Coral Reefs Old Nemesis-Anthropogenic Runoff

by

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MASTER OF SCIENCE IN ENVIRONMENT AND MANAGEMENT

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COMMITTEE APPROVAL

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Abstract

South Coast Marine Park (SCMP) is a marine conservation area with extensive coral reefs in St. Vincent and the Grenadines (SVG). My study evaluated the land-use changes adjacent the SCMP and the impacts of pollution and sedimentation from terrestrial runoff on the health of the SCMP coral reefs. A mixed method approach was utilized using three data types. These included direct survey interview questionnaires (SIQ), marine water quality data which was requested from the National Park Rivers and Beaches Authority, which included physical-chemical parameters. Household and population census data for the SCMP communities were provided in the form of a report by the SVG Statistical Office. Results indicated that there were similarities in the findings between anthropogenic activities, pollution and the health and status of coral reefs within the SCMP. There were three prevalent forms of pollution and sedimentation within and on the SCMP coral reefs were solid waste, building and construction, and erosion along with farming. It was determined that pollution from runoff affected coral reefs by smothering, algal growth, and coral mortality. Key recommendations to reduce pollution and sediment runoff within the SCMP are public education, enforcement, as well as biophysical research and monitoring programs.

Keywords: coral reefs, land-use, pollution, marine environment, sedimentation, St. Vincent, Grenadines, South Coast Marine Park, SCMP.

Table of Contents

List of Figures

List of Tables

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Introduction

Coral reefs are the physical foundations of many coastal marine ecosystems. These living underwater structures are composed of calcium carbonate and are some of the most diverse and biologically productive naturally occurring ecosystems in the world (Wild et al., 2011). Coral reefs are a valuable resource, providing key ecosystem goods and services because of its biological diversity (Wild et al, as cited in Gattuso et al., 2014). In addition to providing a habitat for numerous species, coral reefs are natural breakwaters, providing appealing aesthetics for tourism, recreation, as well as support subsistence and commercial fisheries (Kilgo & Edwards, 2010).

Coral reefs protect coastlines from increased shoreline erosion and flooding during natural disasters such as intense tropical storms. Hoegh-Guldberg (2019) underscored the importance of coral reefs for the provision of coastal recreation and protection, and further explained that coral reefs have essential ecological (e.g. habitat maintenance) and biological (e.g. coastal mangrove forests) functions, which in turn provide food and support livelihoods for many coastal communities. Ahmed, Chong and Cesar (2005) noted the diversity of coral reefs globally are a main attraction for tourism and the income derived is vital to coastal communities livelihoods. This economic reliance has resulted in coral reefs around the world coming under increasing pressure from direct and indirect human activities (e.g. coastal development, pollution, climate change, tourism etc.). Over the past half century, there have been a decline in coral reef coverage and biological diversity as a result of anthropogenic activities and one-third of coral species are facing conservation threats (Magris & Ban, 2019; Wear & Thurber 2015).

Human activities alter the biophysical condition of coral reefs. Tourism, pollution, and fisheries are known stressors (Gill et al., 2015). In addition to physical changes, human actions can also alter the conditions needed for coral reef reproduction. McLeod et al.,

(2010) indicated that marine habitats have been destroyed due to the high concentration of contaminants that enter the marine environment. The resulting high levels of sedimentation and turbidity blocks the sunlight needed by corals for photosynthesis and growth. Coral reefs are also affected by sedimentation from agriculture and the associated agro-chemical pollutants. Ekos Communication (2009) noted that increased amounts of soil erosion from construction and agricultural farming in the Eastern Caribbean, led to increased levels of sedimentation and turbidity in the nearshore marine environment. This increase of sediments and chemical nutrients promoted the development of benthic algae covering and inhibiting coral development exacerbating the conservation problems for coral environments in the Caribbean Sea (Ekos Communication, 2009).

Coral reef ecosystems are continuously under pressure due to the monetary value and importance to livelihoods in coastal environments (Hoegh-Guldberg, 2019). Therefore, the study of coral reefs is important not just for the inherent ecological value, but because of the global decline resulting from a variety of anthropogenic activities and the consequences this can have on the coastal marine environment for both nature and coastal societies.

Study Area and Rationale

St. Vincent and the Grenadines (SVG), is located at 12.9843° N, 61.2872° W in the Eastern Caribbean (EC), with a land area totaling only 345 square kilometers (km^2) (Figure 1). St. Vincent is the main island, and the Grenadines comprise 32 islands that have a collective 390 km^2 of land and 406 km of coastline. SVG has two distinct seasons defined by precipitation levels and are known as the wet season and the dry season. The dry season is from December to May and the wet season from June to November. The latter coincides with the hurricane season.

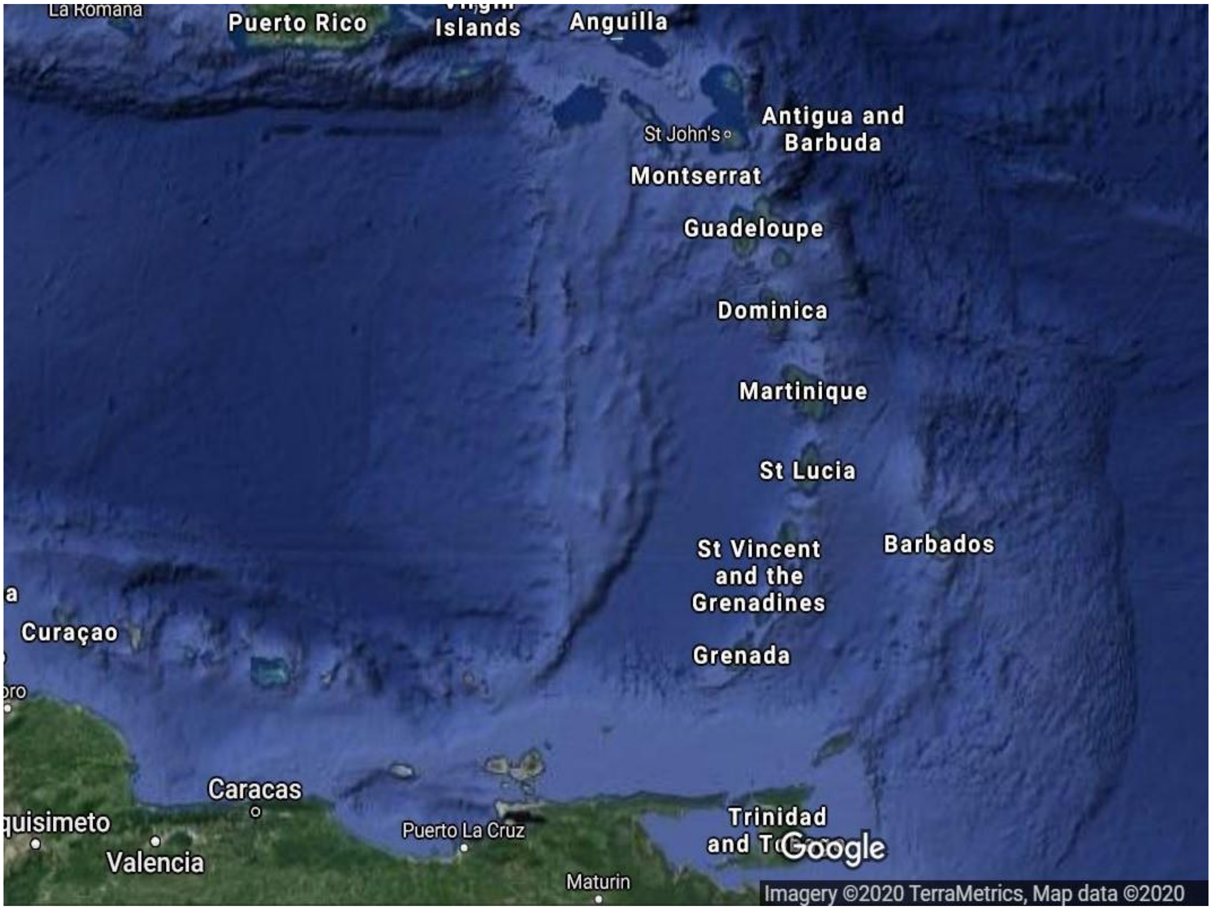

Figure 1. Map of St. Vincent and the Grenadines within the Eastern Caribbean Islands. Google Maps (2020).

SVG has the largest coverage of coral reefs of the six Eastern Caribbean (EC) countries (Antigua and Barbuda, Dominica, Grenada, St. Kitts and Nevis, and St. Lucia) (Nature Conservancy, 2016). These extensive coral reefs encompass 168 km^2, with seagrass beds that provides habitat for a diversity of terrestrial, marine, and avian life. Further to this, the marine ecosystem in SVG are utilized as a primary resource by coastal communities and the likelihood of the resources being exploited was a primary concern of the SVG government. As such, the government of SVG established several legal marine conservation and protected areas (Wildlife Protection Act, 1987).

Under the SVG Fisheries Conservation Act, the South Coast Marine Park (SCMP) (also known as the South Coast Marine Conservation Area (SCMCA) was declared a marine conservation area in 2015. The SCMP is located on the southern tip of St. Vincent between latitudes 13º 07.2 N and 13º .0 N and longitudes 61º 11.9 W and 61º 13.0 W and is adjacent to a populated area (Figure 2). This marine protected area encompasses a total (land and sea) of 3.27 km, with over half (2.60 km) in the marine environment (Baldwin, 2014).

Figure 2. South Coast Marine Park (SCMP) Communities. Google Maps (2020).

The SCMP has five adjacent coastal communities: Canash, Calliaqua, Ratho Mill, Rose Cottage and Villa. These proximal communities share common environmental and social characteristics. The SCMP has four major bays (Indian, Calliaqua, Canash, and Villa) and three watercourses providing fluvial and estuarine habitats (Baldwin, 2014). In addition, the community of Arnos Vale is adjacent to the SCMP and has two rivers that also border the SCMP. These water courses have both natural and man-made river banks. An example of the man-made river banks is shown in Figure 3. These SCMP communities are largely agricultural, with a heavy reliance on the coastal waters that provide the main source of food and livelihoods (Baldwin, 2014; Lockhart et al., 2013).

Figure 3. The Arnos Vale River Non-Natural River Bank

The fluvial and estuarine habitats include a diversity of species; nearshore pelagic, demersal fish, sea turtles, octopus, sea urchins, and various types of crustaceans (Global Parks, 2014). The SCMP is also home to 17 coral species but is dominated by Mustard Hill coral (*Porites astreoides*), starlet coral (*Siderastrea sidereal*), brain coral (*Diploria* *strigosa*), and boulder star coral (*Montastraea annularis*) (Kilgo & Edwards, 2010). The endangered elkhorn coral (*Acropora palmata*) is also found within the SCMP (Kilgo & Edwards, 2010). The SCMP is also the tourism epicenter in St. Vincent with many hotels, marinas, and sandy beaches used for recreational activities such as snorkeling and diving.

The SVG government supported research over the past 10 years that noted a decline in the spatial area that coral reefs cover within the marine environment (Baldwin, 2014; Christie & Teelucksingh, 2012; Global Parks, 2014; Lockhart et al., 2013; Maisonneuve, 2014). Christie and Teelucksingh (2012) noted that human pressures have contributed to the degradation of the SCMP coral reefs, marine habitats, and resources. Evidence suggests the increasing rate of anthropogenic activities such as land development, deforestation, agricultural farming, agro-chemical use, and sewage within the SCMP communities has the potential to adversely affect the SCMP coral reefs (Baldwin, 2014; Christie and Teelucksingh (2012)). Similarly, Global Parks (2014) indicated that the waters of the SCMP are contaminated by sewer outflows, agricultural runoff, and waste from the surrounding SCMP communities, industries, hotels, and household chemicals. Global Parks (2014) explained that the levels of pollution within the waters of the SCMP has become an increasing concern over the past decade. Correspondingly, Kilgo and Edwards (2010) noted that “anecdotal evidence suggests that the health of marine habitats within the SCMP has declined over the last two decades” (p. 1). Moreover, they indicated that coral reefs once a main feature of Calliaqua Bay have declined as a result of polluted runoff water.

Much of the pollution within the SCMP has been identified as originating on land (Baldwin, 2014; White-DeRiggs, 2012; Global Parks, 2014; Kilgo & Edwards, 2010). According to OAS (2001) “divers have reported large amounts of polythene (from agriculture) and diapers (from community solid waste) sitting on coral reefs” (p. 17). Global

Parks (2014) and OAS (2001) noted that rivers leading into the SCMP are significant sources of pollution transporting sediments and microbes, which can present a serious challenge to the health of coral reefs and other important marine habitat and species (Figure 3). Contaminant levels have recently been considered sufficient to effectively block sunlight from the coral reefs possibly leading to substantial coral reefs death (Baldwin, 2014; Global Parks, 2014; Kilgo & Edwards, 2010).

Other work conducted within the SCMP included several management plans that assessed and made recommendations on the status of the SCMP and its alternative livelihood opportunities such as restaurants, dive shops, tour guides, and eco-tourism (Gaudin, 2014; Lockhart et al., 2013; Maisonneuve, 2014). To date, no biophysical studies have been conducted on the possible impacts of land-use changes on the SCMP coral reefs.

