



MRRCP

Montserrat Ridae to Reef Conservation Project

Coral Cay Conservation Marine Progress Report

Montserrat 2013 – 2016

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Tom Dallison & Alex Ferguson

In partnership with the
The Government of Montserrat
Ministry of Agriculture, Trade, Land,
Housing and the Environment





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Executive Summary

- Coral Cay Conservation (CCC) conducted holistic coral reef based surveys from 2013 – 2016 along the north-western coastline of Montserrat, Caribbean, utilising international volunteers through a citizen-science based approach.
- The study contextualises the results found in a relatable manner that ensures clear dissemination of scientific data for the prosperity of Montserrat's fishery and tourism sectors.
- An augmented Reef Check protocol was conducted with data recorded regarding the abundance and diversity of fishes and invertebrates. Data were collected in combination with anthropogenic impacts and benthic substratum composition. Throughout the temporal scale, this equated to a total of $n = 380$ individual 100m transects. Each 100m transects was separated into four 20m replicates with 5m inter-replicate gaps.
- 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.
- Overall, it was determined that the north-western coastline of Montserrat experienced low levels of anthropogenic impacts however the abundance and proximity of mooring yachts highlighted a concern. Additionally, fishing practices (commercial, artisanal and invertebrate harvest) were considered low whilst destructive fishing gears were non-existent.
- Fishes were recorded in densities of $N = 226.36 \pm 15.18 \text{ } 500\text{m}^3^{-1}$ across the 5 geographically constrained sites with Labridae (Wrasse) holding the greatest density ($142.35 \pm 10.36 \text{ } 500\text{m}^3^{-1}$). 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.
- Herbivorous fishes were recorded in densities of $N = 71.20 \pm 7.09 \text{ } 500\text{m}^3^{-1}$ with Pomacentridae (Damsel fish) the most dominant subsequently followed by Acanthuridae (Surgeonfish) ($N = 58.68 \pm 6.70 \text{ } 500\text{m}^3^{-1}$, $N = 10.68 \pm 0.99 \text{ } 500\text{m}^3^{-1}$, respectively). Lime Kiln Bay held the greatest's density of herbivorous fishes of which differed significantly from Carr's Bay ($p = <0.05$) and Isle's Bay ($p = <0.01$). Cluster analysis indicated three clusters with Lime Kiln Bay holding greatest similarity to Woodlands Bay with regards to herbivorous community structure.
- Location was shown to not significantly impact the variability observed in biomass ($\text{kg } 500\text{m}^3^{-1}$) from commercially important fish families. Additionally, Coney (Serranidae) held the greatest standing biomass ($1.02 \pm 0.07 \text{ kg } 500\text{m}^3^{-1}$) of commercially important families surveyed with Scaridae (Parrotfish) biomass recorded at $0.17 \pm 0.02 \text{ kg } 500\text{m}^3^{-1}$. All individual fishes recorded were $<50\text{cm}$ with the dominant size classes being $<20\text{cm}$. Scaridae held the greatest frequency ($f = 760$) with the majority $<10\text{cm}$. Grouper (Serranidae) were all $<30\text{cm}$ with the dominant size class being $<10\text{cm}$.
- 2,092 individual target invertebrates were surveyed at a density of $16.87 \pm 1.95 \text{ } 100\text{m}^2^{-1}$ where *Eucidaris tribuloides* (Pencil Urchins) were the dominant invertebrate (11.71 ± 1.36

100m²⁻¹). *Diadema* sp. were recorded at a density of 1.65 ± 0.34 100m²⁻¹. The greatest invertebrate densities were found at Lime Kiln Bay ($N= 25.5 \pm 2.64$ 100m²⁻¹) whilst the impact of location on density proved significant ($p= <0.001$).

- Gorgonians (GO) were the dominant invertebrate recorded, however due to their role in facilitating complexity, they were removed from invertebrate analysis. 37,560 individual GO colonies were recorded throughout all locations with 35.72% of all colonies recorded within the 5 geographically constrained locations. Lime Kiln Bay promoted a density of 181.36 ± 9.25 100m²⁻¹ that differed significantly to all other locations ($p= <0.001$).
- Sand (SD) was the dominant substrate of which was found in greatest composition at Old Road Bay ($95.31 \pm 3.36\%$), whilst Lime Kiln Bay held the lowest composition of SD of which was significantly lower than Isle's Bay, Old Road Bay and Woodlands Bay. Hard Coral (HC) was found in low composition throughout surveyed locations with the greatest recorded at Lime Kiln bay $5.12 \pm 0.59\%$. The greatest composition of nutrient indicator algae (NIA) was also recorded at Lime Kiln Bay ($23.48 \pm 2.23\%$) of which was significantly higher than Old Road Bay, Carr's Bay and Isle's Bay.
- Positive, significant correlations between the abundance of fishes and HC composition were also found. The diversity of fishes at each location were shown to be positively influenced to a greater extent by the abundance of GO than HC. Herbivorous fish abundance positively correlated with the composition of NIA as well as with HC whilst *E. tribuloides* demonstrated the strongest relationship with NIA. Herbivorous fishes also held a strong positive correlation with HC composition, in combination with *Diadema* sp. and *E. tribuloides*.
- Conservation Management Values (CMV) highlighted the value of Lime Kiln Bay and Carr's Bay with regards to the seven tested variables. The majority of Lime Kiln Bay's surveyed sites were classified as CMV= >5 with the majority of Carr's Bay sites between CMV= 1 and CMV= 4. 29% of all surveyed sites were classified as CMV= 0 with 7 as CMV= 7.
- 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.
- CCC will enter into their respective third phase of the Montserrat Ridge to Reef Project which will see a location-specific report with subsequent survey methodology. Phase three will focus on the species composition and benthic habitat in order to provide MATLHE with the scientific capacity to implement conservation driven aims and goals through protected area establishment.



Acknowledgements

Coral Cay Conservation would like to express our sincere gratitude to all our project partners who have supported the Montserrat Ridge to Reef Conservation Project (MRRCP) since 2013. Our work would not be possible without the support of the Montserrat Ministry of Agriculture, Trade, Lands, Housing and the Environment (MATLHE). In particular, CCC would like to thank, Gerard Gray (Director, Department of Environment), Melissa O'Garro (Director, Department of Agriculture), and all the staff within MATLHE.

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Finally, CCC would like to thank all of our past and current field staff and volunteers for their passion and commitment to the project. In particular, thank you to Susan Robertson and Claire Ogg.



Abbreviations

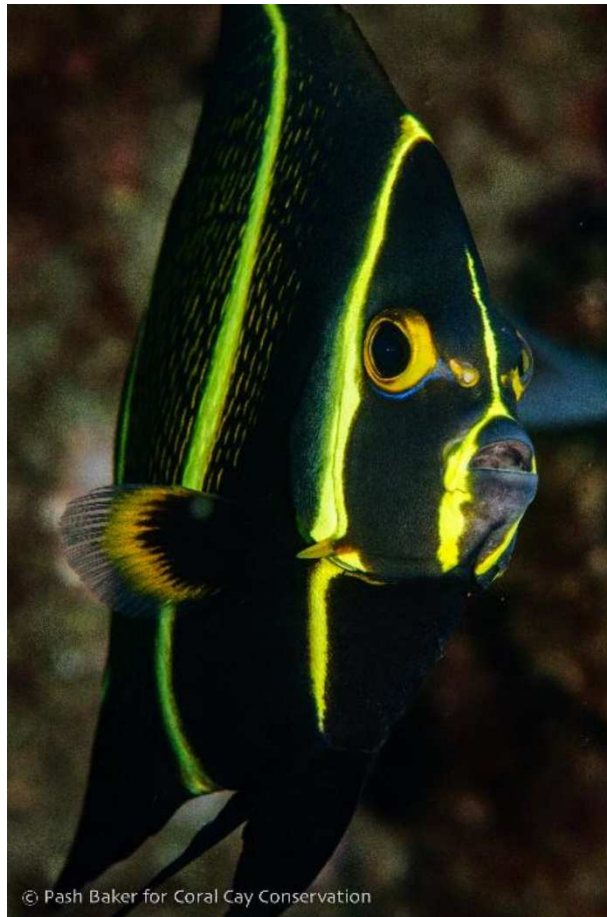
CaCO ₃	Calcium Carbonate
CCC	Coral Cay Conservation
CPUE	Catch Per Unit Effort (kg/effort ⁻¹)
EAF	Ecosystem Approach to Fisheries
EAM	Epithilic Algal Matrix
EBM	Ecosystem Based Management
FAD	Fish Aggregation Device
H'	Shannon-Wiener Diversity Index
ha	Hectare (1ha = 0.01km ²)
HC	Hard Coral
IUCN	International Union for Conservation of Nature
L	Length (cm)
L _M	Length of first maturity
ln	Natural Logarithm
LRFFT	Live Reef Food Fish Trade
LWR	Length-Weight Relationships
MPA	Marine Protected Area
MR	Marine Reserve
MSY	Maximum Sustainable Yield
N	Abundance/Density
NIA	Nutrient Indicator Algae
NTA	No-Take Area
NTMP	No-Take Marine Park
OT	Other
PIT	Point Intercept Transect
RB	Rubble
RC	Rock
RKC	Recently Killed Coral
SC	Soft Coral
SD	Sand
SDP	Skills Development Programme
SE	Standard Error (±)
SI	Silt
SST	Sea Surface Temperature (°C)
TL	Total Length (cm)
UVC	Underwater Visual Census
W	Individual Mass (g/500m ³ ⁻¹)



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Coral Cay Conservation

Founded in 1986, Coral Cay Conservation (CCC) is dedicated to:

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

CCC works in collaboration with the government and non-governmental organisations within a specific host country and does not receive monetary payment for the services provided (Fig. 1). CCC is primarily self-financed through an innovative 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) that trains them in marine fauna and flora identification, underwater visual census (UVC) methodologies and further underwater data collection methods. The SDP is conducted under the guidance of

highly experienced and qualified marine scientists, prior to assisting in the acquisition of data. 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 community 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 (NTMP) around Sogod Bay, Southern Leyte, the Philippines.

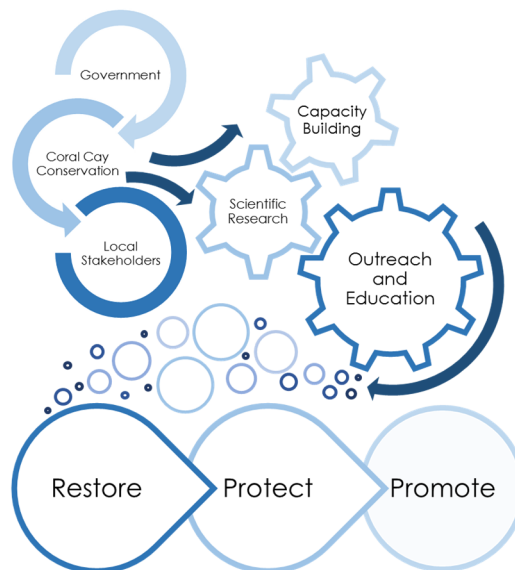


Figure 1. Schematic diagram demonstrating Coral Cay Conservation's (CCC) implementation strategy within a specified host country of which CCC are based, implementing their objectives to accomplish their dedication statement. The sustainment of livelihoods and poverty alleviation are completed through the restoration and protection of socio-economical valuable ecosystems (coral reefs and forests) accompanied with the promotion of sustainable resource extraction and building local capacity.

1. Introduction

1.1 Coral Reefs

Coral reefs are highly productive systems with the majority residing in shallow, nutrient-poor tropical and sub-tropical coastal waters (Polovina, 1984; Cardini *et al.*, 2014). Corals are of the taxonomic phylum Cnidaria and form a symbiotic relationship with a photosynthetic single-celled dinoflagellate alga (*Symbiodinium* sp.) colloquially called Zooxanthellae (Rädecker *et al.*, 2015). This relationship enables the coral or coral polyp to fix carbon and as a result produce a hard, calcium carbonate (CaCO_3) structure or skeleton termed a corallite (Fig. 2). Coral polyps form large colonies of individuals, with each polyp building their respective corallite. Over a long period of time, with mortality and reproduction (Fig. 2a & 2b), large hard coral structures are built. These large structures confer the highly complex three-dimensional architecture of coral reefs; hosting highly bio-diverse communities.

The coral reef matrix provides both ecological and socio-economic benefits and services. Evidence indicates that an increased architectural complexity confers higher ecological, economic and social

significance in comparison to coral reefs that demonstrate a reduced complexity (Fig. 3). The high levels of complexity on coral reefs provide niche opportunities for fish and other fauna, consequently relating to the increased abundance of fishes and invertebrates, species richness and biomass (e.g. Gratwicke and Speight, 2005). The architectural complexity of coral reefs also provide important services to the benefit of human society (Alvarez-Filip, 2010), for example, the dispersion of wave energy along coastlines reduces the rate of erosion, acting as a natural coastal defence (Spalding *et al.*, 2014). Additionally, highly complex coral reefs have the ability to support essential fisheries, utilised by local communities for subsistence and to generate income.

The social and economic importance of coral reefs can be further highlighted when placed into economic terms. Studies have previously attempted to quantify the global value of coral reefs (Martinez *et al.*, 2007; Brander *et al.*, 2007; Cesar *et al.*, 2003) with estimates of a total net benefit up to USD\$29.8 billion per year. Conversely, Brander *et al.* (2007) estimated that the average value of one hectare (ha) of coral

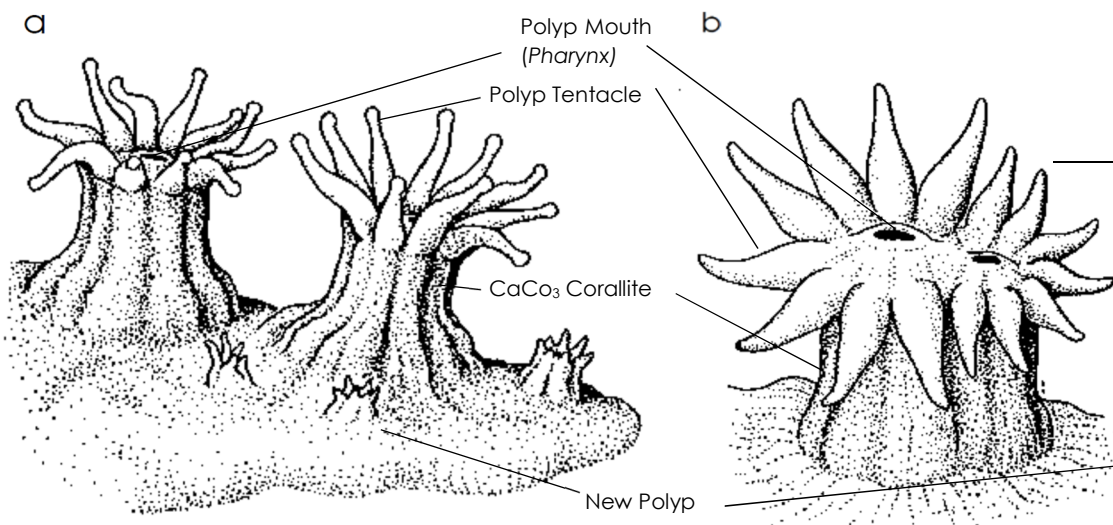


Figure 2. Structural diagrams of a coral polyp's key morphological features. Represented are two different methods of coral polyp asexual reproduction under the term of budding; extratentacular budding (a), and intratentacular budding (b). Retrieved and modified from Barnes (1986).

reef held the annual value of USD\$2,800. The true value of coral reef ecosystems differs amongst countries; however, all demonstrate their socio-economic and service values. It was estimated that the annual net benefits of coral reefs in the Caribbean through fisheries, tourism and shoreline protection was US\$3.1 – US\$4.6 billion in 2000. The greatest share of this total was calculated to be tourism at US\$2.1 billion followed by shore protection and fisheries; US\$700 million and US\$300 million respectively (Burke and Maidens, 2004). With the global value of bio-diversity and fisheries from coral reef ecosystems being USD\$5.5 billion (18%) and USD\$5.7 billion (19%) of the total USD\$29.8 billion value, respectively, the pressures currently placed on coral reefs on a global scale are extensive. As the world population increases these pressures are only set to rise, placing greater resource pressure and economic dependence on reef ecosystems.

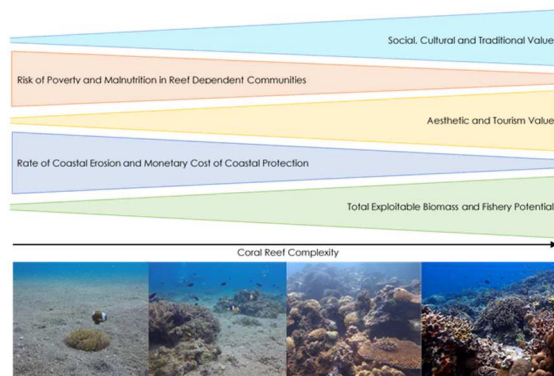


Figure 3. A schematic diagram describing the value and cost of particular ecosystem services and goods with regards to their respective relationship with a coral reef; characterised by high levels of complexity. Within the diagram, the x axis represents increasing complexity, aided by photographs of coral reef topography. The respective triangular shapes depict value or number of goods received with an increasing width, representing an increase in value or amount.

1.2 Threats to Coral Reefs

The threats that face coral reefs throughout the world's oceans are diverse; each with its own significant impact on the reef's respective ecosystem. The stressors and impacts experienced by coral reefs can be categorised into three tiers; "far-field", "regional-field", "near-field".

Regional and far-field stressors are those that act over larger, even global, scales (McClanahan *et al.*, 2014). The root cause for the majority of these stressors is the result of the anthropogenic modification of the Earth's surface, its climate and ocean chemistry (McClanahan *et al.*, 2014). Regional and far-field stressors can include global warming, sea-level rise and ocean acidification. Recently, questions and resultant research has focused on the resilience of coral reefs at an individual, community and ecosystem level to adapt and acclimate to such changes. In most scenarios, the true impact of far-field stressors is exasperated by near field stressors (Ban *et al.*, 2014; Hoegh-Guldberg, 2014; McClanahan *et al.*, 2014; Pandolfi and Kiessling, 2014).

Near field stressors are impacts or stressing factors that are a result of local activity or local phenomena under the direct influence of the local human population. Near field stressors such as point-source pollution, local overfishing and destructive fishing practices are often ubiquitous amongst coral reef systems. In contrast to regional and far field stressors, near field stressors do not pose the same barriers to mitigation, and thus, management practices can be tailored to each individual reef, or stressor. The impact of fisheries on coral reefs is widely published (e.g. Bozec *et al.*, 2016; Mumby, 2006; Hughes, 2003) and is known to be a problematic combination in tandem with increasing human population trends.

Coral reef fisheries are considered small-scale, non-target and multi-gear in nature with artisanal, technologically poor fishing gears utilised by their respective fishers (Fig. 4) (Teh *et al.*, 2013), and have been shown to have a strong impact on coral reefs (McClanahan *et al.*, 2013). In 2000, it was estimated that 15-35% of the 6.2 million fishers throughout the global coral reef regions operate on a small-scale (Sadovy 2005), further highlighted in 2008, was that small-scale fishers account for 90% of fishers



Figure 4. Artisanal fishermen reel in their gill-net on board their wooden constructed boat, within a tropical coral reef fishery. Gill-nets can be highly detrimental to coral reef associated fish stocks, as smaller mesh sized gill-nets are deployed as catches decrease, ultimately removing a greater percentage of the juvenile cohort. The majority of the fish caught within tropical fisheries are for subsistence; however, some are commercially sold to local markets. As human populations increase in coastal and fishery dependent communities, the demand for resources increases often resulting in a 'race to fish' mentality by fishers that increases the number of fishers and the amount of fish removed from the fishery – often tipping the fishery from sustainable to overfished. Photo credited to Tristan Brown (2016).

worldwide (Teh *et al.*, 2013; Gonzalez *et al.*, 2008). In 2013, it was approximated by the UN Oceans Atlas (2013) that 3.5 billion people lived within 200km of the coast, suggestive of immense pressures on already highly impacted ecosystems.

Coral reef fisheries are over-exploited on a global scale (Teh *et al.*, 2013): 55% of the world's coral reefs are considered to be threatened with 33% highly threatened through overfishing and destructive fishing practices. Mitigating these near field stressors is a necessity for local and national governments (McClanahan *et al.*, 2012; Teh *et al.*, 2013; Cinner and McClanahan, 2006).

Fish are an important component of any coral ecosystem, playing a key role in the maintenance of the coral reef whilst providing a large proportion of the standing biomass and promoting local biodiversity through niche occupation (Dallison, 2015; Aquilar-Medrano and Calderon-Aquilera, 2015). Coral reef fishes occupy a range of functional groups (e.g. herbivore, coralivore, invertivore) (Bellwood *et al.*, 2004). A functional group can be categorised as a collection or group of different species that all perform a similar role on the reef, despite their

taxonomic differences, i.e. herbivorous parrotfish (Scaridae) are essential in preventing coral being smothered by algae on reefs. These functional groups are essential to preserving the ecosystem services and goods and there have been many studies that have explored their importance (e.g. Cheal *et al.*, 2013). Over-exploitation of these fishes and their respective functional groups through overfishing can often lead to devastating consequences on coral reefs, such as trophic cascades and reduced resilience, proving detrimental for their long-term sustainable exploitation (Cinner *et al.*, 2009). With a healthy community comprising of fishes, invertebrates and other coral reef associated organisms, coral reefs maintain the ability to resist phase shifts, regenerate and retain critical function (Bellwood *et al.*, 2004). In combination with the removal of functional groups, disrupting the coral reef ecosystem's respective communities, the removal of juvenile cohorts with varying rates can also have a significant impact on the ecosystem services provided (Weatherdon *et al.*, 2016). The selectivity of particular fishing gear results in individuals and species being removed at varying rates with, often, the larger individuals

being removed first (Jackson *et al.*, 2001). One of the indicators of overfishing is the total composition of catch that are sexually immature juveniles (Froese, 2004). For many species of fish, their length is related to their ability to spawn and thus, their life-stage. Therefore, by examining a species-specific length (cm) of first maturity (L_M), fisheries managers can determine the total composition of juveniles within a catch. This is an essential component of fisheries management, as the removal of such juvenile cohorts, before the individual fish reach their respective L_M , can result in the natural and fishing mortality level surpassing the rate of recruitment, ultimately reducing population size and fish stocks. Furthermore, as the size of fish decreases, resulting in a decrease in the amount of biomass (kg) caught for a unit of effort, fishers will place more effort into the fishery in order to maintain catch rates (Fig. 5). This principle can be encapsulated under a measure of fishery well-being; termed as the Catch per Unit Effort (CPUE) ($\text{kg}/\text{effort}^{-1}$). Decreases in CPUE and the resulting decrease in fishery productivity can form the basis of the first signs of an array of negative and positive feedback loops that stem from the socio-economical behaviour of fishers (Cinner 2011). With the strong influence of these social and economic drivers, fishers enter into a 'race to fish' mentality and employ Malthusian fishing practices which often prove disastrous to coral reef communities, as wholesale destructive fishing gears are utilised (Wallner-Hahn *et al.*, 2016). The use of dynamite or other explosives along with the use of poisons such as cyanide are often common within Malthusian fisheries (Saila *et al.*, 1993). The use of such destructive fishing practices can lead to a loss of the highly complex architectural reef structure, reducing complexity and becoming detrimental to the coral reef associated fishes (Fig. 6) (Saila *et al.*, 1993). The development of Malthusian practices within artisanal fisheries is an indicator that the fishers and their respective communities have entered into what is termed a "Poverty Trap" which is coupled

with the inability of coral reefs and their respective biota to exhibit both ecological and economic recovery, and the lack of alternative livelihoods (Smith, Clifton and Unsworth, 2010).

