Queen conch in the Grenadines islands: A preliminary assessment on its abundance and current management needs

Alba García Rodríguez

Graduate Research Project
Master of Marine Management
Dalhousie University, Halifax (Nova Scotia)
November 2016

QUEEN CONCH (*LOBATUS GIGAS*) IN THE GRENADINE ISLANDS: A PRELIMINARY ASSESSMENT ON ITS ABUNDANCE AND CURRENT MANAGEMENT NEEDS

By

Alba García Rodríguez

Submitted in partial fulfillment of the requirements for the degree
of
Master of Marine Management

at

Dalhousie University
Halifax, Nova Scotia

November 2016

Table of contents

List of Tables

List of Figures

Abstract

The queen conch (*Lobatus gigas*) is a very important fisheries resource among Caribbean countries due to its cultural and economic value. However, queen conch has been overexploited in many areas of the Caribbean. In Union Island, St. Vincent and the Grenadines, the conch fishery has been an essential part of local livelihoods for the past century. Despite the importance of conch in the area, knowledge of the current status of the population is limited. Therefore, an abundance assessment was conducted to contribute data on conch density and distribution. In addition, the effectiveness of current conch conservation measures was assessed. Conch density was determined following the underwater survey methods of a study conducted in 2013 in the same study area. Surveys were completed within the Tobago Cays Marine Park (TCMP), as well as outside the marine protected area. Results showed reduced conch density in comparison to results from the 2013 study. In addition, the TCMP seemed to have no effect towards conch protection, as there was no significant difference in conch abundance inside and outside the park. Furthermore, the abundance of juveniles inside the park was lower in 2016 when compared to results from 2013. Multiple factors could have influenced these findings and, therefore, further research is required to better understand the current density of this species. The results and recommendations of this study, combined with continued monitoring, could contribute to better-informed conch fishery management in St. Vincent and the Grenadines.

Keywords: Queen conch, Fisheries management, MPA effectiveness, St. Vincent and the Grenadines, Tobago Cays Marine Park.

List of Abbreviations

CARICOM	The Caribbean Community
CFMC	Caribbean Fisheries Management Council
CFRAMP	Caribbean Fisheries Resource Assessment and Management Programme
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CRFM	Caribbean Regional Fisheries Mechanism
EBM	Ecosystem-based Management
ECLSP	Exuma Cays Land and Sea Park
IQCI	International Queen Conch Initiative
MPA	Marine Protected Area
OECS	Organization of Eastern Caribbean States
SCUBA	Self-contained underwater breathing apparatus
SPAW	Specially Protected Areas and Wildlife
SusGren	Sustainable Grenadines Inc.
SVG	St. Vincent and the Grenadines
TAC	Total Allowable Catch
TCMP	Tobago Cays Marine Park
UNEP	United Nations Environment Program

Acknowledgements

This study was conducted under the Eastern Caribbean Marine Managed Areas Network (ECMMAN) Project, in collaboration with the Tobago Cays Marine Park (TCMP), the National Parks and Beaches Authority of St. Vincent and the Grenadines, and Sustainable Grenadines Inc. I would like to first thank my supervisor Dr. Lucia Fanning for her continuous support, help, and guidance during this research. I would also like to thank Sustainable Grenadines Inc. for the opportunity of conducting this research in Union Island as part of my internship, in particular to Orisha Joseph. I am also grateful to the monitoring team, formed by Sonia Jind (SusGren), and the TCMP Rangers Albert Hansen and Benjamin Wilson for their help and participation on this research. Furthermore, I would like to thank the entire fishing and local community of Union Island for their support and collaboration during this research, with a special mention to Matthew Harvey, Peter Regis, and Alvin Thomas. Moreover, I would like to acknowledge the collaboration of the diving center Grenadines Dive, in particular the continuous help of Hyacinth Mayers and Keon Murray during this research. I would also like to acknowledge Adrian Gerhartz for his help on the development of the GIS maps included in this study. Finally, I would like to thank my family for their unconditional and continuous support. Without them, this research could have never been possible.

Chapter 1. Introduction

The marine environment supports three billion livelihoods on the planet (Nino, 2016), a number that continues to rise as more people rely on the ocean every day. However it is a difficult task to find the balance between the resources that can be used, and what should be left untouched for ecosystem functioning purposes. The increased anthropogenic pressure on the marine environment during the past decades has led to rapid biological and physiological changes, which exacerbate the need for adequate marine management and for marine conservation.

Effective marine management is the required mechanism to ensure the sustainable use of the ocean's resources, to secure future marine-dependent livelihoods, and it is also the way in which marine conservation can be put into practice. Marine conservation is a protection tool used across the globe to maintain marine ecosystems health and minimize the damage generated through anthropogenic activities. Through marine management and conservation, the impacts of climate change, overfishing, pollution, etc. can be mitigated, and ecosystem resilience can be enhanced (Micheli et al., 2012; Barner et al., 2015).

The queen conch, *Lobatus gigas* (originally known as *Strombus gigas*) (Bouchet, 2011), is a very important fisheries resource among Caribbean countries due to its cultural and economic value (Appeldoorn, Gonzalez, Glazer, & Prada, 2011). This species has been harvested as a food source in the region for approximately 5000 years, but the increase in its consumption during the past decades has caused its overexploitation (Lawrence & Phillips, 2013). This has resulted in a rapid decline of the stocks, a situation that many other commercially important marine species share. Due to this rapid decline, and the slow response to implement effective management measures, the queen conch was listed under Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1992 (NOAA, 2014). The inclusion of *L. gigas* under CITES has allowed a more controlled trade and the establishment of specific fishing quotas to reduce threats in the local populations (Appeldoorn et al., 2011).

1.1. Queen Conch in St. Vincent and the Grenadines

Saint Vincent and the Grenadines (SVG), located in the southeast Caribbean, also depends on the queen conch fishery as part of its economy and livelihoods. In the Grenadines Islands, only 15-20% of the total harvest is consumed locally, while the rest is currently being exported to nearby nations such as St. Lucia and France (Martinique) (FAO, 2007). The conch fishery in the Grenadines Islands was already reported to be important by 1950, especially in Union Island, where the species was apparently most abundant (Mohammed, Straker, & Jardine, 2003). But, due to overfishing, by 1966 the queen conch population in established fishing areas started showing signs of depletion, and in 1988 its absence was reported on the Tobago Cays (Hoggarth, 2007). Currently, status information on this species in Union island and Tobago Cays is limited, although the fishery still exists (Mohammed & Lindop, 2015).

Ecosystem-based management (EBM) has been proposed for this species, as they are vulnerable to overfishing, and they are very sensitive to water quality conditions (Appeldoorn et al., 2011). According to Appeldoorn et al. (2011), managing conch populations

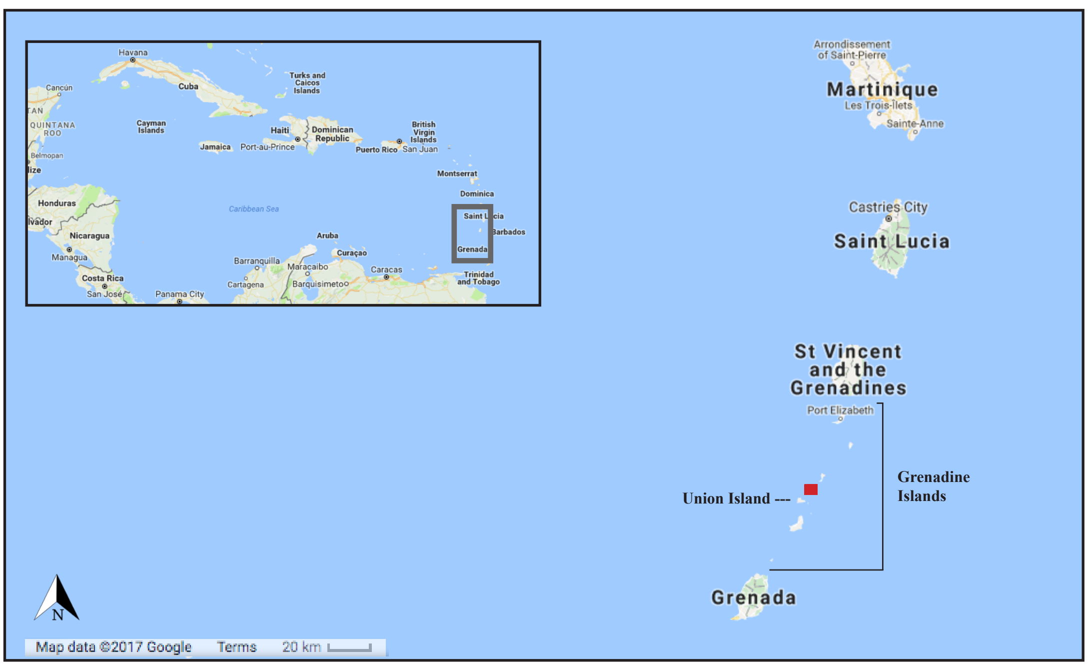

Figure 1: Location of St. Vincent and the Grenadines, St. Lucia , and Martinique within the southeast Caribbean Sea.
Union Island and the TCMP (red square) can be identified within the Grenadine Islands. Map source: Google Maps, 2016.

through EBM should include: (1) Protection of coastal habitats; (2) Protection of juveniles; (3) Protection of spawning adults; (4) Establishment of Marine Protected Areas (MPAs); and (5) Monitoring the fishery. In addition, in 2007 FAO concluded that conch stocks should be rebuilt or maintained above 50% of unexploited levels (FAO, 2007). However, in areas such as the Grenadines, where data on the unexploited levels is not available or very limited, this might be very challenging to determine.

1.2. Management Problem

Current management regulations for queen conch in the Grenadines include size limits and protected fishing areas such as the Tobago Cays Marine Park (FAO, 2007). However, the Tobago Cays Marine Park (TCMP) has had many management problems since its creation, and the effect that this MPA might be having in regards to queen conch conservation is not clear. In addition, lack of human resources and enforcement are a major problem in the Grenadines, resulting in the inadequate management of this resource (Cruickshank & Morris, 1996; FAO, 2007).

In order to implement suitable and effective measures for the sustainable use of queen conch in this area, its status and the effect of current measures on this species' population should be determined. This research focused on assessing the density of *L. gigas* in Union Island and the Tobago Cays Marine Park (TCMP), and it adds new information to a previously conducted study in the area in 2013 (Prada et al., 2013). In addition, the effectiveness of the TCMP towards conch protection in the region was evaluated. Due to the importance of TCMP, and the many irregularities that appeared to exist since its designation in 1997, such as the lack of a management plan until 2007, it is key to examine the effect that this MPA is having on the conch of the area (Hoggarth, 2007). The local community is also aware of the significance of this resource and the need for its conservation (Cruickshank & Morris, 1996). Uncertainties regarding the effectiveness of current management measures combined with the high importance of this species highlight the need for conducting this preliminary assessment on the current conch density and management impacts to the population.

1.3. Objectives and research questions

This assessment is essential as lack of information on the current conch state could cause the failure of the fishery and generate negative impacts on the environment and all dependent livelihoods. The purpose of this research is to better understand what management measures are needed, and to ensure that current and future management measures in place will have the desired effects for queen conch conservation and sustainable use. The three objectives of this study can be summarized as:

1. Assess the current status (density) of *L. gigas* in the TCMP and Union Island.
2. Determine the effect that the TCMP has on queen conch density, and analyze its effectiveness as an established management measure.
3. Analyze current and other existent management measures required in the area for the conservation and sustainable use of queen conch.

These objectives were achieved by researching the following five questions:

1. What is the current density of queen conch in Union Island and the TCMP? What is the proportion of juveniles and adults in the surveyed area?
2. How has conch density changed in comparison to the previous study conducted in 2013?
3. What is the effect of Tobago Cays Marine Park regarding conch abundance? Is the Park increasing the abundance of conch within its boundaries?
4. How do the current management measures relate to the previously proposed ecosystem-based management approach?
5. What are the gaps and challenges of current management measures in the area? What are the most suitable management measures for conch queen conservation in the area?

Chapter 2. Literature Review

This chapter presents background information regarding the queen conch, as well as a review regarding MPA effectiveness. The morphology, habitat, diet, and life cycle of this species were explored. In addition, the threats that are impacting it were included, as well as information on its status and management measures. Since MPAs have been proposed as a key aspect of EBM for conch, it is very important to understand when an MPA can be considered to be effective, and how that effectiveness can be evaluated. This subject was explored at the end of this chapter.

2.1. Queen conch

The queen conch, *L.gigas*, is a large herbivorous marine gastropod with a shell length up to 30 cm. Their common name is queen conch or pink conch; but many countries use other local names such as lambi in the Caribbean Windward Islands (Brownell & Stevely, 1981). Queen conch is distributed throughout the Caribbean Sea and the Gulf of Mexico, primarily present in the Western Atlantic Caribbean region, but also extending into the northern coast of South America (Davis, 2003) (Figure 2).

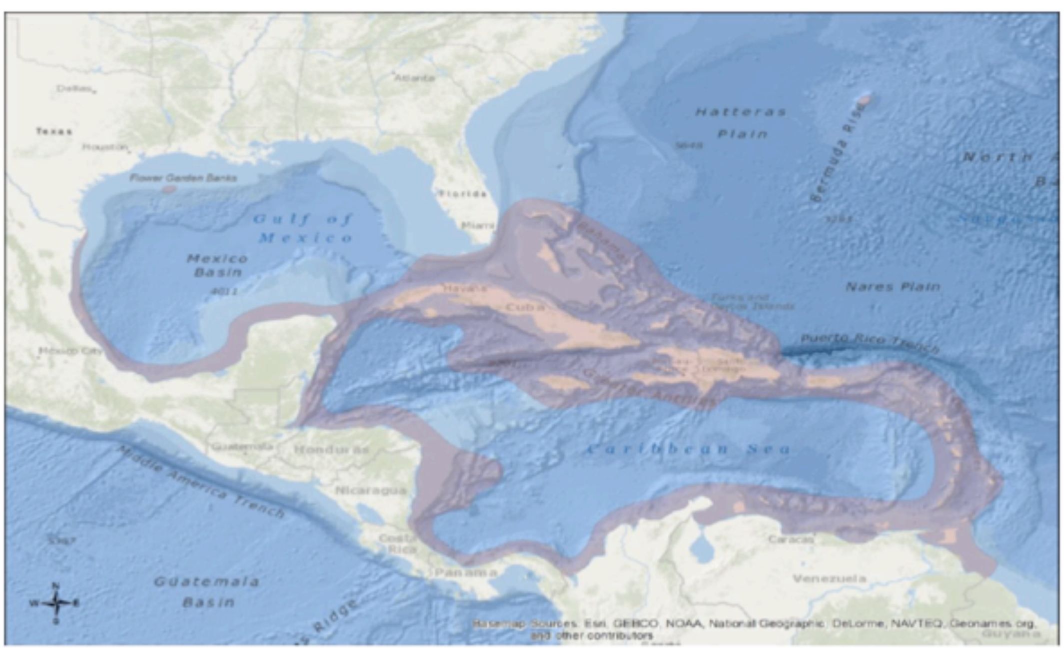

Figure 2: Geographic distribution of the queen conch (*L. gigas*) (NOAA, 2014)

Their length varies depending on the area due to multiple local factors (Theile, 2001). In addition, the shell length growth of this species is not continuous throughout its life cycle. The shell will grow until they reach maturity when they are between two and a half to three years old, and after that time a flared lip will develop (Egan, 1985). Shell weight and thickness, including the flared lip, will increase over time as nacre is continuously deposited inside the shell (Stoner, Mueller, Brown-Peterson, Davis, & Booker, 2012). The queen conch possesses a large muscular foot that ends in a corneous hook-shaped operculum, which is characteristic of this species (Figure 3) (NOAA, 2014). Queen conch has separate sexes, a usual ratio of 1:1, and the fertilization is internal (Stoner et al., 2012). Queen conch can live up to 20 years but the average life span of this species is approximately six years (Egan, 1985; Theile, 2001)

2.1.1. Habitat

The queen conch generally inhabits clean waters, and their typical habitats include sandy, rubble, gravel, hard coral or beach rock bottoms that support the growth of seagrass and algae (Brownell & Stevely, 1981; Theile, 2001). Adults prefer sandy algal flats or seagrass beds (Randall, 1964; Davis, 2003), and they are rarely, if ever, found on high coral cover bottoms (NOAA, 2014). Ideal nurseries for this species are shallow areas with medium seagrass density, and reduced predator abundance. In addition, these areas must have high macroalgae production and high water exchange (Stoner, 1989; NOAA, 2014).

The average home range for an individual can vary between 0.15 ha to 1.2 ha depending on the area (NOAA, 2014). This species can be found in depths from a few centimeters, up to 100 meters (330 feet), but they are rarely found below 30 meters (100 feet) due to their dependence on the light needed for algae and plant growth (Egan, 1985; Theile, 2001). Adults can be more often found in shallow areas between 10-18 meters, while juveniles are usually associated with shallower and sheltered areas (Davis, 2003). Besides their preferences, conch habitats can also be determined by fishing pressure. In fished areas with scuba gear restrictions, adult conch can be most frequently found in deeper areas (25-35 meters), where their accessibility is lower (Glazer & Kidney, 2004; Ehrhardt & Valle-Esquivel, 2008). This distribution shift as a response to fisheries has also been demonstrated

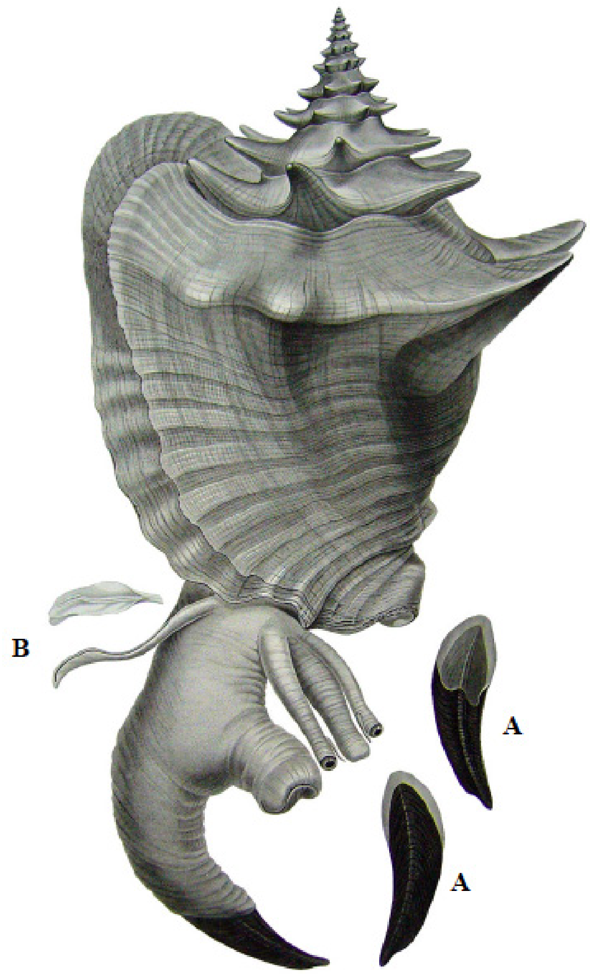

Figure 3. Drawing of *Lobatus gigas*.
The shell and the visible parts of this species when in nature were represented in this drawing. The operculum (A) (corneous hook-shaped structure at the end of the feet) is showed with more details, as well as the male sexual features (B) that can be seen. Modified from Duclos 1844 (Duclos, 1844).

by the higher abundance of adults in shallow areas of certain marine protected areas where conch fishing is not allowed (NOAA, 2014)

2.1.2. Diet and predators

The queen conch is an opportunistic herbivores and presents a large extendable proboscis to feed on algae, which compose most of their diet, although some seagrass species such as *Thalassia sp.* are also be grazed upon (Randall, 1964; Brownell & Stevely, 1981; Davis, 2003; NOAA, 2014).

Several species consume queen conch as part of their diet: other species of gastropods, hermit crabs, the red cushion sea star, spiny lobster, spotted eagle ray, nurse shark, sea turtles (particularly loggerhead turtles), and multiple species of fish. However, predation is higher on juveniles, due to mature conch being only available to hermit crabs, certain sharks, rays, and sea turtles as a result of the hardness of the shell (Brownell & Stevely, 1981). Finally, humans also prey upon conch, mostly during their adulthood, where they are the most significant predator (Egan, 1985).

2.1.3. Life cycle

Queen conch reach sexual maturity six months after the flared shell lip develops. The flared lip continues to thicken during the rest of their life. When conchs have begun to develop a flared lip, but have not reached sexual maturity, they are considered sub-adults. Conchs are sexually mature approximately a year after maximum shell length is reached between the ages of two and a half to three years (Egan, 1985; Theile, 2001). Adult queen conch migrates seasonally in relation to reproduction. The regularity of these migrations and benthic movements increase with age (Brownell & Stevely, 1981; Theile, 2001). Conchs will migrate inshore to shallower waters during the spring in order to reproduce, and they will retreat offshore to deeper areas established as feeding grounds during the autumn (Theile, 2001; Davis, 2003).

Reproductive activity occurs year-round although it peaks between March and September, favored by changes in the weather and temperature (Egan, 1985; Davis, 2003). It is very important to mention that this species is density dependent for its reproduction, and require aggregations to successfully conduct that process (Appeldoorn et al., 2011). A previous study demonstrated that reproductive activity ceased when conch density was about 50 adults/ha. This study also found that maximum reproductive activity was found at a minimum of 200 adults/ha (Appeldoorn et al., 2011).

Female conchs can store fertilized eggs for several weeks before laying, and a single egg mass can be fertilized by multiple males (NOAA, 2014). The egg mass is laid in relatively shallow waters (3-45 m), and sand grains stick to it during that process, so that it becomes a compact mass camouflaged within the surrounding environment (Brownell & Stevely, 1981) (NOAA, 2014). Under favorable environmental conditions a female can lay an average of 10 million eggs during the spawning season. Under less favorable environmental conditions, a female may produce an average of 3.3 million eggs (Appeldoorn, 1993).

After the egg mass is laid, hatching occurs in approximately five days (Davis, 2003). The veligers are planktonic for an average of 14 to 28 days, but they can remain in the water column for up to 60 days. Throughout the larval stage, they can drift to other locations, or if the conditions are favorable, they will start to descend in the water column to settle within the local environment (NOAA, 2014). When they reach an average of 0.3 to 1 mm shell length, they can settle in the benthos (usually seagrass areas), and metamorphose into the post-larvae (Davis, 2003; NOAA, 2014). After six days in the substratum, if the metamorphosis has not occurred due to lack of the required habitat conditions, the larvae will lose the ability to do so (Theile, 2001).

Once they settle into the benthos, the post-larvae shell reaches an average length of 1 to 2 mm, and bury themselves in the sediment to hide. They emerge one year later as juveniles with an average shell length of 6 cm (NOAA, 2014). Both the post-larvae and queen conch juveniles are nocturnal, and emerge at night to feed (Egan, 1985).

After their first year buried in the sandy benthos up to 20 cm deep, juveniles will start frequenting the surface, and will emerge during the summer months to migrate to deeper areas. In addition, their daylight activity will increase over time (Egan, 1985; Theile, 2001; Davis, 2003). Juveniles will mostly remain buried in seagrass areas as a predatory avoidance tactic until they reach 5 to 10 cm. Juveniles will continue their growth until they are two and a half to three years old, where they will start developing the flared lip and becoming sexually mature. A diagram with the complete queen conch life cycle can be found in Figure 4.

