

Montserrat Ridge to Reef Conservation Project;

A Summary of the Marine
Coastal Zone &
Recommendations for
Management

CORAL CAY
CONSERVATION



Expeditions



This report has been produced by Coral Cay Conservation as an output of the Montserrat Ridge to Reef Project, specifically the Montserrat Marine Conservation Project, in partnership with the Montserrat Ministry of Agriculture, Lands, Housing and Environment (MATHLE).

April 2020

Thomas Dallison
Marisa Sorrell

Coral Cay Conservation
The Kiln
Grange Road
Tongham
Surrey
GU10 1DJ
United Kingdom

+44 (0) 207 620 1411
info@coralcay.org
www.coralcay.org

Suggested Citation; Dallison, T & Sorrell, M. (2020). Montserrat Ridge to Reef Conservation Project; a summary of the marine coastal zone and recommendations for management. *Coral Cay Conservation*. Tongham, United Kingdom.

Montserrat Ridge to Reef Conservation Project; a summary of the marine coastal zone and recommendations for management

Thomas Dallison^{a,*}, Marisa Sorrell

^a*Coral Cay Conservation, The Kiln, Grange Road, Tongham, Surrey, GU10 1DJ, UK*

Abstract

In 2013, Coral Cay Conservation established the Montserrat Ridge to Reef Conservation Project (MRRCP) in partnership with the Montserrat Ministry of Agriculture, Lands, Housing and Environment (MATHLE) and the Royal Society for the Protection of Birds (RSPB) (and funded, in part, by the Darwin Initiative). A key component of the MRRCP was the Montserrat Marine Conservation Project (MMCP) that was inceptioned under the aim of assessing and monitoring the marine resources of Montserrat's nearshore environment whilst working alongside stakeholders and resource managers to build capacity; promoting the sustainable use of the marine environment. A definitive output of the project was to provide recommendations for the establishment of a Marine Protected Area to protect critical ecosystems and services. These outputs were designed to facilitate Montserrat's (and the UK's) contributions to the Aichi Targets (Target 11). During the project's time frame, Montserrat (voluntarily) committed to the United Nation's Sustainable Development Goal (SDG) 14 to which the MMCP further contributes.

Data were collected through enhanced Reef Check protocols by teams of trained surveyors from 2013 - 2017 with bio-physical *in-situ* surveys conducted along Montserrat's western coastline. These efforts resulted in a total of 101 individual surveys from Lime Kiln Bay, Old Road Bay, Woodland's Bay, Isle's Bay and Carr's Bay (with additional baseline and temporal monitoring surveys). Abiotic and biotic variables were recorded including the abundance and diversity of coral-reef associated communities, commercially important fish biomass (kg) and substrate composition (%). Impacts, including coral disease and coral bleaching, were also recorded. To present the overall health and management value of Montserrat's near-shore environment, a Conservation Management Value (CMV) index was developed; awarding a maximum value of '7'. This index produced a ranked spatial distribution of key variables enabling marine spatial planning to consider areas of high biodiversity, resilience and value for protection.

Throughout the sample period, Lime Kiln Bay and Carr's Bay consistently presented greater CMVs with 27% of surveyed locations in Lime Kiln Bay scoring a '6' and 10% scoring a '7'. 14% of Carr's Bay surveys scored a CMV of '7'. Each site consistently ranked greater than other surveyed areas in terms of abundance, diversity and biomass of coral reef-associated fishes, low accounts of disease, high compositions of complex biotic structure and low indications of overall impact. During the project's time frame, Lime Kiln Bay was highlighted as an important social and commercial area, holding high value within the tourism industry (reflected by its 'healthy' reef system and Alcyonacea plains).

Based on project outputs, Coral Cay Conservation recommends the establishment of a multi-use and zoned Marine Protected Area protecting 408.10ha of nearshore environment. The recommended marine spatial plan is composed of a No-Take Area (77.20ha) (enveloping Lime Kiln Bay) and two marine reserves, extending north and south, that protect 330.90ha. Coral Cay Conservation have also recommended that further discussions are held regarding Carr's Bay, placing the bay under 'Special Consideration', due to the area's evident ecological value combined with value from other sectors due to its proximity to Little Bay. There is clear advocacy in this report for collaborative discussions regarding the recommendations portrayed to ensure the most effective marine spatial plan is generated for the prosperity of Montserrat.

Keywords: Montserrat, coral reef, marine spatial management, marine protected area

1. Introduction

Founded in 1986, Coral Cay Conservation (CCC) is a UK-based NGO that is dedicated to:

“Providing resources to help sustain livelihoods and alleviate poverty through the protection, restoration and management of coral reefs and associated ecosystems”.

Working in collaboration with government and non-governmental organisations within a specific host country, CCC does not receive monetary payment for the services provided. Operating through a three-tiered approach, CCC is primarily self-financed through a volunteer participatory scheme in which international volunteers are given the opportunity to gain valuable experience by joining a phase of each project in return for a financial contribution towards project costs. Upon arrival, volunteers are entered into a Skills Development Programme (SDP). The SDP provides training in marine fauna and flora identification, underwater visual census (UVC) methodologies and further data collection methods. Finances generated from the volunteer programme allow CCC to provide a range of services, including data collection, assimilation and synthesis as well as conservation and environmental education, technical skills training and other capacity building programmes not only for international volunteers but also for local stakeholders.

CCC has been successfully operating volunteer-based conservation programmes in developing countries since 1986 with several internationally notable accomplishments, including the establishment of several Marine Protected Areas around the world. This includes but is not limited to the creation of the UNESCO World Heritage Site in Belize, the Danjungan Marine Reserve and Wildlife Sanctuary for Negros in the Philippines and the development of several no-take areas (NTAs) and no-take marine parks around Sogod Bay and Cabalian Bay, Southern Leyte, the Philippines.

CCC established the Montserrat Ridge to Reef Conservation Project (MRRCP), by request of the Montserrat Government Ministry of Agriculture, Trade, Lands, Housing and Environment (MATHLE), in 2013 until 2017, with financial support from the Darwin

Initiative, UK Government, and in partnership with the Royal Society for the Protection of Birds (RSPB). The project focused on marine, shore and terrestrial environments throughout Montserrat, forming the Montserrat Marine Conservation Project (MMCP) and the Montserrat Terrestrial Conservation Project (MTCP).

The MRRCP aimed to achieve the conservation of key habitats across Montserrat, that would enhance food security and promote the sustainable use of natural resources secured through the development of a stakeholder agreed Locally Managed Marine Area (LMMA) and improved management of the Central Hills forest. By improving the management of natural resources, the MRRCP aimed to support local livelihoods by increasing the productivity of fisheries for local fisherfolk and enhancing opportunities for sustainable ecotourism. Such efforts were further complemented by a comprehensive training programme provided to Montserratians that would enable the autonomous management of natural resources; The CCC Scholarship Programme.

The MRRCP built upon the conservation management work already conducted for the Central Hills, thus contributing significantly to the establishment of a holistic conservation management plan for Montserrat, feeding into Montserrat’s Sustainable Development Plan (2008-2020) which identifies biodiversity conservation as a key strategic goal.

The following report will focus on the key outputs from the MMCP and provide recommendations for the protection of the nearshore environment.

1.1. Nearshore waters of Montserrat

The Caribbean is in the northern and western hemisphere with tropical climates around the archipelago. The Caribbean holds three main coastal habitats: coral reefs, mangroves and seagrass meadows, all of which hold importance for the many islands’ biological life, fisheries and cultural resources. Many marine habitats have been highly impacted through the use of various fishing gears such as trawls and dredges, resulting in reduced seabed complexity and the removal of coral reefs (and the related macro-benthic organisms) [55, 13], in addition to other anthropogenic, environmental and biological stressors [41]. The resulting loss of reef structure directly and indirectly impacts complex interactions throughout systems reducing overall habitat

*Corresponding Author: Tel. +44 (0) 333 347 0134; Tel. +44 (0) 207 620 1411; URL. www.coralcay.org

Email address: headofscience@coralcay.org (Thomas Dallison)

health and ecosystem services [46, 32]. A 2004 study indicated that the degradation of Caribbean coral reefs could result in annual losses of up to USD\$420.0 million from reduced coastal protection within the next 50 years [8, 16].

Montserrat is a small island within the Leeward Isles in the Lesser Antilles and has an area of approximately 102 km² (maritime claim area of 8,120 km²) [29, 4]. It is located at 16° 45.0N, 062° 12.0W and like most islands in the region, is volcanic.

Historically, Montserrat had mangrove forests composed of four species located over four bays; Carr's Bay, Collin River, Fox's Bay, and Old Road Bay. Grazing livestock and coastal development, however, has resulted in the loss of most of these forests (FAO 2007; Blue Halo, 2015). These mangrove forests, specifically those located at Carr's Bay, were known to be habituated by the red-footed tortoise (*Chelonoidis carbonarius*), now considered locally extinct. By 2010, the FAO reported that Montserrat had no remaining mangrove habitat [25].

Seagrass meadows are found throughout Montserrat's coastal waters, with three species identified; shoalgrass (*Halodule wrightii*), manatee grass (*Syringodium filiforme*), and turtle grass (*Thalassia testudinum*) [4]. Studies suggest that large storm events, and boat anchor damage have detrimentally affected the abundance and health of Montserrat's seagrass meadows [31]. There are currently (2018) large sea grass meadows located between Bransby Point and Old Road Bluff, including within the Maritime Exclusion Zone, and smaller patches close found along the east, south, and west coasts [35, 4].

A variety of surveys have been conducted on Montserrat's coral reef communities over the past decade, including official Reef Check surveys and surveys by LTS International and Blue Halo [4]. Sedimentation has been highlighted as a significant threat to the health of reefs, especially on the eastern coast of the island. However, the south of the island has indicated healthier reefs due to water currents increasing water turnover [41]. Coral diseases are also present around Montserrat: white-band disease has killed most of the elkhorn and staghorn coral on the Northwest coast of the island [41]. The increasing numbers of the invasive Lionfish (*Pterois* spp.) are also causing ecosystem disruption through the predation of smaller, juvenile fishes and invertebrates.

Montserrat's reef system is perturbed by anthropogenic activities. The estimated true impact of fishing practices around Montserrat was emphasised with at least 100 non-licensed fishermen who are unsustainably fishing around the island, including within the exclusion zone [48]. Further studies identified a variety of gear types and fishing practices used by Montserratian fishers, including beach seines, traps, bottom lines, hand-lines, cast nets, gill nets, long-lines, rod and reel, and spearfishing. Species targeted were large fish species available and megafauna such as sharks and turtles during opportunistic moments. Annotated responses from fisherfolk described a decreased trend in total catch and size of individual fishes over the decade with catches also becoming less frequent. The conditions described by the Montserratian fisherfolk are indicative of a system that is overfished, possibly leading to a change in composition of reef fish [36, 27]. Due to both natural and anthropogenic causes, the reefs on the western coastline of Montserrat have experienced, and continue to experience degradation. This is varied along the coastline, exasperated by changing topography and human population centres [12, 4].

1.2. Mitigating Detrimental Impacts

In order to minimise detrimental threats and remediate historic impacts, a common solution turned to by resource managers is the establishment of Marine Protected Areas (MPA). A key aspect of the establishment of an MPA is the identification of areas of ecological significance; value, aggregation, nursery and spawning grounds [18]. The International Union for the Conservation of Nature (IUCN) defines an MPA as:

“A clearly defined geographical space, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with the associated ecosystem services and cultural values.”

These protected areas provide areas of reduced human activities to coral reef and pelagic fishes during their respective life-stages; essential to the recruitment and ecological recovery of communities. Adaptive management within MPAs is an essential aspect when considering an Ecosystem-based management (EBM) approach; an approach that recognizes the interactions between ecosystems and humans and works across sectors to manage species and habitats, economic activities, conflicting uses, and the sustainability of

resources. The protection of marine areas can achieve conservation and resource management targets simultaneously and are therefore considered instrumental to sustainable ocean utilization [47]. As Montserrat utilises its waters for recreation, tourism and sustenance, the necessity for a network of effective MPAs is increasing and required [18].

2. Quantifying Montserrat's Marine Resources

The MMCP aimed to promote the sustainable use of marine resources in Montserrat, resulting in increased livelihood opportunities through sustainable fisheries and ecotourism. The project was composed of three phases over a four year period; systematic baseline data collection, site-specific ecological surveys, and Lime Kiln Bay-focused data collection. Collectively, efforts resulted in biophysical surveys being conducted along the western coastline of Montserrat enabling the spatial assessment of ecological status and resource distribution.

2.1. Study Site

The surveying period from 2013 – 2017 resulted in a total of $n = 101$ independent marine bio-physical surveys being undertaken (Fig. 1). Phase I was a preliminary baseline study where divers systematically surveyed every 500m of the western coastline of Montserrat at 6m and 12m depths, resulting in $n = 45$ Baseline sites. Phase II focused on site-specific surveys, identified from Phase I efforts, at Lime Kiln Bay, Isle's Bay, Old Road Bay, Woodlands Bay, and Carr's Bay where reef was present. Surveys were also conducted at 6m and 12m depths.

Phase III saw efforts focused on Lime Kiln Bay, located on the South-West coast of Montserrat (16°45.0382 N, -62°13.5781 E) (Fig. 1). Phase I and Phase II highlighted the relative conservation value of Lime Kiln Bay [18] and therefore, the need was recognised for higher resolution data.

2.2. Data Collection Protocols

The assessment of the surveyed areas was conducted through an enhanced Reef Check protocol. CCC augmented the protocol to reflect the biodiversity of the focus region with the addition of extra target organisms to supplement the MMCP's goals and objectives

(Appendix A.4, Appendix A.5, and Appendix A.6).

100m transects were laid on benthic substratum at each survey focus area, parallel to the shoreline, on a north to south bearing at depths of 6m and 12m. Each transect was segmented into four 20m sections, separated by a 5m gap, where no data were collected to ensure independent samples. This equated to a total surveyed transect length of 80m per transect. Each transect was separated by approximately 100m.

