was greatest at GF1, on the forereef of the GUZ, with 1748.17 ± 557.02 g 100 m^{-2}. Lionfish were recorded at two sites only – GF1 (General Use, Forereef) and PF2 (Preservation, Forereef, Western Ridge) – and contributed less than 1% of the biomass.

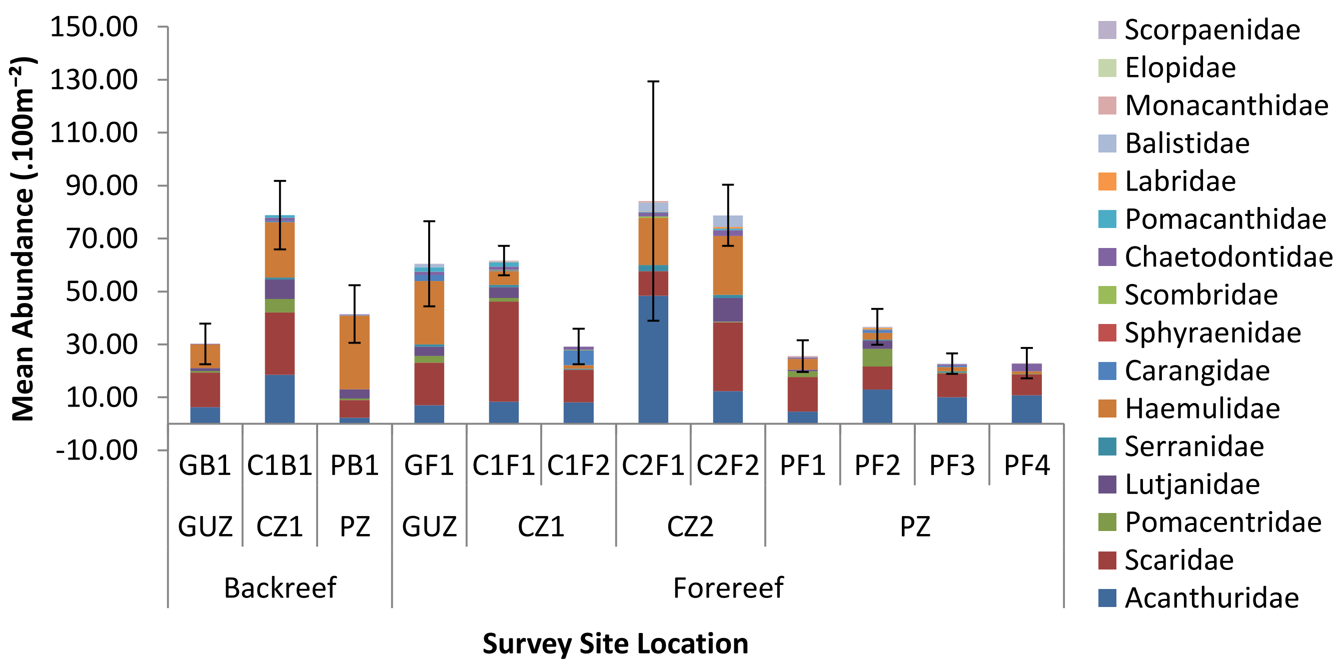


Figure 3.10. ***Mean abundance of priority fish species by family***

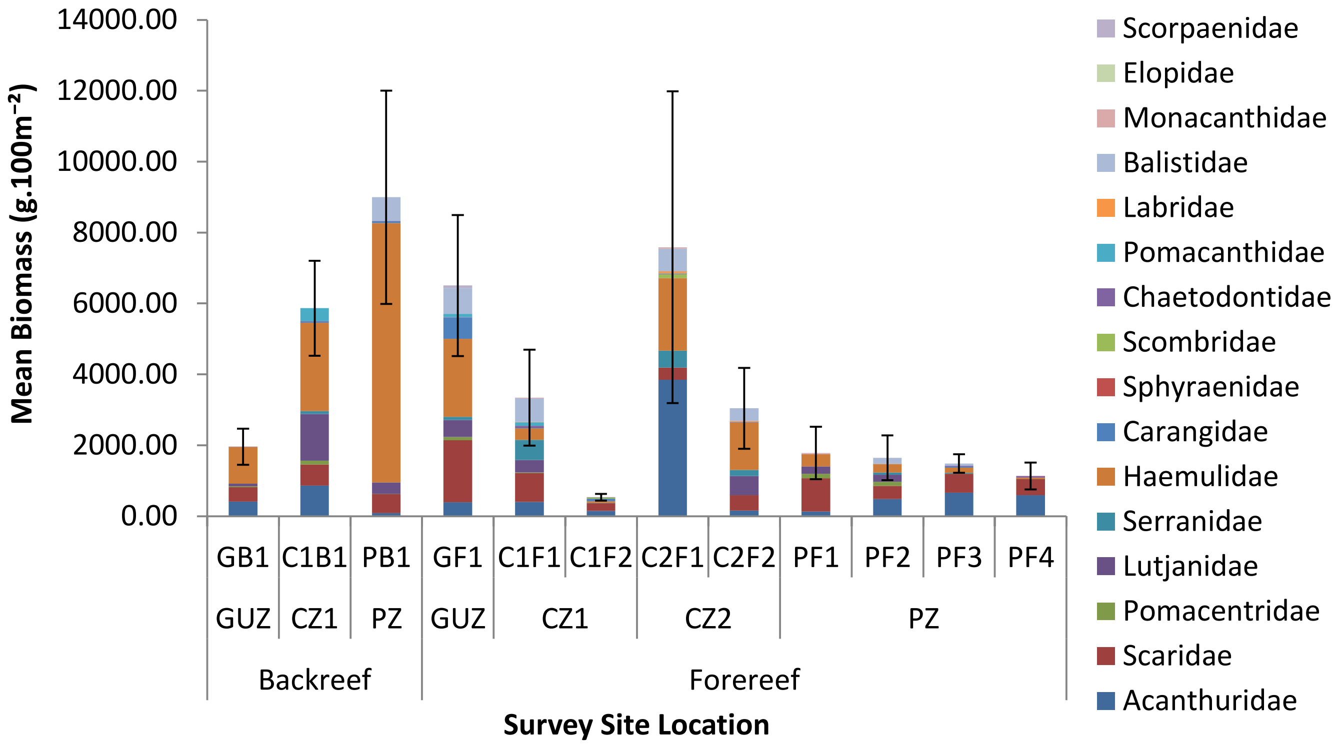


Figure 3.11. ***Mean biomass of priority fish species by family***

Omnivores, predominantly *Haemulon sciurus* and *H. flavolineatum*, were the largest contributor to biomass in all backreef sites. On the forereef, herbivorous species (scarids and acanthurids) were the greatest contributor to the biomass at all sites, except in the GUZ, and at one site each in CZ 1 (C1F1) and in CZ 2 (C2F2) (Figure 3.12). GF1 represents the site with the greatest heterogeneity in fish trophic guilds. Biomass of piscivorous carnivores is greatest at all sites in CZ 1 and in C2F2. At C1B1, this biomass is almost entirely composed of *Lutjanus apodus* and *L. mahogoni*. At C1F1, the piscivorous biomass is composed primarily of *L. apodus* and two large *Epinephelus striatus*. Two species composed the entirety of piscivorous biomass at both C1F2 (*Carangoides ruber* and *Scomberomorus regalis*) and C2F2 (*L. apodus* and *Cephalopholis fulva*).

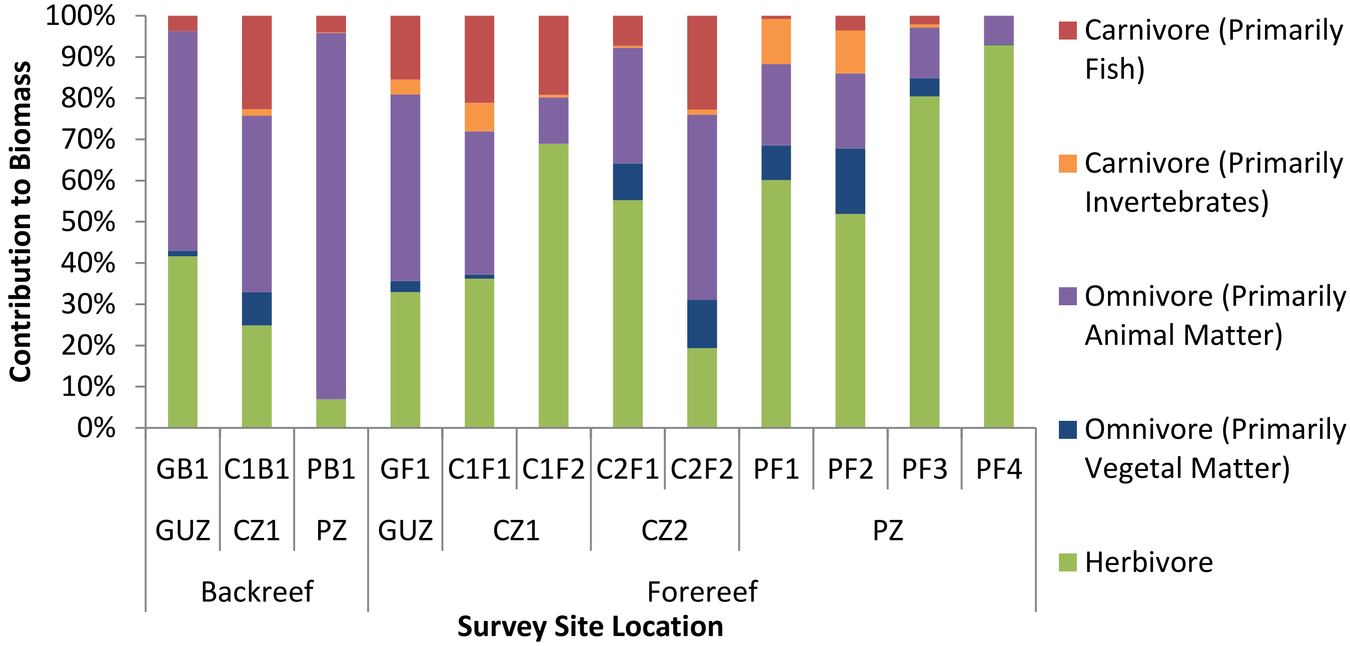


Figure 3.12. ***Percentage contribution of fish trophic guilds to biomass***

3.1.3a Fish Community Diversity

Species richness and Simpson's Diversity Index (SDI) were calculated using fish belt data of priority species (Figure 3.13). The greatest species richness was found on the forereef in CZ 1 (C1F1, 26 species) and the GUZ (GB1, 26 species). The lowest species richness was recorded at site PF4 (13 species), closely followed by PF3, C1F2 and GB1 (all 14 species).

The greatest diversity of species was observed in the backreef in CZ 1 (C1B1, SDI = 0.84 ± 0.02). The least diverse site was C2F1 (SDI = 0.68 ± 0.10), located on the forereef in CZ 2 (Figure 3.13).

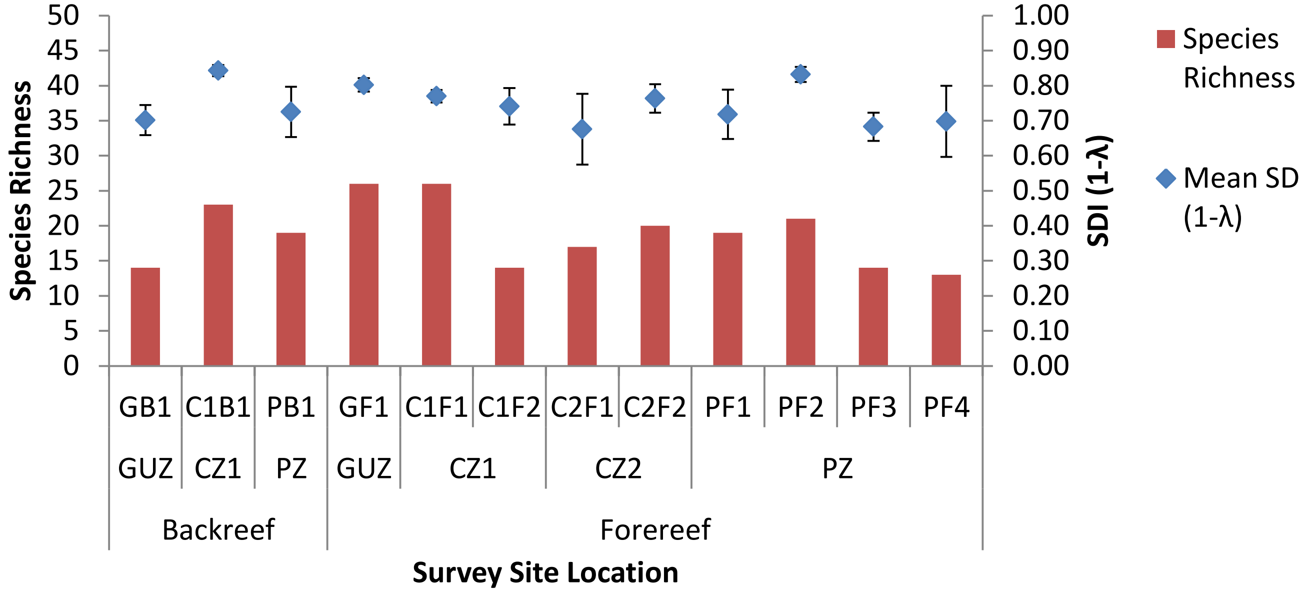


Figure 3.13. ***Species richness and Simpson's Diversity Index (SDI) by survey site and conservation zone***

In fish rover surveys, the greatest number of families was observed at C1F2 (21 families) and C2F1 (20 families). The greatest number of species was observed in the forereef of CZs 1 and 2 (C1F1, 53 species; C1F2, 52 species; C2F1, 49 species; C2F2, 52 species) (Figure 3.14).

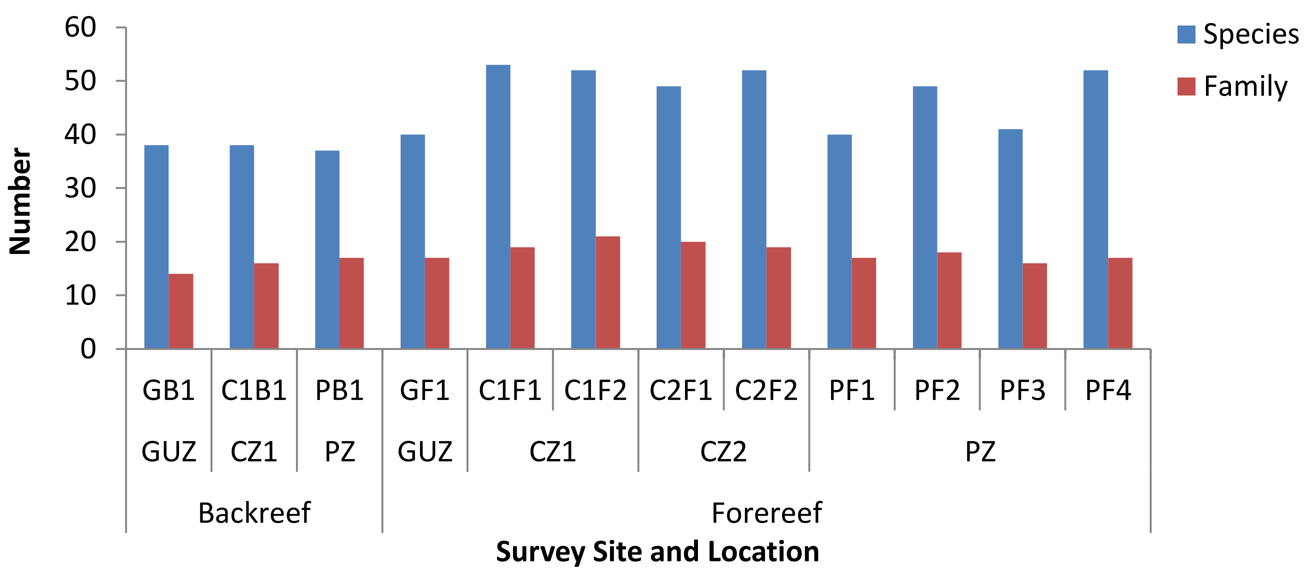


Figure 3.14. ***Number of fish species and families observed during fish rover surveys***

Labrids and scarids were consistently observed in high densities (greater than 3.00) at all sites during fish rovers (Figure 3.15). Pomacentrids, haemulids and acanthurids were also consistently observed, typically at high densities. Pomacentrid density was lowest at site PF3 (Den = 2.50), Haemulid density was lowest in CZ 1 (C1B1, Den = 2.67; C1F1, Den = 2.75; C1F2, Den = 2.25) and in the backreef of the GUZ (GB1, Den = 2.60). Acanthurid density was lowest on the forereef of the PZ (PF2, Den = 2.75; PF4, Den = 2.80).

Kyphosids were seen at only two sites, C2F1 and C1F2, where they were consistently seen at intermediate densities (‘Few’ and ‘Many’). Ephippids were consistently observed at only one site, C2F1, in low densities. Tetraodontids, specifically *Canthigaster rostrata*, were observed at all sites except PB1. Typically, *C. rostrata* was observed in low densities (0.25-2.00), though on the eastern ridge of the forereef of the Preservation Zone they were present in high densities (PF3, Den = 4.00; PF4, Den = 3.00). Elasmobranchs species observed on fish rovers were the spotted eagle ray and southern stingray, sighted at low densities and infrequently.

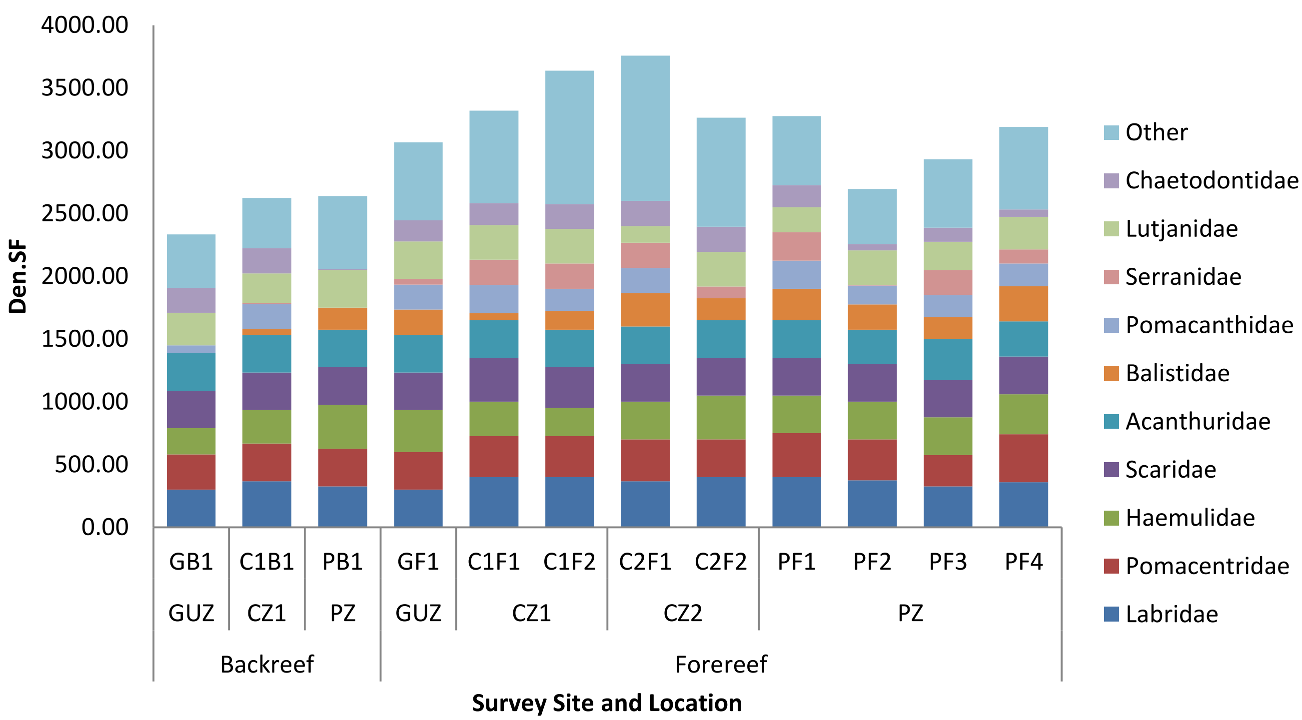


Figure 3.15. Fish family prevalence at each site for the ten most frequently encountered fish families during fish rover surveys, expressed as a product of a measure of abundance (Den) and the sighting frequency (SF)

The most commonly encountered species was *Acanthurus coeruleus,* which was sighted on every survey and at every site. Density of individual species varied between sites (Table 3.3) with *A. coerulus* and *Sparisoma iserti most frequently* observed at high densities.

