Effectiveness of Different Levels of Management on Three Marine Protected Areas. A Case Study from Belize, Central America.

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Abstract

Coral reefs worldwide are degrading at an accelerated rate. Coupled with predictions of near-future climate change, increased coastal development and increased dependence on reef resources, the future for coral reefs looks bleak. The need for improved management is paramount in order to preserve reefs for the future. Belize hosts the longest barrier reef in the Western Hemisphere, which forms part of the Mesoamerican Reef (MAR) system. In addition to climate change threats such as coral bleaching and increased hurricane activity, localized risks to reefs within this area include over-fishing, coral disease, and coastal and caye development. An effective network of marine reserves with good connectivity between sites is essential. Marine Protected Areas have the ability to act as 'stepping stones' allowing larval supply and dispersal from one region to another. SEA co-manages 3 Marine Protected Areas within the Southern Belize Reef Complex; Laughing Bird Caye National Park (LBCNP), Gladden Spit and Silk Cayes Marine Reserve (GSSCMR) and Sapodilla Cayes Marine Reserve (SCMR). The three reserves exhibit a gradient in their level of protection, ranging from a fully protected no-take national park, to a marine reserve with established zoning, to a marine reserve with new zoning that has only been enforced since 2010. Abundance and size data for commercially important species (conch, lobster and certain fish) is presented and results are displayed over time in order to show the effectiveness of the differing levels of management. The future of these southern Belize reef ecosystems is considered in the context of future threats and potential management strategies.

1.0 Introduction

Coral reefs are one of the most valuable ecosystems on earth, with the value of reef resources being estimated at approximately $375 billion per year (Bryant *et al.*, 1998). They provide many essential commodities including building material and food, as well as mass employment for thousands of people. With 8% of the world's population (0.5 billion) living within 100 km of a coral reef (Pomerance, 1999), great demand is being put on these resources. Reefs provide natural sea defenses, protecting the coastline from storm damage, erosion and flooding, by dissipating wave energy, and provide habitats for hundreds of species of marine flora and fauna (Hoegh-Guldberg, 1999). Associated ecosystems such as seagrass beds and mangroves act as nursery grounds for many species and play an important role in rejuvenating fish stocks (Parrish, 1989).

The great biodiversity of the coral reef ecosystem provides high economic gain from tourism and fisheries, and due to the location of tropical coral reefs (generally between 25°N and 25°S), reefs provide essential resources to coastal populations in less developed countries. In 1995 it was estimated that the Caribbean attracts one hundred million tourists per year, generating $140 billion from the SCUBA diving industry (Jameson *et al*., 1995). World-wide coral reef fisheries have been estimated to produce 6 million tonnes per year and reef fisheries contribute 25% of total fish catches in developing countries (Bryant *et al*., 1998).

Plates 1-3: Reef community of North Silk Caye wall, a popular tourist dive site at Gladden Spit and Silk Cayes Marine Reserve. Photos: Annelise Hagan, November 2010.

Coral reef growth is bound within upper and lower threshold limits of different environmental parameters, and any event that pushes corals beyond these limits could result in mortality. Future suggestions of global climate change and increased anthropogenic impacts on reef ecosystems will affect reef communities and it is not yet known how reefs will respond to such an altered environment (Brown, 1997). Coral reef degradation is not a new phenomenon, with natural degradation events occurring throughout history. Pandolfi *et al*. (2003) documented long-term reef ecosystem change, from 'pre-human' to the present day, over a global scale. Categorizing the 'pre-human' reefs as pristine and including a hypothetical endpoint as 'ecologically extinct', the most healthy present-day reefs were shown to be those of the Great Barrier Reef, but even these are a third to a quarter of the way along the pristine to extinct time trajectory. The reefs of Belize were shown to sit approximately half way along this degradation gradient.

A 'strategy shift' (certain species being replaced by opportunistic species; Done, 1999) has been seen in Belize, where the dieback of the coral *Acropora cervicornis* due to band diseases and a limited number of viable *A. cervicornis* larvae has led to an increase in the opportunist species *Agaricia tenuifolia* (Aronson and Precht, 1997). The sudden increase in *A. tenuifolia* was greatly aided by its ability to reproduce both sexually and asexually, and its relative tolerance to band diseases (Done, 1999). If a very severe disturbance occurs (or a succession of major degradation events), reefs may suffer a 'phase shift' whereby a community dominated by reef building organisms (corals and coralline algae) is replaced by one dominated by non reef building organisms (soft corals and fleshy algae) (Done, 1992).

Plate 4: *Turbinaria* sp. macroalgae overgrowing the reef in the no-take zone of Gladden Spit and Silk Cayes Marine Reserve. Photo: Annelise Hagan, September 2010.

In the Caribbean, coral cover has been reduced by 80% (from 50% to 10%) in the last three decades (Gardner *et al*., 2003). It has been suggested that recent coral mortality in the Caribbean has led to several critical function groups being either removed from the reef ecosystem, or being represented by only a few species (Bellwood *et al*., 2004). For example, the dramatic loss of *Acropora cervicornis* and *Acropora palmata* has removed the elkhorn '*palmata* zone' and the staghorn '*cervicornis* zone', two key shallow water habitats (Bellwood *et al*., 2004). Critical function groups of fish have been reduced through over-fishing, resulting in a shift from fish-dominated to echinoid-dominated herbivory. Although both fish and echinoids (urchins) remove algae, a vital function to resist a phase shift, echinoids are far more destructive to the ecosystem as they are bioeroders, burrowing into and eroding the reef structure (Bellwood *et al*., 2004). These recent degradation events have not been due to global phenomena, but have resulted from local natural and anthropogenic impacts occurring at a Caribbean-wide scale, within the context of overfishing. Current predictions for increased human activity in the Caribbean, coupled with predicted global climate change suggests that in neither the short nor the long term does the situation for Caribbean coral reefs look set to change (Gardner *et al*., 2003). In 2008 it was reported that the world had already lost 19% of coral reefs worldwide. A further 15% were said to be seriously threatened by loss in the next 10-20 years and 20% were said to be under threat of loss in 20-40 years (Wilkinson, 2008).

2.0 Geographical Setting

Belize is a small country (22,960 km^2) home to approximately 300,000 people, giving it the lowest population density in Central America (United Nations, 2009). The country hosts the 280 km long, 1,400 km^2 Belize Barrier Reef (McField and Bood, 2007). Running from the Mexican border in the north (18^oN) to Sapodilla Cayes in the south (16^oN) at a longitude of approximately 88^oW, this is the longest barrier reef in the western hemisphere and the second longest in the world. Forming part of the Mesoamerican Reef (MAR) system, the Belize Barrier Reef has been recognized for its high level of biological diversity, ecological processes and natural beauty, by being declared a UNESCO World Heritage Site in 1996. The barrier reef complex displays a variety of reef types (barrier reef, lagoon patch reef, fringing reefs and offshore atolls) and associated habitats (mangroves, seagrass beds, estuaries and islands or cayes) (Cooper *et al*., 2009), and exhibits the classic barrier reef zonation patterns described by Rützler and Macintyre (1982). Faros, rhomboid-shaped, steep-sided continental shelf atolls (believed to be uplifted fault blocks resulting from tectonic movement) are an interesting and unusual feature of Belize's reef system (Perkins, 1985).

Belize experiences a subtropical climate; average air temperatures range from 24^oC to 27^oC and variations in rainfall induce notable dry (February-May) and wet (June-October) seasons. Belize lies within the zone of the Northeast Trade winds, which blow with greatest consistency between April and September. Hurricanes can occur during the months of July to October, and have been recorded in Belize since 1787 (McField, 2001). Hurricane activity has significant effects on coral reefs, and there is evidence that they play an important role in creating the zonations of the barrier reefs and atolls (Rützler and Macintyre, 1982). Annual rainfall increases moving south; rainfall at the cayes is likely to reflect this pattern and the southern cayes experience a more humid environment than those in the north. The wettest months induce peak transport of fresh water and fluvial sediments and the flux of freshwater from the high rainfall areas of southern Belize, Honduras and Guatemala give rise to easterly flowing, density-driven surface currents that exit from the Gulf of Honduras (Heyman and Kjerfve, 2001). The southern reefs therefore experience greater variation in salinity and fluvial run-off and the seawater is known to be less saline around the Sapodilla Cayes (Perkins, 1983). At Gladden Spit, water temperatures vary from 27^oC to 31^oC and surface salinities are high throughout the year (36-37), but may drop to 32 at the end of the rainy season or after a hurricane (Heyman and Kjerfve, 2001). Mean spring tidal range is 0.2 m (Stoddart *et al*., 1982) and although the astronomical tide is weak, tidal currents are strong in reef passes and near river mouths, playing a key role in dispersing sediment, nutrients and larvae (Heyman and Kjerfve, 2001).

Like all reefs worldwide, the reefs of Belize are under increasing pressure. In addition to large-scale climate change threats such as temperature induced coral bleaching and increased hurricane activity, localized threats to reefs include over-fishing, pollution, sedimentation, coral disease, and coastal and caye development. A comprehensive survey of 326 reefs in the Mesoamerican region revealed average live coral cover of only 11% (11% Belize, 7.5% Mexico Yucatan and 14.4% Honduras and Guatemala combined), indicating that there has not been substantial recovery following the severe bleaching event and Hurricane Mitch which caused extensive coral mortality in 1998 (Garcia-Salgado *et al*., 2008). It is possible for reefs to recover after major degradation events, but not under stressed conditions. A recent study of *Montastraea faveolata* (Mountainous Star Coral) recovery following the major bleaching event of 1998 showed growth rates were suppressed where anthropogenic impacts were higher. Corals in the Sapodilla Cayes, which are exposed to higher levels of anthropogenic stress (principally through sedimentation and nutrient enrichment) had suppressed growth rates 8 years after the 1998 bleaching event, but at Turneffe Atoll, Belize, where anthropogenic stress is considerably lower, coral growth rates resumed to normal within 2-3 years (Carilli *et al*., 2009).

The value of the resources that the reefs of Belize provide (reef and mangrove related fisheries, tourism, and shoreline protection) has been estimated at US$395 - $559 million per year (Cooper *et al*., 2009). With such a valuable asset lying just offshore (approximately 300 m offshore in the north and 40 km offshore in the south), the protection of the reefs of Belize for future generations is paramount.

Plates 5 and 6: Coral bleaching at Sapodilla Cayes Marine Reserve, September 2010. Photos: Annelise Hagan.

3.0 Marine Protected Areas (MPAs) of Southern Belize

There is no doubt that fishing, and the over-exploitation of reef resources is causing detrimental effects and exacerbating reef degradation due to climate change. Long-term intensive fishing pressure will reduce population densities and may lead to certain species being eliminated (Roberts and Hawkins, 2000). Effectively managed Marine Protected Areas (MPAs) can be used to regulate human activities (Sale *et al*., 2005), specifically addressing the threats of tourism, development and the over-exploitation of commercially important species (McField, 2001). It is important that tropical MPAs encompass all key ecological features; coral reef, seagrass beds and mangroves, so that all life-stages are protected. Although reef fish are most obvious on coral reefs, seagrass beds and mangroves provide vital nursery habitats for fish, conch and lobster and play an important role in connectivity between reef ecosystems.

Within an MPA, zoning schemes can be used to allow multiple uses (such as diving, sports-fishing and small scale fishing) in some areas and full protection of marine resources in adjacent areas. 'No-take areas' (NTAs), where all extraction is prohibited, can help reverse the trends of over-exploitation and provide a refuge for fish population, particularly large individuals which will produce more offspring (McClanahan and Arthur, 2001). No-take areas have two potential goals; 1) to protect a portion of the fishery stock as insurance against future over-fishing and 2) to sustain and potentially enhance fishery yields in the surrounding area (Sale *et al.*, 2005).

The majority of marine species have a pelagic larval stage and many disperse eggs. The pattern of larval and egg dispersion is dictated by currents, and life history, and some may be transferred great distances, generating inter-connections between areas (Roberts, 1997). For example, Caribbean spiny lobster larvae are planktonic for 6 months or more, and are thus able to cover large distances (Appeldoorn and Lindeman, 2003). A network of reserves, with good connectivity (through physical processes such as current patterns) between sites is essential. MPAs have the ability to act as 'stepping stones' allowing larval supply and dispersal from a protected area to a degraded area downstream. In addition, there may be a net outward movement of juveniles which mature within the reserve and subsequently move out into the fisher area, this is termed the 'spill-over effect'. It has been suggested that Belize is among the most important source areas of fish, coral and other invertebrate larvae in the Mesoamerican region (Cortés, 1997) and that Belizean reefs are strategically located in terms of reef connectivity (Roberts, 1997). It is vital that there are strong links between scientific researchers and reef managers, in order to ensure that marine reserves are managed correctly in terms of the resources they provide.

Marine conservation efforts in Belize have grown significantly in the past two decades (Cooper *et al.*, 2009) and there are now 18 MPAs throughout the country, covering approximately 250,000 ha (McField *et al.*, 2008) (Fig. 1). Southern Environmental Association (SEA) co-manages 3 MPAs within the system-level management unit of the Southern Belize Reef Complex; Laughing Bird Caye National Park (LBCNP), Gladden Spit and Silk Cayes Marine Reserve (GSSCMR) and Sapodilla Cayes Marine Reserve (SCMR) (Fig. 2). The three MPAs are managed under differing levels of protection, exhibiting a gradient in the levels of legal extraction, ranging from 'no-take areas' where all extraction is illegal to 'general use' zones where fishing is allowed, but may be controlled by banning certain fishing techniques. Marine Protected Areas can only be effective through enforcement. In addition to SEA's marine park rangers, who patrol all the parks twice a day every day, SEA employs a special enforcement team to focus on combating illegal fishing activities day and night, in the buffer zones between the reserves. These buffer zones, outside the reserves, are integral to the effectiveness of the marine protected areas in terms of connectivity between adjacent reserves. The special enforcement team spends 4 consecutive days in the field and conducts 16 patrols per month. In 2009, a total of 101 warnings, 67 arrests, 87 charges and 70 convictions were made by SEA's rangers and special enforcement team. Infringements included being caught with undersized products, or products not allowed to be fished (e.g. lobsters with eggs), not having the relevant license, and using spear guns or nets within a marine reserve.