Target fish abundance and sample diversity data were collected through Underwater Visual Census (UVC) techniques via SCUBA. Data were recorded using 'belt' transects where fish were observed along each 20m segment within an imaginary 5x5x20m (Wx-HxL) box, equating to a surveyed volume of 500m³. Surveyors paused at 5m intervals for one-minute to allow for fish to return to 'normal' behaviour (data collection continued during this period). In addition, the abundance and estimated Total Length (TL (cm)) (placed into 10cm size increments) of fishes considered to be commercially important around Montserrat was recorded (Parrotfish (Scaridae), Coney (*Cephalopholis fulva*), Hind (*Epinephelus guttatus* and *E. adscensionis*), Nassau Grouper (*Epinephelus striatus*) and other Groupers (Epinephelinae)). The biomass (kg) of commercially important fishes was estimated through Length-Weight Relationships (Equation 1).

Equation 1. Length-Weight relationship used to determine the biomass (kg) of individual fishes recorded during Underwater Visual Census (UVC) surveys.

$$W = aL^b \quad (1)$$

Where W = mass (g), a = the condition factor, b = species-specific growth parameter. L = total length (TL) measured of the individual fish.

Data were sourced from Fish Base (www.fishbase.org) to generate the appropriate allometric coefficients for the commercially important fishes, with geometric means calculated for each surveyed family (Table. 1). The abundance and diversity of selected target invertebrate organisms were recorded along the same belt transect utilised for fish data collection. Two divers recorded invertebrates 2.5m either side of the transect line whilst swimming in a U-shaped pattern. A total area of 100m² was surveyed per 20m segment.

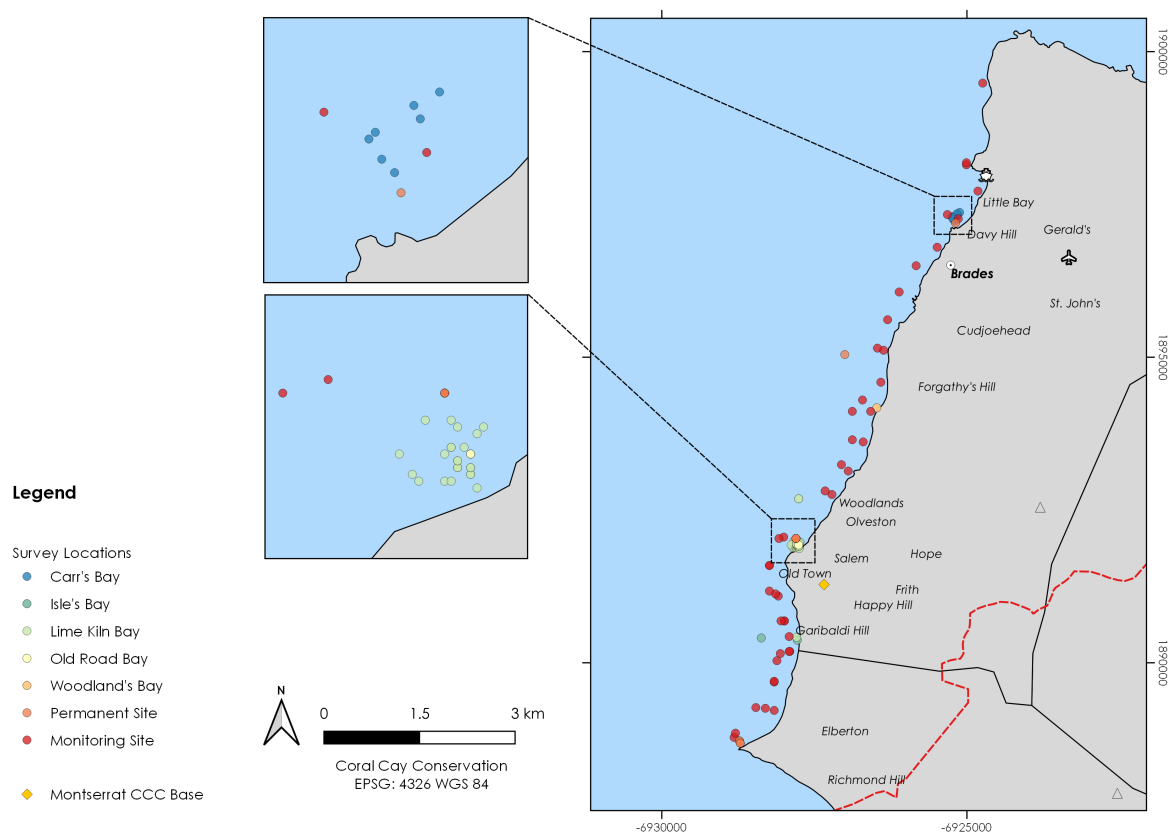


Figure 1: Visual representation of locations surveyed by Coral Cay Conservation from 2013 - 2017

Table 1: Allometric Coefficients for Length-Weight Relationships to determine individual fish mass (g)

	Target Fish	Common Name	<i>a</i>	<i>b</i>
Epinephelinae	<i>Cephalopholis fulva</i>	Coney	0.0162	3.0061
	<i>Epinephelus striatus</i>	Nassau Grouper	0.0098	3.1306
	<i>E. guttatus</i> ; <i>E. adscensionis</i>	Hind	0.01330	3.0391
	Other	Grouper	0.0118	3.0625
Scaridae	Other	Parrotfish	0.0158	3.0433

Within the same area assessed for invertebrates, divers also recorded observable impacts. The total percentage (%) of bleached coral cover was estimated together with an indication of severity through the percentage (%) of bleaching present on each coral colony. Coral diseases were identified where present and recorded as a percentage of the colony infected. Damage was recorded in three categories; boat/anchor damage, dynamite, and other. Impacts were graded on an ordinal scale from 0-3 (0 = none, 1 = low, 2 =

medium, 3 = high). The impact of trash was recorded on the same scale and sub-categorised into 'general' and 'fish nets/traps'.

Benthic diversity and community composition were measured by recording biotic and abiotic substrate categories (Appendix A.6) along a Point Intercept Transect (PIT). Substrates were recorded directly beneath each 50cm increment along the same 20m segment (resulting in 40 recorded points per 20m) and

respective 100m transect.

The Conservation Management Value (CMV) was calculated to present the level of biological richness within each site. The CMV for each transect was determined through comparative studies between location specific and holistic means for the grouping variable. Seven grouping variables were used: Scleractinian hard coral composition (%); Alcyonacea abundance; fish abundance; fish diversity; invertebrate abundance; invertebrate diversity; and commercially important fish biomass. The mean was determined for each transect and was compared to the overall mean of the grouping variable from the survey area. If the transect mean was found to be above the overall mean, the transect was given a score of '1'. This was repeated for each of the grouping variables. As a result, a site may have a maximum CMV of 7 and a minimum of 0. It must be noted that due to the method of calculation for CMV, a low value does not definitively represent an area that is biologically 'poor'. This is due to the CMV being a comparative score for surveyed sites and thus the CMV for a defined site is of relative value to others.

2.3. Data Analysis

Each 20m belt transect segment was treated as an independent sample. This produced a total of $n=404$ samples throughout the entire survey period, following data-sorting where data entries with known errors and/or missing data points were removed. Tests for distribution (Shapiro Wilks test) indicated the data deviated from a normal distribution (non-parametric) [52] and attempts of transformation did not satisfy parametric testing assumptions (O'Hara and Kotze 2010; Morris et al., 2014). Thus, non-parametric Wilcoxon-Mann-Whitney U (W) tests were used to test for statistically significant ($p < 0.05$) median (Mdn) differences across collected variables between all transects. To determine diversity for coral reef associated communities of target fishes and invertebrates, Shannon-Wiener Diversity Index (H') was produced.

In order to assess correlations between two continuous factors, Pearson's product-moment correlation tests were deployed. Results reported display the r statistic, indicating the trend of the correlation and the statistical significance of the correlation ($p < 0.05$).

Univariate statistical analyses were conducted using the statistical software 'R' [49] and 'Vegan' package

[42]. Cluster analysis was conducted through R utilising the 'Vegan' package. Data were organised into community matrices for each tested variable and organised using 'Jaccard' indices of similarity. Dendrograms were then subsequently produced and presented with the mean 'Jaccard' indices. Clusters were taken from the mean slice (termed the JDI split).

Baseline and permanent transects were excluded from site-specific analysis and are clearly defined.

3. Results

Throughout the survey period, from 2013 – 2017, a total of 101 surveys ($n=404$ replicates) were conducted throughout Lime Kiln Bay, Old Road Bay, Woodlands Bay, and Carr's Bay including baseline and permanent transects. Underwater horizontal visibility in relation to turbidity ranged from 2m to 30m with a mean of 15.71 ± 4.87 m. Furthermore, the mean Sea Surface Temperature (SST) ($^{\circ}\text{C}$) was $29 \pm 1.41^{\circ}\text{C}$. No significant difference in visibility and temperature was observed between survey sites over time indicating homogenous turbidity levels and temperatures.

The location of transects relative to human population centres varied considerably along the coast ranging from 0.5km to 5km. Over the survey period, two hurricanes were recorded, however, these were not deemed to be detrimental to the marine environment with no direct or indirect damage observed.

Surveyed sites experienced overall 'low' levels of anthropogenic impact (sewage, live food trade, commercial fishing, personal consumption and fishing invertebrates for consumption) throughout the sample period (Fig. 2). Diving and snorkelling were considered 'low/medium' impact. Consequently, yacht anchorage within 1km of study locations was recorded as 'high' impact, mostly prevalent within Lime Kiln Bay, Isles Bay and Carr's Bay.

3.1. Fish Community Assemblages

A total of 82,661 individual fishes were recorded with samples varying greatly between survey locations ranging from 0 to 1,284.00 500m^3^{-1} representing a collective mean density of 203.20 ± 205.42 500m^3^{-1} (Mdn = 155; Fig. 3a). Concerning the diversity (H') of community assemblages recorded at each survey

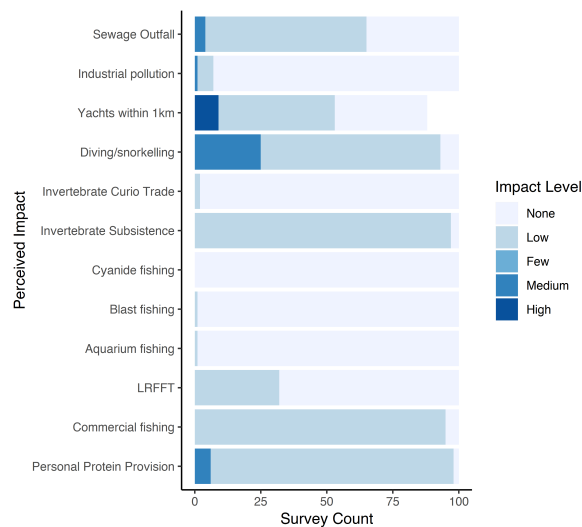


Figure 2: Proportional recorded impact levels (none, low, few, medium and high) across all surveyed sites throughout the sample period

site, samples also varied throughout the survey period, ranging from $0.00 \text{ } 500\text{m}^3\text{ }^{-1}$ to $2.07 \text{ } 500\text{m}^3\text{ }^{-1}$ (Mean = $0.73 \pm 0.49 \text{ } 500\text{m}^3\text{ }^{-1}$; Mdn = 0.82; Fig. 3b).

From the five geographically constrained sites (Carr's Bay, Isle's Bay, Lime Kiln Bay, Old Road Bay, and Woodland's Bay), 37,740 individual fishes were recorded (Mean = $224.64 \pm 163.43 \text{ } 500\text{m}^3\text{ }^{-1}$; Mdn = 216). In comparison to all sites, Lime Kiln Bay hosted the highest abundance of fishes ($237.18 \pm 162.86 \text{ } 500\text{m}^3\text{ }^{-1}$) followed by Carr's Bay ($235.61 \pm 150.99 \text{ } 500\text{m}^3\text{ }^{-1}$). Isle's Bay and Old Road Bay hosted the lowest abundant fish communities ($98.17 \pm 146.52 \text{ } 500\text{m}^3\text{ }^{-1}$ and $145.75 \pm 110.53 \text{ } 500\text{m}^3\text{ }^{-1}$, respectively). Despite recording a relatively high mean abundance of fishes ($230 \pm 242.46 \text{ } 500\text{m}^3\text{ }^{-1}$), Woodland's Bay demonstrated highly variable sample-level abundances ranging from 0 – 571 alongside a small sample size ($n=4$). Further investigation highlighted differences in fish abundance between Lime Kiln Bay (Mdn = 235) and Isles Bay (Mdn = 12.50) (Wilcoxon Test, $W = 1,035.5$, $p < 0.05$). Additionally, Carr's Bay (Mdn = 224.50) also differed to Isles Bay (Mdn = 12.50) ($W = 259.5$, $p < 0.05$).

The most commonly observed target fishes across the entire sample period were Wrasse (Labridae) with 49,997 individuals ($123.75 \pm 124.92 \text{ } 500\text{m}^3\text{ }^{-1}$; Mdn = 89) followed by Damselfish (Pomacentridae) (22,865 individuals; Mean = $56.60 \pm 98.55 \text{ } 500\text{m}^3\text{ }^{-1}$; Mdn = 15)

and Surgeonfish (Acanthuridae; excluding blue tangs) (3,489 individuals; Mean = $8.64 \pm 10.41 \text{ } 500\text{m}^3\text{ }^{-1}$; Mdn = 5). Invasive Lionfish (*Pterois* spp.) were observed on 8 occasions across the five survey locations, though others were observed anecdotally outside of survey parameters. There were no clear trends associated with fish abundances over time throughout the sample period.

