ASSESSING FISHING PRESSURE IN A SMALL-SCALE FISHERY IN ST. EUSTATIUS, DUTCH CARIBBEAN

by

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Executive Summary:

World fisheries are an important source of food and income for millions of people around the world, and represents a billion dollar industry (FAO, 2018). As a result, research on fisheries has mainly focused on large, commercial fisheries and less on small-scale, subsistence and artisanal fisheries (Anticamara et al., 2011). The result is a perceived lack of data from small-scale fisheries, and therefore less is known about their impact on the surrounding environment and importance to the communities that utilize them. Recent research on small-scale fisheries (SSF) has shown that data deficiencies can impact sustainability efforts and have a large impact on small island developing states (Nash et al. 2016, Gill et al. 2019). Global fisheries are at risk, and SSF even more so, as anthropogenic effects reduce catch, change the range distribution of fish, change productivity, and drive the decline of fish stocks (Brander, 2010; Doney et al., 2012; Hanich et al., 2018). In order to curb these potentially dangerous declines, more research and capital needs to be invested in researching small-scale fisheries.

St. Eustatius, a small island developing nation, which is part of the Dutch Caribbean, has a marine park surrounding the entire island from the high-water line down to 30 meters, as well as two marine reserves. As a small developing island territory, maintaining their coral reef ecosystem and their reef fisheries is important for the island economy, nutrition, and food security (de Graaf et al., 2015). However, up until now the effects of different gear types and fishing pressure on the surrounding coral reefs, fish populations, fish size, and how those trends have changed over time in St. Eustatius has been poorly understood. In this Masters Project, we will utilize the fisheries landings data and GCRMN data collected by STENAPA and the Ministry of Economic Affairs, Nature and Food Quality (LNV) to assess fishing intensity and its potential effects on the surrounding reef ecosystem, in an effort to help with future management

strategies, and offer a cost effective approach to addressing some of the knowledge gaps surrounding St. Eustatius fisheries.

We were able to calculate the total number of landings, total number of trips taken, and the fishing intensity throughout the whole fishing area, from 2012 to 2018. The results showed a total average landing of 2448.23 + 284.56 kilograms (mean + SD) of fish per year with 148.1 ± 10.8 trips. This resulted in an average fishing intensity of 37.73 ± 4.39 kg/km^2/yr. We also calculated the yearly summaries for within the marine park. These results showed that within the marine park, they were catching 1377.42 ± 323.31 kilograms of fish per year using 72.7 ± 9.9 trips per year . The average fishing intensity as 50.09 ± 11.76 kg/km ^{2}/yr within the marine park. We then mapped these results for the whole fishing area, the marine park, and by each of the major fishing gears. This showed that Zone 2 and Zone 1 were the zones experiencing the most fishing intensity for the whole fishing area; that Zone 2 and Zone 4, where the northern marine reserves is, were experiencing the most fishing intensity within the marine park; and the most utilized gear types were pot traps and beach seines, with the most intense usage occurring in Zone 2 and Zone 1. We also show the relative abundance of each fish family catch based on a sampled subset of landings. The top five fish families caught are: *Serranidae* commonly known as the grouper family; *Acanthuridae* also known as surgeonfish and tangs; *Ostraciidae* including boxfish, cowfish, and trunkfish; *Holocentridae* family containing squirrel and soldier fish; and *Scaridae* also known as the parrotfish family.

Since the critical coral reef habitat is a priority conservation area for STENAPA, as well as sustainably managing the marine park, we would recommend the following policies:

1. Gear restrictions: Restrict gear types, such as beach seines and pot traps to reduce damage to coral reefs and other benthic habitats.

2. Expand the marine reserves: This would be in order to protect, monitor, and enforce more of the critical coral reef habitat.
3. Increase patrols in the marine reserves: By increasing patrols in just the reserves, illegal fishing could be curtailed.
4. Increase stakeholder engagement: This is of vital importance for the fishermen. Engage them as monitors, enforcers, and even data collectors.
5. Increase education and outreach: This is important for visitors or recreational users who are not from St. Eustatius.
6. Expand monitoring and evaluation efforts: Rigorous monitoring, reporting, and evaluation can encourage transparency, as well as offer the opportunity to learn from experience while processing new information (Lockwood et al., 2010). It requires input from scientific, local, and indigenous sources in order to adequately capture the management environment (Bennett & Dearden, 2014; Lockwood et al., 2010).
7. Enhance adaptive management strategies: The ability of the governing body to respond to changing conditions will determine its success in managing the ecosystem; coming up with novel solutions to problems; and understanding the needs of the surrounding community. STENAPA should explicitly allow for continued engagement and support from stakeholders and local peoples; outline increased outreach and education initiatives; and craft rigorous monitoring, evaluation, and reporting mechanisms in their adaptive management plan.

Introduction:

Global status of fisheries

World fisheries are an important source of food and income for millions of people around the world, and represents a billion dollar industry (FAO, 2018). In 2016, 88% of 171 million tons of fish products were used for human consumption (FAO, 2018). This provided billions of people on average, with approximately 20% of their daily protein, and the percentage continued to increase for people in developing countries (FAO, 2018). Research on fisheries has mainly focused on large, commercial fisheries and less on small-scale, subsistence and artisanal fisheries (Anticamara et al., 2011). There are a few factors that contribute to this, such as data deficiencies due to a lack of consistent management and reporting methods for small-scale fisheries (SSF); as well as the multi-species and multi-gear type nature of SSF (Gill et al., 2019; A. F. Johnson et al., 2017; Nash et al., 2016; Saldaña et al., 2017). This is mainly due to the high costs of implementing vessel monitoring systems and reporting programs, as well as the costs incurred by countries to monitor and enforce these programs (Hilborn & Ovando, 2014; Worm et al., 2009). The result is a perceived lack of data from small-scale fisheries, and therefore less is known about their impact on the surrounding environment and importance to the communities that utilize them. More recently, there has been a push to use different, more cost effective methods in small-scale fisheries to try and gain some insights into the fishing intensity and impact on coastal areas (Chuenpagdee et al., 2006; Costello et al., 2012; Damasio et al., 2015; Hilborn & Ovando, 2014; Jacquet et al., 2010; A. F. Johnson et al., 2017; McClenachan et al., 2012; Saldaña et al., 2017; Worm et al., 2009). Data-poor fisheries have a few different methods at their disposal, which include logbooks, interviews, and other historical records (McClenachan et al., 2012). It has been found that these alternative, low cost methods have been invaluable in providing insights into changes in fish assemblages over time, and the effectiveness of current fisheries management polices (Costello et al., 2012; McClenachan et al., 2012; Nash et al., 2016; Rochet & Trenkel, 2003; Shin et al., 2005).

Recent research on SSF has shown that data deficiencies can impact sustainability efforts, and have a large impact on small island developing states (Nash et al. 2016, Gill et al. 2019). Since SSFs are widespread, difficult to track, and utilize hundreds of boats, it is estimated that they could be catching just as much, if not more, than large-scale fisheries. (Damasio et al., 2015; Jacquet et al., 2010; Lunn & Dearden, 2006; R. White et al., 2018; D. Zeller et al., 2015). Trying to define what constitutes as a small-scale fishery has proved difficult, as there are many different definitions and variations around the world (Chuenpagdee et al., 2006; Salas et al., 2007; Smith & Basurto, 2019). This could be one of the reasons the FAO has underreported the catch small-scale fisheries, and thus the impact on global fisheries (Anticamara et al., 2011; FAO, 2018; Pauly & Zeller, 2016; Worm et al., 2009; Zeller et al., 2015). They could also be experiencing and helping drive the global trend of decreasing total catch (Chuenpagdee et al., 2006; FAO, 2018). Additionally, due to chronic underreporting, these fisheries are some of the most at risk for overexploitation, overfishing, and illegal fishing, which can lead food and economic security issues (Hanich et al., 2018; Jacquet et al., 2010; A. F. Johnson et al., 2017; Lunn & Dearden, 2006; Salas et al., 2007; Saldaña et al., 2017; D. Zeller et al., 2015). Underlying this are increasing pressures due to climate change. Global fisheries are at risk, and SSF even more so, as anthropogenic effects reduce catch, change the range distribution of fish, change productivity, and drive the decline of fish stocks (Brander, 2010; Doney et al., 2012; Hanich et al., 2018). In order to curb these potentially dangerous declines, more research and capital needs to be invested in researching small-scale fisheries.

Fisheries in small island developing states are usually considered data-poor due to a lack of management, monitoring, and enforcement, and thus are at high-risk for exploitation (Gill et al., 2019; Nash et al., 2016; Newton et al., 2007). This offers a management and policy opportunity to work with local communities to ensure that their natural resources, such as fisheries, are maintained sustainably. One of the ways to do that are through coral reef conservation efforts. The coral reefs that surround many small island developing nations are among the most diverse, valuable and productive ecosystems on the planet (Alvarez-Filip et al., 2011; De'ath et al., 2012; Hughes et al., 2017; Mora, 2008; Sheppard et al., 2017). However, coral reefs and the associated fisheries are especially vulnerable to climatic and other human driven threats (Abesamis et al., 2014; Bellwood et al., 2004; Bruno & Selig, 2007; De'ath et al., 2012; Gardner et al., 2003; Hughes et al., 2017; Mora, 2008; Mumby, 2006). With storm events increasing in prevalence and intensity, sea level rise, ocean acidification, and increasing sea surface temperatures, coral reefs are especially vulnerable to climate change. On average, stony coral cover declined by approximately 80% in the Caribbean between 1977 and 2001, and has only continued to decline annually (Alvarez-Filip et al., 2011; Gardner et al., 2003; Jackson et al., 2014; Mora, 2008). The impact of overfishing on sensitive coastal areas, such as coral reefs, has also been shown to compound the anthropogenic effects on reef health and facilitate additional declines in hard coral cover (Jackson et al., 2001; Newton et al., 2007; Oberle et al., 2016). This highlights the importance for small island developing nations to develop conservation and management plans for SSF, so that this valuable resource can be used and enjoyed for years to come.