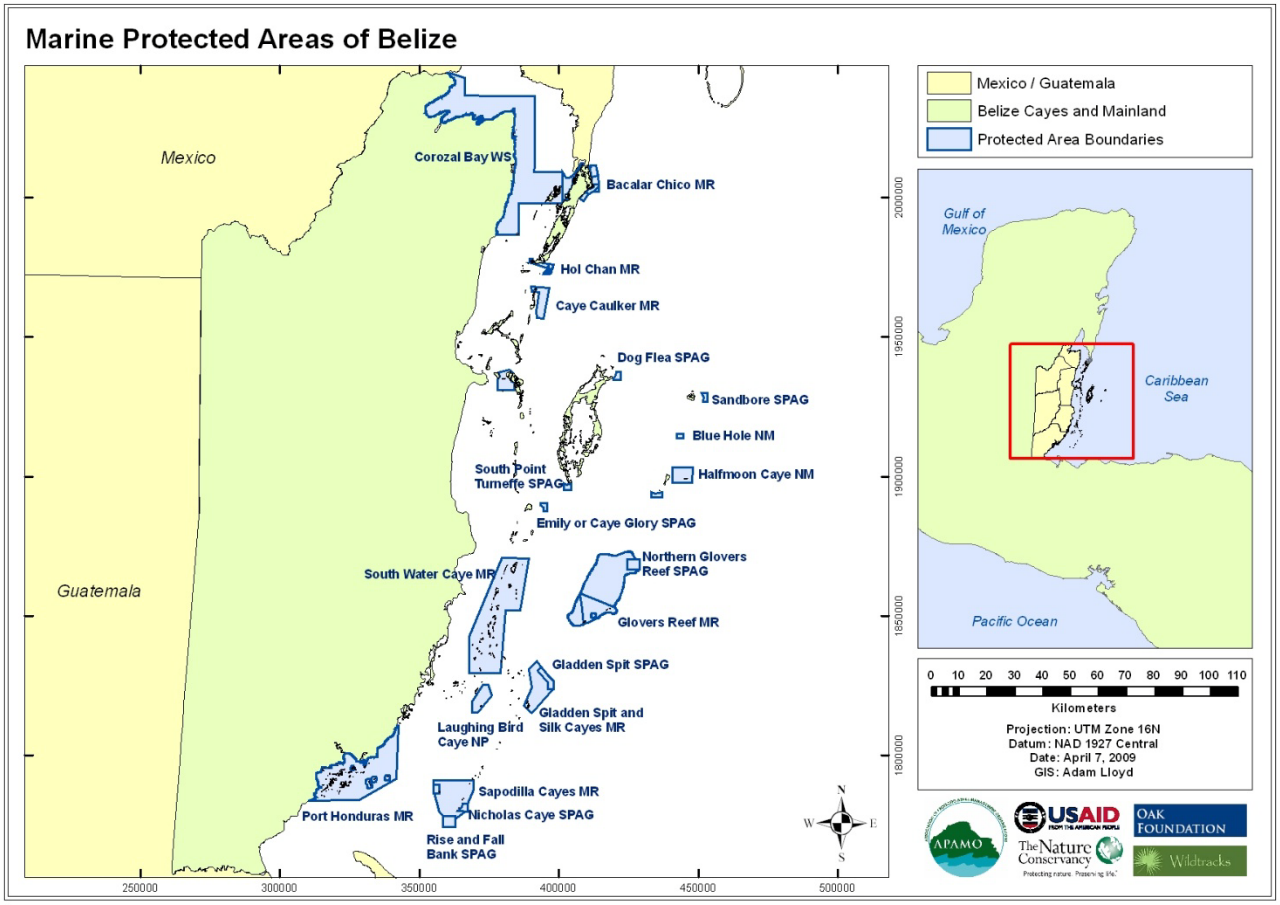


Figure 1: Map of Belize showing all Marine Protected Areas. Those co-managed by Southern Environmental Association are in the south; Laughing Bird Caye National Park, Gladden Spit and Silk Cayes Marine Reserve and Sapodilla Cayes Marine Reserve.

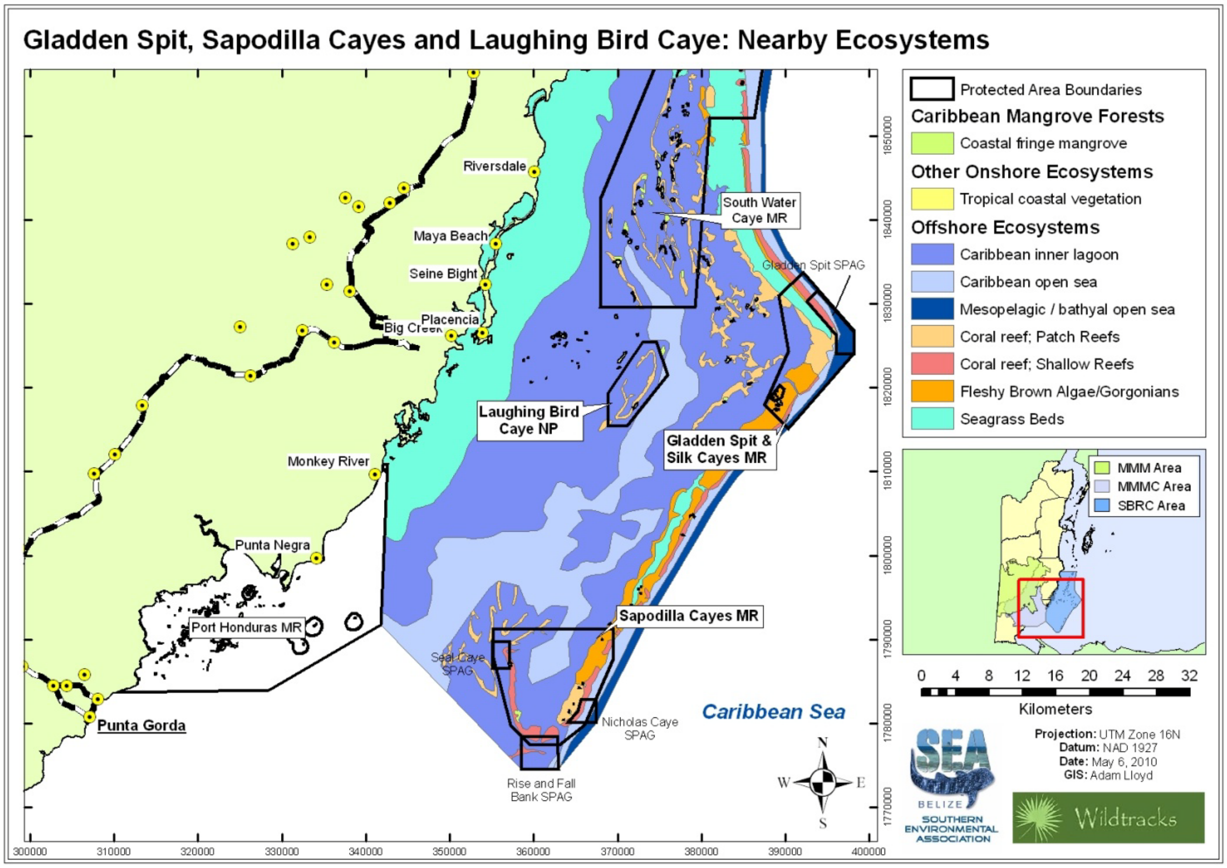
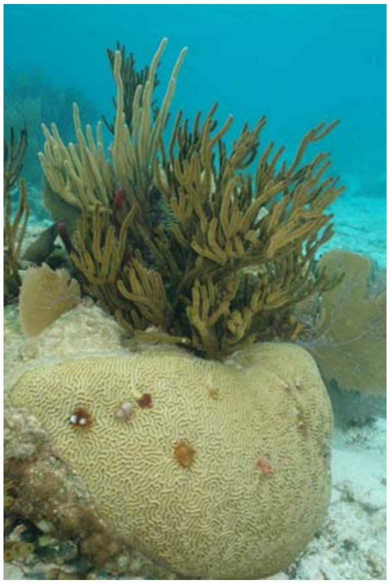


Figure 2: Marine benthic habitats for the marine reserves of southern Belize.

3.1 Laughing Bird Caye National Park (LBCNP)

Located 18 km east-southeast off the coast of Placencia, at a location of 16°27'N; 88°11'W, Laughing Bird Caye National Park (total size = 4,095 ha; island size = 0.57 ha) experiences high pressure on its resources from tourism. In order to manage these pressures, the area was designated a National Park in 1991 and declared part of the Belize Barrier Reef UNESCO World Heritage Site in 1996. The island, named after the Laughing Gull (*Larus atricilla*) which once nested on the north end of the island, is the most southern island of the Belize Barrier Reef lagoon system and sits on the southeastern side of a continental shelf atoll, or faro (Fig. 3). The faro rises out of deep water, with the Victoria Channel to the east and the inner lagoon to the west. The rim of the faro is an almost continuous ring of narrow reef enclosing a central lagoon (maximum depth 30 m), with some reef promontories which project inwards. The lagoon floor is composed of a fine sandy-mud substrate and patch reefs are scattered throughout. The outer walls of the faro drop off to an average of 30 m depth.

Plates 7-9: Reef community at Laughing Bird Caye National Park. Photos: Annelise Hagan, November 2010.

Plate 10: *Acropora palmata* colony at Laughing Bird Caye National Park. Photo: Annelise Hagan, November 2010.

LBCNP is a fully protected NTA, co-managed by SEA and Belize Forest Department. Only non-extractive recreational activities such as swimming, snorkelling, SCUBA diving, kayaking and sailing can be undertaken within the park and nothing can be removed. Principally, LBCNP is used for snorkelling and SCUBA diving, with 4,655 people and 1,453 people participating in these activities respectively in 2009. The park regulations are well enforced, 24 hours a day; there is a ranger station situated on the island, and there is permanent presence by 2 full time rangers. The rangers patrol inside and outside the park twice a day. The total running costs for LBCNP amount to approximately US$40,000 per annum. This reflects the size of the park, the number of staff employed (2 full time rangers employed on a rotation basis), the number of boats and amount of fuel used to patrol the area, and associated equipment and island maintenance costs.

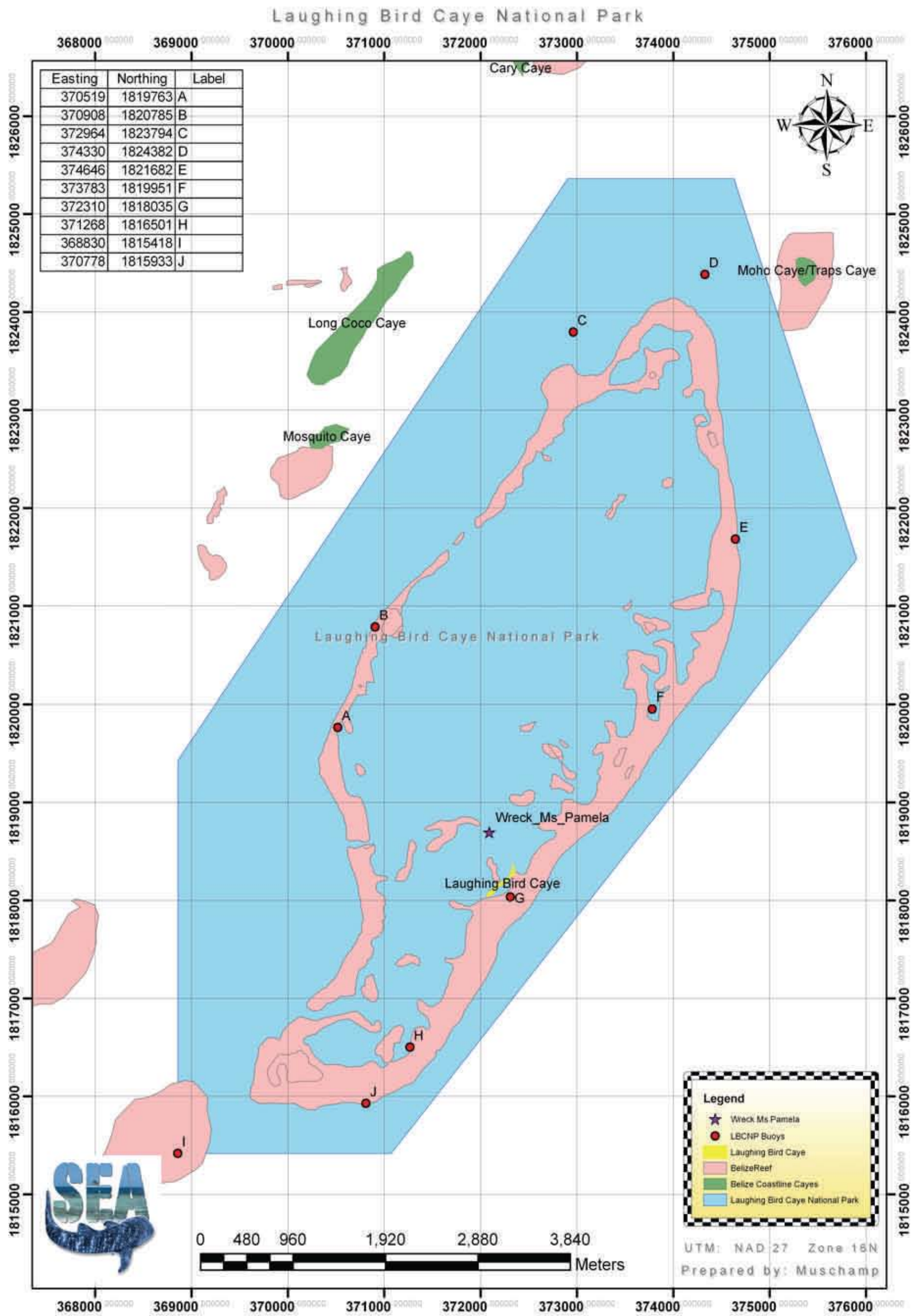


Figure 3: Map of Laughing Bird Caye National Park (LBCNP) showing park boundary; the entire park is designated a no-take area (NTA).

