First indication of the abundance and distribution of protected seagrass associated species in the introduced *Halophila stipulacea* meadows on Sint Eustatius

Bachelor Thesis Coastal and Marine Management

Thesis

Yara van Weert (000012036) &
Danique van Wijk (000011518)

CARIBBEAN NETHERLANDS SCIENCE INSTITUTE

van hall larenstein
university of applied sciences

First indication of the abundance and distribution of protected seagrass associated species in the introduced *Halophila stipulacea* meadows on Sint Eustatius

Bachelor Thesis Coastal and Marine Management

Thesis

Module: LKZ428VNAO1
Hogeschool van Hall Larenstein
Oranjestad, August 2020

Commissioning party

Kimani Kitson-Walters
Kimani.Kitson-Walters@cnsi.nl
Data Monitoring Officer at Caribbean Netherlands Science Institute (CNSI)
L.E. Saddlerweg, PO Box 65, St. Eustatius Caribbean Netherlands

Supervisors

Jorien Rippen
Jorien.rippen@hvhl.nl
Lecturer marine biology and ecology
Van Hall Larenstein, University of Applied Science
Agora 1, PO Box 1528, 8901 BV Leeuwarden Netherlands

Tjibbe Stelwagen
Tjibbe.stelwagen@hvhl.nl
Lecturer marine ecological research
Van Hall Larenstein, University of Applied Science
Agora 1, PO Box 1528, 8901 BV Leeuwarden Netherlands

Authors

Yara van Weert
Yara.vanweert@hvhl.nl
Student number: 000012036
Student BSc Coastal and Marine Management
Van Hall Larenstein, University of Applied Science
Agora 1, PO Box 1528, 8901 BV Leeuwarden Netherlands

Danique van Wijk
Danique.vanwijk@hvhl.nl
Student number: 000011518
Student BSc Coastal and Marine Management
Van Hall Larenstein, University of Applied Science
Agora 1, PO Box 1528, 8901 BV Leeuwarden Netherlands

Photograph on front: slender seahorse using H. stipulacea as holdfast on St. Eustatius

Acknowledgements

We would like to acknowledge everyone involved in the execution and completion of this thesis research.

First, we would like to express our thanks to **Kimani Kitson-Walters**, *Data Monitoring Officer at Caribbean Netherlands Science Institute (CNSI)*, for the opportunity to execute this research under his supervision and with his expertise. We appreciate his guidance and support throughout the process of our research (and more).

We would also like to thank our supervisors **Jorien Rippen** en **Tjibbe Stelwagen** for supporting us from beginning to end, even if that meant working during holidays. We appreciate their guidance throughout this process.

We hope this research will contribute to sustainable management of natural resources, and will be our first accomplishment as coastal and marine managers.

Summary

The present study investigated the abundance and distribution of protected seagrass associated species within the introduced *Halophila stipulacea* meadows on St. Eustatius. These species are the queen conch, Caribbean spiny lobster, slender seahorse, green turtle and several species of grouper (E*pinephelus striatus, Mycteroperca interstitialis, Mycteroperca venenosa*), snapper (*Lutjanus cyanopterus, Lutjanus analis*) and the rainbow parrotfish. These species are commercially and ecologically valuable through fisheries, tourism and their contribution to biodiversity which maintains important ecosystem services. The introduction of *H. stipulacea* altered the seagrass meadows as it has significantly shorter shoots compared to native seagrasses, potentially affecting these protected seagrass associated species as they benefit from high complexity e.g. shelter. Current nature management however is based on outdated research which describes the situation prior to the introduction of *H. stipulacea* and no monitoring efforts are being made to update this. Furthermore, no baseline knowledge regarding the effect of *H. stipulacea* on the protected seagrass associated species or even the location of meadows was known prior to this study, resulting in a knowledge gap. Effective nature management is hindered by this knowledge gap and the aim of this research is to take the first step in providing an indication of the abundance and distribution of protected seagrass associated species to help close it.

Data was collected from May 5th to July 6th,2020, in Oranje Bay, St. Eustatius Marine Park. Visual surveys along belt transects using SCUBA were conducted at 31 sampling sites after verification of the meadow's location by manta tow. Sampling sites were selected using random stratified sampling. Most of the research species were absent in the meadow. Only the queen conch (n = 10) and the slender seahorse (n = 2) were observed. Most of the queen conch were found in the southern half of the meadow, whereas the slender seahorses were found more to the north. Both species were most abundant in homogeneous characterised habitat. The absence of the other protected seagrass associated species was unexpected. This may be the result of overfishing and habitat degradation as population numbers have been declining for years prior to the introduction of *H. stipulacea* and are currently quite low. Associated grouper and snapper species with similar habitat requirements as the protected seagrass associated grouper and snapper species were found in the meadow, indicating that it might be suitable (nursery) habitat. The green turtle is known to interact with *H. stipulacea*, and their absence from this study is likely coincidental. It is recommended that the seagrass associated species distribution and preferred habitats will be identified on St. Eustatius to create baseline knowledge regarding the species and its threats. Executing this additional research will enable responsible authorities to focus the island specific management plans on conservation and recovery of these protected seagrass associated species to ensure effective nature management.

Table of contents

1. Introduction

One of the most productive ecosystems found in the oceans are seagrass meadows (Grech et al., 2012). Seagrasses are marine flowering plants comprising a total of 50 species worldwide (Hemminga & Duarte, 2008). They have shoots above ground and root systems below, and can form extensive meadows (Kaiser et al., 2011).

Seagrass meadows provide a variety of ecological services that are valuable to surrounding coastal systems and humans. These services include food provision, providing (nursery) habitat, connecting coastal habitats, carbon sequestration, sediment stabilization and nutrient cycling (Green & Short, 2003). Seagrass meadows can be found in most shallow coastal waters, and cover 0.1-0.2% of the ocean's benthic surface (Duarte, 2002). The distribution of seagrasses is controlled by light availability and clarity of water as they rely on photosynthesis for energy (Kaiser et al., 2011). The majority of seagrasses grow on soft substrates such as sand and mud (Kaiser et al., 2011). Based on the assembly and distribution of seagrass species in ocean basins, two tropical and four temperate bioregions can be defined (figure 1) (Short, Carruthers, Dennison, & Waycott, 2007).

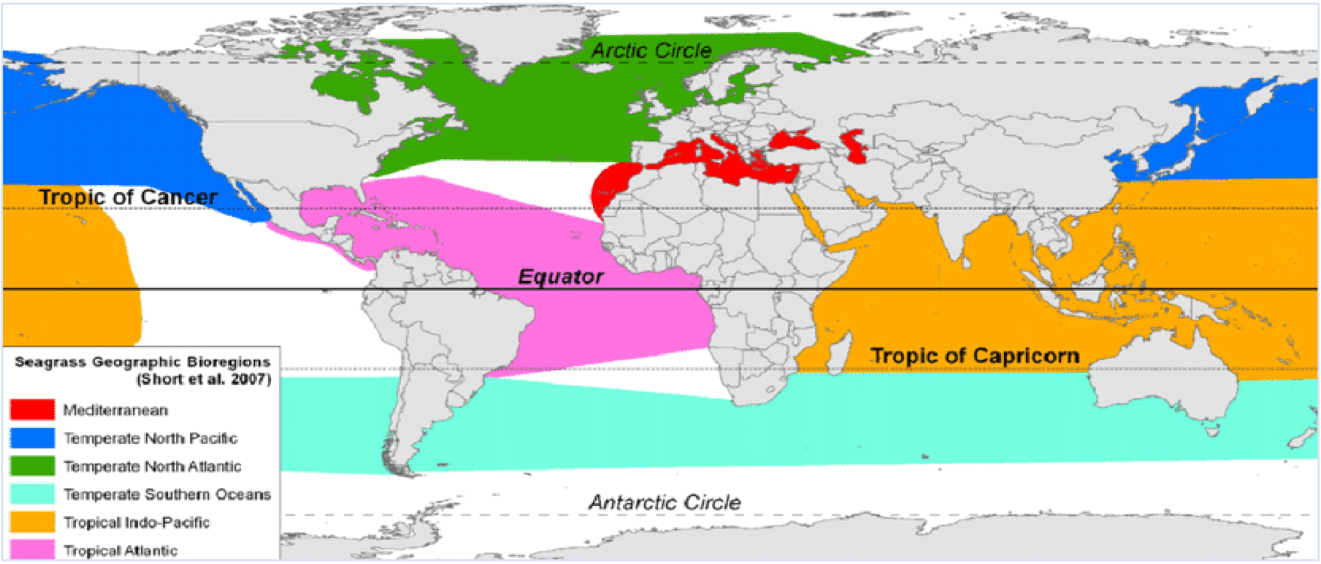


Figure 1: Seagrass Bioregions. Retrieved from "A Comparison of threats, vulnerabilities and management approaches in global seagrass bioregions" by A. Grech et al., 2012, *Environmental Research Letters*, *7*(2).

The Caribbean is part of the Tropical Atlantic bioregion where a total of 9 seagrass species originally occur (Debrot, Henkens, & Verweij, 2017). In the Dutch Caribbean, dominant native species are *Thalassia testudinum*, *Syringodium filiforme, Halophila decipiens* and *Halodule wrightii* (Viana, Siriwardane-de Zoysa, Willette, & Gillis, 2019). Amongst the Dutch Caribbean islands the most important seagrass meadows can be found on Bonaire and St. Eustatius (Jongman, Meesters, & Debrot, 2010; Debrot et al., 2017). For these islands the seagrass meadows provide important ecosystem services such as sediment stabilization, nursery habitat and carbon sequestration (Debrot et al., 2017). The island of St. Eustatius is located in the North-Eastern Caribbean and has a surface area of 21 square kilometres (figure 2) (De Freitas, Rojer, Nijhof, & Debrot, 2014).

Figure 2: Location of St. Eustatius. Retrieved and adapted from *Sint Eustatius* from Britannica, 2019, (https://www.britannica.com/place/Sint-Eustatius).

In 2007 it was reported that *T. testudinum* and *S. filiforme* dominated seagrass meadows all around St. Eustatius and were present at depths ranging from 10-35 meters (MacRae & Esteban, 2007). However, at this time native seagrass occurrence was already declining for decades due to severe habitat degradation and discontinuity, caused by hurricanes, anchoring of tankers and change in seawater dynamics (MacRae & Esteban, 2007; van Kuijk, de Graaf, Nagelkerke, Boman, & Debrot, 2015; Debrot et al., 2014).

In 2012, the *Halophila stipulacea*, a seagrass species native to the Red Sea, was first recorded in St. Eustatius changing the seagrass species composition (Willette et al., 2014). It's migration to the area can be traced to the opening of the Suez Canal between the Red Sea and the Mediterranean, where its established itself in late 1800 (Forsskål & Niebuhr, 1775; Willette et al., 2014). It has since migrated to the western Atlantic (Tropical Atlantic bioregion), likely facilitated by shipping between the Mediterranean and Grenada where it was first seen in 2002 (Ruiz & Ballantine, 2004; Willette et al., 2014). From here, it has spread further into the Caribbean (Willette et al., 2014).

Since the first observation of *H. stipulacea* in St. Eustatius in 2012, it has been colonizing areas that were previously dominated by native seagrasses, as well as areas covered with bare sand (Willette et al., 2014; Davies & Piontek, 2016). In 2014 dense seagrass meadows were found to be dominated by *H. stipulacea* and sparse seagrass beds by *H. decipiens* (Debrot et al., 2014). The *S. filiforme* was only present at densities < 2% and *T. testudinum* was absent (Debrot et al., 2014). *H. stipulacea* has been very successful due to its high dispersal potential and fast growth (Becking, Bussel, Engel, Christianen, & Debrot, 2014a).

The native seagrass *T. testudinum* is characterised by long shoots providing food and shelter for fish and invertebrates (Viana et al., 2019; Becking et al., 2014a). The newly introduced *H. stipulacea* on the other hand has significantly shorter shoots, influencing the meadow structure resulting in lower complexity[1] (figure 3) (Viana et al., 2019; Becking et al., 2014a). As seagrass associated species benefit from high complexity, a change in overall habitat structure by *H. stipulacea* might influence the habitat quality for associated species. Loss of high complexity may result in loss of nursery habitat due to lack of shelter and influence interconnections between different habitats in general (Viana et al., 2019; Debrot et al., 2017). A change in seagrass species composition will also change the diet of seagrass consuming animals such as green turtles (Becking et al., 2014a).

Figure 3: A T. testudinum shoot surrounded by H. stipulacea shoots. Retrieved from DW. (2020). St. John *H. stipulacea vs T. testudinum* [Photograph]. *Retrieved from https://www.euromarinenetwork.eu/system/files/2017/2017GA_flash_Gideon_Winters_Seagrass.pdf.*

Some species that are associated with seagrass habitats which might be negatively affected by this change in habitat quality are protected[2] on the island by international treaties because of their local and global importance (Ministerie van Economische zaken, 2013; K. Kitson-Walters, personal communication, 29 November 2019). The species, and the biodiversity to which they contribute, are especially important for small islands such as St. Eustatius as they depend on natural resources for economic and cultural value and the maintenance of ecosystem services (Convention on Biological Diversity, 2009; Ministerie van Economische zaken, 2013).

[1] Complexity comprises shoot length and number of shoots (Becking et al., 2014).
[2] Species that are included as protected in policy and management documentation applicable to St. Eustatius. These species have been observed in the last five years (Hoeksema, 2016; Christianen, 2016).

On the island of St. Eustatius the protected seagrass associated species are the queen conch (*Lobatus gigas*), Caribbean spiny lobster (*Panulirus argus)*, slender seahorse (*Hippocampus reidi*), green turtle (*Chelonia mydas*) and several species of grouper (E*pinephelus striatus, Mycteroperca interstitialis, Mycteroperca venenosa*), snapper (*Lutjanus cyanopterus, Lutjanus analis*) and the rainbow parrotfish who use the seagrass meadows for food and (nursery) habitat (Appendix I) (Debrot et al., 2017; Viana et al., 2019; Becking et al., 2014a; Headley & Seijo, 2014; Meijer zu Schlochtern, 2014; Stoner, 1997). The international treaties aim to safeguard the survival of these species by regulating trade, protecting and preserving habitat and implementing effective governance by international cooperation (Ministerie van Economische Zaken, 2013; Jongman et al., 2010; International Union for Conservation of Nature, 2020a).

The above mentioned fish species along with the queen conch and spiny lobster are commercially valuable to the islands small scale fisheries (Kitson-Walters, 2018; de Graaf, Piontek, Miller, Brunel, & Nagelkerke, 2015). Besides being economically important, the queen conch also has a traditional value because of the long fishing history of the island (van Rijn, 2013). Although the fisheries sector is relatively small, the sector has a significant socio-economic impact on the local community (Dilrosun, 2004). Money generated by the sector is reinvested through trade of catch, and indirectly through, for example, the need for fuel and boat/gear maintenance (Dilrosun, 2004). The beaches of St. Eustatius are one of the two local green turtle nesting beaches in the BES islands[3], making the neighbouring seagrass meadows important as feeding grounds (Jongman et al., 2010; Becking et al., 2014a). The tourism sector on the island is also supported by high biodiversity of species, as 60 percent of all tourists come to the island to dive (Jongman et al., 2010; Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020). Changes in seagrass habitat around the island may change the abundance and distribution of these species, and in return influence the economy and culture of the island.