St. Eustatius fisheries

St. Eustatius, a small island developing nation, which is part of the Dutch Caribbean, has a marine park surrounding the entire island from the high-water line down to 30 meters, as well as two marine reserves. Their reefs and fisheries have been impacted by hurricanes, bleaching events, and the introduction of invasive species; recovery from these events has been ongoing (de Graaf et al., 2015; MacRae & Esteban, 2007). There are approximately 25-30 consistent fisherman on the island, who utilize small, wooden fishing boats covered by fiberglass, with small offboard gasoline engines, and this does not seem to have changed very much over the years (de Graaf et al., 2015; Dilrosun, 2004). The main target species are *Panulirus argus* or spiny lobsters, mixed reef fish, *Strombas gigas or* queen conch, and large pelagic fish (de Graaf et al., 2015; MacRae & Esteban, 2007). The marine park and no-take/no anchor reserves were established in 1996 and have been maintained by the St Eustatius National Parks Foundation (STENAPA) since its inception.

As a small developing island territory, maintaining their coral reef ecosystem and their reef fisheries is important for the island economy, nutrition, and food security (de Graaf et al., 2015). However, up until now the effects of different gear types and fishing pressure on the surrounding coral reefs, fish populations, fish size, and how those trends have changed over time in St. Eustatius has been poorly understood. There was a survey in 2006, which found that fish diversity had significantly increased, and that the creation of the marine park had been beneficial for the fish populations so far (MacRae & Esteban, 2007; J. White et al., 2006). This started a pattern of assessment every few years, and resulted in STENAPA agreeing to join the Global Coral Reef Monitoring Network (GCRMN) in 2015 (de Graaf et al., 2015; J. White et al., 2006).

STENAPA has access to fisheries landings data (2012-present) and the results of the Global Coral Reef Monitoring Protocol (GCRMP) (2015-present). Despite these efforts, there is still not a clear picture of fishing pressure around St. Eustatius, what is being caught, or trends over time. Analyzing the results of these data is important to assess the effectiveness of the marine park and its two marine reserves; help shape future management policies to aid with the conservation of island fisheries and this delicate ecosystem; and offer insights into the status of these fisheries. It also has the potential to demonstrate the effectiveness of low-cost methods of fisheries surveys in data-poor small-scale fisheries. In this Masters Project, I will utilize the fisheries landings data and GCRMN data collected by STENAPA to assess fishing intensity and its potential effects on the surrounding reef ecosystem, in an effort to help with future management strategies, and offer a cost effective approach to addressing some of the knowledge gaps surrounding St. Eustatius fisheries.

Objectives:
Here I will address the following questions:
Describe fishing activity:

- How much are people fishing and how much are they actually catching?
- What types of gear are they using and where are they using it?
- Where are the most heavily fished areas?
- What species are most highly sought out?
- What are these trends showing over time?

Examine potential effects on important ecosystems

- Which species are being heavily exploited and where?
- Is there a correlation between fishing pressure and coral reef health?
- What are the management implications of heavy exploitation of key species and habitats?

Methods:

Study Area

Our study site is St. Eustatius, commonly referred to as Statia, an island in the windward Dutch Caribbean island chain, located at 17.50˚N and 62.98˚W (Figure 1). It is a small island, approximately $21km^2$ around, with a population of approximately 3200 (MacRae & Esteban, 2007; STENAPA, 2018) A dormant volcano, known as The Quill, is a prominent land feature on the island (MacRae & Esteban, 2007). There is an oil transshipment facility in the northern part of the island, which employs approximately 10% of Statia's population, and contributes to about 7% of the island economy (MacRae & Esteban, 2007). The main city of Oranjestad is located in the south west region of the island, as well as the local harbor known as Gallows Bay.

Figure 1: St. Eustatius, Dutch Caribbean aerial view.

The national parks on the island include The Quill/Boven Park, a Botanical Garden, and the Marine Park, all of which STENAPA monitors and controls. The marine park was established in 1996 to, "manage and conserve natural, cultural and historical marine resources of St. Eustatius for sustainable use with continued stakeholder participation, for the benefit of current and future generations,"(MacRae & Esteban, 2007). This entailed managing 27.5km^2 of the marine environment around St. Eustatius from the high-water line down to the 30m depth contour. It included a general use zone (22.61km^2), and two no-take and no-anchor marine reserves in the north (1.61km^2) and the south (3.29km^2) of the marine park (Figure 2)(MacRae & Esteban, 2007; J. White et al., 2006). The marine park contains sand, coral, seagrass, and rock and rubble habitats (MacRae & Esteban, 2007). It can be characterized into three zones; near-shore, open water, and pelagic (MacRae & Esteban, 2007). The coral reef habitat has also been cited as an important stop-over point for migratory and critically endangered species (MacRae & Esteban, 2007). At least 14 IUCN Red List species, and 108 CITES listed species have been known to frequent the area during migrations or breeding seasons, such as Manta Rays, Leatherback sea turtles, and Humpback whales (MacRae & Esteban, 2007).

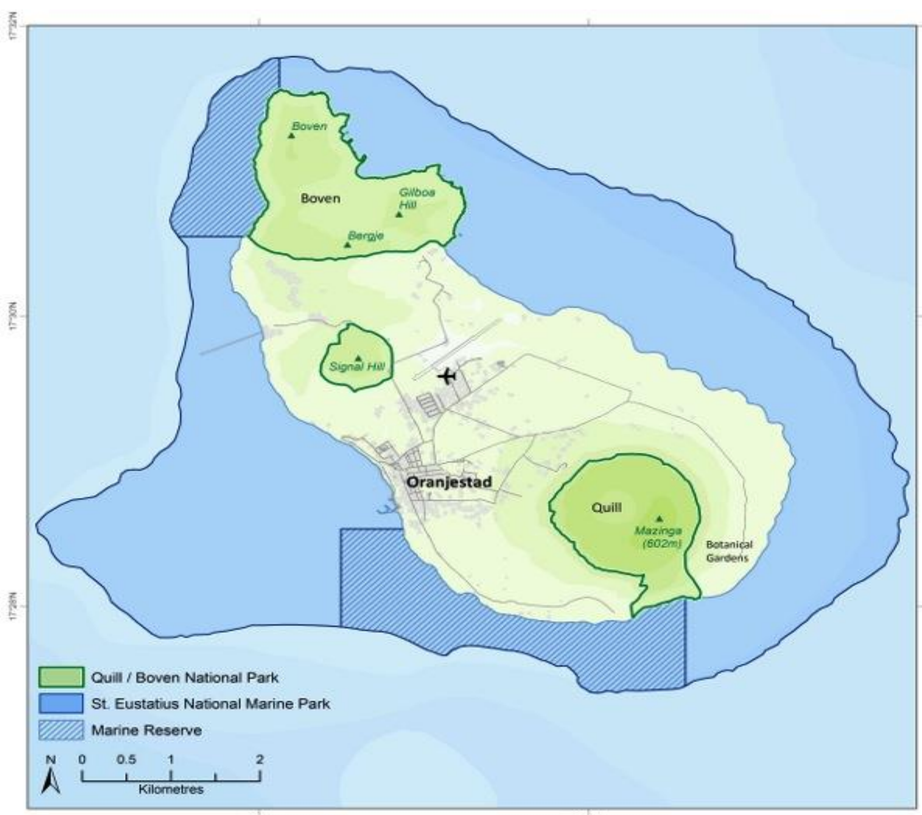


Figure 2: Map showing the outline of the marine park (blue) from the high-water line down to the 30m depth contour as well as the two no-take Marine Reserves (hashed blue), and land national parks (green) (http://www.mpatlas.org/mpa/sites/67706929/)

Fisheries landings surveys

STENAPA has access to fisheries landing data since 2012 from the Ministry of Economic Affairs, Nature and Food Quality (LNV), from sites located in and around the marine national park and within the two marine sanctuaries, which covers most, if not all, of the small-scale fishing occurring around St. Eustatius. For this study, we will focus on 2012 through 2018, because 2019 does not offer a complete data set. Additionally, for some of the trips, species composition, size/length, and other stock assessment indicators, such as shell length, lip thickness, and sex, were recorded for approximately 50% of the trips. Each trip was given a unique record identification number, however if multiple trips were taken by the same boat in one day, the same trip identification number was assigned. This allowed for more accurate catch references. A breakdown of the surveys are shown by the diagram below, and further descriptions of the breakdown can be found in Appendix 1 (Figure 3)(de Graaf et al., 2015).

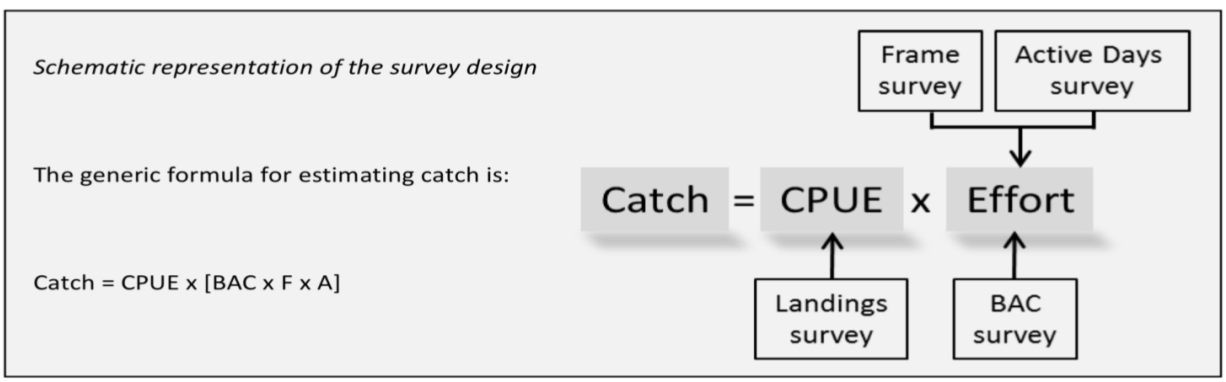


Figure 3: Figure depicting the components of the survey design for recording fisheries landings data in St. Eustatius (refer to Appendix 1 for definitions of the Frame Survey, Active Days survey, Landings survey, and BAC or Boat Activity survey) (de Graaf et al., 2015).