Fish community assemblages at Lime Kiln Bay were dominated by Wrasse ($152.46 \pm 114.97 \text{ } 500\text{m}^3\text{ }^{-1}$; Mdn = 149) and Damselfish ($59.31 \pm 73.91 \text{ } 500\text{m}^3\text{ }^{-1}$; Mdn = 36). Isle's Bay presented the most diverse (H') fish communities ($0.85 \pm 0.64 \text{ } 500\text{m}^3\text{ }^{-1}$, Mdn = 0.97) however results were highly heterogeneous at the sample-level with no significance recorded in comparison to other sites ($p > 0.05$). High levels of comparative diversity were recorded at Lime Kiln Bay ($0.84 \pm 0.45 \text{ } 500\text{m}^3\text{ }^{-1}$, Mdn = 0.92) of which were greater than those recorded at Carr's Bay and Old Road Bay ($0.73 \pm 0.28 \text{ } 500\text{m}^3\text{ }^{-1}$; Mdn = 0.69 and $0.40 \pm 0.34 \text{ } 500\text{m}^3\text{ }^{-1}$; Mdn = 0.39, respectively) ($W = 1272.50$, $p < 0.05$ and $W = 96.50$, $p < 0.05$).

3.1.1. Herbivorous fishes

A total of 27,947 individual herbivorous fishes were recorded throughout all surveys sites with samples varying greatly ranging from $0.00 \text{ } 500\text{m}^3\text{ }^{-1}$ to $939.00 \text{ } 500\text{m}^3\text{ }^{-1}$ representing a collective mean herbivore density of $69.18 \pm 105.15 \text{ } 500\text{m}^3\text{ }^{-1}$ (Mdn = 35; Fig. 4).

When considering the five geographically constrained sites, 11,011 herbivorous fishes were recorded ($65.54 \pm 71.09 \text{ } 500\text{m}^3\text{ }^{-1}$; Mdn = 51). Herbivorous fishes were further categorised into seven target families; Acanthuridae ($9.52 \pm 9.03 \text{ } 500\text{m}^3\text{ }^{-1}$); Blue Tangs (*Acanthurus coeruleus*) ($1.83 \pm 2.49 \text{ } 500\text{m}^3\text{ }^{-1}$); Chubs (Kyphosidae) ($0.01 \pm 0.08 \text{ } 500\text{m}^3\text{ }^{-1}$); Trunkfish (Ostraciidae) ($0.20 \pm 0.70 \text{ } 500\text{m}^3\text{ }^{-1}$); Pomacentridae ($53.02 \pm 67.04 \text{ } 500\text{m}^3\text{ }^{-1}$); Angelfish (Pomacanthidae) ($0.18 \pm 0.46 \text{ } 500\text{m}^3\text{ }^{-1}$); and Scaridae ($0.78 \pm 1.29 \text{ } 500\text{m}^3\text{ }^{-1}$). Pomacentridae were the dominant herbivorous target family recorded across all five survey sites with no Hemiramphidae (Halfbeaks) being recorded.

The comparative composition of herbivory communities can be described through cluster analysis, in which each site presented highly variable herbivorous abundances. Lime Kiln Bay ($71.31 \pm 76.39 \text{ } 500\text{m}^3\text{ }^{-1}$) and Woodlands Bay ($74.50 \pm 89.78 \text{ } 500\text{m}^3\text{ }^{-1}$) held the largest similarity of 69%. Isles Bay ($32.42 \pm 54.59 \text{ } 500\text{m}^3\text{ }^{-1}$)

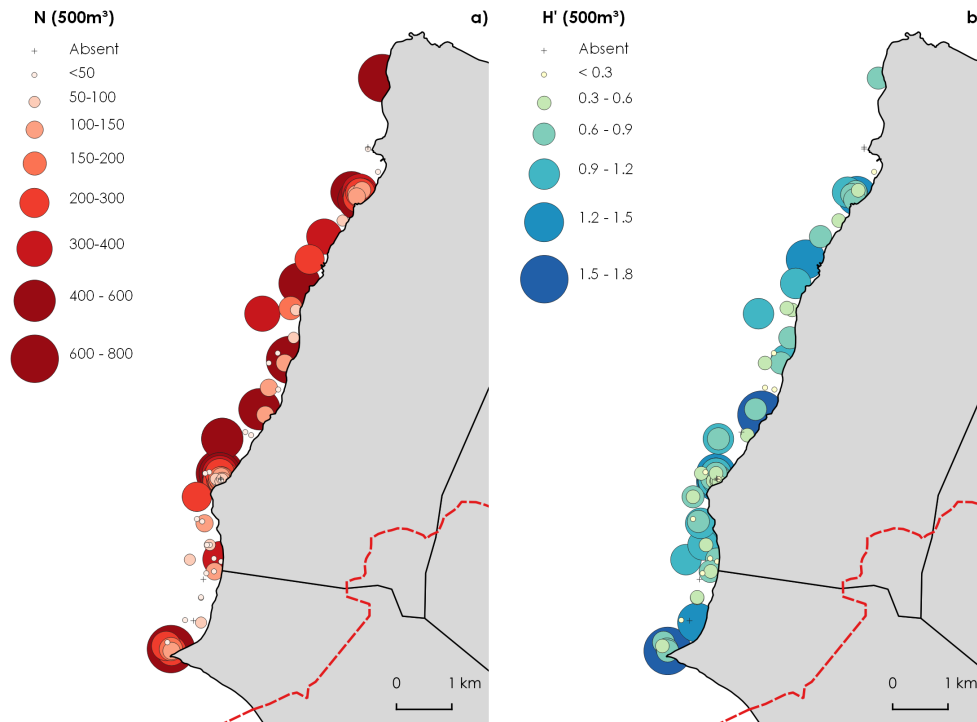


Figure 3: Spatial distribution of target fish density (a) and sample diversity (H') recorded from all surveyed locations.

and Old Road Bay ($22.75 \pm 26.09 \text{ 500m}^3^{-1}$) also clustered at 65% (Appendix A.12).

3.2. Community Characteristics of Commercially Important Fishes

Commercially important fishes were composed of individual species, genera and families resulting in individuals from five 'groups' being recorded. A total of 1,888 individuals were recorded ($4.67 \pm 9.65 \text{ 500m}^3^{-1}$; $\text{Mdn} = 2$) from all survey locations. Samples also varied with a maximum abundance of $138.00 \text{ 500m}^3^{-1}$. Coneys (*Cephalopholis fulva*) were recorded in the greatest abundance with $932 (2.32 \pm 3.61 \text{ 500m}^3^{-1})$ individuals. Parrotfish (Scaridae) were the subsequent most abundant ($2.07 \pm 8.90 \text{ 500m}^3^{-1}$) followed by Other Groupers (Epinephelinae) ($0.23 \pm 1.41 \text{ 500m}^3^{-1}$), rock and red hind (*Epinephelus* spp.) ($0.05 \pm 0.30 \text{ 500m}^3^{-1}$) and Nassau Groupers (*Epinephelus striatus*) ($0.03 \pm 0.35 \text{ 500m}^3^{-1}$). The low density of commercially important fishes is supported by the relatively low biomass (kg) recorded throughout the survey period ($0.34 \pm 0.75 \text{ kg 500m}^3^{-1}$) with *C. fulva* recording a mean biomass of $0.22 \pm 0.59 \text{ kg 500m}^3^{-1}$ (total standing biomass of 89.50kg; Fig. 5). *C. fulva* were recorded in their greatest abundances within the size class 11-20cm

(477), with a further 171 individuals recorded $>21\text{cm}$.

The low abundances recorded throughout the survey period were also apparent when considering site-specific abundance and biomass (kg), highlighting that the majority of all large fish were absent from surveys with 4 commercially important individuals recorded $>50\text{cm}$ and 31 recorded between 31-40cm. *C. fulva* were recorded in greater biomass densities at Lime Kiln Bay in comparison to both Carr's Bay ($W = 2837.50$, $p = < 0.05$) and Isle's Bay ($W = 1215.50$, $p = < 0.05$) as well as Woodland's Bay ($W = 394$, $p = < 0.05$). The recorded biomass of *Epinephelus* spp. was greater at Lime Kiln Bay in comparison to Woodland's Bay ($W = 187$, $p = < 0.05$) with Woodland's Bay hosting a greater biomass than Carr's Bay ($W = 47$, $p = < 0.05$). Lime Kiln Bay also hosted a greater biomass of Parrotfish when compared to Isle's Bay ($W = 452.50$, $p = < 0.05$) whilst Isle's Bay recorded a greater biomass than Carr's Bay ($W = 104$, $p = < 0.05$). Three clusters were indicated, following complete linkage, with a mean similarity slice at 0.69% (Appendix A.13).

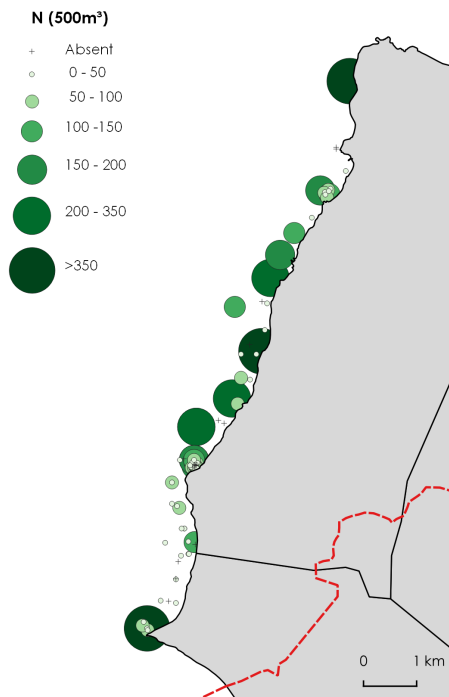


Figure 4: Spatial distribution of herbivorous fishes recorded across all locations.

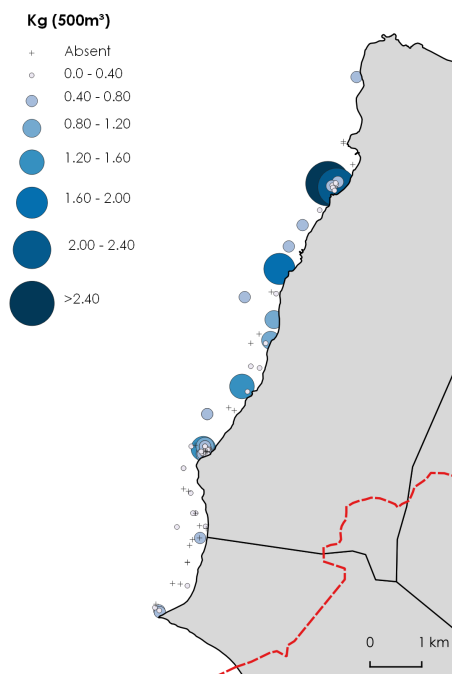


Figure 5: Spatial distribution of commercially important fish biomass (kg) recorded across all locations.

3.3. Invertebrate Communities

A total of 49,210 invertebrates were recorded during the survey period with all target organisms being represented. Gorgonians (Alcyonacea) were the most abundant invertebrate (44,421), however, due to their dominance throughout the survey area, were analysed independently (Section 3.3.1).

Excluding Alcyonacea from analyses, the mean abundance of invertebrates throughout the sample period and across all sites was $11.85 \pm 20.76 \text{ } 100\text{m}^{-2-1}$ (Mdn = 4.5), with Pencil Urchins (*E. tribuloides*) being the most abundant ($8.04 \pm 14.07 \text{ } 100\text{m}^{-2-1}$). Samples were highly heterogeneous throughout the sample period ranging from $0.00 \text{ } 100\text{m}^{-2-1}$ to $178.00 \text{ } 100\text{m}^{-2-1}$. When considering constrained sites, the mean abundance increased ($16.40 \pm 20.17 \text{ } 100\text{m}^{-2-1}$; Mdn = 10) with Lime Kiln Bay presenting the greatest proportion ($7.12 \pm 23.74 \text{ } 100\text{m}^{-2-1}$). *E. tribuloides* was also the most abundant invertebrate ($11.90 \pm 14.79 \text{ } 100\text{m}^{-2-1}$, Mdn = 6) and was recorded in significantly greater abundances at Lime Kiln Bay (Mdn = 10) when compared to Carr's Bay (Mdn = 1.5) ($W = 685, p = < 0.05$) (Fig. 6a).

Location also influenced the diversity of target invertebrate community samples at each of the five surveyed sites (Fig. 6b). The diversity (H') of invertebrate communities assessed at Carr's Bay were the most diverse ($0.55 \pm 0.43 \text{ } 100\text{m}^{-2-1}$, Mdn = 0.66), greater than those recorded at Isles Bay ($0.17 \pm 0.40 \text{ } 100\text{m}^{-2-1}$, Mdn = 0) ($W = 970, p = < 0.05$) and Lime Kiln Bay ($0.32 \pm 0.32 \text{ } 100\text{m}^{-2-1}$, Mdn = 0.28) ($W = 2230.5, p = < 0.05$).

3.3.1. Gorgonian (Alcyonacea) Abundance

Throughout the survey period, 44,421 individual Alcyonacea colonies were recorded, equating to $109.95 \pm 162.22 \text{ } 100\text{m}^{-2-1}$ (Mdn = 38). (From all surveys sites, including baseline and permanent sites). Accounting for site-specific mean abundance ($123.83 \pm 99.93 \text{ } 100\text{m}^{-2-1}$, Mdn = 130.50), Lime Kiln Bay held the highest ($158.28 \pm 92.01 \text{ } 100\text{m}^{-2-1}$), followed by Carr's Bay ($52.04 \pm 67.83 \text{ } 100\text{m}^{-2-1}$). Isles Bay presented the lowest abundance of Alcyonacea colonies ($1.50 \pm 3.45 \text{ } 100\text{m}^{-2-1}$). Wilcoxon tests further indicated a significantly greater Gorgonian abundance recorded at Lime Kiln Bay (Mdn = 160.50) in comparison to Carr's Bay (Mdn = 32) ($W = 719.5, p = < 0.05$), Isles Bay (Mdn = 0) ($W = 120, p = < 0.05$), Old Road Bay (Mdn = 24) ($W = 386, p = < 0.05$), and Woodlands Bay (Mdn = 29.50) ($W = 405.5, p = < 0.05$).