The Caribbean Netherlands, as part of the Kingdom of the Netherlands, is concerned with the protection of these seagrass associated species found within their Exclusive Economic Zone (EEZ) (Ministerie van Economische Zaken, 2013). The national governmental bodies that are responsible for the execution of the treaties are mainly the Ministry of Economic Affairs and the Ministry Agriculture, Nature and Food Quality (International Union for Conservation of Nature, 2020b; Ministerie van Economische Zaken, 2013). The treaties are incorporated in national legislation by the Nature Policy Plan for the Dutch Caribbean (2013-2017 & 2020-2030). The aim of this plan is to provide a generic framework and objectives for the islands to write sound management plans regarding the sustainable use of nature and protection of species (Ministerie van Economische Zaken, 2013; Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020). The island government is in charge of writing an island specific management plan and is responsible for the protection and management of species in their territorial waters together with St. Eustatius National Parks (STENAPA) and the Dutch Caribbean Coast Guard (de Graaf, Meijer zu Schlochteren, & Boman, 2014; Dutch Caribbean Nature Alliance, 2014a; Ministerie van Economische Zaken, 2013). However, even though the responsible Board of Directors[4] are legally obligated to write island specific management plans, no current or former plans can be found (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2019). These plans are needed to make policy locally applicable and relevant. STENAPA is responsible for the implementation and enforcement of the management plans on the island and is part of the Dutch Caribbean Nature Alliance (DCNA) (Ministerie van Economische Zaken, 2013; Dutch Caribbean Nature Alliance, 2014b). DCNA is an umbrella organization that supports nature conservation and management organisations in the Dutch Caribbean (Dutch Caribbean Nature Alliance, 2014b).

It has been suggested that *H. stipulacea* has negatively altered the habitat complexity of the seagrass meadows around St. Eustatius, potentially influencing the protected seagrass associated species and therefore impacting the island (Viana et al., 2019; Becking et al., 2014a). However, current management of these species is based on outdated research which describes the situation before the introduction of *H. stipulacea* (MacRae & Esteban, 2007). There is also no active research and monitoring program in place or baseline knowledge available regarding the impact of *H. stipulacea* on (protected) seagrass associated species, resulting in a knowledge gap. This was addressed in a report from Jongman et al. (2010), which stated that basic descriptions of the seagrass meadows of the islands were missing and seagrass meadows must be monitored. The Nature Policy Plan states more recently that active research and monitoring is needed for effective nature management (Ministerie van Economische Zaken, 2013; Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020).

[3] Special municipalities of the Kingdom of the Netherlands: Bonaire, St. Eustatius and Saba.

[4] Board of directors from the special municipalities of the islands Bonaire, St. Eustatius and Saba.

It also states that responsible authorities should have a clear understanding of the threats related to the protected seagrass associated species to establish the focus of the island specific management plans to ensure sustainable exploitation and protection (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020).
The knowledge gap regarding the new situation needs to be closed in order for the responsible authorities to be informed about the status and threats of protected seagrass associated species to be able to re-evaluate current management and ensure effective nature management in the future.

1.1 Problem statement

Effective nature management is hindered by the knowledge gap that exists regarding the impact of *H. stipulacea* on protected seagrass associated species.

1.2 Research aim

The aim of this research is to take the first step in providing an indication of the distribution and abundance of protected seagrass associated species to help close the knowledge gap, which can be used as input for the island specific management plans.

1.3 Research question

What is the distribution and abundance of protected seagrass associated species in the introduced *Halophila stipulacea* meadows on St. Eustatius?

1.4 Reading guide

In chapter 2 *Methods*, the scope of the research is described as well as the methods used to execute this research. In chapter 3 *Results*, the results of the collected data are presented and in chapter 4 *Discussion* these findings are interpreted and explained using relevant literature. In the following chapter, chapter 5 *Conclusion*, the research question is answered. Based on this, recommendations are made in chapter 6 *Recommendations*, about further research and management of rare species. Added as appendix is information with regards to protected seagrass associated species and the applicable international treaties, as well as supporting materials for chapter 2 and 3.

2. Methods

The data was collected between the 5th of May 2020 and the 6th of July 2020 in St. Eustatius Marine Park (figure 4). The location of the seagrass meadows was unknown as the most recent benthic habitat map was published in 2014 (Debrot et al., 2014). Based on information from the commissioning party three anecdotal meadows dominated by *H. stipulacea* were known before the start of this research (K. Kitson-Walters, personal communication, 12 February 2020). One anecdotal seagrass meadows was located in Oranje bay (meadow 2) and the others were located within the marine reserves known as the North- and South Reserve (meadow 1 and 3) (figure 4) (St. Eustatius National Parks, 2020). The location of all three meadows was verified, but this study focussed on the abundance and distribution of protected seagrass associated species in meadow 2.

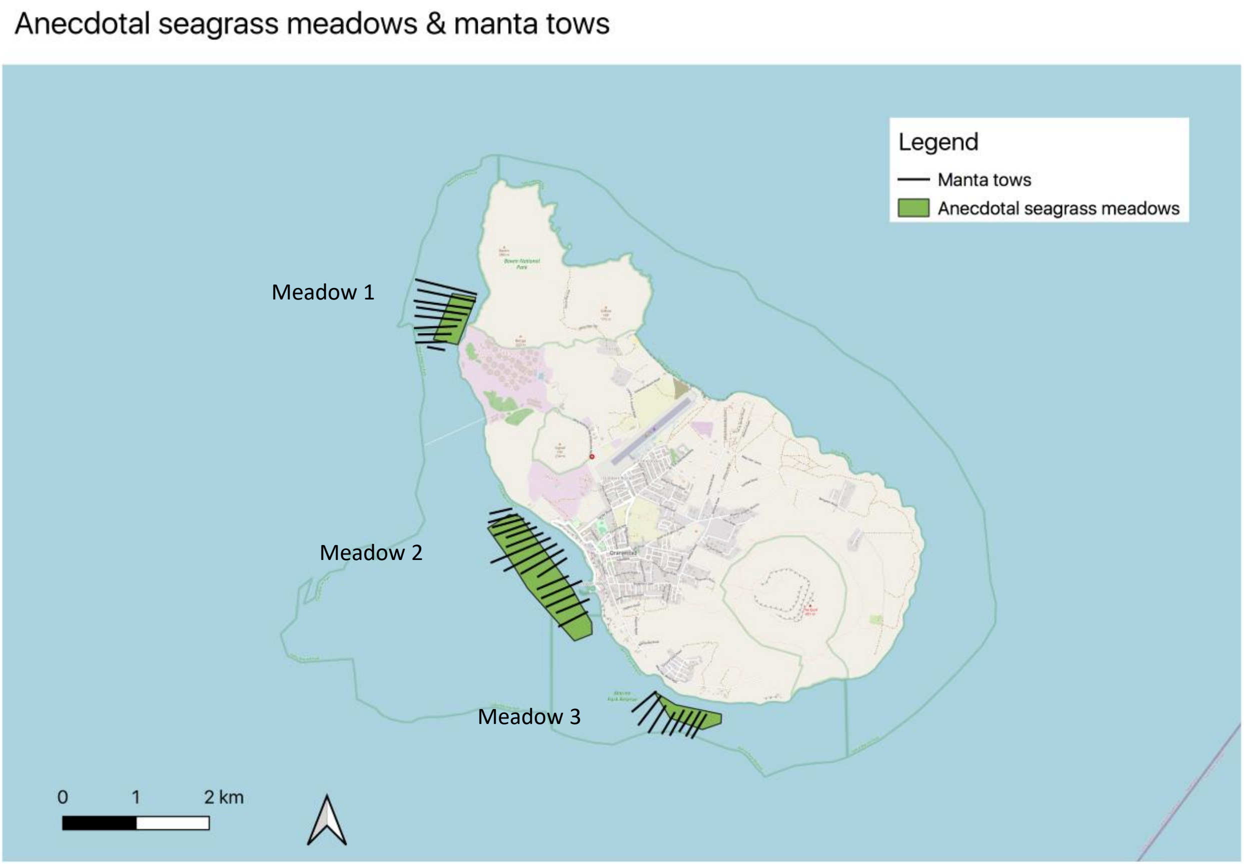


Figure 4: Overview of completed manta tows over anecdotal seagrass meadows. Adapted from QGIS 3.8.

In the next paragraphs a detailed process description is given regarding the (sub)steps that were executed to complete this research:

Step 1. Verification of the location of the seagrass meadows
Step 2. Selecting sampling sites
Step 3. Data collection
Step 4. Data summary

2.1 Verification of the location of the seagrass meadows

As the precise location of the seagrass meadows was unknown, the first step in this research was to verify this. The anecdotal locations of the seagrass meadows were verified using the manta tow method following the Global Coral Reef Monitoring Network protocol (GCRMN) (Hill & Wilkinson, 2004). The goal of this step was to obtain a general description of the location and coverage of the seagrass meadows. Included in the description is seagrass cover (shoot density), which corresponds to the habitat complexity which influences the meadows capacity to provide shelter and protection (Viana et al., 2019; Becking et al., 2014a; Geevarghese, Akhil, Magesh, Krishnan, Purvaja, & Ramesh, 2017). Secondary habitats[5] were also included, as they facilitate habitat interconnections and influence the distribution and abundance of species as they are associated with multiple habitats (Debrot et al., 2017; Debrot et al., 2014).

The manta tow was conducted by towing a snorkeler behind the CNSI boat with use of a manta board at a constant speed of 6,5 km/h, across the anecdotal meadows in parallel lines with an average of 100 meter in between (see figure 4). To ensure safety of both snorkeler and gear a predetermined set up was used which can be found in the appendix II. The manta tow required three persons to execute and each individual had specific tasks:

- *The snorkeler* recorded seagrass cover and secondary habitats, as presented in table 1. The snorkeler communicated to the boat researcher using predetermined hand signals to indicate speed (speed up/slow down), the end of the tow and request additional waypoints to indicate start/end[6] and/or zonation within the meadow. After each tow the snorkeler recorded the observations on the data sheet in coherence with the recorded waypoints.
- *The boat researcher* was responsible for getting the snorkeler and manta board safely in and out of the water, and communicate the waypoints to the boat captain during the tow when indicated by the snorkeler. The boat researcher also recorded the waypoints on the data sheet for the snorkeler to use after each tow.
- *The boat captain* was in charge of driving the boat within the anecdotal meadows (following predetermined speed and distance) and also saved the waypoints (GPS points, Garmin echomap SV) requested by the boat researcher.

To ensure consistency in the collection of data, the roles were assigned to one person per meadow. The data sheets can be found in appendix III. After completing the manta tows a general description of the meadow was obtained.

Table 1: Variables for the general description of the seagrass meadow as recorded by snorkeler

Snorkeler recordings				
Seagrass cover*: *Geevarghese, et al., 2017	**Category 3:** *Abundant 70-100%*	**Category 2:** *Medium 40-70%*	**Category 1:** *Sparse 10-40%*	**Category 0:** *No seagrass cover*
Secondary habitat:	Examples: - Rocks	Examples: - Sand	Examples: - Habitat patch (e.g. reef)	

[5] A secondary habitat is defined as a habitat type, other than seagrass, enclosed by the meadow.
[6] The end of the meadow was identified by the following criteria: less than 10% coverage or lack of sight.

2.2 Selecting sampling sites

Step 2a. Identifying and grouping habitat types within the meadows

The habitat varieties within the meadow were identified and grouped based on the observations made during the manta tow (step 1). Based on these findings it was concluded that there were two main seagrass ecotopes[7] within the meadow: the seagrass had either a homogeneous or patchy character. By making an overview of the different habitat varieties (using cover and secondary habitat) within the two ecotopes a habitat list was created. A specific combination of the variables within an ecotope is further referred to as a habitat type.

Step 2b. Choosing habitat types

Given the available time frame, 31 transects could be conducted. It was decided to sample multiple habitat types within meadow 2, as the amount of transects would give detailed information on the abundance of the seagrass associated species along the length and width of the meadow. This could all be done while taking into account the minimum of three transects per area of a selected habitat type as required according to Coles and Short (2001). Habitat types were prioritized based on seagrass cover, abundance and secondary habitat. High seagrass cover was favoured (seagrass cover >70%) because it contributes to habitat complexity which influences the meadows capacity to provide shelter and protection (Viana et al., 2019; Becking et al., 2014a). A homogeneous character was favoured over a patchy character as large interconnected areas with higher coverage contributes to interconnections between different habitats in general (Debrot et al., 2014). The most abundant habitat types in meadow 2 were sampled to say something about the whole meadow in general. These habitat types were also present in meadow 1 and/or 3.When deciding between two different habitat types, secondary habitats were taken into account as they may influence the distribution and abundance of certain species which use multiple habitats throughout their life cycle. The order was as follows: reefs over sand (beach & subtidal), and sand over everything else (Debrot et al., 2017). Consequently 2 out of 6 habitat types in meadow 2 were not sampled, namely patchy with cover 1/2 and cover of 2.

The following habitats were identified and selected for sampling (in no particular order):

- Homogeneous (figure 5, A)
- Homogeneous with sand (figure 5, B)
- Reef patch (figure 5, C)
- Patchy (figure 5, D)

These habitat types will be further referred to as 'selected habitat types' and a description can be found in figure 5.

[7] Spatial unit within an ecosystem which is typified by a characteristic homogeneity of vegetation growth as landscape element.

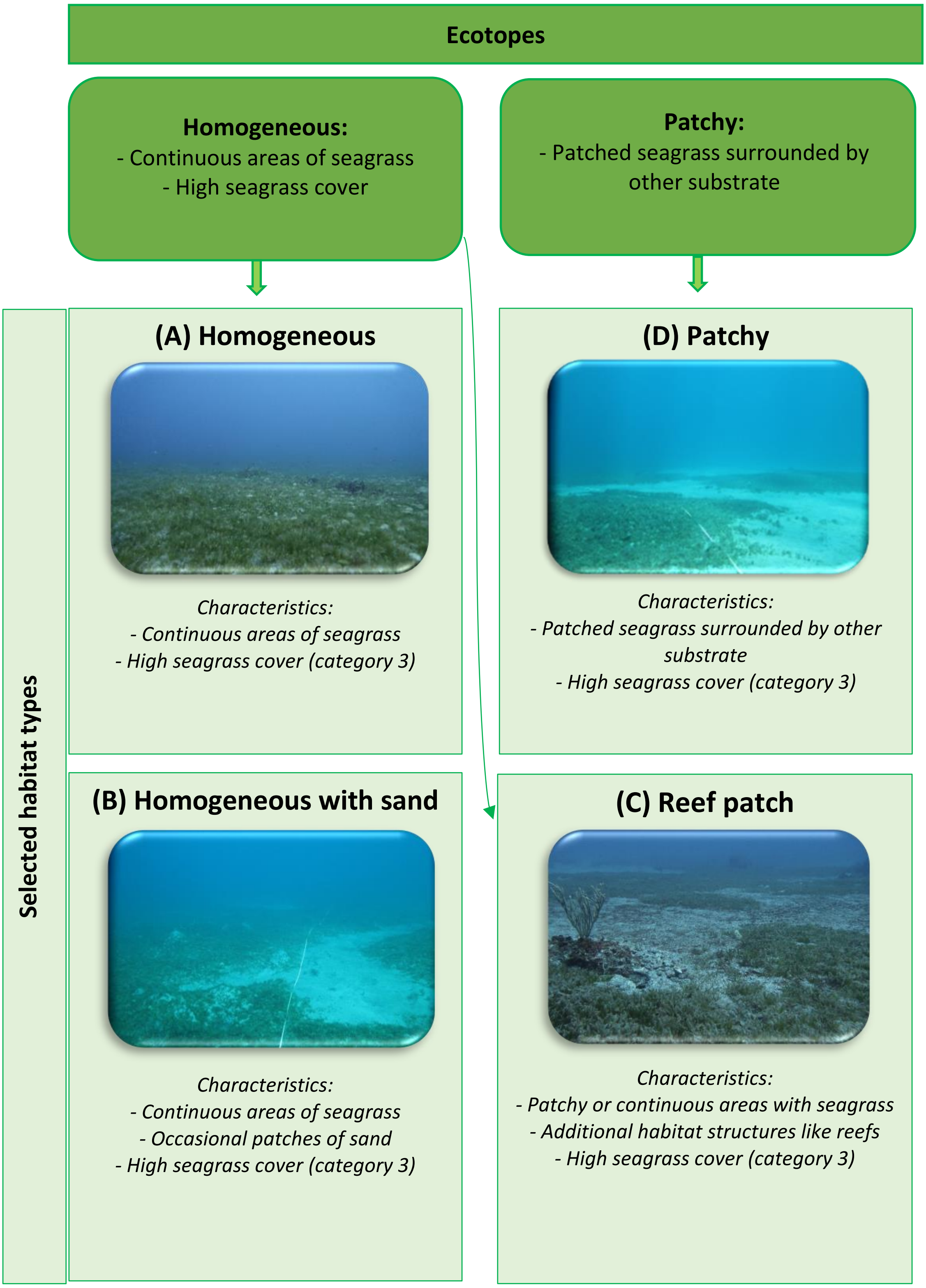


Figure 5: Overview of the selected habitat types and their main characteristics.