Table 3.3. ***Fish species observed with* Den *values greater than 3.00, i.e. most commonly recorded as 'Many' or 'Abundant'***

Reef Type:	**Backreef**			**Forereef**								
Management Zone:	**GUZ**	**CZ1**	**PZ**	**GUZ**	**CZ1**		**CZ2**		**PZ**			
Species **Site:**	**GB1**	**C1B1**	**PB1**	**GF1**	**C1F1**	**C1F2**	**C2F1**	**C2F2**	**PF1**	**PF2**	**PF3**	**PF4**
A. coerulus	3.00	3.00		3.00			3.00		3.00		3.00	3.00
A. bahianus					3.00		3.00	3.00			3.25	
Haemulon sciurus			3.00	3.00			3.00					
H. flavolineatum	3.00		3.00	3.00			3.00	3.00				
H. plumierii							3.00	3.00				
Chromis cyanea		3.00		3.00	3.00				3.00			3.00
Stegastes partitus					3.00	3.25		3.00	3.00	3.00		
Mycrospathadon chrysurus									3.00	3.00		
Lutjanus mahogoni			3.00									
L. apodus				3.00								
Clepticus parrae					3.25			3.00		3.25		
Thalassoma bifasciatum								3.75				
Sparisoma iserti					3.00	3.00		3.00	3.00		3.00	3.00
S. aurofrenatum					3.00	3.00		3.00	3.00		3.00	
S. viridae									3.00	3.00		
Kyphosus sectatrix/incisor						3.00						
C. rostrata											4.00	3.00

3.1.3b Fish Recruitment

Not all fish recruitment abundance data met criteria for parametric testing (Shapiro-Wilk test for normality, $p < 0.05$; Levene's test for equal variance, $p < 0.05$), therefore the non-parametric Kruskal-Wallis One-Way ANOVA on ranks was performed to compare differences across all sites and pair-wise comparisons made using the Mann-Whitney rank sum test to test for site specific differences.

There was a significant difference between the number of fish recruits on the forereef between management zones (CZ 1 and 2) in November ($U = 0.500$, $p \leq 0.001$), with the median abundance greater in CZ 2 than CZ 1 (Figure 3.16).

The median abundance of fish recruits at C1F1, on the forereef of CZ 1 in November, was significantly different to all other sites, with a lower median abundance at this site ($H = 25.411$, $df = 5$, $p < 0.05$).

No significant difference was detected among the remaining sites.

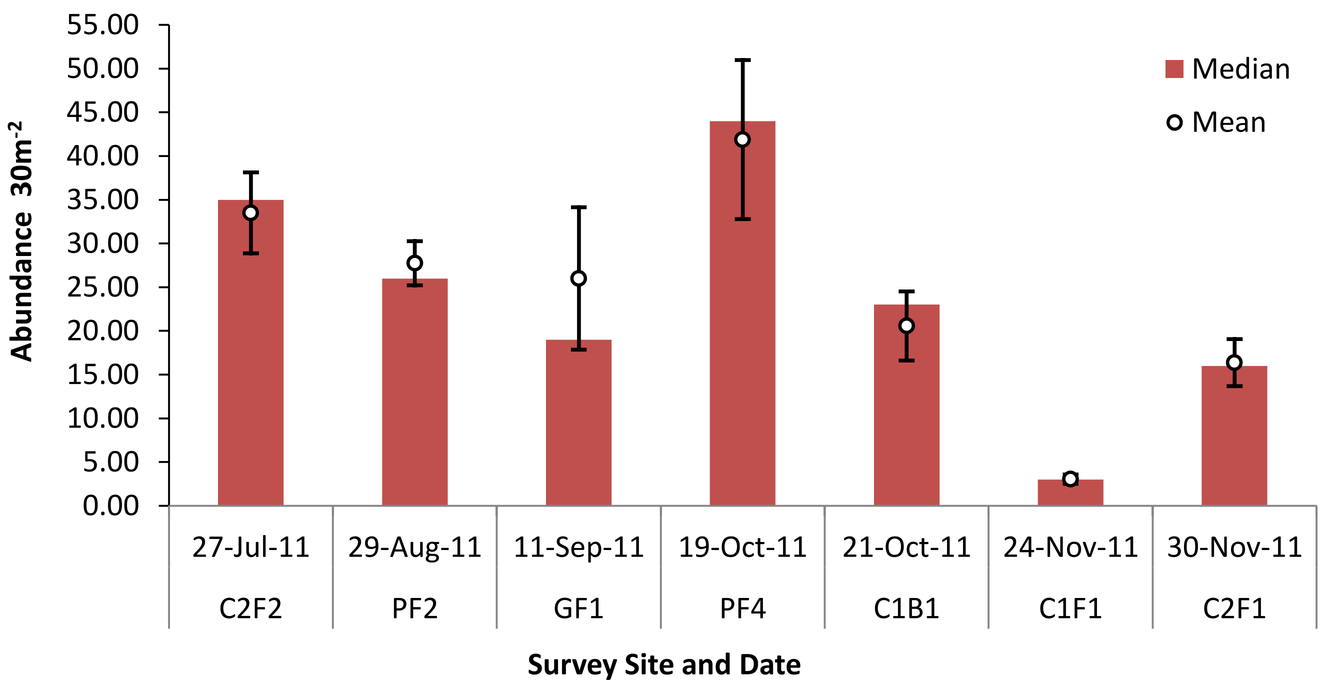


Figure 3.16. ***Median and mean (± standard error) abundance of fish recruits along 30 m^2 belts, presented chronologically***

3.1.3c Target Commercial Species

The most commonly sighted target commercial species was *Sphyraena barracuda*, with 339 sightings in 354.9 hours of diving. The majority of *S. barracuda* sightings were within the backreef of CZ 1 (1.02 ± 0.17 per hour) (Figure 3.17).

Megalops atlanticus was the least frequently sighted species, with a total of 23 sightings in 354.9 hours of diving. It was only sighted in the forereef of CZ 1, at a frequency of 0.12 ± 0.06 per hour (Figure 3.17).

Target species of the family Serranidae were sighted most frequently in the forereef of CZ 1 (1.95 ± 0.28 per hour, Figure 3.17). Most of target serranid sightings (48.84%) were *Mycteroperca bonaci*, with a mean size of 66.1 ± 2.6 cm (Figure 3.18). The critically endangered *Epinephelus striatus* comprised 37.79% of target serranid sightings, with a mean size of 51.3 ± 1.4 cm (Figure 3.18). The remaining 13.37% of target serranid sightings were *M. tigris*, with a mean size of 55.5 ± 2.6 cm (Figure 3.18).

Target species of the family Lutjanidae were sighted most frequently in the forereef of the PZ (1.34 ± 0.21 per hour). Mean frequency of lutjanid sightings in CZ 2 was the second highest within Bacalar Chico, though with a high degree of variation around the mean (1.15 ± 1.02 per hour). *Lutjanus analis* (mean size 41.3 ± 1.4 cm), *L. jocu* (mean size 54.2 ± 2.2 cm) and *L. cyanopterus* (mean size 68.2 ± 2.5 cm) sightings were relatively evenly spread, comprising 39.20%, 33.80% and 26.99% respectively.

Lachnolaimus maximus was sighted most frequently on the forereef of CZ 2 (0.84 ± 0.20 per hour, Figure 3.17), with a mean size of 34.9 ± 1.2 cm (Figure 3.18). Sighting frequency was lowest on the backreef (GUZ = 0.28 ± 0.14 per hour; CZ1 = 0.10 ± 0.04 per hour), and none were sighted within the backreef of the PZ.

Most sightings of *Scomberomrorus regalis* were on the forereef, with the greatest sighting frequency in CZ 2 (1.52 ± 0.29 per hour; Figure 3.17). Mean size of *S. regalis* was 39.0 ± 1.0 cm (Figure 3.18). *Trachinotus falcatus* was almost exclusively sighted in the forereef, most frequently in the GUZ (0.49 ± 0.35 per hour; Figure 3.17). There was only one sighting of *T. falcatus* on the backreef, in a total of 156.15 hours. Mean size of *T. falcatus* was 55.2 ± 3.8 cm (Figure 3.18).

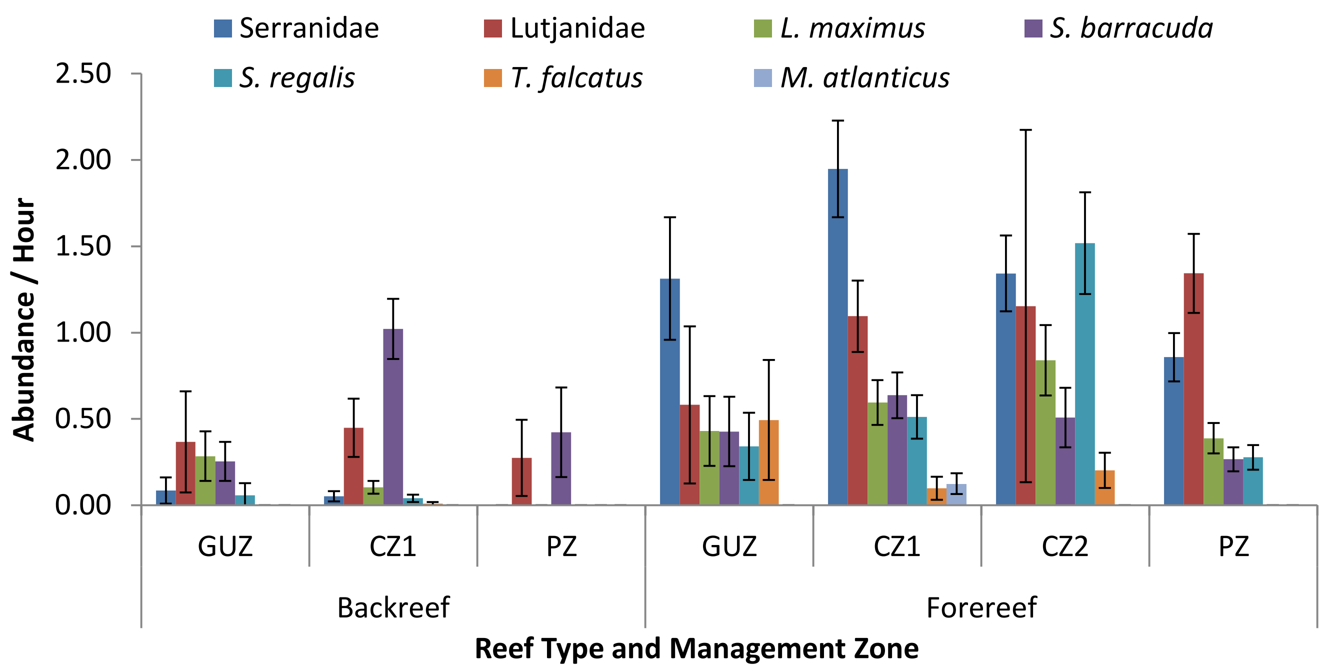


Figure 3.17. ***Sighting frequency of target commercial species of finfish***

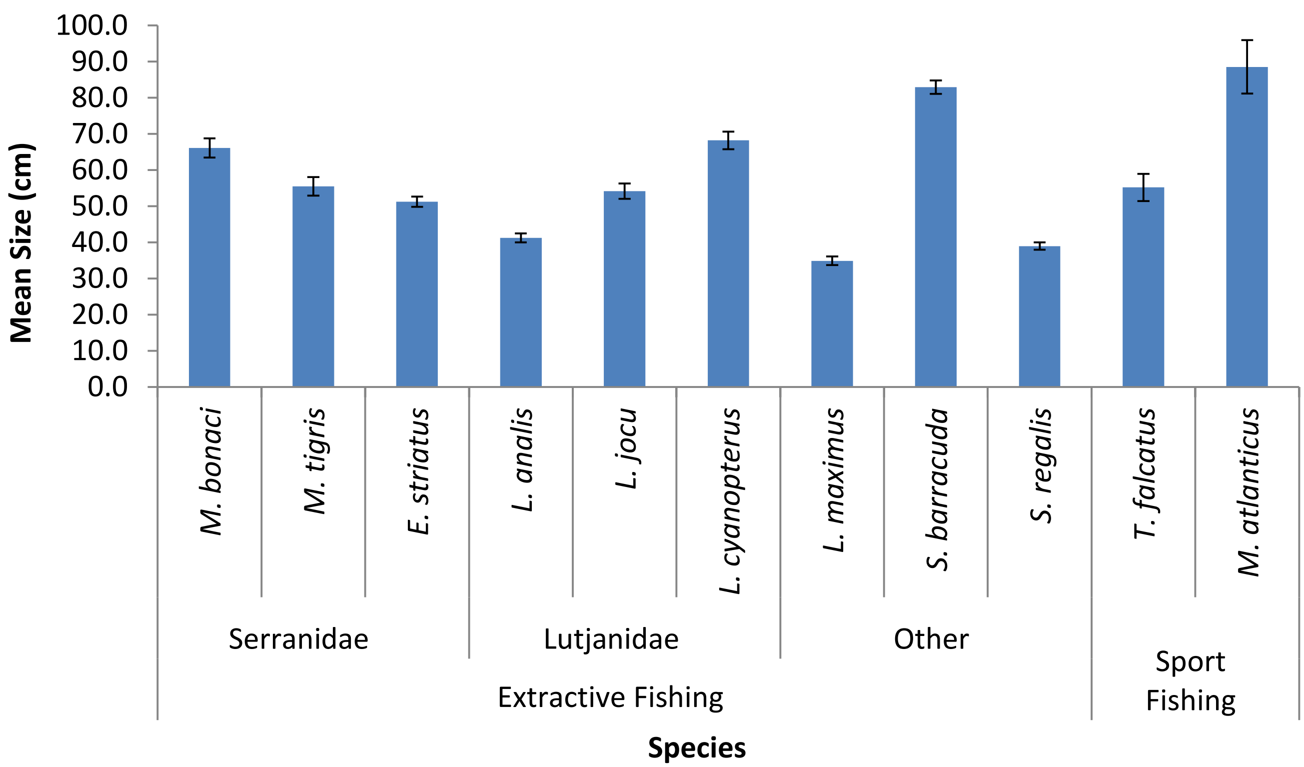


Figure 3.18. ***Mean size of target commercial species by common fishing method***

3.1.4 Invertebrate Populations

3.1.4a Commercially Significant Species

Lobsters (*Panulirus argus*, *P. guttatus*, *Scyllarides aequinoctialis*) were rarely seen along invertebrate belts (Figure 3.19). The site with greatest mean abundance of lobster was C1B1 (CZ 1, backreef), with 2.57 ± 0.95 individuals per 100 m^2. Complementing invertebrate belt data, population distribution was analysed using target species sightings data, showing that lobster were most commonly sighted in the forereef of the PZ (1.25 ± 0.28 per hour of diving; Figure 3.20). *P. argus* was the most sighted lobster species (81.36%).

Queen conch was more abundant on the backreef than on the forereef. Only one site on the forereef, C2F1 in CZ 2, had conch recorded along invertebrate belts (Figure 3.19). Supporting these findings, target species log for sighting frequency on all dives shows the majority of conch sightings to be on the backreef and the forereef of CZ 2 (Figure 3.20). PB1 on the backreef of the PZ was the site with the greatest number of conch (3.00 ± 0.97 individuals per 100 m^2; Figure 3.19), however the greatest sighting frequency was on the backreef of CZ 1 (0.72 ± 0.13 per hour; Figure 3.20).

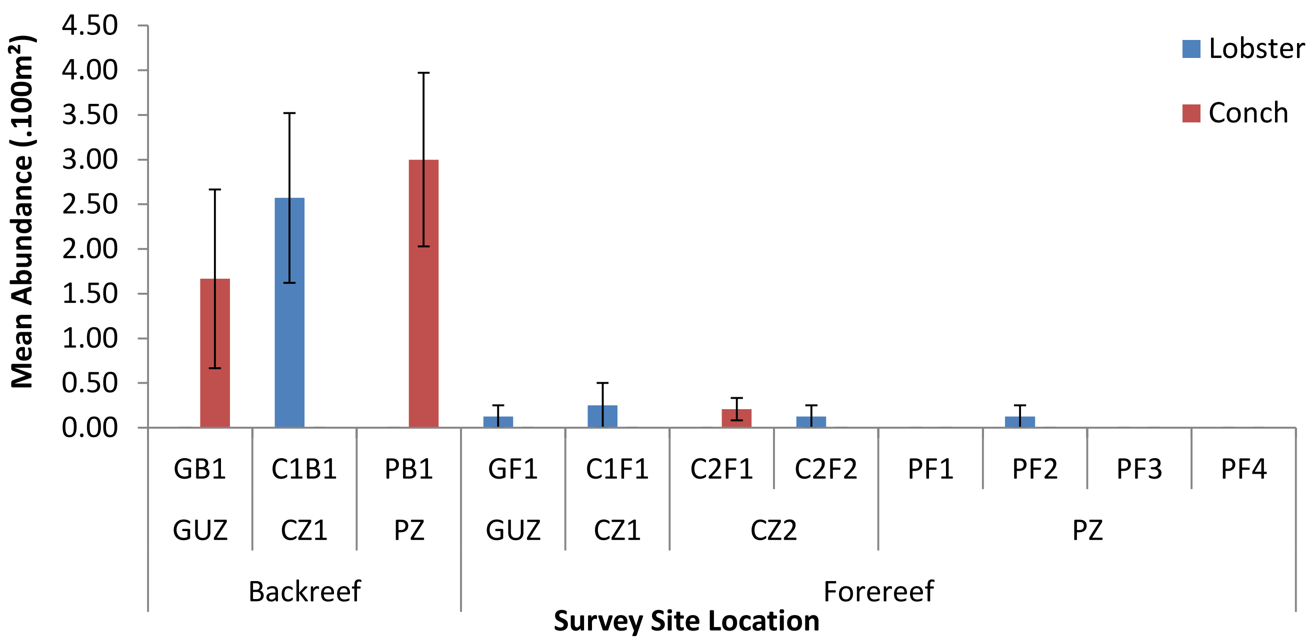


Figure 3.19. ***Mean abundance of lobster and conch recorded along invertebrate belts by survey site and reef type***

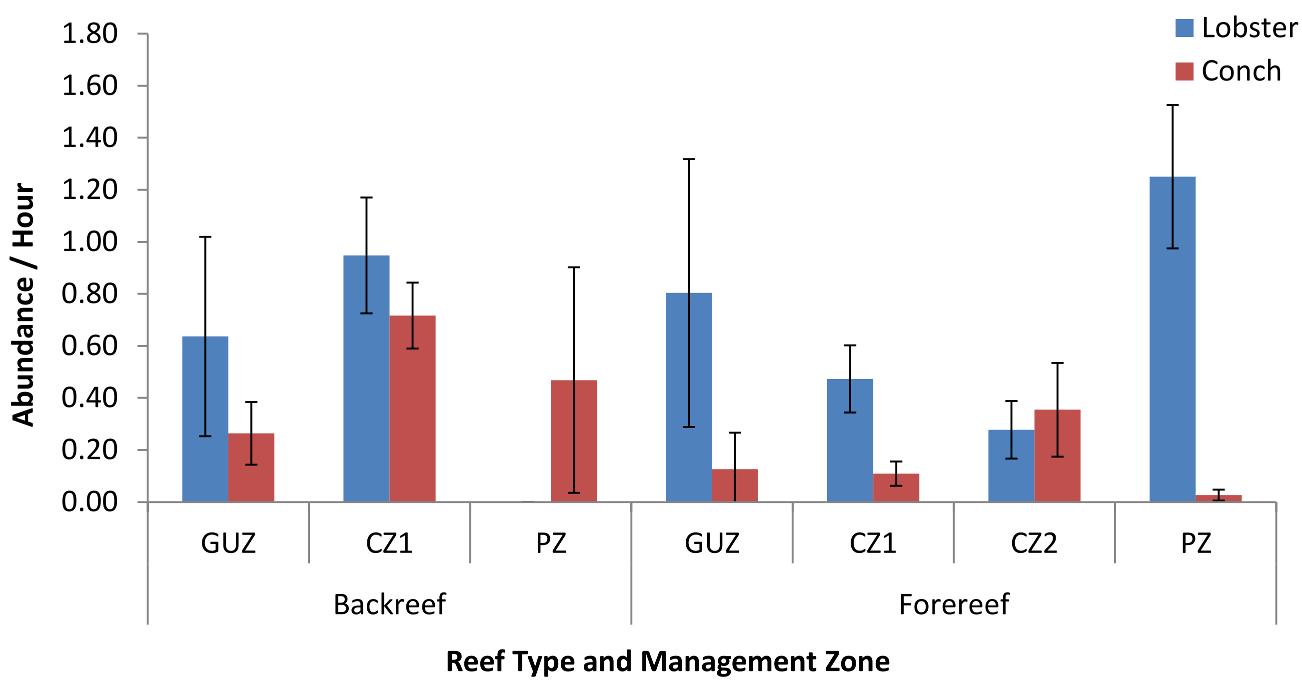


Figure 3.20. Sighting frequency of lobster and conch

3.1.4b Ecologically Significant Species

Generally, *Cyphoma gibbosum* and both adult and juvenile *Diadema antillarum* had low abundances. *C. gibbosum* was rare in most sites with greatest mean abundances of 0.04 ± 0.02 and 0.02 ± 0.01 individuals per m^2, recorded at PF2 (PZ, forereef, western ridge) and C1B1 (CZ 1, backreef) respectively (Figure 3.21). No surveys were made for this species at sites PB1 (PZ, backreef) and PF1 (PZ, forereef). Abundances of adult and juvenile *Diadema antillarum* were greatest at PF2, both at densities of 0.03 ± 0.01 individuals per m^2 with low abundance at GB1, PB1 and GF1 (Figure 3.21).

