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Bacalar Chico Marine Reserve 2010: a survey of the coral reefs in Bacalar Chico Marine Reserve, Belize

blue ventures
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Acronyms

BV	Blue Ventures
CZ	Conservation Zone
GUZ	General Use Zone
MBRS	Mesoamerican Barrier Reef System
MPA	Marine Protected Area
NGO	Non-governmental Organisation
NOAA	National Oceanic and Atmospheric Administration
PIT	Point Intercept Transect
PZ	Preservation Zone
UNESCO	United Nations Educational, Scientific and Cultural Organisation

Abstract

Bacalar Chico Marine Reserve ("Bacalar Chico") is one of thirteen marine reserves found in Belize, and includes mangrove habitat, seagrass beds, sublittoral forest and the Mesoamerican Barrier Reef. This report focuses on the establishment of a long term coral reef monitoring programme in the Bacalar Chico Marine Reserve and the analysis of baseline data collected between March 2010 and November 2010 by the marine conservation organisation Blue Ventures.

Bacalar Chico Marine Reserve is divided into four zones: the Preservation Zone (PZ) where all marine activities (e.g. fishing, tourism) is banned, Conservation Zones 1 and 2 (CZ1 & CZ2) where limited marine resource exploitation is allowed and the General Use Zone (GUZ) where artisanal fishing is regulated. Cover of major substrate and benthic groups and coral species was surveyed using Point Intercept Transects (PITs). Coral mortality, bleaching and disease were surveyed for 50 coral colonies within haphazardly selected transects. Fish species assemblages in each zone were monitored using fish belt transects and the 'Rover Diver' fish survey, a haphazard sampling technique that covers all habitats including crevices and overhangs.

The majority of sites surveyed had low scleractinian coral cover, high cover of turf and fleshy algae. Average scleractinian coral cover was 10.5%, and ranged between 2.8 and 17.2%. Coral cover was 6.5 ± 1.4% on the back reef, 9.4 ± 1.7% on the fringing reef and 12.5 ± 0.9% on the fore reef. It was highest on CZ1 (13.6 ± 1.2%) and lowest on the GUZ (4.4 ± 1.9%) with CZ2 and PZ having 9.4 ± 1.7% and 10.2 ± 1.2% cover respectively. Species richness and diversity in the coral community was higher on the fringing and fore reef than on the back reef. It was highest on CZ1 and CZ2 and lowest on the GUZ.

Total abundance and abundance of the major fish families and species diversity were higher on the fore reef and fringing reef than the back reef and similarly higher in the conservation/preservation zones than in the general use zone. Haemulids were an exception, having highest abundance on the GUZ. Patterns in total fish biomass and biomass of economically and commercially important fish species showed high levels of variability and no clear trends between different reef habitats and conservation zones.

In general the observations made here indicate that the reefs of Bacalar Chico are similar to other degraded Caribbean reefs in their benthic, coral and fish composition, dominated by fleshy and turf algae and with low fish biomass and diversity. Despite the higher coral cover and coral and fish diversity in fisheries closures, the full benefit of management in attaining high biomass of key fish functional groups and diversity is not achieved yet and it is recommended that management efforts should be intensified within this area. It is also recommended that the collection of reef health data is continued in the area to assess the effectiveness of marine reserve management and monitor the health of the coral reef ecosystem.

Introduction

Coral reefs represent one of the most globally threatened ecosystems on earth due to cumulative local, regional and global pressures (Hoegh-Guldberg 1999; Hughes *et al.* 2003; Hoegh-Guldberg *et al.* 2007; Baker *et al.* 2008; Veron *et al.* 2009; Burke *et al.* 2011). Local and regional causes of destruction are those linked to overexploitation and the destructive use of resources, coastal development and marine pollution (Wilson *et al.* 2008). Global threats result from climate change related extreme temperature events that cause coral bleaching, ocean acidification and reduced calcification rates, as well as increases in global sea levels and storm frequency and intensity (Burke *et al.* 2011; Kaufman *et al.* 2011). As a result, major ecological processes within the reef ecosystem may become altered and proper reef functioning reduced, which in turn will have a significant influence on the goods and services provided to millions of coastal communities, many with a high economic dependence on natural resources.

In recent decades the coral reefs of the Caribbean region have reportedly shown drastic declines in coral cover (by almost 80%), with a concomitant shift to turf and fleshy algal dominance during the last few decades (Carpenter 1990a; Hughes 1994; Shulman and Robertson 1996; Lapointe *et al.* 1997; Szmant 1997; Gardner *et al.* 2003; Lapointe 2004). This shift has occurred in conjunction with episodic events of coral disease and bleaching (Aronson and Precht 2006, Schutte *et al.* 2010), in addition to overfishing, destructive fishing, excessive input of nutrients and other pollutants and coastal development (Smith *et al.* 1981; Littler and Littler 1984; Hughes 1994; Lapointe *et al.* 1997; Lapointe 1999; Gardner *et al.* 2003; Lapointe *et al.* 2004; Gardner *et al.* 2005; Aronson and Precht 2006; Rogers and Miller 2006; Schutte *et al.* 2010).

The Caribbean wide decline in coral abundance is largely associated with the white band disease outbreak of the late 1970s and successive bleaching events in 1982/83, 1987 and 1998 (Aronson and Precht 2006; Schutte *et al.* 2010). The strong mass coral bleaching event in 1982/83 (Glynn 1984, 1991; Glynn and de Weerdt 1991) was followed by the 1987 and the strong 1998 bleaching events; the latter causing unprecedented damage to the MBRS with a reported 19% reduction in scleractinian coral cover (Kramer and Kramer, 2000). In October of the same year the category 5 Hurricane Mitch hit the region causing significant damage and exacerbating the effects of bleaching (Kramer and Kramer, 2000), resulting in the mortality of more than 50% of coral colonies on some reefs (Garcia-Salgado *et al.*, 2004). Record temperatures and associated thermal stress induced bleaching were observed again in the region in 2005 and 2010 (Donner *et al.* 2007; García-Salgado *et al.* 2008; Eakin *et al.* 2010; Edwards *et al.* 2010). Declines in sea urchin biomass and herbivorous fish populations due to overfishing and disease outbreaks, as well as increases in nutrient input have contributed to altering the equilibrium of the reef system in favour of turf and fleshy algae, resulting in reduced levels of coral recovery and reef resilience in the face of environmental stress (Hughes 1994; Hughes *et al.* 2003; Bellwood *et al.* 2004; Mumby *et al.* 2006; Hoegh-Guldberg *et al.* 2007; Carilli *et al.* 2009).

The Mesoamerican Barrier Reef

The Mesoamerican Barrier Reef System (MBRS) in the western Caribbean, stretches over 1000 km, and includes four countries, Mexico, Belize, Guatemala and Honduras. It is the second largest barrier reef in the world and the largest in the western hemisphere. The MBRS provides income to over one million people (Global Environmental Facility, 2001; Wilkinson *et al.* 2008), primarily through tourism and fishing (Gorrez and McPherson, 2006). In 1996, the MBRS was declared a 'World Heritage Site' as it contains important and significant habitats for threatened species, areas of exceptional natural beauty and examples of unique ecological and biological processes.

The World Wildlife Fund (WWF) has identified the MBRS as a global priority for conservation (McField 2000a). A collaborative effort between the four bordering countries resulted in the creation of the 'MBRS Synoptic Monitoring Program' which uses standardised surveying methodologies and describes in detail the health of the coastal and marine ecosystems of the Mesoamerican region. The aim is to monitor changes in ecosystem health in order to advise and implement effective management procedures.

The Belize Barrier Reef

The core region of the MBRS is within Belize and is one of the world's biodiversity hotspots - recognised as one of the seven wonders of the underwater world (Conservation International, 2003). The area is of great conservation importance with endangered marine and terrestrial species, commercially important invertebrate species, turtle nesting colonies and fish spawning aggregations (Graham *et al.* 2008; Heyman and Kjerfve 2008). However, fish stocks are on the decline (Sala *et al.*, 2001; Gibson *et al.*, 1998; Heyman and Kjerfve 2008) and a large proportion of the coral reef is at risk of further large scale disturbances from coral bleaching and disease (Harvell *et al.* 2007; García-Salgado *et al.* 2008).

Efforts are being made to try to relieve the pressure on the coral reefs. A landmark ban on all trawling in Belizean waters went into effect on December 31st 2010 (www. eu.oceana.org). This is envisaged to limit the amount of habitat destruction and overexploitation of both target and non-target species. Fishing for conch and lobster is common throughout Belize and seasonal closures (conch, July 1st to September 30th; lobster, February 15th to June 14th) have been introduced to reduce their exploitation.

Considering its global significance for biodiversity conservation and the benefits to local communities (Global Environment Facility, 2001; Conservation International, 2003), the collection of baseline data and establishment of long term monitoring programmes is of key importance to assess the health and sustainability of the coral reef ecosystem of Belize.

The Bacalar Chico Marine Reserve

Location and Geography

Bacalar Chico Marine Reserve ("Bacalar Chico") is the most northern marine reserve found in Belize, where the coral reef runs parallel to the entire 300 km coastline. Bacalar Chico is found on the northern section of Ambergris Caye, bordering Mexico and spans 15,529 acres of coastal water (Grimshaw and Paz 2004). Established in 1996 as a Marine Protected Area (MPA), it is the only point along the MBRS where two marine reserves, Bacalar Chico of Belize and Arrecife de Xcalak of Mexico, are connected to each other. The waters surrounding Bacalar Chico host a diverse array of terrestrial and marine wildlife, as well as a wide range of marine ecosystems, including seagrass beds, mangroves, lagoons and sand cays.

The Bacalar Chico Marine Reserve is divided into four sections (Figure 1): the Preservation Zone (PZ) is found furthest north, adjacent to the Mexican border. It has the greatest restrictions in place as no fishing or water-based activities are allowed. The fore reef is separated by a wide, sandy channel which runs from Mexico down the length of the Preservation Zone, creating a double reef system. Either side of the valley are reef walls that extend upwards into rocky plateaus and reef flats. On the western side, reef flats extend from the reef crest into a steep wall leading into the valley. The eastern edge rises from the valley to form a rocky plateau, before sloping into deeper water forming spur and groove channels. The back reef consists of shallow patch reef and seagrass beds.

Conservation Zone 1 (CZ1) is adjacent to the Preservation Zone (PZ) and while fishing is still banned, SCUBA diving is permitted under permission of the Fisheries Department. The reef is predominantly spur and groove with reef tops separated by narrow, deep sandy channels, which open up moving into deeper water. Some deeper patch reefs can be found on the back reef, as well as additional seagrass beds close to shore.

In Conservation Zone 2 (CZ2), only non-extractive activities are permitted, and sport fishing is regulated. It is a unique area as it contains the only point along MBRS where the reef meets the land (Rocky Point). There are fossil limestone remains of the coral reef that once thrived here when sea levels were higher. South of Rocky Point, at the end of Conservation Zone 2, the spur and groove formations continue into the area of highest coral cover in Bacalar Chico. The back reef up until Rocky Point consists of patch reefs with large sandy patches separated by large coral colonies.

The General Use Zone (GUZ), located either side of Conservation Zone 2, is the only area in the reserve where fishing is permitted. Queen Conch (*Strombus gigas*) and Spiny Lobster (*Panulirus argus*) are the main target species, but line fishing and beach traps are also used. The lagoon is shallow, with an average depth of 2-3 metres, whilst the fore reef continues with spur and groove reef formations until continuing into relatively barren reef flats.

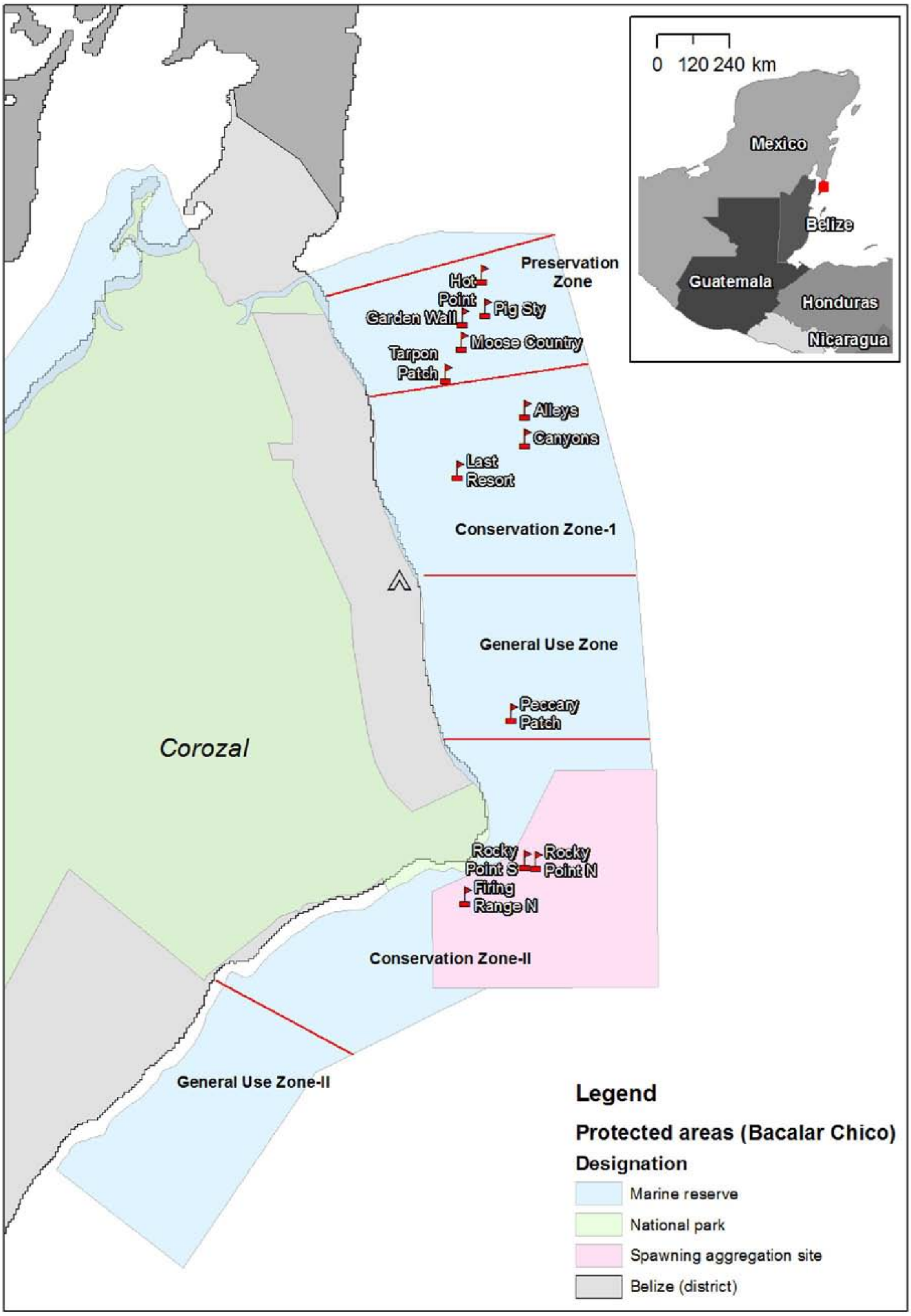

Figure 1 Map of monitoring sites and four management zones in Bacalar Chico Marine Reserve.

History and Context of Bacalar Chico Marine Reserve

Bacalar Chico is an MPA and UNESCO World Heritage site that was set up in 1996 under the National Park Systems Act (Laws of Belize Chapter 215, Revised 2000) as a result of lobbying from local fishermen from the village of Sarteneja. The marine reserve together with the National Park, the terrestrial area of Bacalar Chico, encompasses 60 km^2 and includes mangroves, lagoons, sub littoral forests and coral reef habitats.

The aims of establishing Bacalar Chico as an MPA were to ensure fish stocks remained sustainable, regulate water-based sports, prohibit illegal fishing and conduct monitoring and research. The reserve is managed by the Belize Fisheries Department, which has a ranger station on the western side of Ambergris Caye, facing the Corozal Bay Wildlife Sanctuary at San Juan. Despite Fisheries Officers being present year round and their regular patrols, fishing incursions still occur. The fishermen are predominantly from San Pedro on Southern Ambergris Caye and Xcalak, Mexico. At present the Bacalar Chico Fisheries Department carries out coral reef, mangrove, seagrass, bird nesting, turtle nesting, invertebrate and spawning aggregation monitoring.

Threats to the Reef

Natural disturbances have had devastating effects on the coral reefs of Belize in the last three decades including hurricanes, bleaching events and disease epidemics (Garcia-Salgado *et al.* 2004). The increasing sea surface temperatures observed in the region have resulted in an increase in both the number and severity of mass bleaching events (Koltes *et al.* 1998; Aronson *et al.* 2000).

Direct anthropogenic threats include overfishing, particularly that of key herbivorous fish species, the decline of which has been linked to the observed increases in fleshy macroalgal growth (Lewis and Wainwright 1985; Lewis 1986; Carpenter 1990a; Done 1992; Hughes 1994). Increases in macroalgal coverage could have a severe impact on the coral reef as macroalgae compete directly with scleractinian corals for space and sunlight (Steneck 1994; Box and Mumby 2007; Vu *et al.* 2009). Therefore, herbivorous fish are vital in maintaining the health of the reef environment (Lewis 1985, 1986; Carpenter 1990b; Littler *et al.* 1989; Bellwood *et al.* 2004; Bellwood *et al.* 2006; Hughes *et al.* 2007). In the absence of large biomass of herbivorous fish, mass mortality of *Diadema antillarum* urchins, due to a disease epidemic in the 1980's and 1990's throughout the Caribbean, is also believed to have played a large role in subsequent increases to macroalgal biomass (Carpenter 1990b; Lessios 1995; Edmunds and Carpenter 2001a; Liddel and Ohlhurst 1986; Garcia-Salgado *et al.* 2004).