3.2 Gladden Spit and Silk Cayes Marine Reserve (GSSCMR)

Lying 36 km off the coast of Placencia, at a location of 16°30'N; 87°59'W, Gladden Spit and Silk Cayes Marine Reserve (GSSCMR) was declared in 2002 (total size = 10,523 ha) (Fig. 4). In part this declaration was due to the importance of the spawning aggregation site at Gladden Spit promontory. Deep water to the east (up to 250 m depth), underwater bathymetry and associated oceanographic processes have made this an attractive fish spawning sites. Identified as the highest priority spawning aggregation site in the country it supports up to 30 species of fish, many of which (such as snappers and groupers) are commercially important. Although spawning occurs year round for some species, the key months are from April to June, when, at every full moon, thousands of fish, particularly snappers, congregate here. Mutton snapper (*Lutjanus analis*) have been targeted by local fishermen here since the 1920s (Heyman *et al*., 2001). This fishery is now regulated through the issuing of special licenses to fishermen who are traditional users of the site.

At the same time, whale sharks (*Rhincodon typus*) come to feed on the spawn, making it a popular tourist destination, and one of the largest predictable whale shark congregations in the Mesoamerican region (Heyman *et al*., 2001). The reef structure is a northeast-southwest escarpment that lies parallel to the coastline and to the west, the shallow lagoon is protected behind the barrier reef. Situated on the barrier platform are the dynamic sand cayes of Northern, Middle and South Silk Cayes, popular tourist destinations. The reserve displays excellent examples of well developed barrier reef structure; fore-reef (with spur and groove formations), reef-crest and back-reef. Seagrass beds are found in the shallow back-reef lagoon.


Plates 11-12: Reef community at Gladden Spit and Silk Cayes Marine Reserve. Photos: Annelise Hagan, November 2010.

The reserve has a multi-zone approach, with 98.55% being designated as a ‘general use’ zone (10,370 ha) where regulated fishing activities are allowed (no nets or spear guns and no fishing or wearing of gloves whilst SCUBA diving) and the remainder (153 ha), around the Silk Cayes, being designated a NTA, for non-extractive activities only. The reserve is co-managed by SEA and Belize Fisheries Department. There is a ranger station on Little Water Caye, adjacent to the marine reserve and two patrols per day are conducted inside and outside the park. The total running costs for GSSCMR amount to approximately US$55,000 per annum. This reflects the size of the park, the number of staff employed (3 rangers full time but up to 5 rangers during whale shark season, plus an island caretaker permanently on site), the number of boats and amount of fuel used to patrol the area, and associated equipment and island maintenance costs.

In 2009, GSSCMR was principally used for commercial fishing (3,806 people), snorkelling (2,450 people) and SCUBA diving (873 people). All activities were high during the spawning aggregation and whale shark season (April – June); June 2008 saw the highest number of commercial fishermen (n = 535). December (n = 377) and March 2009 (n = 347) saw the highest number of snorkelers and May (n = 143) and April 2009 (n = 130) saw the highest number of SCUBA divers.

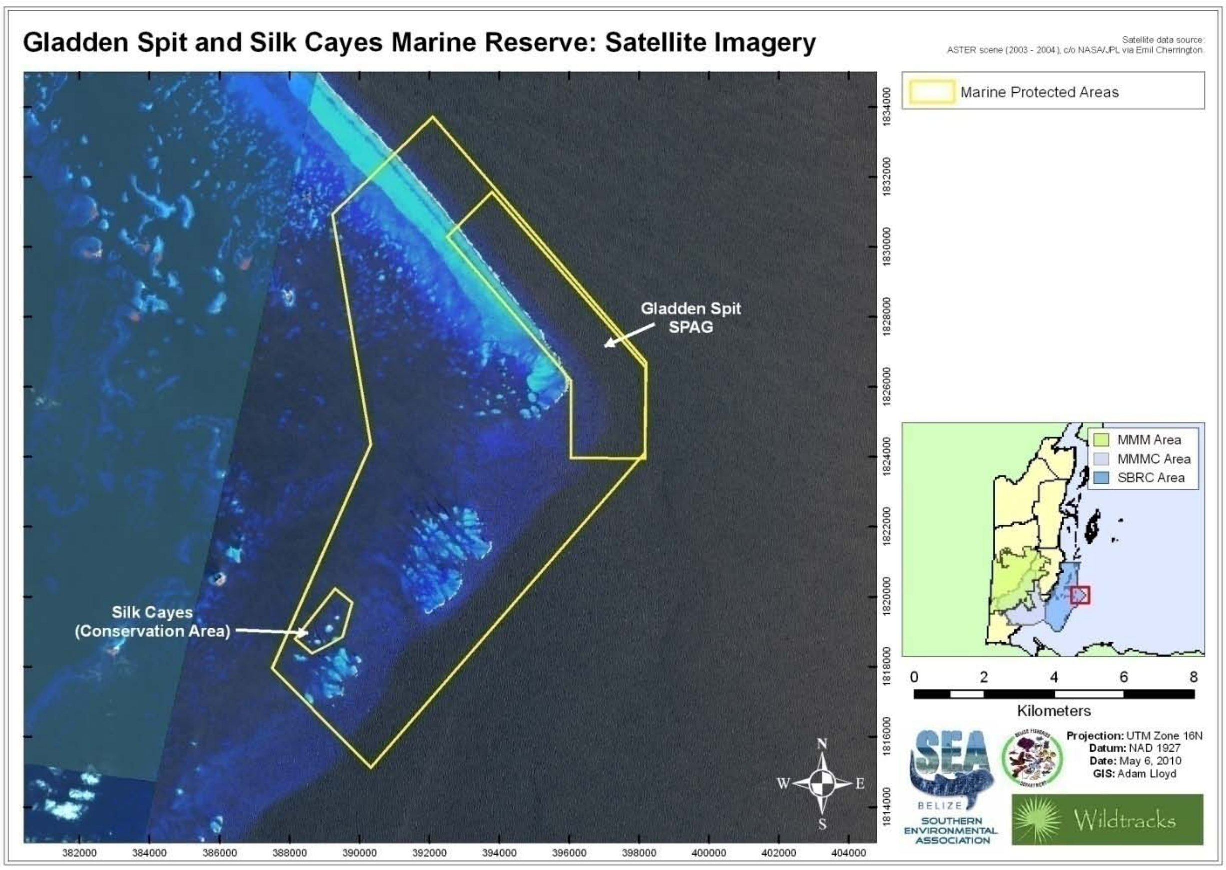


Figure 4: Map of Gladden Spit and Silk Cayes Marine Reserve (GSSCMR) showing park boundary and zones within the park.

3.3 Sapodilla Cayes Marine Reserve (SCMR)

The Sapodilla Cayes, are located at the southern extremity of the Belize Barrier Reef system, at 16°8'N; 88°2'W. Situated 75 km east off the coast of Punta Gorda, within the Gulf of Honduras, Sapodilla Cayes Marine Reserve (SCMR) (total size = 15,618 ha) was declared in 1996, as part of the Belize Barrier Reef UNESCO World Heritage Site, however it remained a 'paper park' until 2001. A zoning scheme (encompassing 4 different zones; Fig. 5) has recently been put in place and enforcement of these zones started in 2010. The largest area within the reserve (13,145 ha) is designated for 'general use'. This zone is designed for recreational use, research and fishing in accordance to the rules and regulations of the marine reserve (no nets or spear guns and no fishing or wearing of gloves whilst SCUBA diving). No extraction in the general use area is allowed without prior written authorization from the fisheries administrator. Conservation zone 1 (263 ha) is designated for recreational use only; SCUBA diving, snorkelling and non-extractive sports fishing. Conservation zone 2 (1,988 ha) is an area designed for recreational use. Catch and release fishing is allowed, as well as subsistence fishing with restricted gear types for traditional fishermen only. A preservation zone (222 ha) has been designed total protection; no activities are allowed within this area.

Fourteen sand and mangrove cayes sit within the park boundary and due to its far southern location, the islands and marine reserve are frequently used by Guatemalans and Hondurans (and to a lesser extent by Belizeans). The reserve is co-managed by SEA and Belize Fisheries Department and there is a station situated on Hunting Caye, ensuring permanent ranger presence within the park boundary. Rangers conduct two patrols per day inside and outside the park. The total running costs for SCMR amount to approximately US$65,000 per annum. This reflects the size of the park, the number of staff employed (typically 2 full time; a park manager and a biologist/ranger), the number of boats and amount of fuel used to patrol the area, and associated equipment and island maintenance costs. The far southern location, proximity to Guatemala and Honduras, and the lack of trans-boundary agreements make this area more challenging to manage in terms of visitation and recreational use.


Plates 13-14: Reef community at Sapodilla Cayes Marine Reserve. Photos: Annelise Hagan, November 2010.

The reef structure forms a distinctive hook shape and is considered geomorphologically unique within the region; it lies on a fault line and has been shaped by tectonic activity. The outer portion of the reserve is characterized by shallow reefs (sometimes less that 3 m deep) that fringe the cayes. East of the islands, there is a gently sloping drop-off and the lagoon area is characterized by seagrass beds and sand. Three spawning aggregation sites are situated within the reserve, at Nicholas Caye, Rise and Fall Bank and Seal Caye. These are important on a national and regional scale for the viability of several commercially important fish species.

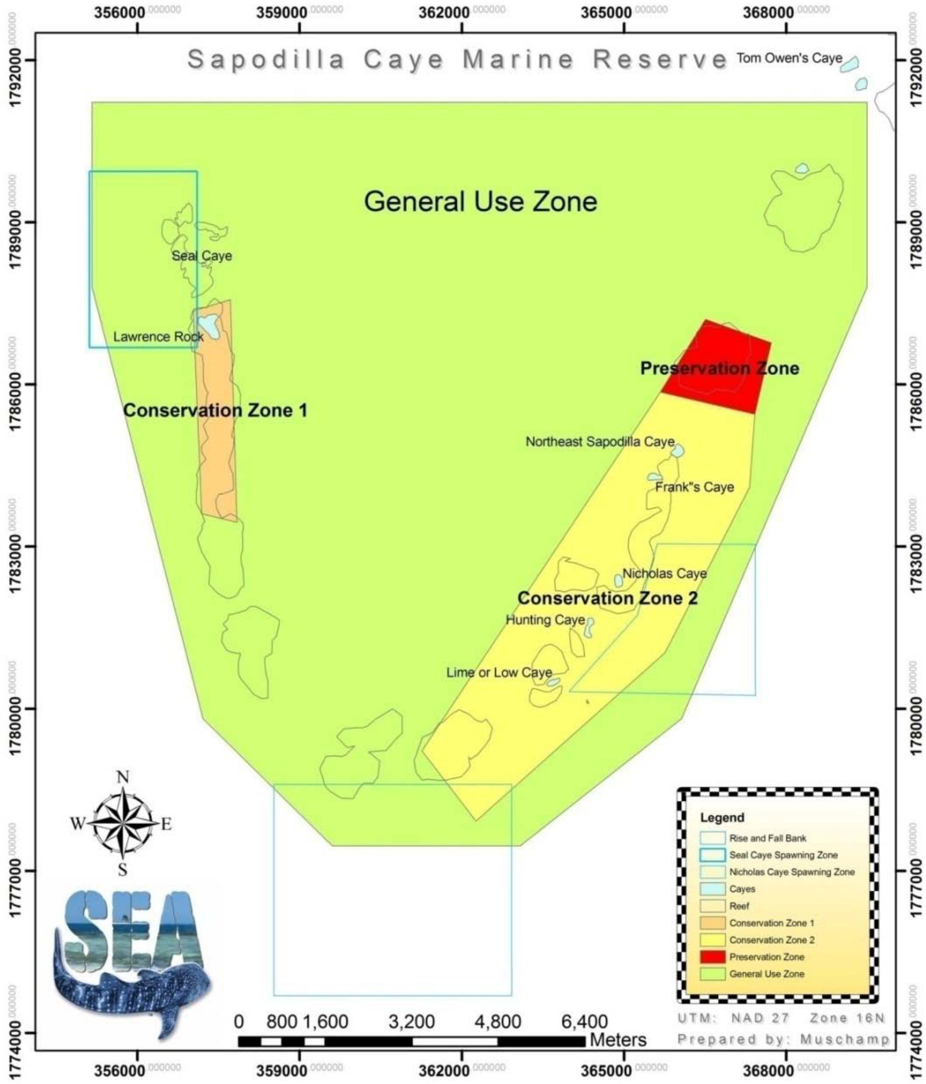


Figure 5: Map of Sapodilla Cayes Marine Reserve (SCMR) showing park boundary and newly established zones within the park.

4.0 Results from Monitoring: Commercially Important Species

4.1 Queen Conch (*Strombus gigas*)

The queen conch (*Strombus gigas*) is a marine gastropod mollusc, the largest of 6 species in the genus *Strombus*. Typically they inhabit shallow (less than 30 m depth) waters and their preferred habitat is seagrass beds, coral rubble and algal plains and sandy substrates, where they feed on macroalgae, seagrass and occasionally detritus. The queen conch is a targeted fishery throughout the Caribbean and was once the second most valuable fishery throughout the region (Berg and Olsen, 1989), generating US$30 million in 1992 (Appeldoorn and Rodriguez, 1994). Due to a steady decline through extreme overfishing, driven by the demand for their meat, conch are now protected under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) agreement. Although not yet truly endangered, it is a commercially threatened species in many areas of the Caribbean. Unlike some other Mesoamerican Reef countries, Belize does not have commercial fishing fleets, thus the conch fishery is conducted purely on an artisanal scale. In order to help manage Belize's queen conch populations, regulations have been set by Belize Fisheries Department. A closed season is in effect from 1st July to 30th September during which time it is illegal to remove conch. Size restrictions state that the shell length must exceed 7 inches (17.8 cm / 178 mm), the market clean and fillet weight should exceed 3 ounces (85 g) and 2.75 ounces (78 g) respectively, and no fisherman should buy, sell, or have in possession diced conch meat.