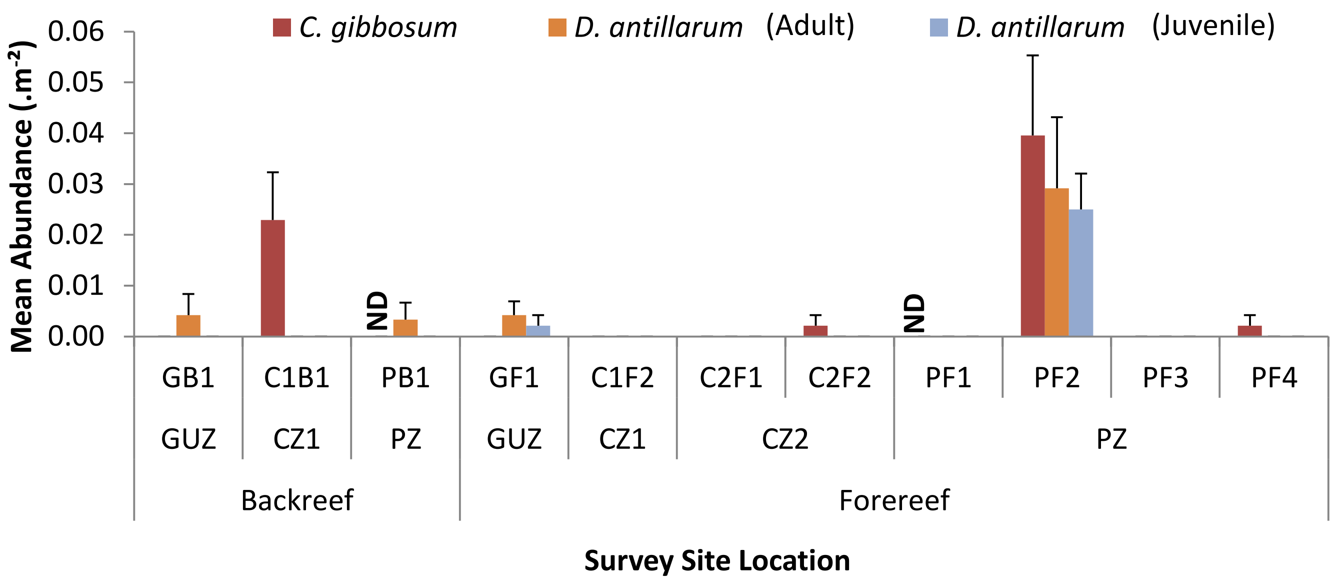


Figure 3.21. ***Mean abundance of* C. gibbosum *and* D. antillarum *(adult and juvenile) by survey site, location and reef type***

3.1.5 Megafauna

3.1.5a Marine Turtles

There were 126 marine turtle sightings in total in 2011, of which 87 individuals were sighted while diving. 61.11% (n = 77) of the individuals were hawksbills, 18.25% (n = 23) were loggerheads and 15.08% (n = 19) were green turtle. The remaining 5.56% (n = 7) of the turtles sighted were not identified to species level. The frequency of sightings per diving hour was 0.25 ± 0.03 individuals, which was greater than the frequency observed in 2010 (0.19 ± 0.02 individuals per hour) (Figure 3.22).

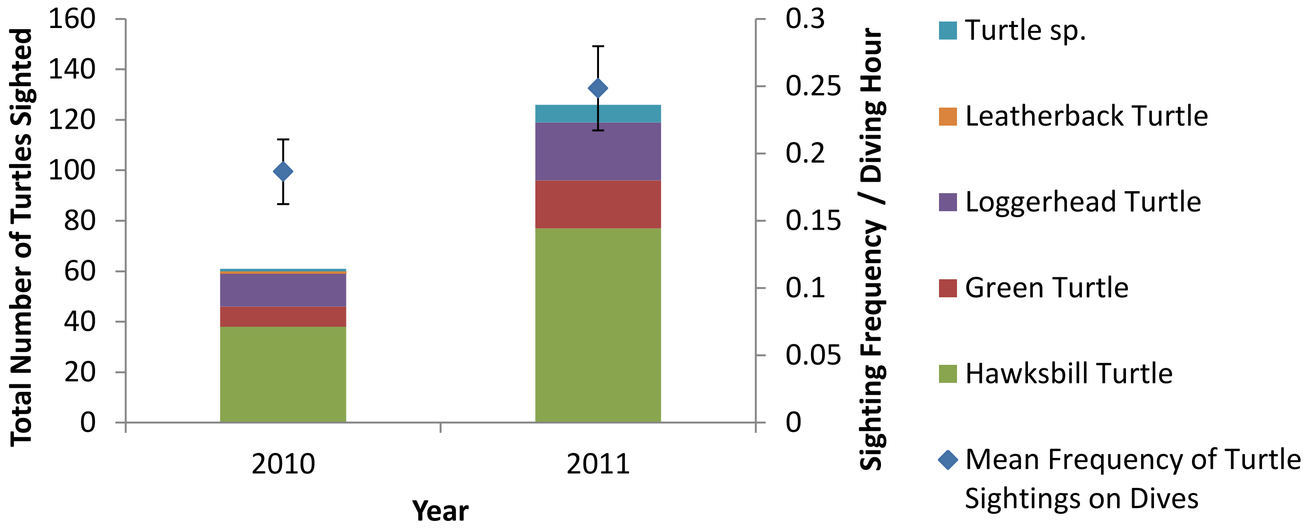


Figure 3.22. ***Total number of marine turtle species encountered in Bacalar Chico in 2010 and 2011, with mean turtle sighting frequency (± standard error) per hour of diving***

Average standard carapace length (SCL) for hawksbill turtles was 60.33 ± 2.30 cm. For the individuals for which size was determined, 75% (n = 55) were immature, and 100% (n = 17) of adults for which sex was determined were female.

Of the 77 hawksbill turtles sighted, 61% (n = 47) were observed on the backreef, the majority of which (77%, n = 36) were at Barracuda Patch, a large patch reef in CZ 1. 39% (n = 30) of the sightings occurred forereef, where Garden Wall (PF1) and Firing Range (a deep, spur-and-groove formation site in CZ 2) accounted for 50% (n = 15), and therefore the majority, of the forereef sightings.

Loggerhead turtles were sighted 23 times and average carapace length was 105.75 ± 6.19 cm. A relatively small proportion (15.00%, n = 3) of the animals for which size was determined were immature. Of the adults, 41.18% (n = 7) were female, 29.41% (n = 5) were male and 29.41% (n = 5) had their sex undetermined. Loggerhead turtles were observed all year round, except for the months of October and December. Most of the sightings were concentrated on the forereef of the CZs (48%, n = 11, in CZ2 and 26%, n = 6, in the CZ1).

The least frequently sighted species of marine turtle was the green turtle. With 19 sightings over the course of the year, 83.33% (n = 15) of those for which size were determined were immature. Green turtles were observed all year round, except for the months of August and September. It was encountered most frequently in October (31.58%, n = 6). 31.58% (n = 6) of sightings occurred in the mangroves.

A further seven marine turtles were sighted for which the species was not determined.

3.1.5b Marine Mammals

Antillean manatees were observed in all months of the year except January, comprising of a total of 59 individual sightings. In February, March, April and December, 97.62% of sightings were in the mangroves, whereas in September, October and November, 90.91% of sightings were on the backreef. There were six sightings of Antillean manatees between May and August, two of which were on the backreef and four in the mangroves.

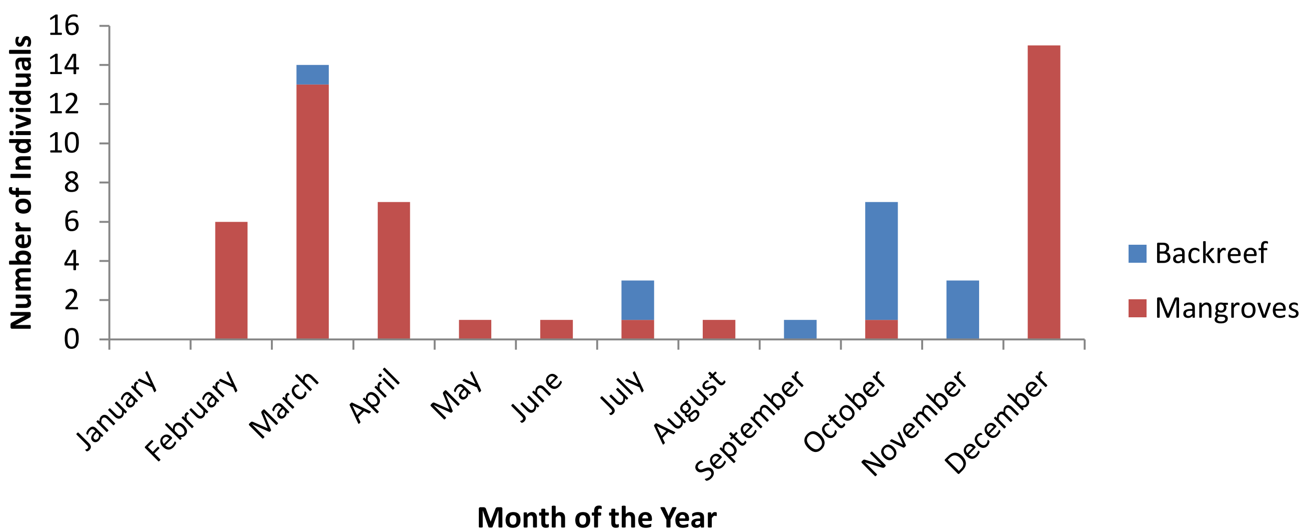


Figure 3.23. Manatee sightings in 2011. Backreef sightings refer to individuals sighted either swimming on the reef proper or the perimeter, over the surrounding seagrass beds

When encountered feeding in the seagrass beds, all sightings were of one or two individuals, however in the mangroves they were frequently seen in groups of two to five individuals. Calves and sub-adults were observed from February to April, and again in October to December. For 15 individuals, size was not determined.

Two species of dolphin were encountered in Bacalar Chico in 2011; the Atlantic spotted dolphin and the bottlenose dolphin. Furthermore, the species of dolphin was undetermined for 15 encounter occasions (29.17%), comprising 46 individuals. 69.39% (n = 23) of dolphin sightings occurred in front of Blue Ventures Dive

Camp in Bacalar Chico, which is situated on the border of the GUZ 1 and CZ 1. Dolphins were also observed on the forereef of CZ 2 (14.29%, n = 7), the backreef of CZ 1 (6.12%, n = 3), the forereef of CZ 1 (4.08%, n = 2), in the mangroves (4.08%, n = 2), and on the backreef of GUZ 1 (2.04%, n = 1).

The majority of dolphin encounters were bottlenose, with 72 individuals seen over 33 encounter occasions throughout the year. A mother and calf (estimated body lengths 230 cm and 150 cm respectively) were seen whilst diving off Rocky Point, a dive site on the forereef of CZ 2. One group of 6 individuals, one of which was young (approximately 100 – 150 cm in length), was seen very frequently in the seagrass beds of CZ 1 and GUZ 1 in October. The average size of the individuals for which the size was estimated was 181.78 ± 4.74 cm. 100% (n = 45) of the individuals where size was determined were immature.

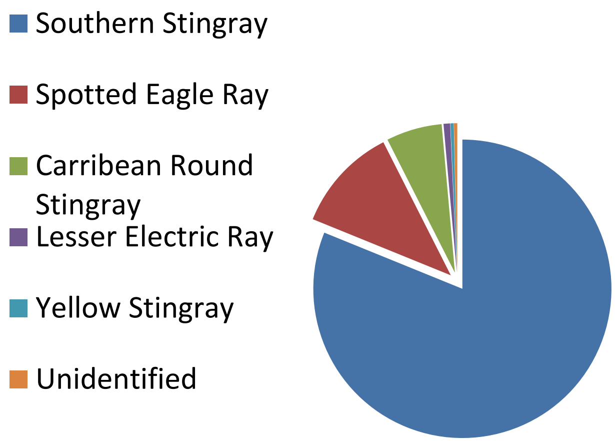
S. frontalis was only observed on one occasion in July, when four individuals were observed together on the forereef in CZ 1.

3.1.5c Elasmobranchs

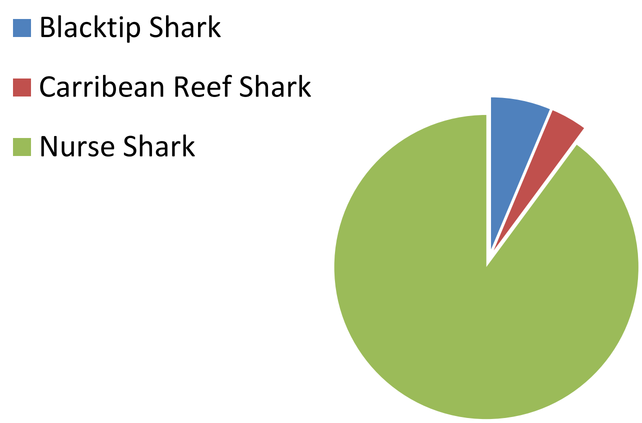
A total of 281 ray sightings, comprising five species, and 79 shark sightings, comprising three species, occurred in Bacalar Chico in 2011 (Table 3.4, Figure 3.24).

Table 3.4. Total number of individuals (*n*), mean size and standard error for each species of shark and ray encountered in Bacalar Chico in 2011

	Species Common Name	Species Latin Name	*n*	Mean Size (cm)	Standard Error of the Mean
Rays	Southern Stingray	*Dasyatis americana*	228	79.75	1.71
	Spotted Eagle Ray	*Aetobatus narinari*	32	97.07	7.06
	Caribbean Round Ray	*Himantura schmerday*	17	76.47	7.05
	Lesser Electric Ray	*Narcine bancroftii*	2	22.50	14.50
	Yellow Stingray	*Urolophus jamaicensis*	1	30	-
	Unidentified Ray	-	1	100	-
Sharks	Nurse Shark	*Ginglymostoma cirratum*	71	158.31	4.84
	Blacktip Shark	*Charachinus limbatus*	5	220.00	12.25
	Carribean Reef Shark	*Charachinus perezi*	3	153.33	3.33



(a)



(b)

Figure 3.24. ***Total (a) ray and (b) shark individuals sighted in Bacalar Chico Marine Reserve in 2011***

The majority of shark and ray sightings occurred whilst diving (70.83%), therefore a correction factor to account for uneven diving effort was applied before comparing sighting frequency of individuals sighted during dives between zones (Table 3.5). The correction factor was not applied to non-dive sightings to prevent exaggeration of results due to uneven sampling effort through unlogged snorkel and boat journeys.

Table 3.5. ***Diving effort and correction factor for each management zone.***

Management Zone	Number of Dives (Actual)	Number of Dives (Expected)	Correction Factor
General Use Zone 1	65	82.8	0.78
General Use Zone 2	2	82.8	0.02
Conservation Zone 1	239	82.8	2.89
Conservation Zone 2	87	82.8	1.05
Preservation Zone	99	82.8	1.20
Mangroves	5	82.8	0.06
Total	492	492	5

The highest corrected sighting frequency (%SF_C) for sharks and rays was in the backreef of GUZ 1 (40.84% and 48.15% respectively). Rays were observed in all management zones of Bacalar Chico in 2011 except GUZ 2.

The most frequently sighted species of ray was the southern stingray, which was most commonly observed in the backreef of GUZ 1 (%SF_C = 42.93) and on the backreef of CZ 1 (%SF_C = 32.26). The next most common species was the spotted eagle ray, for which the majority of sightings occurred in the forereef of the PZ (%SF_C = 40.80) and the backreef of General Use Zone 1 (%SF_C = 12.43).

Caribbean round stingrays were most frequently observed in the mangroves (n = 7), though never during dives. The greatest corrected sighting frequency for Caribbean round stingrays was in the backreef of GUZ 1 ($\%SF_C$ = 39.02). Lesser electric rays were observed on the forereef of CZ 2 and the backreef of GUZ 1, though never on dives, and the single sighting of a yellow stingray was on the backreef of GUZ 1.

Nurse sharks were most frequently sighted on the backreef of GUZ1 ($\%SF_C$ = 53.54), of which over half (50.99%) were at one location (Saraweh Patch, a shallow patch reef in the backreef area of GUZ 1).

Caribbean reef sharks were observed on two occasions in 2011: 2 individuals were sighted at the Spawning Aggregation Site No Take Zone (NTZ), nested within the forereef of CZ 2, and the third sighting of the species happened on the forereef of the PZ. Three individuals of black-tip sharks were observed together at the Spawning Aggregation Site NTZ, and two were observed on one dive in the forereef of CZ 2.

3.1.5d Finfish

There was one sighting of the critically endangered goliath grouper (*Epinephelus itajara*) on the forereef of GUZ 1.

3.1.6 Invasive Species

Lionfish were most frequently observed on the forereef (Figure 3.25). Sightings on the forereef were lowest in the PZ (1.46 ± 0.19 per hour), and greatest in CZ 2 (4.56 ± 0.64 per hour). Sightings on the backreef were greatest in CZ 1, with 0.34 ± 0.08 sighted per hour (Figure 3.25). Mean size of observed individuals was 22.0 ± 0.26 cm.