2.1.4. Threats

The biologic characteristics of this species make them particularly vulnerable to the threats

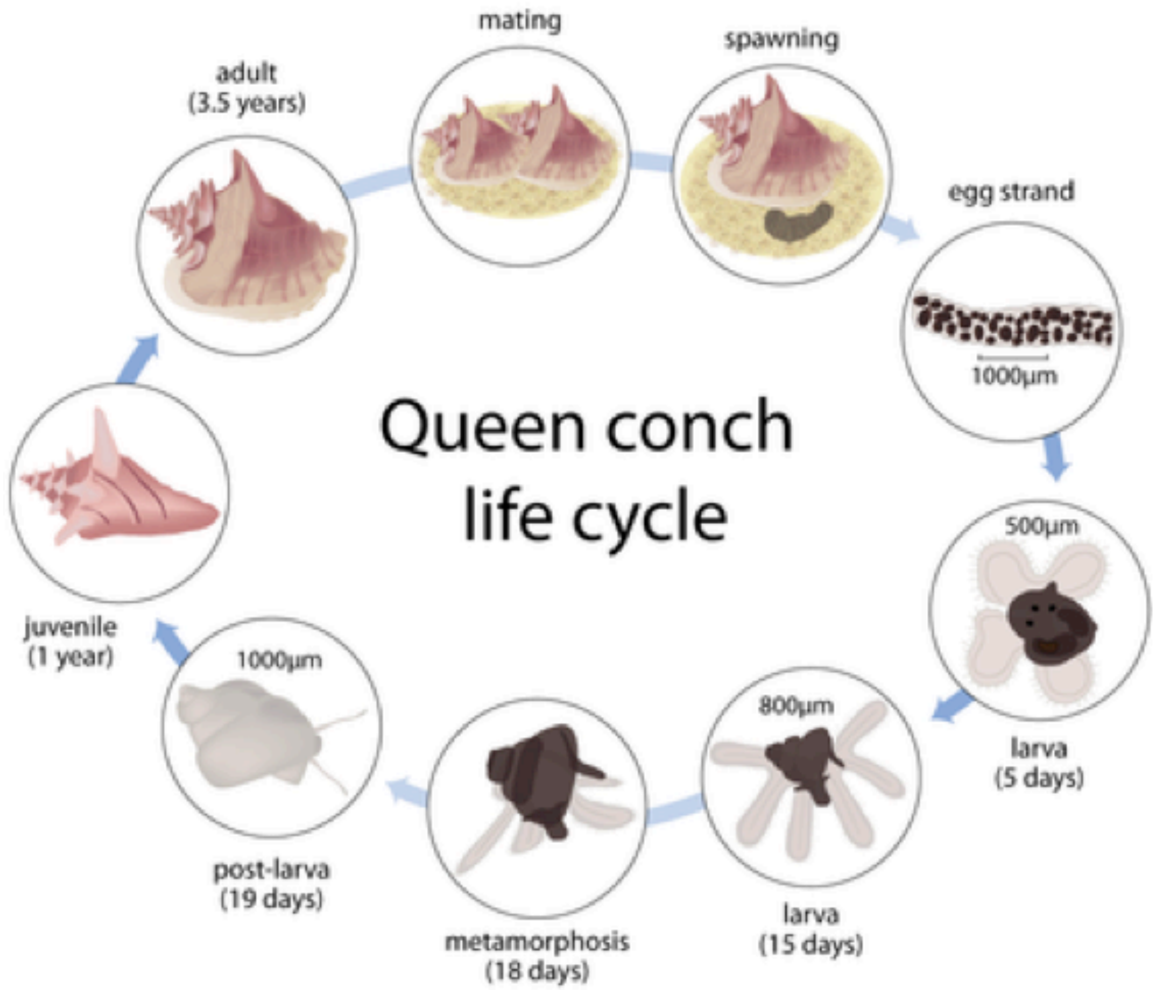

Figure 4: Conceptual diagram of the queen conch life cycle (Kruczynski & Fletcher, 2012).

to witch they are exposed. These characteristics include their slow growth, late maturity, large aggregations during the spawning season, occurrence in shallow waters, and limited mobility (Townsend, 2012). They are exposed to overfishing and illegal fishing, to habitat degradation, water pollution, and also to the impacts of climate change (Appeldoorn et al., 2011; Townsend, 2012; NOAA, 2014).

Conch density is one of the most important factors determining conch productivity and reproductive success. Low conch densities can result in the lack of reproductive aggregations and the inability to find a mate to reproduce (Appeldoorn et al., 2011). According to a study conducted in 2000 in the Bahamas, densities of a minimum of 50 adults/hectare are required for successful reproduction due to the Allee effect (Stoner & Ray-Culp, 2000). The Allee effect is a biological phenomenon characterized by the positive outcomes that the density of individuals can have on the overall population fitness, especially when population size is low. This effect is known to occur in species that aggregate for reproduction purposes, such as queen conch (Stoner & Ray-Culp, 2000).

Exploitation by fishermen is the major threat for this species and the main cause of stocks declines (Townsend, 2012). Improvements in fishing technology and the ability to use SCUBA gear has allowed the exploration of deeper habitats that were once unexploited, and has led to an increased fishing capacity (Appeldoorn et al., 2011). Conch overfishing, which started to be very evident since the late 1960s, has been reported throughout all the Caribbean. Overfishing has been the result of a higher demand from local populations, but mainly due to the growing international market (Townsend, 2012). In SVG, a major part of conch landings were exported to other countries, mainly to Martinique until 1997, and to nearby islands in recent years (CITES, 2003). Signs of overfishing in SVG were reported in 1970 around Union Island (Brownell & Stevely, 1981). Illegal fishing and trade has also been identified as a problem for conch populations among many Caribbean countries (Salcedo, 1997; Theile, 2001; Townsend, 2012), as well as in St. Vincent and the Grenadines specifically (Adams, 1978; Theile, 2001; Prada et al., 2013).

Habitat degradation and water quality also have a severe impact on this species due to its very specific habitat requirements and sensitivity to changes. Particularly, shallow habitats close to shore are specially vulnerable to degradation and pollution (Theile, 2001; Appeldoorn et al., 2011). Sedimentation and eutrophication reduce the extent of suitable conch habitat; and pollutants such as heavy metals have been found to cause changes in conch behavior and physiology, reducing growth rate and increasing predation (Appeldoorn et al., 2011; NOAA, 2014). Eutrophication can also impact conch at the larvae stage by inducing metamorphosis before they are competent to undergo this process (Appeldoorn et al., 2011).

The presence of healthy seagrass habitat is crucial for conch development and survival, and therefore, any anthropogenic activity or environmental changes that reduce the abundance or quality of these habitats will also negatively impact conch (Townsend, 2012). Hurricanes can also cause habitat degradation, temporarily reducing conch population abundance (NOAA, 2014). The combination of overexploitation of adult conch, and the degradation of juvenile habitat has been identified as a particularly dangerous threat (Townsend, 2012).

Finally, it is important to mention that climate change is impacting conch populations, mainly through temperature increase and acidification (Aldana Aranda, 2016). Conch development and reproduction are temperature-dependent processes. The increase of sea surface temperature will likely increase the length of spawning seasons, increasing their vulnerability to fishing practices (Appeldoorn et al., 2011). In addition, modifications in the saturation rate of aragonite will result in lower calcification rates and thinner shells in conch that inhabit deeper habitats. Therefore, deeper habitats, which are refugia from fishing activities currently, could become undesirable habitats for conch in the future. Furthermore, ocean acidification will make conch shells, which are 99% aragonite, susceptible to dissolution (NOAA, 2014).

The combined effects of all these threats and others that are not explained in this section (e.g. parasites, population connectivity and genetics, etc.) (NOAA, 2014) can lead to the severe decline of conch populations if adequate management measures are not implemented. Because of that, it is essential to have information regarding the status of conch stocks in different countries, as well as about their management needs. This information will be crucial to minimize the threats to which conch populations are currently exposed.

2.1.5. Queen conch status and management in the Caribbean

Although queen conch is one of the most important fisheries in the Caribbean, it is a resource that has been widely overexploited (Appeldoorn et al., 2011). The queen conch fishery is very different among Caribbean countries; therefore its status and management practices will vary depending on the country. In range states such as Jamaica or Turks and Caicos, it is a very well developed industrial fishery with high production and exports (Aiken, Kong, Smikle, Appeldoorn, & Warner, 2006). In countries such as St. Vincent and the Grenadines or St. Lucia, it is mainly an artisanal fishery that supplies local demand but also exports to nearby countries. Finally, countries such as Dominica or Barbados have a very small conch fishery that is opportunistic and mainly involves subsistence fishing (Theile, 2001). Because of its importance, it has been essential to understand the status of this resource and the necessary measures that should be implemented for its adequate management. In the next sections, queen conch status and management is explored at a regional scale, with a special focus in St. Vincent and the Grenadines.

2.1.5.1. Queen conch status

In 1996, the First International Queen Conch Conference was held in Puerto Rico (San Juan) as a result of a regional concern for the status and management of this species (Posada & García-Moliner, 1997). Pushed by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) requirements (this species is included under Appendix II); the meeting aimed the gathering of all information available at the moment on queen conch stocks in the different countries (Table 1), and to promote its assessment in countries that had no information on their stock status (Posada & García-Moliner, 1997). Table 1 shows the conch status information that was available at that conference, as well as the assessments that were conducted as a result of that meeting, and published in 2001.

Table 1 shows how most of the stocks across Caribbean countries (67%) had been overfished and or overexploited, which in some cases is a situation that prevails to the present. Many countries lack adequate information about the queen conch stocks, which could jeopardize their conservation and sustainable use. On the other hand, there are some stocks that have increased in abundance, and have shown signs of recovery (Table 1).

In Saint Vincent and the Grenadines, the fishery is mainly conducted during the closed season for lobster (May 1 to August 31), although some fishermen harvest this species year-round (NOAA, 2014). Information on this species is considered limited in multiple studies and reports (Theile, 2001; CITES, 2003; NOAA, 2014). In the early 1970s there were concerns about overfishing, since the fishing area around Union was depleted, and the continuation of fishing was driven by to the high demand from Martinique (Brownell & Stevely, 1981). By the late 1990s near shore declines were observed in other areas of the Grenadines (NOAA, 2014). In 2001, the Fisheries Division aimed to implement a data-col-

Table 1. Queen conch status across the Caribbean before and after 2001.

	Stable		Harvest rate not sustainable		Partically overfished		Overfished		Severelly overfished		Partially overexploited		Overexploited		Fully exploited		Collapsed		Closed		Recovering	Density (conch/ha)		References
	1990-2001	2002-2016	1990-2001	2002-2016	1990-2001	2002-2016	1990-2001	2002-2016	1990-2001	2002-2016	1990-2001	2002-2016	1990-2001	2002-2016	1990-2001	2002-2016	1990-2001	2002-2016	1990-2001	2002-2016	2002-2016	1990-2001	2002-2016	
Antigua and Barbuda													blue	orange								17.2	-	1,12
Aruba							blue												blue	orange	orange	-	126	1,11
Bahamas						orange					blue											20.8-88	122	1,11,17,19
Barbados														orange								-	4.3-14.4	1,11
Belize							blue						blue									14.3-14.9	337.4	1,3,11,14
Bermuda		orange															blue		blue		orange	0.52-2.94	280-520	1,13
British Virgin Islands							blue										blue	orange				0.007-12.25	0-0.656	1,11
Caribbean Netherlands (Bonaire)							blue	orange														20.2	21.8	1,4,11,14
Caribbean Netherlands (Saba)							blue															-	-	4
Caribbean Netherlands (St. Eustatius)																						-	121	1,4,16
Cayman Islands																						-	70-100	1,14
Costa Rica																						-	-	1,3
Colombia					blue		blue												blue		orange	2.4-317.5	1.8-151	1,3,10,14
Cuba	blue														blue							20-35	-	1,3
Dominican Republic				orange			blue						blue									0.6-14.4	-	9,14,15
Dominica									blue													-	-	1
Florida																	blue		blue			1.5-2.4	-	1,5,17
Grenada					blue			orange														-	-	1,11
Haiti				orange	blue		blue		blue	orange			blue									15-160	0-35	3,8,11,15
Honduras													blue								orange	7.3-14.6	73-298	1,3,1,11,14,15,17
Jamaica			blue																			89.1-277	136-243	1,11,14
Martinique					blue		blue		blue													-	45-95	1,3,11
Mexico							blue						blue									84	9-96	1,3,11,14
Nicaragua																						-	112-267	1,11
Panama													blue									1.4	-	7
Puerto Rico					blue			orange													orange	5.68-7.28	5.5-73.8	1,5,11
St Kitts and Nevis					blue																orange	-	-	1,11
St Lucia											blue		blue								orange	-	242	1,11,18
St Vincent and the Grenadines	blue				blue																	-	306.4	1,16
Trinidad and Tobago																						-	-	1
Turks and Caicos	blue																					-	44.8-204	1,14
US Virgin Islands							blue															7.7.-12.25	234.1	1,4,11
Venezuela							blue		blue				blue						blue	orange		0.82-18.8	18.8	1,6,11,14,17

Cells in blue color represent management measures implemented before 2001, while cells in orange color represent measures implemented after 2001. Data presented for each time period show only most recent available data for that period. Partially overfished or overexploited refers to the overfishing or overexploitation of conch in specific areas, depths, or by different stages in their life cycle (juveniles or adults). The densities in individuals per hectare were also included if they were present in the reports, documents, and journal articles reviewed. Information of queen conch density or status inside marine protected areas was not included. References mentioned in the table can be identified as follows: (Chakalall, 1997)[1]; (Tewfik, Archibald, James, & Horsford, 2001)[2]; (Theile, 2001)[3]; (van Buurt, 1997)[4]; (García-Moliner, 1997)[5]; (Carrasquel, 1997)[6]; (Martans, 1997)[7]; (Garnier, 1997)[8]; (Salcedo, 1997)[9]; (Perez Molina, 1997)[10]; (NOAA, 2014)[11]; (FAO, 2016)[12]; (Sarkis, 2009)[13]; (Theile, 2005)[14]; (NOAA, 2015)[15]; (Prada et al., 2013)[16];(Appeldoorn & Baker, 2013)[17]; (Hubert-Medar & Williams Peter, 2014)[18]; (Gittens, 2014)[19].

lection method for catch, effort, and biological data; but such a plan was not implemented (Theile, 2001). In 2008, a study was conducted to assess the current conch status. In this study, fishermen reported a declining and smaller stock (NOAA, 2014). However, it seems that it was not until 2013, that a formal stock assessment was conducted in St. Vincent and the Grenadines.

The study developed by Prada et al. (2013) surveyed the Union Island and Tobago Cays Marine Park area by conducting a visual census. They found a total conch density of 306.4 ind/ha, and estimated a total population size of 7,256,446 individuals. The overall adult density found was 52 adults/ha, and therefore the authors recommended that the fishery should proceed with caution, as the limit for successful reproduction is known to be around 50 adults/ha (Prada et al., 2013). Prada et al. concluded that even though a better assessment of the adult population was needed, the overall population seemed to be recovering; which could be the result of a reduced fishing pressure induced by the implementation of the Tobago Cays Marine Park (Prada et al., 2013).

2.1.5.2. Queen conch management

During the mid-1980s, and due to overexploitation, several countries started to implement management measures to ensure sustainable fishing practices (Theile, 2001). However, rapid decline of this species resulted in its inclusion under Appendix II of CITES in 1992 (Appeldoorn et al., 2011). This measure regulated conch trade and required exporting countries to establish export quotas and report information on the population status on a yearly basis. In fact, all range states with a conch fishery needed to determine the sustainability of their fishery (Oxenford, Fields, Taylor, & Catlyn, 2007). Despite the inclusion of this species under Appendix II, illegal and unregulated fishing and trade continued to occur (Catarci, 2004; Oxenford et al., 2007). On the other hand, this measure resulted in the development of many stock assessments and the implementation of management measures across the Caribbean (Oxenford et al., 2007).

During the First International Queen Conch Conference conducted in 1996 it was recognized that the management of this species was critical due to its extensive exploitation and its high value (Appeldoorn, 1997). During this conference, all participants agreed to promote regional management for this species, as well as to create a common international management strategy for the Caribbean region (Posada & García-Moliner, 1997). Currently, most countries within the queen conch distribution area have implemented some form of management for the fishery (Theile, 2001).

Other measures to ensure the sustainable use of this species have been implemented at the regional level. Previous to the inclusion under CITES, *L. gigas* was listed on Annex III of the SPAW (Specially Protected Areas and Wildlife) Protocol of the Cartagena Convention in 1991 (CEP-UNEP, 1991; Oxenford et al., 2007). This measure provided the basis for the protection of this species and its habitat within the Caribbean. In addition, the Organization of Eastern Caribbean States (OECS) has developed a variety of fisheries regulations for the queen conch fishery such as gear restrictions and season closures (Oxenford et al., 2007). Furthermore, the Caribbean Fisheries Management Council (CFMC) is important for this fishery's governance, as it promotes the monitoring of conch stocks across the Caribbean to support adequate measures for its management. Finally, other efforts to achieve effective management strategies for this species included the International Queen Conch Initiative (IQCI) created by CFMC, and The Caribbean Community (CARICOM) Fisheries Resource Assessment and Management Programme (CFRAMP), now the Caribbean Regional Fisheries Mechanism (CRFM), under the auspices of CARICOM (Oxenford et al., 2007).

The measures that range states have implemented for queen conch management are summarized in Table 2. These measures include:

1. Minimum size restriction: Minimum size restrictions ensure that only adult conch are being harvested. Since each conch is individually handled, this measure could ensure that no undersized conch are taken from the environment. The morphologic characteristic that has been conventionally used to implement this measure has been the shell length. However, it must be considered that queen conch length at maturity varies within an area and among areas. Therefore, specific minimum conch shell lengths for each area should be designated (Appeldoorn, 1997). The different minimum sizes adopted by Caribbean countries can be found in the technical report developed by Theile (2001) for the CITES Secretariat. However, recent studies have shown that shell length is not correlated with conch maturity lev-

Table 2. Review of the different management measures adopted by different countries across the Caribbean for queen conch management.

	Legislation	Fisheries closure	Season closure	Season closure during reproduction	Area closure	Size limit	Weight limit	Lip tickness regulation	Gear restriction	Scuba gear regulation	Hookah regulation	Quota harvest	Export quota
Antigua and Barbuda	Orange		Orange	Orange		Orange	Orange	Orange					
Aruba		Orange											
Bahamas	Orange		Orange	Orange	Yellow			Yellow	Orange	Orange	Orange		Orange
Barbados													
Belize	Orange		Orange	Orange	Yellow	Orange	Orange		Orange	Orange		Orange	Orange
Bermuda		Orange							Orange		Orange		
British Virgin Islands	Orange		Orange	Orange		Orange	Orange	Orange	Orange	Orange			
Caribbean Netherlands (Bonaire)	Orange					Orange	Orange		Yellow				
Caribbean Netherlands (Saba)		Green				Orange	Yellow	Orange	Orange	Orange	Orange		
Caribbean Netherlands (St. Eustatius)	Orange					Orange	Yellow	Orange	Yellow				
Cayman Islands	Orange		Orange	Orange	Yellow				Orange	Orange	Orange	Yellow	
Costa Rica		Orange											
Colombia	Orange		Orange	Orange	Yellow	Yellow	Orange	Yellow	Orange	Orange	Orange	Orange	Orange
Cuba	Orange		Orange	Orange	Yellow	Yellow		Orange	Orange	Orange	Orange	Orange	
Dominican Republic	Orange		Orange	Orange	Yellow	Orange		Yellow					
Florida		Orange											
Grenada		Blue	Yellow			Orange	Orange	Orange					
Haiti		Blue						Yellow	Yellow				
Honduras		Orange	Yellow		Yellow	Yellow			Yellow				Orange
Jamaica	Orange		Orange	Orange	Yellow	Yellow	Yellow		Orange	Orange		Orange	Orange
Martinique	Orange		Yellow			Orange	Orange	Yellow	Orange	Orange			
Mexico			Orange	Orange	Yellow	Orange						Orange	
Nicaragua	Orange		Orange	Orange	Yellow	Orange	Orange	Orange					Orange
Panama													
Puerto Rico	Orange		Orange	Orange		Orange		Orange	Orange	Orange	Orange	Orange	
St Kitts and Nevis	Orange		Yellow			Orange	Orange	Orange	Orange	Orange	Orange		
St Lucia	Orange					Orange	Orange	Orange					
St Vincent and the Grenadines	Orange					Orange	Orange	Orange					Orange
Trinidad and Tobago													
Turks and Caicos	Orange		Orange	Orange	Yellow	Orange	Orange	Yellow	Orange	Orange	Orange	Orange	Yellow
US Virgin Islands	Orange		Orange		Yellow	Orange	Yellow	Orange	Orange	Orange	Orange	Orange	
Venezuela		Orange											

Yellow / Orange	Regulations/management in place
Green	Commertial fisheries closure
Blue	Trade Suspension

Information included in this table was extracted from two reports, one conducted in 2005 by TRAFFIC EUROPE (yellow cells) (Theile, 2005); and the other one conducted in 2014 by NOAA (orange, green, and blue cells) (NOAA, 2014). The most recent information was prioritized (marked as orange, green, or blue) when marking a cell in the table.

el. Instead, lip thickness has been proposed as a more accurate measure to determine conch maturity level, and to avoid fishing immature conch (Stoner et al., 2012). Although many countries prohibit the harvesting of conch without a flared lip, this morphologic parameter is not currently being accurately measured with the adequate equipment (calipers) when conducting conch fisheries (Theile, 2001). Limits on shell lip thickness have been identified as one of the measures for the optimal management of this species (Stoner et al., 2012). According to the summary presented in Table 2, about 65% of the queen conch range states currently have established a minimum size to harvest this species.

2. Gear restrictions: The decrease of conch populations in shallow areas, mainly due to overexploitation, has led fishermen to harvest conch in deeper areas. In order to fish in deeper areas, almost all fishermen now use diving gear (Hookah or SCUBA). The use of these new technologies has also increased the capacity of the fishery and increased catch per unit effort (i.e. more conch being harvested per hour and fishing trip) (Theile, 2001). Deep-water habitats are known to be important refugia for spawning conch stocks, and in some cases (e.g. Bahamas, Belize) these can be crucial to maintain the overall recruitment of the population (Appeldoorn, 1997). Therefore, total or partial restrictions of hookah or Scuba aim to reduce the fisheries effort (harvest rate), to protect spawning stocks, and can be also implemented to improve safety for fishers (Appeldoorn, 1997; Theile, 2001). However, it must be considered that some islands present very limited shallow water areas, and banning the use of diving gear can highly impact the conch fishery, resulting in negative economic and cultural impacts to the community (Appeldoorn, 1997; Theile, 2001). In addition, it is very important to ensure that such a measure does not increase fishing pressure on conch juveniles inhabiting shallower areas (Appeldoorn, 1997). According to the summary presented in Table 2, approximately half of the range states have implemented this measure.

3. Closed season: This management measure aims to effectively limit fishing activities, and to allow the successful reproduction of this species (Appeldoorn, 1997; Theile, 2001). The queen conch mainly reproduce during the summer months (March-September), with the highest rates on July and August (Appeldoorn, 1997). During this time, conch are more vulnerable, as they usually migrate to shallower areas and aggregate. Establishing a closed season can protect conch populations when they are most vulnerable (Appeldoorn, 1997). It is crucial that conch can successfully reproduce to maintain the future population, therefore a fishing closure during reproductive season has been identified as one of the measures for the optimal management of this species (Stoner et al., 2012). Approximately half of the range states have currently implemented this measure (Table 2). It should be considered that this measure is likely to be unpopular among fishermen, as their livelihoods will be negatively impacted in the short-term.