Step 2c. Stratified sampling
Stratified sampling was applied to select the sampling sites by assigning the amount of transects per selected habitat type in the same ratio as their areal claim (percentage) within the meadow.

The selected habitat types were mapped in Google Earth using the coordinates/waypoints collected in step 1. The size of each habitat type was calculated by creating polygons (per habitat type) to calculate its abundance within the meadow (% of total surface area). This percentage was used to determine the amount of transects for each habitat type by dividing the doable amount of transects (31) by this percentage. The habitat type was verified during the data collection (step 3) by looking at previously described habitat type characteristics within the transect area (30m x 10m) (figure 5). This resulted in the following:

- Homogeneous number of transects: 15
- Homogeneous with sand number of transects: 4
- Reef patch number of transects: 7
- Patchy number of transects: 5

Step 2d. Random selection of sampling sites
In Google Earth a grid was made by dividing the longest side of the surface area (of all the areas of same selected habitat type combined) by the assigned amount of transects. The grid width was set on 30m to allow for sampling the meadow from the shallow beginning to the deeper (known) end of the meadow. The grid was placed over the polygons made in step 2c. The number of available grid cells was determined prior to the random selection of sampling sites. In order to be considered an available grid cell for a selected habitat type, the top line of the grid cell had to be covered for 50% or more with the selected habitat type.
Via the website Random.org (Random Integer Generator) sampling sites were selected by filling in the following information indicated below in **bold**:

- Generate: **1** random integers
- Each integer should have a value between 1 and **maximum available grid cells for that habitat type in that row**
- In **1** column(s)

In Google Earth the right upper corner of the grid cell was marked, giving the GPS location of the sampling site which were used to find the sites out on the water. The list with sampling sites can be found in appendix IV and the location of the sampling sites is visually displayed in figure 6.

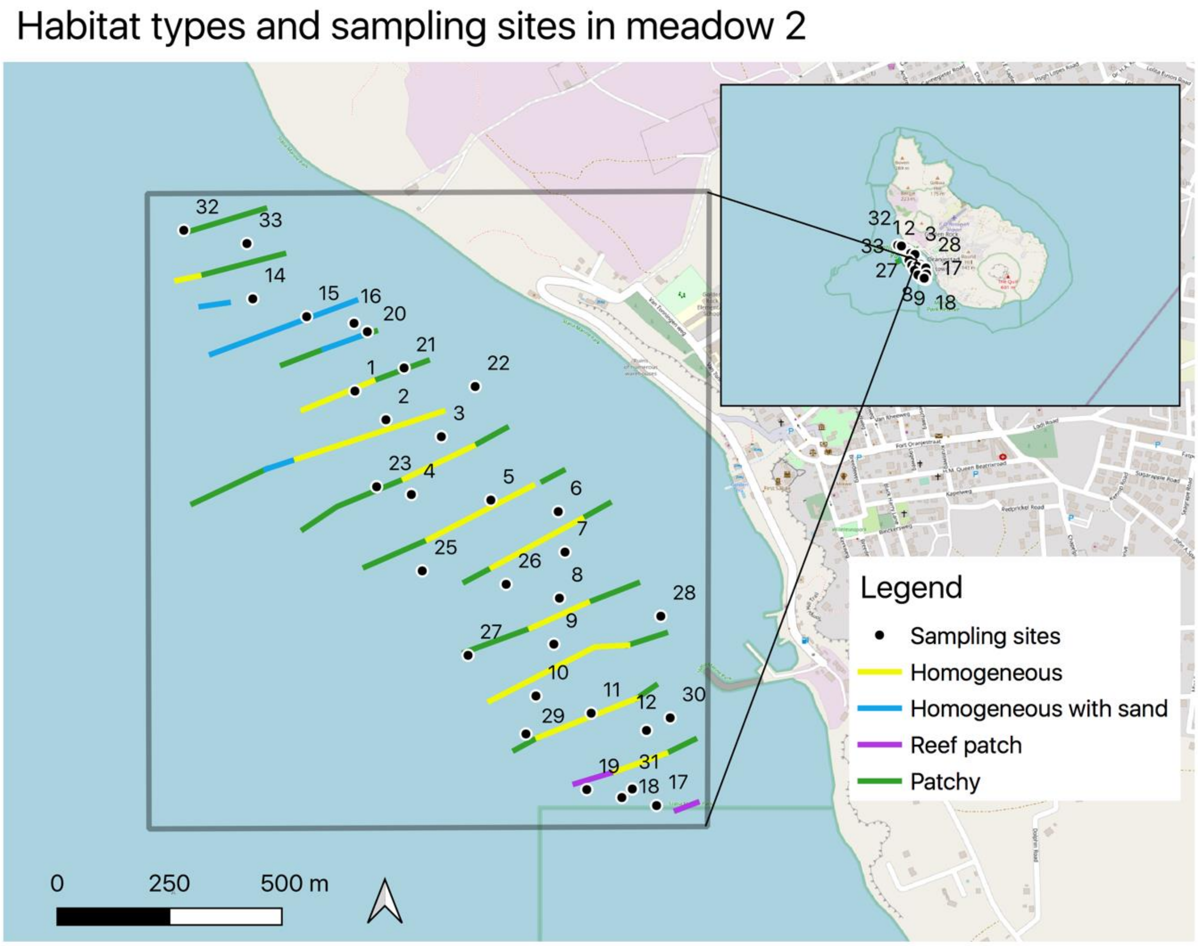


Figure 6: Map of sampling sites and location of selected habitat types. Adapted from QGIS 3.8.

2.3 Data collection

During the third step the transect surveys were executed at the selected sampling sites where the abundance of the protected seagrass associated species was recorded. As the protected species consist of several animal groups, different data collection methods were used for each group. The groups were as follows:

- **Fish:** nassau grouper (*Epinephelus striatus*), yellowmouth grouper (*Mycteroperca interstitialis*), yellowfin grouper (*Mycteroperca venenosa*), mutton snapper (*Lutjanus analis*), cubera snapper (*Lutjanus cyanopterus),* rainbow parrotfish (*Scarus guacamaia*) and the slender seahorse (*Hippocampus reidi*).
- **Invertebrates**: queen conch (*Lobatus gigas*) and Caribbean spiny lobster (*Panulirus argus*)
- **Turtle:** green turtle (*Chelonia mydas*)

The abundance of a species was determined along each transect where visual census surveys using SCUBA were executed. Divers descended along the anchor line of the boat or underneath the boat. Abundance data was collected along a transect line of 30m in length, which were laid out parallel to the coast as depth fluctuated over 1 meter when carried out perpendicular to the same. The fish and turtle survey was done first to account for species mobility. The invertebrate was done next, followed by the seahorse survey. Lastly, the quadrant pictures were taken and visibility was measured before reeling in the transect line. Data collected during the visual census surveys was recorded on data sheets, which can be found in appendix V. As baseline information was missing, all encountered macro-organisms were counted and identified during data collection. Species which could not be identified underwater were photographed and identified after each dive.

Fish
To measure the abundance of fish, observations of these species along a belt transect (30m length x 10m width x 5m height) were counted. To account for the mobility of fish, divers swam at a slow constant speed and the first diver who counted the fish, swam ahead of the second diver who reeled out the transect line (Hill & Wilkinson, 2004). The first diver was always the same person to ensure consistency, and in this case the task was given to the researcher with the most experience identifying tropical fish species.

The abundance of the slender seahorse was measured by counting individuals along the 30 meter transect with a width of 2 meters. Each diver surveyed one side of the transect (1m).

Invertebrates
The abundance of the queen conch and the spiny lobster was measured along the same 30 meter transect with a width of 10 meter. Each diver surveyed one side of the transect (5m). Conchs were photographed on a slate for size reference and species verification. The shell length was measured using ImageJ, to determine the life phase (adult/juvenile) of the queen conchs (adult >18 cm) (de Graaf et al., 2014). Only live conchs were recorded.

Green turtle
The abundance of green turtles was measured by counting individuals along the transect. The activity of the turtle (resting, swimming, foraging) was also noted on the data sheet to indicate the degree of interaction with the seagrass meadow (Smith, 2008).

Seagrass cover
To verify the seagrass cover that was estimated during the manta tows, a 1 x 1 meter quadrant was placed and photographed along the transect at the 1 meter, 15 meter and 30 meter mark. Pictures were visually inspected to verify the cover following table 1. The median of the three quadrants per transect was used to indicate the overall cover.

Associated species
As baseline knowledge of the seagrass meadows was missing, all observed species were recorded. This research focussed on the protected species, but there are species associated to the research species which could help explain the ecological and biological factors influencing research species abundance and distribution (Campbell et al., 2002). This can be species associated to the target species as competitor (Campbell et al., 2002). Competitor species often belong to the same family as they display similar traits or life history (habitat requirement) (Blondel, 2003). Special attention was given to those species to help explain abundance and distribution of the (rare) research species (further referred to as associated species).

Control variables
The following control variables were measured to control for environmental conditions that may influence the distribution and abundance of the research species and the execution of the research.
The **visibility** (ft) was estimated using a secci disc which was held by one diver at the start of the transect. The second diver swam along the transect until the disc was no longer visible and noted distance of this point on the transect line as the visibility. Just like the fish identification, the task to note visibility was also given to one diver to ensure consistency. Visibility was included as control variable because it can influence the sight of researchers during the survey and the distribution and abundance of the fish species who prefer clear water (Sadovy & Eklund, 1999; Lindeman et al., 2016a).

Salinity (PSS-78) measurements were taken by the boat captain during the dive using CastAway CTD.
Salinity was included as a control variable as salinity is a main driver influencing the distribution of all marine species (Smyth & Elliott, 2016).

Temperature (°C) was included as a control variable as it is also an important driver influencing the distribution of marine species (Stuart-Smith, Edgar, & Bates, 2017).

Depth (m) was also measured to account for depth related distribution and abundance of the research species.
The materials needed for the execution of this research can be found in appendix VI.

2.4 Data summary

Recorded numbers were too low for any statistical analysis, therefore the data was summarised. To summarize the abundance data, bubble maps were made using QGIS 3.8. The bubble maps showed abundance data for each individual species per sampling site. The size of the bubble is proportional to the number of observed individuals. A stacked bar graph was made using Excel to visualise the distribution of the species among the selected habitat types.

3. Results

Over a period of 6 weeks, 31 sites were sampled and a total of 10 queen conch individuals and 2 slender seahorses were observed in the sampled *H. stipulacea* meadow. No other protected seagrass associated species were found (table 2). However, associated grouper and snapper species were recorded, namely the coney (*Cephalopholis fulva*, n=22), red hind (*Epinephelus guttatus*, n= 10) and the yellowtail snapper (*Ocyurus chrysurus*, n=37). A total of 1993 individuals belonging to 73 different species were recorded during this research (appendix VII).

Recordings of salinity (35.99 ± 0.24) and temperature (29.16 ± 0.69) were relatively constant at all sampling sites. The seagrass cover was in general a category 3 (abundant). The depth (14.33 ± 3.00) and visibility (88.97 ± 11.20) showed more variation across sampling sites. A summary of the variables can be found in appendix VIII.

Table 2: Count data protected seagrass associated species in meadow 2

Species		**Count data meadow 2**	
Common name	**Scientific name**	**Total # recorded**	**Min – max # per transect**
Queen conch	*Lobatus gigas*	10	1 - 4
Slender seahorse	*Hippocampus reidi*	2	1
Nassau grouper	*Epinephelus striatus*	0	0
Yellowmouth grouper	*Mycteroperca interstitialis*	0	0
Yellowfin grouper	*Mycteroperca venenosa*	0	0
Cubera snapper	*Lutjanus cyanopteru*	0	0
Mutton snapper	*Lutjanus analis*	0	0
Caribbean spiny lobster	*Panulirus argus*	0	0
Rainbow parrotfish	*Scarus guacamaia*	0	0
Green turtle	*Chelonia mydas*	0	0

3.1 Queen conch and slender seahorse

The queen conch individuals were found at six sampling sites, and the slender seahorse was found at two. Most of the queen conch were found in the southern part of the meadow (figure 7), whereas the slender seahorses were found more to the North. The queen conchs observed during the surveys were all epifaunal juveniles based on their shell length (mean: 10.84 cm) (de Graaf et al., 2014). The two observed seahorses were found using *H. stipulacea* shoots as holdfast (figure 8).

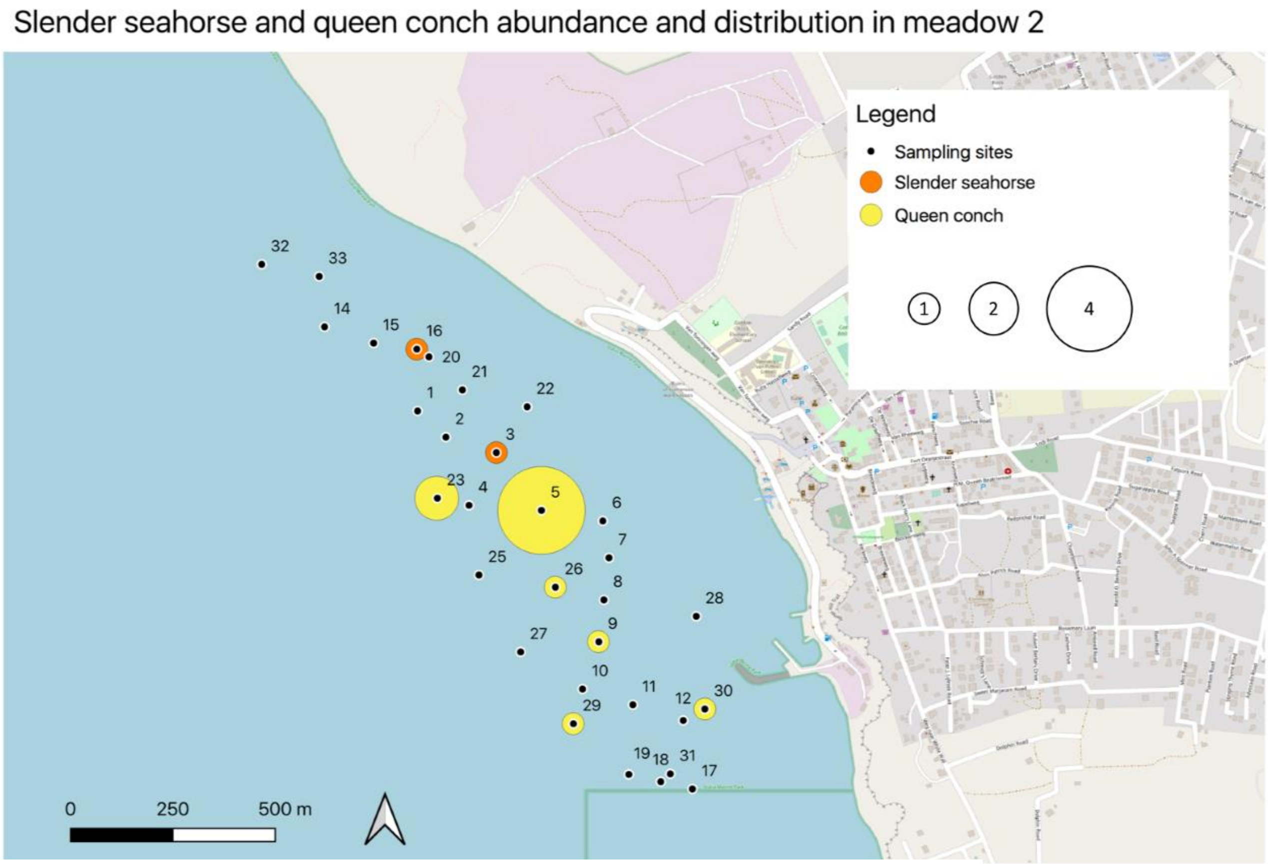


Figure 7: Abundance and distribution of queen conch and slender seahorse in meadow 2.