In order to manage any biological resource, it is important to know its life history. Conch are dioecious and undergo internal fertilisation. The females may store eggs for several weeks before spawning occurs, after which embryonic development is fast, and temperature dependent. The larval shell develops within 24 hours and free swimming, phytoplankton eating veliger larvae emerge from the eggs within 72 hours. The larval phase is typically less than one month (Appeldoorn and Rodriguez, 1994), but this still suggests the potential for long distance dispersal by surface currents. Larval dispersal in this way is an important consideration for marine reserves as reserve areas can re-populate areas outside the protected (no-take) zone. Conch may live up to 30 years, and although juveniles suffer high mortality through predation, natural adult predation rates are low (McCarthy, 2007).

Within SEA's Marine Protected Areas, conch size and abundance is monitored on a quarterly basis, using Dr Charles Acosta's Long-term Atoll Monitoring Protocol (LAMP). These data have been used to show differences between the zones of the reserves and changes over time. Laughing Bird Caye National Park is a complete no-take area, with all fishing prohibited inside the park. Size of conch has shown little variation over the past 3 years, and very similar sizes were displayed inside and outside the park (Fig. 6). Except for in 2005, the average size of all conch within and outside LBCNP was well over the legal catch size limit.

The total number of conch encountered during a 1 hour time period increased markedly between 2004 and 2009, followed by a decrease in number in 2010 (Fig. 7). For all years, except 2004, inside the no-take area had a higher number of encounters per hour than outside the reserve. The multivariate statistical test ANOSIM (Analysis of Similarities) was conducted using the Bray-Curtis similarity coefficient. The difference in number of encounters inside and outside the reserve was found to be statistically significant (ANOSIM; $P < 0.05$). In 2009, when the largest difference was seen, there were 4 times as many conch inside the reserve compared to outside.

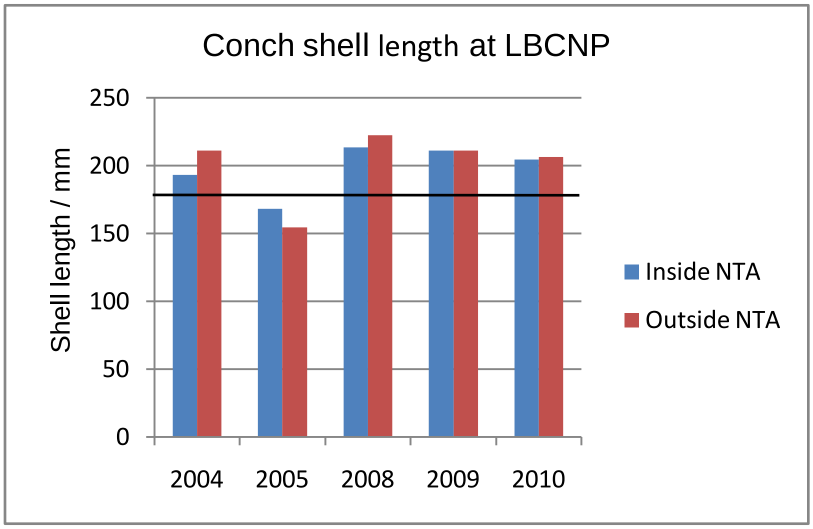


Figure 6: Average conch shell length inside and outside Laughing Bird Caye National Park (LBCNP). LBCNP is an entire no-take area (NTA). Horizontal line shows 178 mm legal catch size.

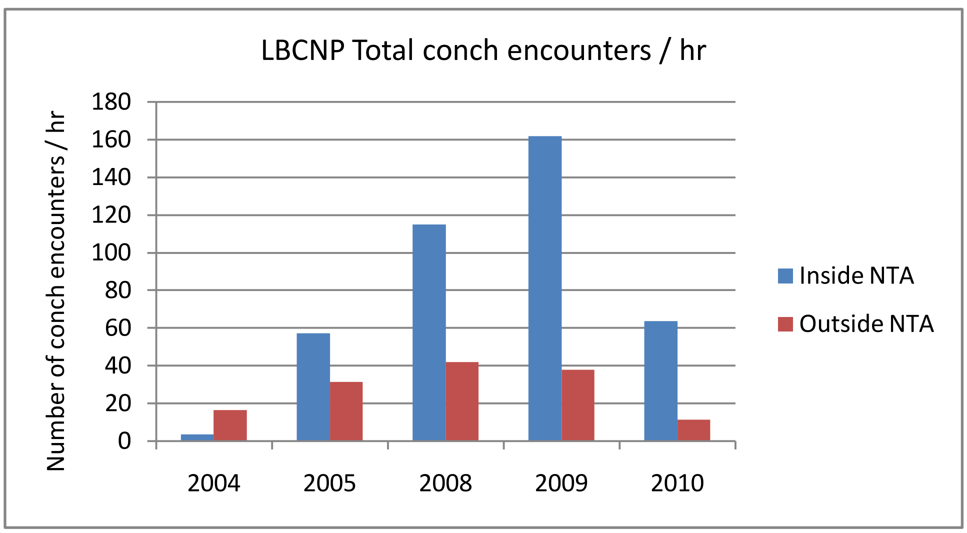


Figure 7: Number of conch encounters per hour inside and outside Laughing Bird Caye National Park (LBCNP). LBCNP is an entire no-take area (NTA).

Based on the Bray-Curtis similarity coefficient, a cluster analysis and MDS (Multi-Dimensional Scaling) plot were used to calculate the similarity in terms of conch encounters between the different zones over the 5 year time period (Fig. 8). All samples were seen to be 30% similar to each other, at the 40% similarity level, two discrete clusters occur and at the 60% similarity level

4 discrete clusters occur. There was no clear clustering based on the zone (inside / outside protected area).

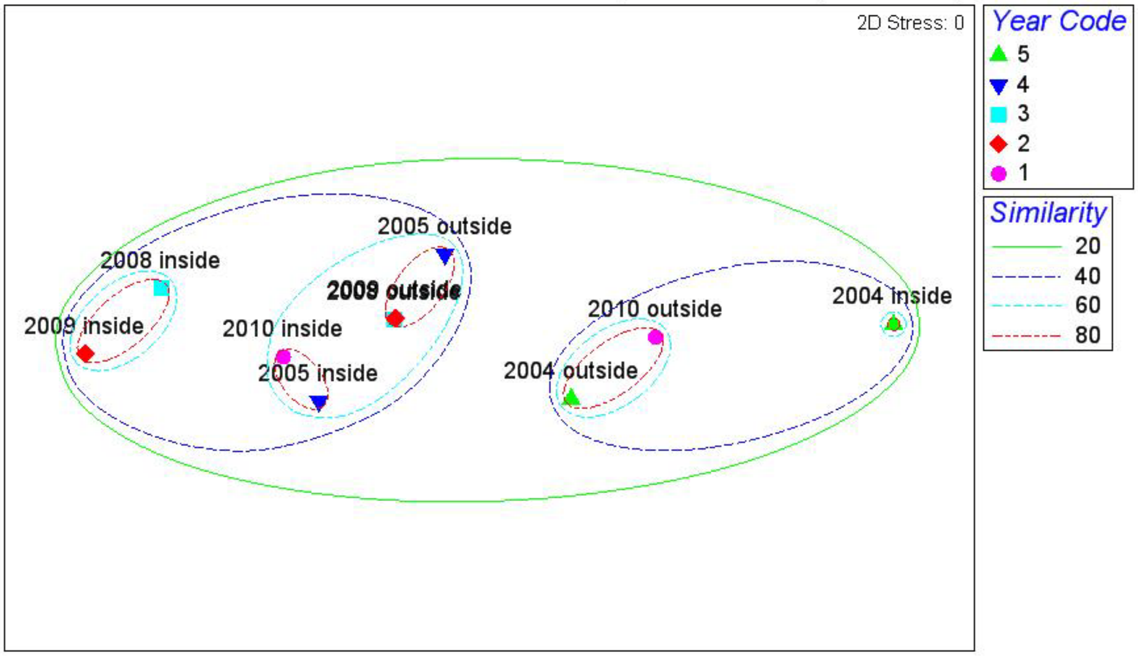


Figure 8: Combination plot of Multi-Dimensional Scaling (MDS) and cluster analysis using Bray-Curtis similarity coefficient to show level of similarity in number of conch encounters between different zones and different years at Laughing Bird Caye National Park (LBCNP). LBCNP is an entire no-take area (NTA). Year codes: 1 = 2010, 2 = 2009, 3 = 2008, 4 = 2005, 5 = 2004. Level of similarity indicates percentage similarity between surveys.

At Gladden Spit and Silk Cayes Marine Reserve, 2003-2010, conch were found to be larger in the no-take zone compared to in the general use zone or outside the reserve for all years, and the average size in the NTA was always above the legal size limit. However, this size difference was not found to be statistically significant (ANOSIM; $P > 0.05$. Comparing size of conch in the no-take zone compared to the general use zone, $P = 0.054$). The average size in the general use zone was less than the legal catch size in the last 3 years and less than the legal catch size outside the reserve in 2004, 2008 and 2010. It the latter 2 years, conch sizes in the no-take zone and outside the reserve were very similar (Fig. 9).

The total number of conch encountered during a 1 hour time period in GSSCMR was highest in the no-take area in all years except 2007 and 2010. In all years except 2003, the general use zone had the lowest number of conch encounters (Fig. 10). The differences between years, and the differences between zones were not found to be statistically significant.

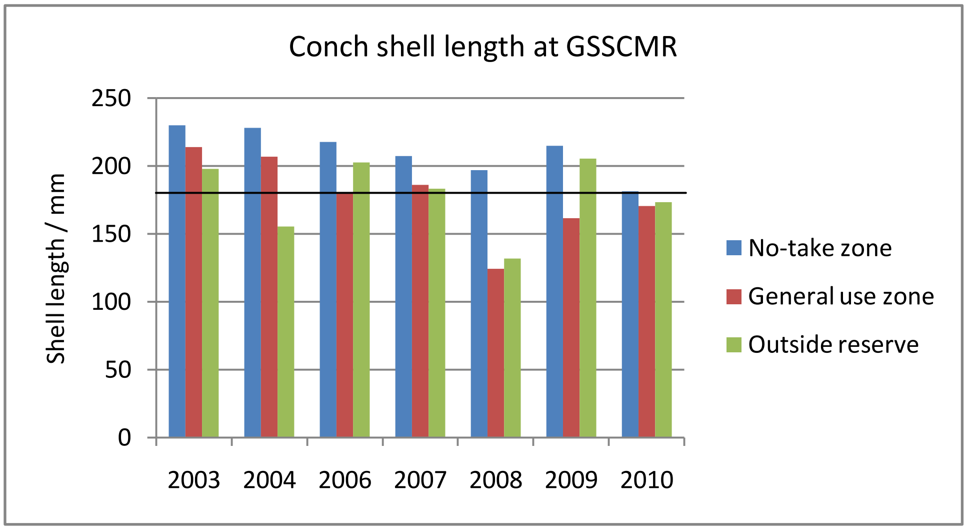


Figure 9: Average conch shell length in different zones of Gladden Spit and Silk Cayes Marine Reserve (GSSCMR), 2003-2010. Horizontal line shows 178 mm legal catch size.

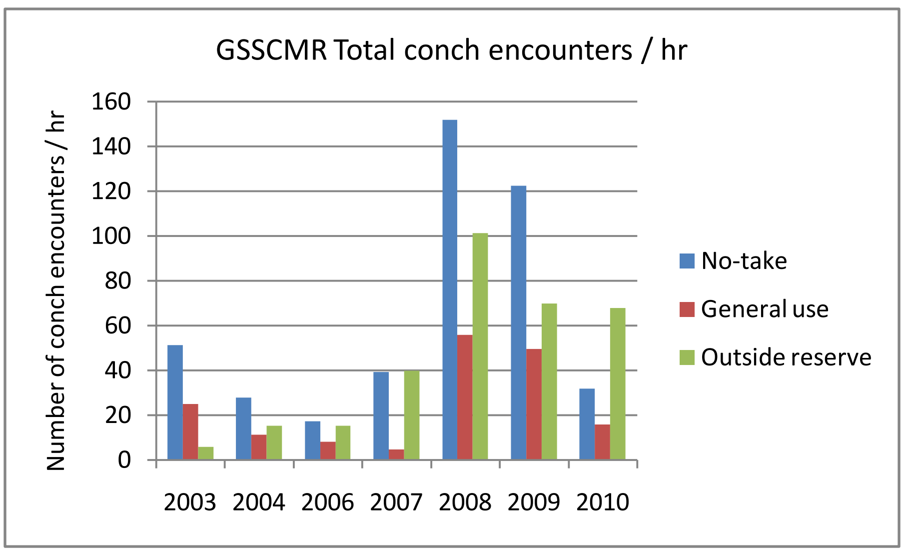


Figure 10: Number of conch encounters per hour in different zones of Gladden Spit and Silk Cayes Marine Reserve (GSSCMR).

At Sapodilla Cayes Marine Reserve (SCMR), there was little variation in average conch size 2006-2009, although a gradual increase to 2009 followed by a slight decrease between 2009 and 2010 was seen (Fig. 11). The average size of all conch encountered was only above the legal catch size limit in 2009.

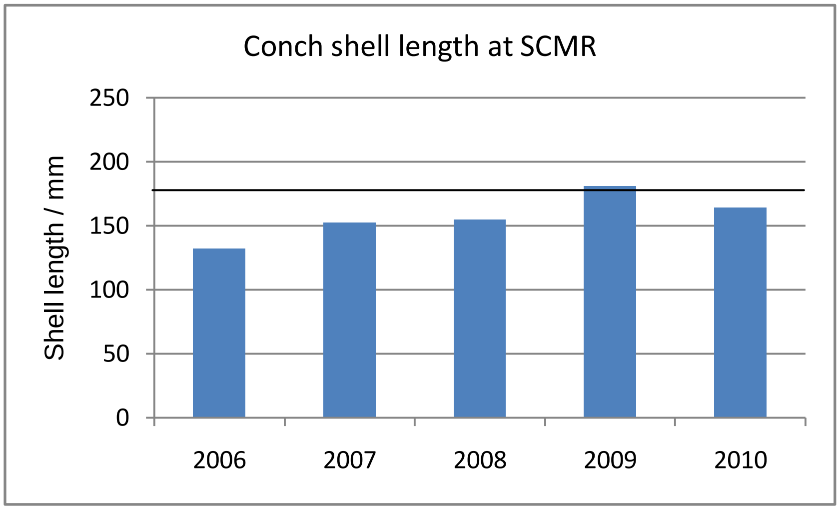


Figure 11: Average conch shell length at Sapodilla Cayes Marine Reserve (SCMR). Horizontal line shows 178 mm legal catch size.