Due to the value of marine resources within the SCMP, the reliance of coastal communities on these waters, and the known degradation of the marine environment, it is of paramount importance to identify additional anthropogenic changes that have occurred that could also be negatively affecting the coral reefs of the SCMP. Based on previous research, I hypothesized that the increased anthropogenic activities within the SCMP and adjacent communities would increase the levels of sedimentation and pollution, which would result in a decline in the health of the coral reefs. The health of the coral reefs was defined by coral mortality, smothering, and the growth of damaging algae.

Thesis Research Question and Objectives

My MSc thesis research focused on the land-use changes adjacent to the SCMP and associated impacts on the coral reefs. My specific research question was: What are the impacts of sedimentation and pollution from terrestrial runoff on coral reefs of the SCMP? My four research objectives were:

1) To identify the sources of pollution and sediment runoff within the SCMP.

2) To understand how pollution and sediment in runoff affects coral reefs within the SCMP.

3) To quantify the existing impacts related to sedimentation and pollution to create a baseline for future studies.

4) Provide recommendations for improved land-use practices to reduce the rate of sedimentation and pollution that affects the SCMP coral reefs.

Methods

My research framework involved using a mixed methods approach that integrated qualitative and quantitative data. Data were collected directly and indirectly. The direct data collection involved a survey of SCMP community members for the acquisition of new information related to the sources and effects of terrestrial sediment and pollution in runoff. The indirect data collection involved the acquisition of the best available water quality and census data collected by the SVG government in conjunction with the National Parks, Rivers and Beaches Authority. Qualitative data from survey questionnaire interviews, government reports, and academic articles, and quantitative data on water quality and human population were integrated to evaluate the impacts of sedimentation and pollution from terrestrial runoff on the coral reefs of the SCMP, and to determine whether a correlation existed between sedimentation, pollution, and coral reef decline.

The mixed methods framework has been shown to be an effective method when the complexity of the research problem, such as environmental pollution, is the product of many components that cannot be addressed using only one method (Ponce and Maldonado, 2015). I specifically used the triangulation method approach (Creswell, 2014) that compares and validates the various data sources (O'Leary, 2017). This approach was selected to be used because there were insufficient bio-physical data on the SCMP coral reefs.

Survey Interview Questionnaires (SIQ) Data Collection

A survey interview questionnaire (SIQ) was developed to collect quantitative and qualitative which consisted of up to nine general and profession specific questions (Appendix A). SIQ participants were targeted through a national radio program (Farmers Magazine[1]) where I solicited volunteers who worked and lived within the SCMP to participate in the study. Additionally, I distributed flyers within the SCMP communities to advertise the SIQ's (Appendix B). Interested participants contacted me through my email and phone that was provided.

The SIQ data collection was conducted from 10 to 19 June 2019, inclusive with the assistance of two data collectors from the Fisheries Division of SVG. In addition, five direct observations were made during field work to document and photograph the types and sources of pollution within the SCMP rivers, beaches and marine waters. The SIQ data collection targeted SCMP fishers, divers, community residents[2], environmental groups, agricultural extension officers, farmers, marine biologists, and hotel and commercial businesses owners. SIQ respondents data were grouped and aggregated in the following categories; fishers and divers (the majority of fishers are also divers and vice-versa, whether recreationally or professionally); farmers (included environmental groups and agricultural extension officers as they work in the agricultural and environmental sector), and hotel and commercial businesses owners (render similar goods and services within the SCMP).

For SIQ data collection purposes, the SCMP communities were divided into three zones identified as Zones A, B and C (Figure 4). The division of zones was done to gather

[1] Farmers Magazine is a national radio program created by the Communications Unit in the Ministry of Agriculture Forestry and Fisheries in SVG dedicated to farmers. It is a primary source of information sharing reporting, highlighting, and promoting initiatives surrounding the agricultural sector.

[2] Community residents are persons solely living within the SCMP communities.

data from all SCMP communities in a timely and efficient manner. Data collection commenced in Zone A (Calliaqua, Canash, and Ratho Mill), followed by Zone B (Villa and Indian Bay), and Zone C (Arnos Vale). Bio-ecological data collection included questions related to: reef condition, reef status, and reef changes over time. The data collected from Zones A, B and C were pooled into a single SCMP community dataset. The pooled data set was subsequently grouped by respondent type, to determine whether differences existed in their observations and knowledge of the pollution types and sources within the SCMP.

Figure 4. South Coast Marine Park SIQ data collection zone map. Google Maps (2020).

SIQ respondents were asked to provide their number of years of experience living and/or working within the SCMP; their utilization of the SMCP; land-use changes they had observed in the SCMP; identify point sources of pollution; identify the types of pollution observed within the SCMP, and provide details on their own methods of waste disposal (Appendix A).

Ethical approval was granted by the Royal Roads University (RRU) Research Ethics Board on the 29 November 2018 by email correspondence. In accordance with the RRU Ethics Board guidelines, respondents were asked to sign a consent form and were assured that all information given will be held in strict confidence (Appendix A). Respondents consent forms were detached from the SIQ leaving no personal identifiable data, ensuring the SIQ was completely anonymous. The consent form was also used as a method to prevent duplication of respondents.

The SIQ data collected from the respondents were entered into Microsoft Excel spreadsheets and grouped into respondent types as follows: marine biologists, commercial business owners, community residents, divers, environmental groups, extension officers, farmers, fishers, and hoteliers. Grouped data were analyzed thematically in relation to the sources and impacts of sedimentation and pollution within the SCMP coral reefs. The frequency of each theme was used to determine whether differences were present amongst the data provided by respondents. Statistical analyses were conducted using SPSS software to determine whether statistically significant differences occurred between and within the data sources, as well as to illustrate the data graphically.

Marine Water Quality Data

I requested marine water quality data via an official email correspondence from the National Parks, Rivers and Beaches Authority. Marine water quality data were provided by the National Parks, Rivers, and Beaches Authority of SVG, in the form of Microsoft Excel spreadsheets. The water quality data included the following physical-chemical parameters: temperature, pH, turbidity, salinity, nitrates, phosphates, iron, fecal coliform, dissolved oxygen, and dissolved solids. These data were classified by year and month and had been collected bi-weekly at the Villa Bay in the SCMP from 2014-2018. Sampling frequencies were executed according to the monitoring objectives of the organization and varied between parameters.

The marine water quality data were also classified by season (dry season [December-May] and wet season [June-November]) annually. Descriptive statistics were calculated in Microsoft Excel for the period 2014-2018 for each physical-chemical parameter. Statistical evaluation using SPSS software was conducted to determine whether significant differences existed over time.

Census Data Collection

A data request was made by official email correspondence, followed by phone conversation to the SVG statistical office for SCMP communities' population household census data. Population and household census data for the SCMP communities were provided by the St Vincent and the Grenadines Statistical Office. The data were provided in a report for the period 1980-2012 (Statistical Office, 2012). The data were provided in 10-year increments as this is the frequency of population and household census data collection in SVG (Statistical Office, 2012). The population and household census data were divided into 13 geographic units called census divisions (CD). The community of Calliaqua, is a CD and this includes the five SCMP communities (Villa, Canash, Indian Bay, and Ratho Mill). The population and household census data for the SCMP communities was entered into Microsoft Excel sheets in the following categories: census division, surface area, number of people per household, and years. The data were used to calculate the CD population increase or decrease by calculating the mean and standard deviation of the population household for the twelve-year period of the CD in Microsoft Excel. Statistical evaluation using the SPSS software was conducted to determine whether any significant differences existed in the household population for the twelve-year period.

Lastly, the SIQ data, marine water quality data, and population housing and census data were examined collectively to determine if there were any significant relationships between anthropogenic activities and the health of the SCMP coral reefs (coral mortality, smothering and algal growth). This was done by comparing the SIQ responses to water quality data, to determine whether the identified sources and types of pollution observed from terrestrial runoff mentioned by respondents, had any correlation to marine water quality. In addition, whether the increased household and population influenced marine water quality and terrestrial runoff as identified by SIQ respondents.

Results

Survey Interview Questionnaires (SIQ)

A total of 76 SIQ's were distributed in zones A, B, and C to marine biologists (who are employed by privately owned businesses and the SVG government), hotel and commercial business owners, community residents, fishers and divers, environmental groups, agricultural extension officers, and farmers within the SCMP. The SIQ respondents had varied years' experience working and living within the SCMP. Additionally, they had variant knowledge on the land-use changes within the SCMP which have occurred over the pass fifteen to twenty years. The SIQ's had a 93.4% (n=71) return rate from participants, with 6.6% (n=5) that did not respond (Table 1).

Table 1. *Number of Respondents for Survey-Interview Questionnaires (SIQ's) in the SCMP Zones.*

Participants	Zones	Respondents	Non-Respondents
Marine Biologists	A, B, C	12	3
Commercial Businesses Owners	A & B	9	
Community Residents	A, B, C	21	
Divers	A & B	5	
Environmental group	B	1	
Extension Officers	A, B, C	4	
Farmers	A & B	5	1
Fishers	A, B, C	12	
Hoteliers	A & B	2	1
Total		71	5
Percentage		93.4(%)	6.6 (%)

Respondents Number of Years of Experience

The average number of years' experience for the 71 respondents within zones A, B, and C of the SCMP was 20.3 years (Figure 5). It was noted that hotel and commercial business owners had the highest number of years' experience working and living within the SCMP, while biologists had the least number of years' experience also working and living within the SCMP (Figure 5).

Community residents averaged 21.8 years of experience (Figure 5), and described their experience as both living and working within the SCMP. Farmers averaged 18.1 years of experience, while fishers and divers who accessed the marine resources on a daily to monthly basis had an average 22.3 years (Figure 5). Although differences existed between respondent types, results indicated no statistically significant differences amongst respondent types in the number of years' experience working and living within the SCMP (Kruskal-Wallis One-Way ANOVA, $H = 8.129$, $d.f. = 4$, $p = 0.08693$).

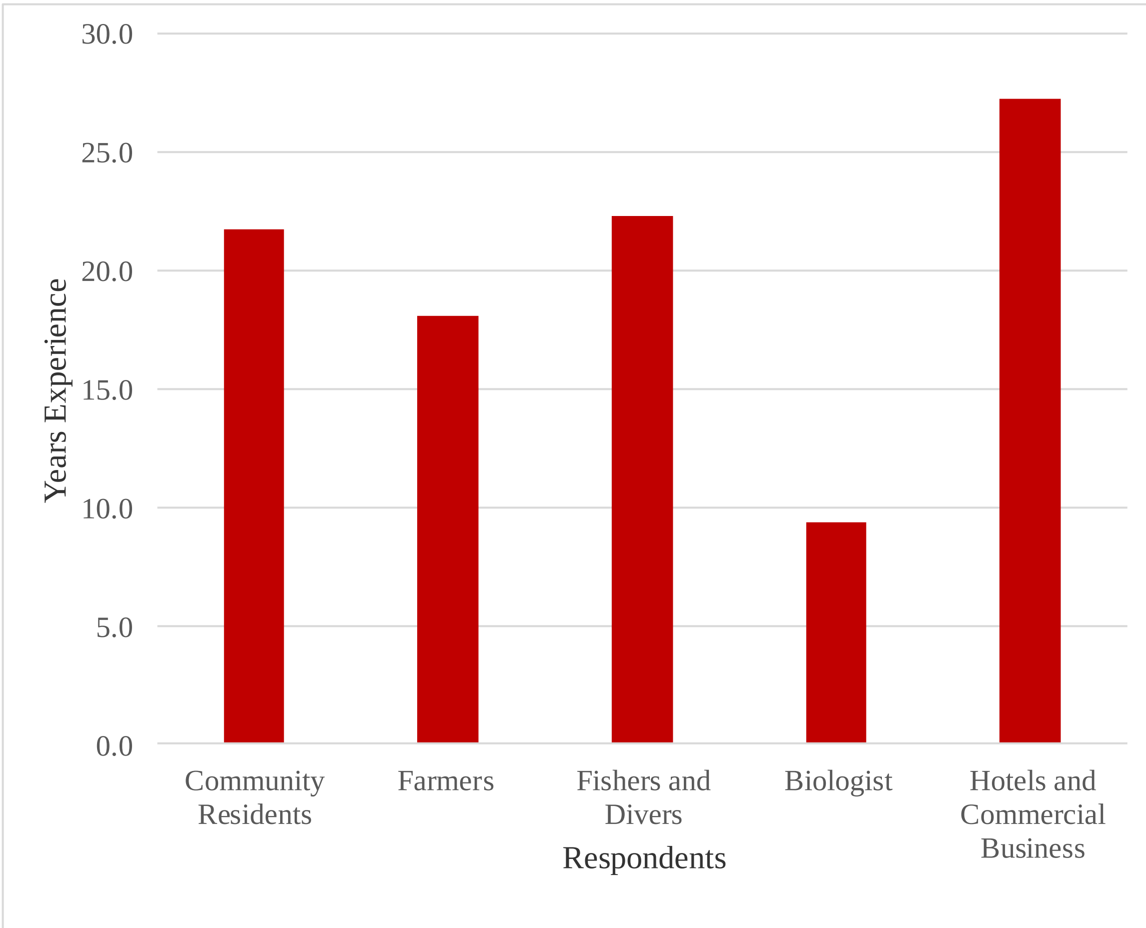

Figure 5. Respondents total number of years' experience within the SCMP.