4. Closed areas: This management measure could refer to the closure of a nursery area, a spawning area or the creation of a marine reserve (Appeldoorn, 1997). The creation of marine reserves and their effectiveness will be explored further in section 2.2, and was not included as part of area closure in Table 2. Closed areas can be very important to protect conch populations and their habitat. This measure aims to effectively limit fishing activities, but also to reduce any other threats to this species and their habitats (Appeldoorn, 1997). Habitat protection has already been considered as a crucial part of ecosystem-based management (Appeldoorn et al., 2011), and it has been highly recommended for any marine species management. Finally, maintaining areas with a high conch density could also be crucial to preserve healthy and productive conch populations (Appeldoorn, 1997). Currently, only about 37% of the queen conch range states have established closed areas as part of their conch management measures (Table 2).

5. Limited entry: The establishment of a specific number of vessels, or/and a specific number of fishermen allowed in the conch fishery are measures to control the fishing pressure and avoid overfishing (Theile, 2001). Such measures can promote conch conservation, but they can also have significant economic and social impacts (Appeldoorn, 1997; Theile, 2001). In addition, how the fisheries licenses are allocated is a very sensitive matter that needs to be carefully studied before issuing such licenses (Theile, 2001).

6. Catch and export quotas: Even though this measure was imposed by CITES in 1992, only 25% of range states seem to have implemented them to date (Table 2). This measure is another tool to control fishing pressure and ensure the sustainable use of this resource (Theile, 2001). CITES considers this measure as one of the most effective tools to control and regulate international trade, which could lead to overexploitation and overfishing if

not adequately regulated (Theile, 2001). However, one of the difficulties to designate and implement annual quotas is the need to obtain information on the stock status and the annual landings, since this information in most of the range states is very difficult to obtain on a continuous basis (Appeldoorn, 1997). The monitoring of the fishery and conch trade is another major challenge for the effective implementation and enforcement of this measure.

7. Fisheries closure or moratoria: In cases where the fishery collapsed or conch abundance was at critically low levels, the closure of the entire fishery was necessary. This measure could allow the stocks to recover. However, in some cases this measure has not resulted in the recovery of already depleted stocks (Stoner, Davis, & Booker, 2012). Currently, it appears that the conch fishery has been closed in only six range states (19%) (Table 2).

The characteristics for inclusion in national and regional management plans were described by Chakalall in 1997 as part of the First International Queen Conch Conference (Chakalall, 1997). Among others, the author stated that any management plan should include the duration of the plan and reviewing cycles; as well as the objectives, restrictions being implemented, and status of the fishery (Chakalall, 1997). Finally, in order to manage the queen conch fishery (and to report queen conch status) in any of the range states, it is crucial to monitor multiple parameters. In 2008, FAO identified the required parameters for the monitoring of this fishery to be: "(1) biomass; (2) fishing effort; (3) spawning stock status/biomass; (4) shell lip thickness; (5) mean meat weight; (6) and illegal, unreported, and unregulated (IUU) fishing" (Medley, 2008, p. 41).

2.1.5.2.1. Queen conch management in St. Vincent and the Grenadines

St. Vincent and the Grenadines currently has several management regulations. "The Statutory Rules and Orders Act 1986, Part IV section 18 prohibits the possession of Queen Conch with a shell length of less than 7 inches (18cm) or without a flared lip, or with a total meat weight of less than 8 oz (225 g) without a digestive gland" (Government of SVG, 1990). In addition, the Ministry of Agriculture and Fisheries can establish a fishery season closure for conch if considered necessary (Government of SVG, 1990). However, such season closures have not been established to date. Furthermore, an export quota has also been implemented in this country (NOAA, 2014). Other measures have been considered since 2003, such as gear restrictions and a limited entry system, but they have not been implemented yet (CITES, 2003; Isaacs, 2014).

Even though these regulations have been established, it is very difficult to monitor and enforce them due to lack of resources. In addition, it is very likely that illegal fishing and trading of this species is still occurring, which is a high conservation concern (Theile, 2001). In order to ensure the sustainable use and the effective management of this resource, monitoring activities are crucial to determine the state of the stock, establish closed seasons, etc. (Cruickshank, 1997). Regarding data collection and monitoring, the Fisheries Division collects catch data from local markets, and from individual landing sites (CITES, 2003; Isaacs, 2014). Monthly landings reports are also generated for fishing areas within St. Vincent and the Grenadines, and sent to the Fisheries Division (K. Isaacs, personal communication, October 30, 2016). Therefore, even though a plan to collect catch, effort, and biological data does not appear to have been implemented in 2003, progress has apparently been made.

Management measures established in 1987 have not been modified due to the lack of any new recommendations for queen conch management and conservation (Isaacs, 2014). This could be due to the fact that a formal assessment of the queen conch stock and population in this area was not made until 2013. However, it is essential to ensure that current regulations in place are adequate for the management of this species considering their current threats, status, and conservation needs.

2.2. Marine Protected Areas effectiveness

Marine protected areas are important tools towards the conservation of marine wildlife, including queen conch. The establishment of such areas, as seen in the areas closure for management purposes section, could improve water quality, reduce fishing pressure, and enhance or increase the presence of suitable nursery and spawning areas. The establishment of such areas could result in long-term benefits for this species.

However, it cannot be assumed that by establishing an MPA, it will inherently result in positive impacts for the environment, and for queen conch in this case. It must be considered that MPAs are not physical barriers; therefore, the ecosystem existing within an MPA could still be exposed to pollution, temperature increase, ocean acidification, and other indirect threats (García Rodríguez, 2016). In addition, it will be necessary to ensure that the size of the MPA is adequate to meet its conservation purposes (Agardy, di Sciara, & Christie, 2011). Furthermore, even though the MPA is established, there could be a lack of compliance and/or enforcement of its regulations, resulting in a legally recognized MPA that is actually not being managed (García Rodríguez, 2016). However, if effectively managed, MPAs have been proven to reduce anthropogenic impacts to marine ecosystems, and increase biodiversity, biomass, and ecosystem health (Halpern & Warner, 2002; Claudet, Pelletier, Jouvenel, Bachet, & Galzin, 2006).

To date, only 2.2% of the world's oceans are protected (MPAtlas, 2016), and only about 33% of these MPAs might be truly effective (Pomeroy, Watson, Parks, & Cid, 2005). However, marine protected areas effectiveness is rarely evaluated after their designation (Selig & Bruno, 2010). This results in a lack of information regarding the effects that MPAs really have on the ecosystems they aim to protect (García Rodríguez, 2016). It is essential to assess the effect that all implemented MPAs have on marine ecosystems and human activities to ensure they are achieving their conservation goals. Otherwise, "we will continue investing in conservation measures with unclear results at a time where effective marine management and protection are urgently required" (García Rodríguez, 2016, p. 1).

It is important to recognize that the effectiveness of MPAs needs to be evaluated in a case-by-case study. Each MPA has a specific context with specific threats impacting the area, human activities, vulnerability, needs for conservation, etc. (García Rodríguez, 2016). Therefore, assessments should be conducted at an individual scale to conclude if management improvements or other conservation measures are necessary for that particular area (Selig & Bruno, 2010).

2.2.1. Measuring MPA effectiveness

MPA effectiveness can be defined as "the degree to which management actions are achieving the goals and objectives of the protected area" (Pomeroy et al., 2005). However, there are many ways of measuring how management actions are achieving conservation goals. These actions and goals can refer to ecological parameters (effect on the biota, food webs, etc.), governance (compliance, enforcement, planning, etc.), social (stakeholders awareness, equity, etc.), or others (Pomeroy et al., 2005). Therefore, there is a need to specify the set of parameters that are being considered to measure effectiveness when conducting such assessment (García Rodríguez, 2016).

Due to the wide variety of indicators that can be measured to evaluate MPA effectiveness, there is a wide variety of protocols that can be used to evaluate MPAs. No standard method has been recognized to date, and thus the MPA effectiveness evaluation will vary among MPAs (García Rodríguez, 2016). Currently, some management plans and monitoring protocols mainly include ecological indicators, while others also include socio-economic, and governance indicators. In addition, some protocols include the monitoring of areas outside the MPA to test the real effect that the MPA is having, while other methodologies only focus in the habitat included within the MPA borders. Finally, some protocols include information prior to the MPA establishment, while others only include data for the indicators after the MPA was established (García Rodríguez, 2016).

An essential step in the implementation of MPAs is the development of monitoring and evaluation activities, so data collected can be analyzed in order to understand the MPA capacity to meet the conservation goals stated on its management plan. Only by conducting effectiveness evaluations, can the real effect of MPAs in the marine environment be known. Currently, lack of data collection and analysis, lack of funding for monitoring, lack of adequate equipment and human resources, etc. can be major challenges to assess the effect of MPAs. If these challenges are not overcome, this can result in poor or nonexistent MPA management, and the inability to achieve the planned conservation goals. In order to overcome these challenges, it is important to create strategies in which an annual budget for MPA management can be secured and the staff number is adequate to do the required management activities (García Rodríguez, 2016). In addition to securing an annual budget, management strategies, including monitoring methods, should be developed accordingly to the budget available. Thus, monitoring and management activities could be conducted continuously (R. Mahon, personal communication, January 5, 2017).

2.2.2 Tobago Cays Marine Park effectiveness

The Tobago Cays Marine Park (TCMP) is a marine protected area located in the southern area of St. Vincent and the Grenadines, and it is part of the focus area of this research (Figure 5). This area is regulated under the St. Vincent and the Grenadines National Parks Authority, and managed by the Tobago Cays Marine Park as a statutory body. In addition, regulations and laws are implemented by the Tobago Cays Marine Park (Hoggarth, 2007). The effectiveness of the TCMP has been previously assessed by using the scorecard developed in 2004 by the World Bank with some modifications (García Rodríguez, 2016). But, in order to understand its challenges and success, it is important to consider its context.

The TCMP was designated as a conservation area under the Fisheries Regulations in 1987 while the Tobago Cays were under private ownership, but it was not until 1997 that the Marine Park was designated under the Marine Parks Act of St Vincent and the Grenadines. The regulations to manage the TCMP were submitted in 1998, and a year after, the Cays were purchased by the Government of St. Vincent and the Grenadines (Hoggarth, 2007; UNEP, 2014).

The Park was originally proposed in 1986 for increasing tourism within the Grenadines. Currently, the Tobago Cays are crucial to the economy of the Grenadines since they are the most popular destination for marine tourism in the region (Hoggarth, 2007; UNEP, 2014). Therefore it seems that their original tourism-oriented goal has been reached. However, it appears that the carrying capacity of the park has not been estimated or considered since the park was created, which is essential to determine for its sustainable use. According to the United Nations Environment Program (UNEP) and the TCMP Management Plan of 2007, the TCMP objectives can be summarized as: (1) Enhance conservation and management of biological diversity of the area; (2) Sustain economic benefits from the use of existing natural resources; (3) Increase public awareness of environmental issues and create a strong resources management system; and (4) Contribute to public education to increase engagement and achieve the objectives of the management plan.

However, the TCMP had major management problems since its creation. For instance, the boundaries of the MPA were not agreed until 2006, when the park was relaunched. In addition, the only management plan that has been implemented was created

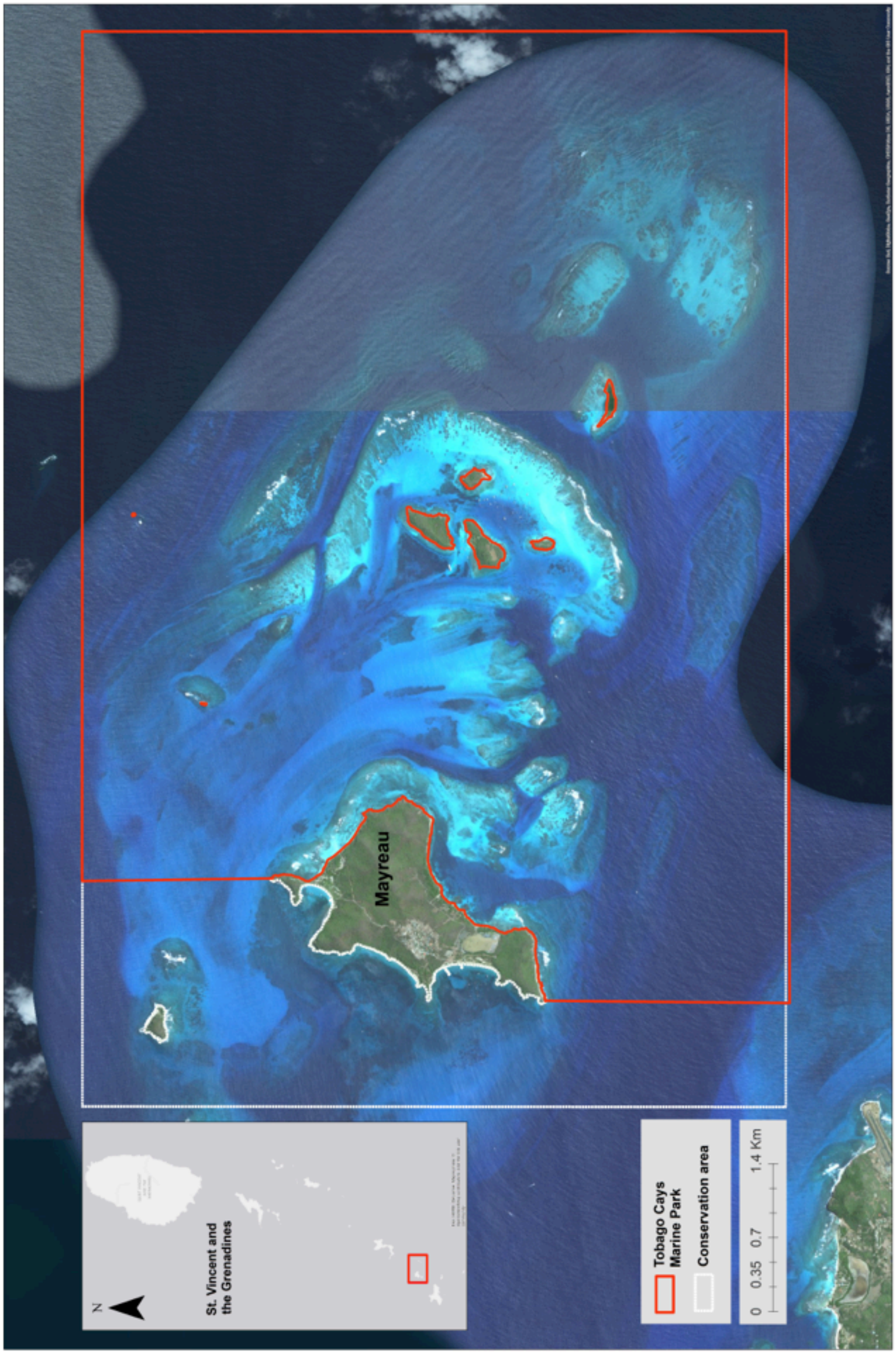

Figure 5. Satellite map of the Tobago Cays Marine Park.
The boundaries of the Park are shown with a red line. The dashed white line, which covers the entire TCMP and the west side of Mayreau Island, shows the zone considered as conservation area. This map was created using ArcGIS software.

in 2007, ten years after its designation, and could be currently out of date. Furthermore, not all objectives have been fully implemented (García Rodríguez, 2016). Due to its initial tourism increase purposes, major threats to the marine environment were not assessed until 2006. Therefore, unsustainable human activities were probably not being controlled before that time (García Rodríguez, 2016). Finally, a consistent and continuous monitoring program does not exist; and even though there is external collaboration, there is a lack of funding, capacity, and human resources (García Rodríguez, 2016).

Although there seem to be many gaps and challenges in the implementation of this MPA, it has made many improvements since it was first established. Currently, the legal status, regulations, boundary demarcation, enforcement, and stakeholder awareness have improved. In addition, the current visitor fees system provides this MPA the capacity to conduct many management activities regardless of external funding (Hoggarth, 2007; García Rodríguez, 2016). For queen conch conservation purposes, it is important to determine if this MPA is specifically contributing to conch protection. To contribute to this need, the effect of the TCMP was assessed in this study using biological indicators, and measuring these indicators inside and outside the TCMP, as well as over time in this research.

Chapter 3. Methods

This chapter provides information on the area of study of this research, as well as the procedures that were followed to measure queen conch abundance. In addition, the methodologies followed to determine the survey sites as well as the underwater surveys are described. Finally, how the data was collected, processed and analyzed to meet the purposes of this research are explained.

3.1. Study area

The Grenadine Islands are a chain of volcanic islands in the West Indies, located in the southeastern Caribbean Sea. The Grenadines rest on a narrow submarine ridge known as the Grenada Bank (Adams, 1978). They are a transboundary island chain shared by SVG and Grenada. This study was conducted in St. Vincent and the Grenadines, where there are 32 islands and Cays, of which some are privately owned (O. Joseph, personal communication, July 12, 2016). Current queen conch abundance was measured in Union Island and the Tobago Cays Marine Park (TCMP) due to their strong relation to this fishery for the past decades (Hoggarth, 2007).

The study area comprises 226 km^2 (Figure 6), and it was selected considering previous concerns about the Union Island conch stocks and due to the interest of assessing the effect of the TCMP on this species. Therefore, the study area comprised both Union Island and the Tobago Cays Marine Park, located at the southernmost edge of the SVG territory (Figure 6). Union Island is the third largest island within the Grenadines island chain (Adams, 1978). In 2012, the SVG government estimated a total of 2096 inhabitants in the island (The Census Office, 2012). Union Island is a major tourism hotspot due to its central location and the proximity to the Tobago Cays (Adams, 1978). The TCMP, which is also a major tourism destination, is a 53 km^2 MPA that comprises the east side of Mayreau Island, five uninhabited Cays (Petit Bateau, Petit Rameau, Baradel, Jamesby, and Petit Tabac), and the surrounding marine area (Hoggarth, 2007). According to the SVG Census Office, in 2012 Mayreau had an estimated population of 271 inhabitants (The Census Office, 2012). The study area includes many types of coral reefs, sea grass beds, and patches of endangered mangrove ecosystems (Hoggarth, 2007; UNEP, 2014). More information regarding the habitat types of the study area can be found in Figure 7.

3.2. Survey design

The management of the conch fishery requires data of specific parameters for adequate decision-making. The focus of this study is to contribute to this need for informed decision-making by measuring conch density, size, and shell lip thickness using underwater surveys.

In order to design an effective survey plan, a stratified random sampling approach was conducted (Prada et al., 2013). Three different criteria based on conch distribution were considered to determine the survey area. Since conch is mostly distributed among depths from 0 to 30 meters (Medley, 2008), the bathymetry of the area was included as a criterion. In addition, the bottom type was also considered due to conch preferences for sandy and seagrass habitats (Appeldoorn et al., 2011). Finally, participatory mapping was conducted among the fishermen and local community of Union Island to include local knowledge on conch distribution as the third stratum (Figure 8).

Participatory mapping involved seven fishermen, two members of the local community, and four members of the Tobago Cays Marine Park. A satellite map of the study area was presented to all 12 participants (Figure 6), and they were asked to draw, to the best of their knowledge, conch distribution within the study area.

Considering the size of the study area, its depth characteristics (relatively shallow), and the limit for safe recreational diving (25m), surveys were planned only in areas from 0 to 20 meters depth. In addition, only sandy, seagrass, and mixed bottom habitats were considered as suitable for conch surveys. A habitat map of the study area (Figure 7) was combined with the results of participatory mapping (Figure 8), and bathymetry maps (Figures 9 and 10) in order to obtain the final area to conduct underwater surveys inside the study area. The navigational application Navionics was used to obtain the bathymetry maps of the area outside the TCMP, while an already available map was used for the area inside the TCMP (Figure 9).

Once the final survey area was determined (Figure 11), due to time and capacity constraints, a grid was applied to randomly select 12 survey sites with an online number

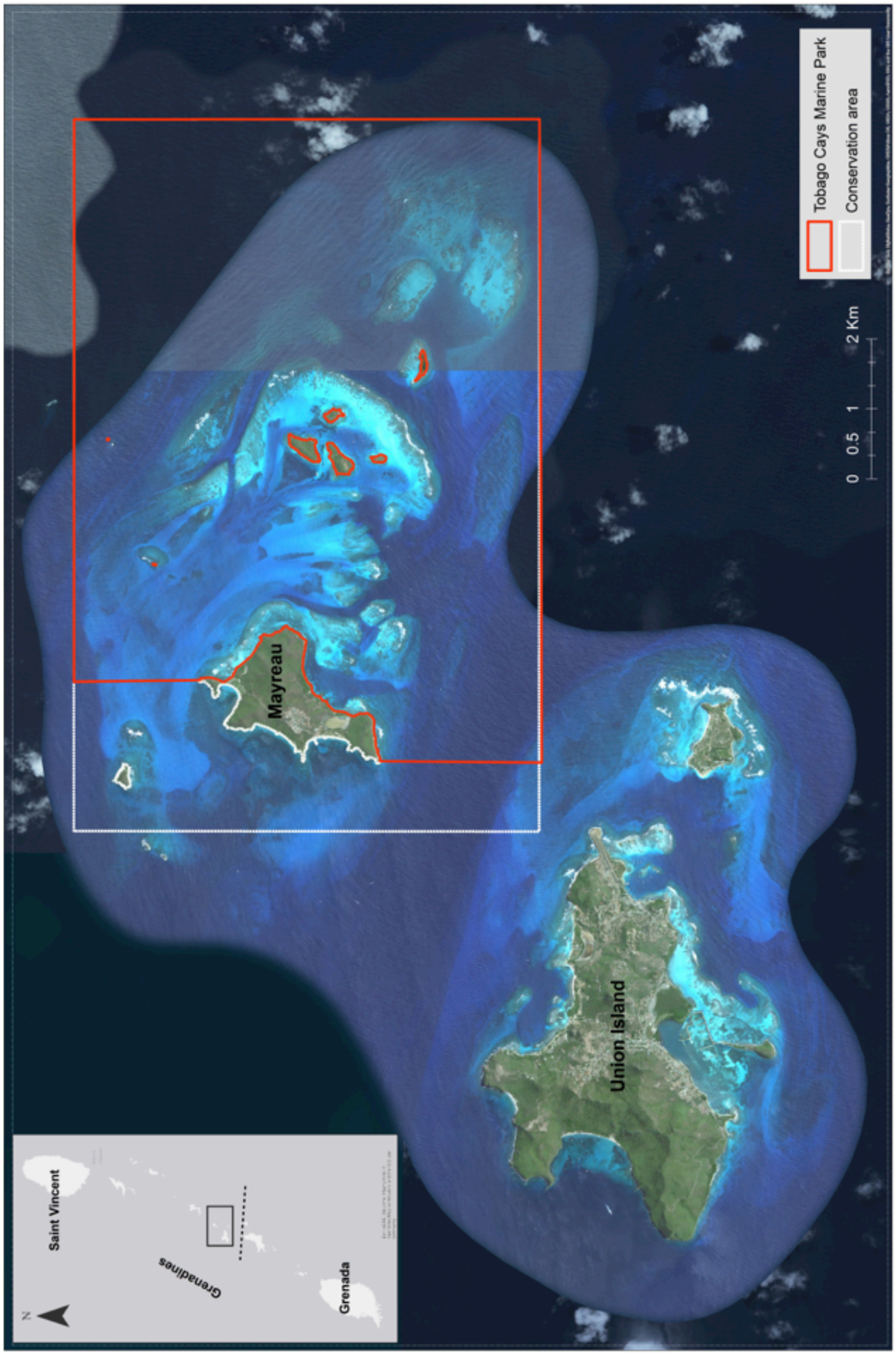

Figure 6. Satellite map of the study area.
The boundaries of the Tobago Cays Marine Park are shown with a red line. The dashed white line, which covers the entire TCMP and the west side of Mayreau Island, shows the zone considered as conservation area. Union Island is located outside the boundaries of the protected area, in the bottom left corner of the study area. This map was created using ArcGIS software.