As a result of the detrimental outcomes of overfishing on coral reefs and the induced negative and positive feedbacks by local fishers for sustenance, in addition to far, regional and near-field stressors, mitigation, remediation and prevention efforts by local, regional and national governments, as well as resource managers, are needed.

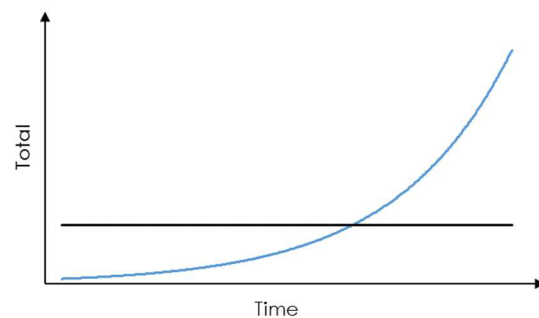


Figure 5. A schematic displaying the relationship between effort (blue) on behalf of a fisher and the total catch (black) when fishers within the fishery are practicing overfishing by removing juvenile fish. As more fish are removed from the fishery and populations start to decrease, the fisher must increase their effort to maintain their catch. Eventually, the fisher will reach the highest economically feasible effort, and catches will start to decline. This relationship is also witnessed as more fishers enter the fishery, often associated with increasing human population sizes.

1.3 Mitigating the threats to coral reefs

The overall aim of coral reef management should be to sustain the ability of coral reefs to provide the ecosystem services, goods and resources that human communities and their subsequent welfare depends upon (Bellwood *et al.*, 2004). As previously discussed, coral reefs support the livelihood of millions of communities, especially those that are integrated in subsistence fisheries (Cinner 2014). With coral reefs exhibiting a high sensitivity to climate change and near-field induced stressors, there is a great need for mitigation and remediation.

There are numerous fishery and coral reef management tools that aim to protect biodiversity, and instigate ecological and economic recovery, whilst preserving the livelihoods of fishery dependent

community members and the sustainable exploitation of marine resources. Communication, education and outreach efforts in combination with appropriate training are all critical elements of coral reef protection and conservation. Through the promotion of sustainable methods for exploiting marine resources, managers are able to improve people's understanding of risks and ensure the correct implementation of management measures (Burke *et al.*, 2011). Local-scale actions during a short-term time scale (<1 year) can include diversification within the fishery, incorporating lower-impact fishing gears such as artisanal hook-and-line, as opposed to high-pressure gears (Cinner *et al.*, 2011). Mid-term time frame actions including fish aggregation devices (FADs), which enable fishers to exploit pelagic species, thus relieving pressure on coral reef associated fishes. Long-term time frame induced measures can incorporate and aim for the diversification and provision of alternative livelihood and economic streams. The most common management measures that span over short, mid and long-term time frames are the implementation of marine protected areas (MPA), no-take areas (NTA) and marine reserves (MR) (Burke *et al.*, 2011). MPAs are loosely defined as a marine area that is actively managed for conservation. They can range in their respective conservation efforts from completely restricting activity (NTAs) within extensive, complex frameworks, to limiting fishing activities or certain gears for the ecological benefit of the protected area (Burke *et al.*, 2011). The protection of marine areas can achieve conservation and resource management targets simultaneously and are therefore considered instrumental to sustainable ocean utilisation (Pauly *et al.* 2002). 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.”

Generally, the most desired benefit of an MPA is increased fish production. This occurs as a result of overspill and larval export from an NTA into surrounding waters, termed the ‘spill-over’ effect (Fig. 7). Over time, the displacement of fishing effort from the MPA increases the adult fish biomass and fecundity. This results in adult fish and larvae being exported to the buffer zone and its surrounding waters. Local fishery yields subsequently increase because they have a continual and sustainable supply of stock (Mallao *et al.* 2004). In areas where there is the potential for increased tourism, and anthropogenic pressure on the marine environment for food, recreation and other resources, the benefits and necessities of having a network of functioning MPAs are increased.

MRs are areas of the marine environment where activities are partially restricted. MRs are preferable to areas of no protection but are not as effective as NTAs due to fishing pressure remaining present and being indiscriminate in nature. The sizes, life-stages and species of fish and invertebrates within an MR can be extracted at the doctrine of the established framework.



Figure 6. Common results of the use of destructive fishing practices within coral reef ecosystems such as blast fishing and cyanide fishing. Blast fishing is the practice of using explosives to shock and stun fish resulting in them floating on the surface. A consequence of this practice is a reduction in the complexity of coral reefs as the complex three-dimensional architecture is destroyed. Cyanide fishing is often deployed by the Live Reef Fish Food Trade (LRFFT) with the cyanide (or other poison) temporally stunning the fish enabling the fisher to collect it. As fish swim away from the cyanide, before they succumb to its toxic effects, fishes can hide amongst the coral instigating the fisher to aggressively damage coral in order to reach the fish. Furthermore, cyanide and other poisons can have highly detrimental impacts on the coral organisms themselves ultimately leading to mortality.

The success of a protected area is entirely dependent upon the compliance of local stakeholders. Research has shown that the involvement of local stakeholders in the planning, implementation and management of their own MPA increases the sense of ownership and pride (Exton, 2010). Only when local stakeholders feel they are adequately considered and regularly consulted on their MPA's management, will it be possible for the full potential of the MPA to be attained (Human and Davies 2010).

A key aspect of the establishment of MPAs, NTAs and MRs is the identification of areas of ecological significance; aggregation, nursery and spawning grounds. These areas are utilised by coral reef and pelagic fishes during respective life-stages and are therefore essential to the recruitment and ecological recovery of communities. This approach is termed ecosystem based management (EBM) or an ecosystem approach to fisheries (EAF), whilst also including anthropogenic activities. The main goal for local managers should be the successful implementation of EAF into local communities through the integration of

social and economic dimensions. In this way managers may achieve sustainability through co-management, and by demonstrating triangulation of local user group decision making, monitoring of the fisheries and the overall ecological status of coral reef systems.

1.4 Caribbean Region

Of all the coral reef regions of the world the Caribbean is arguably the most overexploited and degraded. As for many near shore environments, coral reefs in the Caribbean face a multitude of stressors that serve to weaken reef resilience and reduce productivity. Since the 1980s the broad scale decline of Caribbean reefs has been attributed to increasing natural and anthropogenic pressures. Of direct near-field human-induced impacts, overfishing is widely regarded as the dominant driver in reef decline, facilitating phase shifts from coral-dominated systems to less desirable and potentially less productive, algal-dominated systems (Scheffer *et al.*, 2001). Other stressors including coastal development, sedimentation, bleaching

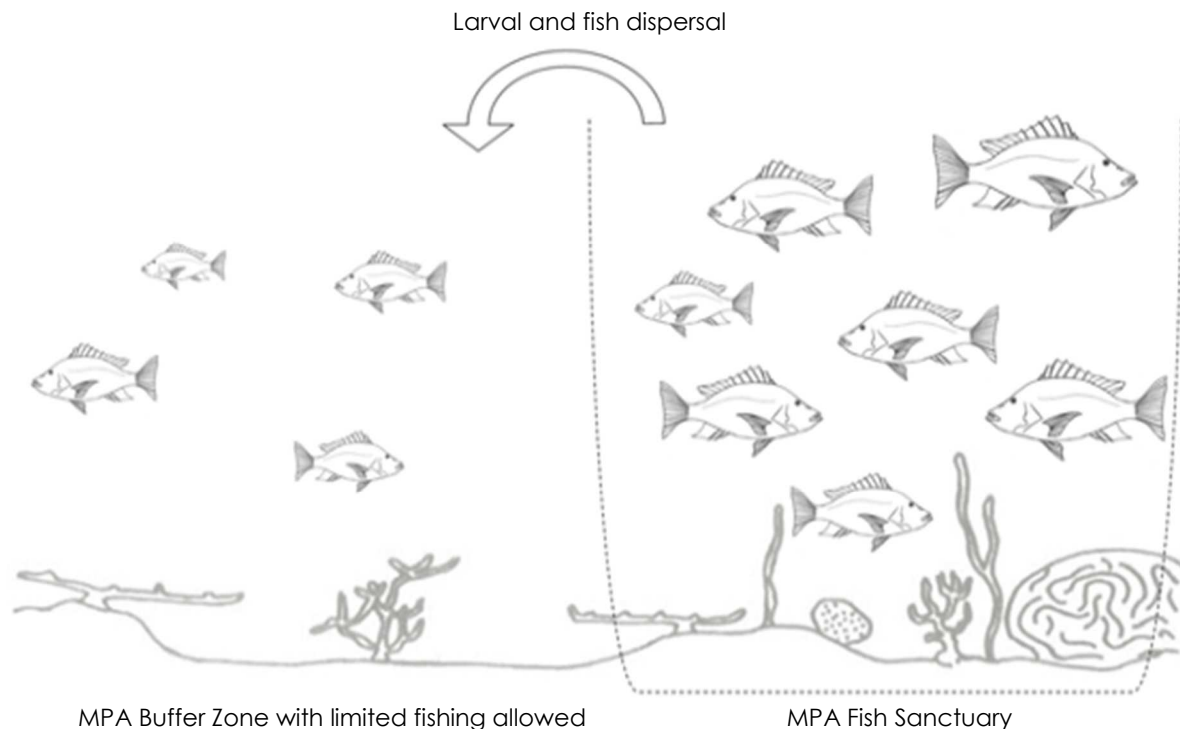


Figure 7. A schematic displaying the 'spill-over' effect that is witnessed through the establishment of marine protected areas (MPAs). As an area is protected from fishing activity, a resilient, ecological community develops. As populations increase and spawning, as well as other life-stage events occur, juveniles or larvae spill outside of the MPAs boundaries, establishing themselves within previously degraded areas.

events, pollution and disease outbreaks also have a spatially variable impact on reef habitats (Burke et al., 2004). Historic overfishing of apex predators has been reported by some studies to have been occurring across the region for centuries (Jackson, 2001), their removal resulted in the targeting of other important functional groups such as herbivorous Parrotfish (Williams et al., 2016). As a primary grazer of macro algae on reefs, Parrotfishes play an important role in maintaining low algal abundance and reducing competition for juvenile coral recruits. (Mumby et al., 2006). The survivorship of coral recruits is fundamental to the ability of a reef habitat to maintain its resilience to, and recover from, disturbance (McClanahan et al., 2012). In the absence of herbivorous fish, the reliance on other keystone grazers, such as Long-spine Urchins (*Diadema antillarum*), increased across the region until the 1980s when a disease outbreak caused mortality rates of up to 100% in some areas (Hughes et al., 1985). With high fishing pressure and the reduced grazing pressure of *D. antillarum*, reefs across the region exhibited phase shifts to less productive macro-algal dominated states, from which they have been struggling to recover (Lessios, 1995 and Lessios, 2016). Recovery of *D. antillarum* numbers has been greatest in the eastern Caribbean; however, average abundances are still only 12% of the pre-mortality figures (Lessios, 2016). The apparent recruitment limitations of *D. antillarum* and the sustained fishing pressure across the Caribbean have ultimately prevented the potential recovery of the region back to a coral dominated ecosystem. Whether this shift is reversible is an area of debate amongst marine scientists, but in the short and medium term the situation seems unlikely to change given the impact of chronic local stressors.

1.5 Montserrat

There exists a distinct paucity in published work considering the marine environment around Montserrat. This is undoubtedly as a result of the socio-economic changes that have affected the island since volcanic eruptions of the Soufrière Hills began in 1995. Since this time, monitoring of the reefs has been of small concern relative to the other challenges facing the country.

Smith et al. (1997), suggest that patch reefs are most abundant off the west and north coasts and that distribution in other areas is likely limited by the steep topography and associated sediment run-off, especially in areas adjacent to freshwater outflows. They also suggest that due to the relatively small population, as a result of the volcano, anthropogenic impacts from pollution and dive tourism are minimal and the reefs around Montserrat are relatively pristine and diverse. Fishing practices on the island are listed as pot fisheries and spearfishing. It is also worth noting that the exclusion zone implemented in the wake of the volcanic eruptions extends out to sea by up to 1km, and as such can be viewed as a pseudo-Marine Protected Area. However, volcanic sediment runoff in these areas is known to be high and impacting the reefs on the southern extent of the island (Smith et al., 1997).



2.0 Methodology

2.1 Characterization of Montserrat

Montserrat, part of the Leeward Isles in the Lesser Antilles, is a small Caribbean island with an area of approximately 102 km² located at 16° 45' 0" N, 062° 12' 0" W. The island, like most in the region, is volcanic in nature which is evident from its topography which shows three distinct volcanic ranges.

Climatic condition across the region are dominated by North Easterly Trade winds. Average annual temperatures range from 25°C in the dry season (December – June) to 29°C during the wet season (July – November). During the wet season the region is affected by hot and humid conditions that may result in hurricane events. Monthly rainfall during these months can be greater than 200mm.

Over the last two and a half decades, Montserrat has experienced a number of large natural disasters which have resulted in severe and prolonged impact on the country's population, environment and economy. Hurricane Hugo struck the island in 1989, leading to widespread defoliation, destruction of property and loss of livestock. In 1995, the Soufrière Hills volcano became active and subsequently erupted three times. The effects of the eruptions have been wide reaching; forcing much of the population to leave the island and causing significant impacts to the island's marine and terrestrial ecosystems. An exclusion zone has been implemented across the southern half of the island and near shore environment (Fig. 8).

2.2 Data Collection

2.2.1 Biophysical Survey

The assessment of the near shore environment was conducted using an enhanced ReefCheck method. The ReefCheck methodology is widely recognised and was developed in the 1990s. CCC has augmented the methodology by adding additional target species of fish and invertebrates to better reflect the biodiversity of the area

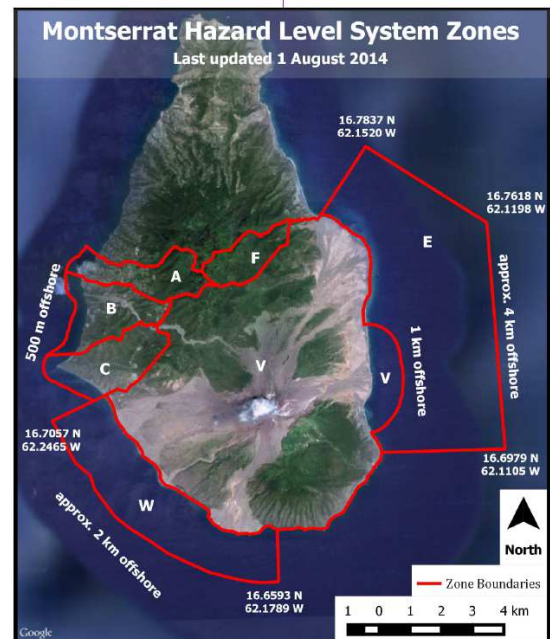


Figure 8. A map indicating the current location of the exclusion zones on Montserrat, Caribbean. At the time of writing the Hazard level is 1, which permits only daytime transit through maritime zones 'W' and 'E'. Zones 'A', 'B', 'C' and 'F' have unrestricted access. Zone 'V' is under controlled access. Map adapted from Montserrat Volcano Observatory publication. Available at: www.mvo.ms/pub

(Appendix A). Two phases of survey effort have been conducted since 2013. During the first phase surveys were conducted at set locations every 500m along the northwest coast (Fig 9a). Each survey site contained one transect at 6m and one at 12m. Each transect was 100 metres long and divided into 4 replicates of 20m. Between each replicate there was a 5m inter-replicate gap where no data was recorded enabling for robust statistical analysis of the collected data.

Following review of the first phase data, surveys in phase two were targeted on sites along the coast which were considered to have the greatest conservation potential. The sites surveyed were; Carr's Bay, Woodlands Bay, Lime Kiln Bay, Old Road Bay and Isles Bay. Permanent transect sites were also installed at selected sites; Carr's Bay, Woodlands Bay, Lime Kiln Bay and Foxes Bay (Fig 9b).

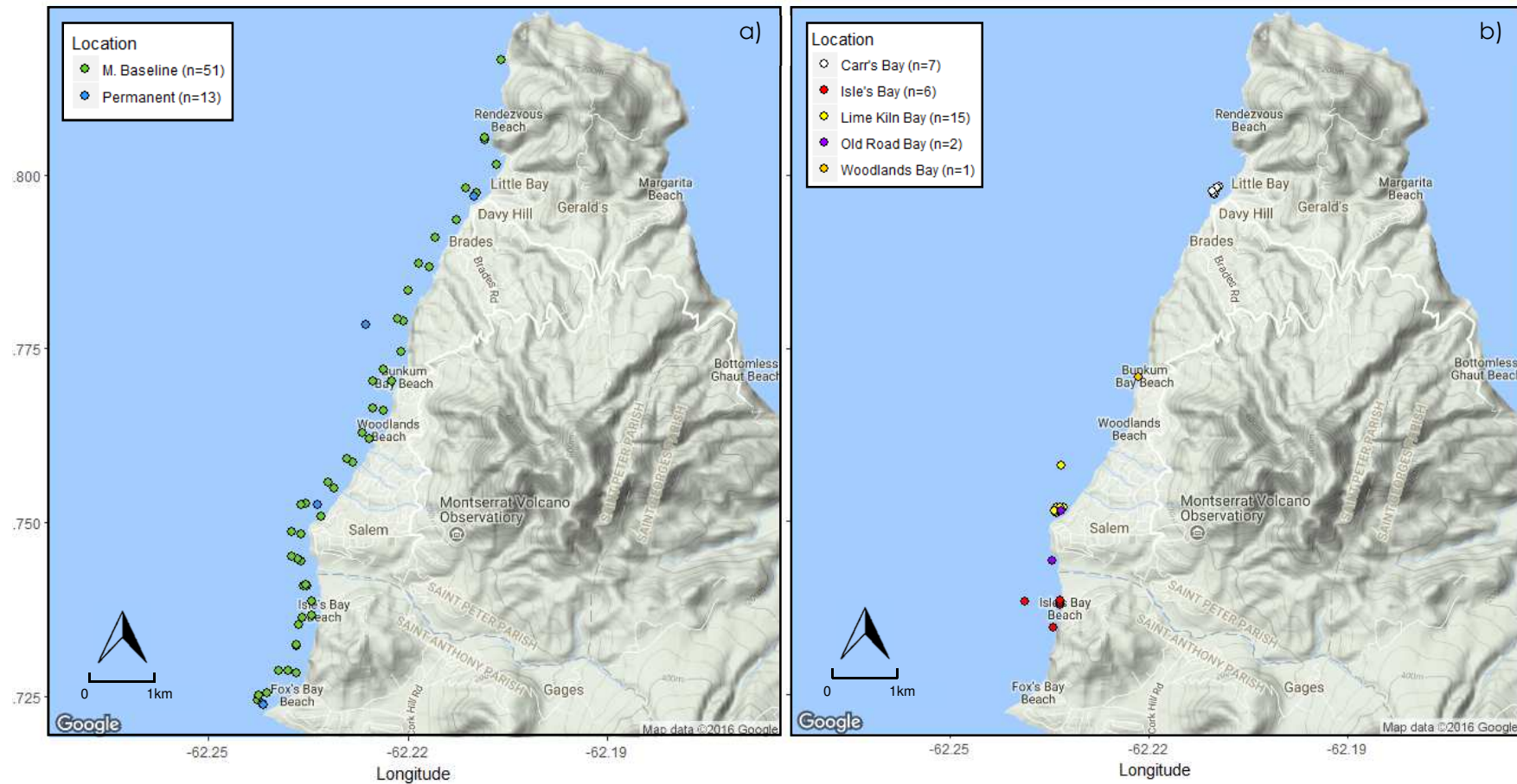


Figure 9. Maps that portray the location of surveys conducted by Coral Cay Conservation on the western coastline of Montserrat, Caribbean during Phase I (a) and Phase II (b) of the "Montserrat Ridge to Reef Conservation Project". Locations are defined by respective colours as given in the corresponding legends.

2.2.2 Underwater Visual Census (UVC) for the Assessment of Fishes

The diversity and abundance of fishes was recorded using UVC. Selected fish families and species recognised as being indicators of fishing pressure, LRFFT and reef health were recorded (Table A1). The total length (TL) (cm) of two commercially important fish families and two species and one collective sub-species was also recorded to enable biomass (kg) calculations to be determined - Groupers (Serranidae), Parrotfish (Scaridae), Coney (*Cephalopholis fulva*), Nassau Grouper (*Epinephelus striatus*) and Hind (*Epinephelus guttatus* & *Epinephelus adscensionis*)

Fish data were collected along a 'belt' transect, where fish abundance was recorded within a 5x5x5m box along the four 20m replicates (Fig. 10). This equated to a total area surveyed per transect of 2,000m³. Surveying was carried out by two SCUBA divers swimming side by side along the transect and recording the indicator fish. The divers stopped every 5m and waited 1 minute for the indicator fish to resume natural behaviour before proceeding.