The rapid increase in human development along the Belize coastline is a further major anthropogenic threat. Roberts *et al.* (2002) identified the Belize Barrier Reef as one of the reef systems most threatened by human impact. The removal of mangrove habitats is of particular concern, as they are vital to the success of coral reef ecosystems; they provide vital habitat for juvenile reef fish, filter terrestrial run-off and prevent erosion of the land (Ronnback 1999; Alongi 2002; Mumby *et al.* 2004; Harborne *et al.* 2006). At present, there is very limited development in Bacalar Chico, and the closest settlements are the village of Xcalak in Mexico to the north, which is outside the reserve, and Tranquillity Bay Hotel, 25 km south. However, with much of the coastline privately owned, an increasing number of hotel complexes have been built in the southern part of the reserve and land has been cleared for development. Therefore coastal development seems likely to become a greater threat to Bacalar Chico.

An increasing number of invasive lionfish, *Pterois miles* and *Pterois volitans,* have been found in Belize including Bacalar Chico. A highly fecund species with a voracious appetite, lionfish populations are fast growing throughout the Caribbean (Hixon *et al.* 2009; Schofield 2009; Whitfield *et al.* 2007; Albins and Hixon 2008). Lionfish feed on a wide range of recruits and juveniles of reef fish species, including endangered species such as serranids and herbivorous fishes such as scarids (Albins and Hixon 2008; Morris and Akins 2009). Lionfish removal has been undertaken in Belize and the rest of the Caribbean (ECOMAR, accessed 21/2/2011), and NOAA has designed lionfish traps for catching the animals more efficiently at greater depths.

Previous Assessment of Bacalar Chico Marine Reserve

The Bacalar Chico Marine Reserve management plan was prepared in 1995 (Dotherow *et al.* 1995), making it amongst the first of seven Marine Reserves to come under the direct management of the Belizean Fisheries Department.

The MBRS Synoptic Monitoring Programme identified areas for monitoring in Mexico, Belize, Honduras and Guatemala (Garcia-Salgado *et al.* 2008). Eight MPAs in Belize were selected for monitoring, including the Bacalar Chico Marine Reserve. Within Bacalar Chico, five sites were chosen for monitoring purposes. During baseline surveys of the selected MPAs in 2004, Bacalar Chico was found to have the largest populations of herbivorous fish species (Acanthuridae and Scaridae) (García-Salgado *et al.* 2008). However, overall fish abundance dropped from an average of about 40/100 m^2 in 2004-2006 to below 22/100 m^2 in 2007 (García-Salgado *et al.* 2008). Initial analysis of the 2004 data indicated that Bacalar Chico was in 'alert status' with less than 19% of scleractinian coral cover, though by 2008 it was reported to be in good condition as the data showed that hard coral cover had increased by 15%, (18% in 2004 to 33% in 2008) (García-Salgado *et al.* 2008). Initial environmental impact assessments showed Bacalar Chico to have particularly high biodiversity, with a mix of terrestrial and marine habitats (Raines *et al.,* 2005). Assessing the success of the management practices in place in Bacalar Chico depends on the availability of relevant data on the different ecosystems found in the reserve, including the coral reef benthic and reef fish assemblages.

This report presents the findings of Blue Ventures'[1] coral reef monitoring programme in Bacalar Chico between March 2010 and November 2010. The findings are discussed in context of current knowledge on the status of other coral reefs found within the MBRS, elsewhere in the Caribbean and globally, with a view to advising the

[1] Blue Ventures is an award-wining marine conservation organisation, dedicated to working with local communities to conserve threatened marine environments. In depth research and the establishment of a long term coral reef monitoring programme by Blue Ventures will help to assess the health of the coral reef in greater depth as well as evaluating the success of Bacalar Chico Marine Reserve with a view to advising the Belize fisheries department on management of the MPA.

Bacalar Chico Fisheries Department and other governmental and non-governmental organizations on the management of the Marine Reserve.

Four main survey methods were used in the collection of coral reef data in Bacalar Chico. All of the methodology used was in keeping with the MBRS Network model (Almada-Villela *et al.* 2003) used throughout the MBRS, by governmental and non-governmental organisations (NGOs).

Research Methodology

Study Area

Site selection was determined through identification of different reef habitats throughout Bacalar Chico. Initially, manta towing was carried out by recording all possible monitoring sites on a Geographical Positioning System (GPS). A further review was carried out using SCUBA, to locate reefs characteristic of each reef type, in each zone. Reef sites also needed to be large enough to perform an appropriate number of surveys and without too much variation in reef height (the spur and groove formations on the fore reef meant that this was not possible at some sites where narrow sand channels were present, particularly at Alleys and Canyons in Conservation Zone 1). The exact point that the first transect was positioned at each site was randomly selected, under a defined GPS position, with the same first transect position to be used in all future monitoring of the site.

Three back reef and ten fore reef sites were selected, with representations from each zone of the Marine Reserve when possible. No sites in the back reef of Conservation Zone 2 or the fore reef of the General Use Zone are currently being monitored as no appropriate site has yet been located.

Back Reef Sites

The back reef sites are all shallow patch reef, within close proximity to coastal mangroves and surrounded by seagrass beds.

Peccary Patch (General Use Zone, GUZ)

Depth: 1-2 m

Description: The eastern side of the patch is shallow, with the tips of the reef exposed at low tide. Coral cover is poor across the site, with cover predominantly algal based. However, fish abundance is good with large schools of *Haemulon flavolineatum*. The transects run east to west.

Last Resort (Conservation Zone 1, CZ1)

Depth: 3-5 m

Description: The site is located west of the largest channel across the reef in Bacalar Chico, with 2 large (4 m wide) *Agaricia tenuifolia* colonies covering the south eastern side of the reef. Small Lutjanidae and Haemulidae congregate at the north of the site, which is more sheltered from the channels. The transects run north to south.

Tarpon Patch (Preservation Zone, PZ)

Depth: 1-2 m

The site is located on back of the barrier reef crest, where large Atlantic tarpon (*Megalops atlanticus)* can be found in the surf zone. The reef is split in 2 sections, with a 3-5 m wide sandy/seagrass area separating the reef. The transects run north to south.

Fore Reef Sites

The fore reef in the Preservation Zone comprises a double reef system, separated by a deep sandy valley, approximately 500 m wide. In Conservation Zone 1, a spur and groove reef system dominates the topography, with reef tops running east-west separated by sandy channels. Conservation Zone 2 comprises of a fringing reef (Rocky Point) in the north and a barrier reef, again with a spur and groove system in the south.

Hot Point (Preservation Zone, PZ)

Depth: 6-10 m

Located on the eastern side of the double reef system, Hot Point is the most northerly of all monitoring sites in Bacalar Chico. The western edge of the site rises from the sandy valley at 20 m to form a rocky plateau at 6 m where large *Acropora palmata* colonies are found. A large *Dendrogyra cylindrus* colony can be seen on the north west edge of the slope. The plateau is 40 m x 40 m in size, with reef flats surrounding the pinnacle. The transects run north to south.

Pig Sty (Preservation Zone, PZ)

Depth: 5-9 m

Pig Sty is also found on the eastern edge of the double reef system, south of Hot Point. The reef slopes at 60° angle to form a flat rocky plateau at 6 m. The rocky plateau is 40 m x 40 m, however coral cover is very poor as hurricane damage appears to have affected the majority of the site. Fish abundance is very high with large schools of *H. flavolineatum* and *Lutjanus adopus*, as well as many Pomacentridae and Holocentridae hiding in the crevices. The transects run north to south.

Garden Wall (Preservation Zone, PZ)

Depth: 7-9 m

Located close to the reef crest on the western edge of the double reef system, the reef extends from the reef crest about 300 m before dropping off into a sharp wall and into a sandy valley. Garden Wall is found on top of the reef parallel to the western edge of the wall. It is located in the north of the Preservation Zone, with a patchy distribution of large *A. palmata* around the site. The transects run north to south.

Moose Country (Preservation Zone, PZ)

Depth: 5-8 m

Moose Country is located south of Garden Wall and is very close to the reef crest. *A. palmata* colonies are dominant, with the greatest percent coverage of *A. palmata* anywhere in Bacalar Chico. The reef slopes off to the east leading into a sandy valley. The transects run north to south.

Alleys (Conservation Zone 1, CZ1)

Depth: 14-16 m

The reef tops are separated every 10-20 m by thin sandy channels 16-18 m deep. Large sheets of *Montastraea faveolata* can be seen covering the reef tops, while *Montastraea annularis* bommies can also be found. The channels open up on the eastern edge of the site as the reef gets deeper. The transects run north to south.

Canyons (Conservation Zone 1, CZ1)

Depth: 14-16 m

The reef tops are separated by deep sandy channels, which become increasingly deeper eastwards until eventually the reef structure breaks up deeper than 30 m. There is a relatively high diversity of coral species throughout the site, with large *M. faveolata* colonies on the reef tops and *Mycetophyllia lamarckiana, Mycetophyllia aliciae, Agaricia lamarcki* and *Agaricia fragilis* colonies on the reef walls. The transects run north to south.

Firing Range North (Conservation Zone 2, CZ2)

Depth: 15-18 m

Located south of Rocky Point in Conservation Zone 2, Firing Range has a relatively large abundance of the triggerfish *Melichthys niger* and *Canthidermis sufflamen*. The spur and groove reef here has the best coral cover in Bacalar Chico and has a high diversity. The channels between reef tops are wider than in Conservation Zone 1, giving the appearance of small island patches of reef, that slope off into deeper water. The transects run north to south.

Firing Range South (Conservation Zone 2, CZ2)

Depth: 15-18 m

Firing Range South is the most southerly monitoring site in Bacalar Chico, the spur and groove formations here also have good coral cover. A range of fish species can be found, including Serranidae, taking advantage of the numerous cleaning stations around the site.

Fringing Reef

Rocky Point North (Conservation Zone 2, CZ2)

Depth: 10-14 m

Located in Conservation Zone 2, Rocky Point is a unique area of the MBRS, as it is the only point where the reef meets the land, and essentially forms a fringing reef. The reef slopes gently until a steep slope which drops down to 20 m on the eastern edge. There is a high abundance of fish, with large schools of reef bottom associated fish as well as large schools non-bottom associated fish, such as *Caranx latus, Trachinotus falcatus, Scomberomorus regalis, Kyphosus sectatrix* and *Chaetodipterus faber*. The focal point of the site is a large hole in the reef where the large schools of the latter group congregate. The transects run south to north from this focal point.

Rocky Point South (Conservation Zone 2, CZ2)

Depth: 8-10 m

Found at the southern end of the Rocky Point wall, it has numerous caves and overhangs at the base of the wall that shelter huge schools of fry. The top of the reef is dominated by gorgonians, with fish and coral abundance being greatest on the sea sides of the reef. Non-bottom associated species also frequently swim over the top of the reef, while large groupers can be found in the caves. The transects run north to south.

Benthic Surveys

Point Intercept Transects

Point Intercept Transects (PITs) were used to assess the percentage cover of the different benthic organisms.

In pairs, observers completed a PIT at the chosen site with one qualified individual collecting all the data along a single transect. The first transect was placed at a predetermined location, chosen by reef topography or a dominant feature, so that subsequent surveys of the site can place transects in the same location to more accurately assess long term changes in reef health. Transects were 30 m long and followed the contours of the reef. All subsequent transects were laid parallel to the first transect and at least 2 m apart from each other. A minimum of 4 transects were completed at each site. The organism directly underneath the transect was recorded every 25 cm under one of the following headings with specific details as required:

- Bare rock
- Sand
- Dead coral
- Turf algae
- Fleshy macroalgae (*Dictyota*, *Lobophora*, other fleshy macroalgae)
- *Halimeda*
- Coralline algae
- Erect sponge
- Encrusting sponge
- Soft coral (e.g. sea fans, sea plumes or sea rods)
- Stony coral (to the species level)

- Other Anthozoa (e.g. anemones, zoanthids, corallimorphs)
- Other benthic organisms (e.g. tunicates, hydrozoa)

Reef Health

General Procedure

In pairs, individuals completed a coral PIT at the chosen site as in the substrate/benthic monitoring (above). Thirty metre long transects were laid in the same positions as used for the benthic sampling following the contours of the reef. Temperature and depth were recorded at the start and end of each transect. Every coral over 10 cm, directly under the transect line was recorded to the species level until 50 coral colonies were included. Where coral density was low, e.g. at Pig Sty, the coral PIT was extended until the intended number of coral colonies (50) was reached.

Incidences of coral bleaching were recorded under the following categories:

- Pale
- Partial Bleaching
- Full Bleaching

Any incidence of mortality in the coral colonies was recorded along with an estimate of the percentage of mortality (normal = 0% mortality, 0-25%, 26-50%, 51-75%, 76-100%).

Any incidences of the following coral diseases were recorded:

- Black Band Disease
- White Band Disease
- White Plague
- Yellow Blotch
- Dark Spot Disease
- Red Band Disease

Any other causes of coral mortality, including sedimentation, storm damage, and predation by invertebrates, parrotfish and other corallivores were recorded.

The height and maximum diameter of the colonies were measured to the nearest cm. After 50 coral colonies had been monitored, the position of the final coral colony as a distance along the transect was recorded for future monitoring.

Fish Surveys

Belt Transect for Priority Fish Species

General Procedure

In pairs, individuals completed a Belt Transect at the chosen site with one individual collecting all the data. The first fish transect was laid in the same position as transect 1 of the benthic sampling, with subsequent transects laid parallel at about 5 m apart. The transect was 30 m long and followed the contours of the reef. A minimum of 5 transects was performed per site. Temperature and depth at the start and end point of each transect were recorded. The observer waited for 2 minutes after setting the transect line to allow for the fish to resettle. The observer swam in a straight line along the transect and recorded the abundance of each fish species, as well as an estimate was made of the size of each fish observed in the belt (<5 cm, 5-10 cm, 10-20 cm, 20-30 cm, 30-40 cm and >40 cm). The belt extended to 1 m either side of the transect line and 5 m above, so that the observation area was 2 x 5 x 30 m. The observer swam at a speed that covered the 30 m transect in 6-8 minutes and ensured that only those individuals that pass within the belt were recorded.

The 'Rover Diver' Fish Survey Technique

General Procedure

In pairs, both individuals completed a general survey of the reef fish species at a given site. Observers swam around a set area of about 200 m^2 of a site for 30 minutes and recorded all fish species observed. Observers tried to find as many species as possible by searching under overhangs and in caves. The density of each species was approximated if an exact count of abundance was not possible.

Monitoring of Invasive, Commercially Important and Endangered Species and Megafauna

In all dives undertaken in the Bacalar Chico Marine Reserve, the identity, abundance, size and location of invasive, commercially important and endangered species and megafauna were recorded. Only records by volunteers and staff trained in identification of the species were considered to ensure accuracy of data.

Statistical Analysis

Percentage cover of each benthic/substrate group and coral species was determined from the proportions of the point intercepts of that group to the total point intercepts per transect (120). Frequencies and percentages of coral colonies with mortality, bleaching and disease infections were also determined as proportions to the total number of colonies per transect (50). Abundance was determined for each fish species as the number of individuals per transect. The wet weight of each individual of every species was determined from the length-weight relationship power function:

$$W = aL^b$$

where W is weight (g), L is length (cm), a and b are constants of the relationship obtained for Caribbean-Atlantic species.

Abundance data from the 'Fish Rover' survey were classified into four categories:

- Single: 1 individual
- Few: 2-10
- Many: 11-100
- Abundant: >100

Average abundance of each species was used to estimate the population of fish species at a given site. Further analysis was performed using the abundance categories above to determine a Density Index (Den) and Sighting Frequency (%SF) for each species, calculated using the following formulae (REEF 2007):

$$Den = (1S + 2F + 3M + 4A)/n$$

$$\%SF = (S + F + M + A)/n \times 100$$

where, S, F, M and A are the number of times a fish is recorded in the categories Single, Few, Many and Abundant and n is the number of sampling occasions.

Density Indices greater than three (3.0) indicate that the fish is observed in high densities, and less than three (3.0) indicates that the fish is observed in low densities. This information, combined with the Sighting Frequency, gives a description of the fish population.

Species richness (S), Shannon-Wiener diversity (H), Simpson's diversity (1-D) and Pielou's equitability (J) were calculated for the coral species and fish abundance data. The Shannon – Wiener Diversity Index (H) is a widely used measure of community diversity as it takes into account the number of individuals as well as number of taxa and is given by the following equation:

$$H = -\Sigma p_i (\ln p_i)$$

where p_i is the relative abundance of each species, calculated by n_i/N where n_i is the number of individuals of each species and N is the total number of individuals in the population. Where all species are found in equal numbers an H_{max} is found. H value of 0 signals low species diversity (a community with a single taxon) with all species the same and 4.6 high species diversity (a community with all taxa having equal abundance). The Shannon-Wiener Diversity Index (H) in conjunction with Pielou's Index for Equitability (J) gives a good representation of community diversity. It is calculated using the equation

$$J = H/\ln(S)$$

where H is the Shannon-Wiener Index and S is the total number of taxa (Species Richness in the sample). It is measured between 0 and 1, with 0 representing dominance at a location by a small number of species and 1 representing a population with perfect equitability (e.g. 2 of every species found).

