Marine Scientific Assessment:

A Description of Montserrat's Nearshore Marine Environment

November 2018

AUTHORS:

ANDY ESTEP, *WAITT INSTITUTE*
JASON FLOWER, *SUSTAINABLE FISHERIES GROUP*
JACKIE MANDOSKE, *WAITT INSTITUTE*
KELSEY MILLER, *WAITT INSTITUTE*
ALDO CROQUER, *SIMON BOLIVAR UNIVERSITY*
VIKTOR BRANDTNERIS, *UNIVERSITY OF THE VIRGIN ISLANDS*
DR. MARK BOND, *GLOBAL FIN PRINT INITIATIVE*

Acknowledgments

The Waitt Institute prepared this Marine Scientific Assessment with essential analysis support provided by researchers from the University of California Santa Barbara, Sustainable Fisheries Group and University of California San Diego, Scripps Institution of Oceanography. The research for this report was led by Mr. Andrew Estep (Waitt Institute).

The Institute especially thanks the Captain and crew of the Waitt Foundation Research Vessel, *M/Y Plan b*, Waitt Institute staff, Joe Lepore and Michael Dessner, as well as Barbuda Fisheries and Codrington Lagoon National Park Officers, Roy Morris and Alexander Desuza for their support during the marine surveys in November 2015.

The Institute also expresses its gratitude to the Government of Montserrat, specifically Member of Parliament Mr. Claude Hogan, Director of Agriculture Ms. Melissa O'Garro, Chief Fisheries Officer Mr. Alwyn Ponteen, and other members of the Blue Halo Montserrat Steering Committee who provided key support, resources and information. Special thanks goes to the Disaster Management and Control Agency manager Mr. Billy Daroux, and Montserrat Volcano Observatory manager Mr. Rod Stewart for their assistance in ensuring safety throughout the expedition. In addition, the Institute thanks Dr. Ayana Johnson and Ms. Stephanie Roach who were instrumental in this research. The contents of this report, including any errors or omissions, are solely the responsibility of the Waitt Institute.

About the Waitt Institute

The Waitt Institute endeavours to ensure the economically and culturally sustainable use of ocean resources. The Institute partners with governments committed to developing and implementing comprehensive, knowledge-based, community-driven solutions for sustainable ocean management. Our goal is to benefit coastal communities while restoring fish populations and habitats. Our approach is to engage stakeholders, provide the tools needed to design locally appropriate policies, facilitate the policymaking process, and build capacity for effective implementation of management measures to ensure their long-term success.

About Blue Halo Montserrat

Blue Halo Montserrat is a partnership between the Government of Montserrat and the Waitt Institute, and is a part of the Blue Halo Initiative that aims to empower communities to restore their oceans, and use ocean resources sustainably, profitably, and enjoyably for present and future generations. The Initiative engages stakeholders in a knowledge-based, community-driven approach. Governments, local communities, and scientists partner to develop and implement ocean policies, such as sustainable fishing practices and comprehensive ocean zoning. The Waitt Institute provides the toolkit, and partner governments provide the political will.

An electronic retrievable copy (PDF file) of this report may be obtained at no cost from the Waitt Institute website at www.waittinstitute.org.

Cover Image: Montserrat Reef (© Emanuel Goncalvez, 2015). Other report photos by Joe Lepore & Shayna Brody.

BLUE HALO MONTSERRAT

WAITT INSTITUTE

Table of Contents

Article I. Table of Contents

EXECUTIVE SUMMARY

Like many nations in the Eastern Caribbean, Montserrat is composed mainly of marine environments with only one percent of the territory being land. The island is composed of a complex of three volcanoes: the active Soufriere Hills and the dormant Silver and Centre Hills. Since 2000, the human population has been stable at approximately 5,000. The island's economy is mainly supported by the UK with a small tourism market and artisanal agriculture and fisheries sectors, and low-density infrastructure.

Significant natural disasters have impacted Montserrat's environment, which continues to be influenced by anthropogenic impacts. In 1989, Hurricane Hugo made landfall as a Category 4 hurricane, causing major destruction on land. Anecdotal reports indicate that all native seagrass beds were scoured away as a result of the storm. Additional impacts on the marine environment are currently unknown. The Soufriere Hills volcano began to erupt in in 1995, releasing large amounts of volcanic ash and highly acidic, nutrient-rich pyroclastic flows into the nearshore waters and burying the largest mangrove forest on the island along with considerable sections of coral reef habitats. Active eruptions continued through 2012. The leaching of volcanic sediments and lahars from runoff continue to the present day, impacting nearshore water quality.

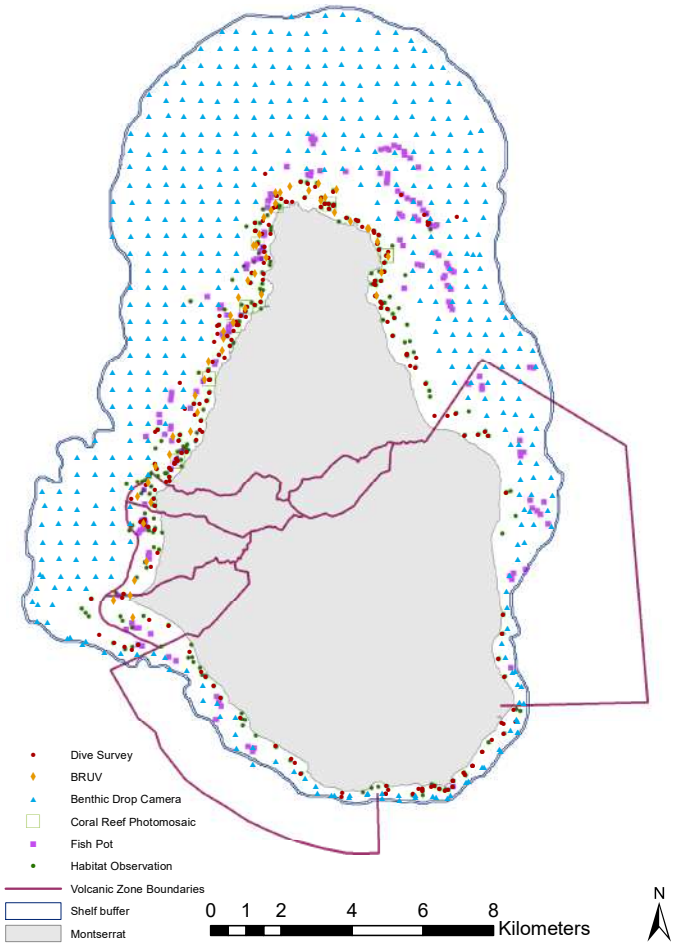


Figure 1. Scientific Assessment survey sites from all studies between 2015-2017.

While the marine environment exhibits many of the common symptoms of decline documented at the regional and global levels (bleaching, disease, overfishing, pollution, etc.), the condition of marine ecosystems prior to disturbances and colonialism remain unknown. A robust scientific history does not exist. Notably absent are quantitative data that describe Montserrat's marine ecosystems prior to the disturbances described above. Despite this uncertain baseline, natural and anthropogenic impacts are clearly evident.

This study aims to create a baseline for the current distribution and condition of Montserrat's shallow, nearshore marine ecosystems in order to inform the establishment of a marine spatial plan and the future of marine resource management in

Montserrat. This scientific assessment of Montserrat's nearshore marine environment provides detailed information on the benthic habitats, flora and fauna, and fish populations surveyed. We conducted 212 surveys of shallow (<30m depth) hard-bottom and seagrass sites to quantify the benthos and abundance of invertebrates. We surveyed fish species at 164 of these sites and conducted rapid habitat observations at an additional 200 sites to inform broader habitat mapping. Using drop cameras, we surveyed mesophotic habitats (in this case 30 – 100m depth), recording the seafloor at 481 sites around the island. We deployed baited remote underwater videos (BRUVs) at 50 locations at depths ranging from 10 – 25m to record sharks and rays present around Montserrat. All surveys, displayed in Figure 1, were conducted by the Waitt Institute between 2015 and 2017, with the SCUBA surveys and rapid habitat observations completed in October 2015. Mesophotic habitats were recorded in July 2016 and August 2017, while BRUVs were deployed from 20-29th of November 2016. Additionally, to map and understand the patterns of marine resource use, 122 qualitative surveys were completed with fishers and divers between January and September 2016. All field observations were compiled and used to update Montserrat's existing benthic map and to extend its range out to 100 meters of depth (Figure 2).

Our surveys of shallow sites showed that reef and other hard-bottom habitats were dominated by turf algae (23-50% cover), macroalgae (8-18%) and non-biogenic substrates (e.g. rocks, rubble, sand; 16-40% cover). Coral cover averaged only 10%, with an average of 15 coral species, hence 'coral reef' habitat is actually dominated by algae. This finding is common across many locations in the Caribbean. Higher coral cover (18-21%) and greater species diversity (up to 20 hard coral species) were found on reefs off the north coast and at the southeast end of the islands. Giant barrel sponges were noted as providing 3-dimensional structure to the reefs at many sites. Seagrass beds constituted 19% of sites surveyed, and were composed of the invasive seagrass *Halophila stipulacea*. In the southwest and east sides of the island, colonized volcanic boulders form a unique habitat.

We found hard bottom, mesophotic zone (30 - 100m) habitats at the northeast side of the island shelf, and also offshore from Little Bay in the northwest. Fleshy macroalgae and sponges dominate these survey sites, though corals of the genera Agaricia, Montastraea, and Orbicella were found in low

abundances. The remainder of the mesophotic shelf area surveyed was composed of soft bottom, with a few seagrass beds of the invasive species *Halophila stipulacea*.

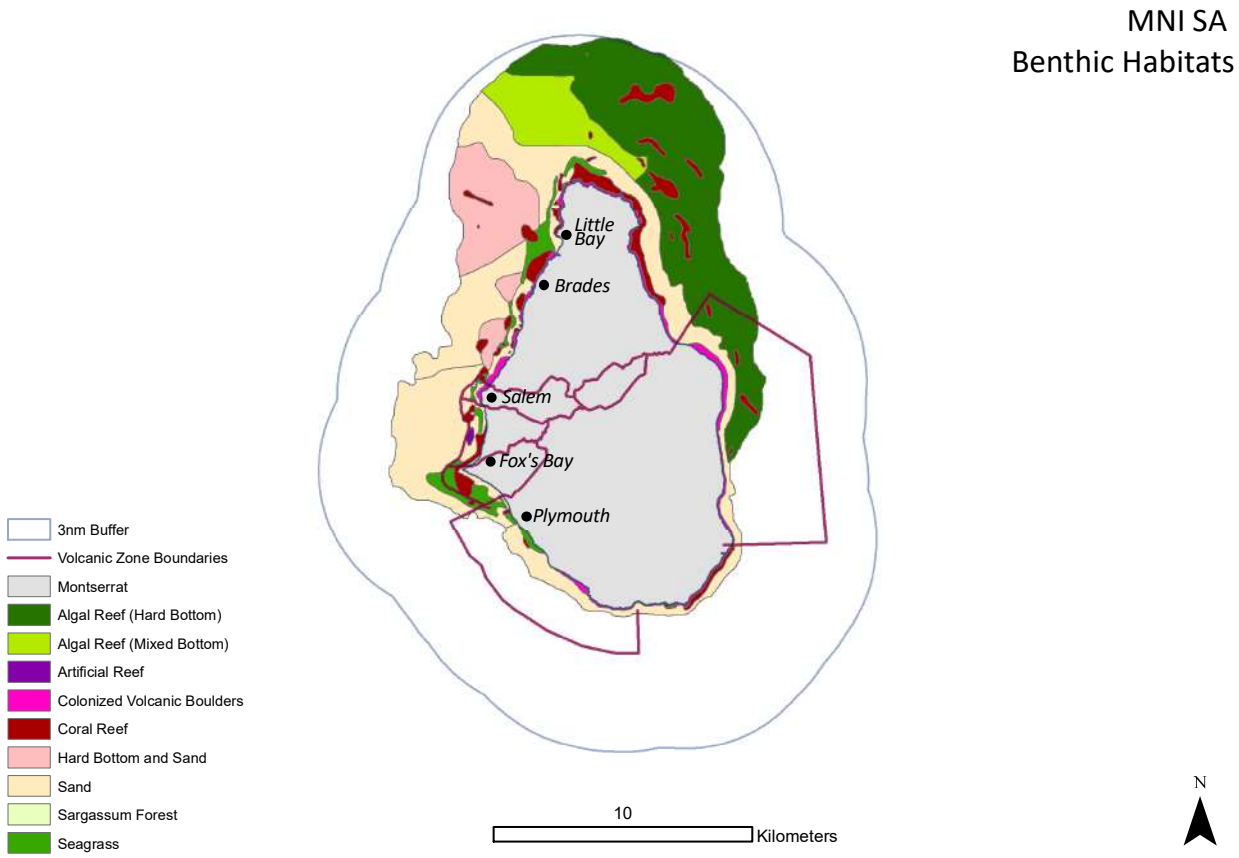


Figure 2. Benthic habitats of Montserrat. This map was drafted using knowledge from previous studies and over 600 field data points collected during this study.

One hundred and fifty-seven reef fish species were observed during the SCUBA surveys, with seagrass sites having fewer species than other habitat types. Reef fish biomass was observed to be highest at the southern end of the island and along the west coast, extending around the north end of the island. The average island-wide fish biomass of 94 gm^{-2} (SD = 121 gm^{-2}) is lower than the average biomass at other island sites in the region. This could be due to the impacts of volcanic eruptions and fishing pressure. Parrotfish biomass is also low (5.1 gm^{-2}, SD = 7.3 gm^{-2}) compared to regional averages, and two-thirds of parrotfish are less than 15 cm in length. Large groupers and snappers were absent from the survey sites. Two-thirds of fish classified as carnivorous were less than 25 cm in length. These results strongly suggest fishing pressure is impacting fish populations by selectively removing larger individuals. Invasive lionfish were found at 24% of sites surveyed as both juveniles and adults suggesting they are well established, yet their density is less than half that found on reefs in the Bahamas.

Sharks were present on 18% of the BRUV deployments and rays on 50%, with 3 species of each seen; Southern stingray (*Hypanus americanus*), Roughtail stingray (*Dasyatis centroura*), and yellow round ray (*Urobatis jamaicensus*), Caribbean reef shark (*Carcharhinus perezi*), nurse shark (*Ginglymostoma*

cirratum), and lemon shark (*Negaprion brevirostris*). Reef shark presence was half that found in a well-protected MPA in Belize, possibly indicating that numbers in Montserrat have the capacity to increase.

Data from qualitative interviews indicate that fishing pressure around Montserrat is highest along the northwest coast, close to the principal fishers' landing site at Little Bay. Fishing pressure was indicated to be lowest off the north and east coasts, potentially due to rougher seas and longer travel times to reach these areas.

Although we have drawn some conclusions from the data collected, discussions of change in the marine environment are limited due to the lack of comparable historical data, particularly from before the impact of the volcanic activity starting in 1995. Compared to other Caribbean islands where anthropogenic impacts are dominant, the natural impact of the volcano has probably done more to shape the marine environment in Montserrat. However, data from the fish surveys strongly suggest that fishing pressure is impacting fish populations. It is clear that Montserrat's marine resources could be managed more sustainably to increase the resilience of Montserrat's marine ecosystems to on-going natural stressors, while improving the quality of marine ecosystems and livelihoods of those who depend on them.

However ambiguous the causes of declines in Montserrat's marine resources are, we find a clear pattern in areas that have developed resilience to these stressors over time. This study shows, across numerous parameters, that areas to the north from northwest bluff to Pinnacles and to the southeast from Old Fort Point to Roche's Bluff have maintained the most diverse and robust resources. These areas should be given the highest priority to ensure the use and livelihoods that rely on the health of its waters can continue.

We recommend that 1) areas to the north and southeast, or significant portions of them, are placed in no take marine reserves; 2) that Montserrat strengthen its ecological and fisheries monitoring programs to better understand the status and trends of their resources and support more effective and adaptive management; and 3) exploitative use of Montserrat's natural environment should be managed conservatively, factoring in the significantly reduced carrying capacity of the environment caused by immense and continuous impacts from volcanic activity.

I. Introduction

Blue Halo Montserrat is a partnership between the Government of Montserrat, the people of Montserrat, and the Waitt Institute. The goal of Blue Halo Montserrat is to foster the sustainable, profitable, and enjoyable use of ocean resources for current and future generations. In February 2015, the Government of Montserrat and the Waitt Institute signed a Memorandum of Understanding to develop and implement a Sustainable Ocean Policy for Montserrat that is based on scientific, social, and economic data.

The purpose of the Marine Scientific Assessment is to inform the development of a Sustainable Ocean Policy in order to improve the health of marine ecosystems so they can sustainably support coastal economies and livelihoods. Here we describe the diversity, distribution, and abundance of marine habitats and their fish communities. We provide insight into both natural and anthropogenic factors impacting Montserrat's marine environment. The report considers how the effects of volcanic eruptions, fishing, and development have impacted the marine environment and what implications these impacts have for the long-term health of Montserrat's marine environment.

The Assessment synthesizes data from three sources: First, researchers conducted marine surveys to evaluate the abundance, distribution, and quality of distinct habitats and their associated fish communities at over 600 sites around the island. Second, the Waitt Institute and partners conducted a spatial analysis of ocean uses and how people value those ocean-use areas. The spatial analysis was based on 122 interviews with fishers and divers on Montserrat who provided information on their fishing/diving locations and the importance of each area. Third, the Marine Scientific Assessment incorporates existing information from peer-reviewed literature to further evaluate the state of Montserrat's marine resources and the value of these systems for the people of Montserrat.

In addition to the Marine Scientific Assessment, the Waitt Institute and its partners conducted community consultations, an analysis of Montserrat's legal system, a marine science literature review, a fisheries stock assessment, fisheries projections modelling, and an analysis of gear-based fisheries management tools for the Caribbean. Collectively, these reports informed our design of policy recommendations to achieve a Sustainable Ocean Policy.

In the following Assessment, we present the research methodology for each of the three sources of data (Section Two). Section Three summarizes the results of the research. Finally, Section Four utilizes the results to evaluate and discuss the implications of these findings for the future of the island's marine resources.

Coastal habitats in Montserrat (e.g. coral reefs, seagrass beds, volcanic boulders, etc.) are unique compared to other Caribbean islands. For example, hard-bottom substrates are composed of volcanic rocks of different forms and sizes that add high spatial heterogeneity, rendering highly complex habitats in which corals are not necessarily the foundation species (i.e., those species used by others as shelter). Live coral cover averages below 10%, and large barrel sponges often provide significant structural complexity to the reefs. The presence of pyroclastic flows also makes the hard-bottom habitats of Montserrat distinct from other Caribbean ecosystems. Finally, seagrasses thrive in a range of depths,

from very shallow habitats, up to 20m depth. Thus, in view of the uniqueness of these habitats, the proper assessment of their status and distribution was extremely important to achieving the goals of Blue Halo in Montserrat.

1.1 BRIEF OVERVIEW OF MONTSERRAT'S NATURAL HISTORY AND GEOLOGICAL CONTEXT

According to Myers (2013), Montserrat is a mountainous and heavily forested island that has been dominated by an active volcano, which has changed both terrestrial and marine ecosystems over the past 17 years. Unlike many marine habitats of the world where stresses are mostly man-made, it has been the volcanic activity that has most impacted this area with far less influence from anthropogenic stressors (Myers 2013).

Montserrat's volcanic landscape is rugged, with steep hillsides and an unprotected coastline lacking natural harbors (Cook et al. 1981). The coastal shelf along the southern portion of the island is narrow, and upwelling events have been reported to result in highly-productive waters (SFG 2015). Sedimentation is largely concentrated on the eastern and western coasts (Wild et al. 2007). Furthermore, most beaches are exposed to high wave energy and prone to erosion (Godley et al. 2004). On the southern half of Montserrat is a narrow coastal shelf with depths of up to 200m located only 650m from the shoreline, but a gentler slope is found along the north and west coasts (Godley et al. 2004).

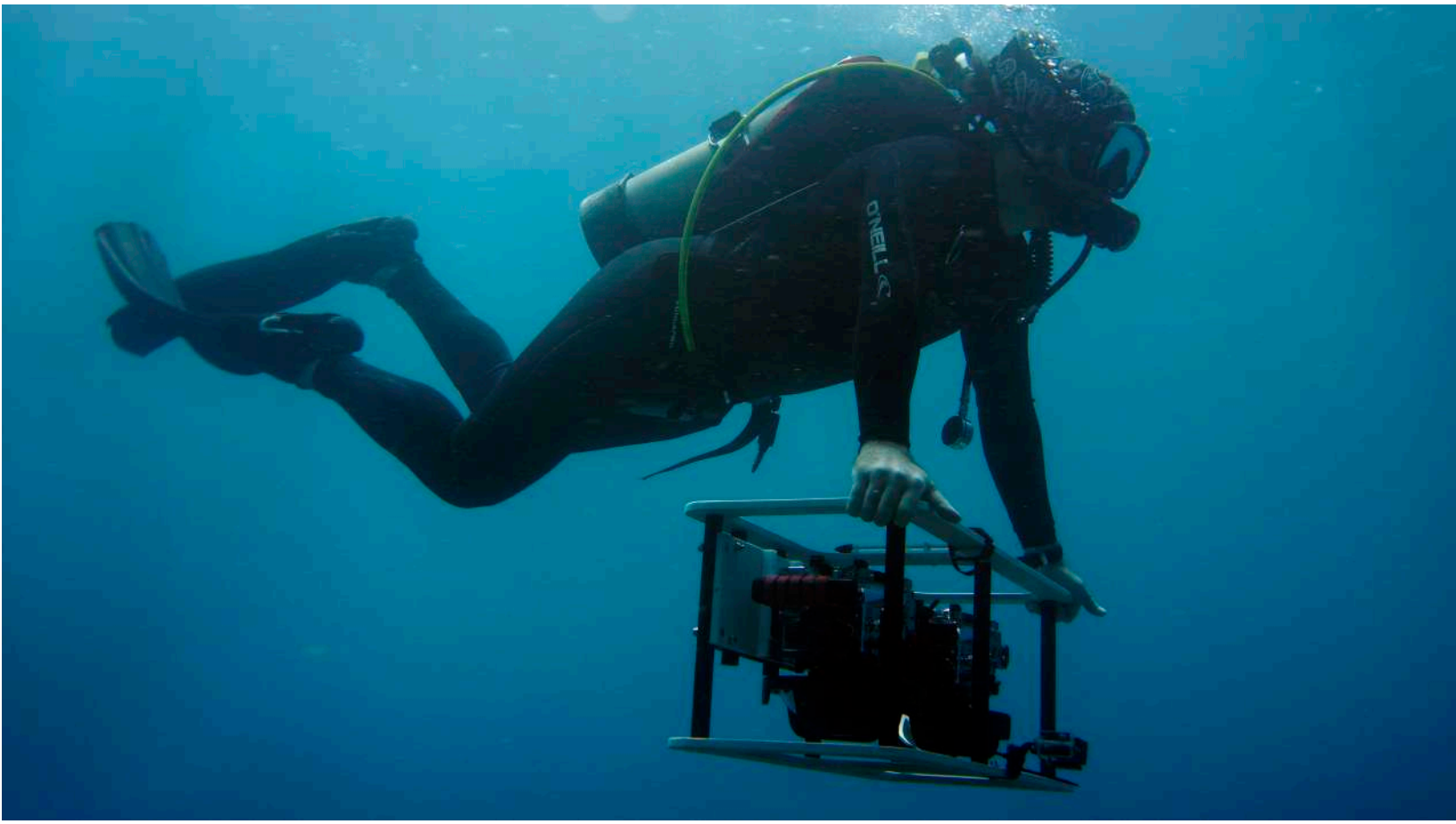
The Island of Montserrat has been shaped by both ancient and recent volcanic activity, as such its marine ecosystems have been heavily impacted by a series of disturbances originated by these eruptions (Carey et al. 2014). High-resolution bathymetric mapping around Montserrat revealed the importance of volcanic collapses that generate large landslides, known as debris avalanches, as a critical mechanism for transporting large amounts of volcanic material into the marine environment (Deplus et al. 2001; Lebas et al. 2011). Because of its unique geological and ecological value, Montserrat is

considered one of the most important Caribbean islands to practice alternative tourism (Bovey et al. 1986; Weaver 1995).

1.2 MONTSERRAT SCIENTIFIC ASSESSMENT – HISTORICAL SCIENCE SUMMARIES

Appendix C contains a detailed summary of relevant studies regarding the marine environment of Montserrat that were used to orient the marine science assessment. The studies evaluated in Appendix C are outlined below.

1. Bovey et. Al 1986: Montserrat National Park: Ecological and Cultural Feasibility Study
2. JNCC 1991: Montserrat
3. IRF 1993: Montserrat Environmental Profile: *An Assessment of the Critical Environmental Issues Facing Montserrat With an Action Agenda for the Future*
4. Brosnan et al. 1997: The Coral Reefs of Montserrat, West Indies Diversity, Conservation, and Ecotourism
5. Wild et. Al 2007: Towards Multi-user Marine Management in Montserrat – Marine Ecosystem Survey Chapter
6. Myers 2013: Coral Reefs of Montserrat
7. MNI Progress Report: Coral Cay Conservation Marine Progress Report Montserrat 2013-2016



II. METHODOLOGY

From 2015 to 2017, the Waitt Institute conducted a Marine Scientific Assessment (MSA) to characterize the composition and distribution of Montserrat's nearshore (<100m) marine resources, understand patterns of use, and discern natural and anthropogenic impacts. The results of the scientific assessment provided data to facilitate the development of a marine spatial plan and supporting legal framework. This section briefly describes the data collection methodologies utilized in the MSA.

The MSA methodology consists of the following sections: A) Visual Surveys of Nearshore Marine Ecosystems to evaluate benthic, reef fish, and macroinvertebrate communities, B) Three Dimensional Models and Orthographs of Coral Reefs to visualize the marine benthic environment, C) Drop Camera Surveys in Mesophotic Habitats of Montserrat to characterize deeper marine environments, D) Benthic Habitat Mapping to improve existing benthic map data, E) Human Use of Nearshore Marine Resources to determine fishers' and divers' valuations of Montserrat's ocean resources, and F) Shark and Ray Diversity, Abundance, and Distribution on Coral Reefs to quantify elasmobranch species.

2.1 MARINE SCIENTIFIC ASSESSMENT SITES

Starting in November 2015, the Waitt Institute partnered with researchers from Simón Bolívar University, University of the Virgin Islands, University of the West Indies Mona, Discovery Bay Marine Lab, Barbuda Fisheries, Codrington Lagoon National Park, Moss Landing, and Oregon State University to conduct detailed marine surveys around the island of Montserrat evaluating hard bottom and seagrass habitats. The following three indicators provided an estimate of the health and condition of the marine communities at each site: (1) the abundance, diversity and health of reef building organisms and their dominant competitors, including the density of juvenile corals, (2) the diversity, abundance, and biomass of all reef-associated fishes, and (3) the presence of mobile invertebrates such as lobsters, sea urchins and conch.

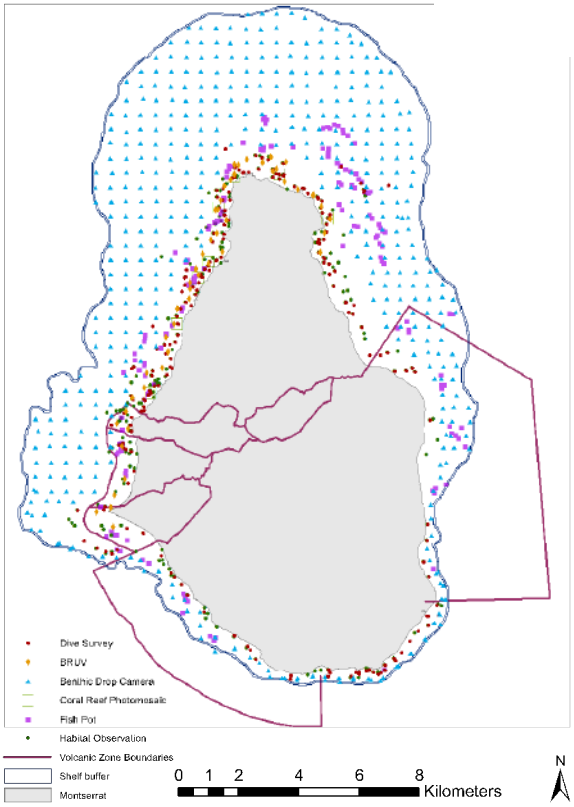


Figure 3. Survey sites for all data collected during the Montserrat Scientific Assessment.

We conducted detailed marine surveys on SCUBA at 212 nearshore sites (Figure 3). Sites were located randomly and targeted between 5m and 20m depth in hard bottom and seagrass habitats. We sampled one 30-meter transect (Figure 2) following, where possible, the guidelines established by the Global Coral Reef Monitoring Network (GCRMN). Due to the small area of hard bottom habitats, GCRMN methods were modified to design a more rapid assessment that would characterize a larger area. Appendix D provides the GCRMN guidelines. Over 200 rapid habit observations were also conducted to describe the distribution of non-target habitats (typically sand, rubble, or mixed hard bottom sites with less than 50% hard bottom). We made observations using SCUBA, free diving, drop cameras, or sonar during the November 2015 expedition.

To evaluate deeper waters (30 – 100 meters depth), we collected imagery of the seafloor at 481 sites in July 2016. We used these data to provide a coarse quantitative and qualitative description of the abundance, distribution, and quality of upper mesophotic (30 – 100m) habitats in Montserrat. This investigation of Montserrat's 108 square kilometre shelf helped us to better understand how the upper mesophotic habitats may play a significant role in supporting the fish communities of Montserrat and act as a buffer to volcanic impacts.

Apex predators are a functionally important part of the marine environment. We worked with the Global Fin Print Initiative to collect baited remote underwater video camera (BRUV) data for information on the diversity, abundance, and size classes of sharks and rays around Montserrat at 50 sites.

The following section provides descriptions of the site design and field methods used during primary data collection events in the MSA.

2.2 VISUAL SURVEYS OF NEARSHORE MARINE ECOSYSTEMS

We implemented a rapid assessment method using SCUBA to collect quantitative and qualitative information on benthic, fish, and macroinvertebrate communities throughout all waters less than 20m depth. We surveyed 212 survey sites at 5-20m depth around the entire island with a focus on hard bottom and seagrass habitats. At each site we used five proxies to describe the status of the habitat: (1) benthic cover of different substrates (i.e., live cover of different sessile invertebrates [e.g. corals, octocorals, sponges and hydrocorals], (2) species richness, (3) the density of juvenile corals, (4) presence/absence of health indicators and (5) the abundance, species composition and biomass of fish. Figure 4 illustrates the survey design at each site, which consisted of combining quantitative (i.e., photo quadrats to determine benthic cover, juvenile corals, and fish biomass) and qualitative assessments (descriptions of the habitat type and relief).

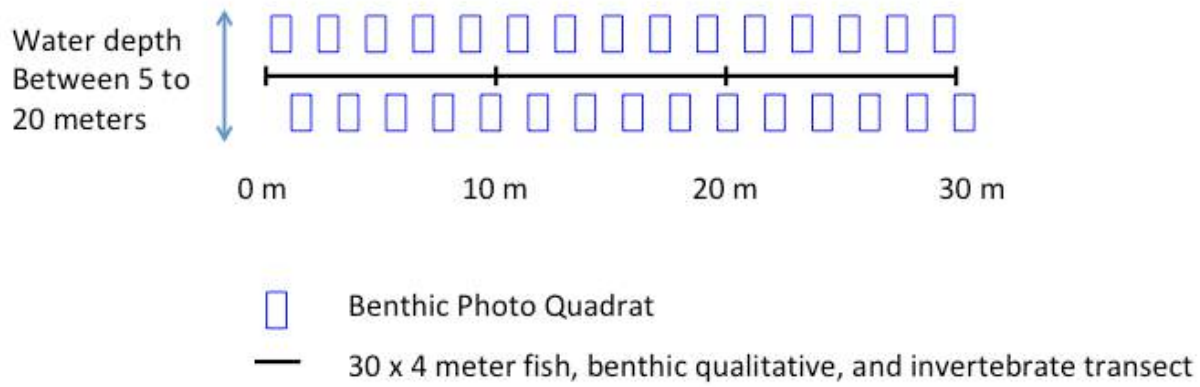


Figure 4. Marine survey design to describe benthic, fish, and invertebrate communities at each dive site.

The surveys focused on more extensive sampling along the north side of the island (60% of the survey sites) and habitats closer to the shoreline (92% of the survey sites, Figure 5). Sampling effort was constrained by natural factors, including the bathymetry of the island that contains precipitous drop-offs, and the uneven distribution of the different habitat types and marine communities across the island.

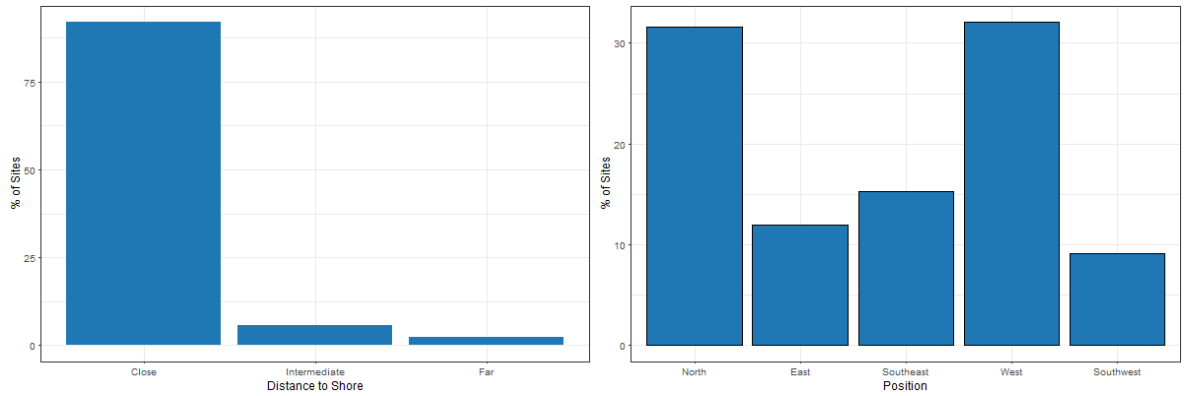


Figure 5. Marine survey design to describe benthic, fish, and invertebrate communities at each dive site.

2.2.1. BENTHOS: REEF BUILDING ORGANISMS AND THEIR DOMINANT COMPETITORS

Benthic cover is the percent of the seafloor that is covered by a given species or group of organisms. We evaluated percent cover of reef building organisms (hard corals and crustose coralline algae) and their dominant competitors (fleshy macroalgae and turf algae) along the transect lines as described previously. We estimated benthic cover from analysis of thirty 90 x 60cm photo quadrats taken at every other meter along each transect. Using the Coral Point Count with Excel Extensions software (CPCe; Kohler and Gill, 2006), a total of 25 points were randomly assigned to each image and then identified to broad functional groups (e.g. hard corals, octocorals, sponge, fleshy macroalgae and macro algae (see Appendix A). Hard corals were identified to the lowest taxonomic level possible. This approach follows the benthic classifications of the GCRMN protocol. We averaged values to produce site-wide estimates of species abundance and cover.

We determined abundance of juvenile corals from image analysis of the photo quadrats. For this, five 90 x 60cm photo quadrats were randomly selected from each belt transect surveyed per site. We analysed each image using Microsoft viewer to count each coral with a maximum diameter of 4cm. Each individual coral was classified to genus level when possible. The density of juvenile corals was used as a proxy of individuals that settled and survived to the size of 4 cm (e.g., juvenile corals at early stages of their life cycle). Thus, this is a proxy of replacement success of coral populations in Montserrat.

The benthic surveyor at each site also collected qualitative data. All mature coral species within the 30 x 2m belt transect were identified to species level using Humann & DeLoach 2002 as a reference. These surveys also recorded the presence or absence of coral bleaching, coral disease, and coral recruits, and the diversity of sponges and habitat complexity at each site.

2.2.2. FISH BIODIVERISTY, ABUNDANCE, AND BIOMASS

To measure fish biomass, we visually identified fish along each transect line (utilizing a belt transect approach of 30 meters in length by 4 meters wide) to the lowest taxonomic level possible and recorded fish sizes to the nearest centimeter. Survey times were limited to approximately 12 - 15 minutes per transect. These data provide an estimate of the abundance, size structure and biomass of all fish species at each site.

For the purposes of comparing biomass, density and species richness between sites on the island, sharks (only 2 nurse sharks were observed) and pelagic species were omitted following the method of MacNeill et al (2015). Pelagic species are not reef resident, and can therefore distort estimates of biomass, density and species richness. Although nurse sharks are reef resident, their extremely high biomass compared to other reef species can also distort comparisons.

Fish species were assigned to trophic groups of carnivore, invertivore, herbivore or planktivore, based on the diet as determined from the literature (Appendix B). The benthic habitat map was used to determine the habitat type at sites surveyed, and differences in fish species richness and biomass between habitat types were tested using one-way ANOVAs. Tukey's HSD post-hoc test was then used to determine which habitats differed if the ANOVA result was significant.

2.2.3. MOBILE INVERTEBRATE ABUNDANCE

Figure 6. Spiny lobsters (*Panulirus argus*) on reef. Photo credit: Emanuel Gonçalvez

Common mobile invertebrates on Caribbean coral reefs include sea urchins, conch and lobster. Many species of sea urchin, especially the historically common long-spined sea urchin (*Diadema antillarum*), are important herbivores on Caribbean reefs. These herbivores help prevent the overgrowth of macroalgae (large fleshy algae that compete with coral for seafloor space). As such, sea urchins can play an important role, comparable to that of seaweed-consuming herbivorous fishes. We also recorded commercially exploited species, including queen conch (*Strombus gigas*) and lobster (*Panulirus argus*). Abundance of mobile invertebrates was very low at all survey sites, and so for simplicity only their presence/absence is reported. Transect dimensions for mobile invertebrate surveys were 30 meters long by 2 meters wide.

2.3 THREE DIMENSIONAL MODELS AND ORTHOGRAPHS OF CORAL REEFS

This research initiative employs novel approaches for studying coral reef community dynamics through the application of underwater photomosaic technology. Working with colleagues from the University of

Miami, researchers at Scripps Institution of Oceanography have built a camera system that allows images of large swaths of the reef surface to be captured. By combining these image-based data with reliable information about the composition of the fish community, the general oceanography, and the human population of each location, we can begin to elucidate the conditions that are more (or less) conducive to the maintenance of 'healthy' coral reefs. Eight sites were evaluated using this method, with one model generated per site.

2.3.1. THREE DIMENSIONAL MODELS CREATED USING STRUCTURE-FROM-MOTION TECHNOLOGY

Benthic photomosaics were completed to collect a permanent record of reef habitat on a large scale ($100m^2$). The benthic photomosaic system consists of a diver-operated camera system, including dual SLR cameras and a video camera mounted to a custom frame. The first still camera is setup to use a wide-angle 18 mm focal length lens to ensure adequate overlap among adjacent images, while the second still camera uses a 55 mm focal length lens to capture images with sub-cm resolution. The high-resolution wide-angle video camera serves as a backup in the event that images from the still cameras are compromised. To obtain the large-area imagery covering 10m x10m, the diver operating the camera system swims in a gridded pattern while maintaining approximately 1.5 m distance from the benthos and recording images at one second intervals throughout the plot. A pair of lasers is mounted within the frame of the 55 mm camera to provide scale in the high-resolution imagery. Images are later stitched together using custom analytical algorithms to create a single image file representative of the $100m^2$ plot.

2.3.2. ORTHOGRAPHS STITCHED USING MOSAIC TECHNOLOGY

Each mosaic is stitched together from approximately 2,000 photos acquired by swimming back and forth over the reef as described above. Once stitched, each mosaic is ecologically post-processed by hand-tracing individual coral colonies and algae species of interest. Once individual colonies are traced and identified by researchers, the data are exported and run through custom algorithms to calculate standard metrics, including percent coral cover and more complex spatial statistics.

2.4 MESOPHOTIC HABITATS OF MONTSERRAT (BENTHIC DROP CAMERAS)

Characterization of the mesophotic realm of Montserrat was carried out over 14 days on two field expeditions between July of 2016 and August of 2017. We collected imagery of the benthic environment by deploying a drop camera rig to the seafloor. This approach allows rapid and inexpensive evaluation of habitat in areas below SCUBA diving depths. We conducted drop cam deployments along the shelf area from Fox's Bay Beach northward and around to Margarita Beach as this region represents the largest portion of Montserrat's shelf system. The specific site selection process relied largely on using historic naval charts due to a lack of modern bathymetry data for the Montserrat shelf. A polygon overlaying the 30-100m depth range of the chart was created and used to constrain a 478 m^2 grid of sampling points. The center point for each grid cell was taken as the sampling point, resulting in a total

of 481 surveyed sites. Where possible, a GPS location of the camera drop was also recorded during sampling. Sampling was carried out following an updated protocol from Smith et al. (2016).

The drop camera system consisted of two GoPro Hero 4 cameras, set to capture images continuously every 10 seconds, which were placed into deep water housings (Benthic2, GroupB Inc.) and attached to an armature and fin—one pointing outward and the other directly downward. The camera system was attached three meters above a soft weight belt and balanced with Styrofoam buoys to keep the cameras from contacting the benthos. This buoy system also reduced the fall rate of the camera and housing to below 1m/s, which prevents unnecessary benthic damage. Sampling was achieved by operating the vessel to within 10m of the sampling point and deploying the armature over the side of the boat while capturing a precise deployment location. Sixty seconds after contacting the benthos, the camera was retrieved from the water by operators on the vessel pulling the cameras up by hand. This process ensured the capture of at least one clear benthic image covering an area of approximately 14-16m^2 depending on the current, and descriptive images during the camera's fall and retrieval. These photographs taken during the descent and ascent of the camera system can also be used to inform the scale of any features captured in the bottom photography.

Depth was measured using different methods for each field expedition. During the July 2016 mission, a handheld digital sonar unit (Vexilar Inc.) was used, which recorded in feet. For the August 2017 mission, a Star-Oddi DST milli-TD was added to the drop camera system that recorded temperature and depth (in meters) every ten seconds throughout each sampling day.

We estimated benthic cover using the Coral Point Count with Excel Extensions software (CPCe; Kohler and Gill, 2006) to analyse the clearest image from each site. Fifty random points were laid over each image and the uppermost biotic or abiotic feature under each point was categorized (Smith et al. 2016). The proportion of each benthic category represents the makeup of each sampling site.

In addition, we carried out opportunistic camera tows using a live-view video camera system. A video camera attached to a video cable was lowered over the side of the boat and the camera was maintained at 1 to 5 meters above the bottom. An operator watched the live feed on a screen and recorded videos when the camera passed over any features of interest. Another operator recorded GPS position, depth, and descriptive notes regarding the benthic habitats at each location.

2.5 BENTHIC HABITAT MAPPING

We conducted benthic habitat mapping using visual surveys and remote sensing techniques to improve existing benthic maps and extend information past the 100m depth contour. A 2016 benthic habitat map was digitized by hand using data from the marine survey, habitat observation, fish trap, and drop camera sites. Data from Google Earth aerial imagery was exported and georeferenced in areas where visibility allowed for accurate photo interpretation. A small area of multi-beam imagery was also available from the north west portion of the shelf. Preliminary context for mapping was gleaned from benthic maps in IRF 1993 and Wild et. al 2007. These maps provided valuable insight into dominant benthic features and the interpretation of site observations.

Benthic classification was divided into two categories: bottom type, and habitat. Bottom type delineates substrate composition, categorized as hard bottom, soft bottom, or mixed bottom (a combination of both hard and soft bottom). Habitat refers to the dominant habitat per polygon and describes a combination of the geoform and biological cover. Benthic classification identified nine distinct habitat classes within the survey area: (1) algal reef (hard bottom), (2) algal reef (mixed bottom), (3) artificial reef, (4) colonized volcanic boulders, (5) coral reef, (6) hard bottom and sand, (7) sand, (8) sargassum forest, and (9) seagrass habitats.

The benthic habitat map was not drafted with any minimum mapping unit and has yet to undergo an accuracy assessment. Ground truthing was conducted using all field survey points where habitat classifications were made or where georeferenced photos were collected.

2.6 HUMAN USE OF NEARSHORE MARINE RESOURCES

In addition to the marine surveys, researchers interviewed fishers and divers to gain a better understanding of ocean use patterns, and how these ocean users value Montserrat's marine ecosystems. These surveys helped establish an inventory of areas that were most used and most valued by fishers and divers. To conduct the surveys, the Waitt Institute partnered with SeaSketch. Between January and September 2016, the team completed 122 surveys with 53 fishers and 69 divers. These surveys were independent from the Ocean Stakeholder Survey and the General Public Survey that supported the community consultation report (Waitt Institute 2016).

Each survey instrument asked fishers to draw their fishing grounds on a map using Seasketch, an interactive mapping tool (McClintock, 2013). In addition, researchers asked fishers to identify how much they value each area where they fish or dive. We compiled all responses to generate island-wide maps indicating which areas were fished and valued the most. This resulted in two types of maps: (1) a fishing pressure map indicating areas of use; and (2) a fishing value map indicating the importance of sites to fishers. Because not all of Montserrat's fishers participated in this survey, these data show relative patterns (i.e., "more" vs. "less" fished areas), but do not reflect total fishing activity or intensity. Researchers repeated the same process for divers (SCUBA divers, free divers/snorkelers) producing the same types of maps as those described above for fishing.

2.7 SHARK AND RAY DIVERSITY, ABUNDANCE, AND DISTRIBUTION ON CORAL REEFS

Many of the world's top ocean predators are experiencing severe population declines. Aside from a handful of iconic teleost fish groups (e.g. tuna, *F. Scombridae* and swordfish, *F. Xiiphidae*), there is a lack

of data on the population status of many of the world's commercially harvested, upper trophic level piscivores. We used baited remote underwater videos (BRUVs) to assess the species diversity and relative abundance of reef-associated predatory fish assemblages of Montserrat. The BRUVs rigs consisted of a video camera (GoPro™ Hero Basic) inside an underwater housing, mounted on a metal frame with a small pre-weighed bait source (1 kg of crushed baitfish) that was then mounted on a pole in the camera's field of view (see Bond et al. 2012 for more detail on BRUV design). BRUV sampling locations were chosen by using a random number generator to produce latitude and longitude points on the fore-reef of each site from a map constructed using ArcGIS software. BRUVs were then deployed in these randomly selected locations during daylight hours. Upon arrival at a sampling location, the vessel captain would find the closest suitable location for deployment (an area at a depth of 10-25 m and with bottom substrate flat enough to maximize line of sight). The BRUV was deployed from the boat using a rope and in-water personnel to guide it away from live coral, and to orient the BRUV facing down current. The BRUV was left for at least 95 minutes, allowing it to film continuously for ~ 90 min after settling to the bottom. BRUVs simultaneously deployed were at least 500m apart. Units were manually retrieved using the rope, which terminated in a small marker float to facilitate relocation. At both the start and end of each deployment, environmental variables were measured including mid water current speed and direction (with a General Oceanics, Mechanical Flowmeter), bottom depth (Lowrance XD85), underwater visibility (secchi disc) and water temperature, salinity, pH and dissolved oxygen (YSI, R85-25).

Post deployment, video files were copied to external hard drives, stitched together to allow for consecutive time-stamps throughout one BRUV deployment and then viewed at normal play speed by one experienced observer. Putative Caribbean reef shark observations were time-logged and then species identification was verified by a second experienced observer. The Caribbean and Atlantic sharpnose sharks, which were recorded to family level (*Rhizoprionodon spp*.), were the only common carcharhinids that were likely to be mis-identified as Caribbean reef sharks within this study area. All BRUV deployments were scored as "1" or "0" corresponding to sharks being "present" or "absent" respectively. Estimates of the maximum number of sharks and rays observed per deployment were made (the maximum number of individuals to a species level observed in a single frame (MaxN)).

