Re:GCP/TRI/003/GEF

FINAL REPORT ON THE ECOLOGICAL BASELINE STUDY ASSESSING THE STATUS OF SELECTED INDICATOR SPECIES IN SIX PROTECTED AREAS IN TRINIDAD AND TOBAGO

Department of Life Sciences

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Final Report to the United Nations Food and Agriculture Organisation/Global Environmental Facility, on the Project for the Preparation of an Ecological Baseline Study Assessing the Status of Selected Indicator Species in Six Protected Areas in Trinidad and Tobago

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EXECUTIVE SUMMARY

Background

In 2011, the Government of the Republic of Trinidad and Tobago partnered with the UNFAO, GEF and stakeholder agencies to develop the Project for Improving Forest Protection and Management for Trinidad and Tobago (IFPAMTT), which was later approved by cabinet in 2014.

One of the expected outcomes of the IFPAMTT project is the strengthening of biodiversity conservation at 6 project sites, namely Caroni Swamp, Nariva Swamp, Trinity Hills and Eastern Extension, Matura National Park, Main Ridge Tobago and North East Tobago Marine Protected Area. A key requisite to this is the establishment of baseline data for indicator species, and species of special concern, which inhabit the 6 proposed protected areas (PAs), and the improvement of management capacity of these areas and their inhabiting species. The IFPAMTT Project Document identified 99 indicator species– a listing developed via stakeholder consultation.

In order to set a baseline of as many of the 99 indicator species identified by the stakeholders, the UNFAO engaged the University of the West Indies (UWI) in 2016, to conduct rapid surveys of flora and fauna within the 6 PA's in a bid to verify the stakeholder indicator species as suitable indicator species, provide a baseline for the status of indicator species and/or taxa groups, and to propose means and methods for monitoring these species/groups of species in future. These groups include: avifauna, marine organisms (invertebrates, macroalgae and fish species), freshwater and brackish fish, decapod and benthic invertebrate species, herpetofauna (reptiles and amphibians), non-volant mammals, tree and other plant species canopy cover and endemic vascular plants, and arthropods (specifically butterflies and dragon and damselflies).
These particular taxa groups were proposed by UWI because:

1. They contained the majority of the indicator species selected by stakeholders
2. They were able to be surveyed using methods that captured many indicator species in a taxa group during the same survey
3. UWI had knowledge and experience in surveying these taxa.

Findings

During the baseline survey varying numbers of species of flora and fauna in various taxa groups were observed and identified in the different PAs (Table 1) and most of the stakeholder nominated indicator species were observed. The experts in the different taxa had the capacity to identify the majority of species observed as well as the indicator species. As a result, many of the project's researchers have presented records of all the species encountered during their taxonomic surveys, a summary of which is tabulated below (Table 1).

Despite most species being surveyed in the baseline survey, it is recognized that monitoring of entire taxa groups poses a potentially difficult task for monitoring staff with limited training. In light of this, project researchers have proposed a revised group of indicator species which can act as representatives of the larger taxa groups. Some of the original stakeholder generated indicator species are not recommended as they were not well represented in the data set, probably because they are fairly rare and require specialized monitoring methods that would not be suitable for picking up any other species. The revised indicator species would prove a more practical approach, until sufficient knowledge and skills training is provided to potential monitoring staff. It is likely that once monitoring personnel gain more experience, they will be able to identify the majority of species in a taxa group as well as the indicator species and generate more complete species lists.

In order to monitor marine ecosystem health, the marine survey also suggests the monitoring of indicator indices, namely: percentage benthic cover of hard coral, gorgonians, macroalgae and sponges; coral species richness and diversity; coral disease and bleaching prevalence, new incidence and mortality; coral reef structural complexity; and overall fish community biomass. In the same way, the plant taxa group recommended using remote sensing to assess canopy closure and degradation of the dominant plant species in the ecosystems to be monitored.

Collectively, this project proposes 113 species to act as indicators - 22 birds, 2 mammals, 6 dragonflies, 10 butterflies, 17 herpetofauna, 9 marine species (3 coral, lobster, conch, 3 fishes (lionfish, groupers, snappers) 1 sea urchin), 28 endemic plants, 3 freshwater decapods, 15 freshwater fish and 1 freshwater mollusc (Table 2).

The data, summarised below, along with the suggestions for future monitoring, is intended to serve as the basis for gathering biological data for species and habitat management within the six PAs.

Study 2: Marine Survey: Coral Reefs and Fisheries

Study leader: Guy Marley
Author: Guy Marley

2.1. Introduction

A hawksbill turtle resting amongst the corals on Angel Reef, Speyside. ©Richard Parkinson

The coral reefs of Tobago have evolved in a marginal environment where sediment-laden water from the Orinoco and Amazon Rivers block sunlight needed for photosynthesis and stress coral with low salinities and high sedimentation (Mallela et al., 2010; Hu et al., 2004). In spite of this, Tobago has some of the largest brain corals in the region and hard coral cover at some locations exceeds many Caribbean islands (Wilkinson, 2008). More recently however, poorly managed watersheds are compounding this natural stress. Heavy rains wash soil onto reefs where land and steep slopes have been cleared for agriculture and construction. While poor sewage treatment and unregulated fertiliser use are the source of concentrated nutrient pollution. As well as stressing corals, these nutrients stimulate harmful algal blooms which overgrow corals and prevent juveniles replenishing the reef (Lapointe et al., 2010; Kuffner et al., 2006).

Global threats to Tobago's reefs may be even more alarming. Climate models predict that coral reefs worldwide may be eradicated by the end of the century (Hoegh-Guldberg et al., 2007). Coral bleaching, disease outbreaks, storm damage and ocean acidification are the protagonists of this decline and all are exacerbated by climate change. In response, coral reef scientists and managers are promoting efforts to build resilience in coral reefs to resist these threats or give them the best chance to recover when they are affected. This requires mitigation of local stressors in order to maintain reefs in the best possible condition. This is a multistage management process, the first of which is an assessment of the status of the coral reefs, identifying impacted areas and sources of those impacts, as well as identifying reefs with the greatest potential resilience which may be earmarked for special conservation efforts.

This study targets a number of important reef health and resilience indicators that can help assess the status of coral reefs and their potential resilience to climate change. By establishing a baseline survey that can then be repeated annually in a comprehensive monitoring program, the effectiveness of future management measures may be judged.

The objectives of this project were therefore to

1. conduct a baseline survey that characterises the coral reef communities and ecosystem health indices at representative locations in the proposed north-east Tobago marine protected area (NETMPA);
2. evaluate the commercial and subsistence fisheries occurring in the NETMPA, particularly for top reef predators, parrotfishes, lobsters and conch;
3. propose a coral reef monitoring programme that can be applied by governmental or non-governmental organisations.

2.1.1. Coral Health Indicators

There is no single descriptor that characterises a healthy coral reef. For example, an abundance of coral is naturally preferable, but if that coral is all a single species monoculture it belies the real condition of the reef. A rich and diverse coral community might therefore be a better metric, but this was the case in Jamaica right before the reefs were overwhelmed by algae because disease and overfishing had eroded the herbivore community (Hughes, 1994). Instead, a suite of practical, quantitative indicators is needed to characterise the status of NETMPA reefs and track changes as management measures are implemented. The following section justifies the inclusion of the reef health indicators selected for this survey. This is not an exhaustive list of important indicators, and there are others we identify in section 2.4 with recommendations for their inclusion in the future monitoring program.

Hard coral cover

Scleractinian corals, also known as hard corals, are the structural engineers of coral reefs and responsible for the architectural complexity that provides critical habitat for many coral reef organisms. Coral cover, typically calculated as a 2D percentage cover of the substrate, is thus a fundamental indicator of reef health.

Coral Diversity

Higher biodiversity is largely synonymous with superior ecosystem health, resilience to climate change and disease outbreaks (Elmqvist et al., 2003). Coral bleaching and disease can often be species specific, and a diverse community fosters new species to adopt the ecological role of those more severely impacted. Moreover, the range of shapes and sizes of different coral species creates a myriad of holes and crevices for other reef organisms. This diverse reef architecture is fundamental to supporting invertebrates and fishes (Nash et al., 2013). A decline in coral diversity is therefore indicative of a decline in ecosystem health and ecosystem resilience.

Focal Species

This survey has a focus on the IUCN endangered coral species *A. cervicornis* and *A. palmata*, as well as the important reef building corals *Orbicella* spp.. These 'flagship' species can often be indicative of ecosystem changes that affect many reef organisms. *Acropora* spp. have been badly affected by disease since the 1980s (Aronson and Precht, 2001), so much so, that they are now considered critically endangered (IUCN Red List). *Orbicella* spp. are the most important reef building corals on Tobago's reefs, but were badly affected by coral bleaching in 2005 and 2010, leaving them susceptible to an outbreak of Yellow Band disease which still persists today (van Bochove and McVee, 2012). Important commercial invertebrate species, spiny lobsters (Palinuridae) and queen conch (*Lobatus gigas*), are also included here as they are overexploited across the Caribbean.

Coral recruitment

Coral recruitment is the reproductive process by which tiny juvenile corals settle out of the water column to establish a new colony. Recruitment rates depend on the abundance, distribution and reproductive output of adult corals. Large, old corals have higher fecundity than small corals and healthy corals have higher fecundity than stressed corals (Foster et al., 2008). Floating coral recruits also require specific conditions to settle and survive. Reefs with ample crustose coralline algae and negligible macroalgae are the most suitable (Kuffner et al., 2006; Negri et al., 2001). Reefs with high recruitment have the best potential to replenish the community in the event adult corals are devastated by disease, bleaching or storms.

Bleaching

Warm sea water associated with climate change causes corals to expel their algal symbionts, starving them of the food the algae provided. The loss of the colourful algae leaves the coral 'bleached' white. In 2005, 66% of corals in Tobago were bleached, with many sites as high as 85% (van Bochove and McVee, 2012). Interestingly, sites in the NETMPA fared better than the rest of Tobago. But in 2010, Speyside was badly affected, with 100% of some reefs on Little Tobago bleached. Corals can recover if they take back new algae once the high temperatures have abated, but the stress can still leave them susceptible to diseases. Bleaching events are becoming more frequent as global seawater temperatures continue to rise and greenhouse gas emissions show no sign of declining anytime soon. As more carbon dioxide ($C0_2$) absorbs into the oceans, coral reefs will be faced by a new threat of an acidified ocean dissolving away the limestone coral skeleton (Hoegh-Guldberg et al., 2007).

Disease

Climate change is increasing corals susceptibility to disease, pathogen abundance, pathogen virulence and the number of novel pathogens (Maynard et al., 2015). Corals stressed by bleaching events, nutrient and sediment pollution are particularly susceptible to infection - as are corals damaged by divers, anchors and storms. The threat is so severe that diseases are projected to kill as many corals as bleaching in coming decades (Maynard et al., 2015). These diseases can kill corals at up to 2cm per day - far exceeding coral growth rates of 2cm per year. A healthy reef is a reef free of disease, but traditional methods of quarantining, culling and vaccinating are not viable options for coral reefs (Burge et al., 2014). Therefore, detecting conditions that initiate outbreaks and identifying outbreak 'hotspots' will help guide management actions.

Coral mortality

Coral mortality is measured as the percentage of a coral colony that is dead. Natural mortality occurs on reefs due to competition and predation, but 'hotspots' of high recent mortality can help identify stressors on reefs. As monitoring programs are often annual, observations of recent coral mortality highlight any impacts since the last survey, and are important to monitor in the aftermath of a bleaching event.

Fish Diversity

Similar to coral diversity, superior fish diversity is equated with better ecosystem health. A diverse fish community improves the potential ecological redundancy of the community - whereby multiple species can fulfil certain functional roles in the event one species declines (Nyström, 2006). The training needed to identify all species on a reef is often prohibitive, so monitoring programs focus on a subset of ecologically or commercially important fishes that can still serve as a proxy for overall fish biodiversity (McField and Kramer, 2007).

Fish biomass

We categorise fish communities into functional roles and commercial value. Functional fish biomass can be used as an indicator of the trophic diversity needed to maintain a harmonious healthy ecosystem, while commercial fish biomass is an indicator of the status of fish stocks as a consequence of fishing pressure.

Fish biomass is often closely associated with habitat destruction or deterioration, especially when the architectural complexity of the reef is compromised. Healthy reefs are reliant on many fish species for certain ecological roles (e.g., controlling macroalgae) and fish communities should not be depleted in functional groups or commercially important top predators.

Macroalgal cover

A coral reef is a competitive environment with coral vs algae being the headline event. On undisturbed reefs, corals generally outcompete algae. But nutrient pollution, storms and loss of herbivores can skew the balance in favour of algae. Several macroalgal species are unpalatable to herbivorous fishes and can form an alternative stable state that is hard to recover from (Hughes et al., 2007). Macroalgae block sunlight needed by the coral for photosynthesis and prevent juveniles settling on the reef.

Herbivorous fish biomass

The most important functional group of fishes in terms of maintaining ecosystem resilience are the herbivores. Herbivorous fishes graze on benthic algae - preventing succession to larger unpalatable types of macroalgae. In Jamaica, historical overfishing reduced herbivorous fishes to only the smallest individuals, but the macroalgae were still kept in check by a herbivorous sea urchin (Klomp et al., 2001). When all the sea urchins died of a disease outbreak, and a hurricane opened up new space on the reef, the algae were released from grazing pressure and quickly took over. Many of Jamaica's reefs have still not recovered (Gardner et al., 2005).

Sea urchin density

The long-spined sea urchin, *Diadema antillarum,* is considered a keystone species on coral reefs. Similar to herbivorous fishes, these urchins keep benthic algae in check. In 1982, a disease outbreak spread through the Caribbean wiping out 99.9% of all *D. antillarum* (Mumby et al., 2006). *Diadema* populations are still recovering, and this recovery needs to be monitored and encouraged throughout the Caribbean.

Soft coral and sponges

Soft corals and sponges are important aesthetically for scuba diving tourism. The barrel sponge, *Xestospongia muta* in particular, is a prominent and spectacular feature of Speyside reefs. Sponges also have important functional roles on coral reefs, including the recycling of organic matter and nutrients (Diaz and Rützler, 2001; de Goeij et al., 2013). In the face of climate change, sponges and soft corals are expected to colonise space left vacant by struggling corals (Norström et al., 2009). However, some species overgrow corals and some sponges bore into corals (Carballo et al., 2013). They are also susceptible to bleaching and disease, and diseases of the giant barrel sponge (*X. muta)* have already been observed in the NETMPA (Goreau et al., 1998; van Bochove and McVee, 2012).

2.1.2. Literature Review

The coral reefs of north-east Tobago have received comparatively little attention compared to other nearby Caribbean islands such as Barbados and Bonaire. A literature review (Web of Science and Google Scholar search) revealed 26 peer-reviewed studies relating to the coral reefs of the proposed NETMPA dating back to 1984 (Sup. mat. 2.1.2). Of those, just 12 addressed the status of coral reef organisms (Table 2.1.2). Coral reef studies are more common in the 'grey' literature, with reef assessments commissioned by governmental and non-governmental organisations such as the Buccoo Reef Trust (BRT), Coral Cay

Conservation (CCC), the Institute of Marine Affairs (IMA), The University of the West Indies (UWI) and Environmental Research in Charlotteville (ERIC). Current coral reef monitoring programs are administered by the IMA and ERIC, and CCC/BRT ran a monitoring program from 2007 to 2011 (van Bochove and McVee, 2012; Alemu and Clement, 2012). The UWI also has a continuing project that specifically targets lionfish habitat characteristics (Mohammed in progress).

A review of empirical studies that address the reef health indicators used in this study reveals some important historical omissions and limited coverage of others (Table 2.1.2.). A number of studies have targeted benthic community composition, including hard corals, soft corals, sponges and macroalgae. However, the majority of this work is not peer-reviewed, and would benefit from being pursued into scientific journals where its quality can be standardised. Little research has been published on the fish communities, despite their functional and commercial importance and the presence of a spearfishing fishery. No studies have addressed fish recruitment. Coral recruitment is also a fundamental ecological process, yet studies have only addressed the rate of coral recruitment, and questions of sources of coral recruits and survival remain unanswered.

Table 2.1.2. Previous empirical studies on the coral reef health indicators used in this report.

Target Category	Peer-Reviewed	Other literature
Hard corals	Lapointe et al. (2003, 2010); Mallela and Crabbe (2009); Mallela et al. (2010); Alemu and Clement (2014); Buglass et al. (2016)	Laydoo (1985a); O'Farrell and Day (2005); McGann and Creary (2008); Moses and Swart (2006); Hassanali (2009); Armstrong et al. (2009); Creary (2010) d'Abadie (2011); Alemu and Clement (2010, 2011, 2012); IMA (2016)
Soft corals and sponges	Lapointe et al. (2003, 2010); Mallela et al. (2010)	McGann and Creary (2008); Hassanali (2009); Armstrong et al. (2009); Creary (2010); van Bochove and McVee (2012)
Macroalgae	Lapointe et al. (2003, 2010); Mallela et al. (2010)	McGann and Creary (2008); Hassanali (2009); Armstrong et al. (2009); Creary (2010); van Bochove and McVee (2012)
Disease and bleaching	Guppy and Bythell (2006); Harding et al. (2008); Mallela and Crabbe (2009); Mallela et al. (2016)	Laydoo (1984); O'Farrell and Day (2005); Hassanali (2009); Armstrong et al. (2009); Creary (2010); van Bochove and McVee (2012)
Coral recruitment	Mallela and Crabbe (2009); Crabbe (2012); Buglass et al. (2016)	
Coral reef fish community	Alemu (2014)	Armstrong et al. (2009); van Bochove and McVee (2012)
Herbivorous fishes	Alemu (2014)	Armstrong et al. (2009); van Bochove and McVee (2012)
Commercial fishes	Alemu (2014)	Armstrong et al. (2009); van Bochove and McVee (2012)
Lobster (Palinuridae)		Armstrong et al. (2009)
Queen conch (*L. gigas*)		Armstrong et al. (2009)
Sea urchin (*D. antillarum*)		(Laydoo, 1985b) Hassanali (2009); Armstrong et al. (2009)
Lionfish (*Pterois spp.*)	Alemu (2016)	Mohammed (in progress)

2.2. Methodology

2.2.1. Survey Sites

Permanent transect markers were established at 10 sites in the NETMPA and an additional 4 "temporary" sites were surveyed without establishing permanent markers (Fig. 2.2.1.1). Sites were selected to represent the breadth of the proposed NETMPA - incorporating nearshore and offshore reefs, important dive-tourism locations, and sites with varying exposure to population centres (Fig.2.2.1.2). Transect starting points were randomly selected on the reef crest or reef slope by dropping a sinker from the surface at between 8-12m depth. Permanent markers were fixed in advance using corrugated iron stakes hammered into pre-drilled holes in dead coral and secured with marine epoxy (Fig. 2.2.1.1). Each transect was 10m long and separated by at least 5m. Transect markers were labelled with plastic cattle-tags to allow repeat sampling of specific transects in future surveys. All permanent sites had six transects with the exception of Spiny Colony which had nine (due to the variable conditions at the site). Sisters South and Sisters Deep were at the same location but were shallow and deep-water sites respectively. Details of the procedures for repeat surveying of permanent sites (including GPS locations and transect orientations) is provided in the *Supplementary material.*

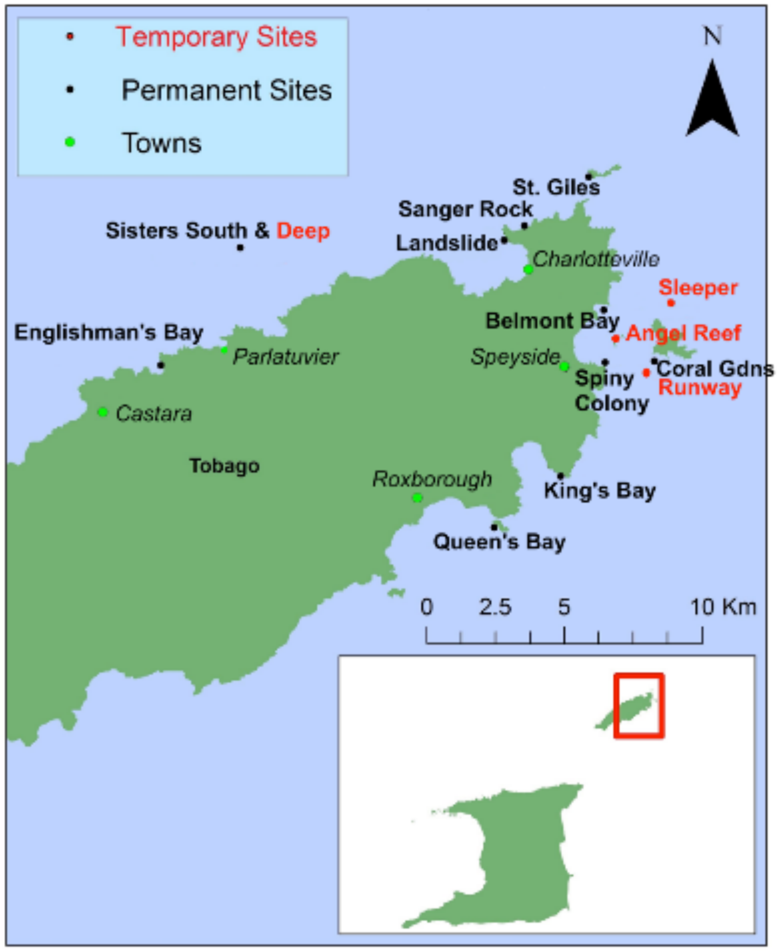

Fig. 2.2.1.2. Permanent and temporary survey sites in the NETMPA sampling in future years.