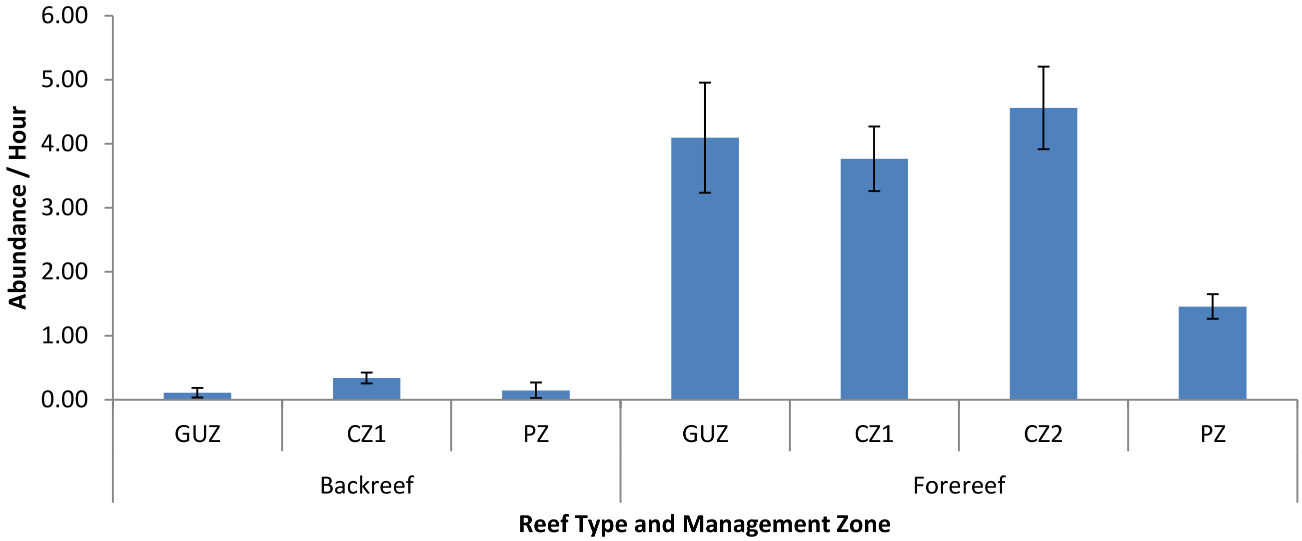


Figure 3.25. ***Sighting frequency of lionfish in 497 dives (356.42 hours of diving) conducted by Blue Ventures throughout 2011***

For the entire year, mean sighting frequency of lionfish was 3.21 ± 0.23 individuals per hour of diving on the forereef, and 0.32 ± 0.06 per hour of diving on the backreef. Mean sighting frequency of lionfish was greatest in August, with 5.74 ± 1.29 individuals seen per hour on the forereef (Figure 3.26).

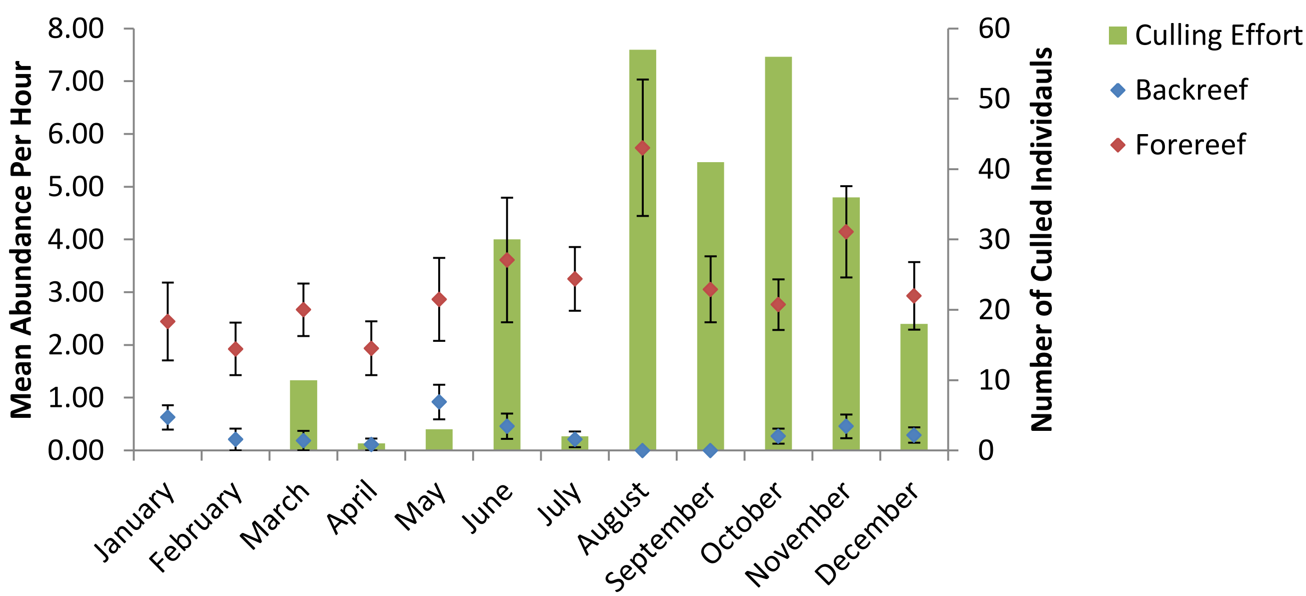


Figure 3.26. ***Monthly mean sighting frequency of lionfish and total culling effort***

Maximum sighting frequencies were 22.80 individuals per hour observed on one dive on the forereef in August, and 19.57 individuals per hour observed on one dive on the forereef in November (Figure 3.27).

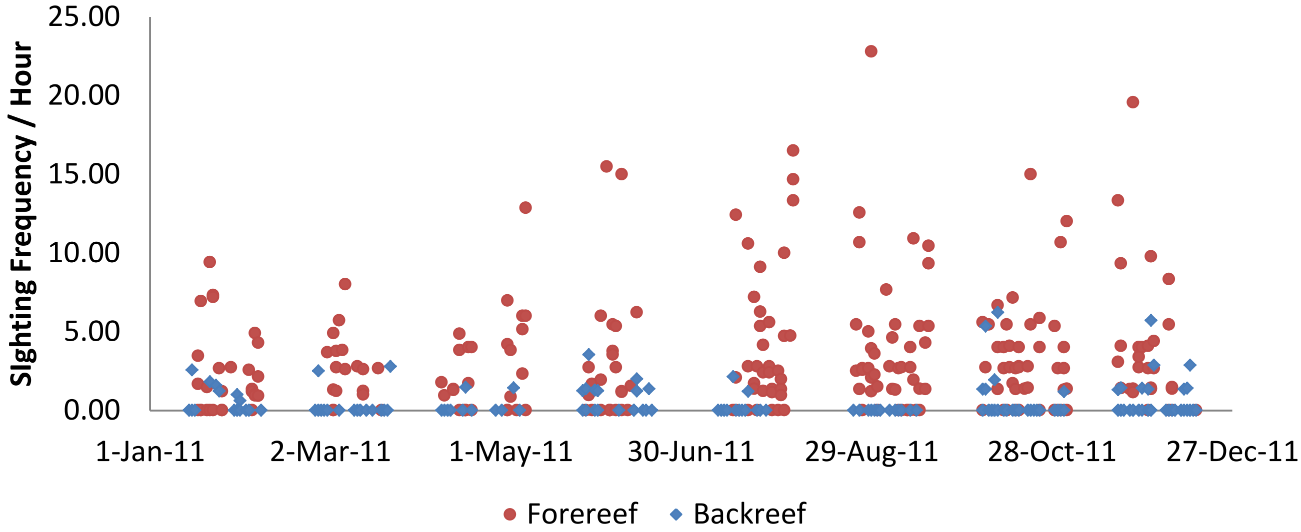


Figure 3.27. ***Number of lionfish sighted per hour for each dive conducted by Blue Ventures in Bacalar Chico in 2011***

Blue Ventures began participating in lionfish culling dives in March 2011. Presence or absence of roe, stomach content analysis and morphometrics has been recorded for 254 lionfish. The largest lionfish caught was 38.0 cm total length, and average total length was 26.04 ± 0.29 cm. On average, individuals contained 2.16 ± 0.18 prey items within their stomachs, though some individuals had up to 19 prey items within their stomachs.

The greatest proportion of lionfish diet consisted of fish (68%), the majority of which were too digested to identify further (Figure 3.28). 'Other Fish' included acanthurids, pomacentrids, grammatids, serranids, lutjanids and bothids. A large proportion of lionfish diet consisted of shrimp (31%), with other crustaceans and molluscs contributing the remainder of observed prey.

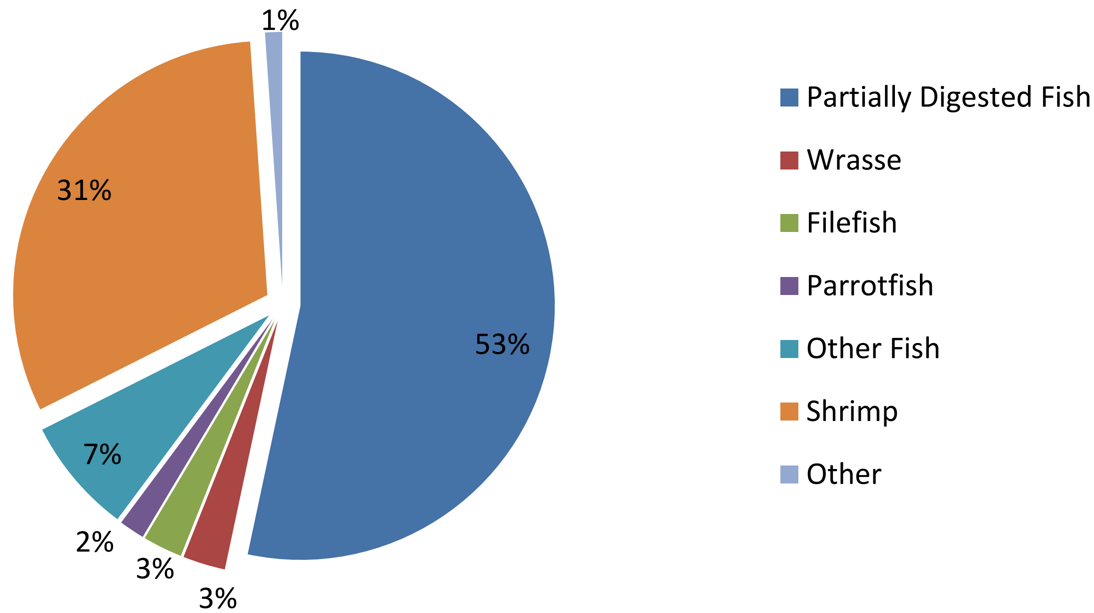


Figure 3.28. Stomach contents of culled lionfish

Presence or absence of roe was also recorded for culled individuals. Generally, the number of lionfish without roe exceeded the number of lionfish with roe, except in June, when 63.3% of individuals contained roe (Figure 3.29).

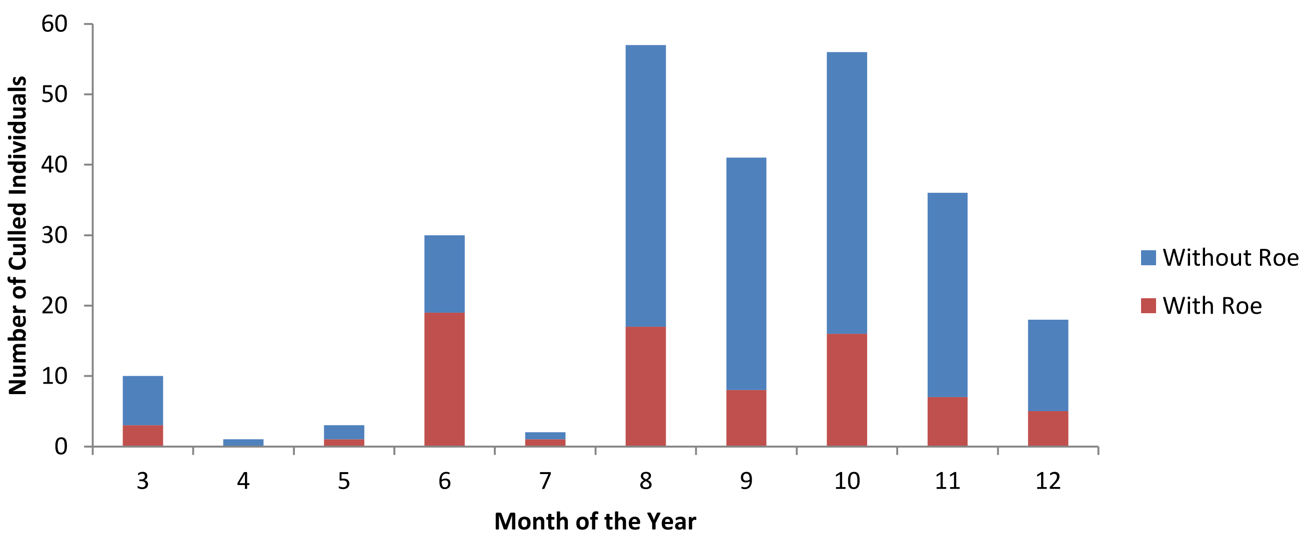


Figure 3.29. Presence and absence of roe in culled lionfish

3.2 Mangrove Monitoring

Basic information on mangrove fish populations was obtained by fish rovers. Lutjanidae was the most prevalent family, sighted on every occasion at high densities (Den = 3.76) (Figure 3.30). Haemulids and gerreids were also sighted on every sampling occasion, at intermediate to high densities (Den = 2.97 and 2.93 respectively) (Figure 3.30).

The most frequently encountered species were *Lutjanus griseus* (Den.SF = 365.52), *L. apodus* (Den.SF = 282.76), *Haemulon sciurus* (Den.SF = 286.21) and *Gerres cinereus* (Den.SF = 286.21) (Figure 3.30). The commercially significant *L. cyanopterus* and *L. analis* were observed infrequently and at low densities (Den.SF = 16.05 and 9.16 respectively) (Figure 3.30). Juvenile *Chaetodon capistratus* and *Pomacanthus arcuatus* were sighted only occasionally (both Den.SF = 0.12) (Figure 3.30).

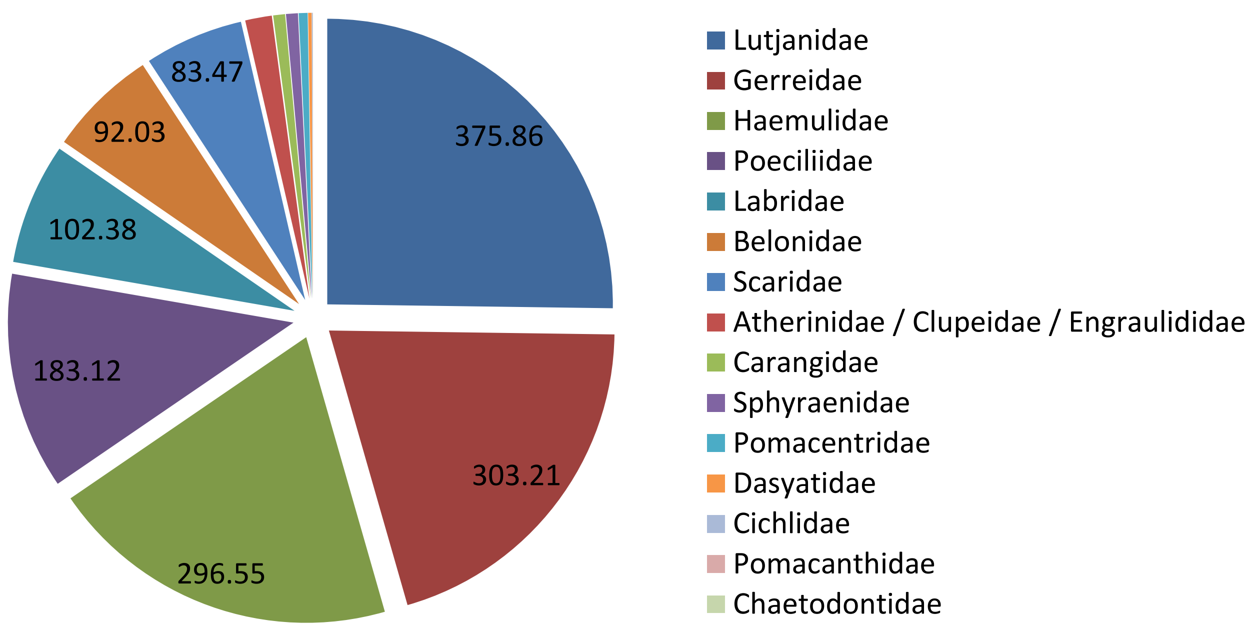


Figure 3.30. Fish family prevalence (Den.SF) within a small channel and lagoon system in the coastal mangroves of Bacalar Chico

3.3 Bird Monitoring

A total of 72 species of birds were identified during surveys in Bacalar Chico. The number of sightings per species often varied by site. For example, at Cantena Lagoon white ibis (*Eudocimus albus*) were sighted on every survey, whilst they were never sighted on the Coast. At Belize Island and on the Coast brown pelicans (*Pelecanus occidentalus*) were sighted on almost every occasion, though never sighted at Cantena or Crocodile Lagoon. At all sites, double-crested cormorants (*Phalacrocorax auritus*) and magnificent frigate birds (*Fregeta magnificens*) were sighted frequently.

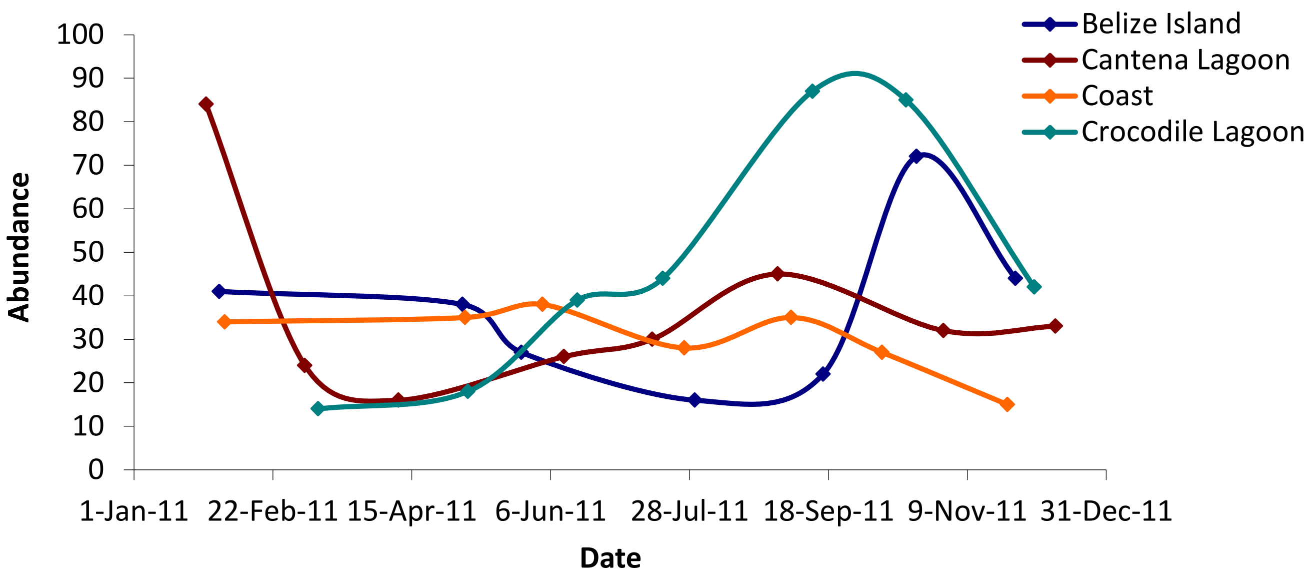


Figure 3.31. ***Total abundance of birds sighted during dawn surveys at four locations in Bacalar Chico***

Bird sightings were initially high at Cantena Lagoon, dropping from February to April, followed by a gradual increase for the remainder of the year (Figure 3.31), with the small peak in bird numbers in August accounted for by a unique encounter of 25 barn swallows (*Hirunda rustica*). Sightings along the coast remained relatively constant for the majority of the year, though they showed some signs of decrease after September.