2.8 SECONDARY DATA SOURCES

In addition to primary data collection efforts described above, we incorporated numerous existing data sources into this assessment to understand the long term perspective and put our data in context. These existing data sources provided information on coastal development, population density and historical coral cover, as well as previous monitoring and research. Key studies referenced herein include:

- Montserrat Physical Planning Unit – GIS database of physical geography, marine geography, maritime boundaries, multi beam sonar, population, and infrastructure data
- Coral Cay – Montserrat Annual Marine Report 2013-2014
- Montserrat Reef Check Data –provided by Professor James Hewlett
- Benthic habitat maps and distribution of marine resources (Wild et al 2007, IRF 1993)
- Coral reefs of Montserrat ([1998])
- Montserrat Fisheries Division – Catch data from 1999 - 2015
- Sustainable Fisheries Group – Fisheries Assessment and Gear-Based Assessment

Summaries of these studies are included in Appendix C.

III. RESULTS AND ANALYSIS

This section presents results from the marine surveys and the spatial analysis of ocean usages and values (fishing and diving). Understanding not only the ecological characteristics, but also local stressors, will help managers and decision-makers design appropriate and tailored protection measures for specific locations around the island.

3.1 VISUAL SURVEYS OF NEARSHORE MARINE ECOSYSTEMS

3.1.1. BENTHOS: REEF BUILDING ORGANISMS AND THEIR DOMINANT COMPETITORS

Hurricanes and volcanic eruptions have had a huge impact on Montserrat's marine environment, including physical destruction and modification of habitats along with lingering chronic stressors, such as elevated sedimentation and nutrients. The waters of Montserrat are composed of a small shelf area with a significant portion of its marine environment being pelagic and deep sea habitats. Montserrat has relatively few shallow reefs, mangroves, and seagrass habitats compared to other Caribbean islands. Areas that support marine life, especially fisheries, are small and highly disturbed with limited capacity to support commercial exploitation.

The shallow (<10 m) habitats we surveyed around the island of Montserrat are dominated by hard-bottom habitat types (Figure 7, Table 1). More than 50% of the sites were comprised of fringing coral reefs or reef patches, and 28% of the sites consisted of colonized volcanic boulders (Figure 7). Seagrass communities comprised 19% of the survey sites, and 3% were sargassum forests that are unique to Montserrat (i.e., ephemeral habitats of macroalgae attached to hard bottoms that grow vertically in the

water column). Coral reef habitats were most abundant in the north (68% of sites) and west (57%) of the island (Figure 6). The high frequency of colonized volcanic boulders (69%) partly defined the habitat features along the south-eastern coastline of Montserrat, whereas seagrasses and coral reefs dominated the south-west (Figure 8). Thus, the spatial distribution of distinct benthic habitats on Montserrat is clear (Figure 9). The island's north-eastern shelf is dominated by a large mesophotic (30 – 100 m) algal reef with scattered mesophotic coral reefs, and a sand channel separating it from the tightly fringing shallow coral reefs (0 – 30 m) and colonized volcanic boulders that are nearly continuous around the entire coastline. The western nearshore environment has an assemblage of highly diverse, smaller habitats, comprised of shallow coral reefs, invasive seagrass, colonized volcanic boulders, sargassum forest and sand. The mesophotic zone of the western shelf is mainly sand and mixed bottom habitats. The shelf becomes increasingly narrow to the south and contains similar tightly fringing shallow coral reefs, colonized volcanic boulders, and a continuous sandy shelf edge.

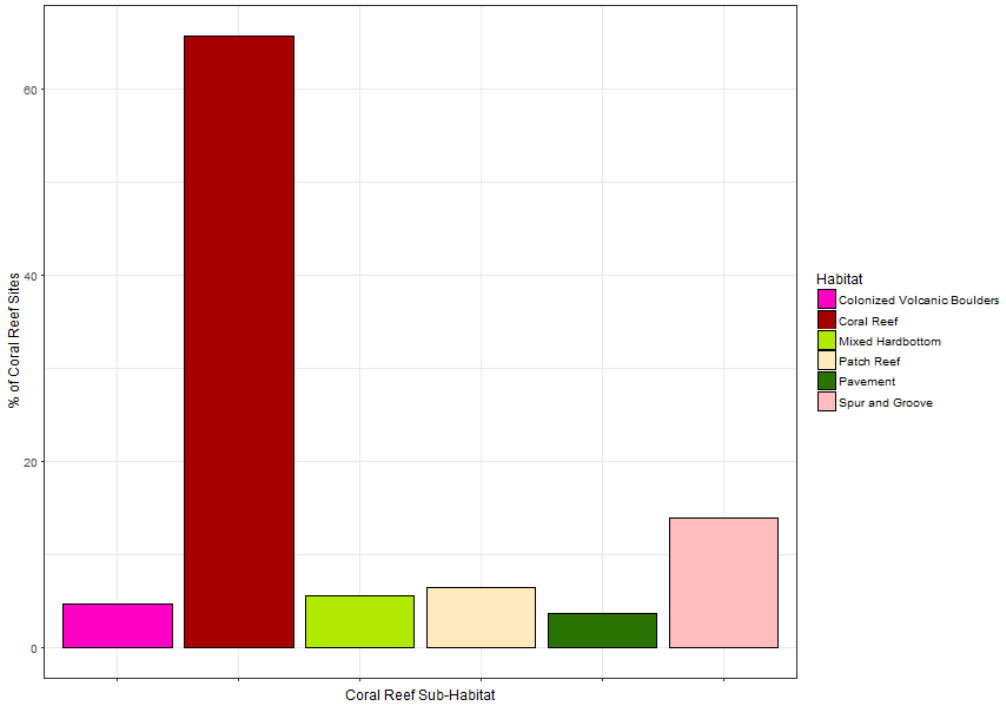


Figure 7. Distribution of benthic habitats surveyed in Montserrat. Habitat types include: Colonized Volcanic Boulders, Coral Reef, Mixed Hardbottom, Patch Reef, Pavement and Spur and Groove

Table 1. Qualitative description of benthic habitats of Montserrat.

Habitat Type	Description
Colonized Volcanic Boulders	Describes a habitat where the substrate for benthic organisms is provided by boulders of different sizes and forms deposited into the ocean by volcanic eruptions. These rocks are colonized by crustose algae, algal turfs, hard corals, soft corals, sponge and other sessile invertebrates.
Coral Reefs	Biogenic structures that extend for hundreds of meters. Topographic relief is variable but always higher than surrounding habitats. The habitat is hard-bottom covered by hard corals, soft corals, various types of algae and diverse sponge communities.
Mixed-Hard Bottom	A habitat composed of rocks, flat pavement and sand patches. The community consists of scattered or dispersed hard corals, sponges, soft corals and other sessile organisms.
Patch Reef	Similar to coral reefs but smaller in extension. Seldom extends beyond 100 m.
Pavement	Flat hard-bottom habitats covered by scattered hard corals, soft corals, sponges and other sessile organisms. Algal turfs are conspicuous.
Spurs-Grooves	A reef consisting of promontories (ridges) intercalated with sand channels. Hard and soft coral communities and other sessile invertebrates settle on top of the ridges.
Sargassum Forest	A habitat composed of *Sargassum spp.* algae attached to mixed-hard bottom substrates that rise from the bottom towards the surface. The habitat could be ephemeral and might serve as refuge and nursery areas for fish.
Seagrass	Soft bottom habitats covered by seagrasses (invasive), algae (fleshy or calcareous) and sand patches. Native seagrasses include *Thalassia testudinum* and *Syringodium filiformis* formerly reported in Montserrat were absent. We only observed *Halophila stipulacea*, the invasive species.
Soft-Bottom	Denuded flat and sandy habitats. The substrate is composed of sand (fine to coarse) grains.

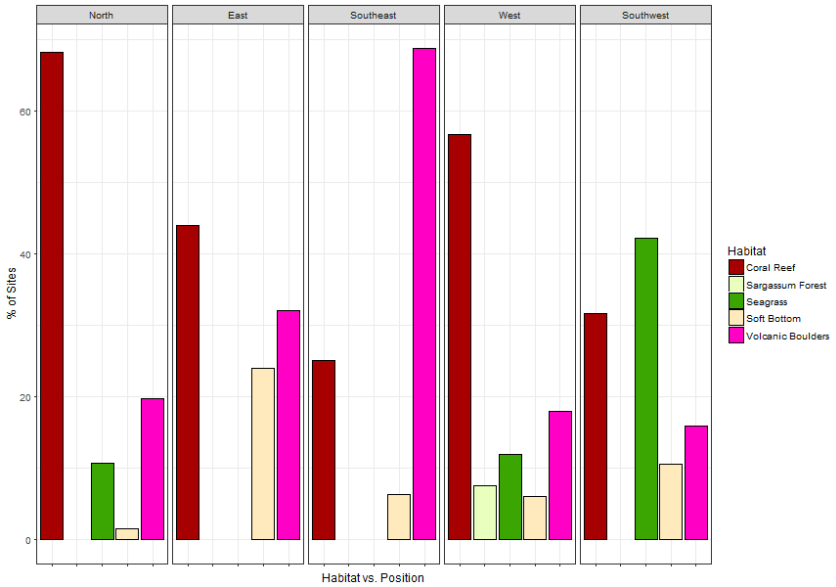


Figure 8. Distribution of benthic habitat surveyed by position relative to the island of Montserrat. Habitat types include: Coral Reef, Sargassum Forest, Seagrass, Soft Bottom and Volcanic Boulders.

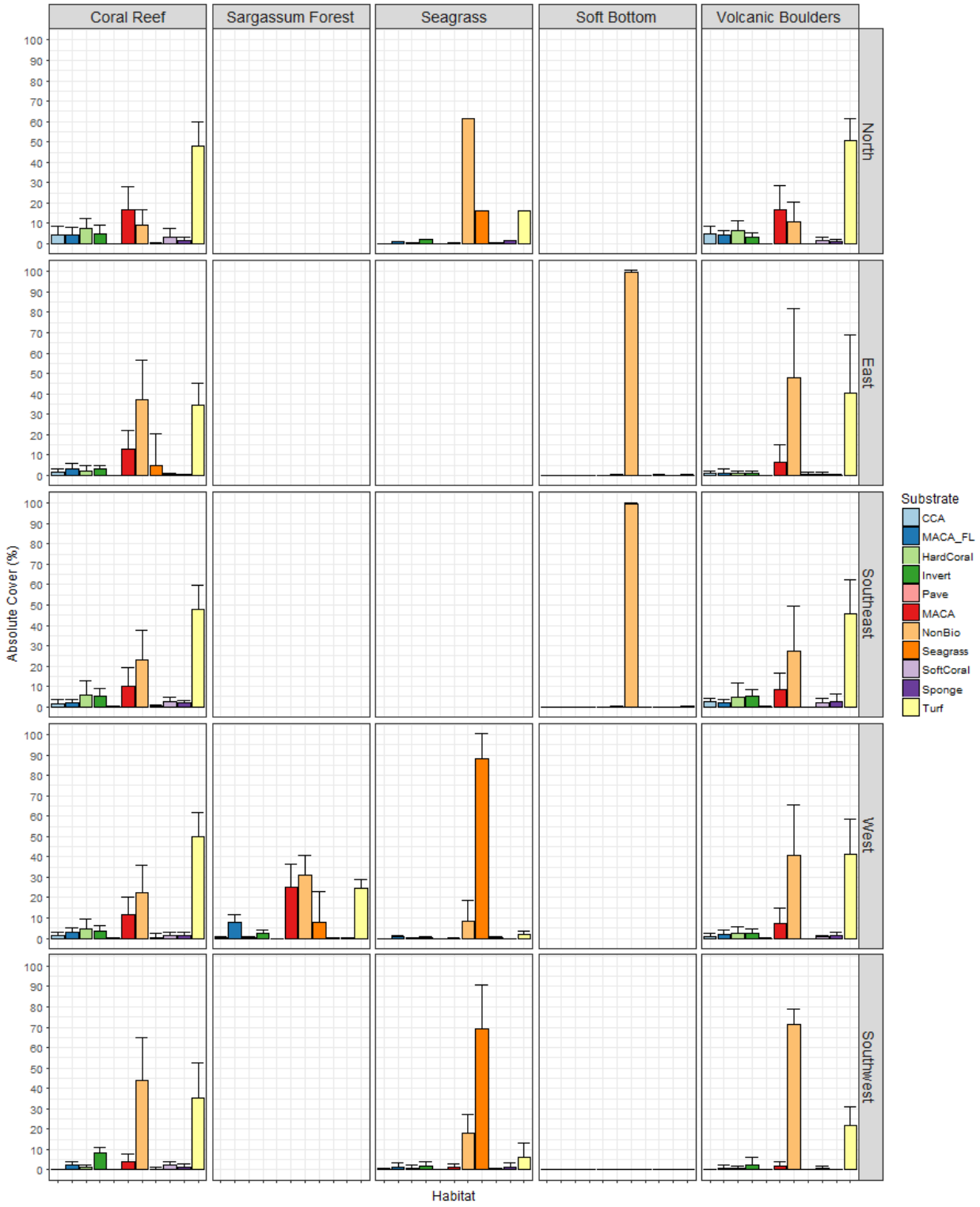


Figure 9. Benthic cover of major substrates by habitat type and position relative to the island of Montserrat.

3.1.2. HARD BOTTOM (CORAL REEFS, PATCH REEFS, COLONIZED VOLCANIC BOULDERS)

Benthic Cover

The coarser classifications of coastal habitats in Montserrat include coral reefs, sargassum forests, seagrass beds, soft bottom substrates and volcanic boulders (Figure 8). The composition and cover of the benthic community differs for each of these habitats (Figure 9). The largest number of substrate types are associated with hard-bottom habitats (i.e., volcanic boulders and coral reefs), whereas soft-bottom habitats are composed largely of non-biogenic substrates (e.g. sand) and algal turfs (Figure 9).

We observed six morphological types of hard bottom communities along the coast of Montserrat: 1) coral reefs (i.e., biogenic structures fringing the coastline with high topographic relief formed by scleractinian corals, octocorals and sponges); 2) mixed hard bottoms (i.e., consolidated substrates with patches of sand, seagrass, pavement and scattered corals); 3) patch reefs (i.e., hard substrates of variable sizes with corals, sponges and octocorals surrounded by sandy floors); 4) pavement (flat and hard substrates that are denuded and/or covered by algal turfs, octocorals and scattered corals, and sponges); 5) spur and groove (reef formations consisting of hard-bottom promontories bearing coral communities interspersed with sandy channels that run from the coast towards the continental shelf); and 6) volcanic boulders (Figure 8).

The distribution of these hard-bottom habitats varied depending on the relative position to the island. Along the northern coast of Montserrat, we observed coral reefs, patch reefs, spur and groove habitats. Along the east coast, these formations, as well as mixed hard bottom and pavement habitats were recorded. We recorded no mixed hard bottom and flat pavement along the east and west sites, while no pavement substrates and volcanic boulders were observed along the west coast (Figure 10). Finally, along the south-eastern coast we observed coral reefs, mixed hard bottom, and spur and groove habitats (Figure 10).

Hard bottom habitats were clearly dominated by turf algae (32-50%) (Figure 10). The highest averages of algal turfs were recorded in spur and groove formations (50%), coral reefs (48%) and patch reefs (47%). The mixed hard bottom habitats exhibited the lowest average of algal turf (32%). The percentage of sand and macroalgae cover were highly variable across habitat types, whereas live coral cover was less variable. The percent benthic cover of sand ranged from 16-40%, and macroalgae from 8-18%, however, live coral cover seldom varied, ranging from 0.5 to 9% (Figure 8). The highest averages of live coral cover were associated with volcanic boulders (9%), while the lowest were recorded on pavement substrates (<1%). These results indicate that Montserrat's coral reefs are actually dominated by algal turfs and macroalgae with low live coral cover. This pattern is consistent regardless of proximity to the shore.

Sponges also define a unique feature of sessile invertebrate communities associated with hard-bottom habitats in Montserrat (Figure 8). For instance, these organisms provided similar values of live cover (2.5% of the substrate) to that of live coral cover in patch reefs and pavement substrates (Figure 10). During the surveys, we frequently observed large barrel sponges (*Xestospongia muta*) in these habitats. The importance of these organisms in providing shelter for invertebrates and even corals (e.g. *Porites porites*) while adding topographic relief is comparable to that of stony corals.

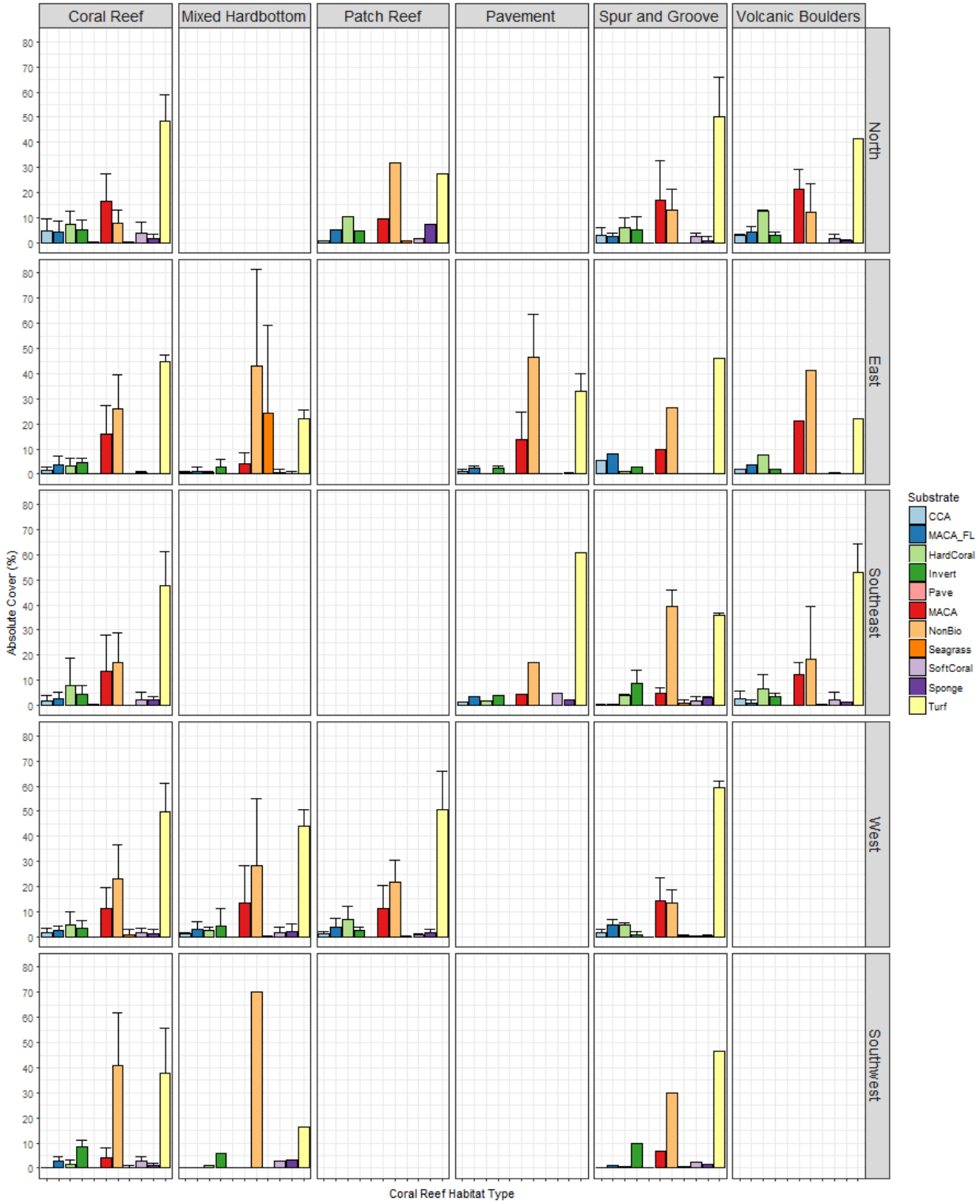


Figure 10. Benthic cover of hard substrate by position relative to the island of Montserrat.

Coral Species Diversity

Overall, coral species richness in reef habitats throughout Montserrat is low (<20 species) compared to elsewhere in the Caribbean (20-30 species). In coral reef and volcanic boulder habitats located on the northern, western and south-eastern coastlines, the number of scleractinian coral species ranged from 17 to 21. The most abundant and widespread coral species were in the genera Diploria (e.g. *Diploria strigosa* and *D. clivosa*), Porites (e.g. *Porites astreoides*, *P. porites*, *P. furcata*), Madracis (e.g. *Madracis mirabilis* and *M. decactis*), Montastraea (e.g. *Montastraea cavernosa*), Orbicella (e.g. *Orbicella faveolata*, *O.franksiand*, and *O. annularis*), and to a lesser extent *Colpophyllia natans*. Thus, results from these surveys indicate that coral species diversity is highest along the northern, south-eastern and north-western coasts of Montserrat (Figure 11).

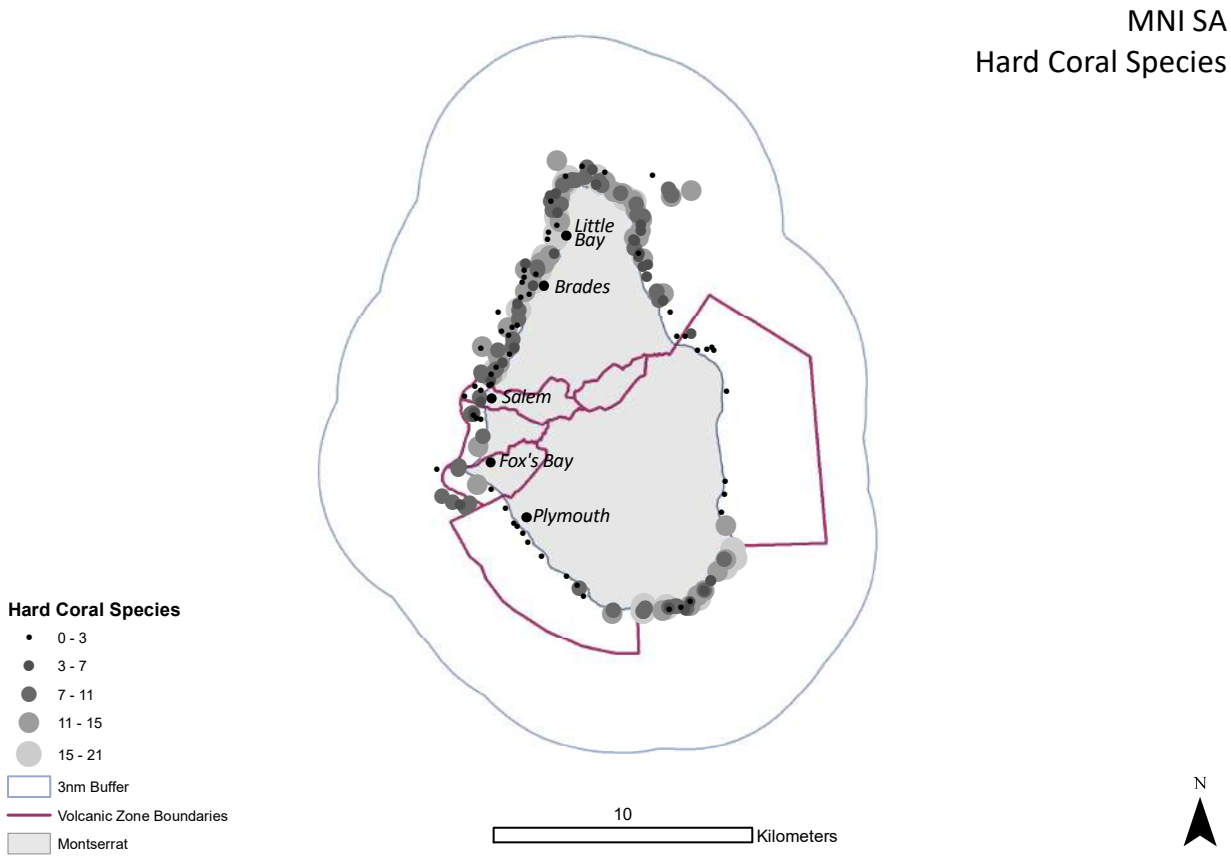


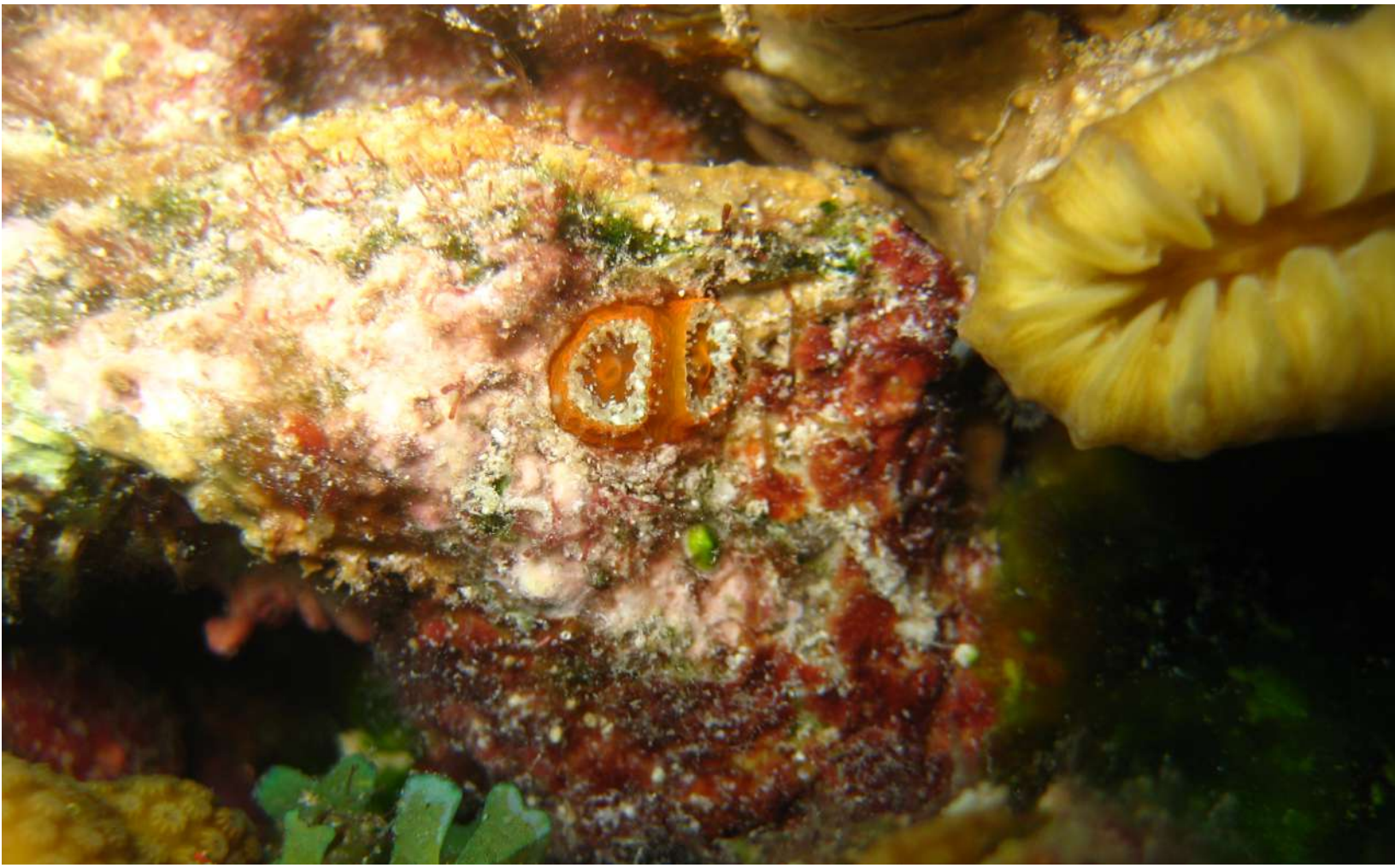
Figure 11. Spatial distribution of hard coral species diversity

Juvenile Corals

Juvenile corals serve as an indicator for coral recruitment and of the reef's ability to "renew" itself as existing corals die. Without a healthy population of juvenile reef builders that form calcified reef structures, impacts from stressors such as sedimentation, storms and disease can lead to decline in coral cover and a loss of reef structure (Burke et al. 2011).

Table 2. ***Mean density (Ind/m²) and Standard deviation of juvenile corals (<4 cm) by genera by location in Montserrat.***

Mean density of juvenile corals (Ind/m^2) by genera													
Location	Agaricia		Madracis		Porites		Siderastrea		Millepora		Others		Total counts
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
East	0.04	0.2	0	0	0.58	1.2	0.33	0.8	0	0	0.04	0.2	24
North	1.07	2.5	0.04	0.2	2.38	4.3	1.22	2.6	0.42	0.9	0.18	0.4	55
Southeast	0.38	0.8	0.77	3.9	1.73	2.9	5.38	13.5	0.04	0.2	0.19	0.6	26
Southwest	0.06	0.2	0	0	0.12	0.5	0.88	1.9	0	0	0.06	0.2	17
West	0.37	1	2.07	10.3	2	3.3	1.59	2.4	0.3	0.9	0.46	1.3	54



Juvenile corals were observed to be abundant in Montserrat with densities ranging from 0.04 to 5.38 individuals/m^2 (Table 2). We found the highest juvenile coral densities along the northern and south-eastern coasts of the Island (Table 2; Figure 12). A total of four coral genera were recorded across the hard-bottom habitat. The most abundant genera included *Siderastrea spp.* (0.33-5.38 individuals/m^2), *Porites spp.* (0.12-2.38 individuals/m^2), *Agaricia spp.* (0.04-1.07 individuals/m^2), and *Madracis spp*. (0.04-2.07 individuals/m^2). Other genera, such as *Stephanocoenia spp., Orbicella spp.,* and *Colpophyllia spp*. were seldom recorded and their densities never exceeded 1 individual/m^2 (Table 2). We found juveniles belonging to all of the above genera growing on top of volcanic boulders, pavement flats, mixed hard bottoms, patch reefs, spur and groove, and coral reefs habitats. In addition to corals, other juvenile sessile invertebrates such as sponges, octocorals and zoanthids were conspicuous across these habitats. These results indicate that in terms of species composition juvenile communities are very similar to adult benthic communities. Furthermore, the results also suggest that populations of scleractinian corals in Montserrat seem to be frequently exposed to intense disturbance regimes. Thus, the community seems to receive input of new individuals that manage to survive at least to 4 cm before new disturbances arrive, however, live coral cover does not exceed 10%.

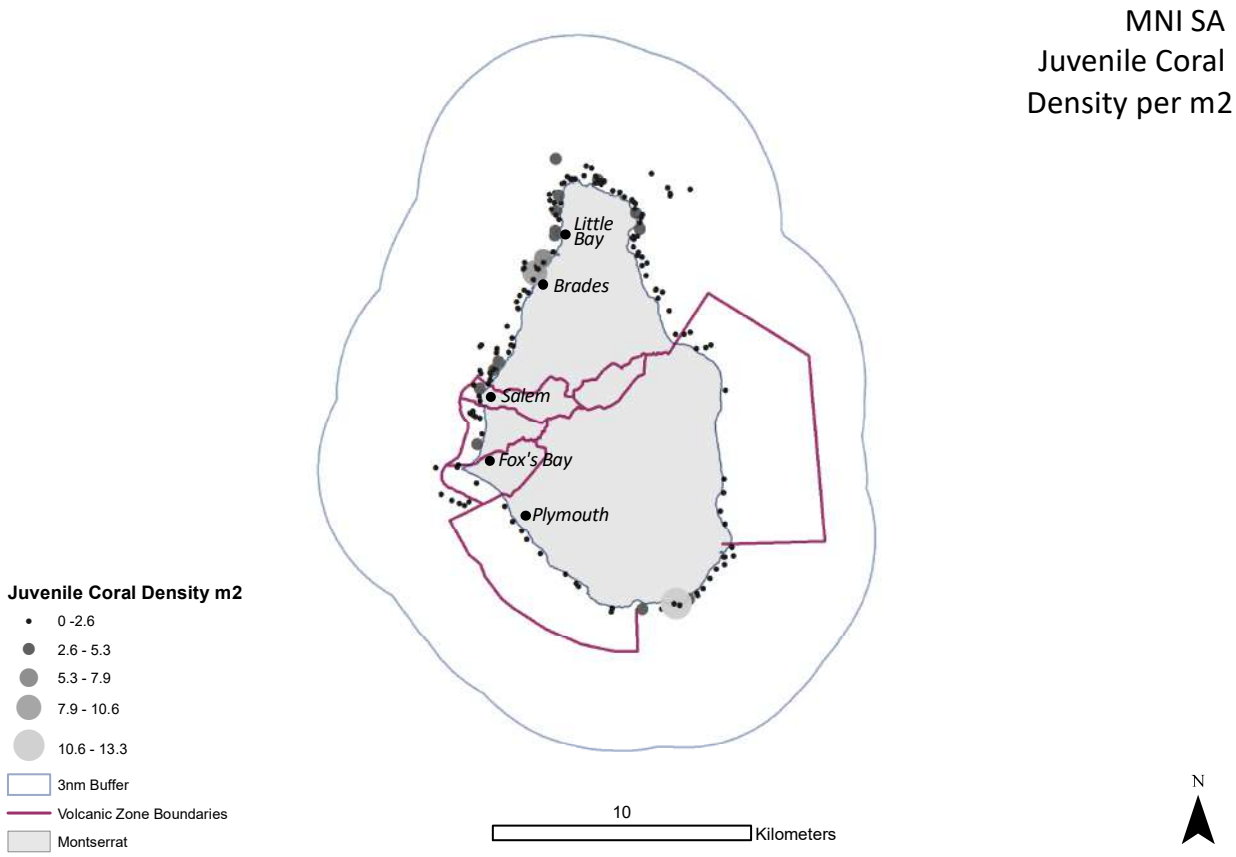


Figure 12. Spatial distribution of juvenile corals throughout Montserrat.

Juvenile corals were present at 19% of the 212 marine survey sites. These sites are scattered around the island, however, very few juvenile corals were found in the exclusion zone. The average site has eight different species of juvenile corals. Sites with the highest species diversity are located in the northern and southern tips of the island, and the exclusion zones exhibit the lowest coral diversity. Notably,

almost one-third (32%) of the marine survey sites had four or fewer species of coral, which is indicative of the overall low coral species diversity in Montserrat's near shore environment.

Orbicella

The boulder star coral, *Orbicella spp.*, is protected under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), as well as the United States Endangered Species Act. Throughout the Caribbean, researchers have recorded a massive decline of Orbicella over the past 30 years due to bleaching, disease, and other anthropogenic factors, such as fishing or anchor damage (IUCN 2018). Because of low recruitment and growth rates, mortality is exceeding growth and recruitment of Orbicella across the Caribbean, and thus limiting the scope of recovery for this important reef building boulder coral (IUCN 2018).

The following figures present the distribution of *Orbicella annularis* (Figure 13), *O. faveolata* (Figure 14) and *O. franksi* (Figure 15). *O. faveolata,* the mountainous star coral, is the most common species of Orbicella in Montserrat's waters and was found at 29% of marine survey sites (not including the exclusion zone). The abundance of the boulder star coral is lower, found at 11% (for *O. franksi*) and 7% (for *O. annularis*) of survey sites.

The relatively low abundance of these corals is of concern because *Orbicellids* are important reef-builders. They form calcified reefs through massive boulders, and hence provide the habitat for coral reef fish and other organisms.

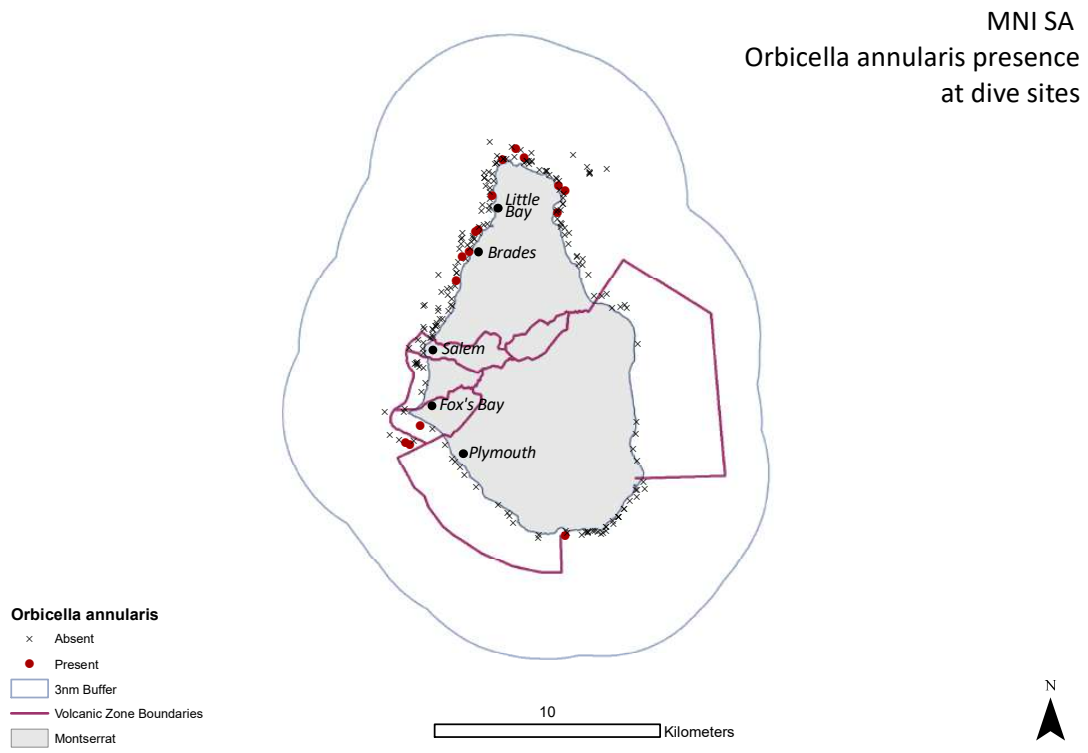


Figure 13. *Orbicella annularis* presence at dive sites.

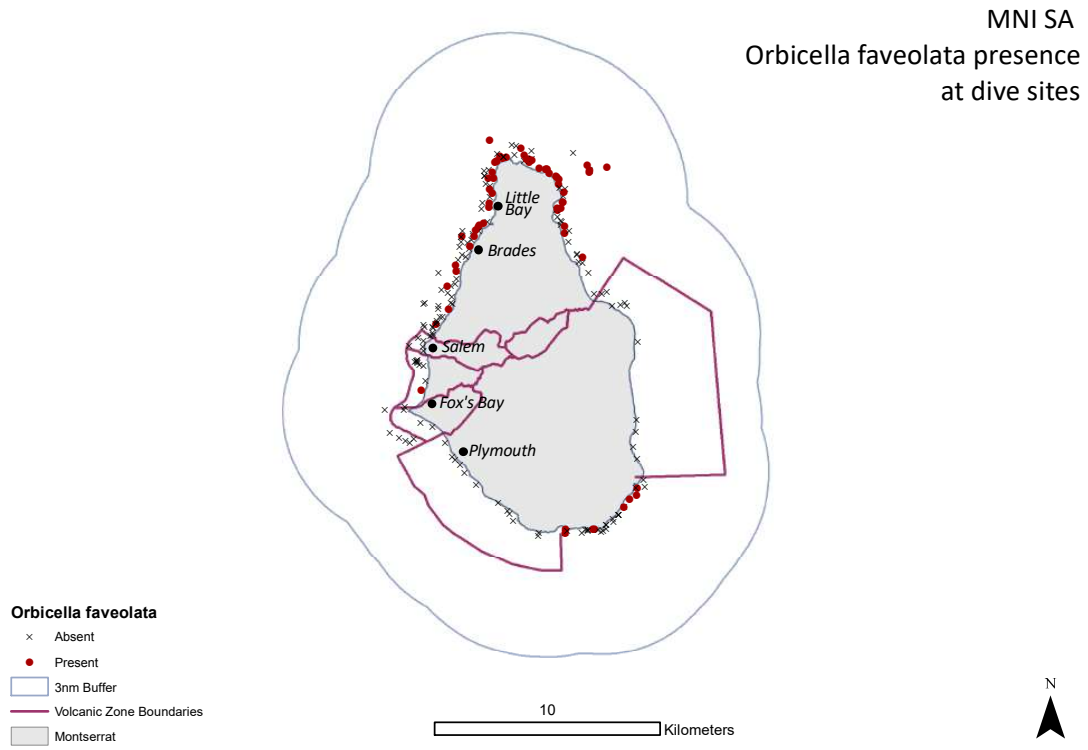


Figure 14. *Orbicella faveolata* presence at dive sites.

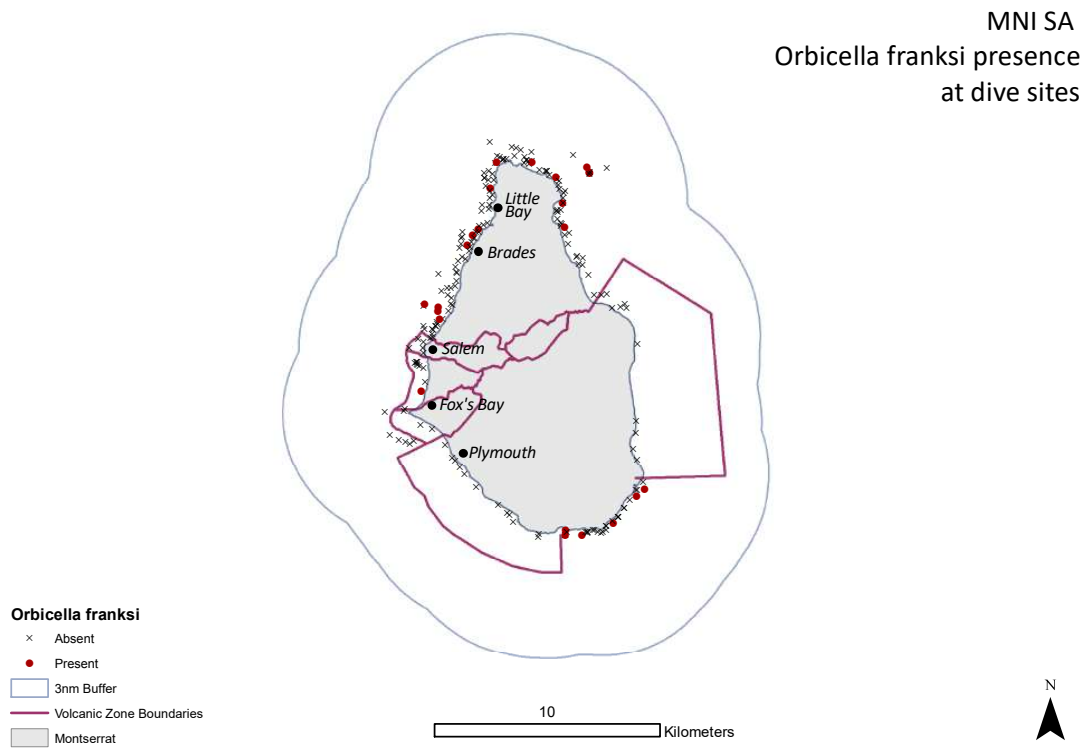


Figure 15. *Orbicella franksi* presence at dive sites.

Acropora

Acroporid corals are important in providing reef structure, reef growth and habitat for fish and invertebrates. They are therefore critical to ensure the diversity of reef communities and the biodiversity of marine ecosystems. Both the elkhorn (*Acropora palmata*) and staghorn coral (*Acropora cervicornis*) used to be dominant species in the Caribbean, but have declined significantly since the 1980's due to white band disease and coral bleaching. Estimates suggest that approximately 80%-98% of these coral species have been lost in certain areas of the Caribbean. Both species are included on the IUCN red list as "critically endangered" and are protected under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Figure 16 and 17 show the distribution of elkhorn coral and staghorn coral, respectively, which are both branching coral species. As the Figures indicate, we found these species at only a few of the survey sites, and mostly at the north end of the island.

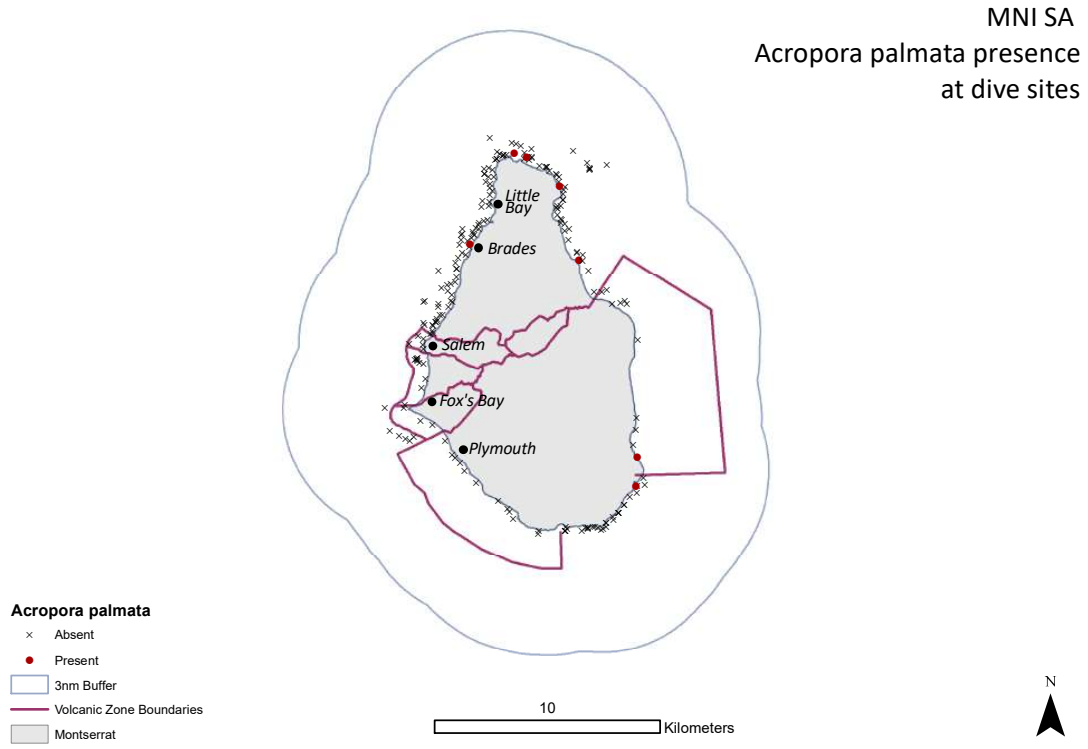


Figure 16. *Acropora palmata* presence at dive sites.

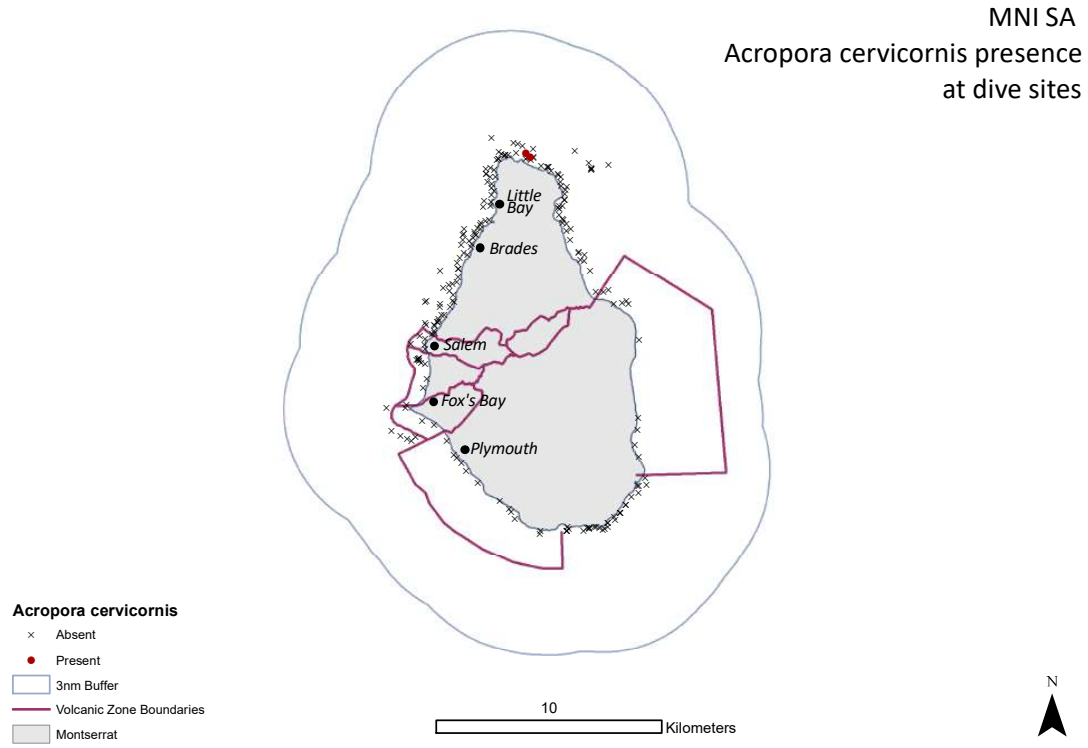


Figure 17. *Acropora cervicornis* presence at dive sites.