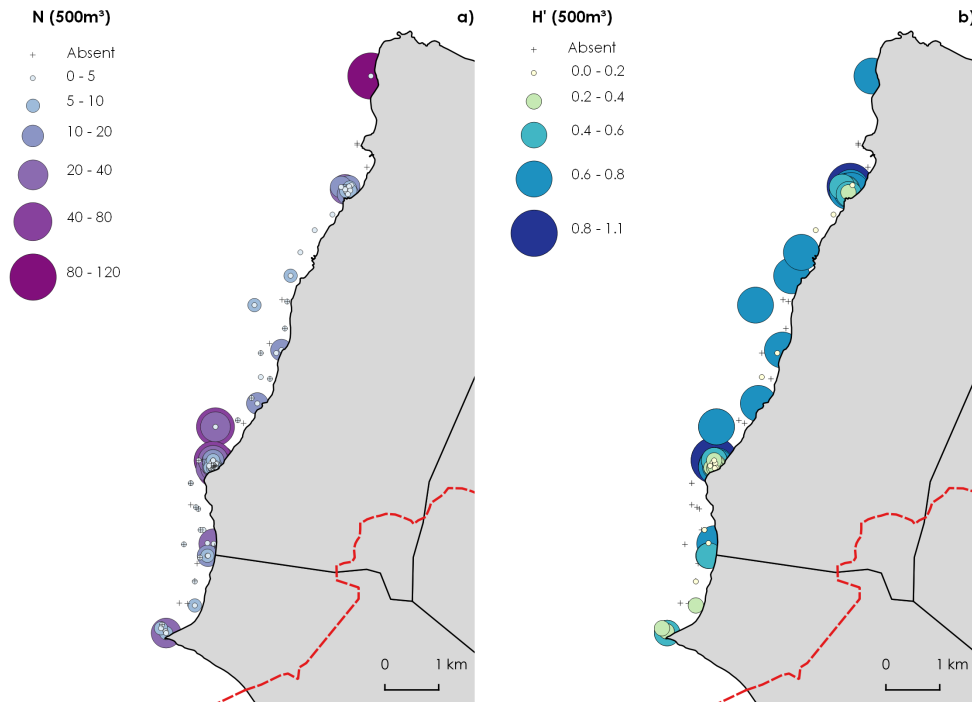


Figure 6: Spatial distribution of target invertebrate density (a) and sample diversity (H') recorded from all surveyed locations

3.4. Benthic Substrate Composition

From 2013 – 2017, a total of 16,160m of substrate was surveyed along the western coastline of Montserrat, from all survey sites. Sand (SD) was the dominant substrate recorded, composing $48.10 \pm 38.97\%$ $20m^{-1}$ (Mdn = 41.25%) of transects, followed by Rock (RC), $15.81 \pm 20.90\%$ $20m^{-1}$ (Mdn = 5%) and substrates that did not conform to a specific criterion (Other), $14.33 \pm 30.05\%$ $20m^{-1}$ (Mdn = 2.50% ; Fig. 10). Hard Coral (HC) was recorded in a relatively low compositions throughout the survey period ($2.90 \pm 4.74\%$ $20m^{-1}$; Mdn = 0%). Nutrient Indicator Algae (NIA) was recorded with a mean composition of $9.52 \pm 14.00\%$ $20m^{-1}$ (Mdn = 1.25%) throughout all surveyed sites (Appendix A.15).

When considering spatially restricted sites, Sand ($47.92 \pm 36.60\%$ $20m^{-1}$; Mdn = 42.50%) and Rock ($18.76 \pm 19.70\%$ $20m^{-1}$; Mdn = 12.50%) continued to dominate, however, 'Other' substrates decreased ($4.14 \pm 9.23\%$ $20m^{-1}$; Mdn = 2.50%) whilst NIA increased ($14.38 \pm 15.60\%$ $20m^{-1}$; Mdn = 10%), becoming the third most represented substrate. Hard Coral continued to be poorly represented amongst survey sites ($3.53 \pm 4.91\%$ $20m^{-1}$; Mdn = 0%).

The composition of NIA at Lime Kiln Bay (Mdn = 15%) was significantly greater than that recorded at Carr's Bay (Mdn = 3.75%) ($W = 1096, p < 0.05$), Isles Bay (Mdn = 0%) ($W = 235.5, p < 0.05$) and Old Road Bay (Mdn = 0%) ($W = 52, p < 0.05$). Similarly, HC showed a significant difference at Lime Kiln Bay (Mdn = 2.5%) compared to Carr's Bay (Mdn = 0%) ($W = 1000, p < 0.05$), Isles Bay (Mdn = 0%) ($W = 276, p < 0.05$) and Old Road Bay (Mdn = 0%) ($W = 92, p < 0.05$), with no significance between Woodlands Bay.

The composition of Sponge (SP) was also found to vary between surveyed sites. Carr's bay (Mdn = 0%) indicated significantly more SP composition than Isles Bay (Mdn = 0%) ($W = 100, p < 0.05$). Lime Kiln Bay (Mdn = 2.5%) also hosted a significantly greater SP composition than Isles ($W = 1082, p < 0.05$) and Old Road Bay (Mdn = 0%) ($W = 374, p < 0.05$). Furthermore, Lime Kiln Bay (Mdn = 17.5%) indicated significantly more RC composition than Isles (Mdn = 0%) ($W = 1117.5, p < 0.05$), Old Road Bay (Mdn = 0%) ($W = 391.5, p < 0.05$) and Woodlands Bay (Mdn = 0%) ($W = 414, p < 0.05$). No differences between

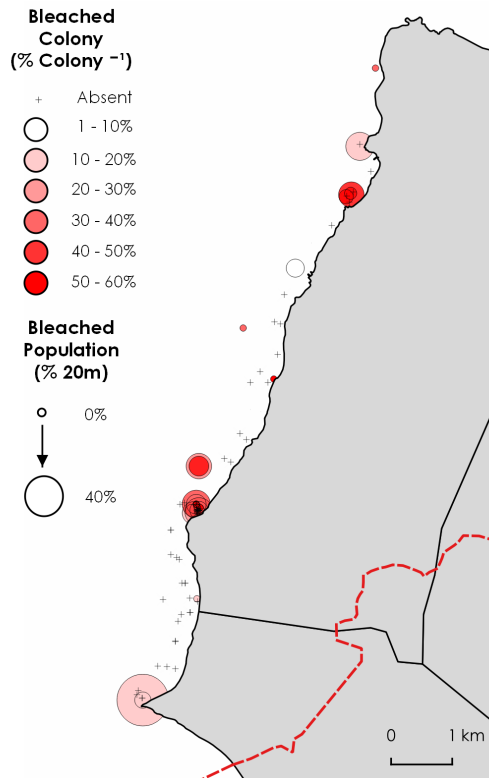


Figure 7: The recorded bleaching (%) per sample population of Scle-ractinia hard corals throughout the sample period with a severity of bleaching indicated by bleaching (%) per colony.

sites were observed regarding the remaining substrates.

Considering the complete benthic structure in its entirety, two clusters were identified through JDI at the mean 50% slice (Appendix A.14). Carr's Bay and Lime Kiln Bay were 48% similar. The sub-cluster between Old Road Bay and Woodlands Bay illustrated a similarity of 89%. Considering benthic impacts, bleached coral colonies were observed on 24% of all samples surveyed throughout the survey period, with $35.24 \pm 27.45\%$ of each individual colony being bleached (Fig. 7). Black band and white syndrome disease were recorded in low incidences throughout the survey period (present on 1% and 2% of all samples, respectively) (Fig. 8). Regarding Gorgonians, 36% of all surveyed samples recorded incidences of Aspergillois (Fig. 8).

3.5. Community Characteristics and Benthic Substratum

Where geographically constrained sites are considered, there was a strong positive correlation observed

between hard coral composition and the abundance of coral reef associated fishes ($r_s = 0.55, p = < 0.05$) (Fig. 9; 2). Hard coral composition was also observed to influence the community assemblage of fishes (H') ($r_s = 0.31, p = < 0.05$) as well as the biomass of commercially important fish species ($r_s = 0.40, p = < 0.05$).

Coral reef associated fishes also demonstrated a positive correlation with Gorgonian composition ($r_s=0.60, p = < 0.05$), H' ($r_s=0.43, p = < 0.05$) alongside biomass of commercially important fishes ($r_s=0.61, p = < 0.05$) (Fig. 9). The variance of H' could be greater described by the abundance of Gorgonian substrates ($r^2 = 0.43\%$) in comparison to the composition of HC ($r^2 = 0.31\%$) at any sampled site (Table. 2).

E. tribuloides held the strongest correlation with NIA composition ($r_s=0.54, p = < 0.05$) (Table. 2). The abundance of *Diadema* spp. also exhibited a positive correlation with NIA composition ($r_s=0.38, p = < 0.05$). Subsequently, out of the seven herbivorous target fish recorded during the survey period, only a significant positive correlation occurred between NIA composition and Pomacentridae ($r_s=0.57 p = < 0.05$) and Acanthuridae ($r_s=0.49 p = < 0.05$).

3.6. Conservation Management Values

The Conservation Management Values (CMV) is an index developed to exemplify the categorisation of locations based on seven key parameters measured in relation to other locations. Of all the locations surveyed ($n= 101$), 8 were categorised with the highest (7) CMV (Carr's Bay $n= 1$, Lime Kiln Bay $n= 3$, Permanent Sites $n= 4$) (Fig. 15). No sites surveyed in 2017 presented a CMV of 7. The most represented CMV was 0 ($n= 29$) with a median CMV of 2 across the survey period. $n= 15$ locations were classified with a CMV of 1, subsequently followed by CMV 5 and 6 ($n= 14$ and $n= 13$, respectively) (Fig. 10).

27% of all surveyed locations within Lime Kiln Bay were categorised with a CMV of 6 with 20% classified as 5 and 13% as both 4 and 0. 10% of Lime Kiln Bay was considered to hold the highest conservation value (7). In addition, Carr's Bay held the greatest (excluding Permanent Sites) composition of locations categorised by the highest CMV (7), 14%, however no 5 or 6 CMVs were recorded.

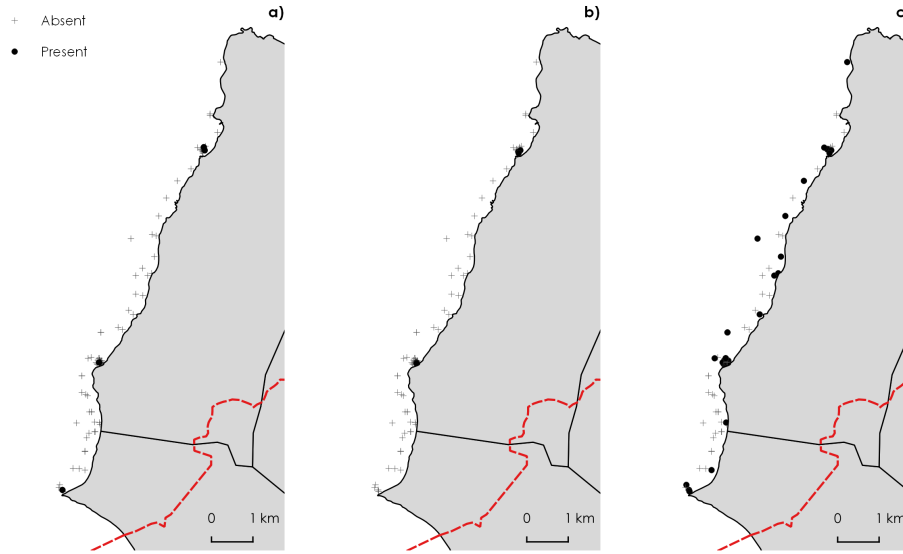


Figure 8: Presence and absence of recorded Black Band Disease (a) and White Syndrome (b) affected Scleractinia corals and Aspergilliosis (c) affected Alcyonacea from surveyed locations throughout the sample time frame

4. Discussion

This study provides MATHLE with a holistic review of the ecological status of the coral reefs and associated systems surveyed between 2013 – 2017 along the western coastline of Montserrat, Caribbean. The report expands on previous assessments and reports submitted by CCC during occupancy in Montserrat ([18]).

4.1. Coral reef associated target fish species and resultant community impacts

The abundance of coral reef associated species surveyed across the survey period, in comparison to other studies [44] was, in general, moderate, with spatially independent sampled bays presenting high transect and site-level variation.

Over 60% of all transects were dominated by shallow depth reef-associated fishes; Labridae and Pomacentridae. This observation is supported by previous studies from Montserrat that demonstrated 90% of fishes recorded during UVCs were within the upper water column (0-10m), indicating the regulatory processes that define reef assemblages. Conversely, this supported dominance of reef-associated fishes may simply be influenced by the protocols utilised throughout the study. Deployed protocols resulted in biophysical transects placed at maximum depths of 12m between 08:30 and 16:00. Therefore, it is unsurprising that the

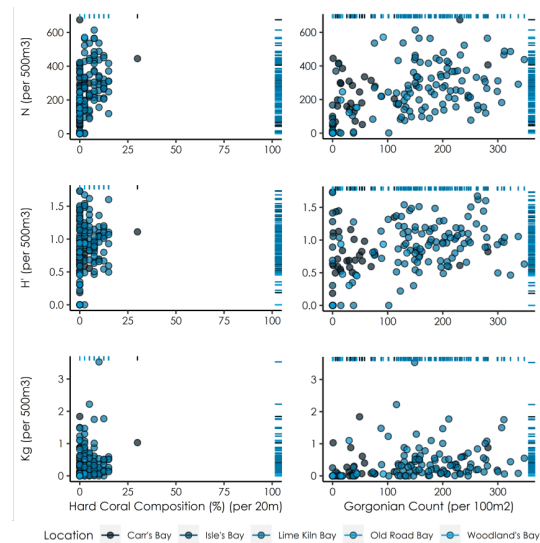


Figure 9: Plotted relationships between abundance (N), Diversity (H'), and Biomass (kg) of recorded target fishes and the composition (%) of Scleractinia corals and Alcyonacea (Gorgonian) counts.

aforementioned dominance within samples is witnessed with minimal influence of more mobile, nocturnally active and/or pelagic (and mesophotic) fishes.