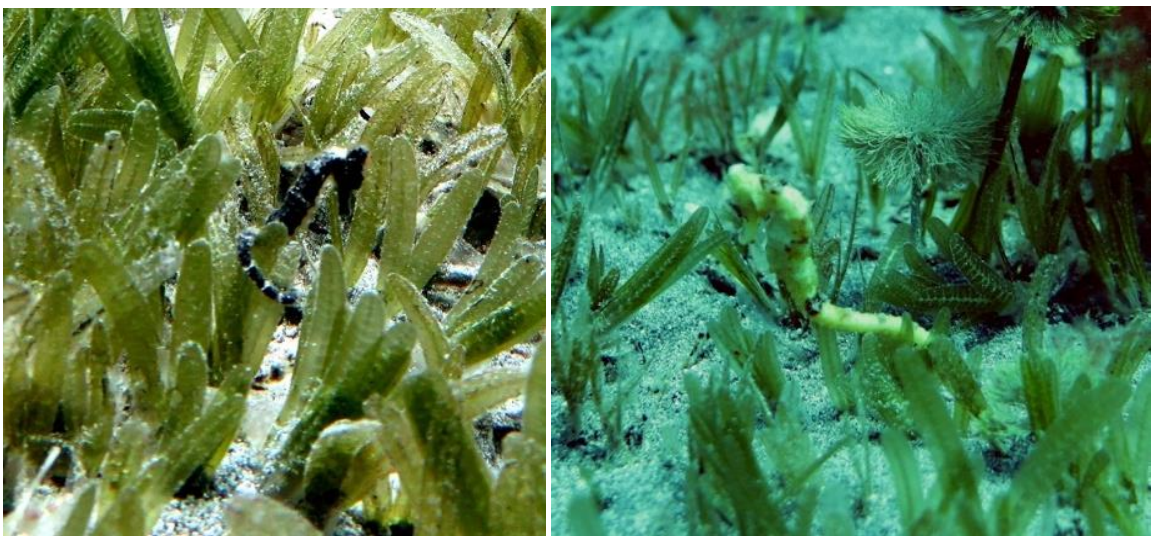


Figure 8: Photographs of counted slender seahorses, on the left seahorse on sampling site 3 and on the right in sampling site 16.

3.2 Groupers and snappers

Two frequently observed grouper species were the coney (n=22) and red hind (n=10). The highest abundance of coney and red hind was found in the most southern sampling sites (figure 9).

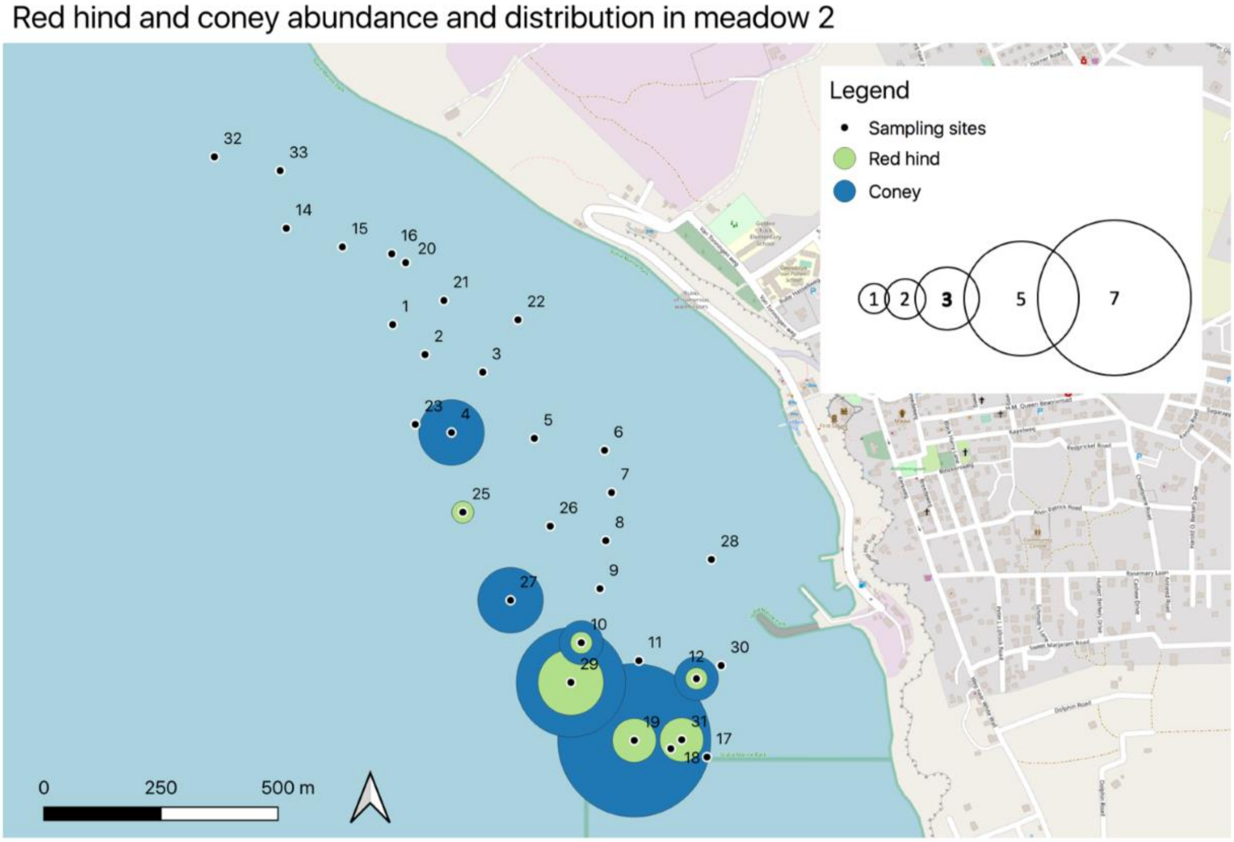


Figure 9: Abundance and distribution of red hind and coney in meadow 2.

A frequently observed snapper species was the yellowtail snapper (n=37). The yellowtail snapper was mostly found in the southern part of the meadow (figure 10).

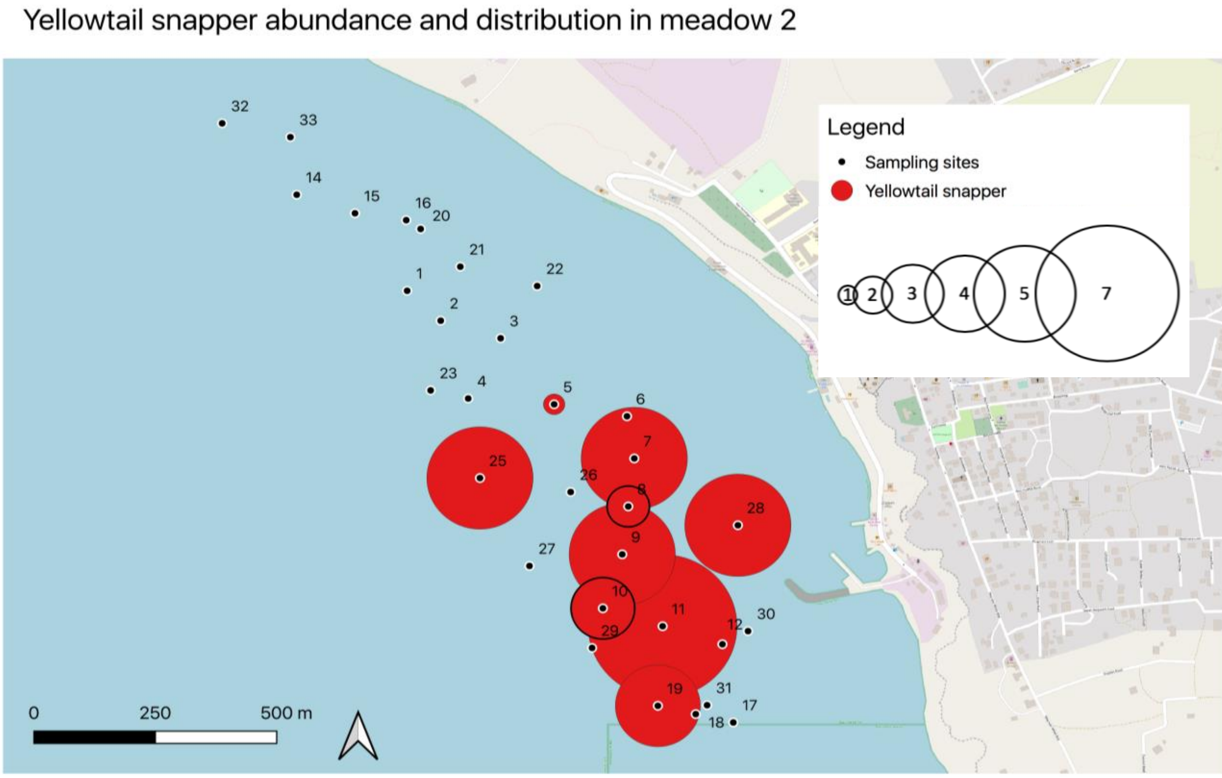


Figure 10: Abundance and distribution of the yellowtail snapper in meadow 2.

3.3 Species abundance in selected habitat types

In figure 11 an overview is given of the species abundance and distribution between the selected habitat types. These findings suggest that 'Reef patch' had the highest (protected) seagrass associated species abundance, while 'Homogeneous' habitat had the highest diversity. The queen conch and yellowtail snapper were most abundant in the 'Homogeneous' habitat type. The slender seahorses were found in homogeneous characterised habitat types. The highest abundance of coney and red hind was recorded in 'Reef patch' habitat. The yellowtail snapper was observed in three of the selected habitat types. Photographs of the species can be found in appendix IX.

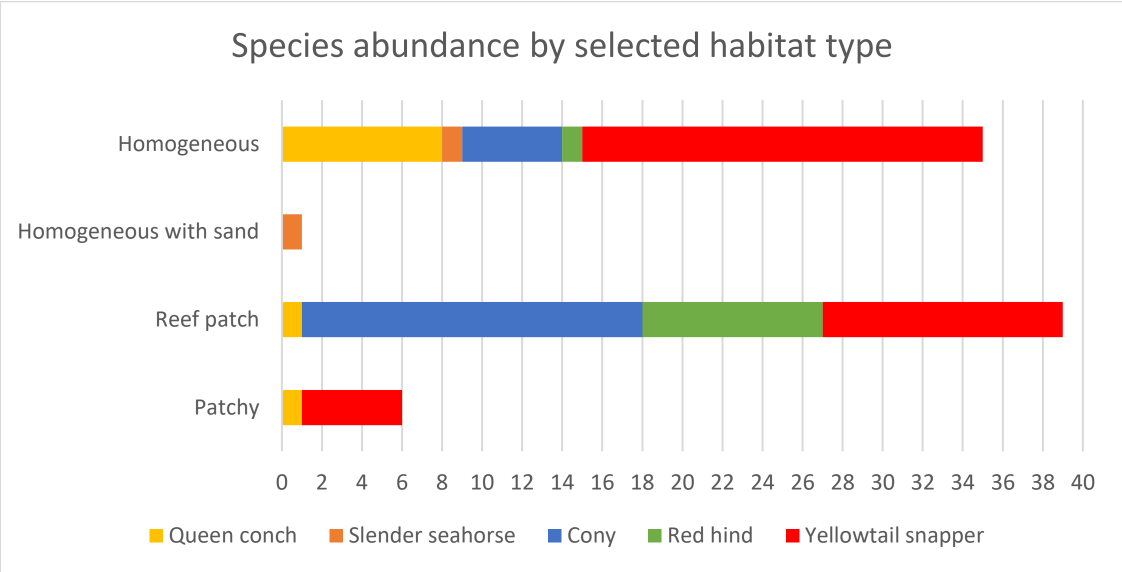


Figure 11: Overview of (protected) seagrass associated species abundance by selected habitat types.

4. Discussion

It became evident that most protected seagrass associated species were absent in the studied *H. stipulacea* meadow. Only the queen conch and slender seahorse were observed. As the species being studied use seagrass as food and (nursery) habitat, their presence was expected and the findings therefore unexpected (Debrot et al., 2017; Viana et al., 2019; Becking et al., 2014a; Headley & Seijo, 2014; Meijer zu Schlochtern, 2014; Stoner, 1997). It is unclear if the species were absent because of low population size (small juvenile recruitment) or due to unsuitability of *H. stipulacea* as habitat. However associated grouper and snapper species were observed indicating that the absence of the protected seagrass associated grouper and snapper species is likely the result of factors other than habitat suitability. Such factors include habitat degradation and overfishing lowering the number of reproductive adults (van Kuijk et al., 2015). Besides the sampled meadow, more (anecdotal) meadows are present around the island raising the question if the protected seagrass associated species reside in these unsampled meadows. The (remaining) knowledge gap hinders management as (potential) threats like a change in seagrass composition cannot be determined and/or addressed (Debrot, de Graaf, Henkens, Meesters, & Slijkerman, 2011; Jongman et al., 2010; Efroymson, Jager, Dale, & Westervelt, 2009). Currently there is no management plan in place for the protected seagrass associated species, hindering sustainable use and protection influencing local economy and ecology (Ministerie van Economische Zaken, 2013; Convention on Biological Diversity, 2009). In order to set species management goals it is required to have information regarding the population distribution and status, habitat preference and threats (Efroymson et al., 2009). The present study made the first effort to close the knowledge gap that exists in regards to the introduced *H. stipulacea* and its suitability as habitat for protected seagrass associated species to help management and focus the island specific management plans.