Pillar Corals

Pillar corals (*Dendrogyra cylindrus*) were present at 6% of survey sites, and only those located at the north and south ends of the island (Figure 18). Pillar corals are typically low in abundance throughout the Caribbean. This species is highly susceptible to disease, which can lead to mortality of individual colonies, and survival rates of juveniles are low (Bruckner and Bruckner 1997; Weil 2005).

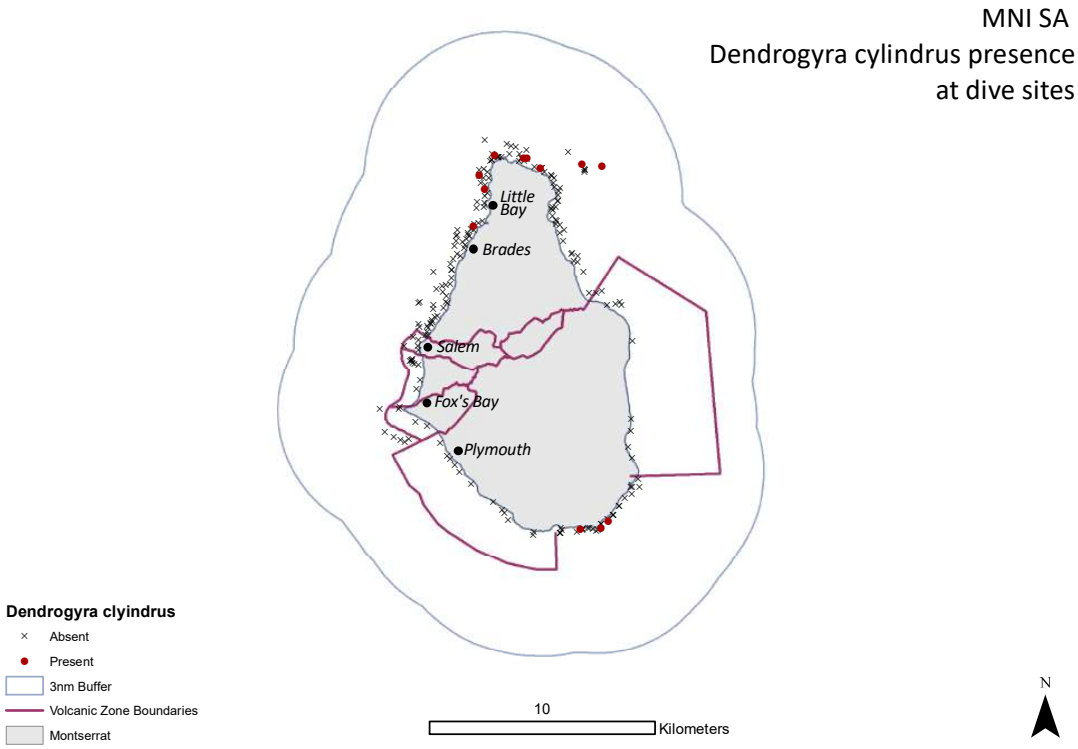


Figure 18. Presence of *Dendrogyra cylindrus* at dive sites.

Coral Health

Coral bleaching and disease can occur in response to dramatic fluctuations in sea temperatures (typically warming), ocean acidification, pollution, and biological stressors such as bacteria, viruses and fungi. Many Caribbean reefs have experienced significant mortality of hard corals over the past 30 years due to coral bleaching and disease. This has led to a reduction in the value of ecosystem services, such as coastal protection and tourism derived from reefs.

The frequency of coral diseases observed in our surveys was low with only 24 out of 212 sites (11%) observed to have one or more colonies with diseases and/or health problems (Figure 19). Only three disease types were observed during these surveys: 1) White plague, affecting massive species such as *Diploria spp*. and *Colpophyllia natans*; 2) Caribbean yellow band disease, affecting *Montastraea cavernosa* and *Orbicella faveolata*; and 3) Dark spots disease, affecting *Siderastrea spp*. No signs of epizootic events or massive mortality due to widespread coral disease were observed. Bleaching was also rarely observed with only 19 out of the 212 sampled sites (9%) reported to have at least one bleached coral colony (Figure 19). No signs of mass bleaching were observed in Montserrat. These results must be considered with caution because both epizootic and bleaching events are extremely variable in time. We should not dismiss the role these events might currently have, and may previously have had in the decline of live coral cover in Montserrat.

While fewer corals were observed in the volcanic maritime exclusion zones, there was also nearly no bleaching or disease observed with the exception of two such observations made in the south and north of the windward zone. The implications for this are unclear but suggest that conditions in these areas are not conducive to chronic disease.

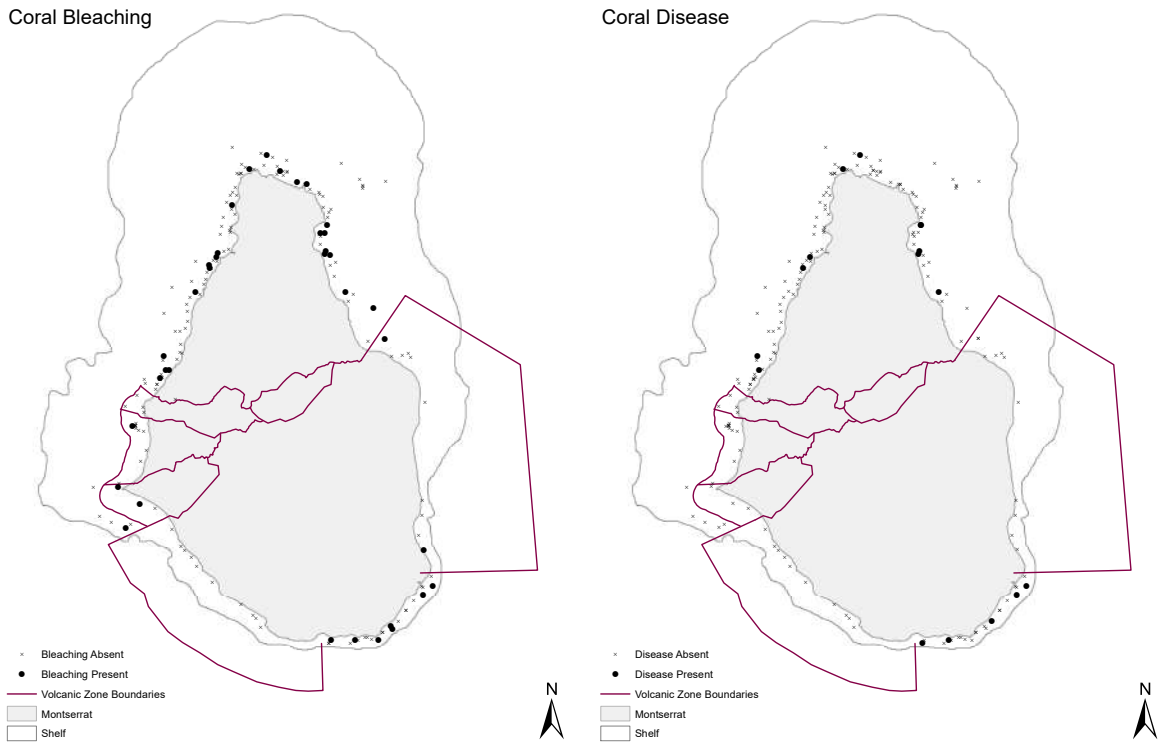


Figure 19. ***Coral bleaching presence (black dots) and absence (black x's) is depicted in the left panel and the same for coral disease (right).***

Sponges

Sponges filter water and can play an important role in improving water quality and making carbon (energy) available to the organisms that inhabit coral reefs. They also provide structural habitat for fish and other invertebrates. This habitat-forming capacity is especially valuable given the massive declines in stony corals, and the shift towards a sponge and macroalgal stable state on many reefs. Sponges are abundant in Montserrat's near-shore waters with the exception of the exclusion zones. Sponges were found at 95% of survey sites. The high abundance of sponges is an indicator of the presence of high levels of organic materials in the near-shore waters. We examined the diversity of sponges in 108 of the 212 survey sites. The majority of the 108 sites (51%) have low sponge diversity. In contrast, almost one-third of all survey sites (30%) show high diversity of sponges. Figure 20 shows that sites with high sponge diversity are commonly located outside of the exclusion zone, including the northern and southern ends, as well as the western side of the island.

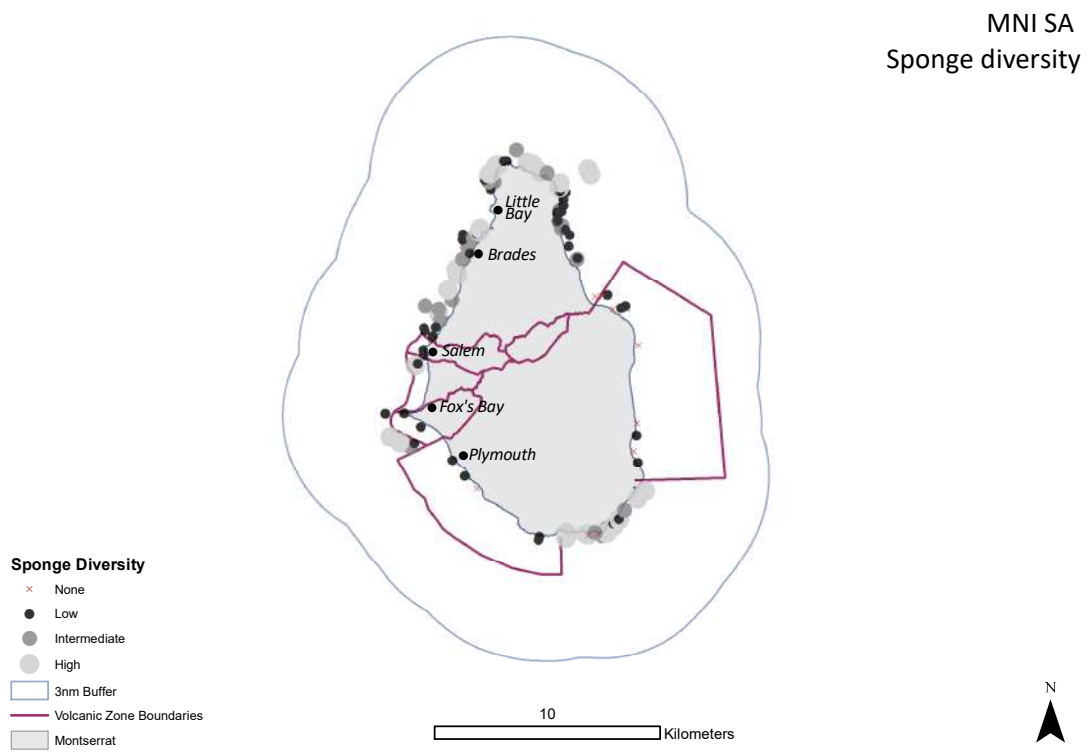


Figure 20. Sponge diversity at dive sites.

3.1.3. SEAGRASSES AND SARGASSUM FORESTS

Seagrass sites had average live cover of seagrass (up to 70%), and were most often observed on non-biogenic substrates. Seagrasses were only found at close and intermediate distances from the coastline predominantly along the north, west and southeast coastlines of Montserrat (Figure 21). All seagrass observed was the invasive species *Halophila situplacea*. Non-biogenic substrates and macroalgae covered up to 20% of the benthos within observed seagrass habitats (Figure 8).

The sargassum forests were also dominated by non-biogenic unconsolidated substrates, macroalgae and algal turfs, with these three substrates accounting for more than 60% of the benthic cover (Figure 8). These habitats were only found close to the shore at a limited number of sites located on the western coastline of Montserrat (Figure 15). Live coral cover within sargassum forests seldom exceeded 2%.

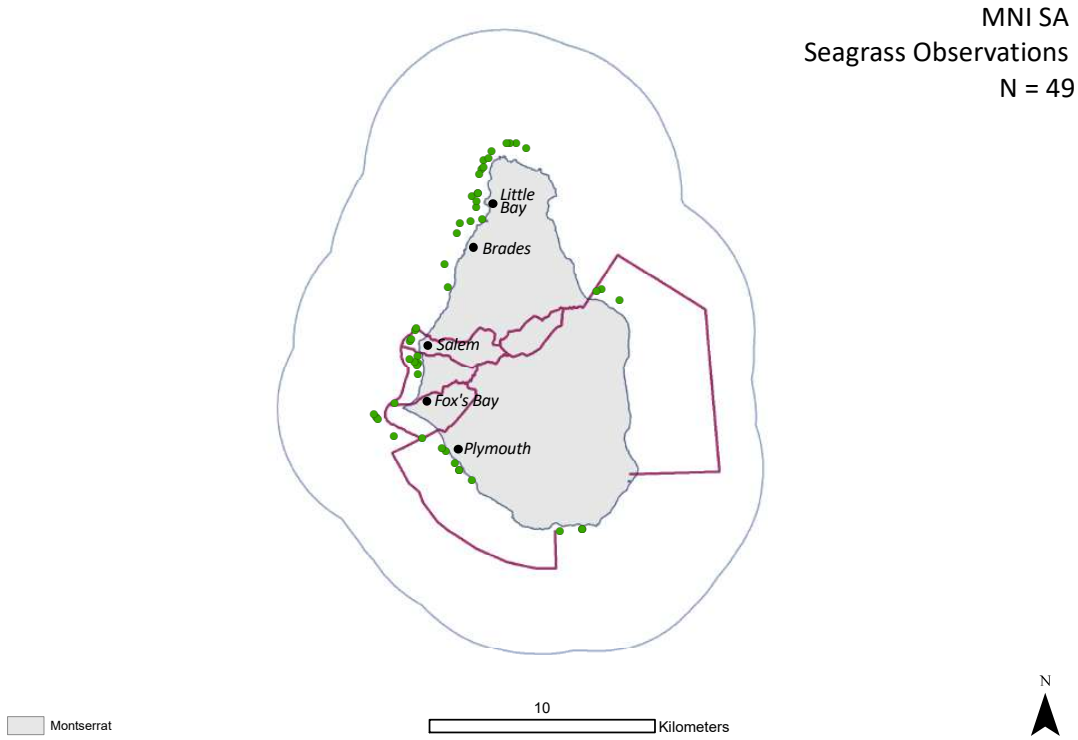


Figure 21. Spatial distribution of seagrass observations across all survey sites in Montserrat.

3.1.5. REEF FISH

Fish Species Richness

We recorded a total of 157 species of fish across the 164 sites where fish surveys were conducted. Fish species richness varied from 0.8 to 34.2 species per 100m^2 with an average (mean) value of 15.8. There were no strong spatial patterns in the number of fish species at these sites, though there do appear to be lower numbers of species at the survey sites on the east and south-west sides of the island, however, these areas also had very few fish survey sites in general (Figure 22). There are no significant differences in species richness between habitat types (one-way ANOVA: $F_{4,156} = 2.62$, $p = 0.037$, but Tukey HSD found no difference between habitats), though seagrass habitats had fewer species on average than other habitat types (Figure 23).

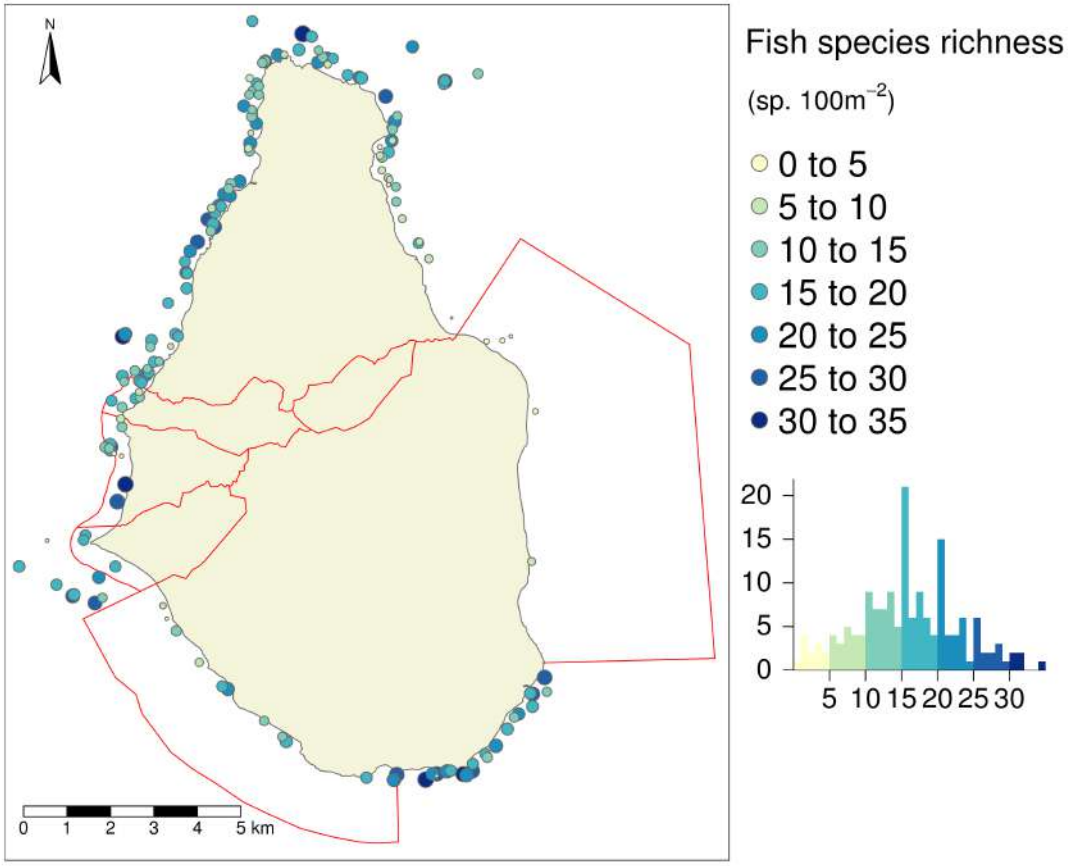


Figure 22. ***Map of fish species richness at all surveyed sites. Bubbles are sized proportionately to biomass. Red border shows volcanic hazard zone. Histogram shows number of sites on y-axis and fish species richness on x-axis. There are few survey points within the hazard zone due to limited availability of target habitats (hard bottom and seagrass).***

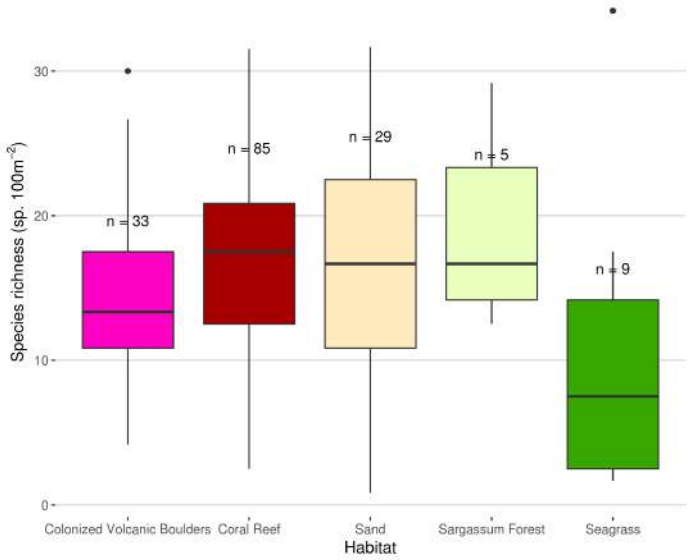


Figure 23. ***Boxplot of fish species richness by habitat type. "n =" above bars indicate number of surveys in a given habitat. Boxes indicate interquartile range (IQR); solid horizontal line is median species richness value; whisker extends to last observations within 1.5 times the IQR; points beyond the whiskers are shown as dots.***

Fish Biomass

The total biomass of reef fish recorded at the survey sites varied widely, ranging from 0.001 gm^{-2} to 778 gm^{-2} with a median value of 56 gm^{-2} (mean = 94 gm^{-2}, SD = 121 gm^{-2}). We observed reef fish biomass to be highest at the southern end of the island, and along the west coast extending around the north end of the island (Figure 24).

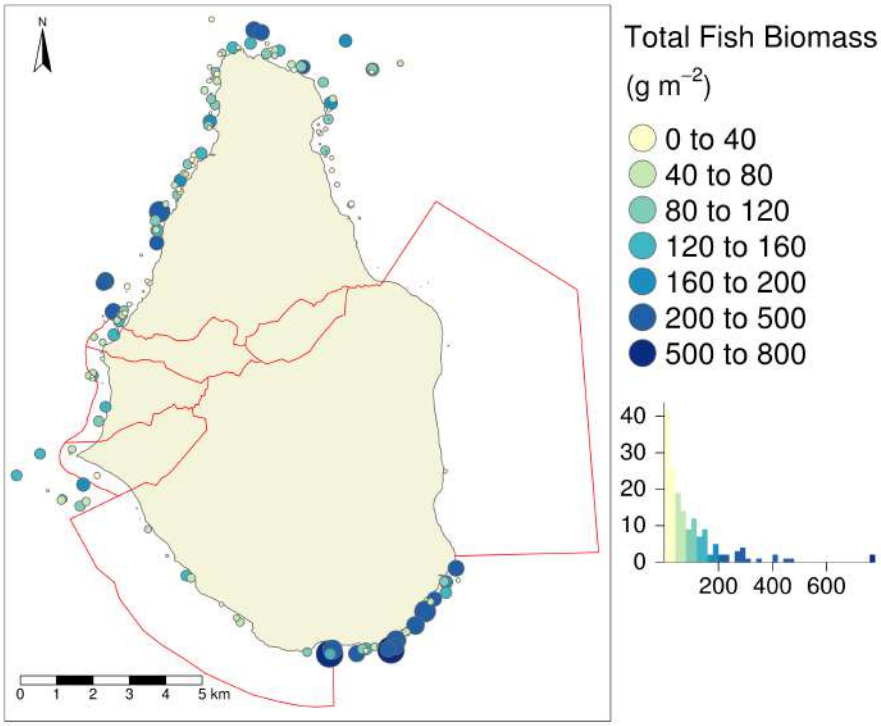


Figure 24. Map of total fish biomass at all surveyed sites. Bubbles are sized proportionately to biomass. Red border shows volcanic hazard zone. Histogram shows number of sites on y-axis and biomass on x-axis. There are few survey points within the hazard zone due to limited access.

Invertivores (fish that feed primarily on invertebrates) had the highest biomass of fish across all sites (median = 16.1 gm^{-2}), though herbivore biomass was also high (median = 14.4 gm^{-2}; Figure 25). Planktivores had the lowest biomass (median = 1.8 gm^{-2}), but all trophic groups had highly heterogeneous biomass values with many outlier sites (Figure 25). We found relatively high biomass of carnivores, herbivores, and invertivores in the southern survey sites (Figure 26). Herbivores also had high biomass along the north western coast, whereas carnivores and invertivores had very patchy biomass around the rest of the island. Planktivore biomass was relatively high along the north-west coast, and low elsewhere (Figure 26).

Only five species of reef fish contributed just over 50% of the total biomass of fish across all sites (Table 3). Black durgons (*Melichthys niger*) and Ocean surgeonfish (*Acanthurus tractus*) alone contributed nearly 30% of all fish biomass, with large schools of both observed at many sites. The grouping of carnivorous fish was comprised principally of smaller groupers (*Serranidae*) and snapper (*Lutjanidae*) species, with 74% of carnivores being less than 25 cm in length. The small grouper species Coney (*Cephalopholis fulva*) comprised 50.3% of the biomass and 60.9% of the number of individual carnivores. Large grouper species were entirely absent from the data, though two small (max. 20 cm length) Yellowmouth grouper (*Mycteroperca interstitialis*) were recorded. One Nassau grouper (*Epinephelus striatus*) was observed during the surveys, however this was not on a transect and is therefore not in the data presented here.

As noted above, herbivores had relatively high biomass at all sites. This biomass was principally made up of Ocean surgeonfish (*Acanthurus tractus*; 34% of total herbivore biomass) and Blue tang (*Acanthurus coeruleus*; 31% of total herbivore biomass). Parrotfish only constituted 12.7% of herbivore biomass, and had low average site biomass (median = 2.1 gm^{-2}, mean = 5.1 gm^{-2}, SD = 7.3 gm^{-2}). Most parrotfish were of relatively small sizes with 67% of all individuals less than 15 cm in length (Figure 27). Only three Rainbow parrotfish (*Scarus guacamaia*) were observed during the surveys; these are the largest parrotfish in the Caribbean and are classified as near-threatened on the IUCN red list (Dorenbosch et al. 2006).

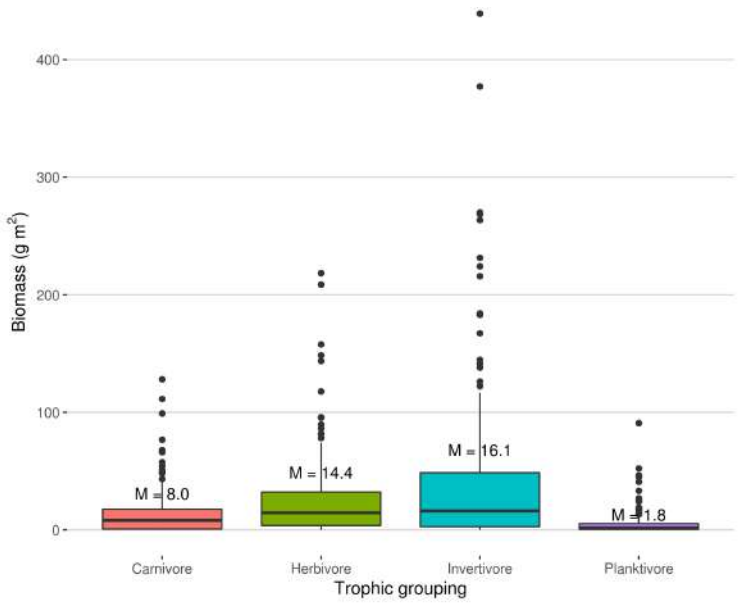


Figure 25. Boxplot of fish biomass by trophic group. "M =" above bars indicate median biomass value for that trophic group. Boxes indicate interquartile range (IQR); solid horizontal line is median species richness value; whisker extends to last observations within 1.5 times the IQR; points beyond the whiskers are shown as dots.

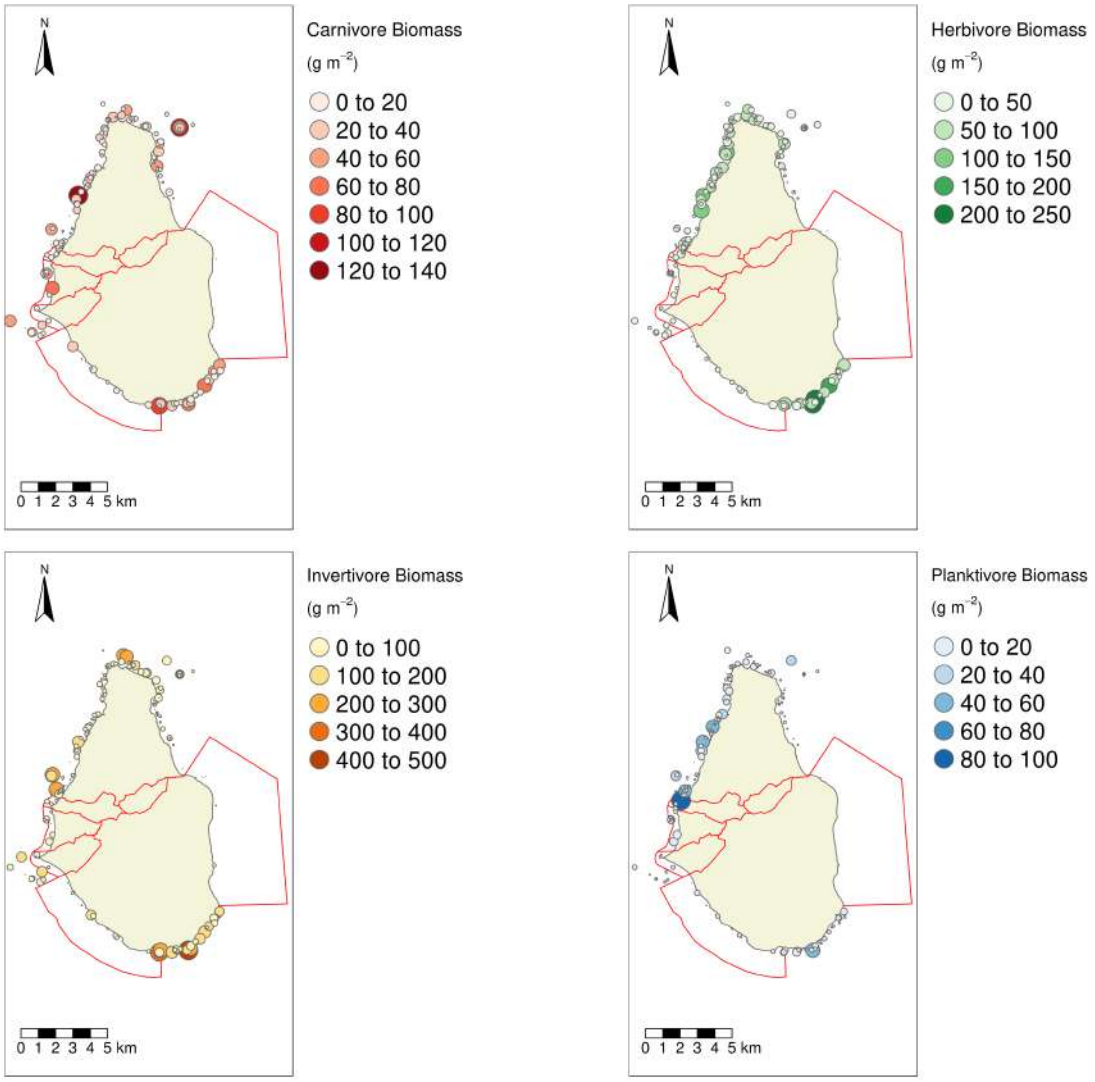


Figure 26. Maps of fish biomass at all surveyed sites, separated by trophic group. Bubbles are sized proportionately to biomass. Red border shows volcanic hazard zone. There are few survey points within the hazard zone due to limited access. Note different biomass scales on maps.

Table 3. Top 10 reef fish species ranked according to their contribution to the total reef fish biomass (pelagic species and sharks excluded)

Biomass Rank	Species scientific name	Species common name	Trophic group	% of total fish biomass	Cumulative sum of % of total biomass
1	Melichthys niger	Black durgon	Invertivore	19.6	19.6
2	Acanthurus tractus	Ocean surgeonfish	Herbivore	10.0	29.6

3	Acanthurus coeruleus	Blue tang	Herbivore	9.2	38.8
4	Cephalopholis fulva	Coney	Carnivore	7.8	46.6
5	Dasyatis americana	Southern stingray	Invertivore	3.8	50.4
6	Stegastes partitus	Bicolor damselfish	Herbivore	2.4	52.8
7	Anisotremus surinamensis	Black margate	Invertivore	2.2	55.0
8	Holocentrus rufus	Longspine squirrelfish	Invertivore	2.2	57.2
9	Acanthurus chirurgus	Doctorfish	Herbivore	2.0	59.2
10	Haemulon flavolineatum	French grunt	Invertivore	1.9	61.1

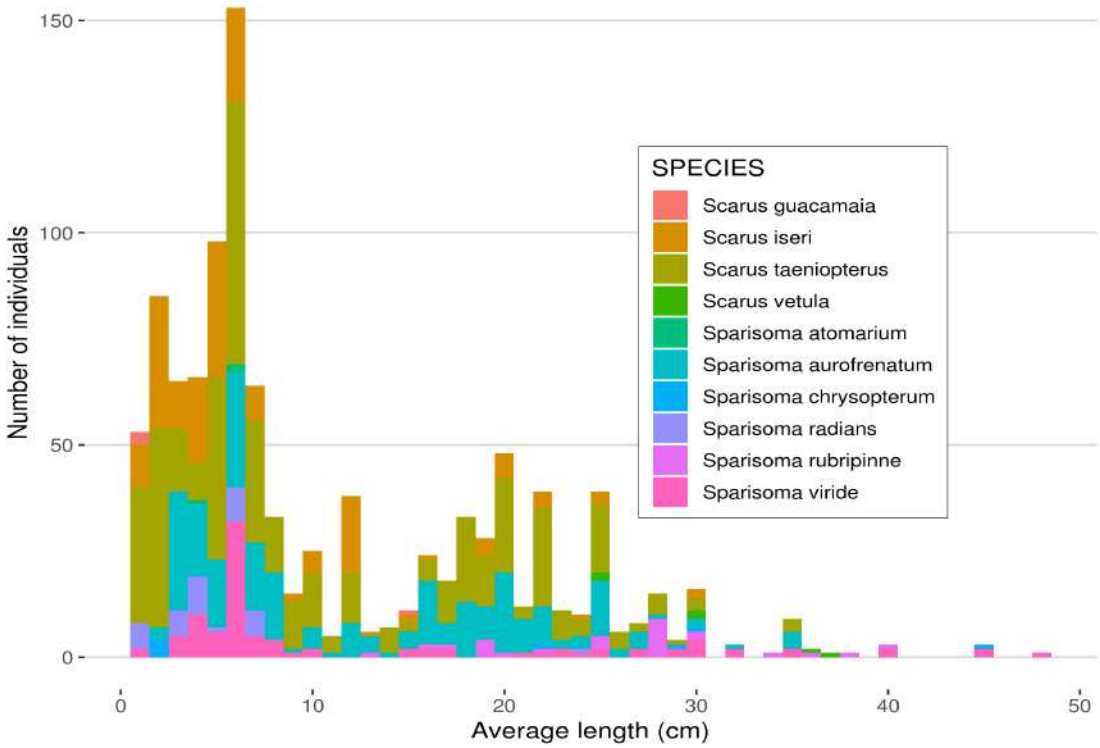


Figure 27. Length-frequency plot of all parrotfish. Colours indicate species.

Fish biomass was highest on coral reef habitats (median = 64.9 gm^{-2}), followed by sand habitats (median = 57.8 gm^{-2}), with the lowest biomass of fish found within seagrass habitats (median = 23.9 gm^{-2}, Figure 28). However, none of the differences in fish biomass between habitat types were found to be significant (one-way ANOVA on log-transformed data: $F_{4,157} = 1.66$, $p = 0.16$). Of the four trophic groups of fish that were used in classification (carnivore, invertivore, herbivore, and planktivore), invertivores had the highest median biomass across all habitat types, with the exception of seagrass where herbivores had a slightly higher biomass (Figure 29). Planktivore biomass was the lowest across all habitat types.

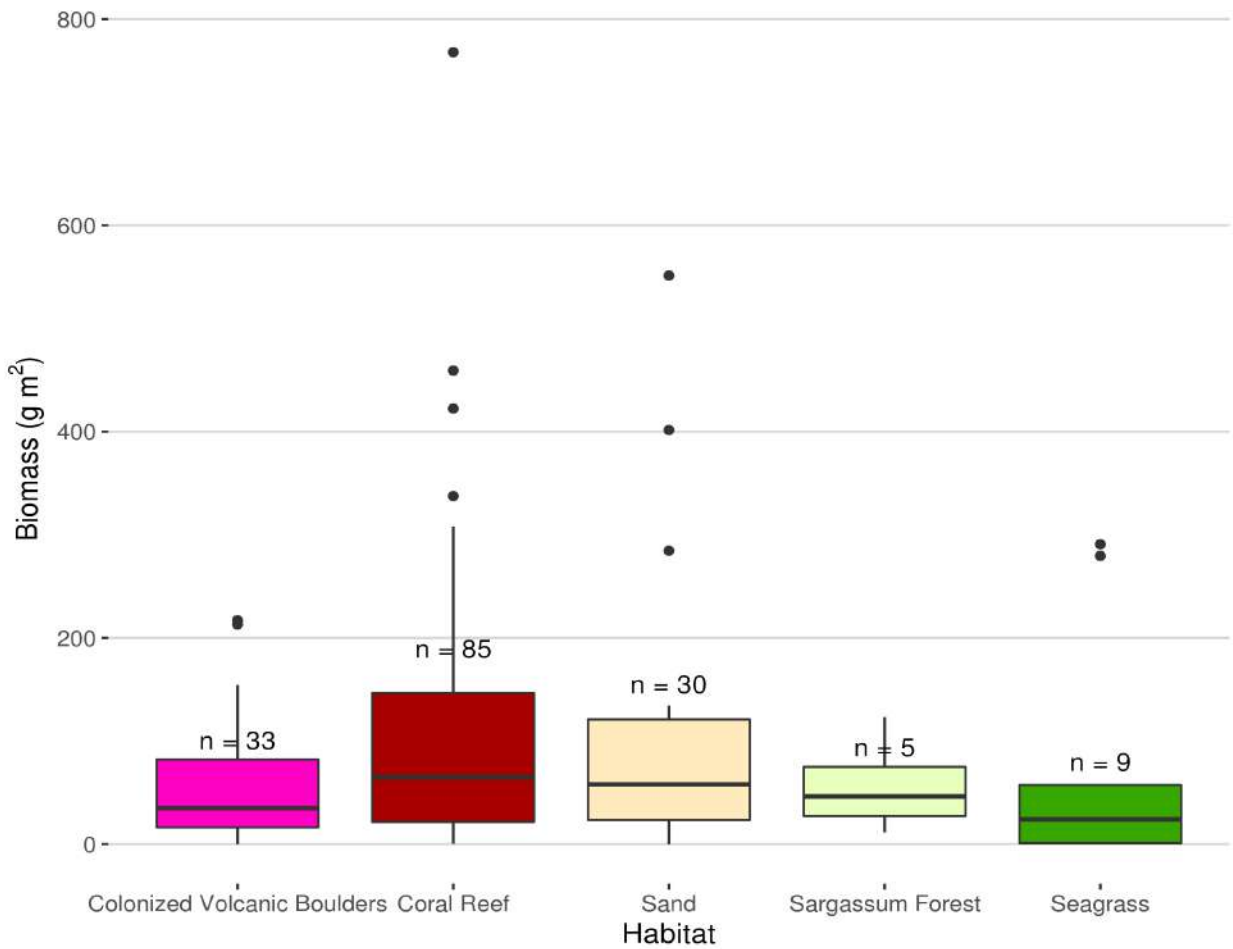


Figure 28. Boxplot of fish biomass by habitat type. "n =" above bars indicate number of surveys in given habitat. Boxes indicate interquartile range (IQR); solid horizontal line is median species richness value; whisker extends to last observations within 1.5 times the IQR; points beyond the whiskers are shown as dots.

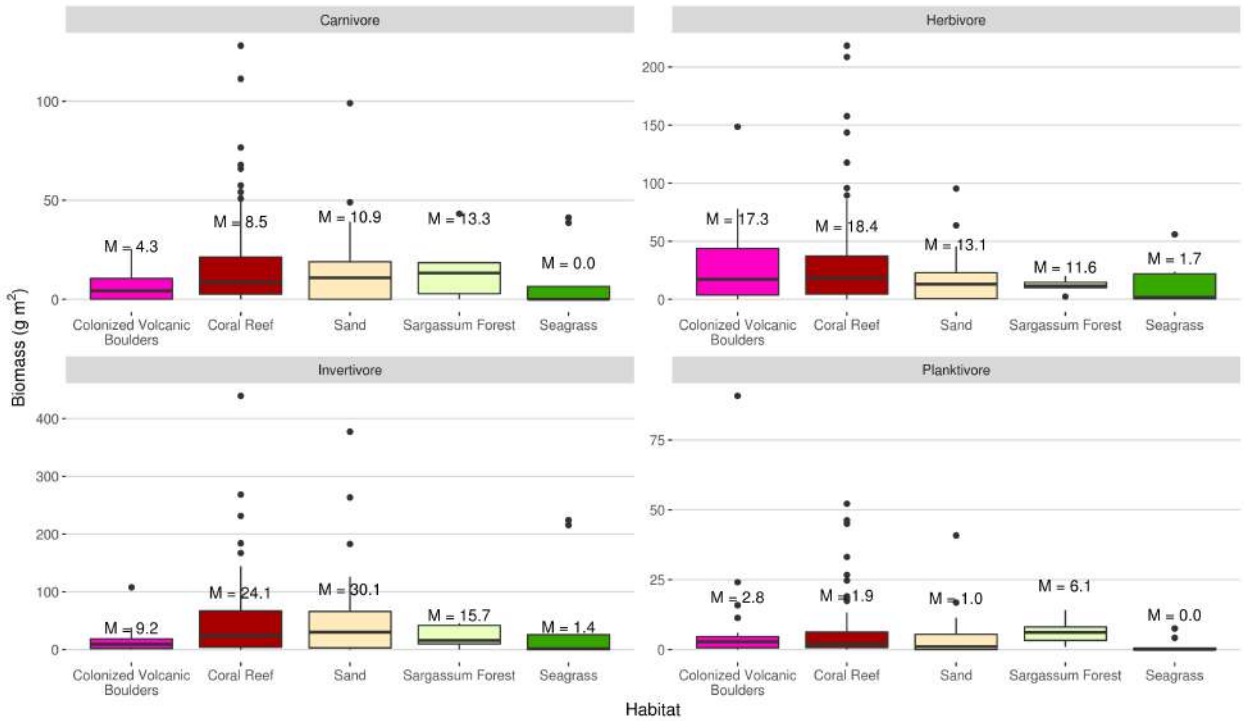


Figure 29. Boxplot of fish biomass by habitat type and trophic group. "M =" above bars indicate median biomass values. Boxes indicate interquartile range (IQR); solid horizontal line is median species richness value; whisker extends to last observations within 1.5 times the IQR; points beyond the whiskers are shown as dots. Note different scales for each plot.

Lionfish

Lionfish density was low at most sites, with a total of 85 lionfish recorded and an average density of 0.44 lionfish per 100 m^2. Lionfish were seen at only 24% (n=39) of all sites surveyed. Incidents of more than 4 lionfish were only recorded at 2 sites, with those 2 sites accounting for 25% of all lionfish observed (Figure 30).

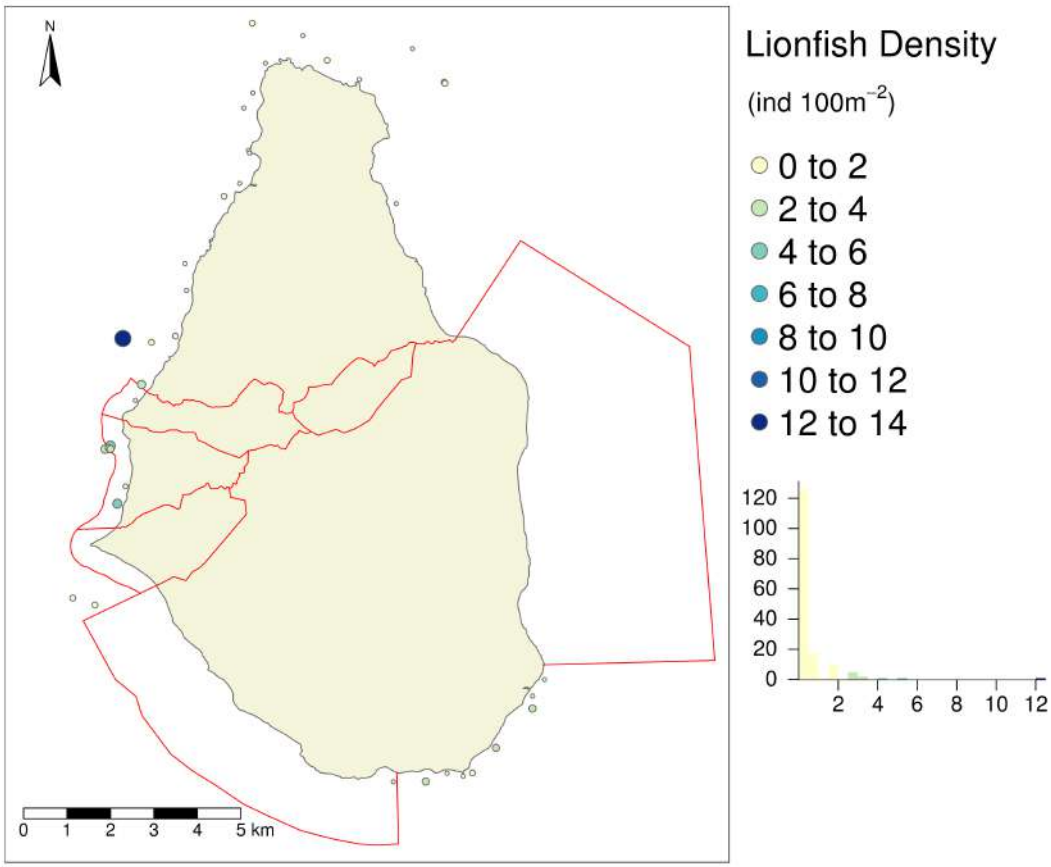


Figure 30. Map of lionfish density at all surveyed sites. Bubbles are sized proportionately to biomass. Red border shows volcanic hazard zone. Histogram shows number of sites on y-axis and density of lionfish on x-axis. There are few survey points within the hazard zone due to limited access.

3.1.6. MOBILE MACROINVERTEBRATES

Diadema, Spiny Lobster, and Queen Conch

Mobile invertebrates play diverse but important roles in shaping reef communities. They function as scavengers and grazers. We examined the presence of lobsters, queen conch, and sea urchins (Figures 31, 32, and 33 respectively). We found extremely low abundances of mobile invertebrates with sea urchins and conch present at less than 6% of the survey sites. The absence of the long spined sea urchin (*Diadema antillarum*) likely has negative impacts on the health of Montserrat's reefs because they are important algal grazers that keep corals from being smothered by algae competing for space on the reefs and allow corals to recruit successfully.