Coral reef monitoring

In addition to the fisheries landings survey, we had access to the results of the Global Coral Reef Monitoring Network surveys conducted since 2015. The GCRMN protocol is a widely accepted scientific protocol for the assessment of coral reef health. The GCRMN methods describe six elements for evaluating the coral reef ecosystem, and these are listed in Appendix 2 (GCRMN, 2016). These elements are meant to offer brief snapshot of the status of the reef and are not meant to be exhaustive. In St. Eustatius, STENAPA collects data in accordance with the GCRMN protocol, from twenty sites selected for long term monitoring efforts (Figure 4). These sites are all around the island, including the marine reserves. Using these data with the fisheries landing data will hopefully provide a snapshot of how fishing pressure could be impacting the coral reefs around St. Eustatius.

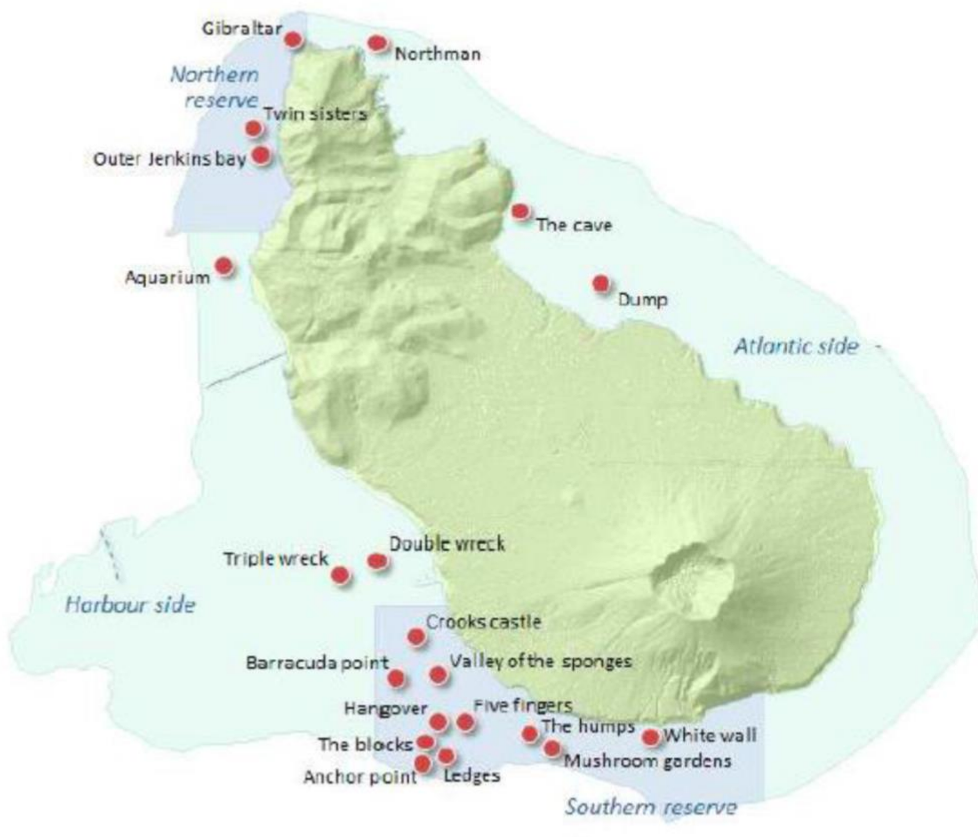


Figure 4: Map showing the twenty GCRMN long term monitoring sites around St. Eustatius (Kitson-Walters, 2017).

Mapping fishing activity

This study used methods adapted from Gill et al. 2019 to develop fishing intensity maps by year, gear type, and seasonal variations. RStudio and Google Earth Pro were utilized to help analyze and present the data. The fisheries landing data were loaded into RStudio from Excel, and using the tidyverse and dplyr packages, the data were aggregated and analyzed into summary tables. We were able to quantify fishing intensity as the sum of the number of trips per year, multiplied by the average amount of trip catch in kilograms, divided by the total area fished in km^2: $Fishing\ Intensity\ Equation\ 1 = \left(\frac{\sum(trips\ yr^{-1})\ \times\ \text{avg.}\,tripcatch\ (kg)}{Total\ areafished\ (km^2)}\right)$

It is important to note that there are two different areas used for these analyses: the one provided by the map in Figure 5, which is the fisheries zone map developed by St. Eustatius fisheries managers in the Ministry of Economic Affairs, Nature and Food Quality; and the area of the marine park, shown in Figure 2.

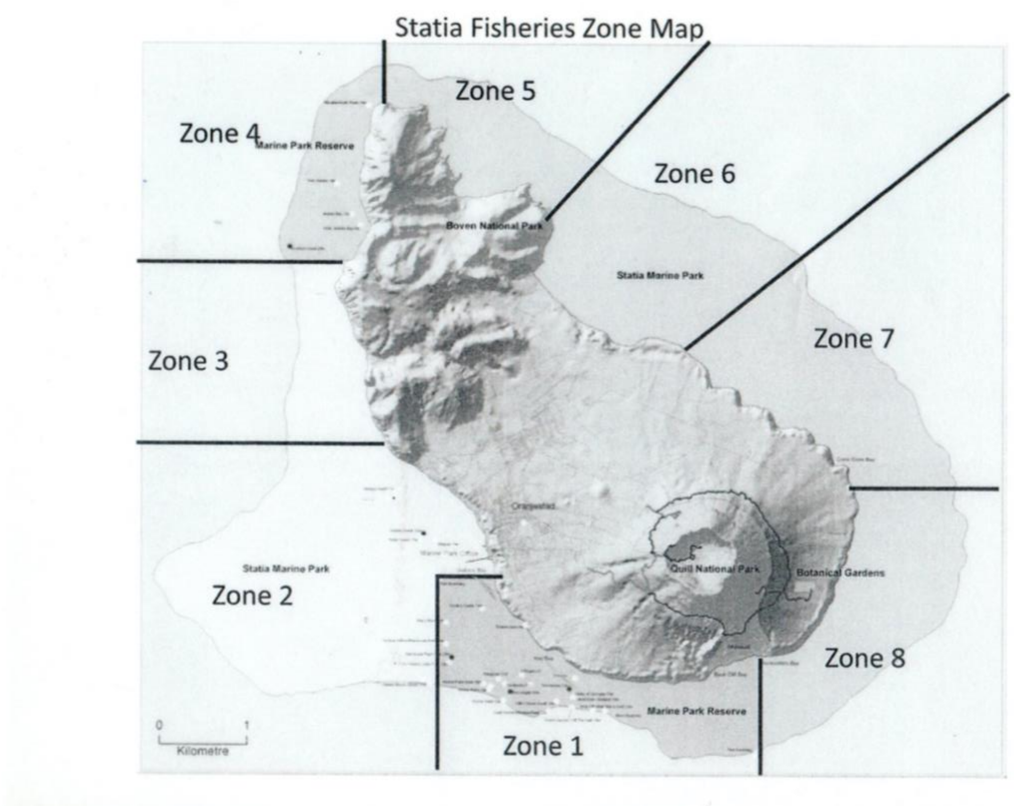


Figure 5: Map showing the waters surrounding St. Eustatius broken up into the eight fisheries zones. These are the zones recorded in the fisheries landings data used for these analyses (Ministry of Agriculture, Nature, and Food Quality).

Figure 5 is used in the fisheries monitoring program, and divided the waters surrounding the island into eight different zones; and this breakdown remained consistent for all subsequent maps shown in this report. This resulted in fishing intensity being calculated separately for each reference map. I created zone polygons, based on these fisheries zones, using Google Earth Pro and the polygon tracing feature, so that each polygon would have its spatial reference and calculated area. I digitized the eight fishing zone polygons, a St. Eustatius land area polygon, and a Marine Park polygon. Using RStudio, these polygons were compiled into a single spatial object, and clipped to the land area of St. Eustatius, to create an empty map (Appendix 3). For the marine park, these zones were clipped to the 30m depth contour, as shown in Figure 2. I then combined the spatial data with the fisheries landings data to estimate fishing intensity for each zone. Using the ggplot2 package, we created fishing intensity maps for each year from 2012-2018, within the marine park from 0m to 30m in depth, and for cumulatively highlighted gear types (Figure 6).

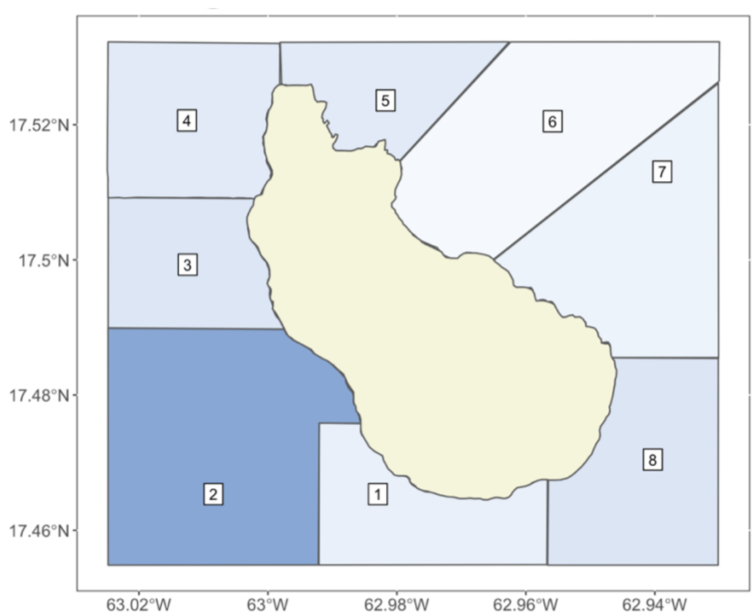
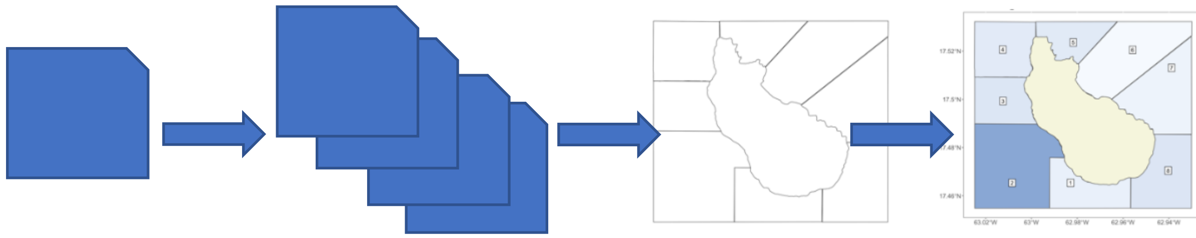


Figure 6: An example of the fishing intensity maps created using our methods. Beige is the St. Eustatius land area, light to dark blue measures fishing intensity, and the numbers represent the different fishing zones. Refer to Figure 7 for an example workflow of how these maps were created.