4.1 Queen conch and slender seahorse

Interesting is that only juvenile queen conch (< 18 cm) were found during this research. Juveniles are known to feed on organic material in the sediment which accumulates within the meadow (Boman et al., 2019; Kennedy et al., 2010). Besides diet, other factors may also determine the presence of queen conch juveniles. Stoner (2003) states that besides habitat features such as seagrass cover, depth and substrate, ecological processes (such as tidal circulation) also influence the suitability of a specific location as nursery ground for the queen conch. The presence of juvenile conch might indicate a nursery area within the meadow, which were not yet identified in 2014 (de Graaf et al., 2014). In this study most conchs were found in the 'Homogeneous' habitat type, indicating that this habitat type may be favoured by juveniles. Although adults are known to use seagrass meadows as foraging grounds, non were observed during this study (Meijer zu Schlochtern, 2014). The study of de Graaf et al. (2014) found that adults inhabit coral rubble and algae fields at depths greater than 16 meters, possibly explaining their absence in this research.
Currently fishery activities in the area utilise illegal methods (SCUBA) to harvest queen conchs within St. Eustatius Marine Park and the quota of 20 conchs per person/per year is exceeded (de Graaf et al., 2014). This has been tolerated for a number of years (de Graaf et al., 2014). These activities may result in decreased abundance of the queen conch in the research area as reproductive adults are captured.

Two slender seahorses were observed within the research area. The fact that the species were found is quite rare as the species is uncommon throughout its range in the Western Atlantic (Pinault, Wickel, Nicet, & Chenoz, 2018). Pinault et al. (2018) also describe a sighting of the slender seahorse in *H. stipulacea* seagrass in the Caribbean. They suggest that the presence is not surprising due to its adaptability to new habitats, and shows the ecological potential of *H. stipulacea* as a substitute habitat in light of the degradation of native seagrasses in the Caribbean (Pinault et al., 2018). The two seahorses observed during this study differed in coloration, namely yellow and brown. These two colours are common colorations amongst the slender seahorse (Duarte, Gawryszewski, Ramineli, & Bessa, 2019). Colouration is said to be driven by e.g. diet, habitat use and genetics (Duarte et al., 2019; Pinault et al., 2018). The present study provides the first record of the slender seahorse in *H. stipulacea* on the island. To our knowledge the slender seahorse was recorded during the marine biodiversity survey of St. Eustatius in 2015 (Hoeksema, 2016). However, no information is provided regarding the abundance, location or habitat of the seahorse(s), therefore indicating a first record of the species in *H. stipulacea*.

4.2 Groupers

None of the selected grouper species were observed during the surveys. It was expected to find juveniles in the seagrass which the species use as nursery habitat (Sadovy, Aguilar-Perera, & Sosa-Cordero, 2018; Brule & Ferreira, 2018). The absence of the selected grouper species is likely a result from a combination of pressures, namely overfishing (they are commercially valuable) and habitat degradation (van Kuijk et al., 2015; de Graaf et al., 2015). They are especially vulnerable to overexploitation due to high demand, late maturity and behaviour (formation of spawning aggregations and migration) (Brightman Claydon & Kroetz, 2007). A decline in nassau and yellowmouth groupers has been noted by the scientific community since 1992 (Sybesma, van 't Hot, & Pors, 1993). In 1992 some individuals were observed on various sites but during a baseline assessment in 2015 nassau groupers were absent and only 1 yellowmouth was observed (van Kuijk et al., 2015; Sybesma et al., 1993). Research by McClellan (2009) also suggested a decline in yellowfin groupers abundance between 2004 and 2008, as they were no longer recorded. In the most recent monitoring surveys (GCRMN) no large grouper species were observed (Kitson-Walters, 2018). The lack of large grouper species on St. Eustatius is an indicator for overfishing and poor management (de Graaf et al., 2015).
The study of Brightman Claydon and Kroetz (2007) in Turks and Caicos islands found that juvenile nassau groupers tend to reside in the native seagrass. Similar to St. Eustatius, in the Turks and Caicos islands fisheries are focussed on local consumption (Lockhart, De Fontaubert, & Clerveaux, 2007). It must be noted that finfish fisheries were underutilized on those islands at that time (Lockhart et al., 2007). The disappearance of native seagrasses around St. Eustatius may therefore be an important pressure on grouper species and it is unknown if *H. stipulacea* is a suitable substitute.

Although the grouper species were absent, two smaller grouper species were observed during the surveys, namely coney's and red hinds. In general, grouper species tend to occupy similar habitats (Munro, 1983). Brightman Claydon and Kroetz (2007) found more specifically that coney, red hind and nassau grouper juveniles all use seagrass as nursery habitat. Their presence might indicate suitable habitats within the *H. stipulacea* meadows for the protected species and may help focus monitoring and management efforts (Efroymson et al., 2009; Campbell et al., 2002). These observations are in accordance with the study of de Graaf et al. (2015) which found 87% of grouper recordings on St. Eustatius to be coney.

The highest abundance of coney's and red hinds in this study was found in the 'Reef patch' habitat type with a few individuals found in the 'Homogeneous' habitat type. It must be noted however that outside of these specific 'homogeneous' transects, but in close proximity, microhabitats such as tires and anchor chains were present. This may indicate that availability of reef patches and artificial structures may influence the distribution and abundance of these species within the meadow. Their distribution in the southern part can be explained by this as that is where the 'Reef patch' habitats were and also might be influenced by the 'spillover effect' from the nearby marine reserve (Russ & Alcala, 1996). Other studies also found that additional structures such as discarded queen conch shells are used by nassau, coney and red hind as microhabitat (Brightman Claydon & Kroetz, 2007).

The presence of these smaller grouper species may be an indication that the 'Reef patch' habitat type can be a suitable habitat for (juvenile) grouper species.

4.3 Snappers

None of the selected snapper species were observed during surveys. Like groupers, a decline in number of large snappers has been observed on St. Eustatius for years (McClellan, 2009; van Kuijk et al., 2015). In the most recent monitoring survey large snappers were observed on only 5 out of 20 dive sites and the snapper biomass is described as poor (Kitson-Walters, 2018). The mutton snapper is considered relatively rare, opposed to the cubera snapper which is commercially targeted throughout the Caribbean (Lindeman et al., 2016a; Lindeman et al., 2016b). Besides fishing pressure, the disappearance of native seagrass (habitat degradation) is said to be a key factor driving the lack of seagrass associated species on St. Eustatius, including snappers (van Kuijk et al., 2015).

Although the protected seagrass associated snapper species were absent, juvenile yellowtail snappers were regularly observed during the surveys. This species is also considered an associated species, and known to use the seagrass meadows as nursery habitat (Bester, 2017). In this research this species was found residing in 'Homogeneous', 'Reef patch' and 'Patchy' habitat. Unlike the grouper the yellowtail snapper was most abundant in 'Homogenous' areas without additional microhabitats. The presence of these snapper species may be an indication that *H. stipulacea* seagrass can be a suitable nursery habitat for snappers.

4.4 Caribbean spiny lobster

No Caribbean spiny lobsters were observed during the surveys. When juvenile lobsters settle in seagrass after dispersal, they remain there until they reach a 6 -15 mm carapace length[8] (Headley & Seijo, 2014). During this time, the lobsters continually molt and are highly vulnerable to predation as their exoskeleton is very soft (Oceana, n.d.). This period last for approximately 10-15 months (Headley & Seijo, 2014). Individuals may not have been seen by the researchers due to their nocturnal behaviour as all surveys occurred during daylight hours and small size (Florida Fish and Wildlife Conservation Commission, 2019; Headley & Seijo, 2014). According to Behringer et al. (2009) spiny lobsters prefer hard bottom macro algal dominated habitats over seagrass as nursery habitat. Furthermore, lobster populations on the reef are considered very low in the most recent monitoring surveys who only saw 10 lobsters in a sample area of 6000m^2 (Kitson-Walters, 2018). De Graaf et al. (2015) express their concern regarding the sustainability of Caribbean spiny lobster fisheries as St. Eustatius has one of the highest landings per km^2 with a high proportion of undersized lobsters. The combination between preferred nursery habitat, research methods and low population numbers might explain their absence from this study. It is unknown where the nursery grounds of spiny lobster are, and what the importance is of seagrass meadows on St. Eustatius in this cycle.

4.5 Rainbow parrotfish

No rainbow parrotfish were observed during the survey. Many studies find that juveniles almost exclusively reside in mangrove habitats whilst adults live on coral reefs (Dorenbosch, Grol, Nagelkerken, & van der Velde, 2006; Machemer, Walter, Serafy, & Kerstetter, 2012). However, when mangroves are absent, the species is known to use seagrass as a nursery habitat (Aguilar-Perera & Hernández-Landa, 2016). This stresses the importance of seagrass as potential habitat as mangroves are not present on St. Eustatius (van Kuijk et al., 2015). Parrotfishes are present on the island but have suffered major population loss in the last 18 years, mostly due to increased fishing pressures (Kitson-Walters, 2018). The most recent recording of the rainbow parrotfish in particular was during the marine biodiversity survey of St. Eustatius in 2015, but no information was given on the number of recordings (Hoeksema, 2016). Besides seagrass, they also use coral rubble and octocorals as nursery ground. The combination between preferred nursery habitat and reduced population size might explain their absence form this study (Aguilar-Perera & Hernández-Landa, 2016). It is unknown where the nursery grounds of rainbow parrotfish are, and what the importance is of seagrass meadows on St. Eustatius in this cycle.

4.6 Green turtle

No Green turtles were observed during the surveys, however, a total of 7 were seen during the manta tows in meadow 2 and 3. The turtles were observed sitting on the seagrass or swimming over. One of the observed individuals was seen eating the seagrass. Based on these observations and supporting research by Becking, van Bussel, Debrot, and Christianen (2014b) it can be concluded that green turtles interact with *H. stipulacea* seagrass meadows. The absence of green turtles during the surveys was unexpected, as using SCUBA for sea turtle research is an advised method to use when executing this type of research (Diez & Ottenwalder, 1999). It is suspected that the absence of green turtle during this research is coincidental.

[8] Carapace length: the distance from the anterior margin of the carapace between the rostral horns to the posterior margin of the cephalothorax

5. Conclusion

What is the distribution and abundance of protected seagrass associated species in the introduced *Halophila stipulacea* meadows on St. Eustatius?

The current study researched the abundance and distribution of seagrass associated species in one meadow, therefore conclusions can only be made with regards to this area. It is concluded that most protected seagrass associated species were not present in the studied *H. stipulacea* seagrass meadow, as only two of the research species were found. Juvenile queen conch (n = 10) were mostly observed in 'Homogenous' habitat type. The presence of juveniles indicates the provision of suitable nursery habitat by the meadow. The slender seahorses (n = 2) were found in homogenous characterized habitats where they were seen using the *H. stipulacea* shoots as holdfast, highlighting the seagrass potential as substitute habitat. Species associated with the protected seagrass associated grouper and snappers (coney, red hind and yellowtail snapper) were observed in the meadow, indicating that factors other than suitability of *H. stipulacea* (overfishing and habitat degradation) are required to explain the absence of protected seagrass associated grouper and snapper species. Associated grouper species were most abundant in 'Reef patch' habitat and were only found in 'Homogeneous' habitat when microhabitats were present, indicating a preference for areas with additional habitat structures. The associated snapper species was most abundant in 'homogeneous' habitat indicating a preference of this habitat type. The Caribbean spiny lobster and rainbow parrotfish populations have also suffered from fishing pressure, but may also prefer other habitats over seagrass as nursery habitat, hence it is unclear due to which factor they were absent. Regarding the green turtle it is known they interact with *H. stipulacea*, and their absence from this study is likely coincidental. The absence of protected seagrass associated species from the meadow is likely the result from poor management and the lack of knowledge which hinders effective nature management. The island specific management plans should focus on the conservation and recovery of protected seagrass associated species from threats like habitat degradation and fishing pressure, while doing further research (in all the meadows) to determine the effect of *H. stipulacea* on these species for the whole island.

6. Recommendations

It has become apparent that protected seagrass associated species face many threats, and without management, local extinction of species is likely. The loss of these species will reflect on the biodiversity influencing local economy, culture and maintenance of ecosystem services (Convention on Biological Diversity, 2009). Recommendations in this chapter aim to close the current knowledge gap that exists, and support management in identifying management goals.

6.1 Follow up research

Research and monitoring is needed for effective nature management, and therefore it is recommended to implement end execute further research (described below) as part of island specific management plans (Ministerie van Economische Zaken, 2013). Integrating the recommendations as part of the island specific management plans will increase local applicability and use for St. Eustatius. Research recommended below can be executed by STENAPA, as they are responsible for the execution of management within the marine park (Ministerie van Economische Zaken, 2013; Dutch Caribbean Nature Alliance, 2014b). This can be done in cooperation with CNSI as they aim to facilitate and support research for the Caribbean islands (Caribbean Netherlands Science Institution, n.d).

6.1.1 Updating seascape habitat maps

During this research, additional anecdotal meadows were identified, which extended to much greater depths and locations around the island than mapped out in this research. It is recommended that the Marine National Park around the island is mapped to update current habitat maps and to identify the true extent of the *H. stipulacea* meadows on St. Eustatius. This can be done by using the manta tow method as demonstrated in the present study. Due to the extension of meadows to deeper water, additional methods are required as the manta tow method will not be sufficient due to lack of visibility. A suitable method to do this is video transects to record the benthic habitat (Kitson-Walters, 2018). CNSI can execute this research as they were involved in the present study. It will take approximately 30 days to map the seascape within the marine park as 1,28 km2 was mapped within 4 days in this research and the marine park has a surface area of 27.3 km2 (St. Eustatius National Parks, 2020).

6.1.2 Distribution and abundance in other meadows

As this present study focussed on only one meadow, it is recommended to replicate this study in all other (anecdotal) seagrass meadows. It is recommended that CNSI will execute the follow up research as they facilitated the present study and already execute annual monitoring surveys on the reefs. This follow up study can use the methods described in this document to ensure comparability. In addition to the methods described, it is recommended to include some other techniques e.g. night surveys to account for the spiny lobster nocturnal behaviour or quantifying sea turtle data during the manta tow for abundance and distribution (Florida Fish and Wildlife Conservation Commission, 2019). The time needed to execute the research will depend on the extent of the meadow and the identified habitat types. This will be influenced by the number of dives that can be executed per week, and the amount of transects needed (amount of different habitat types x minimal number of transects per habitat type). This research was able to do 31 transects in 6 weeks. Understanding the population distribution around the island will support sustainable management (Efroymson et al., 2009).

6.1.3 Determining preferred habitats (other than seagrass)

Besides population distribution it is important to know preferred habitat types by the species for management purposes (Efroymson et al., 2009). For the spiny lobster and rainbow parrotfish the nursery areas on the island are unknown as well as critical habitats (for example deep reef) for groupers (Kitson-Walters, 2018). Identifying preferred habitat and protecting those habitats is a common tool used in species conservation and could help increase species populations and recruitment (Bunting, 2011). Based on literature research preferred habitats can be identified and these can be sampled when their location is known (based on the updated habitat map).

6.2 Management

It is recommended to focus management activities on recovery and conservation of the seagrass associated species (that are still present around the island) to increase population numbers (Campbell et al., 2002).

Once fundamental information is gathered, management goals can be set using a framework specially made for species at risk that fosters active management (Efroymson et al., 2009). This framework includes steps like: identifying species at risk in management area, describe available knowledge and identify knowledge gaps, determine species (potential) distribution and their (preferred) habitats, select ways to identify species status, access the current population status and set metrics, access threats, develop management plans and goals (Efroymson et al., 2009). It is recommended to use this framework as it focuses specifically on rare species (Efroymson et al., 2009). It also aims to minimally impact human activities, while reducing the threat for species extinction in the future (Efroymson et al., 2009). This present study already contributed to the first three steps of the framework so it would be very accessible to implement and integrate in island specific management plans by the island government of St. Eustatius. In order to move on to the next step of the proposed framework additional research is needed which is described in paragraph 6.1.