The number of conch encountered within a 1 hour period fluctuated greatly over the past 5 years at SCMR (Fig. 12). 2007 and 2008 showed the highest number of conch encountered within the park, but there was a decrease by half 2008-2009 and a further decrease by 2010.

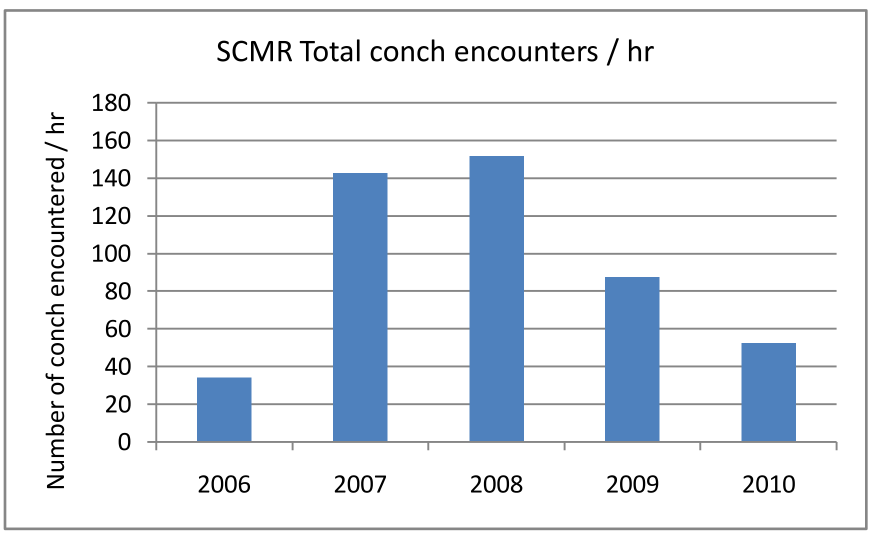


Figure 12: Number of conch encounters per hour in Sapodilla Cayes Marine Reserve (SCMR).

When the zones of the three parks were compared 2009-2010, conch were largest in LBCNP, and were similar in size in GSSCMR no-take area and outside GSSCMR. Average sizes were greater in 2009 compared to 2010 at all sites except GSSCMR general use zone, where the sizes were almost identical, but slightly larger in 2010 (Fig. 13).

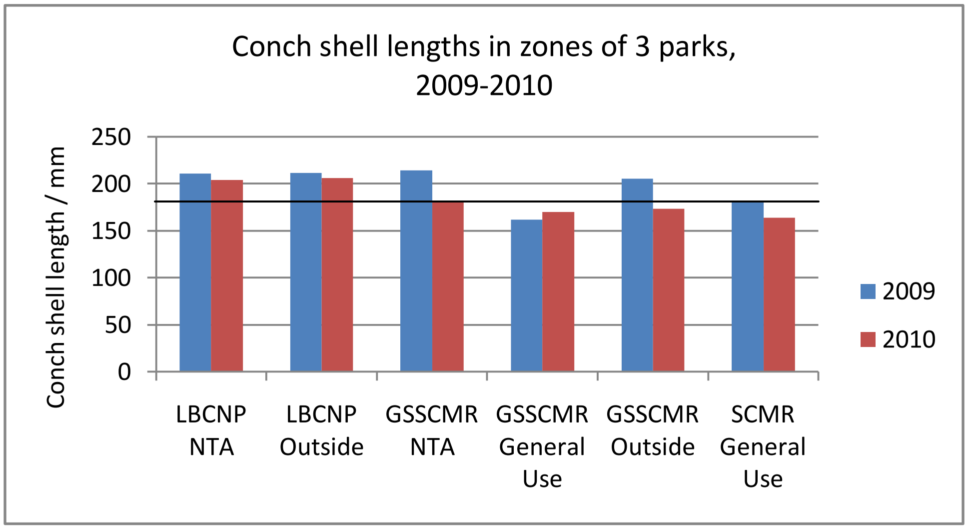


Figure 13: Average conch shell length in different zones of Laughing Bird Caye National Park (LBCNP), Gladden Spit and Silk Cayes Marine Reserve (GSSCMR) and Sapodilla Cayes Marine Reserve (SCMR), 2009-2010. Horizontal line shows 178 mm legal catch size.

When comparing the number of conch encountered in all zones of all parks over recent history, it was seen that the two NTAs of LBCNP and GSSCMR had the highest number of encounters in 2008 and 2009, followed by SCMR (Fig. 14). The lowest number of encounters occurred outside LBCNP and in the GSSCMR general use zone. The highest number of encounters was seen in 2008 at all zones except inside LBCNP. There was no significant difference in the number of conch across the zones but there was a significant reduction in the number of encounters between 2009 and 2010 (ANOSIM; P = 0.05).

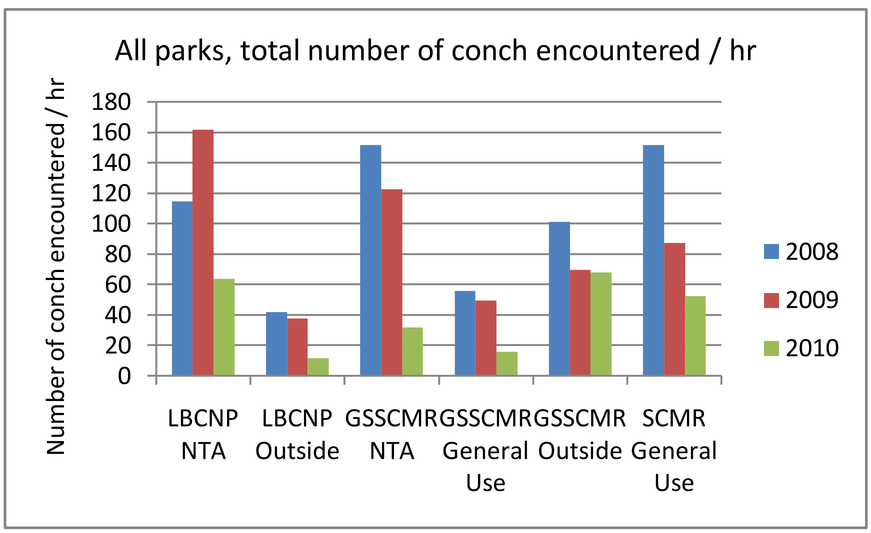


Figure 14: Number of conch encounters per hour in different zones of Laughing Bird Caye National Park (LBCNP), Gladden Spit and Silk Cayes Marine Reserve (GSSCMR) and Sapodilla Cayes Marine Reserve (SCMR), 2008-2010.

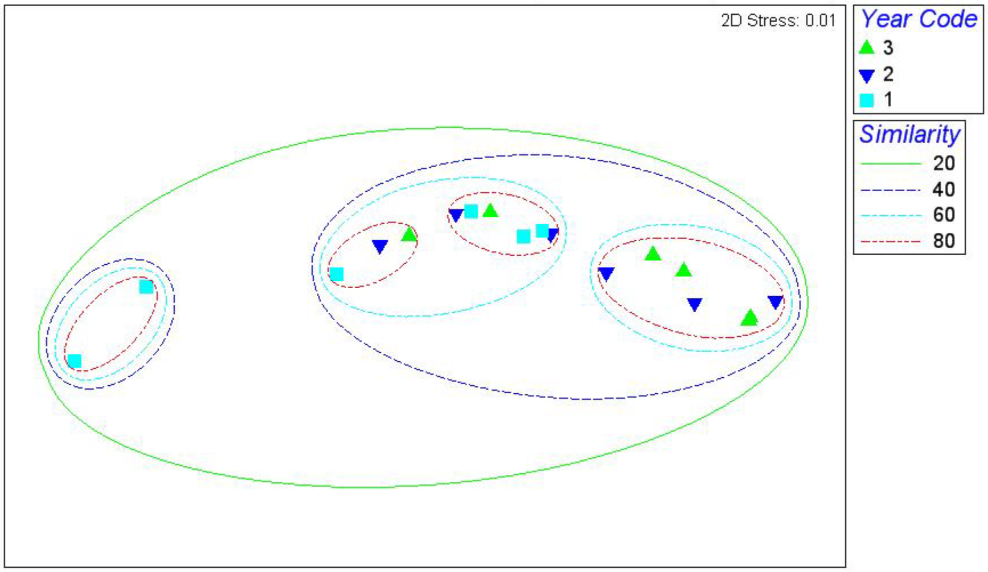


Figure 15: Combination plot of Multi-Dimensional Scaling (MDS) and cluster analysis using Bray-Curtis similarity coefficient to show level of similarity in number of conch encounters between different years across all 3 parks. Year codes: 1 = 2010, 2 = 2009, 3 = 2008. Level of similarity indicates percentage similarity between surveys.

A cluster analysis and MDS (Multi-Dimensional Scaling) plot were used to calculate the similarity in terms of conch encounters between the different zones of the 3 parks over a 3 year time period. At the 40% similarity level, 2 discrete clusters occurred; one containing two 2010 sites (LBCNP outside and GSSCMR general use) and the other containing all other sites (Fig. 15). No discrete clustering occurred based on the level of protection (i.e. zonation). Other factors (physical and environmental) may be influencing the results as it is difficult to compare three spatially distinct environments in this way.

4.2 Caribbean spiny lobster (*Panulirus argus*)

The Caribbean spiny lobster (*Panulirus argus*) is distributed throughout shallow waters (occasionally down to 90 m depth) of the Caribbean, Gulf of Mexico and western Atlantic. The lobster life cycle consists of several different behavioural and developmental stages. Fertilised eggs are carried on the female to the edge of the reef, often several kilometres away, in order for the larvae to be released. The larvae are planktonic for 6 to 10 months (during which time they undergo 11 larval stages) allowing wide distribution throughout the Caribbean (Alfonso *et al*., 1991). The planktonic stage is when they are most vulnerable to predation; of the 10,000 eggs released, there is a 1% survival rate to 1 month in maturity (Greenreef, 2010). Young 'algal phase lobsters' typically settle in areas of *Laurencia* sp. (red algae), mangrove roots and seagrass beds. After 10-15 months they enter the juvenile stage, and move from vegetated areas to reef areas where they seek refuge in caves (Herrnkind, 1980). As an adult, lobsters have a diet of detritus, vegetable matter, and dead animals/fish they find on the seabed. Growth takes place through a regular series of molts; they shed their exoskeleton approximately 2.5 times per year (Lipcius and Herrnkind, 1982).

The Caribbean spiny lobster is a targeted fishery throughout its range (Holthuis, 1991), and in Belize generates approximately US$9 million annually (Greenreef, 2010). As with Belize's conch fishery, the lobster fishery is also conducted purely on an artisanal scale. Similar to the queen conch fishery, there is also a closed season for the spiny lobster in Belize, between 15th February and 14th June. Other ways in which Belize is trying to manage the country's lobster fishery include size limits; minimum carapace length is 3 inches (7.6 cm), minimum tail weight is 4 ounces (113 g) and the law that no fisherman should have in possession fillet or diced lobster tail, soft shell, berried lobster or lobster with tar spots. Like conch populations, lobster size and abundance is monitored on a quarterly basis in all three parks, using Dr Charles Acosta's Long-term Atoll Monitoring Protocol (LAMP). These data have been used to show differences between the different zones of the reserves and changes over time.

Inside LBCNP, a small but steady increase in lobster carapace length was seen between 2004 and 2010, with the exception of a slight decrease in 2009 (Fig. 16). Carapace length was greater inside the reserve compared to outside in 2004, 2005 and 2009, although the differences were not statistically significant (ANOSIM; $P > 0.05$). Average carapace length was above the legal catch size limit in all years, particularly so in 2008 and 2010, implying that the population comprised a number of larger individuals.

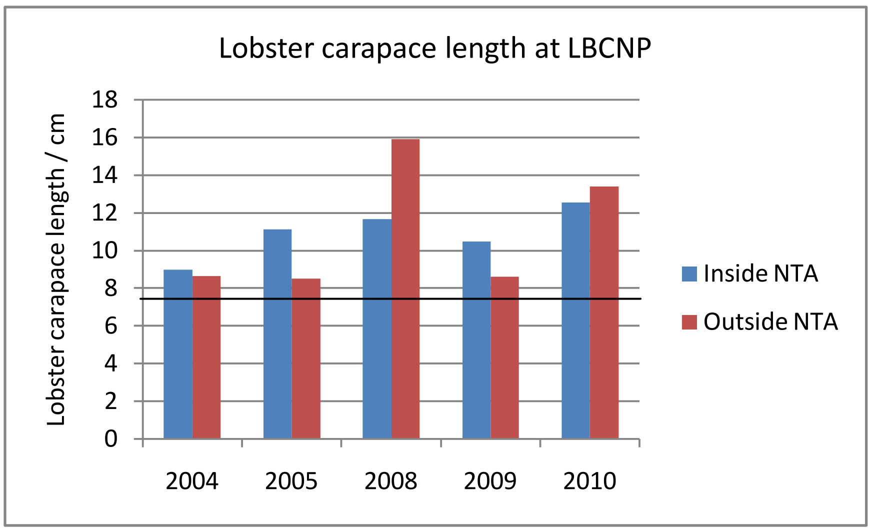


Figure 16: Average lobster carapace length inside and outside Laughing Bird Caye National Park. LBCNP is an entire no-take area (NTA). Horizontal line shows 7.6 cm legal catch size.

In 2008 and 2009, and to a lesser extend in 2005, lobster encounters at LBCNP were more frequent inside the reserve compared to outside (Fig. 17). 2004 and 2010 showed more encounters outside the reserve, and 2010 showed the lowest number of encounters across the time series. None of these differences were found to be statistically significant (ANOSIM; $P > 0.05$).