A diagram shows the workflow for creating these maps below (Figure 7):



1. Create polygon   2. Repeat for each zone   3. Clip to St. Eustatius   4. Fill with fishing intensity

Figure 7: Diagram for creating fishing intensity maps: 1) create polygon to represent the fishing zone 2) repeat for each of the eight zones around St. Eustatius 3) clip the eight polygons to the St. Eustatius land area polygon 4) fill the polygons with the summed fishing intensity for each zone

Results:

Aggregated Fish Landings, Number of Trips, and Fishing Intensity

Using RStudio we were able to calculate the total number of landings, total number of trips taken, and the fishing intensity throughout the whole fishing area, from 2012 to 2018. The results showed a total average landing of 2448.23 + 284.56 kilograms (mean + SD) of fish per year with 148.1 ± 10.8 trips (Table1). This was the result of an average fishing intensity of 37.73 ± 4.39 $kg/km^2/yr$ (Table 1). There are four years with lower than average total landings: 2014, 2015, 2017, and 2018. There are also two years with fewer trips than average, which are 2013 and 2014, which do not overlap with the lower than average landings. Lastly, there were four years with less fishing intensity, 2014, 2015, 2017, and 2018. These lower than average fishing intensity calculations do match up with the lower than average total landings years. We also calculated the yearly summaries for total landings, total number of trips, and fishing intensity within the marine park, or from the high-water line down to 30m in depth, from 2012 to 2018. These results showed that within the marine park, they were catching 1377.42 ± 323.31 kg of fish per year using 72.7 ± 9.9 trips per year (Table 2). The average fishing intensity as 50.09 ±

Table 1: The total landings and total number of trips from each trip are summed for each year from 2012 to 2018. In order to calculate fishing intensity, average trip catch was multiplied by the number of trips per year and divided by the total area of all eight zones (64.89km2).

Year	Total Fish Landings (kg)	Total Number of Trips	Fishing Intensity (kg/km2/yr)
2012	2716.73	170	41.87
2013	2961.14	104	45.63
2014	2125.91	113	32.76
2015	1859.09	162	28.65
2016	3680.68	163	56.72
2017	2391.14	177	36.85
2018	1402.95	148	21.62
Average	2448.23	148.1	37.73
Standard Error	284.56	10.8	4.39

11.76 kg/km 2/yr within the marine park (Table 2). There were four years with lower than average total landings, which were 2014, 2015, 2017, and 2018. These differed slightly from the four years with fewer than average trips, including 2013, 2014, 2017, and 2018. However, the same years with lower than average total landings were the same ones with lower than average fishing intensity in the marine park. On average, about 56% of the total landings were being caught inside the marine park for each year, but only 48.8% of the total trips per year were within those boundaries. Additionally, the same years with lower than average total landings and less fishing intensity were the same for both the whole fishing area and the marine park (2014, 2015, 2017, and 2018). There was also an increase in the amount of fishing intensity happening in the marine park compared to the whole fishing area. This is due to a decrease in area size of the marine park, which causes fishing intensity to increase over a smaller area.

Spatial and Temporal Mapping

Based off of the aggregated tables above, we were able to sum the total landings and trips for each zone and calculate the average catch for each trip (Figure 5). This was then used to calculate the fishing intensity for each fishing zone for each year (Fishing Intensity Equation 1),

Table 2: The total landings and total number of trips are summed for each year within the marine park, from 2012 to 2018. In order to calculate fishing intensity, average trip catch was multiplied by the number of trips per year and divided by the total area of all eight zones in the marine park (27.5km2).

Year	Total Fish Landings (kg)	Total Number of Trips	Fishing Intensity (kg/km2/yr)
2012	1658.09	124	60.29
2013	2547.50	70	92.64
2014	1319.09	58	47.97
2015	592.73	73	21.55
2016	2337.05	81	84.98
2017	888.86	63	32.32
2018	298.64	40	10.86
Average	1377.42	72.7	50.09
Standard Error	323.31	9.9	11.76

from 2012 to 2018 (Figure 8). When looking at the different zones, Zone 2 is experiencing the most fishing intensity from 2012 to 2014. From 2012 until 2015, most of the fishing intensity also seems concentrated on the leeward, or sheltered, rather than windward, or exposed, side of the island. There is a shift from Zone 2 to Zone 1 in 2015, and then a shift back to Zone 2 for 2016 as the area experiencing the most intense fishing intensity around St. Eustatius. Twenty sixteen is also the year with the highest fishing intensity, compared to all of the other years. Another shift occurs between 2016 and 2017, where Zone 1 becomes the most intensely fished area again, and this holds until 2018. In 2017 and 2018, fishing intensity was more widely disperse in comparison to the other years. We were also able to calculate the amount of fishing intensity occurring within the marine park from 2012 to 2018 (Figure 9). As a reminder, the northern marine reserve is Zone 4 and the southern marine reserve is Zone 1. There is fishing happening in at least one of the marine reserves from 2012 to 2018, which can be classified as illegal fishing due to the areas being designated as no-take zones. Zone 2 is where the most fishing intensity is occurring for all years except for 2017, where the northern marine reserve, Zone 4, is where the most intensity is occurring. Following trends seen previously for the whole

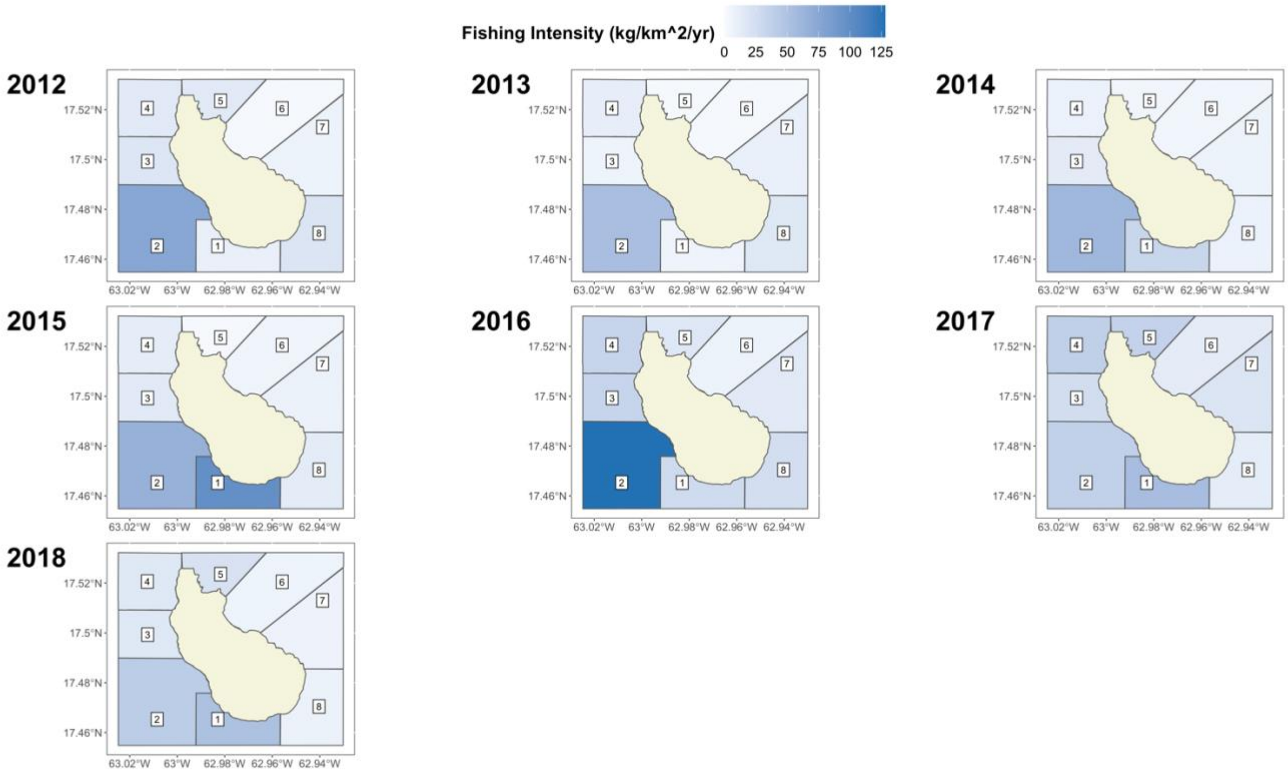


Figure 8: Map showing the spatial and temporal extent of fishing intensity around St. Eustatius from 2012 to 2018 for all eight fishing area zones. The color scale goes from light blue to dark blue, showing increasing intensity in fishing intensity (kg/km2/yr). The beige is the land area.

fishing area, there was a large increase in fishing intensity in Zone 2 for 2016, and for 2017 there was more fishing occurring around the whole island within the marine park. Unlike the whole fishing area, we did not see shifts from Zone 2 to Zone 1 for 2015 or 2017, but we did see a shift back to Zone 2 for 2018, for where the most fishing intensity is occurring within the marine park. It is important to note the scale change for this set of maps, since a smaller area increases intensity calculations, and this is reflected in the scale bar going from 0 to approximately 175, compared to the previous set of maps for the whole fishing area, where the scale goes from 0 to 125 for fishing intensity. Lastly, we mapped the cumulative fishing intensity for each of the major fishing gears: drop and hand line, trolling and long line, SCUBA and free diving, pot traps, and beach seines from 2012 to 2018, for all eight zones of the whole fishing