2.2.3 Biomass Calculations

During UVC fish surveys, the individual size of commercially important fish families were characterised through length (cm) (L) estimations which were subsequently placed into appropriate size classes: 0-10cm; 11-20cm; 21-30cm; 31-40cm; 41-50cm; 51-60cm; >60cm. Length-weight relationships (LWR) (Equation. 1) were utilised to calculate the individual mass (g) (W) and biomass (kg). The individual weight of species in a given sample can vary considerably, therefore within this study, specific steps were taken when assessing the W of individuals in each commercially important fish family in accordance with Froese *et al.* (2014) and Froese and Pauly (2000).

The biomass (kg) of each size class of family was derived through allometric LWRs. The relationship between L and W for fish species is expressed by equation (1):

(1)

$$W = aL^b$$

Equation 1. Length-weight relationships were used to determine the biomass (kg) of each individual recorded on coral reefs around Montserrat. W = mass (g), *a* = the condition factor (Hilborn and Walters, 1992), *b* = species specific growth parameter (Quinn and Deriso, 1999), L = the total length (TL) (cm) measured of the individual fish.

a and *b* are termed allometric coefficients, and each LWR requires both values. *a* is the condition factor in that it describes the body-shape of the species, where parameter *b* indicates the isometric growth of a species (Froese *et al.*, 2014).

In order to determine the respective *a* and *b* coefficients for the two prescribed commercially important fish families, utilising data sources from FishBase (www.fishbase.org) (Froese and Pauly, 2000), the geometric mean value for *a* and *b* was calculated. This was due to the described potential variation of individual subjects. The components of each calculation were selected based on their reported location (Montserrat, Lesser Antilles) due to the natural abiotic impacts as well as differential spatial fishing intensity. Studies that categorically stated the species body-form and length measurements reported in TL were recorded. Therefore, Standard Length (SL) studies and where FishBase listed the study as "doubtful" were excluded.

The respective genera within each family were individually analysed and the subsequent geometric mean determined for the allometric LWR coefficients. To establish the overall allometric coefficient values for the family, the geometric mean was subsequently calculated. For genera that did not supply studies of values that complied with this report's selection criteria, a Bayesian approach was taken in accordance with Froese *et al.* (2014).

If the location of the study and reference were not obtainable, the species-range and native habitat were explored of the fish species through FishBase archives. If the species resided within the Caribbean region, the assumption was made that the allometric coefficients were obtained from individuals caught within the native habitat – the desired range. If the native range was

outside the Caribbean region, the study was excluded. Following the discussed process, the appropriate α and b values for each commercially important fish family were determined (Table 1).

2.2.4 Underwater Visual Census (UVC) for the Assessment of Invertebrates

The abundance and diversity of invertebrates (Table A2) was recorded along the same 100m belt transect locations as were used for the assessment of fish. Divers using SCUBA followed an 'S' shape to ensure even area coverage. Target invertebrates were established based on their respective value as commercially important species, as a food source for local fishers and their relative functional group including their value in the collection of curios. Data were collected along a 20m replicate, assessing the area 2.5m either side of the transect line equating to a total area of 100m² replicate⁻¹ (400m² transect⁻¹) (Fig. 11). No data were recorded within the 5m inter-replicate gap.

2.2.5 Point Intercept Transect (PIT) for the Benthic Substrate Composition

Benthic composition was measured by recording biotic and abiotic benthic categories along a point intercept transect (PIT). Along the transect line, benthic organisms and substrate types were recorded at 0.5m intervals (Fig. 12). To minimize bias, a plumb line was dropped at each designated 0.5m point and the substrate type underneath was recorded. Every replicate contained 40 benthic points.

Benthic categories were: sand (SD), rock (RC), rubble (RB), silt/mud (SI), nutrient indicator algae (NIA), sponge (SP), recently killed coral (RKC), soft coral (SC), hard coral (HC) and any other (OT) biotic lifeforms (Table A3).

2.2.6 Impact Assessment

Within the same area assessed for invertebrates, CCC surveyors recorded the number of impacts on the reef. The total percentage of bleached coral cover as well as the estimated percentage of each

individual coral colony that was bleached was determined. Coral diseases were recorded as a percentage of the colony infected and where possible, the disease was identified. Damage was recorded in three categories: boat/anchor, dynamite and other, on a categorical scale from 0 to 3 (0 = none, 1 = low, 2 = medium, 3 = high). Impact on the site from trash was recorded on the same scale and separated into general and fishing nets/traps.

2.3 Data Analysis

All analysis was conducted using R v3.2.4 (R Core Team, 2016) through the use of various statistical and graphical packages within the user face.

Prior to analysis, data were tested for distribution utilising Shapiro-Wilks Normality test (Shapiro & Wilk 1965). All data analysed were not shown to deviate from a normal distribution and thus no transformations were required. Data concerning means are displayed with respective standard errors ($\pm$ SE). To determine diversity for coral reef-associated communities of target fishes and invertebrates, Shannon-Wiener Diversity Index (H') was produced. H' was derived from the replicates of each transect location with the subsequent mean H' being utilised. Analysis of Variance (ANOVA) was used in order to examine the differences between means throughout multiple samples. Upon testing single factors, one-way ANOVA was used. Results from one-way ANOVA and the respective samples were further tested through post-hoc multiple comparison Tukey tests (Tukey 1949). This enabled observation of where statistical significance (95% confidence-limits, $p = <0.05$) existed between tested sample means. In order to assess correlations between two continuous factors, Pearson's product-moment correlation tests were employed. 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' (R Core Team 2016) and 'Vegan' package (Oksanen *et al.*, 2016).

Table 1. The calculated Length-Weight allometric coefficients to determine the biomass (kg) of sized Grouper, Hind and Parrotfish through geometric mean over the survey period on the north-western coast of Montserrat, Caribbean. Coney and Nassau are reported as species specific values.

Genera	Species	Common Name	Allometric Coefficients	
			a	b
Serranidae	Other	Grouper	0.01176	3.06249
	<i>Cephalopholis fulva</i>	Coney	0.016224	3.006099
	<i>Epinephelus striatus</i>	Nassau grouper	0.00976	3.130622
	<i>Epinephelus guttatus</i> & <i>Epinephelus adscensionis</i>	Hind	0.013301	3.03906
Scaridae	Other	Parrotfish	0.015752	3.043264

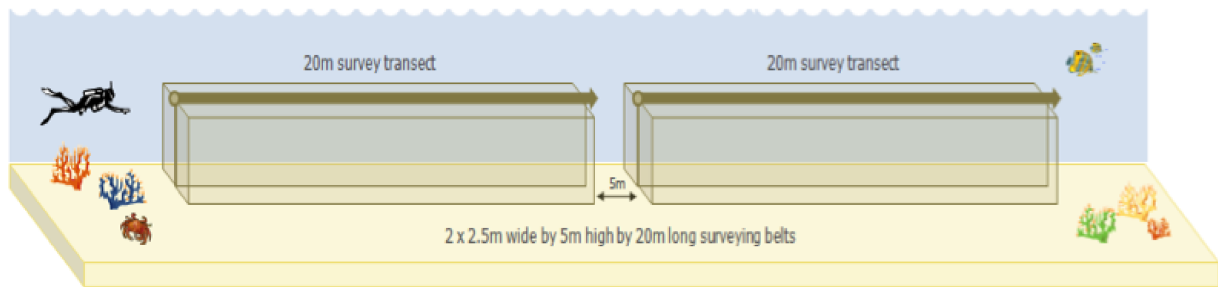


Figure 10. Schematic diagram representing the augmented ReefCheck methodology conducted by Coral Cay Conservation (CCC) surveyors, in the assessment of the diversity and abundance of fishes along the coast of Montserrat. Each conducted transect is separated into 4 20m replicates segmented by 5m inter-replicate gaps with the abundance of fishes recorded 5m either side of the transect. The presented schematic only represents two of the four 20m replicates.

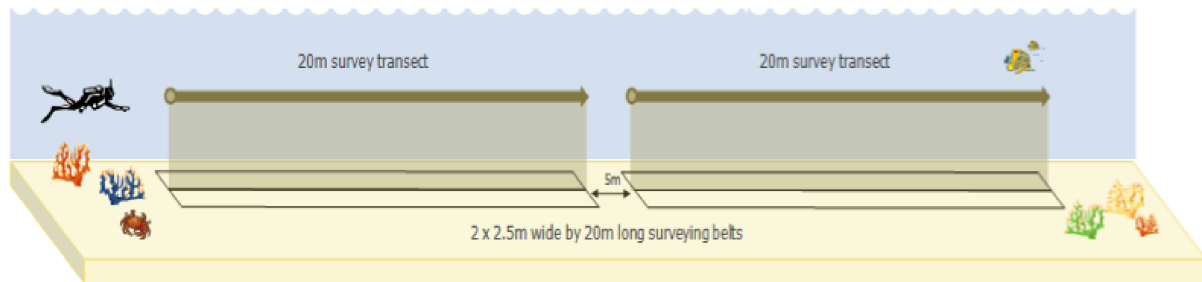


Figure 11. Schematic diagram representing the augmented ReefCheck methodology conducted by Coral Cay Conservation (CCC) surveyors in the assessment of the diversity and abundance of invertebrates along the coast of Montserrat. Each conducted transect is separated into 4 20m replicates segmented by 5m inter-replicate gaps with the abundance of invertebrates recorded 2.5m either side of the transect. The presented schematic only represents two of the four 20m replicates.

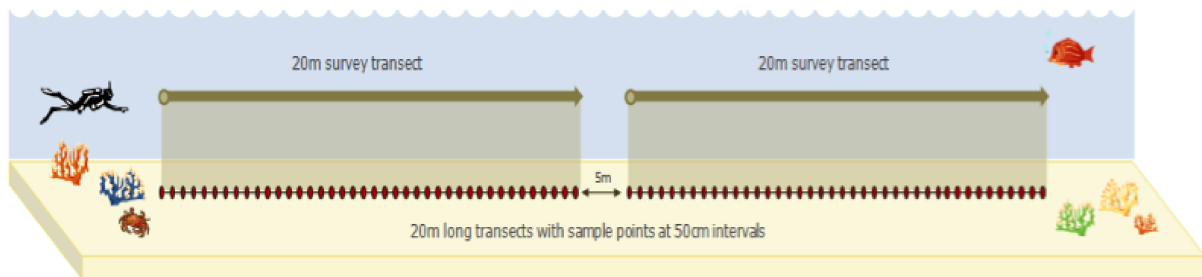


Figure 12. Schematic diagram representing the undertaken point intercept methodology conducted by Coral Cay Conservation (CCC) surveyors in the assessment of benthic composition along the coast of Montserrat. Each conducted transect is separated into 4 20m replicates segmented by 5m inter-replicate gaps with the respective benthic substrate recorded at 0.5m intervals. The presented schematic only represents two of the four 20m replicates.

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. Dendograms were then subsequently produced and presented with the mean 'Jaccard' indices. Clusters were taken from the mean slice.

2.4 Conservation Management Values (CMV) Methodology

For this report, to determine the arbitrarily assigned Conservation Management Value (CMV), an area that exhibited a high level of biological richness, CMV indices were developed. The CMV for a particular location was determined through comparative studies between location-specific means and the holistic mean for the grouping variable. Seven grouping variables were used; Scleractinian hard coral composition (%) (20m^{-1}); Gorgonian (GO) Abundance (N) (100m^2^{-1}); Fish Abundance (N) (500m^3^{-1}); Fish Diversity (H') (500m^3^{-1}); Invertebrate Abundance (N) (100m^2^{-1}); Invertebrate Diversity (H') (100m^2^{-1}); and Commercially Important Fish Biomass (kg) (500m^3^{-1}). The mean was determined for each survey location from the surveyed four replicates for the respective grouping variable. This mean was subsequently compared directly to the overall mean of the grouping variable for the survey site in its entirety (north-western coastline of Montserrat). If the mean of the location was found to be above the overall mean, the location was awarded a score of '1'. This was repeated for each of the aforementioned 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 figure between all sites and thus the CMV for a defined site is of relative value to others. Therefore, a low CMV implies that in comparison to other areas, it is not as biologically 'rich' as others and CMV values must be taken into account with other results.



3.0 Results

3.1 Biophysical Survey

Over the survey period from 2013-2016 a total of $n = 95$ surveys ($n = 380$ replicates) were conducted. Surveys were undertaken by CCC staff and volunteers at an average time of 10:35 with the mean sea surface temperature ($^{\circ}\text{C}$) (SST) being $29.0 \pm 0.2^{\circ}\text{C}$. Underwater horizontal visibility in relation to turbidity ranged from 2m to 30m with a mean of $15.6 \pm 0.5\text{m}$. The location of survey sites relative to population centres varied considerably along the coast with a maximum distance of 5km and a minimum of 0.5km. The mean distance from a population centre was $1.5 \pm 0.1\text{km}$. Major storm events, considered to be significant in strength to physically damage coral structures were not recorded during the survey period. The sampled area was considered to experience low levels of anthropogenic impact with 86% of sites classed as 'low' and 3% as 'high' (Fig. 13). Delineating the overall anthropogenic impact further, harvesting of invertebrates, artisanal and commercial fishing practices were found to be low (Fig. 13). The pollution levels, including industrial pollution were

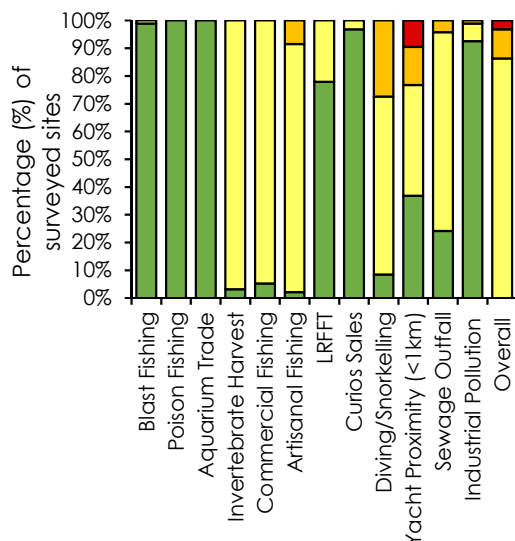


Figure 13. Percentage (%) of survey sites classified by impact as "None" (Green); "Low" (Yellow); "Medium" (Orange); and "High" (Red) as described during surveys between 2013 and 2016 along the north-western coastline of Montserrat.

also considered to be low. The highest anthropogenic impact was found to be tourist diving/snorkelling which was considered to be low/medium (Fig. 13).

3.2 Coral Reef Community Analysis

Overall, 380 replicates were conducted from 95 survey sites of which equated to a total of 190km^3 of coastal water surveyed with results indicating a target fish density of $N = 191.30 \pm 10.56 \text{ } 500\text{m}^3^{-1}$. The assessment of invertebrate density resulted in 38km^2 of coastline being surveyed with GO abundance dominating invertebrate communities ($N = 109.53 \pm 8.79 \text{ } 100\text{m}^2^{-1}$). Excluding the abundance of GO, invertebrate individuals were surveyed at a density of $N = 10.69 \pm 1.1 \text{ } 100\text{m}^2^{-1}$. Subsequently, 7.6km of benthos was surveyed with sand (SD), other (OT) and rock (RC) being the dominant substrates across the overall survey area ($50.66 \pm 2.03\%$; $15.65 \pm 1.62\%$; $13.22 \pm 0.98\%$, respectively).

Charismatic mega-fauna were recorded in low abundance with *Eretmochelys imbricate* (Hawksbill Turtle) recorded 5 times over the sample period. One Nurse shark (*Ginglymostoma cirratum*) was observed on the reef over the survey period. No *Manta* sp. (Manta Ray) were observed throughout the survey period, however 6 Southern Sting Rays (*Dasyatis americana*) and 1 Eagle Ray (*Aetobatus narinari*) were recorded.

3.2.1 Coral Reef Associated Fishes

Over the survey period a total of 72,703 fishes were recorded from 26 families (Table B1). Labridae (Wrasse) were the most commonly observed target family ($N = 113.41 \pm 6.31 \text{ } 500\text{m}^3^{-1}$) with a total of 43,094 individuals recorded (Fig. 14b, Table A1). Subsequently, Pomacentridae (Damselfishes) ($N = 56.88 \pm 5.21 \text{ } 500\text{m}^3^{-1}$) were the second most abundant, 21,616, followed by Acanthuridae (Surgeonfishes) ($N = 9.17 \pm 0.62 \text{ } 500\text{m}^3^{-1}$) accruing 3,486

individuals throughout the period (Fig. 14b, Table B1). The least represented target families were Sparidae (Porgy) and Belonidae (Needlefishes) ($N=2$ and $N=0$, respectively) (Table A1). Scaridae (Parrotfishes) were recorded across all survey sites at a density of $2.00 \pm 0.47 \text{ } 500\text{m}^3^{-1}$, of which presented greater variability in density than Seranidae (Groupers) ($N=2.13 \pm 0.18 \text{ } 500\text{m}^3^{-1}$). Scorpaenidae, including the invasive lionfish (*Pterois* sp.), were found in relatively low abundance along the north-western coastline of Montserrat, with a recorded mean density of 0.11 ± 0.04 , a total of 43 individuals (Fig. 14a, Table A1). When considering only the geographically constrained five survey locations, the total number of surveyed individual fishes decreased to 28,069, equating to a density of $N=226.36 \pm 15.18 \text{ } 500\text{m}^3^{-1}$. Labridae were found in greater abundance throughout the five locations surveyed in comparison to all locations, $N=142.35 \pm 10.36 \text{ } 500\text{m}^3^{-1}$ (Fig. 14a). Scaridae were recorded in lower abundance ($N=0.46 \pm 0.07 \text{ } 500\text{m}^3^{-1}$) than the abundance of Serranidae ($N=2.46 \pm 0.31 \text{ } 500\text{m}^3^{-1}$) (Fig. 14a). Belonidae remained absent (0) (Fig. 14a).

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 ($N=89.50 \pm 27.44 \text{ } 500\text{m}^3^{-1}$) held a significantly lower fish abundance than Carr's Bay ($N=235.61 \pm 28.53 \text{ } 500\text{m}^3^{-1}$) and Lime Kiln Bay ($N=283.70 \pm 19.86 \text{ } 500\text{m}^3^{-1}$) ($p<0.05$ and $p<0.001$, respectively) (Fig. 15a). Furthermore, a significant variation ($p<0.01$) was found between Lime Kiln Bay and Old Road Bay ($N=75.63 \pm 36.93 \text{ } 500\text{m}^3^{-1}$). Location of survey also resulted in variation amongst the diversity (H') of coral reef-associated communities (ANOVA ($F_{(4, 119)}=5.83$, $p<0.001$)). Variation in H' was greatest amongst Old Road Bay ($H'=0.31 \pm 0.12 \text{ } 500\text{m}^3^{-1}$) 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 ($p<0.05$) (Fig. 15b). Lime Kiln Bay was considered to hold the most diverse community of fishes with a H' value of $1.02 \pm 0.05 \text{ } 500\text{m}^3^{-1}$ (Fig. 15b).

3.2.2 Community presence of Herbivorous fishes

Throughout the sample period, a total of 26,247 individuals from target fish families that exhibit herbivorous behavioural traits were recorded equating to $N=69.07 \pm 5.58 \text{ } 500\text{m}^3^{-1}$. Subsequently, the dominant herbivorous family were Pomacentridae with 21,616 individuals ($N=56.88 \pm 5.21 \text{ } 500\text{m}^3^{-1}$) surveyed. Due to the multiple geographic locations of Permanent and Baseline surveys, only geographically constrained survey sites (Isle's Bay, Carr's Bay, Lime Kiln Bay, Old Road Bay, Woodlands Bay) were further included and thus, as a result, from the five constrained sites, 8,829 individuals ($N=71.20 \pm 7.09 \text{ } 500\text{m}^3^{-1}$) were recorded. The recorded herbivores were categorised into 7 target families (mean, SE); Acanthuridae ($N=10.68 \pm 0.99 \text{ } 500\text{m}^3^{-1}$); Kyphosidae ($N=0.01 \pm 0.01 \text{ } 500\text{m}^3^{-1}$); Ostraciidae ($N=0.65 \pm 0.23 \text{ } 500\text{m}^3^{-1}$); Pomacanthidae ($N=0.19 \pm 0.04 \text{ } 500\text{m}^3^{-1}$); Pomacentridae ($N=58.68 \pm 6.70 \text{ } 500\text{m}^3^{-1}$); Scaridae ($N=0.46 \pm 0.07 \text{ } 500\text{m}^3^{-1}$). In summary, Pomacentridae were the dominant herbivorous target family recorded across all five survey sites with no Hemiramphidae being recorded. However, they were present on baseline surveys.

Accumulated totals of herbivorous families categorised by location to provide mean herbivore densities resulted in Lime Kiln Bay having the greatest density, $N=99.88 \pm 11.49 \text{ } 500\text{m}^3^{-1}$, in comparison to other sites (Fig. 16). Old Road Bay demonstrated the lowest density, $N=12.63 \pm 7.47 \text{ } 500\text{m}^3^{-1}$ (Fig. 16). Furthermore, location was demonstrated to have a significant impact on herbivorous densities (ANOVA ($F_{(4, 119)}=5.21$, $p<0.001$)) with a *post-hoc* Tukey test demonstrating that Lime Kiln Bay differed significantly from Carr's Bay ($p<0.05$) and Isle's Bay ($p<0.01$). The results obtained from ANOVA are further supplemented by results through Jaccard Dissimilarity Index (JDI) (Fig. 17). JDI indicated that, following complete linkage, three clusters were identified at the 62% (0.62 dissimilarity) mean JDI slice (Fig. 17).