2.2.2. Benthic surveys

Benthic cover surveys were conducted at all 14 sites with two different methods in order to recommend the best approach for future monitoring programs.

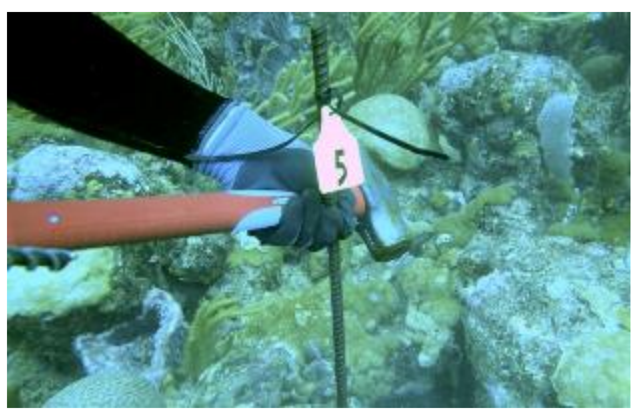

Fig. 2.2.1.1. Establishing permanent transect markers to allow repeat sampling in future years.

Photo-quadrats

At each site, 6-9 10x1m belt transects were delineated between the established transect markers or haphazardly set on the benthos where transect markers were absent (i.e. temporary sites and permanent sites with additional transects). A transect line was set between markers (or on the substrate) with sequential 1m^2 non-overlapping quadrats laid along one side of the line (always the landward/upslope side). Photographs of the quadrats were divided into 4x250cm^2 shots to increase resolution. Images were analysed in Coral Point Count with excel extensions (CPCe) where 15 points were randomly overlaid onto each image (i.e. 60 points per 1m^2). This delivered an assessment of benthic cover at 600 points per transect and more than 55,000 points in the entire NETMPA. Live percentage benthic cover was determined for hard corals, gorgonians, sponges, algae and zoanthids, as well as the abiotic substrate categories; sand, rubble, rock and dead coral. All taxa were identified to species level where possible, although some gorgonians and sponges could only be identified to genus and family. Algae were also categorised as crustose coralline algae, macroalgae and turf algae.

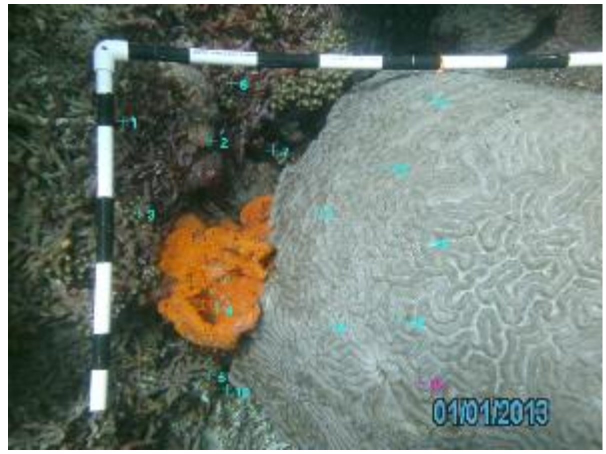

Fig. 2.2.1.3. 50x50cm photo quadrat with 15 randomly generated points assessed for benthic cover. Quadrats are only two-sided to facilitate manoeuvring around corals and the full square is delineated with the CPCe software.

Point intercept transects

Six 10m point intercept transects were surveyed at all sites (except Sisters Deep and St. Giles which had 4 transects each) following the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol but using video and post analysis. Benthic cover categories and resolution were the same as for photo-quadrats but assessed at 10cm intervals along the line. This reflected a benthic assessment at 100 points per transect and 8000 points in the NETMPA - substantially less than the photo-quadrat approach. As such, the benthic cover results presented in this report represent the findings of the photo-quadrat approach which provided a more thorough assessment of the coral reefs in the NETMPA. The line-intercept data is solely used for comparisons of the two methods in light of selecting the most appropriate methodology for a future monitoring program (section 2.4).

Fig. 2.2.1.3. Video point intercept transects.

Coral health belt transects

Coral population stability and health were assessed in 3-9 (mode=4) 10x1m belt transects. Coral size and condition was assessed for all colonies >4cm (planar diameter) whose centre was within the belt. Coral bleaching and coral disease identity and prevalence (% of corals with infection) were documented. Coral recruitment was assessed with 3-7 25x25cm quadrats haphazardly placed along the transect (a small coral recruit was a coral of diameter 0-2cm and a large recruit 2-4cm).

Fig. 2.2.2.1. A researcher conducting the coral health survey while a second researcher video records the reef for a permanent record.

Invertebrate transects

Invertebrates, specifically lobsters, queen conch, spiny sea urchin, and seacucumbers were recorded in 10x1m belt transects in the same frequency and location as line intercept transects. Lobsters were also recorded in the 30x2m belt transects at the same time as fishes (see below), and the two approaches were compared for their potential to best represent the lobster community.

2.2.3. Fish surveys

Coral reef fishes were surveyed following the AGRRA protocol which targets an 83-species subset of the whole fish community (species list in *Appendix 2.3*). Species are selected based on their functional role and commercial value. Sites were surveyed at two depths where depth allowed: 8-13.5m (excluding Sisters Deep) and 13.5-20m (excluding Landslide and Sisters South). 30x2m belt transects were run haphazardly with 6-13 transects (mode=8) in the shallow reefs and 4-9 transects (mode=8) on deep reefs. This totalled 195 transects covering 11,700m^2 (1.2 hectares) of the NETMPA.

Fish size was visually estimated to size categories: 0-5cm, 5-10, 11-20, 21-30, 31-40 and 40+cm. Accuracy of size estimations was calibrated regularly between the two surveyors. Size estimates were converted to biomass using the length-weight relationship, $W=aL^b$, where W is weight, L is length, and a and b are coefficients specific to each species (sourced from Fishbase; see *Supplementary material*). Fish biomass was calculated as g or kg/100m^2 and fish density as individuals/100m^2.

2.2.4. Fishery landings surveys

The four most significant fishery landing sites in the vicinity of the NETMPA were identified through stakeholder consultations. On the Caribbean coast, these sites were Charlotteville, Parlatuvier and Castara, with Roxborough surveyed on the Atlantic coast (Fig. 2.2.1.2). Questionnaires were administered to fishermen at each location to gain an understanding of the fishery and its management (see *supplementary material* for the questionnaire). Species specific fishery landings were recorded to determine the identity and weight of landed species over five days in Charlotteville, six days in Parlatuvier, six days in Castara and three days in Roxborough (time in Roxborough was limited due to bad weather). All species were included and 100% of landings were identified and weighed.

2.3. Status of focal species and ecosystem health indicators

2.3.1. Hard coral

Hard coral cover (% benthic cover) was highly variable between sites in the NETMPA (Fig. 2.3.1.2). Coral cover averaged 17.4±2.9% across the MPA but ranged from 2.0% at Belmont Bay in Speyside to 37% at Sanger Rock on the Caribbean coast. When split into regions of the MPA, hard coral cover on the Caribbean coast (23.2±4.4%) was significantly higher than in Speyside (13.0±1.9%) and the other Atlantic coast sites (11.2±1.0%). Low coral cover was notable at Landslide (8.3±0.7%), Belmont Bay (2.1±1.5%) and Spiny Colony (5.8±1.5%) - the three sites in closest proximity with villages. It followed that offshore sites or sites up-current of villages, typically had the highest coral cover: Sisters Deep (29.8±3.9%), St. Giles (29.7±5,4%), Sleeper (25.7±3.7%) and Sanger Rock (37.0±4.1%). Coral Gardens was an exception to this trend, with particularly low coral cover (5.3±0.8%) despite being an offshore reef. Instead, this site was dominated by sponges (26.5±2.3%; *see sponge section below*).

Fig. 2.3.1.1. The benthic community in Englishman's Bay.

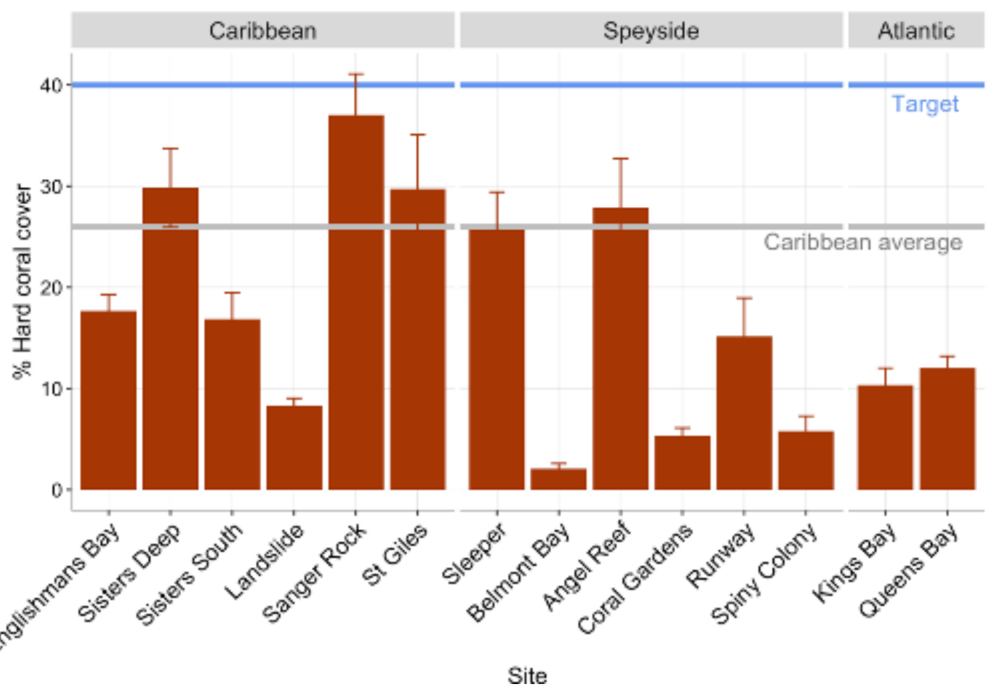

Fig. 2.3.1.2. Mean hard coral cover (% benthic cover) across sites in the NETMPA. Horizontal lines indicate AGRRA Caribbean average for forereefs and a "Very good" target proposed by McField and Kramer (2007)

Coral species richness (total for all sites in a zone in 60m^2 per site) was greatest on the Caribbean coast with 29 species (6 sites), slightly lower in Speyside with 23 species (6 sites) and 17 species on other Atlantic sites (although only 2 sites). Total species richness was highly variable across sites within Speyside, with Belmont Bay and Spiny Colony having the fewest species of any sites in the NETMPA, while Angel Reef nearby had the most species (Fig. 2.3.1.3, data in *Appendix 2.4*). Belmont Bay and Spiny Colony appear to be suffering from sediment stress - certainly in the form of sedimentation - and potentially from high turbidity reducing light penetration as well (Marley pers. obs.). Species diversity was also low in Belmont Bay and Runway, with Runway having 50% of the reef is dominated by *Siderastrea siderea*. Several Caribbean sites have species diversity around the Caribbean average - despite the sediment stress from South American Rivers (Fig. 2.3.1.3). Species diversity is low in Sanger Rock and St. Giles where the benthos is dominated by large brain corals.

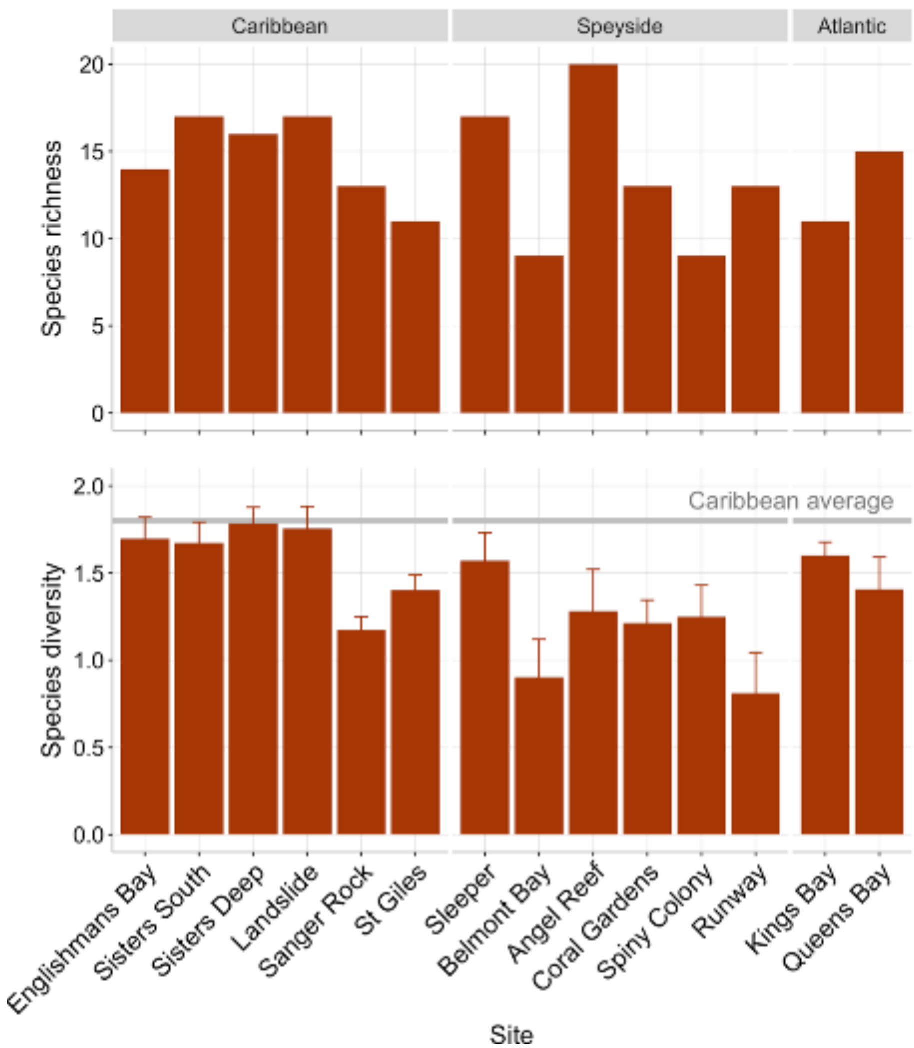

Fig. 2.3.1.3. Total hard coral species richness (in a 60m^{2}area of reef) and mean species diversity (Shannon-Weiner Index) across sites in the NETMPA. Horizontal green line indicates the AGRRA Caribbean average.

When two focal species, *A. cervicornis* and *A. palmata* (both critically endangered), were not observed inside transects, roving searches were made in the vicinity and at new sites suggested by stakeholders. Stands of *A. cervicornis* were observed in Man-O-War Bay near Charlotteville, and in Anse Bateaux near Speyside. These appear to be the only known stands in the NETMPA. No quantitative surveys were made, but recommendations for their inclusion in the future monitoring program have been suggested in section 2.4. *A. palmata* were observed in the vicinity of transects but confined to shallower water and on steep rocky slopes. Semi-quantitative surveys were made by counting stands during snorkel swims (Table 2.3.1.2).

Table. 2.3.1.2. *A. palmata* abundance

Site	Total abundance
Booby Rock, Man-O-War Bay	142
Pirates Bay, Charlottevielle	2
Landslide	205
Castara	140
Englishman's Bay	114
Atlantic side of St Giles	3
Caribbean side of St Giles	52
Angel Reef	0
Flying Manta, Little Tobago	0

Thirty-three coral species were observed in benthic transects (Table 2.3.1.3), two of which were focal species: *Orbicella faveolata* and *O. annularis* (both endangered). Three other species are listed as 'Vulnerable' by the IUCN: *Agaricia lamarcki, Dichocoenia stokesii, Mycetophyllia ferox.* All other species are 'least concern', however this designation should be treated with caution given the threat of climate change to Caribbean coral reefs.

O. faveolata (average cover=8.6±2.7%), *C. natans* (4.6±1.4%), *Millepora alcicornis* (2.2±0.6%) *and Montastrea cavernosa* (1.7±0.4%) were the dominant reef building species on Caribbean reefs - comprising 17.1% of the benthic community and 73.1% of the coral community. On Atlantic reefs, *O. faveolata* was comparatively rare (0.4±0.3%). Instead, *S. siderea* (2.9±0.7%), *C. natans* (1.9±1.1%) and *Pseudodiploria strigosa* (1.4±0.9%) were the dominant corals, with *Madracis auretenra* forming a monoculture on Angel Reef (13.6%), though absent from all other sites. The *M. auretenra* monoculture at Angel Reef boosts the percentage coral cover to amongst the highest for any site.

Table 2.3.1.3. Coral species cover across the NETMPA as a proportion of the benthic community and a proportion of the hard coral community specifically (averaged across sites)

Species	Benthic cover (%)	Proportion of corals (%)
Orbicella faveolata	3.9±1.5	22.5±9.1
Colpophyllia natans	3.0±0.9	17.6±5.2
Siderastrea siderea	2.1±0.4	12.4±2.7
Millipora alcicornis	1.6±0.3	9.4±2.2
Pseudodiploria strigosa	1.4±0.5	8.5±3
Montastraea cavernosa	1.1±0.2	6.6±1.4
Meandrina jacksoni	1.0±0.5	6±3
Madracis auretenra	0.9±0.9	5.5±5.5
Porites astreoides	0.7±0.1	4.3±1
Undaria agaricites	0.3±0.1	1.8±0.8
Diploria labyrinthiformis	0.1±0	1.1±0.3
Madracis decactis	0.1±0	0.7±0.1
Undaria humilis	0.1±0	0.6±0.1
Pseudodiploria clivosa	0.07±0.04	0.4±0.26
Orbicella annularis	0.06±0.04	0.36±0.26
Agaricia lamarcki	0.05±0.04	0.32±0.23
Meandrina meandrites	0.05±0.01	0.31±0.09
Eusmilia fastigiata	0.04±0.02	0.23±0.12
Scolymia cubensis	0.02±0.01	0.15±0.06
Isophyllia rigida	0.02±0.01	0.14±0.1
Mycetophyllia aliciae	0.01±0.01	0.11±0.09
Porites porites	0.01±0	0.1±0.04
Agaricia fragilis	0.01±0.01	0.08±0.06
Mussa angulosa	0.007±0.004	0.043±0.025
Dichocoenia stokesii	0.005±0.004	0.032±0.024
Mycetophyllia ferox	0.005±0.004	0.031±0.023
Siderastrea radians	0.004±0.002	0.023±0.015
Madracis formosa	0.002±0.002	0.017±0.017
Helioseris cucullata	0.002±0.002	0.015±0.015
Scolymia lacera	0.001±0.001	0.011±0.011
Agaricia undata	0.001±0.001	0.009±0.009
Madracis senaria	0.001±0.001	0.009±0.009
Stephanocoenia intersepta	0.001±0.001	0.009±0.009

Table. 2.3.1.4. Hard coral species presence/absence at all sites in the NETMPA

Site	EB	SS	SD	LA	SR	SG	SL	BB	AR	CG	SC	RU	KB	QB
Agaricia fragilis			*						*					
Agaricia lamarcki						*	*		*					
Agaricia undata									*					
Colpophyllia natans	*	*	*	*	*	*	*		*	*	*			*
Dichocoenia stokesi									*					*
Diploria labyrinthiformis	*	*	*	*	*	*							*	*
Eusmilia fastigiata		*					*		*	*				
Helioseris cucullata											*			
Isophyllia rigida		*		*		*	*							
Madracis auretenra									*					
Madracis decactis	*	*	*		*				*	*	*	*	*	*
Madracis formosa										*				
Madracis senaria									*					
Meandrina jacksoni	*	*	*	*	*	*	*		*	*	*	*	*	*
Meandrina meandrites	*		*	*	*	*		*	*	*	*			*
Millipora alcicornis	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Montastraea cavernosa	*	*	*	*	*	*	*		*	*	*	*	*	*
Mussa angulosa							*		*				*	
Mycetophyllia aliciae			*				*							
Mycetophyllia ferox										*				*
Orbicella annularis				*					*					
Orbicella faveolata	*	*	*	*	*	*	*	*	*			*	*	*
Porites astreoides	*	*	*	*	*	*	*		*	*	*	*	*	*
Porites porites		*	*				*	*						*
Pseudodiploria clivosa	*			*	*		*				*		*	
Pseudodiploria strigosa	*	*	*	*	*	*	*	*		*	*	*	*	*
Scolymia cubensis	*		*	*				*	*	*	*			
Scolymia lacera	*													
Siderastrea radians		*		*										
Siderastrea siderea	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Undaria sp.							*							
Undaria agaricites		*	*	*	*		*	*	*	*	*			
Undaria humilis		*	*	*			*	*	*		*	*		*
Total species richness	**12**	**14**	**14**	**15**	**11**	**9**	**16**	**9**	**17**	**13**	**13**	**9**	**10**	**12**

EB=Englishman's Bay
SS=Sisters South
SD=Sisters Deep
LA=Landslide
SR=Sanger Rock
SG= St. Giles
SL=Sleeper
BB=Belmont Bay
AR=Angel Rock
CG=Coral Gardens
SC=Spiny Colony
RU=Runway
KB=King's Bay
QB=Queen's Bay

2.3.2. Gorgonian corals

Benthic cover of gorgonians was 9.7% across the NETMPA but markedly greater on Speyside (14.2%) and other Atlantic reefs (12.4%) than Caribbean reefs (5.0%; Fig. 2.3.2.1). This may be indicative of more favourable conditions in the high-energy environments of the Atlantic coast, or due to more available space in the absence of hard corals on some sites, or most likely a combination of both. High gorgonian cover on Belmont Bay and Spiny Colony is probably due to unfavourable conditions for their hard coral competitors.