At Crocodile Lagoon surveys did not start until March. Bird sightings increased throughout the year, peaking between September and October, after which total sightings dropped (Figure 3.31). Sightings at Belize Island decreased gradually until September, at which point there was a dramatic increase in sightings. Total abundance at this site then dropped to almost the same levels as at the beginning of the year (Figure 3.31).

A more detailed view of bird sightings divides birds into seven functional groups: 'Frigate', 'Pelican', 'Cormorant', 'Egret', 'Heron', Bittern', 'Spoonbill', 'Plover', Sandpiper' and 'Ibis' (0). Other birds sighted included woodpeckers, warblers and orioles (not shown on graphs).

No spoonbills or ibises were observed during the coastal surveys, while sightings of all other functional groups were more or less constant (0). Frigates, pelican and cormorants were seen flying offshore, travelling along the coast rather than feeding. Wading birds (plovers, sandpipers, egrets and herons) typically used the coastline to feed.

At Belize Island sightings of egrets and herons were initially high, dropping for the majority of the year and peaking again in October. The peak of egret and heron sightings in October coincided with a peak in ibis sightings. No plovers or sandpipers were seen, and spoonbills were seen only on one survey in November (Figure 3.32).

Ibis sightings at Cantena Lagoon were very high in January, after which numbers dropped with only one or few individuals sighted on each survey for the remainder of the year. Abundance of egrets and herons was high in January, after which few were sighted on each survey until August, when numbers again climbed. In December, abundance of egrets and herons equalled that observed in January. No pelicans were sighted at Cantena Lagoon and all other functional groups were consistently low throughout the year (Figure 3.32).

Surveys at Crocodile Lagoon started in March, therefore there was no abundance data for birds earlier in the year. From March to October, no spoonbills were sighted, and they were seen in low numbers in October and December. No ibis were sighted until September, after which sightings were low but consistent. No pelicans, plovers or sandpipers were sighted at any time in the year. Egret and herons were observed in small abundance initially, climbing through the year to a peak in September (Figure 3.32).

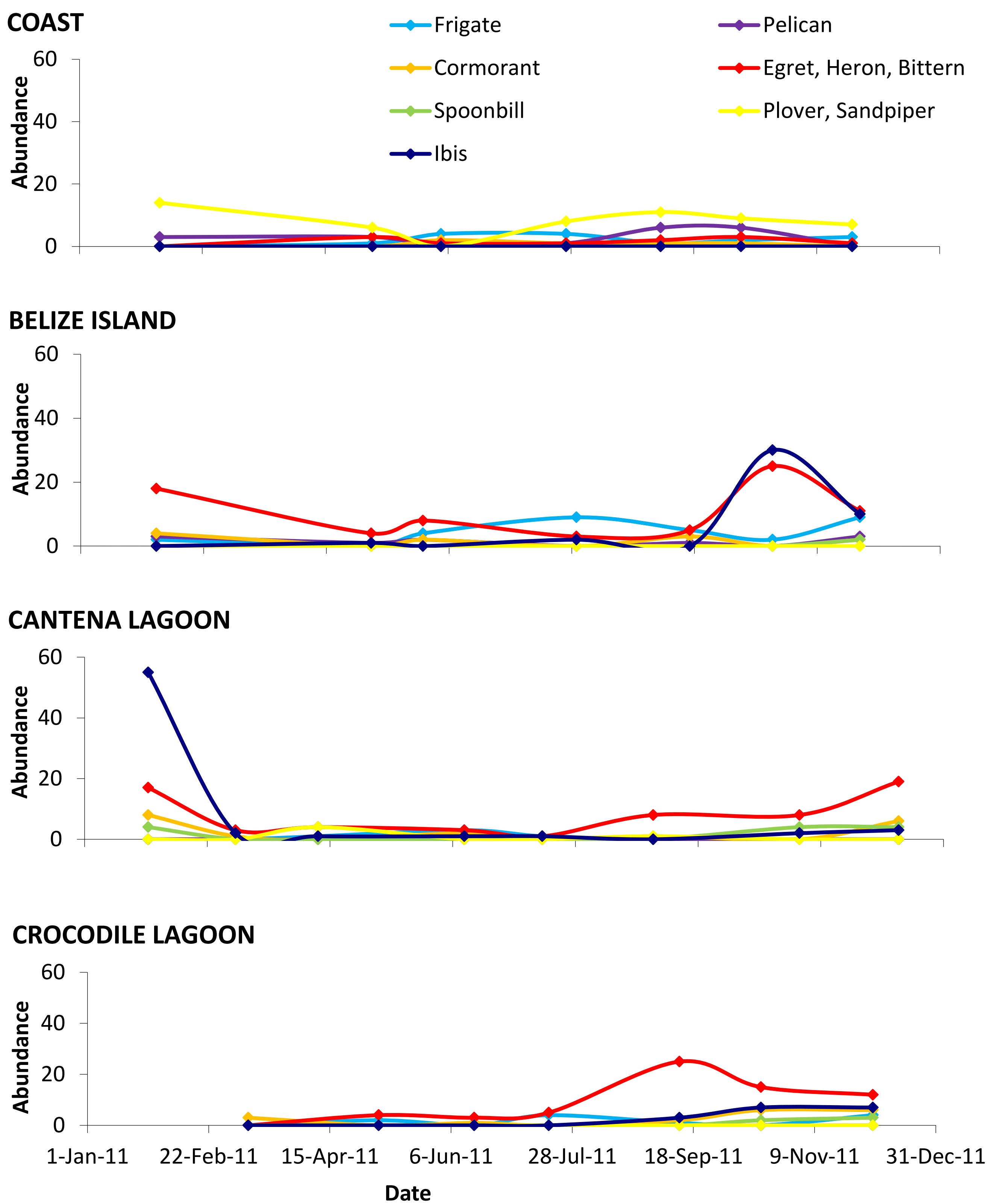


Figure 3.32. ***Total abundance of bird functional groups sighted during dawn surveys at four locations in Bacalar Chico.***

4. Discussion

4.1 Overall Reef Health

In both 2010 and 2011, average reef health in Bacalar Chico was ranked as 'Poor' using the SIRHI. Due to the introduction of one new and removal of two previously surveyed sites, as well as changes made to improve monitoring methodology, it is not possible to make a direct comparison between the years. Despite this, results from 2010 and 2011 both show that reef condition in Bacalar Chico is below the regional average, with low HCC, high macroalgal cover and low fish biomass.

In 2010, 27.27% of reefs were found to be in 'Critical' condition when interpreted using the Simplified Integrated Reef Health Index (SIRHI, Healthy Reefs 2010). However, in 2010 transect location and data collection may have biased the results towards an overestimation of HCC and fish biomass[3]. In 2011, transect placement and data collection were standardised to match regional methods. The results show that 58.33% of reefs to be in 'Critical' condition.

Poor reef health such as this is typical on both global and regional scales. Globally, over 75% of coral reefs are threatened by rising sea surface temperatures and local anthropogenic activities such as fishing and coastal development (Burke *et al*., 2011). Throughout the Mesoamerican region (MAR) 62% of sites included in the Healthy Reefs Initiative 2010 report displayed declines in reef health between 2006 and 2009. Specifically, the BBR was included on the "List of World Heritage Sites in Danger" in June 2009 (UNESCO World Heritage Committee – Decision – 33 COM 7B:33) due to the continuation of decline in reef health, primarily related to unsustainable coastal development (Gibson, 2011).

Hard coral cover within Bacalar Chico (10.1%) is considerably lower than the reported average for Belizean reefs in 2008 (26%, Garcia-Salgado et al 2008*a*), instead aligning more with Caribbean-wide HCC averages (Gardner *et al*., 2003; Schutte *et al*., 2010). Garcia-Salgado *et al.* (2008a) reported an increase in HCC in Bacalar Chico from less than 19% in 2004 to 33% in 2008. Such increases are not reflected in our results; instead HCC has declined by almost 8% from what was considered 'Alert Status' in 2004 (Garcia-Salgado *et al*., 2008*a*).

[3] In 2010:

- Only four point intercept transects were completed for each site, decreasing the accuracy of estimates.
- Some transects were placed deeper than 15 m on the forereef, where hard coral cover is greater.
- Fish belts crossed grooves in spur-and-groove reefs, potentially introducing a bias due to the increase volume of water surveyed as well as the tendency for fish to hide within the grooves.

The Belize Fisheries Department (BFD) also monitors coral reef condition in Bacalar Chico, reporting average coral cover of 16.7% (Brown, 2011). All sites surveyed by BFD are located within CZs, excluding areas within the PZ of critically low HCC. The data presented in this report is the result of thirteen survey sites, covering different habitat types and CZs and is more representative of the ecological status of Bacalar Chico.

Whilst large, healthy colonies of critically endangered *Acropora palmata* are locally common at some sites, the most commonly encountered species of hard coral were *Agaricia agaricites*, *Siderastrea siderea* and *Porites astreoides*, species recognised as either being opportunistic with fast growth and encrusting life form or being particularly tolerant of relatively stressful conditions (Green *et al*., 2008; Huntington *et al*., 2011; McField *et al*., 2008). Over half of the *S. siderea* colonies encountered showed signs of bleaching and 12.75% exhibited evidence of infection with dark spot disease. This raises concerns of reef resilience, specifically with regard to the ability of colonies to withstand 1) the introduction of new stressors, 2) the amplification of existing stressors or 3) the lack of alleviation of current stressors. All three scenarios may individually or collectively affect growth rates and thus reduce hard coral competitive ability.

Of particular concern is the general status of the PZ, which is in extremely poor health. Of the four survey locations within the PZ, one is in ‘Poor’ condition and three are ranked as ‘Critical’. HCC along the eastern ridge is critically low (PF3, 3.96% ± 0.52 and PF4, 2.17% ± 1.01), which may be a lasting effect of hurricane disturbance. Hurricane Mitch in 1998 was reported to have caused “substantial damage” to the reef in Bacalar Chico (Grimshaw and Paz, 2004), with dramatic decline in scleractinian coral cover and an increase in bare rock, encrusting coralline algae and turf algae (McField, 2000). Coral cover throughout the MAR remains low following the combined impact of Hurricane Mitch and a severe bleaching event in 1998, which caused mass coral mortality throughout the region (McField, 2000; Aronson *et al*., 2002). Affected reefs have shown little evidence of recovery (McField *et al*., 2008).

Despite poor overall reef health, lobster populations within the forereef of the PZ are of greatest abundance throughout the reserve, particularly on the eastern ridge. This may be due to the fact that the site is difficult to locate without prior knowledge of its location or use of GPS, and causing fishing incursions into the PZ to not target this region of the reef.

Commercial fish biomass is critically low at all sites within the PZ. The results indicate the reserve is ineffective in enhancing recovery of total biomass or biomass of ecologically key fish populations, nor maintaining ecological processes and fisheries.

4.2 Population Distribution of Commercially Significant Species

The biomass of important commercial fish species (lutjanids and serranids) was not linked to reserve zonation or to overall reef health. Fish biomass was greatest within the backreef of the PZ, where haemulids were the major contributor to fish biomass. Whilst haemulids are consumed locally and are recognised as commercially significant throughout the MBRS region, their value within Belize is low[4] and the fishery is considered to be one of subsistence or artisanal value. Given that there is no community directly buffering BCMR, it is unsurprising that haemulid populations have flourished. Furthermore, Hawkins and Roberts (2004) have shown that haemulid biomass is not affected by artisanal fishing pressure.

In 2011, total fish biomass was exceptionally low at C1F2 (536.89 ± 94.51 g 100 m^{-2}), though abundance at this site (29.17 ± 6.70 fish 100 m^{-2}) was low to average for all records (range 22.71 ± 3.86 to 84.17 ± 45.17; median value = 39.06 fish 100 m^{-2}), implying the majority of fish observed along fish belts belonged to small size classes. This site was reported to have had high abundance and biomass of priority species along fish belts in 2010. The significant difference in fish biomass and SIRHI between years at this site can be explained by the change in methodology – in 2010 transects were laid crossing grooves, where many large serranids and lutjanids dwell. To align methods with regional standards, transects are now laid along spurs, meaning fish within grooves no longer fall within fish belt areas. During recreational dives serranids were sighted most frequently at C1F2, supporting the explanation that the reduction in SIRHI rating from 'Poor' in 2010 to 'Critical' in 2011 is a result of change in methodology, rather than a dramatic decline in reef health at this site.

As free diving is the most common method to capture lobster and conch, the shallow lagoon area is more frequented by fishers than the forereef sites. Therefore, these shallow areas are most relevant to analysis of management effectiveness of reserve zoning in terms of retaining commercial invertebrate stocks.

[4] Haeumlids are not bought by the National Fishermen Cooperative, and are the lowest value fish bought by the Northern Fishermen Cooperative. Lutjanids and serranids, however, are target species, carrying the highest profit for fishermen selling to cooperatives. As a result, the majority of fishermen do not target haemulids when fishing commercially (Product Management Departments, Northern and National Fishermen Cooperatives, pers. comm.).

Density of conch was greatest in the backreef of the PZ (3.00 ± 0.97 per 100 m^2), when surveyed in February, in the middle of the open season for conch[5]. However, this density is far less than reported in other Belizean MPAs. For example, a density of almost 20 individuals per 100 m^2 was reported from Laughing Bird Caye National Park in 2008 (Wildtracks, 2010). No conch were encountered during surveys conducted within CZ 1, however this site, a heterogenous patch reef, does not provide much suitable conch habitat. During dives at this site, conch are occasionally observed at the reef perimeter on the seagrass bed, which is outside of survey area boundaries.

Lobster are absent from the backreef survey location in the PZ, this site is a patchy reef habitat with low reef rugosity and few crevices, providing less habitat. Therefore, the absence of lobster is not necessarily indicative of ineffective reserve management.

Backreef sites in CZ 1 and the GUZ both provide suitable lobster habitat. Throughout the year, lobsters were observed in the backreef of the GUZ at a frequency of 0.64 ± 0.38 per hour of diving, however none were observed within invertebrate belts. Surveys at this site took place shortly after opening of the lobster fishing season[6] and therefore may indicate localised overexploitation of stocks.

Within the backreef of CZ 1, lobsters were observed at a frequency of 0.95 ± 0.22 per hour of diving, and at densities of 2.57 ± 0.95 per 100 m^2. Surveys took place in October – the middle of the lobster fishing season. Although fishing incursions into the zone were occasionally observed, the density of lobsters relative to the adjacent GUZ indicates relative success in zone boundary maintenance. However, such populations are lower than populations reported from other Belizean MPAs (Carballo and Cantun, 2008; Finch *et al*., 2008).

Surveys conducted by Greenreef in 2004 (Grimshaw and Paz, 2004) indicated lobster populations were greatest on the forereef in the southern portion of the reserve, which is not evident from our data. Catch shares and managed access, fisheries management tools with proven success in preventing fishery collapse (Costello *et al*. 2008), were implemented in Glover's Reef and Port Honduras Marine Reserves in 2011 to manage lobster and conch fisheries (EDF, 2011; Foley, 2012) These could be applied in Bacalar Chico and assist in ensuring extraction does not fully deplete stocks.

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[5] Conch season is open from 1st October to June 30th
[6] Lobster season is open from 15th June to 14th February

Although Bacalar Chico is primarily utilised for tourism and not extractive fishing (Walker and Walker, 2009), the data indicates that finfish, conch and lobster fisheries are severely depleted. It is therefore possible that an interruption of broader ecological processes may be influencing the commercial fish stocks within the reserve to a greater extent than direct extraction. It is of critical importance to implement more effective monitoring of lobster and conch populations to improve understanding of population dynamics within the reserve.

4.3 Reef Ecology

Fish recruitment is known to be affected by habitat type and seasonality of larval delivery (Shima, 2001), with peak fish recruitment in the Bahamas occurring in July and August (Albins and Hixon, 2008). The significant difference between sites within the same month suggests fish recruitment within Bacalar Chico is site specific. However, no sites were surveyed more than once in the year and so it was not possible to determine whether fish recruitment in Bacalar Chico exhibits seasonal variations.

Long-term monitoring and increased frequency in surveys are needed to detect species-specific peak recruitment seasons as well as identify areas which act as key recruitment sites within the reserve. Fish recruitment has been shown to be negatively affected by the presence of lionfish (Albins and Hixon 2008). Thus, continued monitoring of lionfish and fish recruitment population trends is important to facilitate understanding of long-term ecological impacts of lionfish.

Hard coral cover is critically low (less than 5%) on the eastern ridge of the forereef of the PZ, where the benthos is composed predominantly of turf algae, and a large proportion of it is occupied by fleshy macroalgae and cyanobacteria. Such conditions are likely to impede or prevent recovery as there is little free substrate available for coral recruitment. In addition, herbivorous fish biomass is 'Poor' and herbivorous *Diadema antillarum* were absent, affording little prospect for reduction in algal cover.

Diadema antillarum have been shown to be critical in reversing algal dominance (Idjadi *et al*., 2006; Macia *et al*., 2007), thereby promoting recruitment of hard corals (Edmunds and Carpenter, 2001; Carpenter and Edmunds, 2006). Results showed that *Diadema* are rare, having only been encountered at four of the thirteen survey sites, and that when present they exist at densities far lower than what is considered to be critical to exert pressure on macroalgae (McField and Kramer, 2007). Similarly, Dahlgren (2009) found *Diadema* to be absent from all surveys in Bacalar Chico in 2007. It is uncertain if local population recovery to pre-disturbance (disease outbreak) densities (Belize: 1.06 m^{-2}; Lessios, 1988) will occur.

As key reef herbivores, diverse and abundant populations of acanthurids and scarids are able to graze sufficiently to maintain reefs in a state of hard coral dominance (Mumby, 2006; Mumby *et al*., 2007; Burkepile and Hay, 2008; Burkepile and Hay, 2010). However, whilst many reef herbivores will graze on turf and low-canopy height erect macroalgae, few species graze on late succession, high canopy height macroalgae (McClanahan *et al*., 2001; Bellwood *et al*., 2006). Therefore, typical reef herbivore populations may play a critical role in preventing a phase shift to macroalgal dominance, but not reversing it (Bellwood *et al*., 2006; McClanahan *et al*., 2002, 2011; Mumby, 2006; Mumby and Harborne, 2010).

Phase shifts on Caribbean reefs from scleractinian coral dominance to macroalgae dominance has been ultimately attributed to coral mortality (Aronson and Precht, 2006), resulting from hurricane disturbances (Hughes, 1994; Gardner *et al.*, 2005; Garcia-Salgado *et al*., 2008*b*) bleaching events (Quinn and Kojis, 2008; Garcia-Salgado *et al*., 2008*b*) and coral disease outbreaks (Schutte *et al.*, 2010). The effects of these events have been compounded by further stress factors (Gardner *et al.*, 2003), particularly the overexploitation of fish populations (Hughes, 1994; Jackson *et al*., 2001), the mass mortality of *Diadema* urchins in the 1980s (Idjadi *et al*., 2006; Lessios 1988) and other local stressors such as pollution and sedimentation (LaPointe *et al*. 2004; Coelho and Manfrino, 2007; McManus and Polsenberg, 2004).

As thirteen years have passed since the combined hurricane and bleaching disturbances of 1998, there has been sufficient time to expect reefs to exhibit steady recovery toward pre-disturbance benthic assemblage[7] (McField, 2000; Stoddart, 1974). It is therefore proposed that reefs located along the eastern ridge of the forereef of the PZ have undergone a macroalgal phase-shift, possibly initially triggered by hurricane disturbance in 1998, though exacerbated and maintained by depleted herbivore populations (both *Diadema* and fish).

Reefs located on the forereef of CZ 2 also exhibit critically high coverage of macroalgae, though they were not affected by Hurricane Mitch (Grimshaw and Paz, 2004), nor are herbivorous fish populations significantly

[7] One year before the 1998 hurricane and bleaching disturbance events, mean HCC in affected areas of Bacalar Chico was 35% and fleshy macroalgal cover was 17% (McField, 2000). McField (2000) described these sites as being comparable to the ‘moderate’ rating applied by Stoddart (1974) when categorising damage to some reefs in Belize affected by Hurricane Hattie in 1961. Stoddart (1974) reported full recovery of those reefs within eleven years of disturbance.

depleted. *Diadema* were absent from all sites surveyed. Hard coral cover continues to persist, though the majority of the benthos is occupied by fleshy macroalgae, turf algae, coralline algae and gorgonians.