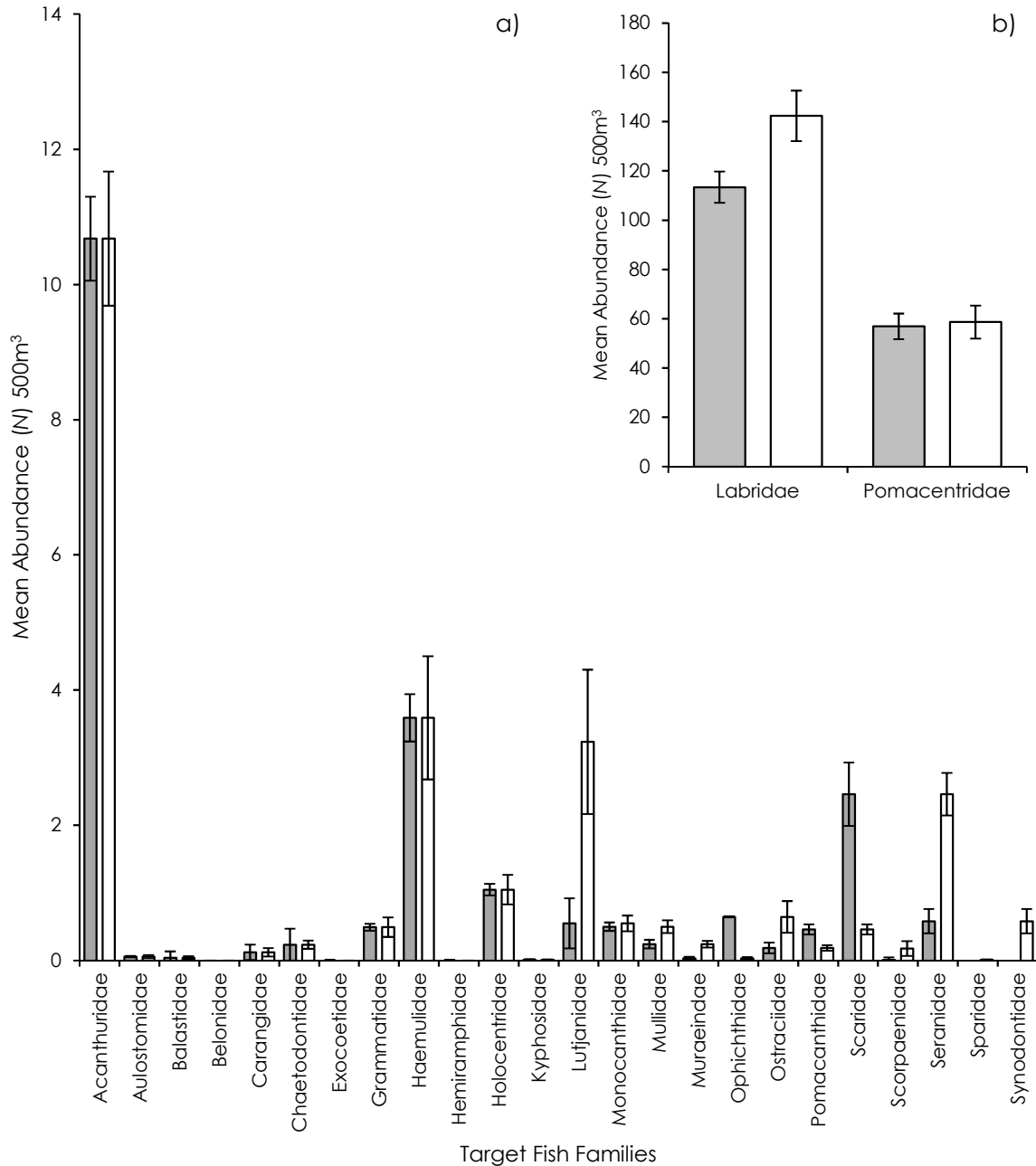


Figure 14. Mean abundance (N) of coral reef associated target fish families surveyed throughout the sample period (2013 – 2016) along the north-western coastline of Montserrat (grey) with the mean abundance derived from five geographically constrained sites (white). Where further delineations of families were recorded, they were grouped into respective families. Taxonomic nomenclature (common name) is as follows, a): Acanthuridae (Surgeonfish); Aulostomidae (Trumpetfish); Balastidae (Tirggerfish); Belonidae (Needlefish); Carangidae (Jacks & Trevally); Chaetodontidae (Butterflyfish); Exocoetidae (Flyingfish); Grammatidae (Basslets); Haemulidae (Grunts); Holocentridae (Squirrelfish); Kyphosidae (Chub); Lutjanidae (Snapper); Monocanthidae (Filefish); Mullidae (Goatfish); Muraenidae (Moray Eel); Ophichthidae (Snake Eels); Ostraciidae (Boxfish); Pomacanthidae (Angelfish); Scaridae (Parrotfish); Scorpaenidae (Scorpionfish and Lionfish); Seranidae (Grouper); Sparidae (Porgy); Synodontidae (Lizardfish). b) Labridae (Wrasse); Pomacentridae (Damsel fish). Standard error ($\pm$ SE) bars are presented

Lime Kiln Bay and Woodlands Bay held the greatest similarity of 74% (0.26 dissimilarity) with regards to their respective herbivorous target communities, B (Fig. 17). Subsequently, Carr's Bay and Isle's Bay formed a cluster of 53% similarity (0.47

dissimilarity), C, with Old Road Bay herbivorous community structure being the third cluster, A, with a minimum similarity of 12% (0.88 dissimilarity) between Lime Kiln Bay (Fig. 17).

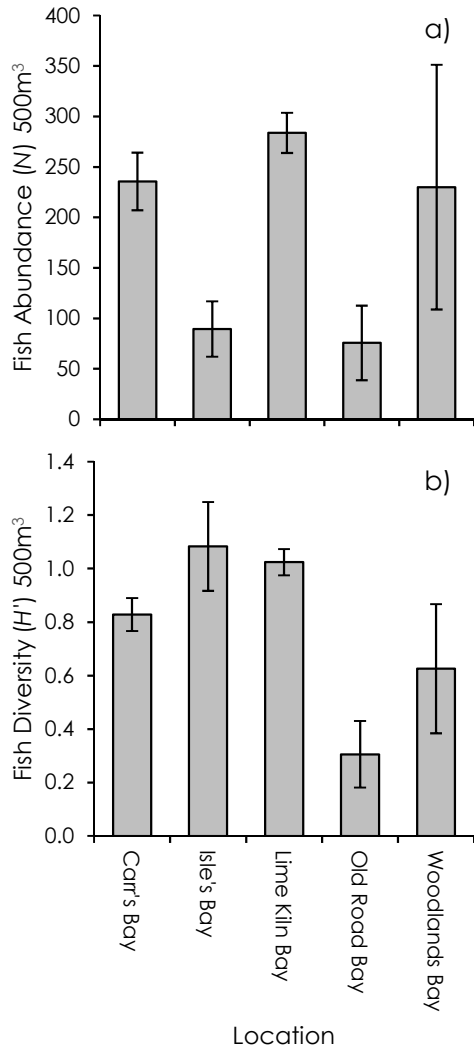


Figure 15. Mean abundance (N) (a) and Shannon-Wiener Diversity Index (H') (b) of fishes recorded for each surveyed location (500m³⁻¹). Standard Error (SE ±) values are displayed.

3.2.3 Community Characteristics of Commercially Important Fishes

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. Comparatively, the removal of permanent and baseline sites resulted in a decrease in recorded biomass (28.21 kg). Subsequently, the mean biomass of commercially important fishes decreased by 0.4kg, equating to 0.23 ±0.04 kg/500m³⁻¹. Location was observed to have no impact on biomass (ANOVA (F_(4, 119)=2.3, p= n.s), however a *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

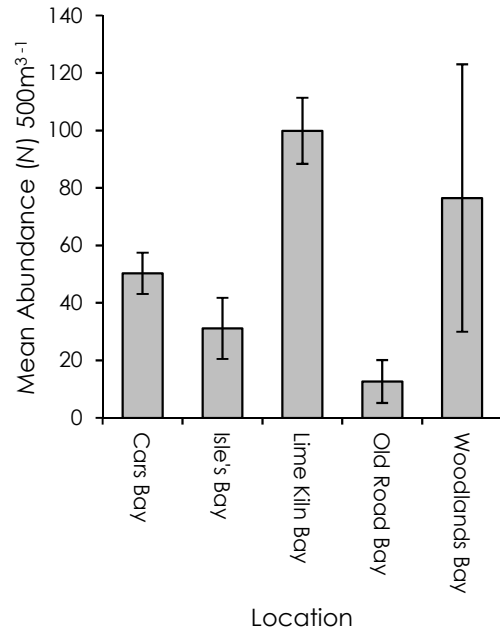


Figure 16. Mean abundances(N) (500m³⁻¹) of accumulated herbivore target families categorised by their respective survey site, geographically located along the north-western coastline of Montserrat, Caribbean. Accumulated abundances are composed of Acanthuridae; Kyphosidae; Monocanthuridae; Ostracidae; Pomacentridae; Pomacanthidae; Scaridae; and Hemiramphidae. Mean values are displayed with standard error (SE ±) bars.

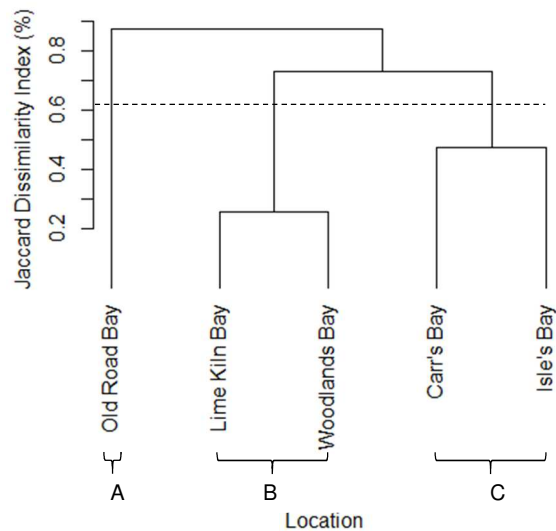


Figure 17. Cluster analysis (Jaccard Dissimilarity Index (%)) (JDI) of the target herbivorous communities surveyed at five survey sites along the north-western coastline of Montserrat, Caribbean. A slice at 62% is presented (dashed line), of which indicates the mean JDI value for the total sample. Clusters are identified accordingly (A, B and C).

of location on the individual mass (g) of fishes was significant (ANOVA (F_(4, 119)= 2.86, p= <0.05)), however, further analysis through *post-hoc* Tukey tests provided no further significant variation amongst sites (p= n.s) (Fig. 18b). To compartmentalise

biomass further, Coney (*Serranidae* sp.) were the most represented commercially important Genus with an accumulated mean across all sites of $1.02 \pm 0.07 \text{ kg/500m}^3$ with Hind (*Serranidae*) and Nassau Groupers (*Serranidae*) the least represented ($0.05 \pm 0.01 \text{ kg/500m}^3$, both respectively). The mean biomass of Coney was greatest at Old Road Bay, $0.42 \pm 0.42 \text{ kg/500m}^3$, with Coney the only commercially important family recorded at that location (Fig. 19). Furthermore, the biomass of Coney was shown to differ significantly between Lime Kiln Bay ($0.25 \pm 0.03 \text{ kg/500m}^3$) and Isle's Bay ($0.02 \pm 0.02 \text{ kg/500m}^3$), ANOVA ($F_{(4, 119)} = 2.62$, $p < 0.05$). Parrotfish were recorded as the second greatest contributor to biomass ($0.17 \pm 0.02 \text{ kg/500m}^3$) whilst only occurring at Carr's Bay ($0.10 \pm 0.05 \text{ kg/500m}^3$) and Lime Kiln Bay ($0.06 \pm 0.02 \text{ kg/500m}^3$) (Fig. 19). Grouper were also poorly represented across all sites ($0.20 \pm 0.03 \text{ kg/500m}^3$) with the greatest contribution recorded at Lime Kiln Bay (Fig. 19). No further commercially important fishes were demonstrated to be impacted by location (ANOVA, $p = \text{n.s.}$). The community structure of commercially important fishes at each location can be further described through cluster analysis (Fig. 20). Three clusters were indicated (A, B and C), following complete linkage, with the similarity slice presented at 79% (0.79) - the mean JDI (Fig. 20). Old Road Bay, Carr's Bay and Lime Kiln Bay, A, held the greatest similarity of 39% (0.61 dissimilarity) with regards to their respective commercially important fish communities (Fig. 20). Furthermore, Lime Kiln Bay and Carr's Bay were the most similar locations, 61% (0.39 dissimilarity) (Fig. 20). Clusters B and C were formed from Isle's Bay and Woodlands Bay of which indicated <15% similarity (<0.85 dissimilarity) (Fig. 20). Throughout the sample period, no individuals, from all target families, were recorded >50cm with the dominant size being <20cm (Fig. 21). Parrotfish (*Scaridae*) held the greatest frequency (f) throughout the sample period ($f = 760$) with 615 individuals recorded <10cm in length (Fig. 21). No

Parrotfish were recorded >50cm with 6 individuals classed between 31 and 50cm.

Coney (*Serranidae*) were subsequent to Parrotfish with a total of 694 individuals recorded with 10-20cm being the dominant size class ($f = 379$) (Fig. 21b). Hind (*Serranidae*) and Nassau Grouper (*Serranidae*) were the most poorly represented ($f = 16$ and $f = 9$, respectively). The majority of Nassau grouper recorded where >10cm in size ($f = 6$) (Fig. 21d). In addition, the majority of Grouper (*Serranidae*) recorded were below 30cm with the dominant size class >10cm ($f = 39$) (Fig. 21a), however, 1 individual was recorded between 41-50cm at Lime Kiln Bay in 2016.

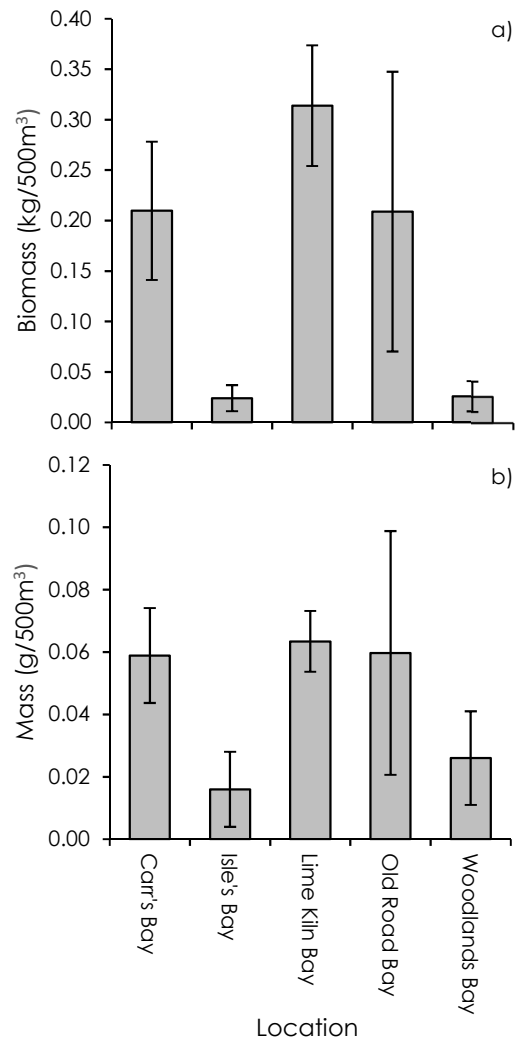


Figure 18. Mean biomass (kg/500m^3) (a) and mean individual mass (g/500m^3) (b) of commercially important fishes surveyed at five locations along the north-western coastline of Montserrat, Caribbean. Standard error (SE $\pm$) are presented.

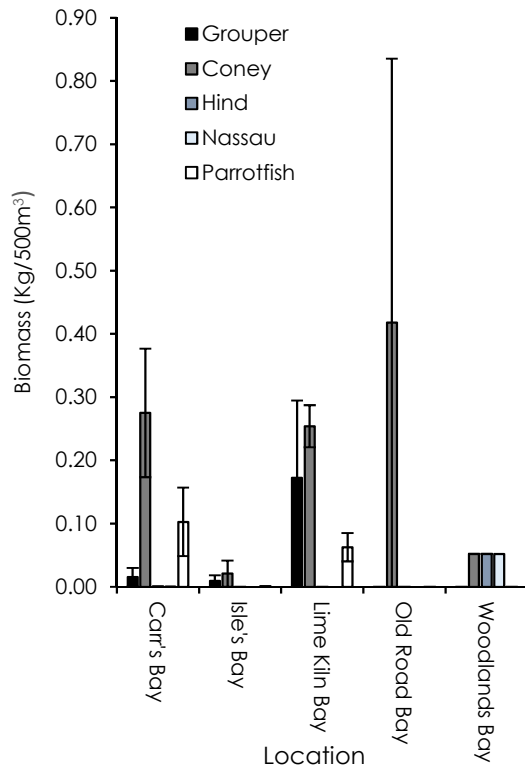


Figure 19. Mean biomass ($\text{kg}/500\text{m}^3$) of commercially important fishes grouped by respective family; Grouper (*Serranidae*); Coney (*Serranidae* sp.); Hind (*Serranidae*); Nassau Grouper (*Serranidae*); and Parrotfish (*Scaridae*). Target fishes were recorded from five surveys sites located on the north-western coastline of Montserrat, Caribbean.

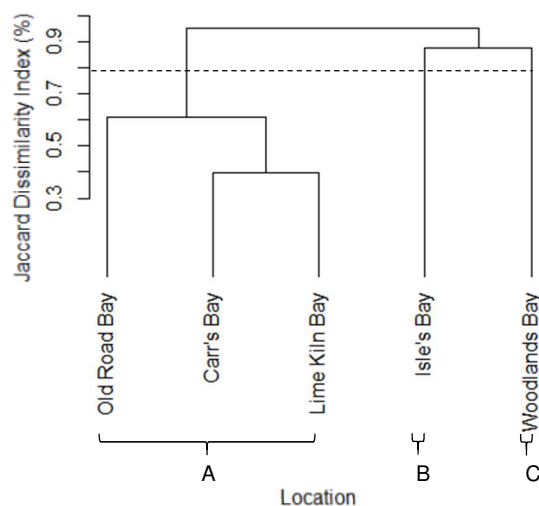


Figure 20. Cluster analysis (Jaccard Dissimilarity Index (%)) (JDI) of the target commercially important fish communities surveyed at five survey sites along the north-western coastline of Montserrat, Caribbean. A slice at 79% is presented (dashed line), of which indicates the mean JDI value for the total sample. Clusters are identified accordingly (A, B and C).

3.3.4 Target Invertebrate Communities

A total of 41,621 marine invertebrates were recorded over the survey period, from all survey sites, on the reefs around Montserrat;

composed of 1 Order, 1 Family and 6 species (Table B2). Gorgonians (Gorgonacea) comprised 90.2% of the observed invertebrates (37,560). Of the other target invertebrates, Pencil urchins (*Eucidaris tribuloides*) and Long-Spined Urchins (*Diadema antillarum*) were the most commonly observed invertebrates at 6.4% (2668) and 1.8% (766). Atlantic Triton's Trumpet (*Charonia variegata*) was recorded in the least abundance (3). Due to the role gorgonians play within communities, providing refugia and complexity, they were removed from subsequent invertebrate community analysis in this section in addition to the removal of permanent and baseline survey sites. As a result, 2, 092 invertebrates ($N = 16.87 \pm 1.95 \text{ } 100\text{m}^2^{-1}$) were recorded. Pencil urchins held the highest density of $N = 11.71 \pm 1.36 \text{ } 100\text{m}^2^{-1}$, subsequently followed by *Diadema* sp. ($N = 1.65 \pm 0.34 \text{ } 100\text{m}^2^{-1}$). Atlantic Triton's Trumpet was also the most poorly represented target invertebrate with 1 individual recorded from the 5 survey sites (Fig. 22). Lime Kiln Bay ($N = 25.5 \pm 2.64 \text{ } 100\text{m}^2^{-1}$) held the greatest abundance of target invertebrates in relation to the other four surveyed sites (Fig. 23a). Comparatively, Isle's Bay held the lowest, $N = 1.25 \pm 0.53 \text{ } 100\text{m}^2^{-1}$ (Fig. 23a). 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. 23a). Carr's Bay was demonstrated to hold the greatest diversity of target invertebrates ($H' = 0.55 \pm 0.08 \text{ } 100\text{m}^2^{-1}$), with Isle's Bay being the least diverse ($H' = 0.10 \pm 0.07 \text{ } 100\text{m}^2^{-1}$) (Fig. 23b). In combination with abundance, location also had a significant impact on the diversity of target invertebrates at each sites (ANOVA ($F_{4, 119}$) = 5.28, $p = <0.001$). The diversity recorded at Isle's Bay was significantly lower than that recorded at both Carr's Bay ($p = <0.001$) and Lime Kiln Bay ($p = <0.05$), respectively, following *post-hoc* Tukey tests (Fig. 23b). Pencils urchins were found in greatest abundance at Lime Kiln Bay ($N = 20.56 \pm 2.06 \text{ } 100\text{m}^2^{-1}$) with Isle's

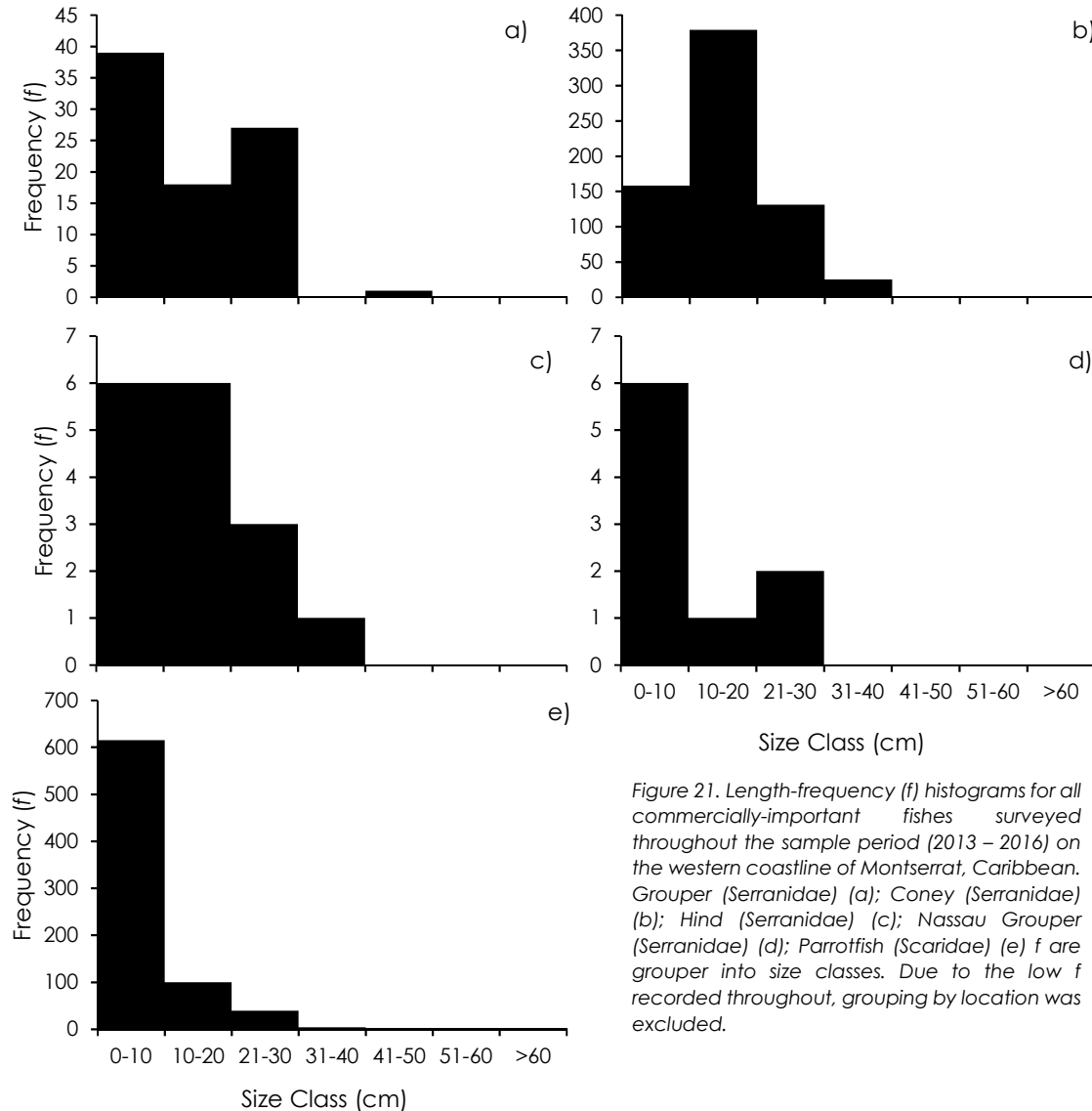


Figure 21. Length-frequency (f) histograms for all commercially-important fishes surveyed throughout the sample period (2013 – 2016) on the western coastline of Montserrat, Caribbean. Grouper (Serranidae) (a); Coney (Serranidae) (b); Hind (Serranidae) (c); Nassau Grouper (Serranidae) (d); Parrotfish (Scaridae) (e) f are grouper into size classes. Due to the low f recorded throughout, grouping by location was excluded.