There is little protection for invertebrates under existing conventions and treaties that are relevant to Montserrat. Only the harvest and trade of queen conch is banned under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

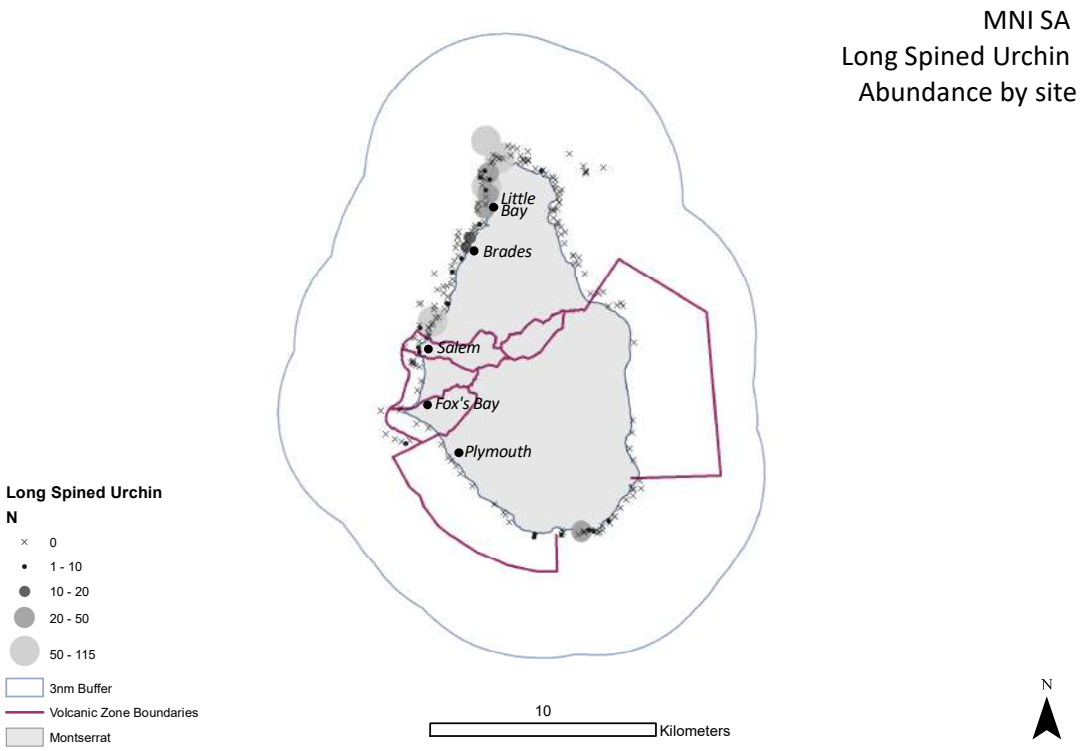


Figure 31. Distribution of long spined sea urchin (*Diadema antillarum*) abundance at dive survey sites.

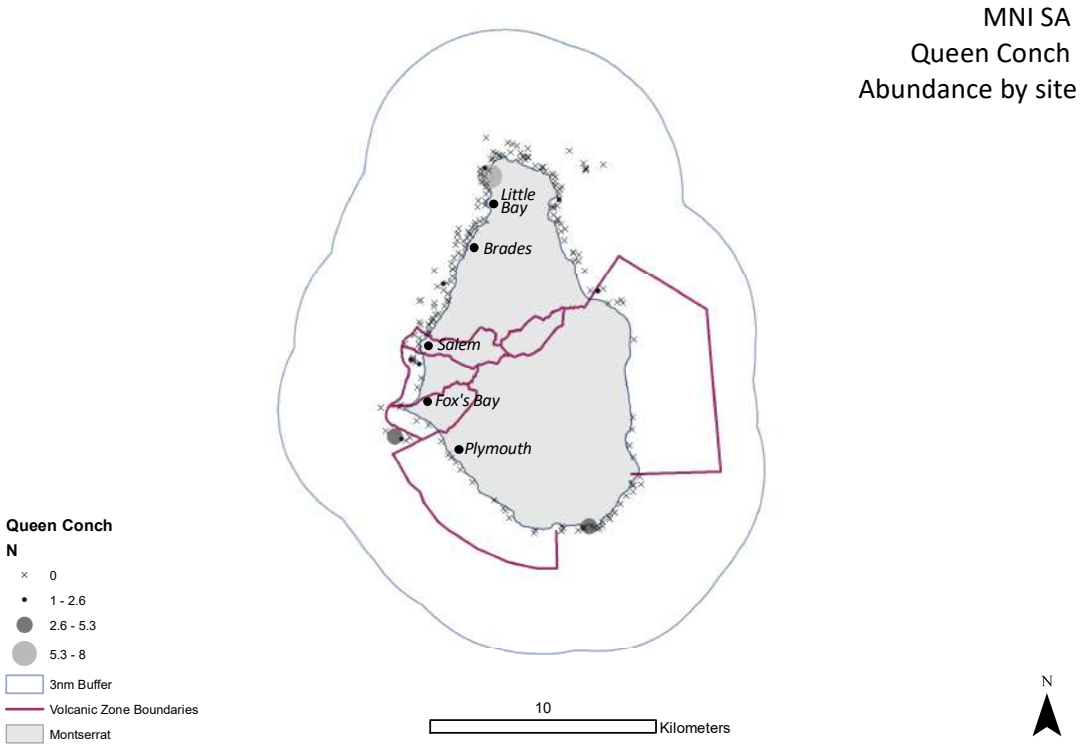


Figure 32. Distribution of queen conch (*Strombus gigas*) abundance at dive survey sites.

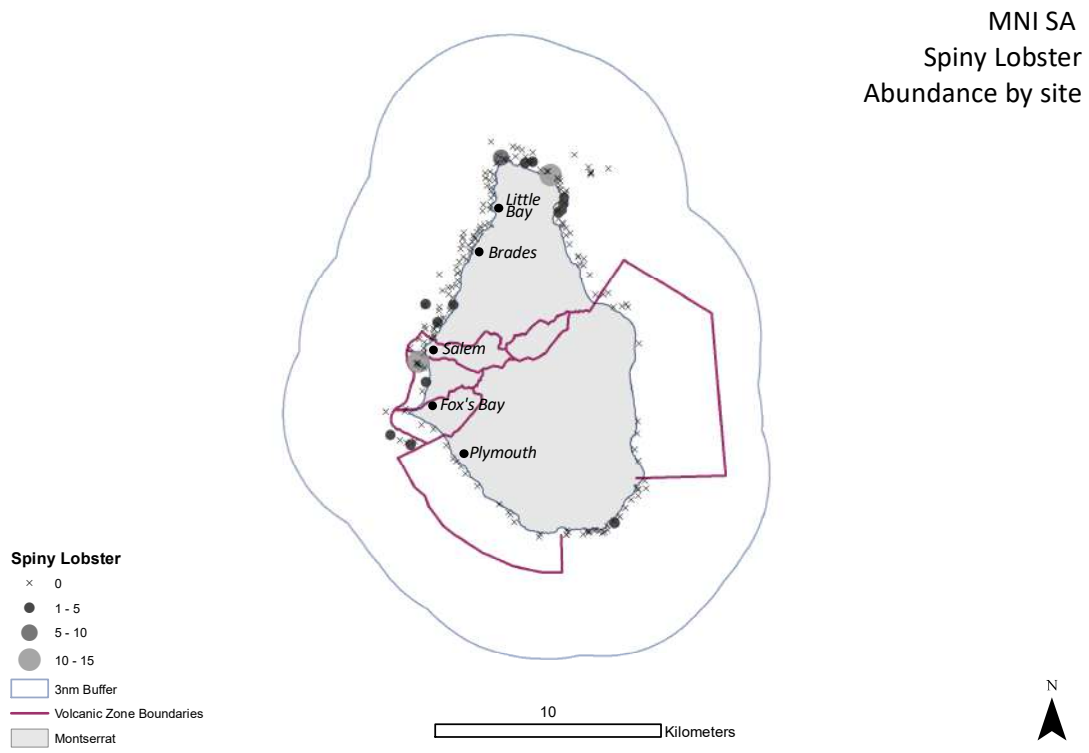


Figure 33. Distribution of spiny lobster (*Panulirus argus*) abundance at dive survey sites.

3.2. MESOPHOTIC HABITATS OF MONTSERRAT

Data collected from 481 mesophotic coral reef sites (Figure 34) across the Montserrat shelf system has indicated four primary areas of interest: mesophotic hard bottom areas; fleshy algae-dominant areas; seagrass patches; and sponge cover.

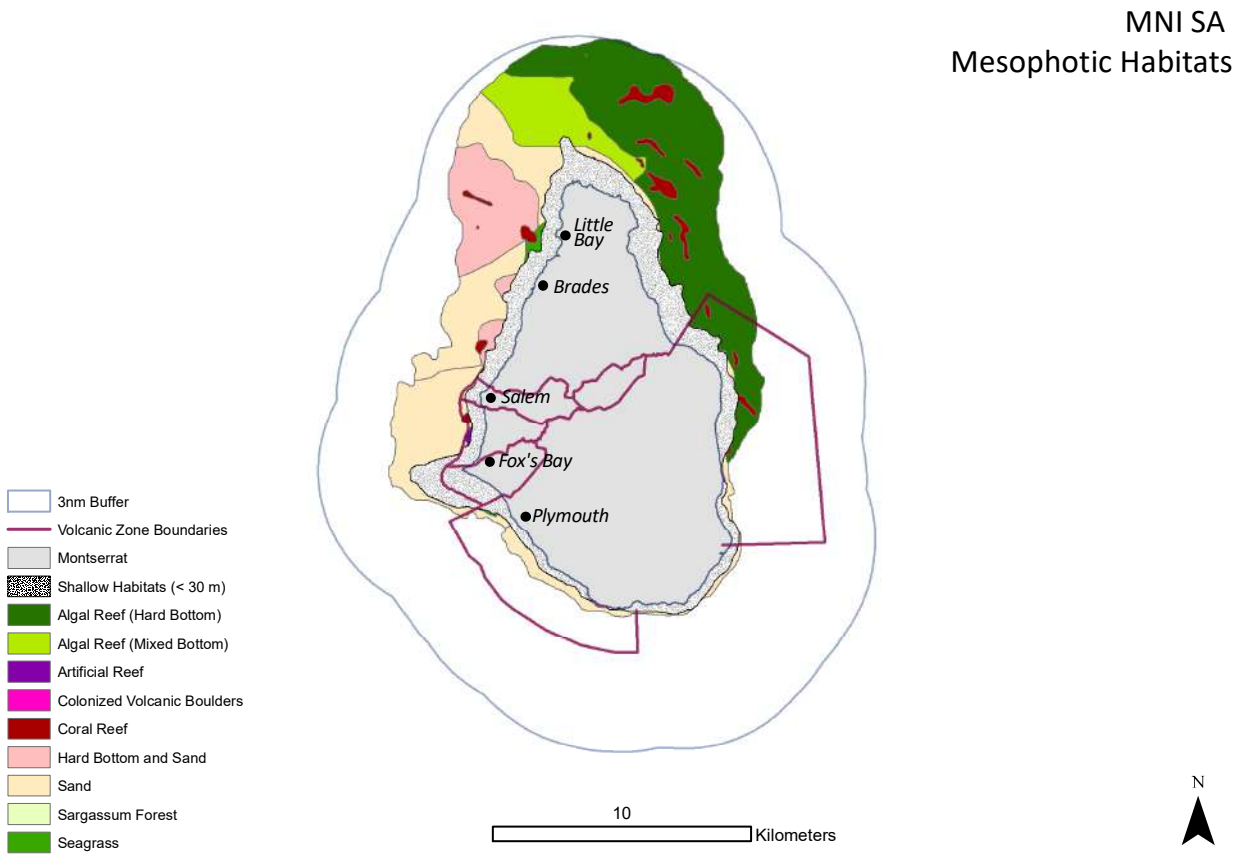


Figure 34. Mesophotic habitat types mapped across 481 survey sites in Montserrat.

3.2.1. DESCRIOPTION OF MESOPHOTIC HABITATS

Mesophotic hard bottom areas, which are valuable for both coral reef and fisheries habitats were predominately found on the northeast corner of the shelf, as well as the western region offshore of Plymouth. We found extant corals of the genera Agaricia, Montastraea, and Orbicella in both areas in small proportions. Exposed hard bottom areas in the northeast corner have been largely colonized by the alga *Lobophora variegate* (in some places covering as much as 94% of the seafloor), which is known to smother corals (Figure 35). The abundance of Lobophora in this area may be a result of nutrient enrichment from volcanic runoff that is pushed northward by the predominant currents in the area. The western hard bottom habitats appear interspersed with soft bottom habitat types, suggesting that heavy sedimentation may have smothered the reefs in this area.

There is a large area of seafloor on the northwest corner of the shelf (approximately 10 km^2) with greater than 30% coverage of a large, fleshy alga we believe to be in the genus Dictyopteris (Figure 35). However, without further sampling of the algae it is not possible to identify the species. Numerous questions arise from the identification of this algae patch, including: What is the total biomass of the patch? What influence is this algae patch having on local nutrient flux and carbon fixation? What role is

the patch playing in sediment capture in the region? Additionally, a study of *Dictyopteris deliculata* in the Grenadines showed that chemical defences produced by the species were significantly reducing the feeding pressure exerted by reef fishes (Hay et al. 1988). Could the large patch of *Dictyopteris spp*. be affecting local food chains and inhibiting fish communities in the nearby area? Further study is required to answer the above questions.

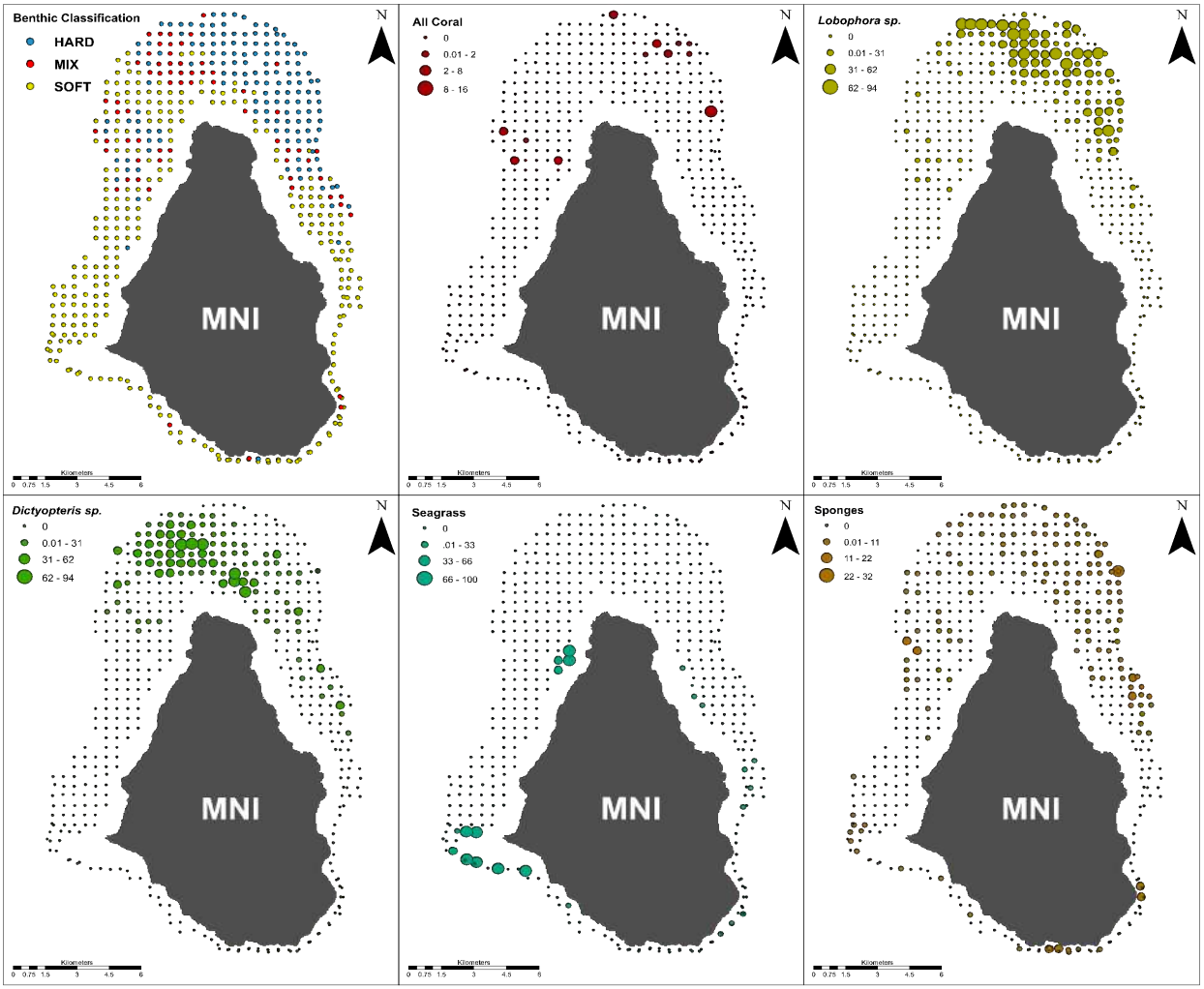


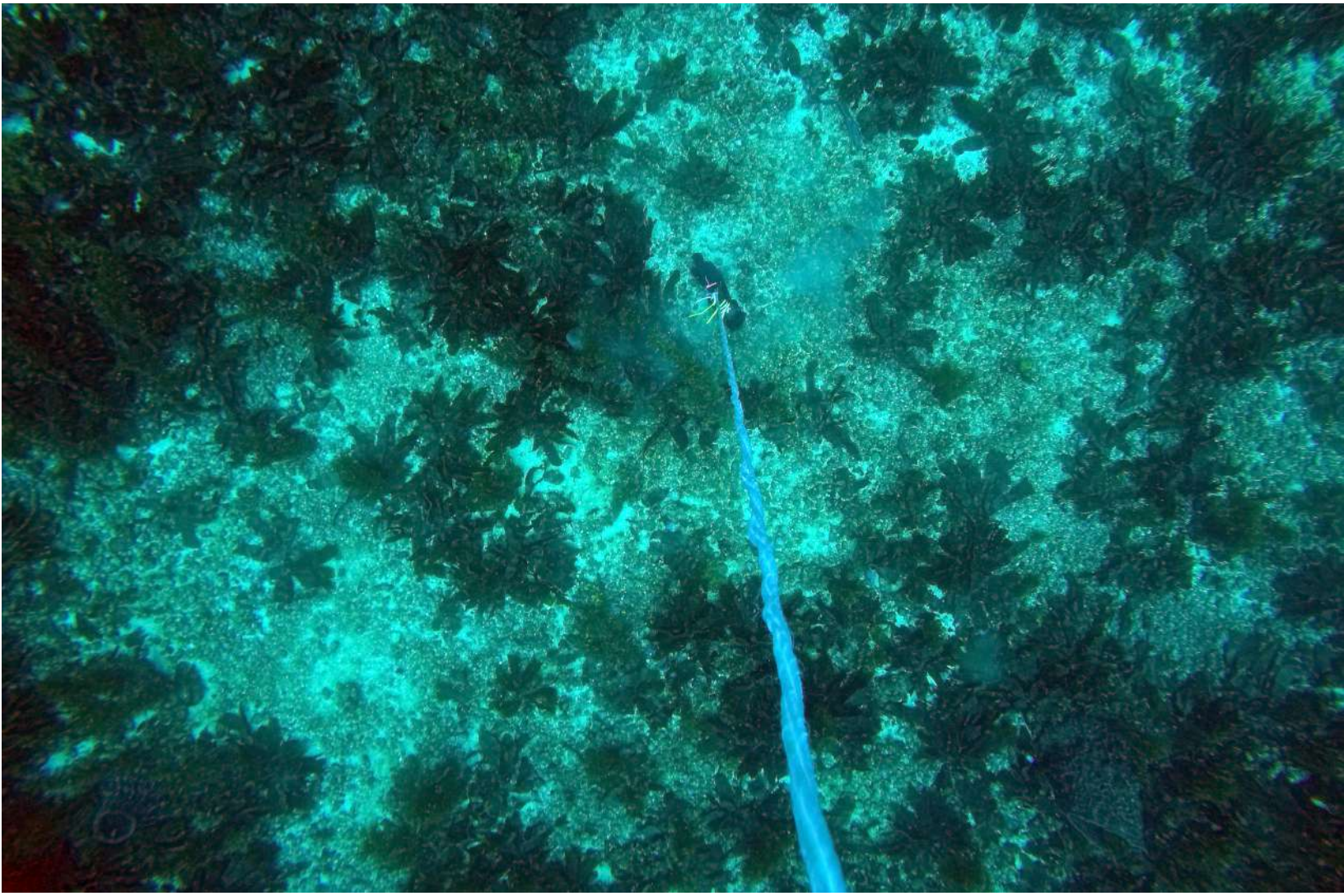
Figure 35. Mesophotic reef benthic classification around Montserrat as either Hard, Soft, or Mix (top left); Mesophotic reef benthic distribution of corals (top centre); Mesophotic reef benthic distribution of Lobophora species (top right); Mesophotic reef benthic distribution of Dictyopteris species (bottom left); Mesophotic reef benthic distribution of seagrass (bottom centre); Mesophotic reef benthic distribution of sponge cover (bottom right).

There are a handful of mesophotic seagrass patches that appear dominated by the species *Halophila stipulacea*—an invasive seagrass in the Caribbean (Figure 35). These areas are limited to the portions of the shelf that are dominated by soft sediments. Care should be taken to monitor these areas and prevent the expansion of *H. stipulacea* to the adjacent sediment planes.

Sponge cover across the mesophotic portion of the shelf system is relatively high (Figure 35). This is likely driven by increased sediment loads providing an environment that supports the growth of these filter-feeding animals. The role that sponges play in the maintenance and support of a shelf system with such heavy sedimentation cannot be understated. Further work in this area is needed to quantify both the diversity of local sponge communities and the functional role those communities play in supporting life on the Montserrat shelf system.

3.3 BENTHIC HABITAT MAPPING

Overall, nine benthic habitat types were observed and analysed across all survey sites in Montserrat. The major habitat types observed and described in this study are: 1) Coral Reefs; 2) Patch Reefs; 3) Seagrass; 4) Colonized Volcanic Boulders; 5) Hard Bottom and Sand; 6) Algal Reef (hard bottom); 7) Algal Reef (mixed bottom); 8) Sand; and 9) Sargassum Forest. These habitats and their dominant locations are illustrated in Figure 36.



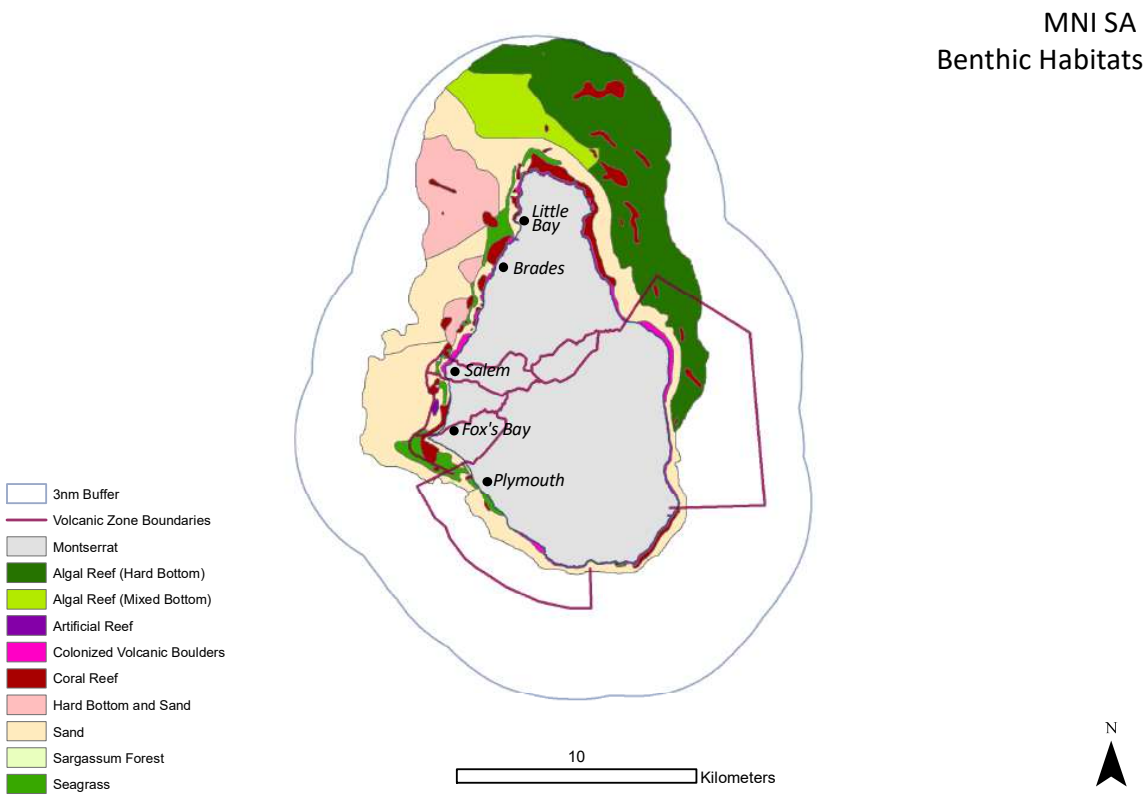


Figure 36. Benthic habitat types mapped across survey sites in Montserrat.

3.4 SHARK AND RAY DIVERSITY, ABUNDANCE, AND DISTRIBUTION ON CORAL REEFS

Fifty BRUVs were deployed in the coastal waters around Montserrat between the 20-29th of November 2016, capturing over 4,500 minutes of video data. Across these deployments we observed six species of elasmobranchs. For all species combined, rays were present on 50% (N=25) of BRUVs and sharks were present on 18% (N=9) of deployments.

We observed three species of rays: the Southern stingray (*Hypanus americanus*), Roughtail stingray (*Dasyatis centroura*), and Yellow round ray (*Urobatis jamaicensus*). Southern stingrays were the numerically dominant species, present on 42% (N=21) of BRUVs and the only elasmobranch for which MaxN values recorded were greater than one (Figure 37). The Caribbean reef shark (*Carcharhinus perezi*), nurse shark (*Ginglymostoma cirratum*), and lemon shark (*Negaprion brevirostris*) species were observed during the surveys. Caribbean reef sharks were numerically dominant, being present on 12% (N=6) of BRUVs. However, we did not record multiple individuals of any shark species within a single deployment.

In addition to elasmobranchs, predatory teleost species that were present on BRUVs included the great barracuda (*Sphyraena barracuda*, n=9), lionfish (*Pterois volitans*, n=3) and Nassau grouper (*Epinephalus striatus*, n=5).

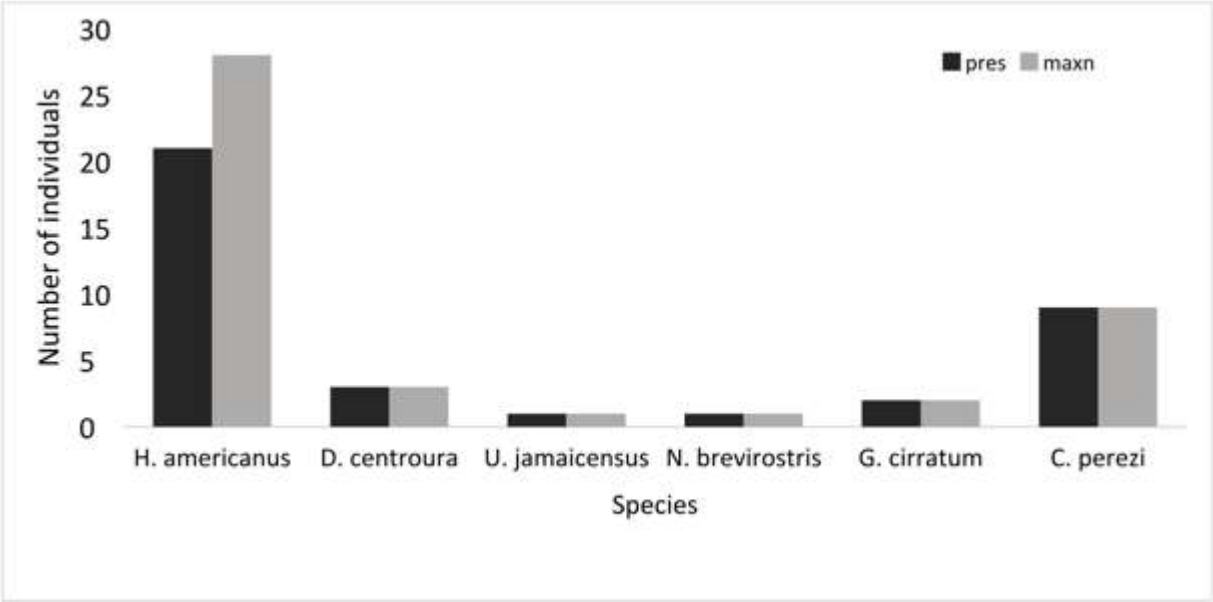


Figure 37. Graphic representation of the number of BRUVs where an elasmobranch species was present out of 50 deployments (black), and the number of individuals observed by species derived from the MaxN values (grey).

3.5 DIVING AND FISHING IN NEARSHORE MARINE RESOURCES

Reef fisheries have long sustained coastal communities by providing sources of both food and livelihoods. Effectively managed fisheries can be a sustainable resource, but growing human populations

and more efficient fishing methods, as well as increasing demand from tourism and international markets have significantly impacted fish stocks. Removing just one group of fish from a reef food web can have cascading impacts across the entire ecosystem. While large predatory fishes such as grouper and snappers are often preferred target species, fishers are forced to switch to smaller and often herbivorous reef fish as the numbers of larger fish decline (in a process known as "fishing down the food chain") (Sandin et. al, 2010). Heavily fished reefs are thus left with low numbers of mostly small fish, and without herbivores become prone to algal overgrowth. Such overfished reefs may be less resilient to (global) stressors, more vulnerable to disease, and slower to recover from other natural and human impacts (Hughes et. al, 2007).

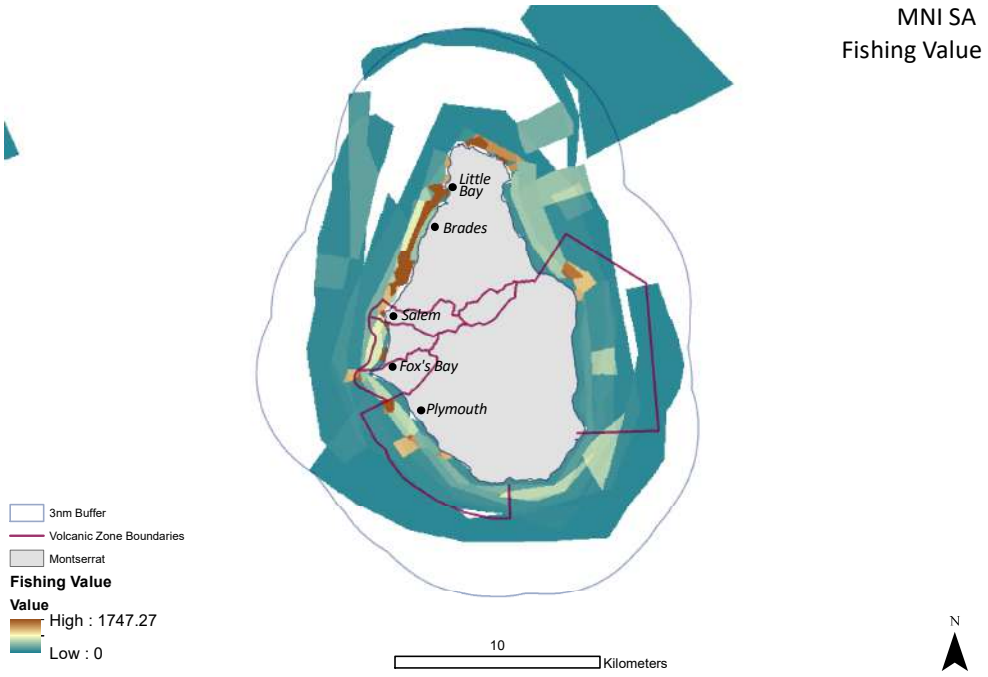


Figure 38. Fishing value derived from interviews with fishers using SeaSketch.

Figure 38 shows fishing value (as a proxy of fishing pressure) on Montserrat, based on survey responses from 53 fishers. Not surprisingly, fishers most value the sites that also attract other fishers resulting in a tight positive relationship between "fishing pressure" and "fishing value". Fishers may be attracted to sites based on ease of accessibility, reliability of catch, and whether they are fishable during rough weather conditions. Fishing pressure is highest along the north-western coast as many fishers launch from Little Bay. Fish stocks in coastal waters off the island's northern tip and along the east coast experience the lowest fishing pressure on the island. This is likely due to rougher sea conditions in the north and east sides of the island, as well as longer boat travel times required to reach these fishing areas.

Montserrat is a destination for SCUBA divers with two dive shops and a water sports operator. SeaSketch was used to evaluate proxies of diving pressure using survey responses from 69 SCUBA divers (Figure 39). These surveys focused on identifying the dive sites most valued by the survey respondents, which is a good proxy for dive pressure as the more valuable sites tend to receive the most dive-visits, and therefore pressure. Accessibility, especially during inclement weather, and popular demand are likely key factors in determining dive-site value to the dive operators of Montserrat. As shown in Figure 39, divers generally tend to visit dive sites along Montserrat's northwest coast.

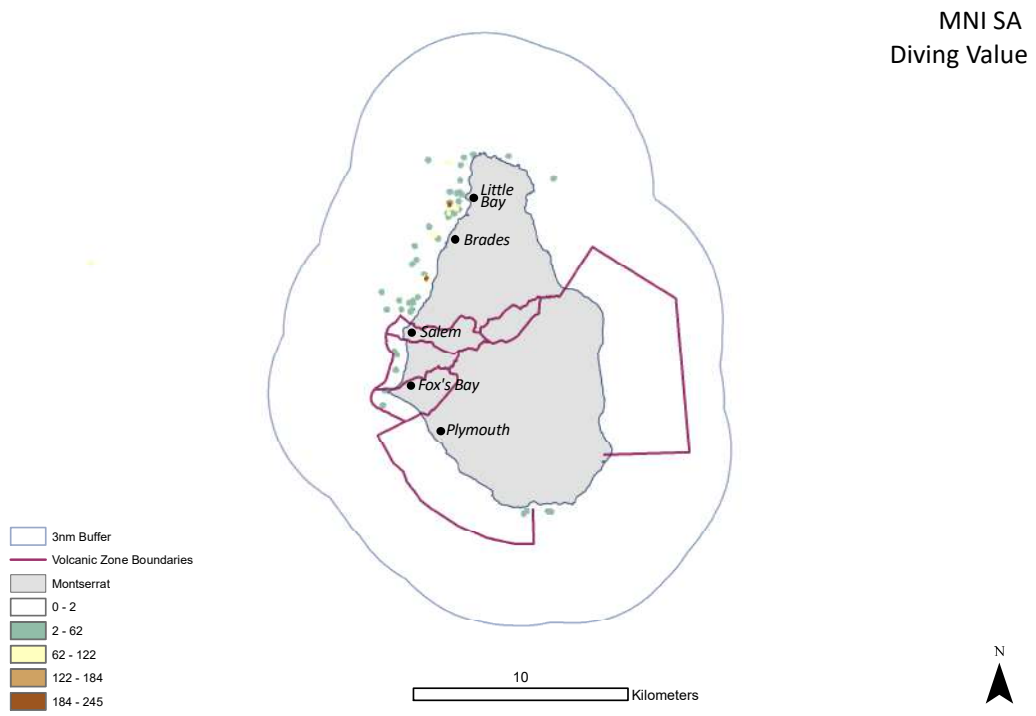


Figure 39. Diving value derived from SeaSketch surveys with divers.

Quantifying ocean usage is important to determine realistic trade-offs among competing users, to identify potential user conflicts, and to minimize cumulative impacts on Montserrat's coastal environment. Although the SeaSketch Ocean Use surveys did not inquire about actual conflict among

user groups, it is important to recognize that substantial overlap can result in conflict and should therefore be considered in the marine spatial planning process.

IV. Discussion

The following discussion provides a synthesis and evaluation of the Marine Scientific Assessment results.

4.1 MONTSERRAT IN A SUBREGIONAL CONTEXT

Coral reefs worldwide are degrading rapidly with current estimates suggesting that 27% of the world's reefs have already been lost. The cause of this degradation is a combination of natural and human impacts (Wilkinson 2000). If present rates of decline continue, researchers project that 60% of the world's coral reefs will be lost over the next 30 years. The cumulative impacts from runoff, pollution, tourism, destructive fishing and climate change contribute synergistically to these global trends.

When compared to habitat sizes of other nations and territories in the Eastern Caribbean, Montserrat has substantially less coral reef and seagrass habitat (Figure 40). With the development of Little Bay came the complete loss of mangrove habitat on Montserrat. However, comparing the marine habitats of Montserrat to those of other islands in the Eastern Caribbean only tells a small part of the story.

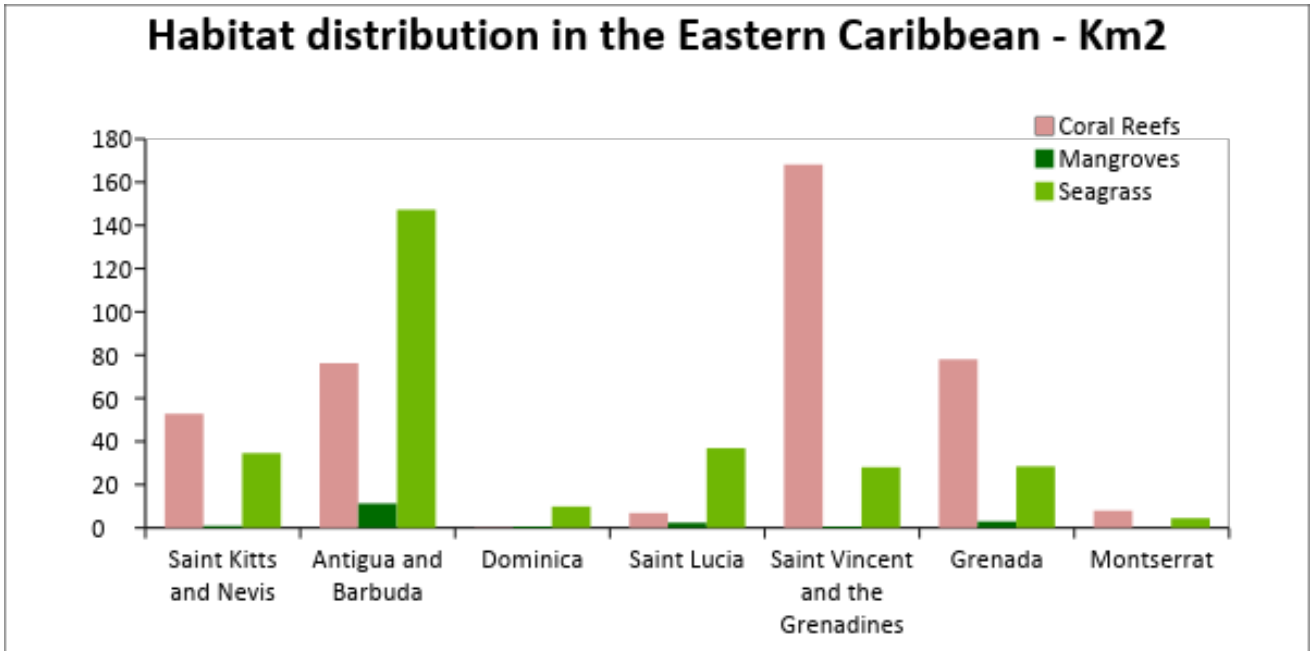


Figure 40. Habitat size comparisons within the Eastern Caribbean using data from CaribNode; in general Montserrat has much less area of marine habitat than most of the other regions in the Eastern Caribbean.

4.2 CORAL REEFS

Average live coral cover on Montserrat's coral reefs is below 10% with less than 15 coral species on average. However, exceptional sites with 18-21% live coral cover and up to 20 coral species can be found between 200-500 m off the northern coast and in particular along a fringing reef located at the southeast coast. There are a number of interesting and unique features of coral reef habitats in Montserrat. The influence of volcanic activity seems to have had a central role in shaping coral communities around the island both from a geological and ecological perspective.

Environmental and geomorphologic features

From the geological point of view, it is clear that volcanic rocks provide the primary substrate for corals and other sessile invertebrates that build the reef framework around the island. The majority of sites located north-north-west of the island consist of benthic sessile communities growing on top of these volcanic rocks that provide stable and suitable substrate for recruitment and reef development over the long term. Furthermore, volcanic activity must also play a very important role in shaping the geomorphologic structure of the coast line. In particular, the topographic relief, the slope of the coastal shelf, and the relative abundance of unconsolidated-sandy sediments are all known to be factors controlling the abundance and distribution of coral communities (Dubinsky 1990).

In Montserrat, volcanic boulders add structural complexity and heterogeneity to reef habitats. These highly-complex sites provide habitat for a myriad of fish and invertebrate species. In marine ecosystems there are multiple examples demonstrating the key role habitat complexity has in determining the structure of ecological communities (Laegasgard Johnson 2001; Angel Ojeda 2001 Beck 2000). This is particularly true for coral reef communities where the habitat is provided by sessile organisms such as corals, which have complex body plans and growth forms (Coates & Jackson 1985; Jackson 1985). In fact, high species diversity of fish at multiple spatial scales has been associated with the highly-heterogeneous nature of these habitats (Sale 1977; Connell 1978; Sale & Douglas 1984). Nonetheless, under certain scenarios, the relationships between habitat complexity and community metrics have been found to be negative or unimodal rather than positive (Tews et al. 2004; Gazol et al. 2013). This has been explained by the "Heterogeneity-Trade-off Hypothesis" whereby complex habitats have more fundamental niches and can support more species diversity, yet as heterogeneity increases the area suitable for each species decreases to the point where the population size decreases and the probability of stochastic extinction increases (Kadmon et al. 2007; Allouche et al. 2012). Surveys in Montserrat clearly showed that areas with higher topographic relief had higher fish biomass compared to more flattened habitats.

The slope is also an important geomorphological feature that determines the environmental setting for reef communities (Achituv and Dubinsky 1990). One of the most important environmental variables for corals is light, the intensity of which drops rapidly with depth (Falkowski et al. 1990). Thus, steep slopes often produce a rapid gradient of light availability for corals. Corals are known to derive their carbon and other important metabolic compounds from zooxanthellae photosynthesis (Muscatine 1981). In

Montserrat steep slopes are common across the island, probably because of seismic activity. We found that most of the hard-bottom habitats are located close to the coastline which is another example of how the morphologic features of the island influence the distribution and the structure of the habitats. There are other important environmental variables relevant to coral development (e.g. oxygen and temperature) that also change across depth gradients (Achituv and Dubinsky 1990). Finally, the form of the coast partly determines shelf-ocean interactions (Andrews and Pickard 1990) that are extremely important for larvae transport, recruitment and settlement of new individuals into the system (Underwood and Keough 2001).

Sedimentation regimes and the relative abundance of unconsolidated substrates are important variables related to volcanic activities that might influence for the distribution of benthic coral habitats in Montserrat. Sedimentation effects corals and benthic communities in many different ways. For instance, the percent cover of unconsolidated substrates, such as sand will limit the space for coral recruitment, which often settles on crustose coralline algae or hard bottom substrates (Harrison and Wallace 1990). Space limitation might increase inter and intra-specific competition between corals, and therefore could have negative consequences for the replacement of populations of adult corals (Lang and Chornesky 1990).

The historic and more recent volcanic activity in Montserrat is clearly important to determining the distribution of available substrates for coral and sessile benthic communities. Sedimentary dynamics in areas close to the volcano (south-west and east coasts) are dominated by the deposition of sands and are not suitable for the establishment and development of benthic communities dominated by corals and other co-occurring faunas. Sediments are known to produce a series of direct and indirect negative consequences at different levels of organization (Rogers 1990). For instance, heavy sedimentation is associated with fewer coral species, less live coral, low coral growth rates, greater abundance of branching forms, reduced coral recruitment, decreased calcification, decreased net productivity of corals and slower rates of reef accretion (Rogers 1990). All of these negative effects may vary depending on particular features of the sediments. For example, fine sediments rich in organic matter tend to lead to coral death more rapidly than coarse sediments that are poor in organic matter (Weber et al. 2006).

Volcanic eruptions in Montserrat along with hurricanes might also represent important disturbances for coral communities and hard-bottom habitats. The role of disturbances in forming the structure of benthic communities has long been acknowledged (Sousa 2001). According to Connell (1978), communities exist in multiple equilibrium states, however, on one end of the scale there are communities exposed to low-frequency, mild disturbances, whereas at the opposite end there are communities exposed to high-frequency, severe disturbances. Communities in these extremes are low-diversity communities, whereas intermediate levels of disturbance in both frequency and magnitude increases species diversity (Connell 1978). However, this theory has been criticized due to the scarcity of supporting empirical evidence (Fox 2013). While the role of volcanic eruptions and hurricanes on benthic community structure has not been quantified, it is clear that the features of hard-bottom benthic communities vary across the island and these spatial patterns might be related to varying exposure levels to such disturbance events.

Ecological features

Coral reefs in Montserrat also possess particular ecological features. Overall, the hard-bottom habitats were dominated by algal turf, and in some cases fleshy macroalgae. This result suggests that the reefs of Montserrat might be in a later successional stage (i.e., a benthic community composed of species that colonized long after a disturbance occurred) (de Bakker et al. 2017). Algal turfs consist of a large consortium of species, including cyanobacteria (Connell et al. 2014). They may develop to later successional taxa, such as standing crops of macroalgae or cyanobacterial benthic mats (CBM) depending on local and global conditions. For instance, reduced water quality, high grazing pressure and elevated water temperature stimulate CBM growth over macroalgal growth (Kuffner & Paul 2001; Bender et al. 2014). The most abundant macroalgae recorded during our surveys were *Dictyota spp.* and *Lobophora variegata*, the latter being particularly abundant in deeper reefs. While the majority of macroalgae recorded in Montserrat are grazed by parrotfish and other invertebrate grazers (Hay 1997), CBM are not (O´Neil 1999; Charpy et al. 2012). Consequently, conditions leading to increased CBM cover might represent a serious threat for coral reefs in Montserrat as currently reported across many areas in the Caribbean (Brocke et al. 2015; de Bakker et al. 2017).

The dominance of algae over corals in Montserrat might also be a result of low coral larvae input, poor recruitment rates, compromised survivorship of corals during their early life stages, eutrophication, overfishing and/or a combination of these factors. These disturbances are recognized to be critical to determining coral-algal phase shifts observed across the Caribbean (Jackson et al. 2014). Nevertheless, because of the lack of large-scale coastal development occurring in Montserrat, chronic land-based impacts seem to be a less important factor in coral mortality compared to natural factors. Overfishing is likely the most impactful human activity on herbivore-algae-coral interactions in Montserrat.

CBM covering the substrate in Montserrat were rarely found, further suggesting that anthropogenic impacts in Montserrat might not be as great as other regions in the Caribbean. CBM are known to prosper in eutrophic conditions (i.e., high levels of nitrogen, phosphorus, and dissolved inorganic carbon) (Brocke et al 2015; de Bakker et al. 2017). These mats not only avoid herbivory control, but they also limit coral settlement and survivorship as they monopolize the substrate and enhance macroalgal growth by releasing dissolved organic carbon (DOC) (Brocke et al. 2015), which in turn limits space for corals. CBM are also known to be poisonous to corals as they produce a series of toxic metabolites capable of killing coral tissues (Titlyanov et al. 2007). Furthermore, many cyanobacterial species associated with CBM have also been associated with coral diseases (e.g. black band disease) (Charpy et al. 2012) with demonstrated potential for wiping out coral populations in the wider Caribbean (Weil et al. 2006).

Coral diseases, bleaching and other health problems were seldom recorded along transects and across survey sites. However, diseases and bleaching tend to be seasonal (Harvell et al. 2002), and depending on environmental conditions might increase and/or decrease rapidly (Bruno et al. 2007). Thus, the low incidence of coral health problems observed during the sampling period cannot be taken as an indicator of good overall reef health. There is still a very real possibility that coral diseases, epizootic and

bleaching events have played, and will continue to play a central role in determining the live coral cover in Montserrat.

Abundance of threatened coral species

The Caribbean region has a large number of red-listed coral species (the IUCN's comprehensive inventory of the global conservation status of plant and animal species) in different categories (e.g. lesser concern, threatened, and endangered). The Caribbean acroporids, *Acropora palmata* and *A. cervicornis* were seldom found on the reefs of Montserrat. Populations of these species have declined in the past 40 years across the Caribbean with a limited number of areas showing recovery trends (Cróquer et al. 2016). At this point, it is impossible to know whether these species have always been rare in Montserrat or have experienced decreases in their distribution and abundance. These species are known to be important as habitat for various fish species of high commercial value (Agudo-Adriani et al. 2016). Other endangered species, such as the pillar coral *Dendrogyra cylindrus* are also rare in Montserrat. Survey sites located at the northern and southern tips of the island harbored healthy populations of species in the genus Orbicella (e.g. *Orbicella faveolata* and *O. franksi*). These species are known to be highly susceptible and vulnerable to coral diseases (e.g. white plague, white band disease, and Caribbean Yellow Band Disease) (Weil et al. 2006). None of these diseases were frequently observed across sites.