Although forereef sites in CZ 2 were found to support a large number of different fish species, Simpson's Diversity Index values were low. Specifically, six scarid species[8] were encountered at low densities, and all three acanthurid species were encountered at high densities. Burkepile and Hay (2010) demonstrated that grazing by acanthurids on early successional algal communities prevents community development to a macroalgal-dominated assemblage. However, within established, late-successional algal communities larger scarid species such as *S. aurofrenatum* play a more significant role in removing upright stands of fleshy macroalgae (Burkepile and Hay, 2010).

Diversity in herbivore populations is essential to prevent macroalgae outcompeting corals for space (Mumby *et al*, 2007; Burkepile and Hay, 2008; Burkepile and Hay, 2010), but even more so to facilitate phase-shift back to a coral-dominated state. This is because the tipping point away from a macroalgal dominated state requires greater herbivory rates, as well as the presence of key phase-shift reversing species (Hughes *et al*, 2010; McClanahan *et al*, 2011).

It seems that fleshy macroalgae in the forereef of CZ 2 have exceeded the canopy height fed upon by acanthurids, and other herbivore populations are not sufficient to prevent the gradual change in benthic assemblage macroalgal dominance. The ultimate cause for decline in HCC in this specific area cannot be attributed to a single acute disturbance event. Regional decline in general reef health, limiting growth rates, competitive strength and recruitment must also be considered, as well as the effect of reduced herbivory resulting from direct overexploitation and destruction of nursery grounds such as mangroves (Mumby *et al*., 2004).

4.4 Megafauna

Hawksbills were the most commonly observed marine turtle species in Bacalar Chico, with observations spread throughout the year. The majority of the hawksbills observed were likely to have been immature, which could suggest that Bacalar Chico provides important developmental as well as foraging grounds for the species.

[8] *Scarus iserti*, *S. taeniopterus*, *Sparisoma aurofrenatum*, *S. viridae*, *S. chrysopterum*, and *S. rubripinne*

Maturity and therefore sex of marine turtles should be interpreted cautiously, as the majority of species and populations exhibit a great deal of variation and are poorly determined, particularly with regard to loggerheads (Brown-McNeill *et al.*, 2008).

The sighting frequency of bottlenose dolphins in 2011 was consistent with the observations in 2010, however, given that 98% of the individuals, where size was determined, were immature, it is likely that size of individuals was underestimated. The Atlantic spotted dolphin was more frequently observed in 2010 (45 individuals observed on 7 occasions) than in 2011 (4 individuals observed on one occasion). The coloration of the Atlantic spotted dolphin can resemble that of the bottlenose dolphin in certain life stages, when spots are not obvious or absent (Herzing, 1997), therefore misidentification may have occurred, biasing results towards the more familiar bottlenose dolphin.

Bacalar Chico has been identified as a potentially important area for manatees, primarily due to its close proximity to the Corozal Bay Wildlife Sanctuary (Belize) and Chetumal Bay (Mexico), which is known to have a healthy manatee population (Morales-Vela *et al*., 2000). The Corozal Bay Wildlife Sanctuary has been purposely enacted to protect local manatee populations as the area is considered to be a population stronghold (Auil, 1998).. In 2011, four mother-and-calf pairs, as well as a potentially pregnant female, were observed. Manatees have been known to travel long distances to mate (Self-Sullivan, pers comms.), and the possibility that Bacalar Chico may act as a biological corridor or breeding ground should be explored.

The total number of manatee sightings increased in 2011 from 2010 (59 in 2011 versus 15 in 2010). The majority of observations reported occurred on the seagrass beds of the mangroves or backreef, supporting the conclusions of Alegria and Majil (2004), that Bacalar Chico Marine Reserve provides feeding grounds for the Antillean manatee. Anecdotal evidence from fishermen suggests that manatees use the mangroves of Bacalar Chico to shelter from strong winds and currents during the Norte season (November to February). All manatee sightings in December, January and February of 2011 were in the mangroves. Furthermore, sightings during those months comprise over a third (36%) or all manatee sightings for the year, supporting this hypothesis.

4.5 Conclusions and Recommendations

Despite public perception that Bacalar Chico retains healthy reefs, literature and research have demonstrated that management zones appear to be ineffective and that reef health is in decline (Grimshaw and Paz, 2004;

Dahlgren, 2009; Ateweberhan *et al*; 2011). Frequent extractive and non-extractive fishing incursions (e.g. sports fishing) have been observed by Blue Ventures personnel, undermining current management structure and making it difficult to determine whether the current zonation could theoretically support healthy fisheries and reef ecology.

Despite this, it appears that coral reefs within BCMR are in poor health as a result of global change in sea conditions and historical and persistent interruption of ecological processes, rather than direct anthropogenic activity such as fishing.

McClanahan *et al*. (2011) found herbivore populations do not affect macroalgal or HCC on post-disturbance coral reefs, concluding that protecting areas which currently retain high hard coral cover may be more important in retaining functional and healthy reef systems. The healthiest site in Bacalar Chico is found on the forereef of GUZ 1, being the only site with none of the reef indices scored 'Critical'. Additionally, there was one sighting of the critically endangered *E. itajara* and 'Good' coral cover. Macroalgal cover at this site is 'Fair', and scarid biomass is the highest recorded throughout the reserve.

In the *Revised Bacalar Chico National Park and Marine Reserve Management Plan* (Grimshaw and Paz, 2004), it was recommended to revise the zonation of the reserve to move the PZ away from the Mexican border (preventing transboundary incursions), and to nest it within a CZ, followed by General Use. Should zonation be revised, it is proposed that the forereef of GUZ 1 should be placed under complete protection, as fisheries closures are considered to be most effective when applied to reefs with high herbivore abundance, low macroalgal levels and high hard coral cover (Mumby and Harborne, 2010; McClanahan *et al*., 2011).

Furthermore, in order to make informed and effective management decisions, it is of critical importance to identify key habitat and nursery sites for commercially and ecologically significant species, as well as identify which species may be instrumental in instigating phase-shift reversal. In addition, water quality monitoring would enable further identification of factors affecting coral reef condition.

Such information can be ascertained by the development and implementation of:

1. Comprehensive monitoring programmes of lobster and conch in seagrass and reef areas;
2. Herbivory assays within disturbed sites to ascertain which species may be instrumental in reversing phase-change on coral reefs;

3. Improved mangrove and seagrass fish population monitoring to identify nursery areas;
4. Basic scheduled water quality monitoring as well as permanent water temperature logs;
5. Manatee population mapping to investigate population connectivity and use of the area.

It is important to recognise that re-designation of zones would be ineffective in precipitating change in reef health and fish stock sustainability if enforcement of the management is not concomitantly increased.

5. References

Albins, M.A. and Hixon, M.A. 2008. Invasive Indo-Pacific lionfish *Pterois volitans* reduce recruitment of Atlantic coral-reef fishes. *Marine Ecology Progress Series* 367: 233-238

Alegria, V. and Majil, I. 2004. Damage assessment of the Basil Jones area in the vicinity of Nova Shrimp Hatchery, Bacalar Chico National Park/Marine Reserve. Submitted to the Belize Fisheries Department. In: The Revised Bacalar Chico National Park & Marine Reserve Management Plan, March 2004.

Alvarez-Filip, L., Cote, I., Gil,l .JA., Watkinson, A.R. and Dulvy, N.K. 2011. Region-wide temporal and spatial variation in Caribbean reef architecture: is coral cover the whole story? *Global Change Biology* 17: 2470-2477

Auil, N. 1998. Belize Manatee Recovery Plan. Sustainable Development and Management of Biologically Diverse Coastal Resources – Belize Project No. BZE/92/G31, UNEP.

Aronson, R.B. and Precht, W.F. 2000. Herbivory and algal dynamics on the coral reef at Discovery Bay, Jamaica. *Limnology and Oceanography* 45: 251–255

Aronson, R.B., Precht, W.F., Toscano, M.A. and Koltes, K.H. 2002. The 1998 bleaching event and its aftermath on a coral reef in Belize. *Marine Biology* 141: 435-447

Belize, MNREI. 2005. *The Belize National Protected Areas System Plan.* Ministry of Natural Resources, Environment and Industry, Belize.

Bellwood, D.R., Hughes, T.P. and Hoey, A.S. 2006. Sleeping functional group drives coral reef recovery. *Current Biology* 16: 2434-2439 doi: 10.1016/j.cub.2006.10.030

Bentacur-R., R., Hines, A., Acero P., A., Ortí, G., Wilbur, A.E. and Freshwater, D.W. 2011. Reconstructing the lionfish invasion: insights into Greater Caribbean biogeography. *Journal of Biogeography* 38: 1281-1293

Bonham, K. 2011. Insights into Belize's Marine Turtle Populations: an Investigation Utilizing Recreational Divers as Marine Observers. MSc Thesis, Centre for Ecology and Conservation, University of Exeter, UK.

Brown, H. 2011. Biologist Quarterly Report for June, 2011. Bacalar Chico Marine Reserve and National Park, Belize Fisheries Department.

Brown-McNeill, J., Epperly, S.P., Avens, L., Snover, M.L. and Taylor, J.C. 2008. Growth rates of loggerhead sea turtles (*Caretta caretta*) from the Western North Atlantic. *Herpetological Conservation and Biology* 3 (2): 273-281

Burke, L., Reytar, K., Spalding, M. and Perry, A. 2011. Reefs at Risk Revisited. World Resources Institute, Washington, DC.

Burkepile, D.E. and Hay, M.E. 2007. Predator release of the gastropod *Cyphoma gibbosum* increases predation on gorgonian corals. *Oecologia* 154: 167-173

Burkepile, D.E. and Hay, M.E. 2008. Herbivore species richness and feeding complementarily affect community structure and function on a coral reef. *Proceedings of the National Academy of Sciences* 105 (42): 16201-16206 doi: 10.1073/pnas.0801946105

Burkepile, D.E. and Hay, M.E. 2010. Impact of herbivore identity on algal succession and coral growth on a Caribbean reef. *PLoS ONE* 5 (1): e8963. doi: 10.1371/journal.pone.0008963

Carpenter, R.C. and Edmunds, P.J. 2006. Local and regional scale recovery of *Diadema* promotes recruitment of scleractinian corals. *Ecology Letters* 9: 271-280

Carballo, R. and Cantun, E. 2008. Glovers Reef Marine Reserve Annual Report, January-December 2008.

Coelho, V.R. and Manfrino, C., 2007. Coral community decline at a remote Caribbean island: marine no-take reserves are not enough. *Aquatic Conservation: Marine and Freshwater Ecosystems* 17: 666-685

Costello, C., Gaines, S.D. and Lynham, J. 2008. Can catch shares prevent fisheries collapse? *Science* 321: 1678-1681

Chiappone, M., Dienes, H., Swanson, D.W. and Miller, S.L. 2003. Density and gorgonian host-occupation patterns by flamingo tongue snails (*Cyphoma gibbosum*) in the Florida Keys. *Caribbean Journal of Science* 39: 116–127

CZMAI. 2000. State of the Coast Report 2000 (Belize), Coastal Zone Management Authority and Institute, Belize City.

Dahlgren, C. 2009. An evaluation of the effectiveness of the Caye Caulker and Bacalar Chico Marine Reserves in Belize: an Ecological, Socioeconomic and Governance Analysis. PhD Thesis, Perry Institute for Marine Science.

Done, T.J. 1992. Phase shifts in coral reef communities and their ecological significance. *Hydrobiologia* 247: 121-132

Dudgeon, S.R., Aronson, R.B., Bruno, J.F. and Precht, W.F. (2010) Phase shifts and stable states on coral reefs. *Marine Ecology Progress Series*, 413: 201-216 doi: 10.3354/meps08751

Edmunds, P.J. and Carpenter, R.C. 2001. Recovery of *Diadema antillarum* reduces macroalgal cover and increases abundance of juvenile corals on a Caribbean reef. *Proceedings of the National Academy of Sciences* USA 98: 5067–5071

Environmental Defence Fund (EDF). 2011. Belize Inaugurates New Managed Access Program to Prevent and End Overfishing. http://blogs.edf.org/edfish/2011/07/07/belize-inaugurates-new-managed-access-program/. Accessed 09/05/2012.

Environmental Defence Fund (EDF). 2012. Belize Inaugurates New Managed Access Program to Prevent and End Overfishing. http://www.edf.org/oceans/catch-shares. Accessed 09/05/2012.

Finch, J., Garcia, C., Garcia, D. and Muschamp, W. (2008) Southern Environmental Association State of the Parks Report 2008.

Fishelson, L. 1997. Experiments and observations on food consumption, growth and starvation in *Dendrochirus brachypterus* and *Pterois volitans* (Pteroinae, Scorpaenidae*). Environmental Biology of Fishes* 50: 391–403

Foley, J. 2012. Managed Access: Moving Towards Collaborative Fisheries Sustainability in Belize. *Proceedings of the 12th International Coral Reef Symposium*, Cairns, Australia, 9-13 July 2012.

Froese, R. and Pauly, D. 2011. FishBase: a global information system on fishes (http://www.fishbase.org). Accessed 20/10/2012.

Garcia-Salgado, N., Nava-Martinez, G., Bood, N., McField, M., Molina-Ramirez, A., Yañez-Rivera, B., Jacobs, N., Shank, B., Vazquez, M., Majil, I., Cubas, A., Dominquez-Calderon, J.J. and Arrivillaga, A. 2008*a*. Status of Coral Reefs in the Mesoamerican Region. pages: 253-264 *In:* Wilkinson, C. (ed), *Status of Coral Reefs of the World: 2008*, Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville, Australia. 296 pp.

García-Salgado, M.A., Nava-Martinez, G.G., Vazquez, M., Jacobs, N.D., Majil, I., Molina-Ramirez, A., Yañez-Rivera, B., Cubas, A., Dominquez-Calderon, J.J., Hadaad, W., Maldonado, M.A. and Torres, O. 2008*b*. Declining Trend on the Mesoamerican Reef System Marine Protected Areas, *Proceedings of the 11th International Coral Reef Symposium*.

Gardner, T.A., Côté, I.M., Gill, J.A., Grant, A. and Watkinson, A.R. 2003. Long-term region-wide declines in Caribbean corals. *Science* 301: 958–960

Gardner, T.A., Côté, I.M., Gill, J.A., Grant, A. and Watkinson, A.R. 2005. Hurricanes and Caribbean coral reefs: impacts, recovery patterns, and role in long-term decline. *Ecology* 86 (1): 174-184

Gibson, J., McField, M. and Wells, S. 1998. Coral reef management in Belize: an approach through Integrated Coastal Zone Management. *Ocean & Coastal Management* 39: 229-244

Grimshaw, T. and Paz, G. 2004. The Revised Bacalar Chico National Park and Marine Reserve Management Plan. Green Reef Environmental Institute, San Pedro, Belize.

Gibson, J. 2011. The Belize Barrier Reef: a World Heritage Site. *In*: Palomares M.L.D., Pauly D. (eds), *Too Precious to Drill: The Marine Biodiversity of Belize*, pp 8-13, Fisheries Centre Research Reports 19 (6). Fisheries Centre, University of British Columbia.

Goshe, L.R. 2009. Age at maturation and growth rates of green sea turtles (*Chelonia mydas*) along the Southeastern U.S. Atlantic Coast estimated using skeletochronology. Master's Thesis: University of North Carolina.

Green, D.H., Edmunds, P.J. and Carpenter, RC. 2008. Increasing relative abundance of *Porites astreoides* on Caribbean reefs mediated by an overall decline in coral cover. *Marine Ecology Progress Series* 359: 1-10

Hawkins, J.P. and. Roberts, C.M. 2004. Effects of artisanal fishing on Caribbean coral reefs. *Conservation Biology* 18: 215-226

Healthy Reefs Initiative, 2010. Report Card for the Mesoamerican Reef. Available at www.healthyreefs.org.

Hertzing, D.L. 1997. The life history of free-ranging Atlantic spotted dolphins (*Stenella frontalis*): Age classes, color phases, and female reproduction. *Marine Mammal Science* 13 (4): 576-595

Heyman, W.D. 2001. Spawning Aggregations in Belize: A Report Generated for the Workshop, "Towards a Sustainable Management of Nassau Groupers in Belize". The Nature Conservancy.

Heyman, W.D. and Kobara, S. 2011. Snapper and Grouper assemblages of Belize: potential impacts from oil drilling. *In*: Palomares MLD, Pauly D (eds.), *Too Precious to Drill: the Marine Biodiversity of Belize*, pp. 43-47. Fisheries Centre Research Reports 19(6). Fisheries Centre, University of British Columbia.]

Heyman, W.D. and Requena, N. 2002. Status of Multi-Species Spawning Aggregations in Belize. The Nature Conservancy.

Hilton-Taylor, C. (ed.). 2001. 2000 IUCN Red List of Threatened Species. IUCN, Gland, Switzerland and Cambridge, UK.

Hughes, T.P. 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. *Science* 265: 1547–1551

Hughes, T.P., Graham, N.A.J., Jackson, J.B.C., Mumby, P.J. and Steneck, R.S. 2010. Rising to the challenge of sustaining coral reef resilience. *Trends in Ecology and Evolution* 25 (11): 633-642

Huntington, B.E., Karnauskas, M. and Lirman, D. 2011. Corals fail to recover at a Caribbean marine reserve despite ten years of reserve designation. *Coral Reefs* 30: 1077-1085

Idjadi, J.A., Lee, S.C., Bruno, J.F., Precht, W.F., Allen-Requa, L. and Edmunds, P.J. 2006. Rapid phase-shift reversal on a Jamaican coral reef. *Coral Reefs* 25: 209–211

Jackson, J.B.C., Kirby, M.X., Berger, W.H. and Bjorndal, K.A.. 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293: 629–638

Jones, N., Ateweberhan, M., Chapman, J., Humber, F. and Gough, C. 2011. Bacalar Chico Marine Reserve 2010: a survey of the coral reefs in Bacalar Chico Marine Reserve, Belize. Blue Ventures Conservation Report.
Kopp, D., Bouchon-Navaro, Y., Louis, M., Mouillot, D. and Bouchon, C. 2010. Herbivorous fishes and the potential of Caribbean marine reserves to preserve coral reef ecosystems. *Aquatic Conservation: Marine and Freshwater Ecosystems* 20: 516-524

Lapointe, B.E., Barile, P.J., Yentsch, C.S., Littler, M.M., Littler, D.S. and Kakuk, B. 2004. The relative importance of nutrient enrichment and herbivory on macroalgal communities near Norman's Pond Cay, Exumas Cays, Bahamas: a "natural" enrichment experiment. *Journal of Experimental Marine Biology and Ecology*, 298: 275-301

Lessios, H.A. 1988. Mass Mortality of Diadema Antillarum in the Caribbean: What Have We Learned? *Annual Review of Ecology and Systematics*, 19: 371-393

Macia, S., Robinson, M.P. and Nalevanko, A. 2007. Experimental dispersal of recovering *Diadema antillarum* increases grazing intensity and reduces macroalgal abundance on a coral reef. *Marine Ecology Progress Series* 348: 173-182

Marks, K.W. and Klomp, K.D. 2003. Fish biomass conversion equations. *In* Lang, J.C (ed.), *Status of Coral Reefs in the western Atlantic: Results of initial Surveys, Atlantic and Gulf Rapid Reef Assessment (AGRRA) Program,* pp 625-628. Atoll Research Bulletin 496.