Identification of Sources of Marine Pollution

Respondents were asked to identify the sources of marine pollution that they considered to be the most important factors affecting the marine environment of the SCMP. The responses varied between the different respondent types.

In addition, from direct field observations were made on 10, 12, 13, 15, and 18 June 2019 respectively to Arnos Vale River, Calliaqua River, Calliaqua Bay, Villa beach, and Canash, a number of different types of pollution were observed:

- Tyres
- Diapers
- Plastic wrappers
- Cans
- Bottles
- Dead animals
- Derelict fishing gears
- Household garbage

Additionally, sources of pollution observed as:

- Domestic drains
- Business drains
- Mechanical shops
- Rivers
- Farms

Direct observations of underwater marine pollution in the SCMP were made from 15 to 19 June 2019. Types of included:

- Plastic waste
- Fishing gear,
- Tyres
- Bottles
- Cans

Community Residents

Community residents of the SCMP identified five main types of marine pollution that they considered to be the most important. Solid waste was identified by over two-thirds (41.9%) of the respondents (Figure 6). The other four sources were identified by lower proportions of the respondents, and included chemicals (23.3%), siltation (14.0%), air pollution (11.6%) and sewage (9.3%) (Figure 6). The two main sources of pollution identified by community residents were solid waste and chemicals (Figure 6). Interestingly, siltation, sewage, and air pollution, were reported in near equal percentages by these respondents (Figure 6). A statistical difference was found between the types of marine pollution identified by the community resident respondents with solid waste identified as the primary source (*Chi-square test*, $p < .05$. x^2 (1, n = 20) = 15.24, p = 0.004).

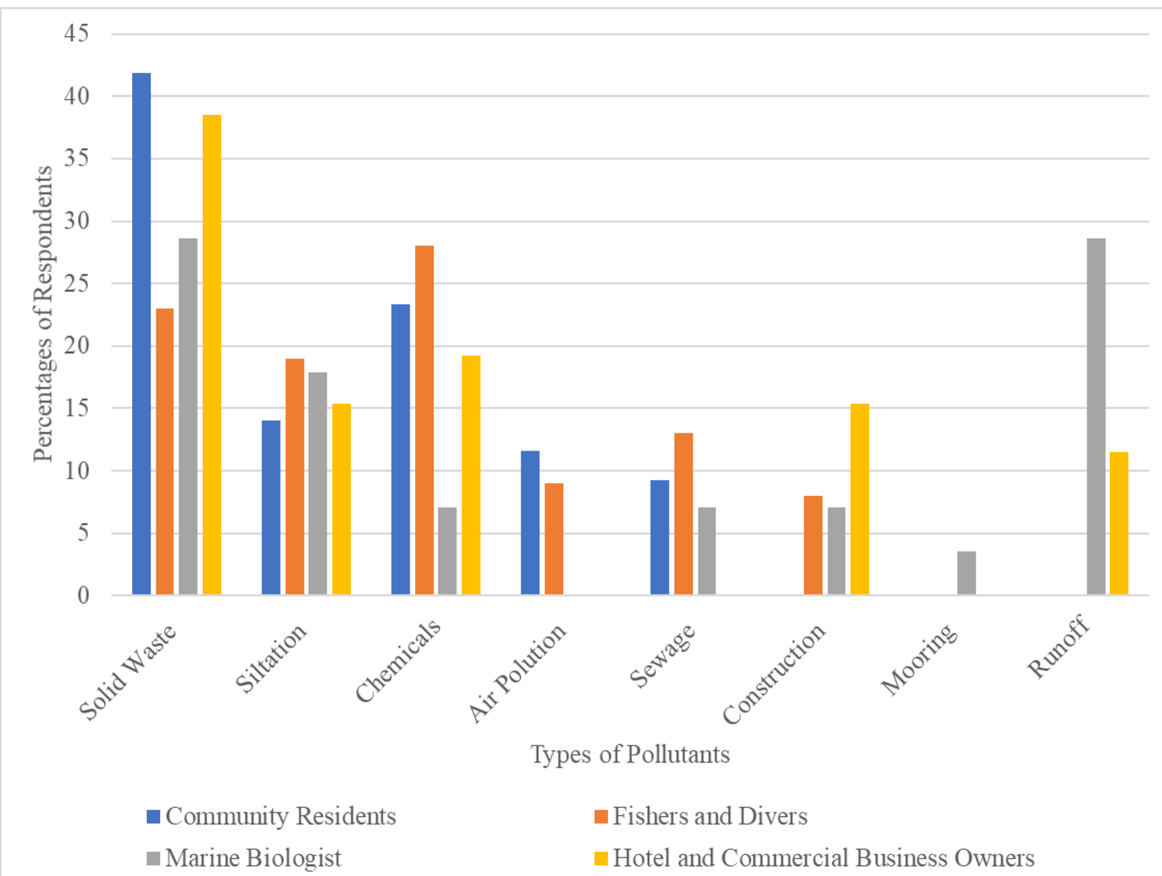

Figure 6. Types of pollution reported observed in the SCMP by respondents.

Fishers and Divers

Fishers and divers of the SCMP were also asked to identify the most important types of marine pollution that they considered were affecting the SCMP (Figure 6). This group identified six main types of marine pollution that included: chemicals (28.0%), solid waste (23.0%), siltation (19.0%) sewage (13.0%), air pollution (9.0%) and construction (8.0%) (Figure 6). While the latter source was identified by fishers and divers as a marine pollutant affecting the SCMP, it was not identified by community residents. Fishers and divers identified chemicals as the primary pollutant within the SCMP. There were no statistically significant differences in the sources of pollution reported by the fishers and divers (*Chi-square* test, $p < 0.5$. x^2 (1, $n = 20$) = 4.89, $p = 0.30$).

Responses varied between community residents and fishers and divers on the sources of pollutants present within the SCMP. Results indicated that there were no statistically significant differences in their response (Kruskal-Wallis One-Way ANOVA, $H = 0.026$, *d.f.* = 2, $p = 0.873$).

Marine Biologists

Marine biologists identified seven main types of marine pollution in the SCMP including: solid waste (28.6%), siltation (17.9%), chemicals (7.1%), sewage (7.1%), construction (7.1%), moorings (3.6%), and runoff (28.6%) (Figure 6).

Chemicals, sewage, and construction were reported in equal percentages (Figure 6). Construction was identified by both fishers and divers and marine biologists as a pollutant affecting the SCMP. Moorings were not identified by community residents or the fishers and divers.

There were differences in the marine biologists responses in the types of marine pollution present within the SCMP. Results indicated that there were statistically significant differences in their responses (*Chi-square* test $p < 0.5$. x^2 (1, n = 20) =19.52, p = .001, Figure 8). There was no statistically significant difference in responses amongst the three groups of respondents (community residents, fishers and divers, and marine biologists) in the types of pollutants identified within the SCMP (Kruskal-Wallis One-Way ANOVA, H=0.071, *d.f.* = 2, p = 0.965).

Hotel and Commercial Business Owners

Hotels and commercial business owners identified five main types of pollution including: solid waste (38.5%), chemicals (19.2%), siltation (15.4%), construction (15.4%) and runoff (11.5%) with solid waste being the most commonly reported (Figure 6).

Sewage and mooring were not identified as pollution sources by the hotel and commercial business owners. Analysis indicated that there was a statistically significant difference in the hotel and commercial business owners' responses of the most important pollution sources (*Chi-square* test $p < 0.5$. x^2 (1, n = 20) = 9.57, p = 0.048).
Community residents, fishers and divers, marine biologist, and hotel and commercial business owners responses of the different types of pollutants present in the SCMP were compared to determine if there were any significant differences in their responses.
Results indicated that there were no statistically significant differences in their responses (Kruskal-Wallis One-Way ANOVA, H=0.089, *d.f.* = 3, p = 0.993).

Sources of Pollution

The survey respondents; farmers, hotel and commercial business owners, and marine biologists were asked to identify the sources of marine pollution within the SCMP. The responses varied between the different groups of respondents.

Farmers

Farmers identified seven different sources of pollution within the SCMP with farming (26.3%), rivers (21.1%), and private homes (15.8%) being identified by more than 15% of respondents (Figure 7). The remaining point sources included mechanical shops (10.5%), construction (10.5%), drains (10.5%) and tourism (5.3%) (Figure 7). This group of respondents identified tourism as the smallest point source of pollution (Figure 7). Analysis of results found statistically significant differences in the farmers responses (*Chi-square* test $p < 0.5$. x^2 (1, $n = 15$) = 9.50, $p = 0.050$).

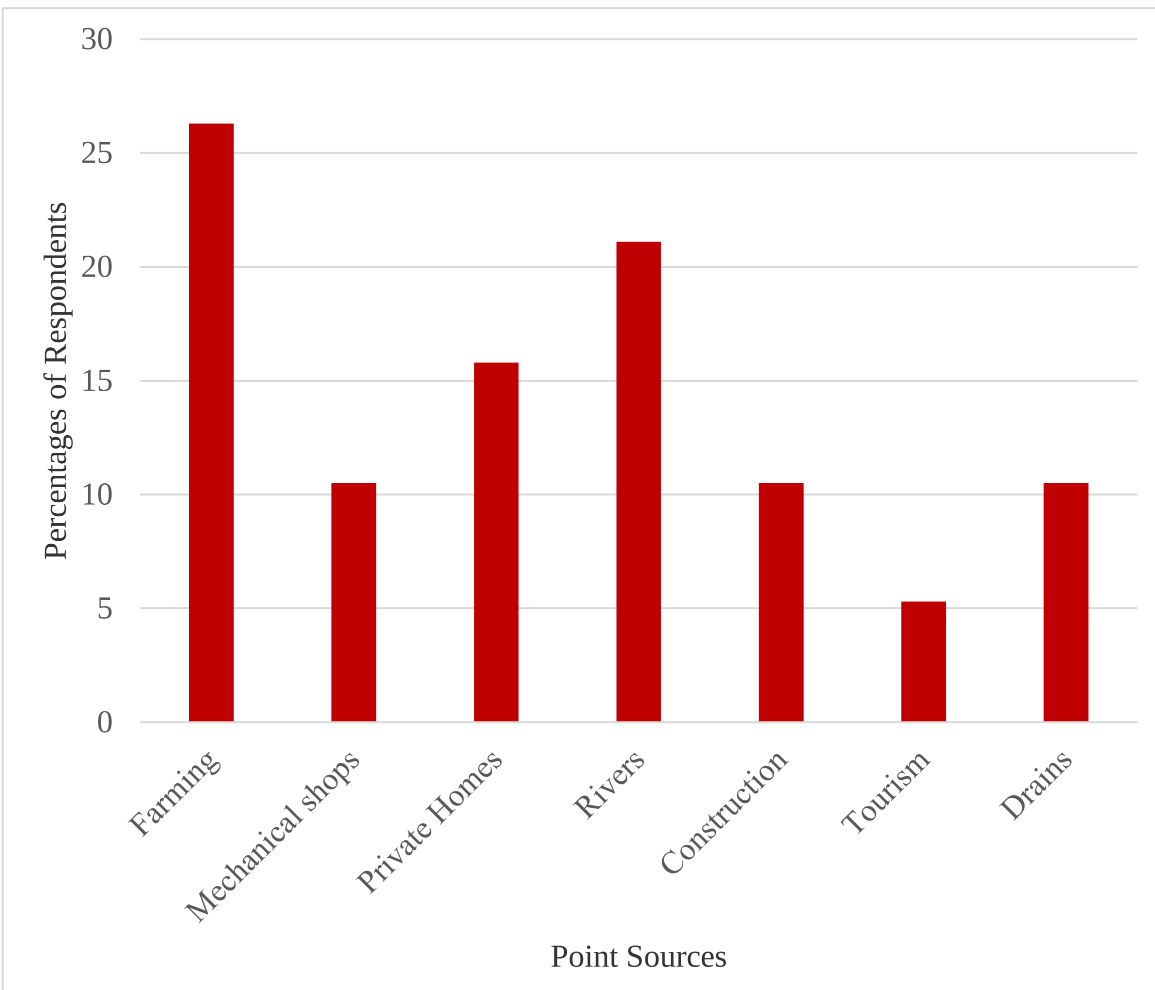

Figure 7. Sources of pollution identified by farmers within the SCMP

Hotel and Commercial Business Owners

Hotel and commercial business owners were asked to identify sources of pollution within the SCMP. Nearly a quarter (23.1%) of the hotels and commercial business owners identified the Calliaqua community as a principal point source of pollution within the SCMP (Figure 8). Interestingly, Canash (15.4%), Villa (15.4%), and Arnos Vale (15.4%) were reported in equal percentages by hoteliers and commercial business owners (Figure 8). However, the majority of respondents in this group (30.8%) reported they were unsure as to which communities were main sources of pollution (Figure 8). Although, responses varied there were no statistically significant differences in the hotel and commercial business owners responses on the point sources of pollution (*Chi-square* test $p < 0.5$. x^2 (1, n =10) = 3.10, p = 0.542).