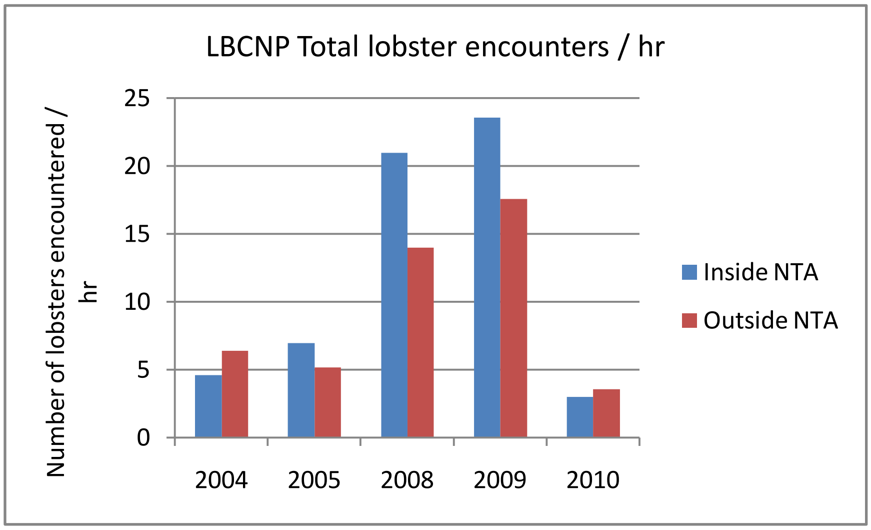


Figure 17: Number of lobster encounters per hour inside and outside Laughing Bird Caye National Park (LBCNP). LBCNP is an entire no-take area (NTA).

At GSSCMR, 2007, 2009 and 2010 showed the same trend, with largest lobsters being found inside the NTA, followed by the general use zone and outside the reserve having the smallest individuals (Fig. 18). The largest lobsters were observed in 2008, and these were almost twice the size of the previous and successive year. The results were almost identical across the 3 zones in 2008. Only 2007, 2008 and 2010 displayed average carapace lengths greater then the legal catch size in all zones.

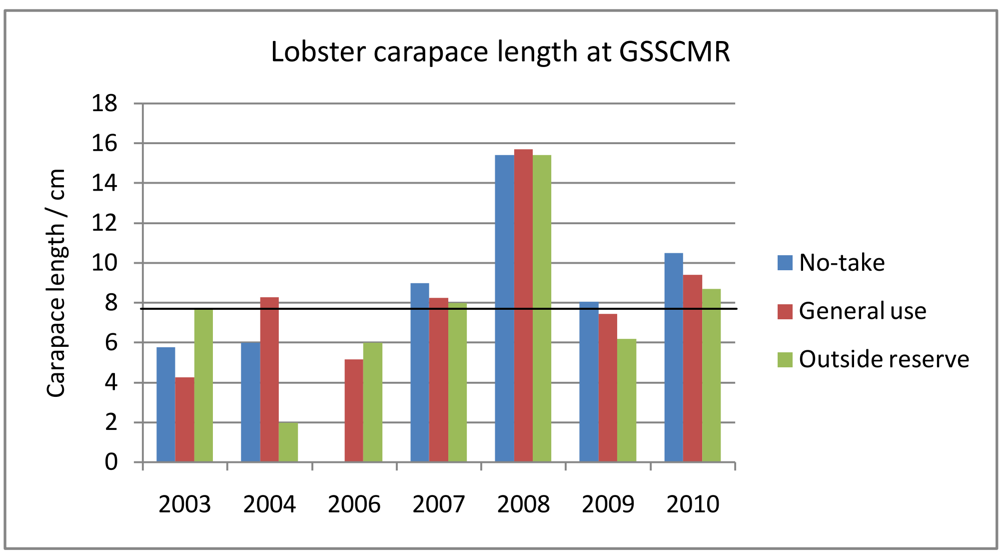


Figure 18: Average lobster carapace length in different zones of Gladden Spit and Silk Cayes Marine Reserve (GSSCMR). Horizontal line shows 7.6 cm legal catch size.

No clear trends were seen in the data from the total number of lobsters encountered at GSSCMR (Fig. 19). 2009 peaked inside the NTA, but by 2010, numbers inside the NTA had markedly decreased. In 2010, the largest lobsters were found outside the reserve, and the smallest inside the NTA. There were no statistical differences in carapace size or encounter numbers in GSSCMR, either when comparing the sample years, or when comparing samples from different zones within the park (ANOSIM; $P > 0.05$).

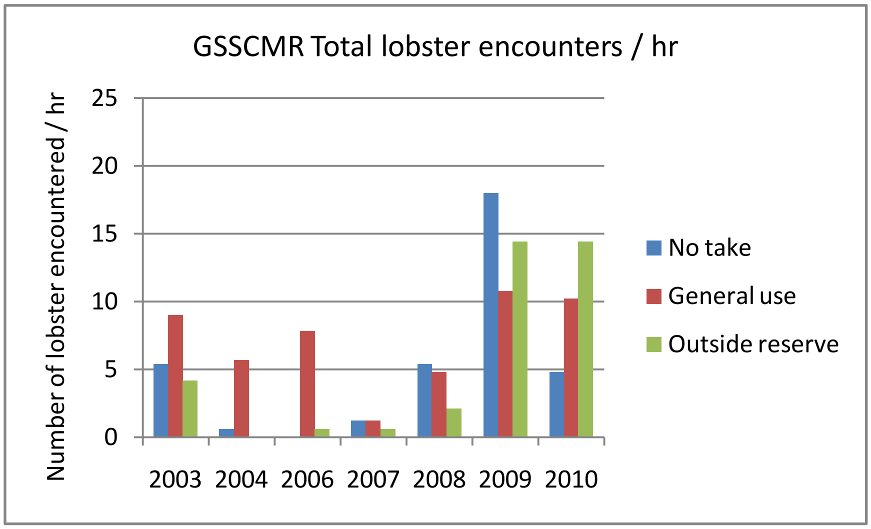


Figure 19: Number of lobster encounters per hour in different zones of Gladden Spit and Silk Cayes Marine Reserve (GSSCMR).

At SCMR, lobster carapace length was virtually identical across the time period (2006-2010), with only a 2 cm difference between the largest year (2010) and smallest year (2007) (Fig. 20). The number of lobsters encountered fluctuated greatly over the time period (Fig. 21). 2009 had the most encounters, and 2010 had the least. Average carapace length exceeded the legal catch size limit in all years except 2007.

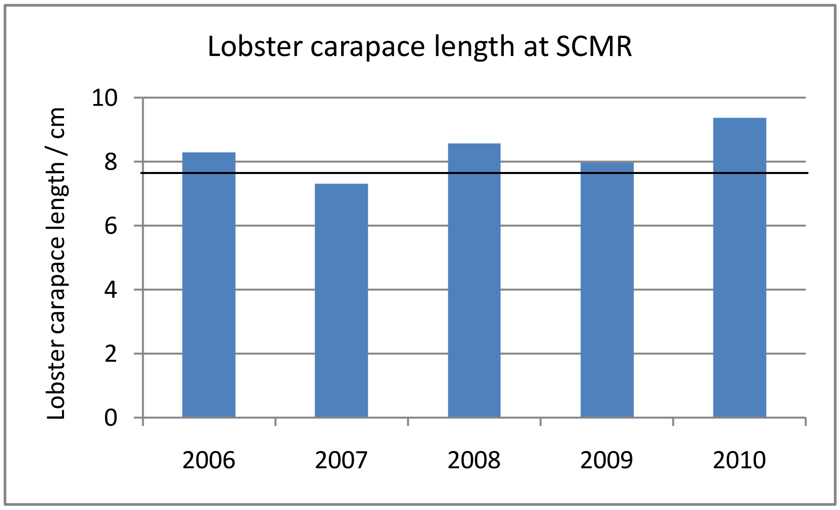


Figure 20: Average lobster carapace length at Sapodilla Cayes Marine Reserve (SCMR). Horizontal line shows 7.6 cm legal catch size.

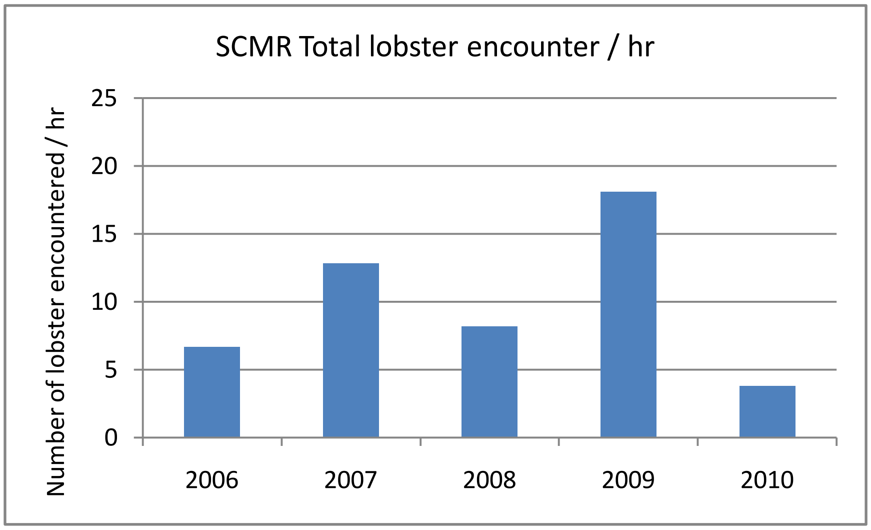


Figure 21: Number of lobster encounters per hour in Sapodilla Cayes Marine Reserve (SCMR).

When comparing the number of lobster encountered in all zones of all parks over recent history, larger lobsters were observed in 2010 compared to 2009 at all sites (Fig. 22). In 2009 the largest lobsters were seen within LBCNP, and in 2010 the largest lobsters were seen outside LBCNP. None of these differences were found to be statistically significant (ANOSIM; $P > 0.05$). Average lobster carapace length exceeded the legal catch size limit at all sites in 2010, and in 2009 average size of the population was below the legal limit in the general use zone of GSSCMR and outside GSSCMR.

The lobster encounter data from the past 3 years showed that 2009 experienced the highest number of encounters per hour in all zones (Fig. 23). 2010 showed a reduced number of encounters compared to previous years at all sites except for outside GSSCMR where there was no change in number 2009-2010. There was no statistical difference when comparing the number of encounters in different zones of the parks, but there were statistical differences in the number of encounters when compared by year. 2008 encounter numbers were statistically different to 2009 (ANOSIM; $P < 0.05$), and 2009 encounter numbers were statistically different to 2010 (ANOSIM; $P < 0.05$). There was no statistical difference in encounter numbers between 2008 and 2010.

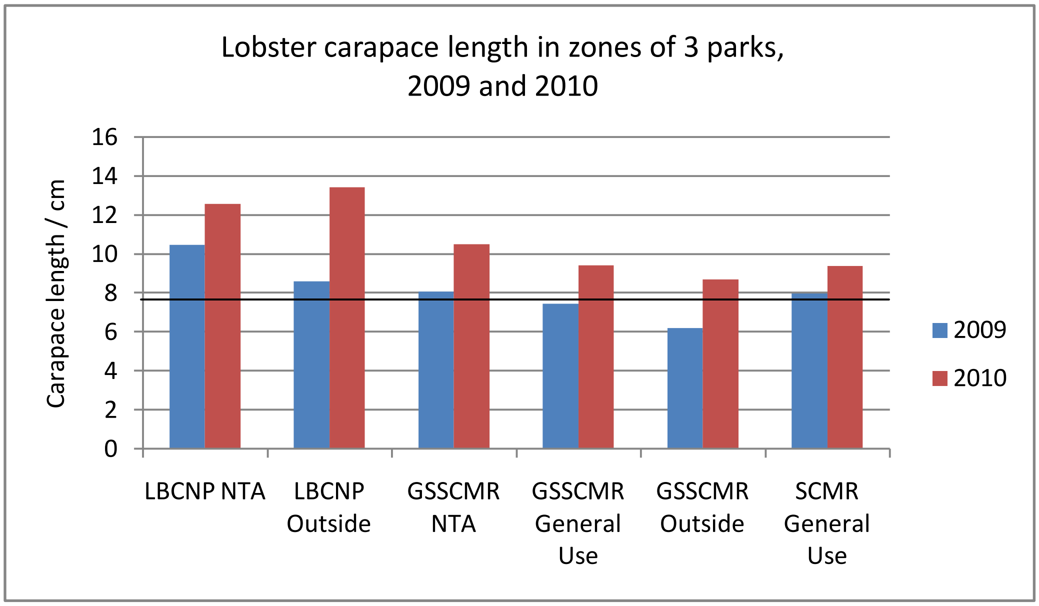


Figure 22: Average lobster carapace length in different zones of Laughing Bird Caye National Park (LBCNP), Gladden Spit and Silk Cayes Marine Reserve (GSSCMR) and Sapodilla Cayes Marine Reserve (SCMR), 2009-2010. Horizontal line shows 7.6 cm legal catch size.