6.2.1 Reducing threats

It has been noted by the scientific community that grouper, snapper, spiny lobster and rainbow parrotfish are threatened by fishing pressure and population numbers have been declining around St. Eustatius (de Graaf et al., 2015; van Kuijk et al., 2014; Kitson-Walters, 2018). The Nature Policy Plan for the BES islands (2020-2030) aims to have stable fish population by 2030 (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020). In order to preserve species, damaging activities must be limited, such as unsustainable fisheries. On small island like St. Eustatius this can be extra challenging as the local community is directly linked to the sector through economic and cultural reasons (Convention on Biological Diversity, 2009). However, there is another important source of income that depends on biodiversity namely, tourism (van de Kerkhof, Schep, van Beukering, Brander, & Wolfs, 2014). Healthy ecosystems are therefore crucial to the island (van de Kerkhof et al., 2014). It is recommended to focus on development of sustainable tourism and limit unsustainable fisheries to maintain this important source of income. Management of fisheries can be incorporated in the fisheries management plan that is currently being written to maintain these ecosystems to use for tourism (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020).

6.2.2 Habitat restoration

The new Nature Policy Plan for the BES islands (2020-2030) recommends restoring damaged habitats, like seagrass meadows and prevent further spreading of invasive species (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2020). Restoring the meadows on St. Eustatius would be challenging as the native seagrasses are completely replaced, whereas on Bonaire native seagrasses are still present (Debrot et al., 2014; Becking et al, 2014a). On St. Eustatius native seagrasses were already declining before the introduction of *H. stipulacea* due to hurricanes, anchoring by tankers and change in seawater dynamics (MacRae & Esteban, 2007; van Kuijk et al., 2015; Debrot et al., 2014). It is recommended to address these factors in a management plan, as meadows can most likely not be restored when this is not dealt with. Besides this, controlling the spread of *H. stipulacea* would also require other factors such as eutrophication to be addressed as it favours the growth of *H. stipulacea* meadows. Managing the eutrophication would also benefit other ecosystems such as coral reefs which are also negatively influenced by the excess nutrients and are considered important habitats for protected seagrass associated species (van Tussenbroek et al., 2016; St. Eustatius National Parks, 2019). Secondly, the effects of the newly introduced seagrass on protected seagrass associated species is poorly understood. In some cases like the slender seahorse, the new seagrass species might even substitute the native seagrasses (Pinault et al., 2018).

It can be concluded that in order to restore native seagrass meadows and control the spreading of *H. stipulacea* much larger problems on the island must be addressed. This will take time while population numbers of seagrass associated species are going down most likely due to other pressures than the introduced *H. stipulacea.* It is recommended to execute all research mentioned in paragraph 6.1 to be able to assess the impact of *H. stipulacea* and focus current management by the island government on reducing direct pressures on the species such as fishing pressure and habitat degradation through habitat disconnectivity and damaging of other important habitats such as coral reefs.

6.2.3 Habitat enrichments

Conserving reef patches

The present study shows that, especially in the case of groupers, species abundance was highest in seagrass habitats with additional structures such as reef patches ('Reef patch'). Besides the researched species other species resided in these patches highlighting the complementary role of reefs and seagrass. The 'Reef patch' areas are vulnerable to degradation due to damage caused by e.g. anchoring boats, disturbing the interconnections with other reefs, as they are located outside the marine reserves (Debrot et al., 2014). As coral reefs are already facing multiple stressors it is important that habitat interconnections are preserved and important habitats of which species with changing habitat dependency rely on are conserved (Bellwood, Hughes, Folke, & Nystrom, 2014; Debrot et al., 2014; Debrot et al., 2017). To preserve these functions provided by the patches of reef within the meadow, current zoning plans should be revalued by the island government to include this type of habitat and these habitat functions.

Additional habitat

It is known that especially the current grouper species composition is a result from poor management (de Graaf et al., 2015). Besides management measures incorporated in the island specific management plan, the introduction of additional microhabitat in the seagrass meadow can help current grouper populations recover and redistribute around the island, positively influencing the island fisheries. This can be done by deploying solitary discarded queen conch shells within the meadow as this has proven to be a shelter for e.g. Nassau grouper (Claydon, Calosso, & Jacob, 2010).

6.2.4 Interisland management

Is must also be noted that some of the species are highly mobile and move outside St. Eustatius waters. It is expected that migratory species (e.g. green turtle) will be negatively affected by the effects of climate change, especially in combination with other pressures already effecting (habitat of) the species (UNEP/CMS Convention on Migratory Species & DEFRA, 2006). This emphasizes the complexity to conserve migratory species and the need for management and research of pressures at a broader scale. DCNA that already functions as an umbrella organisation could support local governments in the management of these type of species and help synchronize management efforts between the islands on a larger scale (Dutch Caribbean Nature Alliance, 2014b).

Literature

Aguilar-Perera, A., & Hernández-Landa, R. C. (2016). The rainbow parrotfish (Scarus guacamaia) does not depend on mangroves as nursery habitats in the Parque Nacional Arrecife Alacranes, Southern Gulf of Mexico. *Marine Biodiversity*, *47*(1), 13–14. https://doi.org/10.1007/s12526-016-0491-4

Becking , L. E., Bussel , T., Engel , M. S., Christianen, M. J. A., & Debrot , A. O. (2014a). *Proximate response of fish, conch, and sea turtles to the presence of the invasive seagrass Halophila stipulacea in Bonaire* (456875). Retrieved from https://www.researchgate.net/publication/267865352_Proximate_response_of_fish_conch_and_sea_turtles_to_the_presence_of_the_invasive_seagrass_Halophila_stipulacea_in_Bonaire

Becking, L. E., van Bussel, T. C. J. M., Debrot, A. O., & Christianen, M. J. A. (2014b). First Record of a Caribbean Green Turtle (Chelonia mydas) Grazing on Invasive Seagrass (Halophila stipulacea). *Caribbean Journal of Science*, *48*(2–3), 162–163. https://doi.org/10.18475/cjos.v48i3.a05

Behringer, D. C., Butler, M. J., Herrnkind, W. F., Hunt, J. H., Acosta, C. A., & Sharp, W. C. (2009). Is seagrass an important nursery habitat for the Caribbean spiny lobster,panulirus argus, in Florida? *New Zealand Journal of Marine and Freshwater Research*, *43*(1), 327–337. https://doi.org/10.1080/00288330909510003

Bellwood, D. R., Hughes, T. P., Folke, C., & Nystrom, M. (2014). Confronting the coral reef crisis. *Nature Publishing Group*, *429*, 827–833. Retrieved from http://myweb.facstaff.wwu.edu/~shulld/ESCI%20432/Bellwood2004.pdf

Bester, C. (2017, May 10). Lutjanus chrysurus. Retrieved July 22, 2020, from https://www.floridamuseum.ufl.edu/discover-fish/species-profiles/lutjanus-chrysurus/

Blondel, J. (2003). Guilds or functional groups: does it matter? *Oikos*, *100*(2), 223–231. https://doi.org/10.1034/j.1600-0706.2003.12152.x

Boman, E. M., Bervoets, T., de Graaf, M., Dewenter, J., Maitz, A., Meijer Zu Schlochtern, M. P., … Nagelkerke, L. A. J. (2019). Diet and growth of juvenile queen conch Lobatus gigas (Gastropoda: Strombidae) in native, mixed and invasive seagrass habitats. *Marine Ecology Progress Series*, *621*, 143–154. https://doi.org/10.3354/meps12990

Brightman Claydon, J. A., & Kroetz, A. M. (2007). The Distribution of Early Juvenile Groupers Around South Caicos, Turks and Caicos Islands. *Gulf and Caribbean Fisheries Institute*, *2007*(60), 345–350. Retrieved from https://core.ac.uk/download/pdf/33719203.pdf

Britannica. (2019, May 29). *Sint Eustatius*. Retrieved August 17, 2020, from https://www.britannica.com/place/Sint-Eustatius

Brule, T., & Ferreira, B. (2018). Yellowfin Grouper. Retrieved August 7, 2020, from https://www.iucnredlist.org/species/44683/46915269

Bunting, J. (2011, June). *Fish protection measures to ensure Fish For The Future* (141). Fisheries Western Australia. Retrieved from http://www.fish.wa.gov.au/documents/management_papers/fmp141.pdf

Campbell, S. P., Clark, J. A., Crampton, L. H., Guerry, A. D., Hatch, L. T., Hosseini, P. R., … O'Connor, R. J. (2002). AN ASSESSMENT OF MONITORING EFFORTS IN ENDANGERED SPECIES RECOVERY PLANS. *Ecological Applications*, *12*(3), 674–681. https://doi.org/10.2307/3060977

Caribbean Netherlands Science Institute. (n.d.). History, Mission, Ambition. Retrieved February 21, 2020, from https://www.cnsi.nl/History-Mission-Ambition

Christianen, M. (2016, August 25). 36 turtles tagged in St. Eustatius| Marjolijn Christianen. Retrieved March 4, 2020, from http://penyu.nl/2016/08/25/36-turtles-tagged-in-st-eustatius/

Claydon, J. A. B., Calosso, M. C., & Jacob, S. E. (2010, November). *Large-Scale deployment of discarded conch shells enhances juvenile habitat for spiny lobster, Nassau grouper and red hind*, 457–461. Presented at the 63rd Gulf and Caribbean Fisheries Institute, South Caicos, Turks & Caicos Islands: Center for Marine Resource Studies.

Coles, R. G., & Short, F. T. (2001). *Global Seagrass Research Methods*. Maarssen, Netherlands: Elsevier Gezondheidszorg.

Convention on Biological Diversity. (2009, September 10). Island Biodiversity - Why is it Important? Retrieved August 12, 2020, from https://www.cbd.int/island/whymatters.shtml#:%7E:text=For%20example%2C%20biodiversity%20is%20a,are%20important%20sources%20of%20income.

Davies, M. R., & Piontek, S. (2016). The marine fishes of St. Eustatius, Dutch Caribbean. *Marine Biodiversity*, *47*(1), 27–35. https://doi.org/10.1007/s12526-016-0575-1

Debrot, A. O., de Graaf, M., Henkens, R., Meesters, H. W. G., & Slijkerman, D. M. E. (2011, September). *A status report of nature policy development and implementation in the Dutch Caribbean over the last 10 years and recommendations towards the Nature Policy Plan 2012-2017* (C065/11). IMARES. Retrieved from https://www.dcbd.nl/sites/www.dcbd.nl/files/documents/C065%252011%2520%2520NPP%2520Dutch%2520Carribean%25202012-2017%2520DD-tv.pdf

Debrot, A. O., Henkens, R. J. H. G., & Verweij, P. J. F. M. (2017). *Staat van de Natuur van Caribisch Nederland 2017* (532788). Retrieved from https://library.wur.nl/WebQuery/wurpubs/532788

Debrot, A. O., Houtepen, E., Meesters, E. H., van Beek, I., Timmer, T., Boman, E., … Ballantine, D. L. (2014). *Habitat diversity and bio-diversity of the benthic seascapes of St. Eustatius* (263322965). Retrieved from https://www.researchgate.net/publication/263322965

Diez, C. E., & Ottenwalder, J. A. (1999). Habitat Surveys. In K. L. Eckert, K. A. Bjorndal, F. A. Abreu-Grobois, & M. Donnelly (Eds.), *Research and Management Techniques for the Conservation of Sea Turtles* (4th ed., Vol. 1999, pp. 41–44). Washington , United States of America: IUCN/SSC Marine Turtle Specialist Group.

Dilrosun, F. (2004, February). *Inventory of the Fishery sector of St. Eustatius*. Retrieved from https://www.dcbd.nl/sites/www.dcbd.nl/files/documents/Dilrosun%25202004%2520Report.pdf

Dorenbosch, M., Grol, M. G. G., Nagelkerken, I., & van der Velde, G. (2006). Seagrass beds and mangroves as potential nurseries for the threatened Indo-Pacific humphead wrasse, Cheilinus undulatus and Caribbean rainbow parrotfish, Scarus guacamaia. *Biological Conservation*, *129*(2), 277–282. https://doi.org/10.1016/j.biocon.2005.10.032

Duarte, C. M. (2002). The future of seagrass meadows. *Environmental Conservation*, 29(2), 192–206. https://doi.org/10.1017/s0376892902000127

Duarte, M., Gawryszewski, F. M., Ramineli, S., & Bessa, E. (2019). Disruptive coloration and habitat use by seahorses. *Neotropical Ichthyology*, *17*(4), e190064. https://doi.org/10.1590/1982-0224-20190064

Dutch Caribbean Nature Alliance. (2014b). DCNA | Safeguarding nature in the Dutch Caribbean. Retrieved February 21, 2020, from https://www.dcnanature.org/

Dutch Caribbean Nature Alliance. (2014a). St. Eustatius National Marine Park. Retrieved February 21, 2020, from https://www.dcnanature.org/st-eustatius-national-marine-park/

DW. (2020, July 3). *St. John H. stipulacea vs T. testudinum* [Photograph]. Retrieved from https://www.euromarinenetwork.eu/system/files/2017/2017GA_flash_Gideon_Winters_Seagrass.pdf

Efroymson, R., Jager, H., Dale, V., & Westervelt, J. (2009). A Framework for Developing Management Goals for Species at Risk with Examples from Military Installations in the United States. *Environmental Management*, *44*(6), 1163–1179. https://doi.org/10.1007/s00267-009-9385-6

Florida Fish and Wildlife Conservation Commission. (2019). Spiny Lobster—General Facts. Retrieved July 22, 2020, from https://myfwc.com/research/saltwater/crustaceans/lobster/facts/

Forsskål, P., & Niebuhr, C. (1775*). Flora Aegyptiaco-Arabica : sive descriptiones plantarum quas per Aegyptum inferiorem et Arabiam felicem*. https://doi.org/10.5962/bhl.title.6625 de Freitas, J. A., Rojer, A. C., Nijhof, B. S. J., & Debrot, A. O. (2014). *Landscape ecological vegetation map of sint eustatius (lesser antilles)*. Royal Netherlands Academy of Arts and Sciences. Retrieved from http://www.researchstationcarmabi.org/wp-content/uploads/2015/08/Sint-eustatius_web.pdf

Geevarghese, G. A., Akhil, B., Magesh, G., Krishnan, P., Purvaja, R., & Ramesh, R. (2017). A comprehensive geospatial assessment of seagrass distribution in India. *Ocean & Coastal Management*, 159, 16–25. https://doi.org/10.1016/j.ocecoaman.2017.10.032

de Graaf, M., Piontek, S., Miller, D. C. M., Brunel, T. P. A., & Nagelkerke, L. A. J. (2015). *Status and trends of St. Eustatius Coral reef ecosystem and fisheries: 2015 report card* (C167/15). IMARES. Retrieved from https://research.wur.nl/en/publications/status-and-trends-of-st-eustatius-coral-reef-ecosystem-and-fisher

de Graaf, M., Meijer zu Schlochteren, M., & Boman, E. (2014). *Non-Detriment Finding Regarding the Export of Queen conch (Lobatus gigas) from St Eustatius (Caribbean Netherlands)* (328935). Retrieved from https://edepot.wur.nl/328935

Grech, A., Chartrand-Miller, K., Erftemeijer, P., Fonseca, M., McKenzie, L., Rasheed, M., … Coles, R. (2012). A comparison of threats, vulnerabilities and management approaches in global seagrass bioregions. *Environmental Research Letters*, *7*(2), 024006. https://doi.org/10.1088/1748-9326/7/2/024006

Green, E. P., & Short, F. T. (2003). *World Atlas of Seagrasses* (First American Edition). Amsterdam, Netherlands: Amsterdam University Press.