The role of sponges in Montserrat

Sponges have many biological and ecological properties that make them an important part of Caribbean coral-reef ecosystems. Sponges have a higher diversity than all coral groups combined. They are also highly abundant (i.e. area coverage), with biomass (weight, volume) that may exceed values for all other reef epibenthics in some areas and reef zones. Sponges have the capacity to mediate non-animal processes, such as primary production and nitrification through complex symbioses. Sponges compete for space via chemical and physical adaptations, and are able to impact the reef carbonate framework through calcification, cementation, and bioerosion. Sponges also have the potential to alter the water column and its processes through high water filtering capabilities and exhalation of secondary metabolites (Diaz and Rützler 2001). Additionally, coral reef sponges serve as habitats for a large number of other invertebrate taxa (Duffy 1992; Henkel and Pawlik 2005), and host a diverse array of microbes that may take part in primary production or nitrification (Rutzler 1985; Diaz and Ward 1997).

The giant barrel sponges (genus Xestospongia, family Petrosiidae, order Haplosclerida) are widely distributed throughout multiple tropical oceans. Giant barrel sponges are large, long-lived and conspicuous organisms that can reach more than 2.5 m in diameter (Nagelkerken et al. 2000), covering up to 9% of some reefs (Zea 1993). This species is acknowledged to be an important component of habitat heterogeneity (Humann & DeLoach 2002; Büttner 1996). In Montserrat, large (0.8 m to 1.8 m) barrel sponges were observed, adding spatial complexity in many hard-bottom and reef habitats. This is particularly true along the northern and southeast coast of the island where sponge cover was

comparable to scleractinian coral cover. Associated with these giant sponges are fish (e.g. groupers, grunts, and snappers) and invertebrates (e.g. lobsters) that were also observed. Therefore, these long-lived organisms are as important to overall reef health as corals in Montserrat.

Reef Fish

Comparing the total fish biomass in Montserrat to that in other areas of the Caribbean is complicated due to the high variability of biomass we recorded across survey sites. Montserrat's median total fish biomass (56 gm^{-2}) is approximately half the average biomass (130.6 gm^{-2}) found at unfished sites in the region (Karr et al. 2015). Comparing the mean value in Montserrat (94 gm^{-2}, SD = 121 gm^{-2}) gives the appearance that Montserrat's reefs have relatively healthy fish populations, however, the mean total biomass value is distorted by a small number of outlier sites. Montserrat would not be expected to have comparable fish biomass to unfished reefs in other locations because the carrying capacities of its reefs are most likely lower due to the impacts of volcanic activity and fishing pressure around the island, including trap fishing, which is known to have negative impacts on reef fish populations.

The Montserrat average parrotfish biomass of 5.1 gm^{-2} (SD = 7.3 gm^{-2}) is low compared to a study of 12 islands in the Eastern Caribbean that found a regional average of 7.9 gm^{-2} for fished sites and 14.5 gm^{-2} for unfished sites (Steneck et al. 2018). This indicates that parrotfish biomass in Montserrat is one-third of what it could be without fishing pressure and currently below regional averages for unfished sites. Parrotfish are of particular importance because they are the principal algal grazers on most Caribbean reefs (Mumby et al. 2007). Montserrat's parrotfish populations are principally composed of small individuals with 67% of those observed being less than 15 cm in length. This length corresponds to the approximate minimum size at which parrotfish are caught in fish traps (Bozec et al. 2016), further suggesting that fishing has had an impact on the population by selectively removing the larger individuals. A lack of large parrotfish is of concern as larger parrotfish contribute disproportionately to algal grazing (Mumby et al. 2006).

The lack of large groupers and snappers, and the predominance of mesopredators (principally coneys, *Cephalopholis fulva* making up 60.9% of all observed carnivores) in the carnivore trophic group suggests that the abundance of larger carnivores has been reduced by fishing pressure. High abundance of coneys and other mesopredators has been associated with the loss of larger carnivorous species in Belize where fishing was also the primary explanation (Mumby et al. 2012). In Montserrat's case, impacts from the volcano have likely also had an impact on carnivorous fish populations, however, the lack of larger individuals strongly indicates that fishing pressure is a factor.

Lionfish (*Pterois volitans*) are an invasive species in the Caribbean and have been shown to severely reduce biomass, abundance and species richness of other reef fishes where they are present (Albins 2012; Green et al. 2012). Lionfish were observed at 24% of surveyed sites in Montserrat, and their density across the island is less than half that found on Bahamian reefs (0.44 individuals/m^2 in Montserrat compared to 1.02 individuals/m^2 in the Bahamas) (Darling et al. 2011). This means that the impact of lionfish on local fish populations in Montserrat may be relatively modest, however, local

control efforts should be maintained and ideally enhanced to ensure that lionfish abundance remains low.

Sharks and Rays in Montserrat

The study and results presented here can serve as an important baseline of elasmobranch diversity and abundance from which to monitor changes through time. Baited remote underwater video (BRUV) surveys have been widely used to measure the relative abundance of carnivorous fish in a variety of ecosystems (Brooks et al. 2011; Bond et al. 2012; Whitmarsh et al. 2016). The remote operation of these cameras removes the element of diver-bias, either through the alteration of animal behavior in the presence of divers or diver observational errors that are associated with other underwater visual census (UVC) techniques. The standardized nature of this survey means that these data can also be compared both regionally and globally as part of the Global FinPrint Project (www.globalfinprint.org). This will allow the direct comparison of diversity and abundance metrics across varying management zones and jurisdictions to help identify factors underpinning these patterns in order to help improve management decisions.

The three observed shark species are representative of some of the most common large-bodied reef-associated shark species found throughout the broader Caribbean. A large absence of sharks has been reported for the region based on historical fishing records and trained diver observations (Ward-Paige et al. 2010), which is consistent with our results for Montserrat that showed a lack of multi-shark observations. Nurse sharks are less affected by overfishing, having rarely been the target species for fisheries. Caribbean reef sharks, however, can be used as an indicator of reef health. Caribbean reef sharks were present on 18% of Montserrat BRUVs, compared with a similar study inside a well-enforced marine protected area (MPA) in Belize that found reef sharks were present on 35% of BRUVs. The lower presence value, and lack of multi-shark observations suggest that the populations of Caribbean reef sharks have been negatively impacted. With the appropriate protections, the shark populations have the scope to increase within this region. The single observation of a juvenile lemon shark was surprising and encouraging, given the low mangrove coverage and lack of nursery habitat.

Southern stingrays are currently listed as being data deficient by the International Union for the Conservation of Nature (IUCN). The species' relative abundance around Montserrat suggests that they are not experiencing the declines observed at other sites across the Caribbean. The data collected have been communicated to the chair of the IUCN shark specialist group (IUCN SSG) for inclusion in the upcoming reassessment for the Caribbean region. Of particular interest was the absence of the highly mobile spotted eagle ray (*Aetobatus narinari*), a species that is relatively common throughout the region. This absence could be an artefact of the reduced coral reef structure observed around Montserrat due to the pyroclastic flow from the volcano smothering the live corals.

4.3. SEAGRASS

Seagrass beds provide a series of ecosystem services to human societies. For instance, they are important nursery grounds for many species of fish and invertebrates. Many studies have demonstrated that these ecosystems enhance recruitment of fish larvae, and provide food and shelter from predation for juvenile and larval fish. Thus, seagrasses enhance biological productivity and biodiversity.

In Montserrat, seagrass beds were found along the western coast of the island, particularly close to the shore in areas more protected from wave energy. The largest densities of Queen Conch and juvenile lobsters were recorded at these sites, further illustrating the importance of these habitats as nurseries for commercially valuable species in Montserrat.

Several studies have examined the relative habitat value of seagrass beds to fishery species by comparison with other habitat types, such as kelp forests (Wheeler 1980), mangroves (Ronnback 1999), salt marshes (Boesch & Turner 1984), coral reefs (Jones 1991) and bare sand (Gibson et al. 1998). Seagrass beds are also known to enhance water quality in coastal ecosystems. Seagrass canopies dampen water movement and favor the retention of suspended particles, both living and dead, becoming a sort of a filter for coastal waters. The particle trapping capacity of seagrass is enhanced by epiphytic organisms associated with their blades, either through filter-feeding and active capture or through the direct attachment of the suspended particles to the mucus-covered seagrass surface that result from their activity. Seagrasses are also important to protecting coastlines from erosion by reducing the force of superficial currents and favoring the deposition of sediments, thereby stabilizing the substrate.

Finally, seagrass beds have a primary role in the carbon cycle as they sequester significant amounts of carbon in their sediments and via photosynthesis. In Montserrat, seagrass beds were composed of the invasive species *Halophila stipulacea*, which has replaced the native seagrass species. No native species of seagrasses were observed during this study. The impact of this invasive seagrass in Montserrat remains to be determined.

4.4 MACROINVERTEBRATES

The most common invertebrates we recorded in Montserrat were sea urchins (e.g. *Diadema antillarum* and *Echinometra spp*). There is overwhelming evidence showing the importance of *D. antillarum* in controlling macroalgal growth on Caribbean coral reefs (Hughes 1994; Jackson et al. 2014). The long-spined sea urchin, *Diadema antillarum* was found forming aggregations in hard-bottom habitats, particularly in between crevices and volcanic boulders. In Montserrat, the dominance of turf and macroalgae over corals and other benthic organisms seems to suggest that these urchins alone cannot control algal growth.

Large aggregations of *Astropiga magnifica*, a deep-water urchin species, were found in deep mixed seagrass habitats located along the north-western coast of Montserrat. An interesting association between this urchin species and juvenile spiny lobsters (*Palinurus argus*) was observed, as 2-3 lobsters

were recorded hiding behind the spines of the urchins. Nevertheless, lobsters occurred in low density with only a small number of transects having juvenile or adult individuals present. Previous technical reports and assessments in Montserrat show that lobsters represent an important natural resource for locals in Montserrat. Thus, low abundance of lobsters in the island might be the result of overfishing, lack of proper sampling effort and/or replication within each site, or a combination of these factors. Sea cucumbers were also rarely found across survey sites, and were mostly associated with seagrass beds and/or bare sand.

V. CONCLUSIONS AND MANAGEMENT IMPLICATIONS

In summary, effective marine spatial planning and management must take into account the unique characteristics of Montserrat outlined herein. While the coral reef habitats of Montserrat have a relatively low diversity of corals, some exceptional sites can be found at the Northern and Southern tips of the island. On average, live coral cover seldom exceeds 10% with volcanic boulders playing an important role in determining habitat complexity and substrate availability for benthic organisms, including corals, sponges, zoanthids, octocorals and milleporids. The high abundance of algal turfs and fleshy macroalgae might be an indication of weak herbivory, which is unable to control algal growth. Thus, overfishing seems to be the major human-induced impact, significantly influencing the structure and function of reefs in Montserrat. Coral recruitment was commonly observed across the island, particularly at the north-western and south-eastern coastline. Juvenile corals were recorded growing on top of volcanic boulders and hard-bottom substrates. The high density of juvenile corals (up to 5 individuals/m^2) and low live coral cover seems to suggest successful settlement but high mortality rates during the early stages of their life cycle. This might be a consequence of communities being frequently exposed to natural disturbances, such as volcanic activity. We also found that brooding larvae species are dominant compared to broadcast corals. Management strategies should consider the influence of natural disturbances in the area when determining protection measures, specifically regarding protected areas and fisheries regulations.

Sponges are important reef-building organisms in Montserrat, as they provide structural habitat for many fish and invertebrate species. Montserrat also contains rich and diverse mesophotic habitats between 30-100 m, which warrant further investigation and protection. The status of lionfish and Nassau grouper in Montserrat should be closely monitored, as these species serve as indicators of overall reef health and can help guide conservation measures. High abundances of the invasive lionfish (*Pterois volitans*) can have negative impacts on the reef as they are able to consume large volumes of reef fish and have no natural predators. Therefore, local control efforts should be enhanced or at least maintained to ensure that lionfish abundance remains low in Montserrat. Nassau grouper populations throughout the Caribbean have seen dramatic declines, largely owing to over-exploitation of adult fish at spawning aggregations. There is a concerted regional effort to conserve this iconic species, and data on the abundance of Nassau grouper outside of spawning aggregations is a valuable tool in monitoring

the effectiveness of newly implemented temporal closures of the fishery in spawning season within some Caribbean nations.

Overall, the coastal marine habitats in Montserrat have clear patterns of distribution with the most diverse and important hard-bottom communities located at the north and southeast ends of the island. Standard ecological monitoring should be implemented at regular intervals to assess and manage these areas. The data we present here provide insight to the unique environmental conditions of Montserrat, and can serve as a baseline from which to continuously monitor and adaptively manage the valuable marine resources of the island.

VI. References

1. Achituv, Y., & Dubinsky, Z. (1990). Evolution and zoogeography of coral reefs. *Ecosystems of the world*, *25*, 1-9.

2. Agudo-Adriani, E. A., Cappelletto, J., Cavada-Blanco, F., & Croquer, A. (2016). Colony geometry and structural complexity of the endangered species Acropora cervicornis partly explains the structure of their associated fish assemblage. *PeerJ*, *4*, e1861.

3. Albins, M. A. (2012). Effects of invasive Pacific red lionfish *Pterois volitans* versus a native predator on Bahamian coral-reef fish communities. *Biological Invasions, 15*(1), 29–43. doi: 10.1007/s10530-012-0266-1.

4. Allouche, O., Kalyuzhny, M., Moreno-Rueda, G., Pizarro, M., & Kadmon, R. (2012). Area–heterogeneity tradeoff and the diversity of ecological communities. *Proceedings of the National Academy of Sciences*, *109*(43), 17495-17500.

5. Andrews, J.C. & Pickard, G.L. (1990). The physical oceanography of coral-reef systems In Z. Dubinsky (Ed.) *Coral Reefs. Ecosystems of the World. Volume 25.* (pp. 11-48). Elsevier, Amsterdam.

6. Angel, A., & Ojeda, F. P. (2001). Structure and trophic organization of subtidal fish assemblages on the northern Chilean coast: the effect of habitat complexity. *Marine Ecology Progress Series*, *217*, 81-91.

7. Beck, M. W. (2000). Separating the elements of habitat structure: independent effects of habitat complexity and structural components on rocky intertidal gastropods. *Journal of Experimental Marine Biology and Ecology*, *249*(1), 29-49.

8. Bender, D., Diaz-Pulido, G., & Dove, S. (2014). The impact of CO2 emission scenarios and nutrient enrichment on a common coral reef macroalga is modified by temporal effects. *Journal of phycology*, *50*(1), 203-215.

9. Boesch, D. F., & Turner, R. E. (1984). Dependence of fishery species on salt marshes: the role of food and refuge. *Estuaries*, *7*(4), 460-468.

10. Bond, M.E., Babcock, E.A., Pikitch, E.K., Abercrombie, D.L., Lamb, N.F., et al. (2012). Reef Sharks Exhibit Site-Fidelity and Higher Relative Abundance in Marine Reserves on the Mesoamerican Barrier Reef. *PLOS ONE 7*(3): e32983. https://doi.org/10.1371/journal.pone.0032983.

11. Bovey, R., et al. (1986). Montserrat National Park: Ecological and cultural feasibility assessment. Joint effort of the Montserrat National Trust, World Wildlife Fund UK, and the University of Alberta.

12. Bozec, Y. M., O'Farrell, S., Bruggemann, J. H., Luckhurst, B. E., & Mumby, P. J. (2016). Tradeoffs between fisheries harvest and the resilience of coral reefs. *Proceedings of the National Academy of Sciences*, *113*(16), 4536-4541.

13. Brocke, H. J., Polerecky, L., De Beer, D., Weber, M., Claudet, J., & Nugues, M. M. (2015). Organic matter degradation drives benthic cyanobacterial mat abundance on Caribbean coral reefs. *PLoS One*, *10*(5), e0125445.

14. Brooks, E. J., Sloman, K. A., Sims, D. W., & Danylchuk, A. J. (2011). Validating the use of baited remote underwater video surveys for assessing the diversity, distribution and abundance of sharks in the Bahamas. *Endangered Species Research*, *13*(3), 231-243.

15. Bruckner, A. W., & Bruckner, R. J. (1997). Outbreak of coral disease in Puerto Rico. *Coral Reefs*, *16*(4), 260-260.

16. Bruno, J.F., Selig, E.R., Casey, K.S., Page, C.A., Willis, B.L., Harvell, C.D., et al. (2007). Thermal Stress and Coral Cover as Drivers of Coral Disease Outbreaks. *PLoS Biology 5*(6), e124. https://doi.org/10.1371/journal.pbio.0050124.

17. Büttner, H. (1996). Rubble Mounds of Sand Tilefish Mala Canthus Plumieri (Bloch, 1787) and Associated Fishes in Colombia. *Bulletin of Marine Science*, *58*(1), 248-260.

18. Burke, L., Reytar, K., Spalding, M., & Perry, A. (2011). *Reefs at risk revisited*. Washington, DC: World Resources Institute.

19. Carey, S., Bell, K. L. C., Sparks, S., et al. (2014). Impact of volcanic eruptions on the seafloor around Montserrat, West Indies. *Oceanography, 27*(1), 36-37.

20. Charpy, L., Casareto, B. E., Langlade, M. J., & Suzuki, Y. (2012). Cyanobacteria in coral reef ecosystems: a review. *Journal of Marine Biology*, *2012*.

21. Coates, A. G. & Jackson, J. B. C. (1985). Morphological themes in the evolution of clonal and aclonal marine invertebrates. In: Jackson, J. B. C., Buss, L. W., and Cook, R. E. (E.ds.) *Population Biology and Evolution of Clonal Organisms* (pp. 67–106). Yale Universitt Press, New Haven.

22. Connell, J. H. (1978). Diversity in tropical rain forests and coral reefs. *Science*, *199*(4335), 1302-1310.

23. Connell, S. D., Foster, M. S., & Airoldi, L. (2014). What are algal turfs? Towards a better description of turfs. *Marine Ecology Progress Series*, *495*, 299-307.

24. Cook, R.J., Barron, J.C., Papendick, R.I., & Williams III, G.J. (1981). Impact on agriculture of the Mount St. Helens eruptions. *Science, 211*, 16-22.

25. Croquer, A., Cavada-Blanco, F., Zubillaga, A. L., Agudo-Adriani, E. A., & Sweet, M. (2016). Is Acropora palmata recovering? A case study in Los Roques National Park, Venezuela. *PeerJ*, *4*, e1539.

26. Darling, E. S., Green, S. J., O'Leary, J. K., & Côté, I. M. (2011). Indo-Pacific lionfish are larger and more abundant on invaded reefs: a comparison of Kenyan and Bahamian lionfish populations. *Biological invasions*, *13*(9), 2045-2051.

27. De Bakker, D. M., Van Duyl, F. C., Bak, R. P., Nugues, M. M., Nieuwland, G., & Meesters, E. H. (2017). 40 Years of benthic community change on the Caribbean reefs of Curaçao and Bonaire: the rise of slimy cyanobacterial mats. *Coral Reefs*, *36*(2), 355-367.

28. Deplus, C., Le Friant, A., Boudon, G. et al. (2001). Submarine evidence for large-scale debris avalanches in the Lesser Antilles Arc. *Earth and Planetary Science Letters, 192*, 145–157.

29. Diaz, M. C., & Rützler, K. (2001). Sponges: an essential component of Caribbean coral reefs. *Bulletin of Marine Science*, *69*(2), 535-546.

30. Diaz, M. C., & Ward, B. B. (1997). Sponge-mediated nitrification in tropical benthic communities. *Marine Ecology Progress Series*, *156*, 97-107.

31. 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.

32. Dubinsky, Z. (1990). Ecosystems of the World. *Coral reefs*, *25*, 49-73.

33. Duffy, J. E. (1992). Host use patterns and demography in a guild of tropical sponge-dwelling shrimps. *Marine ecology progress series. Oldendorf*, *90*(2), 127-138.

34. Falkowski, P. G., Greene, R., & Kolber, Z. (1993). *Light utilization and photoinhibition of photosynthesis in marine phytoplankton*. Brookhaven National Lab., Upton, NY. United States.

35. Fox, J. W. (2013). The intermediate disturbance hypothesis should be abandoned. *Trends in ecology & evolution*, *28*(2), 86-92.

36. Gazol, A., Tamme, R., Price, J.N., Hiiesalu, I., Laanisto, L. & Pärtel, M. (2013). A negative heterogeneity–diversity relationship found in experimental grassland communities. *Oecologia, 173,* 545–555.

37. Gibson, R.N., Pihl, L., Burrows, M.T., Modin, J., Wennhage, H. & Nickell, L.A. (1998). Diel movements of juvenile plaice *Pleuronectes platessa* in relation to predators, competitors, food availability and abiotic factors on a microtidal nursery ground. *Marine Ecology Progress Series*, *165*, 145-159.

38. Godley, B. J., Broderick, A. C., Campbell, L. M., Ranger, S., & Richardson, P. B. (2004). An assessment of the status and exploitation of marine turtles in Montserrat. In *An assessment of the status and exploitation of marine turtles in the UK Overseas Territories in the wider Caribbean* (pp. 155-179). Final Project Report for the Department of Environment, Food and Rural Affairs and the Foreign and Commonwealth Office.

39. Green, S. J., Akins, J. L., Maljković, A., & Côté, I. M. (2012). Invasive lionfish drive Atlantic coral reef fish declines. *PloS one*, *7*(3), e32596.

40. Harrison, P.L. & Wallace, C.C. (1990). Reproduction, dispersal and recruitment of scleractinian corals In Z. Dubinsky (Ed.) *Coral reef ecosystems* (pp. 133–207). Elsevier, Amsterdam.

41. Harvell, C.D., Mitchell, C.E., Ward, J.R., Altizer, S., Dobson, A.P., et al. (2002). Climate warming and disease risks for terrestrial and marine biota. *Science 296*, 2158–2162.

42. Hay, M. E. (1997). The ecology and evolution of seaweed-herbivore interactions on coral reefs. *Coral reefs*, *16*(1), S67-S76.

43. Hay, M. E., Duffy, J. E., Fenical, W., & Gustafson, K. (1988). Chemical defense in the seaweed *Dictyopteris delicatula*: differential effects against reef fishes and amphipods. *Marine Ecology Progress Series*, 185-192.

44. Henkel, T. P., & Pawlik, J. R. (2005). Habitat use by sponge-dwelling brittlestars. *Marine Biology*, *146*(2), 301-313.

45. Hughes, T.P. (1994). Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. *Science, 265*, 1547–1551.

46. Hughes, T.P., Rodrigues, M.J., Bellwood, D.R., Ceccarelli, D., Hoegh-Guldberg, O., et al. (2007). Phase shifts, herbivory, and the resilience of coral reefs to climate change. *Current Biology, 17*, 360–365.

47. Humann, P. & DeLoach, N. (2002). *Reef coral identification, Florida Caribbean Bahamas*. New World, Jacksonville, FL.

48. IUCN. (2018). *The IUCN Red List of Threatened Species*. Version 2018-2. Retrieved from: http://www.iucnredlist.org. Downloaded on 14 November 2018.

49. Jackson, J.B.C. (1985). Distribution and ecology of clonal and aclonal benthic invertebrates. In: Jackson, J.B.C., Buss, L.W., & Cook, R.E. (E.ds.). *Population Biology and Evolution of Clonal Organisms*. Yale University Press; New Haven.

50. Jackson, J. B. C., Donovan, M. K., Cramer, K. L., & Lam, V. V. (2014). Status and trends of Caribbean coral reefs. *Gland: Global Coral Reef Monitoring Network, IUCN.* Available at http://cmsdata. iucn. org/downloads/caribbean_coral_reefs___status_report_1970_2012. pdf.

51. Jessen, C., & Wild, C. (2013). Herbivory effects on benthic algal composition and growth on a coral reef flat in the Egyptian Red Sea. *Marine Ecology Progress Series*, *476*, 9-21.

52. Jones, G.P. (1991). Postrecruitment processes in the ecology of coral reef fish populations: a multifactorial perspective In P.F., Sale (Ed.), *The ecology of fishes on coral reefs* (pp. 294-328). Academic Press, San Diego.

53. Kadmon, R., & Allouche, O. (2007). Integrating the effects of area, isolation, and habitat heterogeneity on species diversity: a unification of island biogeography and niche theory. *The American Naturalist*, *170*(3), 443-454.

54. Karr, K. A., Fujita, R., Halpern, B. S., Kappel, C. V., Crowder, L., Selkoe, K. A., et al. (2015). Thresholds in Caribbean coral reefs: implications for ecosystem-based fishery management. *Journal of Applied Ecology*, *52*(2), 402-412.

55. Kohler, K.E. & Gill, S.M. (2006) Coral Point Count with Excel Extensions (CPCe): A Visual Basic Program for the Determination of Coral and Substrate Coverage Using Random Point Count Methodology. *Computers and Geosciences, 32,* 1259-1269. https://doi.org/10.1016/j.cageo.2005.11.009.

56. Kuffner, I. B., & Paul, V. J. (2001). Effects of nitrate, phosphate and iron on the growth of macroalgae and benthic cyanobacteria from Cocos Lagoon, Guam. *Marine Ecology Progress Series*, *222*, 63-72.

57. Laegdsgaard, P., & Johnson, C. (2001). Why do juvenile fish utilise mangrove habitats?. *Journal of experimental marine biology and ecology*, *257*(2), 229-253.

58. Lebas E, Le Friant A, Boudon G et al (2011) Multiple widespread landslides during the long-term evolution of a volcanic island: Insights from high-resolution seismic data, Montserrat Lesser Antilles. *Geochemistry Geophysics Geosystems, 12*(5), 1-20.

59. Lang, J. C. & Chornesky, E. A. (1990). Competition between scleractinian reef corals—a review of mechanisms and effects In Z. Dubinsky (Ed.), *Coral reefs* (pp. 209-252). Elsevier, Amsterdam.

60. MacNeil, M. A., Graham, N.A.J., Cinner, J.E., Wilson, S.K., Williams, I.D., Maina, J., et al. (2015). Recovery potential of the world's coral reef fishes. *Nature, 520*, 341–344.

61. McClintock, W. (2013). Geodesign: Optimizing stakeholder-driven marine spatial planning. *Coast Guard Journal of Safety & Security at Sea, Proceedings of the Marine Safety & Security Council*, *70*(3).

62. Mumby, P. J., Dahlgren, C. P., Harborne, A. R., Kappel, C. V., Micheli, F., Brumbaugh, D. R., et al. (2006). Fishing, trophic cascades, and the process of grazing on coral reefs. *Science*, *311*(5757), 98-101.

63. Mumby, P. J., Hastings, A. and Edwards, H. J. (2007). Thresholds and the resilience of Caribbean coral reefs. *Nature, 450*(7166), 98–101. doi: 10.1038/nature06252.

64. Mumby, P. J., Steneck, R. S., Edwards, A. J., Ferrari, R., Coleman, R., Harborne, A. R., & Gibson, J. P. (2012). Fishing down a Caribbean food web relaxes trophic cascades. *Marine Ecology Progress Series*, *445*, 13-24.

65. Muscatine, L., R. McCloskey, L., & E. Marian, R. (1981). Estimating the daily contribution of carbon from zooxanthellae to coral animal respiration 1. *Limnology and Oceanography*, *26*(4), 601-611.

66. Myers, A. (2013). Coral Reefs of Montserrat. In C.R.C. Sheppard (E.d.), *Coral Reefs of the United Kingdom Overseas Territories* (pp. 89-96). Springer, Netherlands.

67. Nagelkerken, I., Van der Velde, G., Gorissen, M. W., Meijer, G. J., Van't Hof, T., & Den Hartog, C. (2000). Importance of mangroves, seagrass beds and the shallow coral reef as a nursery for important coral reef fishes, using a visual census technique. *Estuarine, coastal and shelf science*, *51*(1), 31-44.

68. O'Neil, J. M. (1999). Grazer interactions with nitrogen-fixing marine Cyanobacteria: adaptation for N-acquisition?. *Bulletin-Institut Oceanographique Monaco-Numero Special*, 293-318.

69. Rogers, C. S. (1990). Responses of coral reefs and reef organisms to sedimentation. *Marine ecology progress series. Oldendorf*, *62*(1), 185-202.

70. Rönnbäck, P. (1999). The ecological basis for economic value of seafood production supported by mangrove ecosystems. *Ecological Economics*, *29*(2), 235-252.

71. Rützler, K. (1985). Associations between Caribbean sponges and photosynthetic organisms In K., Rützler (Ed.) *New perspectives in sponge biology* (pp. 455–466). Smithsonian Institution Press, Washington, D.C.

72. Sale, P. F. (1977). Maintenance of high diversity in coral reef fish communities. *The American Naturalist*, *111*(978), 337-359.

73. Sale, P. F., & Douglas, W. A. (1984). Temporal variability in the community structure of fish on coral patch reefs and the relation of community structure to reef structure. *Ecology*, *65*(2), 409-422.

74. Sandin, S.A., Walsh, S.M., Jackson, J.B.C. (2010). Prey release, trophic cascades, and phase shifts in tropical nearshore marine ecosystems. In: Terborgh, J., Estes, J.A. (E.ds.). *Trophic Cascades: Predators, Prey, and the Changing Dynamics of Nature* (pp. 71–90). Washington, DC: Island Press.

75. Smith, J.E. et al. (2016). Re-evaluating the health of coral reef communities: baselines and evidence for human impacts across the central Pacific. *Proceedings of the Royal Society B: Biological Sciences, 283*(1822). http://dx.doi.org/10.1098/rspb.2015.1985.

76. Sousa, W. P. (2001). Natural disturbance and the dynamics of marine benthic communities. *Marine community ecology*, 85-130.

77. Steneck, R. S., Mumby, P. J., MacDonald, C., Rasher, D. B., & Stoyle, G. (2018). Attenuating effects of ecosystem management on coral reefs. *Science advances*, *4*(5), eaao5493. doi: 10.1126/sciadv.aao5493.

78. Tews, J., Brose, U., Grimm, V., Tielbörger, K., Wichmann, M. C., Schwager, M., & Jeltsch, F. (2004). Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. *Journal of biogeography*, *31*(1), 79-92.

79. Titlyanov, E. A., Yakovleva, I. M., & Titlyanova, T. V. (2007). Interaction between benthic algae (Lyngbya bouillonii, Dictyota dichotoma) and scleractinian coral Porites lutea in direct contact. *Journal of Experimental Marine Biology and Ecology*, *342*(2), 282-291.

80. Underwood, A.J. & Keough, M.J. (2001). Supply-side ecology: the nature and consequences of variations in recruitment of intertidal organisms In M.D. Bertness, S.D. Gaines, M.E, Hay (Eds.). *Marine community ecology* (pp. 183-200). Sinauer Associates, Sunderland, MA.

81. Waitt Institute. (2016). *Community Consultation Findings*. Retrieved from: https://docs.wixstatic.com/ugd/47d1fd_6efb3180d4ac4a5994c1c905a45df064.pdf.

82. Ward-Paige, C. A., Mora, C., Lotze, H. K., Pattengill-Semmens, C., McClenachan, L., Arias-Castro, E., & Myers, R. A. (2010). Large-scale absence of sharks on reefs in the greater-Caribbean: a footprint of human pressures. *PloS one*, *5*(8), e11968.

83. Weaver, D. B. (1995). Alternative tourism in Montserrat. *Tourism Management*, *16*(8), 593-604.

84. Weber, M., Lott, C., & Fabricius, K. E. (2006). Sedimentation stress in a scleractinian coral exposed to terrestrial and marine sediments with contrasting physical, organic and geochemical properties. *Journal of experimental marine biology and ecology*, *336*(1), 18-32.

85. Weil, E. (2004). Coral reef diseases in the wider Caribbean. In *Coral health and disease* (pp. 35-68). Springer, Berlin, Heidelberg.

86. Weil, E., Smith, G., & Gil-Agudelo, D. L. (2006). Status and progress in coral reef disease research. *Diseases of aquatic organisms*, *69*(1), 1-7.

87. Wheeler, W. N. (1980). Effect of boundary layer transport on the fixation of carbon by the giant kelp Macrocystis pyrifera. *Marine Biology*, *56*(2), 103-110.

88. Whitmarsh, S. K., Fairweather, P. G., & Huveneers, C. (2017). What is Big BRUVver up to? Methods and uses of baited underwater video. *Reviews in Fish Biology and Fisheries*, *27*(1), 53-73.

89. Wild, R., Slade, L., Pardee, M., & Carleton, C. (2007). Towards multi-user marine management in Montserrat. LTS International.

90. Wilkinson, C. (2000). Status of coral reefs in the world 2000. Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre. Townsville, Australia.

91. Zea, S. (1993). Recruitment of demosponges (*Porifera, Demospongiae*) in rocky and coral reef habitats of Santa Marta, Colombian Caribbean. *Marine Ecology*, *14*(1), 1-21.

VII. CONCLUSIONS AND MANAGEMENT IMPLICATIONS

A. ANALYSIS OF PHOTOQUADRATS TO DERIVE BENTHIC COVER

Latitude	Longitude	Depth (m)	Habitat Type	Crustose Coralline Algae	Fleshy Macroalgae	Hard Coral	Invertebrates	Lime Pavement	Macroalgae	Non-Biological	Seagrass	Soft Coral	Sponge	Turf Algae
16.77887	-62.22114	7	Coral Reef, Patch Reef	0.444444444	8	4.222222222	0.888888889	0	19.77777778	28.11111111	0	0	3.77777778	34.77777778
16.79008	-62.21669	10	Coral Reef	0.965517241	1.103448276	4.965517241	1.655172414	0	12.96551724	24.55172414	0.4137931	0.27586207	3.72413793	49.37931034
16.81905	-62.1657	20	Coral Reef	1.419354839	2.064516129	2.838709677	15.74193548	0	11.87096774	3.096774194	0	9.41935484	5.67741936	47.87096774
16.81883	-62.16554	26	Coral Reef	4.903225806	2.193548387	8.387096774	10.4516129	0	7.35483871	1.677419355	0	14.3225807	5.67741936	45.03225806
16.69802	-62.21845	20	Seagrass	0	0.470588235	0	0.705882353	0	0	36.11764706	57.5294118	1.29411765	0.11764706	3.764705882
16.70332	-62.22222	10		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.67431	-62.16147	10	Colonized Volcanic Boulders	0	1.161290323	0	2.064516129	0.129032258	2.064516129	60.77419355	0	0.51612903	0.12903226	33.16129032
16.67491	-62.16717	5	Colonized Volcanic Boulders	3	1.875	0.25	4	0	28.625	11.375	0	0.375	0	50.5
16.67469	-62.1607	20	Colonized Volcanic Boulders	2.545454545	2.909090909	3.272727273	13.81818182	0	2.545454545	21.45454545	0	0.72727273	14.9090909	37.81818182
16.67701	-62.15941	10	Colonized Volcanic Boulders	1.25	3.875	0	8.5	0	3.25	26.625	0	2.125	1.75	52.625
16.67701	-62.15941	5	Colonized Volcanic Boulders	1.125	0.625	1	1.75	0.625	10.125	14.375	0	0	0	70.375
16.67552	-62.15949	20	Colonized Volcanic Boulders	0	0.129032258	2.709677419	11.74193548	0	1.677419355	37.29032258	0	5.67741936	4.90322581	35.87096774
16.826	-62.17256	20	Coral Reef, Spur and Groove	0	1.806451613	0.903225806	9.290322581	0	19.74193548	14.58064516	0	1.67741936	0	52
16.80866	-62.2074	11	Patchy Seagrass	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.765817	-62.223083	2	Colonized Volcanic Boulders	0.666666667	1.333333333	0	0.666666667	0	7.066666667	24.93333333	0	0	0	65.33333333
16.76625	-62.223667	5	Coral Reef, Patch Reef	2.787878788	3.636363636	5.333333333	1.212121212	0.121212121	2.787878788	32.12121212	0	0.96969697	1.45454546	49.57575758
16.7637	-62.224683	8	Reef Balls	0	0	0.347826087	1.043478261	0	0.869565217	85.39130435	0	0	0	12.34782609
16.78244	-62.17024	5	Colonized Volcanic Boulders	3.2	4.8	3.466666667	2.4	0	6.133333333	7.466666667	0	0.53333333	0	72
16.78455	-62.16873	12	Coral Reef	1.2	7.066666667	2.133333333	6.533333333	0	6.666666667	27.2	0	1.2	0.26666667	47.73333333
16.81641	-62.17935	11	Coral Reef	1.806451613	5.161290323	6.193548387	4.258064516	0	7.096774194	6.967741935	0	4.12903226	2.70967742	61.67741935
16.81799	-62.18246	12	Coral Reef	2.322580645	12.51612903	4.774193548	2.451612903	0	12.77419355	17.67741935	0	2.58064516	0.38709677	44.51612903
16.825	-62.20301	11	Coral Reef	7.741935484	1.677419355	6.580645161	0.516129032	0	16.12903226	1.806451613	0	1.41935484	0	64.12903226
16.82412	-62.20188	8	Coral Reef	3.333333333	3.066666667	1.466666667	0.266666667	0	18.4	9.6	0	0.4	0	63.46666667
16.74203	-62.23773	22	Sargassum Forest, Hardbottom, Seagrass	0	6.4	0.266666667	0.666666667	0	13.6	17.46666667	35.4666667	0.13333333	0	26
16.743	-62.238	17	Sargassum Forest, Hardbottom	0.625	8.25	1.125	2.375	0	25.5	35	0.75	0.125	0.625	25.625
16.75599	-62.23108	8	Coral Reef	0.533333333	4.266666667	5.333333333	6.8	0	2.133333333	21.06666667	0	1.6	0.66666667	57.6
16.75768	-62.23007	8	Coral Reef	5.6	5.066666667	8.533333333	2.266666667	0	4.133333333	10.26666667	0	2.26666667	0	61.86666667
16.82361	-62.19096	11	Coral Reef	3.151515152	4.363636364	12.36363636	6.666666667	0	19.87878788	8.606060606	0	2.90909091	2.18181818	39.87878788
16.67366	-62.17654	10	Colonized Volcanic Boulders	4.888888889	2.777777778	23.11111111	5	0.222222222	7.333333333	21.88888889	0	1.22222222	6.77777778	26.77777778
16.67366	-62.17654	20	Coral Reef, Spur and Groove	0.375	0.625	4	5.375	0	3	44	2	0.625	3.375	36.625
16.70458	-62.2234	20	Seagrass	0	1.161290323	0	0.258064516	0	0.129032258	16.90322581	80.516129	0	0	1.032258065
16.81689	-62.20955	9	Colonized Volcanic Boulders	0.25	4	2.75	7.875	0	6.375	38.5	0	1.25	1.5	37.5
16.81602	-62.20571	4	Colonized Volcanic Boulders	0.64516129	2.322580645	5.161290323	1.677419355	0	8.258064516	15.87096774	0	0.51612903	3.22580645	62.32258065
16.81289	-62.2072	5	Coral Reef	14.42857143	4.142857143	22.42857143	4.714285714	0	14.57142857	4.142857143	0	0.71428571	0	34.85714286
16.67562	-62.17636	20		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.81602	-62.20781	11	Coral Reef	0.888888889	3.62962963	5.555555556	6.444444444	0	32.14814815	18.14814815	0.88888889	2.74074074	2.59259259	26.96296296
16.76574	-62.235	20	Coral Reef	3.612903226	0.129032258	4.387096774	8.516129032	0	29.93548387	14.70967742	0	1.03225807	0.90322581	36.77419355
16.791383	-62.215133	7	Coral Reef	4.903225806	2.709677419	20.77419355	0.903225806	0	5.677419355	4.903225806	0	0	0.51612903	59.61290323
16.69308	-62.21349	20	Seagrass	1.363636364	0.090909091	4.454545455	1.909090909	0	4.363636364	20	53.4545455	0.09090909	2.18181818	12.09090909
16.7487621	-62.241137	18	Seagrass	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.75105	-62.22516	5	Coral Reef	0.387096774	2.838709677	2.967741935	1.935483871	0	1.548387097	40.64516129	0	0.51612903	0.12903226	49.03225806
16.7531414	-62.23134	20	Patchy Seagrass	0	1.052631579	0	0.421052632	0	0	21.68421053	73.6842105	0	0	3.157894737
16.6728	-62.18776	9	Coral Reef, Colonized Volcanic Boulders	0.117647059	0	2.235294118	2.352941176	0	15.76470588	33.05882353	0.35294118	0	1.41176471	44.70588235
16.78445	-62.2174	5	Coral Reef	0.129032258	1.677419355	0	0	0	0.516129032	66.83870968	0	0	0	30.83870968
16.76358	-62.22906	14	Coral Reef, Mixed Hardbottom	1.290322581	6.064516129	1.548387097	12.12903226	0.129032258	9.032258065	10.58064516	0	4.25806452	5.5483871	49.41935484
16.81689	-62.20955	10	Soft Bottom	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.778317	-62.22885	26	Soft Bottom	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.78865	-62.220067	17	Patchy Seagrass	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.771567	-62.227517	20	Soft Bottom	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

16.82264	-62.20498	10	Colonized Volcanic Boulders	3.096774194	3.35483871	2.322580645	2.322580645	0	29.03225806	9.806451613	0	0.25806452	2.19354839	47.61290323
16.7586175	62.2324194	10	Coral Reef	1.25	1.75	4	2.875	0	7.875	30.375	0.125	1.875	0.75	49.125
16.752382	-62.23741	10	Coral Reef, Mixed Hardbottom	0.129032258	0	1.161290323	1.161290323	0	1.419354839	59.09677419	0.25806452	0.25806452	0.12903226	36.38709677
16.7529	-62.23228	6	Coral Reef	0.516129032	0.129032258	5.290322581	4.903225806	0	2.193548387	18.83870968	0	2.4516129	0.77419355	64.90322581
16.7590179	-62.229699	4	Colonized Volcanic Boulders	0.516129032	1.419354839	0.903225806	0.903225806	0	0.64516129	81.5483871	0	1.29032258	0.90322581	11.87096774
16.79309	-62.21886	16	Coral Reef, Patch Reef	0.258064516	1.806451613	16.12903226	2.322580645	0	13.80645161	26.70967742	0.12903226	0.25806452	0	38.58064516
16.81891	-62.20968	18	Coral Reef, Patch Reef	0.666666667	5.066666667	10.26666667	4.933333333	0	9.6	32	0.93333333	1.6	7.46666667	27.46666667
16.67373	-62.16956	20	Colonized Volcanic Boulders	0	0	2.307692308	3.538461538	0	0.461538462	72.46153846	0	0.92307692	7.69230769	12.61538462
16.7835	-62.2205	13	Coral Reef	1.058823529	0.705882353	6.705882353	2.588235294	0	7.411764706	11.76470588	0.11764706	0.23529412	2.82352941	66.58823529
16.7565108	-62.231471	5	Coral Reef	1.6	0.133333333	2.133333333	1.6	0	12.26666667	25.6	0	1.06666667	0	55.6
16.81945	-62.2077	18	Seagrass	0.140350877	0.912280702	0.350877193	2.105263158	0	0.701754386	61.47368421	16.3508772	0.35087719	1.40350877	16.21052632
16.770083	-62.224967	12	Sand	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.80883	-62.17685	10	Colonized Volcanic Boulders	3.612903226	4	10.32258065	3.35483871	0	34.06451613	7.225806452	0	5.41935484	0	32
16.790533	-62.219217	19	Patchy Seagrass	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.773533	-62.221967	8	Sand	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.772867	-62.2238	12	Seagrass	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.70112	-62.22017	13	Seagrass	0	0	0	2.193548387	0	0	10.06451613	86.8387097	0	0	0.903225806
16.79381	-62.17605	9	Coral Reef, Colonized Volcanic Boulders	1.75	3.5	7.75	2	0	21	41.25	0	0.5	0	22.25
16.6749	-62.168083	4	Colonized Volcanic Boulders	5.5	0.6	22.7	5.9	0	3.2	6.9	0	6.1	0.8	48.3
16.67491	-62.16717	5	Colonized Volcanic Boulders	3.225806452	1.032258065	3.870967742	8.774193548	0	8.387096774	26.06451613	0	2.32258065	3.09677419	43.22580645
16.77576	-62.22125	5	Colonized Volcanic Boulders	0.875	1	2.25	1.625	0	16.375	11.5	0	0.375	4.5	61.5
16.67558	-62.16418	5	Colonized Volcanic Boulders	6.64	0.8	17.68	4.08	0	4.08	1.28	0	4.24	1.2	60
16.82355	-62.18969	15	Coral Reef, Spur and Groove	3.454545455	1.636363636	10.54545455	15.27272727	0	11.45454545	6.545454545	0	3.09090909	4.72727273	43.27272727
16.82808	-62.1943	22	Coral Reef	1.125	2.875	1	8	0	3.5	9.375	0.125	2.875	0.875	70.25
16.76967	-62.16406	11	Sand	0	0	0	0	0	0	100	0	0	0	0
16.79511	-62.21871	18	Coral Reef	0.125	0	0.5	11.25	0	5.625	39.125	5.5	2.25	6.625	29
16.8313	-62.20715	5	Coral Reef	14.13333333	4.666666667	22.8	5.2	0.8	16.93333333	1.333333333	0	1.46666667	1.2	31.46666667
16.72444	-62.24303	10	Coral Reef, Mixed Hardbottom	0	0.129032258	1.161290323	5.677419355	0	0.129032258	70.32258065	0	2.96774194	3.35483871	16.25806452
16.67497	-62.16289	10	Sand	0	0	0	0	0	0	100	0	0	0	0
16.82868	-62.19622	20	Coral Reef, Spur and Groove	0.64516129	2.322580645	3.483870968	2.709677419	0	3.612903226	13.41935484	0	5.29032258	0.25806452	68.25806452
16.68892	-62.14654	23	Coral Reef, Spur and Groove	0.105263158	0.210526316	4.315789474	12.52631579	0	6.526315789	34.94736842	0	3.05263158	3.15789474	35.15789474
16.78131	-62.22161	10	Colonized Volcanic Boulders	0.823529412	7.058823529	4.352941176	8.352941176	0	2.705882353	36.58823529	0	0.47058824	2.82352941	36.82352941
16.79876	-62.20829	12	Seagrass	0	1.828571429	0.228571429	1.028571429	0	0.114285714	10.85714286	81.3714286	1.14285714	0	3.428571429
16.79292	-62.2143	10	Coral Reef, Patch Reef	0.64516129	2.193548387	2.580645161	2.838709677	0	23.48387097	17.29032258	0	0.38709677	0.12903226	50.4516129
16.80594	-62.20756	7	Coral Reef	16	1.733333333	13.2	2.8	0.4	15.73333333	1.6	0	0.13333333	0.13333333	48.26666667
16.77034	-62.15872	25	Coral Reef, Mixed Hardbottom	0.125	0	1	5.125	0	7.375	15.5	48.875	1.5	0.75	19.75
16.76969	-62.1608	20	Sand	0	0	0	0	0	0	100	0	0	0	0
16.78518	-62.17122	8	Coral Reef, Pavement	0.5	1.625	0.25	3.5	0.125	9.25	47.5	0	0.125	0.375	36.75
16.80356	-62.21088	20	Seagrass	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.67836	-62.15628	17	Colonized Volcanic Boulders	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.79473	-62.17433	20	Colonized Volcanic Boulders	0.242424242	0	0.484848485	0	0	2.303030303	12.72727273	3.03030303	0	0	81.21212121
16.798	-62.20983	7	Colonized Volcanic Boulders	5.44	6.88	10.24	4.64	0	7.52	17.6	0	0.8	4	42.88
16.79875	-62.1778	20	Coral Reef, Spur and Groove	5.419354839	8	0.903225806	2.709677419	0.258064516	9.677419355	26.58064516	0	0.12903226	0.25806452	46.06451613
16.76479	-62.15654	5	Colonized Volcanic Boulders	0	0	0	0.121212121	0	1.090909091	72.96969697	0	0	0	25.81818182
16.82536	-62.19707	6	Colonized Volcanic Boulders	9.2	4.4	13.06666667	1.333333333	0.4	15.46666667	1.333333333	0	2.26666667	0.13333333	52.4
16.75421	-62.23149	5	Coral Reef, Patch Reef	0.5	0.625	2	3.875	0	2.25	9	0	1.25	1	79.5
16.74864	-62.23544	4	Colonized Volcanic Boulders	0	0.5	0.25	4.25	0	0.25	52.75	0	2.25	0.5	39.25
16.79385	-62.21447	5	Coral Reef, Spur and Groove	0.516129032	6.064516129	3.741935484	0.129032258	0	23.74193548	8	0	0	0	57.80645161
16.80612	-62.21051	19	Seagrass	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.78541	-62.21893	10	Colonized Volcanic Boulders	1.161290323	1.161290323	2.967741935	1.161290323	0	19.35483871	24.38709677	0	0	0.51612903	49.29032258