Cover of the major substrate types and coral species and fish abundance and biomass and diversity were compared among sites, reef habitat types and conservation zones. Because not all reef habitats types were represented within a conservation zone, multi-level comparisons could not be conducted. Instead comparisons were made among sites within reef habitat types, between reef habitat types and conservation zones. Data were first tested for normality using the Shapiro-Wilk Test and homogeneity of variance using the Levene's Test. The non-parametric Kruskal-Wallis (K-W) ANOVA was used when assumptions of parametric tests were not met. In addition coral cover was evaluated in accordance with the Simplified Integrated Reef Health Index (SIRHI) categorisation (Healthy Reefs Initiative 2010).

Results

Substrate and Benthic Composition

Overall coral cover on the reefs of Bacalar Chico was 10 .46 ± 0.76%. The reefs were generally dominated by fleshy algae (23.08 ± 1.33%) and turf algae (17.90 ± 1.39%). Fleshy algae were mainly composed of *Dictyota* (9.73 ± 0.94 %) and the category 'other fleshy algae' containing several taxa (5.48% ± 0.89). Crustose corallines had 5.51 ± 0.93% cover while the category dead substrate/rubble/sand composed 6.39 ± 1.26%. Gorgonians made 8.92 ± 0.61%. Most of the benthic data did not meet the criteria for parametric test (Shapiro-Wilk normality test: $p < 0.05$; Levene's homogeneity test: $p < 0.05$). Therefore, the non parametric Kruskal-Wallis (K-W) ANOVA was used in comparing differences among sites within reef habitat types and among reef habitat types within conservation zones. Except for turf algae, fleshy macroalgae and 'other Anothozoa' there was a significant variation in cover of other benthos/substrate between reef habitat types (Table 1). Aside from turf algae, the remaining benthic and substrate groups showed a significant variation in cover among conservation zones.

Table 1 Statistical comparison of cover of major benthic/substrate within and between reef habitat types and between conservation zones. Kurskal-Wallis (K-W) ANOVA χ^2 and p values presented. Comparisons were not made where degrees of freedom (df) were very small (==).

	Back Reef		Fore Reef		Fringing Reef		Between reef types		Between conservation zones	
Group	χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p
Hard corals	3.37	0.19	20.60	0.004	1.24	0.27	11.15	0.004	18.50	0.0003
Turf algae	0.86	0.65	10.64	0.16	0.59	0.44	1.51	0.46	2.78	0.43
Fleshy macroalgae	9.59	0.008	16.31	0.02	1.41	0.23	4.77	0.09	17.12	0.0007
Crustose corallines	1.29	0.53	15.19	0.03	0.08	0.78	11.84	0.002	11.29	0.01
Sponges	5.48	0.06	9.23	0.24	1.73	0.19	13.63	0.001	14.15	0.003
Gorgonians	3.32	0.19	23.22	0.002	0.47	0.49	13.82	0.001	15.12	0.002
Other Anothozoa	6.15	0.05	21.52	0.003	==	==	5.28	0.07	18.70	0.0003
Tunicates	==	==	==	==	==	==	==	==	==	==
Seagrass	8.20	0.02	==	==	==	==	==	==	10.41	0.02
Dead substrate, bare rock, sand	1.27	0.53	8.10	0.32	==	==	13.13	0.001	12.66	0.005

There were significant differences among reef types and conservation zones in hard coral cover (Table 1). Generally, coral cover was highest on fore reef and lowest on back reef sites but one fore reef site, Pig Sty, had the lowest cover (Figure 2). The category bare rock, rubble and sand and seagrass had a higher cover on the back reef but also at Firing Range North (fore reef) and Rocky Point South (Fringing Reef). Turf and fleshy macroalgae didn't show any variation among reef habitat types. Only the category 'other' composed of several rare taxa of macroalgae showed significant difference; fore reef locations had higher cover than back reef and fringing reef. The dominant genus within fleshy macroalgae, *Dictyota,* showed a marginally significant by habitat variation (Kruskal-Wallis $\chi^2 = 6.01$; $p = 0.05$). Crustose coralline cover was higher on fore reef locations than on the fringing reef. Gorgonian cover was higher on fringing reef sites than on back reef and fore reef sites.

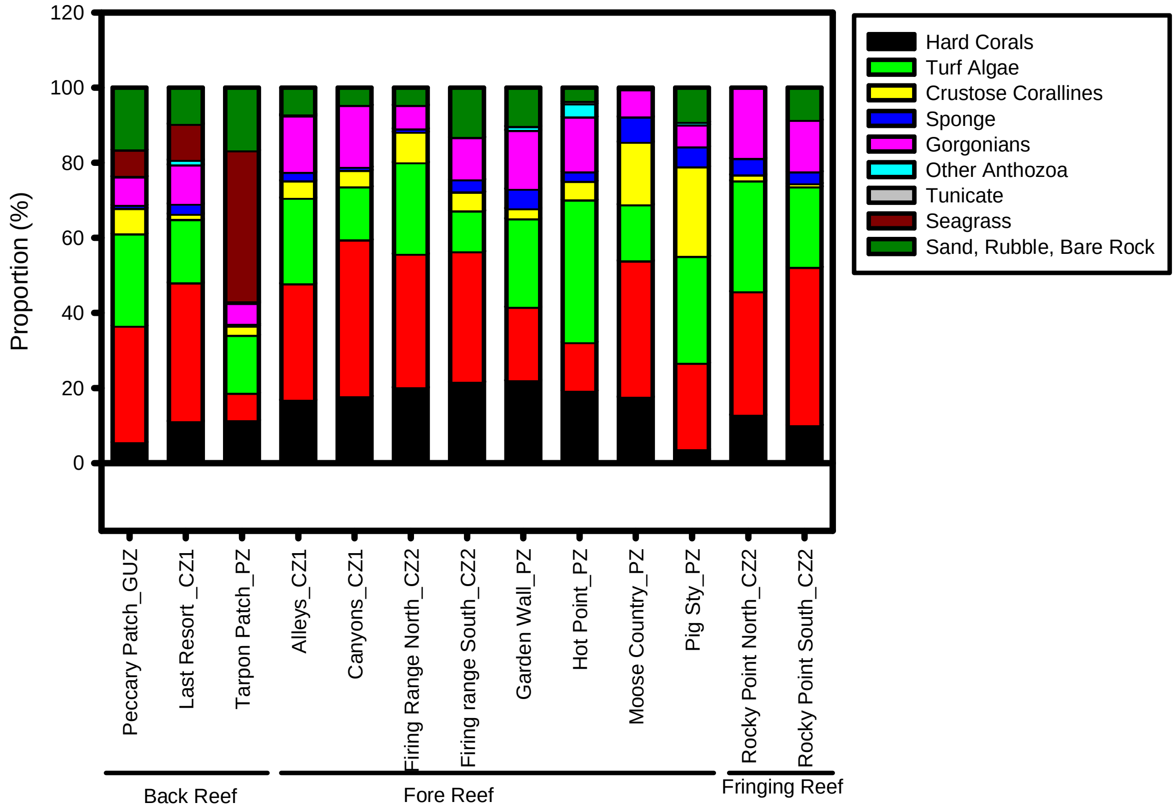

Figure 2 Benthic composition in the different conservation zones within the three main reef habitat types in Bacalar Chico. Values represent percentage composition at each site calculated from all transects. GUZ: Gneral Use Zone; CZ1: Conservations Zone 1; CZ2: Conservation Zone 2; PZ: Preservation Zone

Coral cover on the back reef was generally low (Figure 2). Peccary Patch (GUZ) and Last Resort (CZ1) were largely dominated by fleshy algae (Figure 2). *Halimeda* and *Dictyota* were the most abundant macroalgae representing 5.7% and 9.3% of the entire benthic community respectively at Peccary Patch and 14.2% and 9.0% at Last Resort. The group 'other zoanthids' also had higher cover at Last Resort. In the PZ fleshy algae were largely replaced by seagrass, primarily *Thalassia testudinum*. On the fore reef, coral cover was lowest at Pig Sty while the remaining sites didn't show significant differences. The cover at Pig Sty could be rated as 'Critical' while those at the remaining sites as "Fair to Good" according to the Simplified Integrated Reef Health Index (SIRHI) categorisation (Healthy Reefs Initiative 2010). Fleshy macroalgal cover was lower at Garden Wall, Hot Point and Pig Sty. Coralline cover was higher at Moose Country and Pig Sty.

CZ1, located south of the PZ, had deep spur and groove reef formations, with large amounts of fleshy and turf algal coverage (Figure 2). *Dictyota* was the major contributor to the fleshy algal composition in CZ1, comprising 20.1% of all benthos and 64.8% of fleshy algae in Alleys, and 17.71% of all benthos and 42.5% of fleshy algae in Canyons. Similarly, fleshy algae dominated the benthic composition of the two sites in CZ2 comprising at Firing Range North and Firing Range South. In Firing Range South, 62.3% of the fleshy algae was composed of *Dictyota*. However, macroalgal species encountered in Firing Range North were much more varied, with approximately equal contributions of *Dictyota*, *Halimeda* and *Lobophora.*

Fleshy and turf algae dominated over coral species on the PZ. Turf algae were the dominant group in Garden Wall and Hot Point, whilst fleshy algae dominated in Moose Country and Pig Sty. *Halimeda* constituted the majority of benthos on the western side of the double reef system in Garden Wall and Moose Country. *Halimeda* was replaced largely by *Dictyota* on the eastern side (64.5% and 51.1% of macaroalgal species encountered in Hot Point and Pig Sty respectively).

The fringing reef at Rocky Point is a unique location along the Mesoamerican Barrier Reef in that it is the only point where the reef is connected to the land, rather than being separated by a lagoon. It is also a place where live coral grows on top of fossilised reef. Hard coral cover was relatively low and turf and fleshy macroalgae were the dominant benthic components, whilst Gorgonian abundance was high along the reef top. *Dictyota* was the most dominant genus (14.4% and 15.2% of all benthos in Rocky Point North and South respectively).

Hard coral community composition

Porites porites was the species with the highest cover with 6.82 ± 1.51% at Fringing Range South. Other species that had relatively high cover were *Agaricia agaricites* at Canyons (5.19 ± 0.21%), *A. tenuifolia* at Garden Wall (4.71 ± 1.39%), *Porites astreoides* at Fringing Range North (4.22 ± 1.56) and Peccary Patch and *Siderastrea siderea* at Rocky Point South (4.06 ± 1.14%).

Statistical comparison was made for the seven most abundant coral species (> 1% cover at any site) and the two critically endangered Acroporid species in the Caribbean (*Acropora cervicornis* and *A. palmata*) and for the four diversity indices (Table 3-4). Except for species richness (Shapiro-Wilk normality test: $W = 0.97$; $p = 0.07$; Levene's homogeneity test: $F = 1.82$; $p = 0.17$), cover and diversity data didn't meet criteria for parametric tests ($p < 0.01$). Therefore, the non parametric Welch's ANOVA was used in comparing differences. There was a significant variation between reef types and conservation zones for most taxa and variation within reef types was larger on the fore reef (Table 2).

P. astreoides and *S. siderea* were the most abundant species on the back reef; *P. astreoides*, *A. agaricites* and *P. porites* on the fore reef, and *S. siderea*, *Millepora alcicornis* and *A. agaricites* on the fringing reef (Table 2). *A. cervicornis* and *A. palmata* were both completely absent on the back reef; *A. palmata* had a relatively higher cover on the fore reef. *A. cervicornis* was absent on the fringing reef while *A. palmata* had a lower cover.

Table 2 Statistical comparison of cover of the seven most abundant coral species (cover > 2%) and the two critically threatened Caribbean species (*A. cervicornis and A. palmata*) and coral diversity within and between reef habitat types and between conservation zones. Kruskal-Wallis (K-W) ANOVA χ^2 and p values presented. Comparisons were not made where sample size was too small (==).

	Back Reef		Fore reef		Fringing reef		Between reef types		Between conservation zones	
									K-W	
Taxon	χ^2	p	χ^2	p	χ^2	p	χ^2	p	χ^2	p
Acropora cervicornis	==	==	23.00	0.002	==	==	5.11	0.07	==	==
Acropora palmata	==	==	28.53	0.0002	==	==	==	==	==	==
Agaricia agaricites	3.61	0.16	23.99	0.001	4.30	0.04	8.25	0.02	27.37	<0.0001
Agaricia tenuifolia	4.50	0.11	25.00	0.0008	==	==	5.54	0.06	22.35	<0.0001
Montastraea franksi	==	==	24.00	0.001	==	==	15.63	0.0004	20.28	0.0001
Porites astreoides	1.09	0.58	15.81	0.03	6.50	0.01	8.46	0.02	9.78	0.02
Porites porites	0.98	0.61	29.14	0.0001	==	==	8.65	0.01	9.71	0.02
Siderastrea siderea	0.06	0.97	17.67	0.01	3.23	0.07	11.11	0.004	16.81	0.0008
Millepora alcicornis	6.27	0.04	14.15	0.05	1.14	0.29	22.52	<0.0001	24.48	<0.0001
Species Richness (S)	3.61	0.16	21.31	0.003	4.79	0.05	12.18	0.002	17.54	0.0005
Shannon-Wiener Diversity (H)	2.86	0.24	21.55	0.003	6.11	0.03	10.13	0.006	15.06	0.002
Simpson Diversity (1-D)	1.96	0.38	19.43	0.05	5.62	0.04	8.96	0.01	11.71	0.008
Equitability (J)	1.56	0.46	6.13	0.05	1.76	0.21	1.30	0.52	2.78	0.43

P. astreoides and *S. siderea* were the most abundant species in GUZ and *P. astreoides*, *Acropora tenuis* and *A. palmata* on PZ. Five species (*A. agaricites, P. astreoides, P. porites, Montastrea franksi* and *S. siderea*) were the most abundant species in CZ1 and three species (*S. siderea, M. alcicornis, A. agaricites*) in CZ2. *P. astreoides* was the most common coral species represented on all reef habitat types and conservation zones except in CZ2.

On the back reef, *A. tenuifolia, M. annularis, P. astreoides* and *S. siderea* had the highest coral cover in PZ. Large *A. tenuifolia* and *M. annularis* colonies were particularly present. The deepest of the back reef monitoring sites, Last Resort, situated in CZ1, had a relatively high coverage of encrusting corals with *P. astreoides*, *A. agaricites,* and *S. siderea* found in highest abundance. Two large *A. tenuifolia* colonies, measuring about 4 m in diameter each were found on the eastern edge of the reef. The GUZ had the lowest coral cover, with *P. astreoides* and *S. siderea* being the most common.

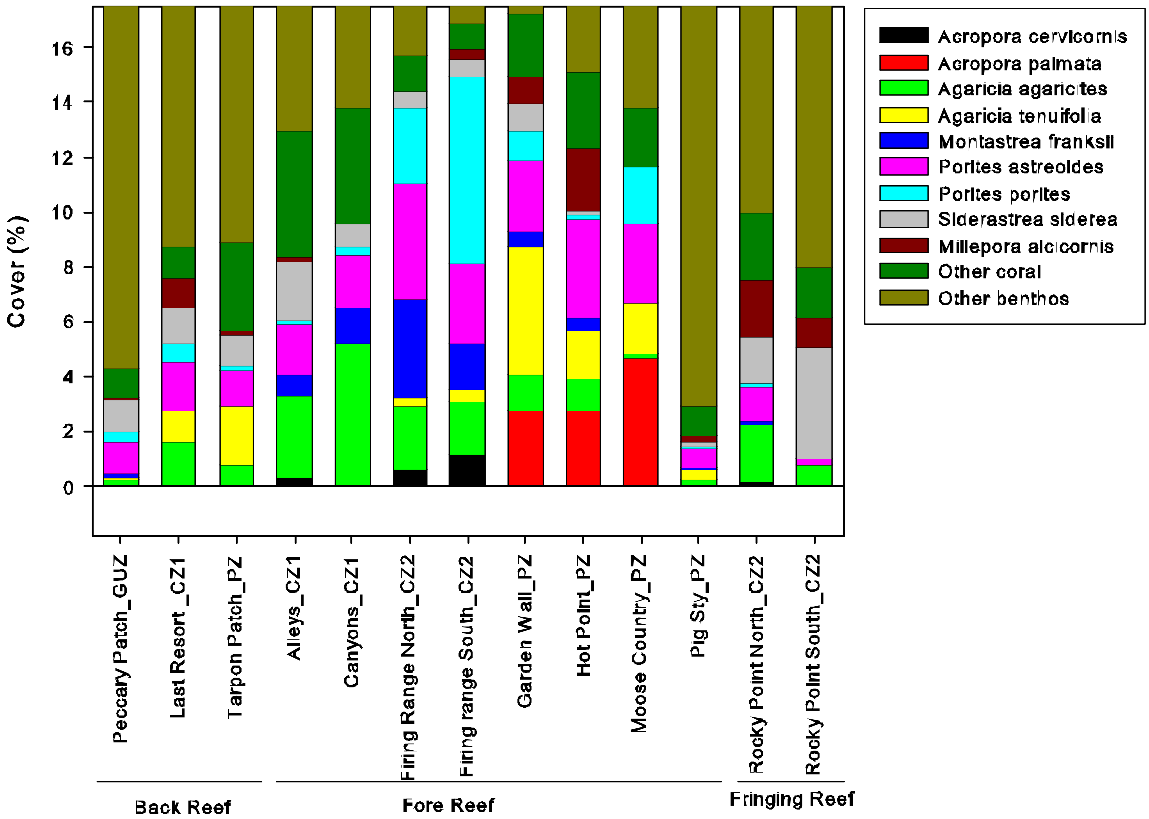

Figure 3 Coral species composition in the different conservation zones within the three main reef habitat types in Bacalar Chico. GUZ: General Use Zone; CZ1: Conservations Zone 1; CZ2: Conservation Zone 2; PZ: Preservation Zone. Cover above 18% not shown.