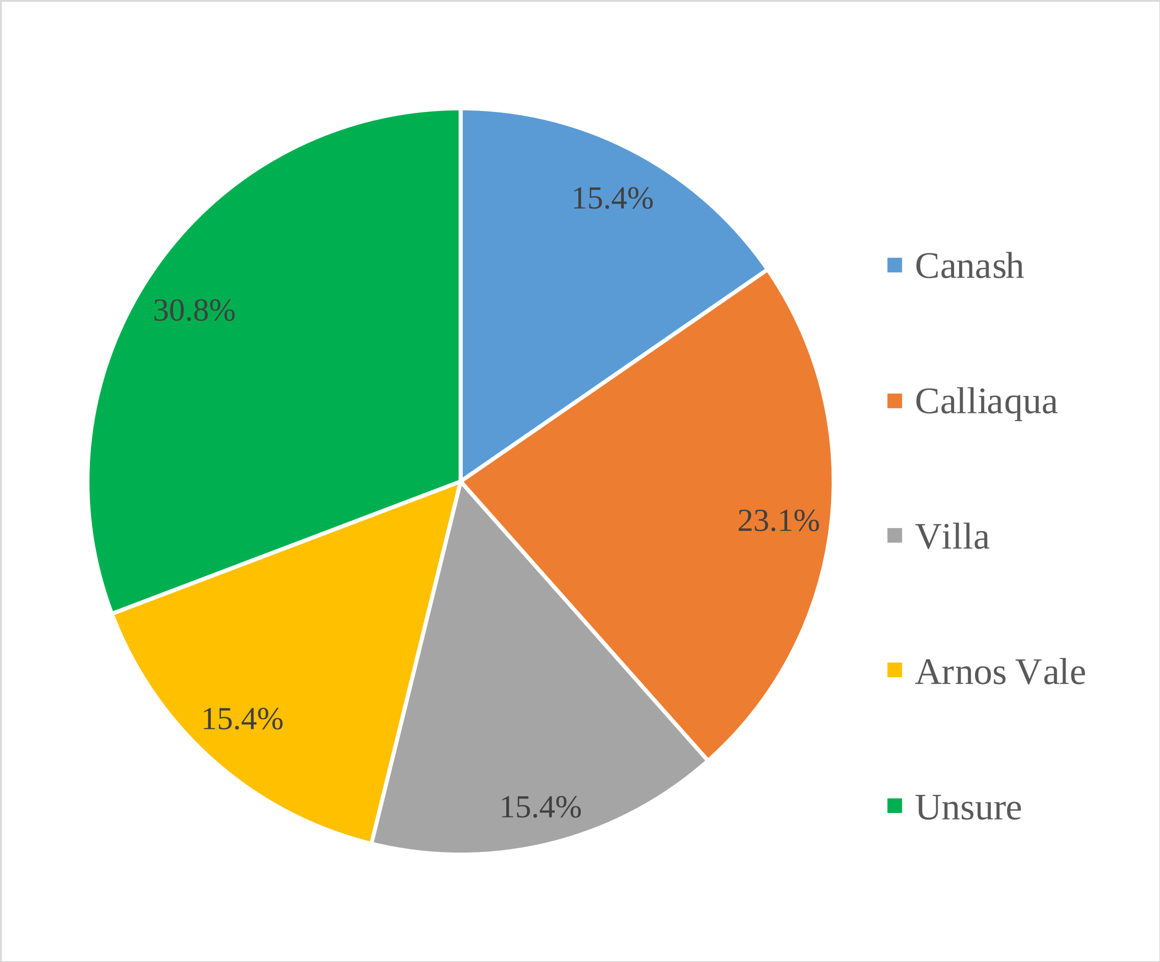

Figure 8. Community point sources of pollution identified by hotel and commercial business owners within the SCMP

Marine Biologists

Nearly half (40.0%) of the marine biologists identified pollution as the major threat affecting coral reefs in the SCMP. This was followed by land-use changes (20.0%), and terrestrial runoff (16.0%) (Figure 9). Smaller proportions of the biologist respondents also identified siltation (12.0%) and climate change (8.0%) as important point sources of pollution (Figure 9).

Amongst this group there were also other threats identified that accounted for less than 5% of the responses. These included changes in biodiversity as a result of invasive species (e.g. Lion fish (*Peterois volitans)* and increased tourism activities (Figure 9). There were statistically significant differences in the marine biologists responses (*Chi-square* test $p < 0.5$. x^2 (1, n = 15) =12.18, p = 0.016).

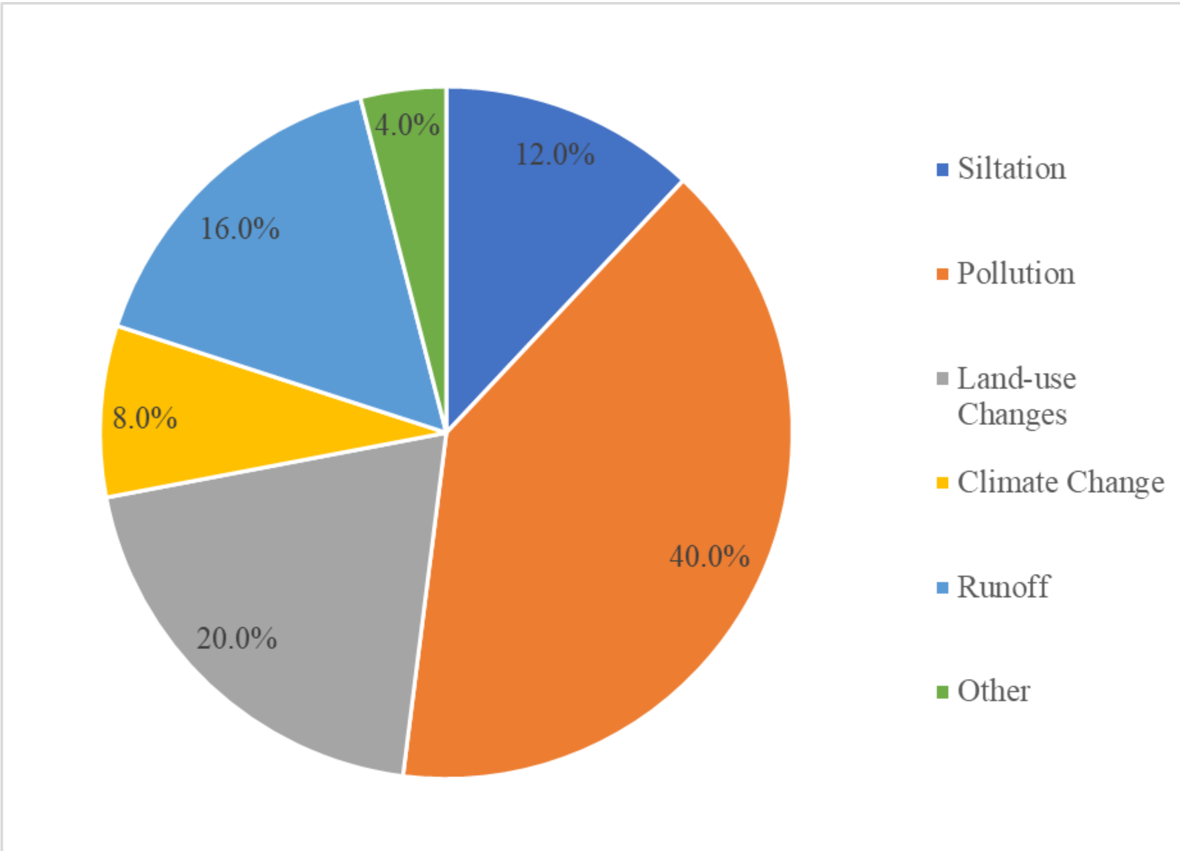

Figure 9. The marine biologist response data on the major threats impacting the SCMP.

Land-use Changes

Community Residents

Respondents were asked to identify the land-use changes they have observed over the last 15-20 years in the SCMP communities. As with other questions, the responses varied between the different groups of respondents.

The main land-use change that the community residents identified was construction (34.7%), but this group also identified pollution (20.4%), erosion (14.3%) and marine biodiversity (14.3%) as key changes that have occurred (Figure 10). In addition to these more consistent responses, some community residents also identified population increase

(6.1%), deforestation (6.1%) and tourism (4.1%) in near equal, albeit lower percentages (Figure 10). There were statistically significant differences in the data provided by community residents on the land-use changes that have occurred over the past 15-20 years within the SCMP communities (*Chi-square* test, $p < 0.5$. $x^2 (1, n = 15) = 21.18$, $p = 0.0003$).

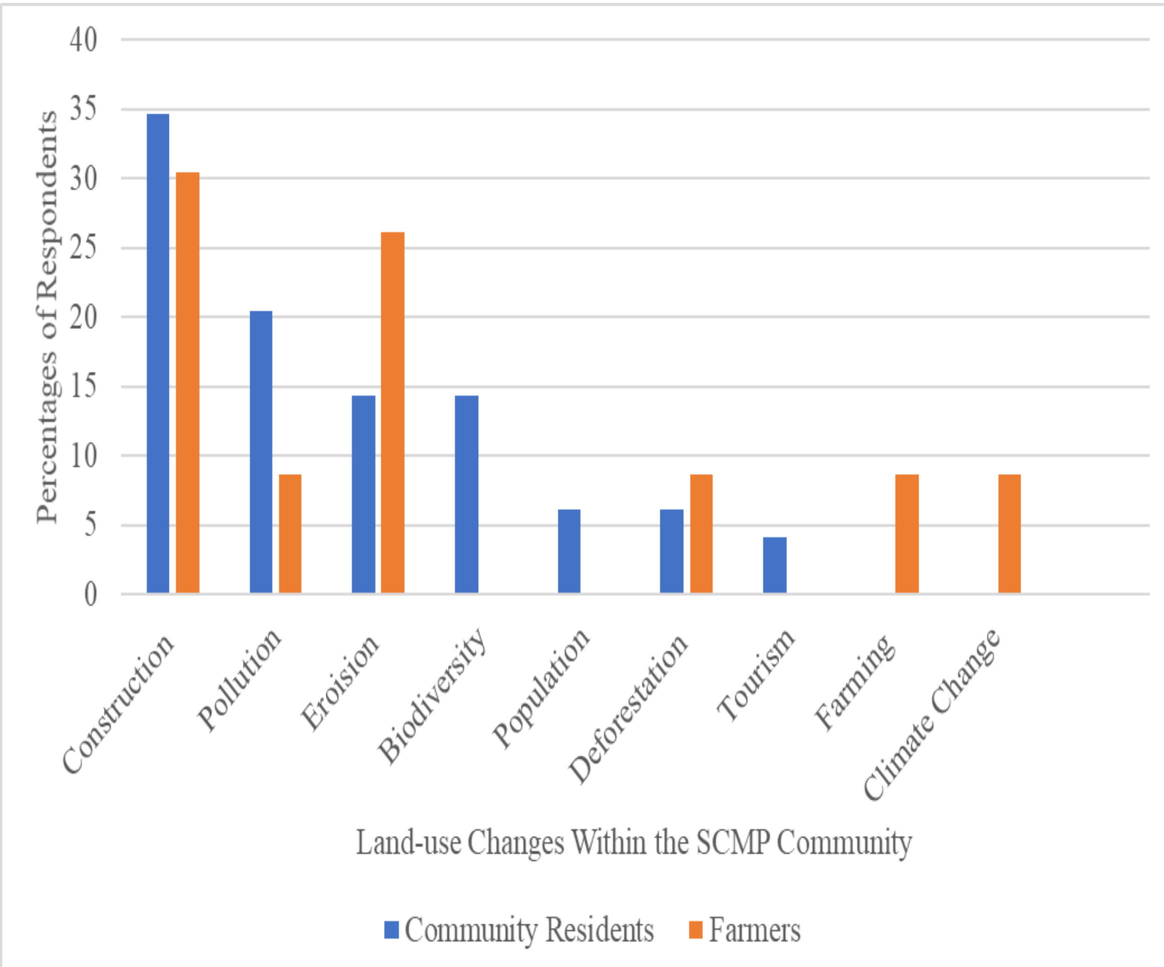

Figure 10. Land-use changes within the SCMP as identified by respondents.

Farmers

Farmers also identified construction (30.4%), erosion (26.1%) and pollution (8.7%), as main land-use changes within the SCMP (Figure 10). This group of respondents also identified deforestation (8.7%), farming (8.7%) and climate change (8.7%) in equal percentages as pollution (Figure 10). It is interesting to note that farming and climate change were identified by farmers but not by community residents. A statistical difference was found between the types of land-use changes identified by farmer respondents (*Chi-square* test, p < 0.5. x2 (1, n = 20) = 13.84, p = 0.008).

Health and Status of Coral Reefs

The survey respondents were asked to qualitatively indicate what were the conditions (i.e. health) of the SCMP reefs 15-20 years ago compared to the present day. As with other SIQ responses, there was variation between the different groups of respondents.