Headley, M., & Seijo, J. C. (2014, June). *A review of the methodologies used for monitoring and evaluation of the spiny lobster stocks in the WECAFC countries and the development of a common methodology*. Caribbean Regional Fisheries Mechanism. Retrieved from http://www.crfm.net/~uwohxjxf/images/Lobster_Methodology_Report.pdf

Hemminga, M. A., & Duarte, C. M. (2008). *Seagrass Ecology* (1st ed.). Cambridge, United Kingdom: Cambridge University Press.

Hill, J., & Wilkinson, C. (2004). *Methods for Ecological Monitoring of Coral Reefs*. Retrieved from https://www.researchgate.net/publication/242384503_Methods_for_Ecological_Monitoring_of_Coral_Reefs

Hoeksema, B. (2016). *Marine Biodiversity Survey of St. Eustatius, Dutch Caribbean, 2015*. Retrieved from https://www.dcbd.nl/sites/www.dcbd.nl/files/documents/Hoeksema_et_al_2015_Report_Statia_Marine_Biodiversity_Expedition_2015.pdf

International Union for Conservation of Nature. (2020a). Programme. Retrieved February 13, 2020, from https://www.iucn.org/about/programme-work-and-reporting/programme

International Union for Conservation of Nature. (2020b). IUCN Members. Retrieved February 21, 2020, from https://www.iucn.org/about/members/iucn-members

Jongman, R. H. G., Meesters, H. W. G., & Debrot, A. O. (2010*). Biodiversiteit voor de BES-eilanden: Bonaire, St. Eustatius en Saba* (2080). Retrieved from https://edepot.wur.nl/158543

Kaiser, M. J., Attrill, M. J., Williams, P. J. B., Jennings, S., Thomas, D. N., Barnes, D. K. A., … Skiftesvik , A. B. (2011). *Marine Ecology* (2nd ed.). Oxford, United Kingdom: Oxford University Press.

Kennedy, H., Beggins, J., Duarte, C. M., Fourqurean, J. W., Holmer, M., Marbà, N., & Middelburg, J. J. (2010). Seagrass sediments as a global carbon sink: Isotopic constraints. *Global Biogeochemical Cycles*, *24*(4), n/a. https://doi.org/10.1029/2010gb003848

van de Kerkhof, S., Schep, S. W., van Beukering, P., Brander, L., & Wolfs, E. (2014, May). *The Tourism Value of Nature on St Eustatius* (R-14/07). Institute for Environmental Studies. Retrieved from https://www.wolfscompany.com/wp-content/uploads/2014/06/R14-07-The-tourism-value-of-nature-on-St-Eustatius.pdf

Kitson-Walters, K. (2018). *St. Eustatius GCRMN Caribbean final report 2017*. Retrieved from https://www.dcbd.nl/sites/www.dcbd.nl/files/documents/St.%20Eustatius%20GCRMN%202017%20Report%20LNV%20CNSI.pdf van Kuijk, T., de Graaf, M., Nagelkerke, L., Boman, E., & Debrot, A. O. (2015, July). *Baseline assessment of the coral reef fish assemblages of St. Eustatius* (C058/15). IMARES. Retrieved from https://library.wur.nl/WebQuery/wurpubs/fulltext/350721

Lindeman, K., Anderson, W., Carpenter, K. E., Claro, R., Cowan, J., Padovani-Ferreira, B., … Zapp-Sluis, M. (2016b). Cubera Snapper. Retrieved August 7, 2020, from https://www.iucnredlist.org/species/12417/506633

Lindeman, K., Anderson, W., Carpenter, K. E., Claro, R., Cowan, J., Padovani-Ferreira, B., … Zapp-Sluis, M. (2016a). Mutton Snapper. Retrieved August 7, 2020, from https://www.iucnredlist.org/species/12416/161245983

Lockhart, K., De Fontaubert, C., & Clerveaux, W. (2007). *Fisheries of the Turks and Caicos Islands: Status and Threats*. Department of Environmental and Coastal Resources, Government of the Turks and Caicos. Retrieved from https://www.researchgate.net/publication/266186529_Fisheries_of_the_Turks_and_Caicos_Islands_Status_and_Threats

MacRae, D. R., & Esteban, N. (2007). *St Eustatius National Marine Park Management Plan 2007*. Retrieved from http://parkscaribbean.net/wp-content/uploads/2013/11/St%20Eustatius%20National%20Marine%20Park%20Management%20Plan%20(2007).pdf

Machemer, E. G. P., Walter, J. F., Serafy, J. E., & Kerstetter, D. W. (2012). Importance of mangrove shorelines for rainbow parrotfish Scarus guacamaia: habitat suitability modeling in a subtropical bay. *Aquatic Biology*, *15*(1), 87–98. https://doi.org/10.3354/ab00412

McClellan, K. (2009, May). *Evaluating the Effectiveness of Marine No-Take Reserves in St. Eustatius, Netherlands Antilles* (Thesis). Retrieved from https://www.dcbd.nl/sites/www.dcbd.nl/files/documents/McClellan%25202009%2520MSc%2520Thesis.pdf

Meijer zu Schlochtern, M. (2014). *Population status and reproductive biology of queen conch (Lobatus gigas) in the coastal waters around St Eustatius* (MSc Thesis nr. T 1916). Retrieved from https://www.dcbd.nl/sites/www.dcbd.nl/files/documents/Meijer%202014%20MSc%20Thesis%20AFI%20Melanie%20Status%20Queen%20Conch%20Statia%20JAN2014.pdf

Ministerie van Economische Zaken . (2013). *Nature Policy Plan for The Caribbean Netherlands 2013-2017*. Retrieved from https://www.dcbd.nl/document/nature-policy-plan-caribbean-netherlands-2013-2017

Ministerie van Landbouw, Natuur en Voedselkwaliteit. (2019, January 1). wetten.nl - Regeling - Wet grondslagen natuurbeheer- en bescherming BES - BWBR0028434. Retrieved August 5, 2020, from https://wetten.overheid.nl/BWBR0028434/2019-01-01

Ministerie van Landbouw, Natuur en Voedselkwaliteit. (2020, March). *Natuur- en milieubeleidsplan Caribisch Nederland 2020-2030*. Retrieved from https://www.rijksoverheid.nl/documenten/beleidsnotas/2020/04/24/natuur--en-milieubeleidsplan-caribisch-nederland-2020-2030

Munro, J. L. (1983). *Caribbean Coral Reef Fishery Resources* (2nd ed., Vol. 1983). Manila, Philippines: International Center for Living Aquatic Resources Management.

Oceana. (n.d.). Caribbean Spiny Lobster. Retrieved July 22, 2020, from https://oceana.org/marine-life/cephalopods-crustaceans-other-shellfish/caribbean-spiny-lobster

Pinault, M., Wickel, J., Nicet, J. B., & Chenoz, M. (2018). First record of the near threatened native seahorse Hippocampus reidi (Teleostei: Syngnathidae) in an ecosystem dominated by the invasive seagrass Halophila stipulacea in the Caribbean Sea. *Cybium: International Journal of Ichthyology*, *2018*(1081). Retrieved from https://www.researchgate.net/publication/328052531_First_record_of_the_near_threatened_native_seahorse_Hippocampus_reidi_Teleostei_Syngnathidae_in_an_ecosystem_dominated_by_the_invasive_seagrass_Halophila_stipulacea_in_the_Caribbean_Sea van Rijn, J. (2013, February). *Initial Queen conch (Strombus gigas) studies on St. Eustatius*. Retrieved fromhttps://www.dcbd.nl/sites/www.dcbd.nl/files/documents/Rijn%202013%20Initial%20Queen%20Conch%20studies%20on%20Statia.pdf

Ruiz, H., & Ballantine, D. (2004). Occurrence of the seagrass Halophila stipulacea in the tropical west Atlantic. *Bulletin of Marine Science -Miami-*, *75*(*1*)(131). Retrieved from https://www.researchgate.net/publication/236869810_Occurrence_of_the_seagrass_Halophila_stipulacea_in_the_tropical_west_Atlantic

Russ, G. R., & Alcala, A. C. (1996). Do marine reserves export adult fish biomass? Evidence from Apo Island, central Philippines. *Marine Ecology Progress Series*, *132*, 1–9. https://doi.org/10.3354/meps132001

Sadovy, Y., Aguilar-Perera, A., & Sosa-Cordero, E. (2018). Nassau Grouper. Retrieved August 7, 2020, from https://www.iucnredlist.org/species/7862/46909843

Sadovy, Y., & Eklund, A. M. (1999, July). *Synopsis of Biological Data on the Nassau Grouper, Epinephelus striatus (Bloch, 1792), and the Jewfish, E. itajara (Lichtenstein, 1822)* (NOAA Tech. Rep. NMFS 146). U.S. Department of Commerce. Retrieved from https://www.researchgate.net/publication/237381012_Synopsis_of_Biological_Data_on_the_Nassau_Grouper_Epinephelus_striatus_Bloch_1792_and_the_Jewfish_E_itajara_Lichtenstein_1822

Short, F., Carruthers, T., Dennison, W., & Waycott, M. (2007). Global seagrass distribution and diversity: A bioregional model. *Journal of Experimental Marine Biology and Ecology*, *350*(1–2), 3–20. https://doi.org/10.1016/j.jembe.2007.06.012

Smith, J. (2008). *In-water monitoring of sea turtle aggregations in St. Eustatius National Marine Park*. Retrieved from http://www.widecast.org/What/Country/Eustatius/Docs/In_Water_Monitoring_of_Sea_Turtle_Aggregations_in_St_Eustatius.pdf

Smyth, K., & Elliott, M. (2016). Effects of changing salinity on the ecology of the marine environment. In N. Whiteley & M. Solan (Eds.), *Stressors in the Marine Environment* (1st ed., Vol. 2016, pp. 161–174). Oxford, United Kingdom: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198718826.003.0009

St. Eustatius National Parks. (2020). Our parks. Retrieved February 21, 2020, from https://www.statiapark.org/our-park/

St. Eustatius National Parks. (2019, September 5). Issues Affecting Nature Discussed in Meeting with Schouten. Retrieved August 15, 2020, from https://www.statiapark.org/nature-with-schouten/

Stoner, A. (1997). The Status of Queen Conch, Strombus gigas, Research in the Caribbean. *Marine Fisheries Review*, *59*(3), 14–33. Retrieved from https://www.researchgate.net/publication/242472717_The_status_of_queen_Conch_Strombus_gigas_research_in_the_Caribbean

Stoner, A. W. (2003). What constitutes essential nursery habitat for a marine species? A case study of habitat form and function for queen conch. *Marine Ecology Progress Series*, *257*, 275–289. https://doi.org/10.3354/meps257275

Stuart-Smith, R. D., Edgar, G. J., & Bates, A. E. (2017). Thermal limits to the geographic distributions of shallow-water marine species. *Nature Ecology & Evolution*, *1*, 1846–1852. https://doi.org/10.1038/s41559-017-0353-x

Sybesma, J., van 't Hot, T., & Pors, L. P. J. J. (1993, August). *Marine area survey*. CARMABI. Retrieved from https://www.dcbd.nl/sites/www.dcbd.nl/files/documents/Sybesma%2520et%2520al%25201993%2520Marine%2520area%2520survey%2520Statia.pdf

van Tussenbroek, B. I., van Katwijk, M. M., Bouma, T. J., van der Heide, T., Govers, L. L., & Leuven, R. S. E. W. (2016). Non-native seagrass Halophila stipulacea forms dense mats under eutrophic conditions in the Caribbean. *Journal of Sea Research*, *115*, 1–5. https://doi.org/10.1016/j.seares.2016.05.005

UNEP/CMS Convention on Migratory Species, & DEFRA. (2006). *Migratory Species and Climate Change: Impacts of a Changing Environment on Wild Animals* (9). UNEP/CMS. Retrieved from https://www.cms.int/sites/default/files/document/ScC14_Inf_09_Migratory_Species&Climate_Change_E_0.pdf

Viana, I. G., Siriwardane-de Zoysa, R., Willette, D. A., & Gillis, L. G. (2019). Exploring how non-native seagrass species could provide essential ecosystems services: a perspective on the highly invasive seagrass Halophila stipulacea in the Caribbean Sea. *Biological Invasions*, *21*(5), 1461–1472. https://doi.org/10.1007/s10530-019-01924-y

Willette, D. A., Chalifour, J., Debrot, A. O. D., Engel, M. S., Miller, J., Oxenford, H. A., … Védie, F. (2014). Continued expansion of the trans-Atlantic invasive marine angiosperm Halophila stipulacea in the Eastern Caribbean. *Aquatic Botany*, *112*, 98–102. https://doi.org/10.1016/j.aquabot.2013.10.001

Appendix I

Information protected seagrass associated species

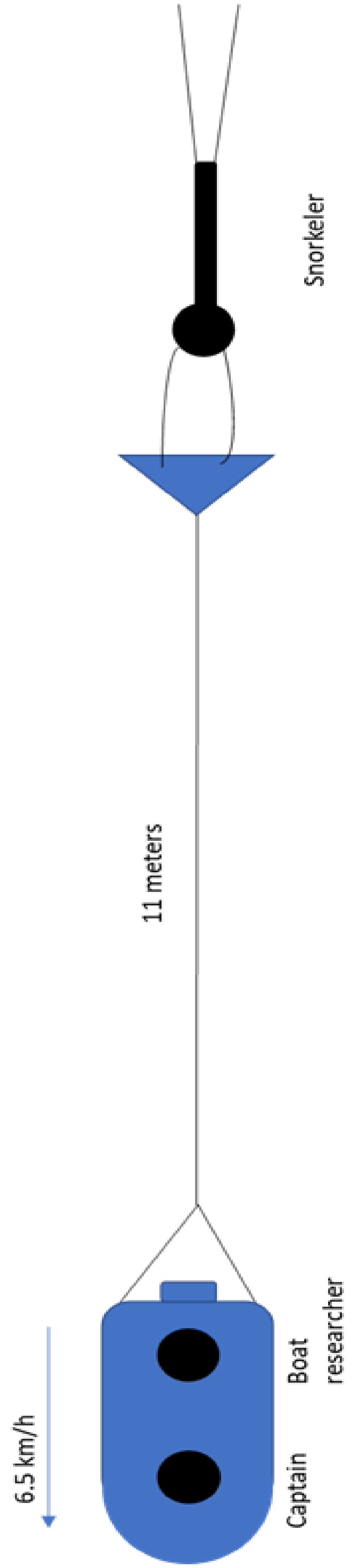
Species		Habitat			International treaties*			Management
Species	**Scientific name**	**Cover**	**Associated Habitats** Debrot et al., 2017	**International Union for the Conservation of Nature (IUCN) Category***	**Cartagena Convention,** Specially Protected Areas and Wildlife Protocol **(SPAW) annex**	**Convention of Migratory Species (CMS) annex**	**Convention on International Trade of Endangered Species (IUCN)** Category	**Management tools**
Caribbean spiny lobster	*Panulirus argus*	Uses seagrass as nursery habitat (Headley & Seijo, 2014).	Seagrass Reef Rock (Dutch Caribbean Nature Alliance, 2014c)	Data deficient	3			Fishing regulations and zoning (designating marine reserve) (Dutch Caribbean Nature Allience, 2014a; Poiesz, 2013)
Cubera snapper	*Lutjanus cyanopterus*	Uses seagrass as nursery habitat, therefore higher complexity is favoured (Lindeman et al., 2016b; Viana et al., 2019).	Mangrove Seagrass Reef	Vulnerable				
Green turtle	*Chelonia mydas*	Uses seagrass as food source (Becking et al., 2014).	Beach Seagrass	Endangered	2	2	I	Zoning (designating marine reserve) (Dutch Caribbean Nature Alliance, 2014a)
Mutton snapper	*Lutjanus analis*	Uses seagrass as nursery habitat, therefore higher complexity is favoured (Lindeman et al., 2016a; Viana et al., 2019).	Mangrove Seagrass Reef	Vulnerable				