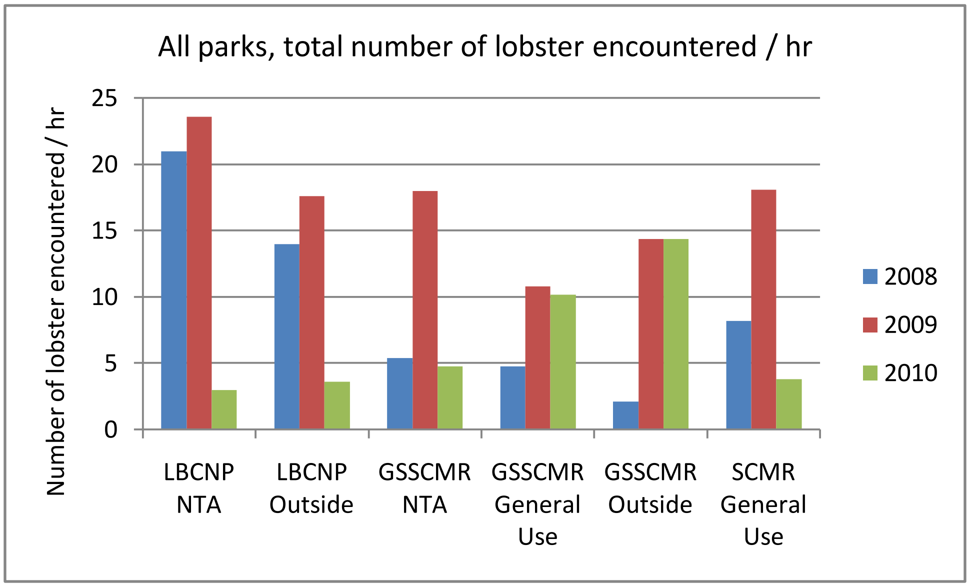


Figure 23: Number of lobster encounters per hour in different zones of Laughing Bird Caye National Park (LBCNP), Gladden Spit and Silk Cayes Marine Reserve (GSSCMR) and Sapodilla Cayes Marine Reserve (SCMR), 2008-2010.

4.3 Reef Health

It is important to set these fisheries parameters within a context of reef health, as a healthy reef is vital to support such populations. One index of measuring reef health is the relationship between percentage cover by hard corals, and by macroalgae. Percentage cover by different types of benthos (coral, macroalgae, sponges etc.) and coral diversity is monitored on an annual basis using the transect-based MBRS (Mesoamerican Barrier Reef System) Regional Synoptic Monitoring Program method. Coral bleaching monitoring is conducted on an *ad hoc* basis, the time of monitoring being dictated by Belize's National Coral Reef Monitoring Network.

The two 10 m depth outer reef sites at GSSCMR (GSMBRS 3 and GSMBRS 6 on Fig. 24) showed opposite trends. One displayed nearly twice as much macroalgae compared to coral, and the other showed nearly twice as much coral compared to macroalgae. The shallow (2 m) back reef site at GSSCMR (site 9) had more than twice the amount of macroalgae compared to coral and the site at Laughing Bird Caye displayed more than three times the amount of macroalgae compared to coral. The two sites at Sapodilla Cayes showed the highest coral cover (up to 34%) of any of the sites and here, coral cover was approximately three times that of macroalgae.

The coral community at all sites comprised *Montastraea* spp., *Agaricia* spp., *Porites* spp., *Siderastrea* spp. and *Millepora* spp. *Diploria* sp. and *Acropora* spp. were found at GSSCMR and SCMR and *Colpophyllia natans* also occurred at SCMR. The coral community at SCMR was dominated by *Montastraea* spp. (*M. annularis*, *M. cavernosa*, *M. faveolata*), *Agaricia tenuifolia* and *Porites porites* but LBCNP and GSSCMR did not display a dominance by any specific species. Although seasonal warm water induced coral bleaching (especially of *A. tenuifolia* and *P. porites*) has been observed in all 3 parks in recent years, the level of coral recovery following bleaching events has been good and little mortality has occurred.

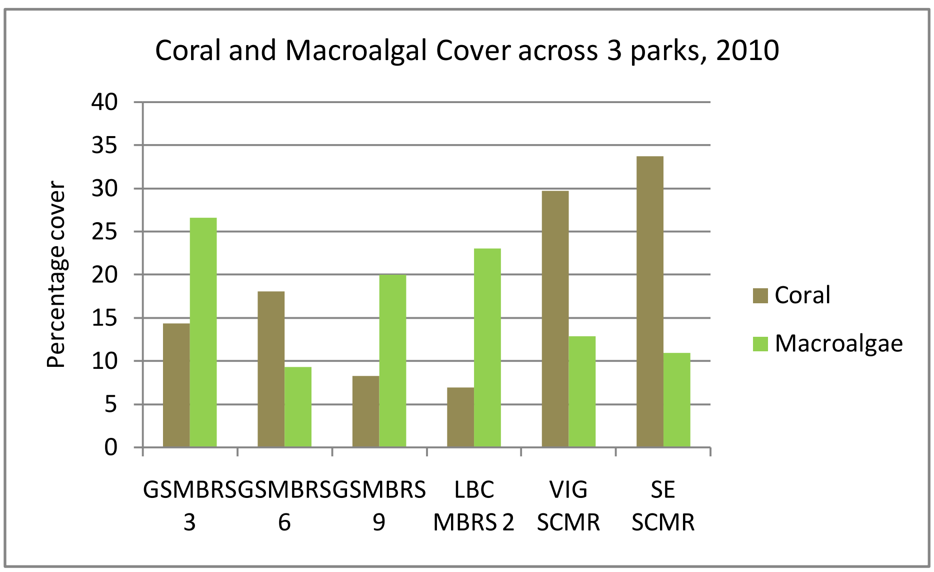


Figure 24: GSMBRS3 and GSMBRS6 are outside the barrier reef (10 m depth), GSMBRS 9 is a back reef site (2 m depth), LBC MBRS 2 is a 10 m site close to Laughing Bird Caye, VIG SCMR is a patch reef (2 m depth), SE SCMR is patch reef site (2 m depth). LBC site is in a no-take area, all other sites are within general use zones.

Bare space created through coral mortality is quickly overgrown by macroalgae and may result in a phase shift. Parrotfish, and other grazers are imperative to a reef system for regulating algal growth, which would out-compete and thus infringe new coral growth. Following the Caribbean wide die-off of the urchin *Diadema antillarum* in 1983, parrotfish have become the dominant reef grazer (Mumby *et al*., 2006). In many areas, the targeted removal of herbivorous fish species as a food resource has exacerbated algal overgrowth and further undermined the resilience of many marine ecosystems (Hughes *et al*., 2005). It is for these reasons that grazing fish are now protected in Belize by law. Since 2009, Belize Fisheries Department has enforced the regulation that no person shall take in the waters of Belize, buy or sell or have in possession any fish grazer. That is parrotfish, of the Family *Scaridae* (Genera *Scarus* and *Sparisoma*), and surgeonfish and tangs, of the Family *Acanthuridae*.

Fish species of commercial importance, including parrotfish due to their integral importance to overall reef health, are monitored by SEA on a quarterly basis, using Dr Charles Acosta's Long-term Atoll Monitoring Protocol (LAMP). The early years of monitoring at Laughing Bird Caye resulted in very low numbers of commercially important fish, although 2005 showed the highest number of snappers (double the number inside the NTA compared to outside; Fig. 25). Parrotfish numbers have increased greatly in recent years, with 2010 showing the highest numbers. Although in both 2009 and 2010, higher numbers occurred outside the NTA, this does not reflect fishing pressure as parrotfish have been fully protected since 2009. Many of the parrotfish surveyed in 2009-2010 (principally striped parrotfish, *Scarus iserti*) were juveniles and the overall parrotfish population had an average length of 17 cm. The parrotfish population at LBCNP is dominantly comprised of striped, stoplight (*Sparisoma viride*), redband (*Sparisoma aurofrenatum*) and redtail parrotfish (*Sparisoma chrysopterum*). In 2008 the average parrotfish length was 28 cm suggesting that there were fewer juveniles in the population at this time. Smaller numbers of snappers, groupers and 'others' (e.g. hogfish, jacks) were observed in 2010 compared to the previous two years.

Plate 15 (left): School of juvenile parrotfish, Sapodilla Cayes Marine Reserve and Plate 16 (right): School of surgeonfish, Gladden Spit and Silk Cayes Marine Reserve. Photos: Annelise Hagan, September 2010.

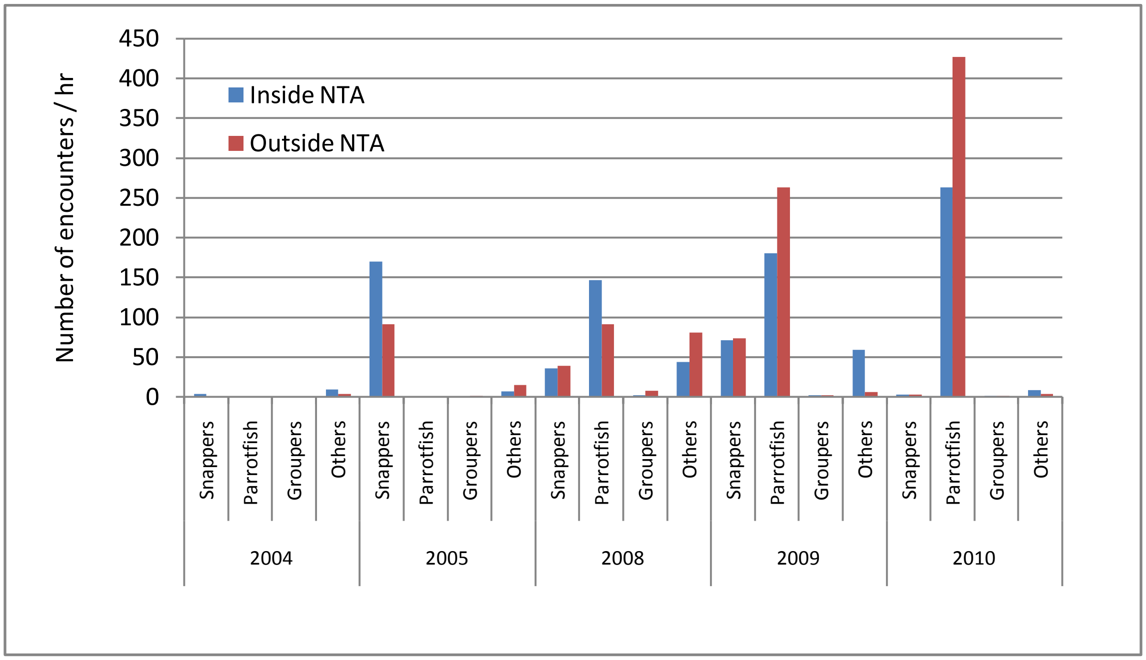


Figure 25: Number of commercially important fish encounters per hour inside and outside Laughing Bird Caye National Park (LBCNP).

At GSSCMR, minimal fish were encountered in all areas of the reserve 2003-2006. By 2007 numbers in all groups had started to increase and numbers of parrotfish increased considerably 2007-2010 (Fig. 26). Excluding parrotfish, which have been protected in all zones since 2009, typically, the NTA area showed higher numbers for snappers and other fish species. The parrotfish community at GSSCMR is dominantly comprised of stoplight (*Sparisoma viride*), striped (*Scarus iserti*), redband (*Sparisoma aurofrenatum*), princess (*Scarus taeniopterus*) and redtail parrotfish (*Sparisoma chrysopterum*). Many juveniles were observed in the parrotfish population in later years, resulting in a decrease in average size from 26 cm in 2008 to 17 cm in 2009 and 2010.

At SCMR, parrotfish increased in number 2007-2010, but all other fish groups showed a decrease in abundance (Fig. 27). The parrotfish community at SCMR is dominantly comprised of stoplight (*Sparisoma viride*), striped (*Scarus iserti*), princess (*Scarus taeniopterus*), redband (*Sparisoma aurofrenatum*) and redtail parrotfish (*Sparisoma chrysopterum*). As at the other two parks, many juveniles were observed in the parrotfish population in later years, and average size fell from 25 cm in 2008 to 17 cm in 2009 and 18 cm in 2010.

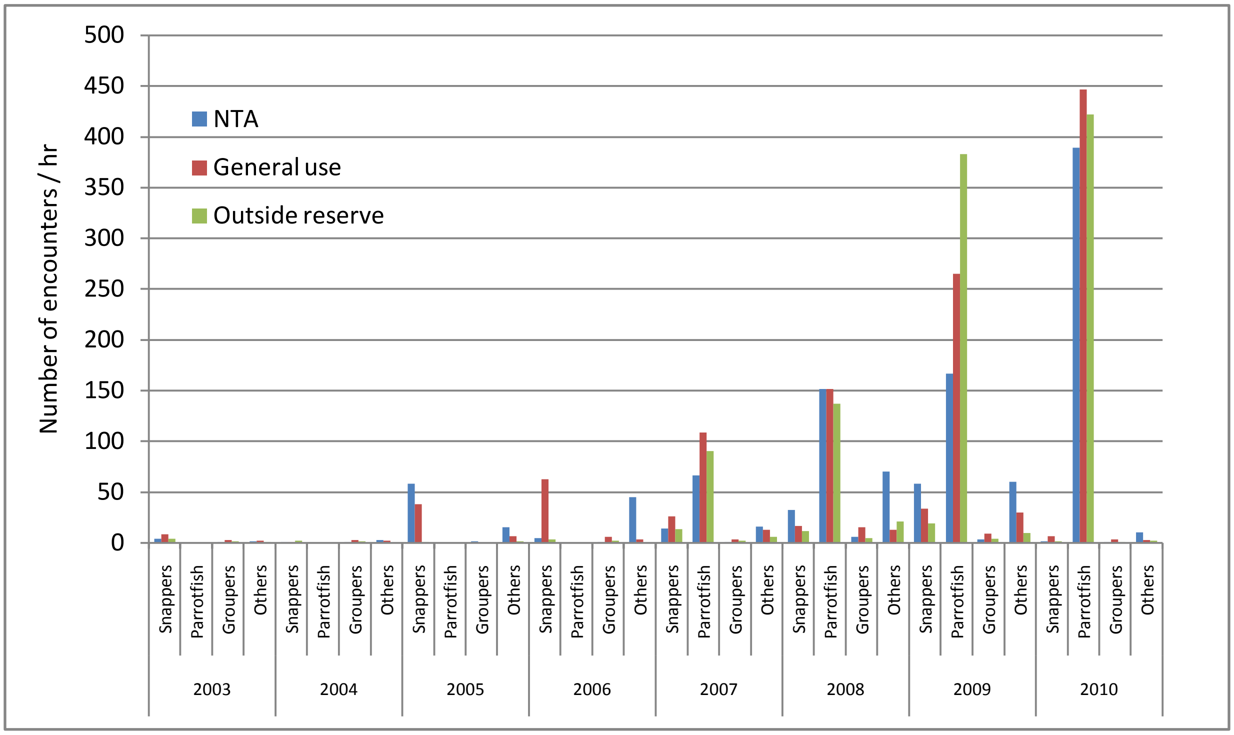


Figure 26: Number of commercially important fish encounters per hour in different zones of Gladden Spit and Silk Cayes Marine Reserve (GSSCMR).