Fishers and Divers

The majority of fishers and divers (55.6%) reported that the current conditions of the SCMP reefs are presently very poor compared to 15-20 years ago (Figure 11). Interestingly, equal proportions of the fishers and divers reported that the SCMP reefs were both in good condition and in poor condition (16.7%, 16.7%, respectively) (Figure 11).

A statistical difference was found between the responses on the heath and status of coral reefs, identified by fishers and divers' respondents (*Chi-square* test, $p < 0.5$. x^2 (1, n = 20) = 15.08, p = 0.002).

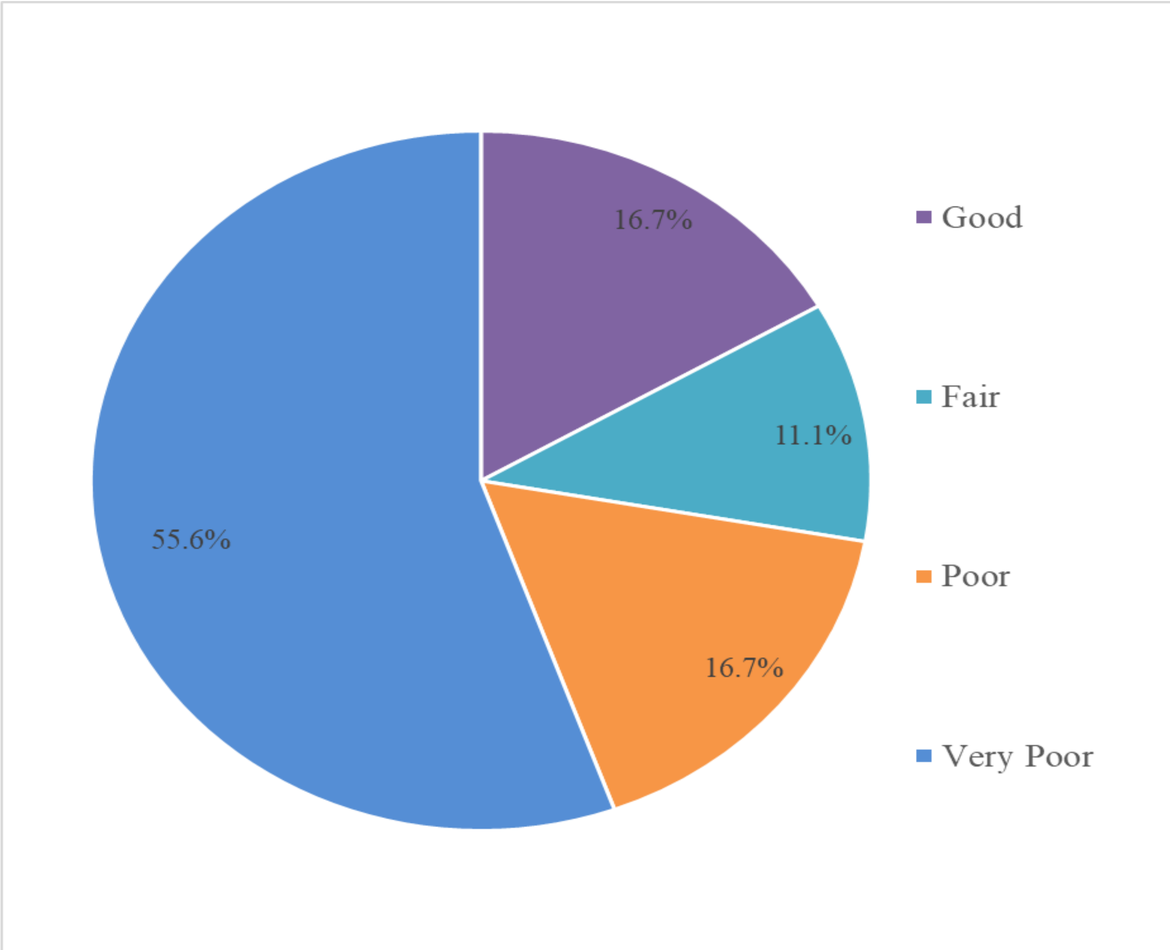

Figure 11. Conditions of the SCMP reefs as observed by fishers and divers.

Marine Biologists

About a third (36.4%) of marine biologist respondents indicated that the coral reefs of the SCMP were in fair condition (Figure 11). This category was only reported by just over a tenth of the fishers and diver respondents (11.1%) (Figure 11). Unlike the fishers and divers, none of the marine biologists indicated that the SCMP coral reefs were in good condition (Figure 12). There were differences in responses of the health and status of the SCMP coral reefs by marine biologists. Results indicated that there were statistically significant differences in their responses (*Chi-square* test, $p < 0.5$. x^2 (1, n = 20) =30.01, p = 0.00001). A comparison between these two groups (fishers and divers, and marine biologists) indicated statistically significant differences in their responses (*Chi-square* test, $p < 0.5$. x^2 (1, n = 20) = 60.38, p = 0.00001).

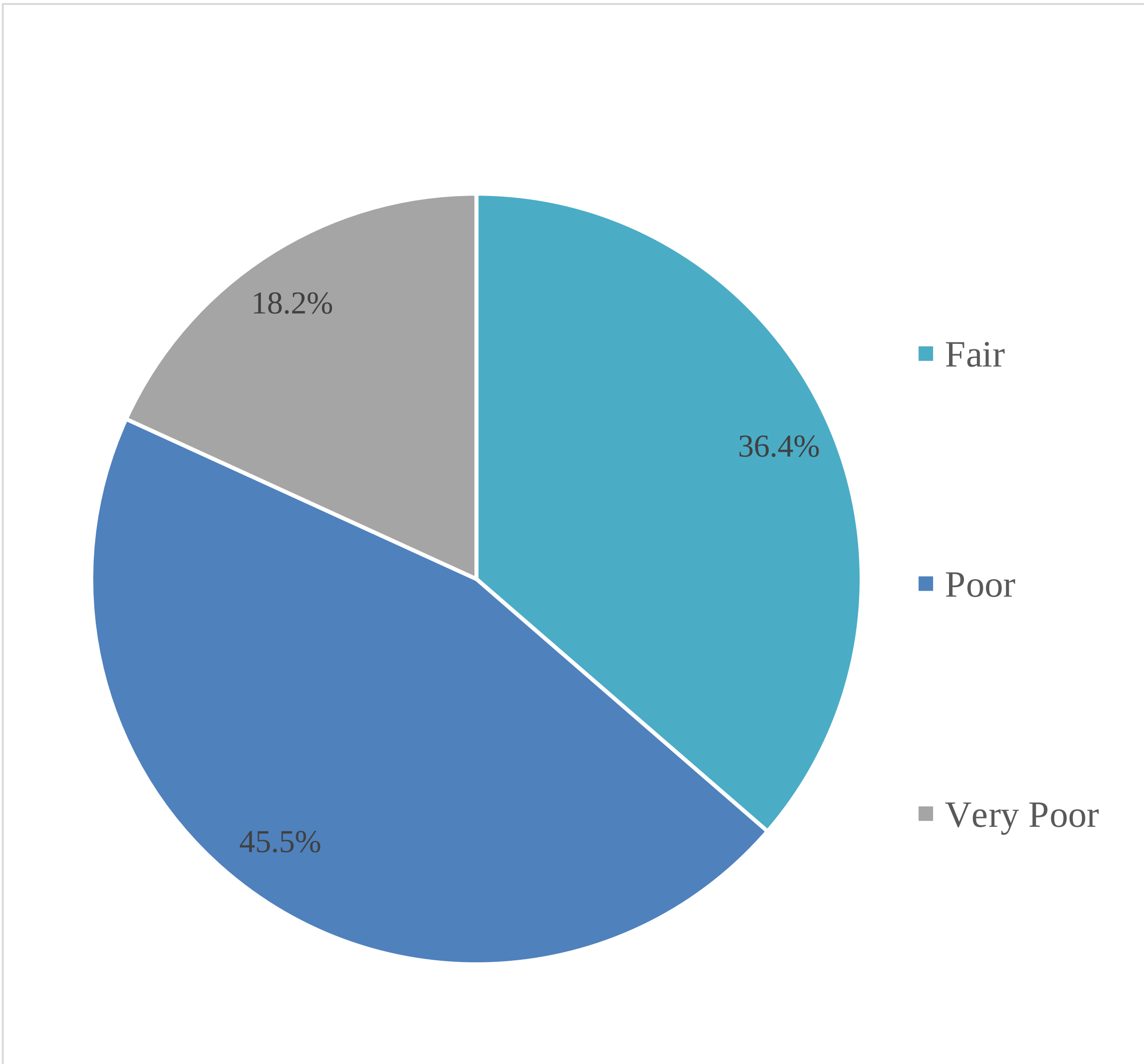

Figure 12. Conditions of the SCMP reefs as observed by marine biologist.

Methods of Garbage Disposal Within the SCMP

The survey respondents were also asked to report their methods of garbage disposal within the SCMP, and again responses varied though four main methods were commonly identified. Seventy-four-point eight percent of respondents indicated that they utilized the CWSA to dispose of their garbage.

Community Residents

Most community residents (71.4%) utilized the solid waste management facility provided by the CWSA-solid waste to dispose of their garbage (Figure 13). While, approximately one third of the community residents indicated they also utilized composting (14.3%), recycling (7.1%), and burning (7.1%) to dispose of their garbage (Figure 13). A statistical difference was found between the methods of garbage disposal identified by community residents' respondents (*Chi-square* test, $p < 0.5$. x^2 (1, n = 20) = 59.35, p = 0.00001).

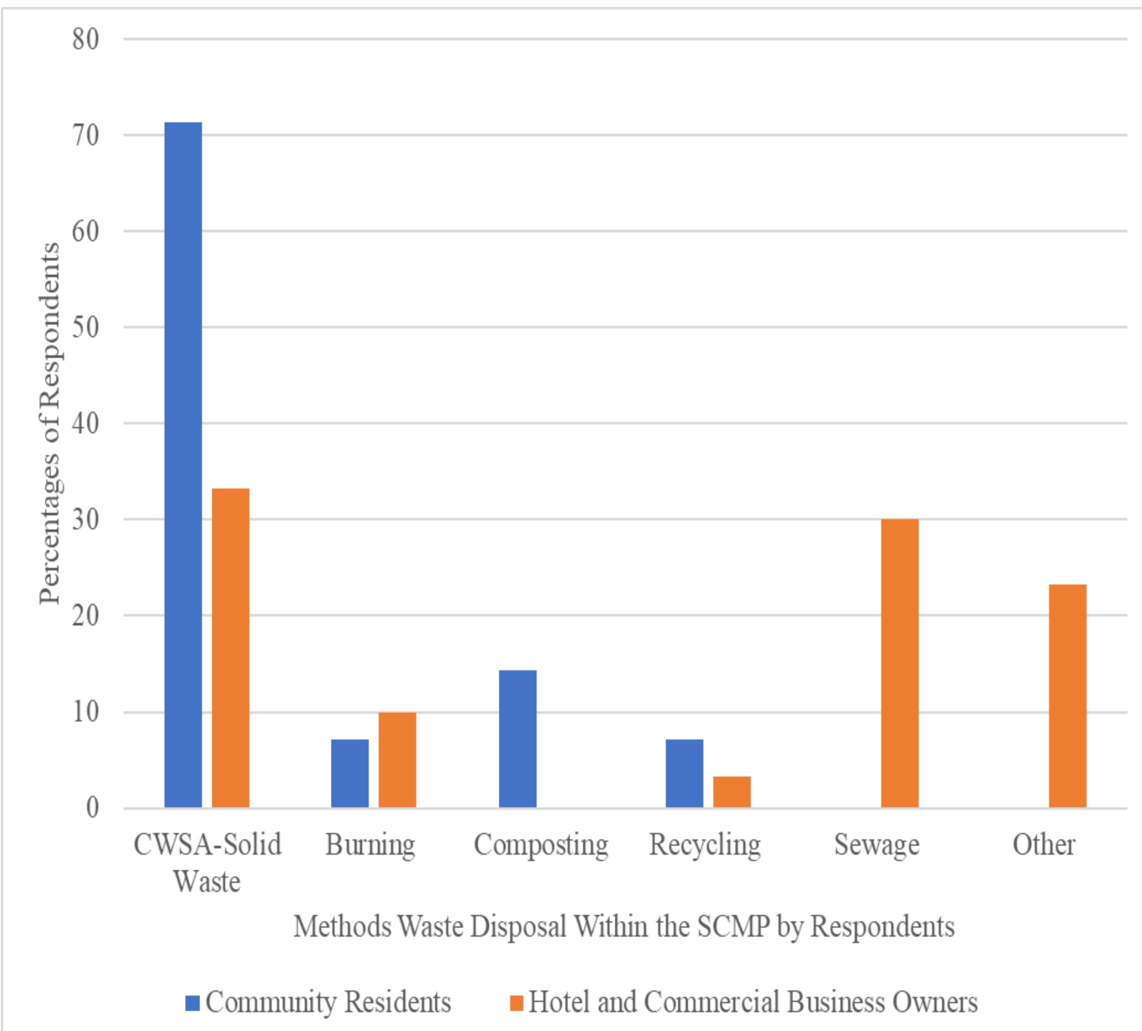

Figure 13. Methods of garbage disposal within the SCMP by respondents.