In CZ2, on the fore reef, the most common species encountered were *M. franksi*, *A. agaricites*, *P. astreoides*, *P. porites*. The two sites on the western side of the double reef system, Garden Wall and Moose Country, both had some large *A. palmata* colonies. *A. tenuifolia* (at Garden Wall and Moose Country) and *P. porites* were also common. The shallow fore reef on the western side of the double reef system in PZ was very different to that on the eastern side. The reef top at the southern site, Pig Sty, is a network of dead *A. palmata* and *P. porites* colonies, covered by turf, fleshy and coralline algae. Large live *A. palmata* and *A. tenuifolia* were the most abundant coral species followed by encrusting *P. astreoides* and *A. agaricites*. *A. agaricites* was the most abundant coral at Alleys and Canyons, while large encrusts of *M. faveolata* (1.8%, Alleys; 1.7% Canyons) were observed at both sites. *P. astreoides*, *S. siderea* and *M. franksi* were also common. *Montastraea cavernosa* (1.5%) was common at Canyons but it was absent from Alleys. *Agaricia humilis* and *Diploria strigosa* were more common at Alleys (1.8% and 0.9% respectively) than at Canyons (0.2%, 0.4%).

Of the coral species present on the fringing reef, *A. agaricites*, *P. astreoides*, *S. siderea* and *M. cavernosa* (1.2% North, 0.2% South) were most abundant.

Coral Species Diversity

Twenty-five hard coral species (23 Scleractinian and 2 Hydrozoan) were recorded during the point intercept bottom surveys. Patterns in Species Richness, Sannon-Wiener and Simpson's diversity were similar (Figure 4). There was no significant difference in evenness (J) among sites within and between reef habitat types and conservation zones (Table 2). Diversity was highest at Garden Wall and lowest at Pig Sty. There was a significant difference among reef habitats (Table 2). Diversity was higher on fore reef and fringing reef sites than on back reef sites. On the back reef, the GUZ site at Peccary Patch had lower coral species diversity than at Last Resort (CZ1) and Tarpon Patch (PZ). On the fore reef, diversity was highest on Garden Wall (PZ) and lowest at Pig Sty (PZ). Rocky Point North had higher diversity than Rocky Point South on the Fringing reef. There was a strong correlation between coral community diversity and coral cover for three of the diversity indices (Species Richness-coral cover: $r = 0.95$, $p < 0.0001$; Shannon-Wiener H-coral cover: $r = 0.90$; $p < 0.0001$; Simpson's 1-D-coral cover: $r = 0.87$; $p < 0.0001$; Equitability J-coral cover: $r = 0.46$, $p = 0.12$).

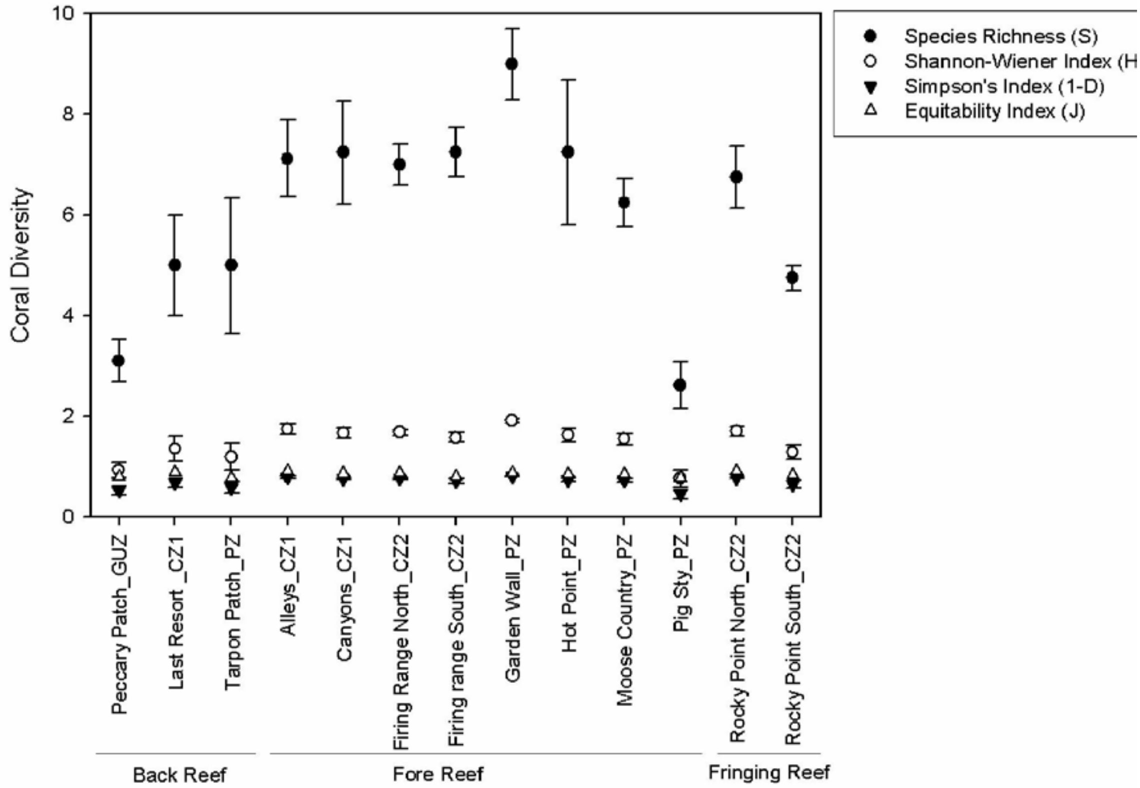

Figure 4 Patterns in Coral species diversity in the different conservation zones within the three reef habitat types in Bacalar Chico. GUZ: Gneral Use Zone; CZ1: Conservations Zone 1; CZ2: Conservation Zone 2; PZ: Preservation Zone.

Fish community composition and biomass

The most common fish species found in Bacalar Chico were bicolour damselfish (*Stegastes partitus*), striped parrotfish (*Scarus iserti*), French grunt (*H. flavolineatum*), blue tang (*Acanthurus coeruleus*), red-band parrotfish

(*Sparisoma aurofrenatum*) and blue chromis (*Chromis cyanea*). Average fish abundance per transect on the reefs of Bacalar Chico was 66.5 ± 0.74. It was highest at Rocky Point North on the fringing reef and lowest at Firing Range South on the fore reef (Figure 5). It was higher on the fringing reef (108.8 ± 8.5) than on the fore reef (62.2 ± 5.0) and back reef sites (47.7 ± 6.7; K-W $\chi^2 = 32.60$; $p < 0.0001$).There was a strong variation in total abundance between reef types and conservation zones (Table 3). Variation among sites within a reef type was significant only for the fore reef where Pig Sty had the largest abundance and Firing Range South the lowest. CZ2 had much higher abundance than the remaining three conservation zones.

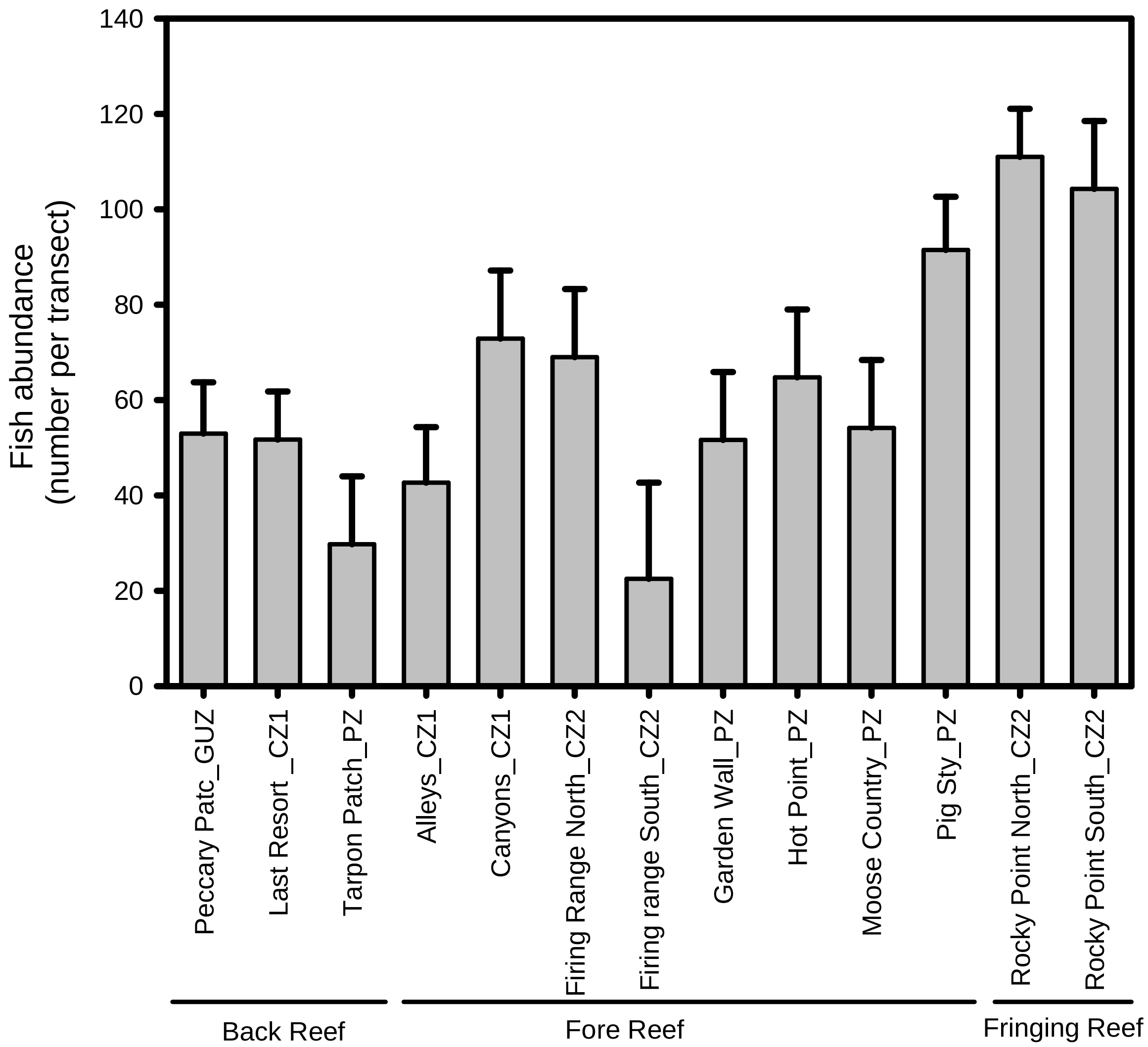

Figure 5 Total fish abundance per transect in the different conservation zones within the three reef habitat types in Bacalar Chico. GUZ: Gneral Use Zone; CZ1: Conservations Zone 1; CZ2: Conservation Zone 2; PZ: Preservation Zone.

Overall, Labridae (22.6 ± 2.0 per transect) were the most abundant group, followed by Pomacentridae (17.4 ± 2.06), Scaridae (7.9 ± 0.6), Haemulidae (7.0 ± 1.0) and Acanthuridae (5.6 ± 0.3). By site, reef type and conservation zone comparisons were made for these five most abundant fish families (Figure 6; Table 3). Except in Acanthuridae, variation between reef types and conservation zones was strongly significant. Only haemulids showed between site variations on the fringing reef. Except in labrids, there was a significant variation in the abundance of the remaining four families on the back and fore reefs.

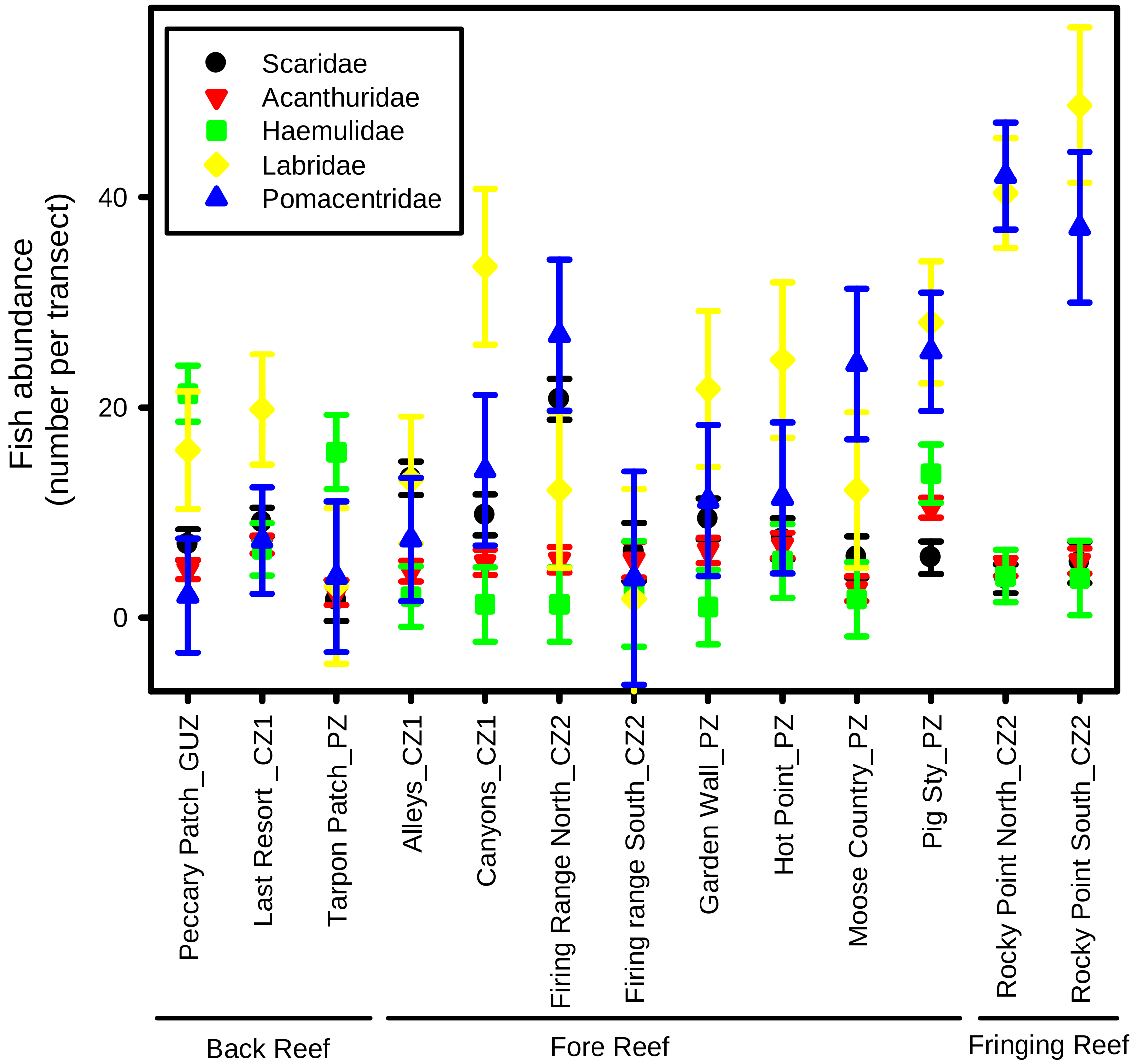

Figure 6 Mean abundance of the five most abundant fish families in each of the conservation zones within the three reef habitat types at Bacalar Chico. GUZ: Gneral Use Zone; CZ1: Conservations Zone 1; CZ2: Conservation Zone 2; PZ: Preservation Zone.

Haemulidae and Labridae were the most abundant fish populations in all sites on the back reef. *H. flavolineatum*, *Haemulon sciurus* and *A. coeruleus* were the most dominant on all back reef zones, with *H. flavolineatum* in greatest abundance in GUZ (46.9%) and *H. sciurus* in PZ (38.2%). Labridae and Pomacentridae were the dominant families in the PZ's shallow western fore reef (41.9% and 21.4% Garden Wall; 22.4% and 44.5% Moose Country). *Microspathodon chrysurus* (10.1%), *S. partitus* (5.3%) and *Stegastes adjustus* (13.1%) were particularly dominant at Moose Country. Scaridae were a key contributor to the fish assemblage at both sites (18.1% Garden Wall, 10.6% Moose Country). *S. iserti* (5.8% Garden Wall, 3.9% Moose Country) and *S.*

aurofrenatum (5.8%, 3.0%) were of particularly high abundance. As with the rest of the PZ, Labridae and Pomacentridae were the most abundant fish families on the eastern side of the double reef. However, they were not as common as on the western edge of the double reef system. Large schools of Acanthuridae and Haemulidae were also present on this side (Figure 5). *H. flavolineatum* (8.0%), *H. sciurus* (2.2%) and *A. coeruleus* (8.6%) were observed at Pig Sty, the site with the highest abundance of fish anywhere in PZ. Pomacentridae, especially *C. cyanea* and *M. chrysurus* were found in high abundance in both Hot Point and Pig Sty. Hot Point had a higher abundance of Scaridae than Pig Sty, with *S. aurofrenatum* and *S. iserti* the most frequently observed species. Additionally, large schools of *Clepticus parrae* (12.1%) and *Inermia vittata* (3.8%) were observed grazing on algae. Species belonging to Labridae and Pomacentridae were the most abundant on the two fringing reef sites (40.4% North, 46.7% South and 40.2% North, 37.1% South respectively). The dominant species was *S. partitus* (21.3% North, 30.9% South). Abundance and coral cover and coral diversity was statistically significant only for Haemulidae (r = -0.85 to -0.68; $p < 0.05$).