Bay holding the lowest abundance, $N = 0.25 \pm 0.20 \text{ } 100\text{m}^2^{-1}$ (Fig. 24). Location proved significant for the abundance of collector urchins (ANOVA ($F_{(4, 199)} = 3.22, p = <0.001$) with Isle's Bay being significantly lower than that recorded for both Lime Kiln Bay and Carr's Bay ($N = 2.18 \pm 0.49 \text{ } 100\text{m}^2^{-1}$). Collector urchin abundance also significantly differed with location (ANOVA ($F_{(4, 119)} = 3.22, p = <0.05$) with Isle's Bay the only site that recorded their respective presence (Fig. 24). Location was not shown to impact the abundance of Banded Coral Shrimp, *Diadema* sp., Atlantic's Triton Trumpet and Lobster (Fig. 24). The surveyed community structure at each site can be further described through cluster analysis (Fig. 25). Three clusters were identified (A, B

and C), following complete linkage, with the similarity slice presented at 77% (0.77) – the mean JDI (Fig. 25). Lime Kiln Bay, Old Road Bay and Woodlands Bay (cluster C) held the greatest similarity of 28% (0.72) (Fig. 25). Additionally, cluster C was 19% similar (0.81 dissimilar) to cluster B (Carr's Bay) whilst 4% similar (0.96) to Cluster A (Isle's Bay) – the greatest dissimilarity index (Fig. 25). The target surveyed invertebrate communities at Carr's Bay were 7% similar (0.93) to those surveyed at Isle's Bay (Fig. 25).

3.3.5 Gorgonian Abundance

A total of 37,560 gorgonian colonies were recorded from all survey locations that equated to $N = 98.84 \pm 8.49 \text{ } 100\text{m}^2^{-1}$. 35.72%

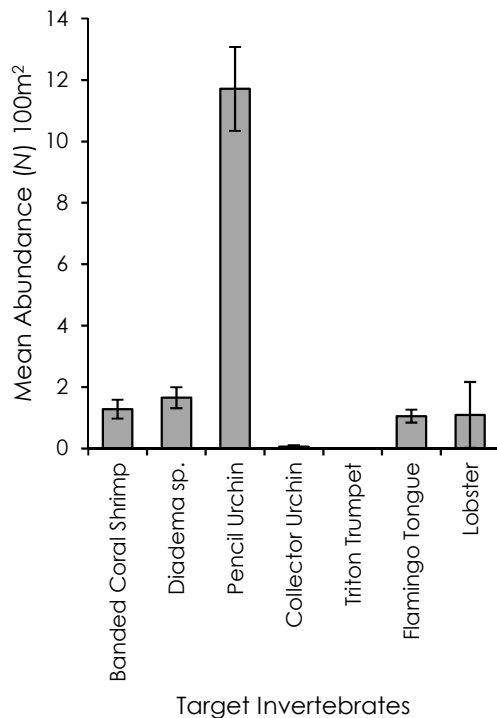


Figure 22. The mean Abundance (N) 100m²-¹ of target invertebrates surveyed across five surveyed sites; Carr's Bay; Isle's Bay; Lime Kiln Bay; Old Road Bay; and Woodlands Bay located along the north-western coastline of Montserrat.

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 $N = 108.2 \pm 9.25$ 100m²-¹. Lime Kiln Bay held the highest density of gorgonians at 181.36 ± 10.23 100m²-¹ with Isle's Bay recording the lowest ($N = 0.90 \pm 0.61$ 100m²-¹) (Fig. 26). 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 ($p = < 0.001$).

3.3 Benthic Substrate Analysis

Hard coral (HC) was shown to vary in composition amongst the five surveyed locations (ANOVA ($F_{(4, 119)} = 7.45$, $p = < 0.05$)) with Lime Kiln Bay holding the greatest composition, $5.12 \pm 0.59\%$ (Fig. 27a). The composition at Lime Kiln Bay was

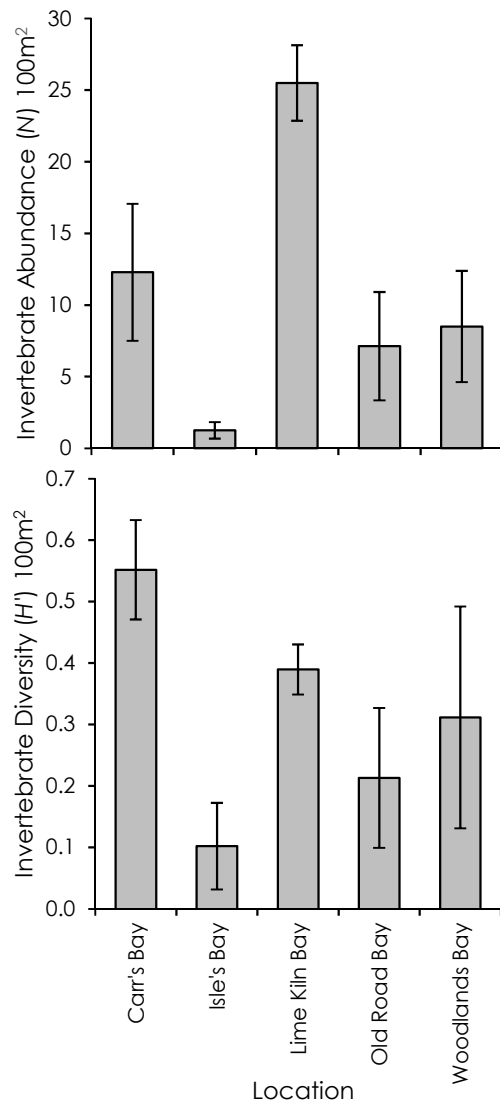


Figure 23. Mean abundance (N) (a) and Shannon-Wiener Diversity Index (H') (b) of invertebrates recorded for each surveyed location (100m²-¹). Standard Error (SE $\pm$) values are displayed.

significantly greater than that recorded at Carr's Bay ($1.96 \pm 1.12\%$, $p = < 0.05$), Isle's Bay (0% , $p = < 0.01$) and Old Road Bay (0% , $p = < 0.05$) (Fig. 27a), following *post-hoc* Tukey tests. The coverage of sponge (SP) was presented to be greater at Lime Kiln Bay ($2.63 \pm 0.39\%$) than Isle's Bay ($0.13 \pm 0.13\%$) (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 ($17.92 \pm 1.99\%$ and $18.30 \pm 4.81\%$, respectively) (Fig. 27e). Location had a significant impact on the composition of RC (ANOVA ($F_{(4, 119)} = 4.208$, $p = < 0.01$)) whilst *post-hoc* Tukey tests highlighted that Lime

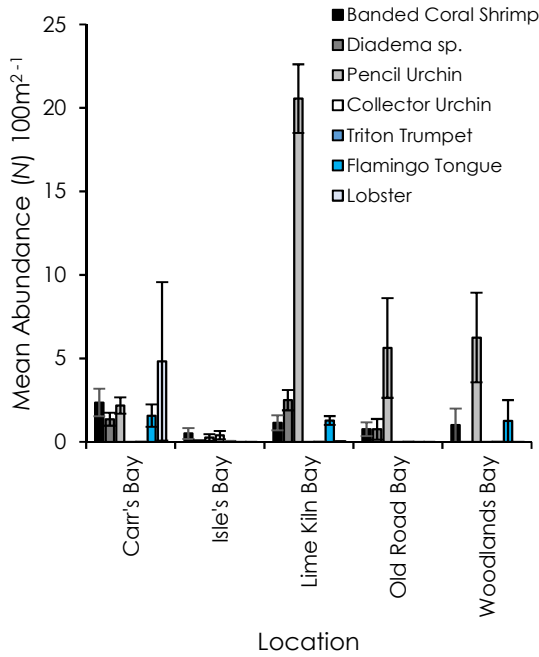


Figure 24. Mean abundance (N) 100m² ⁻¹ of target invertebrates; Banded Coral Shrimp; Diadema sp.; Pencil Urchin; Collector Urchin; Triton Trumpet; Flamingo Tongue; and Lobster, for each individual location surveyed along the north-western coastline of Montserrat.

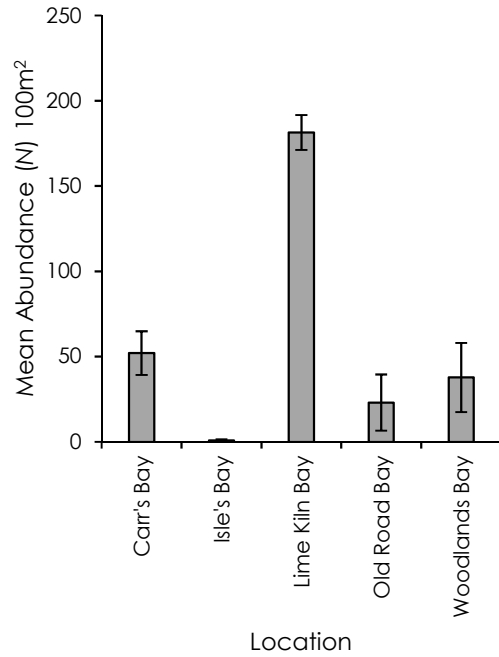


Figure 26. Mean Abundance (N) 100m² ⁻¹ of Gorgonian colonies recorded across the five geographically constrained survey locations along the north-western coastline of Montserrat.

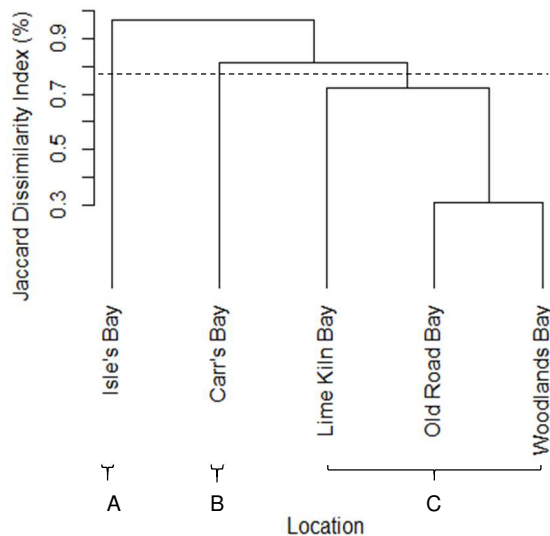


Figure 25. Cluster analysis (Jaccard Dissimilarity Index (%)) (JDI) of the target invertebrate communities surveyed at five survey sites along the north-western coastline of Montserrat, Caribbean. A slice at 77% is presented (dashed line), of which indicates the mean JDI value for the total sample. Clusters are identified accordingly (A, B and C).

Kiln Bay's coverage of RC was significantly higher than Isle's Bay ($p = <0.05$). Sand (SD) was the most prevalent substrate with Old Road Bay composing of $95.31 \pm 3.36\%$ whilst Lime Kiln Bay recorded the lowest composition of SD ($35.20 \pm 4.06\%$) (Fig. 27h). The overall composition of SD was significantly dependent upon location

(ANOVA ($F_{(4, 119)} = 9.52, p = <0.01$)). Post-hoc Tukey analysis indicated that Lime Kiln Bay was significantly lower in composition that Isle's Bay ($p = <0.01$), Old Road Bay ($p = <0.01$) and Woodlands Bay ($p = <0.01$) (Fig. 27h). Carr's Bay was also shown to be significantly lower in composition that Old Road Bay, $p = <0.05$ (Fig. 27h). Location was shown to be a significant factor in the variation of Nutrient Indicator Algae (NIA) composition through ANOVA ($F_{(4, 119)} = 15.13, p = <0.05$). Lime Kiln Bay was shown to hold the greatest composition of NIA ($23.48 \pm 2.23\%$), of which was significantly greater than Isle's Bay ($p = <0.01$), Carr's Bay ($p = <0.01$) and Old Road Bay ($p = <0.01$) (Fig. 27i). Where the benthos was composed of a non-target substrate, such as Zooanthids, it was recorded as other (OT) (Fig. 27j). Isle's Bay held the greatest composition of OT substrates ($24.25 \pm 7.88\%$) of which was demonstrated to be significantly influenced by location (ANOVA ($F_{(4, 119)} = 8.69, p = <0.01$)). Isle's Bay was significantly greater than all other surveyed locations following post-hoc Tukey tests ($p = <0.01$). Taking into account the complete benthic structure in its entirety, two clusters (A and B) were identified through JDI at the mean

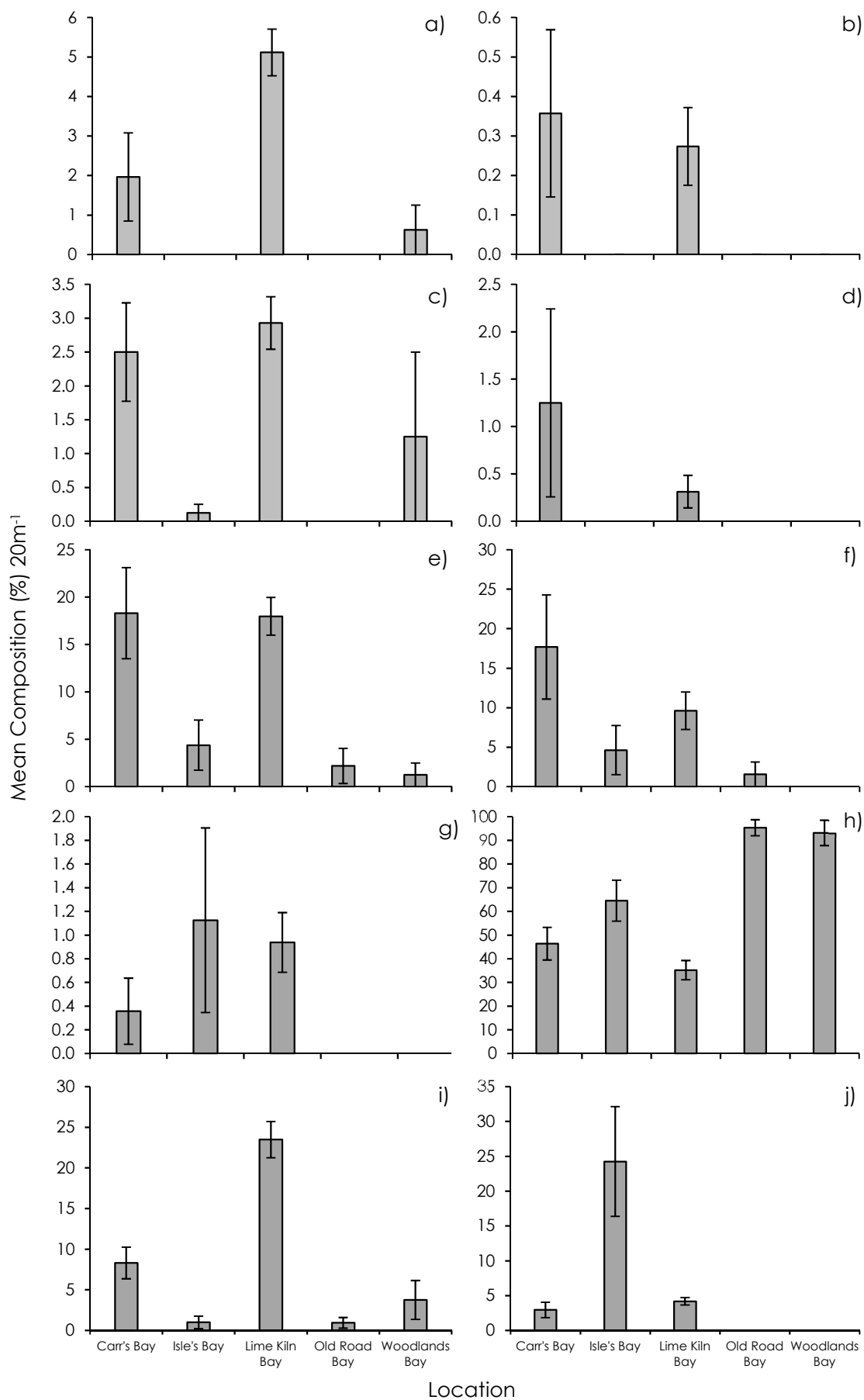


Figure 27. Mean composition (%) 20m⁻¹ of benthic substrate; a) Hard Coral (HC); b) Soft Coral (SC); c) Sponge (SP); d) Recently Killed Coral (RKC); e) Rock (RC); f) Silt (SI); g) Rubble (RB); h) Sand (SD); i) Nutrient Indicator Algae (NIA); j) Other (OT), recorded across five geographically constrained locations along the north-western coastline of Montserrat.

54% dissimilarity slice (Fig. 28). Cluster A is formed from Carr's Bay and Lime Kiln bay of which was 25% similar (0.75 dissimilarity) to cluster B composed of Isle's Bay, Old Road Bay and Woodlands Bay (Fig. 28). Within cluster A, the benthic composition was 66% similar (0.34 dissimilarity) between Carr's Bay and Lime Kiln Bay (Fig. 28). Furthermore, within cluster B, Old Road Bay and Woodlands Bay held the greatest similarity (91%, 0.09 dissimilarity) (Fig. 28).

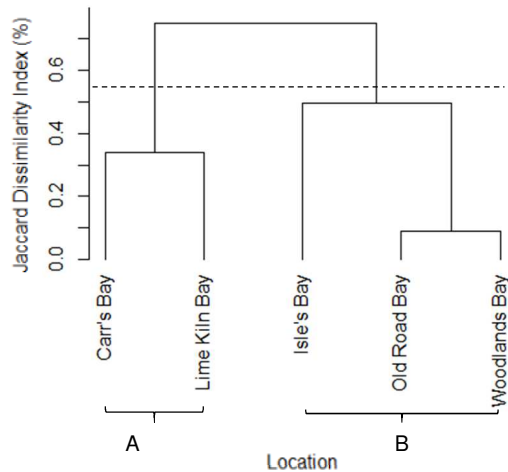


Figure 28. Cluster analysis (Jaccard Dissimilarity Index (%)) (JDI) of the benthic composition of the five surveyed sites along the north-western coastline of Montserrat, Caribbean. A slice at 54% is presented (dashed line), of which indicates the mean JDI value for the total sample. Clusters are identified accordingly (A and B).

3.4 Community Based Correlations

3.4.1 Relationships between community characteristics and benthic substratum

Figure 29 provides a visual representation of relationships between two variables measured at transect locations along the north-western coastline of Montserrat. A significant moderate positive association was observed between HC composition and the abundance of coral reef associated fishes ($r_{(378)} = 0.51$, $p = <0.05$) (Table 1). However, the relationship between both variables can only account for 26.01% of the variation in fish abundance (Table 1, Fig. 29). The variance of fish diversity (H') could be greater described by the abundance of Gorgonian substrates ($r^2 = 14.44\%$) in comparison the composition of HC ($r^2 = 9.00\%$) at any sampled site (Table 1, Fig. 29). This is further accompanied by a stronger correlation ($r_{(378)} = 0.38$, $p = <0.05$) than that

observed for HC composition, respectively (Table 2). Despite significant results, the correlations between both substrate variables and the biomass ($\text{kg}/500\text{m}^3$) and individual mass ($\text{g}/500\text{m}^3$) of commercially important species were too weak to draw relationships. As a result, the measured benthic composition can only minimally account for the variation observed across sampled sites (Table 1, Fig. 29).