Nassau grouper	*Epinephelus striatus*	Uses seagrass as nursery habitat, therefore higher complexity is favoured (Sadovy et al., 2018; Viana et al., 2019).	Subtidal sand Seagrass Reef	Endangered				
Queen conch	*Lobatus gigas*	Uses seagrass as nursery habitat and foraging ground (Meijer zu Schlochtern, 2014). Juveniles specifically use seagrass meadows as nursery habitat (Stoner, 1997). However, on St. Eustatius little is known about juveniles habitat and nursery areas (de Graaf et al., 2014)	Seagrass Reef Subtidal sand				II	Permits and fishing regulations (Ministerie van Economische Zaken, 2013; de Graaf et al., 2014)
Rainbow parrotfish	*Scarus guacamaia*	Uses seagrass as nursery habitat, therefore higher complexity is favoured (Viana et al., 2019).	Mangrove Seagrass Reef	Vulnerable				
Slender seahorse	*Hippocampus reidi*	Uses seagrass as habitat (Pinault et al., 2018).	Seagrass Reef	Data deficient			II	
Yellowfin grouper	*Mycteroperca venenosa*	Uses seagrass as nursery habitat, therefore higher complexity is favoured (Brule & Ferreira, 2018; Viana et al., 2019).	Seagrass Reef	Near threatened				
Yellowmouth grouper	*Mycteroperca interstitialis*	Uses seagrass as nursery habitat, therefore higher complexity is favoured (Viana et al., 2019).	Seagrass Reef	Vulnerable				

*Ministerie van Economische Zaken, 2013

Appendix II

Manta tow set up



Appendix III

Manta tow data collection sheet

Snorkeler sheet:

Snorkeler:		**Date:**	**Time:**	**Site**
Stop	**Seagrass cover (1,2,3)**	**Adjacent habitat**	**Secondary habitat**	**Notes:**
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				

Boat researcher sheet:

Boat researcher:		Date:	Time:	Site
Stop	**GPS coordinates (waypoint)**	**Length or width tow**	**Start of tow (S)** **End of tow (E)** **Intermediate (I)**	**Water depth**
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				

Appendix IV

Location sampling sites and verified habitat types

The habitat types correspond with the following colours:

Yellow = homogeneous; blue = homogeneous with sand; purple = reef patch & green = patchy

Habitat	Grid cell	Number	GPS	Habitat	Grid cell	Number	GPS
Yellow	101 M	1	17.483699 -62.9955336	Purple	303 J	18	17.4751928 -62.9899127
Yellow	102 L	2	17.4831059 -62.9949838	Purple	304 L	19	17.4753717 -62.9906904
Yellow	103 I	3	17.4827817 -62.9937702	Blue	401 J	20	17.4847825 -62.995003
Purple	104 M	4	17.4816103 -62.994358	Green	402 I	21	17.4841563 -62.9946479
Yellow	105 H	5	17.4815559 -62.9927387	Green	403 E	22	17.4837789 -62.9930807
Yellow	106 D	6	17.4812411 -62.9914149	Yellow	404 O	23	17.4818969 -62.9949368
Yellow	107 E	7	17.4804778 -62.9909767	Purple	406 O	25	17.4799657 -62.9941541
Yellow	108 G	8	17.4793443 -62.9912135	Yellow	407 J	26	17.4796502 -62.992428
Yellow	109 I	9	17.4783967 -62.9914321	Yellow	408 O	27	14.4781832 -62.9931657
Purple	110 L	10	17.28660 -62.59519	Green	409 A	28	17.4790208 -62.9892031
Yellow	111 I	11	17.4769848 -62.9908343	Purple	410 N	29	17.4765442 -62.9919365
Yellow	112 F	12	17.476602 -62.9894543	Green	411 D	30	17.4768431 -62.9889689
Blue	203 F	14	17.4855448 -62.997837	Purple	412 I	31	17.4753703 -62.9897534
Blue	204 C	15	17.8452942 -62.9966948	Yellow	414 E	32	17.4869822 -62.9990622
Blue	205 A	16	17.4851242- 62.9956547	Green	415 B	33	17.4867857 -62.9978235
Yellow	302 H	17	17.29239 -62.59968				

Appendix V

Data sheet transect survey

Name researcher:		Date:	Time:	Site:
		Transect 1	Transect 2	Transect 3
Fish				
Grouper	Nassau			
	Yellowmouth			
	Yellowfin			
Parrotfish	Rainbow			
Snapper	Cubera			
	Mutton			
Seahorses	Slender			
Invertebrates				
	Queen conch			
	Spiny lobster			
Turtles				
	Resting			
	Swimming			
	Foraging			
Other				

Appendix VI

Material list research execution

Meadow verification:

- Boat
- 17 m rope (10mm diameter)
- Rope harness to attach to boat
- Data sheet
- Garmin echomap SV
- Manta board
- Gloves
- Fins
- Snorkel gear

D**ata collection:**

- SCUBA gear
- Dive computer
- Slates, clips & pencils
- Data collection sheets printed on waterproof paper
- Transect line (30 m)
- Underwater camera
- Surface marker buoy
- Quadrant
- Secci disk
- CastAway CTD

Appendix VII

Recorded species list

Common name	Scientific (family) name	Total count
Amber Penn shell	*Pinna carnea*	382
Banded Butterfly fish	*Chaetodon striatus*	1
Banded coral shrimp	*Stenopus hispidus*	3
Bandtail puffer	*Sphoeroides spengleri*	3
Bar jack	*Caranx ruber*	11
Bicoloured damselfish	*Stegastes partitus*	39
Blackear wrasse	*Halichoeres poeyi*	8
Blue chromis	*Chromis cyanea*	5
Blue head wrass	*Thalassoma bifasciatum*	59
Blue lip parrotfish	*Cryptotomus roseus*	1
Brittle star	*Chaetodon capistratus*	>34
Brown Garden eel	*Heteroconger longissimus*	71
Cardinal fish	*Apogonidae*	5
Caribbean reef octopus	*Octopus briaeus*	1
Caribbean reef squid	*Sepioteuthis sepioide*	1
Cero mackerel	*Scomberomorus regalis*	1
Chalk bass	*Serranus tortugarum*	27
Coney	*Cephalopholis fulva*	22
Cottonwick grunt	*Haemulon melanurum*	8
Diadema	*Diadema* antillarum	41
Filefish	*Monacanthidae*	4
Fireworm	*Amphinomidae*	177
Flame box crab	*Calappa flammea*	1
Flying gurnard	*Dactylopterus volitans*	2
Four eyed butterfly fish	*Chaetodon capistratus*	3
French angelfish	*Pomacanthus paru*	1
Fringed filefish	*Monacanthus ciliatus*	9
Frogfish	*Antennariidae*	1
Gold spotted snake eel	*Myrichthys ocellatus*	2
Golden coral shrimp	*Stenopus scutellatus*	2
Great Barracuda	*Sphyraena barracuda*	9
Green razorfish	*Xyrichtys splendens*	93
Hawk wing conch	*Strombus raninus*	1
Helmet conch	*Cassis tuberosa*	1
Hermit crab	*Paguroidea*	28
Honeycomb trunkfish	*Acanthostracion polygonius*	1
Hovering Dartfish	*Ptereleotris helenae*	1

Common name	Scientific (family) name	Total count
Juvenile razerfish (species unknown)	*Labridae*	14
Lantern bass	*Serranus baldwini*	93
Magnificent sea urchin	*Astropyga magnifica*	3
Mantis shrimp	*stomatopods*	3
Milk conch	*Strombus costatus*	13
Mottled flounder	*Bothus maculiferus*	1
Ocean surgeon	*Acanthurus tractus*	34
Pederson *cleaner shrimp*	*Ancylomenes pedersoni*	2
Pipefish	*Syngnathinae*	2
Queen conch	*Lobatus gigas*	10
Queen triggerfish	*Balistes vetula*	3
Red heart urchin	*Meoma ventricosa*	6
Red hind	*Epinephelus guttatus*	15
Rock beauty angelfish	*Holacanthus tricolor*	1
Rosy Razorfish	*Xyrichtys martinicensis*	278
Rough Box Crab (?)	*Calappa gallus*	1
Sand dollar	*Clypeasteroida*	3
Sandtile fish	*Malacanthus plumieri*	19
Sharpnose pufferfish	*Canthigaster rostrata*	122
Slender seahorse	*Hippocampus reidi*	2
Slippery dick	*Halichoeres bivittatus*	13
Smooth trunk fish	*Lactophrys triqueter*	5
Soap fish	*Serranidae*	1
Southern Stingray	*Hypanus americanus*	8
Spotted drum	*Equetus punctatus*	4
Squirrel fish	*Holocentrus adscensionis*	10
Swallowtail headshield slug	*Chelidonura hirundinina*	1
Tabacco fish	*Serranus tabacarius*	12
Tomtate	*Haemulon aurolineatum*	154
Trumpet fish	*Aulostomidae*	2
West Indian Fighting Conch	*Strombus pugilis*	17
West Indian sea egg	*Tripneustes ventricosus*	5
Yellow Head Wrass	*Halichoeres garnoti*	18
Yellow jaw fish	*Opistognathus aurifrons*	13
Yellowline Arror Crab	*Stenorhynchus seticornis*	9
Yellowtail snapper	*Ocyurus chrysurus*	37
	Total count	**1993**

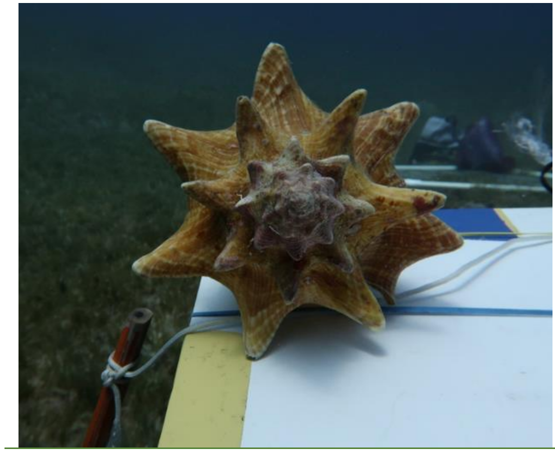
Appendix VIII

Summary of control variables

Control variables	Depth (meter)	Temperature (degrees)	Salinity (PSS78)	Visibility (ft)
Valid	31	31	25	31
Mean	14.33	29.16	35.99	88.97
Minimum	8.5	28	35.33	53
Maximum	18.5	30	36.22	100
	3 x < 10m 15 x 10 – 15m 13 x 10 – 18m			

Appendix IX

Photographs researched (protected) seagrass associated species



Photograph 1: queen conch, the posterior end of the shell.

Photograph 2: yellowtail snapper

Photograph 3: coney in different colour variations.

Photograph 4: red hind

Literature appendix

Becking , L. E., Bussel , T., Engel , M. S., Christianen, M. J. A., & Debrot , A. O. (2014). *Proximate response of fish, conch, and sea turtles to the presence of the invasive seagrass Halophila stipulacea in Bonaire* (456875). Retrieved from https://www.researchgate.net/publication/267865352_Proximate_response_of_fish_conch_and_sea_turtles_to_the_presence_of_the_invasive_seagrass_Halophila_stipulacea_in_Bonaire

Brule, T., & Ferreira, B. (2018). Yellowfin Grouper. Retrieved August 7, 2020, from https://www.iucnredlist.org/species/44683/46915269

Debrot, A. O., Henkens, R. J. H. G., & Verweij, P. J. F. M. (2017). *Staat van de Natuur van Caribisch Nederland 2017* (532788). Retrieved from https://library.wur.nl/WebQuery/wurpubs/532788

Dutch Caribbean Nature Alliance. (2014a). St. Eustatius National Marine Park. Retrieved February 21, 2020, from https://www.dcnanature.org/st-eustatius-national-marine-park/

Dutch Caribbean Nature Alliance. (2014c). Spiny Lobster. Retrieved February 21, 2020, from https://www.dcnanature.org/spiny-lobster/

de Graaf, M., Meijer zu Schlochteren, M., & Boman, E. (2014). *Non-Detriment Finding Regarding the Export of Queen conch (Lobatus gigas) from St Eustatius (Caribbean Netherlands)* (328935). Retrieved from https://edepot.wur.nl/328935

Headley, M., & Seijo, J. C. (2014, June). *A review of the methodologies used for monitoring and evaluation of the spiny lobster stocks in the WECAFC countries and the development of a common methodology*. Caribbean Regional Fisheries Mechanism. Retrieved from http://www.crfm.net/~uwohxjxf/images/Lobster_Methodology_Report.pdf

Lindeman, K., Anderson, W., Carpenter, K. E., Claro, R., Cowan, J., Padovani-Ferreira, B., … Zapp-Sluis, M. (2016a). Mutton Snapper. Retrieved August 7, 2020, from https://www.iucnredlist.org/species/12416/161245983

Lindeman, K., Anderson, W., Carpenter, K. E., Claro, R., Cowan, J., Padovani-Ferreira, B., … Zapp-Sluis, M. (2016b). Cubera Snapper. Retrieved August 7, 2020, from https://www.iucnredlist.org/species/12417/506633

Meijer zu Schlochtern, M. (2014). *Population status and reproductive biology of queen conch (Lobatus gigas) in the coastal waters around St Eustatius* (MSc Thesis nr. T 1916). Retrieved from https://www.dcbd.nl/sites/www.dcbd.nl/files/documents/Meijer%202014%20MSc%20Thesis%20AFI%20Melanie%20Status%20Queen%20Conch%20Statia%20JAN2014.pdf

Ministerie van Economische Zaken . (2013). *Nature Policy Plan for The Caribbean Netherlands 2013-2017*. Retrieved from https://www.dcbd.nl/document/nature-policy-plan-caribbean-netherlands-2013-2017

Pinault, M., Wickel, J., Nicet, J. B., & Chenoz, M. (2018). First record of the near threatened native seahorse Hippocampus reidi (Teleostei: Syngnathidae) in an ecosystem dominated by the invasive seagrass Halophila stipulacea in the Caribbean Sea. *Cybium: International Journal of Ichthyology*, *2018*(1081). Retrieved from https://www.researchgate.net/publication/328052531_First_record_of_the_near_threatened_native_seahorse_Hippocampus_reidi_Teleostei_Syngnathidae_in_an_ecosystem_dominated_by_the_invasive_seagrass_Halophila_stipulacea_in_the_Caribbean_Sea

Poiesz, P. (2013). *The status of the Caribbean spiny lobster (Panulirus argus) and its fishery in the coastal waters of St Eustatius*. (851208660120). Retrieved from http://www.spaw-palisting.org/uploads/files/cc1ec4a21cb152bbca46e7bdee2405678748cb9f.pdf

Sadovy, Y., Aguilar-Perera, A., & Sosa-Cordero, E. (2018). Nassau Grouper. Retrieved August 7, 2020, from https://www.iucnredlist.org/species/7862/46909843

Stoner, A. (1997). The Status of Queen Conch, Strombus gigas, Research in the Caribbean. *Marine Fisheries Review*, *59*(3), 14–33. Retrieved from https://www.researchgate.net/publication/242472717_The_status_of_queen_Conch_Strombus_gigas_research_in_the_Caribbean

Viana, I. G., Siriwardane-de Zoysa, R., Willette, D. A., & Gillis, L. G. (2019). Exploring how non-native seagrass species could provide essential ecosystems services: a perspective on the highly invasive seagrass Halophila stipulacea in the Caribbean Sea. *Biological Invasions*, *21*(5), 1461–1472. https://doi.org/10.1007/s10530-019-01924-y