16.82569	-62.2042	20	Patchy Seagrass	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.71424	-62.14688	18	Colonized Volcanic Boulders	0	0	0	0	0	0.258064516	97.5483871	0	0	0	2.193548387
16.7098	-62.22629	10	Seagrass	0	0	0	0.129032258	0	0.258064516	10.19354839	85.4193548	0	0	4
16.7233	-62.25128	20	Seagrass	0	0	0	0.129032258	0	0.129032258	8.516129032	89.4193548	0	0	1.806451613
16.82694	-62.18982	21	Patchy Seagrass	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.6826	-62.200533	10	Colonized Volcanic Boulders	0.266666667	0	0.266666667	1.066666667	0.133333333	0	66.8	0	0.13333333	0	31.33333333
16.67545	-62.164967	6	Colonized Volcanic Boulders	2.4	0.4	4.933333333	3.333333333	0	4.533333333	21.86666667	0	4.26666667	2.4	55.86666667
16.82042	-62.1584	8	Colonized Volcanic Boulders	4.8	9.485714286	5.714285714	2.171428571	0	18.17142857	14.4	0	1.14285714	0.8	43.31428571
16.82931	-62.19808	25	Patchy Seagrass	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.678783	-62.1981	28	Sand	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.681567	-62.199633	6	Colonized Volcanic Boulders	0.114285714	2.514285714	2.171428571	6.742857143	0	0.685714286	66.51428571	0	0.34285714	0.45714286	20.45714286
16.71639	-62.23167	10	Sand	0	0	0	0	0	0	0	0	0	0	0
16.71109	-62.24283	20	Coral Reef, Spur and Groove	0	1.257142857	0.8	9.828571429	0	6.857142857	30.05714286	0.68571429	2.4	1.6	46.51428571
16.79279	-62.21934	5	Colonized Volcanic Boulders	1.032258065	0.387096774	4	1.677419355	0	21.67741935	21.80645161	0	0.12903226	0.90322581	48.38709677
16.76463	-62.15045	20	Sand	0	0	0	0	0	0	100	0	0	0	0
16.70343	-62.1463	8	Colonized Volcanic Boulders	2.709677419	0.516129032	2.709677419	1.419354839	0	26.58064516	39.87096774	0	0.12903226	0	26.06451613
16.81002	-62.20625	5	Colonized Volcanic Boulders	4.774193548	5.032258065	11.87096774	4.387096774	0.258064516	9.548387097	6.709677419	0	3.22580645	0.12903226	54.06451613
16.81835	-62.20617	3	Colonized Volcanic Boulders	8.827586207	2.482758621	5.655172414	3.172413793	0.275862069	13.10344828	6.896551724	0	0.82758621	0.96551724	57.79310345
16.76057	-62.22715	5	Coral Reef	1.222222222	0.333333333	1.888888889	2.555555556	0	8.444444444	25.22222222	0	1.88888889	0	58.44444444
16.82232	-62.19086	8	Coral Reef	2.705882353	6.588235294	5.529411765	4.470588235	0	11.76470588	2.235294118	0	9.41176471	2.47058824	54.82352941
16.8116	-62.17582	18	Coral Reef, Spur and Groove	0.947368421	2.842105263	3.894736842	5.789473684	0	10.63157895	26	0.10526316	2.10526316	0.10526316	47.57894737
16.82527	-62.19283	9	Coral Reef, Spur and Groove	2.555555556	5	5.777777778	5	0.111111111	9.333333333	2.111111111	0	4.11111111	1.11111111	64.88888889
16.77795	-62.16633	14	Colonized Volcanic Boulders	0.125	0.5	0.5	3.125	0	9.75	17.25	0	2.625	1.25	64.875
16.79841	-62.17746	10	Coral Reef, Pavement	1.032258065	3.35483871	0.129032258	1.935483871	0	26.32258065	29.29032258	0	0	0.51612903	37.41935484
16.8228	-62.19297	5	Coral Reef	8.258064516	10.32258065	12.90322581	1.419354839	0	12.90322581	3.870967742	0	1.41935484	0.38709677	48.51612903
16.73141	-62.23616	8	Coral Reef	1.384615385	5.538461538	4.307692308	4.615384615	0.153846154	3.384615385	31.69230769	0	0.76923077	0	48.15384615
16.71035	-62.24096	20	Coral Reef	0.129032258	2.838709677	2.580645161	5.032258065	0	8.387096774	28.25806452	0	2.06451613	0.25806452	50.4516129
16.80432	-62.20771	5	Coral Reef, Colonized Volcanic Boulders	3.272727273	3.03030303	12.96969697	2.181818182	0.121212121	15.75757576	20.12121212	0	0.36363636	0.96969697	41.21212121
16.73502	-62.23441	4	Colonized Volcanic Boulders	0	0.909090909	0.545454545	1.818181818	0	3.272727273	56.90909091	0	0.90909091	0	35.63636364
16.67912	-62.15677	6	Colonized Volcanic Boulders	2.322580645	0.774193548	3.096774194	1.806451613	0.129032258	11.35483871	7.096774194	0	5.41935484	0.77419355	67.22580645
16.79733	-62.1777	7	Coral Reef, Pavement	2.25	2	0.125	1.125	0	6	63.375	0	0.375	0	24.75
16.67394	-62.18747		Coral Reef	0.774193548	1.677419355	1.290322581	0.64516129	0.387096774	30.32258065	3.870967742	0	0	0.25806452	60.77419355
16.69495	-62.143933	12	Coral Reef, Colonized Volcanic Boulders	4.823529412	2	10.58823529	4.588235294	0.117647059	8.470588235	3.411764706	0	4.23529412	0.94117647	60.82352941
16.81148	-62.20728	7	Coral Reef	3.096774194	2.064516129	6.967741935	2.451612903	0	37.67741935	8.64516129	0.12903226	3.61290323	0.38709677	34.96774194
16.80303	-62.17909	10	Coral Reef	12.77419355	1.419354839	5.161290323	4.516129032	0.258064516	26.83870968	12.12903226	0.12903226	0.90322581	0	35.87096774
16.80339	-62.17953	5	Coral Reef	15.39393939	0.242424242	3.03030303	2.181818182	0.121212121	29.45454545	3.757575758	0	0	0	45.81818182
16.74695	-62.23518	5	Colonized Volcanic Boulders	0	0.387096774	0.387096774	2.967741935	0.129032258	1.032258065	75.35483871	0	0.12903226	0.12903226	19.48387097
16.74143	-62.23687	15	Seagrass	0	0.129032258	0	0	0	0	1.806451613	97.2903226	0	0	0.774193548
16.74274	-62.23883	30	Sargassum Forest, Hardbottom	0	6.064516129	0.64516129	2.967741935	0	31.74193548	28.51612903	0.64516129	0.12903226	0.12903226	29.16129032
16.6859	-62.204433	2	Colonized Volcanic Boulders	0	0	0	0	0	4.129032258	80.38709677	0	2.19354839	0	13.29032258
16.81688	-62.17962	11	Colonized Volcanic Boulders	3.5	7.875	5.875	4.375	0	2.875	3.875	0	3.5	0.875	67.25
16.7409	-62.23526	8	Seagrass	0	0	0.137931034	0	0	0	0.275862069	99.5862069	0	0	0
16.78769	-62.21606	5	Colonized Volcanic Boulders	0.875	0.875	4.75	1.125	0.125	8.375	20.625	0	0.625	0.75	61.875
16.81961	-62.18402	14	Coral Reef	2.838709677	6.838709677	8.387096774	9.032258065	0	5.935483871	8.774193548	0	3.09677419	1.67741936	53.41935484
16.81828	-62.16578	22	Coral Reef	0.8	2.4	3.866666667	9.333333333	0.133333333	3.6	4.8	0	15.4666667	1.6	58
16.82298	-62.20435	9	Coral Reef	2.580645161	1.677419355	0.387096774	0.516129032	0	33.80645161	12	0	0.25806452	0	48.77419355
16.8105	-62.17637	12	Coral Reef	2.222222222	0.888888889	12.44444444	5.555555556	0	16.88888889	3.777777778	0	4.66666667	2.22222222	51.33333333
16.79646	-62.21217	10	Coral Reef	4	3.487179487	16.92307692	1.128205128	0	18.76923077	6.974358974	0	2.66666667	0.20512821	45.84615385
16.691533	-62.1465	15	Colonized Volcanic Boulders	2.967741935	1.290322581	5.032258065	2.709677419	0	7.096774194	20.51612903	0	0	1.80645161	58.58064516
16.69165	-62.147	7	Colonized Volcanic Boulders	2.193548387	1.161290323	0.387096774	0.516129032	0	28.38709677	9.290322581	0	0.12903226	0	57.93548387

16.68735	-62.149517	13	Coral Reef, Pavement	1.230769231	3.384615385	1.692307692	4.153846154	0	4.461538462	16.92307692	0	4.92307692	2.30769231	60.92307692
16.743	-62.238	18	Sargassum Forest, Hardbottom	0.827586207	4.413793103	0.137931034	4.551724138	0	39.72413793	32.4137931	0.13793103	0	0	17.79310345
16.79499	-62.21195	6	Coral Reef, Mixed Hardbottom	1.733333333	2.933333333	4.266666667	0	0	30	15.06666667	0	0	0	46
16.7928	-62.21382	7	Coral Reef	0.625	2	2.875	0.25	0	8.625	19	0	0.25	0	66.375
16.78912	-62.2156	3	Coral Reef	2.967741935	2.322580645	2.709677419	1.161290323	0.129032258	18.58064516	5.290322581	0	0	0.12903226	66.70967742
16.81366	-62.20895	15	Coral Reef	1.454545455	1.818181818	3.272727273	6.636363636	0.090909091	21.09090909	21.54545455	1.81818182	0.45454546	3.63636364	38.18181818
16.75635	-62.23473	11	Coral Reef	0.129032258	2.838709677	0.258064516	2.451612903	0	3.870967742	41.93548387	0	2.58064516	2.4516129	43.48387097
16.76626	-62.23446	19	Coral Reef	0.516129032	0	1.419354839	5.806451613	0	25.5483871	16.38709677	0	0.51612903	3.48387097	46.32258065
16.76583	-62.15125	20	Sand	0	0	0	0	0	0	100	0	0	0	0
16.76498	-62.15308	10	Sand	0	0	0	0.266666667	0	1.066666667	97.33333333	0	0.66666667	0	0.666666667
16.78195	-62.16896	11	Coral Reef	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16.70551	-62.17103	10	Coral Reef	0	0	0.774193548	3.483870968	0	12.90322581	38.83870968	0	0	0.38709677	43.61290323
16.81892	-62.16559	22	Coral Reef	0.129032258	0.516129032	3.612903226	14.70967742	0	5.290322581	5.290322581	0	13.5483871	3.74193548	53.16129032
16.821	-62.1667	25	Coral Reef	0.774193548	0.903225806	4.64516129	10.70967742	0.129032258	13.16129032	8.129032258	0	12.7741936	5.41935484	43.35483871
16.75027	-62.14595	10	Colonized Volcanic Boulders	0	0	0	0	0	1.290322581	77.03225806	0	0.12903226	0	21.5483871
16.71905	-62.14674	5	Colonized Volcanic Boulders	0.375	4.25	0	1.25	0.125	5.25	58.625	0	0	0	30.125
16.70794	-62.14794	9	Sand	0	0	0	0	0	0	100	0	0	0	0
16.692	-62.14342	22	Coral Reef	0.64516129	0.516129032	2.193548387	7.870967742	0	4.64516129	26.4516129	0	5.5483871	3.35483871	48.77419355
16.67447	-62.16721	10	Sand	0	0	0	0	0	0.129032258	99.61290323	0	0	0	0.258064516
16.81366	-62.17857	10	Coral Reef, Spur and Groove	9.290322581	2.322580645	10.96774194	0.387096774	0	14.06451613	14.70967742	0	1.16129032	0	47.09677419
16.81215	-62.17816	5	Colonized Volcanic Boulders	4	3.35483871	0.903225806	0.258064516	0	43.74193548	5.935483871	0	1.03225807	0	40.77419355
16.8157	-62.17833	19	Colonized Volcanic Boulders	1.290322581	1.290322581	1.290322581	6.838709677	0	13.29032258	14.32258065	0.12903226	0.64516129	3.22580645	57.67741935
16.82012	-62.18653	10	Coral Reef, Colonized Volcanic Boulders	2.580645161	5.806451613	12.12903226	3.741935484	0.129032258	26.96774194	4	0	2.70967742	0.51612903	41.41935484
16.82433	-62.20023	7	Coral Reef, Spur and Groove	1.548387097	0.387096774	0.903225806	0.516129032	0	54.58064516	22.70967742	0	0.38709677	0	18.96774194
16.82328	-62.18979	20	Coral Reef	2.838709677	4.129032258	5.935483871	6.709677419	0	6.193548387	5.032258065	0	2.96774194	1.93548387	64.25806452
16.76862	-62.22346	6	Colonized Volcanic Boulders	0.324324324	0.756756757	1.081081081	1.837837838	0	1.081081081	66.05405405	0	0.75675676	2.5945946	25.51351351
16.79531	-62.21321	16	Coral Reef, Spur and Groove	3.096774194	5.935483871	4.774193548	0.516129032	0	13.41935484	14.32258065	0	0	0.12903226	57.80645161
16.79752	-62.21174	11	Coral Reef, Spur and Groove	1.466666667	1.866666667	5.6	2.266666667	0	6	18.13333333	0.93333333	0.53333333	0.93333333	62.26666667
16.8065	-62.17702	19	Coral Reef	4.774193548	2.967741935	10.58064516	1.935483871	0	17.41935484	2.580645161	0	0.38709677	0	59.35483871
16.80652	-62.17685	10	Coral Reef	4.258064516	1.548387097	4	4.903225806	0.129032258	20.12903226	10.58064516	0.12903226	1.41935484	1.41935484	51.48387097
16.80409	-62.1777	15	Coral Reef	3.35483871	6.580645161	8.516129032	1.161290323	0.129032258	19.74193548	7.096774194	0	0.77419355	0	52.64516129
16.80409	-62.17917	10	Coral Reef	10.19354839	4.258064516	10.06451613	2.709677419	0	13.67741935	7.741935484	0	1.03225807	0	50.32258065
16.80032	-62.17913	7	Coral Reef	3.741935484	2.838709677	1.032258065	2.967741935	0	50.19354839	4	0	1.93548387	0	33.29032258
16.7969	-62.17609	13	Coral Reef	2.709677419	4.129032258	6.580645161	3.225806452	0	28.38709677	12.12903226	0	0.12903226	0	42.70967742
16.79029	-62.17972	13	Coral Reef, Mixed Hardbottom	0.774193548	2.451612903	0.129032258	0.774193548	0	1.290322581	70.19354839	0	0	0	24.38709677
16.82383	-62.19196	10	Coral Reef	1.894736842	19.68421053	5.684210526	4.631578947	0	5.157894737	9.263157895	0	3.68421053	1.36842105	48.63157895
16.82383	-62.19196	5	Coral Reef	5.9	15	13.8	1.2	0	14.8	4.8	0	4.4	2	38.1
16.67365	-62.1764	18	Coral Reef	4.516129032	5.806451613	20.64516129	4.903225806	0.258064516	5.806451613	20.90322581	0	0.64516129	2.58064516	33.93548387
16.67472	-62.17581	10	Colonized Volcanic Boulders	0.470588235	0.941176471	0.470588235	3.529411765	0	2	48.58823529	0	2.11764706	1.88235294	40
16.71209	-62.24547	20	Coral Reef, Seagrass, Mixed Hard Bottom	0.774193548	6.580645161	0.64516129	6.580645161	0	3.612903226	25.67741935	27.483871	1.41935484	5.93548387	21.29032258
16.71794	-62.23655	7	Coral Reef	0.387096774	3.35483871	3.225806452	10.19354839	0	1.161290323	29.41935484	1.67741936	1.03225807	2.19354839	47.35483871
16.71415	-62.24926	21	Coral Reef, Seagrass, Mixed Hard Bottom	0	0.64516129	0.774193548	2.838709677	0	0.387096774	15.74193548	72.7741936	0	2.4516129	4.387096774
16.72343	-62.24344	9	Coral Reef	0	1.161290323	0.129032258	8.516129032	0	0.129032258	72.12903226	0	5.29032258	1.41935484	11.22580645
16.823	-62.2043	17	Coral Reef, Spur and Groove	4.636363636	3.363636364	10.18181818	2.454545455	0.090909091	11.63636364	5.272727273	0	0.90909091	0.54545455	60.90909091
16.77904	-62.2214	9	Coral Reef	0.625	4.625	3.125	1.875	0	19.375	11	0	0.375	3	56
16.75827	-62.22941	18	Coral Reef	4.837209302	3.627906977	13.86046512	2.418604651	0.093023256	18.04651163	21.02325581	0	2.13953488	0	33.95348837
16.68075	-62.15441	10	Colonized Volcanic Boulders	2.451612903	7.612903226	1.161290323	5.548387097	0	9.161290323	16.25806452	0	2.70967742	0.90322581	54.19354839
16.68075	-62.15441	20	Colonized Volcanic Boulders	0.903225806	2.193548387	0.129032258	7.612903226	0	4.516129032	54.19354839	0	1.41935484	4.12903226	24.90322581
16.68075	-62.15441	5	Colonized Volcanic Boulders	4.875	2.125	2.75	1.25	0.125	24.625	1.5	0	0.125	0.125	62.5
16.68425	-62.15192	10	Colonized Volcanic Boulders	1.75	6.625	0.625	7.5	0	7.25	19	0	1	1.125	55.125

16.68425	-62.15192	20	Colonized Volcanic Boulders	0.387096774	0.258064516	0.64516129	5.161290323	0	1.806451613	73.03225806	0	0.38709677	1.67741936	16.64516129
16.82432	-62.20167	10	Colonized Volcanic Boulders	3.75	5	4.875	1.875	0	10.125	11.75	0	1.375	0.25	61
16.82432	-62.20167	5	Colonized Volcanic Boulders	14.75862069	1.517241379	16.13793103	4.413793103	0.275862069	11.17241379	0.275862069	0	2.62068966	0.82758621	48
16.81951	-62.18352	10	Coral Reef	0.727272727	1.696969697	3.757575758	4.96969697	0	21.33333333	10.78787879	0.12121212	0.72727273	1.33333333	54.54545455
16.81951	-62.18352	20	Coral Reef	1.575757576	8.848484848	6.787878788	4	0	3.636363636	19.27272727	0	1.6969697	2.66666667	51.51515152
16.75752	-62.2351	20	Coral Reef	0.125	5.625	1	3.5	0	8.5	24	0	4.75	3.125	49.375
16.76494	-62.22884	20	Coral Reef	1.25	4.25	1	9.25	0.125	26.625	13.25	0	8	1.875	34.375
16.76049	-62.2283	10	Coral Reef	2.451612903	3.225806452	7.741935484	3.612903226	0	7.483870968	16	0	2.58064516	0.51612903	56.38709677
16.77271	-62.22524	19	Coral Reef	0.484848485	4	0.727272727	2.545454545	0	8.606060606	33.33333333	10.0606061	1.09090909	2.78787879	36.36363636
16.7434	-62.23771	20	Coral Reef	1.032258065	3.096774194	0.129032258	7.741935484	0	22.32258065	22.58064516	2.06451613	0	1.67741936	39.35483871
16.74252	-62.23793	18	Sargassum Forest, Coral Reef, Mixed Hardbottom	0	14.11764706	0.117647059	1.411764706	0	14.23529412	42.82352941	1.17647059	0.11764706	0.35294118	25.64705882
16.71145	-62.23936	17	Coral Reef	0.25	4.625	0.5	11	0	6.75	33.125	0	2.25	0.125	41.375
16.75781	-62.23009	10	Coral Reef, Patch Reef	2.322580645	7.870967742	10.19354839	3.741935484	0	4.516129032	18.4516129	0.25806452	0.77419355	2.32258065	49.5483871

B. FISH SPECIES OBSERVED AND A AND B VALUES USED TO CALCULATE FISH BIOMASS

Species	Common name	a	b	Trophic group
Abudefduf saxatilis	sergeant major	0.017	3.12	Planktivore
Acanthemblemaria aspera	roughhead blenny	0.0077	2.962	Cryptic
Acanthemblemaria maria	secretary blenny	0.0077	2.962	Cryptic
Acanthemblemaria spinosa	spinyhead blenny	0.0077	2.962	Cryptic
Acanthostracion polygonius	honeycomb cowfish	0.0179	3	Invertivore
Acanthostracion quadricornis	scrawled cowfish	0.0178	3.08	Invertivore
Acanthurus chirurgus	doctorfish	0.0923	2.744	Herbivore
Acanthurus coeruleus	blue tang	0.0286	3	Herbivore
Acanthurus tractus	ocean surgeonfish	0.0191	3.08	Herbivore
Aluterus scriptus	scrawled filefish	0.0022	3	Invertivore
Amblycirrhitus pinos	redspotted hawkfish	0.0026	3.427	Invertivore
Anisotremus surinamensis	black margate	0.0233	3.01	Invertivore
Anisotremus virginicus	porkfish	0.0148	3.167	Invertivore
Apogon maculatus	flamefish	0.0157	3.073	Invertivore
Apogon quadrisquamatus	sawcheek cardinalfish	0.0157	3.073	Invertivore
Aulostomus maculatus	trumpetfish	0.004	2.866	Carnivore
Balistes capriscus	gray triggerfish	0.0139	0.0251	Invertivore
Balistes vetula	queen triggerfish	0.0864	2.784	Invertivore
Bodianus rufus	Spanish hogfish	0.0145	3.053	Invertivore
Bothus lunatus	peacock flounder	0.0098	3.189	Carnivore
Calamus calamus	saucereye porgy	0.0429	2.801	Invertivore
Calamus pennatula	pluma porgy	0.0178	3.1	Invertivore
Cantherhines macrocerus	American whitespotted filefish	0.0561	2.653	Invertivore
Cantherhines pullus	orangespotted filefish	0.0683	2.563	Invertivore
Canthidermis sufflamen	ocean triggerfish	0.0217	3	Invertivore

Canthigaster rostrata	sharpnose puffer	0.0729	2.5	Invertivore
Carangoides bartholomaei	yellow jack	0.0259	2.908	Carnivore
Caranx crysos	blue runner	0.0524	2.69	Carnivore
Caranx latus	horse-eye jack	0.021	2.97	Carnivore
Caranx lugubris	black jack	0.0572	2.794	Carnivore
Caranx ruber	bar jack	0.0214	2.954	Carnivore
Cephalopholis cruentata	graysby	0.0121	3.082	Carnivore
Cephalopholis fulva	coney	0.0223	2.933	Carnivore
Chaetodipterus faber	Atlantic spadefish	0.0591	2.26	Invertivore
Chaetodon capistratus	foureye butterflyfish	0.047	2.86	Invertivore
Chaetodon ocellatus	spotfin butterflyfish	0.0318	2.984	Invertivore
Chaetodon sedentarius	reef butterflyfish	0.0251	3.076	Invertivore
Chaetodon striatus	banded butterflyfish	0.0222	3.14	Invertivore
Chromis cyanea	blue chromis	0.0642	2.518	Planktivore
Chromis multilineata	brown chromis	0.0642	2.518	Planktivore
Clepticus parrae	creole wrasse	0.0135	3.043	Planktivore
Corvula batabana	blue croaker	0.01995	3.01	Invertivore
Coryphopterus dicrus	colon goby	0.0345	2.68	Cryptic
Coryphopterus eidolon	pallid goby	0.0345	2.68	Cryptic
Coryphopterus glaucofraenum	bridled goby	0.0345	2.68	Cryptic
Coryphopterus lipernes	peppermint goby	0.0345	2.68	Cryptic
Coryphopterus personatus/hyalinus	masked/glass goby	0.0345	2.68	NA
Coryphopterus tortugae	patch-reef goby	0.0345	2.68	Cryptic
Cryptotomus roseus	bluelip parrotfish	0.0505	3.182	Cryptic
Dasyatis americana	southern stingray	0.0732	2.81	Invertivore
Decapterus macarellus	mackerel scad	0.0078	3.14	Planktivore
Diodon holocanthus	baloonfish	0.0219	3	Invertivore
Diodon hystrix	porcupinefish	0.5322	2.276	Invertivore
Elacatinus chancei	shortstripe goby	0.008	3.137	Invertivore
Elacatinus evelynae	sharknose goby	0.008	3.137	Cryptic
Elacatinus genie	cleaning goby	0.008	3.137	Cryptic
Epinephelus adscensionis	rock hind	0.0153	3	Carnivore
Epinephelus guttatus	red hind	0.0084	3.1	Carnivore
Equetus lanceolatus	jackknife fish	0.0011	3.844	Invertivore
Equetus punctatus	spotted drum	0.0011	3.844	Invertivore
Gerres cinereus	yellowfin mojarra	0.0147	3.12	Invertivore
Ginglymostoma cirratum	nurse shark	0.0255	2.86	Carnivore
Gnatholepis thompsoni	goldspot goby	0.0035	3.766	Cryptic
Gramma loreto	fairy basslet	0.0128	3.036	Invertivore

Gymnothorax funebris	green moray	0.0041	2.856	Carnivore
Gymnothorax miliaris	goldentail moray	0.01	3.158	Carnivore
Gymnothorax moringa	spotted moray	0.001	3.158	Carnivore
Haemulon album	margate (white)	0.014	3.09	Invertivore
Haemulon aurolineatum	tomtate	0.011	3.2	Invertivore
Haemulon carbonarium	caesar grunt	0.04	2.74	Invertivore
Haemulon chrysargyreum	smallmouth grunt	0.0141	3.08	Invertivore
Haemulon flavolineatum	French grunt	0.0111	3.23	Invertivore
Haemulon macrostomum	Spanish grunt	0.0244	3.029	Invertivore
Haemulon parra	sailors choice	0.028	2.89	Invertivore
Haemulon plumierii	white grunt	0.0098	3.17	Invertivore
Haemulon sciurus	bluestriped grunt	0.02	3.01	Invertivore
Halichoeres bivittatus	slippery dick	0.0094	3.15	Invertivore
Halichoeres cyanocephalus	yellowcheek wrasse	0.0094	3.15	Invertivore
Halichoeres garnoti	yellowhead wrasse	0.0052	3.375	Invertivore
Halichoeres maculipinna	clown wrasse	0.0028	3.693	Invertivore
Halichoeres pictus	rainbow wrasse	0.0101	3.04	Invertivore
Halichoeres poeyi	blackear wrasse	0.094	3.15	Invertivore
Halichoeres radiatus	puddingwife	0.0131	3.038	Invertivore
Heteroconger longissimus	brown garden eel	0.00102	3.06	Invertivore
Heteropriacanthus cruentatus	glasseye snapper	0.0188	3	Invertivore
Holacanthus ciliaris	queen angelfish	0.0377	2.9	Invertivore
Holacanthus tricolor	rock beauty	0.0428	2.858	Invertivore
Holocentrus adscensionis	squirrelfish	0.0216	3	Invertivore
Holocentrus rufus	longspine squirrelfish	0.015	3.059	Invertivore
Hypoplectrus indigo	indigo hamlet	0.009	3.04	Invertivore
Hypoplectrus puella	barred hamlet	0.009	3.04	Invertivore
Kyphosus sectatrix	chub (bermuda/yellow)	0.0174	3.08	Herbivore
Lactophrys bicaudalis	spotted trunkfish	0.0294	3	Invertivore
Lactophrys triqueter	smooth trunkfish	0.0309	3	Invertivore
Lutjanus analis	mutton snapper	0.0056	3.175	Carnivore
Lutjanus apodus	schoolmaster	0.0172	3.01	Carnivore
Lutjanus buccanella	blackfin snapper	0.0747	2.735	Carnivore
Lutjanus cyanopterus	cubera snapper	0.0093	2.88	Top predator
Lutjanus griseus	gray snapper	0.0184	2.94	Invertivore
Lutjanus jocu	dog snapper	0.0085	3.2	Carnivore
Lutjanus mahogoni	mahogany snapper	0.0429	2.719	Carnivore
Lutjanus synagris	lane snapper	0.018	2.981	Invertivore
Malacanthus plumieri	sand tilefish	0.0269	2.629	Invertivore
Malacoctenus macropus	rosy blenny	0.0341	2.72	Cryptic

Malacoctenus triangulatus	saddled blenny	0.0341	2.72	Cryptic
Megalops atlanticus	tarpon	0.0053	3	Carnivore
Melichthys niger	black durgon	0.0058	3.554	Invertivore
Microspathodon chrysurus	yellowtail damselfish	0.0239	3.082	Herbivore
Mulloidichthys martinicus	yellow goatfish	0.0161	3	Invertivore
Mycteroperca interstitialis	yellowmouth grouper	0.0141	3	Top predator
Myripristis jacobus	blackbar soldierfish	0.111	2.72	Invertivore
Neoniphon marianus	longjaw squirrelfish	0.01514	2.98	Invertivore
Ocyurus chrysurus	yellowtail snapper	0.0117	2.65	Planktivore
Ophioblennius macclurei	redlip blenny	0.0324	2.379	Cryptic
Opistognathus aurifrons	yellowhead jawfish	0.0153	3	Invertivore
Paranthias furcifer	atlantic creolefish	0.0135	3.043	Planktivore
Pareques acuminatus	highhat	0.00871	3.202	Invertivore
Pempheris schomburgkii	glassy sweeper	0.0165	3.072	Invertivore
Pomacanthus paru	French angelfish	0.0203	3.126	Invertivore
Priacanthus arenatus	bigeye	0.013	3.039	Invertivore
Prognathodes aculeatus	longsnout butterflyfish	0.047	2.86	Invertivore
Pseudupeneus maculatus	spotted goatfish	0.002	3.806	Invertivore
Pterois volitans	red lionfish	0.02243	2.89	Carnivore
Rypticus saponaceus	greater soapfish	0.0121	3.082	Invertivore
Sargocentron vexillarium	dusky squirrelfish	0.015	3.059	Invertivore
Scartella cristata	molly miller	0.00812	3.27	Cryptic
Scarus guacamaia	rainbow parrotfish	0.0352	2.88	Herbivore
Scarus iseri	striped parrotfish	0.0147	3.055	Herbivore
Scarus taeniopterus	princess parrotfish	0.0177	3	Herbivore
Scarus vetula	queen parrotfish	0.0177	3	Herbivore
Scomberomorus regalis	cero	0.0202	2.8	Carnivore
Scorpaena plumieri	spotted scorpionfish	0.0244	2.949	Carnivore
Seriola rivoliana	almaco jack	0.0145	3.055	Carnivore
Serranus baldwini	lantern bass	0.0128	3.036	Invertivore
Serranus tigrinus	harlequin bass	0.0145	3.048	Invertivore
Serranus tortugarum	chalk bass	0.0128	3.036	Invertivore
Sparisoma atomarium	greenblotch parrotfish	0.0122	3.028	Herbivore
Sparisoma aurofrenatum	redband parrotfish	0.0744	2.336	Herbivore
Sparisoma chrysopterum	redtail parrotfish	0.0171	3	Herbivore
Sparisoma radians	bucktooth parrotfish	0.0122	3.028	Herbivore
Sparisoma rubripinne	yellowtail parrotfish	0.0156	3.064	Herbivore
Sparisoma viride	stoplight parrotfish	0.0099	3.121	Herbivore
Sphoeroides spengleri	bandtail puffer	0.042	2.61	Invertivore
Sphyraena barracuda	great barracuda	0.005	3.083	Top predator

Sphyraena picudilla	southern sennet	0.067	2.942	Carnivore
Stegastes adustus	dusky damselfish	0.01995	2.99	Herbivore
Stegastes diencaeus	longfin damselfish	0.0353	2.896	Herbivore
Stegastes leucostictus	beaugregory	0.0303	2.887	Herbivore
Stegastes partitus	bicolor damselfish	0.0182	3.152	Herbivore
Stegastes planifrons	threespot damselfish	0.0379	2.857	Herbivore
Stegastes variabilis	cocoa damselfish	0.0324	2.836	Herbivore
Synodus intermedius	sand diver	0.0099	2.999	Carnivore
Thalassoma bifasciatum	bluehead	0.0101	3.04	Planktivore
Tigrigobius dilepis	orangesided goby	0.008	3.137	Cryptic
Trachinotus falcatus	permit	0.0016	3.19	Carnivore
Xyrichtys martinicensis	rosy razorfish	0.018	3.078	Invertivore
Xyrichtys splendens	green razorfish	0.01	3	Invertivore

C. SUMMARY OF HISTORICAL RESEARCH

This section provides a summary of historical studies conducted pertaining to Montserrat's marine resources.

MNI Progress Report: Coral Cay Conservation Marine Progress Report Montserrat 2013-2016

DATE	2017
AUTHORS	Tom Dallison and Alex Ferguson
PARTNERS	Officially: Government of Montserrat Ministry of Agriculture, Trade, Land, Housing and the Environment (MATLHE); Coral Cay Conservation (CCC)
AREA OF INTEREST /DATA	Coral reef surveys; augmented Reef Check protocol for abundance and diversity of fishes and invertebrates (added more target species). Data were collected in combination with anthropogenic impacts and benthic substratum composition.

SURVEY PERIOD	2013 - 2016			
LOCATION	North-western coastline of Montserrat			
SITE SELECTION	Surveys completed in two phases since 2013. Phase I sampled locations along shoreline at set locations: Baseline (n=51) and Permanent (n=13) sites. Total of 500m along shoreline. Each site contained one transect at 6m and 12m. Each transect was 100m, divided into 4 replicates of 20m; 5m gap between replicates. Phase II sampled at five locations with "greatest conservation potential"; Carr's Bay (n=7), Isle's Bay (n=6), Lime Kiln Bay (n=15), Old Road Bay (n=2), and Woodlands Bay (n=1). EXECUTIVE SUMMARY: A total of 5 locations were surveyed (Lime Kiln Bay, Carr's Bay, Isle's Bay, Woodlands Bay, Old Road Bay) whilst surveys were also conducted along the entirety of the coastline (Baselines and Permanent). Permanent and Baseline surveys were not geographically constrained and thus were omitted from analysis, unless otherwise stated. This was to enable spatial representations of coral reef community variables.			
FIELD METHODS	Underwater Visual Census (UVC) **(fishes)**	Underwater Visual Census (UVC) **(invertebrates)**	Point Intercept Transect (PIT) **(benthic substrate composition)**	Impact Assessment **(coral bleaching)**
Description	Diversity and abundance of fishes recorded. Selected fish families and species recognized as being indicators of fishing pressure, LRFFT and reef health recorded (Table A1).	Diversity and abundance of invertebrates recorded (Table A2) along same 100m transect.	Measured by recording biotic and abiotic benthic categories along a point intercept transect (PIT).	Within same area assessed for invertebrates, CCC recorded number of impacts on reef.
Stratification/ Measurements	Fish abundance recorded within 5x5x5m box along four 20m replicates, total area 2,300 m3 (Fig. 10). Surveys conducted by two divers recording indicator species. Divers stopped every 5m and waited 1 minute for fish to	Invertebrates were recorded 2.5m on either side of transect line along four 20m replicates, total area of 400m2 per transect. Divers using SCUBA followed an 'S' shape to ensure area coverage. Target invertebrates were	Benthic organisms and substrate types were recorded at 0.5m intervals (Fig. 12). A plumb was dropped at each interval and substrate type underneath was recorded to avoid bias. Every replicate contained 40 benthic	Total percentage of bleached coral cover and estimated percentage of each individual coral colony that was bleached was determined. Coral diseases were recorded as percentage of colony infected and if possible, disease was identified. Damage was recorded in three categories: Boat/anchor; dynamite, and other on categorical scale from (0=none; 1=low; 2=medium, 3=high).

	resume natural behavior before proceeding. Total length (TL) in cm of five species recorded for biomass (kg) calculations: Serranidae, Scaridae, Cephalopholis fulva, Epinephelus striatus, Epinephelus gattatus and Epinephelus adscensionis.	established based on their respective value as commercially important species, as food source and relative functional group including their value in collection of curios. No species recorded within 5m inter-replicate gap.	points. Benthic categories include: Sand (SD), Rubble (RB), Silt/Mud (SI), Nutrient indicator algae (NIA), soft coral (SC), hard coral (HC), and any other (OT) biotic lifeforms (Table A3.)	Trash was recorded on same scale and separated into general and fishing nets/traps.
RESULTS *Overall*	Total of n=95 surveys (n=380 replicates). Mean distance of sites from population center was 1.5 ± 0.1km. Major storm events were not recorded. Sampled area was considered to experience low anthropogenic impact with 85% of sites classified as 'low' and 3% as 'high' (Fig. 13). Pollution levels, including industrial pollution, also considered to be 'low'. The highest anthropogenic impact was snorkelling/diving and considered 'low/medium'.			
FISH	DENSITY	ABUNDANCE/DIVERSITY	BIOMASS / SIZE	
Total sites	Total of 190 km3 of coastal water surveyed with results indicating a target fish density of N= 191.30 ±10.56 500m3 -1. Herbivorous fishes were recorded in densities of N= 71.20 ±7.09 500m3 -1 with Pomacentridae (Damselfish) the most dominant subsequently followed by Acanthuridae (Surgeonfish) (N= 58.68 ±6.70 500m3 -1, N= 10.68 ±0.99 500m3 -1) Scaridae (Parrotfishes) were recorded across all survey sites at a density of 2.00 ±0.47 500m3 -1, of which presented greater variability in density than Seranidae (Groupers) (N= 2.13 ±0.18 500m3 -1).	A total of 72,703 fishes were recorded from 26 families (Table B1). Labridae (Wrasse) were the most commonly observed target family (N= 113.41 ±6.31 500m3 -1) with a total of 43,094 individuals recorded (Fig. 14b, Table A1). Pomacentridae (Damselfishes) (N= 56.88 ±5.21 500m3 -1) were the second most abundant, 21,616, followed by Acanthuridae (Surgeonfishes) (N= 9.17 ±0.62 500m3 -1) accruing 3,486 individuals throughout period (Fig. 14b, Table B1). A total of 26, 247 individuals from target fish families that exhibit herbivorous behavioural traits were recorded equating to N= 69.07± 5.58 500m3 -1. Dominant herbivorous family were Pomacentridae with 21, 616 individuals (N= 56.88 ±5.21 500m3 -	Overall, including all locations, the total biomass surveyed was 101.57kg that equated to a mean value biomass of 0.27 ±0.03 kg/500m3 -1. Coney (Serranidae sp.) were the most represented commercially important Genus with an accumulated mean across all sites of 1.02 ±0.07 kg/500m3 -1 with Hind (Serranidae) and Nassau Groupers (Serranidae) the least represented (0.05 ±0.01 kg/500m3 -1, both respectively).	

		1).	
Constrained sites (five)	Fishes were recorded in densities of N= 226.36 ±15.18 500m3 -1 with Labridae (Wrasse) holding the greatest density (142.35 ±10.36 500m3 -1).	Total number of surveyed individual fishes decreased to 28,069. Labridae were found in greater abundance throughout the five locations surveyed in comparison to all locations, N= 142. 35 ±10.36 500m3 -1 (Fig. 14a). Total herbivorous fish from constrained sites: 8,829 individuals (N= 71.20 ±7.09 500m3 -1) were recorded. Herbivores were recorded into 7 target families (details on page 16). Pomacentridae were the dominant herbivorous target family recorded across all five survey sites.	Removal of permanent and baselines sites resulted in a decrease in recorded biomass (28.21 kg). The mean biomass of commercially important fishes decreased by 0.4kg, equating to 0.23 ±0.04 kg/500m3 -1.
Location-specific	Location was found to hold a significant impact on both the density and diversity of fishes (p= <0.001, respectively) with Lime Kiln Bay conferring the greatest values for both variables. location was demonstrated to have a significant impact on herbivorous densities (ANOV A (F(4, 119)=5.21, p= <0.001) with a post-hoc Tukey test demonstrating that Lime Kiln Bay differed significantly from Carr's Bay (p= <0.05) and Isle's Bay (p= <0.01). Lime Kiln Bay held the greatest's density of herbivorous fishes of which differed significantly from Carr's Bay and Isle's Bay. Old Road Bay had lowest density of herbivorous fish N= 12.63 ±7.47 500m3 -1 (Fig. 16). Cluster analysis indicated three clusters with Lime Kiln Bay holding greatest similarity	The effect of location on the abundance of fishes was significant (ANOVA (F(4, 119)= 8.78, p= <0.001)). A post-hoc Tukey test indicated that Isle's Bay (N= 89.50 ±27.44 500m3 -1) held a significantly lower fish abundance than Carr's Bay (N= 235.61 ±28.53 500m3 -1) and Lime Kiln Bay (N= 283.70 ±19.86 500m3 -1) (p= <0.05 and p= <0.001, respectively) (Fig. 15a). A significant variation (p= <0.01) was found between Lime Kiln Bay and Old Road Bay (N= 75.63 ±36.93 500m3 - 1). Location of survey also resulted in variation amongst the diversity (H') of coral reef-associated communities (ANOV A (F(4, 119)= 5.83, p= <0.001). Variation in H' was greatest amongst Old Road Bay (H'= 0.31 ±0.12 500m3 -1) and those sites with the greatest H' recorded following posthoc- Tukey tests; Lime Kiln Bay (p= <0.001); Isle's Bay (p= <0.001); Carr's Bay (p= <0.05)	Location was observed to have no impact on biomass (ANOVA (F(4, 119)=2.3, p= n.s), post-hoc Tukey test indicated that the variance in biomass between Lime Kiln Bay (0.31 ±0.06 kg/500m3 -1) and Isle's Bay (0.02 ±0.01 kg/500m3 -1) was significant (p= <0.05) (Fig. 18a). The impact of location on the individual mass (g) of fishes was significant (ANOVA (F(4, 119)= 2.86, p= <0.05)), but not significant on post-hoc Tukey tests. The mean biomass of Coney was greatest at Old Road Bay, 0.42 ±0.42 kg/500m3 -1. Biomass of Coney was shown to differ significantly between Lime Kiln Bay (0.25 ±0.03 kg/500m3 -1) and Isle's Bay (0.02 ±0.02 kg/500m3 -1), ANOVA (F(4, 119)= 2.62, p= <0.05). Parrotfishes were second greatest contributor 0.17 ±0.02 kg/500m3 -1) whilst only occurring at Carr's Bay (0.10 ±0.05 kg/500m3 -1) and Lime Kiln Bay (0.06 ±0.02 kg/500m3 -1). Grouper poorly represented at 0.20 kg/500m3 -1). No individuals were recorded >50cm, dominant size was <21cm (Fig. 21). Parrotfish (Scaridae) held the greatest frequency (f) throughout the sample period (f= 760) with 615 individuals recorded <10cm

	to Woodlands Bay with regards to herbivorous community structure. More details on cluster analysis and Jaccard Dissimilarity Index (JDI) on page 16.	(Fig. 15b). Lime Kiln Bay was considered to hold the most diverse community of fishes with a H'= value of 1.02 ±0.05 500m3 -1 (Fig. 15b)	in length (Fig. 21). 6 individuals classed between 31 and 50cm. Coney (Serranidae) had a total of 694 individuals recorded with 10-20cm being the dominant size class (f= 379) (Fig. 21b). Hind and Nassau Grouper were most poorly represented.
INVERTS	DENSITY	ABUNDANCE/DIVERSITY	GORGONIAN-SPECIFIC INFORMATION
Total sites	Total of 38km3 of coastal water surveyed with GO abundance dominating invertebrate communities (N= 109.53 ±8.79 100m2 -1). Excluding GO, invertebrate individuals surveyed had density of N= 10.69 ±1.1 100m2 -1.	A total of 41,621 marine invertebrates were recorded from all survey sites composed of 1 Order, 1 Family and 6 species (Table B2). Gorgonians (Gorgonacea) comprised 90.2% (37,560). Pencil (Eucidaris tribuloides) and Long-Spined Urchins (Diadema antillarum) were observed invertebrates at 6.4% (2668) and 1.8% (766). Atlantic Triton's Trumpet (Charonia variegata) was recorded in the least abundance (3).	A total of 37,560 gorgonian colonies were recorded from all survey locations that equated to N= 98.84 ±8.49 100m2 -1.
Constrained sites (five) AND with Gorgonians removed from analysis	Pencil urchins held the highest density of N= 11.71 ±1.36 100m2 -1, subsequently followed by Diadema sp. (N= 1.65 ±0.34 100m2 -1)	In total, 2, 092 invertebrates (N= 16.87 ±1.95 100m2 -1) were recorded. Atlantic Triton's Trumpet most poorly represented with 1 individual recorded.	35.72% of all gorgonian colonies were recorded at the 5 geographically constrained locations (Carr's Bay; Isle's Bay, Lime Kiln Bay, Old Road Bay and Woodlands Bay) resulting in a mean density of N= 108.2 ±9.25 100m2 -1.
Location-specific	Location was demonstrated to have a significant impact on invertebrate abundance (ANOVA ($F(4, 119)= 7.22$, $p= <0.001$) with post-hoc Tukey tests indicating that Lime Kiln Bay's variation was significant to Carr's Bay ($p= <0.05$) and Isle's Bay ($p= <0.001$) (Fig.		Lime Kiln Bay held the highest density of gorgonians at 181.36 ±10.23 100m2 -1 with Isle's Bay recording the lowest (N= 0.90 ±0.61 100m2 -1) (Fig. 26).

	23a). Lime Kiln Bay (N= 25.5 ±2.64 100m2 -1) held the greatest abundance of target invertebrates and Isle's Bay held the lowest, N= 1.25 ±0.53 100m2 -1 (Fig. 23a). Location also had a significant impact on the diversity of target invertebrates at each sites (ANOVA (F4, 119)= 5.28, p= <0.001). Carr's Bay was demonstrated to hold the greatest diversity of target invertebrates (H'= 0.55 ±0.08 100m2 -1), with Isle's Bay being the least diverse (H'= 0.10 ±0.07 100m2 -1).	The variance observed between locations was demonstrated to be significant through ANOVA (F(4, 119) =38.79, p= <0.001). Lime Kiln Bay showed significantly greater densities of gorgonians than all other geographically constrained locations; Isle's Bay (p= <0.001); Carr's Bay (p= <0.001); Old Road Bay (p= <0.001); and Woodlands Bay (p= <0.001).
BENTHOS	PERCENT COVER (%)	CORAL DIVERSITY
Sites	Total of 7.6km of benthos was surveyed with sand (SD), other (OT) and rock (RC) being the dominant substrates across the overall survey area (50.66 ±2.03%; 15.65 ±1.62%; 13.22 ±0.98%, respectively).	Hard coral (HC) varies composition amongst the five surveyed locations (ANOVA (F(4, 119)= 7.45, p= <0.05)) with Lime Kiln Bay holding the greatest composition, 5.12 ±0.59% (Fig. 27a).
Location-specific	The coverage of sponge (SP) was greater at Lime Kiln Bay (2.63 ±0.39%) than Isle's Bay (0.13 ±0.13 %) (Fig. 27c), through ANOVA (F(4, 119)= 4.75, p= <0.05) and post-hoc Tukey tests (p= <0.01). Rock (RC) was found in varying coverage between sites with Lime Kiln Bay and Carr's Bay recording the highest compositions (17.92 ±1.99% and 18.30 ±4.81%, respectively) (Fig. 27e). Location had a significant impact on the composition of RC (ANOVA (F(4,119)= 4.208, p= <0.01)) Sand (SD) was the most prevalent substrate with Old Road Bay composing of 95.31 ±3.36 % whilst Lime Kiln Bay recorded the lowest composition of SD 35.20 ±4.06 %). Sand was significantly dependent on location.	Composition at Lime Kiln Bay was significantly greater than that recorded at Carr's Bay (1.96 ±1.12%, p= <0.05), Isle's Bay (0%, p= <0.01) and Old Road Bay (0%, p= <0.05) (Fig. 27a).
OTHER	Low abundance of charismatic mega-fauna; 5 Hawksbill, 1 nurse shark, 6 sting rays and 1 eagle ray.	
OUTCOMES / RECOMM.	It is recommended that as a result for this study, MATLHE begin the necessary processes to implement the establishment of two MPAs that protect areas within the geographic designation of Lime Kiln Bay and Carr's Bay. An ecosystem approach to fisheries (EAF) management is suggested that involves local stakeholders throughout; aiming for autonomous management.	