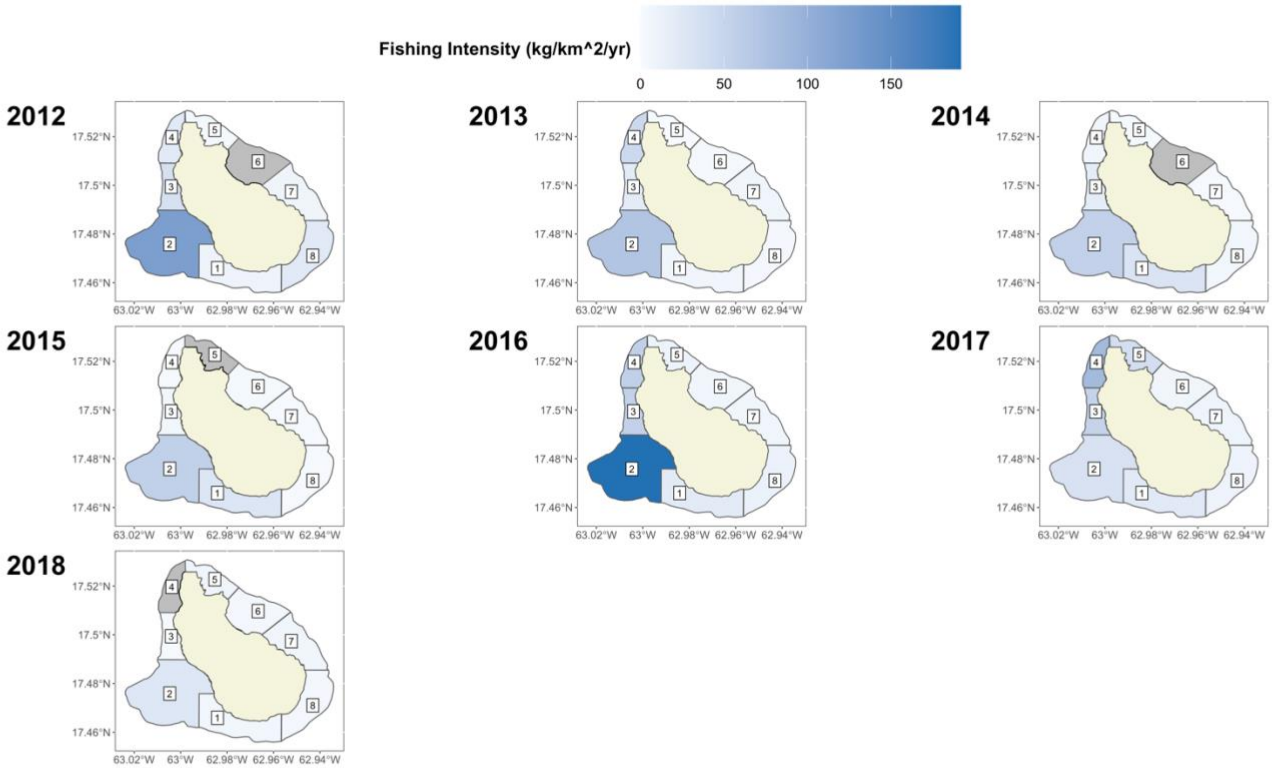


Figure 9: Map showing the spatial and temporal extent of fishing intensity around St. Eustatius from 2012 to 2018 within the marine park. The color scale goes from light blue to dark blue, showing increasing intensity in fishing intensity (kg/km$_{2}$/yr). The beige is the land area; there are also some zones denoted in grey, which represents NAs, since there were not enough data recorded (2012, 2014, 2015, and 2018)

area surrounding St. Eustatius (Figure 10). All gear types except for beach seines were utilized in all zones around the island. Pot traps exerted the most fishing intensity overall and was concentrated in Zone 1 and Zone 2. Beach seines seemed to be exclusively used in Zone 2, and also seemed to have a large, concentrated amount of fishing intensity happening in that zone as a result. The other gear types seemed to have a moderate amount of intensity around the island.

Fisheries landings by gear type and fish family

Figure 11 shows the total fisheries landings for each year, separated out by gear type. The gears were grouped the same way as the maps above (Figure 10). Total landings peaked in 2016 and were lowest in 2018, which is also supported by Table 1. There were temporal fluctuations between use of all of the gear types. Drop and hand lines were used each year, however, catch

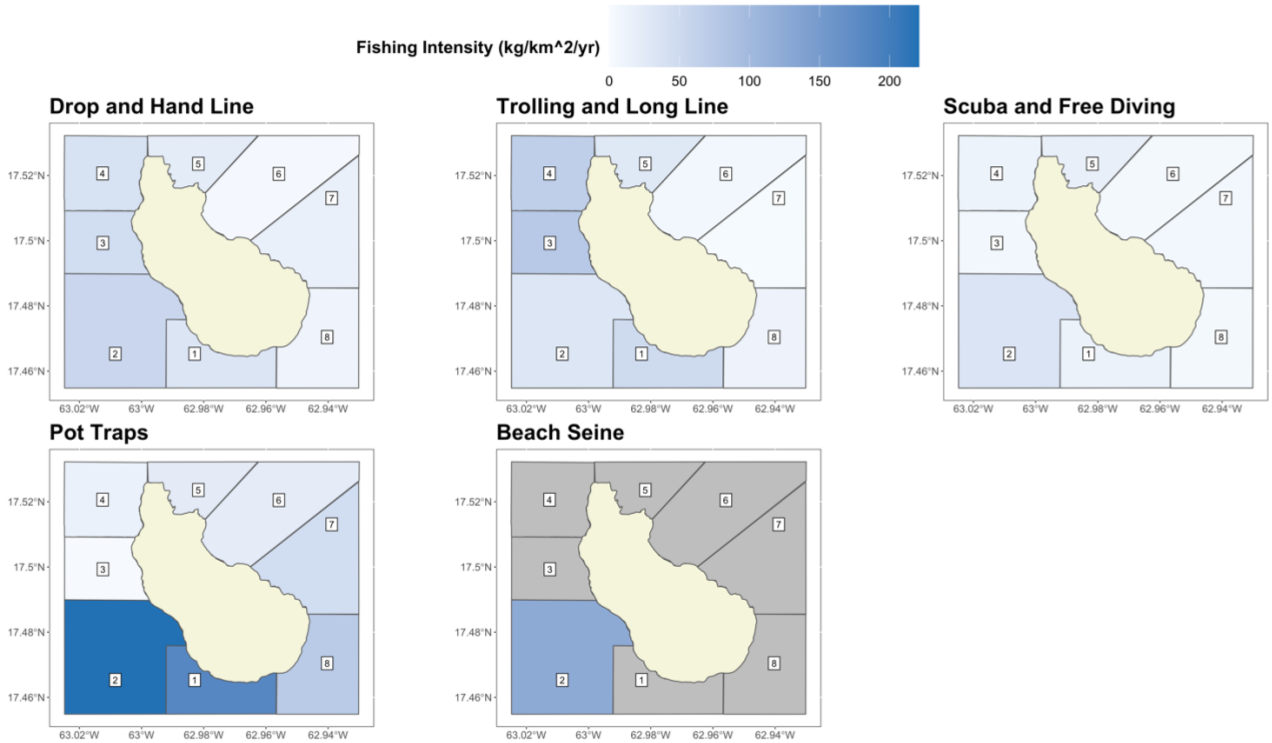


Figure 10: Map showing the cumulative fishing intensity of certain gear types summed from 2012 through 2018, for the entire fishing area around St. Eustatius. The color scale goes from light blue to dark blue, showing increasing intensity in fishing intensity (kg/km^2/yr). The beige is the land area and the grey area is denoted as NA zones.

and usage seemed to shrink in 2015, increase in 2016, and shrink again in 2017 and 2018. Pot trap usage seemed to peak in 2015 and was also the gear that caught the most fish that year. Although it was third to drop and hand line and beach seines in 2016, it became dominant again in 2018. Additionally, this graph shows that between 2013 and 2014, beach seines dropped out of use, until they re-emerged in 2016, and then they dropped out of use again in 2017 and 2018. This is also a visual representation of the variability in total landings over time, despite similar gear usage. Our last set of results show the relative abundance of each fish family catch based on a sampled subset of landings. By using length: weight ratios for each recorded fish length, we were able to estimate the weight of each fish and group them by family. Not every catch was speciated, so we analyzed the subset by summing the total weight of catch for each family, and