Fig. 2.3.2.1. A coral researcher delicately manoeuvring a gorgonian coral

Twelve species of gorgonian coral were recorded in the NETMPA[1], although four of those species were only identifiable to genus (Table 2.3.2.1). All twelve species were found in Speyside (no. of transects n=42), nine species on the two Atlantic sites (n=12) and only seven species in the Caribbean (n=39). Four species were present on all sites (bar Runway). *Erythropodium caribaeorum* and *Pseudoplexaura* spp. were the most common species in Speyside (11.9% mean benthic cover) and Atlantic reefs (9.3%) - comprising 75.7% and 69.4% of the gorgonian community respectively. On Caribbean reefs, *Antillogorgia bipinnata* (1.6%) and *E. caribaeorum* (1.2%) were the most common species.

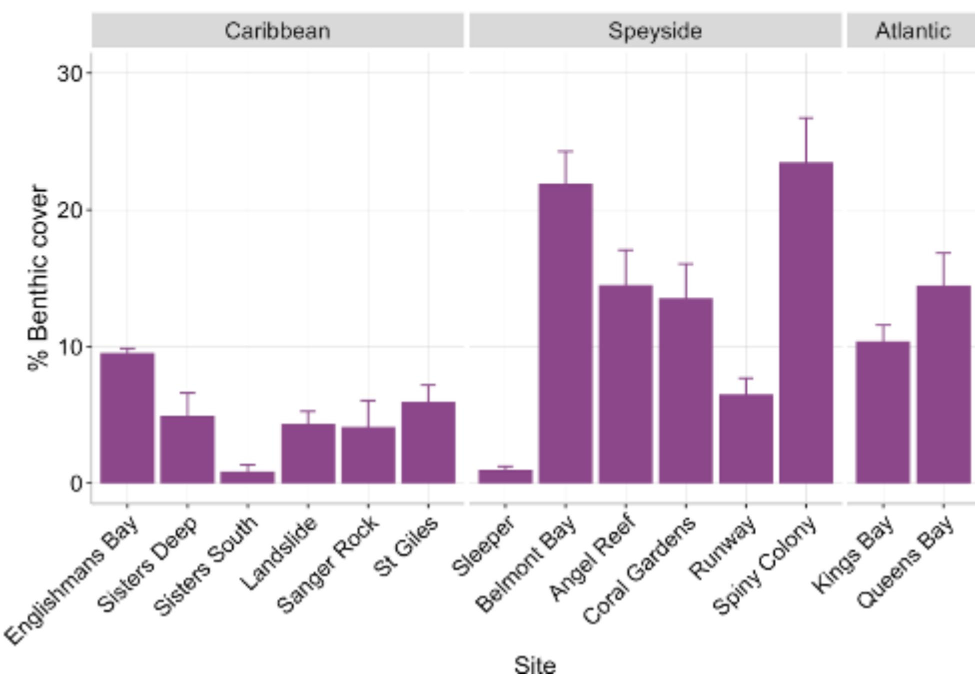

Fig. 2.3.2.1. Gorgonian cover across sites in the NETMPA

1. Gorgonians that were only identified to genus were omitted in the species richness count if other gorgonians were already identified in that genus in order to avoid duplication in the event they were the same species. Thus, species richness may be an underestimation.

Table. 2.3.2.1. Gorgonian species at sites in the NETMPA

Species	Mean benthic cover (%)	Caribbean							Speyside					Atlantic	
		EB	SS	SD	LA	SR	SG	SL	BB	AR	CG	SC	RU	KB	QB
Erythropodium caribaeorum	5.3±1.6	*	*	*	*	*	*	*	*	*	*	*		*	*
Pseudoplexaura spp.	1.6±0.4	*	*	*	*	*	*	*	*	*	*	*		*	*
Muricea laxa	1.2±0.3	*	*	*	*	*	*		*	*	*	*		*	*
Antillogorgia bipinnata	0.9±0.2	*	*	*	*	*	*		*	*	*	*	*	*	*
Muriceopsis flavida	0.3±0.07	*	*	*	*	*	*	*	*	*	*	*		*	*
Eunicea calyculata	0.3±0.07			*	*	*	*	*	*	*	*	*			*
Muricea spp.	0.2±0.07	*		*	*		*			*		*			*
Gorgonia ventalina	0.1±0.08					*		*				*		*	*
Plexaura spp.	0.1±0.09													*	*
Antillogorgia americana	0.05									*					
Gorgonian unidentified	0.04±0.02							*		*					
Eunicea succinea	0.04±0.03								*		*				
Pterogorgia spp.	0.02											*		*	
Eunicea spp.	0.01									*					
Pseudopterogorgia spp.	0.01									*					
Species richness[1]		**5**	**5**	**6**	**6**	**7**	**6**	**5**	**7**	**8**	**7**	**8**	**1**	**8**	**8**

EB=Englishman's Bay
SS=Sisters South
SD=Sisters Deep
LA=Landslide
SR=Sanger Rock
SG= St. Giles
SL=Sleeper
BB=Belmont Bay
AR=Angel Rock
CG=Coral Gardens
SC=Spiny Colony
RU=Runway
KB=King's Bay
QB=Queen's Bay

2.3.3. Macroalgae

Table. 2.3.3.1. Important species of macroalgae in the NETMPA

Species	% Benthic cover
Peyssonnelia sp.	3.05
Dictyota ciliolata	0.20
Halimeda spp.	0.13
Wrangelia sp.	0.03
Porolithon pachydermum	0.004
Amphiroa tribulus	0.003
Dictyota spp.	0.003
Amphiroa rigida	0.002
Valonia ventricosa	0.002
Caulerpa sertulariodes	0.001

Macroalgal cover averaged 4.0±2.6% across reefs in the NETMPA, ranging from 6.4% in Speyside to 5.4% in the Atlantic and just 1.2% across the Caribbean reefs. Benthic cover was consistently below the Caribbean average of 23.2% (Jackson et al., 2014), and would be classified as 'good' in the reef health index (McField and Kramer, 2007). However, only 5 sites were at or below the optimum target of 0-1% (McField and Kramer, 2007). Significant macroalgal stands were however observed in Speyside at Spiny Colony and Sleeper, and would be classified in the same index as 'poor' (i.e. within 12.1-25% cover). Nutrient pollution and depauperate herbivore communities at Spiny Colony (see also section 2.3.8) are likely favouring algal succession. However, the findings at Sleeper, which was solely attributed to the red alga *Peyssonnelia* sp., cannot be explained without further studies of the site (particularly nutrient levels). In fact, *Peyssonnelia* sp. was the most common macroalga in the NETMPA (Table 2.3.3.1), but only in Belmont Bay (7.1%), Sleeper (11.4%) and Queen's Bay (7.3%) was it a significant component of the benthic community

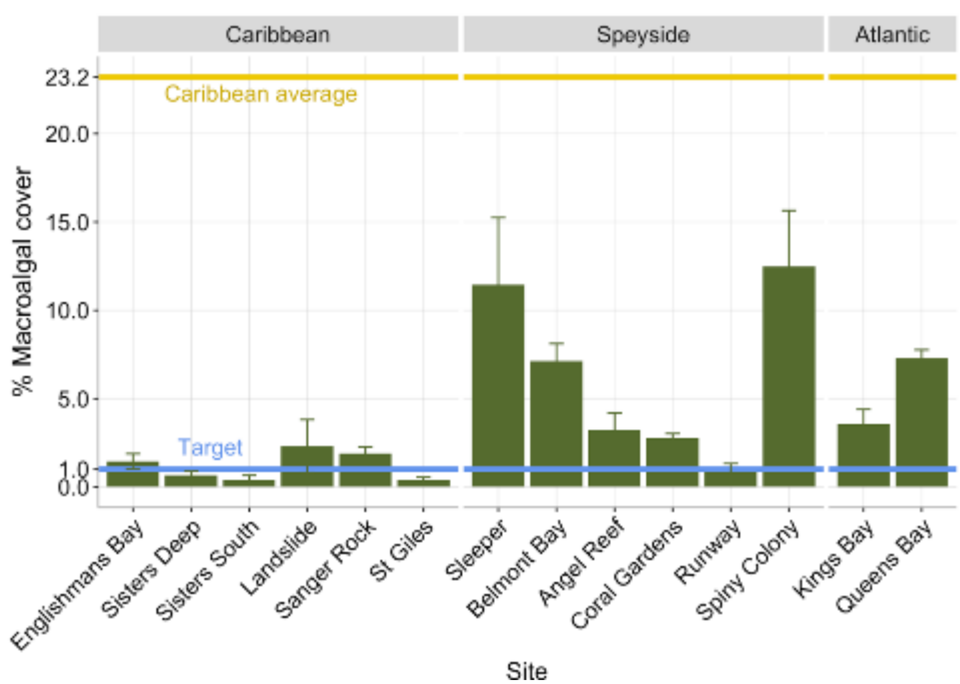

Fig. 2.3.3.1. Mean macroalgal cover (% benthic cover) across sites in the NETMPA. Horizontal lines indicate Caribbean average (Jackson et al., 2014) and a 'Very good' target (McField and Kramer, 2007).

The ratio of hard coral to algae is a very useful indicator of which one is winning the competition for space on the coral reef (Fig. 2.3.3.2). In the Mesoamerican region, McField and Kramer (2007) set a management target of no less than 2:1 coral to algae across all sites and habitats. In the NETMPA, the rate of herbivory is generally sufficient to keep algal levels in check (see section 2.3.10). However, in sites close to Speyside (i.e. Belmont Bay and Spiny Colony) macroalgae is already outcompeting coral. Of further concern is Queen's Bay with a ratio below a target of 2:1, and two other borderline sites in Speyside (Sleeper and Coral Gardens). These sites are also at risk of switching from a coral dominated state to an algal state, and the algal state can be quite stable and hard to recover from (Hughes et al., 2007).

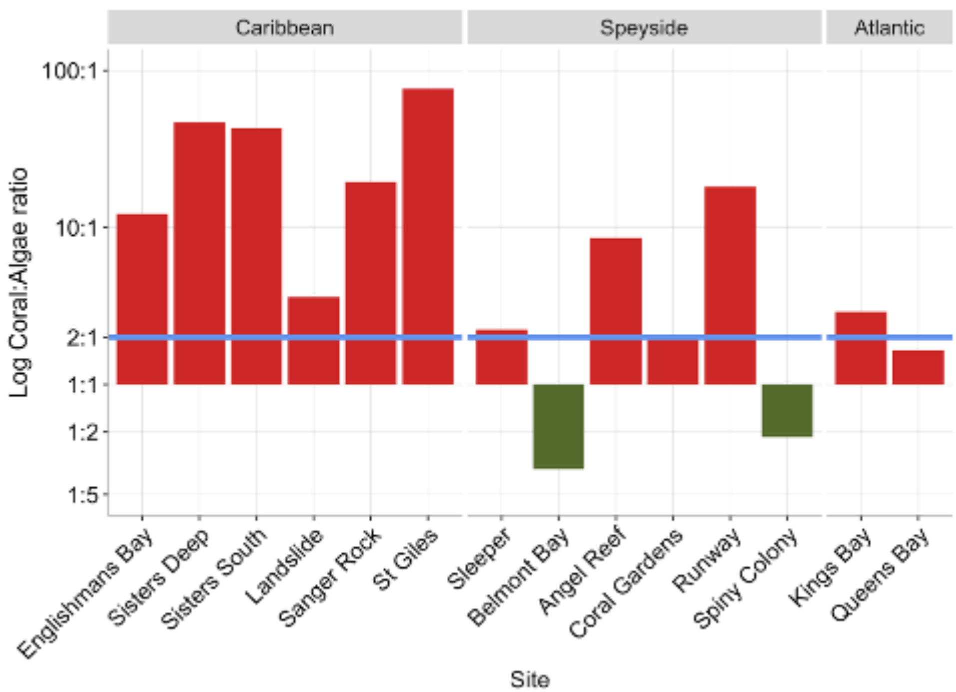

Fig. 2.3.3.2. Ratio of % hard coral cover to % macroalgal cover. Horizontal line indicates a minimum target of 2:1 hard coral to algae (McField and Kramer 2007).

2.3.4. Sponges

As filter feeders, sponges are thought to benefit from the productive waters coming from the Orinoco and Amazon rivers - which are more concentrated on the Atlantic coast of Tobago. This is consistent with our observations of Atlantic reefs supporting more abundant sponge communities than most Caribbean reefs (Fig. 2.3.4.2). Coral Gardens in particular, supports a rich sponge community *Appendix 2.7*.

Mean benthic cover for specific species across all sites is provided in *Appendix 2.7*, and transect data is provided in *supplementary material*. Harmful 'boring' species were rare in the NETMPA, with only insignificant densities of any clionid species. The giant barrel sponge, *X. muta*, was the most common member of the benthic community and averaged 3% of benthic cover across the NETMPA (Fig. 2.3.4.2).

Fig. 2.3.4.1. French angelfishes roaming under giant barrel sponges (*X. muta*). *Photo credit*

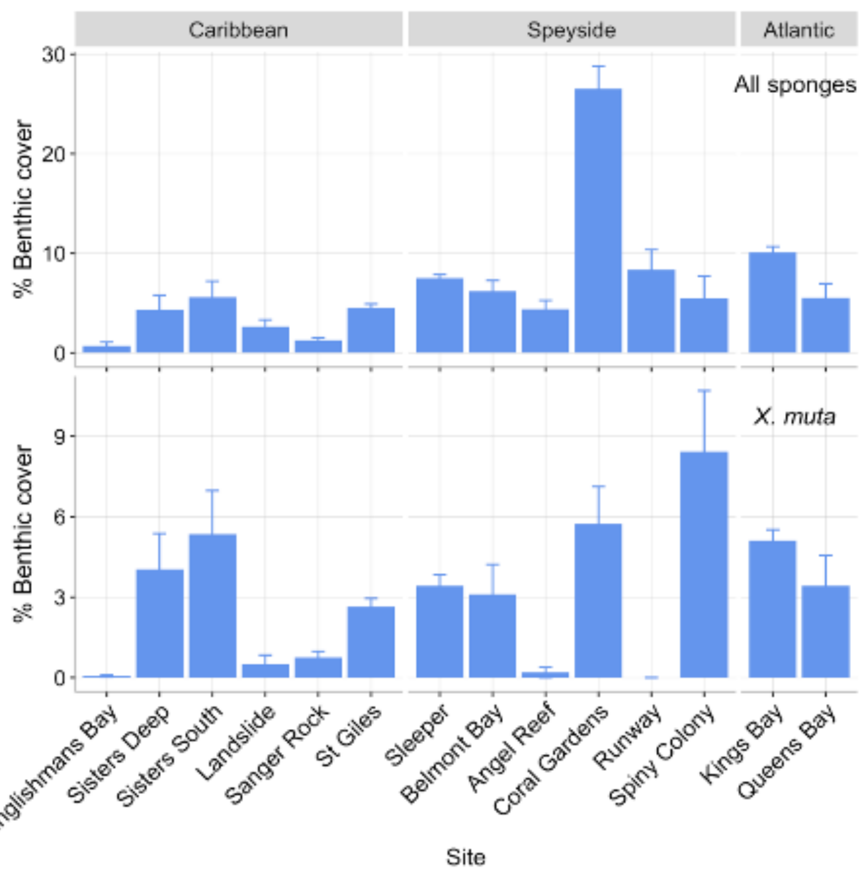

Fig. 2.3.4.2. Mean sponge cover (% benthic cover) for all species combined and for the giant barrel sponge (*X. muta*).

2.3.5. Diseases

1935 corals were assessed for disease in the NETMPA, of which 170 were visibly infected, equating to 8.8% of all corals. This is beyond a 6% ‘critical’ designation for Caribbean coral reefs and a long way from a 1% target (Mcfield and Kramer 2007). Coral species were differentially infected, both in terms of prevalence and pathogens (Table 2.3.5.1). Two of the most important reef building species on NETMPA reefs*, S. siderea* and *O. faveolata*, were also the most commonly infected. *S. siderea* suffered primarily from dark spot disease (26% of colonies infected), white plague disease (6%), and several other diseases in smaller incidences (Table 2.3.5.1).

Yellow band disease (YBD) is known to particularly affect *Orbicella* species (Gil-Agudelo et al., 2004) and was the sole affliction of *O. faveolata* (19.1%). YBD is a conspicuous and dramatic infection of *O. faveolata* in the NETMPA (Fig. 2.3.5.1), causing considerable loss of coral tissue in some of the largest colonies of reef building corals. The pathogens associated with dark spot disease (DS) and YBD have yet to be conclusively identified and are likely to be a consortium of bacteria (Gil-Agudelo et al., 2004; Closek et al., 2014). Other coral diseases in the NETMPA were white plague disease, white band disease, Caribbean white syndrome and black band disease. It should also be noted that several barrel sponges (*X. muta*) were observed outside of transects with what appeared to be a wasting disease and severe tissue disintegration. Further investigations are needed as the barrel sponges are a functionally and aesthetically fundamental component of coral reefs (de Goeij et al., 2013). The good news is that a large number of coral species showed no sign of infection in our transects.

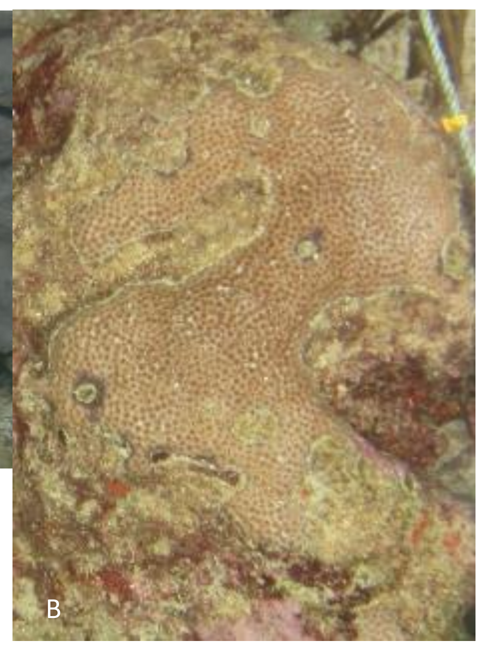

Fig. 2.3.5.1. (A). Yellow Band Disease on *O. faveolata* and (B) dark spot disease on *S. siderea*.