NOTES	There were additional descriptions for methodology that I did not cover in this summary, including 2.2.3 Biomass Calculations, 2.3 Data analysis, and 2.4 Conservation Management Values (CMV) Methodology. Other topics not addressed in this summary include 3.4 Community Based Correlations: 3.4.1 Relationships between community characteristics and benthic substratum and 4.4.2. Herbivory, Nutrient Indicator Algae (NIA), and Hard Coral (HC) Composition; as well as 3.5 Conservation Management Values.		
CITATION	Dallison, T. & Ferguson, A. (2017). Coral Cay Conservation Marine Progress Report, Montserrat 2013 – 2016. Coral Cay Conservation. Available Online: http://www.coralcay.org/science- research/scientific-reports/.		
SPECIES LISTS	TARGET FISHES	TARGET INVERTS	BENTHIC COVER
	Angelfish (Pomacanthidae) Ballyhoo (Hemiramphidae) Basslet (Grammatidae) Butterflyfish (Chaetodontidae) Chromis/Damselfish (Pomacentridae) Chub (Kyphosidae) Filefish (Monacanthidae) Goatfish (Mulidae) Grouper (Serranidae) Coney (Cephalopholis fulva) Hamlet (Hypoplectrus sp.) Hind (Epinephelus guttatus and adscensionis) Nassau grouper (Epinephelus striatus) Grunt (Haemulidae) Jack (Carangidae) Lionfish (Pterois spp.) Lizardfish (Synodontidae) Moray Eel (Muraenidae) Needlefish (Belonidae) Parrotfish (Scaridae) Porgy (Sparidae) Scorpionfish (Scorpionidae) Snake eel (Ophichthidae) Snapper (Lutjanidae) Squirrelfish/Soldierfish (Holocentridae) Surgeonfish (Acanthuridae) Blue tang (Acanthurus coeruleus) Triggerfish (Balistidae) Trumpetfish (Aulostomidae) Trunk/Box/Cowfish (Ostraciidae) Honeycomb cowfish (Acanthostracion polygoina) Wrasse (Labridae)	Banded Coral Shrimp (Stenopus hispidus) Collector Urchin (Tripneustes spp.) Flamingo Tongue (Cyphoma gibbosum) Gorgonians (Gorgonacea) Long Spined Sea Urchin (Diadema antillarum) Pencil Urchin Triton's Trumpet (Charonia variegate) Lobster (Palinuridae)	Hard Coral (including fire coral) Sponge Rubble Other Soft Coral (including zoanthids) Nutrient indicator algae Sand Recently Killed Coral Rock Silt

Wild et. Al 2007: Towards Multi-user Marine Management in Montserrat – Marine Ecosystem Survey Chapter

DATE	December 2007				
AUTHORS	R. Wild, L. Slade, M. Pardee & C. Carleton				
PARTNERS	At the request of the Montserrat tourist Board, LTS International carried out a feasibility study into the establishment of a 'multiple-use marine park' for Montserrat.				
AREA OF INTEREST	Reef Check Surveys for Substrate Percent Cover, Fishes, and Invertebrates; Present/Absent Surveys for Fishes and Invertebrates				
SURVEY PERIOD	Study fieldwork was undertaken by a team of four personnel during October and November, 2007.				
LOCATION	A limited marine survey was carried out predominantly in the near-shore waters of the North West side of the Island.				
SITE SELECTION	Three sites (n=3) (Rendezvous shallow, Rendezvous Dive Site and Woodlands South) were selected on the west coast for intensive survey based on the following logic: They represent a range of accessible sites with higher (Woodlands) to lower (Rendezvous) stress levels from the volcano and other terrestrial activities; They have been the focus of past ((Sustainable Ecosystems Institute (SEI), and ongoing studies from Finger Lakes Community College New York State (USA) (using Reefcheck methodology) survey and past data is available; Include both shallow and deeper sites; Rendezvous ranked as possible site for conservation; and Woodlands recommended as good juvenile fish habitat. Seven (n=7) other sites were selected for rapid species presence/absence survey within the short field time allowed. Approximately 30-minute snorkel or dive excursions were made to collect the lists of species noted. These seven sites include: Lime Kiln North, Woodlands Bluff, Woodlands Dive Site, Woodlands North, Little Bay Shoreline, Pot of Gold Divesite and Little Redonda Shoreline. This allowed the study to: Gain better understanding of more sites to facilitate MPA zoning recommendations; Assess inshore areas for juvenile fish habitat; Assess sites for recreational snorkelling; gain insight into inshore/offshore differences in biodiversity.				
FIELD METHODS	Line Intercept (Reef Check) and Species Point Intercept **(substrate cover diversity and photos)**	Line Intercept (Reef Check) – **(fishes and invertebrates diversity and abundance)**	Species Present/ Absent Rapid Surveys **(fishes)**	General Survey (**GPS Points, bottom depth, secchi depth, salinity, distance from shore**)	Habitat and Risk Assessments **(volcano impacts and fishing grounds)**

Description	In addition to Reef Check target species, species level point intercept line transects were also carried out to detail benthic species diversity and composition. Photo documentation only, not used in analysis.	Fish surveys included all species and counts for diversity and abundance (not just target species on Reef Check). Collection of this level of data was deemed important for more detailed site interpretation that could also be compared with the SEI more detailed studies of 1995-1996.	Species presence/ absence surveys could further the basic understanding of the area as well as species composition for other select sites, where time and depth constraints limited the ability to utilize the Reef Check protocol and line intercept methodology.	GPS coordinates were taken utilizing a Garmin 12 GPS with accuracy +/-3m. A total of 180 GPS points were taken during the course of the field work for site and mapping evaluations. All 10 site coordinates in ANNEX IV SURVEY SITES LOCATION COORDINATES (pg. 129).	Listed in small table of dates and events of all surveys. There is a table in the ANNEX III (iii) FISHERMAN'S KNOWLEDGE AND FISH TRAP STUDY that has a list fish species and number of pots on Page 128 in report.
Stratification/ Measurements	Reef Check Line Intercept: 100m transect line parallel to shore at preferred depths 2-6m and >6-12m. Transect divided into 4x20m sections with 5m intervals between, for total of 80m. Observer records substrate at 0.5m interval. Species point intercept line transects data recorded at each change in substrate type with minimum intervals of 0.1m. Sites: (n=3)	Belt transect: Four 5m wide (centered on the transect line) by 20m long segments sampled for fish species. Fish seen up to 5m above the line included. Survey teams will stop at each 5m mark and observe indicator species within a 125m3 volume of water (5 meters wide, 5 meters along transect, and 5 meters above the reef surface).	This includes presence/absence during a 30m swim of each site (n=7). This method of assessment does not record abundance, but does give an overview of the species found at each site. Additionally, the number of different juvenile species seen at each site was recorded.	Bottom depth was taken utilizing a Speedtech 400 depth sounder, secchi depth was taken utilizing a standard secchi disk, salinity was taken utilizing a refractometer, with distance from taken utilizing YardagePro 1000 rangefinders, with distance capability to 600m.	Interview with fisherman.
RESULTS *Overall*	From the species level point intercept analysis, species area curves and species diversity indices were also generated for hard corals.	Species diversity indices were also calculated from the total count information Separately, invertebrate indicator species counts from the Reef Check protocol is included.	Simple presence/ absence of fish was recorded as above for the seven other sites surveyed.		

BENTHOS	DEPTH AND SITE DESCRIPTION	PERCENT COVER (%) OF SUBSTRATE **(Reef Check Protocol)**	POINT INTERCEPT ANALYSIS (Species Level) (Comparison with Reef Check Protocol)
Rendezvous Shallow	The site named Rendezvous Shallow ranges in depth from 3-10m with the survey line placed along an average depth of 4-5m. Reef relief varied fairly dramatically at this site.	Data extrapolated from the survey indicates that there is live coral cover of 21.25% hard corals, 4.4% soft corals, no recently killed corals, 8.8% algae cover, and 6.3% sponge. Non-living substrate cover indicates 51.3% rock, 5% rubble, 3% sand, no silt recorded.	Total of 60m was recorded. Values were comparable for the Rendezvous Shallow site when comparing Reef Check methodology vs. this type of data collection (max change 5%). [Algae (NIA) 3.67%; HC 20.83%; SC 6.3%; SD: 1.83%; RB 6%; RC 51.33%; SP 7%; SC 3%.].
Rendezvous Divesite	Site is located further offshore of the previous site at an average depth of 20m (65ft) that then progresses to 28m (85ft). Reef relief was less dramatic at this site with the reef underlying structure appearing to be a large boulder with corals attached.	The substrate composition for this site varied greatly from the shallow water site and included 17.5% hard corals, 2.5% soft corals, 0.6% recently killed corals, 13% algae and 11% sponge habitat. Non-living substrate cover included 16% rock, 6% rubble and 32.5% sand.	Total of 40m was recorded due to dive time limitations. Values "did differ rather significantly". Major difference were noted in the Rock and Sand categories, with the amount of rock being double for the 40m transect line, and the amount of sand being half of the Reef Check estimations. [Algae (NIA) 20.5%; HC 18.25%; SC 0.75%; SD: 18%; RB 1.75%; RC 32%; SP 7.75%; SC 1%.].
Woodlands South	The Woodlands South site is located in water depths averaging 10m (33ft) and is a considerable distance south of the other two monitoring stations. This area was limited in reef relief, being primarily flat hard-bottom relief of 1-2m above the sand.	Live cover included 8.8% hard corals. 4.4% soft corals. 7.5% algae and 3% sponge. Non-living cover included 43.8% rock, 4% rubble, 19% sand and 8% silt.	Total of 40m was recorded due to dive time limitations. Values "did differ rather significantly". Similar discrepancies for the rock, sand and hard coral. [Algae (NIA) 4%; HC 15.5%; SC 4%; SD: 3.75%; RB 2.75%; RC 51.75%; SP 5.25%; SC 2%. Silt 11%].
Comparison of sites – their overview	The three sites varied overall in substrate cover, with Rendezvous Shallow and Dive site live cover totals being 40.7% and 45.5% respectively as compared to 25.2% of live cover for the Woodlands south site. Only the Rendezvous Dive site contained some recently killed coral at .6%. For the non-living cover components, Rock cover was the highest for Rendezvous Shallow (51.3%) with only a small amount of sand (3%), while the Dive site contained little rock (16%) and 32.5% sand. Woodlands had the highest non-living cover at 74.8% total, with 43.8% rock, 19% sand, 4% rubble and silt at 8%. No silt was found at the other two sites farther north and is conceivably a result of the proximity to volcanic sediments.		
FISH	REEF CHECK ANALYSIS	TOTAL FISH COUNTS	FISH PRESENCE/ABSENCE
Various site results	Total sites (n=3); Grunts and Parrotfish were found at all	Total sites (n=5); Fish counts were undertaken for a total of five sites	Total sites (n=7);. Rendezvous Shallow and the Woodlands Dive Site contain the highest

1. Rendezvous Shallow *2. Rendezvous Divesites* *3. Woodlands South* *4. Pot of Gold* *5. Woodlands Divesites* *Additional:* *6. Lime Kiln North* *7. Woodlands Bluff* *8. Woodlands North* *9. Little Redonda Shoreline* *10. Little Bay Shoreline*	three sites with the Rendezvous Shallow site containing the most grunts and a moray eel, the Rendezvous Dive site having the largest concentration of Parrotfish and the only recorded grouper of size, with the Woodlands South site containing the least quantities of grunts and parrots and none of the other species. It should be noted that groupers (represented mostly by coney and occasionally rock hind) were recorded at all sites but were lower than the requisite Reef Check size class.	utilizing two different methodologies. In addition to the three Reef Check sites, 5minute stationary fish counts were undertaken for the Pot of Gold and Woodlands Divesites during the Rapid Assessment of those sites. A total of 21 fish families are represented throughout the five sites, with 10-12 families found at each site. Two families of fish (Wrasse- Labridae and Chromis/Damselfish-Pomecentridae) dominate all sites with minor proportions (5-15%) of all other families encountered. When comparing counts of the three main species encountered versus the counts of other species, the Bluehead Wrasse is dominant for the first three sites, with the Bicolor Damsel being dominant for the Pot of Gold Site and the Brown Chromis being dominant for the Woodlands Dive Site. Noted that site methodologies should not be compared.	number of adult species found, followed by Pot of Gold Dive Site and the Little Bay Shoreline area. These sites are fairly different; with two sites being shallow and near to shore and the other two deep water sites being at distance from shore. Rendezvous Shallow and Little Bay Shoreline contain the highest numbers of species recorded as juveniles. Little Redonda Shoreline contained no juvenile species, and was also the most limited in adult numbers. (Possible explanations could be habitat-related (very large boulders with limited cover) or sea conditions (predominantly winds and waves.

INVERTS	REEF CHECK ANALYSIS
Rendezvous Shallow	The Rendezvous Shallow site had high mean values for the 4x20m segments surveyed for both the Long-spined Urchin (Diadema) and the Sea Fan and Sea Whips (Gorgonians), with an overall total of 259 urchins and 62 gorgonians found for the total 80m line. One Banded Coral Shrimp was also found at this site.
Rendezvous Divesite	The rendezvous Dive Site contained slightly more Gorgonians (66), a total of six Banded Coral Shrimp and only two Diadema.
Woodlands South	The Woodlands South site had the highest overall number of Gorgonians (155) and also a total of 31 Flamingo Tongues, which were not noted on the other survey transects (although they were present at the sites). No Pencil or Collector Urchins, Trumpet Triton or Lobster were found along the survey lines nor were they noted in the presence/absence surveys undertaken at the other seven sites.
OUTCOMES/RECOMM.	The team have subsequently developed a set of recommendations towards marine management in Montserrat. These include five marine zones, with an implementation plan and budget.
NOTES	There were additional descriptions for results that I did not cover in this summary, including 4.33 Species/Area Curves; Species Diversity Indices; 4.3.6 Comparisons of Substrate Cover; 4.3.7 A Discussion of Monitoring Methodology; 4.4.4.

	Fish Species Diversity Indices; 4.5.2 Comparisons of Fish and Invertebrate Counts; 4.5.3 Monitoring Methodology; 4.6 Survey results – Ecological Monitoring (considerations)		
SPECIES LIST	FISH (Annex III (ii) Invertebrates and Fish Lists)	TARGET INVERTS	BENTHIC COVER CATEGORIES
	PRESENT/ABSENT SURVEYS Angelfish - Pomacanthidae Pomacanthus arcuatus (Gray Angelfish) Holacanthus tricolor (Rock Beauty) Barracuda - Sphyraenidae Sphyraena barracuda (Great B arracuda) Basslet - Grammatidae Gramma loreto (Fairy Basslet) Bigeye Priacanthus cruentatus (Glasseye Snapper) Blenny - Blennidae Ophioblennius atlanticus (Redlip Blenny) Boxfish - Ostraciidae Lactophrys triqueter (Smooth Trunkfish) Butterflyfish - Chaetodontidae Chaetodon striatus (Banded Butterflyfish) Chaetodon capistratus (Foureye Butterflyfish) Chromis (Damselfish) - Pomacentridae Chromis cyanea (Blue Chromis) Chromis multilineata (Brown Chromis) Stegastes leucostictus (B eaugregory) Stegastes partitus (Bicolor Damselfish) Stegastes fuscus (Dusky Damselfish) Abudefduf saxatilis (Sergeant M ajor) Stegastes planifrons (Threespot Damselfish)	Flamingo Tongue (Cyphoma gibbosum) Long-spined Urchin (Diadema antillarum) Collector Urchin (Tripneustes esculentas) Pencil Urchin (Eucidaris tribuloides) Trumpet Triton (Charonia variegata) Banded Coral Shrimp (Stenopus hispidus) Lobster (family Palinuridae) Sea Fans/Sea Whips (family Gorgonacea) PRESENT/ABSENT SURVEYS Palythoa caribaeorum (white encrusting zoanthid) Zoanthus pulchellus (mat zoanthid) Sabellastarte magnifica (magnificent feather duster) Diadema amtillarum (long-spined urchin) Anamobaea orstedii (split crownl feather duster) Condylactis gigantea (giant anemone) Dentitheca dendritica (feather bush hydroid) Clypeaster rosaceuas (sand dollars) Pinna carnea (amber penshell) Spirobranchus gigantus (christmas tree worm) Eupolymnia crasicornis (spaghetti worm) Hermodice carunculata (bearded fireworm) Gymnangium sp. (feather hydroid) Sertularella speciosa (branching hydroid) Parazoanthus tunicans (hydroid zoanthid) Epicystis crucifer (beaded anemone) Stichodactyla helianthus (sun anemone) Bartholomea annulata (corkscrew anemone) Lebrunia coralligens (hidden anemone) Stenopus hispidus (banded coral shrimp) Isostichopus badionotus (three-rowed sea cucumber) Davidaster rubiginosa (golden crinoid) Periclimenes pedersoni (pederson cleaner shrimp) Aranchnanthus noctumus (banded tube-dwelling anemone)	HC=Hard Coral SC=Soft Coral** RKC=Recently Killed Coral NIA=Nutrient Indicator Algae*** SP= Sponge RC=Rock RB=Rubble SD=Sand SI=Silt/Clay OT=Other According to Reef Check protocol, the following changes have been made to accommodate survey overlaps of techniques and for further comparison of data. **SC=Soft Coral category only includes Zoanthids for the Atlantic, but all soft corals of the Subclass Octocorallia were noted and included zoanthids (Hexacorralia). ***NIA=Nutrient Indicator Algae only includes a few species of algae that often indicate eutrophication, none of which were found at the sites. NIA in this survey indicates all species of algae found.

	Squirrelfish - Holocentridae Myripristis jacobus (Blackbar Soldierfish) Holocentrus rufus (Longspine Squirrelfish) Surgeonfish - Acanthuridae Acanthurus coeruleus (Blue Tang) Acanthurus chirurgus (Doctorfish) Acanthurus bahianus (Ocean Surgeonfish) Triggerfish - Balistidae Melichthys niger (Black Durgon) Balistes vetula (Queen Triggerfish) Wrasse - Labridae Halichoeres poeyi (Blackear Wrasse) Thalassoma bifasciatum (Bluehead) Clepticus parrae (Creole Wrasse) Halichoeres garnoti (Yellowhead Wrasse) Wrasse spp. Trumpetfish - Aulostomidae Aulostomus maculatus (Trumpetfish) Lizardfish - Synodontidae Synodus intermedius - (Sand Diver) Hawkfishes - Cirrhitidae Amblycirrhitus pinos (Redspotted Hawkfish) Rypticus saponaceus (Greater Soapfish)	Bunodosoma granulifera (red warty anemone)	
SEAGRASSES!	*Halophila decipiens* (1=present) observed at Woodlands Dive site (shallow)		

IRF 1993: Montserrat Environmental Profile: *An Assessment of the Critical Environmental Issues Facing Montserrat With an Action Agenda for the Future*

DATE	1993
AUTHORS	Prepared for: The Government of Montserrat; with technical support from: Island Resources Foundation (St. Thomas Virgin Islands) and the Assistance of: Montserrat National Trust
PARTNERS	Funding by: UN Development Program
AREA OF INTEREST /DATA	Study of Montserrat and priority environmental issues or problems with recommendations in the last chapter to prioritize and integrate key environmental issues in greater detail. Basis of report is 10 chapters: institutional framework for environmental management; planning and growth management; rural land use and watershed management; biodiversity; coastal and marine resources; energy planning, waste management and pollution control; historical heritage; tourism.
SURVEY PERIOD	Various studies mentioned in this report: (1897-1992: Fish Landings Data); 1992 two studies listed below (Notes in Intro); other marine studies referenced in report in bold: Bovey's, et al. (1986), Goodwin's, et al. (1985), Hepburn, et al., 1992).
NOTES IN INTRO:	In 1992, two new areas were targeted for Environmental Profiles in the Eastern Caribbean — Montserrat and Anguilla. Both efforts are part of larger environmental management programs funded by the Barbados-based office of the United Nations Development Program (UNDP) In Montserrat, the Profile Project is phase one of a three-year project agreement entered into by UNDP and the Government of Montserrat. The larger project is entitled "Management of Natural Resources and the Environment" (UNDP Project No. MOT/92/002/A/01/99) and, in addition to the Environmental Profile sub-component, it includes support for ecotourism, environmental education, and training.
Coastal Resource Legislation	Beach Protection Ordinanco (No. 9, 1970) (amended No. 24, 1980) Fisheries Ordinance (No. 18, 1982) Turtle Ordinance (Cap. 112, 1951) Prevention of Oil Pollution Act, 1971 (Overseas Territories) Order 1982 (No. 1668)
Institution	Focused resource monitoring and regular environmental data collection programs - however modest they may be at

al Framework : Issue Six:	the beginning - are essential in a continual process of environmental assessment and evaluation which, in turn, helps to inform and direct the planning and growth management process.
Past studies	Several assessments of Montserrat's land and water resources have been carried out, but in general these are not used effectively to inform land use planning and development control. Initial efforts in this regard include Corker's (1986) land suitability classification scheme, which identifies nine classes of land use suitability based on soil type, quality, and slope; Bovey's, et al. (1986) ecological and cultural assessment of the proposed Montserrat National Park; studies as part of the Tropical Forestry Action Plan; and Goodwin's, et al. (1985) fishery sector assessment.
Biodiversity: Issue One SYSTEMS APPROACH (pg. 59)	*Without a fully-developed "systems" approach to park and protected area management, a national program to conserve biodiversity is likely to be fragmented and lack focus. It will also fail to develop constructive links with tourism and the private sector.* At present (1993), no terrestrial or marine site in Montserrat is legally protected or receives the institutional support necessary to ensure the conservation of biodiversity. During the late 1970's and early 1980's, the wetlands and pond at Fox's Bay were leased to the Montserrat National Trust for the establishment of a Bird Sanctuary; landmarks at Carr's Bay, Bransby Point, and Woodlands Beach were also acquired along with additional landmarks in the 1990's at Lime Kiln Beach and Runaway. Table 5.3 Biodiversity and Conservation Summary in Montserrat (Question marks listed for fish and inverts).
Recommend.	5.2 A national park resource assessment and feasibility study has already been completed (Bovey, et al., 1986). What is now required is a comprehensive management plan which places program planning for Montserrat's parks and protected areas within a framework of national conservation and development priorities.
RAMSAR Wetland Sites	Montserrat has been included in the United Kingdom's ratification of Ramsar since 1976. In a recently completed consultancy, two Montserratian wetlands - Fox's Bay Bird Sanctuary and Belham River Estuary -- were recommended for consideration as Ramsar candidate sites; a third site -- Chance Pond - was targeted for further study and possible inclusion as a candidate site (Hepburn, et al., 1992). Fox's Bay is a mangrove swamp of approximately 6 ha (15 ac) that since 1979 has been leased to the Montserrat National Trust as a wildlife sanctuary by the Montserrat Company*. Belham River Estuary, also owned by the Montserrat Company, is managed as part of golf course to the apparent mutual satisfaction of environmentalists and golfers. The 14 ha (35 ac) site contains a series of small freshwater ponds and marshes and a sandy beach at the mouth of the Belham River. Chance Pond is a unique site formed in a depression at the summit of Chances Peak; it varies seasonally from being a pond to a marsh (Hepburn, et al., 1992)
Montserrat and the Sea: *Issue Two:* *SAND*	*The regulation (including monitoring procedures) of sand mining, coastal reclamation, and shoreline dumping will minimize the risk of increased shoreline erosion, coastal pollution, and destruction of wildlife habitat.* The quantities of sand removed appear to be in excess of natural replenishment rates, raising concerns about the potential impact on tourism, shoreline erosion, and sea turtle nesting (Cambers, 1981b and 1990; Meylan, 1983; von Rabenau, 1987; and Cross, 1992). Unregulated removal of sand and vegetation in Montserrat's coastal zone has increased the rate of coastal erosion

MINING

and elevated risks of storm damage. It has also increased sedimentation in nearshore environments, where the effects of sediments on coral reef communities and associated organisms have previously been well documented (see, for example, Rogers, 1990).

Issue Three:

FISHERIES MANAGEMENT

Rational decision-making for optimal fisheries management requires reliable estimates of available stock sizes. The establishment of marine fishery reserves is also a useful management tool to aid in the sustainable development of the fishery and associated marine habitats.

Table 6.1 Recorded fish landings for Plymouth, Montserrat (1897-1992)

Table 6.1. Recorded fish landings for Plymouth, Montserrat, 1987 - 1992 (excluding 1990, for which no data were provided).

1987	1988	1989	1991	1992
41,418 lbs.	17,976 lbs.	15,367 lbs.	66,577 lbs.	27,384 lbs.

NOTES:
1. 1987 catches recorded for January to August.
2. 1988 catches recorded for February to August.
3. 1989 catches recorded for 8 January - 29 December.
4. 1991 catches recorded for 5 January - 23 December.
5. 1992 catches recorded for 6 January to 9 June.
6. Landings not recorded amounted to 20-25 percent. Landings recorded are for Monday to Friday, 8:00 AM to 4:00 PM.

Source: Fisheries Division, Government of Montserrat.

The coastal shelf is too small to support significant demersal (bottom-dwelling) stocks that are primarily non-migratory residents. Deeper shelf-edge stocks offer more potential, and migratory (open ocean) pelagics are increasingly sought from November to March (pers. comm., J. Howe, commercial fisher man). These target species include conch, spiny lobster, reef and shallow demersal fish, sea turtle, and shark, in addition to the principal species of snapper, grouper, kingfish, barracuda, and skipjack tuna. Fish of the former group are often landed undersized, while those of the latter group are known to occasionally contain ciguatera toxins (pers. comm., J. Jeffers, Fisheries Officer).

Issue Four:

BENTHIC SURVEYS

Damage or loss of critical coastal habitats reduces their importance in nearshore tropical marine environments, where they influence the productivity of inshore fisheries and serve as protection against shoreline erosion.

Throughout the Lesser Antilles, including Montserrat, there is a lack of detailed information on marine-bottom communities, and comprehensive benthic surveys and mapping have been carried out in only a few locations. The Caribbean Fisheries Resource Assessment and Management Program (CFRAMP), a joint CARICOM/CIDA program, will during the next three years undertake marine surveys (principally of commercial fishery resources) throughout the region. This will include Montserrat, and GOM plans to extend the data collection to include mapping of benthic

CORAL DISTRIBUTION (general)	habitats, and faunal and floral communities (pers. comm. J. Jeffers, Chief Fisheries Officer). Patch coral reefs are scattered along the north, west, and south coasts of the island (see Figure 6.1). These are not extensive areas but have remained in relatively healthy condition according to local observers. The larger branching corals suffered considerable damage during Hurricane Hugo in 1989, although today they show signs of healthy regrowth. No significant coral bleaching has been reported.
ARTIFICIAL REEFS	An artificial reef project was initiated in 1981, with approximately 100 derelict vehicles placed at 14-21 meters depth between lies Bay and Fox's Bay. The project was undertaken to augment nearshore fish habitat and to provide an alternative disposal method for scrap metal. The reef was monitored over a period of four years; fish and benthic invertebrates established successfully, and the man-made structure is functioning much like a natural reef (Goodwin and Goodwin, 1985). Hurricane Hugo caused solid waste on site and needs further review.
SEAGRASS BEDS!	The largest seagrass bed in Montserrat comprises approximately 750 ha (1,850 ac) at the northern tip of the island. Lesser "islands" of seagrass are found closer to shore along the east, south and west coasts (see Figure 6.1). Such beds are perhaps best known as conch habitat and as a food source for sea turtles, three species of which occur in Montserrat's waters (see Figure 6.2) — green turtle, Chelonia mydas; hawksbill turtle, Neretmochelys imbricata; and leatherback turtle, Dermochelys coriacea. Seagrass beds also provide significant energy inputs to reef systems by serving as feeding grounds for adult N reef fishes and protecting corals by filtering out sediments from land run-off. Reefs in turn protect the shoreline from the destructive effects of storm-driven waves.

Bovey et. Al 1986: Montserrat National Park: Ecological and Cultural Feasibility Study

DATE	1986
AUTHORS	Robin Bovey, James Butler, Elaine Butler, Jim Butler, Helen Fabia Collinson, Greg Fenton, and John Lunn
PARTNERS	Montserrat National Trust, World Wildlife Fund, University of Alberta (Parks and Wilderness Recreation Program at Forest Science Dpt.)
AREA OF INTEREST /DATA	Technical assessment and feasibility study of a National Park in MNI. Report contains: Historic resources of Montserrat, principal natural habitats, species of national important. Refers to existing proactive legislation and recommends early establishment and enforcement of a series of protected historic and natural sites, linked under a National Park.
STUDY PERIOD	February and March 1986 (team of 35 person/days) in MNI over a divided 14-day period as independent external review to assess and advice Government of Montserrat (GOM).

LOCATION	Team members visited several sites of interest for the proposed park which included Great Alp Falls, South Soufriere hot springs, the Bamboo Forest, Upper Galways sugar mill and refinery, Centre Hills, Little Bay, Rendezvous Bay, Woodlands Bay, Bunkum Bay, and Pinnacle Rock.		
NEED FOR MARINE SURVEYS*	Little information exists on the marine environment of Montserrat. The East Caribbean Natural Areas Management Program (1980 and 1982), Raymond Lynch {1979) and A. Meylan (1983) all make reference to Montserrat, but there is little resource data of any substance in these references. There are two principal marine habitats in the coastal waters of Montserrat, coral reef and seagrass beds. We have been unable to find any definitive map or description of either of these habitats. It is difficult to comment on the status of either habitat at this point in time, and an initial survey needs to be undertaken as soon as possible to map and describe the areas. There is a great deal of incomplete information for all coastal habitats, and a full survey needs to be undertaken as soon as possible. The advice of those who have worked the habitats is essential, and in particular, the advice and help of Dr. Richard Howard should be sought as he has a unique knowledge of the vegetation of Montserrat. The effects of sand mining and recreational activities require study; as does the proposal to develop Little Bay and the likely implications of such development. Close monitoring of this development at all stages should be undertaken. Moreover a mangrove swamp monitoring project needs to be established as soon as possible.		
HABITATS	CORAL REEFS	SEAGRASSES !!	MANGROVES
	There are small areas of coral reefs around the north, west and south shores of Montserrat. The eastern (windward) side of the island has no living coral formations (the East Caribbean Natural Areas Management Program Preliminary Data Atlas refers to coral harvesting off the east coast at Blackburne Airport). On the west coast of the island an artificial reef project was initiated with success in 1983 as part of a fisheries project to provide additional reef fishery grounds. The reef is composed of old car bodies and is situated between lies Bay and Fox's Bay.	The largest seagrass bed is at the north end of the island and covers some 750 hectares (1900 acres). However, there are significant seagrass beds off Little Bay, Rendezvous Bay and Bransby Point, on the west side of the island and along the south coast between Old Fort Point and Shoe Rock, and offshore from Blackburne Airport on the east coast, important habitat for turtles.	Fox 's Bay--Rhizophora mangle (red mangrove) is the dominant mangrove species of this swamp. The whole mangrove swamp is included in the Fox ' s Bay Bird Sanctuary, which was established in 1979 by the Montserrat National Trust and covers approximately 6 hectares (15 acres). There has been concern about the survival of the swamp, and a number of possible causes have been suggested for its decline, including damage by the increasing number of cattle egrets. Wayne Arendt looked at the problem in 1984 and concluded that this was not the likely cause (Arendt 1985). He cites the likely causes as overgrazing, wood cutting (for charcoal burning and fire wood) and changes in the drainage patterns due to heavy rain, landslips and nearby urban development. When the site was visited in February and March 1986, all these symptoms were much in evidence, and a change in drainage patterns is probably the most likely cause. There appears to be little flushing of the site by the river; the site shows signs of drying up, and due to infrequent flushing there is now a significant sand bank between the sea and the swamp.
CURRENT RESOURCES USE:	The fishing industry on Montserrat is not highly developed and supplies the island's needs with only a comparatively small surplus. In 1979 (C.1.0.A. 1981) fishermen landed 54.500 kgs. (120.000 lbs) of fish. Most of the fishing is done using small boats, and no deep sea fishery exists. Fish are caught using gill nets. fish traps. long lines and spearing. A		

FISHING	report on the fishing industries of the smaller Caribbean islands (no ref.) states that there are approximately 200 part-time fishermen on Montserrat. Principal problems that the industry faces include the theft of fish traps and lobster pots. the non-enforcement of turtle legislation and the poor image that fishing portrays to the potential fisherman - that of a poorly paid, hard-working and unskilled job. There has been no study on the impact of fishery activities on the wildlife resources of the sea around Montserrat.
RECOMMENDATIONS	4. It is the unanimous assessment of the advisory team that the cultural and natural features of the Montserrat National Park proposed in this report meet the standard for national park status in comparison to similar designations around the world. 9. As a prerequisite to the establishment of a National Park, certain studies will be mandatory. These include the following: 9i. The Montserrat National Park should contain a marine component. and the proposed park boundary. as previously discussed solely in a land context. should logically embrace prime areas of importance beyond the coastline to protect selected marine environments as appropriate. An initiative to establish a nature sanctuary on the island of Redonda might also be undertaken by the Government of Montserrat. in conjunction with the establishment of the Montserrat national park. This could require the form of preliminary discussions with the Government of Antigua.

JNCC 1991: Montserrat

DATE	1991
PARTNERS	Funding was provided by WWF-UK to the Montserrat National Trust for a project to carry out ecological restoration and management of the sanctuary before the recent hurricanes and volcanic activity.
AREA OF INTEREST /DATA	Work included an ecological assessment of the biotic community and water quality at the site, together with an assessment of the impact of Hurricane Hugo and damaging activities such as housing development around its perimeter.
RAMSAR SITES	Ramsar: Montserrat has been included in the UK's ratification of Ramsar since 1976. One site, Fox's Bay Bird Sanctuary, was proposed for Ramsar listing in 1986 but was considered not to meet the criteria for listing at the time. However, a re-appraisal of information on the site suggested that the present Ramsar criteria are met (Hepburn et al. 1992).
PROTECTED AREAS	Fox's Bay Bird Sanctuary, owned by the Montserrat Company, is on lease to the Montserrat National Trust, and was a declared a protected wildlife area in 1979. A few other areas have also been set aside for conservation, land being vested with the National Trust or the tourism authorities.

HABITATS **MANGROVES**	The most important wetland site on Montserrat is the small area of mangrove protected as Fox's Bay Bird Sanctuary. The only other area of mangrove is at Carr's Bay. This was reported in 1993 as severely deteriorated as a result of siltation, lack of water flow from land, and excessive dumping of hurricane debris.
SIGNIFICANT SPECIES	Green turtle Chelonia mydas (EN): green turtles are resident around Montserrat and, together with hawksbill turtles Eretomochelys imbricata, are the most common species in Montserrat waters (Groombridge & Luxmoore 1989). Nesting possibly occurs at Yellow Hole, Bunkum Bay and Limekiln Bay; feeding areas include O'Garros, Bransby Point, Bunkum Bay and Trants Bay (Groombridge & Luxmoore 1989). Hawksbill turtle Eretomochelys imbricata (CR): a species is relatively common year round in Montserrat waters, and reported nesting sites include Farm Bay, Yellow Hole, Rendevous Bay, Little Bay, Carr's Bay, Bunkum Bay, Woodlands Bay, Limekiln Bay, Old Road Bay, Fox's Bay and Isles Bay (Groombridge & Luxmoore 1989). Foraging sites include O'Garras, Bransby Point, Rendezvous Bluff, Yellow Hole, and Trant's Bay (Groombridge & Luxmoore 1989). Leatherback turtle Dermochelys coriacea (EN): rarely encountered around Montserrat. Nesting is also rare but has been recorded (Meylan 1983). Loggerhead turtle Caretta caretta (EN): has been recorded off Montserrat but very rarely. Nesting has not been recorded (Meylan 1983). Migrating humpback whales Megaptera novaeangliae (VU) and sperm whales Physeter catodon (VU) occasionally pass by the west coast (Gricks 1994). The sei whale, Balaenoptera borealis (EN) may occur in Montserrat's waters, although this requires confirmation.

Myers 2013: Coral Reefs of Montserrat

DATE	1991			
AUTHOR	Andrew Myers			
PARTNERS	Funding was provided by WWF-UK to the Montserrat National Trust for a project to carry out ecological restoration and management of the sanctuary before the recent hurricanes and volcanic activity.			
AREA OF INTEREST /DATA	Work included an ecological assessment of the biotic community and water quality at the site, together with an assessment of the impact of Hurricane Hugo and damaging activities such as housing development around its perimeter.			
HABITATS	CORAL REEFS	SHALLOW WATER BOLDER/ROCK SUBSTRATE	RIDGES AND LOW PROFILE SHELVES	SANDY BOTTOM

	The reef system of Montserrat is not created by coral growth exclusively but includes much coral growth on rock, boulders, and hard, low profile substrate Each of these zones support different marine life.	Extending from shore to approximately the 10m depth contour, much of the island is surrounded by the remnants of the erosional decay of the island, with varying sized rocks. As the softer material eroded/erodes from the sea cliffs an intricate marine topography and habitat is formed. Some of the boulders found here measure over 20 m across and 15 m tall. The resulting substrate hosts an extensive variety of corals, invertebrates, sponges, juvenile and adult fish species, marine creatures, and marine plants and algae which are typical of Caribbean coral reef areas. This zone appears to be significant in terms of providing juvenile fish nursery areas.	Further offshore, with increasing depths, the reef has a lower profile, with elevations and ridges typically less than 2–3 m high. Heavily sloping bottom contours create ridges in the 15–20 m depth span, and within this zone "islands" of rock create scattered patch reef between 10 and 30 m depth (Fig. 8.4). The reef substrate is often eroded into a honeycombed rock base. Though many of the same species of corals and sponges are found on these reefs as occur on the shallower ones, there is a greater abundance of gorgonians and far larger barrel sponges, again typical of reefs in the eastern Caribbean region. Pelagic species, such as jacks and mackerels, are most common in this depth zone.	This zone supports species that live or feed off of the sand flats. Several reef inhabitants leave the shelter of the protective coral reef to forage for molluscs, crustaceans and marine plants within the sand flats near the reef. Within this zone, Montserrat's marine habitat supports a healthy population of southern stingrays, flying gunards, and spotted snake eels, as well as tobacco fish and conch.
GEOGRAPHIC	NORTHERN REEF	WESTERN LEEWARD	EASTERN WINDWARD	SOUTHERN REEF
	The hard substrate shelf extends to 5 km off shore in this region, and consistent wave action and open ocean currents have created bunkers within the reef that allow for protective areas for reef life. The corals of this area are exposed to constant water movement and, as a consequence, appear to be amongst the most healthy around the island. This region is affected only occasionally by sedimentation from the volcano.	Coral health varies greatly along this coast with healthier reefs, in general, existing further from the volcanic runoff plains, but there are anomalies to this, where multiple, small reefs exist close to these runoff plains where they still support healthy reef habitat, possibly as a result of water currents redirecting sediment though the area.	The reefs here are consistently subject to heavy wave action. Exploration of this region has been limited, although visits have found eroded rock substrate forming overhangs and 'swim throughs'. Corals are affected and stressed by frequent heavy sedimentation from volcanic runoff.	This zone is also only visited rarely because of sea conditions. The reefs are found close to shore and quickly drop to considerable depths. Visits have shown healthy corals and abundant fish populations. Though flanked by two volcanic plains, water currents direct sediment away from these reefs.
INVASIVE SPECIES	**Lionfish:** The first sightings occurred in Montserrat the summer of 2011, and by 2012, multiple lionfish can be found on every dive. **Orange Cup Coral:** Another Indo-Pacific introduction which has established itself within the region since the 1940s.			

	It is believed to be the only stony coral introduced within the Caribbean/Western Atlantic. It is found abundantly on several shallow reefs, often in shaded areas, around MNI. (Humann Deloach 2002).
CORAL DISEASES	**White-band Disease (WBD)** which, with other White Syndromes, has killed a majority of Elkhorn and Staghorn colonies within the region. Other diseases that most likely are affecting Montserrat's reefs are **black-band, red-band, and yellow blotch diseases** (reported sightings though not confirmed) (Humann, Deloach 2002) .
FISHING THREATS	Antiquated fishing practices, and un-regulated fishing and over fishing are prevalent. Montserrat fishermen use hand- made fish traps or pots, gill nets and seine nets to catch most of the fish that are landed. Fish pots are often poorly placed on the reefs, left unchecked because of sea conditions, or become lost when the marker buoys get cut. This results in damage not only to the corals but also causes loss of fish that die due to these lost "ghost" pots that continue to kill. Because of volcanic activity and the change in the island's population base, accessible fishing areas have been reduced and overfishing in some areas is occurring (Fig. 8.9).
ARTIFICAL REEFS	Montserrat does not have marine protected areas, though discussions into the possibilities are being conducted. Currently a program known as the Montserrat Reef Project (MRP) is creating new reef habitat through the installation of designed artificial reefs. The project also identifies imperilled corals for propagation to the new reef system. The MRP is a grant funded project and is currently finishing the second phase of reef creation. The project has created over 240 reef structures known as Reef Balls since late 2010 whose intent is to generate new areas of hard substrate and bottom relief.

Brosnan et al. 1997: The Coral Reefs of Montserrat, West Indies Diversity, Conservation, and Ecotourism

DATE	1997
AUTHORS	Dr. Deborah M. Brosnan, Timothy L.J. Grubba, D. Kent Backman, Kathleen Boylon, and Lori T. Moore
PARTNERS	Sustainable Ecosystem Institute (Under Emerald Waters, the Coral Reefs of Montserrat West Indies video); Project supported by: American Airlines, Cochran Undersea Technologies, Montserrat Tourism Board, New England Biolabs Foundation, National Science Foundation, PADI Project Aware, US Divers, Montserrat National Trust (MNT).
AREA OF INTEREST	Study designed to explore and document the marine life of the island with a view to the development of a marine protected area for use in education, research, and recreation through ecotourism. Using studies to evaluate the biological diversity and changes over 18 months of study.

SURVEY PERIOD	July 1995 - 1996 (Two visits for a total of 18 months survey period); (Volcano began erupting when team arrived during first visit in July 1995).					
LOCATION	Various, western and northern regions sampled for biological surveys, physical surveys conducted across the entire island.					
SITE SELECTION	Various, depending on survey type. Following sites were used in some capacity during this study: Carr's Bay (fish, sessile invertebrates), Rendezvous (Fish, sediment depth, secchi disk); Woodlands Bay (sessile invertebrates, secchi disk); Garibaldi Bluff (Fish, sediment depth, secchi disk).					
FIELD METHODS	Permanent Quadrats **(Sessile invertebrates, Algae, Corals)**	Mobile Invertebrate Surveys **(Inverts)**	Visual Fish Surveys **(Fish)**	Physical factors: **Sediment depth**	Physical factors: **Secchi Disk**	**Sediment trap**
Description *Sites*	To allow long-term monitoring of sessile species such as corals, sponges and algae. Permanent quadrats on West coast of Montserrat: In 1995 reefs at Carrs Bay and Woodlands Bay chosen. In late 1996 Hurricane Luis destroyed sites and no data collected then. In 1996 two new sites chosen, Rendezvous Bay and Garibaldi Bluff. (A third was selected by not able to be completed/sampled due to visibility issues).	No additional data regarding descriptions of this survey, or sites where survey was conducted.	Visual survey on density and diversity of species. Fish surveys conducted on reefs along West coast during both visits. 1995: Rendezvous Bay, Carrs Bay and Woodlands Bay. 1996: Rendezvous Bay, Garibaldi Bluff (inner reef) and Garibaldi Bluff (outer reef).	Measured at three reef sites during January 1996: Rendezvous Bay, inner (20m offshore) and outer (100m offshore) Garibaldi Bluff. At Rendezvous and Garibaldi Bluff (outer) measurements taken on two dates (1/23/96, 1/30/96 and 1/27/96, 2/2/96).	Measurements taken at a series of transects around western and southern portions of the island, taken at two separate dates (1/21/96 and 1/27/96). Sampling date transects were run at three locations, Garibaldi Bluff, Woodlands Bay and Rendezvous.	Rate and quantity of sediment accumulation were measured at two sites: Rendezvous and Garibaldi Bluff (outer) – third site Garibaldi (inner reef) but hazardous conditions did not allow sampling.
Stratification/ Measurements	Each quadrat covers an area of $2m^2$ and for purposes of photographic data collection, was divided in four $1m^2$ plots.	Mobile invertebrates (crabs, starfish, etc.) recorded using 10m transects.	Diver on SCUBA lays out 20m transect (waits 5 min), then swims along transect identifying and	Measurements taken in water approximately 10m deep using SCUBA. Sediment	During the first sampling date secchi disk readings were taken at 9 sites along a transect running south from the Vue Pointe and	Traps were constructed out of plastic (Odwalla brand) and measured 5x5 cm wide and 10cm height,

	Quadrats permanently marked with rebar spikes in substrate, four in corners and one in middle. Using underwater photography (Nikonis V); photographic tetrapod stands with frame base and top 1x1 meter giving a basal area of $1m^2$. The frame and camera height 0.42m allowed camera with 20mm lens to take picture at $1m^2$.	Diver sets out 10m tape randomly across the reef. The diver then swam slowly along the transect recording the identify and abundance of each species.	counting all fish within 1m either side of 20m transect. Transects replicated 8 times at each site during 1995 visit and 10 times during 1996 visit. (Only 2 transects completed at Garibaldi Bluff (inner reef) due to low visibility.	depth was measured by placing a ruler onto coral/rock and recording depth of sediment. Measurements replicated 50 times at random points on reef. Measurement points were spaced by two fin kicks.	concluding at Radio Antilles. At each site depth was taken using 2 disks at 50, I00 and or 200 meters offshore. At each location transects at 25, 50, 75, 100, 150, 200, and 300 meters offshore were run with readings along each transect. The secchi disk line was marked in increments of 0.5 meters allowing an accuracy to roughly 1.25 of a meter.	providing width height ratio of 1:2. Traps were attached to permanent quadrat rebar spikes and left out for periods of 3-5 days. Collected by placing plastic bag over trap and sealing with surrounding water.
Analyses	Identification of species and percent cover determined using combination of three techniques: 1) 6x4 inch vinyl sheet with 100 randomly inscribed dots, which was overlaid over standard 6x4 inch color photograph of plots. A species was counted and identified if it fell under a dot. 2) Scanning 6x4 inch photographs onto a personal computer and digitized image was rescaled to the size of monitor and vinyl sheet with 100 randomly inscribed dots was laid over the monitor. 3) Used NIH image to estimate percent cover of each species in the scanned image.	No additional data provided.	No additional data provided.	Measurements were graphics and t-tests were performed to compare sites and dates.	Depth of disk (secchi depth) was recorded at the point where the disk was on the borders. Secchi depths were then averaged and t-tests were conducted to compare differences between dates, sites, and distance from shore.	Water and sediments collected were filtered through #100 filter type paper. Filter paper and trapped sediment were then dried and weighted.