The community characteristics recorded at Lime Kiln Bay were expected due to the bay's levels of recorded complexity and substrate composition, as well as the

Table 2: Results obtained from Spearman’s Rank Correlation Test to visualise relationships between benthic substrate variables, hard coral (HC) and Gorgonian abundance (GO) in correlation with three coral reef community variables. Coral reef associated fish communities are described with abundance (N) and Shannon-Weiner Diversity Indices (H') with biomass (kg/500m³) of commercially important fish species (B). Data are grouped by the five survey sites located along the western coastline of Montserrat, Caribbean.

x	y	r_s	r^2	df	p	c
HC	N	0.55	0.30	166	1.74×10^{-14}	+
	H'	0.31	0.10	166	5.65×10^{-5}	+
	B	0.40	0.16	166	8.03×10^{-8}	+
GO	N	0.60	0.36	166	2.20×10^{-16}	+
	H'	0.43	0.19	166	4.24×10^{-9}	+
	B	0.61	0.37	166	2.20×10^{-16}	+
NIA	<i>Diadema spp.</i>	0.38	0.14	166	4.81×10^{-7}	+
	<i>Eucidaris tribuloides</i>	0.54	0.29	166	2.32×10^{-14}	+
	<i>Tripneustes spp.</i>	-0.14	0.02	166	0.08	-

dominance of Alcyonacea colonies ([57, 30]), further supported by correlation outputs. This result also followed previous studies that quantified Montserrat’s western coastline’s ecological characteristics [18]. The relationship between structural complexity and coral reef associated fish abundance and community diversity is well publicised (E.g. [30]). However, throughout this study, the presence of Scleractinian corals could only account for 30% of the observed transect-level variation recorded. With Alcyonacea abundance accounting for 36% of transect-level variation, the importance of Alcyonacea within Montserrat’s coastal waters in driving fish community assemblage diversity is highlighted in this study. This result contrasts previous studies that have quantified the effect of Alcyonacea on fish abundance in the Caribbean suggesting that Alcyonacea do not provide the same levels of refugia for small bodied fishes that is observed in coral dominated systems [60].

Within coral reef systems, structurally complex reef building corals are often highlighted for their role in supporting highly diverse communities. Other studies within the Caribbean found that some components of reef fish assemblages were influenced by the abundance of smaller individuals (8–20 cm), including juvenile reef fish species. This suggests that fish presence holds a dependency to coral diversity, especially providing important habitat for the abundance of smaller juvenile fish recruits [19]. However, Lime Kiln Bay, despite holding the highest HC composition, was lower in comparison to other Caribbean reefs [1].

When considering herbivorous fishes, samples

presented high levels of variability within, and between, sites most likely driven by the benthic substrate composition and three-dimensional complexity [57]. Herbivorous density within reef systems can often be associated with high biomass and intensive grazing resulting in spatial variation, especially within heterogeneous systems [21]. The presented results are further supported by the spatial variation and general topographic composition of Montserrat’s reefs with Hard Coral exhibiting great variability between samples. This variability is most likely generated by reefs that are separated by large sandy areas, providing a network of patch reefs and coral bommies, as well as the presence of Alcyonacea plains [59].

4.2. Commercially important target fishes

Following the exclusion of permanent and baseline surveys, it is highly likely that the commercially important target fish families recorded showed higher preference to shallow, coastal waters, where the majority of smaller, juvenile fish resided. The size-class of Epinephelinae surveyed across the five locations illustrated a dominance of individuals <10cm throughout the survey period. The size and abundance of Epinephelinae recorded, in comparison to other studies within Caribbean waters was low [4]. However, these comparative studies were conducted in waters adjacent to an uninhibited island that experienced low fishing pressure, and in deeper waters that were inhabited by larger, mature individuals. It can be suggested that the establishment of large MPAs have the potential to drive the recruitment of fishes such as Epinephelinae through

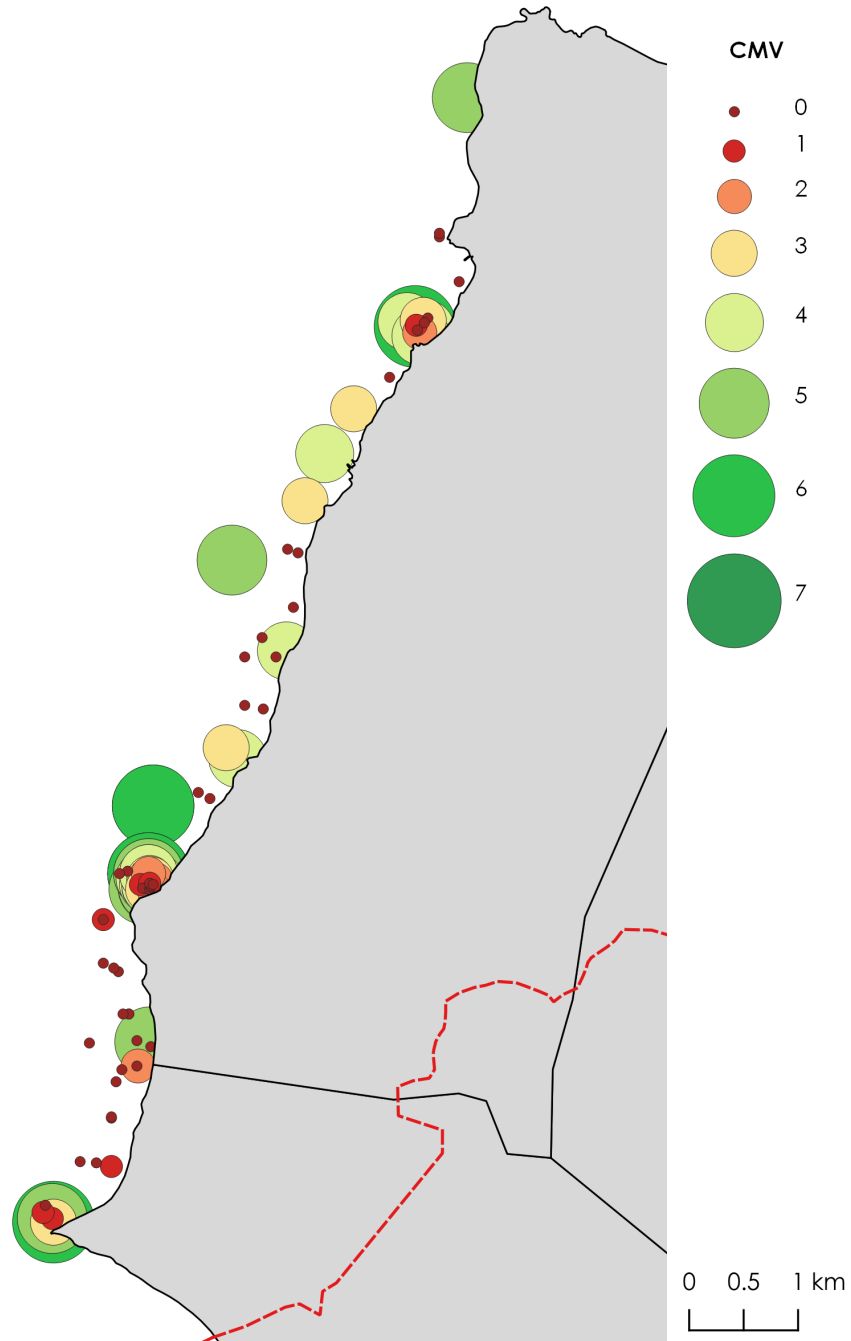


Figure 10: Calculated Conservation Management Values (CMV) for all sampled locations throughout the sample period with larger bubbles indicating a greater CMV for respective sites.

growth and spawning aggregations, increasing the fishery capacity around Montserrat and subsequently result in a spill-over. Throughout the study period, there were no MPAs established within the survey area, and as such no influence occurred during data collection.

Overall, fish biomass presented smaller observations comparative to other Caribbean studies [11, 4], possibly indicating evidence of overfishing throughout Montserrat's coastal waters. To classify this justification further, the home ranges and dispersion of larger, adult commercially important fishes must be considered. Epinephelinae occupy large home ranges (1.8ha) during adult phases and are diurnally active, measuring migrations of over 2km [56]. This increased home range directly influences surveyor/fish exposure, reducing the probability of recording larger individuals. Therefore, although larger, commercially important individuals were present in lower abundances within survey parameters, this does not conclude their absence due to a reduced exposure rate [17]. Smaller and sexually immature Epinephelinae tend to habituate more restricted and local home-ranges [54], increasing exposure rates. In contrast, Epinephelinae within the 21-30cm size class were recorded which indicated the potential presence of mature adult species contributing to the observed biomass, however due to the broad criteria applied to some 'target organisms', species-specific life-histories cannot be derived for general Epinephelinae.

In contrast, where specific species counts were recorded, direct species information could be called upon and subsequently translated to the ecological status of Montserrat's reefs. *C. fulva* were the most frequently recorded commercially important species, with most individuals up to 40cm. *E. guttatus* were recorded infrequently with eight counts throughout the sample period and therefore not common. However, Blue Halo (2016) recorded a mean length of 35cm from fishery length sampling and have recorded hind species as deep as 100m. Epinephelinae found in warm-temperate and tropical regions have experienced intense fishery exploitation. Indicators of intense fishing include declines or change in abundance, size, spawning aggregations, and species composition [11]. Intense fishing pressure often leads to a decrease in the abundance and mean size of fish also resulting in the decline in spawning individuals. Intensively fished areas exhibited lower species richness, reflecting a dominance by smaller, non-fished targeted species [11]. Previous studies expressed how benthic features

tend to hold an important role in structuring coral reef communities [53] with relationships existing between reef habitat and Epinephelinae abundance [18]. *C. fulva* are greatly influenced by community structure, and their respective presence is an indicator of the removal of direct carnivorous competition, such as Epinephelinae overfishing [15]. *C. fulva* in high abundance and biomass around Lime Kiln Bay is a clear indicator of overfishing referring to behavioural competition and predation or larger, target species being eradicated.

The majority of Scaridae individuals were under 10cm with minimal individuals recorded over 30cm. It can be assumed that a large proportion of these sized Scaridae individuals were sexually immature, however as species-specific counts were not taken, this cannot be concluded. Other studies on Montserrat fish biomass such as Acanthuridae, Lutjanidae and *E. guttatus* concluded that individuals are below the species-specific length of first maturity (L_m) which is heavily indicative of a system experienced medium/high levels of fishing pressure [5]. The size distribution of Scaridae is not only a trend throughout survey locations in Montserrat, but also globally [2]. It is known that Scaridae species are fished on Montserrat [4], though intensity is still being studied. Scaridae are known to hold an important functional role on coral reefs by facilitating and promoting coral recruitment, growth and fecundity [40]. With Scaridae removing high levels of sediment, algae (including macro and turf-algae) and coral tissue, the results obtained in this report concur and highlight the need for the conservation of herbivorous species and subsequent HC areas; namely Lime Kiln Bay.

4.3. Coral reef invertebrate assemblages

Within coral reef communities, invertebrates occupy important functional roles, supporting food webs and providing a trophic link between corals and associated fishes [18].

Eucidaris tribuloides occupy low trophic levels due to their algivorous and spongivorous feeding traits [51, 33, 18]. *E. tribuloides* were recorded in greatest abundance (when not considering Gorgonians) throughout the sample period, with Lime Kiln Bay holding the greatest density. Although other studies present greater populations of *E. tribuloides* within the Caribbean (E.g. [6]), it must be noted that some species of Echinodermata are more nocturnally active [24] when considering grazing behaviour, and could therefore explain the seemingly lower populations as a

product of CCC's deployed protocols.

Diadema antillarum were the second highest recorded invertebrate found through the survey period. Alongside *E. tribuloides*, *D. antillarum* were recorded in greatest densities at Lime Kiln Bay. However, no studies were conducted on grazing pressure, therefore extensive analysis on invertebrate behaviour and grazing impact was not included. The mass die-off of *D. antillarum* in the 1980's within the Caribbean is well documented [37, 7, 40, 26]. Whilst some populations have shown signs of recovery following the impacts from the Soufrière hills eruption [23, 50], populations are still yet to recover and not at original numbers prior to the estimated abundance before the 1980's. Throughout the Caribbean, and most likely Montserrat, the reduction of *D. antillarum* as a primary grazer on complex coral reef systems resulted in increases of NIA. As NIA composition was not deemed to be dominating, in comparison to other Caribbean locations [34, 6], the reduction of supportive habitats may be hindering the ability of said populations to recover and overtime become outcompeted by other urchin species such as *E. tribuloides* and *Tripneustes spp.* [18, 26]. Their role can be especially important on reefs where other herbivores around Montserrat's reefs have been depleted. Carpenter and Edmunds (2006) provide evidence that with increased densities of *Diadema spp.* in the Caribbean, coral recruitment increases by providing areas for colonization after algal grazing.

It must be considered that management decisions are implemented to benefit the recovery of urchin species within Lime Kiln Bay and around Montserrat for the promotion of natural coral reef recovery [18]. Furthermore, through designation of marine reserves, natural predation recovers, eventually evening out trophic levels such as urchin abundance and grazing impacts [45]. Some studies conversely suggest that restricted fishing activities result in an increase in urchin predation, increasing respective recruitment [14]. Other studies have stated that when urchin populations reach outbreak densities, the scraping effects of urchin feeding can remove new coral recruits, reducing cover of HC and important coralline algae, leading to unsustainable bio-erosion [43]. It is suggested that populations can recover through the implementation of an MPA, as HC cover increases and NIA presence reduces, returning the system to a highly complex coral reef community [6]. However, more specific studies on other target invertebrates is required for further understanding on individual composition of invertebrate

populations around the coastline of Montserrat.

4.4. Benthic Substrate Composition

Coral reefs were considered patchy around Montserrat and were considered to be present at depths between 2 – 30m, excluding seagrass meadows which were observed at deeper depths. The substrate recorded in greatest abundance was sand (SD). The high levels of NIA recorded during the survey period from 2013 - 2017 suggest it as a consequence of anthropogenic land-based pollution from factors such as run-off and volcanic ash [48]. There are no previous studies that investigated the type of sedimentation in Montserrat waters and its effect on reef health, however, NIA presence has been known to boost coral metabolism and skeletogenesis [22]. Furthermore, higher levels of NIA cover illustrated a positive correlation with the abundance on algal grazers such as *D. antillarum* and *E. tribuloides*. The presence of algal grazers can decrease the rate of post-settlement mortality of coral species, and increase overall reef health [39]. The highest levels of HC and SC were present at Lime Kiln Bay and Carr's Bay. Studies have suggested that coral mortality events such as coral bleaching, sedimentation or space competition can increase the colonization space for algae, decreasing shelter and food abilities for fishes [20].