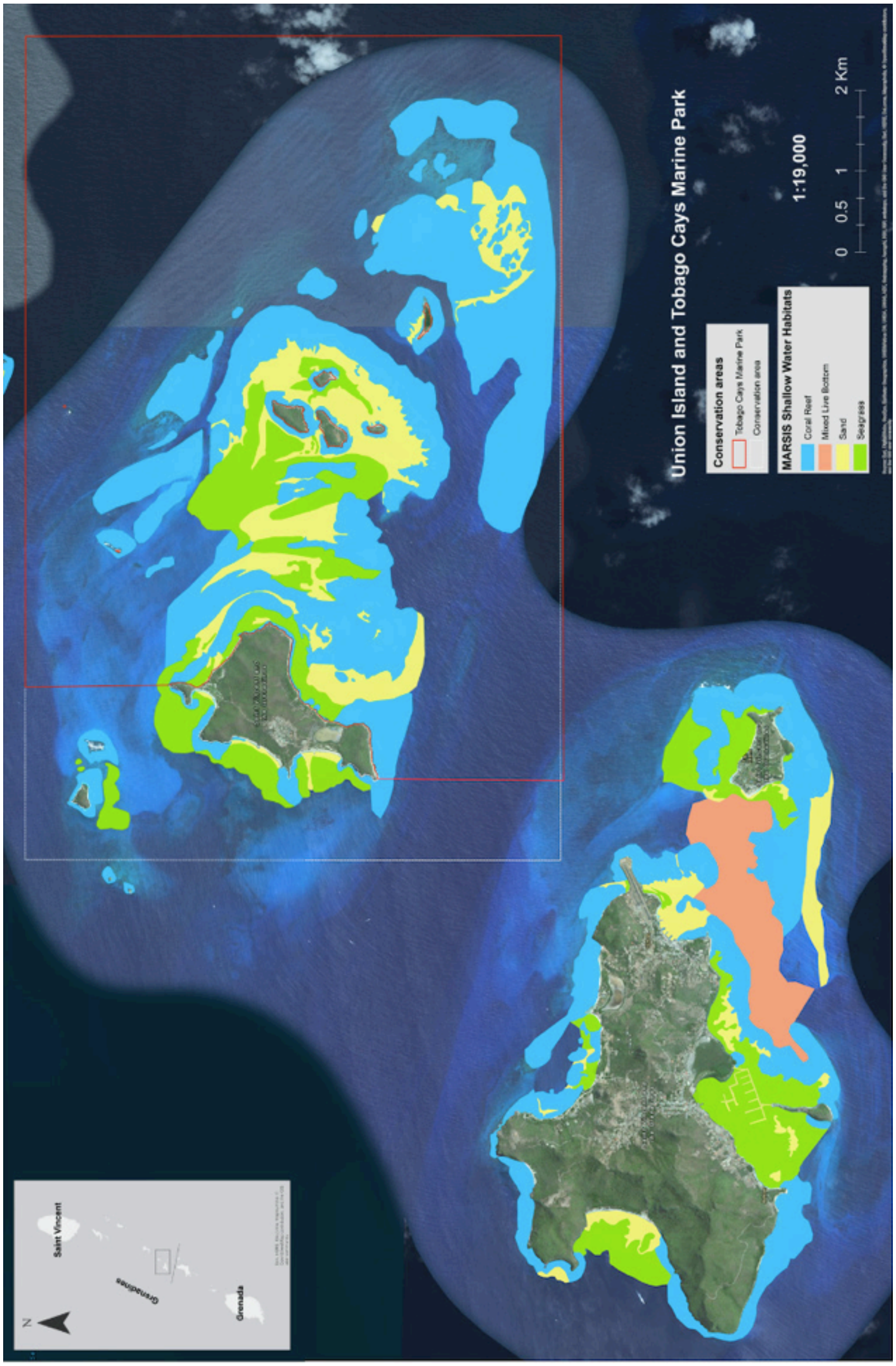

Figure 7. Satellite image of the study area with habitat types for shallow waters.
Shallow water habitats (from 0-20 meters) information was included from GIS MarSIS data (K. Baldwin, 2012). Blue color represents coral reefs, orange represents mixed bottom habitats, yellow represents sand habitats, and green represents seagrass habitats. The boundaries of the Tobago Cays Marine Park are shown with a red line. The location of the study area within the Grenadines can be found on the upper left corner. This map was created using ArcGIS software..

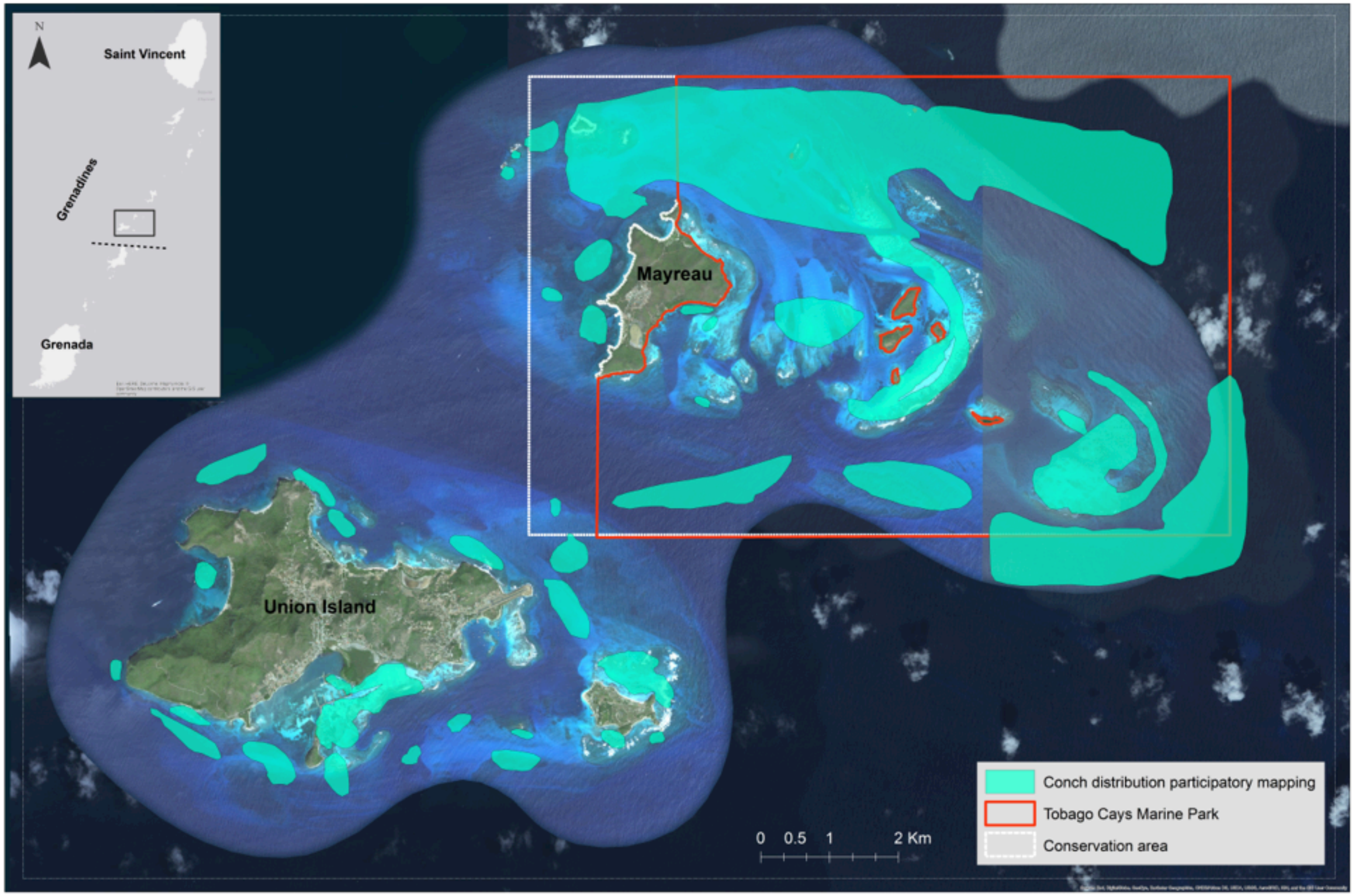

Figure 8. Participatory mapping results regarding conch distribution in the study area.
Satellite map of the study area (Figure 6) in which the turquoise color represents the areas identified by the fishermen and members of the local community as queen conch distribution area. Traditional knowledge information was digitalized into ArcGIS to create this map.

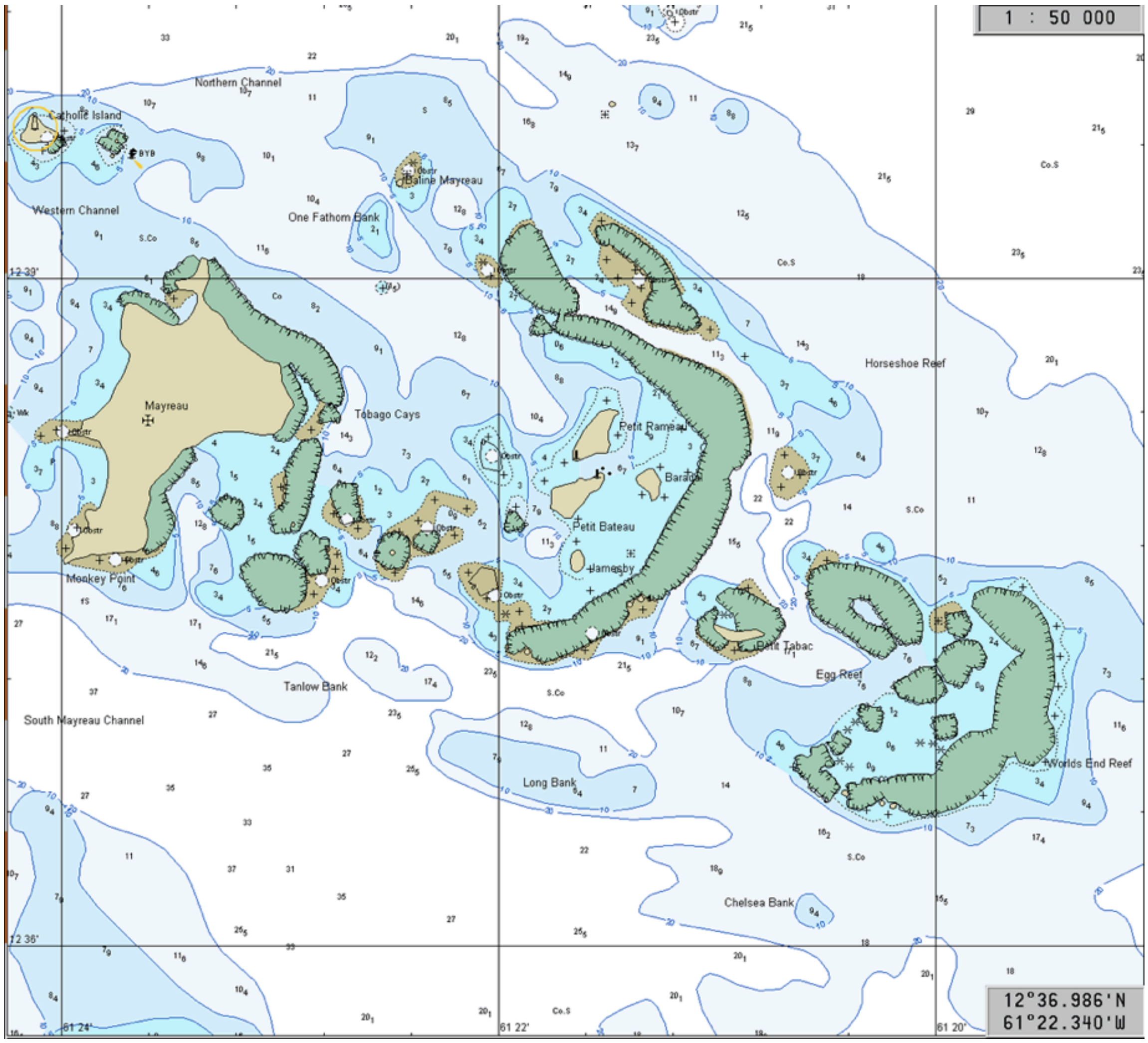

Figure 9. Bathymetric map of the Tobago Cays Marine Park and surrounding area. Map source: (Turnbull, 2016).

Figure 10. Example of the bathymetric maps that were used to obtain depth information for the study area not included in Figure 9.

The nautical navigation application Navionics was used to obtain these maps. This particular example shows most of the north area of Union Island and the waters surrounding it.

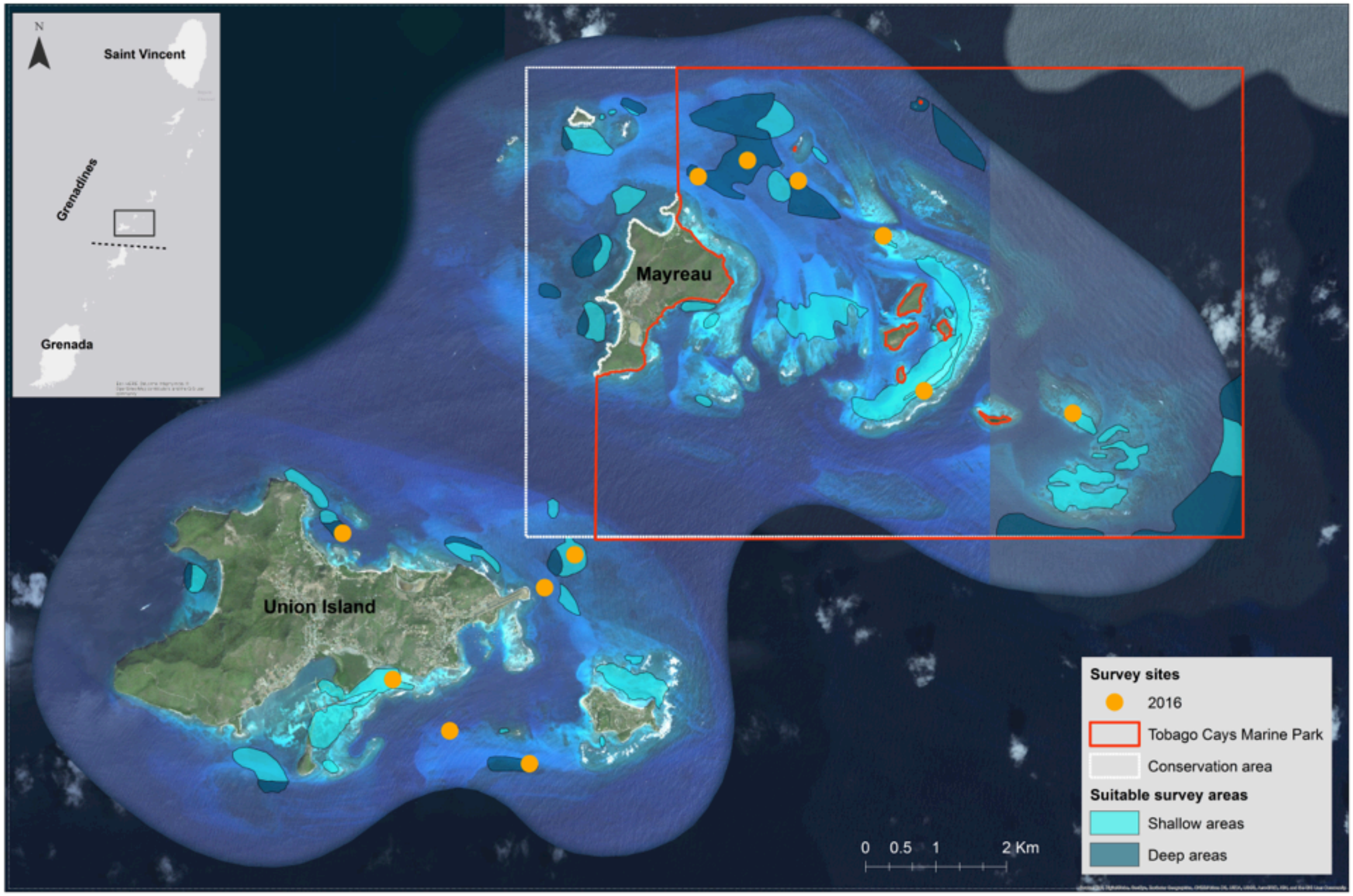

Figure 11. Survey sites map using the satellite map (Figure 6) as the baseline.
This map is the result of the combination of the habitats map, the bathymetric maps, and the participatory mapping map. Colored areas in the map show areas matching the three criteria (suitable conch habitat, depth from 0 to 20 meters, and current conch distribution according to participatory mapping). Light blue areas indicate shallow areas (from 0 to 10 meters), and dark blue areas indicate deeper areas (from 10 to 20 meters). Survey sites selected in 2016 are marked with an orange circle.

randomizer. The coordinates of each selected site were obtained during that process. The area on the west side of Mayreau Island currently considered as a conservation area was not included to avoid bias regarding protection level. Six surveys were conducted inside the park (three surveys in a depth range of 0-10 meters and other three surveys in a depth range of 10-20 meters), and six surveys were conducted in the waters around Union Island (three surveys in a depth range of 0-10 meters and other three surveys in a depth range of 10-20 meters) (Figure 11).

3.3. Underwater surveys and data collection

Each underwater survey conducted was carefully planned following diving safety measures and using a dive planner (PADI, 2003). The depth of each survey site, the time spent to conduct each survey, and the required surface interval were considered before and during the monitoring activities. During each monitoring day, three survey sites were sampled considering their depth and using dive profiles (PADI, 2006). Diving activities were conducted from 17 July 2016 through 23 July 2016.

The survey sites were accessed with the TCMP Rangers 7 m patrol boat and located using a GPS (Garmin interface, Map Datum: WGS 84). Once the sites were located, a demarcation buoy was deployed to signalize the start point of all four transects when underwater. The underwater survey protocol was based on belt transects (also known as band transects), and included four transects of 30 m length (north, west, south, and east of the deployed buoy), and two meters wide on each side (each transect was four meters wide in total) (Figure 12) (Medley, 2008). All conch found inside the transects (or on their borders) were measured. Belt transects of the described characteristics resulted in a total of 0.48 km^2 surveyed per survey site (30m x 4m x 4), and a total of 5.76 km^2 were surveyed within the entire study area.

In order to conduct the belt transects, four members of the monitoring team divided tasks. One person was in charge of laying and recovering the 30 m fiberglass tape. Another member of the team was in charge of carrying a 1m PVC pipe to measure the transect width in combination to that person arm's length. Finally, an underwater notebook to record the data collected and the calipers to measure conch's physical parameters were carried by the

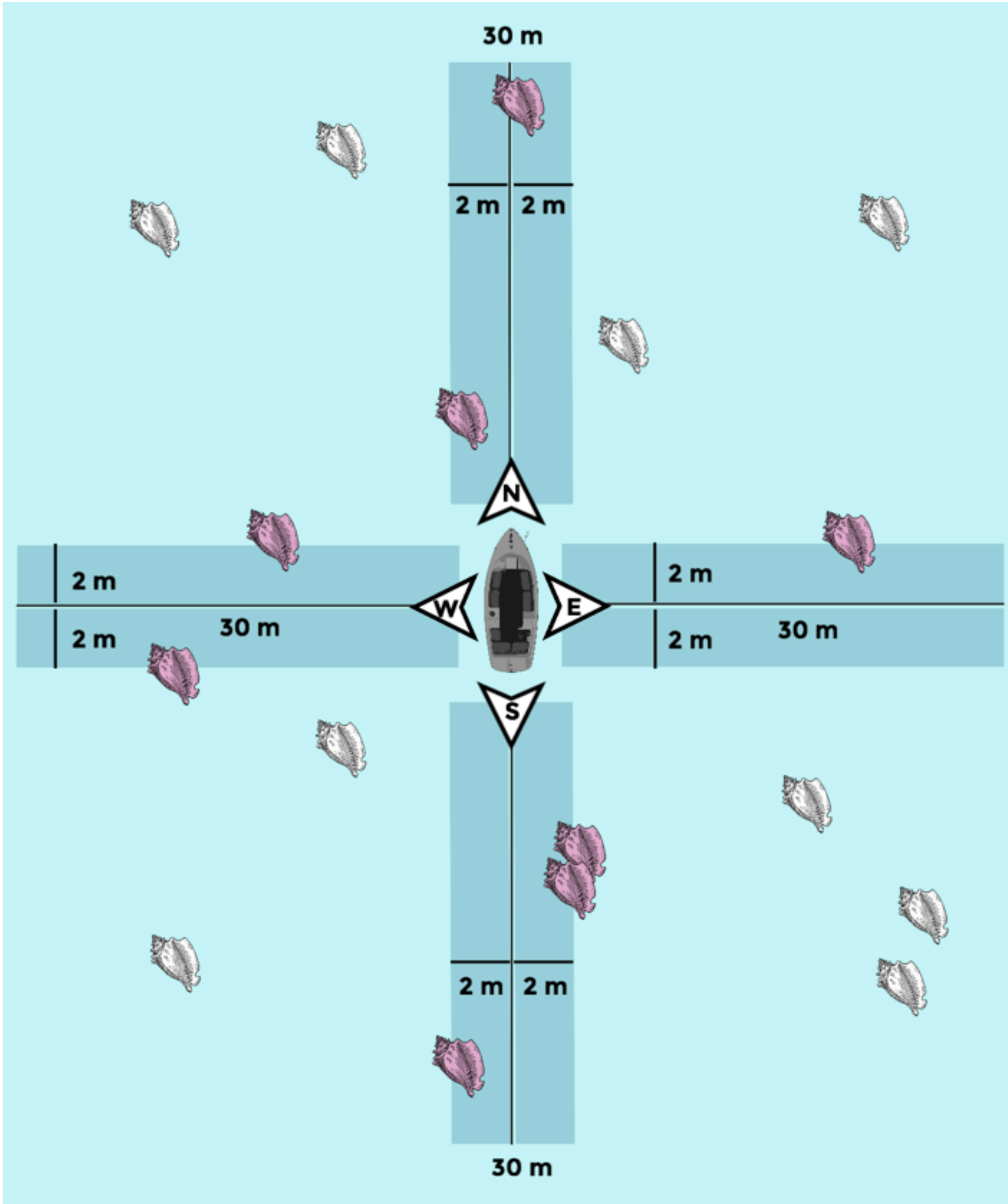

Figure 12. Diagram of the survey protocol followed at each sample site.
Four transects of 30m length and 4m width each (darker blue color) were sampled at each survey site. All queen conch inside the delineated transects (including conch found on the border of the transect) were counted and measured (pink conch), while conch outside the transects were not considered (white conch). The four transects were laid considering the deployed buoy (boat image) as reference.

other two members of the team.

The two recorded conch physical parameters were shell length (from the siphon to the end of the spiral using a large caliper), and lip thickness (with a small caliper in the closest place to the last spire of the shell) (Figures 13 and 14) (Prada et al., 2013). Besides measuring conch abundance and their physical characteristics, other data was recorded during the surveys. The depth, sea state, wind speed, current presence, habitat type, visibility, weather, and any anomalies encountered were also recorded for each survey site. All data were recorded in the underwater notebook then transferred to a personal computer using Microsoft Excel.