Table 3 Summary of fish abundance comparison for the five most abundant fish families, total abundance and reef fish community diversity within and between reef habitat types and between conservation zones in Bacalar Chico. Kruskal-Wallis (K-W) ANOVA χ^2 and p values presented.

	Back Reef		**Back Reef**		**Fringing Reef**		**Between reef types**		**Between conservation zones**	
Taxon	χ^2	**p**	χ^2	**p**	χ^2	**p**	χ^2	**p**	**K-W** χ^2	**p**
Acanthuridae	11.13	0.004	25.81	0.0005	0.05	0.83	3.28	0.19	3.44	0.33
Haemulidae	8.04	0.02	21.40	0.003	4.18	0.04	19.83	<0.0001	21.55	<0.0001
Labridae	5.09	0.08	10.26	0.17	1.22	0.27	29.60	<0.0001	28.77	<0.0001
Pomacentridae	11.50	0.003	24.35	0.001	0.27	0.60	46.97	<0.0001	42.63	<0.0001
Scaridae	11.05	0.004	29.20	0.0001	1.69	0.19	32.60	<0.0001	31.52	<0.0001
Total abundance	5.02	0.08	15.93	0.03	0.30	0.58	18.92	<0.0001	26.98	<0.0001
Species Richness (S)	6.76	0.03	6.84	0.45	4.90	0.03	10.15	0.05	9.43	0.02
Shannon-Wiener Diversity (H)	4.30	0.12	6.98	0.43	2.34	0.13	21.87	<0.0001	24.70	<0.0001
Simpson Diversity (1-D)	1.77	0.40	11.66	0.11	2.34	0.13	21.74	<0.0001	23.72	<0.0001
Equitability (J)	1.58	0.45	15.78	0.03	0.14	0.71	26.35	<0.0001	28.66	<0.0001

Fish Abundance from 'Rover Fish' Surveys

One hundred and two fish species belonging to 32 families were recorded during the 'Rover Fish' surveys. Acanthuridae, Balistidae, Carangidae, Chaetodontidae, Haemulidae, Holocentridae, Labridae, Lutjanidae, Pomacanthidae, Pomacentridae, Scaridae and Serranidae were the families with the highest percentages of both sight frequency (%SF) and Density (Den). *Acanthurus bahianus* (Ocean Surgeonfish), *Lutjanus apodus* (Schoolmaster), *Sparisoma viride* (Stoplight Parrotfish), *S. iserti* (Striped Parrotfish), *S. aurofrenatum* (Red band Parrotfish), *H. flavolineatum* (French Grunt) and *A. coeruleus* (Blue Tang) were the species with the highest representation.

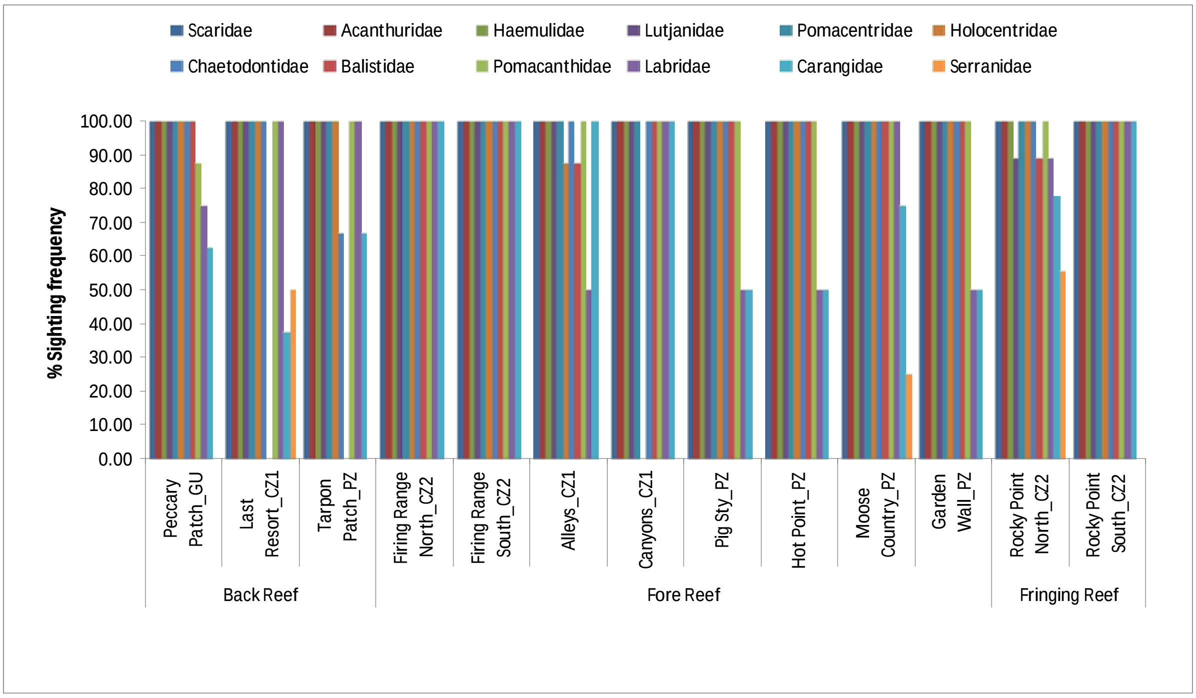

Figure 7 Most frequently observed families in the Bacalar Chico reef based on sighting frequency (%SF).

Haemulidae and Labridae were the most abundant fish families in all conservation zones on the back reef. Haemulidae were particularly abundant, with high densities (Den = 3.0-4.0) and 100% Sighting Frequency (SF) at all sites. Scaridae and Acanthuridae were also common, with 100% SF in all zones. However, density of Scaridae was low in the PZ (Den = 2.67) compared to the high densities in the GUZ and CZ1 (Den = 3.13 and 3.00 respectively). The most frequently observed species of parrotfish was *S. aurofrenatum* (100% SF in both the PZ and CZ1, 87.5% SF in the GUZ), though with low densities (Den = 2.00-2.50). There was greater species diversity of parrotfish in the GUZ and CZ1, with seven species observed in each zone, than in the PZ, where only four species were seen. The species common to all sites were *S. aurofrenatum*, *Scarus rubripinne*, *S. viride* and *S. iserti*. *H. flavolineatum* (22.1% of all fish observed using the 'Fish Rovers' Technique) was the most abundant species in the GUZ, whilst *H. sciurus* was dominant in both CZ1 (11.8%) and the PZ (20.1%). CZ1 was the only site where a threatened species was observed; the hogfish *Lachnolaimus maximus,* listed as vulnerable on the IUCN Red List of Threatened Species, was seen at low densities (Den = 0.63) and 50% of the time.

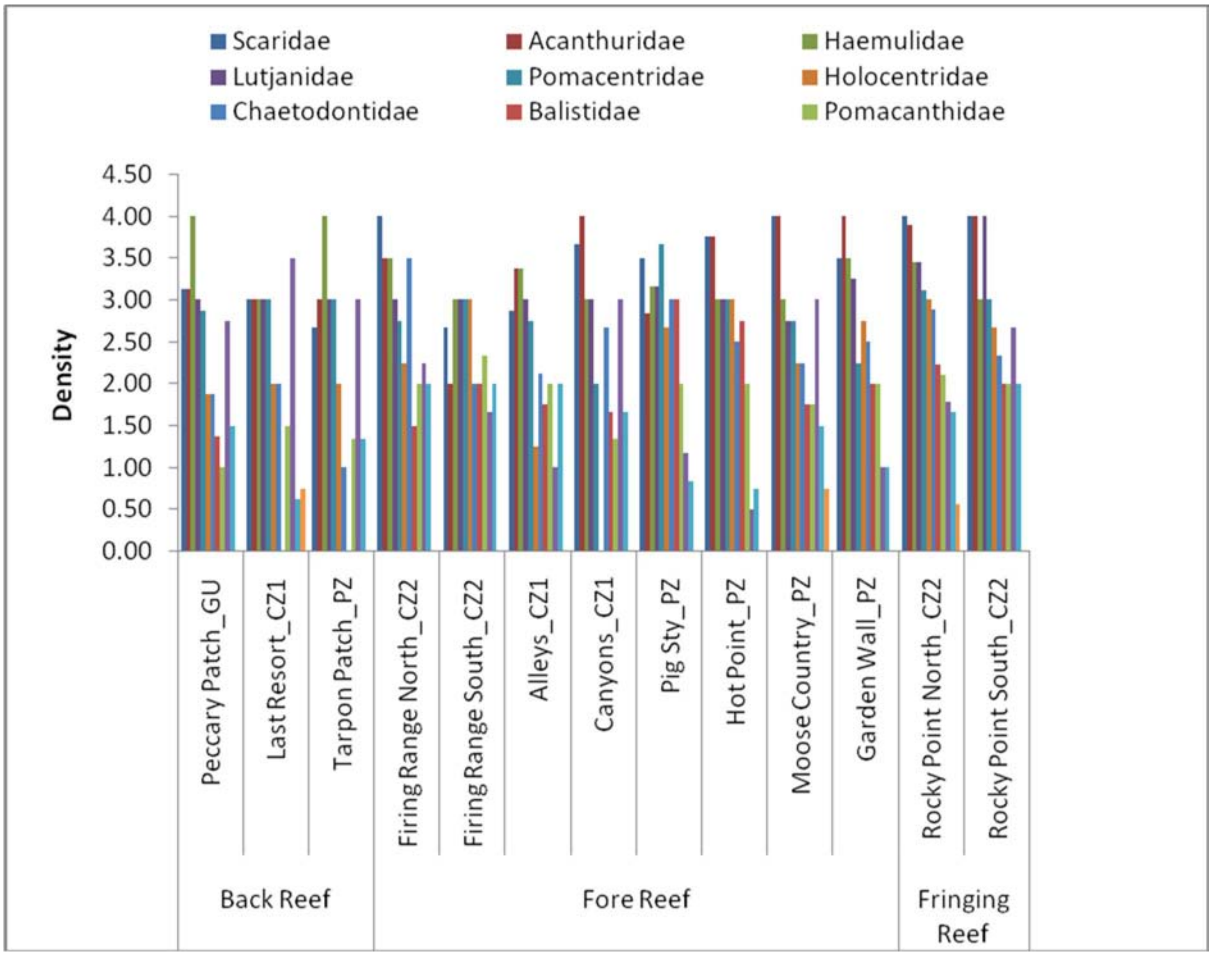

Figure 8 Density score for the most common fish families throughout Bacalar Chico reef sites

Scaridae were consistently abundant in all sites and conservation zones on the fore reef (Den = 3.0-4.0, 100% SF). Labridae, Acanthuridae and Pomacentridae were also consistently observed (100% SF in most sites and zones), usually at high densities (Den = 3.0-4.0). Exceptions were Firing Range South in CZ2 (Labridae Den = 2.0, Pomacentridae Den = 2.7), Alleys in CZ1 (Pomacentridae Den = 2.9), Pig Sty in PZ (Labridae Den = 2.8) and Moose Country, also in PZ (Acanthuridae Den = 2.8). At Garden Wall in the north west of the PZ, *S. iserti, A. coeruleus, C. parrae, C. cyanea* and *M. chrysurus* had all high sightings (100% SF) and densities (Den = 3.0-3.5). At nearby Moose Country, large schools of *Caranx ruber* (Den = 3.0, 100% SF) and *C. parrae* (Den = 3.0, 100% SF) were observed, while *M. chrysurus, S. partitus, C. cyanea* and *Abudefduf saxatilis* (all Den = 3.0, 100% SF) were found in high densities on the reef itself. Similarly, at Hot Point (eastern ridge of the PZ), the pomacentrids *C. cyanea, M. chrysurus* and *C. parrae* (Den = 3.0-3.5, 100% SF) were present in high densities. Additionally, *M. niger* and *Haemulon carbonarium* were found in high densities (Den = 3.0, 100% SF). The herbivorous *A. coeruleus* and *S. viridae* also had high densities (Den = 3.0, 100% SF). Pig Sty also had high densities of *A. coeruleus* (Den = 3.0, 100% SF). Other fish species observed in high densities at Pig Sty were *H. carbonarium*, *H. flavolineatum*, *L. apodus* and *M. chrysurus* (Den = 3.0, 100% SF).

None of the IUCN Red Listed species were observed during fish rover surveys in the PZ, though there was one sighting of the commercially important species *S. regalis* at Pig Sty.

Alleys, in CZ1 had only one species observed at high density (*A. coeruleus*, Den = 3.00, 100% SF). In contrast, seven species had high densities at the second site in CZ1, Canyons, including two scarid species, *S. aurofrenatum* and *S. iserti*, as well as *A. coeruleus*. However, Alleys was one of only two sites where *Ginglymostoma cirratum* was observed during the survey. Conservation Zone 2 was dominated by Pomacentridae (Den = 3.33, SF 100%). Firing Range North and Firing Range South had quite different fish community composition, with no common species being in high density at both sites. However, there were several fish species that had high densities at each site. In Firing Range South, these included the herbivorous *S. viride*, *Acanthurus chirugus* and *A. bahianus* (all Den = 3.00, 100% SF). In Firing Range North, the abundant species included representatives of Pomacentridae, Labridae, Lutjanidae and Scaridae.

On the fringing reef, a total of six fish families were encountered at high densities on Rocky Point North (Haemulidae: Den = 4.0, 100% SF, Labridae: Den = 3.9, 100% SF, Acanthuridae: Den = 3.4, 100% SF, Pomacentridae: Den = 3.4, 100% SF, Scaridae: Den = 3.1, 100% SF, Balistidae: Den = 3.0, 100% SF). Except Balistidae, the remaining five families had high abundance at Rocky Point South. Furthermore, Rocky Point South was one of only two sites where *G. cirratum* was observed during the survey. More species had high densities at Rocky Point South (5 species) than at Rocky Point North (2 species). Species of high abundance and common to both sites were *H. flavolineatum* and *Haemulon plumieri* (Den = 3.0, 100% SF at both sites). Additionally, *S. iserti*, *C. parrae* and *A. coeruleus* were found in high densities at Rocky Point South (all Den = 3.0, 100% SF). The IUCN Red Listed *Lutjanus analis* (Den = 0.22, 11.1% SF) as well as the Endangered *Epinephelus striatus* (Den = 0.11, 11.1%SF) and *Mycteroperca bonaci* (Den = 0.11, 11.1% SF) were also observed at Rocky Point North.

Fish community diversity

Eighty-six fish species were recorded in Bacalar Chico during the fish belt transect surveys. Average fish species richness per transect was 11.4 (± 0.3). The Shannon-Wiener (H), Simpson's (1-D) and Equitability (J) indices were 1.82 ± 0.04, 0.75 ± 0.01 and 0.76 ± 0.01) respectively. Hot Point on the fore reef had the highest diversity and Rocky Point South on the fringing reef the lowest diversity (Figure 9). Species richness was higher on the fore reef than on the back reef and fringing reef while the remaining three diversity indices were much greater on the fringing reef than the back and fore reef (Figure 9; Table 3). Comparison of conservation zones indicated that Richness was higher in PZ than GUZ; the rest of the diversity indices were larger in CZ1 and PR than on GUZ and CZ2 (Table 3).

Analysis of data from 'Rover Fish' survey indicated that Species Richness (S) was highest at Rocky Point North (57 species) on the fringing reef and lowest at Tarpon Patch (back reef) and Canyons (fore reef) both having 33 species. Peccary Patch (48) and Last Resort (52) on the back reef as well as Alleys (51), Firing Range North (50) and Pig Sty (48) on the fore reef had higher species richness. Moose County (fore reef) and Rocky Point South (fringing reef) had lower richness (38). The Shannon-Wiener (3.46-3.67), Simpson's (0.96-0.97) and Equitability (0.91-0.97) indices were all small and similar among sites.