Table 2. A Table of results obtained from Pearson's Product-Momentum Correlation analysis. Conducted between benthic substrate composition and coral reef associated fish communities measured at sample locations along the western coastline of Montserrat, Caribbean. Scleractinian hard coral (HC) composition (%) and Gorgonian (GO) abundance formed the benthic substratum variables (x) with abundance (N) and Shannon-Weiner Diversity Indices (H') of reef fishes as well as the biomass (B) ($\text{kg}/500\text{m}^3$) and individual mass (M) ($\text{g}/500\text{m}^3$) of commercially important species formed the community variables (y). * indicates a significant correlation above 95% confidence limits (<0.05). + provides indication of a positive correlation.

Measured Variables		Pearson's Correlation Results				
x	y	r	r ²	df	p	c
HC	N	0.51	26.01	378	$<2.20 \times 10^{-16} *$	+
	H'	0.30	9.0	378	$<1.76 \times 10^{-9} *$	+
	B	0.23	5.29	378	$8.93 \times 10^{-6} *$	+
	M	0.28	7.84	378	$1.79 \times 10^{-8} *$	+
GO	N	0.34	11.56	378	$6.31 \times 10^{-12} *$	+
	H'	0.38	14.44	378	$1.86 \times 10^{-14} *$	+
	B	0.13	1.69	378	0.01 *	+
	M	0.24	5.76	378	$2.4 \times 10^{-6} *$	+

3.4.2 Herbivory, Nutrient Indicator Algae (NIA) and Hard Coral (HC) composition

Herbivorous fishes were present in varying abundances with NIA composition also significantly variant, however, a significant positive correlation was observed between the two variables ($r_{(378)} = 0.35$, $p = <0.01$) (Fig. 30). In addition, 12.5% of variation observed in the abundance of herbivorous fishes can be described by NIA. Regarding invertebrate grazers, Pencil Urchins prescribed the strongest correlation with NIA ($r_{(378)} = 0.40$, $p = <0.01$), with 15.78% of variation described (Fig. 31b). Subsequently, the abundance of *Diadema* sp. resembled a weak relationship ($r_{(378)} = 0.11$, $p = <0.05$) (Fig. 31a), with only 1.12% of the variation in the data described by NIA composition. No correlation was observed between the abundance of Collector

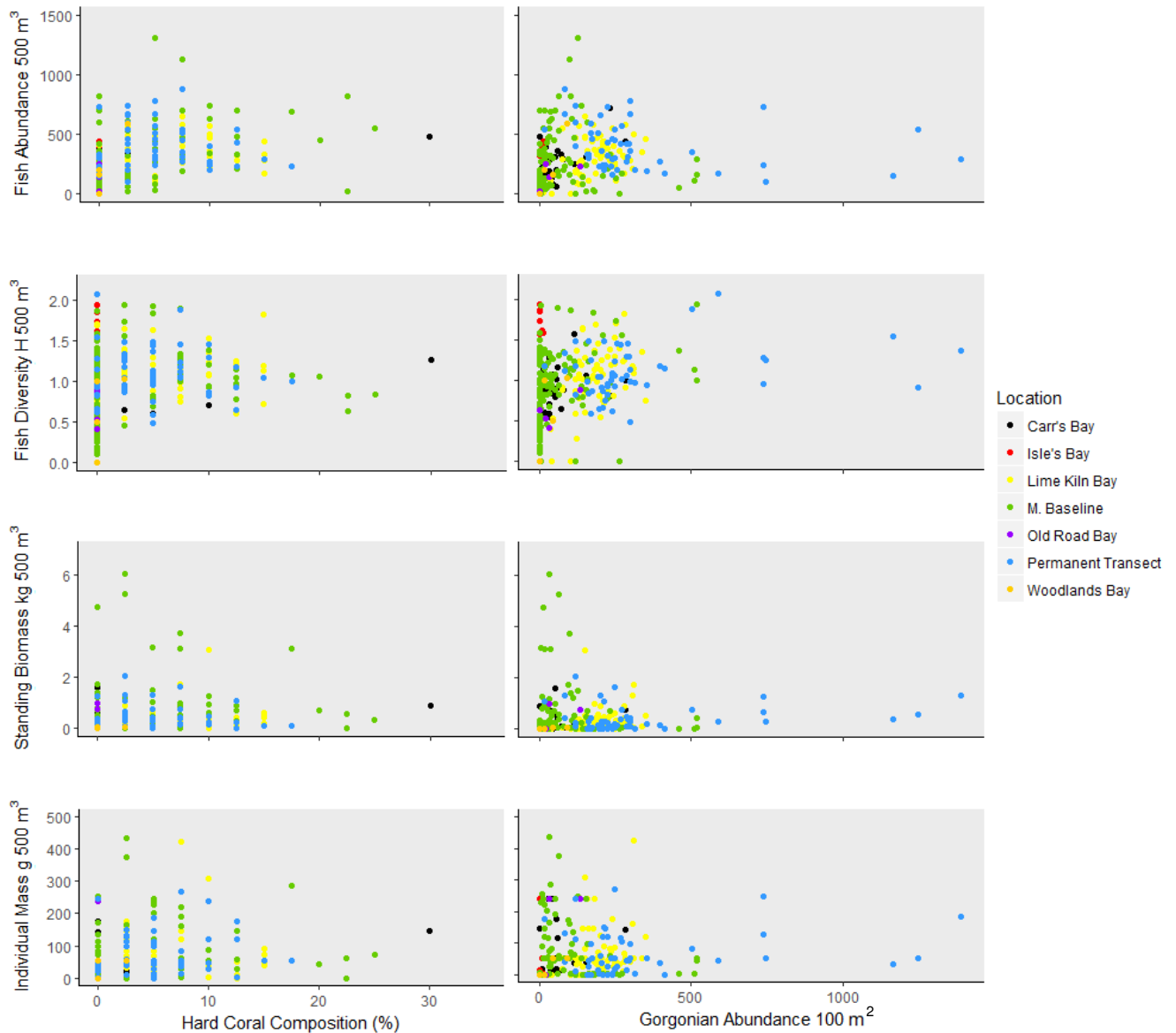


Figure 29. Scatterplots produced to visualise relationships between benthic substrate variables, hard coral (HC) composition (%) (a, c, e, g) and Gorgonian abundance (b, d, f, h), and four coral reef community variables. Coral reef associated fish communities are described with abundance (N) and Shannon-Weiner Diversity Indices (H') with biomass (kg/500m³) and individual mass (g/500m³) describing commercially important fish species. Data are grouped by site location along the western coastline of Montserrat, Caribbean.

Urchins and NIA composition (Fig. 31c). Overall, the accumulated abundance of invertebrate grazers demonstrated a significant positive correlation with the composition of NIA (Fig. 31d). Correlations presented a result of $r_{(378)} = 0.34$, $p = <0.01$, with 11.46% of the variation in the data described by the NIA composition.

The abundance of herbivorous fishes presented a strong positive correlation with the composition of HC found amongst surveyed locations ($r_{(378)} = 0.47$, $p = <0.001$) accounting for 22.47% of variation in

abundance observed. Positive correlations were also observed with the abundance of *Diadema* sp. ($r_{(378)} = 0.39$, $p = <0.001$) and Pencil Urchins ($r_{(378)} = 0.34$, $p = <0.001$) with 14.86% and 11.39% of the variation explained, respectively. Overall for invertebrate grazers, 17.87% of the variation in the data could be explained by HC composition following a significant positive correlation ($r_{(378)} = 0.42$, $p = <0.001$).

3.5 Conservation Management Values

The Conservation Management Values (CMV) are an indices developed to elicit

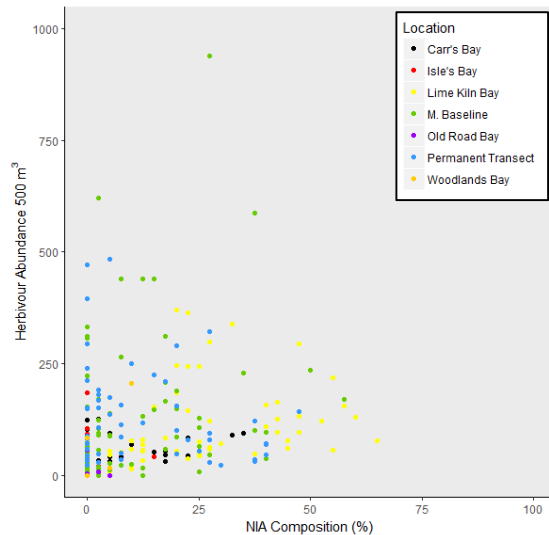


Figure 30. Scatterplot produced to visualise relationship between nutrient indicator algae (NIA) composition (%) and the abundance of herbivorous fishes. Data are grouped by site location along the north-western coastline of Montserrat, Caribbean.

the categorisation of locations based on the 7 key parameters measured in relative to other locations (Fig. 32). Of the locations surveyed ($n = 95$), 7 were categorised with the highest (7) CMV (Carr's Bay $n = 1$, Lime Kiln bay $n = 3$, Permanent Transects $n = 3$) (Table 3). Lime Kiln Bay and Carr's Bay locations were recorded and categorised in 2016 with Permanent Transects between 2014 and 2015. CMV 0 ($n = 29$) was the greatest represented amongst all surveyed transect locations with CMV 4 ($n = 5$) the least (Table 3). Subsequently, CMV 5 and 1 were the third greatest represented amongst sites ($n = 13$, respectively). A total of 10 locations held a CMV of 6, of which were composed of Lime Kiln Bay ($n = 4$), Permanent Transects ($n = 4$) and Montserrat Baseline Transects ($n = 2$). Lime Kiln Bay and Permanent transects held the greatest composition of sites valued at 7. However, in contrast, transect sites valued at 7 contributed 18.75% of Lime Kiln Bay's transects and a subsequent 23.07% of Permanent Transects (Table 4). The spatial distribution of CMV are provided in figure 32.

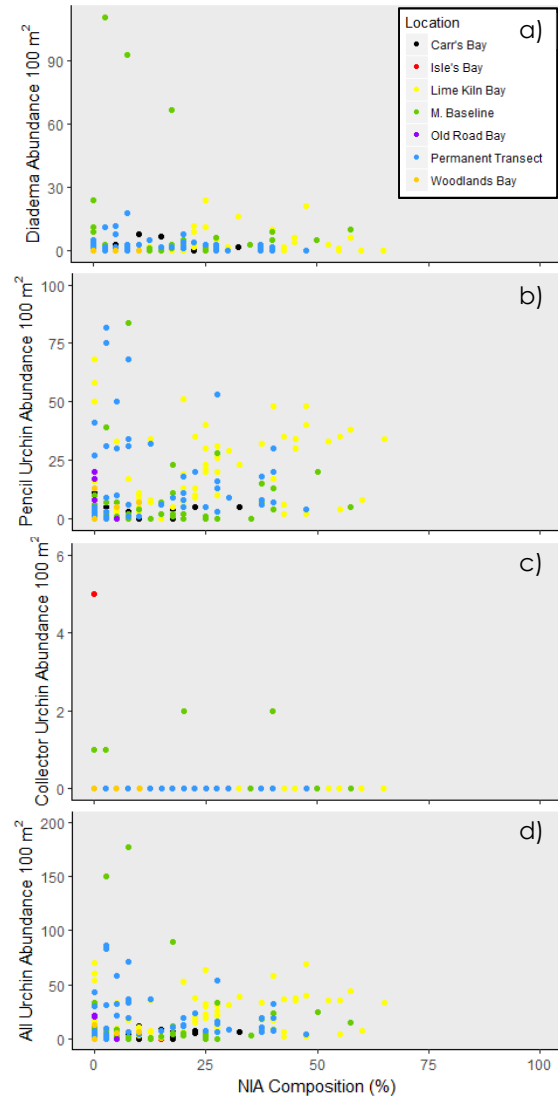


Figure 31. Scatterplots produced to visualise relationships between nutrient indicator algae (NIA) composition (%) and the abundance of invertebrate grazers; a) *Diadema* sp.; b) Pencil Urchins; and c) Collector Urchins. d) presents the accumulated abundance. Data are grouped by site location along the north-western coastline of Montserrat, Caribbean.

Table 3. Accumulated number of sites within each conservation management value (CMV) for the western coastline of Montserrat, Caribbean. Coral reef, benthic substratum and fauna community surveys were conducted between 2013 and 2016 in order to compose the given values from a total of 7 variables. CMV are calculated on ordinal scale (0 – 7) with 7 the greatest.

CMV	Accumulated Total
7	7
6	10
5	13
4	5
3	7
2	11
1	13
0	29

Table 4. The percentage composition of each conservation management value (CMV) as calculated for specific surveyed geographical locations on the western coastline of Montserrat, Caribbean. *n* identifies the total number of CMV determined for the location. CMV are calculated on an ordinal scale (0 – 7) with 7 being the greatest.

Conservation Management Value (CMV) Percentage (%) of Total Transects (n)									
Location	n	0	1	2	3	4	5	6	7
Carr's Bay	7	0	14.29	28.57	14.29	28.57	0	0	14.29
Isle's Bay	5	40	40	0	20	0	0	0	0
Lime Kiln Bay	16	0	0	12.5	12.5	0	31.25	25	18.75
Mont. Baselines	51	50.98	19.61	9.80	0	5.88	9.80	3.92	0
Old Road Bay	2	0	0	0	0	50	0	0	50
Permanent Transect	13	0	0	7.69	15.38	0	23.08	30.77	23.08
Woodland's Bay	1	0	0	0	0	0	100	0	0

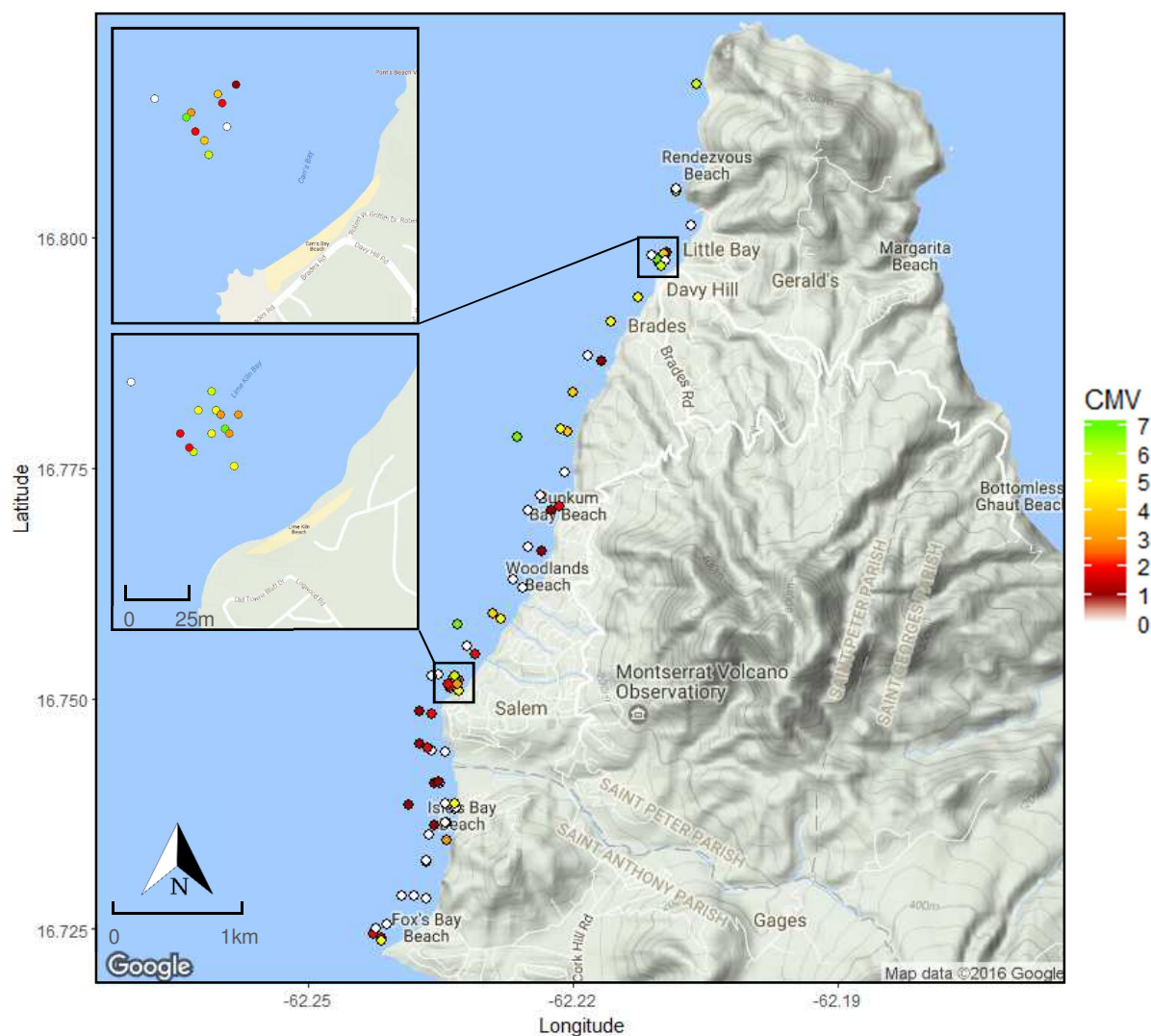


Figure 32. Conservation Management Values (CMV) presented for each location surveyed on the western coastline of Montserrat, Caribbean. Each location is categorised by a specific colour that directly relates to its respective CMV; those towards the green end of the spectrum hold a higher CMV in respect to other locations.

4.0 Discussion

This study aimed to provide The Montserrat Government Ministry of Agriculture, Trade, Lands Housing and the Environment (MATLHE) with a holistic interpretation of the current ecological status of the coral reefs and associated systems surveyed between 2013 – 2016 along the north-western coastline of Montserrat, Caribbean. This report will expand on the assessments from previous reports. The over-arching aim is for the report to be utilised as a means of scientific capacity to facilitate in the designation of marine protected area(s) (MPA), for the prosperity of Montserrat's tourism, environmental and fishery sectors. The results portrayed throughout are preliminary assessments and can be further analysed to assess specific ecological traits and behaviours. This report, as a result, has highlighted key areas that would benefit from protection; Lime Kiln Bay and Carr's Bay. The waters around Montserrat mirror the conditions found throughout the Caribbean; however, the widely reported detrimental impacts are thought to be experienced to a lesser extent, whilst the Soufriere Hills eruptions make for a relatively unique opportunity to study the current status of tropical communities that surround Montserrat.

4.1 Coral Reef and Associated System's Fauna and Flora Communities

4.1.1 Charismatic Mega-Fauna

The low abundance of charismatic mega-fauna throughout the survey period is of concern for the surveyed area, in both ecological and eco-tourism related contexts. A total of 5 Hawksbill Turtles (*E. imbricate*) were observed, indicative of critically low numbers. The low numbers observed are supported by the trends witnessed throughout the Caribbean, with estimated reports suggesting a decrease in population size of 80% over three-generations (Mortimer & Donnelly 2008). *E. imbricate* are invertivores, with sub-populations within the Caribbean more

specifically classed as spongivorous (Bjornal & Jackson 2003), that remove large quantities of sponges from coral reefs, exposing rock and other hard substrates that subsequently increase recruitment levels of hard coral (HC) (Lutz *et al.*, 1996). The removal of sponges by *E. imbricate* is a key process in the maintenance and promotion of healthy coral reefs, by reducing spatial competition between structurally complex reef building corals and sponges (Bjornal & Jackson 2003). The composition of sponges throughout the surveyed sites was relatively low in comparison to other substrates, indicative that other processes are present that are driving composition; other than the absence of *E. imbricate*. Listed as critically endangered by the IUCN Red List of Threatened Species in 2008 (Mortimer & Donnelly 2008), *E. imbricate*'s low abundance can be attributed to a range of detrimental impacts. These impacts (within the Caribbean) include; commercial fishing; supplementation of the shell and curios trade; coastal development; increased spatial competition for nesting females; light and coastal pollution; fishing entanglement; and physical injuries (boat strikes etc.). Such impacts are still highly prevalent throughout the Caribbean with an estimated <5,000 nesting females present in 2006 (Mortimer & Donnelly 2008). In contrast, the estimated level of impacts experienced by survey sites were low; however, there were high levels of boat presence along the north-western coastline which could be contributing to boat strikes, however, *E. imbricate* specific studies will need to be conducted to be conclusive. Such studies enable managers to distinguish between near or far field stressors contributing to the recorded decline of *E. imbricate* and other marine turtle species, within the waters surrounding Montserrat. Due to the migratory behaviour of *E. imbricate*, population impacts are often widely experienced and therefore

drastic action must be taken to protect nesting sites along the north-western coastline of Montserrat. As *E. imbricate* are charismatic, their value to the eco-tourism is high. Divers and tourists will place preference on coral reefs and regions which hold a high probability of sightings, thus increasing revenue within the tourism sector. It is important; however, that this tourism-base does not become industrialised to a level that proves detrimental to populations, and thus any initiatives proposed must hold true to conservation values.



4.1.2 Coral Reef Associated Fishes and the Resultant Community Impacts

The abundance of coral-reef associated species surveyed across the survey area, in comparison to other studies was in general, moderate (Rakitin & Kramer 1996; Chiappone *et al.*, 2000). The low abundance of herbivores such as Parrotfish, as well as the low overall abundance of reef fishes, are supported by current trends experienced throughout the Caribbean, with fish density estimated to decline between 2.7 – 6% year⁻¹ since 1955 (Paddock *et al.*, 2009). Temporal data sets will need to be established for location sites throughout the survey area to further establish this.