Disease prevalence also varied spatially across the NETMPA (Fig. 2.3.5.2). Coral diseases were more prevalent in Speyside (12.5±2.3% of corals) and Atlantic reefs (10.8±.2.1%) than in the Caribbean (6.7±1.2%), but there was considerable variation within regions. Englishman’s Bay and the Sisters, which are geographically close, exhibited contrasting disease prevalence, surprisingly, with the offshore site (Sisters) worse affected than the nearshore site (Englishman’s Bay). The reason for this is unclear. Similarly, Belmont Bay, Angel Reef and Sleeper are in close proximity in Speyside, but with considerable disparity in disease prevalence. This may be more reasonably explained by the elevated sediment load in

Belmont Bay causing stress to corals and increasing susceptibility to disease (Pollock et al., 2014). Greater abundance of *S. siderea* in Belmont Bay will also skew the prevalence. However, this does not follow for the Sisters, which have less *O. faveolata* than Englishman's Bay and only slightly more *S. siderea* (Fig. 2.3.5.3). Very high disease prevalence in The Sisters - more than 50% for *S. siderea* and 30% for *O. faveolata* - is very concerning, and could be evidence that non-land-based impacts are affecting corals in the MPA

Table. 2.3.5.1. Diseases of corals and select sponges totalled for the NETMPA. Mean disease prevalence is averaged across all transects with the target coral present. DS=Dark Spot disease; WP=White Plague; CWS=Caribbean White Syndrome; WBD=White Band Disease; BB=Black Band; YB=Yellow Band

Species	No. of corals assessed	No. of diseased corals	Mean disease prevalence (%)	Principle diseases and their prevalence
Siderastrea siderea	355	132	38.3±3.6	DS 26%; WP 6%; CWS 4%; WBD; BBD; YB
Undaria humilis	287	17	8.5±3.8	DS
Orbicella faveolata	72	12	19.1±6.3	YB
Pseudodiploria strigosa	288	3	0.8±0.5	DS 0.69%; CWS 0.35%;
Acropora palmata	2	1	50.0±50.0	WPD
Dichocoenia stokesi	8	1	8.3±8.3	DS
Diploria labyrinthiformis	15	1	10±10	DS
Madracis auretenra	9	1	25±25	YB
Montastraea cavernosa	135	1	1.2±1.2	YB
Porites astreoides	352	1	0.3±0.3	YB
Scolymia cubensis	59	0		
Colpophyllia natans	57	0		
Undaria agaricites	54	0		
Madracis decactis	51	0		
Meandrina jacksoni	40	0		
Xestospongia muta	39	0		
Meandrina meandrites	26	0		
Helioseris cucullata	14	0		
Pseudodiploria clivosa	10	0		
Isophyllia rigida	9	0		
Eusmilia fastigiata	7	0		
Porites porites	7	0		
Stephanocoenia intersepta	7	0		
Millipora alcicornis	4	0		
Orbicella annularis	4	0		
Agaricia fragilis	4	0		
Agaricia lamarcki	3	0		
Madracis senaria	3	0		
Gorgonia ventalina	2	0		
Orbicella franksi	2	0		
Siderastrea radians	2	0		
Solenastrea bournoni	2	0		
Manicina areolata	1	0		
Mussa angulosa	1	0		
Mycetophyllia lamarckiana	1	0		
Oculina diffusa	1	0		
Mycetophyllia aliciae	1	0		
Porites furcata	1	0		

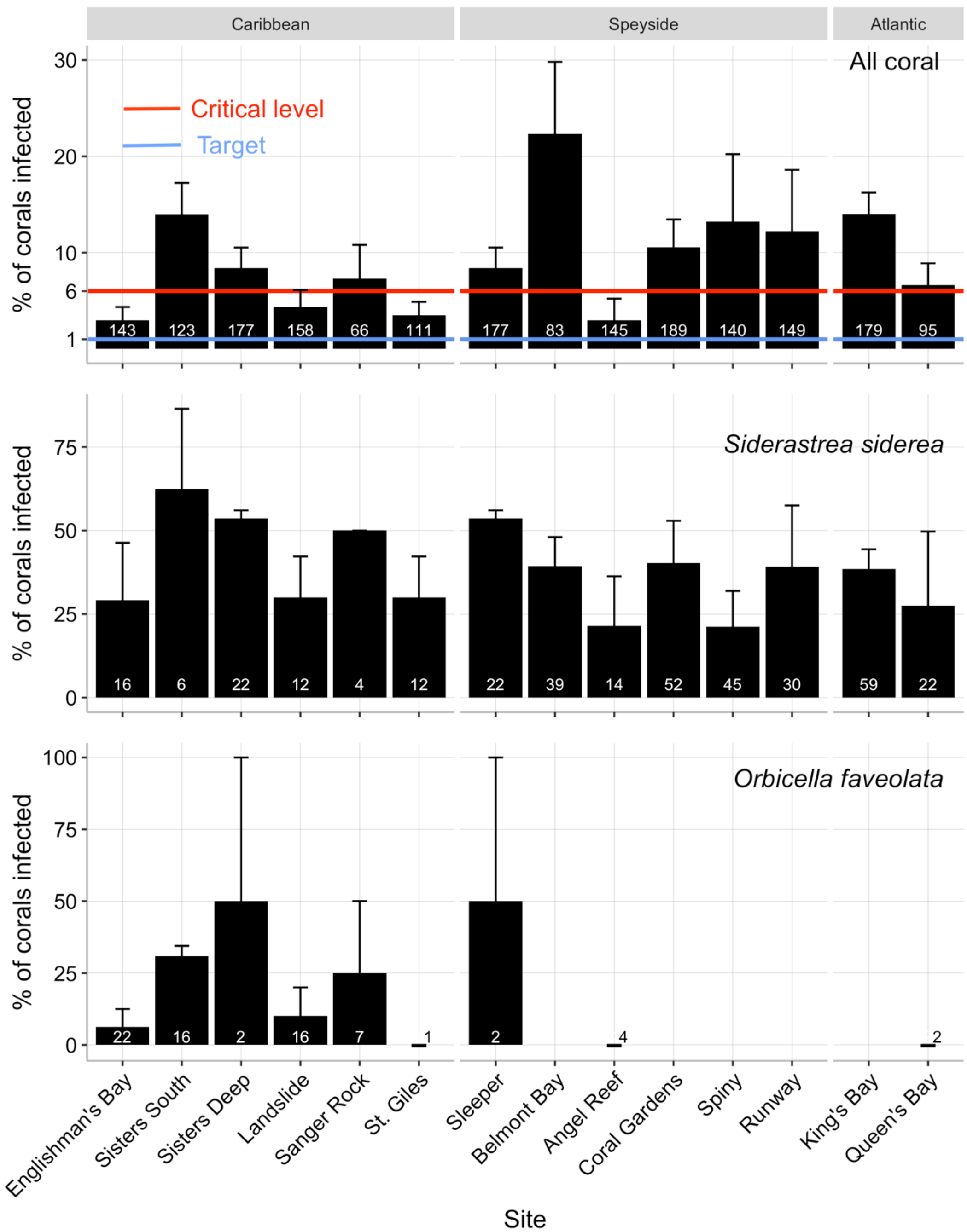

Fig. 2.3.5.2. Disease prevalence (percentage of corals infected) for all corals combined and the two principle reef building corals in the NETMPA (mean per $10m^2$ transect). Numerical labels on bars indicate total number of corals surveyed. Sites with numbers but no bars indicate corals were surveyed but with no disease. Sites with no numbers and no bars indicate no target corals were present. Blue line indicates a 1% target, and red 'critical level' line delineates the lower boundary above which coral disease is a major concern (McField and Kramer 2007).

2.3.6. Coral bleaching

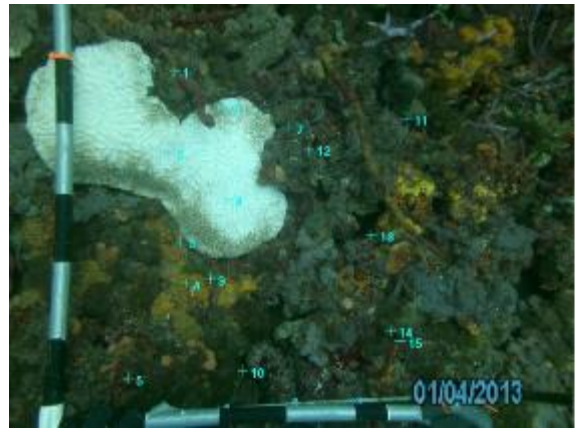

Fig. 2.3.6.1. A fully bleached (>80%) *M. meandrites* on Coral Gardens, Little Tobago.

The surveys of the NETMPA took place during September and October – the time of year when corals are most susceptible to bleaching. Bleaching events in 2005 and 2010 were both in September – October (Alemu and Clement, 2014; O'Farrell and Day, 2005). During this period, high seawater temperatures coincide with peak discharge of low salinity Orinoco River water (Alemu and Clement, 2014; Hu et al., 2004).

Corals were categorised as *Pale* or *Bleached*: where *Pale* denotes some loss of zooxanthellae pigment (e.g. pre-bleaching); and *Bleached* implies total loss of zooxanthellae and a distinctly white appearance. For the purpose of this report, we have tallied all *Pale* colonies together no matter what portion of the colony was affected, and subdivided *Bleached* colonies into 1) *Minor* bleaching = 0-30% of colony affected; 2) *Moderate* bleaching = 30-80% of colony affected; and 3) *Full* bleaching = 80-100% of colony affected (Fig. 2.3.6.1).

The prevalence of fully bleached corals was encouraging low (Fig. 2.3.6.2). Only four sites had corals with more than 80% of the colony bleached and prevalence at each of those sites was below 2%. Full bleaching was only observed on Speyside reefs and St. Giles. *Moderate* and *Minor* bleaching of colonies was also

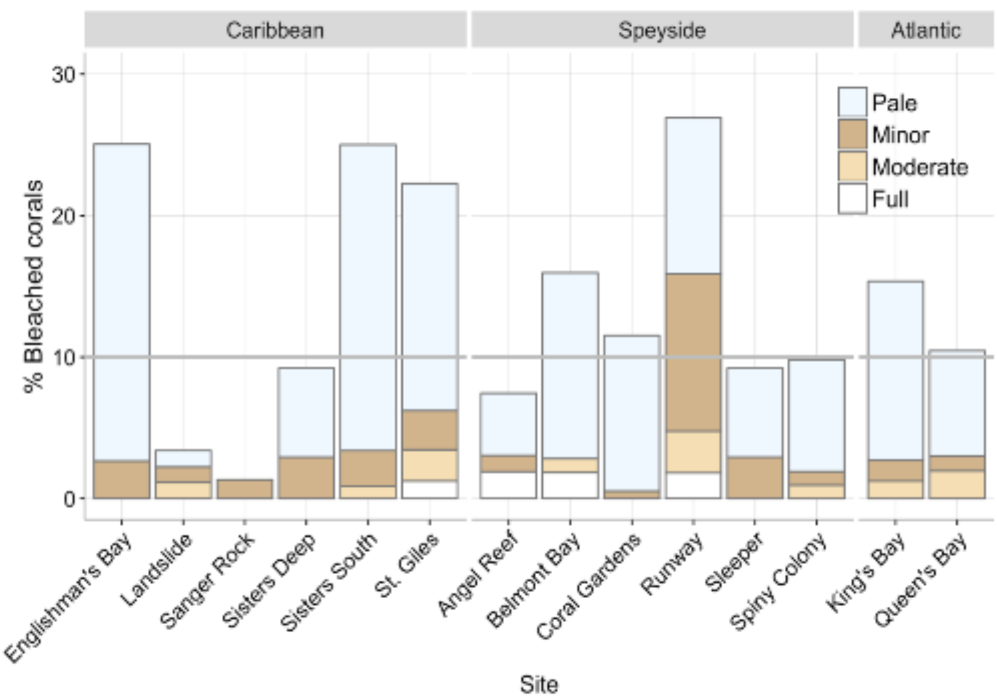

Fig. 2.3.6.2. Mean bleaching prevalence of all species combined (across $10m^2$ transects for each site). Pale = partial loss of zooxanthellae; Minor = 0-30% of colony bleached; Moderate=30-80% of colony bleached; Full=80-100% of colony bleached. Horizontal line indicates a 'red flag' or major cause for concern if fully bleached corals exceed 10% (McField and Kramer, 2007)

minimal, with only Runway having a substantial number of partially bleached corals. The number of pale colonies however was high at a number of sites, particularly in the Caribbean - indicating the beginning of a bleaching event or the recovery from bleaching.

The susceptibility of coral species varied substantially, with the most abundant corals being the most frequently observed pale or with some level of bleaching, but not necessarily with the highest percentage of coral colonies affected (Table 2.3.6.1). Overall, there were no specific coral species with major bleaching concern during our surveys.

Table. 2.3.6.1. Pale and bleached coral species and the percentage of colony affected

Species	n	No. of affected colonies	Total % affected	Bleaching prevalence (% of corals)			
				Pale	Minor (0-30%)	Moderate (30-80%	Full (80-100%)
Siderastrea radians	2	1	50.0	0.0	0.0	50.0	0.0
Meandrina jacksoni	40	11	27.5	12.5	5.0	7.5	2.5
Orbicella annularis	4	1	25.0	25.0	0.0	0.0	0.0
Siderastrea siderea	355	86	24.2	16.1	5.1	1.7	1.4
Montastraea cavernosa	135	32	23.7	20.7	3.0	0.0	0.0
Orbicella faveolata	72	16	22.2	18.1	4.2	0.0	0.0
Pseudodiploria clivosa	10	2	20.0	20.0	0.0	0.0	0.0
Porites astreoides	352	65	18.5	14.2	3.7	0.6	0.0
Meandrina meandrites	26	4	15.4	3.8	3.8	3.8	3.8
Helioseris cucullata	14	2	14.3	0.0	14.3	0.0	0.0
Porites porites	7	1	14.3	0.0	14.3	0.0	0.0
Dichocoenia stokesi	8	1	12.5	12.5	0.0	0.0	0.0
Pseudodiploria strigosa	288	24	8.3	7.6	0.3	0.3	0.0
Diploria labyrinthiformis	15	1	6.7	6.7	0.0	0.0	0.0
Undaria agaricites	54	2	3.7	3.7	0.0	0.0	0.0
Colpophyllia natans	57	2	3.5	1.8	1.8	0.0	0.0
Scolymia cubensis	59	1	1.7	1.7	0.0	0.0	0.0
Undaria humilis	287	3	1.0	0.3	0.3	0.3	0.0
Madracis decactis	50	0	0.0	0.0	0.0	0.0	0.0
Xestospongia muta	39	0	0.0	0.0	0.0	0.0	0.0
Isophyllia rigida	9	0	0.0	0.0	0.0	0.0	0.0
Madracis auretenra	9	0	0.0	0.0	0.0	0.0	0.0
Eusmilia fastigiata	7	0	0.0	0.0	0.0	0.0	0.0
Stephanocoenia intersepta	7	0	0.0	0.0	0.0	0.0	0.0
Agaricia fragilis	4	0	0.0	0.0	0.0	0.0	0.0
Agaricia lamarcki	4	0	0.0	0.0	0.0	0.0	0.0
Mycetophyllia aliciae	4	0	0.0	0.0	0.0	0.0	0.0
Madracis senaria	3	0	0.0	0.0	0.0	0.0	0.0

Species	n	No. of affected colonies	Total % affected	Bleaching prevalence (% of corals)			
				Pale	Minor (0-30%)	Moderate (30-80%	Full (80-100%)
Acropora palmata	2	0	0.0	0.0	0.0	0.0	0.0
Gorgonia ventalina	2	0	0.0	0.0	0.0	0.0	0.0
Orbicella franksi	2	0	0.0	0.0	0.0	0.0	0.0
Solenastrea bournoni	2	0	0.0	0.0	0.0	0.0	0.0
Agaricia tenuifolia	1	0	0.0	0.0	0.0	0.0	0.0
Manicina areolata	1	0	0.0	0.0	0.0	0.0	0.0
Mycetophyllia lamarckiana	1	0	0.0	0.0	0.0	0.0	0.0
Oculina diffusa	1	0	0.0	0.0	0.0	0.0	0.0
Porites furcata	1	0	0.0	0.0	0.0	0.0	0.0

2.3.7. Coral mortality

New coral mortality (Fig. 2.3.7.1) and transitional mortality (recent mortality with a layer of sediment or algae) were low for all sites when all coral species are combined (Table 2.3.7.1). However, the percentage of colonies with mortality was considerably higher when assessments focused on just the most important reef building species (Fig. 2.3.7.2). Only eleven coral species exhibited recent mortality, and of those, only *S. siderea*, *P. asteoides* and *O. faveolata* had a notable number of colonies with recent mortality. Old mortality (Fig. 2.3.7.1) was common for the large reef building species that are often long-lived and have survived multiple sub-lethal disturbances (Table. 2.3.7.2).

Fig. 2.3.7.1. New and old mortality on *S. siderea* at Angel Reef, Speyside

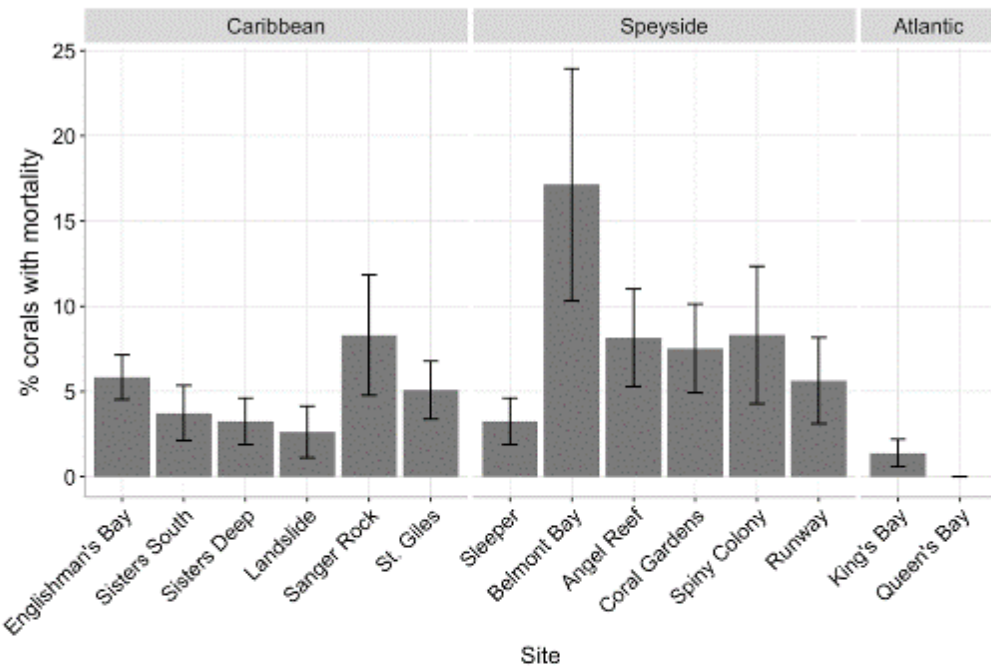

Fig. 2.3.7.2. Percentage of all colonies with new or transitional mortality in a 7-species subset of important reef-building corals: *C. natans, M. cavernosa, O. faveolata, P. astreoides, P. strigosa, S. siderea and U. humilis.*

Table 2.3.7.1. Mean percentage (±SE) of corals with new, transitional and old colony mortality

Site	n	Mortality Type (%)		
		New	Trans	Old
Angel Reef	145	3.9±2.1	2.8±0.4	15.7±1.4
Belmont Bay	83	0.8±0.8	8.7±3.5	33.8±7.3
Coral Gardens	189	0.6±0.6	4.7±1.3	35.7±4.4
Englishman's Bay	143	1.3±0.7	2.8±1.1	17.3±2.6
King's Bay	179	0±0	1.7±1	31.9±4.8
Landslide	158	1.7±1.1	0.5±0.5	10.6±4.8
Queen's Bay	95	0±0	0±0	23.5±5.2
Runway	149	2±1.2	2.7±0.9	31.9±3.7
Sanger Rock	66	0±0	8.5±3	17.2±5.6
Sisters Deep	177	1.3±0.7	1.3±0.8	27.8±7
Sisters South	123	3.2±1.4	0.9±0.9	20.6±1.5
Sleeper	177	1.3±0.7	1.3±0.8	27.8±7
Spiny Colony	140	3.5±2.9	3.6±0.9	13.8±3.6
St. Giles	111	0.7±0.7	3.3±1.2	30.7±5.2

Table. 2.3.7.2. Colonies showing new, transitional and old mortality by coral species across all sites

Species	n	Mortality (No. of colonies affected)			% Colonies affected (exc. old)
		New	Transitional	Old	
Agaricia lamarcki	4	1		1	25.0
Orbicella annularis	4		1		25.0
Siderastrea siderea	355	12	27	182	11.0
Orbicella faveolata	72	4	2	36	8.3
Porites astreoides	352	7	14	49	6.0
Meandrina meandrites	26		1	4	3.8
Madracis decactis	50		1	17	2.0
Colpophyllia natans	57		1	23	1.8
Undaria humilis	287	4	1	19	1.7
Montastraea cavernosa	135		2	40	1.5
Pseudodiploria strigosa	288	1		58	0.3
Acropora palmata	2			1	0.0
Agaricia fragilis	4				0.0
Agaricia tenuifolia	1			1	0.0
Dichocoenia stokesi	8				0.0
Diploria labyrinthiformis	15				0.0
Eusmilia fastigiata	7			4	0.0
Gorgonia ventalina	2			2	0.0
Helioseris cucullata	14			2	0.0
Isophyllia rigida	9			1	0.0
Madracis auretenra	9				0.0
Madracis senaria	3			4	0.0
Manicina areolata	1				0.0
Meandrina jacksoni	40				0.0
Mycetophyllia aliciae	4			12	0.0
Mycetophyllia lamarckiana	1			2	0.0
Oculina diffusa	1				0.0
Orbicella franksi	2				0.0
Porites furcata	1				0.0
Porites porites	7			1	0.0
Pseudodiploria clivosa	10			5	0.0
Scolymia cubensis	59			1	0.0
Siderastrea radians	2				0.0
Solenastrea bournoni	2				0.0
Stephanocoenia intersepta	7				0.0
Undaria agaricites	54			2	0.0
Xestospongia muta	39				0.0

2.3.8. Coral Recruitment

Coral recruitment (e.g. Fig 2.3.8.1) in the NETMPA was generally good, with levels above the Caribbean average for all sites except Sisters South and St. Giles. Nine sites were above or near a target of more than 10 small (<2cm) recruits per m^2 (Fig. 2.3.8.2). Better recruit density at the deeper Sisters site 'Sisters Deep' implies recruitment in The Sisters may not be a major concern. Long-term monitoring is needed to investigate this further. Angel Reef demonstrated unusually high recruitment thanks to the two *Undaria* species (*U. agaricites* and *U. humilis*) (Table 2.3.8.1). However, the high recruitment rates mask concerns for the major reef building corals, *Obicella* spp., and the brain coral *C. natans,* of which no recruits were observed throughout the study. Furthermore, 33 adult coral species were observed in transects in this study (section 2.3.1), yet we found juveniles of just 14 species (Table 2.3.8.1 and Appendices 2.10.4-5). A major concern throughout the Caribbean is that even where overall recruitment is good, this recruitment is dominated by small-bodied species such as *P. astreoides* and *Undaria* spp. (Green et al., 2008). These species have a much smaller functional role than the massive corals in creating reef structure. This is consistent with our observations in the NETMPA, however recruitment of *S. siderea* is still encouraging.