Hotel and Commercial Business Owners

The hotel and commercial business owners used four main methods including: CWSA-solid waste (33.3%), sewer (30.0%), burning (10.0%) and recycling (3.3%) (Figure 13). Unlike the community residents, the hoteliers and commercial business owners did not use composting as a method of garbage disposal, however, they did report utilizing other forms of garbage disposal including dumping into the rivers and oceans (Figure 13). A statistical difference was found between the methods of garbage disposal identified by hotel and commercial business owners' respondents (*Chi-square* test, $p < 0.5$. x^2 (1, $n = 20$) = 21.29, $p = 0.0003$). No statistical difference was found between the methods of garbage disposal identified by community residents and hotel and commercial business owners' respondents (Kruskal-Wallis One-Way ANOVA, H = 0.5345 *d.f.* = 2, $p = 0.4647$).

Water Quality Data

Water quality data were received from the National Parks, Rivers and Beaches Authority. These data had been collected on a bi-weekly basis but several data gaps were identified. These included:

- Marine water temperature data were not available for the dry season of December – May 2017.
- Marine water pH data were not available for the wet season, August – November 2015 and September 2017.
- Marine water dissolved solids data were not available for the dry season (February – May) 2014, 2015, 2017, and December 2016.
- Marine dissolved solids data were not available for the wet season (June – November) 2016, and June, August, and September in 2017.
- Marine water nitrates data were not available for the dry season (December– May) 2015, 2016, and 2017. Additionally, marine water nitrates data were

not available for wet season (June – Novemeber) 2015 and for June, July, September, and October wet season 2016 and 2017.

- Marine water quality turbidity data were not available for the dry season (December – May) 2015, 2016, and 2017. Additionally, marine water turbidity data were not available for the dry season (December, January, and May 2018) and wet season (June – November 2015, 2016, 2018 and June, July, August, November 2017).

Water Temperature

Comparison of the annual mean marine water temperatures in the SCMP was broadly consistent for the 5-year period (2014–2018) (Table 2).

Table 2. *Comparison of Annual Mean Marine Water Temperature for the 5 Year Period 2014-2018.*

Year	Mean (ºC)
2014	28.9
2015	28.1
2016	28.6
2017	29.2
2018	28.2

Note. Min = minimum; Max = maximum; SD = standard deviation;

The mean marine water temperature was compared between the dry (December–May) and wet (June-November) seasons and showed a difference of only 0.5º C. The maximum temperature for the dry season across all years (2014-2018) was 31.0º C in 2014, while the lowest temperature recorded for the dry season was 26.4°C, which occurred in 2018 (Table 3).

In comparison the wet season (June -November) highest recorded temperature was 30.3 º C in 2016 (Table 4), while the lowest temperature was 26.9 º C in 2018, (Table 2). Although, marine water temperatures varied for both seasons yearly there were no statistically significant differences between the mean dry and wet season marine water temperatures for the period 2014-2018 in the SCMP (Kruskal-Wallis One-Way ANOVA, $H = 3.53$, $d.f. = 1$, $p = 0.060$).

Table 3. *Monthly Mean Marine Water Temperature ºC for the Dry Season-December- May, 2014-2018.*

Month	2014	2015	2016	2017	2018
December	28.8	28.0	ND	ND	28.2
January	28.7	ND	28.4	ND	27.0
February	28.3	ND	27.3	ND	26.4
March	28.0	ND	28.4	ND	27.7
April	27.0	27.5	27.9	ND	27.6
May	31.0	28.0	27.6	ND	27.5
Mean	28.6	27.8	27.9	ND	27.4
Min	27.0	27.5	27.3	ND	26.4
Max	31.0	28.0	28.4	ND	28.2
SD	0.5	0.4	0.5	ND	0.6

Note. Min = minimum; Max = maximum; SD= standard deviation; ND = no data.

Table 4. *Monthly Mean Marine Water Temperature ºC for the Wet Season- June-November (2014-2018).*

Months	2014	2015	2016	2017	2018
June	28.8	28.1	ND	ND	26.9
July	29.5	28.4	29.6	29.0	28.9
August	ND	ND	29.4	ND	29.8
September	28.2	ND	30.3	ND	29.8
October	29.8	ND	ND	29.7	29.3
November	29.8	ND	ND	28.8	28.2
Mean	29.2	28.3	29.8	29.2	28.8
Min	28.2	28.1	29.4	28.8	26.9
Max	29.8	28.4	30.3	29.7	29.8
SD	0.7	0.2	0.5	0.5	1.1

Note. Min = minimum; Max = maximum; SD= standard deviation; ND = no data.

pH

The mean annual marine water pH for the period 2014-2018 was 7.9. The annual maximum and minimum mean pH were 8.2 and 7.5, respectively (Table 5). The highest recorded marine water pH during the dry season was 8.4 for the years 2014 and 2016 (Table 6), while the minimum marine water pH was 3.2 in the dry season. In the wet season, the highest recorded marine water pH was 8.5 in 2014, while the lowest recorded marine water pH was 7.4 in 2017 and 2018 (Table 7). Results indicated that there were no statistically significant differences between the dry and wet season for the annual marine water pH during 2014-2018 (Kruskal-Wallis One-Way ANOVA, $H = 1.09$, $d.f. = 1$, $p = 0.296$).

Table 5. *Mean Marine Water pH for 5- Year Period (2014-2018).*

Year	Mean
2014	8.2
2015	8.2
2016	8.0
2017	7.7
2018	7.5
Mean	7.9
Min	7.5
Max	8.2
SD	0.3

Note. Min = minimum; Max = maximum; SD= standard deviation

Table 6. *Monthly Marine Water pH Comparison for the Dry Season- December- May, 2014-2018.*

Months	2014	2015	2016	2017	2018
December	8.4	ND	ND	ND	8.1
January	8.0	ND	8.0	ND	8.1
February	8.1	ND	8.4	ND	6.8
March	8.0	ND	8.4	ND	8.1
April	8.0	8.2	7.8	ND	7.9
May	8.4	8.1	7.9	ND	3.2
Mean	8.2	8.2	8.1	ND	7.0
Min	8.0	8.1	7.8	ND	3.2
Max	8.4	8.2	8.4	ND	8.1
SD	0.2	0.1	0.3	ND	1.9

Note. Min = minimum; Max = maximum; SD= standard deviation; ND = no data.

Table 7. *Monthly Marine Water pH Comparison for the Wet Season- June-November, 2014-2018.*

Months	2014	2015	2016	2017	2018
June	8.3	8.2	ND	ND	7.5
July	8.4	8.3	7.7	7.4	8.0
August	8.3	ND	7.7	ND	7.4
September	8.3	ND	8.0	ND	8.3
October	8.2	ND	8.0	8.0	8.0
November	8.5	ND	ND	7.8	8.0
Mean	8.3	8.3	7.9	7.7	7.9
Min	8.2	8.2	7.7	7.4	7.4
Max	8.5	8.3	8.0	8.0	8.3
SD	0.1	0.1	0.2	0.3	0.3

Note. Min = minimum; Max = maximum; SD= standard deviation; ND = no data.

Dissolved Solids

The mean marine water dissolved solids for the five-year period (2014-2018) was 89.0 mg/l (Table 8). The lowest annual mean value occurred in 2014 at 35.5 mg/l, while the highest annual mean value was 108.5 mg/l in 2018. The maximum mean marine water dissolved solids during the dry season (December – May) was 143.8 mg/l and was recorded in 2018 (Table 9). In contrast, the wet season maximum mean dissolved solids was 120.0 mg/l which was recorded in 2016. (Table 10). Marine water dissolved solids appears to have minimal variation in the dry and wet season for the period 2014-2018. Results indicated that there were no statistically significant differences between dry and wet season for marine water dissolved solids (Kruskal-Wallis One-Way ANOVA, $H = 0.393$, $d.f. = 1$, $p = 0.530$).

Table 8. *Marine Dissolved Solids mg/L for the 5- Year Period- 2014-2018.*

Year	Mean (mg/l)
2014	35.5
2015	101.3
2016	94.2
2017	108.5
2018	105.3
Mean	89.0
Min	35.5
Max	108.5
SD	30.4

Note. mg/L = milligrams per litre; Min = minimum; Max = maximum; SD= standard deviation.

Table 9. *Monthly Marine Water Dissolved Solids mg/L for the Dry Season- December- May, 2014-2018.*

Months	2014	2015	2016	2017	2018
December	35.7	ND	ND	ND	143.8
January	36.8	ND	84.1	ND	95.7
February	ND	ND	90.0	ND	99.0
March	ND	ND	84.6	ND	101.2
April	ND	ND	100.0	ND	100.7
May	ND	ND	100.4	ND	102
Mean	36.3	ND	91.8	ND	107.1
Min	35.7	ND	84.1	ND	95.7
Max	36.8	ND	100.4	ND	143.8
SD	0.8	ND	8.0	ND	18.1

Note. mg/L = milligrams per litre; Min = minimum; Max = maximum; SD= standard deviation; ND = no data.

Table 10. *Monthly Marine Water Dissolved Solids mg/L for the Wet Season- June-November, 2014-2018.*

Months	2014	2015	2016	2017	2018
June	35.4	ND	ND	ND	101.5
July	35.8	101.3	120.0	102.8	82.2
August	35.1	ND	91.4	ND	116.5
September	34.6	ND	59.0	ND	107.7
October	35.3	ND	118.5	115.3	111.2
November	35.4	ND	ND	107.5	101.7
Mean	35.3	ND	97.2	108.5	103.5
Min	34.6	ND	59.0	102.8	82.2
Max	35.8	ND	120.0	115.3	116.5
SD	0.4	ND	28.7	6.3	11.9

Note. mg/L = milligrams per litre; Min = minimum; Max = maximum; SD= standard deviation; ND = no data.

Nitrates

The mean nitrates in the marine waters of the SCMP for 2014-2018 was 0.7 ppm (Table 11). The maximum mean marine water nitrates were 1.8 ppm while the minimum was 0.1 ppm for the 5-year period (Table 11). Interestingly, the marine water nitrates for the dry and wet season had minimal variation. The maximum marine water nitrates for the dry season (December - May) was 2.4 ppm in 2014 (Table 12), while the maximum marine water nitrates for the wet season (June - November) was 2.0 ppm in 2014 (Table 13).

Results indicated that there were no statistically significant differences for marine water nitrates in both seasons (Kruskal-Wallis One-Way ANOVA, H = 0.698, $d.f.$ = 1, p = 0.403).

Table 11. *Marine Water Nitrates Comparison for the 5-Year Period- 2014-2018.*

Year	Mean (ppm)
2014	1.8
2015	ND
2016	0.5
2017	0.1
2018	0.2
Mean	0.7
Min	0.1
Max	1.8
SD	0.8

Note. ppm = parts per million; Min = minimum; Max = maximum; SD= standard deviation; ND = no data.

Table 12. *Marine Water Nitrates Comparison for the Dry Season-December- May, 2014-2018.*

Months	2014	2015	2016	2017	2018
December	1.6	ND	ND	ND	0.2
January	1.2	ND	ND	ND	0.1
February	1.7	ND	ND	ND	0.2
March	2.0	ND	ND	ND	0.1
April	2.4	ND	ND	ND	0.1
May	1.7	ND	ND	0.0	0.2
Mean	1.8	ND	ND	0.0	0.2
Min	1.2	ND	ND	0.0	0.1
Max	2.4	ND	ND	0.0	0.2
SD	1.0	ND	ND	ND	0.1

Note. ppm = parts per million; Min = minimum; Max = maximum; SD= standard deviation; ND = no data.

Table 13. *Monthly Marine Water Nitrates Comparison for the Wet Season- June- November, 2014- 2018.*

Months	2014	2015	2016	2017	2018
June	1.9	ND	ND	ND	0.3
July	1.8	ND	ND	ND	0.3
August	2.0	ND	1.4	ND	0.2
September	2.0	ND	0.1	ND	0.1
October	1.3	ND	ND	0.1	0.0
November	1.5	ND	ND	0.1	0.3
Mean	1.8	ND	0.8	0.1	0.2
Min	1.3	ND	0.1	0.1	0.0
Max	2.0	ND	1.4	0.1	0.3
SD	0.3	ND	0.9	0.0	0.1

Note. ppm = parts per million; Min = minimum; Max = maximum; SD= standard deviation; ND = no data.

Water Turbidity (Dry Season)

Water turbidity data were measured in nephelometric turbidity units (ntu). Water turbidity data were collected only during the dry season in 2014 and 2018. The mean marine water turbidity in the SCMP in 2014 and 2018 was 1.4 ntu, with a standard deviation of 1.1 ntu (Table 14). During the period of data collection, the maximum and minimum mean marine water turbidity were 2.8 and 0.2 ntu respectively. There was variation in marine water turbidity for the dry season. The maximum mean marine water turbidity for this season was 9.0 ntu, while the minimum was 0.7 ntu. Results indicated that there were statistically significant differences in the mean marine water turbidity for the dry season 2014-2018 (Kruskal-Wallis One-Way ANOVA, $H = 13.75$, $d.f. = 4$, $p = 0.008$).