3.4. Data analysis

The data gathered during the 12 underwater surveys was analyzed to obtain the density of conch in the study area. In addition, statistical analyses were conducted to determine the effect of the TCMP with respect to conch protection, changes in abundance over time in the study area and the effect of other factors such as depth and maturity level. Shell length and lip thickness were used to categorize conch according to their maturity level. Conch with lip thickness less than 4 mm and shell length less than 20 cm were considered juveniles, while conch with a lip thickness greater than 4mm and shell length greater than 20 cm were considered adults (Egan, 1985; Clark, Danylchuk, & Freeman, 2005; Prada et al., 2013).

In order to compare over time, data from the study conducted in 2013 by Prada et al. (2013) was obtained from their report. In that study, 51 sites were surveyed, and therefore there was a large difference in the sample size from both studies. In order to avoid differences in the sample size, only the closest and more similar in depth 12 surveys sites' data from the Prada et al. study were considered. Using this approach, conch data obtained in 2013 and 2016 was comparable, as Prada et al. 2013 used the same sampling methodologies. The closest 12 surveys sites were determined by measuring the distance between the 2016 surveys sites and all surveys sites sampled in 2013. The selected sites for comparison, and all sites surveyed in 2016 can be found in Table 3 and Figure 15.

In addition, the study conducted in 2013 also considered the MPA existent in Union Island and Palm Island as a measure of protection. Even though the Union-Palm MPA was

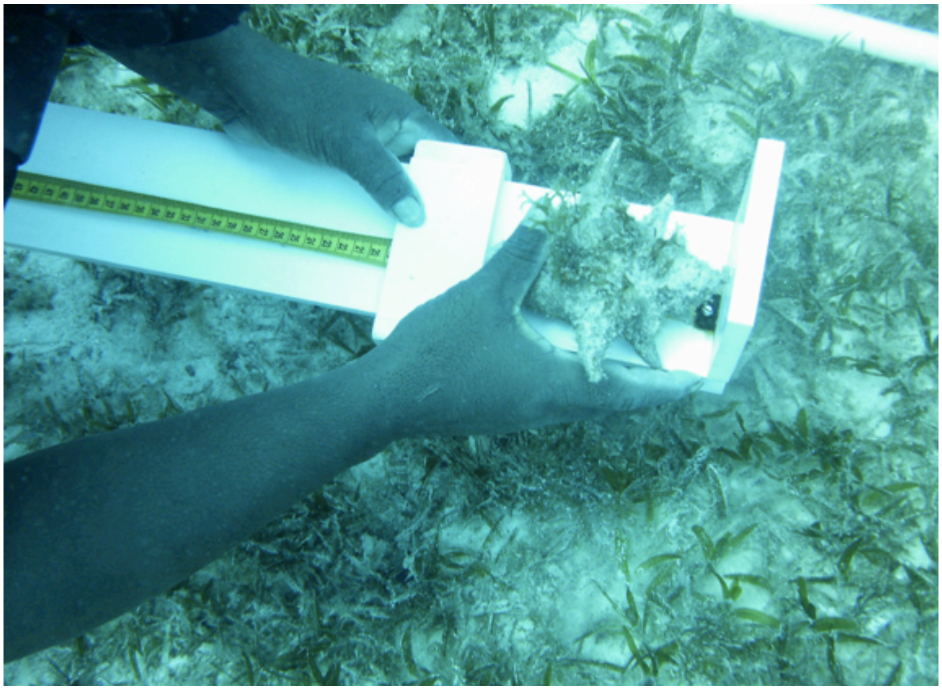

Figure 13. Large caliper used to measure the conch's length.
Each conch encountered was positioned on the caliper, and the total length was obtained by placing the measuring board as close to the shell's siphon as possible. Afterwards, the conch was removed and the corresponding length was recorded in centimeters.

Figure 14. Vernier caliper used to measure the conch's lip thickness.
The vernier caliper was placed on the closest point of the lip to the shell's last spire. Total lip thickness was recorded in millimeters.

designated in the late 80's, it has never been enforced or managed as an MPA (M. Phillips, personal communication, May 4, 2016), and therefore it was not considered as a measure of protection in this study. In fact, most people from the local community inhabiting Union Island are not aware of the presence of this MPA (SusGren, 2016). Only the TCMP was considered as a functional MPA in this study, and therefore comparisons with levels of protection only included the TCMP. Taking that into consideration, survey sites outside the TCMP sampled in 2013 were all considered as not protected when conducting statistical analysis and comparisons.

3.4.1. Conch density and abundance

The total density of conch in the study area was obtained by calculating the total area surveyed and the amount of conch encountered within that area. The total area sampled in the study area was 5,760 m^2 (0.576 hectares), with an equal area surveyed inside and outside the TCMP. Conch density inside the TCMP was obtained using the total area sampled

Table 3. Selected survey sites for 2013 and 2016 with their respective coordinates and the distance between them.

	2013			2016			Distance
	Name	Latitude	Longitude	Name	Latitude	Longitude	
TCMP	UP09	12.64685	-61.3247	3SI	12.645644	-61.363262	0.2057 km
	UF02	12.63541	-61.3176	2SI	12.626548	-61.357898	0.9859 km
	UF34	12.61903	-61.3296	1SI	12.624538	-61.339401	0.6128 km
	UF06	12.64976	-61.357	1DI	12.653097	-61.373562	0.5358 km
	UP17	12.65513	-61.379	2DI	12.652767	-61386348	0.8394 km
	UF03	12.64489	-61.4056	3DI	12.655269	-61.380211	1.258 km
Union Island	UP36	12.59005	-61.3713	3SO	12.590374	-61424846	0.3865 km
	UP26	12.60356	-61.4027	1SO	12.601693	-61.405255	0.3464 km
	UP15	12.59458	-61.4481	2SO	12.607054	-61.401135	1.981 km
	UP20	12.60944	-61.4113	1DO	12.608678	-61.429991	0.5482 km
	UF19	12.57997	-61.3789	3DO	12.580343	-61.407873	0.1189 km
	UF25	12.58499	-61.3735	2DO	12.584385	-61.418645	0.5312 km

The coordinates are expressed in decimal degrees and were obtained with the WGS 84 map datum. The TCMP rows include the sites that were inside the TCMP Marine Protected Area, while the Union row includes the sites that were outside the protected area.

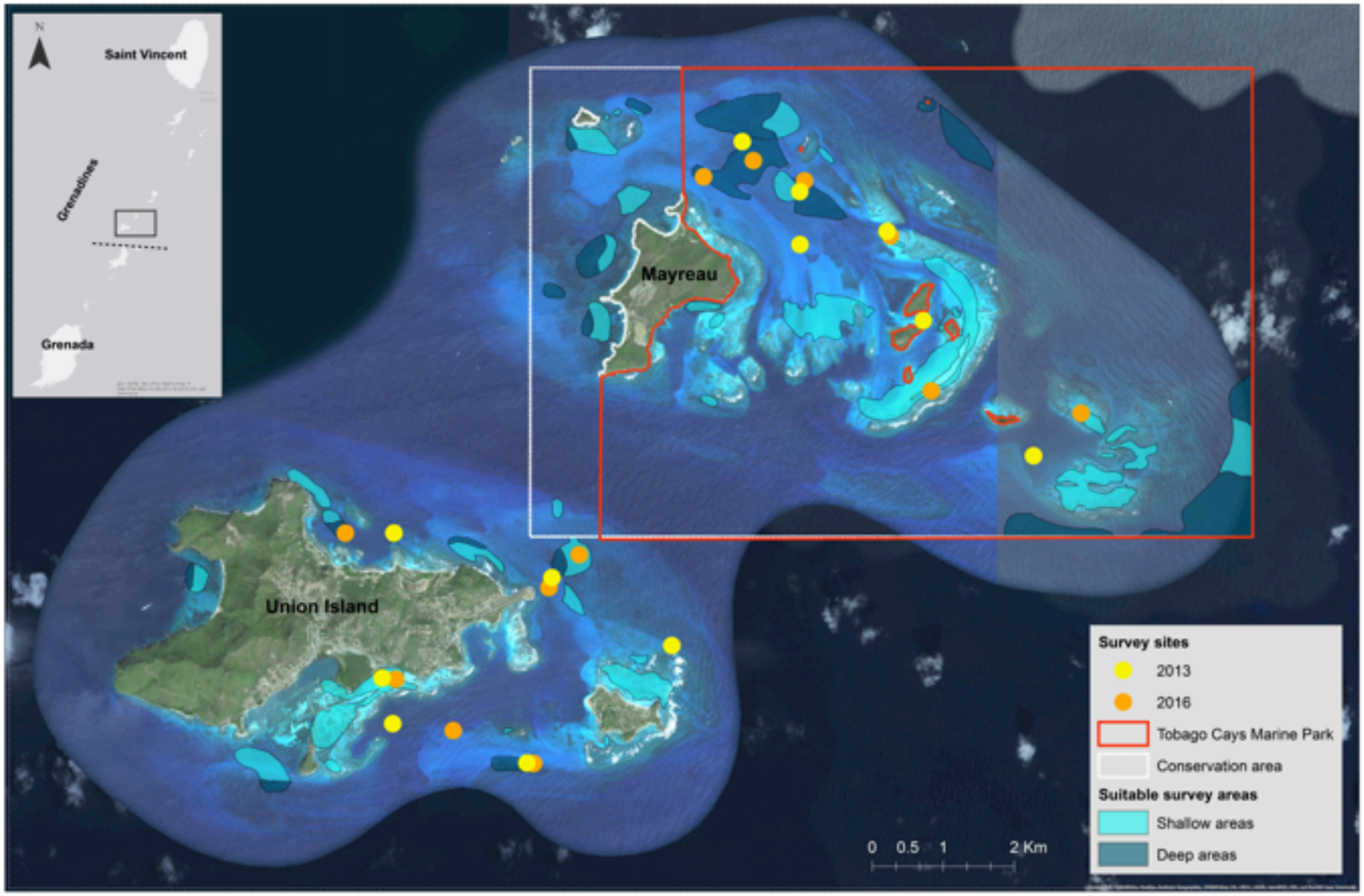

Figure 15. 2013 and 2016 survey sites selected for the over-time comparison.
This map shows Figure 11 with the addition of the 2013 selected surveys sites, represented with the yellow circles. Survey sites sampled in 2016 are marked with an orange circle.

within its boundaries (0.288 hectares). The same procedure was used (amount of conch encountered within the sampled 0.288 hectares) to obtain conch density in the Union area (outside the marine protected area).

Total conch density, as well as conch density inside and outside the TCMP was also obtained for 2013 following the same procedure (total conch abundance in 0.576 ha, and specific conch abundance in 0.288 ha), and by analyzing the selected data published by Prada et al. in their report (Prada et al., 2013).

Using the statistical software SPSS, multiple analyses were conducted to test significant differences on the abundance of conch in the study area. These included: (1) Conch abundance based on maturity in 2016 and 2013; (2) Conch abundance at depth in 2016 and 2013; and (3) Conch abundance over time in the study area during the period 2013 to 2016. In order to conduct these comparisons, Shapiro-Wilk normality tests were used to obtain information on the distribution of the data. Due to the reduced sample size and the distribution pattern of this species, the data did not follow a normal distribution for any of the above-mentioned tests. Therefore, non-parametric analyses were conducted. Specifically, the Wilcoxon signed-rank test was used to conduct pairwise comparison among groups.

3.4.2. TCMP performance

In order to test the effectiveness of the Tobago Cays Marine Park towards conch protection in 2016, conch abundance found inside the Park was compared to conch abundance found outside. In addition, this comparison was also made using the data obtained in the 2013 study, and over time to determine if conch abundance significantly changed during this three-year period. Maturity level was also considered as a factor in these analyses. Using the statistical software SPSS, Shapiro-Wilk normality tests showed lack of normality distribution in the data, and therefore the Wilcoxon signed-rank test was again used to conduct pairwise comparison among groups.

Chapter 4. Results

This chapter provides the information regarding the conch density and abundance found in 2016, as well as in the 12 surveys selected from 2013. The results obtained from both years were compared, and the effect of the MPA, depth, and maturity stage on conch abundance was tested.

4.1. Conch density

A total of 21 individuals were found during the surveys in 2016, 12 of them (57%) were juveniles, while 9 of them (43%) were adults. Conch density found in the study area was 36.5 ind/ha in total, 20.8 juveniles/ha, and 15.6 adults/ha. Of the conch found, 16 individuals were encountered inside the TCMP (77%), while only 5 (24%) were encountered outside the TCMP. Interestingly, no adults were found outside the TCMP. Higher densities of conch were found in deeper areas (52.1 ind/ha in total), both for juveniles and adults. In shallow areas, the density was lower (20.8 ind/ha in total), and the proportion of adults and juveniles was equal (Table 4) (Figure 16).

In 2013, considering only the 12 selected survey sites, a total of 91 individuals were found. Of these, 66 (73%) where juveniles and 25 (27%) adults. Conch density in 2013 was 157.9 ind/ha in total, 114.6 juveniles/ha, and 43.4 adults/ha (Table 4) (Figure 16). Of the conch found at these 12 sites in 2013, 25 individuals were counted inside the TCMP (27%), while 66 (73%) were counted outside the TCMP. In 2013, higher densities were also found in deeper areas (239.6 ind/ha in total), when compared to shallow areas (76.4 ind/ha in total). Interestingly, the proportion of adults and juveniles was also equal in shallow areas in 2013. Further density and abundance information can be found in Table 4 and Figure 16. All conch abundance data for each surveyed site in 2013 and 2016, as well as depth and protection details regarding each particular site, can be found in Table 5.

Physical parameters information of each conch found during the surveys conducted in 2016 (lip thickness and shell length), as well as their classification by maturity level, can be found in Table 6.

Table 4. Abundance and density results for the 12 selected surveys of 2013 and all 2016 surveys, in total and also by maturity level, protection level, and depth.

		2013					2016				
		Study Area	TCMP	Union Island	Shallow	Deep	Study Area	TCMP	Union Island	Shallow	Deep
Abundance (Individuals)	Juveniles	66	16	50	11	55	12	7	5	3	9
	Adults	25	9	16	11	14	9	9	0	3	6
	Total	91	25	66	22	69	21	16	5	6	15
Density (Ind/ha)	Juveniles	114.6	55.6	173.6	38.2	190.9	20.8	24.3	17.4	10.4	31.3
	Adults	43.4	31.3	55.6	38.2	48.6	15.6	31.3	0	10.4	20.8
	Total	157.9	86.8	229.2	76.4	239.6	36.5	55.6	17.4	20.8	52.1

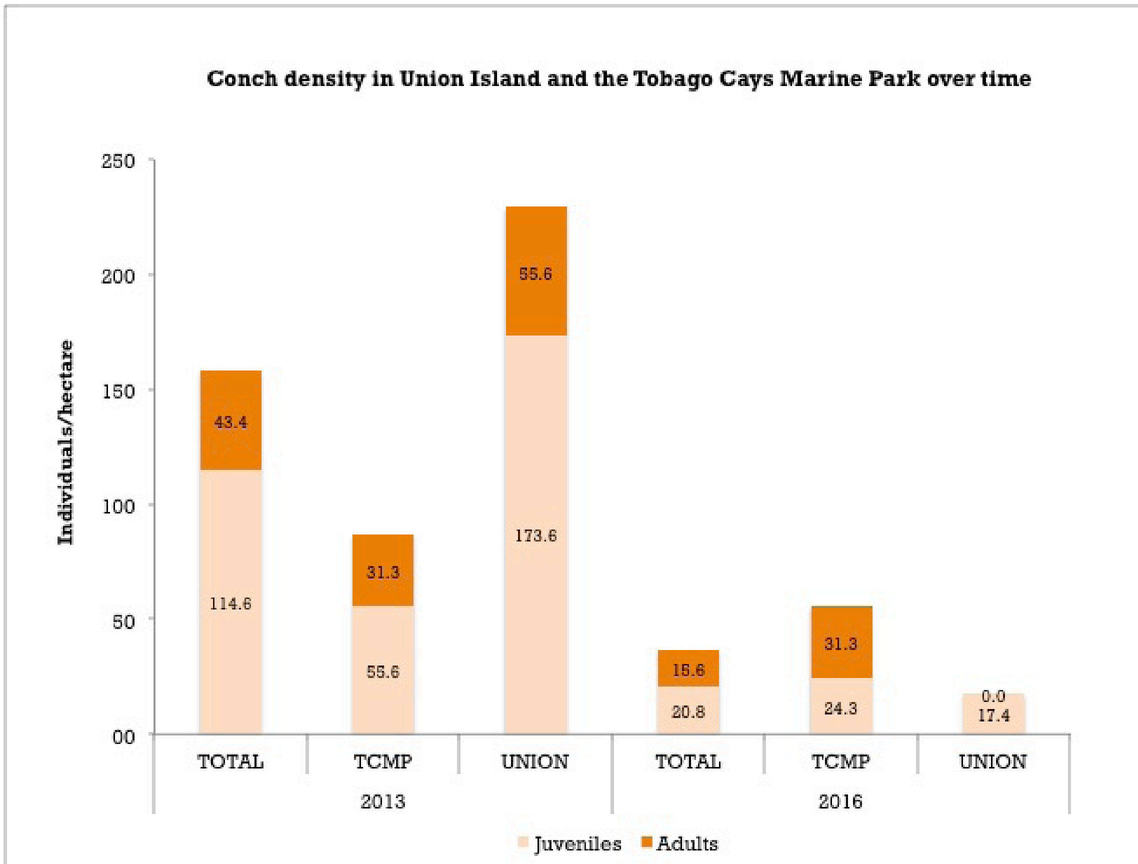

Figure 16. Comparison of conch density in 2013 and 2016 using the 12 selected survey sites in 2013 and all 12 sites surveyed in 2016.

4.2. Conch abundance

Multiple statistical tests were conducted to obtain further information regarding abundance in the study area. Results showed that in 2016 there was no significant difference between the total abundance of juveniles and adults. In addition, even though the total abundance of juveniles was higher in comparison to the total abundance of adults in 2013, that difference was not significant either. The inclusion of the depth as a factor did not show any significant differences in regards to conch abundance in 2016 or the surveys selected from 2013. Results showed that no significant difference regarding conch abundance was found in the study area over time (Figure 17), depending on the depth, or regarding the maturity stage. All hypotheses tested and significance obtained can be found in Appendix 1.

Table 5. Data obtained for each survey site.

Year	Site Identifier	Total # of individuals	Maturity Level		Depth (m)	Protected area status
			Juveniles	Adults		
2013	UF02	0	0	0	3.1	Yes
2013	UF03	7	7	0	10.3	Yes
2013	UF06	5	1	4	11.1	Yes
2013	UF19	0	0	0	10	No
2013	UF25	0	0	0	16.8	No
2013	UF34	2	0	2	7.7	Yes
2013	UP09	4	1	3	10.6	Yes
2013	UP15	1	0	1	12.2	No
2013	UP17	7	7	0	9.0	Yes
2013	UP20	13	4	9	9.0	No
2013	UP26	52	46	6	11.5	No
2013	UP36	0	0	0	1.8	No
2016	1DI	6	6	0	18	Yes
2016	2DI	1	1	0	12	Yes
2016	3DI	6	0	6	11	Yes
2016	1SI	0	0	0	3	Yes
2016	2SI	0	0	0	2.5	Yes
2016	3SI	3	0	3	8	Yes
2016	1DO	0	0	0	20	No
2016	2DO	0	0	0	12	No
2016	3DO	2	2	0	11	No
2016	1SO	3	3	0	9	No
2016	2SO	0	0	0	8	No
2016	3SO	0	0	0	1	No

Table 6. Queen conch physical parameters for each individual found in the 2016 surveys.

Site Identifier	Shell length (cm)	Lip thickness (mm)	Maturity Level Classification	
			Juvenile	Adult
1DI	13.5	1	X	
1DI	11.2	0.5	X	
1DI	13.3	1	X	
1DI	13.7	1	X	
1DI	14.8	1	X	
1DI	13.9	1	X	
2DI	9.9	1	X	
3DI	22	10.4		X
3DI	21.9	20		X
3DI	22.5	10.3		X
3DI	22.2	10.6		X
3DI	20.3	10.8		X
3DI	22.8	10.2		X
3SI	24.8	9		X
3SI	29	4		X
3SI	23.4	4		X
3DO	14	0.5	X	
3DO	22.3	2	X	
1SO	13.9	3	X	
1SO	13.8	2	X	
1SO	13.7	3	X	

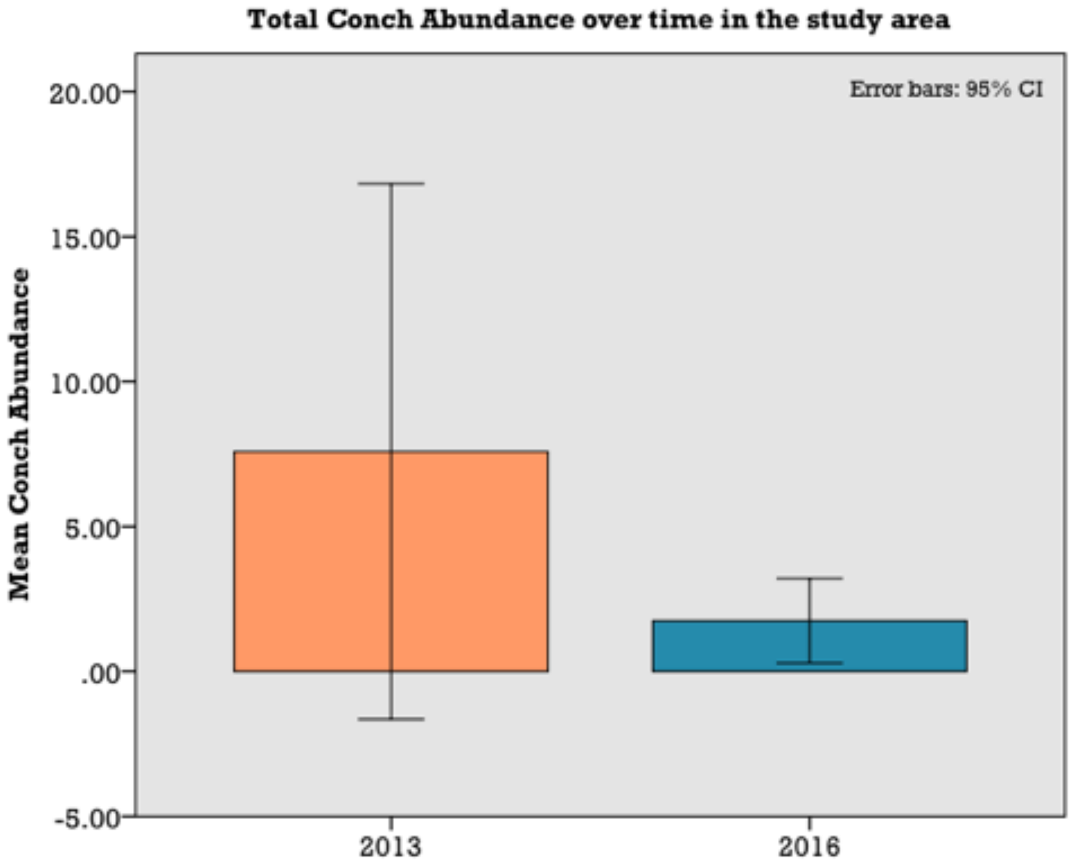

Figure 17. Mean values of total conch abundance in 2013 and 2016.
Error bars show 95% confidence interval. Non-parametric statistic analysis (Wilcoxon test) showed no significant difference in these groups.