Fig. 2.3.8.1. Coral recruits (juveniles) smaller than 4cm on Angel Reef, Speyside.

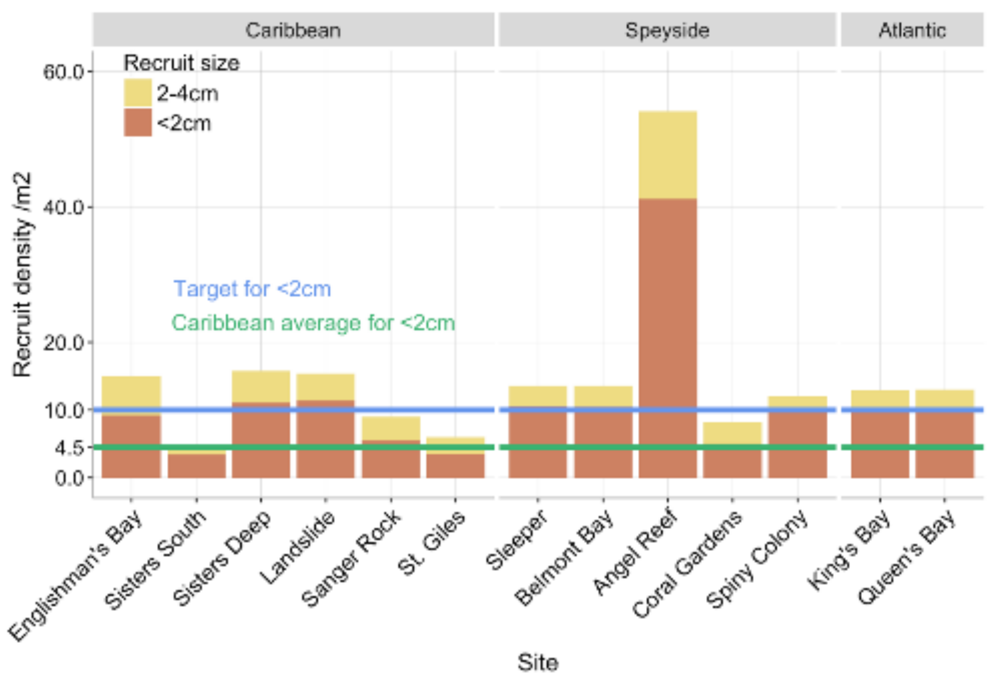

Figure. 2.3.8.2. Coral recruit density (individuals/m^2) for two size classes across sites in the NETMPA (data is provided in *Appendix 2.5*). Horizontal green line indicates AGRRA Caribbean average for <2cm recruits and blue line indicates a target of >10 small recruits per m^2 proposed by McField and Kramer (2007).

Table. 2.3.8.1. Mean coral recruit density (ind./m^2) by species - combined for all sites in the MPA and split into two juvenile size classes

Species	Density (Ind./m^2)	
	Small <2cm	Large 2-4cm
Undaria humilis	34.54±20.2	8.78±5.14
Pseudodiploria strigosa	19.48±5.57	6.15±1.61
Undaria agaricites	14.14±10.43	6.71±4.42
Siderastrea siderea	8.85±2.24	4.07±1.28
Porites astreoides	8.03±2.07	3.83±1.32
Scolymia cubensis	4.42±1.27	0.2±0.2
Millipora alcicornis	1.51±1.1	0.2±0.2
Montastraea cavernosa	1.23±0.88	2.89±0.77
Madracis decactis	1.17±1.02	0.41±0.41
Madracis auretenra	0.82±0.82	0
Isophyllia rigida	0.45±0.3	0.73±0.53
Meandrina meandrites	0.2±0.2	0.6±0.32
Helioseris cucullata	0	0.2±0.2
Meandrina jacksoni	0	0.2±0.2
Unidentified	0.41±0.27	0

2.3.9. Fishes

2.3.9.1. The fish community above a seascape of giant barrel sponges on Goat Island, Speyside. Photo credit Susanne Hirschmann.

5481 fishes were identified in the NETMPA with a total biomass of almost 1.4 tonnes. A subset of the entire fish community (83 species; *Appendix 2.3*) was targeted in surveys to reduce observer load and improve accurate documentation for the target species. Of this subset, 67 species from 20 families were recorded in 196 transects. The Haemulidae and Scaridae were the dominant families by density and biomass across the NETMPA (Table 2.3.9.1). However, only one pomacentrid species is included the 83-species subset, and if the whole family were added they would dominate fish density and biomass. This family is omitted because they have less functional impact on reef processes (Green and Bellwood, 2009) and are so numerous that their inclusion can overwhelm the observer.

There were no clear differences in total fish biomass between regions of the MPA, nor between nearshore and offshore reefs (Fig. 2.3.9.2). The unusually high biomass at Belmont Bay reflects a passing school of Bermuda chub *(Kyphosus sectatrix)* that conveys a substantial, if somewhat misleading, biomass. If that species is removed, the mean biomass of Belmont Bay is 1.03 kg/100m^2 – in line with nearby sites such as Spiny Colony and Coral Gardens.

Functionally important predators and commercially important families such as the Serranidae (groupers) and Lutjanidae (snappers) were poorly represented throughout the NETMPA (Table 2.3.9.1). *Lutjanus apodos* was the most common snapper (Table 2.3.9.2), but this was largely due to an unusually large population at Queen's Bay (Fig. 2.3.9.2). *Cephalopholis cruentata* was the most common grouper, but is a small species with little commercial value. Commercially important groupers were notably absent. Three black groupers (*Mycteroperca bonaci*) were recorded, but the nassau grouper (*Epinephelus striatus*), yellowmouth grouper (*Mycteroperca interstitialis*), tiger grouper (*Mycteroperca tigris)* and yellowfin grouper (*Mycteroperca venenosa*) were not observed. Several of these species were however recorded in the fisheries landing survey which would contribute to their absence on the reefs (see section 2.3.15). These large predators have a pivotal role in structuring the fish community by predating on sick and weak fishes -improving the overall strength of the reproductive community. They are also the only known predators of lionfish in the Caribbean (Maljković et al., 2008).

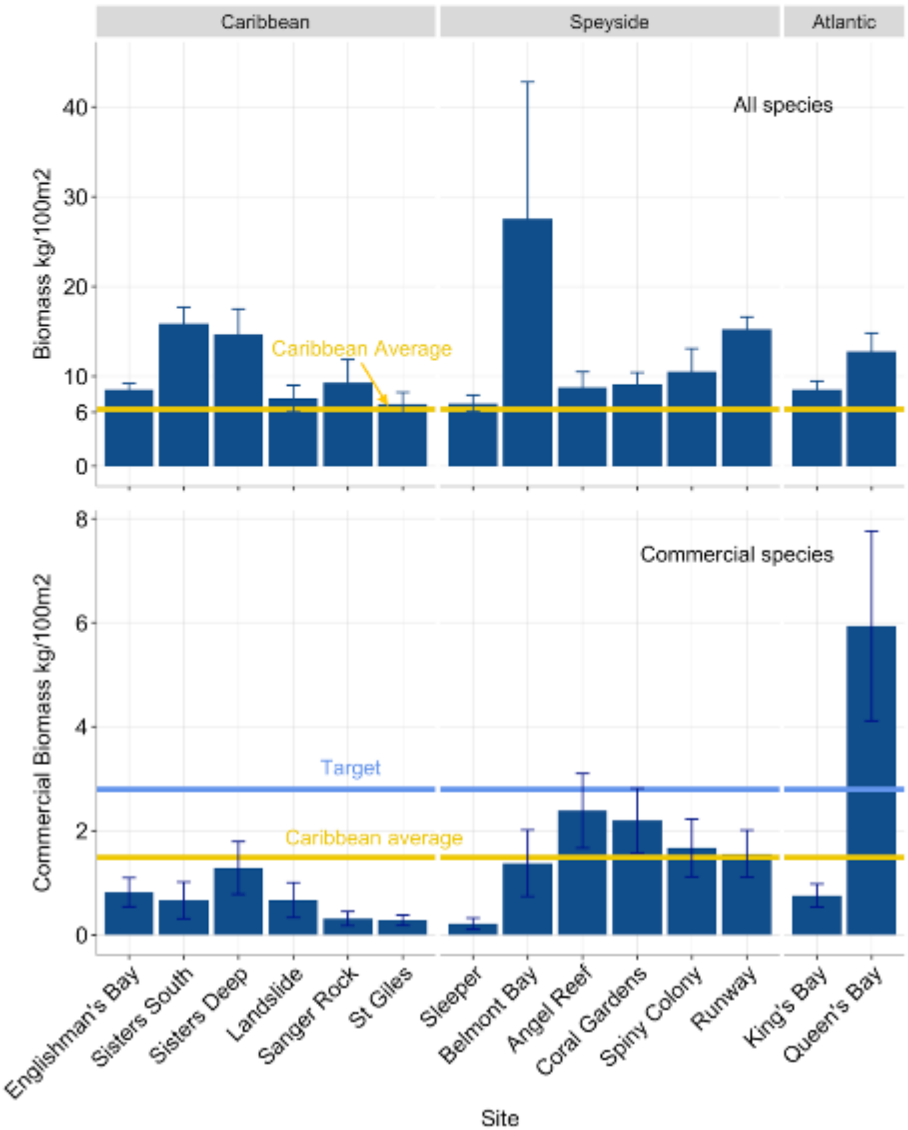

Figure. 2.3.9.2. Fish biomass (+SE) and commercial fish (snapper and grouper) biomass (±SE) across sites in the NETMPA. Yellow line indicates Caribbean average for the AGRRA 83-species subset and a target of 2.8kg/100m^2 (McField and Kramer 2007).

Table. 2.3.9.1. Density and biomass (±SE) of fish families (from a subset of 83 species) averaged across the 13 sites in the NETMPA.

Family	Biomass (g/100m^2)	Density (ind./100m^2)
Haemulidae	2674±330	11.4±2.8
Scaridae	1694±254	9.7±1.3
Balistidae	1504±600	4.7±1.4
Kyphosidae	1236±879	1.2±0.8
Acanthuridae	973±94	8.7±1
Lutjanidae	890±294	1.8±0.6
Pomacanthidae	537±72	0.68±0.08
Muraenidae	356±107	0.14±0.05
Serranidae	277±42	1.7±0.2
Sphyraenidae	240±85	0.1±0.03
Chaetodontidae	209±42	1.6±0.1
Pomacentridae	200±77	1.9±0.5
Labridae	179±27	2±0.3
Ginglymostomatidae	165±148	0.007±0.007
Monacanthidae	134±30	0.4±0.1
Carangidae	117±50	0.4±0.1
Scorpaenidae	110±39	0.37±0.09
Diodontidae	46±31	0.02±0.01
Sparidae	12±10	0.05±0.05
Ostraciidae	0.7±0.4	0.05±0.02

Table. 2.3.9.2. Mean density and biomass of target fish species (an 83-species subset of the whole community) across 13 sites in the NETMPA.

Species	Density (/100m^2)	Biomass (g/100m^2)
Acanthurus chirurgus	4.67	480.3
Melichthys niger	4.46	1395.5
Sparisoma aurofrenatum	3.81	353.7
Haemulon flavolineatum	3.25	263.8
Haemulon chrysargyreum	2.79	255.3
Acanthurus coeruleus	2.65	383.7
Sparisoma viride	2.50	1043.9
Scarus taeniopterus	2.27	271.3
Haemulon sp.	2.14	160.5
Microspathodon chrysurus	1.77	217.7
Cephalopholis cruentata	1.55	301.0
Halichoeres garnoti	1.46	56.6
Lutjanus apodus	1.38	841.9
Kyphosus sectatrix	1.34	1793.1
Acanthurus bahianus	1.17	127.7
Haemulon melanurum	0.80	140.3
Scarus iseri	0.75	54.7
Chaetodon striatus	0.59	65.8
Chaetodon capistratus	0.56	94.3
Bodianus rufus	0.44	100.2
Caranx ruber	0.40	128.4
Pomacanthus paru	0.39	504.8
Haemulon carbonarium	0.38	52.4
Cantherhines macrocerus	0.37	127.4
Haemulon macrostomum	0.35	213.4
Pterois spp.	0.34	116.1
Lutjanus jocu	0.31	243.7
Chaetodon sedentarius	0.26	29.6
Sparisoma rubripinne	0.22	87.2
Anisotremus virginicus	0.22	61.6
Chaetodon ocellatus	0.21	33.2
Haemulon plumierii	0.20	45.2
Halichoeres radiatus	0.17	42.3
Sparisoma chrysopterum	0.15	52.0
Scarus vetula	0.14	47.1
Lutjanus mahogoni	0.14	20.3
Sphyraena barracuda	0.13	289.4
Holacanthus ciliaris	0.13	110.1
Haemulon sciurus	0.13	24.0
Anisotremus surinamensis	0.11	40.9
Lutjanus griseus	0.09	24.4
Holacanthus tricolor	0.09	21.0
Gymnothorax moringa	0.08	6.2
Prognathodes aculeatus	0.08	4.1
Scarus guacamaia	0.06	143.0
Ocyurus chrysurus	0.06	26.1
Cephalopholis fulva	0.06	18.8
Cantherhines pullus	0.06	8.0
Lactophrys bicaudalis	0.05	6.5
Gymnothorax funebris	0.04	270.3
Canthidermis sufflamen	0.04	41.0
Balistes vetula	0.04	37.4
Haemulon album	0.04	18.0
Haemulon aurolineatum	0.04	5.2
Diodon hystrix	0.03	35.8
Pomacanthus arcuatus	0.03	35.2
Mycteroperca bonaci	0.03	14.1
Sparisoma atomarium	0.03	14.0
Lachnolaimus maximus	0.03	11.2
Calamus sp.	0.03	8.4
Calamus pennatula	0.03	5.8
Lutjanus cyanopterus	0.02	18.9
Lutjanus analis	0.02	12.4
Scarus sp.	0.02	5.3
Halichoeres bivittatus	0.02	1.9
Gymnothorax miliaris	0.01	67.6
Sphoeroides spengleri	0.01	0.7
Lutjanus synagris	0.01	0.6

Table. 2.3.9.3. Fish species list for sites in the NETMPA. EB=Englishman's Bay; SR=Sanger Rock; AR=Angel Rock; SS=Sisters South; SG= St. Giles; CG=Coral Gardens; QB=Queen's Bay; KB=King's Bay; RU=Runway SD=Sisters Deep; SL=Sleeper; SC=Spiny Colony; LA=Landslide; BB=Belmont Bay

Species	Caribbean							Speyside					Atlantic	
	EB	SS	SD	LA	SR	SG	SL	BB	AR	CG	RU	SC	KB	QB
Acanthurus chirurgus	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Acanthurus coeruleus	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Cephalopholis cruentata	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Chaetodon striatus	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Halichoeres garnoti	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Microspathodon chrysurus	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Scarus taeniopterus	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Sparisoma aurofrenatum	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Sparisoma viride	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Acanthurus bahianus	*	*	*	*	*	*	*	*	*	*	*		*	*
Bodianus rufus	*	*	*	*	*	*	*	*	*	*	*	*		*
Haemulon carbonarium	*	*	*		*	*	*	*	*	*	*	*	*	*
Haemulon flavolineatum	*	*		*	*	*	*	*	*	*	*	*	*	*
Scarus iseri	*	*		*	*	*	*	*	*	*	*	*	*	*
Cantherhines macrocerus	*	*	*	*	*	*	*	*	*	*	*			*
Haemulon chrysargyreum	*	*	*	*	*	*		*	*	*	*	*		*
Lutjanus apodus	*		*	*	*	*		*	*	*	*	*	*	*
Melichthys niger	*	*	*		*	*	*	*	*	*	*		*	*
Pomacanthus paru	*	*	*	*	*	*	*	*	*	*	*			*
Chaetodon capistratus	*			*	*	*		*	*	*	*	*	*	*
Haemulon melanurum	*	*	*		*	*	*			*	*		*	*
Pterois spp.	*	*	*	*	*	*	*					*	*	*
Chaetodon sedentarius	*		*	*	*	*	*		*	*			*	
Haemulon macrostomum	*			*	*	*		*	*			*	*	*
Holacanthus ciliaris		*			*	*		*	*		*	*	*	*
Sparisoma rubripinne		*	*				*	*		*	*	*	*	*
Sphyraena barracuda	*					*	*	*	*	*	*	*	*	
Caranx ruber	*			*		*			*	*	*	*		*
Chaetodon ocellatus				*	*	*		*	*	*		*		*
Haemulon plumierii					*	*	*		*	*	*		*	*
Kyphosus sectatrix		*	*				*	*	*		*	*	*	
Anisotremus surinamensis	*						*		*	*	*		*	*
Anisotremus virginicus	*					*		*	*			*	*	*
Haemulon sciurus	*			*	*	*			*	*				*
Holacanthus tricolor		*	*	*		*	*					*		*
Prognathodes aculeatus	*		*			*			*	*	*	*		
Cantherhines pullus	*	*	*		*	*	*							

Species	Caribbean							Speyside				Atlantic		
	EB	SS	SD	LA	SR	SG	SL	BB	AR	CG	RU	SC	KB	QB
Gymnothorax moringa		*	*			*				*		*		*
Panulirus guttatus	*							*		*		*	*	*
Balistes vetula					*		*	*		*	*			
Gymnothorax funebris					*					*		*	*	*
Halichoeres radiatus	*	*	*			*	*							
Lutjanus mahogoni	*							*		*		*		*
Scarus vetula		*			*			*					*	*
Stegastes planifrons	*		*				*		*			*		
Lactophrys bicaudalis	*	*								*				*
Sparisoma chrysopterum						*		*				*	*	
Cephalopholis fulva	*									*	*			
Haemulon album	*						*				*			
Lachnolaimus maximus	*				*									*
Lutjanus griseus								*				*		*
Lutjanus jocu								*					*	*
Scarus guacamaia								*	*					*
Canthidermis sufflamen			*							*				
Diodon hystrix								*						*
Haemulon aurolineatum					*					*				
Haemulon sp.		*	*											
Halichoeres bivittatus	*			*										
Lutjanus analis				*										*
Mycteroperca bonaci								*				*		
Ocyurus chrysurus	*								*					
Panulirus argus							*						*	
Calamus pennatula	*													
Calamus sp.	*													
Ginglymostoma cirratum								*						
Gymnothorax miliaris											*			
Lutjanus cyanopterus														*
Lutjanus synagris	*													
Pomacanthus arcuatus						*								
Scarus sp.					*									
Seacucumber							*							
Sparisoma atomarium			*											
Sphoeroides spengleri	*													
Species Richness[1]	**44**	**29**	**30**	**27**	**34**	**38**	**33**	**38**	**35**	**39**	**33**	**35**	**33**	**45**

1. Not including individuals only identified to genus where other individuals of the same genus are identified to species

2.3.10. Herbivore biomass

Herbivorous fishes in the NETMPA were composed of the surgeonfishes (Acanthuridae; Fig. 2.3.10.1.) and parrotfishes (Scaridae), as well as the triggerfish *Melichthys niger*. Herbivore biomass averaged 3.6±0.6kg/100m^2 across sites in the NETMPA. While this far exceeded the Caribbean average of 2.07kg/100m^2, it is still below the optimum target of 4.8kg/100m^2 for healthy coral reefs (McField and Kramer 2007). Biomass was not substantially different at shallow (3.4±0.4kg/100m^2) and deep (3.5±0.3kg/100m^2) parts of the reef when examined for the NETMPA as whole. However, depth differences were observed within sites but trends were not consistent, with some sites having more herbivores in the shallows and others more in the deep (*Appendix 2.9*). Biomass was highly variable across the NETMPA (Fig. 2.3.10.2) but eight sites supported herbivore biomass above the Caribbean average and the other 6 sites were close to the average.