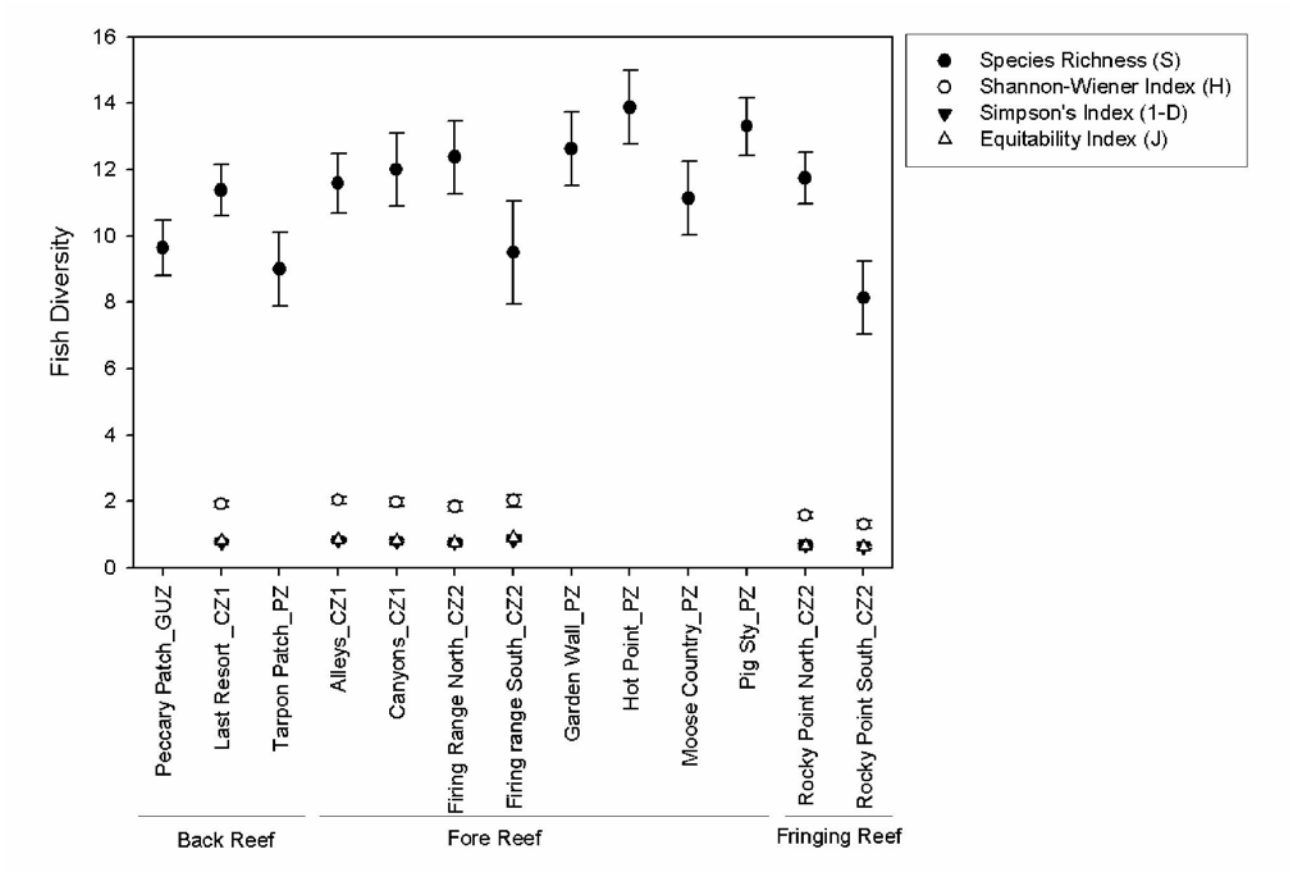

Figure 9 Patterns in abundance based fish diversity on the reefs of Bacalar Chico in each of the conservation zones within the three reef habitat types. GUZ: General Use Zone; CZ1: Conservations Zone 1; CZ2: Conservation Zone 2; PZ: Preservation Zone.

Fish Biomass

Overall mean wet fish biomass on the reefs of Bacalar Chico was 258.4 ± 29.0 kg ha^{-1}. There was significant variation among sites (Kruskall-Wallis $\chi^2 = 28.69$; $p = 0.004$). Biomass was higher at Last Resort, Alleys, Canyons and Rocky Point North than at Tarpon Patch, Firing Point North, Firing Point South, Garden Wall and Moose Country (Figure 10). Peccary Patch, Hot Point and Rocky Point South had intermediate biomass values. There was no significant difference between reef habitat types (Table 4). Comparison by conservation zones indicated that total average biomass was higher on CZ1 than on the remaining zones (Table 4). The blue striped grunt (67.4 ± 19.2 kg ha^{-1}) and blue tang (52.4 ± 10.4 kg ha^{-1}) had the highest mean biomass on the reefs of Bacalar Chico.

There was no significant difference in total biomass among the three sites on the back reef (Figure 10; Table 4). On the fore reef, biomass was higher at Alleys than at Moose Country, Garden Wall and Firing Range South. Higher biomass was recorded at Rocky Point North than Rocky Point South on the fringing reef.

Table 4 Summary of fish biomass comparison for the 11 ecologically or economically important families and total biomass within and between reef habitat types and between conservation zones in Bacalar Chico. Kruskal-Wallis (K-W) ANOVA χ^2 and p values presented. Comparisons were not made where sample size was too small (==).

	Back Reef		Fore Reef		Fringing Reef		Between reef types		Between conservation zones	
Taxon	χ^2	**p**	χ^2	**p**	χ^2	**p**	χ^2	**p**	**K-W** χ^2	**p**
Acanthuridae	1.75	0.42	8.82	0.27	1.74	0.19	4.43	0.11	6.25	0.10
Scaridae	0.80	0.67	19.96	0.006	0.90	0.34	4.73	0.09	12.71	0.005
Balistidae	==	==	20.27	0.0050.04	2.16	0.14	14.35	0.0008	13.86	0.003
Chaetodontidae	1.80	0.41	15.17	0.29	1.40	0.24	4.06	0.13	16.31	0.001
Monacanthidae	2.0	0.37	8.50	0.51	1.00	0.32	0.49	0.78	6.36	0.10
Pomacanthidae	4.46	0.11	6.26	0.75	2.13	0.14	1.68	0.43	2.93	0.40
Pomacentridae	1.23	0.54	4.25	0.78	0.03	0.88	1.25	0.53	0.67	0.88
Carangidae	0.51	0.78	4.03	0.06	2.13	0.14	0.68	0.71	1.89	0.60
Haemulidae	6.04	0.05	6.37	0.30	7.91	0.005	3.77	0.15	8.32	0.04
Labridae	9.92	0.007	13.63	0.03	1.73	0.19	3.35	0.19	13.31	0.004
Lutjanidae	0.12	0.94	8.36		1.00	0.32	12.56	0.02	14.72	0.002
Total biomass	5.0	0.08	16.04		4.34	0.04	2.95	0.23	14.24	0.003

Statistical comparisons were made for 13 fish families that are of ecological or economic importance or both (Figure 11). No comparisons were made for barracudas (Sphyraenidae; commercial and top predator), sharks (Charcharinidae; commercial and top predator) and lionfish (Scorpaenidae; invasive) due to their small representation in most sites. There were strong by site differences in 5 families ($p < 0.002$); Chaetodontidae showed marginally significant differences ($p = 0.05$). Balistids had greater biomass at Firing Range North, Hot Point, Pig Sty and Rocky Point North, carangids and labrids at Hot Point, chaetodontids and haemulids at Rocky Point North. Scarids and serranids were higher at Alleys.

There was significance by conservation zone and reef habitat type difference in Balistidae, Lutjanidae and Serranidae (Table 4). Chaetodontidae, Haemulidae, Labridae and Scaridae showed differences only between conservation zones. Balistid and chaetodontid biomass was greater in CZ2, in CZ1 in labrids, lutjanids and scarids. Balistid, chaetodontid and haemulid biomass was higher on the fringing reef but lutjanid biomass was higher on the back reef.

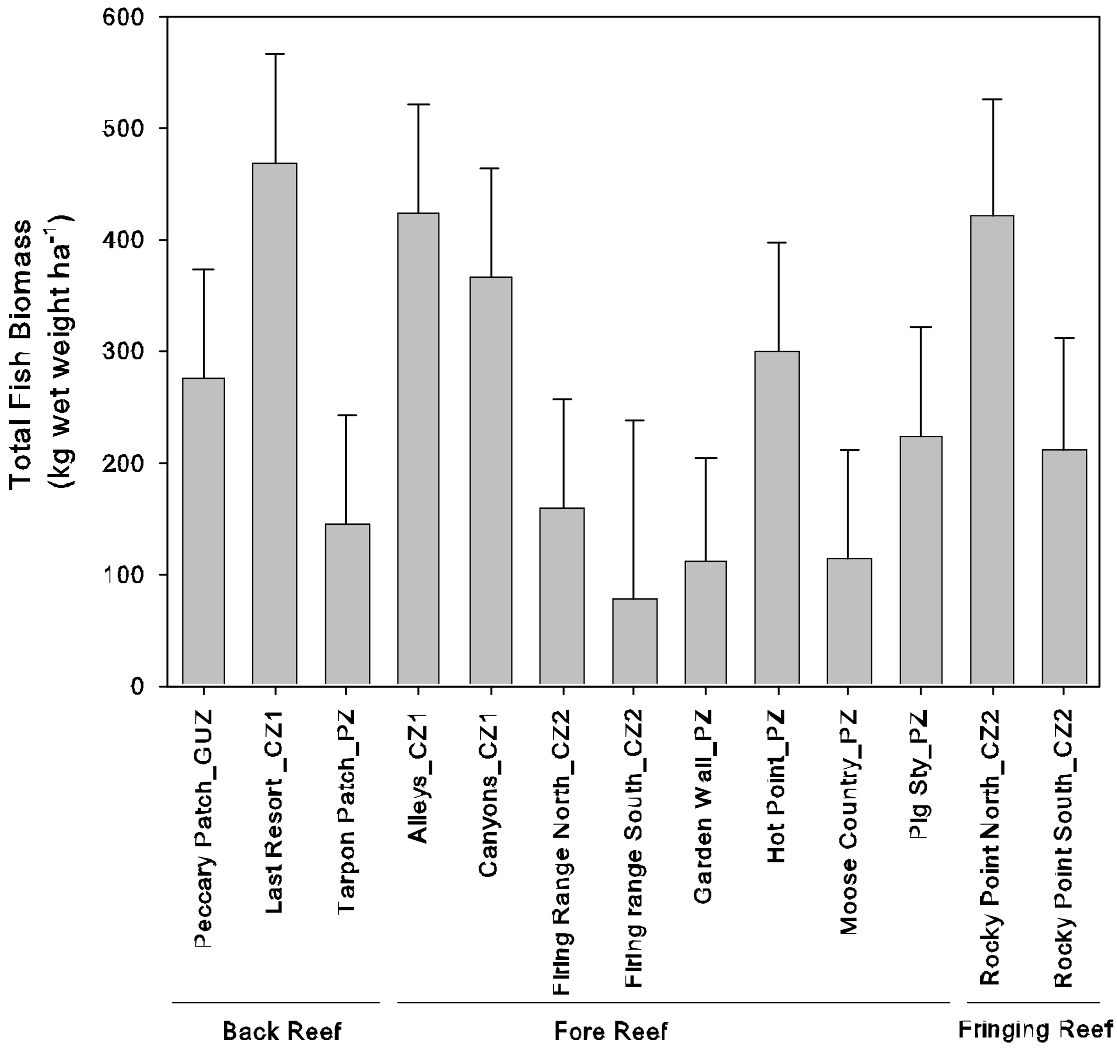

Figure 10 Total wet fish biomass on the reefs of Bacalar Chico in each of the conservation zones within the three reef habitat types. GUZ: General Use Zone; CZ1: Conservations Zone 1; CZ2: Conservation Zone 2; PZ: Preservation Zone.

On the back reef, the majority of the biomass at Peccary Patch and Tarpon Patch was composed of Haemulidae which also made up the highest proportion of the commercial fish biomass (Figure 11). At Peccary Patch the two most dominant species were the blue striped parrotfish (293.9 ± 126.8 kg ha^{-1}) and blue tang (101.0 ± 72.5 kg ha^{-1}) while at Tarpon Patch blue striped grunt (*H. sciurus*) dominated the biomass (316 ± 140.4 kg ha^{-1}). At Last Resort, Pomacanthidae and Acanthuridae made the highest proportion of the biomass. The relatively large biomass of pomacanthids was due to the presence of large individuals of the gray angelfish (*Pomacanthus arcuatus*). Lutjanidae had high biomass at Peccary Patch after Haemulidae. On the fore reef, Scaridae were the dominant group at Alleys, Lutjanidae at Canyons and Balistidae at Firing Range North. The striped parrotfish (*S. iserti*; 136.4 ± 26.8 kg ha^{-1}) had the highest biomass followed by blue tang (88.3 ± 46.7 kg ha^{-1}) and stoplight parrotfish (*S. viride*; 81.9 ± 29.8 kg ha^{-1}). *L. apodus* (school master snapper; 107.9 ± 99.4 kg ha^{-1}) formed the highest biomass at Canyons. At Firing Range North, *C. sufflamen* (ocean trigger; 56.9 ± 56.9 kg ha^{-1}), *S. iserti* (24.6 ± 6.1 kg ha^{-1}) and *S. viride* (22.8 ± 18.7 kg ha^{-1}) had high biomass. Balistidae also formed a greater proportion of the biomass at Hot Point and Pig Sty along Labridae (Hot Point) and Haemulidae (Pig Sty). Creole wrasse (*C. parae*; 81.4 ± 77.1 kg ha^{-1}) was the most abundant fish at Hot Point while blue tang (139.3 ± 126.8 kg ha^{-1}) and Caesar grunt (*H. carbonarium*; 128.0 ± 97.3 kg ha^{-1}) were the most abundant species at Pig Sty. Haemulids composed most of the biomass at Rocky Point North, white grunt (*H. plumieri*; 214.2 ± 75.6 kg ha^{-1}) being the most dominant. White grunt also had the highest biomass at Rocky Point South but its biomass was lower in comparison to that of Rocky Point North (41.3 ± 41.3 kg ha^{-1}).

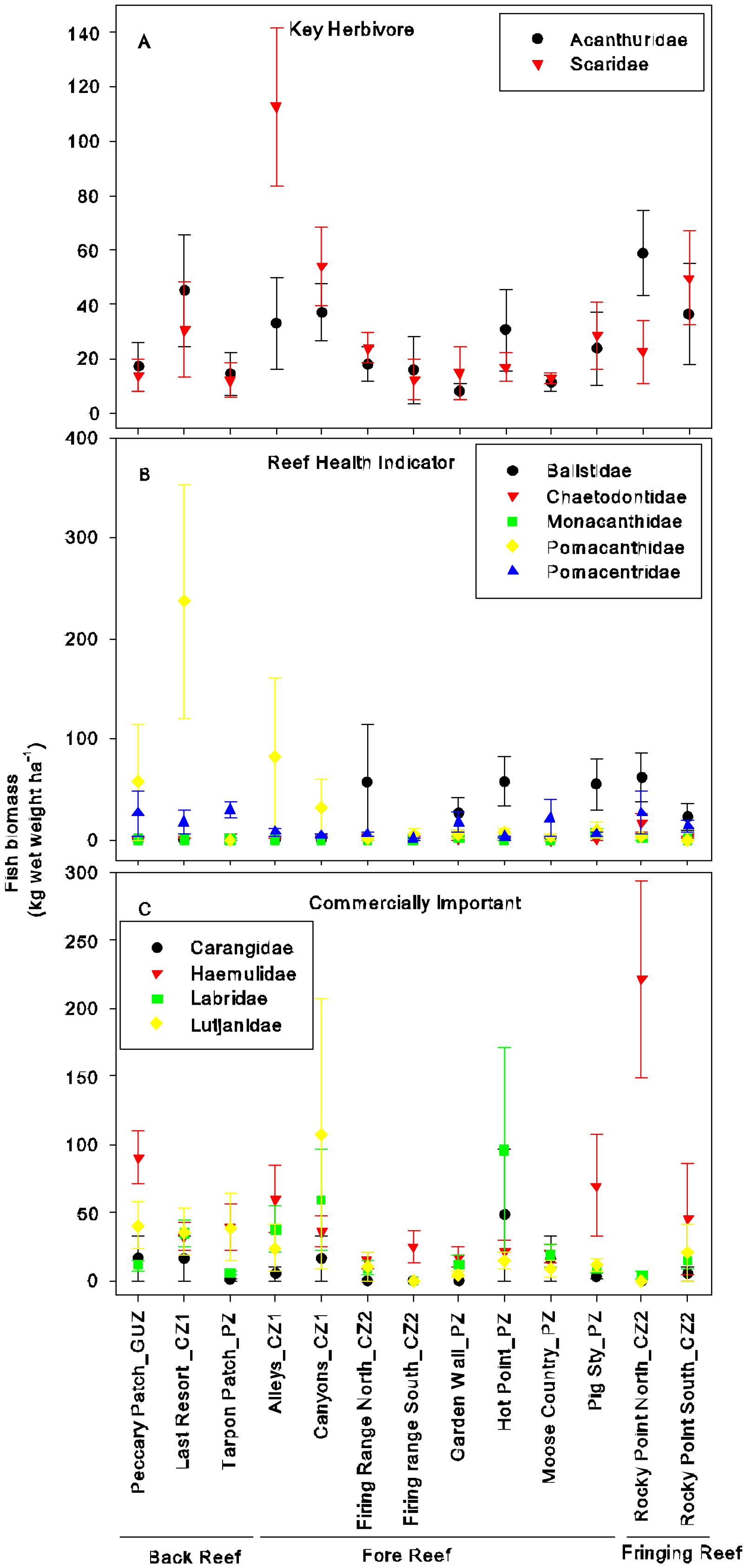

Figure 11 Mean wet fish biomass of ecologically and commercially important reef fish families on the reefs of Bacalar Chico. GUZ: Gneral Use Zone; CZ1: Conservations Zone 1; CZ2: Conservation Zone 2; PZ: Preservation Zone.

Coral Health

Observed mortality of coral colonies was highest on the back reef and two of the fore reef sites with more than 40% of surveyed colonies showing some signs of mortality (Figure 12; Figure 13). The highest incidence of mortality was observed on the back reef site in the General Use Zone, with 22 of the 50 surveyed colonies (44%) showing signs of mortality. The lowest incidence of mortality was in the southeast of the Preservation Zone on the fore reef at Pig Sty in the second sampling period (October), where none of the surveyed colonies showed signs of recent mortality. However, the site did have some mortality in period 1 (April) and large areas of the reef were covered by colonies that had died previously, now covered over by turf and coralline algae. For sites where there were repeat surveys, mortality was higher in period 1 (April-May) than period 2 (October-November).