Table 14. *Marine Water Turbidity for the 5-Year Period- 2014-2018.*

Year	Mean (ntu)
2014	2.8
2015	ND
2016	ND
2017	ND
2018	1.1
Mean	1.4
Min	0.2
Max	2.8
SD	1.3

Note. ntu = nephelometric turbidity unit; Min = minimum; Max = maximum; SD= standard deviation; ND = no data.

Table 15. *Monthly Marine Water Turbidity for the Dry Season- December- May, 2014-2018.*

Months	2014	2015	2016	2017	2018
December	1.5	ND	ND	ND	ND
January	1.8	ND	ND	ND	ND
February	4.3	ND	ND	ND	3.7
March	2.3	ND	ND	ND	9.0
April	4.7	ND	ND	ND	0.7
May	3.8	ND	ND	ND	ND
Mean	3.1	ND	ND	ND	4.5
Min	1.5	ND	ND	ND	0.7
Max	4.7	ND	ND	ND	9.0
SD	1.4	ND	ND	ND	4.2

Note. ntu = nephelometric turbidity unit; Min = minimum; Max = maximum; SD= standard deviation; ND = no data.

Population Census Data

The household population for the CD in 1980 was 17,440 people/square mile (Figure 19). In 1991, during the ten-year period (1980-1991) there was a gradual increase in household population for the CD to 20,689 people/square mile (Figure 14). The CD household population appears to have a steady increase in the following ten-year period (2001-2012), where the household population were 22,706 and 24,205 people/square mile respectively (Figure 14). In the household population comparison for each ten-year period starting from 1980-2012, there was no statistically significant differences in the CD household population (*Chi-square* test, $p < 0.5$. x^2 (1, n = 100) =6.10, p = 0.107).

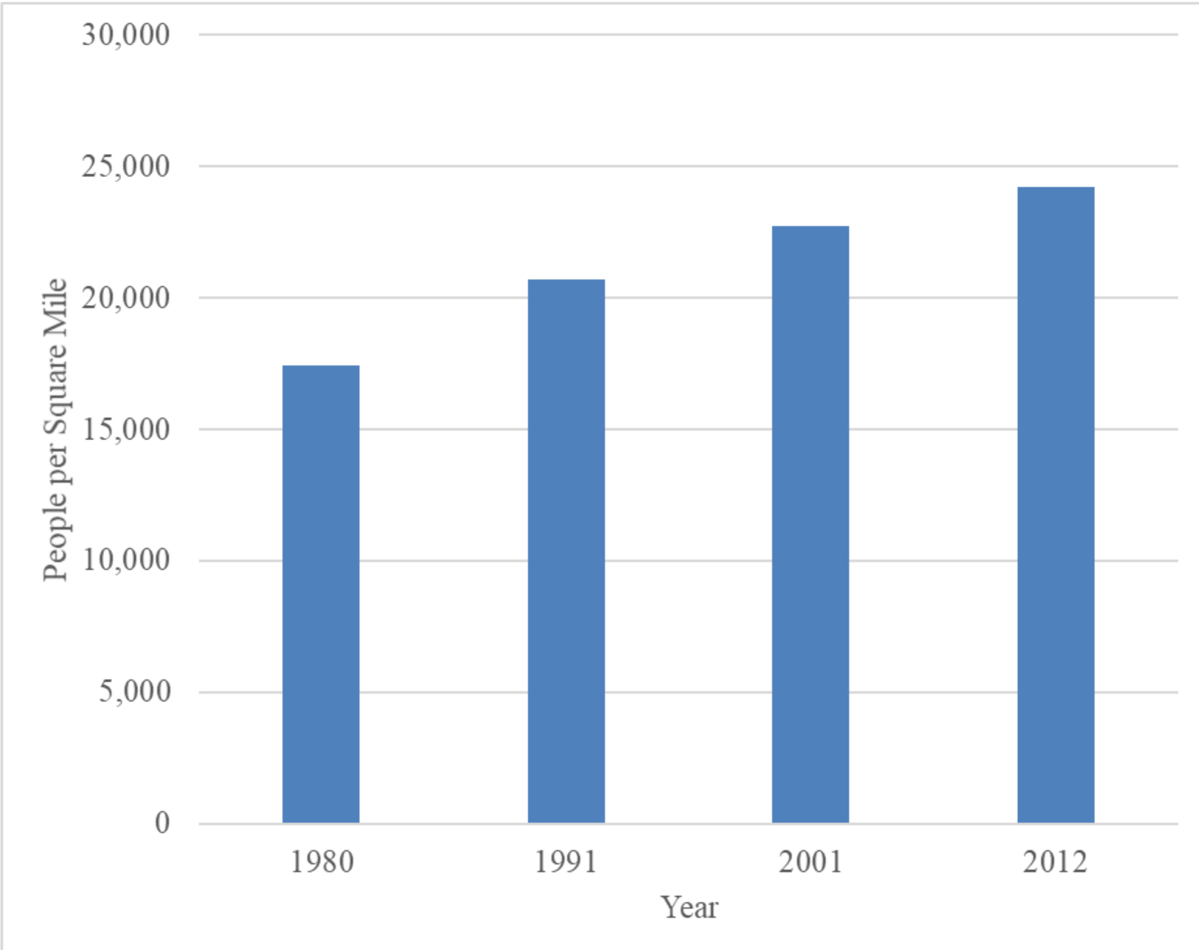

Figure 14. Population and household census for census division (CD) Calliaqua, for the period 1980-2012.

Discussion

Anthropogenic activities are recognized as a contributing factor to the decline of coral reefs globally (Hoegh-Guldberg et al., 2017). Marine habitats, specifically coral reefs have been fundamentally altered by human activities due to high levels of contaminants entering the marine waters (Hoegh-Guldberg, 2019; McLeod et al., 2010). Unfortunately, these factors are also evident in SVG which has the largest coral reef systems in the Eastern Caribbean including the SCMP. This is likely due to the fact that the SCMP is the epicenter for tourism activities on St. Vincent. As such, the coral reefs of the SCMP are potentially under continued threat from further increases in anthropogenic activities.

Recent activities within the SCMP have resulted in increased pollution and sedimentation, which is negatively affecting the health of the coral reefs. The triangulation approach was used to assess the health of the SCMP coral reefs because there were insufficient data on the formal extent of the SCMP coral reefs. This method was specifically used to compare and validate the various data sources.

Evaluation of the SIQ responses revealed that the sources of pollution and sediment runoff on the coral reefs of the SCMP were solid waste, construction, and erosion. Additional sources of marine pollution within the SCMP were identified. These were farming, sewage, chemicals, mooring, and air pollution. Solid waste was identified as a primary source of marine pollution by the majority of respondent groups including community residents, fishers and divers, marine biologists and the hotel and commercial business owners. Surprisingly, nearly three-quarters (71.4 %) of the community residents indicated that they utilized the CWSA-solid waste facility provided to dispose of their waste, while only a third (33.3 %) of the hotel and commercial business owners utilized this resource. While this percentage appears low for the hotel and commercial businesses, they did identify other waste disposal methods including recycling, composting, and burning for waste disposal. It was disappointing to learn that the hotel and commercial business owners also used the rivers and oceans as a method to dispose of their waste. While it was appreciated that the respondents replied with honesty, it is worthwhile to point out that in every data collection process, individuals have characteristics of interest and portray themselves in a favorable manner to what is socially desirable (O'Leary, 2017). For example, nearly three-quarters of community residents indicated that they utilised the CWSA-solid waste facility to dispose of their garbage, but direct observation during field work found waste present within the rivers and waterways (Figure 15).

Figure 15. Household garbage in Calliaqua river.

Direct observations suggest that watercourses were being used for garbage disposal by some members of the adjacent communities. The garbage contributes to the sediments and high levels of turbidity present in the marine waters of the SCMP. These observations confirmed that the rivers, streams, and culverts are point sources of sediment runoff affecting the SCMP coral reefs. During the field work it was through direct observation, the culverts responsible for drainage during the rainy season were collection points for garbage. Although, there was no rain there was evidence of household garbage (diapers, plastics, food containers, etc.) present in the culverts. Likewise, these culverts were dilapidated due to lack of maintenance, where some were not visible. These observations and the data provided by the hotel and business owners provided confirmation of the direct link between terrestrial anthropogenic activities and the aquatic environment. From this, the connection between land-based pollution and the health of coral reefs is likely assured for St. Vincent, particularly within the SCMP.

The terrestrial pollutants that enter the rivers, streams, and oceans stemming from land-based activities effectively fertilizes the nearshore marine environment, resulting in an increased demand for oxygen by the marine and freshwater phytoplankton. In the SCMP this can lead to eutrophication and smothering of coral reefs (Jones, Fisher & Bessell-Browne, 2019). Further to this, the solid plastic waste and chemicals from sewage and agricultural runoff etc. will be entering the marine waters and uptaken by biological systems which have significant and widespread impacts on the health and productivity of coral reefs (Global Parks, 2014; Jones, Fisher & Bessell-Browne, 2019). The underwater observations during the field efforts in the nearshore environment provided confirmatory evidence of the solid plastics being present in the marine waters of the SCMP (Figure 16).

Figure 16. Solid plastic debris in the SCMP marine waters.

It is clear that at least some people working and living within the SCMP, do not practice effective waste disposal methods (Figure 17).

Figure 17. Solid waste present on the Arnos Vale Bay in the SCMP.

Undoubtedly, this is a contributing factor in the accumulation of sediments present in the marine waters of the SCMP and leads to the deterioration of this vitally important coral reef resource for St. Vincent.

In addition to solid waste, the use of chemicals in farming was identified by respondents as a persistent pollutant. Although, there was variability in the percentages, each group considered chemicals to be a contributor. This source of contamination was ubiquitously recognized by respondents and undoubtedly negatively affects the coral reefs.

An influx of chemical contaminants into the marine environment is ecologically detrimental as chemical pollutants can invade coral tissues and reduce the photosynthetic efficiency leading to a reduction of fertilization and productivity of coral reefs (Van Dam, Negri, Uthicke & Mueller, 2011). Agricultural farming practices were identified by over a quarter of farmers (26.3%) as a source of sediments and chemical pollution. This is of particular interest as the farmers also revealed that they utilized different assortments of chemicals towards maximizing their crop production yields. This result was surprising as the farmers identified their own personal practices as being a main contributor to the SCMP pollution levels. This indicates that the farmers are conscious of the negative effects their farming practices and actions have on the nearby coral reefs. This may also indicate that the desire for immediate maximum crop production and financial reward outweighs the environmental concerns and long-term consequences by these respondents.

It is well known that the consistent use of chemicals in agricultural farming that are allowed to enter the marine environment adversely affects and creates chronic stressors on the coral reef ecosystems (Van Dam, Negri, Uthicke & Mueller, 2011). Most of the farming within the SCMP is done in watershed areas and on river banks adjacent to the SCMP coral reefs, further substantiating the link between sediments and the health of the SCMP coral reefs. Likewise, marine biologists also attributed the high levels of marine pollution to siltation and runoff (Figure 9). While, marine biologists indicated these persistent pollutant sources, they were unable to scientifically provide evidence of the main pollutants that may be affecting the SCMP coral reefs. This is likely due to the limited financial resources available to marine biologists in conducting scientific research within the SCMP. These scientists are limited by the resources available to them and are unable to conduct effective and accurate marine assessments on the SCMP marine environment.

Building and construction was implicated with erosion and increased runoff by community residents and the farmers. This was related to land-use changes that have occurred in adjacent SCMP communities over the last 15-20 years (Figure 10). The clearing of lands for building and construction in this time-period has resulted in erosion and runoff – particularly during the annual wet season. Lands left bare and exposed causes soil degradation, resulting in erosion which is a major source of sediments and adversely affects the marine environment (Brady & Weil, 1999). These anthropogenic actions have resulted in increased erosion, terrestrial runoff, and sedimentation from building and construction sites and have degraded the marine environment specifically coral reefs. While data deficiencies preclude quantification of this effect at this time, qualitatively this has likely led to smothering silt and the growth of damaging algae resulting in the decline of the SCMP coral reefs and mortality. Sediments and pollution in runoff can lead to decreased coral growth by abrasion and shading which can reduce zooxanthellae densities and its photosynthetic abilities (Nugues & Roberts, 2003), which further reduces the health of coral reef systems. Negative effects of runoff were identified by both fishers and divers, and marine biologists, all of which have a direct experience in the SCMP. Their knowledge and observations are valuable contributions to establishing the baseline for conservation in this region. Further to this, the data provided by the farmers with regard to the source points for chemical pollution are also vital to developing programs that will help reverse the deterioration of SCMP coral reefs.

It is likely that the consistent levels of farming along the river banks, solid waste disposal, and building and construction adjacent to the SCMP marine waters have likely resulted in increased levels of erosion, runoff, siltation, and sedimentation on the SCMP coral reef ecosystems. It is known that increased runoff, sewage, chemicals, and solid waste (plastics) can lead to elevated nutrient levels and sediment coverage that impacts the reef biota by impeding reproduction and early development of corals - this can result in coral reef death (Risk & Edinger, 2011).