Fig. 2.3.10.1. A feeding frenzy of herbivorous surgeonfish (Acanthuridae). Photo credit Susanne Hirschmann.

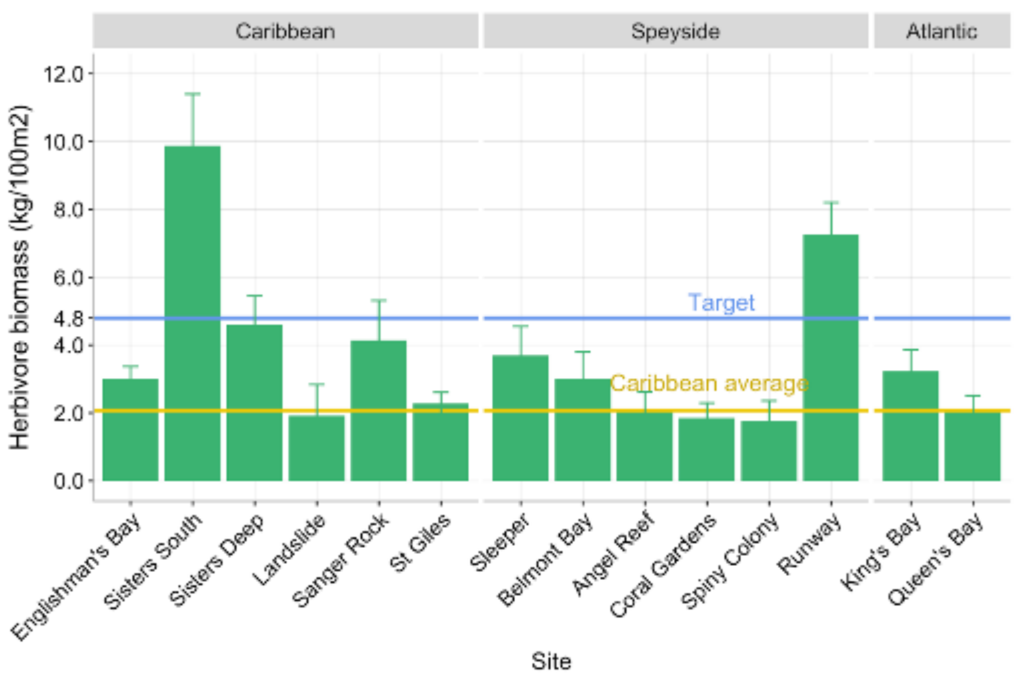

Fig. 2.3.10.2. Mean biomass (+SE) of herbivorous fishes combined for shallow and deep transects. Yellow line indicates the AGGRA Caribbean average and blue line a 'Very Good' target (McField and Kramer 2007)

2.3.11. Spiny lobsters (Palinuridae)

Twenty-nine spiny lobsters were recorded in the NETMPA, 20 of which were the spotted spiny lobster, *P. gutattus,* and just nine Caribbean spiny lobster, *P. argus* (Fig. 2.3.11.2). Two approaches were used to assess the lobster community (data in *Appendix 2.10*) and the merits of both approaches are discussed in *section 2.4.2*. Lobster abundance was greater in Speyside and other Atlantic sites than in the Caribbean. In fact, lobsters were not observed at all in 4 of the 6 Caribbean sites (although Sisters Deep and Landslide were not surveyed with the 10m^2 and 60m^2 approaches respectively).

Fig. 2.3.11.1. *Panulirus argus* in the NETMPA

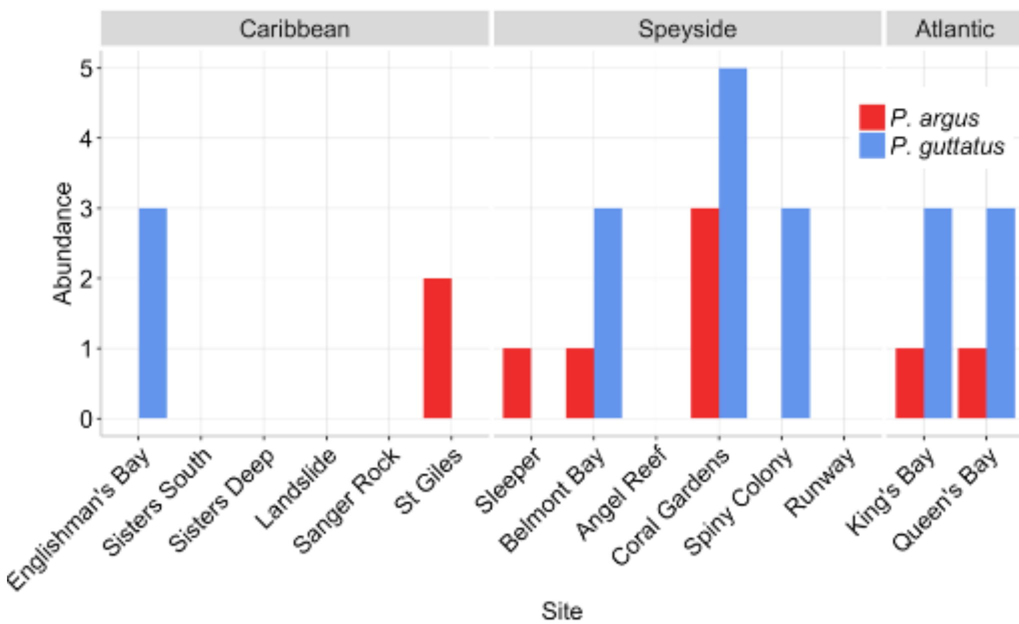

Fig. 2.3.11.2. Total abundance of *P. guttatus* and *P. argus* in the NETMPA combined together for the two survey approaches.

2.3.12. Spiny sea urchin (*Diadema antillarum*)

Only 8 *D. antillarum* (Fig. 2.3.12.1) were observed in the NETMPA, and at only 4 of the 13 sites - despite surveys of 77 transects covering 770m^2 of coral reefs (Fig. 2.3.12.2). The greatest abundance was observed in Spiny Colony but still with just 4 individuals. It should be noted that one patch of high density *D. antillarum* was observed on a section of reef with substantial algal turf in Man-of-War Bay near Landslide. It is hoped that isolated, high-density pockets such as this could be the source for repopulating reefs in the NETMPA.

Fig. 2.3.12.1. The long-spined sea urchin, *D. antillarum*

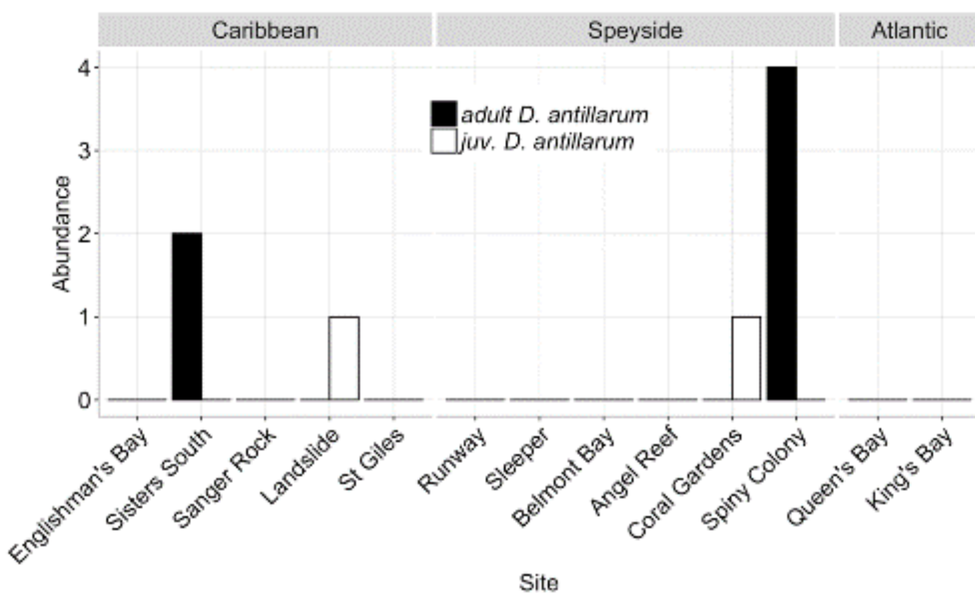

Fig. 2.3.12.2. Total abundance of juvenile and adult *D. antillarum* in the NETMPA. All sites had six 10m^2 transects with the exception of St. Giles (4), Angel Reef (7) and Sleeper (7).

2.3.13. Lionfish (*Pterios spp.*)

Fig. 2.3.13.1. The invasive lionfish, *P. volitans,* displaying its fins used to confuse and corner potential prey

Forty lionfish were observed in surveys of the NETMPA with a mean biomass of 13.2kg/ha and mean density of 38 ind./ha (Table 2.3.13.1). Lionfish distribution highlights certain hotspots on rocky offshore islands and in King's Bay on the Atlantic coast (Fig. 2.3.13.2). Alemu (2016) conducted a targeted survey of lionfish that sampled more than 1000 individuals. He observed densities of 215 ind./ha in the central Caribbean compared to 66 ind./ha in this study; 360 ind./ha in the north-eastern Caribbean compared to 44 ind./ha in this study; and 18 ind./ha in Speyside compared to 28 ind./ha in this study. We suspect these differences are an artefact of the sites chosen and methodologies rather than a decrease in lionfish populations which continue to rise across the Caribbean (Côté et al., 2013).

Table. 2.3.13.1. Mean lionfish density and biomass (± SE) at sites in the NETMPA

Site	n	Biomass ± SE (kg/ha)	Density ± SE (ind./ha)
Angel Reef	14	0±0	0±0
Belmont Bay	16	0±0	0±0
Coral Gardens	15	0±0	0±0
Englishman's Bay	16	1.1±1.1	20.8±20.8
King's Bay	14	33.7±22.9	47.6±32.3
Landslide	8	2.2±2.2	41.6±41.6
Queen's Bay	16	2.4±2.4	9.8±9.8
Runway	16	0±0	0±0
Sanger Rock	14	6.7±4.5	35.7±25.7
Sisters Deep	9	35.6±16.6	74±29.2
Sisters South	8	45.4±22.1	104.1±62.4
Sleeper	16	29.1±8.7	104.1±25.7
Spiny Colony	14	12.1±8.6	35.7±18.9
St Giles	18	16.5±9.2	55.5±23.3

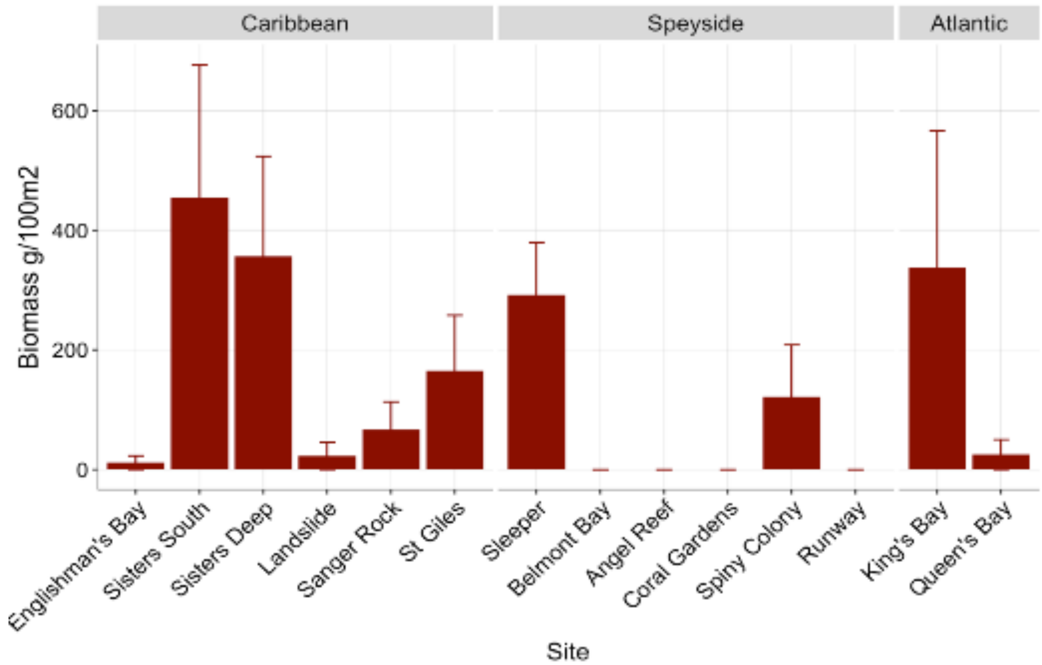

Fig. 2.3.13.2. Mean lionfish (*Pterois* spp.) biomass (+SE) at sites in the NETMPA

2.3.14. Fisheries

Fig. 2.3.14.1. Fish preparation in Parlatuvier fish market

The study captured a total of 2144 fishes that were landed during the 19-day survey period, corresponding to total landings of 5240kg. All of the landings were identified and weighed without omission, however only one market could be monitored on any one day so these figures do not represent total landings in the NETMPA for the period of study.

The total number of fishing vessels active over the survey period was similar in Charlotteville and Parlatuvier, but the number active on any one day was notably higher in Charlotteville (Table 2.3.14.1). Only five fishing boats were active during the surveys of Castara, and only three of those were fishing on a daily basis. A large number of fishing boats were anchored in the bay and pushed-up on the beach. A combination of seasonality and decline in catches have led traditional fisherfolk to seek alternative employment (see fishermen questionnaires section 2.3.16). The Atlantic coast was inundated by sediment-laden water from the Orinoco River during the survey period and sea conditions were particularly bad. Only two fishing boats were active in Roxborough during our surveys as other fishermen chose not to fish due to the prospect of poor catches and the high cost of fuel. The landings per boat were very low, with two boats only landing a single fish on one day.

The total landings per day at a landing site largely reflected the number of fishing vessels active each day, and thus were highest in Charlotteville, followed by Parlatuvier, Castara and lowest in Roxborough (Table 2.3.14.1). However, catch per fishing boat per day (hereon termed catch per unit effort – CPUE) was similar for Parlatuvier and Castara, slightly lower in Charlotteville, and heavily impacted by bad weather in Roxborough (Table 2.3.14.1). As Caribbean sites are relatively close to each other, fishermen all had access to the same fishing grounds. The choice of target species and fishing gear, particularly the use of fish aggregating devices (FADs) and GPS, are therefore likely to contribute to the observed differences in CPUE. Access to the best fishing grounds however, was more important for fishermen in Roxborough, who would navigate to the Caribbean side of the island to avoid the turbid water.

Table 2.3.14.1. Fish landings and fishing effort in four landings sites in the NETMPA. Catch per unit effot (CPUE) based on mean landings per boat per day

Site	No. of active fishing boats*	Average boats fishing per day	CPUE (kg)	Average landings per day (kg)
Castara	5	2.7	46.6	124.3
Charlotteville	26	14.3	35.1	500.7
Parlatuvier	23	8.2	50.5	412.5
Roxborough	2	1	5.3	5.3

*Active fishing boats observed during the surveys. More vessels may fish seasonally, on occasion, or were being repaired

2.3.15. Target species

Forty-five species from fifteen different families were identified in the fishery landings survey. Table 2.3.15.1 shows the combined species landings across all four sites.

Table 2.3.15.1. Species specific fishery landings in the North-East Tobago Marine Protected Area

Species	Common/Local Name	Family	Total landings (kg)	No. of individuals	Proportion of catch by weight
Thunnus albacares	Yellowfin tuna	Scombridae	1668.4	145	31.8%
Coryphaena hippurus	Dolphinfish	Coryphaenidae	1466.6	605	28.0%
Thunnus alalunga	Albacore tuna	Scombridae	295.8	81	5.6%
Acanthocybium solandri	Wahoo	Scombridae	255.6	41	4.9%
Elagatis bipinnulata	Rainbow salmon	Carangidae	198.9	105	3.8%
Seriola dumerili	Amberjack	Carangidae	180.1	101	3.4%
Caranx bartholomaei	Greenback cavali	Carangidae	175.2	237	3.3%
Euthynnus alletteratus	Bonito	Scombridae	173.4	50	3.3%
Rhomboplites aurorubens	Plumhead snapper	Lutjanidae	150.8	297	2.9%
Katsuwonus pelamis	Skipjack tuna	Scombridae	140.6	36	2.7%
Scomberomus cavalla	Blackeye kingfish	Scombridae	116.9	38	2.2%
Ocyurus chrysurus	Yellowtail snapper	Lutjanidae	96.4	78	1.8%
Lutjanus vivanus	Red snapper	Lutjanidae	64.4	77	1.2%
Hyporthodus nigritus	Warsaw grouper	Serranidae	49.4	3	0.9%
H. flavolimbatus	Yellowedge grouper	Serranidae	50.6	9	0.9%
Rhizoprionodon sp.	Sharpnose shark	Charcharhinidae	31.1	11	0.6%
Caranx latus	Horse-eye cavali	Carangidae	30.5	10	0.6%
Haemulon carbonarium	Caesar grunt	Haemulidae	29.0	134	0.6%
Lobotes surinamensis	Tripletail	Lobotidae	16.1	13	0.3%
Mustelus canis	Dusky smooth-hound shark	Triakidae	15.7	6	0.3%
Lutjanus spp.	Snapper	Lutjanidae	5.0	1	0.1%
Lutjanus sp.	Virgin snapper	Lutjanidae	5.0	1	0.1%
Mycteroperca interstitialis or *M. phenax*	Yellowmouth or Scamp grouper	Serranidae	4.5	1	0.1%
Cephalopholis cruentata	Graysby	Serranidae	4.1	10	0.1%
Etelis oculatus	Queen plumhead	Lutjanidae	3.2	7	0.1%
Calamus bajonado	Jolthead Porgy	Sparidae	2.7	4	0.1%

Species	Common/Local Name	Family	Total landings (kg)	No. of individuals	Proportion of catch by weight
Paranthias furcifer	Creole fish	Serranidae	2.7	1	0.1%
Parablax dewegeri	Vieja rock bass	Serranidae	2.6	6	0.0%
Lutjanus campechanus	Red snapper	Lutjanidae	2.0	3	0.0%
Caranx lugubris	Black jack	Carangidae	1.8	3	0.0%
Scarus vetula	Queen parrotfish	Scaridae	1.4	4	0.0%
Balistes vetula	Queen triggerfish	Balistidae	1.1	1	0.0%
Unidentified	Unidentified	Unidentified	0.9	2	0.0%
Panulirus guttatus	Spotted spiny lobster	Palinuridae	0.9	3	0.0%
Caulolatilus cyanops	Tilefish	Malacanthidae	0.9	2	0.0%
Lutjanus analis	Mutton snapper	Lutjanidae	0.9	1	0.0%
Seriola sp.	Amberjack	Carangidae	0.9	1	0.0%
Anisotremus surinamensis	Black margate	Haemulidae	0.7	3	0.0%
Epinephelus niveatus	Snowy Grouper	Serranidae	0.5	1	0.0%
Sparisoma viride	Stoplight parrotfish	Scaridae	0.5	9	0.0%
Mulloidichthys martinicus	Goatfish	Mullidae	0.5	1	0.0%
Anisotremus virginicus	Porkfish	Haemulidae	0.5	1	0.0%
Haemulon sciurus	Bluestriped grunt	Haemulidae	0.5	1	0.0%
Lutjanus synagris	Lane snapper	Lutjanidae	0.4	1	0.0%
Lobatus gigas	Queen conch	Strombidae	N/A	N/A	N/A
Epinephelus itajara	Goliath grouper	Serranidae	N/A	N/A	N/A
Scarus guacamaia	Rainbow parrotfish	Scaridae	N/A	N/A	N/A
Panulirus argus	Caribbean spiny lobster	Palinuridae	N/A	N/A	N/A
Melichthys niger	Black durgon	Balistidae	N/A	N/A	N/A
		Total	**5239.6**	**2144.0**	

Yellowfin tuna (*Thunnus albacares*)

T. albacares constituted the greatest landings by weight with specimens ranging from 1-35kg, with an average of 11.6kg. Two thirds of yellowfin tuna were landed during 3 days in Charlotteville, the other third in Parlatuvier, and no yellowfin tuna were landed in Castara or Roxborough during the survey. Yellowfin tuna landings in Parlatuvier and Castara may have been higher if they were surveyed on the same days as Charlotteville (fishermen pers. comm.). The yellowfin tuna fishery is periodic and dependent on short-term migratory behaviour - potentially influenced by water conditions (Orinoco River influences) or lunar cycles (fishermen pers. comm.).