Alcyonacea were the most abundant structure found on reef systems around the five survey locations. The presence of Alcyonacea occurred in areas of increased flow movement, beneficial for colonies, and likely contributed to the respective dominance. The abundance of Alcyonacea has been postulated to directly regulate primary production and indirectly regulate secondary production in littoral food chains [28], supported by the abundance of herbivorous fishes. The results presented within this study support these findings, with strong positive correlations observed between both fish abundance and diversity with increasing Alcyonacea presence. Additionally, Alvarez et al. (2011) presented that juvenile Scaridae showed a greater dependence on benthic complexity on reef systems than adult individuals, which is supported by the results obtained for Carr's and Lime Kiln Bay. Scaridae abundance and biomass was found to be greater at Lime Kiln Bay and Carr's Bay, of which both locations presented relatively high abundances and composition of Alcyonacea and hard corals. This indicates a dependence on the complex habitat found at these reef systems, offering explanation to the relative high levels of diversity and

abundance at Lime Kiln Bay; providing factors such as refuge and sustenance for species.

Williams et al. (2015) highlight the importance of habitat differentiation when understanding the role of Alcyonacea within reef communities. Due to the low abundance of Scleractinian corals through Lime Kiln Bay and other sites coupled with abundances of Alcyonacea, it is plausible to accept these locations as 'Gorgonian Plains'; a habitat that confers a very different structure to their Scleractinian dominated reef counterparts. Due to this potential new characterisation of habitat within Montserrat's coastal waters, it is recommended that, during future surveys, care is given to understanding the varying habitats within the focus region, giving specific attention to Scleractinian reefs (*Orbicella* spp.) and Gorgonian Plains on fore reefs

4.5. Conservation Management Values

Dallison and Ferguson (2017) highlighted that baseline locations contributed the greatest composition of CMV = '0'. CMVs do not demonstrate that sites with low values would not benefit from conservation-driven actions, but highlights areas that hold a greater possibility of success in the light of limited resources to local managers than others.

Lime Kiln Bay was considered to hold the greatest conservation value with 57% of all transects holding a CMV of 5 and upwards. This excludes permanent transects where 79% scored over five (but are spatially distributed throughout the coastline). Baseline transects, as well as Isle's Bay, hosted the greatest composition of CMV 0; inline with results obtained in 2016 [18]. Furthermore, no transects within Isle's bay presented a value above 2 which is a result of the poorly represented fish and invertebrate communities, compounded by poor substratum composition and fishery capacity; despite hosting the most diverse fish communities. As such, Isle's Bay does not provide adequate opportunity for the Montserrat's limited resources, in this instance, and it is recommended that resources are placed into more advantageous locations such as Lime Kiln Bay and Carr's Bay.

It is surmised that the abundance of lower CMVs found around Old Road Bay and Woodlands Bay, in combination with the previously discussed community parameters, is due to the Soufrière Hills eruptions, with the communities and substrate found within these locations showing attenuated signs of recovery. Though it is predicted that reefs are still recovering due to

low grazing species, sedimentation presence, and NIA blooms [44, 50, 48]. It must be noted, however, that CMV results are likely to be heavily influenced by heterogeneous sampling effort between, and within, locations and over time due to various inhibitions experienced over the sample period.

4.6. Study Limitations

Although this study contextualizes a detailed account of the abundance and diversity of coral reef communities within Bays of Montserrat, there are limitations within the utilized methodology. UVC transects invoke a relatively small soak time through the various limitations of SCUBA based protocols and therefore any semi-diurnal changes in species-specific behaviour could not be accounted for [17] as many exploited reef fishes undertake diurnal intra and inter-reef migrations including those with large territories across entire bays [10]. The limitations of conducting UVC during the day are supported with studies stating that fish activity is minimal between 09:00 and 16:00 [38], therefore making the full community structure difficult to assess due to the differential species-specific behaviours influenced by abiotic factors. As such, CCC's protocols and citizen science methodologies in place made addressing these limitations challenging and unfeasible.

4.7. Marine Management Recommendations for Montserrat

This report presents the spatial distribution of Montserrat's coral reef communities through a high density of samples collected from localised focus areas. As such, the results presented should be utilised in combination with previous and on-going ecological assessments of Montserrat's coastal waters to guide management efforts.

The results, discussion and recommendations presented in this report should be coupled with the values placed upon these systems by stakeholders whether through social and traditional contexts or for livelihood support. Social support for marine spatial management from community members, stakeholders and resource managers must be present alongside strategies that consider capacity building and gender, aiming to empower stakeholders whilst instilling social responsibility and providing the necessary tools to allow for the sustainable use of marine resources. Numerous studies [3, 9] have demonstrated the importance of stakeholder

engagement throughout the planning processes of Marine Spatial Management. Each stakeholder or stakeholder group hold a diverse set of values with regards to the reef systems of Montserrat, and as such, a transparent, community-driven planning processes is required to prolong management support.

Lime Kiln Bay and Carr's Bay are highlighted as two key locations that would highly benefit from management efforts. In order to protect these key areas along the western coastline of Montserrat, CCC have provided three recommendations for protection (Fig. 11). Each option promotes varying multi-use zones and extent of protection (all zones are in addition to the already existing exclusion zones of the island). As a result of the increased density but reduced spatial area of CCC surveys, the recommendations are able to protect key areas of high biodiversity and productivity that risked exclusion from previous recommendations for spatial planning (e.g. [58]). It is important to highlight that due to the nature of spatial assessments deployed by Coral Cay Conservation, these recommendations can only be applied to nearshore reefs. These assessments span a small area in comparison to Montserrat's EEZ and therefore, any planning acting upon these recommendations should coordinate with other active organisations such as Blue Halo and JNCC to establish a network of active, and effective, protected areas.

Considering the perceived levels of fishing effort and other detrimental impacts from this study, the establishment of a multi-use zoned area that includes a No-Take Area (NTA), buffered by a marine reserve, is the most favourable recommendation presented (Option C) (Fig. 11; Table. 3). The NTA should provide a sanctuary for coral reef associated species, increasing recruitment, driving complexity and thus increasing capacity for fishery and tourism sectors.

Throughout each recommendation, Carr's Bay has been highlighted as an area of Special Consideration. Despite the areas high level of conservation value, the bay also holds significant commercial value due to the adjacent bay's ferry port and will experience varying levels of impact. As a result, it is recommended that this designated area be discussed in greater detail in relation to all services generated from the area.

It is recommended that within each option, the following actions are taken;

1. Any designated NTA should be clearly demarcated through shore markers and surface buoys. To ensure maintenance, monitoring and enforcement, financing schemes should be explored such as "Pay-to-Dive" and usage fees, however, if to be implemented, it is recommended that entry into the NTA is prevented for a minimum of 1 year post-establishment, and usage areas are designated and cycled;
2. Local governance should prohibit/limit certain activities within the NTA and marine reserves, particularly fishing gears that are non-selective such as gill nets, and advocate responsible mooring, within this area (limited extraction should be investigated to enable conservation-benefit realisation by stakeholders). Boating activities should remain restricted with large vessels being prohibited;
3. and any established ordinance is recommended to be transparent and a result of numerous working groups, learning exchanges and forums where there are an even representation of key stakeholders, managers and genders.

Throughout the surveyed area, it is clear that Montserrat hosts unique habitats and clear patterns of distribution. In addition to Marine Spatial Management efforts, continued ecological monitoring must be implemented throughout the Island's coastal zones and nearshore reefs. These monitoring protocols should be utilised to assess the efficacy of management actions whilst providing further context for future actions.

The data presented within this report highlight the spatial distributions of Montserrat's ecological fauna and benthos whilst serving as a high-resolution baseline for future monitoring efforts, aiming to protect the ecosystem services of Montserrat's nearshore.

5. Acknowledgements

Coral Cay Conservation would like to express our sincere gratitude to all our project partners who have supported the MRRCP since 2013. Our work would not have been possible without the support of the Montserrat Ministry of Agriculture, Trade, Lands, Housing and Environment (MATHLE).

We would further like to thank Gracelyn Cassel, Alwyn Ponteen, Stephen Mendes, John Jeffers, Rose Willock, staff at the Montserrat Library in Brades, staff at the Department of Labour and staff at the Department

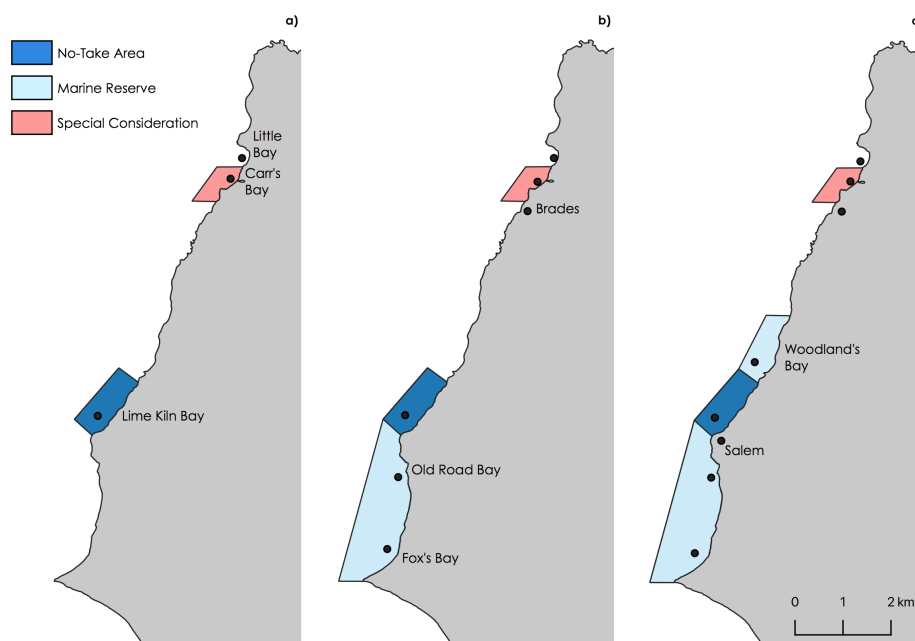


Figure 11: Marine Spatial Management options recommended by Coral Cay Conservation with varying degrees of protection parameters for each option (a, b, c).

Table 3: Montserrat Protected Area Recommendation Parameters for Options A, B and C as well as Carr's Bay. Area is provided in hectares (ha) and perimeter in metres (9)

Recommendation	Area (ha)	Perimeter (m)
Option A	77.20	3,924.00
Option B	338.40	10,973.20
Option C	408.10	13,862.64
Carr's Bay	37.64	2,892.00

of Tourism. We would also like to thank the Darwin Initiative for their initial funding in support of the project.

Finally, we would like to extend our gratitude to all of our past field staff and volunteers for their passion and commitment to the project; Adam Bruce, Adam Mabbott, Adam Taylor, Adam Turner, Adam Westbrook, Adrianna Sandoval, Ailsa Conway, Alex Bartle-Smith, Alex Isac, Alex Langton, Alexander Foster, Alexander (Alex) Weir, Alexander Merrington, Alice Reynolds, Aline Jacobi, Alis Sejourne, Alison Banks, Alissa Tate, Alistair Prenter, Aman Mottaqui-Tabar, Amanda (Amy) Canavan, Amber Rowsell, Amy Hornett, Andrea Mutch, Andrew Wise, Andrew King, Andy Allen, Anna Collinson, Anna Harrison, Anna Zuke, Annabel (Annie) O'Grady, Anne McDonald, Anouk Milewski,

Astrid de Cosson, Aubrey (Dexter) Joseph, Ben Raby, Benjamin (Ben) Thorne, Benjamin Howe, Ben Cresswell, Bleuenn Guilloux, Bonnie Buchanan, Bryony Williams, Carlos Davies, Carole Boardman, Carolyn Bircher, Chantelle Wyatt, Charles Robinson, Charles (Charlie) Hogg, Charlotte (Lottie) Simpson, Charlotte Khan, Ciara Hollis, Claire Ogg, Constance Villa, Curtis Steele, Daisy Antonioni, Daisy Goswell, Daniel Esjomo, David Andrews, David Kirby, David Mogg, Devan Mair, Diane Patrick, Duncan Sharp, Edward (Ed) Drummond-Hay, Edward Dixon, Edward Grieron, Edward Harris, Eleanor (Ellie) Kirkland, Eleanor (Ellie) Davies, Eleanor Fletcher, Eleanor Swire, Elise Fletcher, Eliza Whitfield, Elizabeth Linehan, Ella Pitman, Eloise Le Fevre, Eloise Tulloch, Emily Brookes,