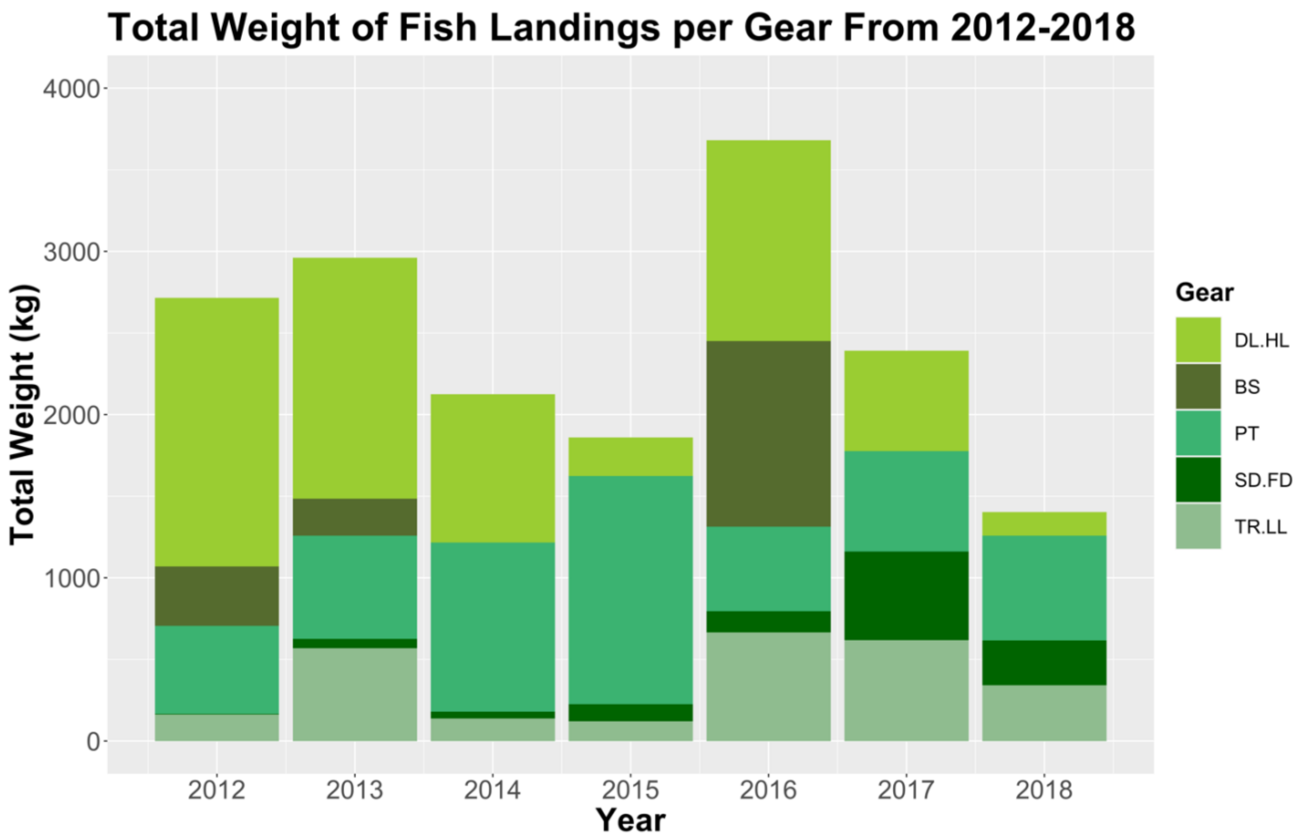


Figure 11: Bar graph depicting total landings (kg) broken down by gear type for each year from 2012-2018. The different groupings were: DL.HL, drop line and hand line; BS, Beach Seine; PT, Pot Traps; SD.FD, SCUBA diving and free diving; and TR.LL, trolling and longline.

dividing it by the total weight of catch for the whole subset. This represents 91% of all the species caught in the subset, removing seven fish families (out of thirty one) and leaving twenty two, as some were considered negligible (<.1 percent). Most of these are common reef fish families, except for: *Scombridae*, which are the mackerels, tuna, and bonito family; *Coryphaenidae*, which are the dolphinfish; and *Istiophoridae*, which are the marlin. Each of these families are known as large pelagic species, but are also below the top ten fish families represented in the chart. The top five fish families are: *Serranidae* commonly known as the grouper family; *Acanthuridae* also known as surgeonfish and tangs; *Ostraciidae* including boxfish, cowfish, and trunkfish; *Holocentridae* family containing squirrel and soldier fish; and

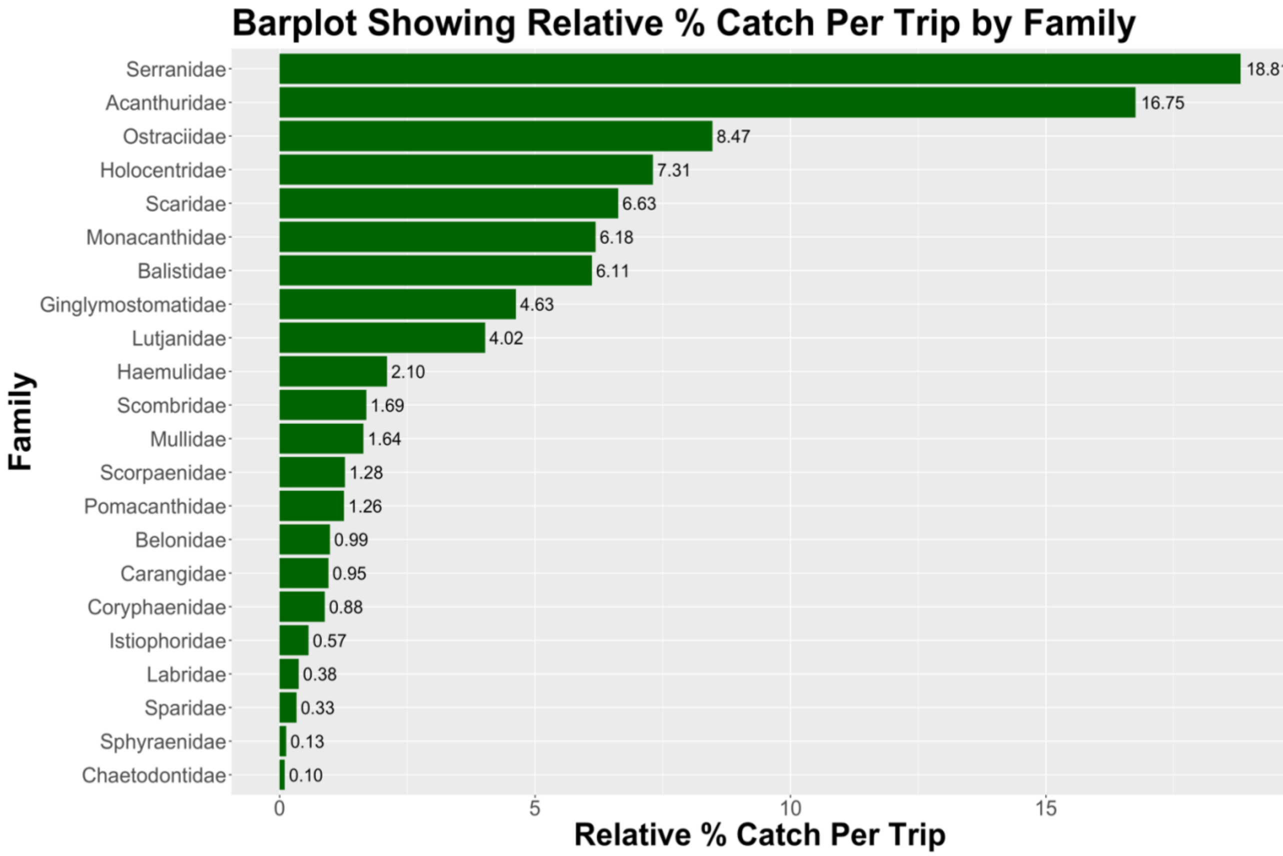


Figure 12: Bar graph showing the relative percent catch composition for each trip recorded in a sampled subset of the fisheries landing data. Most of the catch was made up of *Serranidae* and *Acanthuridae*, while few *Sphyraenidae* and *Chaetodontidae* composed the catch.

Scaridae also known as the parrotfish family. These five families account for 58% of the catch composition of each trip.

Discussion:

When comparing the amount of fish caught in St. Eustatius to other small-scale fisheries, the sector on this island seems to be on the smaller side, averaging only 2448.23 ± 284.56 kg of fish per year, or approximately 2.7 tons (Gill et al., 2019; Lunn & Dearden, 2006; Salas et al., 2007; Saldaña et al., 2017; Vianna et al., 2020; Zeller et al., 2015). Other small-scale fisheries, such as Costa Rica, are utilizing thousands of people an fishing vessels, which would result in more tons of fish caught (Salas et al., 2007). Some estimates for other small scale fisheries include 159.7 tons of fish caught in San Felipe, Yucatan; between 272.6 to 409.0 metric tons in Barbados; and about 364 tons of fish from Ko Chang, Thailand (Gill et al., 2019; Lunn & Dearden, 2006; Saldaña et al., 2017). St. Eustatius has 25-30 consistent fishermen on the island, which is magnitudes smaller than some of these other SSF (de Graaf et al., 2015; Dilrosun, 2004) This also meant that the average amount of fishing intensity was small compared to other small-scale fisheries, however this does not mean that fishermen are not having a significant impact on the surrounding environment.

One of the major findings of this study was how much total landings and the associated fishing intensity, from the entire fishing area, could vary from year to year, but also seemed to be declining annually. While there was a brief peak in 2016, the trend up until that point was one of decline, and the slope continued down until 2018. There were anecdotal reports that some of the older fishermen retired, and there was a lag before and influx of new fishermen started fishing St. Eustatius, however the dates are unconfirmed. It could be following global catch trends, which have estimated that fisheries have been declining since peaking in the 1980s (Chuenpagdee et al., 2006; FAO, 2018; Pauly, 2008; Pauly & Zeller, 2016; D. Zeller et al., 2015; Dirk Zeller & Pauly, 2005). It also could be due to a reduced fishing season, since between 2014 and 2015, and between 2017 and 2018, there were a few large hurricanes that impacted the island. Anecdotally, it was reported by STENAPA staff that many of the pot traps and boats that the fisher folk use were damaged in the storms. The pot traps are homemade, so there could have been a lag in catch due to a reduced number of traps in the water, or even a switch in gear usage until the traps could be repaired. More insight into what may be happening is shown in Figure 11. It shows that there was indeed a switch in gear utilization, from drop and hand line to pot traps between 2014 and 2015; and a switch from beach seines back to the four common gear groups between 2017 and 2018. There were also rumors reported to STENAPA staff that a fisherman from the nearby island of St. Kitts had come over and taught Statia fishermen how to use the beach seines. This could explain the increase in beach seine use in 2016. The rapid decrease in use in 2017 could be because the nets were borrowed, broke, and the fishermen could not repair them; or it was no longer a viable method for catching fish. While previous studies refer to larger fisheries, it is important to note that just because small-scale fisheries are typically underreported does not mean they are not suffering the same consequences of global fisheries decline (Salas et al., 2007; Zeller et al., 2015). It is a foreboding trend since small-scale fisheries are vitally important for economic and food security reasons locally (Lunn & Dearden, 2006; Salas et al., 2007; Saldaña et al., 2017; D. Zeller et al., 2015).

Interestingly, landings and fishing intensity trends within the marine park matched those for the whole fishing area from 2012 to 2018. We predicted a potential deviation or decrease in landings, and potentially intensity, due to the management controls of STENAPA. However, there was an increase in fishing intensity within the marine park compared to the whole fishing area (Table 2). This could be due to increased catch over a smaller area, or the marine park could be more heavily fished on average (Figure 9). However, there were fewer trips inside the marine park compared to the whole fishing area (Table 1). This suggests that fishing efforts within the marine park may not be as efficient as venturing out into deeper ocean waters, where the larger, pelagic fish reside.