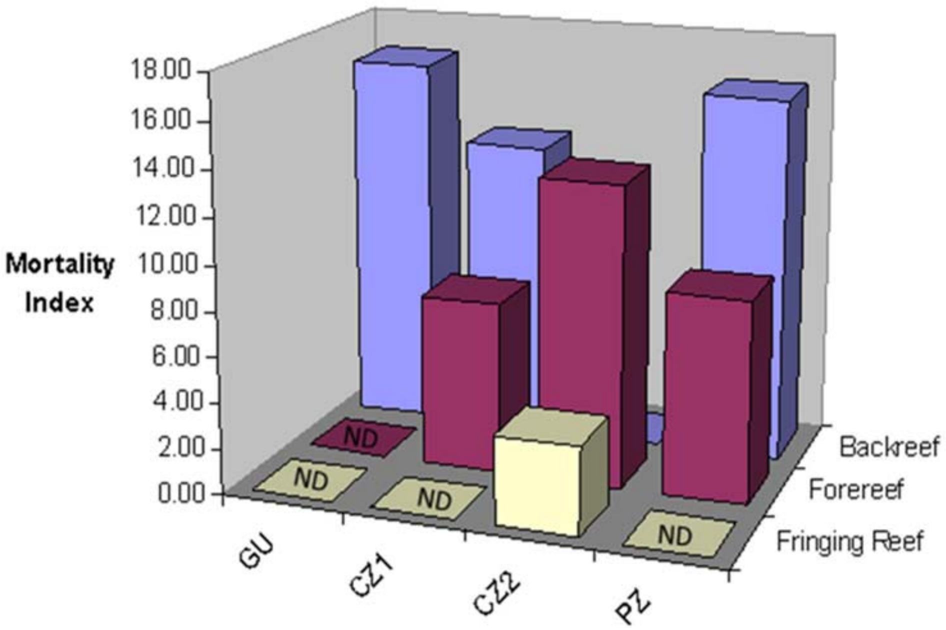

Figure 12 Coral mortality indices of reefs in Bacalar Chico, totalled by reef type and management zone. ND: no data (no reef surveyed). GU: General Use Zone; CZ1: Conservation Zone 1; CZ2: Conservation Zone 2; PZ: Preservation Zone.

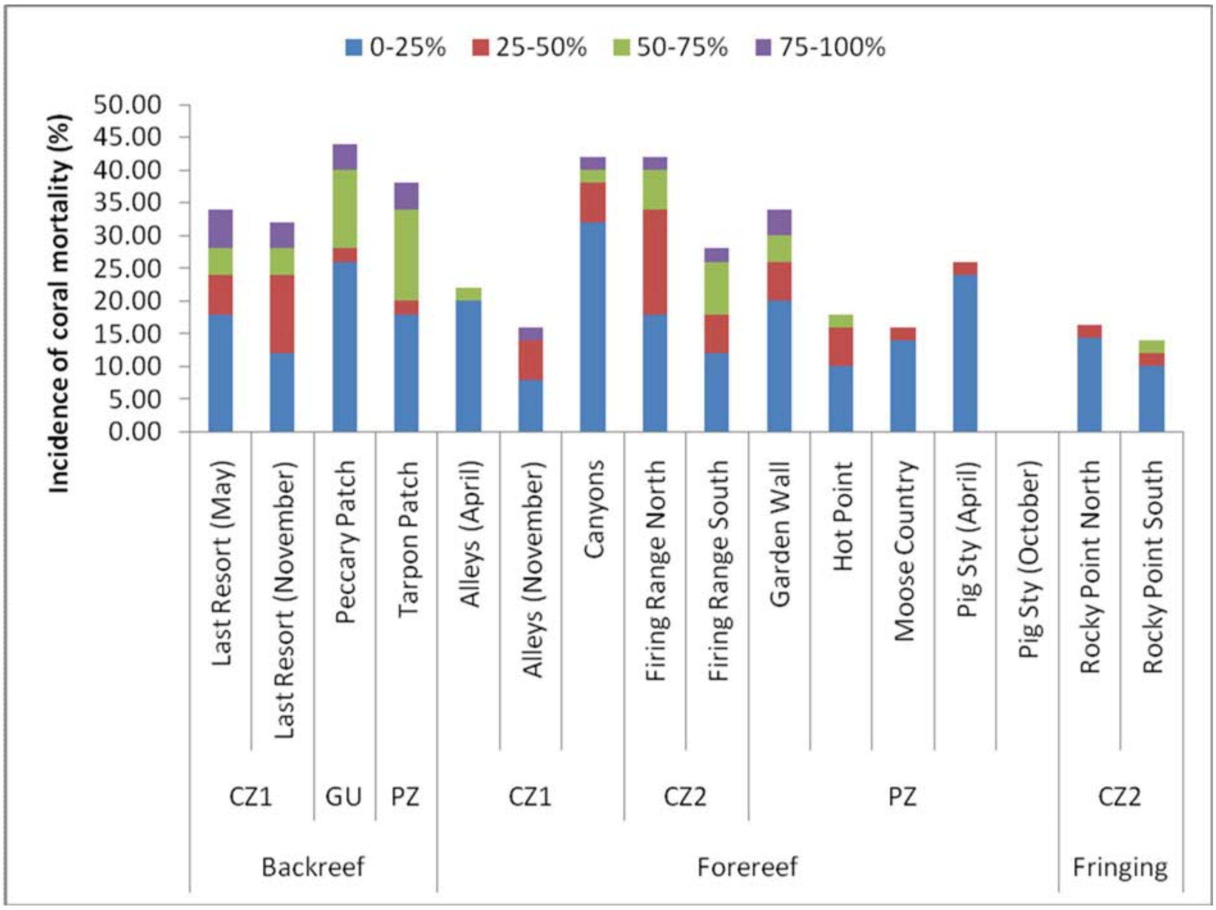

Figure 13 Coral mortality observed at survey sites in Bacalar Chico. GU: General Use Zone; CZ1: Conservation Zone 1; CZ2: Conservation Zone 2; PZ: Preservation Zone.

The greatest amount of bleaching was found in Conservation Zone 1 during the November survey, with 20 colonies showing signs of bleaching and 4 of these colonies being completely bleached (Figure 14). There was a vast increase in bleaching from the March survey on the same site when none of the surveyed colonies exhibited bleaching. The most susceptible species to bleaching were *S. siderea* (100% of colonies in Conservation Zone 2 and 86% in Conservation Zone 1 bleached), *M. cavernosa* (75% in Conservation Zone 1) and *A. agaricites* (46% in Conservation Zone 2), with *M. franksi*, *M. annularis* and *P. astreoides* also showing some bleaching. For sites surveyed twice in 2010, coral bleaching was higher in the second survey (October-November) than in March-April, apart from Last Resort.

Observations of coral disease were low at all sites, with only a few surveyed colonies having evidence of disease (Figure 15). An outbreak of dark spot disease on *S. siderea* colonies was observed in CZ1 on the back reef, with 33% of colonies surveyed having the disease. White plague was also found on *Agaricia spp*. in CZ1 on the fore reef, with both *A. agaricites* and *A. tenuifolia* colonies having the disease.

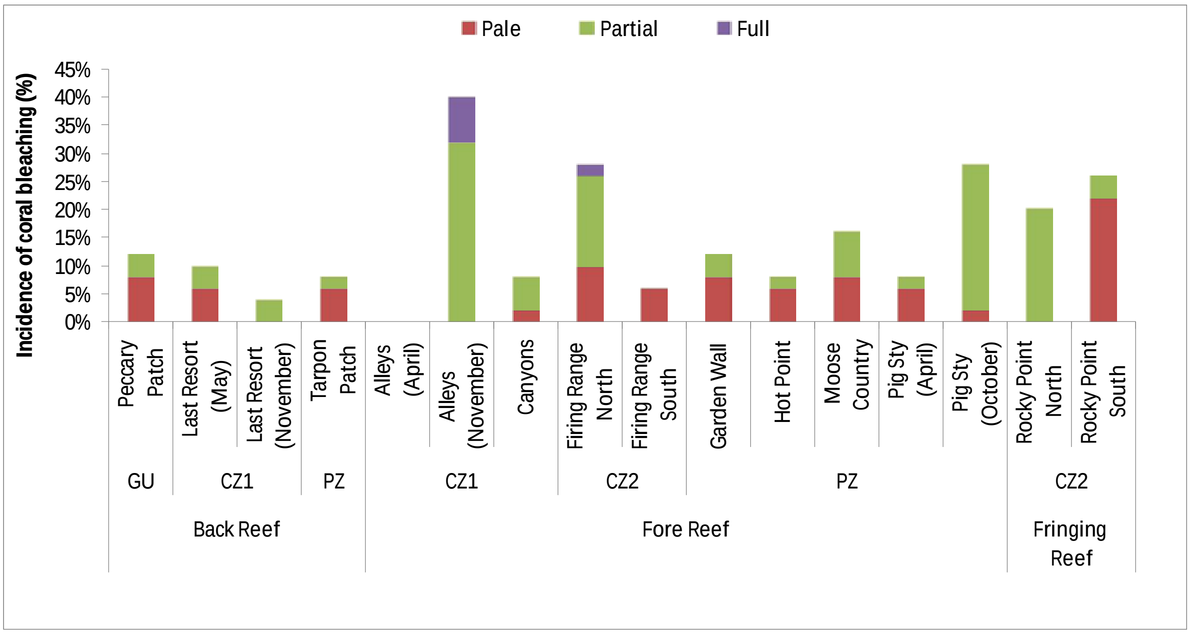

Figure 14 Frequency of coral colonies surveyed that had partial or total bleaching.

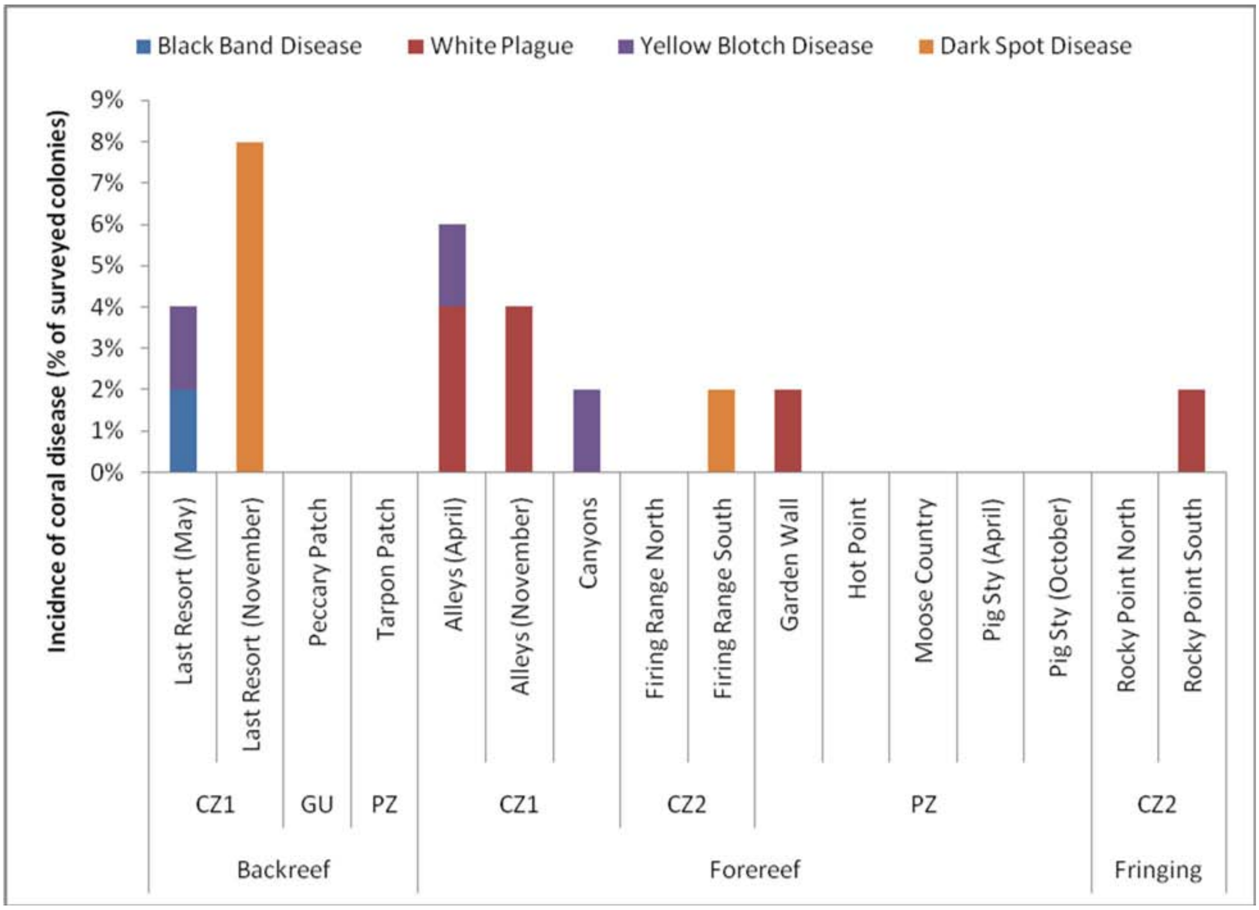

Figure 15 Frequency of coral colonies surveyed that had disease.

Invasive, Commercially Important, Endangered and Megafaunal Species

Invasive Species

In March 2010, lionfish sightings in Bacalar Chico were considered rare (Nick Jones, pers. comm.). However, throughout 2010 sightings had increased. Records of every lionfish sighting began in August 2010 and 208 sightings had been recorded by the end of the monitoring. There were only 78 sightings between 10th September and 5th October 2010 and 109 between 29th October and 22nd November 2010. The vast majority of sightings were on the fore reef and at depths below 10 m. Most sightings were in areas where there were large numbers of recruits and juvenile fish, the primary prey of lionfish.

Spawning aggregations

In spring and summer, large numbers of fish belonging to several species congregate at specific sites to reproduce. These large spawning aggregations can be found in Bacalar Chico off Rocky Point, where large abundances of serranid, lutjanid and carangid species can be seen leading up to the full moon. More than 50 *T. falcatus* were observed schooling from 19th June to 26th June 2010. At the same time, *Lutjanus cyanopterus* were also seen forming spawning aggregations of a similar size around Rocky Point.

Commercially Important and Endangered Species

Serranid sightings in Bacalar Chico were relatively low, with 153 sightings in 118.5 hours. *M. bonaci* (70 sightings) and *E. striatus* (64 sightings) were the most commonly sighted, with juveniles of both species also observed. There were more sightings on the fore reef, with the majority of sightings below 15 m depth. In addition, there were 14 sightings of *Mycteroperca tigris*, 3 of *Mycteroperca phenax* and one each of *Mycteroperca interstitialis* and *Ephinephelus itajara*. Sightings of large Lutjanidae were more frequent, with a total of 196 sightings for *L. cyanopterus, L. analis* and *Lutjanus jocu* in 118.5 hours, with all three species having more or less similar sightings. *L. cyanopterus* was only seen on the fore reef, *L. jocu* was most common below 20 m and *L. analis* most common on the back reef.

Megafauna

Four species of marine turtle were seen in Bacalar Chico, the most frequently encountered was *Eretmochelys imbricata* (hawksbill sea turtle) with 36 sightings over 6 months. *Caretta caretta* (loggerhead sea turtle) was encountered 14 times, with most sightings around the breeding season in May and June. *Chelonia mydas* (green sea turtle) was less frequently encountered and the animals sighted were generally much smaller than the former two species (average shell length of 83 cm). There was also one sighting of *Dermochelys coriacea* (leatherback sea turtle), with shell length of approximately 230 cm, seen in CZ2, just south of Rocky Point.

Shark species were less frequently encountered in Bacalar Chico, with only *G. cirratum* (nurse shark) having the highest number of sightings (23). A single sighting of *Rhincodon typus* (whale shark) was recorded on 8th May 2010. The abundance of rays (Batoidea) was relatively high, with 144 southern stingray *(Dasyatis americana)* and 37 spotted eagle ray *(Aetobatus narinari)* individuals sighted. The majority of *D. americana* and *A. narinari* were sighted on the back reef, with a few larger individuals seen on the fore reef.

Two species of dolphin were encountered in Bacalar Chico, *Stenella frontalis* (Atlantic spotted dolphin) and *Tursiops truncatus* (bottlenose dolphin). *S. frontalis* was only encountered from March to May. *T. truncatus* was seen throughout the year, with calves sighted from June onwards. From October to November, large pods of *T. truncatus* were commonly encountered both on the fore reef and the back reef.

The manatee (*Trichecus manatus)* population in Bacalar Chico appeared to be relatively small, with 15 sightings in both the mangroves and the back reef. Sightings in the mangroves were most common from March to May, with subsequent sightings only on the back reef when animals were observed feeding in seagrass beds.

Discussion

Community Structure

Benthic Community

The benthic community in Bacalar Chico is dominated by turf and fleshy macroalgae and has a relatively low Scleractinian coral cover (10%). According to the Reef Health Index (McField and Kramer 2007) which is used as a guide to reef health throughout the MBRS, only 3 of the 13 sites analysed had good coral cover (> 20%), 4 had poor coral cover (5 - 9.9%) and 1 site had critically low coral cover (< 5%) (Figure 2). One of the three healthier sites, Canyons, is found in Conservation Zone 1 (CZ1), on the western side of the double reef system. The other two, Firing Range North and Firing Range South, are located south of Rocky Point in Conservation Zone 2 (CZ2). All three back reef sites (Peccary Patch, Last Resort and Tarpon Patch) and two of the fore reef sites (Hot Point and Pig Sty) were identified as 'critically low' sites. Pig Sty, the site with the lowest coral cover was located on the eastern side of the double reef, south of the Preservation Zone and on top of the rocky plateau.