Emily Last, Emily Stebbings, Emma Bolton, Emma Trowell, Francesca Clark, Gabriel Hellen, Gemma Galbraith, Gemma Rinzivillo, George Eves, George Davies, George Duckworth, George Eason, George Reeve, George Ridley, Georgia Leaf, Gillian Leeder, Grace Ward-Thomas, Hannah Fish, Harriet Suenson-Taylor, Harriet Patton, Harry Campbell, Harry Morgan, Harry Taylor, Harry Woodger, Hazel Thornton, Heidi Taylor, Helen Russell, Henri (Harry) Naef, Hugo de Vasconcelos, Ian Brown, Ian Rockett, Imogen Trow, Innes Gilling, Iris Yee, Isabel Clark, Isabelle Heatley, Isobel Tear, Jack Coupland, Jack Cross, Jack Lee, Jacob Allman, Jacqueline (Jackie) Ascrizzi, Jake Dixon, James Anderton, James Dewar, James Stacey, James Stirling, James Webster, James Williams, Jamie Pratt, Jasmine Houze, Jenna Poole, Jennie Symondson, Jennifer Ziemba, Jennifer Macgregor, Jenny Lantair, Jerry Slater, Jessica Patel, Jessica Vince, John Horrocks, John Roberts, John Stanley, Jonathan Westwell, Jordan Shapland, Joshua Hudson, Julia Dunn, Julia Smith, Julia Walec, Juliette Claro, Kate Hickey, Kate Matthews, Katharine (Katie) Jones, Katherine (Katie) Bradshaw, Kathryn Farthing, Keanu Barnwell, Kenny McDonald, Keri Dobson, Kimberly Littlewood, Lara Von Der Brelie-Lambin, Laura Steel, Leonora Monson, Lucy Miller, Lydia Tivenan, Magdalena Grabowska, Marina Vestbirk, Marisa Sorrell, Marissa DeSandoli, Mark Wilson, Martyn Lloyd, Massimiliano (Max) Fornasiero, Matthew Adams, Matthew Jarvis, Matthew Thornton, Maud Ahmed, Max Beech, Maxime Woznicki, Melissa Clarke, Menie (Rosie) Norman, Michael McDonnell, Michael Hinks, Michael Soltysiak, Michel Domenjoud, Michelle Hoge, Mila Jovic, Milo Jackson-Brown, Mollie Wood, Molly Jackson, Morgan MacIsaac, Myles Root, Naomi (Nim) Green, Natalia Alexander, Nelly Moret, Nicholas Gwynne, Nicholas Shanky, Oliver (Ollie) Lim, Oliver Rance, Oliver-Connal (Oliver) Hicks, Orlane Van Erps, Paschal (Pash) Baker, Patrick Hales, Paula Borkmann, Pauline O'Hare, Peta Day, Peter Coville, Peter Gray, Peter Hewitt, Phoebe Love, Prashant Patel, Rebecca (Bex) Turner, Rebecca Hills, Richard Payne, Richard Warren, Rob King, Robert Carswell, Rory Graham, Rory Sandison, Ryan Maidment, Saffron Leon, Samuel Woodward, Samuel (Sam) Harding, Sarah Abusaa, Sarena Fonseca, Saskia (Sassie) Patel, Savanna Bull, Sean Smith, Shannon Rushton, Shawn Daniel, Sian Taylor, Simon Harris, Simon White, Sonya Korzeniowsky, Sophia Merola, Sophie Baird, Sophie Gale, Stanley Armour, Stefan Momic, Steffen Oppel, Stella Harrison, Stephanie Michail, Stephen (Steve) Smith, Stephen Atkinson, Stephen Yetman, Susan Robertson, Sybil Williamson, Thakvyka Em,

Thomas (Tom) Allwinton, Thomas Daguerre, Thomas Gordon, Thomas Weigall, Tina Waggott, Tiong Hua (Andy) Sia, Tom Old, Tom Staton, Tom Weigall, Tracy Hall, Vanessa Miller, Veta Wade, Vicky Fong, Victoria (Vicky) Firth, Victoria Aynsley, Weldon Reece, Wendy Boardman, Wendy Hinks, William Clarkson, William Guy, Yana Domnina, Zach Slogget

References

- [1] Alvarez-Filip, L., Paddock, M. J., Collen, B., Robertson, D. R., and Côté, I. M. (2015). Simplification of Caribbean Reef-Fish Assemblages over Decades of Coral Reef Degradation. *PLOS ONE*, 10(4):e0126004.
- [2] Bellwood, D. R., Hoey, A. S., and Hughes, T. P. (2012). Human activity selectively impacts the ecosystem roles of parrotfishes on coral reefs. *Proceedings of the Royal Society B: Biological Sciences*, 279(1733):1621–1629.
- [3] Bennett, N. J. and Dearden, P. (2014). Why local people do not support conservation: Community perceptions of marine protected area livelihood impacts, governance and management in Thailand. *Marine Policy*, 44:107–116.
- [4] Blue Halo (2015). A Review of the Ecology and Economic of Montserrat's Marine Resources. Technical report, Waitt Institute.
- [5] Blue Halo (2016). An Assessment of Montserrat's Fisheries. Technical report, Waitt Institute.
- [6] Bologna, P. A., Webb-Wilson, L., Connelly, P., and Saunders, J. E. (2012). A New Baseline for *Diadema antillarum*, *Echinometra viridis*, *E. lucunter*, and *Eucidaris tribuloides* Populations Within the Cayos Cochinos MPA, Honduras. *Gulf and Caribbean Research*, 24(1):1–5.
- [7] Bruno, J. F., Sweatman, H., Precht, W. F., Selig, E. R., and Schutte, V. G. W. (2009). Assessing evidence of phase shifts from coral to macroalgal dominance on coral reefs. *Ecology*, 90(6):1478–1484.
- [8] Burke, L. and Maidens, J. (2004). Reefs at risk in the Caribbean. Technical report, World Resource Institute.
- [9] Chaigneau, T. and Brown, K. (2016). Challenging the win-win discourse on conservation and development: analyzing support for marine protected areas. *Ecology and Society*, 21(1).
- [10] Chapman, M. R. and Kramer, D. L. (2000). Movements of Fishes Within and Among Fringing Coral Reefs in Barbados. *Environmental Biology of Fishes*, 57(1):11–24.
- [11] Chiappone, M., Sluka, R., and Sealey, K. S. (2000). Groupers (Pisces: Serranidae) in fished and protected areas of the Florida Keys, Bahamas and northern Caribbean. *Marine Ecology Progress Series*, 198:261–272.
- [12] CHL Consulting Ltd (2012). Draft Final Report - 6th July 2012. Technical report, Government of Montserrat.
- [13] Claudet, J., Pelletier, D., Jouvenel, J.-Y., Bachet, F., and Galzin, R. (2006). Assessing the effects of marine protected area (MPA) on a reef fish assemblage in a northwestern Mediterranean marine reserve: Identifying community-based indicators. *Biological Conservation*, 130(3):349–369.
- [14] Clemente, S., Hernández, J. C., and Brito, A. (2008). Evidence of the top-down role of predators in structuring sublittoral rocky-reef communities in a Marine Protected Area and nearby areas of the Canary Islands. *ICES Journal of Marine Science*, 66(1):64–71.
- [15] Coelho, F. d. N., Pinheiro, H. T., dos Santos, R. G., de Albuquerque, C. Q., and Martins, A. S. (2012). Spatial distribution and diet of *Cephalopholis fulva* (Ephraenichelidae) at Trindade Island, Brazil.

- [16] Conservation International (2008). Economic Values of Coral Reefs, Mangroves, and Seagrasses: A Global Compilation. Technical report, Center for Applied Biodiversity Science, Conservation International, Arlington, VA.
- [17] Dallison, T. (2015). *Impact of Fish Fence Fisheries on Fish Community Functionality and the Resultant Catch Composition*. Msc, University of Essex.
- [18] Dallison, T. and Ferguson, A. (2017). Coral Cay Conservation Marine Progress Report, Montserrat 2013-2016. Technical report, Coral Cay Conservation.
- [19] Darling, E. S., Graham, N. A. J., Januchowski-Hartley, F. A., Nash, K. L., Pratchett, M. S., and Wilson, S. K. (2017). Relationships between structural complexity, coral traits, and reef fish assemblages. *Coral Reefs*, 36(2):561–575.
- [20] Diaz-Pulido, G. and McCook, L. J. (2004). Effects of live coral, epilithic algal communities and substrate type on algal recruitment. *Coral Reefs*, 23(2):225–233.
- [21] Downie, R., Babcock, R., Thomson, D., and Vanderklift, A. M. (2013). Density of herbivorous fish and intensity of herbivory are influenced by proximity to coral reefs. *Marine Ecology Progress Series*, 482:217–225.
- [22] Edinger, E. N., Limmon, G. V., Jompa, J., Widjatmoko, W., Heikoop, J. M., and Risk, M. J. (2000). Normal Coral Growth Rates on Dying Reefs: Are Coral Growth Rates Good Indicators of Reef Health? *Marine Pollution Bulletin*, 40(5):404–425.
- [23] Edmunds, P. J. and Carpenter, R. C. (2001). Recovery of *Diadema antillarum* reduces macroalgal cover and increases abundance of juvenile corals on a Caribbean reef. *Proceedings of the National Academy of Sciences*, 98(9):5067 LP – 5071.
- [24] Entrambasaguas, L., Pérez-Ruzafa, Á., García-Charton, J. A., Stobart, B., and Bacallado, J. J. (2008). Abundance, spatial distribution and habitat relationships of echinoderms in the Cabo Verde Archipelago (eastern Atlantic). *Marine and Freshwater Research*, 59(6):477–488.
- [25] FAO (2015). Global Forest Resource Assessment 2015 Country Report: Montserrat. Technical report, Food and Agriculture Organization of the United Nations, Rome.
- [26] Francis, F. T., Filbee-Dexter, K., Yan, H. F., and Côté, I. M. (2019). Invertebrate herbivores: Overlooked allies in the recovery of degraded coral reefs? *Global Ecology and Conservation*, 17:e00593.
- [27] Froese, R. (2004). Keep it simple: three indicators to deal with overfishing. *Fish and Fisheries*, 5(1):86–91.
- [28] Gili, J.-M. and Coma, R. (1998). Benthic suspension feeders: their paramount role in littoral marine food webs. *Trends in Ecology & Evolution*, 13(8):316–321.
- [29] Godley, B. J., Broderick, A. C., Campbell, L. M., Ranger, S., and Richardson, P. B. (2008). 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*, pages 155–179. Department of Environment, Food and Rural Affairs and the Foreign Commonwealth Office.
- [30] Graham, N. A. and Nash, K. L. (2013). The importance of structural complexity in coral reef ecosystems. *Coral Reefs*, 32(2):315–326.
- [31] Gray, G. A. L. (2011). Montserrat. Technical report, Joint Nature Conservation Committee, Peterborough, UK.
- [32] Guarderas, P. A., Hacker, S. D., and Lubchenco, J. (2011). Ecological effects of marine reserves in Latin America and the Caribbean. *Marine Ecology Progress Series*, 429:219–225.
- [33] Hernández-Almaraz, P., Méndez-Rodríguez, L., Zenteno-Savín, T., O'Hara, T. M., Harley, J. R., and Serviere-Zaragoza, E. (2016). Concentrations of trace elements in sea urchins and macroalgae commonly present in Sargassum beds: implications for trophic transfer. *Ecological Research*, 31(6):785–798.
- [34] Hughes, T. P., Graham, N. A. J., Jackson, J. B. C., Mumby, P. J., and Steneck, R. S. (2010). Rising to the challenge of sustaining coral reef resilience. *Trends in Ecology & Evolution*, 25(11):633–642.
- [35] Island Resource Foundation (1993). Montserrat: An Assessment of the Critical Environmental Issues Facing Montserrat with an Action Agenda for the Future. Technical report, United Nations Development Program.
- [36] Jackson, J. B. C., Kirby, M. X., Berger, W. H., Bjorndal, K. A., Botsford, L. W., Bourque, B. J., Bradbury, R. H., Cooke, R., Erlandson, J., Estes, J. A., Hughes, T. P., Kidwell, S., Lange, C. B., Lenihan, H. S., Pandolfi, J. M., Peterson, C. H., Steneck, R. S., Tegner, M. J., and Warner, R. R. (2001). Historical Overfishing and the Recent Collapse of Coastal Ecosystems. *Science*, 293(5530):629 LP – 637.
- [37] Lessios, H. A., Cubit, J. D., Robertson, D. R., Shulman, M. J., Parker, M. R., Garrity, S. D., and Levings, S. C. (1984). Mass mortality of *Diadema antillarum* on the Caribbean coast of Panama. *Coral Reefs*, 3:173–182.
- [38] McMellor, S. and Smith, D. J. (2010). Coral Reefs of the Waka-tobi: Abundance and Diversity. In *Marine Research and Conservation in the Coral Triangle*, chapter 2, page 18. Nova Science Publishers Inc., New York.
- [39] Mumby, P. J. (2006). The Impact Of Exploiting Grazers (Scari-dae) On The Dynamics Of Caribbean Coral Reefs. *Ecological Applications*, 16(2):747–769.
- [40] Mumby, P. J. (2009). Herbivory versus corallivory: are parrotfish good or bad for Caribbean coral reefs? *Coral Reefs*, 28(3):683–690.
- [41] Myers, A. (2013). Coral Reefs of Montserrat. In Sheppard, C. R. C., editor, *Coral Reefs of the United Kingdom Overseas Territories. Coral Reefs of the World*, pages 89–96. Springer, Dordrecht.
- [42] Oksanen, J., Kindt, R., Legendre, P., O'Hara, B., and Stevens, M. H. H. (2007). The vegan package. *Community ecology package*, 10:631–637.
- [43] O'Leary, J. K. and McClanahan, T. R. (2010). Trophic cascades result in large-scale coralline algae loss through differential grazer effects. *Ecology*, 91(12):3584–3597.
- [44] Paddock, M. J., Reynolds, J. D., Aguilar, C., Appeldoorn, R. S., Beets, J., Burkett, E. W., Chittaro, P. M., Clarke, K., Esteves, R., Fonseca, A. C., Forrester, G. E., Friedlander, A. M., García-Sais, J., González-Sansón, G., Jordan, L. K. B., McClellan, D. B., Miller, M. W., Molloy, P. P., Mumby, P. J., Nagelkerken, I., Nemeth, M., Navas-Camacho, R., Pitt, J., Polunin, N. V. C., Reyes-Nivia, M. C., Robertson, D. R., Rodríguez-Ramírez, A., Salas, E., Smith, S. R., Spieler, R. E., Steele, M. A., Williams, I. D., Wormald, C. L., Watkinson, A. R., and Côté, I. M. (2009). Recent Region-wide Declines in Caribbean Reef Fish Abundance. *Current Biology*, 19(7):590–595.
- [45] Partnership for Interdisciplinary Studies of Coastal Oceans (2008). The Science of Marine Reserves. Technical report, Partnership for Interdisciplinary Studies of Coastal Oceans.
- [46] Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., and Torres, F. (1998). Fishing Down Marine Food Webs. *Science*, 279(5352):860 LP – 863.
- [47] Pauly, D., Christensen, V., Guénette, S., Pitcher, T. J., Sumaila, U. R., Walters, C. J., Watson, R., and Zeller, D. (2002). Towards sustainability in world fisheries. *Nature*, 418(6898):689–695.
- [48] Ponteen, A. R. (2014). Montserrat National Fisheries Report. Technical report, Fisheries Division; Government of Montserrat.
- [49] R Core Team (2019). R: A Language and Environment for Statistical Computing.
- [50] Ruiz-Ramos, D. V., Hernández-Delgado, E. A., and Schizas, N. V. (2011). Population status of the long-spined urchin *diadema*