The poorly represented abundance of herbivorous fishes (31.45%), in comparison to historical abundances throughout the Caribbean (e.g Hughes 1994; Miller *et al.*,

1999; Costa Jr *et al.*, 2000; Smith *et al.*, 2001; Fabricus *et al.*, 2005), can be supported by the present composition of nutrient indicator algae (NIA) and HC throughout the surveyed area, following correlation results. A study conducted by Kopp *et al.* (2010) provided an indication of herbivorous fish (Scaridae and Acanthuridae) densities around Guadeloupe in combination with MPAs and NIA. In direct comparison, the surveyed densities on the north-western coastline of Montserrat were considerably lower than those measured by Kopp *et al.* (2010), 50.5 ± 12.4 (Scaridae) and 35.9 ± 9.9 (Acanthuridae). Due to the close proximity to MPAs, an active spill-over effect may have influenced the densities. As there are currently no MPAs established within the survey area, no influence as such occurred during data collection; nevertheless, the densities of herbivorous fish around Montserrat are of concern. The coastal waters that surround Montserrat are classified by Burke & Maidens (2004) as overfished, driving a fishing pressure indices classing as medium. This is in addition to further supporting evidence of high fishery production in 2014 of 41t of marine resources exploited, as well as high levels of reef derived nutrition (Burke 2011; FAO Fish Stat J 2016). Over-fishing of herbivorous fishes can have drastic consequences on coral reef community assemblages as grazing reduces, increasing macro-algae composition, smothering coral and reducing recruitment; ultimately decreasing complexity (Kopp *et al.*, 2010; Hughes *et al.*, 2007). In comparison to documented phase-shifts in the Caribbean (Burke *et al.*, 2011), the coastline of Montserrat is in comparatively better condition, however NIA composition must be noted and monitored to assess trends. The measured variability between locations, with regards to NIA, could be partly attributed to the spatial variation in population densities of herbivorous and grazing fauna fulfilling feeding guilds, such as Parrotfish, *Diadema* sp. and Pencil urchins. This is further supported by the impact of reduced grazing populations on

the composition of NIA (Hughes *et al.*, 2007). The high dominance of Labridae (Wrasse), a categorised predator of urchins, throughout the survey area may also have contributed to variable grazer densities (Morton *et al.*, 2008; Figueiredo *et al.*, 2005; Denny & Schiel 2001). The poor abundance of Balistidae (Trigger fish) throughout survey locations was likely to have a direct impact on urchin numbers due to their feeding ecology, removing a recruitment limitation (McClanahan 2000). Another solution for the disparity recorded for NIA composition may be a result of land usage pollution and run-off resulting in nutrient influxes. Through results portrayed in Burke & Maidens (2004), 70% of the coastal waters surrounding Montserrat are classified as high threat from inland-source pollution. Thus land-based sourced pollution can drastically alter coral reef assemblages, benthic substratum composition and fishery capacity through a range of impacts as discussed by Fabricius (2005). The association observed between HC composition and herbivorous fishes in this study is thought to be highly influenced by the abundance of Scaridae. Scaridae are known to hold an important functional role on coral reefs by facilitating and promoting coral recruitment, growth and fecundity (Mumby 2009). Despite arguments being raised regarding the functional role of corallivory by Scaridae, with concerns focusing on the current trends of HC throughout the Caribbean and Scaridae exasperating this trend, evidence supports their conservation (Mumby 2009). The associated correlations between HC and Scaridae are further supported by results from Roff *et al.* (2011) where it is demonstrated that density of HC greatly influences Scaridae density. Additionally, Roff *et al.* (2011) indicated that due to Scaridae exhibiting feeding preference on species such as *Porites* sp., their projected dominance of HC communities by *Porites* sp. may be attenuated; thereby promoting diversity amongst HC species. With Scaridae removing high levels of sediment, algae (including macro and turf-algae) and coral

tissue, by feeding on the epithelial algal matrix (EAM), 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.

The abundance of fishes was recorded to be the greatest at Lime Kiln Bay followed by Carr's Bay; however, these were not deemed to be significant from each other. Furthermore, the abundance at Lime Kiln Bay was statistically significant to Isle's Bay, which is noteworthy due to the close geographical proximity ($\pm 2\text{km}$) of the two locations. The community characteristics found at Lime Kiln Bay were expected due to the highly publicised relationship found between structural complexity, and coral reef associated fish abundance and diversity (Graham & Nash 2012). Within coral reef systems, structurally complex reef building corals, such as *Acropora* sp., are often highlighted for their role in supporting highly diverse communities; however, Lime Kiln Bay, despite holding the highest HC composition, was lower in comparison to other Caribbean reefs (Burke & Maidens, 2004). In comparison, Lime Kiln Bay HC composition is within HC cover calculated means for the Caribbean as a whole ($\pm 10\%$) (Gardner, 2003). Despite a significant positive correlation determined between HC and fish abundance, further supporting other studies, HC can only account for 26% of the observed variation in abundance. Thus it is stipulated that the high abundance of GO throughout the surveyed area also held a significant effect



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on the abundance of fishes as supported by positive correlations obtained in this report. On the contrary, studies indicate that the GO suggests a poor level of complexity. It has been shown that GO planes throughout the Caribbean do not provide the same levels of refugia to small-bodied fishes as HC dominated reefs, with fish traps laid within GO planes becoming more successful than in their respective HC locations, due to fish seeking refuge (Wolff *et al.*, 1999). Diversity within fish communities showed significance between locations and was demonstrated to be positively correlated with abundance of GO and HC coverage. This concurs with results from other studies (e.g Graham & Nash 2012; Russ *et al.*, 2015) that propose results which indicate that benthic substratum change drives changes in fish community assemblages. It is not surprising, therefore, to find higher abundance and diversity within communities at sites that hold a greater complexity. Contrastingly, GO dominated systems, such as Lime Kiln Bay, are understood to hold a greater resilience to overfishing, with regards to herbivorous species, such as Scaridae (Mumby 2014). Juvenile parrotfish have been shown to hold greater dependence on benthic complexity than their sub-adult and adult cohorts (Alvarez *et al.*, 2011). This supports the results obtained for Carr's and Lime Kiln Bay with parrotfish abundance found to be greater at Lime Kiln Bay, whilst the biomass (composed of larger individuals) was greater at Carr's Bay indicative of smaller and younger

individuals exhibiting dependence on the complex habitat found at Lime Kiln Bay. This could offer a valid supposition as to the relative high levels of diversity and abundance at Lime Kiln Bay, as the three-dimensional structure provides multiple niche partitions through refugia and other factors (Bejarano *et al.*, 2010). The conservation of areas that hold high diversity and abundance amongst fish communities is of high importance due to the provision of trophic support required to sustain higher trophic level predators such as Serranidae – a commercially important family. Furthermore, survivorship is highly correlated to benthic complexity and thus protection of Lime Kiln Bay will result in increased diversity and abundance of fish communities, a factor most desirable to the tourist and fishery industry.

4.1.3 Commercially Important Target Fish Families

The overall mean biomass accumulated for all locations decreased by $0.4\text{kg } 500\text{m}^{-3}$ following the exclusion of permanent and baseline surveys, therefore, it is highly likely that the individuals recorded showed higher preference to shallow, coastal waters. To compartmentalise this justification further, the home ranges of larger, adult commercially important fishes must be taken into account. For example, Serranidae occupy large home ranges during adult phases that can result in over 1.8ha and undertake diurnal migrations of >2km (Samoilys 1997a; Samoilys 1997b; Zeller, 1997; Unsworth *et al.*, 2007 – Triennial). As such, an increased home range will



effectively reduce the probability of recording larger, heavier individuals thus heavier individual commercially important fishes were not present within survey parameters but may have been present within the general area. Furthermore, smaller, younger Serranidae hold more restricted home-ranges (Stewart & Jones 2001 - Triennial) and thus their presence to surveyors is as expected due to an increased probability of being recorded.

Serranidae are an important commodity to local fishers around Montserrat, and were also included within this study due to their high trophic position; both important factors in the designation of MPAs. Benthic features have been known to hold an important role in structuring coral reef communities (Sluke *et al.*, 2001) with relationships existing between reef habitat and Serranidae abundance. This study found no relationship between the biomass and individual mass of the recorded Serranidae, enabling a conclusion of no subsequent relation with abundance. In combination with no significant inter-location variation, results suggest that although other studies have proven grouper assemblage is affected by benthic structural complexity, other variables have a greater influence on the assemblages present along the north-western coastline of Montserrat. The size-class of Serranidae surveyed across locations presented a dominance of individuals <10cm with individuals 21-30cm subsequently, highlighting a larger population of the smaller-sized cohort throughout the survey period. The size and abundance of Serranidae recorded, in comparison to other studies within Caribbean waters (e.g. Miller & Gerstner 2002), was low. It must be mentioned; however, that Miller and Gerstner (2002) conducted surveys in waters adjacent to an uninhibited island that experienced minimal fishery pressure, indicating a potential future prosperity for Montserrat's grouper populations.

Frequency values were low with regards to larger size classes and establishment of temporal monitoring may provide evidence of a population that is maturing. A maturing population indicates increased survivorship (Unsworth *et al.*, 2007) and

could offer a justified reasoning for the stable biomass recorded across surveyed locations. However, as there is no form of protection currently established, this cannot be concluded and therefore it is possible that the population is decreasing, in trend with Caribbean fisheries, calling for a need of long-term species specific studies. Serranidae within the 21-30cm size class were recorded, although relatively small, indicating the potential presence of mature adult species, contributing to the biomass observed. Although species-specific methodology was not undertaken, it can be assumed that a large proportion of these sized individuals are sexually immature and thus do not hold the morphological abilities to reproduce. The other proportion of these small-sized individuals will be small Serranidae species, such as *Cephalopholis cruentatus*. Despite contributing to the standing biomass to a lesser extent, these smaller species will reach sexual maturity at a reduced length in comparison to their larger species counterparts (Froese and Pauly 2000) and hold significant roles within coral reef ecosystems, they therefore must not be underestimated. Many smaller Serranidae species are important food items (Unsworth *et al.*, 2007) to local communities as well as those that reside on the reef, with their presence rendered as positive. Furthermore, these smaller species hold more restricted home-ranges (Stewart & Jones 2001) and thus their presence to surveyors is as expected due to an increased probability of being recorded. Serranidae hold high trophic levels on coral reefs and in combination with their slow growth and tendency to aggregate, they are highly subject to unsustainable



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exploitation (Colin 1992; Sadovy & Colin 1995; Unsworth et al., 2007).

The length of first maturity (L_m) in *Cephalopholis fulva* (Coney) is 14.7cm (Froese & Pauly 2000 – Fish Base) and as a result it can be estimated that approximately >45% of all the Coney surveyed were sexually mature. *C. fulva* is thought to hold a significant role within coral reef communities as a piscivour and invertivour in which it is capable of influencing the densities of prey species (Webster 2003; White 2007). *C. fulva* is an important commercial species within the Caribbean (Coelho et al., 2012), and therefore analysis demonstrating that it was the greatest contributor to standing biomass throughout the studied locations was unexpected. Chiappone et al. (2000) indicated; however, that the presence of *C. fulva* in high abundance and biomass is a clear indicator of overfishing referring to a second-effect of fishing where behavioural competition and predation are eradicated with the removal of larger, target species. The results in the study support the suggestions of Chiaponne et al. (2000) with Coney categorised as “non-target” due to the high composition of adult individuals. The recorded biomass of Coney along the north-western coastline of Montserrat (1.02kg 100m² ⁻¹) was considerably higher than that recorded by Chiaponne et al. (2000). Within their study, they conducted surveys in a range of sites categorised by fishing intensity with

biomasses ranging from 0.7g 100m² ⁻¹ in the Florida Keys to 143g 100m² ⁻¹ in South Exuma. Within both these intensely fished sites and areas of light fishing high levels of Coney biomass were found thus offering an interesting summation of the success of Coney, not only in areas of intense fishing, but also where larger target species are removed. Findings by Coelho et al. (2012) demonstrate that Coney individuals show preference to complex habitats, such findings contrast with those presented in this report. Old Road Bay is dominated by sandy substrate (>90%) thus demonstrating a low complexity, indicating that their dominance must be driven by other variables. Results presented here are indicative that abundance and biomass of Coney are greatly influenced by community structure, resulting in the removal of direct carnivorous competition, therefore their respective presence is a good indicator to Serranidae overfishing.

The trends observed throughout this study for Serranidae are not surprising, with a lack of larger, mature individuals alongside the aforementioned natural justification, the probability of overfishing cannot be ignored. Therefore, it is of high importance that continued monitoring on the Serranidae populations is established that also explores species populations, their behavioural traits and population ecology. It has been demonstrated that initial declines following protection in the abundance of Serranidae are common



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and that numbers increase as a consequential result of MPA protection, suggesting that after three years, populations become stable (Russ & Alcala 1998; Halpern & Warner 2002).

The preference of commercially important individuals for shallow, coastal areas can be further supported by the recorded frequency and length of individuals with mean individual mass (g) also signifying smaller fishes. Scaridae were the most frequently recorded commercially important family, however, the majority of individuals were <10cm with minimal >30cm. The size distribution of Scaridae populations recorded throughout survey locations is heavily indicative of a region that has experienced heavy fishing pressure, which is in trend with other Scaridae populations, not only in the Caribbean but also globally (Bellwood *et al.*, 2011). Bellwood *et al.* (2011) found that on intensely fished coral reefs, parrotfish >25cm only constituted 3-6% of size densities, which is seen within populations of Montserrat. However, in areas that were protected from fishing, large parrotfish formed 43-67% of populations, highlighting the results that can be obtained from spatial protection (Bellwood *et al.*, 2011). This suggests that the Scaridae populations along the north-western coastline of Montserrat are dominated by small, juvenile individuals. The higher relative concentration of smaller sized Scaridae is expected due to the abundance of invertebrates found within survey locations. Juvenile parrotfish inhabit the epilithic algal matrix (EAM), predating on cryptobenthic invertebrates (Welsh, Goatly & Bellwood 2013). The results presented by Welsh, Goatly and Bellwood (2013) indicate that there is a rapidly increasing somatic relationship with home-ranges until individuals reach 100-150mm in length, at which time this relationship breaks down. This rapid increase is thought to be driven by prey and resource availability, and due to the variable densities of invertebrates, smaller parrotfish may be driven to increase their home ranges relatively; increasing their susceptibility to surveys through an

increased cosmopolitan activity. Therefore, perceived populations of Scaridae may be a result of survey error or multiple counts as a result of increased activity. The breakdown in the somatic relationship is thought to occur in some Scaridae species due to the ontogenic switch in behaviour that sees larger adults occupying harems that are often aggressively defended by a dominant male (Welsh, Goatly & Bellwood 2013). This complex social system may offer a suggestion to the low numbers of larger adult Scaridae, in combination with the well documented survival rates that accompany ontogenic life-stage shifts (Booth & Beretta 2004; Depczynski & Bellwood 2005; Almany & Webster 2006) as well as high levels of interspecific competition between harems, reducing availability to surveyors. Contrastingly, the low variability in recorded mass and biomass throughout sampling years proposes that no harems of larger adults were recorded. Furthermore, it can be argued that due to adult Scaridae presenting unprecedented reduced home ranges in comparison to other taxa (Mumby & Wabnitz 2002; Marler *et al.*, 1995; Hinsch, Pen & Komdeur 2013), as well as preferences in species such as *Chlorurus sordidus* to practice place-familiarity (Choat & Bellwood 1985; Welsh & Bellwood 2012), the results obtained are not congruent from those where surveyors recorded the presence of schooling harems. The importance of Scaridae within coral reef communities is highly publicised (e.g. Mumby *et al.*, 2006). Their importance is further highlighted by Mumby (2006) where it is presented that in the absence of



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grazers (Scaridae), the composition of HC substrate declined from 30% to 1% in 40 years. The results obtained for the commercially important Scaridae are analytic of a population that holds high social and commercial value to local stakeholders and it is likely that it is presenting signs of overfishing.

4.1.4 Coral Reef Associated Invertebrates

Within coral reef communities' invertebrates occupy essential functional roles, support food webs by providing an important trophic link between corals and associated fishes, and influence the health of coral colonies. As a result, during this study, it was of no surprise to find higher levels of invertebrate abundance in locations that held higher levels of HC composition as well as high levels of fish abundance, such as Lime Kiln Bay. However, minimal conclusions can be drawn from the presented data due to the low number of target invertebrates recorded, which calls for invertebrate specific studies focusing on the composition of invertebrate communities around the coastline of Montserrat. The target invertebrates recorded in this survey were chosen due to their respective herbivory traits and as such the abundance, interactions and influence of urchins (*Diadema* sp. and Pencil Urchins) is discussed.

Pencil urchins (*Eucidaris tribuloides*) occupy low trophic levels due to their preferential feeding behaviour on algal and sponge substrates (Santos *et al.*, 2002; Hernández-Almaraz *et al.*, 2016) and were recorded in greatest abundance throughout the sample period, with Lime Kiln Bay holding the greatest density. Furthermore, McPherson (1968^a) demonstrated that *E. tribuloides* showed preference to algal or boring sponge dominated rock thus further supporting their dominance at Lime Kiln Bay with regards to its respective NIA composition. *E. tribuloides* has also been demonstrated to exhibit coralivorous traits through the ingestion of hard limestone materials (McPherson 1968^b), further supporting its abundance at Lime Kiln Bay.

The impact of corallivory on coral reefs has briefly been discussed in previous sections and although the predation of *E. tribuloides* on limestone substrates may prove detrimental in the long term, the data presented in this report suggests that this is unlikely and the dominance of *E. tribuloides* is due to the capacity of Lime Kiln Bay's ability to support a diverse community. In comparison to other *E. tribuloides* populations recorded within the Caribbean (Lessios 1998; Bologna *et al.*, 2012), those present around Montserrat are in lower abundance. Lessios (1998) presented results that indicated that *E. tribuloides* densities within the Cayo Cochinos MPA, Honduras, were 0.47m^{-2} , which is much greater than observed throughout this study ($16.87 \pm 1.95\ 100\text{m}^{-2}$). Bologna *et al.* (2012) indicate higher populations within the MPA however their results also show that the HC and NIA composition is between 10.8 and 29.0% and 25.2 and 40.8%, respectively. In comparison, these benthic compositions that hold preference for *E. tribuloides*, are significant against those observed around Montserrat (0 – 6%) and thus, it is possible that the reduced densities around Montserrat are influenced heavily by poor conservation and suitable benthic habitat.

Long-spined urchins or *Diadema* sp. were recorded in densities of $1.65 \pm 0.34\ 100\text{m}^{-2}$; the second highest recorded invertebrate. In combination with *E. tribuloides*, *Diadema* sp. were recorded in greatest densities at Lime Kiln Bay however the variation observed between sites was not significant, indicative of similarly low densities throughout the sample period. Again, in comparison to results by Lessios (1998)



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(0.19m^{-2}) and Bologna *et al.*, (2012), the recorded densities of *Diadema* sp. during this study were lower when directly compared. It is estimated that Bologna *et al.* (2012) recorded *Diadema* sp. densities within the Cayo Cochinos MPA at $\pm 2.11\text{ }100\text{m}^{-2}$, therefore although lower, the reduced densities are not as significant as other urchin species. The mass die-off of *Diadema* sp. in the 1980's within the Caribbean is well documented (e.g Lessios *et al.*, 1984^a; Bruno *et al.*, 2009; Mumby 2009) and whilst some populations have shown signs of recovery (Edmunds & Carpenter 2001; Ruiz-Ramos *et al.*, 2011) it is clear from the data presented in this report that populations are still yet to recover. In combination with reduced *Diadema* sp. populations, HC cover, in tandem with increased widespread anthropogenic impacts, also showed significant decreases (Norstöm *et al.*, 2009; Hughes *et al.*, 2010), which is also evident within the coastal waters of Montserrat. Throughout the Caribbean and most likely Montserrat, the reduction of *Diadema* sp. removed an essential primary herbivore from the complex coral reef mechanism resulting in increases of NIA. Despite NIA composition

being relatively low in comparison to other Caribbean locations (Norstöm *et al.*, 2009; Hughes *et al.*, 2010; Bologna *et al.*, 2012), the abatement of supportive habitat may be hindering the ability of *Diadema* sp. populations to recover. A reduced abundance in *Diadema* sp. has been demonstrated to result in an increase in other urchin species (Lessios *et al.*, 1984^b) which mirrors results observed at Lime Kiln Bay with a dominance of *E. tribuloides* in the absence of direct resource competition. The functional role occupied by *Diadema* sp. and their subsequent impact on coral reefs is highly documented (Carpenter & Edmunds 2006). Carpenter and Edmunds (2006) provide evidence that indicates that with increased densities of *Diadema* sp., coral recruitment has increased, thus highlighting their role within coral reef ecosystems. As such, it is vital that management decisions are implemented that will benefit the recovery of *Diadema* sp. within Lime Kiln Bay and around Montserrat for the promotion of coral reef recovery. Conflictingly, although some studies suggest that restricted fishing activities result in an increase in *Diadema* sp. Predators, thus reducing their respective



recruitment (Clemente *et al.*, 2008; Harbone *et al.*, 2009), location-specific densities around Montserrat may be restricted in recruitment by regional populations throughout the Caribbean (Belonga *et al.*, 2012). It is suggested through data in this report and those provided by Lessios (1998) and Bologna *et al.* (2012) that populations can recover through the implementation of an MPA in combination with an increase in HC cover and reduced NIA as highly complex coral reef communities are re-built.

4.2 Conservation Management Values

The majority ($n = 29$) of survey sites were classified as having no conservation management value (CMV= 0). However, this is not necessarily absolute as the CMVs solely indicate current areas that would benefit from conservation management to succeed within the short term. Although a site holds a CMV= 0, CMV's do not demonstrate that it would not benefit from conservation driven protection, but simply highlights areas that hold a greater possibility of success in the light of limited resources to local managers. Baseline locations held the greatest composition of CMV= 0; however, from the geographically constrained sites, Isle's Bay held the greatest composition. Furthermore, no survey sites at Isle's Bay held a greater value of CMV= 3, this is due to the poorly represented fish and invertebrate communities compounded by poor substratum complexity and fishery capacity; despite holding the highest diversity values for fishes. The sites classified as CMV= 3 are due to the observed diversity of fishes, however, CMV indicated that Isle's Bay would not hold the desired capacity, in coordination with available government resources, to provide management goal attainment. As such, resources should be focused towards other sites such as Lime Kiln Bay and Carr's Bay. The majority of surveyed permanent sites were classified as over CMV= 5; however, due to their large geographical range and distance from the coastline, further studies must be implemented in order to assess their ability to warrant protection. Their

importance in supplementing coral reef communities around Montserrat must be included in future management plans. It is recommended that not only site specific reports be produced, but also further monitoring is undertaken to assess trends. The establishment of large, off-shore MPAs have the potential to drive the recruitment of fishes such as Serranidae through spawning aggregations further increasing the fishery capacity around Montserrat.