The low coral cover is typical of the Caribbean and MBRS reef sites that have seen a dramatic decline in coral cover over the last few decades (Koltes *et al.* 1998; Gardner *et al.* 2003; Mora 2008; Alvarez-Filip *et al.* 2009). A Caribbean wide meta-analysis of coral cover had suggested a continuous decline in cover that started in the late 1970s (Gardner *et al.* 2003). Recent analyses, however, have indicated that the decline started with an outbreak of white band disease in the late 1970s that reportedly decimated the two dominant branching corals (*A. cervicornis* and *A. palmata*) (Aronson and Precht 2006; Schutte *et al.* 2010). Subsequent declines in coral cover were associated with episodic bleaching events in 1982/83, 1987, 1995, 1998, 2005 and 2010 (Kramer and Kramer 2000, 2002; Aronson and Precht 2006; Donner *et al.* 2007; Eakin *et al.* 2010; Schutte *et al.* 2010). Associated with declines in herbivorous fish and sea urchin biomass in addition to increases in nutrient levels, sedimentation, hurricane activity and coastal development overtime, the reefs have become of low ecosystem resilience (Lessios *et al.* 1984; Hughes 1994; Edmunds and Carpenter 2001b; Gardner *et al.* 2005; Vargas-Ángel *et al.* 2007; Wilkinson *et al.* 2008). Most of the reefs are now dominated by fleshy macroalgae and soft bodied invertebrates with altered ecological functioning (Box and Mumby 2007; Baker *et al.* 2008; Crabbe *et al.* 2008; Norström *et al.* 2009; Miloslavich *et al.* 2010; Schutte *et al.* 2010). A region wide analysis of coral cover for the Pacific-South Asia indicated a similar declining trend due to the impact of successive strong bleaching events interacting with local stressors (Bruno and Selig 2007). A new Indian Ocean wide analysis has, however, indicated that the 1998 strong bleaching disturbance explained most of the regional variation with other stressors having only localised effects (Ateweberhan *et al.* 2011).

In Belize, the 1998 bleaching event had an unprecedented catastrophic effect on Caribbean coral reefs in modern history (Carilli and Norris 2008). Its impacts were especially greater in the southern and northern regions and compounded by the destructive power of Hurricane Mitch (McField 2000b; McField *et al.* 2008). In addition to their destructive power on adult coral colonies, hurricanes also result in a lowered coral recruitment, impeding recovery (Crabbe *et al.* 2008). Of the 33.3% coral cover in 1997, only 15.0% were left in 1999 (McField 2000b; McField *et al.* 2008). This was followed by some recovery when 18-19% cover was recorded in 2004-05 in the Bacalar Chico area. Cover had reached 33% by 2008 (García-Salgado *et al.* 2008). This value is significantly large even in comparison to the highest cover found in this study. The difference could not be due to the methodology used as both studies applied point intercept transect in monitoring benthos. Considering the low recovery of coral cover throughout the MBRS the 33% cover recorded in 2008 appears to be an overestimation. In fact, there was an additional 6.5% mortality recorded for Belize during the strong Caribbean wide bleaching event in 2005 (McField *et al.* 2008). It appears that the 2010 bleaching disturbance had caused less mortality in Bacalar Chico (Figure 13) although there could have been some latent mortality on the sites with the highest bleaching (Figure 14).

On the back reef, the higher coral cover in CZ1 and PZ relative to the GUZ may be due to the fishing limitations in the former sites where fishing for conch and lobster is prohibited. CZ1, located adjacent to GUZ has a slightly lower cover than PZ. Numerous sightings of fishing incursions into that zone have been observed and could have influenced the reef health negatively.

The fore reef generally appears a healthier reef habitat, with 7 of the 10 sites in 'good' or 'fair' condition according to the Reef Health Index (McField and Kramer 2007). The healthiest reef sites were found on the fore reef in PZ and CZ2, where high coral cover (> 20%) and species richness and diversity were observed. These two zones are also two of the few places to have relatively high abundances of the IUCN 'critically endangered' coral species, *A. palmata* (PZ) and *A. cervicornis* (CZ2). The presence of large colonies of *A. palmata* on the western side of the double reef system, at Garden Wall and Moose Country is particularly noticeable. The large colonies sculpt the reef and provide crevices for a wide range of fish species. The increased protection in both these regions, topographical features and good water clarity as a result of low sedimentation around the sites probably creates a healthy reef system. Pig Sty, the site with the lowest coral cover and diversity, is located in a shallow area of the fore reef has the lowest herbivorous fish biomass among the studied sites. Large amounts of long dead *A. palmata* colonies are seen around the site indicating the impact of past disturbance events. The consequent loss of the reef framework could impede coral recovery (Halford *et al.* 2004; Sheppard *et al.* 2008). Pig Sty is also the site with the highest sponge cover (Figure 2), known for outcompeting corals (McCook 2001 Aerts 2000).

The two sites on the fringing reef at Rocky Point have poor coral cover and given the ecological importance of the area, this is a concern. Large spawning aggregations of several lutjanid, serranid and carangid species are found in this region as well as large populations of other reef fishes. Macroalgal cover at Rocky Point South is particularly high (over 42%). The two sites have the largest biomass of herbivorous fishes after Alleys (Figure 11). Despite this, fleshy macroalgae seem to be overgrowing the reef. The transects closer to the reef wall reveal higher coral abundance at both sites. The topographical and hydrographical features of the region result in the convergence of currents at Rocky Point and may influence coral cover and benthic community structure. Our results indicate that even the sites with the highest coral cover have high turf and fleshy algal cover (Figure 2). Negative effects of fleshy macroalgae on corals have been observed on coral reefs worldwide (Lirman 2001; Littler and Littler 1984; McCook *et al.* 2001). *Dictyota* and *Lobophora,* the fleshy macroalgal species with high abundance form dense mats which prevent coral settlement. They also induce coral mortality through shading and abrasion (Box and Mumby 2007). The high cover of these species and turf algae even on the high coral cover sites indicates that herbivore biomass is below a certain critical level to control their dominance.

Abundance of the 7 most abundant coral species and the two endangered species was higher in either CZ1, CZ2 or PZ (Figure 3), suggesting the importance of management in promoting coral cover and protection of endangered species. The coral community composition reflects the disturbance history of the region the influence of the hydrological systems in the study area. The most abundant coral species belong to species with opportunistic life history strategy with encrusting growth form. These are more tolerant to bleaching and physical disturbances in comparison to *A. cervicornis* and *A. palmata*, the two species that once dominated Caribbean reefs. Because of their vulnerable morphology, cover of these two was reduced by more than 90% first by disease outbreaks and hurricanes and later by successive bleaching events (Porter *et al.* 1981; Woodley *et al.* 1981; Hughes 1989; Aronson and Precht 2001; 2006; Schutte *et al.* 2010). Another historically dominant Caribbean species in decline is *M. annularis* (Edmunds and Elahi 2007).

Previous studies in the MBRS have found similar results, with *Agaricia spp., Siderastrea spp.*, and *Porites spp* being the main juvenile coral taxa (Van Moorsel 1985; Ruiz-Zarate and Arias-Gonzalez 2004). The relatively high abundance of *P. astreoides*, the most abundant species, is mostly attributed to its opportunistic weedy life-history characteristics (Green *et al.* 2008). Except on Rocky Point South, it had an even distribution on the remaining sites (Figure 3). *Agaricia* is the other genus with a relatively high cover and on the increase in the Caribbean. Its persistence is also attributed to an opportunistic life-history and high environmental tolerance associated with its encrusting growth form (Aronson *et al.* 2004; Sebens *et al.* 2003). *Agaricia* was completely decimated from the reefs of Belize during the 1998 bleaching event (Aronson *et al.* 2002; Carilli and Norris 2008; Carilli *et al.* 2009); the current relatively high cover must be related to a recent recovery. The dominance of northern Belize reefs by *M. annularis* reported in Peckol *et al*. (2003) is not supported by our results.

Fish community composition

The fish abundance found in this study (23-104 individuals per transect; Figure 5) are more or less similar to those found elsewhere in Belize and MBRS (Brown-Saracino *et al.* 2007; Caye Caulker Annual Report 2008). The total average of 66.5 individuals per transect is larger than the 22 individuals per transect reported by Garcia-Salgado *et al.* (2008). The highest abundance recorded on the fringing reef sites (108.8 individuals per transect) is larger even than the largest value recorded for the whole Belize in 2007 (Hol Chan and Sapodilla Caye: 77 individuals per 100 m^2; García-Salgado *et al.* 2008).

At the vast majority of the sites surveyed Labridae were the most abundant in the fish population followed by Pomacentridae. Labridae were also the most common fish family in other MBRS reefs (Brown-Saracino *et al.* 2007; Caye Caulker Annual Report, 2008). The high labrid abundance is associated with the presence of a number of 'cleaning stations' throughout the fore reef, particularly on the deep fore reef in PZ and CZ2 where total fish abundance is also high. These are also the only reefs where the endangered *E. striatus, M. bonaci* and *L. cyanopterus* were seen during the survey. It appears that the overhangs and caves on the two fringing reef sites and Firing Range North on the fore reef provide suitable habitats for bicolour damselfish (*S. partitus*), the species with the largest abundance at any particular site.

The areas with the greatest total abundance of species tend to have specific topographical features which influence abundance rather than the health of the reef itself. For example, Rocky Point had the greatest abundance of fish (Figure 5) while coral cover at the site was only moderate (Figure 2). The reef wall and caves were areas of greatest abundance. The increased flow of current here and sheltered areas are important habitats for juvenile and adult reef fish (Heyman and Kjerfve 2008). Large numbers of the haemulids, *H. flavolineatum* and *H. plumieri* take advantage of the shelter provided by caves and overhangs, as well as the cover provided by an abundance of gorgonians. Despite a critically low coral cover, Pig Sty in the Preservation Zone, also had a high total abundance of fish, particularly Haemulidae and Pomacentridae, with *C. cyanea* and *H. flavolineatum* being particularly dominant. The interconnecting network of crevices created by old *A. palmata* colonies is a prime reason for the high abundance of these species, with abundant hiding places from predators.

The abundance of Scaridae appears to have a link with reef health, with the sites where Scaridae in particular represent a large proportion of the fish assemblage being with the highest coral cover. The greatest abundance and diversity of Scaridae was found at Firing Range North in Conservation Zone 2, where the coral cover is above 20%. Similarly the Preservation Zone sites with good coral cover also have a diverse array of Scaridae, with the most common species being *S. viride, S. aurofrenatum* and *S. iserti*. Previous MBRS surveys by the Belize Fisheries Department found that *S. aurofrenatum* and *S. iserti* were common on Glover's Reef (Glover's Reef Annual Report 2008) and Caye Caulker (Caye Caulker Annual Report 2008). The Preservation Zone also has large schools of the herbivorous *A. coeruleus, A. bahianus* and *Acanthurus chirurgus* which are commonly seen grazing on algae. The importance of herbivorous fish populations has been noted in previous studies in the

Caribbean (Lewis and Wainwright 1985; Lewis 1986; Steneck 1994; Littler *et al.* 1989; Aronson and Precht 2006; Healthy Reefs 2007), where the grazing of these species keeps macro algal coverage low, allowing recruitment and growth of corals.

The total average biomass recorded in this study (260 kg ha^{-1}) falls below the medium range of the Caribbean fish biomass (14-263 g m^{-2}; Newman *et al.* 2006). The largest biomass recorded at Last Resort (467 kg ha-1) is about a sixth of the regional maximum regional biomass (Newman *et al.* 2006) and about a third of the biomass recorded in small closures in the western Indian Ocean (McClanahan *et al.* 2007). The largest biomass of Scaridae (110 kg ha^{-1} at Alleys) is about half the values obtained for Kenyan MPAs (McClanahan *et al.* 2007). For acanthurids, values are less than 12% of those recorded on Kenyan MPAs. In the Caribbean wide study, increased biomass correlated with the proportion of apex predators which were abundant inside large MPAs only (Newman *et al.* 2006). The mismatch in the patterns between total fish abundance and biomass is probably caused by the difference in fish size. Sites with low fish abundance could have large biomasses due to the presence of a few but large individuals. Sites with highest coral cover didn't have a particularly high abundance or biomass of key fish functional groups. In fact, large biomass values were due to the large haemulid biomass in specific areas. The lack of relationship between haemulid biomass and fishing pressure has also been observed in other Caribbean reefs (Hawkins and Roberts 2004).

A major problem faced on the Mesoamerican Barrier Reef is the growing threat of invasive species, primarily the lionfish (*P. volitans*), which feeds voraciously on recruits and juveniles of reef fishes and has no evident predators in the Caribbean. Most sightings were in areas with large numbers of recruits and juvenile fish. The increase in lionfish sightings during the study period is in agreement with other observations in the Caribbean (Schofield 2009) with expected negative effects on indigenous fish populations and reef ecology in general (Albins and Hixon 2008).

Large spawning aggregations are observed in Bacalar Chico off Rocky Point, where large abundances of Serranidae, Lutjanidae and Carangidae species can be seen leading up to the full moon. The specific geomorphology of the reef with a gently sloping contour and the environmental conditions with variable currents provide ideal habitat for spawning aggregations (Heyman and Kjerfve 2008). These spawning aggregations in Conservation Zone 2 are found in an area where sport fishing is permitted and numerous fishing boats can be seen around while these aggregations form. Spawning probably occurs throughout the year with different species forming spawning during a particular season of a year as observed in southern Belize (Heyman and Kjerfve 2008). Thus, any fishing targeting this area is expected to have significant effects on the fish populations involved.

The low abundance of fish species listed as critically endangered by the IUCN, especially that of *E. itajara* is a real concern. The species is a predator of lionfish in the Pacific and therefore a potential controlling agent in the Caribbean. The low number of sightings of these predominantly solitary species and other species again highlights the extent to which their populations have been depleted. Similarly the low sighting frequencies of shark species highlights the extent to which these keystone predators have been fished to critical levels.

Overall Reef Health

Overall reef health in Bacalar Chico varies greatly. Although there was high variability within a reef type and conservation zone, generally coral cover and diversity were much greater on the fore reef and fringing reef than on the back reef. The greatest cover and diversity occur on the fore reef in the two Conservation and Preservation zones. The lowest cover and diversity was recorded on the back reef in the General Use Zone although one low cover site, Pig Sty, is located on the fore reef. The reef health also appears to be connected with a certain fish species present, with high abundances of Scaridae being found on the healthiest reefs. Although not statistically significant, the signs of the correlation between scarid abundance and coral cover and diversity were all positive.

Haemulids composed the largest biomass of the commercially important fish families and their abundance was highest on the GUZ and had a negative correlation with coral cover and diversity (also see Hawkins and Roberts (2004). High haemulid biomass on CZ2 is probably associated with habitat difference. The absence at many sites of predatory fish is a large concern and gives evidence for the large scale overfishing which has occurred in Bacalar Chico. Continued removal of predatory fish species, including *L. cyanopterus, L. analis* and *Sphyraena barracuda* may lead to the complete loss of a functional group which could potentially impair the functionality of the ecosystem (Roberts, 2009) and lead to an increase in the rate with which coral coverage decreases.

The large increase in bleaching seen with water temperature rise is another concern. Over a 350% increase in the number of bleached coral colonies was observed on the fore reef when sites were revisited after 6 months. In combination with the large proportion of coral colonies with partial mortality, the threat of increased water temperatures is a growing concern to the health of the reef in Bacalar Chico. The low incidence of coral disease is supported by previous studies, e.g. Wilkinson (2002), finding the Belize Barrier Reef to have the lowest incidence of disease in the wider Caribbean.

Conclusions

Patterns in benthic and coral composition, fish abundance, biomass and diversity, on the coral reefs of Bacalar Chico can be considered typical of degraded Caribbean reefs dominated by fleshy and turf algae. Considering the time since closure (1996-2010), the full benefit of management has not been achieved yet. The lack of difference in biomass of commercially important taxa between GUZ and the other conservation zones indicates that management is not strongly enforced and has delayed the recovery of the biomass of key families and the recovery of coral cover, diversity and reef complexity. Management effort should be intensified along with continued collection of baseline data to assess the effectiveness of the management of the marine reserve and monitor the health of the coral reef ecosystem.

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Appendix

Priority fish species list

Family	Species	Notes
Pomacanthidae (Angelfish)	All	Recreational value Targeted by aquarium trade
Acanthuridae (Surgeonfish)	All	Key herbivores
Carangidae (Jacks)	*Caranx rubber* (Bar Jack)	Commercially significant
Chaetodontidae (Butterflyfish)	All	Herbivores
Balistidae (Triggerfish)	*Balistes vetula* (Queen Triggerfish) *Balistes capriscus* (Gray Triggerfish) Melichthys niger (Black Durgon)	Commercially significant *Diadema* predators
Monocanthidae (Filefish)	*Aluterus scriptus* (Scrawled Filefish) *Cantherhines pulles* (Orangespotted Filefish) *Cantherhines macrocerus* (Whitespotted Filefish)	Commercially significant *Diadema* predators
Lutjanidae (Snappers)	All	Key commercial species Top predators
Haemulidae (Grunts)	All	Commercially significant
Scaridae (Parrotfish)	All	Key herbivores
Serranidae (Grouper)	*Epinephelus* spp. *Mycteroperca* spp.	Key commercial species Top predators
Serranidae (Grouper)	All other species.	Commercially significant Top predators
Labridae (Wrasse)	*Lachnolaimus maximus* (Hogfish) *Bodianus rufus* (Spanish hogfish)	Commercially significant
Labridae (Wrasse)	*Clepticus parrae* (Creole Wrasse)	Abundant
Pomacentridae (Damselfish)	*Microspathodon chrysurus* (Yellowtail damselfish)	Herbivore
Pomacentridae (Damselfish)	Stegastes partitus (Bicolour Damsel) Chromis cyaneus (Blue Chromis)	Abundant
Sphyraenidae (Barracuda)	*Sphyraena barracuda* (Great Barracuda)	Commercially significant