- antillarum in Puerto Rico 20 years after a mass mortality event. *Bulletin of Marine Science*, 87(1):113–127.
- [51] Santos, C. P., Coutinho, A. B., and Hajdu, E. (2002). Spon-
givory by *Eucidaris tribuloides* from Salvador, Bahia (Echinoder-
mata: Echinoidea). *Journal of the Marine Biological Association
of the United Kingdom*, 82(2):295–297.
- [52] SHAPIRO, S. S. and WILK, M. B. (1965). An analysis of
variance test for normality (complete samples). *Biometrika*, 52(3-
4):591–611.
- [53] Sluka, R. D., Chiappone, M., and Sealey, K. M. S. (2001). Influ-
ence of habitat on grouper abundance in the Florida Keys, U.S.A.
Journal of Fish Biology, 58(3):682–700.
- [54] Stewart, B. D. and Jones, G. P. (2001). Associations between
the abundance of piscivorous fishes and their prey on coral reefs:
implications for prey-fish mortality. *Marine Biology*, 138(2):383–
397.
- [55] Sumaila, U. R., Guénette, S., Alder, J., and Chuenpagdee, R.
(2000). Addressing ecosystem effects of fishing using marine pro-
tected areas. *ICES Journal of Marine Science*, 57(3):752–760.
- [56] Teesdale, G. N., Wolfe, B. W., and Lowe, G. C. (2015). Patterns
of home ranging, site fidelity, and seasonal spawning migration of
barred sand bass caught within the Palos Verdes Shelf Superfund
Site. *Marine Ecology Progress Series*, 539:255–269.
- [57] Vergés, A., Vanderklift, M. A., Doropoulos, C., and Hyndes,
G. A. (2011). Spatial Patterns in Herbivory on a Coral Reef Are In-
fluenced by Structural Complexity but Not by Algal Traits. *PLOS
ONE*, 6(2):e17115.
- [58] Wild, R., Slade, L., Pardee, M., and Carleton, C. (2007). To-
wards multi-user marine management in Montserrat.
- [59] Williams, S., Mumby, P., Chollett, I., and Cortés, J. (2015). Im-
portance of differentiating *Orbicella* reefs from gorgonian plains
for ecological assessments of Caribbean reefs. *Marine Ecology
Progress Series*, 530:93–101.
- [60] Wolff, N., Grober-Dunsmore, R., Rogers, C. S., and Beets, J.
(1999). Management implications of fish trap effectiveness in ad-
jacent coral reef and gorgonian habitats. *Environmental Biology of
Fishes*, 55(1):81–90.

Appendix A. Appendix

Table Appendix A.4: Target fishes recorded by Coral Cay Conservation Survey Teams throughout the study period. Targets are provided by common name and respective taxonomic nomenclature indicating resolution of collected data.

Common	Taxonomic	Common	Taxonomic
Angelfish	Pomacanthidae	Lizardfish	Synodontidae
Ballyhoo	Hemiramphidae	Moray Eel	Muraenidae
Basslet	Grammatidae	Needlefish	Belonidae
Butterflyfish	Chaetodontidae	Parrotfish	Scaridae
Chromis/Damselfish	Pomacentridae	Porgy	Sparidae
Chub	Kyphosidae	Scorpionfish	Scorpionidae
Filefish	Monacanthidae	Snake Eel	Ophichthidae
Goatfish	Mulidae	Snapper	Lutjanidae
Grouper	Serranidae	Squirrelfish/Soldierfish	Holocentridae
Coney	<i>Cephalopholis fulva</i>	Surgeonfish	Acanthuridae
Hamlet	<i>Hypoplectrus sp.</i>	Blue Tang	<i>Acanthurus coeruleus</i>
Hind	<i>Epinephelus guttatus, E. adscensionis</i>	Triggerfish	Balistidae
Nassau Grouper	<i>Epinephelus striatus</i>	Trumpetfish	Aulostomidae
Grunt	Haemulidae	Trunk/Box/Cowfish	Ostraciidae
Jack	Carangidae	Honeycomb Cowfish	<i>Acanthostracion polygoina</i>
Lionfish	<i>Pterois spp.</i>	Wrasse	Labridae

Table Appendix A.5: Target invertebrates recorded by Coral Cay Conservation Survey Teams throughout the study period. Targets are provided by common name and respective taxonomic nomenclature indicating resolution of collected data.

Common	Taxonomic	Common	Taxonomic
Banded Coral Shrimp	<i>Stenopus hispidus</i>	Long-Spined Sea Urchin	<i>Diadema antillarum</i>
Collector Urchin	<i>Tripneustes spp.</i>	Pencil Urchin	<i>Eucidaris tribuloides</i>
Flamingo Tongue	<i>Cyphoma gibbosum</i>	Triton's Trumpet	<i>Charonia variegata</i>
Gorgonians	Alcyonacea	Lobster	Palinuridae

Table Appendix A.6: Target substrata recorded by Coral Cay Conservation Survey Teams throughout the study period. Each substrate is accompanied by respective survey code.

Substrate	Code	Substrate	Code
Scleractinian Corals (incl. Millepora)	HC	Soft Corals	SC
Recently Killed Coral (<1-year)	RKC	Sponge	SP
Nutrient Indicator Algae	NIA	Rock	RC
Rubble	RB	Sand	SD
Silt	SI	Other	OT

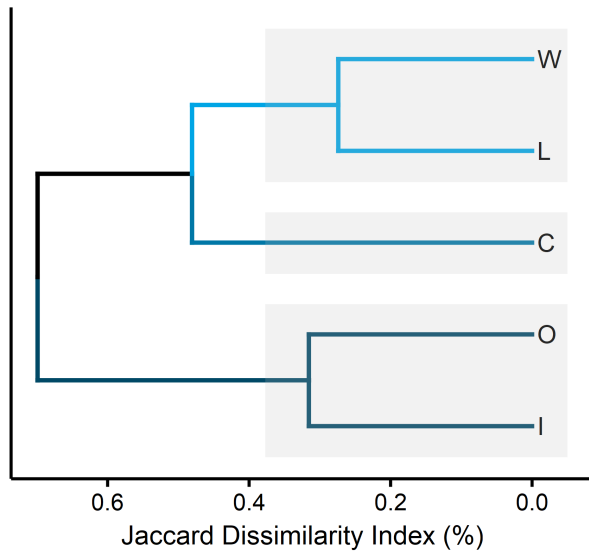


Figure Appendix A.12: Dendrogram presenting the dissimilarity of recorded herbivorous target fishes between sampled sites; Carr's Bay (C), Isle's Bay (I), Lime Kiln Bay (L), Old Road Bay (O), and Woodland's Bay (W). Sites have been grouped based on the mean Jaccard Dissimilarity Index (JDI).

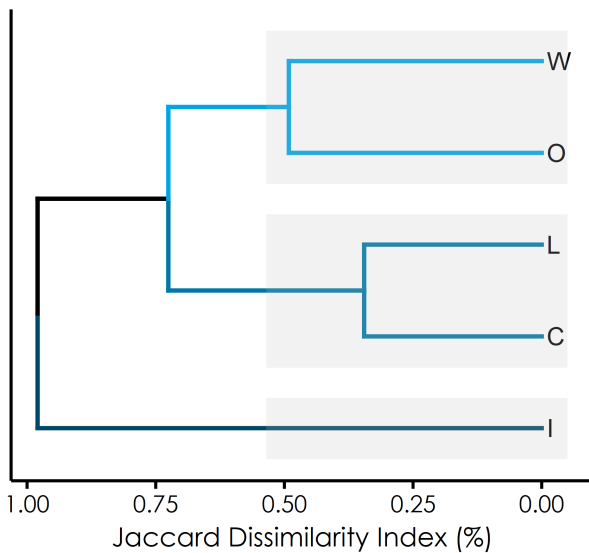


Figure Appendix A.13: Dendrogram presenting the dissimilarity of recorded commercially important fishes between sampled sites; Carr's Bay (C), Isle's Bay (I), Lime Kiln Bay (L), Old Road Bay (O), and Woodland's Bay (W). Sites have been grouped based on the mean Jaccard Dissimilarity Index (JDI).

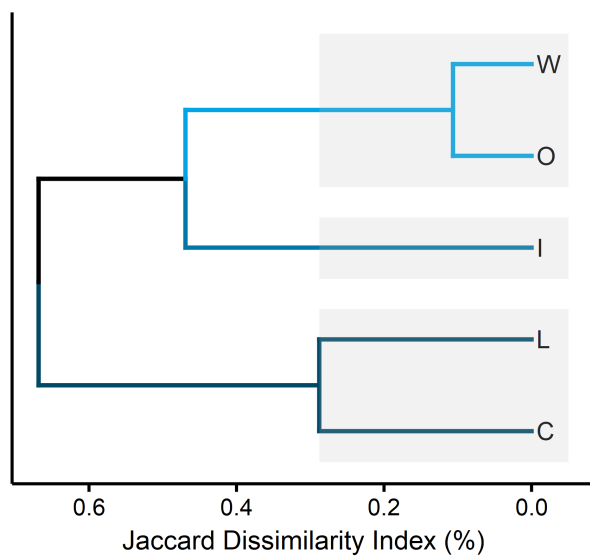


Figure Appendix A.14: Dendrogram presenting the dissimilarity of recorded substrate compositions (%) between sampled sites; Carr's Bay (C), Isle's Bay (I), Lime Kiln Bay (L), Old Road Bay (O), and Woodland's Bay (W). Sites have been grouped based on the mean Jaccard Dissimilarity Index (JDI).

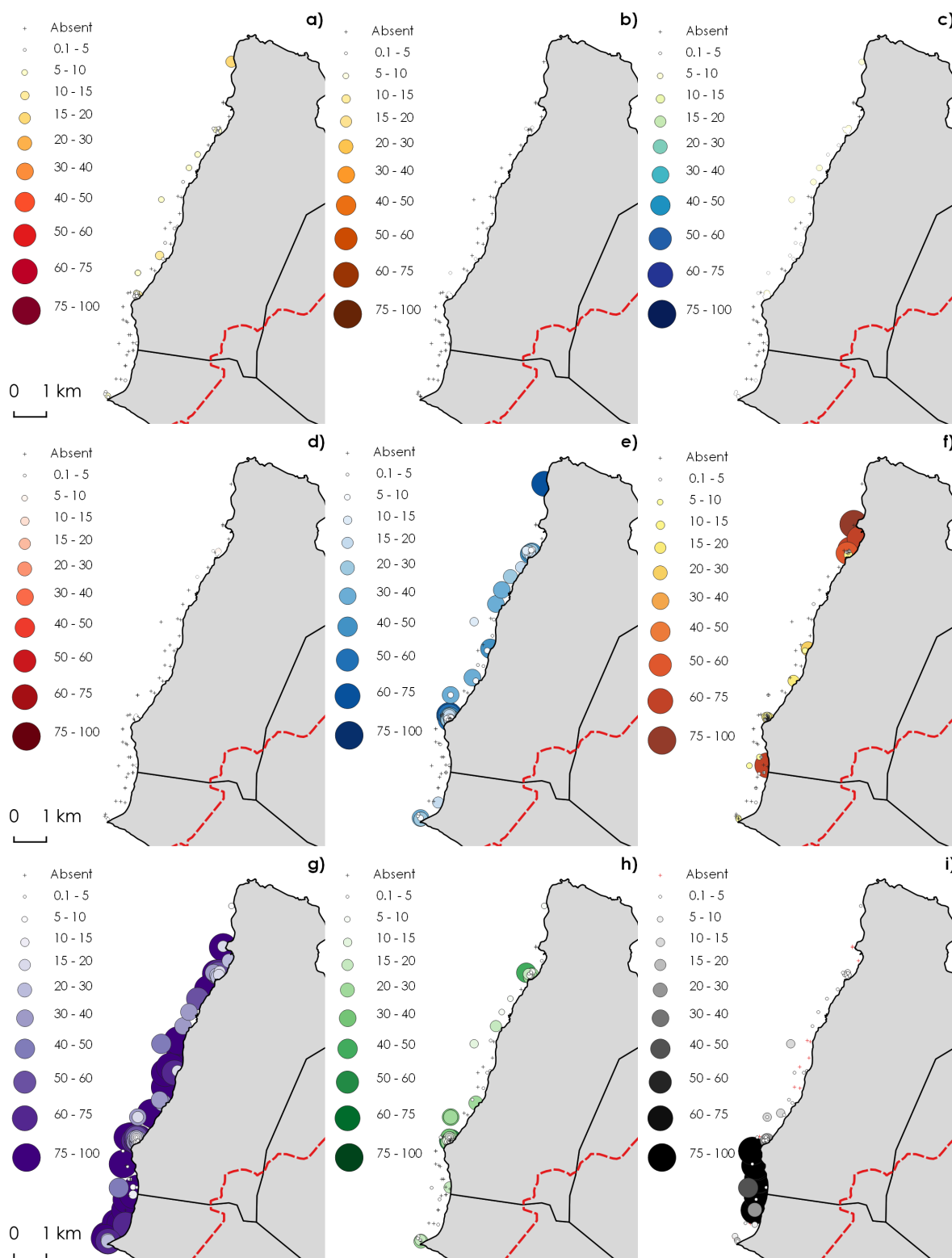


Figure Appendix A.15: Panelled spatial distribution of substrate composition (%) (Hard Coral (a); Soft Coral (b); Sponge (c); Recently Killed Coral (d); Rock (e); Silt (f); Sand (g); Nutrient Indicator Algae (h); and Other (i)) recorded throughout the study period.

Coral Cay Conservation