Understanding the scope and scale of a fishery has important management and sustainability implications (Gill et al., 2019; A. F. Johnson et al., 2017; Lunn & Dearden, 2006). While the scale of the fishery around St. Eustatius may be small, its scope covers the whole island (Figure 8). When breaking it down by year, there was fishing intensity in every zone, around the entire island. There was also an intense concentration of fishing intensity in Zone 2 and Zone 1, which consequently is also where much of the coral habitat is located (Appendix 4). According to STENAPA's management plan, this is a critical area for conservation, since they are concerned about coral bleaching and decline (MacRae & Esteban, 2007). The management report cited robust coral communities in 2007, even though there was a large bleaching event in 2005 that resulted in a large percentage of coral mortality (MacRae & Esteban, 2007). However, since the GCRMN protocol has been implemented, the St. Eustatius reef has been listed as critical, with less than 5% hard coral cover, and more than 35% macro-algal cover (Kitson-Walters, 2017). It was also reported that the amount of herbivorous fish on the reef has declined by over 50% in the last two decades (Kitson-Walters, 2017). As suggested by Figure 12, important grazers, such as parrotfish, surgeonfish, and boxfish are being harvested the most since they are making up the majority of the relative catch. This is an estimation, but the GCRMN reef monitoring results seems to support that herbivores are being heavily exploited on St. Eustatian reefs. The result is a macro-algal dominated reef, rather than a hard coral cover dominated reef, and suggests that intense fishing intensity may be driving decline (Kitson-Walters, 2017; Mumby, 2006a; Mumby, 2006b).

Overfishing has been shown to be damaging to coral reefs, leading to a decline in hard coral cover (Oberle et al., 2016). This can be due to a reduction in the number of herbivores, which graze on algae on reefs, and reduce competition between corals and algae (Mumby, 2006b). It could also be due in part to the type of gear used capture these fish. The gear that seems to have the most fishing intensity is pot traps (Figure 9). Pot traps are usually set on the benthos, which could cause problems for corals by smothering them, blocking photosynthetic activity for the symbiotic algae, or breaking off pieces of the coral skeleton (Suuronen et al., 2012; Valdemarsen & Suuronen, 2003). Additional concerns for pot traps are bycatch and ghost gear. Bycatch, or untargeted catch due to an unselective gear type, can contribute to overfishing and reducing fish stocks (Davies et al., 2009; Peckham et al., 2007). Ghost gear, or gear that is lost, damaged, or forgotten, can continue to fish, also contributing to overfishing and marine pollution (Gilman, 2015; MacRae & Esteban, 2007). This can cause changes in the trophic structure of the reef, which can lead to cascading effects or even phase shifts, and possible collapses of fisheries or ecosystems (Hughes et al., 2010; Mumby, 2006; Valentine & Heck, 2005). Coral reefs are important spawning and nursery sites for fish, as they offer lots of places to hide and feed. Therefore healthy corals and healthy fish stocks are intrinsically linked, and the success of one is dependent on the health of the other (Bonaldo et al., 2017; Mumby, 2006). The more resiliency and protections that can be afforded ecosystems now, will hopefully ensure more robust and recoverable natural resources later, despite climatic shocks.

Another concern for St. Eustatius and STENAPA in particular is that there seems to be illegal fishing happening within the marine reserves. Although it is low for most years, there is a noticeable spike in fishing intensity in 2017. This could be opportunism due to the hurricanes, but that is unconfirmed. Illegal fishing, by ignoring established rules and regulations, can undermine sustainability and resiliency goals (Agnew et al., 2009; Lockwood et al., 2010; Petrossian, 2015). There were also reports that fishermen were again coming from nearby islands to fish. This is a problem for STENAPA as it shows a potential gap in their authority, monitoring and enforcement of the park and reserves, education, and highlights the need for either additional training, staff, or increased presence in the area. Conflicts between STENAPA and the local fishing community have been documented since the reserves were created in 1996 (MacRae & Esteban, 2007). The fisherfolk commented that they felt as though being restricted from the marine park resulted in too much overlap with other users of the marine park (MacRae & Esteban, 2007). This in turn was affecting their livelihoods, for example the shipping tanker anchors were destroying their traps, divers would accidentally destroy their traps, and the illegal fishers were encroaching on their fishing grounds (MacRae & Esteban, 2007). Some of the proposed alternatives were providing fishermen-only spaces in the marine park, or rotating fishing areas seasonally (MacRae & Esteban, 2007). For any of these proposed solutions to be implemented successfully, STENAPA needs to hold true to their mission, and engage stakeholders in these processes. Proper management necessitates that these individuals be included, or it will almost ensure that they will not respect the boundaries in place (Lockwood et al., 2010; MacRae & Esteban, 2007; Westlund et al., 2017). Otherwise, this can lead to more illegal fishing, fishing displacement, or even fishing along the edges of the no-take zones, all of which can reduce the benefits of the marine reserves, and reduce resiliency (Field et al., 2009; Halpern et al., 2004; Jennings & Polunin, 1996; Kellner et al., 2007; Petrossian, 2015; Stevenson et al., 2013; Westlund et al., 2017). As part of a progressive, active, and adaptive management strategy it is important to learn from these short comings, and come up with novel solutions to these problems (Bennett & Dearden, 2014; Lockwood et al., 2010; Mascia, 2004; Ostrom, 2009).

Conclusion:

Although this report highlighted some challenges for STENAPA, it also provided some answers about the state of the St. Eustatius fishery. There seems to be some illegal fishing, but there could be unreported benefits of the marine park and marine reserves. Specifically, the GCRMN did report that the marine reserves seemed to be sustaining fish biomass and diversity for the island (Kitson-Walters, 2017). This means that the fishermen could be benefitting from spill-over effects, which could be supported by Figures 8 and 9. These figures show that while there is some illegal fishing, most of the fishing in Zone 1 is occurring outside of the marine park for years where that was the most intensely fished zone. Reduced fishing activity and intensity within the marine reserves, could have allowed stocks to recover, since they may have been released from intense pressure (Abesamis et al., 2014; Branch, 2015; Essington et al., 2006; Jennings & Polunin, 1996; Walsh et al., 2012). The result of these improvements are spill-over effects attributed to improved larval dispersal and survivorship (Abesamis & Russ, 2005, 2005; Di Lorenzo et al., 2016; Goñi et al., 2008, 2010). This is a positive benefit for the surrounding community, who can enjoy more, larger fish (Di Lorenzo et al., 2016; Goñi et al., 2010). Positive, tangible benefits have the potential to engage and motivate the surrounding community to adhere to the rules and regulations of the MPA. It could also explain why Zone 1, for the whole fishing area, had heavy fishing intensity for certain years, as fishermen might have been experiencing these benefits on the margins of the marine reserves.

We were able to do these analyses in a low-cost manner, through the use of open source software. Successful spatial and temporal representations of the St. Eustatius fisheries were created and can be used for future analyses. Although not included in this report, we were also able to duplicate these methods for spiny lobsters and queen conch, and were able to include some stock assessment analyses based on these data. Some shortcomings of using these methods include some trip records in the logbook have less data than others, and data are not available for all the boats in the fishing fleet. This means that we could be underestimating the amount of fishing intensity around St. Eustatius. Additionally, during the cleaning process for the data, some observations may be excluded due to their incomplete nature. For example, records that did not report landings weight, depth, or gear type used would be excluded from our analyses. While this analysis strategy may not work for every small-scale fishery, we hope that it can work for those with fisheries landing data in the form of logbooks. Examples of what were recorded in this logbook are shown in Appendix 5. Despite these shortcomings, one of the future products of this research is an R Markdown document. This will allow STENAPA to continue their monitoring and evaluation of the marine park and their fisheries, and make it a part of their management plan.

STENAPA is about to engage in a marine spatial planning intensity in 2020, to potentially address some of the concerns raised above. Since the critical coral reef habitat is a priority conservation area for STENAPA, as well as sustainably managing the marine park, I would recommend the following policies:

1. Gear restrictions: Restrict gear types, such as beach seines and pot traps to reduce damage to coral reefs and other benthic habitats. This can be done spatially by not allowing their use within the marine park; they could be permitted so that only a certain number of the gear type are allowed in order to limit the amount of catch; or they are only used during certain seasons. It should also help to reduce bycatch of non-target species. Additionally, by reducing the amount of gear allowed to be used in the water, there is potential to reduce the amount of fish caught, which could cut down on the number of

herbivores extracted from the water. Appendix 6 shows seasonality trends for total landings from 2012-2018 as a reference.

2. Expand the marine reserves: This would be in order to protect, monitor, and enforce more of the critical coral reef habitat. However, expanding the marine reserves may receive push back from fisherfolk and commercial shipping people. Stakeholder engagement will be key for garnering support for this measure. Some of these conflicts over use could be addressed by allowing the reserves to remain open for non-extractive activities such as SCUBA diving or snorkeling. This could facilitate alternative livelihoods and increase local economic inputs (Bennett & Dearden, 2014). Another solution could also be expanding the marine reserves, while designating fishing only zones for the fishermen. This may help reduce conflicts over who gets to use these multi-use zones.
3. Increase patrols in the marine reserves: By increasing patrols in just the reserves, illegal fishing could be curtailed. This is a vital capacity building initiative that will enable STENAPA to reach its conservation mandates. This may require more staff and outside financing, which could be supported by hiring local peoples and soliciting donors.
4. Increase stakeholder engagement: This is of vital importance for the fishermen. Engage them as monitors, enforcers, and even data collectors. The more they are engaged in the process, the more likely they are to follow the rules (D. S. Johnson, 2006; Lockwood et al., 2010). In order for there to be successful management of the marine park, participatory processes should be an integral part of the management plan (Bennett & Dearden, 2014; Berkes, 2003). It prioritizes collaboration and partnerships to help realize and reach community conservation goals (Berkes, 2003).