Aquatic systems are central to food security for humans and other living organisms (Levallois & Villanueva, 2019). Therefore, the collection of water quality data is critical in understanding the physical, chemical, and biological processes to determine the health of aquatic systems. Examination of the biophysical marine water quality data; temperature, pH, dissolved solids, nitrates, and turbidity parameters found no statistically significant differences between the dry and wet season, with the exception of water turbidity. It was noted that there was a difference in the minimum and maximum turbidity for the 5-year period of 0.2 and 2.8 ntu respectively. The difference in the water turbidity could be attributed to the limited or no data collected during 5-year period. Further to this, it could be attributed to the land-use changes; increased farming on river banks and clearing of lands for building and construction. This can be magnified by increased rainfall during the wet season, resulting in erosion, runoff, and increased sediments.

No differences were found in the annual temperatures for pH, the average marine water temperature was 28.6ºC (Table 2) and the average pH was 7.9. It also appeared, based on the limited data available, that the nitrate levels were within the range considered acceptable for coral development; i.e. not exceeding 5.0 ppm (Guan, Hohn & Merico, 2015).

These values were within range for the optimal balance that encourages photosynthesis and calcification of coral reefs (Langdon & Atkinson, 2005). This is reassuring. If steps are taken to reduce the anthropogenic pressures on the SCMP, then at least some of the physical parameters needed for coral reef health remain present.

Evaluation of the water quality, dissolved solids and nitrates data indicated significant temporal gaps existed. This complicates evaluation of these parameters and highlights the need for consistent and effective data collection. Disparity existed between the direct data provided by the SIQ respondents and the quantitative water quality data. This gap needs to be addressed to further evaluate the relationships between terrestrial land use actions and contamination of the marine environment. Improved data collection and future evaluations are required as there could be a correlation with the high levels of pollution present in the SCMP as indicated by SIQ respondents. Further to this, the marine water turbidity had substantial variations during the dry season ranging from 0.2 ntu - 9.0 ntu.

This is potentially a significant finding as this could be impacting the SCMP coral reefs to unknown extents. Figueroa-Pico et al., (2020) noted that turbidity levels may vary within seasons and influence coral reef growth and development. They further noted that areas with low turbidity levels had high abundance in fish species indicating healthy coral reefs. Without effective and regular monitoring, with specific protocols for evaluation, the potentially damaging effects of this variable turbidity, could go undocumented. It is highly likely that the anthropogenic activities in the adjacent SCMP communities, are contributing factors to the high marine water turbidity levels that are impacting the health and status of the SCMP coral reefs and further study is required to determine to what extent.

Although examination of the biophysical water quality data revealed no significant difference between the dry and wet seasons, this may be a result of the sparse data available. Results suggest that the biophysical water quality data was within the normal accepted ranges for coral reef growth and development. This is very likely due to the sampling regime, and may not be reflective of the actual values within the SCMP. This is a very important finding, as without this, detrimental activities could continue risking the complete deterioration of the SCMP upon which so many sectors of St. Vincent society depend. Further studies and regular effective water quality data collection are required. Pollution monitoring programs must be developed to provide the data required to support the high levels of pollution identified by SIQ respondents in the SCMP, and the direct field observations. The health of the marine environment and those who depend upon it requires an effective monitoring program to be implemented.

As the human population increases so does the impact on the environment and natural resources. Population data are essential in understanding the relationship between humans and the environment (Shende, Janbandhu, & Patil, 2015).

It can be noted that throughout the years 1980-2012, there was a steady increase in the SCMP household population. This increased household population (Figure 14), would have contributed to the increased building and construction for homes within the SCMP communities. Building and construction requires clearing of lands which results in increased siltation, erosion, and runoff. It appears that most homes release their waste (waste water, sewage, solid waste, etc.) into culverts, rivers, gutters, and streams which lead directly to the SCMP marine waters.

One of the main rivers (Cane Hall) located in Arnos Vale adjacent to the SCMP is utilized by residents as a dumping site which directly transports waste to the SCMP. This effect will be exacerbated with the intense rainfall during the wet season. This will further intensify the runoff facilitating faster transport of sediments, sewage, and solid waste to the coastal marine environment. This may suggest that there may be similarities between turbidity, nitrates, dissolved solids, and pH present within the SCMP marine waters. Similarly, a study conducted in the Mesoamerican Reef region in Belize noted that coastal development, unsustainable agricultural practices, and pollution were major threats to coral reefs in the region (OAS, 2018). As increasing amounts of sediments and pollutants were consistently transported and deposited on the reefs, negatively impacting reef health and the marine ecosystem (OAS, 2018). As the human population has increased over the past few decades, during which time the health of the coral reefs has been seen to decline, it can be expected that as the population of St. Vincent continues to climb, that these negative effects will as well. This is evident, as marine biologists and fishers and divers indicated that they have seen a decline in coral reef health over the past 15-20 years. In order to lessen these negative effects, steps should be taken to change the methods of waste disposal. Lessening anthropogenic activities impacts coral reefs, making coral reefs more resilient to various stressors (Mellin et al., 2016). In Australia, it was evident with the Great Barrier Reef where it was observed that 21%-38% of the reefs were stable and had lower susceptibility when anthropogenic activities were reduced leading to an increase in recovery times (Harvey et al., 2018; Mellin et al., 2016). Further to this, marine pollutants within the SCMP will pervade the adjacent waters affecting marine habitats, biodiversity, and life throughout SVG. Due to the complex nature of marine pollutants, they have the ability to travel large distances by ocean currents (Maximenko, Hafner & Niiler, 2012). Reduction of the amount of waste and silt that enters the marine environment is paramount for the SCMP biodiversity and coral reef health. Evaluation of its quantitative and qualitative data led to the development of a number of recommendations, these are as follows;

- Effective biophysical research programs such as scientific surveys which includes but not limited to coral, fish, and benthic surveys (Smith et, al., 2016) are needed to determine the health and status of the SCMP coral reefs, this will help in understanding and ensuring the proper management of changes in coral reef systems.
- Long-term monitoring, proper collection of water quality data and observations are needed to help marine management authorities better understand and manage the health of coral reefs.
- Financially supported monitoring and research facilities and programs that provide information to regulate and control marine pollution within coastal communities.
- Clear lines of communication between the government, marine management authorities, coastal communities, NGO’s, and other stakeholders of the importance of coastal marine ecosystems and what is required to safeguard vulnerable marine resources (coral reefs). This may include, but not limited to: proper garbage disposal best practices, roles and responsibilities of law enforcement bodies, governing and regulating marine resources.

- Enforcement of building codes to protect the health and safety of the people and the environment. This can help lessen the high levels of sewage, solid waste, siltation, harmful chemicals, and waste water entering the SCMP marine waters potentially affecting marine biodiversity and specifically coral reefs.
- Public education and awareness of coastal communities, schools, hotels and commercial business, and law enforcement on the importance of a clean and healthy marine environment. Raising awareness will have a positive influence on social attitudes and individual behaviors that will contribute to safeguarding sustainable and responsible use of valuable marine resources including coral reefs and the ecosystems that are dependent on their survival.
- Farmer education on sustainable agricultural practices, which can promote environmental stewardship.
- Careful consideration must be given to revising or developing new policy governing coastal marine ecosystems (specifically coral reefs which are under threat) and stringent measures to protect marine biodiversity.
- Initiatives should be established for regional and international collaboration to promote an integrated approach towards the management of coral reef ecosystem and humans, as coral reefs and ocean protection is a global concern.

In summary, my study results indicated that there were similarities in the findings between anthropogenic activities, pollution and the health and status of coral reefs within the SCMP. It was noted that solid waste, building and construction, population dynamics, and farming on the river banks of the watershed were major contributors to the terrestrial runoff and sediments present within the marine waters of the SCMP. Several limitations affected this study and consistent data collection methods should be considered and adhered to for future research and analysis on the SCMP coral reefs. More research is needed to determine the possible extent of anthropogenic activities within the SCMP communities and their effects on the SCMP coral reef ecosystems. Meanwhile, proper data collection and analysis, sensitization, consultations, policies, and changes in attitudes are the first steps in lessening the impacts of anthropogenic activities within the SCMP and SVG. Moreover, understanding the consequences of each one actions and its effects on coral reef ecosystems is important and providing support and opportunities is valuable.

Conclusion

Based on the research conducted, sources of pollution affecting the health of the coral reefs were identified as solid waste, building and construction, erosion and farming. Based on the qualitative and quantitative analysis of SIQ's, marine water quality, and household population census data, results indicated that there were similarities between building and construction, population dynamics, runoff and high levels of sedimentation present within the SCMP coral reefs. It can be concluded that anthropogenic activities within the SCMP communities have influenced terrestrial runoff adversely affecting the health of the coral reefs. In addition, the effects of anthropogenic sources could saturate the SCMP coral reefs with nutrients, which may result in reduced water quality and coral reef decline. Further to this, the lack of consistent data collection should be addressed. Further studies such as scientific surveys; coral, fish, and benthic surveys, reef assessment, along with frequent and consistent marine water quality data collection are needed to effectively measure and assess coral reef ecosystems within the SCMP. The scientific surveys and marine water quality data collection and testing can help to determine or identify possible linkages and impacts of anthropogenic sources on the SCMP coral reef ecosystems from adjacent SCMP communities. In addition, utilizing such approaches will be central to improving the protection and sustainable management of coral reef ecosystems. Moreover, contributing and supporting informed decision making from SCMP communities, stakeholders, and the government while safeguarding the sustainable use of the SCMP coral reef ecosystems.

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Appendix A

Letter of Informed Consent for Participants and Interview Questionnaires for the Survey Interview Questionnaire Carried out in the SCMP

Coral Reef Old Nemesis-Anthropogenic Runoff

Researcher: Reshevski Jack

Thesis Supervisor: Dr. Anna Hall

Maters of Environmental Management Program Head-Dr. Ann Dale

You are being invited to participate in a research study about the effects of land use on Coral reefs in the South Coast Marine Park. This study is to identify the specific land-use changes that have occurred immediately adjacent to the SCMP and to identify the sources of sedimentation and pollution and estimate the impacts to the SCMP coral reefs. This study is being conducted by Moise J.R. Jack a Master of Science Environmental Management graduate student at the Royal Roads University, Victoria, British Columbia, Canada under the supervision of Dr. Anna Hall my thesis committee supervisor. This study is being conducted as part of my fulfilment of my graduate thesis. My credentials with Royal Roads University can be established by calling Dr. Chris Ling, program head of the Environmental Management Faculty of Royal Roads University.

There are no known risks if you decide to participate in this research study. There are no costs to you for participating in the study. The information you provide will be used to help to identify and better understand the various land use changes that may have occurred adjacent the SCMP. The questionnaire/survey will take about 20 to 30 minutes to complete. The information collected may not benefit you directly but will provide best practices for the protection and management of natural resources (coral reefs) and provide opportunities in the provision of sustainable livelihoods.

This survey is anonymous. No one will be able to identify you or your answers, and no one will know whether or not you participated in the study. Should the data be published, no individual information will be disclosed. The data collected will be analyzed and results will be presented in a written report which will be available through the Fisheries Division and National Parks, Rivers and Beaches Authority. The raw data collected, and results will be archived on a hard drive along with hardcopies, which will be stored in a locked filing cabinet. Your participation in this study is voluntary and you are free to withdraw or decline from participating in the research at any time without a given reason. By completing the survey, you agree that your responses may be used as part of academic research study. Please feel free to ask any questions at any point in time. A copy of this form is available for you to keep for your reference.

Name: ____

Date: ____

Signature: ______________________________________

Questionnaire-Survey

Fishermen and Divers

1. Do you fish/dive commercially or recreationally? Yes ____ No ____.
2. How many years have you been fishing/diving in the SCMP? _____ .
3. How often do you use the SCMP?

   Daily ☐ Weekly ☐ Monthly ☐

   Other____________________________________.
4. Which areas in the SCMP have you observed pollution and what type?

   Calliaqua ☐ Ratho Mill ☐ Indian Bay ☐ Canash ☐ Villa ☐

   Sediments ☐ Plastics ☐ Oil ☐ Sewage ☐ Chemicals ☐ Other

   ________________.
5. What are the conditions (health) of the SCMP corals reefs as compared to when you started to dive/fish?

   Dead ☐ Living ☐ Algal Growth ☐ Fish Stock ☐

   Other____

   ____

   ____

   ____

   ____
6. Are there any other factors you believe are important to the health of coral reefs within the SCMP?
7. Are there any sources of pollution you think are more important that others that are affecting coral reefs?

Interview

Residents of SCMP Communities

1. How long have you been living in the SCMP community?

   ________________________.

2. What changes have you seen over the time you have been living in this community?
3. What kind of pollution have you observed within the community?
4. How do you dispose of your waste?
5. Do you utilise the SCMP bays?
6. What type of pollution have you observed within the SCMP bays?
7. What kind of activities have you observed within the SCMP bays?
8. Do you think pollution, development and construction affect the marine resources specifically coral reefs of the SCMP?

Appendix B

Recruitment Poster for Participants of the Survey-Interview Questionnaire at the SCMP