Fig. 2.3.15.2. Yellowfin tuna (*T. albacares*) landed in Charlotteville fish market

Dolphinfish (*Coryphaena hippurus*)

C. hippurus was the most frequently caught species with more than twice the number of landings than any other species, and 4 times more than yellowfin tuna (Table 2.3.15.1). However, specimens were smaller than the tuna, ranging from 0.5-23kg, with an average size of 2.6kg. 80% of landings were in Parlatuvier, 17% in Castara and only 2% in Charlotteville. Fishermen in Parlatuvier and Castara are using FADs to target dolphinfish, whereby car tyres are filled with concrete and dropped to the seabed up to 50 miles offshore. Ropes secured to the concrete blocks are tied off to palm branches at the surface and marked with GPS. These FADs attract small fish and subsequently higher trophic predators such as dolphinfish. Fishermen use "a-la-vive" or "live-bait" to target the congregating dolphinfish. Fishermen in Charlotteville place less emphasis on the dolphinfish fishery with few people using GPS.

Mackerals (Scombridae)

Kingfish (*Scomberomus cavalla)* and wahoo *(Acanthocybium solandri)* have the highest market demand in Tobago but fishermen are adamant stocks are declining (see section 2.3.16). Landings were low compared to dolphinfish and yellowfin tuna (Table 2.3.15.1). Interestingly, fishermen in Trinidad have reported stable catches of *S. cavalla* on the north-coast (pers. comm.). If this were corroborated by landings data or more thorough oral surveys it could reflect a change in distribution of *S. cavalla*.

Groupers (Serranidae)

Groupers were one of the focal families in this study and were caught in small numbers during the surveys (Table 2.3.15.1). Of the larger-bodied groupers, 20 individuals from four species were caught during the 19-day survey period, amounting to roughly one per day per landing site.

The yellowedge grouper (*Hyporthodus flavolimbatus*) was the most frequently caught species (9 individuals landed), though landings by weight of the warsaw grouper (*Hyporthodus nigritus*) was slightly higher. A single snowy grouper (*H. niveatus)* was landed in Charlotteville*.* These three species are deep-water fish targeted by hook and lines (banking) set below 50m, and adults are rarely seen on coral reefs.

A single goliath grouper *(Epinephelus itajara)* was landed in Charlotteville by spearfishermen. *E. itajara* and *H. nigritis* are critically endangered species, while *H. flavolimbatus and H. niveatus* are listed as vulnerable, with evidence of declines throughout their range, but with little other information available (www.iucnredlist.org).

Fig. 2.3.15.3. Four targeted species of grouper (Serranidae): (Topleft) goliath grouper, *E. itajara*; (Topright) Warsaw grouper*, H. nigritus*; (bottomleft) yellowedge grouper, *H. flavolimbatus*; (bottom right) viejo rock bass, *P. dewegeri.*

Sharks (Selachii)

Two species of shark were landed during the surveys: the sharpnose shark (*Rhizoprionodon* spp.*)* and the dusky smooth-hound shark (*Mustelus canis*) (Fig. 2.3.15.4). The genus *Rhizoprionodon* has three species in Tobago: *R. lalandii, R. porosus,* and *R. terraenovae* which are difficult to distinguish in rapid fish landing assessments. These are the most targeted species of shark in the NETMPA - caught with hand lines at depths exceeding 50m. They are small sharks with landed specimens ranging from 2.5-3.6kg for *Rhizoprionodon* spp. and 1.6-3.6kg for *M. canis*. Sexual maturity for *Rhizoprionodon* species develops at around 1kg or 65cm total length (Motta et al., 2005; Mattos et al., 2001) inferring that all landed individuals would have been sexually

Fig. 2.3.15.4. Sharks being prepared in Parlatuvier fish market

mature. Sexual maturity in *M. canis* however, occurs around 2.5kg (Hoffmayer et al., 2014), so some of the landed specimens were probably juveniles.

Three species of shark present in Trinidad and Tobago are of global importance due to their conservation status and were identified as being of particular interest to this project: the daggernose shark (*Isogomphodon oxyrhynchus),* scalloped hammerhead (*Sphyrna lewini)* and great hammerhead shark *(S. mokarran).* These species were not landed during the surveys but discussions with fishermen revealed the two hammerhead species are landed on rare occasions. There was no information on *I. oxyrhynchus*.

Parrotfishes (Scaridae)

Parrotfishes are generally only targeted by spearfishermen, although occasional catches may occur with baited fish traps. Spearfishermen landed one catch during the surveys in Charlotteville (Fig. 2.3.15.5) but we were only able to make counts and identifications and not take weights. The stoplight parrotfish (*Sparisoma viride*) was the most commonly landed species. Larger species such as the rainbow parrotfish (*Scarus guacamaia*), locally termed "washaroo", were also landed. Two groups of spearfishermen were interviewed about the fishery and the results are presented in section 2.3.16.

Fig. 2.3.15.5. Parrotfishes caught by spearfishing in Charlotteville

The removal of parrotfishes from NETMPA reefs is potentially a serious threat to the health of the ecosystem. However, the impact of the fishery is still unclear. The spearfishermen interviewed fish every 2-3 days and vary their location in the NETMPA between Charlotteville, Castara and Speyside. Assessing the total landings of spearfishermen requires their permission to coordinate measurements upon landing. Interviews revealed that up to 12 different groups of spearfishmen may be involved in the fishery. A thorough assessment should be undertaken, particularly mapping their extraction sites and volume of extracted fish to compare with underwater survey data. The group that we interviewed said they would be willing to stop fishing but needed an alternative income source.

Spiny lobster (Palinuridae)

Two species of lobsters are targeted in the NETMPA: *Panulirus argus* is the best marketed species and the smaller *Panulirus guttatus* was also landed. These species are typically landed by spearfishermen but can also be caught in fish traps. Very few landings were observed during the surveys but a greater focus on the spearfishing industry is needed to establish a more accurate representation of the fishery.

Queen conch (Lobatus gigas; formerly Strombotus gigas)

Only a single *L. gigas* (landed in Charlotteville) was recorded during the surveys (Fig. 2.3.15.6). Discussions with spearfishermen identified a habitat for *L. gigas* in Speyside, but no conch were landed in Speyside during the fishery surveys or the subsequent coral reef surveys which were often based in Speyside. The queen conch fishery appears underdeveloped in the NETMPA but further assessments of the spearfishing fishery should be undertaken.

Fig. 2.3.15.6. Only a single *L. gigas* was landed in Charlotteville during the fishery surveys

2.3.16. Fishery interviews

Twenty-five questionnaires were administered among three of the four fish markets: 13 in Charlotteville (50% of active fishermen), 8 in Parlatuvier (35%) and 4 in Castara (80%). Though only two fishing boats were active in Roxborough, they returned too late at night to conduct interviews. A summary of the questions and responses are given in Table 2.3.16.1, and the full questionnaire is in the *supplementary material*. Trawling, banking and live bait were the most frequently employed fishing gears and are often rotated during a fishing trip based on success that day. This makes it difficult to assess fishing effort for a specific gear or target species. Trawling targets pelagic species such as tuna, kingfish and dolphinfish, while banking targets demersal species such as grouper and snapper.

There was little consensus on the best fishing months for any species and few people could identify peak seasons or breeding seasons for any species. Identifying fishing grounds and the time spent in those areas may have been more accurately assessed by providing fishermen with GPS units. Alternatively, an observer could utilise vantage points in Charlotteville and Parlatuvier to document fishing boats leaving the ports and their destinations. We believe this would be more robust than the vague answers given in the questionnaire, and using maps did not prove effective. However, there was still a consistent trend of fishermen utilising offshore islands (i.e. The Sisters, St. Giles and Little Tobago) and FADs set far offshore (potentially the edge of the continental shelf).

70% of fishermen thought that fish stocks had declined, 20% thought they had increased, and 8% thought they had not changed. Declines are particularly perceived in kingfish, dolphinfish, grouper, snapper and cavali, while tuna landings are perceived to have increased. Declines were largely attributed to oil and gas exploration, especially for kingfish which has the highest market value. Fishermen feel they have not been adequately compensated for the impacts to their fishery and that dialogue between themselves, the government and the energy sector has been poor.

Management of the NETMPA fishery is going to be challenging without functioning fishing associations. Currently, Castara, Bloody Bay and Roxborough have functioning associations, although landings in Bloody Bay are minimal, and few fishermen were operating in Castara and Roxborough. The two most important landings sites, Parlatuvier and Charlotteville, do not have functioning associations. However, they did previously, and several fishermen indicated they should be reinstated. Conversely, several other fishermen questioned the value and feasibility of an association. The reinstating of associations in these landing sites needs to be carefully managed with clear incentives for the fishermen in order to garner support. This may be better facilitated by a NGO as there is widespread disapproval of the Fisheries Division.

Table 2.3.16.1. Summary of fishery questionnaires

Category	Responses and response frequency (No. of people surveyed (n) =25 unless otherwise stated)
Full time/Part time	16 Full time and 9 Part time
Age range and average	26-59, average 46 years
Boat and engine type	All pirogues, all outboards
Boat length	22-28ft, average 23ft, mode[1]=22ft
Horsepower	40hp-13, 50hp-1, 55hp-2, 60hp-3, 75hp-1, 78hp-1, 150hp-1
No. of engines	All single except one twin
No. of boats employing fishing gear:	
Trolling and no. of simultaneous lines	20: 5 lines-11, 4 lines-1, 3 lines-3
Banking (hand lines) and no. of hooks	18: 5-22 hooks, mode = 12
a-la vive (live bait)	15
Fish pots	1: 5 pots
Seining	1
Spearfishing	2: 2 guns
Palangue	3
Gill netting	1
No. of days a week fishing	7 days-7; 6 days-9; 5-1; 4-1; 3-2, 2-1, 1-1 (n=23)
No. of months a year fishing	12 months-22, 5 months-1 (n=23)
Best fishing months	Dec-Mar-15; April-Sept-10
No. of hours at sea per day	Range from 5.5-11.5 hours, mode = 8-9 hours
No. of crew inc. captain	1 person-18; 2 persons -4
No. of boats targeting:	Tuna-16; Kingfish-16; Mahi mahi-13; Wahoo-11; Cavalli-11; Snapper-9; Grouper-8; Parrotfish-2; Amberjack-1; Barracouda-1
How much fish do you land on a normal day?	Range=25-400lbs; average=158lbs; mode=100lbs
Fish landed on a bad day?	Range=30-150lbs; average=90lbs; mode=100lbs
Fish landed on a good day?	Range=100-1500lbs; average=488lbs; mode=200lbs
How many groupers do you land per week?	>2=6; 2=3; 1-2=7; <1=5; never=4
How many snapper per week?	Never=4; Rarely=1; 1-10=11; >10=8
Shark landings per week (pw) or per month (pm)?	Never =3; Rarely=9; Occasionally=6; 1pm=3; 1pw = 3; >1pw=2
Parrotfish landings?	Never=23, >27lbs per dive=1, 2-8 ind. per dive
Are you aware of breeding seasons?	Mahi year round-1; Mahi in Sept.-1; Kingfish on shelf off Castara-1; Tuna 16 miles offshore-1; Grouper on rocky reef 10miles offshore-1; No-19
Where do you fish?	St. Giles-20; The Sisters-18; Speyside-14; Offshore-11; Castara-7; Plymouth-5; nearby coastline-7
Are there restrictions on where you can fish?	No-22; Buccoo-1; Near drill-ships-1
Do you discard any fish?	No-19; Small salmon-1; small mahi-2; small cavali-1
What price/lb do you get for your fish wholesale?	Range TT$9-17, mean =$15.25, mode=$15
What price/lb do you get for your fish retail?	Range TT$15-20, mean=$19, mode=$20
Have catches changed over time?	Declined=16; unchanged=2; Increased=5; mixed=1
How have catches of these species changed:	

[1] mode=most frequent answer

Category	Responses and response frequency (No. of people surveyed (n) =25 unless otherwise stated)
Tuna	Improved-9, Declined-5, Unchanged-1
Kingfish	Improved-2, Declined-12, Unchanged-1
Mahi	Improved-2, Declined-6, Unchanged-3
Grouper	Declined-9, Unchanged-1
Snapper	Declined-8, Unchanged-1
Amber	Declined-5
Cavali	Declined-6
Parrotfishes	Improved-1, Declined-4
Cavali (Bait)	Improved-9, Declined-5, Unchanged-1
What are the causes of the declines? (n=20)	Oil drilling-16, seismic surveys-9, pollution-3, natural change-4, FADs-2, migration change-1, climate change-1, sargassum negative change-1, sargassum positive-2, overfishing-2, lionfish-1
What should be done about it?	Compensation-13, study oil impacts-1, better management-1, not sure-2,, better dialogue-1, artificial wrecks for spearfishing-1, spearfishing season-1
Are there any restrictions on catch from the THA	No-23, Buccoo-1
Should there be restrictions on catch?	No-19, Size limts-5, Yes-1
Should certain areas be protected?	No-18, yes-1, need further studies-2, no spearfishing on reefs-4
Do other fishermen affect your catch	No-17, yes-5, probably-1
Do foreign fishing vessels affect your catch?	No-18, yes-5, don't know-1
Does land development affect your catch?	No-19; Yes-4; chemical pollution-2; maybe-1
Are there other ways to improve your catch?	No-6; Change fishing techniques (i.e. more GPS, fish finders, depth finders)-2; artificial reefs for hunting-1; Better planning and adaptation-1
How important is conservation of the sea to you?	Very-9, important-7, not important-1
Do you have a functional fishing association	Charlotteville-No, Parlatuvier-No, Castara-Yes
Do you have another Job?	No-8, agriculture-1, government laborour-5, Steel bender-2; Tourism-1; Unknown-2
What job would you prefer?	Fisherman-16; keep both jobs-4; other job-2
What can the THA do better to help fishermen?	Better marketing of product-10; Liaise with oil companies/compensation-6; Finish or improve facilities-4; support fishermen-3; Invest in fishing fleet-3; Manage seismic surveys-1; Improve communication-1; Employ processing workers-1; manage plastic waste-1

2.4. Proposed monitoring program

We have established permanent transect markers for a long-term monitoring program at ten sites in the NETMPA. Permanent markers allow monitoring of benthic indicators in precisely the same location - reducing variation caused by surveying slightly different areas - and maximising the potential to detect changes in the reef community. Ten sites are sufficient for the expanse of coral reefs in the NETMPA and should be within the resources of any implementing agency. The indicators and focal species targeted in this study (hereon collectively termed 'indicators') form the basis of this future monitoring program. These indicators, as well as some additional ones, are listed in Table 2.4. Many of the indicators have been well described in the previous sections so only the new indicators are described in more detail (section 2.4.1.). Collectively, these indicators allow managers to describe the state of the ecosystem, and in particular, its resilience to climate change. This is not an exhaustive list of potential indicators that could be included in a coral reef monitoring program, but is certainly an essential minimum. For further information and other possible indicators please see McField and Kramer (2007).

Coral reef monitoring in the NETMPA should be repeated annually, as well as rapid response assessments in the event of severe disturbance from bleaching, storms or other impacts. The resolution of the method must be sufficient to detect changes at the species level, and thus should follow an approach such as AGRRA (www.agrra.com) or the adapted AGRRA approach we have used in this study incorporating photo quadrats (the pros and cons of those two approaches are discussed in section 2.4.2). Reef Check methods are excellent for involving community members, but are not suitable for the annual monitoring program as they do not assess communities at the species level. Community members have already been trained in these higher resolution methods but we strongly recommend training of all surveyors in an official AGRRA training program administered by AGRAA certified trainers. Coral, fish and disease identifications can be challenging in the field, and size estimations of fish can easily be misinterpreted. These can lead to the collection of erroneous data which undermines the usefulness of the monitoring program.

Table 2.4. Proposed indicators for a future monitoring program. Shaded indicators are new indicators.

Indicator/Species	Method
% Hard coral cover	Photo quadrats or AGRRA point intercept
Coral diversity (Shannon Weiner or Simpson Index)	Photo quadrats or AGRRA point intercept
Disease and bleaching prevalence	AGRRA coral health belt transects
Coral recruitment	See section 2.4.3.
% cover of sponges and gorgonians	Photo quadrats or AGRRA point intercept
Fish density and biomass	30x2m roving surveys
Fish diversity (Shannon Weiner or Simpson Index)	30x2m roving surveys
Herbivore biomass	AGRRA 30x2m roving surveys and landing surveys
% Macroalgal cover (or Macroalgae fleshy index)	Photo quadrats or AGGRA point intercept
Coral:algae ratio	Photo quadrats or AGGRA point intercept
Focal coral species:	
Orbicella spp.	Photo quadrats or AGRRA point intercept
S. siderea	Photo quadrats or AGRRA point intercept
Acropora palmata and A. cervicornis	Targeted transects
Focal species biomass or density:	
Groupers (Serranidae)	AGRRA 30x2m roving surveys and landing surveys
Snappers (Lutjanidae)	AGRRA 30x2m roving surveys and landing surveys
Parrotfishes (Scaridae) and surgeonfishes (Acanthuridae)	AGRRA 30x2m roving surveys and landing surveys
Lobster and conch	Targeted transects (see section below) and landing surveys
Diadema antillarum	Targeted transects (see section below)
Lionfish (*Pterois* sp.)	AGRRA fish surveys
Disease incidence (newly diseased corals)	Photo comparison with previous years
Coral mortality	AGRRA coral health belt transects
Rugosity	AGRRA or chain method
Water quality (temperature, salinity, turbidity) and sedimentation	Data loggers and sediment traps

2.4.1. New indicators

Disease incidence

As well as disease prevalence (% of live corals with disease), the incidence of newly diseased corals (number of new cases) within transects is also important. Disease prevalence can remain unchanged between two monitoring years, but this does not address the spread of disease between corals, and the trajectory of outbreaks (i.e. is the number of new cases changing). Disease incidence can be monitored by comparing quadrat photographs from previous years.

Water quality

The greatest local threats to coral reefs in the NETMPA are land-based (Lapointe et al., 2010; Mallela et al., 2010). Nutrient pollution and sediment pollution need to be the target of management measures and should be monitored on the reefs to identify problem areas and effectiveness of remedial actions. We have set up sediment traps on the permanent sites but funding is needed to collect them every 1-2 months. Nutrient pollution can be assessed using isotope analysis of macroalgae collected on the reef, as well as from regular water samples and samples taken after heavy rainfall. These can be analysed at The U.W.I. Temperature, salinity and turbidity can be measured with data loggers fixed on the reefs, retrieved every few months to download the data, and left in place for several years. Temperature and salinity loggers are relatively inexpensive but turbidity loggers are not. These have all been budgeted for in the upcoming Green Fund project.

Rugosity

Rugosity is a measure of the structural complexity of the reef, the concept being that higher complexity creates a greater range of habitats for reef organisms. A visual estimation of complexity is made in the AGRRA methods, it is rapid, adds little extra work for the surveyor, and findings can be compared against the AGRRA dataset. An alternative method, the 'chain method', lays a chain across the reef which is allowed to droop into all the holes and crevices (Hill and Wilkinson, 2004). The output uses the ratio of the taught length to the slack length. This method is more time consuming but is less subjective, has greater accuracy, and is more useful for scientific interpretations. Both methods have their advantages and so we recommend applying both approaches.

2.4.2 Monitoring methods

Benthic method selection

In this report, we presented the results of the photo-quadrat method because it estimates benthic cover based on 600 observations per transect compared to 100 observations per transect in the AGGRA point intercept method (PIM) – a six-fold difference. It is also beneficial to have a permanent photographic record to compare against future surveys and for assessing new disease incidence (see above). However, there are other factors that should be considered when choosing the most appropriate method. The downside of the photo-quadrat approach is that it requires considerable time processing the photos after the field work is complete, and identifications from photos may be compromised by the quality of the photo. A good camera and a well-trained underwater photographer are important.