5. Increase education and outreach: This is important for visitors or recreational users who are not from St. Eustatius. Coupled with stakeholder engagement, increasing education and outreach can help increase community engagement, which then helps with compliance and reaching sustainability goals (Bennett & Dearden, 2014).
6. Develop more monitoring and evaluation efforts: Knowledge incorporation is especially important at all levels as it informs decisions, manages risk, and facilitates self-reflection through monitoring and reporting (Lockwood et al. 2010). It requires input from scientific, local, and indigenous sources in order to adequately capture the proposed management environment (Bennett & Dearden, 2014; Lockwood et al., 2010). Rigorous monitoring, reporting, and evaluation can encourage transparency, as well as offer the opportunity to learn from experience while processing new information (Lockwood et al., 2010). This is a vital part of an adaptive management strategy.
7. Enhance adaptive management strategies: Ecosystems can be characterized as complex, dynamic, ever changing, interdependent and multi-use environments (Lockwood et al. 2010). As a result of this complexity, there is a need to account for changes over time (Bennett & Dearden, 2014; Berkes, 2003; Lockwood et al., 2010). When trying to implement adaptive governance or management regimes, actors are trying to safeguard against extremes, while remaining flexible, in order to achieve their sustainability goals. Natural resource management contains a lot of uncertainty and unpredictability, but building flexibility into the management structure can help mitigate some of the shocks. The ability of the governing body to respond to changing conditions will determine its success in managing the ecosystem; coming up with novel solutions to problems; and understanding the needs of the surrounding community. STENAPA should explicitly

allow for continued engagement and support from stakeholders and local peoples; outline increased outreach and education initiatives; and craft rigorous monitoring, evaluation, and reporting mechanisms in their adaptive management plan.

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Appendix 1: Here is a further description of the components of the fisheries landings survey based on information from de Graaf et al., 2015:

Fish landings monitoring

"Frame Survey: A frame survey is a census-based approach to collate a list of homeports and boat/gear categories which is used as the basis for the Active Days, Boat Activity and Landings surveys. The frame surveys is conducted at the start of each year and is updated monthly throughout the year.

Active Days Survey: Active Day Surveys are conducted at the end of each month to determine the number of active fishing days for each strata in the survey design (e.g. home port, boat/gear category).

Boat Activity Survey: Boat Activity Surveys are conducted at homeports separately for each boat/gear category to determine how many boats are active on a given day. If required, homeport sampling? are weighed based on the number of fishing boats. Weighed homeports are then randomly selected on survey days. However, given that St Eustatius has only one homeport, weighted sampling does not apply.

Landings Survey: Landings Surveys are conducted to collect data on catch, intensity, species composition and length frequency with a minor stratum, for a calendar month and boat/gear category. In addition to the standard landings data, information was collected on the observations of whales and dolphins by fishermen (Scheidat et al., 2015)" (de Graaf et al. 2015).

Appendix 2: GCRMN Assessment Indicators

(1) Abundance and biomass of key reef fish taxa

(2) Relative cover of reef-building organisms and their dominant competitors

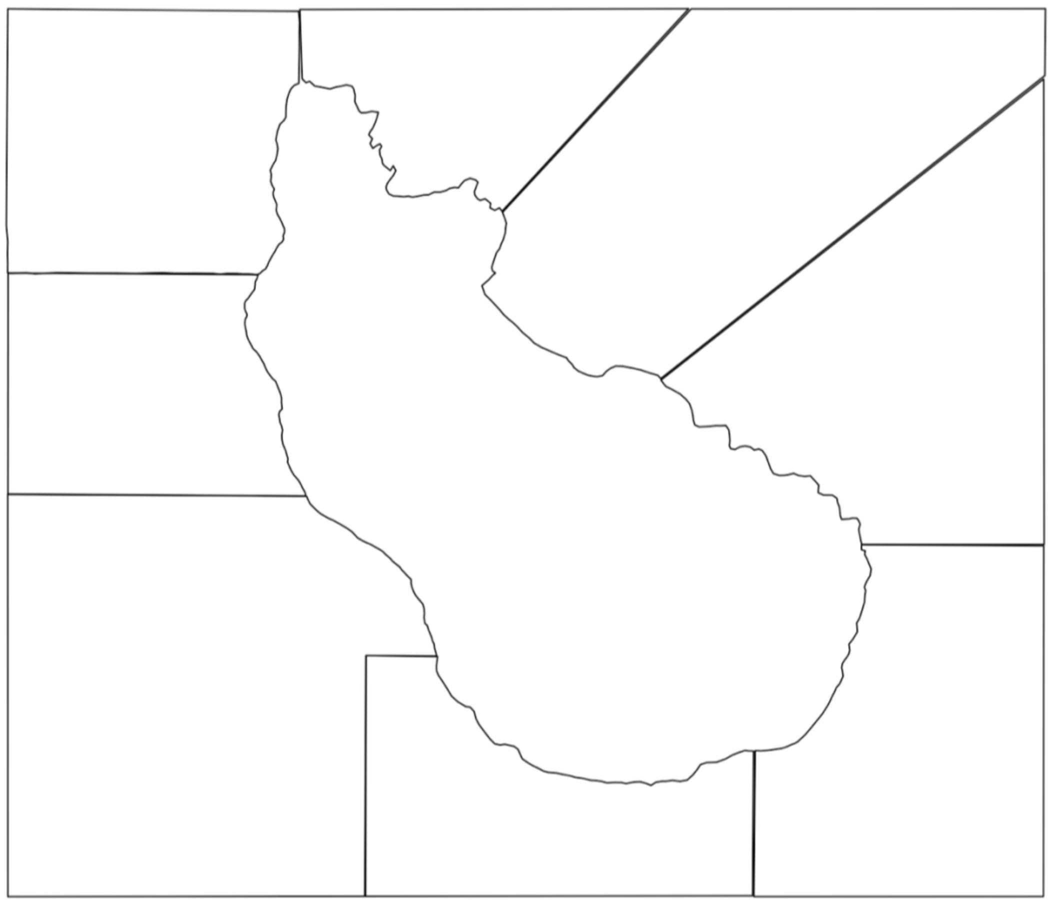
(3) Assessment of health of reef-building corals

(4) Recruitment of reef-building corals,

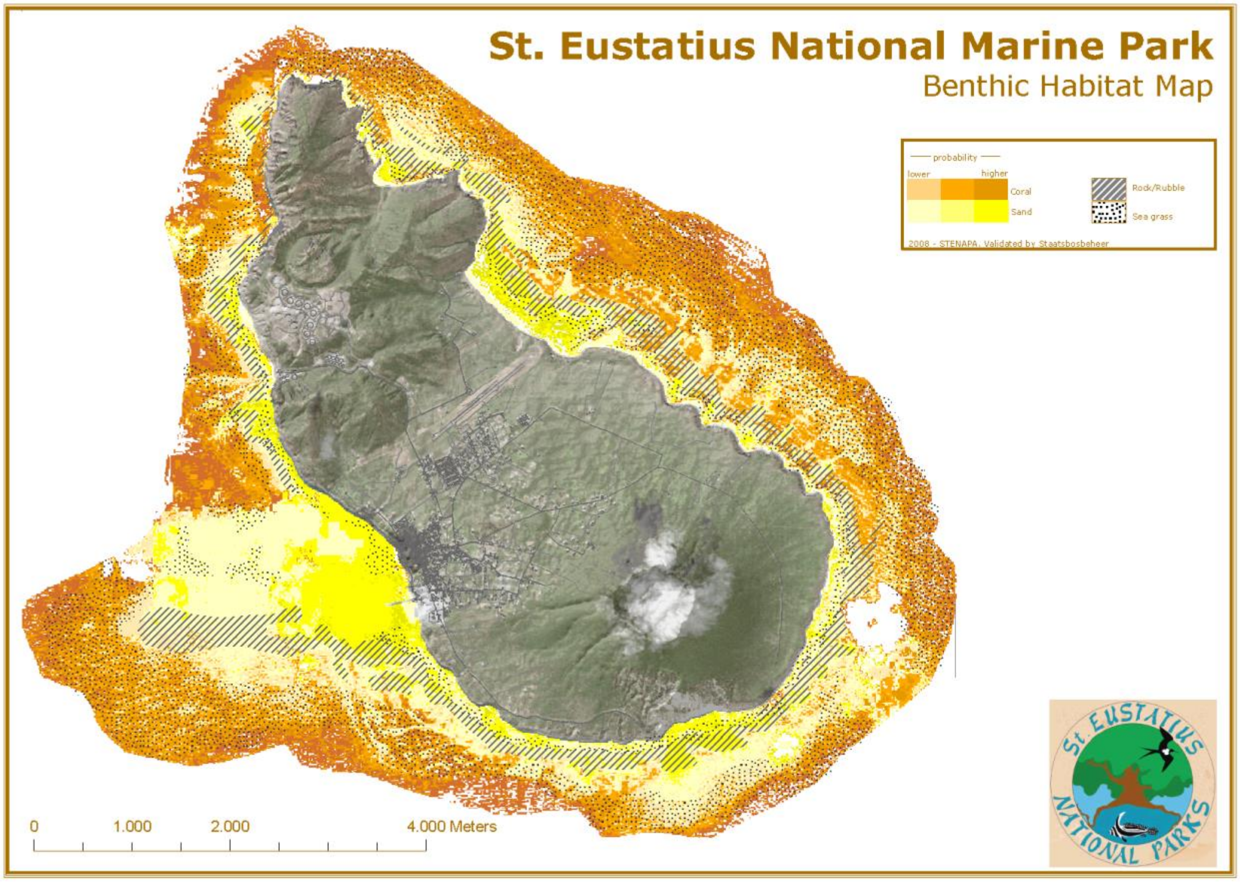
(5) Abundance of key macro-invertebrate species

(6) Water quality

Appendix 3: Example of the blank map created by stitching the polygons together based on Figure 5.



Appendix 4: Map depicting the verified extent of each marine habitat around St. Eustatius. This includes coral reefs, seagrass beds, rock/rubble, and sand. There is also a probability scale for how likely you are to actually find the habitat listed.



Appendix 5:

Examples of what were recorded for the fisheries logbook data utilized here:

Record ID Trip ID Day Month Year Landings

Weight (Lbs) Number of lobster/fish Number undersized (length)

Number Berried Gear Speargun Number lines/pots/divers Duration (hr) Soaking

time Min/Max Depth (ft) Min/Max Depth(m) Zone/Landing Site Number of Crew

Boat ID Trips

Examples of additional information that could be useful:

Family Trophic level Species Scientific Name Species Common Name

Length Male/Female Fin Length or Tail Length

Appendix 6: Graph showing the seasonality of total landings (kg) from 2012 to 2018 around St. Eustatius for each month, from January to December (1-12).