From general observation of the spatial distribution of CMVs along the north-western coastline, it can be suggested that CMVs increase with an increased latitude with the higher CMV found in greater proximity to Little Bay. It is surmised, therefore, that the abundance of lower CMV found around Old Road Bay and Woodlands Bay, in combination with the previously discussed community parameters, is, in part, due to the Soufriere Hills eruptions, with the communities and substrate found within these locations showing attenuated signs of recovery. The effects of the Soufriere Hills eruptions on surrounding coral reefs is not very well documented with little data collected. However, from the small studies, it was demonstrated that the eruptions resulted in severe acute impacts decreasing coral cover and altering community assemblages through increased sedimentation and smothering (Brosnan 2005). Brosnan (2005) expand on this by reporting that the south-west and western coastline of Montserrat were greatly impacted, in comparison to northern sites



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such as Rendezvous Bay, with Garibaldi Bluff one of the most highly impacted areas due to volcanic sediment being deposited on through the Belham river. The input of sediment was estimated to settle within 300m of shore (Brosnan 2005), providing a potential reasoning as to the permanent sites, located at a greater distance from the coastline within proximity to Garibaldi Bay, holding high CMV. Due to minimal composition of sediment found at Isle's Bay, Old Road Bay and Woodlands Bay, it is evident that the presented results are portraying the long-term effect of Soufriere Hills eruptions. The close proximity of Garibaldi Bay and this study's surveyed locations to the pyroclastic flows and ash clouds of the Soufriere Hills eruptions, means that the results obtained in this study are as expected. However, Lime Kiln Bay does indicate surprising results. It is highly likely that due to the sheltered nature of the bay and its increased distance from the volcano, the location was impacted to a lesser extent than the latter locations. As such, the respective HC composition and biomass observed is supported by Vroom and Zgliczynski (2011) where they report a mean HC composition of 7.9% and biomass at $0.22\text{kg } 100\text{m}^{-2}$ following eruptions. It is highlighted that through various mechanisms, coral polyps hold the ability to clear silts and other settling particles from their outer tissues, with some species more successful than others. It is therefore hypothesised that although it is likely that the HC composition recorded at Lime kiln Bay is much lower than historic compositions, the present HC at Lime Kiln Bay, in combination with prevailing currents, is composed of resilient coral species that hold an efficient mechanisms to clear silt such as *Porites* sp.. Moreover, due to the prolonged activity of the Soufriere Hills volcano to current dates, the conservation of Lime Kiln Bay is of high importance as the area holds the potential to hold resilient species that may be critical to the recovery of coral reefs along the north-western coastline of Montserrat in future years and possible eruptions.

Due to the discussed links and driving factors of benthic substratum, it is likely that the observed community parameters and subsequent CMV are a result of severe, natural disruptions, reducing ecosystem capacity, as opposed to heavy overfishing and other anthropogenic impacts within the area. This is further supported by the dominance of SD, also resulting in low CMV.

All of the surveyed sites within Lime Kiln Bay were categorised as $\text{CMV} = >3$, with the majority as $\text{CMV} = 5$, subsequently, 25% of all sites were classified as $\text{CMV} = 6$ with 18.75% as $\text{CMV} = 7$. This further supports the call for Lime Kiln Bay to be protected through the establishment of an MPA and conservation driven management. The high composition of RC in combination with HC as well as the previously discussed parameters, demonstrates Lime Kiln Bay's ability to hold high recruitment levels as well as the capacity to support an aesthetically pleasing, ecologically important coral reef community; one that would be highly attractive to the tourist and fishery sector. However, it must be noted that as no temporal data can be assessed for Lime Kiln Bay, the process for protection must be implemented with immediate effect to minimise any further detrimental impacts. The composition of NIA found at Lime Kiln Bay is of concern, however. NIA is often an ample indicator to increased nutrient input to the water column, and therefore all though not included within the CMV, this parameter indicates that the systems within Lime Kiln Bay are experiencing nutrient pollution from land-based sources. In order for Lime Kiln Bay to become successful and attain the desired conservation goals, an ecosystem based management approach must be practiced that not only addresses direct impacts, but also terrestrial, indirect sources of degradation. Lime Kiln Bay demonstrated the highest values for standing biomass of commercially important species, and although not significant amongst locations, this will have positively impacted the CMV. In light of this high standing biomass, Lime Kiln Bay shows promise for an MPA with an established aim of improving fishery capacity within the

bay. As surrounding CMV are also relatively high, it is likely that the establishment of an MPA within the Lime Kiln Bay area would have significantly positive impacts on surrounding locations through spill-over, thereby increasing HC recruitment and complexity, thus driving diverse community assemblages.

In comparison to Lime Kiln Bay, 14.29% of Carr's Bay sites were held a CMV= 7, whereas the majority of sites were classified as between CMV= 2 and 4. In relation to other geographically constrained sites, the values obtained for Carr's Bay further highlight the need for protection. Due to its close proximity to Little Bay, the establishment of conservation management plans provide a unique opportunity to supplement the tourist sector. Carr's Bay, through results, has shown that it has the potential to increase in ecological health, providing an opportunity for dive related tourism. In contrast, Carr's Bay recorded the highest composition of SI which is likely to be attributed to outflow and water-management from Little Bay; further highlighting the need for ecosystem-based management.

Although this study contextualises a review of the abundance and diversity of coral reef communities, there are limitations of the utilised methodology that must be accounted for. 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 (Dallison, 2015). Coral reef fishes are often considered to be highly sedentary, however there is evidence to suggest that many exploited reef fishes undertake diurnal intra and inter-reef migrations (Chapman and Kramer 2000). However, with UVC transects being conducted during the day, limitations within this study are supported with studies stating that fish activity is minimal between 09:00 and 16:00 (McMellor & Smith 2010), the full community structure was difficult to assess due to the aforementioned differential species-specific behaviours influenced by abiotic factors. Although the methodology utilised in handling the data for this report incorporated seasonality and migratory behaviour into the analysis, aiming to limit the impact of: spawning migrations (Sale *et al.*, 2010), ontogenetic shifts, habitat selectivity (McAfee and Morgan, 1996) and home range relocations (Chapman and Kramer, 2000) as well as diel vertical migrations between feeding sites (Hobson, 1973), their true impact on abundance and diversity cannot be holistically accounted for and could therefore serve as a justified reason for the variability between sites and years in the community characteristics. Throughout this study and future studies, this limitation is accepted due to the diurnal fishing activities within the region and the bio-diversity found on coral reefs (Bellwood *et al.*, 2012) as well as the protocols CCC



have in place. Therefore, addressing this limitation is challenging and unfeasible due to the citizen science structure of CCC.

4.3 Marine Protected Areas and Recommendations

The implementation of MPAs as tools for fisheries and conservation management have become ubiquitous in recent years (e.g. Di Franco *et al.*, 2016). Designation can take a variety of forms and scales from small community led zones to vast internationally governed areas such as the Chagos MPA. MPAs are designed to limit the impact of external stressors on reef habitat. Predominantly, these will involve anthropogenic pressures such as over fishing, destructive fishing and pollution. However, they also have the capacity, when well managed and enforced, to increase resilience and increase ecosystem recovery following large-scale natural disturbances such as coral bleaching and disease outbreak events.

In a fisheries context, MPAs usually combine areas where the extraction of any species is prohibited (NTA), with buffer zones that utilise a range of restrictions that may limit catch size, gear types and seasonal closures. Many studies have shown that for an MPA to actively halt declines and increase fish biomass (a primary objective for fisheries), there must be complete compliance from the communities, with effective regulation and enforcement. Even small levels of poaching within an MPA can have a large detrimental effect on its ability to fulfil its goals. The establishment of any MPA must therefore be balanced against the actual and perceived loss of fishing grounds and the associated social, economic and cultural impacts that result. Consultation and community involvement is fundamental to effective management, in terms of regulation design and uptake. MPAs which are designed to meet the requirements and cultural expectations of local communities are significantly more likely to achieve their goals. Well designated and effectively enforced MPAs may also have other benefits outside of fisheries. Tourism

potential and increases in local income as a result of MPA designation have been widely reported from studies around the world. In the Philippines, recreational dive tourism is valued at US\$5,300 – \$1 million annually with tourists willing to pay a higher price to dive in areas of marine protection.

CCC strongly recommends creating two MPAs that encompass the surveyed locations of Lime Kiln bay and Carr's Bay. Considering the levels of overfishing and other detrimental impacts suggested from this study, the establishment of NTA and MPAs that remove fishing pressure on varying spatial scales is the best course of action. Ideally these areas would be buffered with designated MR zones allowing some restricted (hook and line only) fishing in the area. The no-take zone created by an MPA would provide a sanctuary for coral reef associated species, increasing recruitment, driving complexity and thus increasing capacity for the fishery and tourism sectors. It is recommended that Carr's Bay be protected by such



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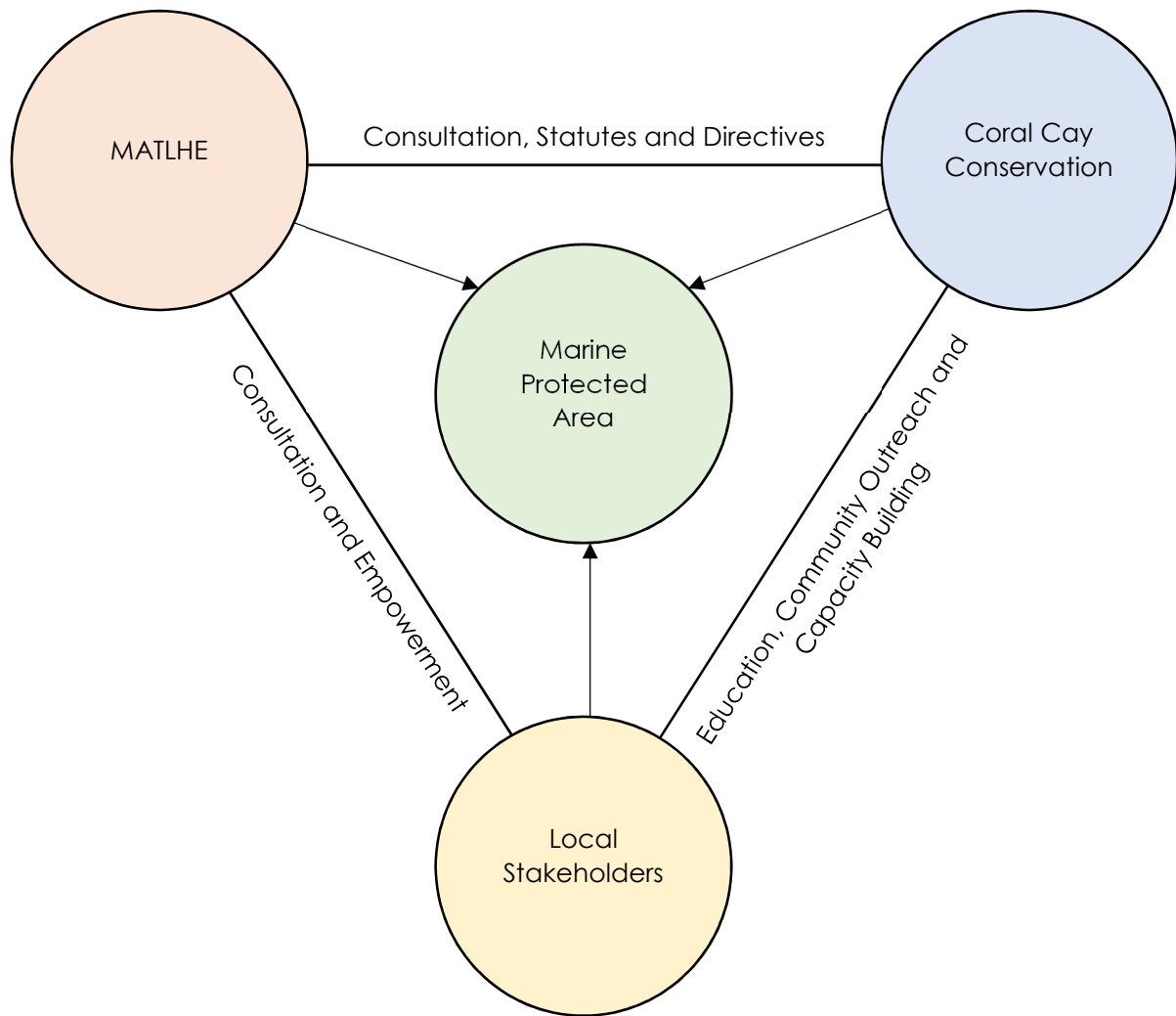


Figure 33. Simple schematic demonstrating flow of information through an established ternary-consortium between The Montserrat Government Ministry of Agriculture, Trade, Lands Housing and the Environment (MATLHE), Coral Cay Conservation and local stakeholders for the success of proposed marine protected areas.

methods in order to increase its viability for hosting marine tourism related excursions. Secondly, Lime Kiln Bay should be protected with the sole aim of increasing fishery capacity. Although their designation and protection are long-term aims, CCC's third phase and consultation processes are critical to achieving success. As a result, CCC will enter the third stage of the Montserrat Ridge to Reef project, focusing solely on Lime Kiln Bay. Through the work undertaken at Lime Kiln Bay, CCC aim to build the relevant capacity throughout Montserrat with the hope that Lime Kiln Bay will be used as a successful template for the establishment of an MPA within the waters encompassing Carr's Bay. CCC's third stage will involve a range of sub-phases that will map the abiotic and biotic substrates and develop a species-specific methodology for surveying. This will enable CCC to advise on detailed, conservation

driven objectives and increase community outreach work to empower local stakeholders and provide them with a sense of ownership towards the MPA; all critical to achieving success (Fig. 33).

A study by Edgar *et al.* (2014) argues that the effectiveness of MPAs relies on five criteria: that they should be no-take zones and well enforced, that they should be both large and old (>10 years), and that they should be isolated by deep water or sand. This is an ideal, but something that should be considered in the process of establishing multiple MPAs within the waters of Montserrat. Local fishers and stakeholders must be considered and it is unreasonable to suggest the designation of large NTAs restricting fishing in the area. By zonation, allowing some restricted level of fishing within buffer zones surrounding the MPA, local fishers can continue to benefit

from subsistence fishing whilst allowing coral reefs of Montserrat to recover for future generations.

That successful MPAs should be old (Edgar *et al.*, 2014) is something that needs to be considered when establishing MPAs. Response times can be slow and it may be a number of years before communities see the benefits of a NTA. To ensure this is understood and that realistic expectations are developed, a consultation and presentation of data is recommended to inform local user groups and respective governmental departments of the health of the surveyed reefs and expected timeframe of results. Perhaps the most important criteria ensuring the success of an MPA is that it is well enforced. If an MPA is designated without empowerment and the provision of ownership to local stakeholders, compliance will be low. Even minimal instances of poaching (whether intentional or accidental) inside an MPA can destroy years of recovery in a relatively short period of time (McCook, *et al.*, 2010). For this, CCC advise the creation of a three-tiered consortium that will act as a method of efficient communication (Fig. 33), to oversee the effective running of the MPA. The committee would coordinate the collection of MPA fees for possible dive and snorkel sites, provide training and support to local MPA guards, oversee the enforcement of the MPA and be a link to the Montserrat Government for matters concerning the MPA. It will be important for the consortium to establish goals and objectives for the MPA based on the criteria of species protection, fisheries and tourism. Reviewing these objectives will help inform management decisions. CCC will offer support throughout this process, and continue in the provision of scientific capacity and recommendations. Following the completion of phase three, two reports will be submitted; a summation of CCC's work continuing on from the results presented in this study; and a site-specific report based on the prospective establishment of an MPA at Lime Kiln Bay. Contrastingly, many of the points argued in their study are not applicable to small-scale

tropical fisheries that are governed at lower levels. Nevertheless, enforcement holds a significant role in any ecosystem approach to fisheries (EAF) management (Fig. 34). The development of a ternary-based consortium between local stakeholders, scientific NGOs and governments will be crucial to the increase in protection. Enabling transparent policy making whilst involving local stakeholders in the decision making process and ultimately empowering them, is highlighted as a key element to successful fishery management (Ferse *et al.*, 2010; Edgar *et al.*, 2014). The study of the north-western coastline of Montserrat emphasised the impact of overfishing within the region. The EAF model proposed for the future management of MPAs around Montserrat must ensure that compliance is high. Low levels of compliance can often be attributed to a top-down approach to management, and although CCC has established recommendations for the use of co-management, there is potential for delineation of MPA establishment justification to be diluted (Ferse *et al.*, 2010). By conducting community outreach and educational programmes throughout Montserrat, CCC addresses these levels of compliance that fluctuate dependent on individuals and hierarchy. By raising awareness of the issues resulting from unsustainable exploitation to younger generations, CCC combats the associated restrictions of culture and traditions in older generations. Thus sustainable practices become integrated into future generations in the hope that these practices will become the 'norm'. Capacity building initiatives practiced throughout Montserrat aim to provide local resource managers with the ability to develop adaptive management, whilst managing for resilience (to local and far-field stressors) and establishing their own objectives and outcomes. In combination with holding the necessary tools for scientific monitoring, autonomous MPA management should be aimed for. Moreover, CCC recommends the direct involvement of local children throughout the pre and post-establishment

processes. Children and younger generations must contribute to the MPA. Methods of involvement are still to be explored; however, initially this can be achieved through the creation of MPA resources such as signage and waste disposal resources, whilst also providing children with the opportunity to snorkel the area, generating potential MPA names, and obtaining supportive efforts from local schools. The key element to their respective involvement is for them to be incorporated into the pre-designation process through the holding of children-specific workshops. This will enable them hold a sense of worth within the MPA whilst assisting in its tailoring for the prospective futures. It must be

noted, however, that such by-laws must only be established with a solid scientific understanding. Whilst this study provides recommendations and a general overview of the study locations, in combination with the instigation of phase three, CCC hopes that such scientific capacity with a holistic, driven effort to protect the waters of Montserrat will resonate throughout the local communities. This will result in increased tourism related income, fishery capacity and improving the well-being and livelihoods of the stakeholders throughout Montserrat. Location and species specific regulations and statutory will be recommended in subsequent reports by CCC.



Figure 34. Schematic diagram representing the 12 key points that must be incorporated into each ecosystem approach to fisheries (EAF) management plan to achieve management aims. The schematic demonstrates that Coral Cay Conservation combines all 12 into their approach to fisheries management with regards to the coastal waters of Montserrat and local stakeholders. EAF key points presented by Pomeroy et al. (2013).

5.0 References

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6.0 Appendices

Table A1. lists the target fish families and species recorded on CCC surveys. Families are shown in bold type and all members of these families are recorded. Additional target species, shown in regular type, are also recorded for some families.

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

Error! Reference source not found.. The target invertebrates recorded on CCC surveys.

Target Invertebrates	
Banded Coral Shrimp (<i>Stenopus hispidus</i>)	Long Spined Sea Urchin (<i>Diadema antillarum</i>)
Collector Urchin (<i>Tripneustes</i> spp.)	Pencil Urchin
Flamingo Tongue (<i>Cyphoma gibbosum</i>)	Triton's Trumpet (<i>Charonia variegata</i>)
Gorgonians (<i>Gorgonacea</i>)	Lobster (<i>Palinuridae</i>)

Table A3. The target substrates which are recorded on CCC surveys. Hard corals also include fire coral and soft corals also include zoanthids.

Target Substrates		
Hard Coral (including fire coral)	Soft Coral (including zoanthids)	Recently Killed Coral
Sponge	Nutrient indicator algae	Rock
Rubble	Sand	Silt
Other		

Table B1. The accumulative abundance of target fish families and species recorded throughout the survey period along the north-western coast of Montserrat, Caribbean

Classification	Taxonomic nomenclature	Common Name	Accumulative Abundance
Family	Acanthuridae	Surgeonfish (Other)	3067
	Aulostomidae	Trumpetfish	15
	Balistidae	Triggerfish	117
	Belonidae	Needlefish	0
	Carangidae	Jack	205
	Chaetodontidae	Butterflyfish	177
	Grammatidae	Basslet	96
	Haemulidae	Grunts	771
	Hemiramphidae	Halfbeak	4
	Holocentridae	Squirrelfish/Soldierfish	249
	Kyphosidae	Chub	6
	Labridae	Wrasse	43094
	Lutjanidae	Snapper	574
	Monacanthidae	Filefish	151
	Mulidae	Goatfish	151
	Muraenidae	Moray Eel	47
	Ophichthidae	Snake eel	5
	Ostraciidae	Trunk/Box/Cowfish	117
	Pomacentridae	Angelfish	107
	Pomacentridae	Chromis/Damselfish	21616
	Scaridae	Parrotfish	760
	Scorpaenidae	Lionfish	35
	Scorpaenidae	Scorpionfish	8
	Serranidae	Grouper (Other)	85
	Sparidae	Porgy	2
	Synodontidae	Lizardfish	101
Species	<i>Acanthostracion polygonia</i>	Honeycomb Cowfish	0
	<i>Acanthurus coeruleus</i>	Blue Tang	419
	<i>Cephalopholis fulva</i>	Coney	694
	<i>Epinephelus adscensionis</i> & <i>Epinephelus guttatus</i>	Hind	16
	<i>Epinephelus striatus</i>	Nassau Grouper	14
	<i>Hypoplectrus</i> sp.	Hamlet	0

Table B2. The accumulative abundance of target invertebrates recorded throughout the survey period along the north-western coast of Montserrat, Caribbean.

Classification	Taxonomic nomenclature	Common Name	Accumulative Abundance
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Coral Cay Conservation Marine Progress Report 2013 - 2016

Order	Gorgonacea	Gorgonian	37560
Family	Palinuridae	Lobster	138
Species	<i>Charonia variegata</i>	Triton trumpet	3
	<i>Cyphoma gibbosum</i>	Flamingo tongue	267
	<i>Diadema antillarum</i>	Diadema/Long spined sea urchin	766
	<i>Eucidaris tribuloides</i>	Pencil urchin	2668
	<i>Stenopus hispidus</i>	Banded coral shrimp	204
	<i>Tripneustes ventricosus</i>	Collector urchin/sea egg	15