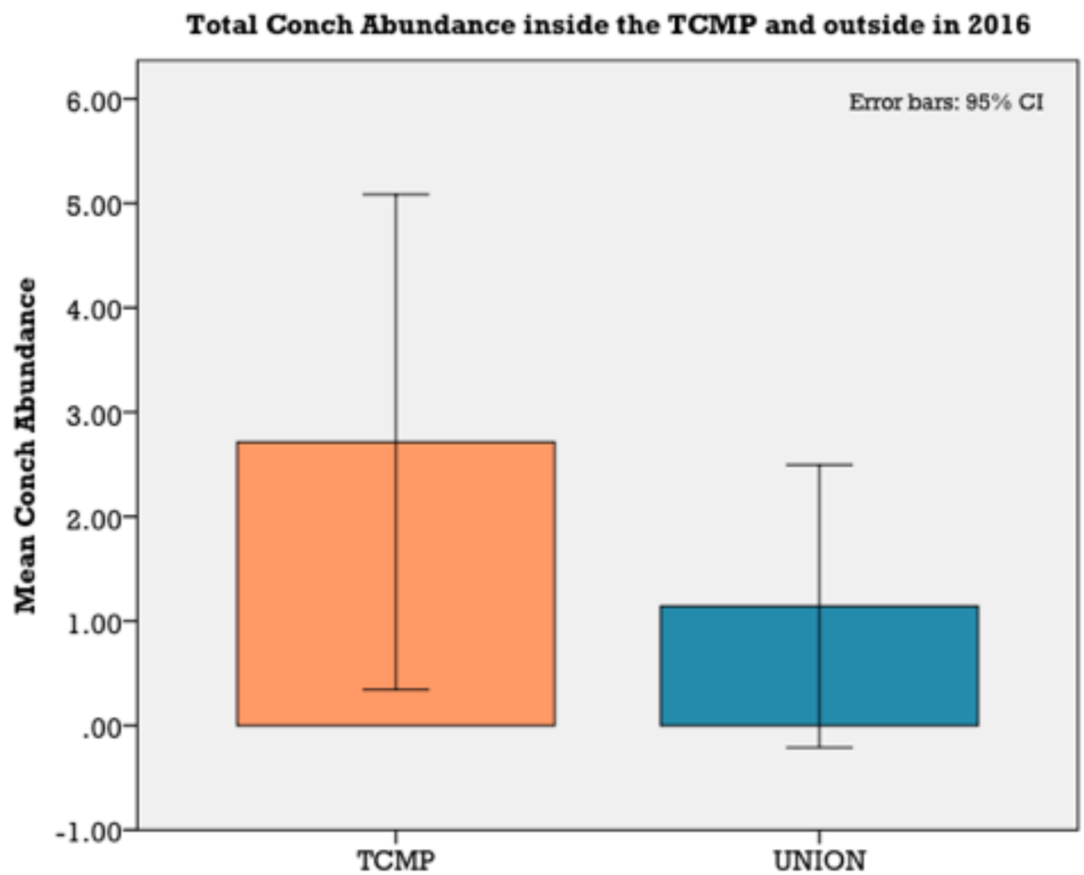

Figure 18. Mean values of total conch abundance inside and outside the Tobago Cays Marine Park (TCMP) in 2016.

Error bars show 95% confidence interval. Non-parametric statistic analysis (Wilcoxon test) showed no significant difference between these groups. The TCMP bar includes conch abundance inside the Marine Protected Area, while UNION refers to conch abundance that outside the Marine Protected Area.

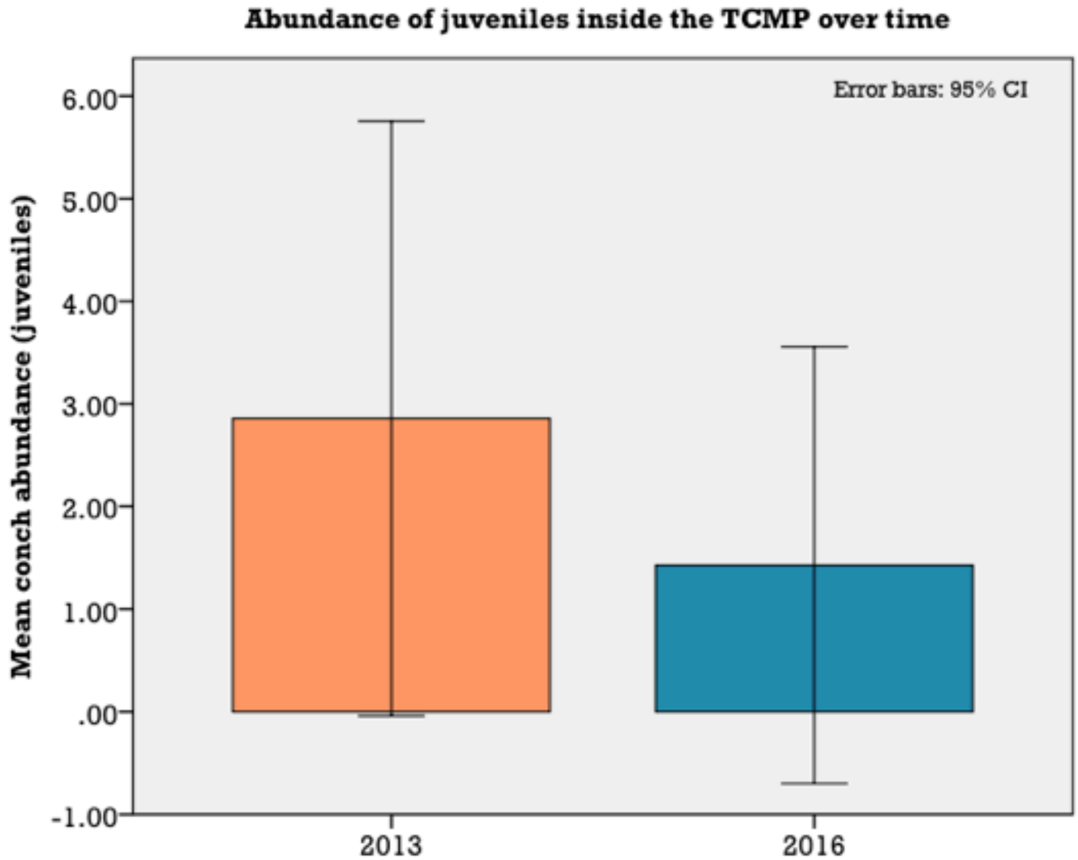

Figure 19. Mean values of total juvenile conch abundance inside the Tobago Cays Marine Park (TCMP) in 2013 and 2016.

Error bars show 95% confidence interval. Non-parametric statistic analysis (Wilcoxon test) showed a significant difference in these groups. A higher abundance of juvenile conch can be assumed for 2013 in comparison to 2016. The TCMP bar includes conch abundance inside the Marine Protected Area, while UNION refers to conch abundance that outside the Marine Protected Area.

4.3. TCMP performance

Statistical analysis showed that the TCMP did not have an effect on conch abundance in 2016 even though conch abundance inside the park was slightly higher than outside (Figure 18). In 2013, conch abundance was higher outside the park; however, these differences were not significant either in the analysis conducted during this study. Results from the over time comparison showed that there were no significant differences in total conch abundance inside the park from 2013 to 2016. However, comparing only the juveniles' abundance, results showed that there was a significant decrease of juvenile conch found inside the park in 2016 (Figure 19). The abundance of juveniles inside and outside the park, as well as the abundance of adults inside and outside the park in 2013 and 2016 showed no significant difference. All hypotheses tested and significance obtained can be found in Appendix 2.

Chapter 5. Discussion

In this chapter, the results found in this research will be discussed and compared to the results of previous studies across the Caribbean, with a special focus in St. Vincent and the Grenadines. The effectiveness of the TCMP as a conservation measure will also be discussed in this section, as well as other current management measures on this species. Even though conch abundance and density differences for protection level, depth, or maturity level were not statistically significant; the factors that could have caused these decline and distribution will be discussed.

Before exploring the different hypotheses that could elucidate current conch density in the study area, it is very important to consider the limited sample size of this study. A sample size of 12 surveys is very small to consider any of the data obtained conclusive. Therefore, the results of this study should only be considered as preliminary from the region. Lack of scientific data is always a constraint to understanding environmental processes, and proposing adequate management approaches. However, this species presently requires special attention due to its importance and historical decline in the Caribbean. The need for further information should not prevent the use of the precautionary approach; and management recommendations should be made using the best available data (Billé, 2008).

In order to fully assess conch density in Saint Vincent and the Grenadines, further research and monitoring will be required. However, the St. Vincent and the Grenadines Fisheries Department should ensure the sustainable use of this species, and the presented results can provide an initial understanding of the current situation in Union Island and the TCMP.

5.1. Total conch density and abundance

Total conch density in the study area was lower in 2016 (36.5 ind/ha) than in 2013 (157.9 ind/ha), which represented a reduction of 77% in the total conch abundance. Although the density of adults was also lower (64%), a major decline was observed in juveniles (82%). Factors involved in the observed conch decline could include fishing activities, climate change impacts, water quality, and the introduction of invasive species among others.

5.1.1. Overfishing

Similar to other areas in the Caribbean where conch stocks have been reduced, fishing activities could be the major cause of the overall conch density decline from 2013 to 2016 (Townsend, 2012). During informal conversations with Union Island fishermen and the local community, a better understanding on their general perception of queen conch abundance, and its relation to fishing activities was obtained. In general, there seemed to be a perception of an overall decline of the queen conch population during the past decades around Union Island waters due to overfishing. This is consistent with previous literature (Hoggarth, 2007). According to that perception, a reduced conch density around Union Island forced fishermen to explore deeper and farther away fishing grounds, as well as to use diving gear to conduct this fishery. On the other hand, other fishermen from the island affirm that the conch population has increased allowing fishermen to increase their total catch. This affirmation could be due to an increase in the fishing effort that does not need to be necessarily related to higher conch abundance. However, no information regarding fishing effort was collected during this study or was found in the previous literature on this area. It is possible that, as by general perception and previous literature, conch stocks have declined in the waters surrounding Union Island. However, areas that were not previously exploited (or that experienced a lower fishing pressure) could still have healthy conch stocks resulting in an increased conch abundance perception.

This higher conch abundance perception held by some fishermen was contradictory with the results found in 2016. In an attempt to contrast that information, a brief exploration was made outside the study area with three fishermen on August 6th, 2016. During this exploration, diving activities were conducted and an extensive conch ground was observed. Specifically, two dives were conducted outside the study area (Figure 20) and a high abundance of adults was observed. About half of the adults observed were females laying eggs. This high abundance did not seem to be the result of a previous aggregation as the dives were not in a specific and narrow area, but following the ocean current, and conch distribution seemed homogeneous.

During the second dive, one transect (30 m x 4 m) was conducted, in which a total

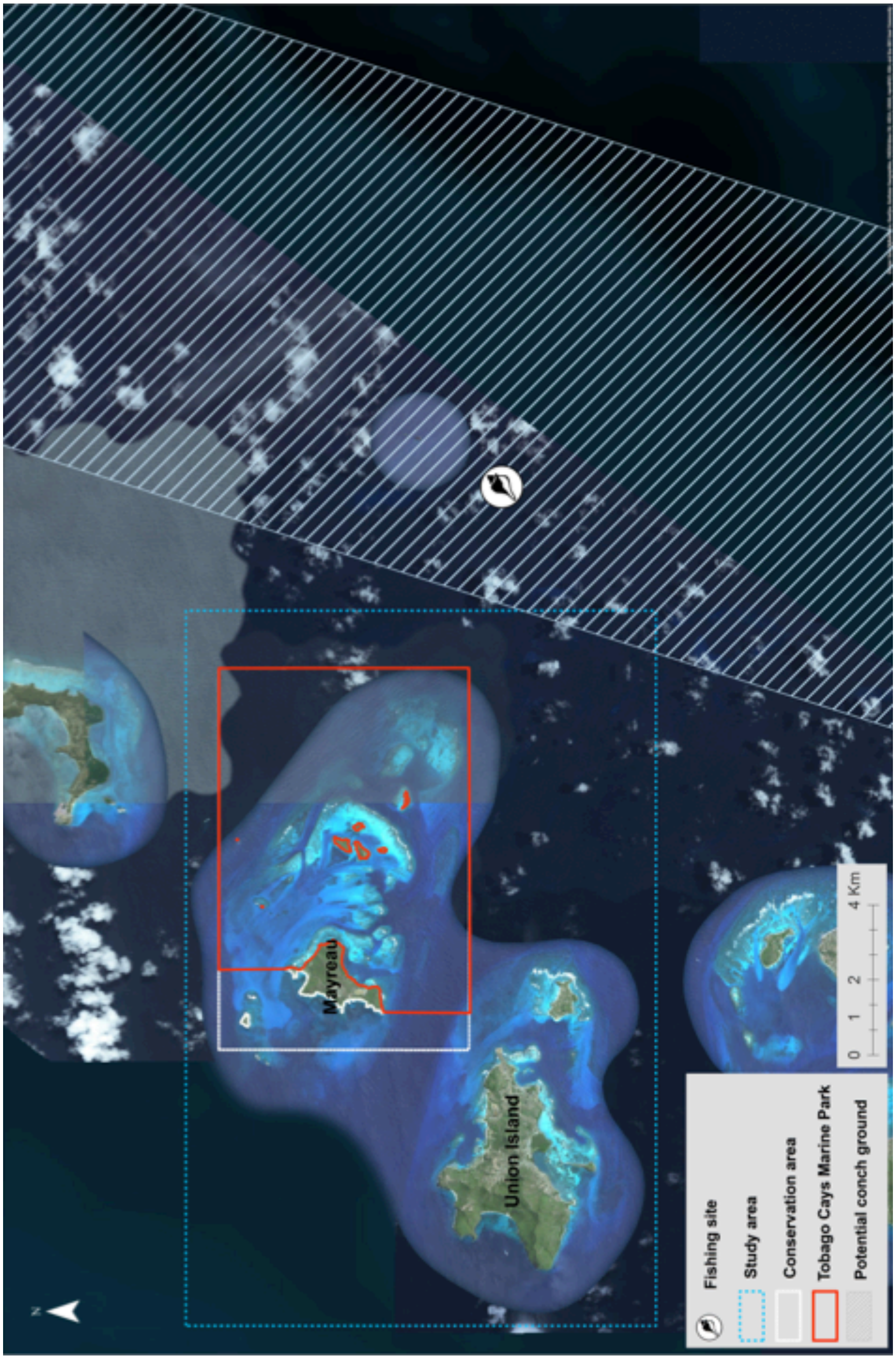

Figure 20. Queen conch ground outside the study area in 2016.
This satellite map shows the study area (blue square), with the TCMP demarcated inside (red square). The potential extensive conch ground according to fishermen local knowledge is represented by the striped area. The site that was explored is represented by the conch symbol in a white circle.

of 31 conch adults were found. In this transect, the conch abundance found was higher than total conch abundance found inside the entire study area in the 12 surveys conducted during 2016. The striped area shown in Figure 20 was claimed by these fishermen to be a very extensive conch ground with high conch abundance. During this brief exploration, another conch fishing vessel was observed in the area. This conch ground outside the study area has never been included in previous research, and therefore should be included in future stock status assessments. The high conch abundance observed could be very promising for increasing conch density inside the study area. In conclusion, it is possible that high fishing pressure inside the study area has caused a reduction in conch abundance over the past three years. However, further information will be necessary to confirm or refute this hypothesis. Observations from this research suggest that several fishermen could have changed their fishing grounds to other areas with apparently higher abundance, but this change could have been made before 2013.

Regarding the decrease of juveniles over time, it is not clear if fishing activities could be responsible for this reduction. On one hand, the implementation of minimum size restrictions and the requirement of a flared lip for harvesting purposes ensure that juveniles are not being harvested. On the other hand, fishing activities can cause an important reduction on the spawning stock biomass (R. Mahon, personal communication, January 5, 2017). In addition, it is possible that fishermen have not complied with the minimum size regulation, resulting in their reduction over the past three years. In order to obtain information on the effectiveness of the minimum size regulation and fishermen compliance, further research should be conducted in this area.

5.1.2. Climate change

The increase of sea surface temperatures and ocean acidification could have had negative impacts on conch density, affecting its abundance in the study area. Even though no information on local sea temperature could be found and analyzed to determine local trends, it is known that sea surface temperature has overall been increasing in the Caribbean region (Glenn, Comarazamy, González, & Smith, 2015).

A recent study has found that ocean acidification and temperature increase have an impact on conch larvae, decreasing their survival and growth rate (Aldana Aranda, 2016). Therefore, climate change could have been reducing queen conch recruitment in the Caribbean, and in St. Vincent and the Grenadines. Since many biological processes of queen conch are temperature sensitive, it is possible that climate change impacts could also reduce adults' reproduction rate, as well as juvenile growth and survival.

5.1.3. Water quality and invasive species

Queen conch is very sensitive to water quality changes, and therefore, this factor could have been responsible for its decline as well (Appeldoorn et al., 2011). Water quality data of the area could not be analyzed. However, it is interesting to notice that the Ashton lagoon, considered a very important nursery area for this species in the past, had zero conch density in the surveys conducted in 2013 and 2016 (survey sites UP36 and 3SO respectively) (Table 5). When the surveys for this area were conducted in 2016, high sedimentation and eutrophication was observed, as well as high water turbidity. Seagrass inhabiting the area was covered in slime, and fleshy macroalgae was also observed (Figure 21). If water quality has been decreasing in this area as a result of land-based activities, it is possible that other areas have also been affected, especially impacting juveniles and reducing its density.

Besides water quality changes, invasive species also could have had a role in overall conch decline, especially juveniles. Although, no studies have been conducted in this regard, it is possible that the arrival of high quantities of sargassum to the coast could have negatively impacted this species. The Caribbean Sea experienced high occurrence of sargassum in multiple Caribbean areas during 2011, 2014, and 2015 (Doyle & Franks, 2015). During 2016, this event could have been repeated, potentially impacting close-to-shore benthic organisms, including conch juveniles.

5.2. Tobago Cays Marine Park conch density and effectiveness

Density comparisons inside and outside the TCMP were conducted to determine its effect towards conch abundance in the area. As seen in the results, total conch density inside the TCMP was higher in 2016 in comparison to non-protected areas, although in 2013 density

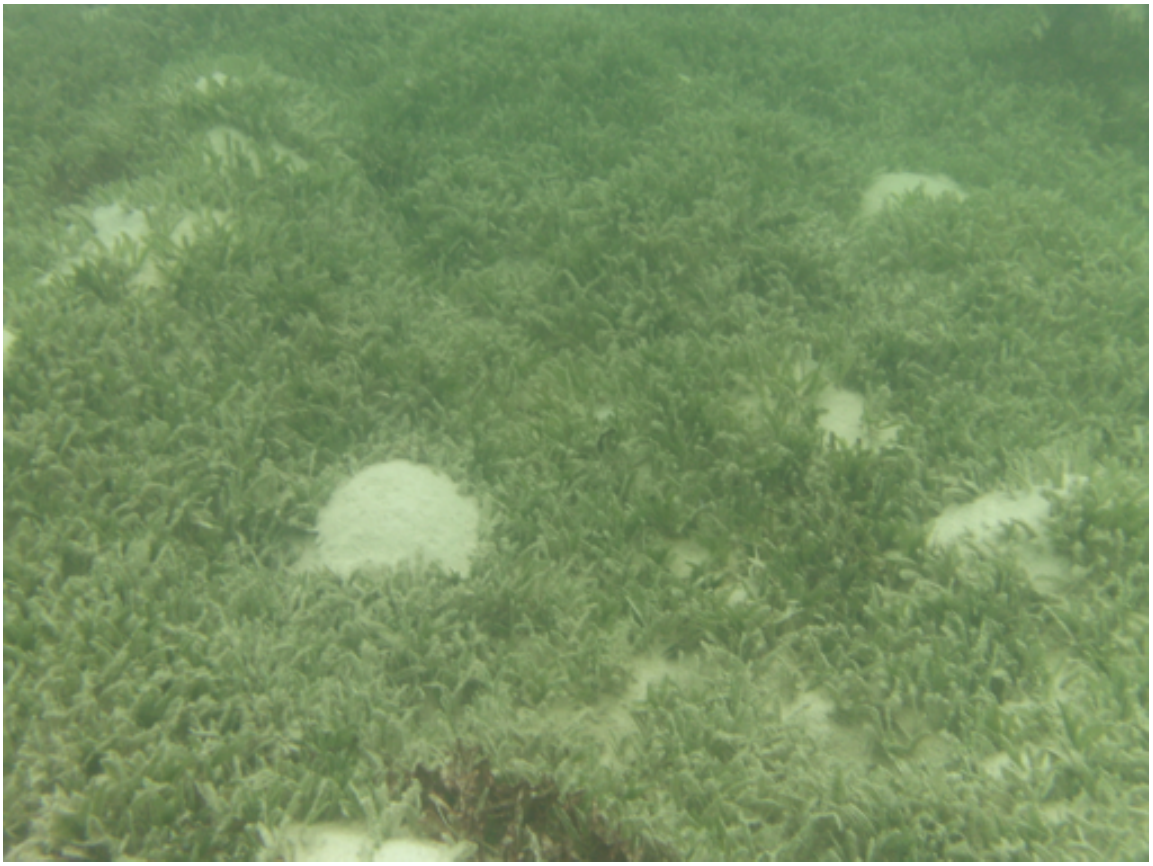

Figure 21. Low conch habitat quality in Union Island.
This photo was taken near survey site 3SO in 2016, in the Ashton lagoon area (Union Island). Sedimentation and eutrophication was observed, as well as turbidity. Sediments seemed to be covering seagrass inhabiting the area.

in non-protected areas was higher. This higher abundance outside the TCMP in 2013 was due to the high abundance of juveniles outside the park.

It is important to consider that even though an overall conch density reduction of 77% was observed between 2013 and 2016, a density reduction of only 34% was observed inside the park over time, while the reduction outside the park was of 92%. These percentages suggest that this protected area could have cushioned the overall decline over time. In fact, conch adult density inside the marine park did not change over time. It was also interesting to notice that no adults were found outside the park in 2016. On the other hand, juveniles' density inside the TCMP significantly decreased over time. Although, the decline on juveniles was more pronounced outside the TCMP (90% lower) than inside (56%

lower).

Therefore, it is possible that a factor mainly affecting juvenile abundance is causing the decline of juveniles inside the Park, as well as outside the park. As mentioned in sub-sections 5.1.2. and 5.1.3., these factors could be linked to climate change or water quality. However, inside the TCMP is more probable that water quality changes are caused by the high tourism rates and yacht visitation. It is less likely that land-based activities could negatively impact water quality in the Tobago Cays, as they are uninhabited and there are no major upstream inhabited areas.

Initially, it was expected that significantly higher conch abundance would be found inside the TCMP. As reported by Béné and Tewfik in 2003, a no-take MPA should reduce conch mortality and increase the abundance of the protected population. In addition, an increase in average size and age after the implementation of this measure should also be expected (Béné & Tewfik, 2003). Since the TCMP is a no-take area and provides protection from the fishery, this could mean that the main factor causing a conch density reduction is not fishing activities. However, it is known within the community in Union Island that illegal fishing is still happening inside the TCMP. Illegal fishing inside the TCMP has also been reported in previous literature (Adams, 1978; Prada et al., 2013), potentially causing its lack of contribution to overall conch conservation. In order to elucidate the factors involved in conch declines and the lack of effect of the TCMP on conch density, further research needs to be conducted.

5.2.1. TCMP impact and effectiveness

Marine protected areas are very important tools to protect exploited species. However, their conservation goals will not be achieved is they are poorly designed, implemented, or protected (Stoner et al., 2012b). It has also been reported that in areas where the fishery poses a major threat, an MPA cannot be effective in protecting target species such as conch if other management measures are not implemented. Furthermore, conch larvae can be transported between sites, and therefore an isolated MPA such as the TCMP may not be enough to ensure the persistence of a metapopulation (Stoner et al., 2012b). This information shows that the success of an MPA is not merely based in the implementation of a no-take area where fishing is not allowed (Béné & Tewfik, 2003).