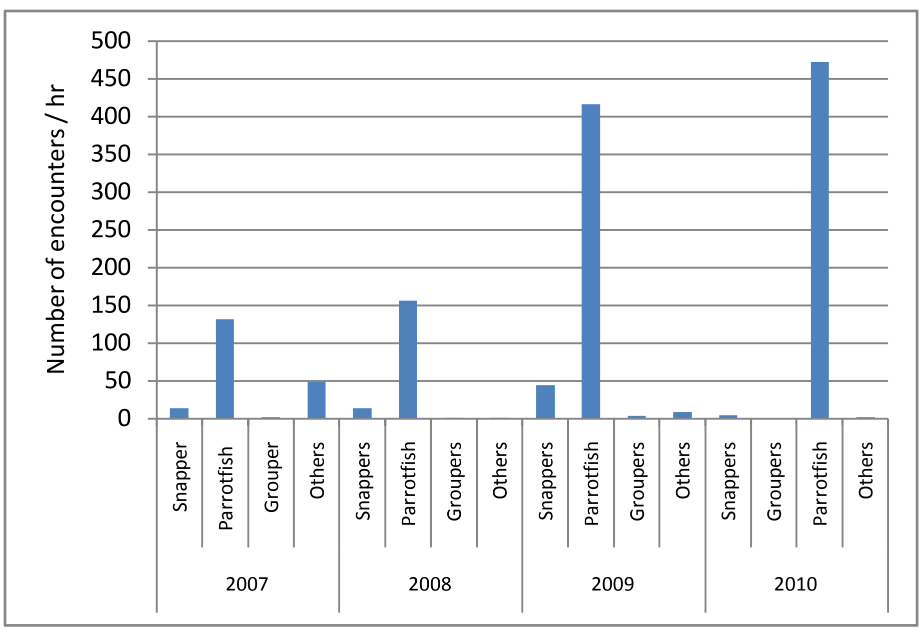


Figure 27: Number of commercially important fish encounters per hour at Sapodilla Cayes Marine Reserve (SCMR).

5.0 Discussion

A way of measuring the effectiveness of marine protected areas is through the fisheries resources they provide; their ability to act as a refuge site providing a coral and fish larval supply, and their ability to produce larger and more abundant commercially important species. Data from the past, up to 5 years, has been analysed to show temporal and spatial variations within different zones of the three parks.

Looking first at conch, when comparing all zones across the three parks, 2008-2009, for the number encountered per hour, the no-take areas of Laughing Bird Caye National Park (LBCNP) and Gladden Spit and Silk Cayes Marine Reserve (GSSCMR) displayed the highest number of encounters. There was a significant difference in number observed inside and outside the no-take area at LBCNP, with some years exhibiting up to four times as many conch inside the no-take area compared to outside. It is evident that this level of total protection has enabled the population to flourish, within the no-take area boundary. LBCNP is renowned both locally and nationally as having a high level of conch productivity. This could be attributed to the plentiful shallow seagrass beds that offer a suitable conch habitat and localised current movement around the faro may increase larval accumulation at this site. Although there was a significant difference in the encounter rate inside and outside the reserve, there was minimal difference in conch size. As this was taken as the average size, it implies that there is a similarly mixed population of adult and juvenile conch inside and outside the reserve. The average size of conch was greatest at LBCNP, suggesting a healthy population comprising many larger individuals. 2010 data showed a reduction in average conch size in both GSSCMR and Sapodilla Cayes Marine Reserve (SCMR), bringing the average size of conch encountered below the legal catch size of 178 mm, implying that fewer large individuals were present in these populations.

It is imperative that an area such an LBCNP is given this high level of protection, and that fishing regulations are enforced effectively as it is clearly a critical conch habitat. The high productivity in this area will enable larval dispersal to adjacent marine reserves, allowing for connectivity between sites. The high number of conch within the no-take area and their large average size, both inside and outside the park, suggests considerable reproductive activity. A ‘spill-over’ effect, whereby adult and juvenile conch cross the boundary to areas outside the no-take area would be expected. The significantly lower numbers of conch encountered outside the no-take area implies that even if a spill-over effect is occurring, this area is heavily targeted by fishermen. Due to the historic nature of LBCNP being an area of high conch productivity, coupled with the effective enforcement of the no-take area, it seems likely that fishermen actively target the areas surrounding the boundary of the reserve. In fact, the lowest number of conch encountered across any of the zones of the three parks was outside the no-take boundary at Laughing Bird Caye National Park.

The next highest number of conch encountered was seen at SCMR, followed by the area outside GSSCMR. It is interesting to note that the numbers encountered in the general use zone were lower than outside the marine reserve at GSSCMR for all years 2008-2010. This may imply that the fishermen target their efforts in the general use area of the marine reserve where they believe there will be a greater fish stock.

Examining the lobster data, when comparing all zones across the three parks 2008-2010, the number of encounters showed different trends across the years. The highest number of lobsters encountered was in 2009 at all sites, with the no-take area of LBCNP having the highest number. The no-take area of GSSCMR followed, but was equalled by the areas outside LBCNP and SCMR. The statistically significant difference in number of encounters 2008 versus 2009 and 2009 versus 2010 across all three parks implies that fishing pressure may be a factor. It is not known why 2010 has such greatly reduced lobster encounter numbers. If it indicates increased fishing pressure, it should not be the no-take areas of LBCNP or GSSCMR that were so markedly reduced, unless this is implying illegal fishing activity has been occurring in these waters. In fact, the GSSCMR zones which are open to fishing (general use zone and outside the reserve) showed the highest number of lobster encounters in 2010. Despite the overall reduction in numbers of lobster encountered in 2010, the average carapace size increased from 2009 to 2010 at all sites and in 2010 average size was well above the legal catch size limit at all sites. This is a good sign; a reduced number of larger lobsters still implies that there is an adequate number of individuals of reproductive size within the population.

Until 2010 Sapodilla Cayes Marine Reserve (SCMR) could be considered entirely for general use. It is anticipated that new zoning measures, coupled with effective enforcement, will increase biological productivity of the area through the use of conservation and preservation zones. SCMR was shown to have the healthiest reef communities in terms of higher live coral cover and lower macroalgal cover. This is important in terms of reef resilience and the future of coral reefs of the region in the face of near future climate change. SCMR sites exhibited up to 34% live coral cover, which is high, considering the country wide average for Belize was stated as 11% cover (Garcia-Salgado *et al*., 2008). The geographical location of Sapodilla Cayes, the hook at the southern extremity of the Belize Barrier Reef is likely to experience favourable oceanographic processes such as localised cool water upwelling, which likely reduced the effects of the 1998 ocean warming event which bleached and killed corals so extensively throughout the region. The resilience these reefs have shown suggests the potential to stand better against future climate change and thus could act as a refuge, re-seeding more degraded reefs downstream.

Looking at the other commercially important fish species, it is concerning to see that the numbers of snappers and groupers are so low at all sites. There has been a reduction in numbers of groupers and snappers at all sites in recent years, with 2010 having very low numbers of encounters. There does not appear to be a reserve effect for snappers and groupers; in some years the no-take areas have higher numbers of encounters, but in other years they do not. Fish monitoring started after the reserves had already been established for at least a few years. The very low numbers of snappers, groupers and other fish species is unlikely to change in the near future as, with the exception of LBCNP, the majority of both GSSCMR and SCMR are open to fishing activity, within their general use zones.

As it has been illegal to catch herbivorous fish, such as parrotfish, in any areas since 2009, there should be no reserve effect in terms of parrotfish numbers in the past two years. Parrotfish numbers were found to be high at all sites in 2009 and 2010 and the large number of juveniles encountered is a promising sign, suggesting good larval recruitment and breeding success. The high level of macroalgal cover at GSSCMR and LBCNP is concerning for the future health of the reef and only a high number of herbivorous fish can help combat coral overgrowth and the potential of a phase shift occurring. The high numbers of parrotfish is one good sign that their total protection at a national level since 2009 may help the future of Belize's reefs.

This case study compared three very different reef areas, which are subject to differing levels of protection. This gradient of protection ranges from the full protection of Laughing Bird Caye National Park, to the partial zoning of Gladden Spit and Silk Cayes Marine Reserve to the newly zoned (enforced since 2010) Sapodilla Cayes Marine Reserve. In addition to the degree of protection through management, the spatial differences in physical and environmental processes which these three parks experience, will, to a significant extent, influence their biological productivity. Laughing Bird Caye National Park is a faro, with a shallow central lagoon, surrounded by deep water. Water circulation patterns will be modified by the faro's structure and the shallow, sheltered lagoon may facilitate larval accumulation, providing a good habitat, particularly for conch where the population is always one of the most productive in the country. Gladden Spit and Silk Cayes marine reserve typically showed the results from patch reef and back reef communities, on the eastern-most stretch of the Belize Barrier Reef. This is a high energy environment, frequently subjected to intensive wave power, and although the back reef, where most of the surveys were undertaken, is relatively protected, these areas are still somewhat exposed. Similarly, the Sapodilla Cayes Marine Reserve at the southernmost point of the Belize Barrier Reef is also an exposed, remote environment. Shallow fringing reefs surrounding the cayes and patch reefs make up the reef community in this area. Extensive terrestrial run-off and riverine input following heavy rains impact these southern reefs, due to the numerous rivers entering the Port Honduras area, from Honduras and Guatemala, as well as southern Belize. The spatial differences between these environmental regimes should be considered when directly comparing the biological resources across the three marine parks.

6.0 Conclusions and Recommendations

This report provides evidence that effectively enforced no-take areas offer a suitable strategy to fisheries management. Laughing Bird Caye National Park (LBCNP) had the most significant differences in size and abundance of the biological resources compared to the other two sites. Having been a fully protected area of 4,095 ha since 1996, the concept of a no-take area, generating more abundant and larger marine resources, appears to be working. This is clear in terms of the conch population, where a statistically significant difference in numbers was observed inside and outside the park. The reserve effect is considerably less at Gladden Spit and Silk Cayes Marine Reserve (GSSCMR). Here, only a very small proportion, less than 2% (153 ha) is designated a no-take area, with the remaining 10,370 ha being declared 'general use' where fishing activity can take place. The results imply that the size of the no-take area at GSSCMR is either too small to have a spill-over effect (the no-take area appears not to be able to successfully contribute to increasing the stocks of such a large surrounding area), or the general use area is simply too heavily harvested. With fishing allowed within almost 99% of the marine reserve, the pressure on this park is substantial. It is recommended that future management strategies of GSSCMR should consider an increase in the size of the no-take area. Although this would cut down the available fishing grounds, it is anticipated that a larger no-take area would have greater potential to create a spill-over effect, thus creating long-term benefits for those that depend on these fisheries resources.

The total nationwide ban on removing grazing fish since 2009 appears to be having a good effect. Numbers of parrotfish increased in recent years, with a large proportion of juveniles in the population, showing successful reproduction and viability. However, the numbers of all other fish species, especially snappers and groupers is very low, implying heavy fishing pressure. It appears that the restriction of certain fishing gear types within the general use zones of marine reserves does little to help the fish populations within these zones. New fisheries management techniques should be considered for the future in order to reduce fishing pressure within the marine reserves. The use of quotas or 'bag limits' and through measures of restricted access, whereby only a certain number of fishermen (typically determined through traditional users of an area) are allowed to access certain fishing grounds could be considered.

The results from LBCNP have shown that an increase in biological resources through total protection is possible. However, despite 24 hour ranger presence, daily patrolling within the parks and day and night patrols of the buffer zones between the parks, illegal fishing activity is still a threat. The increase in stock within a no-take area, and a potential spill-over effect are the benefits, but there are considerable costs; the expense of running a well enforced marine protected area is high. Running SEA's reserves amounts to between US$40,000-65,000 per year. This is not including the initial overhead costs of developing infrastructure, building rangers' stations, purchasing vessels etc. However, Belize generates millions of dollars per year through their conch and lobster fisheries, suggesting that the running and enforcement of these marine reserves is economically viable.

In order to ensure that a new marine protected area is economically viable, it is imperative to consider certain factors. Reef resilience (the ability for some areas to withstand potential degradation events better than others), should drive the location of new reserves. For example, reefs with higher coral cover, or with a more diverse coral community that will be better able to resist warming sea temperatures due to near future climate change should be the first to be protected. Oceanographic factors such as current flow patterns, which disperse larvae, and the presence of localised upwelling which would reduce the effects of ocean warming, should also be considered.

Ultimately, the designation of marine reserves is for ecological and economic gain. Traditionally, southern Belize is heavily dependent on marine resources and in order for all users of these resources (fishermen, tour operators etc.) to respect the rules and regulations of the marine reserves, stakeholder input is needed. SEA works extensively with numerous stakeholder communities throughout southern Belize, working with key users to determine best practices to better drive management and ensure these natural resources will be around for future generations. No-take areas effectively close fishing zones that may have been used throughout history. This has the potential to cause unrest within a community. It is therefore imperative that all users are engaged in designing the zoning process, and that they are given appropriate information so that they understand the concepts and how it should assist them in their industry in the future. The reduction in numbers of conch, lobster and commercially important fish observed at all of SEA's marine parks in 2010 suggests a recent increase in fishing pressure. This could have been driven by external socio-economic factors. Tourism is the number one revenue generator for Belize, but tourist numbers were particularly low in 2010 due to the state of the global economy. Many fishermen that work in SEA's areas also work in tourism. With fewer people worldwide spending money on foreign travel some tour guides may have returned to the fishing industry. In an area where communities are so heavily dependent on marine resources, this highlights the need for potential alternative livelihoods in the future.

As in all areas of the world, the reefs of southern Belize are under increasing threat from climate change, an increasing population and coastal development. The dependence of so many communities on southern Belize's reef resources makes it imperative that all possible steps are taken to protect these reefs and the fisheries resources they provide. The need for robust management strategies through effectively enforced no-take areas, and more stringent regulation of fishing activities within marine parks are necessary to protect the future of Belize's coral reefs.

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