McClanahan, T.R., McField, M., Huitric, M., Bergman, K., Sala, E., Nyström, M., Nordemar, I., Elfwing, T. and Muthiga, N.A. 2001. Responses of algae, corals and fish to the reduction of macroalgae in fished and unfished patch reefs of Glovers Reef Atoll, Belize. *Coral Reefs* 19: 367-379

McClanahan, T.R., Cokos, B.A. and Sala, E. 2002. Algal growth and species composition under experimental control of herbivory, phosphorus and coral abundance in Glovers Reef, Belize. *Marine Pollution Bulletin* 44: 441-451

McClanahan, T.R., Muthiga, N.A. and Coleman, R.A. 2011. Testing for top-down control: can post-disturbance fisheries closures reverse algal dominance? *Aquatic Conservation: Marine and Freshwater Ecosystems* 21: 658–675

McField, M.D. 2000. Influence of disturbance on coral reef community structure in Belize. Proceedings of the 9th International Coral Reef Symposium, Bali, Indonesia 23-27 October 2000. Vol 1.

McField, M.D., Bood, N., Fonseca, A., Arrivillaga, A., Rinos, A.F. and Viruel, R.M.L. 2008. Status of the Mesoamerican Reef after the 2005 Coral Bleaching Event. In: Wilkinson, C., Souter, D. (2008). *Status of Caribbean coral reefs after bleaching and hurricanes in 2005*. Global Coral Reef Monitoring Network, and Reef and Rainforest Research Centre, Townsville.

McField, M. and P. Richards Kramer. 2007. *Healthy Reefs for Healthy People: A Guide to Indicators of Reef Health and Social Well-being in the Mesoamerican Reef Region.* With contributions by M. Gorrez and M. McPherson.

McManus, J.W. and Polsenberg, J.F. 2004. Coral-algal phase shifts on coral reefs: ecological and environmental aspects. *Progress in Oceanography*, 60: 263-279

Mead, J.G. 1990. Natural History of Bottlenose Dolphins Along the Central Atlantic Coast of the United States. In: Leatherwood, S. and Reeves. R.R (eds.) *The Bottlenose Dolphin*, pp 653. San Diego Academic Press.

Meadows, M. 1995. Bacalar Chico Bird Report, Ambergris Caye, Belize. Technical Report to the International Tropical Conservation Fund.

Moncada, F., Carrillo, E., Saenz, A., and Nodarse, G. 1999. Reproduction and nesting of the hawksbill turtle, *Eretmochelys imbricata*, in the Cuban Archipelago. *Chelonian Conservation and Biology* 3 (2): 257-263

Morales-Vela, B., Olivera-Gomez, D., Reynolds III, J.E. and Rathbun, G.B. 2000. Distribution and habitat use by manatees (*Trichechus manatus manatus*) in Belize and Chetumal Bay, Mexico. *Biological Conservation* 95: 67-75

Morris, J.A., Jr. 2009. The biology and ecology of invasive Indo-Pacific lionfish. Ph.D. Dissertation. North Carolina State University, Raleigh, NC.

Morris, J.A. Jr, and Akins, J.L. 2009. Feeding ecology of invasive lionfish (*Pterois volitans*) in the Bahamian archipelago. *Environmental Biology of Fishes* 86: 389-398

Morris, J.A., Jr., and Whitfield, P.E. 2009. Biology, Ecology, Control and Management of the Invasive Indo-Pacific Lionfish: An Updated Integrated Assessment. NOAA Technical Memorandum NOS NCCOS 99.

Mumby, P.J. 1999. Bleaching and hurricane disturbances to populations of coral recruits in Belize. *Marine Ecology Progress Series* 190: 27-35

Mumby, P.J. 2006. The impact of exploiting grazers (Scaridae) on the dynamics of Caribbean coral reefs. *Ecological Applications* 16 (2): 747–769

Mumby, P.J. 2009. Herbivory versus corallivory: are parrotfish good or bad for Caribbean coral reefs? *Coral Reefs* 28: 683-690

Mumby, P.J, Hastings, A. and Edwards, H.J. 2007. Thresholds and the resilience of Caribbean coral reefs. *Nature* 450: 98-101

Mumby, P.J. and Harborne, A,R. 2010. Marine Reserves Enhance the Recovery of Corals on Caribbean Reefs. *PLoS ONE* 5 (1): e8657. doi:10.1371/journal.pone.0008657

Mumby, P.J., Edwards, A.J., Arias-Gonzalez, J.E., Lindeman, K.C., Blackwell, P.G., Gall, A., Gorczynska, M.I., Harborne, A.R., Pescod, C.L., Renken, H., Wabnitz, C.C.C. and Llewellyn, G. 2004. Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Nature* 427: 533–536

Myhre, S. and Acevedo-Gutierrez, A. 2007. Recovery of sea urchin *Diadema antillarum* populations is correlated to increased coral and reduced macroalgal cover. *Marine Ecology Progress Series* 329: 205-210

National Environment and Research Council (NERC). 2012. Saving coral reefs - fishermen use science to influence government. Science Impacts Database, SID0023. Accessed 02 May 2012.

Newman, M.J.H., Paredes, G.A., Sala, E. and Jackson, J.B.C. 2006. Structure of Caribbean coral reef communities across a large gradient of fish biomass. *Ecology Letters* 9: 1216-1227

O'Shea, T. J. and Salisbury, C. A. 1991. Belize - a last stronghold for manatees in the Caribbean. Oryx 25: 156–164

Oceana. 2010. Belize Bans Bottom Trawling in Exclusive Economic Zone. *Press Releases:* December 8 2010, Belize City, Belize. http://oceana.org/en/ca/news-media/press-releases/belize-bans-bottom-trawling-in-exclusive-economic-zone Accessed 03 May 2012.

Paddack, M.J., Reynolds, J.D., Aguilar, C., Appeldoorn, R.S., Beets, J., Burkett, E.W., Chittaro, P.M., Clarke, K., Esteves, R., Fonseca, A.C., Forrester, G.E., Friedlander, A.M., Garcia-Sais, J., Gonzalez-Sanson, G., Jordan, L.K.B., McClellan, D.B., Miller, M.W., Molloy, P.P., Mumby, P.J., Nagelkerken, I., Nemeth, M., Navas-Camacho, R., Pitt, J., Polunin, N.V.C., Reyes-Nivia, M.C., Roberson, D.R., Rodriguez-Ramirez, A., Salas, E., Smith, S.R., Spieler, R.E., Steele, M.A., Williams, I.D., Wormald, C.L., Watkinson, A.R. and Cote, I.M. 2009. Recent region-wide decline in Caribbean reef fish abundance. *Current Biology* 19: 590-595

Parham, J.F. and Zug, G.R. 1997. Age and growth of loggerhead sea turtles (*Caretta caretta*) of coastal Georgia: an assessment of skeletochronological age-estimates. *Bulletin of Marine Science* 61 (2): 287-304

Quinn, N.J. and Kojis, B.L. 2008. The recent collapse of a rapid phase-shift reversal on a Jamaican north coast coral reef after the 2005 bleaching event. *Revisita de Biologia Tropical* 56 (1): 149–159

REEF, 2007. Reef Environmental Education Foundation Volunteer Survey Project Database. www.reef.org, Accessed 16/02/2011.

Rogers, C. 2011. Coral bleaching and disease should not be underestimated as causes of Caribbean coral reef decline. *Proceedings of the Royal Society. Biological Sciences* 276: 197-198

Ruttenberg, B.I., Schofield, P.J., Akins, J.L., Acosta A., Feeley, M.W., Blondeau, J., Smith, S.G. and Ault, J.S. 2012. Rapid invasion of Indo-Pacific lionfishes (*Pterois volitans* and *Pterois miles*) in the Florida Keys, USA: Evidence from multiple pre-and post-invasion data sets. *Bulletin of Marine Science* 88 (4): 1051-1059

Schofield, P.J. 2009. Geographic extent and chronology of the invasion of non-native lionfish (*Pterois volitans* [Linnaeus 1758] and *P. miles* [Bennett 1828]) in the Western North Atlantic and Caribbean Sea. *Aquatic Invasions* 4 (3): 472-479

Schutte, V.G.W., Selig, E.R. and Bruno, J.F. 2010. Regional spatio-temporal trends in Caribbean coral reef benthic communities. *Marine Ecology Progress Series* 402: 115-122

Shank, B.V. and Kaufman, L. 2009. Effectiveness of marine managed areas of central and southern Belize: Spatial variations in major community processes and the implications for local management success. Grant Report for the Belize Ecological Monitoring project 2006 – 2009. Marine Managed Areas Science Program, Conservation International.

Shcherbina, A.Y., Gawarkiewicz, G.G., Linder, C.A. and Thorrold, S.R. 2008. Mapping bathymetric and hydrographic features of Glover's Reef, Belize, with a REMUS autonomous underwater vehicle. *Limnology and Oceanography* 53 (5, part 2): 2264–2272

Shima, J.S. 2001. Recruitment of a coral reef fish: roles of settlement, habitat, and post-settlement losses. *Ecology* 82 (8): 2190-2199

Stoddart, D.R. 1974. Effects of Hurricane Hattie on the British Honduras Reefs and Cayes, October 30-31, 1961. *Atoll Research Bulletin* 95: 1-142

TEWG (Turtle Expert Working Group), 1998. An assessment of the Kemp's ridley (*Lepidochelys kempii*) and loggerhead (*Caretta caretta*) sea turtle populations in Western North Atlantic. NOAA Technical Memorandum NMFS-SEFSC-444.

U.S. Fish and Wildlife Service. 1999. Multi-Species Recovery Plan for South Florida. Southeast Region, Atlanta GA. Approved by Sam D. Hamilton.

UNESCO. 1996. World Heritage Sites: Belize Barrier Reef Reserve System, Belize. United Nations Environment Programme, World Conservation Monitoring Centre.

Walker, Z. (2009) South Water Caye Marine Reserve – Management Plan 2010-2015, Wildtracks.

Walker, Z. and Walker, P. (2009) Status of the Protected Areas of Belize: Bacalar Chico Marine Reserve – Assessment of Management Effectiveness For 2009, Wildtracks.

Waring, G.T., Josephson, E., Fairfield, C.P. and Maze-Foley, K., (eds.). 2006. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments - 2005. NOAA Tech Memo 194, pp 328-320

Whitehead, H. and Mann, J. 1999. Female reproductive strategies of cetaceans. In: Mann, J., Connor, R.C., Tyack, P.L. and Whitehead. H. (eds.) *Cetacean Societies, Field Studies of Dolphins and Whales,* pp 219-246 . The University of Chicago Press, Chicago.

Wildtracks (2010) Laughing Bird Caye National Park – Management Plan 2011-2016.

Williams, I.D., Polunin, N.V.C. and Hendrick, V.J. 2001. Limits to grazing by herbivorous fishes and the impact of low coral cover on macroalgal abundance on a coral reef in Belize. *Marine Ecology Progress Series* 222: 187-196

Wyneken, J. 2001. The Anatomy of Sea Turtles. NOAA Technical Memorandum NMFS-SEFSC-470.

6. Appendix

Appendix 1: Survey Methods 2011

1.1 Site Selection – Manta Towing

The Manta Tow Technique is used to cover a large area of reef quickly, providing a general description of reef location and topography. This information can then be used to select sites fulfilling criteria for reef surveys.

Equipment

- Manta Board
- Boat
- Rope
- GPS
- Underwater Slate and Pencil
- Mask and Snorkel

Method

1. Attach the manta board to the stern of the boat with a rope approximately 20 m long.
2. Ensure conditions are suitable and visibility is above 10 m.
3. Before entering the water record the name of the data collector, date, time and the GPS location.
4. One data collector equipped with mask, snorkel and slate swims to the manta board.
5. Once the data collector is ready, he/she should signal and mark the start location using GPS.
6. Tow data collector at a speed of approximately 4 km/hr for 2 minutes.
7. Researcher signals to the boat if tow path begins to deviate from the reef.
8. Record end location of tow with GPS
9. The data collector then records the data for that tow
    a. Description of topography (e.g. spur-and-groove formation reef, steep wall to sandy bottom, etc.)
    b. Depth estimation
    c. Estimation of hard coral cover
    d. Comments – megafauna sightings, unusual features, etc.
10. Repeat procedure for more tows until the entire target area has been covered.

11. Once potential sites have been identified conduct an exploratory dive to identify an area of the reef for surveying.

1.2 Belt Transects

Populations of priority fish and invertebrate species are identified within haphazardly chosen transects (30 m in length and 1 or 2 m in width). Eight tapes are laid haphazardly within a 200 m^2 area. Along transects, there should be no dramatic changes in depth and at no part should be deeper than 15 m. In spur-and-groove formation reefs the tape is laid along the top of the spurs. To optimise surveys, it is most efficient for a buddy pair to comprise of an individual trained on fish belts, and an individual trained on fish recruits and invertebrates. Therefore, the sequence for surveys is to first complete the fish belt. Following 2 m behind, the second data collector completes the invertebrate belt. Following completion of these two activities, the buddy pair must ensure the survey area is undisturbed for a further two minutes before embarking upon the fish recruit belt. Repeat belts must be laid at least 5 m from one another.

1.2.1 Priority Fish Species

The complete species list can be found in Appendix 2.

Equipment

- 30 m Tape Measure
- Weight
- Compass
- Underwater Slate and Pencil
- SCUBA Equipment
- Bottom Timer
- Dive Computer or Thermometer
- GPS

Method

1. Slates prepared prior to dive (Table A1.1)
2. GPS point for survey location is located and divers enter the water.

3. Survey areas must not be disturbed prior to the start of data collection. If a diver swims into a survey area that area cannot be sampled for 30 minutes.
4. Transect start point is selected to ensure survey area fulfils requirements outlined above. Transects must be at least five metres apart from one another.
5. Data collector checks buoyancy, takes bearing and checks reference point in distance, records start depth, start temperature and start time.
6. Data collector advances slowly, unravelling tape whilst recording data.
7. Data collector tallies abundance of priority fish species present within an area 1 m either side of transect tape, and 2 m in front. Dive buddy follows 2 m behind.
8. Data collector may pause to record fish if they are in great abundance. The entire 30 metres must be covered in six to eight minutes.
9. Upon completion of the 30 m transect, the data collector secures the tape, records end depth, end temperature, and checks time to ensure that the transect was completed within time.
   - If the transect was completed too quickly or too slowly, the data is considered invalid and the method is repeated on an undisturbed portion of the survey site.
10. All data are entered into data entry books immediately after the dive.

Table A1.1 Slate layout for priority fish species belt transect

Site:		Name:		Start: ____m	____°C	
Date:		Transect #		End: ____m	____°C	
Species	**<5 cm**	**6-10 cm**	**11-20 cm**	**21-30 cm**	**31-40 cm**	**>40 cm**

1.2.2 Fish Recruitment

The complete species list can be found in Appendix 3.

Equipment

- 30 m Tape Measure
- Weight
- Compass
- Underwater Slate and Pencil
- SCUBA Equipment

- Dive Computer or Thermometer

Method

1. Slates prepared prior to dive (Table A1.2)
2. GPS point for survey location is located and divers enter the water.
3. Following completion of a fish belt, all data collectors swim away from the transect, ensuring they are outside of the survey area, for two minutes.
4. After the two minute wait, fish recruit data collector swims slowly back along the 30 m transect searching for fish recruits within a 1 m belt (0.5 m on each side of the tape). As these are small, demersal and difficult to spot they should search thoroughly with no time limit.
5. All data entered into data entry books immediately after the dive.

Table A1.2 Slate layout for fish recruit belt

Site:				Date:			Name:		
Species	**Max Size (cm)**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
Ocean Surgeon	5.0								
Blue Tang	5.0								
Banded Butterfly	2.0								
Four-eye Butterfly	2.0								
Fairy Basslet	3.0								
Spanish Hogfish	3.5								
Slippery Dick	3.0								
Yellowhead Wrasse	3.0								
Clown Wrasse	3.0								
Rainbow Wrasse	3.0								
Bluehead Wrasse	3.0								
Puddingwife	3.0								
Blue Chromis	3.5								
Longfin Damselfish	2.5								
Dusky Damselfish	2.5								
Beaugregory	2.5								
Threespot Damselfish	2.5								
Cocoa Damselfish	2.5								
Sergeant Major	3.0								
Striped Parrotfish	3.5								
Princess Parrotfish	3.5								
Greenblotch Parrotfish	3.5								
Redband Parrotfish	3.5								
Stoplight Parrotfish	3.5								

1.2.3 Priority Invertebrate Species

The complete species list can be found in Appendix 4.

Equipment

- 30 m Tape Measure
- Weight
- Compass
- Underwater Slate and Pencil
- SCUBA Equipment
- Dive Computer or Thermometer

Method

1. Slates prepared prior to dive (Table A1.3)
2. GPS point for survey location is located and divers enter the water.
3. Data collector swims slowly along the transect searching for and tallying priority invertebrates within a 2 m belt (1 m on each side of the tape). As these are often cryptic or hidden and therefore difficult to spot, they should search thoroughly with no time limit.
4. Data collector may complete the invertebrate belt whilst swimming one to two metres behind the data collector for the priority species fish belt or fish recruit belt.

Table A1.3 Slate layout for invertebrate belt transect

Site:			Date:			Name:		
Species	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
Diadema Sea Urchin								
Juvenile *Diadema*								
Queen Conch								
Sea Cucumber								
Flamingo Tongue								
Caribbean Spiny Lobster								
Spotted Lobster								
Spanish Lobster								

1.3 Point Intercept Transects

The complete list, with standard codes, can be found in Appendix 5.

Equipment

- 30 m Tape Measure
- Weight
- Compass
- Underwater Slate and Pencil
- SCUBA Equipment
- Dive Computer or Thermometer

Method

1. Slates prepared prior to dive (*Table A1. 4*)
2. GPS point for survey location is located and divers enter the water.
3. Five 30 m tapes are laid haphazardly, with each end secured, within a 200 m^2 survey area defined by the GPS point. Along transects, there should be no dramatic changes in depth and at no part should it be deeper than 15 m. At spur-and-groove reefs, tapes should not cross grooves.
4. Data collector swims along the tape, identifying the organism or substrate directly beneath the tape every 25 cm for the entire 30 m (i.e. 120 points).
5. All data entered into data entry books immediately after the dive.

Table A1. 4 Slate layout for PITs

Site:			Name:			Start: ____m	____°C
Date:			Transect #			End: ____m	____°C
Distance	**ID**	**Distance**	**ID**	**Distance**	**ID**	**Distance**	**ID**
0.25		8.25		16.25		24.25	
0.50		8.50		16.50		24.50	
0.75		8.75		16.75		24.75	
1.00		9.00		17.00		25.00	
1.25		9.25		17.25		25.25	
1.50		9.50		17.50		25.50	
1.75		9.75		17.75		25.75	
2.00		10.00		18.00		26.00	
2.25		10.25		18.25		26.25	
2.50		10.50		18.50		26.50	
2.75		10.75		18.75		26.75	
3.00		11.00		19.00		27.00	
3.25		11.25		19.25		27.25	
3.50		11.50		19.50		27.50	
3.75		11.75		19.75		27.75	
4.00		12.00		20.00		28.00	
4.25		12.25		20.25		28.25	
4.50		12.50		20.50		28.50	
4.75		12.75		20.75		28.75	
5.00		13.00		21.00		29.00	
5.25		13.25		21.25		29.25	
5.50		13.50		21.50		29.50	
5.75		13.75		21.75		29.75	
6.00		14.00		22.00		30.00	
6.25		14.25		22.25			
6.50		14.50		22.50			
6.75		14.75		22.75			
7.00		15.00		23.00			
7.25		15.25		23.25			
7.50		15.50		23.50			
7.75		15.75		23.75			
8.00		16.00		24.00			

1.4 Coral Community Characterisation

This survey aims to monitor the health of scleractinian corals and hydrocorals, as well as supplementing hard coral species diversity data collected during PITs. Monitoring incidence and severity of bleaching and sea temperature facilitates the understanding of species-specific sensitivity, reef resilience and recovery potential. This survey is undertaken only by advanced survey members.