In the case of the TCMP, statistical analysis of data collected in 2016 showed no effect towards conch density increases. However, this area might still be contributing to conch conservation at some level based in the observations made previously. This MPA seems to have minimized overall conch reduction in the study area over the past three years, and seems to have maintained adult density within its boundaries. Other no-take MPAs, have been established across the Caribbean to preserve the marine environment and help sustain fish stocks by eliminating fishing pressures. As an example, In the Bahamas, the Exuma Cays Land and Sea Park (ECLSP), was created to protect multiple fish species, lobster, and conch (Stoner et al., 2012b). This MPA is larger than the TCMP, with a total of 456 km^2, and had effective enforcement in place conducted by local warden and the Royal Bahamian Defense Force. Despite conservation efforts, and an increased density inside the MPA, a study conducted in 2012 concluded that the population inside this MPA was not self-sustaining (Stoner et al., 2012b). The authors found a reduced and aging adult population, and a reduction in larval recruitment, demonstrating that the no-take area will not be enough for the protection of this species (Stoner et al., 2012b). On the other hand, the establishment of a fishing reserve for conch in the Turks and Caicos Islands resulted in increased adult conch density inside the MPA, and the protection of queen conch spawning stocks (Béné & Tewfik, 2003).

Therefore, even though isolated MPAs that exclusively focus in fishing restrictions might not be adequate for queen conch conservation over time, this will need to be examined at the local scale. Further information on the effectiveness of the TCMP was obtained from a desktop assessment made on 2016 based on its management plan and available literature (García Rodríguez, 2016). According to this assessment, the TCMP seemed to not be a fully operating MPA regarding its management, and it was concluded that this MPA required many improvements to achieve its conservation goals. This conclusion was based in multiple evidence found during that assessment: (1) The TCMP has many required management activities for which the staff number might be inadequate; (2) The TCMP does not have a strong and consistent research and monitoring program in place, (3) The TCMP lacks secure funding over time; and (4) Critical management measures to address current threats inside the MPA have not been fully implemented (García Rodríguez, 2016).

Even though the TCMP has resulted in a decrease of the fishing effort in the MPA, it is important to remember that this MPA was originally created as a measure to increase tourism in the region. The tourism sector has highly increased in the area, achieving its original goal. However, the management plan does not include regulations for tourism (UNEP, 2014). The TCMP is self-funded by the fees provided by tourists that anchor inside the MPA or use the TCMP moorings. Therefore, it was not surprising that the main goal observed regarding this MPA management during this research was still the increase of the tourism sector to increase the MPA revenue. The main focus of this MPA management was observed to be mooring maintenance and mooring fees collection. Therefore, other management activities such as the control of illegal fishing, and monitoring activities of marine habitats and species could be a lower priority. The current observed TCMP priorities could be affecting the MPA's overall effectiveness and performance as a management measure for conch and any other marine species protection.

Currently, the TCMP is in the process on implementing a yacht management plan to reduce the impacts that anchoring has inside the MPA (Reed, 2016). Thus, including tourism-oriented management measures for the first time. This plan aims to reduce anchoring in order to preserve seagrass and sandy bottoms inside the area by increasing the number of moorings and reducing benthic physical damage. In addition, the plan aims to prevent the invasion of alien seagrass species by enhancing mooring and decreasing anchoring activities, since these species could be transferred in yacht anchors. This plan will enhance water quality monitoring, as well as data collection on yacht impacts. This information will contribute to a better understanding of the carrying capacity inside the MPA for tourism. In addition, by analyzing water quality data and yacht abundance, poor water quality or degraded areas could be identified. According to this plan, these areas could be temporarily closed to yachts, improving the environmental quality of the TCMP (Reed, 2016). Seagrass and sandy habitats are essential for conch conservation. Therefore, improvements in the quality of these habitats will have positive impacts on conch abundance inside the TCMP.

As a conclusion, even though the TCMP has great potential to increase conch density in the study area, it does not seem that this marine protected area is currently having a major effect on the abundance of this species. The multiple management challenges of this MPA seem to be responsible for this lack of effectiveness. However, current and future improvements on its management could help this MPA to achieve the conservation goals stated in its Management Plan of 2007 (presented in section 2.2.2.), and to specifically act as a protection measure for queen conch.

5.3. Conch density by depth

Regarding conch abundance in shallow and deep areas, an overall higher density was found in deeper areas. It was interesting to note that the same proportion of juveniles and adults was found in 2013 and 2016 in shallow areas; although in 2016, the density was lower (72% lower in shallow areas over time, and 78% lower in deep areas over time). The density of juveniles, which is usually more abundant in shallower areas (NOAA, 2014), was also higher in deeper areas in both studies, but especially in 2013. In 2016, a reduction of 84% was observed in juveniles inhabiting deeper areas when compared to 2013. In addition, a reduction in adults was also observed in deeper areas when compared to 2013 density data (57% lower).

Potential hypotheses for these findings include the use of deeper areas by individuals, including juveniles, as refugia from fishing activities. It has already been described that under high fishing pressure, deep habitats act as refugia, protecting conch and maintaining high densities of this species (NOAA, 2014). In addition, it is also possible that the environmental conditions in deeper areas could have been more favorable for the development of this species, as they are less likely to be impacted by land-based activities. Finally, temperature changes and the arrival of invasive species could have had a much reduced or no impact in deeper areas compared to shallow areas.

5.4. Queen conch management

The successful management of this species requires measures that consider a holistic approach. As seen in section 5.2., the implementation of a single measure could not contribute to the sustainability of this species population if other measures are not implemented at the same time. Ecosystem-based management provides the opportunity to address current threats to this species in an effective and integrate manner (Appeldoorn et al., 2011). In this section the requirements identified to conduct EBM for queen conch in the Caribbean will be compared with current implemented measures, and the achievement of EBM through these measures will be discussed. In addition, current management challenges in the study area for this species will be included.

According to Appeldoorn et al., (2011), queen conch management through EBM should include:

- Protection of coastal habitats: In Union Island this measure has not been implemented. On the other hand, in the TCMP, the east side of Mayreau Island, and the coast of the Tobago Cays have been protected by establishing a no-take area. However, coastal habitats in both locations could be impacted by other threats such as sedimentation, eutrophication, and climate change.
- Protection of juveniles: In order to protect juveniles from fishing activities, a minimum size restriction was implemented in SVG. In addition, the conch must have a flared lip in order to harvest the individuals. These measures protect juveniles from fishing activities. However, specific regulations to protect nursery areas have not been implemented. The management of the TCMP could contribute in the future to protection of juveniles, but currently this measure does not seem to affect juveniles' density.
- Protection of spawning adults: Currently, in St. Vincent and the Grenadines, a season closure has not been established although the Minister has the capacity to do so. Therefore, adult conch are being harvested during their reproductive season. During the brief exploration conducted with the fishermen, all conch encountered were harvested. This included females laying eggs, some of them still with the egg strand attached (Figure 22). In addition, even though the TCMP could be protecting adults, observations from this study suggested that highest spawning adult densities could be outside the MPA, and outside the study area.
- Establishment of marine protected areas: The TCMP was established in 1997 (UNEP, 2014), although it was not created with the specific purpose of conch conservation. In order to achieve conservation goals, this MPA still needs to undergo several manage-

Figure 22. Female conch landed during the reproductive season in Union Island. This photo was taken in Union Island at the beginning of August. The egg strand still attached to the individual can be seen in the photo.

ment improvements as discussed in section 5.2. One of these challenges is the need for better enforcement practices from the TCMP Rangers to ensure that fishing is not occurring inside the protected area.

- Monitoring of the fishery: According to the Fisheries Department, data is being collected on conch landings in Union Island. There is currently one person responsible for the collection of this information in Union Island, although the specific mechanism through which the data is being obtained is not clear. That information is reported to the SVG Fisheries Department on a monthly basis. Even though data collection is currently occurring in this area, the SVG Fisheries Department recognizes that improvements need to be made as some data might be lost in the process (K. Isaacs, personal communication, October 30, 2016). Furthermore, higher enforcement from the Fisheries Officers in this area might be needed to ensure that fishermen are following the minimum size and flared lip regulations. In addition, the illegal fishing and illegal trade to nearby islands that has been reported in Union Island should be addressed through better enforcement. Observations made through this research suggested that the monitoring of this species by measuring its abundance, or biomass might not be an effective method. Underwater surveys are costly if all surveys necessary to obtain conclusive results are conducted. According to observations made, the managers in this area lack the resources to conduct continuous underwater surveys to assess the state of the population and the impacts of the fishery. In addition, the method used in this study should not be used if further surveys are conducted, as this method is only effective when conch abundance is high (Medley, 2008).

According to this information, it seems that in order to conduct EBM of this species, coastal areas around Union should be protected, including nursery areas that can enhance juvenile protection. In addition, spawning adults should be protected, which could be achieved through the implementation of a closed season. Moreover, the TCMP needs to improve its current management in order to address environmental threats that jeopardize the health of multiple marine species within its boundaries. Finally, the fishery and the status of this species should be monitored continuously. The collection of landings data should be improved in Union Island. By addressing these challenges and management gaps, an EBM approach could be achieved for queen conch in Union Island and the Tobago Cays Marine Park.

In order to prioritize all the needed management actions, the mechanisms producing reduced conch abundance will need to be better understand (Gascoigne & Lipcius, 2004). In addition, in order to better-inform management measures, data accessibility in the Caribbean region should be enhanced. Currently, research and reports conducted in St. Vincent and the Grenadines are not easily available to the public and to other researchers. In many cases, such reports could be unpublished and therefore remain within certain organizations, limiting the use of the obtained information. As an example, the previous study conducted by Prada et al. in 2013 was not accessible through a literature research, but through direct contact to the Gulf and Caribbean Fisheries Institute. Therefore, when planning this research, no information on this previous assessment could be obtained to better-inform the current method used. The lack of data accessibility in this region could negatively impact further research, as well as jeopardize future management improvements in the area. Therefore, this issue should be urgently addressed, and some suggestions will be made in the recommendations section (section 6, measure 3).

As a conclusion, in order to improve queen conch abundance in this area, the drivers for this apparent decline should be better identified, and current management measures implemented for this species should be improved. A special focus on juveniles and spawning adults' protection, as well as higher enforcement should be taken.

6. Recommendations and Conclusion

In this chapter, recommendations to improve the management of this species will be made based on the results obtained from this research, and the information presented in the discussion. Recommendations will be presented in order of priority based in current information and observations made during this study. Measures that are more urgent, feasible, and cost-efficient for conch conservation will be prioritized in this recommendation list. However, the order of priority could change if further information regarding the status of this species, management gaps, or management measures' effectiveness is obtained.

6.1. **Recommendations**

6.1.1. Community engagement

Community engagement and consultation sessions are essential for adequate management. The local community should be aware of the research activities being undertaken on Union Island and the Tobago Cays Marine Park. In addition, consultation sessions regarding the natural and/or social environment of the area should be conducted with a double aim. First, to inform the community about current research projects and to engage them. Secondly, to obtain feedback from the community on particular questions or methods being used. Finally, the results obtained from future research must be shared with the local community. Proposed management measures produced after research activities should be developed and agreed by the community as well, not only by scientists. Proposed management measures that could be implemented in the area should be understood by the local community to ensure better compliance and participation.

Consultation and informative sessions could be organized by the local environmental NGO Sustainable Grenadines Inc. (SusGren), or by the TCMP's Education Department. SusGren has previous experience in this field as they already conduct education activities and environmental presentations in schools. Furthermore, extensive information regarding community engagement importance and challenges in the Grenadines has already been published (Baldwin, Mahon, & McConney, 2013), and should be used to develop further activities. SusGren has also been recently conducting informative sessions in regards of queen conch for the local community and TCMP staff. Joint efforts between SusGren and

TCMP are recommended to organize these activities in order to promote participation, support, and engagement of both parties.

Consultation meetings should be conducted before any research is undertaken in Union Island to present the project and obtain feedback, as well as after the research has concluded in order to share the results obtained. If due to time constraints, the intended research cannot be shared prior to its fulfillment, the research outcomes and findings should at least be shared after it has concluded. Informative sessions on the state of this resource should be conducted at least once a year to raise awareness of ongoing actions and current needs. These sessions should include visual presentations and group discussions with the help of moderators in the room. Sessions could be organized by disseminating invitations to key stakeholders within the local community, as well as by the use of posters and other inexpensive advertisement methods. Social media and other communication channels might also be valuable tools to attract people from the community to the event.

In order to enforce the sharing of research projects information and outcomes with the community, scientists conducting research in the island should have a research permit issued by the SVG government. There could be requirements to grant this permit, including the development of informative and consultation sessions in collaboration with the TCMP or SusGren. Even though this measure could generate an increase in the required administrative work for the issuing body, the researchers, and collaborating agencies; it could be an effective measure to provide information, and control the activities being conducted in the Grenadines region. Currently, research permits are required in several Caribbean countries such as Belize and The Bahamas (Pikitch, Chapman, Babcock, & Shivji, 2005; Maljković & Côté, 2011). Local authorities in collaboration with the TCMP Rangers should ensure that research activities are conducted with the possession of a permit exclusively. The implementation and enforcement of this measure will ensure that research activities promote education and community engagement. By including the local community in research projects, in the proposal of future management measures, and enhancing education and participation, the sustainable use of queen conch can be achieved.

6.1.2. Education

Education activities are essential, as the community will only be able to understand the need for conch conservation if they are informed about this issue. Informal presentations at schools of Union Island to explain current conch threats and required management measures will increase awareness among the community. These activities will over time result in higher understanding on conch status, and necessary management measures. Education activities at Union Island schools should be conducted at least once a year to keep students engaged and increase awareness. These activities could be conducted by the use of visual presentations, by the development of coloring contests, or others. They could be organized by contacting the principals of local schools by SusGren or the TCMP's Education Department.

6.1.3. Data accessibility improvement

Scientific and management reports regarding the marine environment conducted in St. Vincent and the Grenadines should be available to practitioners, scientists, and the public. Accessibility could be enhanced if it was required to publish the obtained information after the research is conducted. It should be mandatory that all reports, documents, and scientific articles produced are compiled in a national database, as well as published in a platform where that information can be widespread. By establishing mandatory research permits to conduct such activities in SVG, another required condition should be the need to provide research outcomes and generated documents. Including this condition could ensure the SVG government that all research conducted within the country will contribute to increase knowledge, data accessibility, and improve current management of the natural environment.

In order to create a database where all the obtained information can be published, data-management infrastructure is required (Arzberger et al., 2004). This infrastructure should be developed and maintained by the SVG government, or another designated entity that is capable to conduct such task. Implementing this measure might require hiring additional staff, additional funding, and creating new partnerships with existent organizations. The principle of publishing research data should be openess, and the data should be freely and efficiently accessible. However, some restrictions might need to be considered (e.g. citizens privacy protection) (Arzberger et al., 2004). The capacity of accessing previously obtained information will improve the ability of preserving and ensuring the sustainable use of marine resources in the SVG.

6.1.4. Enforcement increase

Enforcement inside the TCMP and in Union island must be increased. Where compliance is lacking, better enforcement can ensure that no illegal fishing activities occur. Increased enforcement inside the TCMP can ensure that no fishing occurs in the MPA. In addition, enforcement increase in Union Island will ensure fishermen's compliance with current minimum size and flared lip regulations. Better enforcement could be achieved by increasing patrolling efforts across the full extent of the MPA, instead of mainly focusing on the area closer to the Cays to ensure that no illegal fishing is occurring. Currently, surveillance by the TCMP is highly focused in the area surrounding the Cays because it is where tourism activities mainly occur. Instead of increasing the patrolling frequency or extent to cover the MPA boundaries, a more feasible and inexpensive alternative would be to establish a monitoring post on the Mayreau Island hill. A person from the TCMP staff could monitor de MPA with binoculars and contact the rangers if any fishing boat is seen within the MPA boundaries (R. Mahon, personal communication, January 5, 2017).

In Union Island, better enforcement could be achieved by the presence of a Fisheries Officer regularly in the landing and/or conch processing area. This measure might require the incorporation of additional staff, and the increase of governmental funding for surveillance and monitoring activities. Surveillance activities at landing sites should be funded by the government as part of their fisheries management strategies. There are two main areas where landings seem to occur (Clifton harbor and Ashton waterfront), and therefore two officers might be needed for effective monitoring of ongoing activities. As another alternative, people from the local community could be trained to collect data on fisheries landings (L. Fanning, personal communication, December 10, 2016). This strategy will increase community participation and data collection capacity. In addition, the required funding to develop a community monitoring task force decreases significantly.

In order to have a better understanding of the management measures that could be implemented in Union Island to improve fisheries regulations enforcement, an assessment including current budget, capacity, and resources available for these activities should be conducted. In addition, a consultation session should be carried out to understand what will be the preferred methods by fishermen, and therefore increase compliance and management effectiveness.

6.1.5. Enhance environmental focus at TCMP

The TCMP needs a new approach with a higher environmental focus. Current conservation goals should be prioritized over the touristic interest of the area, and a more sustainable way to develop tourism activities should be explored. The Adaptive Moorings Management Plan (Reed, 2016) is a starting point towards that improvement. In addition, the TCMP's yacht carrying capacity should be evaluated, and a stronger monitoring program should be developed. Finally, other funding possibilities besides self-funding from the mooring fees should be explored. External funding (governmental, NGO, or other) could help this MPA to be less-tourism driven, and more environmentally focused.

6.1.6. Fishing pressure reduction during the reproductive season

Fishing pressure during the reproductive months should be eliminated or reduced. In order to protect spawning adults, a season closure should be implemented. However, this measure should be implemented only if negative impacts on fishers are somehow mitigated. In the case of a conch closure season, conch fishermen will lose their livelihoods during at least three months in the summer. The establishment of such measure could be compensated in multiple ways. One possibility is the creation of a fishermen monitoring task force. This option will allow the collection of conch abundance data by fishermen during the reproductive season, providing an alternative temporal livelihood and temporarily eliminating fishing pressure. One of the weaknesses in small scale fisheries in the Caribbean is the lack of inclusion of fishermen in management. Since fisheries assessment are fundamental to develop fishery management plans (Salas, Chuenpagdee, Seijo, & Charles, 2007), fishermen could be involved in this process. Fishermen could be trained to collect scientific data to contribute to better-informed management over time, and the adaptive management of this species. Fishermen possess extensive knowledge on the local environment and queen conch dynamics. The inclusion of fishermen in fisheries monitoring activities has already been reported as successful, although initially challenging, in Kenya and Tanzania for artisanal fisheries (Obura, 2001; Obura, Wells, Church, & Horrill, 2002). This option could generate multiple benefits. First, it will have positive impacts in the fishing community, as fishermen will have a better understanding of the management measures required for queen conch. Secondly, management efforts will be more successful due to a potential higher compliance, and more consistent monitoring conducted during the reproductive season. However, this possibility might not be feasible to implement and other alternatives should be explored.

Other alternative could be the improvement of post-harvesting techniques and the enhanced possibility to storage of conch, which could allow selling this resource year-round even though a closure is established. This measure would not necessarily increase pressure on the stock during the open season as the fishermen could have a certain control on the market price if conch storage was possible. Any alternative that could minimize the negative impacts that a season closure could have on conch fishermen should be considered and consulted with the community. Establishing a season closure in this area seems an important and required measure to protect the conch population.

6.1.7. Enlarge study area for future assessments

The apparently extensive conch ground outside the study area found during the exploration with the fishermen should be included in future stock assessments. This will allow for a better understating of the conch status in the area, as well as the implementation of adequate management measures.

6.1.8. Minimum lip thickness size restriction

It is currently well known than shell length is a week indicator to estimate queen conch maturity level. Instead, lip thickness has been found to be a much better indicative parameter of the maturity level (Aranda & Frenkiel, 2007; Stoner et al., 2012; Foley, 2016).

Therefore, in order to fish only adult conch, a change towards the measurement and limitations on the lip thickness should be made (Foley, 2016). Fishermen could be trained in the identification of suitable adults for harvesting purposes (meeting the minimum lip thickness size). Another option will be the use of calipers by fishermen while conducting conch fisheries. The use of scientific instruments for measuring morphologic parameters have already been reported successful in other areas, such as in Belize (J. Foley, personal communication, November 10, 2016). Therefore, a minimum of 15mm lip thickness to allow conch harvesting could be implemented to ensure the sustainable use of this species (Stoner et al., 2012).

6.1.9. Regulate total fishing effort

A Total Allowable Catch (TAC) for queen conch around Union Island, Mayreau, and the Tobago Cays should be used to determine sustainable efforts that can be conducted by the fishery. All main fishing areas should be considered to implement this measure. Therefore, the waters consisting the study area should be included (Figure 6), as well as the conch fishing grounds outside that area. A new map outlining the total management area should be developed by local fishermen and SusGren or the Fisheries Division to understand the extent of the area that should be regulated. In 2013, Prada et al. estimated that 62,667-85,988 pounds of conch clean meat per year should be the TAC for the study area (Prada et al., 2013). However, this year a conch density decline has been observed, as well as an extensive conch ground outside the study area that has never been included in previous assessments. Due to the mentioned observations, a new TAC limit should be estimated and established. In order to implement this measure, mitigation strategies to minimize negative impacts to fishermen livelihoods should be developed as cited in section 6.1.6.

Until further assessments are conducted, the precautionary approach should be considered. Inside the study area, a TAC of 24,500 pounds of conch clean meat per year should be established. This TAC represents a 77% reduction when comparing to the 2013 average TAC, following the total conch decline of 77% observed in 2016. Nevertheless, since stocks in areas outside the study area could be healthy, the TAC established for the entire fishing area around Union Island should be considered as 74,000 pounds of conch clean meat per year. Therefore, a more restrictive TAC should be established for the study area, while allowing the previous average TAC estimated in 2013 for the entire area. This measure will reduce the pressure on the apparently reduced conch stock inside the study area, but allowing the previously estimated average TAC for apparently abundant and healthy areas.

In order to enforce these regulations, besides providing landings data, fishermen should also determine if conch landed was fished inside or outside the study area by using a map with the Fisheries Officer. Collaboration with the fishermen could be reached by providing benefits to fishermen that collaborate, such as access to storage of conch meat, ice provision, or others. By collecting this information, Officers will ensure that the TAC is not being exceeded, especially inside the study area. Laminated satellite maps, such as the ones used to conduct participatory mapping for this study, could be used. These maps are inexpensive, can be easily understood, transported, and used.

In addition, fishing quotas using the mentioned TACs as a limit reference point should be established to control total fishing effort in the area. A stakeholder impact assessment focusing on the fishermen should be developed to ensure that social impacts due to the establishment of fishing quotas are minimal. This assessment should also be used in order to conduct the adequate allocation of such quotas.

6.2. Conclusion

This research aimed to provide information on the current conch density in Union Island and the TCMP in order to promote the sustainable use of this species in SVG. In addition, the effect of the TCMP towards conch protection was tested to determine if that MPA was being effective for conch conservation. Furthermore, the management measures required for its sustainable use in SVG were researched. Conch density in the study area seemed to have decreased over time, and the TCMP seemed to be having no significant effect towards conch protection and conch density. However, this area has the potential to become a high-density conch ground, as it was in the past, if effective measures are implemented.

In order to improve the current queen conch status inside the study area, several recommendations were made. Future management should focus on the implementation of measures based on EBM. Current management challenges existing at the TCMP should be addressed by developing a higher environmental focus, and increasing the monitoring and enforcement capacity. In addition, the identified conch ground outside the study area should be included in future assessments to have a better understanding of current conch status. Education and community engagement activities should also be continuously conducted in Union Island. Finally, a season for conch might be required in order to increase conch density within the study area. However, the establishment of such measure should be implemented if fishermen can conduct alternative activities while they are not allowed to harvest this species. The feasibility of this last recommendation should be further explored to have a better understanding of its potential success.