RESULTS *Overall/ Overview*	37 true coral species, 17 gorgonian and other octocorals, 3 seagrass, 37 algal species. Corals and sessile species are found on rocky outcrops, rather than old coral remains. Corals, algae and sponges occupy most primary space, coral occupy 20-45% of available space, and algae cover 23-41%. Dictyota is the dominant algae. Number of coral species did not vary by site, except fewer species in heavy sediment areas.	87 invertebrate species. Abundance of invertebrate, anemones are common with range of cleaner shrimp and crabs associated with them. Density of urchins varies significantly among sites.	67 fish species recorded. Plankton feeding fish dominate coral reef fish assemblage. Two families, labrids and pomacentrids dominated the fish community. Juvenile wrasses are the most abundant species.	Sediment depth differed among sites. Rendezvous Bay had least amount of sedimentation. Garibaldi Bluff had higher sediment loads. At Whites River sediment load ranged from 130-150g dry weight/litre of water.	Secci disk measurements showed that water clarity was often significantly reduced within 100m of shoreline. Mainly due to runoff from rains and volcanic activity.	No additional information provided.

INVERTS	***CORALS, SESSIBLE INVERTS, ALGAE***
Overview - Species	37 true coral species, 17 gorgonian and other octocorals, 3 seagrass, 37 algal species. Corals and sessile species are found on rocky outcrops, rather than old coral remains. Corals, algae and sponges occupy most primary space, coral occupy 20-45% of available space, and algae cover 23-41%. Dictyota is the dominant algae. Number of coral species did not vary by site, except fewer species in heavy sediment areas. 87 invertebrate species. Abundance of invertebrates, anemones are common with range of cleaner shrimp and crabs associated with them. Density of urchins varies significantly among sites.
Overview - Structure	Even in the most extensive reefs (Carrs, Garibalidi, Colby's 95 and Rendezvous), living corals do not dominate the community, and they occupy from 20% to 45% of primary space (Figure 11). In more heavily sedimented areas such as Garibaldi inner, and Colby's 96 coral cover is low ranging from 6% to I3%. Fleshy algal cover ranges from 23%-41% on the more external reef and from 13% to 18% in more sedimented areas. The brown algae *Dictyota spp*. Accounts for most of the algal cover, other species are present in trace amounts of less than 2% cover. Coralline algae ranges in abundance from 2% to 8.5%. Sponges are patchily distributed within and among sites and range in cover from 1% to 11% cover at Garibaldi outer and inner reef, respectively). Sediment/sand and coral rubble make up most remaining cover. At Rendezvous Bay, the substrate is primarily sand.
Hydrocorals and Octocorals (Photoquad Analysis)	Coral diversity if relatively high (Figure 12a) but individual coral heads tend to be small. For example, larger colonies of *Millepora alcicornis* (branching fire coral) measured 40 x 10cm or less, larger colonies of *Porities* porities were in the range of 100x30cm; larger *Porites astreoides* measures 50x30cm and larger colonies of *Diplora labyrinthiformis* measured 60x70cm. The number of species did not differ significantly among the main reef sites, except fewer corals at heavily sedimented areas. Finger coral (*Porites porites)* was the most common at Carrs Bay, Garibaldi in 1995 and Colby's and decreased significantly at Garibaldi from 9% in July/August 1995 to 1.5% in January 1996 (probably from Hurricane). Lettuse corals *Agaricia* and *Leptoseris* were common especially at Garibaldi. Brain coral (*Diplora spp)*, fire

	coral (*Millepora spp.)* and Mustard (*Porites asteroids)* were also common at most sites. Fire coral *(Siderastrea sp),* and a relatively large brain coral *(Diplora strigosa)* dominated at Colby '96 (Figure 12a). Elkhorn coral *(Acropora sp)* was conspicuously absent from our surveys. We observed small outcrops of *Acropora palmata* at Woodlands, Rendezvous, and off the south shore. In August 1995 and in January 1996 we saw numerous small colonies (<7cm across) in shallow water (<Sm) off Radio Antilles and O Garr. (outer Garibalid?) suggesting that this species had recently settled in the area. Gorgonians (e.g. *Muricea spp Pseudopterogorgia spp)* were relatively common at most sites. Many of these species, especially sea whips and sea rans *(Pseudopterogorgia spp)* were more common on sandy substrates on the fringes of the reefs. In some areas they formed extensive sea plume beds in relatively shallow waters (<8 meters) e.g., near Woodlands, and Colbys.
Sponges	Sponges are common and patchily distributed in the reefs (Figure 11, and 12b). For instance percent cover ranged from 0% to 60% in some plots at Colbys '95, and Garibaldi. The number of species did not differ significantly among sites. We recorded at least 7 species. (Some, such as encrusting species require microscopic analysis for identification at the species level and could not be identified to that level during our surveys). Giant barrel sponges *(Xestospongia* were relatively common in shallow water at Colbys and Carrs Bay. We observed them at Garibaldi but they did not appear in any of our quadrat plots.
Algae	The brown algae *Dictyota* is the most abundanct algae species on the reefs (Figure 11 12b). We observed at least five species of *Dictyota (D. mertensii, D. ciliolata, D. jamaicensl: cervicornis, and D. divaricata)* Percent cover ranged from 23% at Colbys '95 to 41 .5% at Garibaldi '95. In the more sedimented reefs percent cover ranged from 13% to 15%. I species were present only in trace amounts on the reef(Figure 12b). Sea grasses and green algae, especially *Halimeda, Caulerpa, Avrainvillea* were common in the sandy substrates away from reefs.
FISH	***CORAL REEF FISH***
Overview - Species	67 fish species recorded. Plankton feeding fish dominate coral reef fish assemblage (90% of all fish at some sites). Two families, labrids and pomacentrids dominated the fish community. Juvenile wrasses are the most abundant species.
Overview – structure	Reefs dominated by assemblage of plankton feeding fish, this was true at all sites where quantitative and qualitative surveys were done. Two families, the labrids (wrasses) and pomacentrids (chromis and darnselfish) dominate reef assemblage, made up over 90% of all fish recorded at some sites e.g. Rendezvous Bay and Carrs Bay 1996. In January and February 1996 we observed large schools (>55 individuals) of sergent majors (*Abudefduf saxatillis)* just off edge of Rendezvous Bay. Juvenile wrasses were most abundant species at Rendezvous, Carrs and Woodlands. At Woodlands they made up approximately 90% total fish in summer 1995. Blue chromis (*Chromis cuanea)* and bicolor damselfish (*Stegastes partitus)* were also abundant on most reefs. Angel fish were conspicuously absent from reefs – 6 species recorded, 5 represented by juvenile individuals (queen angelfish *Holocanthus ciliaris*, blue angelfish *H bermudensis*, french angelfish *Pomacanthus paru*, gray angelfish *P. arcuatus*, and the rock beauty *Holocanthus tricolor*). The only adult species recorded was the flameback angelfish (*Centropyge aurantonotus*). (Angelfish – Rock beauty and French were observed in fish pots in 1995 and 1996. Predators were rare on reef, as were large herbivores. Main predators included trumpet fish (*Aulostomus maculates),* barracuda, and noctumal predators such as squirrelfish (*Holocentrus*

	vexillarius, and *H. adscensionis*) and soldierfish (*Myripristisjacobus).*
Fish density	The density of fish decreased significantly between summer 1996 and January/February 1996. At Rendezvous Bay, the total number of fish significantly declined from an average of 153 individuals per 20m transect to 48 individuals per 20m transect (p=0.006 d.f= 10 Table 12, 13). The decrease in fish density was due to an overall decline in most species, but particularly in blue chromis, damselfish, and ocean surgeonfish. At Rendezvous Bay, blue chromis decreased from a relative abundance of 16% in summer 1995, to 4% in January 1996 (Figure 15). Bicolor damselfish decreased from 24% to <1% in the same period. As a result, the relative abundance of juvenile wrasse in the community increased at Rendezvous Bay from 35% to 62% (Figure 15). The density of juvenile fish was consistent among sites and years, except for Garibaldi inner which had a lower number of juvenile fish compared to Rendezvous Bay (t=2.57, p=0.02, df= 9 Table 14). Patchy distribution of fish within and among the reefs and this pattern is reflected in the low mean to various ratio observed for all species (Table 15-20). Density of juvenile wrasses ranged from 0-90 individuals per 20m at Rendezvous Bay in 1996, with a mean of 32 individuals and s.e. of 30.4. Blue chromis, small mouth grunts, sergeant majors, and blue tangs showed similar patchy distribution patterns. Garibaldi – inner reef (higher sedimentation and turbidity) fish abundance significantly less on inner. Grunts, squirrelfish, yellowtail damselfish were found on Outer reef but absent from inner. Schools of black surgeon (*Melichthys niger)* of up to 15 individuals per school frequently observed on reefs omn south and west coast, but in January and February 1996, only observed twice on reefs and in smaller schools. Flying gurnards (*Dactylopterus volitans)* abundant in all sandy substrates. No density estimates recorded.
Fish traps	Many ghost fish traps encountered during surveys. Observed up to 12 fish in a trap at a time. In some, many fish were dying and semi-decomposed indicating traps had been out for long periods of time. (List of species found in traps in Table 21).
INVERTS	***MOBILE INVERTS***
Anemones and Zooanthids	A striking feature on Montserrat's reefs are the anemones and zooanthids (Table 10, Figure 13). Corkscrew anemones *(Bartholomeo annulata)* and hidden *anemone* (*Leburnia corralligens)* were the most commonly recorded species during surveys. Giant anemones (*Condylactis gigantean)* are common and patchily distributed on the sides of boulders, crevices, and rocky outcroppings, and often close to substrate. We observed at least 2 species of cleaner shrimps and arrow crab (*Stenoryhnchus seticornia)* associated with almost every giant anemone, Between July 1995 and January 1996 we noted significant decrease in the anemone density. At Rendezvous Bay and Garibaldi average density decreased from 1.53 individuals per 10m transect to 0.62. This was probably due to hurricane effects and our observation suggest that *Condylactis gigantean* suffered the most decline. This species was most common at Woodlands in January 1995 but observed few individuals at Woodlands in January 1996.
Polychaete worms	Feather duster and Christmas tree worms are common and three species were observed averaged 22 individuals per 10m transect at Garibaldi Bluff, reached a maximum density of 45 individuals. Calcarious tube works (*Spirobranchus*

	giganteus and *Pomastrostegus stellatus)* are also common, especially Garibaldi Bluff where they average 7.25 individuals per 10m.
Echinoderms	Feather starts common at Garibaldi Bluff, especially at night. Basket stars can be found at most sites. Brittle stars are especially abundant where there is plenty of rubble and sand. For instance at Rendezvous Bay the blunt-spines brittle star *(Ophiocomina echin-)* reaches average density of 18 individuals per 10m transect. This species is less common at Garibaldi (mean=2.75, s.e.=4.86). The sea urchin, *Diadema antillarum*, is patchily distributed both within and among reefs but not particularly abundant at any reefs surveyed. (Side note: "On recent field work on norther boulder reef in Little Bay, we recorded one species of a gaudy colored brittle star *Ophioderma ensiferum,* a recently discovered new species found in 15 feet of water.)
Crustaceans	Cleaner shrimp are common, recorded total of 5 species associated with anemones (Table 10). Recorded various crabs: red reef crabs, hermit crabs, two species of porcelain crabs, two xanthid crabs, four spider crabs, and one grapsid crab. On west and northwest reefs, occasionally encountered lobsters *Panulirus argus* but they tended to be small and below legal size.
Molluscs	In general, molluscs were not abundant on reefs. Recorded three species of flamingo tongues (*Cyphoma spp)* that were relatively common on gorgonian corals, especially at Rendezvous. Recorded schools of squid at Vue Point beach and at Rendezvous Bluff, near the north of Little Bay in 1995. Conch are found in the sea grass beds off the west coast, and following Hurricane Luis in August 1995, high numbers of conch were recorded on Secret Spot reef

PHYSICAL	SEDIMENT DEPTH	SEDIMENT TRAPS	SECCHI DISK
	Sediment depth was significantly different across three sites. Rendezvous Bay has least amount of sediment (mean = 0.26 cm; s.e. 0.337); Garibaldi Bluff (inner) had highest (mean = 0.78; s.e. = 0.562) and Garibaldi outer had intermediate (mean = 0.37; s.e. = 0.463) (Table 23). Sediment depth also varied between survey observation dates. Sediment depth on Rendezvous declined by 26.8% over a 7 day period while Garibaldi Bluff (outer) decline 50% over 5 day period. These declines correspond to a storm that occurred on 1/25/96.	Sediment settlement varied spatially and temporally along west coast, but patterns were consistent among sites. Sedimentation was lower in first samples of Rendezvous Bay (mean = 0.088 g/day; s.e. = 0.025) and Garibaldi Bluff (mean = 0.088 g/dau; s.e. = 0.029) prior to storm on 1/25/96. Sedimentation was highest during second set of samples (1/30/96); Rendezvous (mean = 0.261 g/day; s.e. = 0.150) and Garibaldi Bluff (mean = 0.283 g/day; s.e. = 0.101). Sedimentation was still high during third set of samples (2/5/96) at Rendezvous Bay (mean = 0.192 g/day; s.e. = 0.056) and Garibaldi Bluff (mean = 0.150 g/day; s.e. = 0.049).	Water clarity was lower at southern sites. Water clarity significantly lower along 50m transect compared to 100m transect at all southern locations. This indicates that most sediment settles relatively close to shore (i.e. within approximately 150 to 200 m offshore). The values obtained at Rendezvous Bay, Woodlands Bay and Garibaldi Bluff were nearly double values of southern sites; water clarity increased with distance from shore. Water clarity was highest at Rendezvous Bay, decreased at Woodlands Bay and even lower at Garibaldi Bluff.

OUTCOMES/RECOMM.	Purpose of report was to take biological and physical surveys to help inform the development of marine protected area.
NOTES	Additional surveys include "Volcanic Impacts" where helicopter surveys of volcano and coastline indicated vegetation loss from acid rain on top of Chances Peak, and other visual analysis. Also, this summary does not include the details of Chapter 4. Discussion Lastly, there is no mention in the "Methods" section of a site called Colby's, and yet it is referenced to in the results. Very confusing and did not find a good explanation for the discrepancy.
SPECIES LIST	Numerous pages within report of species encountered. Not easy to transcribe into text. Please review in document lists for more information.

D. Global Coral Reef Monitoring Network Caribbean Guidelines for Coral Reef Biophysical Monitoring

GCRMN-CARIBBEAN GUIDELINES FOR CORAL REEF BIOPHYSICAL MONITORING

The Caribbean-GCRMN baseline scientific monitoring methods provide a multi-level framework for existing and developing monitoring programs to contribute data that support a regional understanding of status and trends of Caribbean coral reefs. The purpose of this collaborative effort is to collect, collate, and report reef monitoring data. This data will be widely available for a variety of purposes including contributing to our understanding of the processes that shape coral reefs and providing actionable advice to policy makers, stakeholders, and communities at a variety of spatial scales from local to Caribbean wide. In order to achieve these goals, the Caribbean-GCRMN community seeks to collect comprehensive and regionally comparable data that build from a modern scientific perspective of reef monitoring. **The guidelines are designed for a larger scale objective of detailed regional comparisons for management** (particularly the Level 3 - highly recommended protocol), but cognizant of the fact there are many ongoing long-term monitoring efforts that also want to contribute data which can be included (though minimum standards will apply). The scientific monitoring framework is described herein, and includes several different protocol options based on each monitoring group's operational and provides reference to several well-developed Caribbean monitoring programs with established monitoring protocols available online.

METHODS

The GCRMN - Caribbean methods have been developed to provide a systematic snapshot of the ecosystem health of coral reefs and, when repeated through time, insight into temporal trends in reef condition. Based on the conclusions of a retrospective analysis of trends in reef health over the past decades, GCRMN-Caribbean members have agreed that there is great value in coordinating and standardizing future monitoring efforts. To date, Caribbean regional monitoring efforts have often

collected non-overlapping types of data about coral reefs, or the efforts have used non-comparable or insufficiently documented methods for describing reef ecosystems. The goal of this document is to define a set of data and data collection techniques that will be used by GCRMN-Caribbean members. These methods reflect long-standing, vetted scientific protocols and provide a compromise between practical applicability and ease of comparison between existing methods and long-term datasets. Our objective is to provide guidance clarifying the methodological considerations and suggestions for managers needing monitoring information at local (site) level as well as for use at broader geographic levels.

The GCRMN-Caribbean methods describe six elements of the coral reef ecosystem – (1) abundance and biomass of key reef fish taxa, (2) relative cover of reef-building organisms (corals, coralline algae) and their dominant competitors, (3) assessment of coral health (4) recruitment of reef-building corals and recruit habitat, (5) abundance of key macro-invertebrate species, and (6) water quality. These elements provide an overview of the current condition of the coral reef ecosystem as well as an indication of likely future trajectories. The GCRMN-Caribbean recognizes that by collecting information about these elements across multiple locations, with regular re-sampling through time, it will be possible to more knowingly describe the status of coral reef health in the Caribbean and to assess the effectiveness of local and regional management efforts.

These methods are designed to provide a basic and regional summary of reef health. Importantly, the elements that are included for GCRMN monitoring are not all-inclusive, and many partner members may be interested in collecting more detailed or spatially expansive data that will be valid at the site level. It is important that any necessary additions or amendments to the sampling protocol (sample sizes, etc.) are noted to assure data are also valid at the site level. In general, these **GCRMN-Caribbean methods should be viewed as a minimum set of measurements to provide a reliable regional assessment of reef condition** – data elements should not be selected individually but instead collected in sum. Given the inherent complexity of reef processes, a multi-dimensional description of coral reef health is essential to provide a coherent 'baseline' of coral reef condition in a dynamic and changing world.

Training, standardization, and calibration

A series of references and support tools are available to assure that the GCRMN-Caribbean methods are well-understood by partners and that the data generated are robust. This document provides an overview of the accepted methodologies along with references to supporting documents. In addition, a number of products are intended for production to supplement this document, including – (i) a species identification guides, providing images and descriptions of taxonomic groups to be used for recording fish and benthic data, (ii) a series of instructional videos, intended to visually 'walk through' the implementation of each set of methods, and (iii) an online portal for discussion and consultation, providing a pathway for partners to troubleshoot methodological or reporting concerns. Pending resource availability, the GCRMN-Caribbean group will implement (iv) local training workshops, intended to bring partners together to exchange knowledge in the field setting and to perform cross-checks and calibration of data collection protocols. For those using the Level 2 in situ (non-photographic) transect methods, we recommend referring to the well-developed Atlantic and Gulf Rapid Reef assessment training guides and methodology available on www.agrra.org. For those incorporating programs of 'citizen science', we recommend using established methods of ReefCheck (www.reefcheck.org) and/or REEF (www.reef.org), depending on organizational goals and capacities.

Design of local monitoring

The GCRMN-Caribbean baseline monitoring guidelines have been developed to enable partners to describe the status and trends of specific locations, frequently including multiple sites, in a manner that is directly comparable across geographies. As such, the design of the monitoring protocols must be founded on consistency within locations and standardization across locations. Operational definitions of the recommended spatial design for GCRMN monitoring are provided here.

A given monitoring effort may partner with the GCRMN-Caribbean community if participants provide a reliable description of a coral reef location in the Caribbean region. A *location* is defined as the characteristic reporting unit, and the *location* has a bounded geographic range, representing somewhere between 5 to 100 km of coastline. For example, an island with a total coastline of 78 km may opt to define their *location* as the coral reefs spanning the entire coastline of the island or might separate them into windward and leeward components, for example. In contrast, if an island or mainland coast has >100 km of coastline with coral reefs, the partner will define a specific section or sections of the coast as the *location(s)*. The definition of a *location* is expected to follow from the needs of each partner, for example representing regions of important historical or ecological significance. The partner, however, should begin monitoring only after the specific boundaries of a *location* have been defined. A GCRMN-Caribbean technical committee is available to assist with site selection, as well as an open GCRMN-Caribbean forum with specific discussions on methods. This platform of exchange between coral reef scientists and members of monitoring agencies will allow GCRMN partners to share experiences, ask for advice, and share and store relevant documents. Please contact the GCRMN-Caribbean coordinator to access the Basecamp forum julie.belmont.carspaw@guadeloupe-parcnational.fr or Steering Committee member Melanie McField mcfield@healthyreefs.org.

A GCRMN-Caribbean partner should complete at least the minimum sampling noted in these guidelines in order to provide a statistically robust description of a *location*. The unit of replication within the *location* is called the site and is defined as a particular spot on a map where surveyors will get into the water to collect monitoring data. A *site* can be considered operationally as a 'dive site' or 'monitoring station', and will be reported based upon its geographic coordinates (latitude and longitude). Individual *sites* should be selected randomly from across the location, thereby faithfully (and without bias) representing the variation in the coral reefs across the location. Note that marked permanent sites can be used, but may require modified techniques for data analysis, especially in comparisons with sites using randomized site selection.

The GCRMN recommended minimum level of effort (replication) is 20 sites per location. This level of effort is informed by a statistical power analysis considering the ability of the data to detect a 5% change in coral cover between sampling intervals (e.g., a change from 20% to 15% coral cover). Technical assistance can be provided to groups interested in doing power analysis specific to their locations (which is the preferred design). By sampling at least 20 sites per location, there will be a 50% chance of documenting such a change of 5% in coral cover. Note that the statistical power increases greatly at the number of sampling intervals increase (i.e., with increased sampling through time). As such, these considerations of statistical power should be viewed as a guide for selection of sampling effort rather than as a strict statement of statistical results that are to be expected from a real, long-term monitoring campaign. The GCRMN-Caribbean community is understanding of the challenges associated with monitoring, and locations that are described with fewer than 20 sites (due to operational limitations) will be welcomed, as appropriate.

Monitoring sites to be used in the collective GCRMN effort will be limited to forereef habitats at depths ranging from 8-18 m, in the Zone of most reef development (typically "seaward" or "non-lagoonal" reefs below high-energy reef crest or *A. palmata* Zone), in an effort to maximize comparability across the region. Importantly, this constraint disallows contribution of data from backreefs, lagoons, and deep reef habitats. However, wherever GCRMN partners have local interests in monitoring these (or other) coral reef habitats in their region, they are encouraged to apply these same guidelines. By using comparable methods, there will be greater opportunities in the future to consider cross-comparisons within and among regions, as more comparable data become available. A fundamental goal of GCRMN is to increase standardization of data collection for monitoring, thereby increasing the ability of the management and research community to better understand regional patterns of change in coral reef into the future.

The GCRMN recommended frequency of sampling is once every two years under normal conditions, with increased frequency if needed to evaluate, for example, disturbance events or testing of management effects. In order to reduce seasonal variation in reef composition (e.g., algal blooms, fish spawning), sampling should be completed in the same season, and is highly recommended to be completed in the same month of each sampling year.

METHODS OUTLINE

The methods that follow are organized by individual ecosystem component (fish, benthic, coral health, coral recruitment, key macroinvertebrates, and water quality). Each component has up to three different optional methods - selected by the partner based on the level of detail needed and capacity within their organization. These include: Level 1 (*minimum standard*), Level 2 (*recommended*) and Level 3 (*highly recommended).* The Level 3 method provides the most rigorous and comparable data for current and future applications. In many cases, this method provides higher resolution for archiving reef condition, and thus enables more detailed explorations of reef health today and a permanent archive into the future. The Level 2 method is the basic approach that provides the essential information defined by GCRMN, and uses a common and consistent field approach. The Level 1 method is a collection of viable approaches for collecting the essential information however lacks the detail and resolution provided by Level 2 and Level 3. Level 1 methods provide information that is broadly comparable to the recommended methods, though differ in key aspects that prevent detailed comparisons of the data. The Level 1 and Level 2 methods should be used only in cases where the local GCRMN partner has an established monitoring program, and thus changing methods may compromise the legacy and consistency of the local effort.

For the partners using the Level 1 minimum standards, we recommend considering and implementing a gradual shift towards Level 2 recommended and Level 3 highly recommended methods, without compromising the continuity of monitoring efforts and data comparability over time. The GCRMN-Caribbean community and its steering committee are available to assist in this regard.

1. Abundance and biomass of key reef fish taxa

Core information to collect – The goal of data collection for the fish taxa is to characterize the key species of economic and ecological importance. In total, ***the core data to collect are the density and size structure of all species of snappers (Lutjanidae), groupers (Serranidae), parrotfish (Labridae – Scarinae), and surgeonfish (Acanthuridae)***. These species are among the principal food fishes in Caribbean small-scale fisheries that are still relatively intact, as well as being critical species for maintaining reef ecosystem health. Note that collecting information on both density and size structure is

required to estimate the biomass of each species by using known length-to-weight relationships published for all fish species. Additionally, it is recommended to record the presence of sensitive species (e.g., sharks, rays) or important invasive species (e.g., lionfish).

Beyond the core information, *it is highly recommended to provide estimates of the density and size structure of all fish species* within the survey area. Such high resolution estimations of the fish assemblage maintain the core information (snappers, groupers, parrotfish, and surgeonfish), while also providing fundamental information about other members of the fish assemblage that may serve important roles in fisheries (e.g., barracuda, grunts, and parrotfishes) or ecosystem maintenance (e.g., damselfish, triggerfish) that will be further considered or discovered in the years to come.

Level 3– The GCRMN highly recommended method for estimating the density of coral reef fishes builds on the Atlantic and Gulf Rapid Reef Assessment (AGRRA) – http://www.agrra.org/method/methodhome.html. All fish present (of all species, not just the AGRRA fishes) are counted and sized within a belt transect (30m length x 2m width). At each site, 5 transects are surveyed and the data are pooled to provide an average estimate of the density and size structure of all fishes at the site. In cases where local efforts require more ability to track changes at the site-level, it is possible to survey more transects per site, perhaps including more dive time or more divers. In order to standardize the sampling effort per transect, divers should maintain consistency in survey time with a target of 8-12 minutes per transect.

Level 2– If the taxonomic expertise is limited among the survey team, it is recommended to follow the same modified AGGRA protocol, but to count and size only the core species (snappers, groupers, parrotfish, and surgeonfish).

Level 1– It is required for contribution to the GCRMN database that the core information about the fish assemblage (including estimates of density and biomass) is collected using a vetted and comparable field method. Acceptable protocols are the stationary point count and belt transects (of different dimensions to the AGGRA protocol). Note that the specifications of these protocols are often variable, and GCRMN members should strive to achieve standardization of methods whenever possible and be sure to document the specifics of the methods employed.

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

Core information to collect – The goal of data collection for the assessment of the benthic environment (i.e., organisms attached to the bottom) is to document the relative cover of reef-building, stony corals, and their dominant competitors. As such, ***the core data to collect is the percent of the reef bottom that is covered by stony corals, gorgonians, sponges, and various types of algae (turf algae, macroalgae, and crustose coralline algae)***. The stony corals and some of the calcifying algae are the dominant taxa that build the coral reef structure, while the turf, some macroalgae and benthic invertebrates can compete with reef-builders and thereby limit growth of the reef structure.

Level 3– The GCRMN highly recommended method for estimating the cover of key taxa on the reef benthos is the photoquadrat method. This approach uses digital photographs of the reef surface in standardized quadrat areas (0.9m x 0.6m). Photographs are taken along each of the 5 transect lines set for counting fish, with 15 images captured per transect line (i.e., one image taken at every other meter marker on the transect tape). In total, 75 benthic photographs will be collected at each site (5 transect lines x 15 photographs per transect).

Prior to collecting image data, users will need to calibrate image collection protocol for the specific underwater camera being used. Because cameras vary in their lens configuration, images taken from two different cameras at the same height above the benthos may include different areas of the reef. Two approaches are used commonly to standardize image area:

(i) Users can construct a quadrat out of PVC or other material. The design is simple, including four lengths of PVC (2 that are 0.9m long, 2 that are 0.6m long) that are coupled together with 90˚ angled couplers. The corner of the quadrat then is placed at alternating meter markers along the transect line, and images are collected that contain the standard frame and the benthic habitat within.

(ii) Users also can construct a 'mono-pod', namely a pole that connects to the camera identifying a height above the benthos which will capture an area of approximately 0.9m x 0.6m. Importantly, the length of this mono-pod will be specific to the camera and housing being used. As such, prior to collecting data, the user will need to calibrate the length underwater (note that due to optical distortion due to the air-to-water transition associated with underwater housings, the calibration *must* be completed underwater). To calibrate, the user can lay a transect tape underwater then hover above the tape until the image contains the correct area. The height can be recorded by a second diver measuring the distance between the camera and the transect tape. The mono-pod is constructed by cutting a length of PVC (or other material) to the defined length and either holding between the camera and that benthos for image collection, or constructing a coupler to mount the pole to the camera base. If using a mono-pod, it is important to include the transect line itself along the edge of the image to provide internal scale within the image, especially for archival value.

Note that there are many approaches for standardizing areas collected using photographic methods. For example, the framed quadrat approach described in (i) can be made more elaborate by constructing a PVC 'quad-pod' that mounts the camera to the frame. The decision of exact field approach will be determined based upon resources available, field operational flexibility (e.g., boat space), and personal preference. The critical constraint is to assure that the area captured in each image is of a standard and consistent size, and that details of the methods used are recorded and archived (e.g., writing quadrat area in metadata file or including transect tape in images for reference).

Data are captured from the images through post-processing by a trained observer using image processing software. On each image, the software randomly places 25 points over the image and the benthic type under each point is classified into a standardized benthic category including key species (and some broader groups) of corals and algae (see Table 1). Image processing software is freely available to support the image post-processing (e.g., Coral Point Count, CoralNet).

If taxonomic expertise is limited in the survey team or time is limited for detailed post-processing, it is recommended to collect the images as above but to follow one of two options for post-processing – (i) identify points in the images to coarse functional groupings (principally stony coral, gorgonian, sponges, turf algae, macroalgae, crustose coralline algae; complete list is available in Table 1), or (ii) solicit support from a partner within the GCRMN for high-resolution image post-processing.

Image-based benthic data collection is recommended for a number of reasons. First, images can be collected rapidly in the field, providing operational efficiency. Second, image collection is less prone to user bias than some *in situ* approaches (e.g., selecting the exact point for recording using line-point-intercept when the transect tape moves slightly with surge). Third, images provide the ability for

discussion and repeated post-processing by multiple observers during image analysis. While such discussion can take time in the short-term, there is great value in error-checking across observers as facilitated by image post-processing. Finally, images provide a raw archival data source. While one group may be interested in only particular levels of taxonomic resolution from the images (e.g., coral composition), future changes in the reef may identify another taxon of particularly large importance. Archiving images provides the raw material for future re-analysis to address novel trends in reef benthic change.

Level 2 – In order to be included in regional GCRMN comparisons, the core benthic composition data should be collected using a standardized, accepted, and reliable method, with adequate replication. Given that some programs have long-standing monitoring using an alternative (but generally comparable) method, or that a potential member may not have access to digital cameras, these alternatives will also be accepted. In particular, *in situ* measurement of benthic cover may be collected using field assessment of quadrats (collected in sufficient quantity) or using line-point-intercept methods (estimated over sufficiently long and replicated transects). Note that the specifications of these protocols are often variable, and GCRMN members should strive to achieve standardization of methods whenever possible, such as the widely-used AGRRA methodology.

Level 1. For partners using volunteer and community stakeholder groups for basic monitoring it is recommended to use the line-point intercept approach, potentially using methods from ReefCheck (www.ReefCheck.org).

3. Assessment of coral health

Core information to collect – The goal of data collection for assessing coral health is to document ***the prevalence of disease (not including bleaching) in stony corals (see definition and photos on the AGRRA website [www.agrra.org])***. Disease prevalence is a metric describing the proportion of coral colonies that exhibit signs or pathologies of any disease. Because of the challenges associated with defining the boundaries of individual coral colonies in photographs, the GCRMN core information reports coral disease as the proportion of replicated benthic areas (e.g., photoquadrats) that have diseased corals – herein termed a 'relative prevalence' rate. Note that while this simplified method does not capture many elements of coral disease ecology, like species- or size-specificity of disease incidence, this is a useful approach for collecting standardized and inter-comparable data describing coral health. If, for example, a rapid rise in estimated disease 'relative prevalence' is noted, a survey team could alert the GCRMN-Caribbean community for advice or connection with specialists.

Level 3 – The photoquadrat method for estimating disease relative prevalence in corals uses the photoquadrats collected following the Level 3 highly recommended methods for benthic cover assessment. Data will be recorded as the proportion of images collected that contain a coral with any disease pathology. For example, if there are four colonies in a particular photoquadrat and any of these colonies shows signs of disease, this image would be tagged as "*with disease*". The number of images that are "*with disease*" is divided by the total number of images (15 per transect) to generate a proportional estimate of disease prevalence. A benefit of the photoquadrat approach is that archived images can later be used by coral disease experts for more detailed analyses.

Level 2 option A – Following on from the Level 2 recommended methods for benthic assessment, the surveyor will record whether or not the quadrat is "*with disease*" and the number of these positive disease quadrats will be divided by the total number of quadrats to generate a proportional estimate of disease relative prevalence.

Level 2 option B – Following the AGRRA methodology, surveyors will record the prevalence rate of diseased coral colonies by species along 10m belt transects. This method follows the specifics identified in the 'Coral health' section of the AGRRA methodology (www.agrra.org). This approach records the proportion of coral colonies, rather than the proportion of benthic quadrats, that contain disease. As such, the units are sufficiently different to limit the ability to compare quantitative 'prevalence' values with Level 3 methods. However, in most cases temporal trends within a location should be comparable using either method. . These data will not be directly comparable to the Level 3 disease prevalence.

Level 1 – In some cases, GCRMN members may lack the capacity to collect data on coral disease. Although collection of disease data is encouraged, for GCRMN members using level 1 protocols, the collection of coral disease data is not required for contribution to the core GCRMN database. Further, if a different method for assessing disease relative prevalence is used, GCRMN members should accurately document the specific methods used and strive to achieve standardization of methods whenever possible.

4. Coral recruitment

Core information to collect – The goal of data collection for coral recruitment is to estimate ***the density of young corals that are likely to contribute to the next generation of adult corals*** on the reef, as well as providing a snapshot of the competitive environment in which young corals live. Documenting the early life stages of corals is notoriously challenging, given that many of the smallest coral settlers (e.g., those that recently settled to the reef substrate) are very small and are found in cryptic habitats, such as in cracks or on the hidden surfaces of rocks. As such, this protocol employs an operational definition of coral recruits as those smallest individuals (0.5-4.0 cm) that are visible to a diver *in situ*.

Importantly, much scientific literature employs the use of standardized substrates (e.g., settlement tiles) for providing precise estimates of relative rates of settlement and recruitment. While such efforts are valuable for experimental studies, they are labour-intensive and prone to methodological bias (e.g., tile type and soaking duration can greatly influence settlement rates). Here, we outline an observational approach that integrates across natural variability in the environment and offers a relative estimate of the density of corals that are likely to contribute to the next generation of coral adults in the region.

Levels 2 & 3 – The GCRMN highly recommended method for estimating the density of coral recruits follows the AGRRA methodology – http://www.agrra.org/method/methodhome.html – though with some specific differences. Coral recruits are defined operationally for this assessment as any stony coral that is greater than 0.5 cm and up to 4.0 cm in maximum diameter. The lower limit of this range is established based on the minimum size that can be observed reliably by a diver *in situ*, while the upper limit is established as the approximate size at which many species gain capacities typical of adult corals (e.g., increased competitive ability, reproduction). Further, the upper limit also represents the transition from juvenile to adult, following definitions of AGRRA protocols, and thus provides data that when combined with AGRRA adult surveys represent the full range of size class options. The size class (in increments of 0.5 cm) should be noted along with the genus (if possible) of each recruit.

Estimates of coral recruit density are recorded from replicate 25cm x 25cm (625 cm^2) quadrats. A total of 5 quadrats will be surveyed along each of the first 3 transects used for benthic surveys. The coral recruit quadrats will be placed at 2-meter intervals along each of the first three transects, i.e., with the lower corner of the quadrat placed at the following meter marks – 2, 4, 6, 8, and 10 m. Within each quadrat, each coral within the target size range (0.5-4.0 cm) will be recorded to the finest taxonomic level possible (family, genus, or species). Importantly, many of the smaller coral recruits are very difficult

to identify to species, even for taxonomic experts, so good judgment must be used to identify to the finest taxonomic level that the observer can confidently assess.

Characteristics of the recruit habitat are also recorded within each 25cm x 25cm quadrat. The height of algae provided a robust estimate of the competitive environment for corals, especially for coral recruits. At each corner of the quadrat, the height of two functional groups of algae will be recorded. For turf algae, the height of the turf filaments will be recorded to the nearest mm; for macroalgae, the height of the macroalgal individual will be recorded to the nearest cm. As such, with the quadrat on the bottom, the surveyor will identify the patch of turf algae closest to each corner of the quadrat and use a small ruler to measure height; similarly, the surveyor will find the nearest macroalgal individual to measure height. Note that if no turf algal patches or no macroalgal individuals are found within a particular quarter of the quadrat, it is critical to record "n/a", identifying that no algae of that type were available to measure. In total, there will be 0-4 measurements of turf algal height and 0-4 measurements of macroalgal height per quadrat.

Note that the area of the quadrat used for coral recruits is smaller than that used for benthic cover assessment. The reason for this is that searching for coral recruits is relatively labor-intensive for the observer, as one needs to explore the focal area within the quadrat extensively. Especially in quadrats covering areas of high topological complexity, the observer needs to explore all surfaces within the quadrat, regardless of orientation (e.g., sides of rocks and under loose fleshy algae).

Level 1 – It is required for contribution to the GCRMN database that the core information of the density of coral recruits be determined. If the survey team does not have the taxonomic training to identify coral recruits with any taxonomic detail (i.e., only recognizing scleractinian, reef-building corals), then a surveyor will simply record the number of coral colonies within the defined size range (0.5 – 4.0 cm) within the defined quadrats. A comparable sampling protocol will be used (5 quadrats [625 cm^2] along each of 3 transect lines; total of 15 quadrats). If capacity of the survey team is limited, omitting collection of data on algal heights will be acceptable under Level 1 standards.

5. Abundance of key macro-invertebrate species

Core information to collect – The goal of data collection for key macro-invertebrate species is to provide an estimate of the density of ecologically and economically important species on the reef. ***The core data to collect are the densities of the long-spined sea urchin (*Diadema antillarum*), other sea urchins, all sea cucumbers, lobsters, and conch.***

Many species of sea urchin, especially the historically common long-spined sea urchin (*Diadema antillarum*), are important herbivores on Caribbean reefs with a capacity to control the density of many groups of seaweed. As such, sea urchins can play an important role comparable to that of seaweed-consuming herbivorous fishes. The other key groups of invertebrates, the sea cucumbers, lobster, and conch, include important fisheries targets in some locations. Many species of sea cucumber are harvested and sold to export markets. The sea cucumbers thus can contribute to local reef-based economies. Lobsters and conch, although not common in reef environments, are among the most important commercial invertebrates in Caribbean nearshore habitats. Estimates of density for these key macro-invertebrate species are valuable for considerations of ecosystem functioning and potential fisheries value. The GCRMN Levels 3, 2, and 1 all rely counting all urchins, sea cucumbers, lobsters, and conch within 3 of the benthic transect lines. Each belt will cover the first 10m in a 2m wide belt, giving a total area of $60m^2$. If the AGRRA methodology is used then this $60m^2$ sample is achieved using 6 belt transects 10m x 1m wide.

If photoquadrats are used for benthic cover (from ***2. Relative cover of reef-building organisms and their dominant competitors***), there will be an additional analysis of the 15 photographs from each of the 5 transect lines (75 photographs total). The number and species identity of each sea urchin, sea cucumber, lobster, and conch will be recorded for each image. The density of these key macro-invertebrate species will be calculated by dividing the total number of sea urchins and sea cucumbers recorded by the product of the number of images (*sensu* Level 3 highly recommended as 75) and the size of each photoquadrat of 0.54 m^2 (i.e., 0.6 m x 0.9m).

6. Water quality

Core information to collect – The goal of data collection for water quality is to provide an estimate of the concentration of particulates in the water column. Water quality is influenced by many factors, ranging from oceanographic delivery of nutrients, algal growth in the water column, terrestrial contributions (e.g., mud and silt), and anthropogenic inputs. A standardized and common metric that captures the basic elements of water quality and has a long history of application is the use of Secchi disks. As an estimate of the integrated water quality, ***the core data to collect are the depths at which standardized Secchi disks are visible in the surface waters of the reef.***

Levels 3, 2 and 1 – The method for estimating water quality is to deploy regularly a Secchi disk at sites around the study region. The Secchi disk is a black-and-white disk (20 cm in diameter, for the purpose of GCRMN) that is attached to a measured and marked pole, rope, or chain. The disk is lowered into the water from a boat or a diver at the surface until the disk disappears from sight; at this point the measurement on the pole, rope, or chain is recorded. The disk is lowered a bit more, then pulled back up toward the surface slowly. When the disk is visible again, the measurement on the pole, rope, or chain is again recorded. The average of these two measurements is recorded as the best estimate of the distance at which the Secchi disk is visible through the water.

Note that at many tropical locations, the depth of the forereef site will be less than the vertical Secchi depth (e.g., in cases where one can see the reef from the water's surface). In these cases, horizontal Secchi distances can be substituted and the Secchi disk instead will be placed or held at one location, along with the end of a transect tape. For example, an in-water observer will swim away from the disk, pulling the transect tape and will record the distance at which the Secchi disk is no longer visible. Many operational approaches exist for integrating horizontal Secchi disk measurements into the efforts and responsibilities of members during a survey dive, and teams are encouraged to identify the most efficient approach to record this measurement within the constraints of efficiency and dive safety.

It is Level 3 highly recommended to collect information on water quality at weekly intervals at standardized sites (1-8 total) that are ideally co-located with the monitoring sites. It is Level 2 recommended to collect information on water quality at monthly intervals with a comparable spatial distribution. Notably, the frequency of sampling for water quality is much more frequent than the benthic sampling. As such, it is important to consider complementary on-water efforts (e.g., law enforcement and monitoring, partners in recreational dive industry) to support water quality sampling. Given the relatively low amount of training needed to collect these data reliably, there are a broad set of partners that can be engaged to help gather this information consistently.

The GCRMN-Caribbean community is understanding of the logistical constraints of sampling frequency and will welcome data collected at most frequencies. It is required for contribution to the GCRMN database that the meaningful information of water quality be reported at least annually. In many locations, there are regular programs of water quality monitoring that complement (or often provide

higher resolution than) Secchi disk deployments. It is required to report some reliable and consistently-collected form of information about water quality from each GCRMN partner location. Additional types of water quality information include: dissolved oxygen (DO), total dissolved solids (TDS), nutrient concentration analysis, and bacterial sampling.

Importantly, the same type of information must be collected at regular intervals in order for the data to be useful to the GCRMN partnership. If different forms of data are collected in different years, then there is no capacity to document reliably patterns of change in water quality through time. It is fundamental that a consistent methodology be applied through time.

SITE DATA

In previous efforts to synthesize monitoring data from across the Caribbean community, a major limitation was in data being recorded with insufficient site data and associated metadata. For example, data may be presented without clear information about where the data were collected, when the data were collected, and what methods were used. As such, it is essential for inclusion to the GCRMN-Caribbean effort that all data be recorded with clear and reliable metadata.

Before each dive record the following on the data sheet. (taken from the AGRRA v5.5 methodology).

Surveyor: Name of the person making the survey using 4-letter name code (e.g., John Smith = JOSM).
Date: Enter date as: day, month name, year (e.g., 19 Oct 09).
Site Name: Name of dive site or description of area (e.g., between Boston Beach & Splash Hotel).
Site Code: Sequential site code (e.g., MEX007 = seventh Mexican site).
How Selected: Method used to select the site (e.g., stratified random, stratified strategic, strategic MPA site,
etc.).
Latitude & Longitude: Latitude and longitude recorded for the site, corrected if necessary from a boat or other fixed position. GPS waypoint may be recorded instead, but at least one datasheet per site should have the actual lat./long. Note which datum the GPS is using (WGS84, etc)
Reef Type: Type of reef system (e.g., bank, barrier, fringing, lagoonal, mid-shelf, patch, platform). If different from expected, please describe the reef type surveyed.
Zone: Reef Zone surveyed (e.g., back, crest, fore). If different from expected, please describe the reef Zone surveyed.

DATA ENTRY AND REPORTING

GCRMN partners will use a common database for data entry and archiving. Details of the data entry portal and database platform are currently under development.

Table shows the categories used for benthic surveys. The GCRMN highly recommended method seeks to record high-resolution taxonomic data, as presented in the detailed categories. If taxonomic expertise is not available (in-house or through collaboration), the recommended and required methods seek to record taxonomic data as presented in the coarse categories.

Coarse categories	Detailed categories
Stony corals	*Acropora cervicornis*
	Acropora palmata
	Acropora prolifera
	Agaricia agaricites
	Agaricia humilis
	Agaricia fragilis
	Agaricia grahamae
	Agaricia lamarcki
	Agaricia tenuifolia
	Agaricia undata
	Colpophyllia breviserialis
	Colpophyllia natans
	Dendrogyra cylindrus
	Dichocoenia stellaris
	Dichocoenia stokesi
	Diploria clivosa
	Diploria labyrinthiformis
	Diploria strigosa
	Eusmilia fastigiata
	Favia fragum
	Isophyllia sinuosa
	Leptoseris cailleti
	Leptoseris cucullata
	Madracis carmabi
	Madracis decactis
	Madracis formosa
	Madracis mirabilis
	Madracis pharensis/senaria
	Manicina areolata
	Meandrina meandrites
	Orbicella annularis
	Orbicella cavernosa
	Orbicella faveolata
	Orbicella franksi
	Mussa angulosa
	Mycetophyllia aliciae
	Mycetophyllia danaana
	Mycetophyllia ferox
	Mycetophyllia lamarckiana
	Oculina diffusa
	Porites astreoides
	Porites branneri
	Porites divaricata
	Porites furcata
	Porites porites
	Scolymia cubensis
	Scolymia lacera
	Siderastrea radians
	Siderastrea siderea
	Solenastrea bournoni
	Solenastrea hyades
	Stephanocoenia michelinii
	Tubastraea aurea
	OTHER corals

Coarse categories (cont.)	Detailed categories (cont.)
Macroalgae/ plants	*Dictyota*
	Lobophora
	Sargassum
	Stypopodium
	Caulerpa
	Halimeda
	Branching and calcareous algae (other than CCA)
	Liagora
	Padina
	Seagrass
	Stypopodium
	Turbinaria
	Wrangelia
	OTHER macroalgae
Turf algae	Grazed or thin turf algae (substrate visible)
	Thick turf algae (substrate not visible)
	Turf algae overgrowing recently dead coral
Cyanobacteria	*Schizothrix*
	Cyanobacterial mats
	OTHER cyanobacteria
Crustose coralline algae (CCA)	Crustose coralline algae (CCA)
Gorgonians	*Gorgonia* spp. (FAN)
	Erythropodium (ENCRUSTING)
	Muricea (ROD)
	Briareum (ROD)
	Plexaura (ROD)
	Plexaurella (ROD)
	Eunicea (ROD)
	Pseudoplexaura (ROD)
	Pterogorgia (ROD)
	Iciligorgia (FEATHER)
	Pseudopterogorgia (FEATHER)
	Muriceopsis (FEATHER)
	OTHER gorgonians
other (invertebrates)	*Chondrilla* spp.
	Clionid spp.
	Other encrusting sponges
	Vase or barrel sponge
	Tube or rod sponge
	OTHER sponges
	Ascidians
	Millepora alcicornis
	Millepora complanata
	Millepora squarrosa
	Stylaster spp.
	OTHER hydrozoans
	Palythoa sp.
	Tridiemnum sp.
	OTHER zoanthids
	OTHER (invertebrates)
Sand	sand
Limestone free of overgrowth	Limestone free of overgrowth
Rubble (bare)	Rubble (bare)