Equipment

- 30 m Tape Measure
- 2 m Tape Measure
- Weight
- Compass
- Underwater Slate and Pencil
- SCUBA Equipment
- Dive Computer or Thermometer

Method

1. Slates prepared prior to dive (Table 2.5)
2. GPS point for survey location is located and divers enter the water.
3. One 30 m tape are laid haphazardly within the 200 m^2 survey area, with each end secured, ensuring there is no dramatic changes in depth along the tape and that at no part it is deeper than 15 m.
4. Start and end depth and temperature are recorded for each transect.
5. Two data collectors work together to record species, health descriptors and morphometrics of every coral colony greater than 10 cm in diameter laying directly underneath the transect line. Fifty hard coral colonies are observed. If 50 colonies are not encountered along one tape, further tapes may be laid haphazardly within the 200 m^2 survey area, at least 2 m away from any other tape.
6. *Siderastrea radians* (SRAD), *Agaricia humilis* (AHUM) and *Favia fragum* (FFRA) should always be recorded if encountered, regardless of size, as colonies of these species rarely grow larger than 10 cm. These are recorded in addition to the 50 hard coral colonies greater than 10 cm.
7. For each coral encountered the following data is recorded:
    - Species
    - Size
        i. Greatest height perpendicular to direction of growth. Height = 0.5 cm for encrusting corals

ii. Widest diameter perpendicular to height.

- Mortality
  i. Estimate percentage cover (0%, <25%, 25-50%, 50-75%, 75-100%) of recently killed coral and long dead coral from plan view.
- Bleaching
  i. Estimate percentage cover (0%, <25%, 25-50%, 50-75%, 75-100%) of pale and full bleaching from plan view.
- Disease
  i. Record incidence and type of disease.
- Comments
  i. Any additional information affecting health of coral colony, including, though not restricted to, evidence of competition or predation, presence of orange icing sponge, cause for mortality if able to be determined, etc.

8. Once 50 hard coral colonies have been encountered, the total distance covered is recorded.
9. All data entered into data entry books immediately after the dive.

Table A1. 5 Slate layout for coral community characterisation survey

Site:				Name:			Start: ____m ____°C
Date:				Transect #			End: ____m ____°C
HC (>10cm)	**Species**	**Height (cm)**	**Diameter (cm)**	**Mortality**	**Bleaching**	**Disease**	**Comments**
1							
2							
3							
...							
Fire (>10cm)	**Species**	**Height (cm)**	**Diameter (cm)**	**Mortality**	**Bleaching**	**Disease**	**Comments**
1							
2							
3							
...							
FFRA, AHUM, SRAD	**Species**	**Height (cm)**	**Diameter (cm)**	**Mortality**	**Bleaching**	**Disease**	**Comments**
1							
2							
3							

1.5 Fish Rover

This technique was developed by Reef Environmental Education Foundation (REEF) (http://www.reef.org) to rapidly attain information on abundance and diversity of fish species on reefs. The dive takes place within the 200 m^2 limits of the survey site as specified by GPS Coordinates. Only one data collector is required to fulfil the minimum requirements of the method, however data is enhanced by multiple observers.

Equipment

- Compass
- Underwater Slate and Pencil
- SCUBA Equipment

Method

1. Slates prepared prior to dive (
2. Table A1. **6**)
3. GPS point for survey location is located and divers enter the water.
4. Buddy pairs assemble and set their compasses for U-shaped search patterns around the site, enabling each team to cover different portions.
5. For 30 minutes data collectors actively search for fish (including under overhangs, in caves, etc.), identifying and tallying abundance for all species encountered using the best of their knowledge and ability. Fish should only be recorded if the observer is confident in their identification. Recording fish to family level is acceptable.
6. All data entered into data entry books immediately after the dive.

Table A1. 6 Slate layout for fish rover survey

Site:		Date:	
Name:		Time Start:	
Species	**Tally**	**Species**	**Tally**

1.6 Target and Invasive Species Monitoring

Due to the low population densities of some commercially significant or endangered species, belt transects do not produce accurate estimates of abundance. A target list of species (Appendix 6) was produced based upon anecdotal fisheries targets, IUCN categorisation and/or population trends of the species in other parts of the Mesoamerican Barrier Reef. Lionfish (*Pterois volitans*) are an invasive species in the Caribbean, with sightings being recorded in Bacalar Chico since August 2010.

On every dive, including survey dives, the location, size, depth and abundance of target species and lionfish are recorded as well as any additional comments such as sex, behaviour, etc. For lobster species, size estimation is based on cape length and for fish total length (mouth to tip of tail)

Appendix 2: Priority Fish Species List

Family		Common Name	Genus	Species	Trophic Level	Comments
Surgeonfish:	Acanthuridae	Blue Tang	*Acanthurus*	*coeruleus*	2.0	
		Ocean Surgeonfish	*Acanthurus*	*bahianus*	2.0	
		Doctorfish	*Acanthurus*	*chirurgus*	2.0	
Parrotfish:	Scaridae	Rainbow Parrotfish	*Scarus*	*guacamaia*	2.0	No confirmed sightings
		Midnight Parrotfish	*Scarus*	*coelestinus*	2.0	
		Blue Parrotfish	*Scarus*	*coeruleus*	2.0	Never sighted
		Queen Parrotfish	*Scarus*	*vetula*	2.0	
		Princess Parrotfish	*Scarus*	*taeniopterus*	2.0	
		Striped Parrotfish	*Scarus*	*iserti*	2.0	
		Stoplight Parrotfish	*Sparisoma*	*viride*	2.0	
		Redband Parrotfish	*Sparisoma*	*aurofrenatum*	2.0	
		Redtail Parrotfish	*Sparisoma*	*chrysopterum*	2.0	
		Yellowtail Parrotfish	*Sparisoma*	*rubripinne*	2.0	
Wrasse:	Labridae	Hogfish	*Lachnolaimus*	*maximus*	3.9	
		Spanish Hogfish	*Bodianus*	*rufus*	3.4	
		Creole Wrasse	*Clepticus*	*parrae*		Not included on MBRS-SMP priority list; excluded from analysis
		Wrasse sp.	-	-		Not included on MBRS-SMP priority list; excluded from analysis
Butterflyfish:	Chaetodontidae	Foureye Butterflyfish	*Chaetodon*	*capistratus*	3.0	
		Banded Butterflyfish	*Chaetodon*	*striatus*	3.2	
		Spotfin Butterflyfish	*Chaetodon*	*ocellatus*	3.2	

Family		Common Name	Genus	Species	Trophic Level	Comments
		Longsnout Butterflyfish	*Chaetodon*	*aculeatus*	3.2	
Angelfish:	Pomacanthidae	Grey Angelfish	*Pomacanthus*	*arcuatus*	2.9	
		French Angelfish	*Pomacanthus*	*paru*	2.8	
		Queen Angelfish	*Holacanthus*	*ciliaris*	3.0	
		Blue Angelfish	*Holacanthus*	*bermudensis*	3.3	Never sighted
		Rock Beauty	*Holacanthus*	*tricolor*	3.0	
		Cherubfish	*Centropyge*	*argi*	2.0	Never sighted
Triggerfish:	Balistidae	Black Durgon	*Melichthys*	*niger*	2.4	
		Queen Triggerfish	*Balistes*	*vetula*	3.4	
		Grey Triggerfish	*Balistes*	*capriscus*	3.6	Never sighted
Filefish:	Monacanthidae	Scrawled Filefish	*Aluterus*	*scriptus*	2.8	
		Whitespotted Filefish	*Cantherhines*	*macrocerus*	3.0	
		Orangespotted Filefish	*Cantherhines*	*pullus*	2.6	
Damselfish:	Pomacentridae	Blue Chromis	*Chromis*	*cyanea*		Not included on MBRS-SMP priority list; excluded from analysis
		Sergeant Major	*Abudefduf*	*saxatilis*		Not included on MBRS-SMP priority list; excluded from analysis
		Yellowtail Damselfish	*Microspathodon*	*chrysurus*	2.1	
		Bicolour Damselfish	*Stegastes*	*partitus*		Not included on MBRS-SMP priority list; excluded from analysis
		Damselfish sp.	-	-		Not included on MBRS-SMP priority list; excluded from analysis

Family		Common Name	Genus	Species	Trophic Level	Comments
Mackerel:	Scombridae	Cero	*Scomberomorus*	*regalis*	4.5	Not included on MBRS-SMP priority list; commercially significant; included in analysis
Tarpon:	Elopidae	Tarpon	*Megalops*	*atlanticus*	4.5	Not included on MBRS-SMP priority list; commercially significant; included in analysis
Squirrelfish:	Holocentridae	Squirrelfish	-	-		Not included on MBRS-SMP priority list; excluded from analysis
Barracuda:	Sphyraenidae	Great Barracuda	*Sphyraena*	*barracuda*	4.5	
Grunt:	Haemulidae	French Grunt	*Haemulon*	*flavolineatus*	3.3	
		Cottonwick	*Haemulon*	*melanurum*	2.2	
		Bluestriped Grunt	*Haemulon*	*sciurus*	3.4	
		Caesar Grunt	*Haemulon*	*carbonarium*	3.3	
		Spanish Grunt	*Haemulon*	*macrostomum*	3.3	
		White Grunt	*Haemulon*	*plumierii*	3.6	
		White Margate	*Haemulon*	*album*	3.2	
		Black Margate	*Anisotremus*	*surinamensis*	3.3	
		Sailor's Choice	*Haemulon*	*parra*	3.5	
		Black Grunt	*Haemulon*	*bonariense*	3.5	
		Tomtate	*Haemulon*	*aurolineatum*	3.2	
		Smallmouth Grunt	*Haemulon*	*chrysargyreum*	3.3	
		Porkfish	*Anisotremus*	*virginicus*	3.4	
		Striped Grunt	*Haemulon*	*striatum*	3.4	Never sighted
		Pigfish	*Orthopristis*	*chrysoptera*	3.4	Never sighted
Snapper:	Lutjanidae	Schoolmaster	*Lutjanus*	*apodus*	4.2	
		Grey Snapper	*Lutjanus*	*griseus*	4.3	

Family		Common Name	Genus	Species	Trophic Level	Comments
		Mahogany Snapper	*Lutjanus*	*mahogoni*	4.4	
		Mutton Snapper	*Lutjanus*	*analis*	3.9	
		Lane Snapper	*Lutjanus*	*synagris*	3.8	
		Cubera Snapper	*Lutjanus*	*cyanopterus*	4.2	
		Dog Snapper	*Lutjanus*	*jocu*	4.3	
		Yellowtail Snapper	*Ocyurus*	*chrysurus*	4.0	
		Vermilion Snapper	*Rhomboplites*	*aurorubens*	4.3	Never sighted
		Blackfin Snapper	*Lutjanus*	*buccanella*	3.9	Never sighted
Grouper:	Serranidae	Black Grouper	*Mycteroperca*	*bonaci*	4.5	
		Tiger Grouper	*Mycteroperca*	*tigris*	4.5	
		Goliath Grouper	*Epinephelus*	*itajara*	4.1	
		Yellowmouth Grouper	*Mycteroperca*	*interstitialis*	4.5	
		Yellowfin Grouper	*Mycteroperca*	*venenosa*	4.5	
		Marbled Grouper	*Epinephelus*	*inermis*	4.5	No confirmed sightings
		Nassau Grouper	*Epinephelus*	*striatus*	4.1	
		Red Grouper	*Epinephelus*	*morio*	Unknown	Used 4.1 as trophic level due to similarity of Red Grouper to Nassau Grouper
		Scamp	*Mycteroperca*	*phenax*	4.5	No confirmed sightings
		Graysby	*Cephalopholis*	*cruentatus*	Unknown	Used 4.0 as trophic level in analysis due to similarity of Graysby with Coney and Red Hind
		Coney	*Cephalopholis*	*fulva*	4.1	
		Red Hind	*Epinephelus*	*guttatus*	3.9	
		Rock Hind	*Epinephelus*	*adscensionis*	3.5	No confirmed sightings

Family		Common Name	Genus	Species	Trophic Level	Comments
Jack:	Carangidae	Bar Jack	*Caranx*	*ruber*	4.4	
		Permit	*Trachinotus*	*falcatus*	3.2	
Scorpionfish:	Scorpaenidae	Lionfish	*Pterois*	*volitans*	4.5	

Appendix 3: Fish Recruits

Common Name	**Genus**	**Species**	**Max Size (cm)**
Ocean Surgeon	*Acanthurus*	*bahianus*	5.0
Blue Tang	*Acanthurus*	*coeruleus*	5.0
Banded Butterfly	*Chaetodon*	*striatus*	2.0
Four-eye Butterfly	*Chaetodon*	*capistratus*	2.0
Fairy Basslet	*Gramma*	*loreto*	3.0
Spanish Hogfish	*Bodianus*	*rufus*	3.5
Slippery Dick	*Halichoeres*	*bivittatus*	3.0
Yellowhead Wrasse	*Halichoeres*	*garnoti*	3.0
Clown Wrasse	*Halichoeres*	*maculipinna*	3.0
Rainbow Wrasse	*Halichoeres*	*pictus*	3.0
Bluehead Wrasse	*Thalassoma*	*bifasciatum*	3.0
Puddingwife	*Halichoeres*	*radiatus*	3.0
Blue Chromis	*Chromis*	*cyanea*	3.5
Longfin Damselfish	*Stegastes*	*diencaeus*	2.5
Dusky Damselfish	*Stegastes*	*adustus*	2.5
Beaugregory	*Stegastes*	*leucostictus*	2.5
Threespot Damselfish	*Stegastes*	*planifrons*	2.5
Cocoa Damselfish	*Stegastes*	*variabilis*	2.5
Sergeant Major	*Abudefduf*	*saxatilis*	3.0
Striped Parrotfish	*Scarus*	*iserti*	3.5
Princess Parrotfish	*Scarus*	*taeniopterus*	3.5
Greenblotch Parrotfish	*Sparisoma*	*atomarium*	3.5
Redband Parrotfish	*Sparisoma*	*aurofrenatum*	3.5
Stoplight Parrotfish	*Sparisoma*	*viridae*	3.5
Other juvenile			Specify size observed

Appendix 4: Priority Invertebrates

Common Name	**Genus**	**Species**
Caribbean Spiny Lobster	*Panulirus*	*argus*
Spotted Spiny Lobster	*Panulirus*	*guttatus*
Spanish Lobster	*Scyllarides*	*aequinoctialis*
Long-spine Sea Urchin (Adult)	*Diadema*	*antillarum*
Long-spine Sea Urchin (Juvenile)	*Diadema*	*antillarum*
Queen Conch	*Strombus*	*gigas*
Flamingo Tongue	*Cyphoma*	*gibbosum*
All Species of Sea Cucumber	-	-

Appendix 5: Benthic Identification

Hard Corals

Family	Genus	Species	Code	Common Name
Acroporidae	*Acropora*	*palmata*	APAL	Elkhorn
	Acropora	*cervicornis*	ACER	Staghorn
Poritidae	*Porites*	*porites*	PPOR	Finger
	Porites	*astreoides*	PAST	Mustard Hill
Siderastreidae	*Siderastrea*	*siderea*	SSID	Massive Starlet
	Siderastrea	*radians*	SRAD	Lesser Starlet
Agariciidae	*Agaricia*	*agaricites*	AAGA	Lettuce
	Agaricia	*tenuifolia*	ATEN	Thin Leaf Lettuce
	Agaricia	*humilis*	AHUM	Low Relief Lettuce
	Agaricia	*lamarcki*	ALAM	White Star Sheet Lettuce
	Agaricia	*fragilis*	AFRA	Fragile Saucer
	Helioseris	*cucullata*	HCUC	Sunray Lettuce
Astrocoeniidae	*Madracis*	*decactis*	MDEC	10 Ray Star
	Madracis	*formosa*	MFOR	8-Ray Finger
	Madracis	*auretenra*	MAUR	Yellow Pencil
	Stephanocoenia	*intersepta*	SINT	Blushing Star
Faviidae	*Diploria*	*strigosa*	DSTR	Symmetrical Brain
	Diploria	*clivosa*	DCLI	Knobby Brain
	Diploria	*labrynthiformis*	DLAB	Grooved Brain
	Colpophyllia	*natans*	CNAT	Boulder Brain
	Montastrea	*cavernosa*	MCAV	Great Star
	Montastrea	*annularis*	MANN	Lobed Star
	Montastrea	*faveolata*	MFAV	Mountainous Star
	Montastrea	*franksi*	MFRA	Boulder Star
	Favia	*fragum*	FFRA	Golfball
Meandrinidae	*Dichocoenia*	*stokesi*	DSTO	Elliptical Star
	Meandrina	*meandrites*	MMEA	Maze
	Dendrogyra	*cylindrus*	DCYL	Pillar
Caryophylliidae	*Eusmilia*	*fastigiata*	EFAS	Smooth Flower
Mussidae	*Isophyllia*	*sinuosa*	ISIN	Sinuous Cactus
	Isophyllastrea	*rigida*	IRIG	Rough Star
	Mycetophyllia	*lamarckiana*	MLAM	Ridged Cactus
	Mycetophyllia	*aliciae*	MALI	Knobby Cactus
	Mycetophyllia	*ferox*	MFER	Rough Cactus
	Mussa	*angulosa*	MANG	Spiny Flower
	Scolymia	*spp.*	SCOLYMIA	Artichoke/Solitary Disk/Atlantic Mushroom

Fire Corals

Family Milleporidae	*Millepora*	*alcicornis*	MALC	Branching Fire
	Millepora	*complanata*	MCOM	Blade Fire

Gorgonians

Order Gorgonacea			SROD	Gorgonian Sea Rod
			SPLUM	Gorgonian Sea Plume
			SFAN	Gorgonian Sea Fan
			ENGOR	Encrusting Gorgonian

Other Anthozoans

Order Actiniaria			ANEM	Anemone
Order Corallimorpharia			CMORPH	Corallimorph
Order Zoanthidea			ZOAN	Zoanthid

Algae

Cyanobacteria			CYA	Cyanobacteria
Phaeophyceae	*Dictyota*	spp.	DICT	Y-Branched Algae
	Lobophora	*variegata*	LOBO	Encrusting Fan-Leaf Algae
Rhodophyta			CCA	Crustose Coralline Algae
Chlorophyta	*Halimeda*	spp.	HALI	Halimeda
Rhodophyta			ARTIC	Articulated Coralline Algae
			TA	Turf Algae
			FMA	Fleshy Macro Algae

Others

Class Ascidiacea			TUNI	Tunicate
Phylum Porifera			ERSP	Erect Sponge
			ENSP	Encrusting Sponge
Class Angiospermae			SG	Seagrass
Substrate			BR	Bare Rock
			SD	Sand
			RB	Rubble
			RKC	Recently Killed Coral

Appendix 6: Target Species List

Family - Common	Family - Latin	Common Name	Genus	Species
Commercially Significant				
Wrasse	Labridae	Hogfish	*Lachnolaimus*	*maximus*
Snapper	Lutjanidae	Mutton Snapper	*Lutjanus*	*analis*
		Cubera Snapper	*Lutjanus*	*cyanopterus*
		Dog Snapper	*Lutjanus*	*jocu*
Grouper	Serranidae	Black Grouper	*Mycteroperca*	*bonaci*
		Tiger Grouper	*Mycteroperca*	*tigris*
		Nassau Grouper	*Epinephelus*	*striatus*
Jack	Carangidae	Permit	*Trachinotus*	*falcatus*
Mackerel	Scombridae	Cero	*Scomberomorus*	*regalis*
Tarpon	Elopidae	Tarpon	*Megalops*	*atlanticus*
Barracuda	Sphyraenidae	Great Barracuda	*Sphyraena*	*barracuda*
Invasive				
Scorpionfish	Scorpaenidae	Lionfish	*Pterois*	*volitans*
Invertebrates				
Palinuridae	Spiny Lobsters	Caribbean Spiny Lobster	*Panulirus*	*argus*
		Spotted Spiny Lobster	*Panulirus*	*guttatus*
Scyllaridae	Slipper Lobsters	Spanish Lobster	*Scyllarides*	*aequinoctialis*
Strombidae	Conchs	Queen Conch	*Strombus*	*gigas*
Sharks, Rays, Reptiles, Mammals				
All sightings to maximum level of identification and detail possible				