As a conclusion, the queen conch is a very important species in Union Island, and in SVG. It has a high cultural, economic, and environmental value. Current threats impacting queen conch in the area should be better identified for a more effective management. The proposed recommendations will contribute to the sustainable use of this species in the area if implemented. A special focus on juveniles and spawning adults' protection should be taken. By preserving queen conch and developing adequate fishing practices, this resource will continue to provide ecosystem services, and economic benefits.

7. Bibliography

Adams, J. E. (1978). Union Island, West Indies: An Historical and Geographic Sketch. *Caribbean Studies*, *18*(3/4), 5–45.

Agardy, T., di Sciara, G. N., & Christie, P. (2011). Mind the gap: addressing the shortcomings of marine protected areas through large scale marine spatial planning. *Marine Policy*, *35*(2), 226–232.

Aiken, K., Kong, A., Smikle, S., Appeldoorn, R., & Warner, G. (2006). Managing Jamaica's queen conch resources. *Ocean & Coastal Management*, *49*(5), 332–341.

Aldana Aranda, D. (2016). *The effect of ocean acidification and temperature on larval development and calcification of the queen conch Strombus gigas.* Presented at the 69th Annual Gulf and Caribbean Fisheries Institute, Caymans Islands.

Appeldoorn, R. S. (1993). Reproduction, spawning potential ratio and larval abundance of queen conch off La Parguera, Puerto Rico. *Manuscript, Report to Caribbean Fishery Management Council, San Juan. Puerto Rico*, 1993.

Appeldoorn, R. S. (1997). Status of Queen Conch Fishery in the Caribbean Sea (pp. 40–59). Presented at the International Queen Conch Conference, San Juan, Puerto Rico: Caribbean Fishery Management Council.

Appeldoorn, R. S., Gonzalez, E. C., Glazer, R., & Prada, M. (2011). Applying EBM to Queen Conch Fisheries in the Caribbean. In L. Fanning, R. Mahon, and P. McConney (Eds.) *Towards Marine Ecosystem-based Management in the Wider Caribbean* (pp. 177–186). Amsterdam University Press.

Aranda, D. A., & Frenkiel, L. (2007). Lip thickness of Strombus gigas (Mollusca: Gastropoda) versus maturity: a management measure. *Proceedings of 58th Gulf and Caribbean Fisheries Institute*, *58*, 431–442.

Arzberger, P., Schroeder, P., Beaulieu, A., Bowker, G., Casey, K., Laaksonen, L., … Wouters, P. (2004). Promoting access to public research data for scientific, economic, and social development. *Data Science Journal*, *3*, 135–152.

Baldwin, K. (2012). *A Participatory Marine Resource and Space-use Information System for the Grenadine Islands: An ecosystem approach to collaborative planning and* *management of transboundary marine resources.* (PhD Dissertation). University of the West Indies, Barbados.

Baldwin, K., Mahon, R., & McConney, P. (2013). Participatory GIS for strengthening transboundary marine governance in SIDS. In *Natural Resources Forum* (Vol. 37, pp. 257–268). Wiley Online Library.

Barner, A. K., Lubchenco, J., Costello, C., Gaines, S. D., Leland, A., Jenks, B., … Spring, M. (2015). Solutions for Recovering and Sustaining the Bounty of the Ocean Combining Fishery Reforms, Rights-Based Fisheries Management, and Marine Reserves. *Oceanography*, *28*(2), 252–263.

Béné, C., & Tewfik, A. (2003). Biological evaluation of marine protected area: evidence of crowding effect on a protected population of queen conch in the Caribbean. *Marine Ecology*, *24*(1), 45–58.

Billé, R. (2008). Integrated Coastal Zone Management: four entrenched illusions. *S.A.P.I.EN.S*, *1*(2).

Bouchet, P. (2011). Lobatus gigas (Linnaeus, 1758). MolluscaBase (2015). Retrieved from http://www.molluscabase.org/aphia.php?p=taxdetails&id=564730

Brownell, W. N., & Stevely, J. M. (1981). The biology, fisheries, and management of the queen conch, Strombus gigas [Caribbean]. *Marine Fisheries Review*, *43*(7), 1-12.

Carrasquel, C. A. (1997). Situación actual de la pesquería del botuto, Strombus gigas en Venezuela (pp. 136–138). Presented at the International Queen Conch Conference, San Juan, Puerto Rico: Caribbean Fishery Management Council.

Catarci, C. (2004) World markets and industry of selected commercially-exploited aquatic species with an international conservation profile. *FAO Fisheries Circular*. No. 990. Rome, FAO. 186p.

CEP-UNEP. (1991). *Final act of the conference of plenipotentiaries for the adoption of the annexes to the protocol concerning specially protected areas and wildlife in the wider Caribbean region* (SPAW Final Act, Resolution, and Appendix). Kingston.

Chakalall, B. (1997). The queen conch fishery in the Caribbean: An approach to responsible fisheries management (pp. 60–76). Presented at the International Queen Conch Conference, San Juan, Puerto Rico: Caribbean Fishery Management Council.

CITES. (2003). *Review of Significant Trade in specimens of Appendix-II species (Resolution Conf. 12.8 and Decision 12.75)* (Progress on the implementation of the review of significant trade (Phases IV and V) No. AC19 Doc. 8.3 (Rev. 1)) (p. 71). Nineteenth meeting of the Animals Committee Geneva (Switzerland): Convention on International Trade in Endangered Species of Wild Fauna and Flora.

Clark, S. A., Danylchuk, A. J., & Freeman, B. T. (2005). The Harvest of Juvenile Queen Conch(Strombus gigas) off Cape Eleuthera, Bahamas: Implications for the Effectiveness of a Marine Reserve. In *Proceedings of the Gulf and Caribbean Fisheries Institute* (Vol. 56, pp. 705–714).

Claudet, J., Pelletier, D., Jouvenel, J.-Y., Bachet, F., & Galzin, R. (2006). Assessing the effects of marine protected area (MPA) on a reef fish assemblage in a northwestern Mediterranean marine reserve: Identifying community-based indicators. *Biological Conservation*, 130(3), 349–369.

Cruickshank, A. (1997). Status of the queen conch, Strombus gigas in St. Vincent and the Grenadines (pp. 119–120). Presented at the International Queen Conch Conference, San Juan, Puerto Rico: Caribbean Fishery Management Council.

Cruickshank, A., & Morris, K. (1996). Status of the Queen conch, Strombus gigas in St. Vincent and the Grenadines. In *International Queen conch conference* (pp. 119–120). San Juan, Puerto Rico: Caribbean Fishery Management Council.

Davis, J. E. (2003). Population assessment of queen conch, Strombus gigas, in the St. Eustatius Marine Park, Netherlands Antilles. St. Eustatius Marine Park 15pp.

Doyle, E., & Franks, J. (2015). Sargassum Fact Sheet. *Gulf and Caribbean Fisheries Institute*.

Egan, B. D. (1985). *Aspects of the reproductive biology of Strombus gigas*. University of British Columbia.

Ehrhardt, N. M., & Valle-Esquivel, M. (2008). Stock Assessment Manual. *Caribbean Fishery Management Council*, 128.

FAO. (2007). *Regional workshop on the monitoring and management of queen conch, Strombus gigas* (FAO Fisheries Report No. 832) (p. 186). Kingston, Jamaica: FAO.

FAO. (2016). Status of stocks and resources 2004: Queen conch Antigua EEZ [Marine

Resource Fact Sheet].

Foley, J. (2016). *Size-Maturity Indicators in Queen Conch (Lobatus gigas)of Port Honduras Marine Reserve, Belize; Strenghtening Management for Improved Fisheries Sustainability*. Presented at the 69th Annual Gulf and Caribbean Fisheries Institute, Caymans Islands.

García Rodríguez, A. (2016). *The challenge of measuring MPA effectiveness*. Unpublished. MARA 5013 Major Paper, Dalhousie University, Halifax.

García-Moliner, G. (1997). Status of the fisheries and regulations regarding queen conch, Strombus gigas, in the United States, including Florida, the Commonwealth of Puerto Rico and the territory of the Virgin Islands (pp. 124–135). Presented at the International Queen Conch Conference, San Juan, Puerto Rico: Caribbean Fishery Management Council.

Gascoigne, J., & Lipcius, R. N. (2004). Conserving populations at low abundance: delayed functional maturity and Allee effects in reproductive behaviour of the queen conch Strombus gigas. *Marine Ecology Progress Series*, *284*, 185–194.

Glazer, R. A., & Kidney, J. A. (2004). Habitat associations of adult queen conch (Strombus gigas L.) in an unfished Florida Keys back reef: applications to essential fish habitat. *Bulletin of Marine Science*, *75*(2), 205–224.

Glenn, E., Comarazamy, D., González, J. E., & Smith, T. (2015). Detection of recent regional sea surface temperature warming in the Caribbean and surrounding region. *Geophysical Research Letters*, *42*(16), 2015GL065002.

Government of SVG. (1990). *Laws of Saint Vincent and the Grenadines: Revised Edition* 1990 (Vol. 52). Government of Saint Vincent and the Grenadines.

Halpern, B. S., & Warner, R. R. (2002). Marine reserves have rapid and lasting effects. *Ecology Letters*, *5*(3), 361–366.

Hoggarth, D. (2007). *Tobago Cays Marine Park 2007-2009 Management Plan*. Organisation of Eastern Caribbean States, and Environment and Sustainable Development Unit.

Isaacs, K. (2014). National Summary Report on the Status of Queen Conch Fisheries in St. Vincent and the Grenadines 2014 (Vol. SLC/FIPS/SLM R1097, pp. 219–222).

Presented at the Second meeting of the CFMC/OSPECA/WECAFC/CRFM working group on queen conch, Panama City, Panama: Western Central Atlantic Fishery Commision.

Kruczynski, W. L., & Fletcher, P. J. (2012). Queen conch life cycle. In *Tropical Connections: South Florida's Marine Environment* (p. 343). IAN Press, University of Maryland Center for Environmental Science.

Lawrence, D. L., & Phillips, L. D. (2013). A sustainable future for queen conch: New approaches to the conservation and sustainable development of Strombus gigas and related species. Strombus Gigas Alliance.

Maljković, A., & Côté, I. M. (2011). Effects of tourism-related provisioning on the trophic signatures and movement patterns of an apex predator, the Caribbean reef shark. *Biological Conservation*, *144*(2), 859–865.

Medley, P. (2008). Monitoring and managing queen conch fisheries: A manual. *FAO Fisheries Technical Paper*, *514*, 90.

Micheli, F., Saenz-Arroyo, A., Greenley, A., Vazquez, L., Montes, J. A. E., Rossetto, M., & Leo, G. A. D. (2012). Evidence That Marine Reserves Enhance Resilience to Climatic Impacts. *PLOS ONE*, *7*(7), e40832.

Mohammed, E., & Lindop, A. (2015). St. Vincent and the Grenadines: Reconstructed Fisheries Catches, 1950-2010. *Fisheries Centre, University of British Columbia.*

Mohammed, E., Straker, L. E., & Jardine, C. (2003). St. Vincent and the Grenadines: Reconstructed Fisheries Catches and Fishing Effort, 1942-2001. *Fisheries Centre Research Reports*, *11*(6), 23.

MPAtlas. (2016). MPAtlas: Discover the world's marine protected areas. Retrieved from http://www.mpatlas.org/explore/

Nino, F. S. (2016). Sustainable development goals: 17 goals to transform our world. Retrieved from http://www.un.org/sustainabledevelopment/oceans/

NOAA. (2014). Queen Conch, Strombus gigas (Linnaeus 1758): Status Report.

Obura, D. O. (2001). Participatory monitoring of shallow tropical marine fisheries by artisanal fishers in Diani, Kenya. *Bulletin of Marine Science*, *69*(2), 777–791.

Obura, D. O., Wells, S., Church, J., & Horrill, C. (2002). Monitoring of fish and fish catches by local fishermen in Kenya and Tanzania. *Marine and Freshwater Research*, *53*(2), 215–222.

Oxenford, H. A., Fields, A., Taylor, C., & Catlyn, D. (2007). *Fishing and marketing of queen conch (Strombus gigas) in Barbados* (Technical Report No. 16) (p. 44). University of the West Indies, Barbados: Centre for Resource Management and Environmental Studies (CERMES).

PADI. (2003). Recreational Dive Planner. Diving Science & Technology, Corp. Retrieved from http://elearning.padi.com/company0/tools/RDP_Table%20Met.pdf

PADI. (2006). Recreational Dive Planner. PADI Americas Inc. Retrieved from http://elearning.padi.com/company0/tools/RDP%20InsforUseMet.pdf

Pikitch, E. K., Chapman, D. D., Babcock, E. A., & Shivji, M. S. (2005). Habitat use and demographic population structure of elasmobranchs at a Caribbean atoll (Glover's Reef, Belize). *Marine Ecology Progress Series*, *302*, 187–197.

Pomeroy, R. S., Watson, L. M., Parks, J. E., & Cid, G. A. (2005). How is your MPA doing? A methodology for evaluating the management effectiveness of marine protected areas. *Ocean & Coastal Management*, *48*(7), 485–502.

Posada, J. M., & García-Moliner, G. (1997). *International Queen Conch Conference*. San Juan, Puerto Rico: Caribbean Fishery Management Council.

Prada, M., Glazer, R., Edwards, L., Fernandez, E., Ferary, T., George, L., … Williams-Peter, S. (2013). Assessment of the Queen Conch Population in the Southern Grenadines from Underwater Visual Surveys. SOFRECO.

Randall, J. E. (1964). Contributions to the Biology of the Queen Conch, Strombus Gigas. *Bulletin of Marine Science*, *14*(2), 246–295.

Reed, M. (2016). *Adaptive Moorings Management Plan for Tobago Cays Marine Park, Saint Vincent and the Grenadines.* Prepared by Monica Reed, Sustainable Grenadines Inc. and The Nature Conservancy for Tobago Cays Marine Park with funding from USAID.

Salas, S., Chuenpagdee, R., Seijo, J. C., & Charles, A. (2007). Challenges in the assessment and management of small-scale fisheries in Latin America and the Caribbean. *Fisheries Research*, *87*(1), 5–16.

Salcedo, R. L. (1997). Estado de la pesquería del lambi, Strombus gigas, en Republica Dominicana (pp. 114–116). Presented at the International Queen Conch Conference, San Juan, Puerto Rico: Caribbean Fishery Management Council.

Selig, E. R., & Bruno, J. F. (2010). A Global Analysis of the Effectiveness of Marine Protected Areas in Preventing Coral Loss. *PLoS ONE*, *5*(2), e9278.

Stoner, A. W. (1989). Density-dependent growth and grazing effects of juvenile queen conch Strombus gigas L. in a tropical seagrass meadow. *Journal of Experimental Marine Biology and Ecology*, *130*(2), 119–133.

Stoner, A. W., & Ray-Culp, M. (2000). Evidence for Allee effects in an over-harvested marine gastropod: density-dependent mating and egg production. *Marine Ecology Progress Series*, *202*, 297–302.

Stoner, A. W., Davis, M. H., & Booker, C. J. (2012). Negative consequences of Allee effect are compounded by fishing pressure: comparison of queen conch reproduction in fishing grounds and a marine protected area. *Bulletin of Marine Science*, *88*(1), 89–104.

Stoner, A. W., Mueller, K. W., Brown-Peterson, N. J., Davis, M. H., & Booker, C. J. (2012). Maturation and age in queen conch (Strombus gigas): Urgent need for changes in harvest criteria. *Fisheries Research*, *131–133*, 76–84.

SusGren. (2016). *Eastern Caribbean Marine Managed Areas Network (ECMANN) Project Component 3: Prioritizing sites in the SVG MMA system for application of key management actions. Report for site 7: Union Island/ Palm Island Marine Conservation Area.* (Prepared by Alba García Rodríguez). Union Island, St. Vincent and the Grenadines: Sustainable Grenadines Inc.

Tewfik, A., Archibald, S., James, P., & Horsford, I. (2001). *Antigua and Barbuda queen conch abundance survey* (1999) (CARICOM Fishery Report No. 7) (p. 30). Belice City: CARICOM Fisheries Unit.

The Census Office. (2012). 2012 Population & Housing Census: Preliminary Report. St. Vincent & The Grenadines Population & Housing, Central Planning Division, Ministry of Finance and Economic Planning.

Theile, S. (2001). *Queen conch fisheries and their management in the Caribbean*. TRAF-

FIC Europe.

Theile, S. (2005). Status of the Queen Conch Strombus gigas Stocks, Management and Trade in the Caribbean: A CITES Review. Presented at the 56th Gulf and Caribbean Fisheries Institute, BVI: TRAFFIC Europe.

Townsend, J. (2012). Petition to list the Queen Conch (Strombus gigas) under the Endangered Species Act. *WildEarth Guardians*.

Turnbull, S. (2016). Dive Locations. Retrieved from http://steveturnbull.co.uk/scuba/dive-locations.htm

UNEP. (2014). *Proposed areas for inclusion in the SPAW list. Annotated format for presentation report for: Tobago Cays Marine Park, Saint Vincent and the Grenadines* (United Nations Environment Program) (p. 38).

van Buurt, G. (1997). Legal considerations for fishery management in the Netherland Antilles (pp. 110–111). Presented at the International Queen Conch Conference, San Juan, Puerto Rico: Caribbean Fishery Management Council.

8. Appendix 1

Hypotheses tested regarding conch abundance in the study area, and the significance values obtained through the Wilcoxon signed-rank non-parametric test.

Hypothesis	Statistical significance (Wilcoxon)	Rejected H_0
H_0: There is no difference between the abundance of juveniles and adults in the study area in 2016. H_1: There is a significant difference between the abundance of juveniles and adults in the study area in 2016.	0.551	No
H_0: There is no difference between the total conch abundance among shallow and deep areas in the study area in 2016. H_1: There is a significant difference between the total conch abundance among shallow and deep areas in the study area in 2016.	0.279	No
H_0: There is no difference between the total abundance of conch juveniles among shallow and deep areas in the study area in 2016. H_1: There is a significant difference between the total abundance of conch juveniles among shallow and deep areas in the study area in 2016.	0.279	No
H_0: There is no difference between the total abundance of conch adults among shallow and deep areas in the study area in 2016. H_1: There is a significant difference between the total abundance of conch adults among shallow and deep areas in the study area in 2016.	0.276	No
H_0: There is no difference between the total abundance of conch juveniles in shallow areas and the total abundance of conch adults in shallow areas in 2016. H_1: There is a significant difference between the total abundance of conch juveniles in shallow areas and the total abundance of conch adults in shallow areas in 2016.	0.564	No
H_0: There is no difference between the total abundance of conch juveniles in deep areas and the total abundance of conch adults in deep areas in 2016. H_1: There is a significant difference between the total abundance of conch juveniles in deep areas and the total abundance of conch adults in deep areas in 2016.	0.581	No
H_0: There is no difference between the abundance of juveniles and adults in the study area in 2013. H_1: There is a significant difference between the abundance of juveniles and adults in the study area in 2013.	0.476	No
H_0: There is no difference between the total conch abundance among shallow and deep areas in the study area in 2013. H_1: There is a significant difference between the total conch abundance among shallow and deep areas in the study area in 2013.	0.600	No
H_0: There is no difference between the total abundance of conch juveniles among shallow and deep areas in the study area in 2013. H_1: There is a significant difference between the total abundance of conch juveniles among shallow and deep areas in the study area in 2013.	0.752	No

H_0: There is no difference between the total abundance of conch adults among shallow and deep areas in the study area in 2013. H_1: There is a significant difference between the total abundance of conch adults among shallow and deep areas in the study area in 2013.	0.686	No
H_0: There is no difference between the total abundance of conch juveniles in shallow areas and the total abundance of conch adults in shallow areas in 2013. H_1: There is a significant difference between the total abundance of conch juveniles in shallow areas and the total abundance of conch adults in shallow areas in 2013.	1.000	No
H_0: There is no difference between the total abundance of conch juveniles in deep areas and the total abundance of conch adults in deep areas in 2013. H_1: There is a significant difference between the total abundance of conch juveniles in deep areas and the total abundance of conch adults in deep areas in 2013.	0.400	No
H_0: There is no difference between the total conch abundance in 2013 and 2016. H_1: There is a significant difference between the total conch abundance in 2013 and 2016.	0.083	No
H_0: There is no difference between the abundance of juveniles in the study area in 2013 and 2016. H_1: There is a significant difference between the abundance of juveniles in the study area in 2013 and 2016.	0.065	No
H_0: There is no difference between the abundance of adults in the study area in 2013 and 2016. H_1: There is a significant difference between the abundance of adults in the study area in 2013 and 2016.	0.140	No
H_0: There is no difference between total conch abundance in shallow areas in 2013 and 2016. H_1: There is a significant difference between total conch abundance in shallow areas in 2013 and 2016.	0.176	No
H_0: There is no difference between total conch abundance in deep areas in 2013 and 2016. H_1: There is a significant difference between total conch abundance in deep areas in 2013 and 2016.	0.673	No

9. Appendix 2

Hypotheses tested regarding conch abundance in the study area, and the significance values obtained through the Wilcoxon signed-rank non-parametric test.

Hypothesis	Statistical significance (Wilcoxon)	Rejected H_0
H_0: There is no difference between total conch abundance inside and outside the TCMP in 2016. H_1: There is a significant difference between total conch abundance inside and outside the TCMP in 2016.	0.176	No
H_0: There is no difference between the abundance of juveniles inside and outside the TCMP in 2016. H_1: There is a significant difference between the abundance of juveniles inside and outside the TCMP in 2016.	0.588	No
H_0: There is no difference between the abundance of adults inside and outside the TCMP in 2016. H_1: There is a significant difference between the abundance of adults inside and outside the TCMP in 2016.	0.180	No
H_0: There is no difference between total conch abundance inside and outside the TCMP in 2013. H_1: There is a significant difference between total conch abundance inside and outside the TCMP in 2016.	0.917	No
H_0: There is no difference between the abundance of juveniles inside and outside the TCMP in 2013. H_1: There is a significant difference between the abundance of juveniles inside and outside the TCMP in 2013.	0.344	No
H_0: There is no difference between the abundance of adults inside and outside the TCMP in 2013. H_1: There is a significant difference between the abundance of adults inside and outside the TCMP in 2013.	0.916	No
H_0: There is no difference between total conch abundance inside the TCMP in 2013 and 2016. H_1: There is a significant difference between total conch abundance inside the TCMP in 2013 and 2016.	0.131	No
H_0: There is no difference between total conch abundance outside the TCMP in 2013 and 2016. H_1: There is a significant difference between total conch abundance outside the TCMP in 2013 and 2016.	0.273	No
H_0: There is no difference between the abundance of juveniles inside the TCMP in 2013 and 2016. H_1: There is a significant difference between the abundance of juveniles inside the TCMP in 2013 and 2016.	0.034	Yes
H_0: There is no difference between the abundance of adults inside the TCMP in 2013 and 2016. H_1: There is a significant difference between the abundance of adults inside the TCMP in 2013 and 2016.	0.785	No
H_0: There is no difference between the abundance of juveniles outside the TCMP in 2013 and 2016. H_1: There is a significant difference between the abundance of juveniles outside the TCMP in 2013 and 2016.	0.285	No

juveniles outside the TCMP in 2013 and 2016.		
H_0: There is no difference between the abundance of adults outside the TCMP in 2013 and 2016. H_1: There is a significant difference between the abundance of adults outside the TCMP in 2013 and 2016.	0.109	No