In the AGGRA PIM, all data is recorded in the field and this eliminates post-analysis. However, it also requires the observer to be very adept at benthic identifications, and for this region (the NETMPA), would require instant identification of more than 70 benthic species - not impossible - but it does require training and there can be no subsequent quality control. Most importantly though, is whether the PIM is still able to accurately characterise the benthic community when it uses far fewer observations. Figure 2.4.2 compares the coral cover observations of the two methods. Both methods produced roughly the same mean coral cover in the permanent sites[1]. The concern with the PIM however, is the variation in percentage cover within a site that produces large errors around the mean. Table 2.4.2. shows an example for Englishman's bay. There is considerable discrepancy in coral cover when examined on a transect specific basis between the two methods. This would make detecting significant differences in coral cover from year to year or between sites far harder, and may mask losses of up to 20% coral cover.

Table. 2.4.2. Comparison of coral cover estimation in transects of Englishman's bay assessed with two methodologies

Transect	Coral cover %	
	Point intercept	Photo quadrat
1	9	18.63
2	51	15.00
3	0	22.67
4	23	21.83
5	20	13.33
6	9	14.50
Mean	17.60%	18.60%

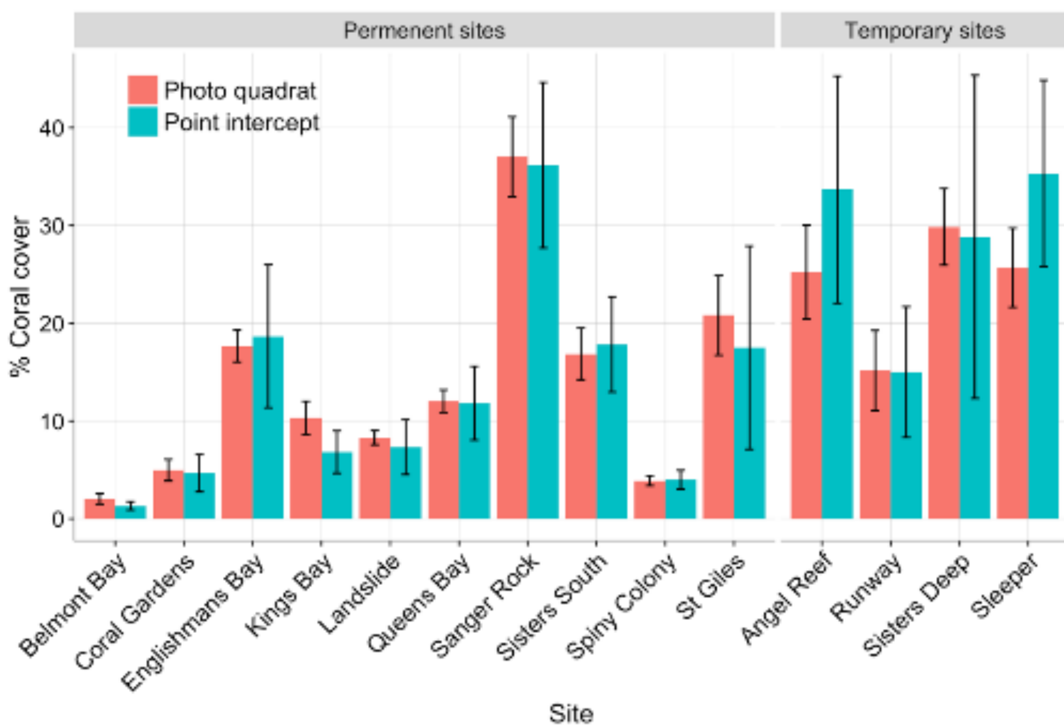

Fig. 2.4.2. Coral cover determination from two methodological approaches

[1] the permanent sites are where the exact same transect or section of reef has been assessed, whereas in temporary sites, the two methods would have been applied to slightly different areas of the reef, and some level of variation would be expected.

It is also important to note that the Reefcheck method uses 50 observations per transect, with typically 3 transects per site, amounting to 150 observations per site. This compares to 3600 observations per site with the photo quadrat method and 600 observations with the PIM method (assuming 6 transects per site). The Reefcheck method would thus be inadequate for a robust monitoring program in the NETMPA.

In summary, we recommend continuing with the photo quadrat approach for future monitoring because of its accuracy and the permanent record it establishes, but all PIM data is available for comparison in the *supplementary material* if the implementing agency prefers this approach. In this event, we would recommend increasing the number of permanent transects per site to 10.

Lobsters, conch and sea urchins

The AGGRA protocol documents lobsters, conch and sea urchins in 10x1m^2 belt transects, however we also recorded lobsters specifically in the 30x2m^2 fish transects to increase the data pool. The benthic transects recorded 8 lobsters in 840m^2 of transects (0.095 individuals per 100m^2), while the fish transects recorded 20 individuals in 5460m^2 (0.036 individuals per 100m^2). The results are clearly contrasting, but it is difficult to interpret this when the number of sightings is so low. There are advantages and disadvantages of both methods. The advantage of the 10m^2 benthic transects is that sedentary organisms (lobster, conch, sea urchin) are the sole focus of the surveyor, which is important when their cryptic behaviour requires the surveyor to search under corals and in obscured crevices. This is also the standardised AGGRA survey approach which allows comparisons with the regional AGGRA dataset. The downside is that the small area of reef covered by these transects is not conduce to assessing species with such low densities. In contrast, the fish transects cover a vast area but the surveyor is unable to simultaneously document fish and search in cryptic habitats for the invertebrates. This has the propensity to underrepresent invertebrates, and may explain the lower lobster densities found in the fish transects. We therefore recommend that the 10x1m^2 benthic transects continue documenting lobster and conch to allow the comparison with the AGGRA dataset. In addition to this, once the surveyor has finished a fish transect and is returning along the transect and winding up the tape, that they use this opportunity to survey lobster, conch and sea urchins in a 30x2m^2 belt transect. This will cover a far greater area and allow the surveyor time to focus on the cryptic species.

Acropora cervicornis and A. palmata

These two branching corals are critically endangered in the Caribbean. Their distribution in the NETMPA is not best represented by the permanent transects we have established. We recommend establishing permanent transects across current known distributions and in the close vicinity to monitor potential expansion of the populations. For *A. cervicornis,* these need to be established for the two populations in front of Charlotteville and in Anse Bateaux. For *A. palmata,* we recommend permanent stations at Booby Rock, Landslide, Englishman's Bay, and Castara. Further roving searches should also be made on the Atlantic coast to confirm their presence or absence there.

2.5. Management

The GEF/FAO have convened a committee of stakeholders from various sectors to help develop a marine protected area for north-east Tobago. Park-user fees will help support MPA management and there is evidence that having designated MPAs increases the attraction of a destination for scuba divers and tourists (Depondt and Green, 2006). Government and local community support for this MPA is critical if the health of the marine environment is to improve.

Climate change poses the greatest threat to the future of coral reefs in the NETMPA. Local management needs to target local impacts that are stressing corals and undermining their resilience to survive and adapt to climate change. Sediment and nutrient pollution are the foremost of these impacts. Government, local communities and NGOs need to find ways to limit these pollutants entering coastal waters. Improved sewage treatment, better land management, protecting steep hillsides, reforestation, and storm-water management systems all have excellent potential to reduce the quantities of nutrients and sediments being washed onto coral reefs. Expert consultants in land management and storm-water management need to assess villages in the NETMPA to identify where limited financial resources should be spent.

A detailed assessment of the spearfishing industry is desperately needed: including landings, fishing effort, fishing grounds and alternative livelihoods. These were not possible from monitoring fish markets in this study. Instead, this requires cooperation and coordination with the spearfisherfolk who rotate fishing days and fishing locations. Studies from Jamaica show that coral reefs are extremely sensitive to any loss of herbivorous grazing, and that even light exploitation has the potential to release macroalgal blooms (Mumby et al., 2007). Developing a market for lionfish would be an excellent way to reduce the targeting of important herbivores while also controlling the lionfish population. Spearfishing restrictions could be cost effectively enforced at landing sites without the need for patrol teams (as has been recommended in previous reports). In fact, many local fishermen support a ban on targeting of reef fish by spearfisherfolk, and if a legal ban were in place, we suspect that support from local communities would make enforcement quite feasible.

Aside from spearfishing, the only other activity in the NETMPA that could warrant patrol boats is unregulated anchoring. The Department of Marine Resources and Fisheries already has a mandate to maintain mooring buoys in Tobago, and with financial support, would have the skills and resources to implement and maintain a system of mooring buoys for the NETMPA. A system of patrol boats in the NETMPA should not be a management priority, as it will not address the primary threats to NETMPA reefs. It would be far wiser to allocate limited resources to target the land-based impacts that are truly damaging the ecosystem. If additional resources are available, then fisheries officers could patrol landing sites without the need for an unsustainable system of patrol boats.

The demersal and pelagic fisheries of the NETMPA have been sorely neglected in terms of data collection, management and communication between fisherfolk, government and the oil and gas industry. Many fishermen are adamant their stocks are declining but have no data to support their assertions. Fisherfolk need to be encouraged to record data themselves or a fisheries officer needs to regularly collect data at landing sites. The fisheries division has tried distributing landing books before but only one person we spoke to continues to record their catch. Thus, having a landings officer rotating around the landing sites would be the most reliable method of collecting data. Determining fishing effort and time spent in fishing grounds is more complicated. If fishermen were willing, asking them to carry GPS recorders would be the simplest way. Failing that, an observer can record time spent at sea and general fishing grounds by observing fisherfolk from vantage points. Such observation points exist in Parlatuvier and Charlotteville/Speyside, and would enable viewing of the principal fishing grounds between The Sisters, St. Giles and Little Tobago, as well as recording boats heading further offshore. There have already been extensive consultations to develop an ecosystem-based approach to fisheries management for the country (Mohammed 2013).

Given the extensive use of fishing grounds around The Sisters, St. Giles and Little Tobago, any imposed restriction on these grounds will be met with strong resistance and consequently non-compliance. In fact, there is little justification for restrictions given the data poor fishery. Instead, we recommend a minimum size limit of 3lbs on dolphinfish and the adoption of the national strategy towards the shark fishery (in development). While only two shark species were landed during this survey, one of those species was already showing signs of being overfished, and landings of larger species are known to occur. The grouper fishery is difficult to assess at this stage without information on exact fishing grounds and depths, whether these target species are migrating to reefs, and the trend in the catch per unit effort. Hopefully, longer-term monitoring of landings will address these questions.

2.6. Community and government collaboration

One of the objectives of this project was to work with local community members and representatives of the THA, specifically the Department of Marine Resources and Fisheries (DMRF), in order to develop their capacity to continue such studies in the future. Zolani Frank of the Speyside Eco-Marine Park Rangers and Kimron Eastman of North-East Sea Turtles donated their time to the project on multiple occasions and received training in coral identifications and measurements. Kirwin Sampson represented the DMRF and has been involved in projects with the IMA in the past. As such, he already possessed the skills to be an asset to a future monitoring program. We endeavoured to use different boat drivers from the closest villages to the target sites to foster support for the project in the local communities and spread the training and employment of community members. Amin in Charlotteville, Lehron Brooks and Kern Roberts in Roxborough, Smithy and Spencer in Speyside, and Neptune in Parlatuvier were all enthusiastic and reliable team members.

The fisheries survey required considerable local support at each landing site in order for fishermen to allow us to weigh their catch. We employed community members at the landing sites to help weigh the fish, and their enthusiasm for the objectives of the project was the sole reason we were able to measure 100% of landings at all sites during our surveys. Support from Ian Daley of the Bloody Bay Fishermen's Association and Junior Quashiu from Castara Fishing Association were instrumental to this end.

2.7. Conclusion

Tobago's coral reefs have evolved in a marginal environment where only sediment tolerant species can survive. Despite this, Tobago's reefs are in better condition that many Eastern Caribbean islands. However, this should not be the standard by which the reefs are judged. Coral cover on Caribbean reefs has declined by 50% since 1970, while macroalgae have increased by 300-400% (Jackson et al., 2014). Clearly, macroalgae are winning. Early travellers to the Caribbean found biodiversity very different to that of today;

> "*I am very certain that during the first ten years after the isle was inhabited, we pulled out (from the sea) every year more than three to four thousand turtles, a very large number of manatees and we still pull out every day quantities of them, and it will continue until the end of the world without depleting them.*" - Father du Tertre describing Guadeloupe in 1670 (Bouchon et al., 2008)

This is a baseline survey of the condition of the coral reefs today, and acts as a reference point against which future conditions can be compared. At this reference point, the reefs have already been hit by bleaching events in 1998, 2005 and 2010; by disease outbreaks in 1982 and 2005; by hurricanes in 1963 and 2010; and by chronic human impacts dating back to indigenous cultures. This baseline therefore, is not a target for management goals, but instead just the opposite. We hope it is a baseline by which coastal managers can show how much coral reefs have improved through their concerted management efforts. We have included targets suggested by McField and Kramer (2007) for many of the indicators we addressed and refer managers to the associated website www.healthyreefs.com which addresses the social aspects that should also be combined in a management plan.

2.8. Acknowledgements

This report is heavily indebted to the excellent field team who was responsible for establishing permanent monitoring stations, conducting the first baseline survey, and processing hours of photo and video footage: Marianna Rampaul, Susanne Hirschmann, Richard Parkinson and Brian Parkinson. We were greatly assisted in the field by local community members who devoted their time both underwater, Zolani Frank and Kimron Eastman, and in logistics, Ian Daley, Amin, Lehron Brooks and Kern Roberts. The fishing villages and many fishermen therein were very supportive of the project and helped in weighing every single fish that was landed in 3 weeks of surveys. The Department of Marine Resources and Fisheries were also very generous in providing support for the project and the assistance of Kiwin Sampson in particular. Pat Turpin of Environment Tobago was the ideal host for the field team at Man-Of-War Cottages. Jahson Alemu has been extremely helpful in advising on field techniques and Dawn A T Phillip provided a thorough review of this report that greatly improved the content.

2.9. References

ALEMU, J. B. 2014. Fish assemblages on fringing reefs in the southern Caribbean: biodiversity, biomass and feeding types. *Revista de Biología Tropical,* 62**,** 418-431.

ALEMU, J. B. 2016. The status and management of the lionfish, *Pterois sp*. in Trinidad and Tobago. *Marine pollution bulletin,* 109**,** 402-408.

ALEMU, J. B. & CLEMENT, Y. 2010. Status of Coral reefs of Tobago 2010. Institute of Marine Affairs. Chaguaramas.

ALEMU, J. B. & CLEMENT, Y. 2012. Status of Coral reefs of Tobago 2012. Institute of Marine Affairs. Chaguaramas.

ALEMU, J. B. & CLEMENT, Y. 2014. Mass coral bleaching in 2010 in the southern Caribbean. *PLoS one,* 9**,** e83829.

ARMSTRONG, H., VAN BOCHOVE, J.-W., LOW-DÉCARIE, E., ALEMU J, I. & RAINES, P. 2009. Speyside Marine Area Community-based Management Project (SMACMP). Final Report October 2008 – September 2009

ARONSON, R. B. & PRECHT, W. F. 2001. White-band disease and the changing face of Caribbean coral reefs. *The ecology and etiology of newly emerging marine diseases.* Springer.

BOUCHON, C., PORTILLO, P., BOUCHON-NAVARO, Y., LOUIS, M., HOETJES, P., DE MEYER, K., MACRAE, D., ARMSTRONG, H., DATADIN, V. & HARDIN, S. 2008. Status of coral reefs of the Lesser Antilles: The French West Indies, The Netherlands Antilles, Anguilla, Antigua, Grenada, Trinidad and Tobago. *Status of coral reefs of the world,* 3**,** 265-280.

BUGLASS, S., DONNER, S. D. & ALEMU I, J. B. 2016. A study on the recovery of Tobago's coral reefs following the 2010 mass bleaching event. *Marine Pollution Bulletin,* 104**,** 198-206.

BURGE, C. A., MARK EAKIN, C., FRIEDMAN, C. S., FROELICH, B., HERSHBERGER, P. K., HOFMANN, E. E., PETES, L. E., PRAGER, K. C., WEIL, E., WILLIS, B. L., FORD, S. E. & HARVELL, C. D. 2014. Climate change influences on marine infectious diseases: implications for management and society. *Ann Rev Mar Sci,* 6**,** 249-77.

CARBALLO, J. L., BAUTISTA, E., NAVA, H., CRUZ-BARRAZA, J. A. & CHÁVEZ, J. A. 2013. Boring sponges, an increasing threat for coral reefs affected by bleaching events. *Ecology and Evolution,* 3**,** 872-886.

CLOSEK, C. J., SUNAGAWA, S., DESALVO, M. K., PICENO, Y. M., DESANTIS, T. Z., BRODIE, E. L., WEBER, M. X., VOOLSTRA, C. R., ANDERSEN, G. L. & MEDINA, M. 2014. Coral transcriptome and bacterial community profiles reveal distinct Yellow Band Disease states in *Orbicella faveolata*. *The ISME Journal,* 8**,** 2411-2422.

CÔTÉ, I. M., GREEN, S. J. & HIXON, M. A. 2013. Predatory fish invaders: insights from Indo-Pacific lionfish in the western Atlantic and Caribbean. *Biological Conservation,* 164**,** 50-61.

CRABBE, M. J. C. 2012. The influence of extreme climate events on models of coral colony recruitment and survival in the Caribbean. *American Journal of Climate Change*.

CREARY, M. 2010. Coral Reef Monitoring for the Organization of Eastern Caribbean States and Tobago - Status of the Coral Reefs. *Technical Report 5C/MACC-11-08-3 published by the Caribbean Community Climate Change Centre Digital Edition (November 2010) ISBN 978-976-8236-21-0 (PDF)* http://www.caribbeanclimate.bz/.

D'ABADIE, J. 2011. Marine Protected Areas–Zoning for conservation and rehabilitation of coral reefs in data poor areas.

DE GOEIJ, J. M., VAN OEVELEN, D., VERMEIJ, M. J. A., OSINGA, R., MIDDELBURG, J. J., DE GOEIJ, A. F. P. M. & ADMIRAAL, W. 2013. Surviving in a Marine Desert: The Sponge Loop Retains Resources Within Coral Reefs. *Science,* 342**,** 108.

DEPONDT, F. & GREEN, E. 2006. Diving user fees and the financial sustainability of marine protected areas: Opportunities and impediments. *Ocean & Coastal Management,* 49**,** 188-202.

DIAZ, M. C. & RÜTZLER, K. 2001. Sponges: an essential component of Caribbean coral reefs. *Bulletin of Marine Science,* 69**,** 535-546.

ELMQVIST, T., FOLKE, C., NYSTRÖM, M., PETERSON, G., BENGTSSON, J., WALKER, B. & NORBERG, J. 2003. Response diversity, ecosystem change, and resilience. *Frontiers in Ecology and the Environment,* 1**,** 488-494.

FOSTER, N. L., BOX, S. J. & MUMBY, P. J. 2008. Competitive effects of macroalgae on the fecundity of the reef-building coral Montastraea annularis. *Marine Ecology Progress Series,* 367**,** 143-152.

GARDNER, T. A., COTE, I. M., GILL, J. A., GRANT, A. & WATKINSON, A. R. 2005. Hurricanes and Caribbean coral reefs: impacts, recovery patterns, and role in long-term decline. *Ecology,* 86**,** 174-184.

GIL-AGUDELO, D. L., SMITH, G. W., GARZÓN-FERREIRA, J., WEIL, E. & PETERSEN, D. 2004. Dark spots disease and yellow band disease, two poorly known coral diseases with high incidence in Caribbean reefs. *Coral health and disease***,** 337-349.

GOREAU, T. J., CERVINO, J., GOREAU, M., HAYES, R., HAYES, M., RICHARDSON, L., SMITH, G., DEMEYER, K., NAGELKERKEN, I. & GARZON-FERRERA, J. 1998. Rapid spread of diseases in Caribbean coral reefs. *Rev Biol Trop,* 46**,** 157-171.

GREEN, A. L. & BELLWOOD, D. R. 2009. *Monitoring functional groups of herbivorous reef fishes as indicators of coral reef resilience: a practical guide for coral reef managers in the Asia Pacific region*, IUCN.

GREEN, D. H., EDMUNDS, P. J. & CARPENTER, R. C. 2008. Increasing relative abundance of *Porites astreoides* on Caribbean reefs mediated by an overall decline in coral cover. *Marine Ecology Progress Series,* 359**,** 1-10.

GUPPY, R. & BYTHELL, J. C. 2006. Environmental effects on bacterial diversity in the surface mucus layer of the reef coral *Montastraea faveolata*. *Marine Ecology Progress Series,* 328**,** 133-142.

HARDING, S., VAN BOCHOVE, J., DAY, O., GIBSON, K. & RAINES, P. Continued degradation of Tobago's coral reefs linked to the prevalence of coral disease following the 2005 mass coral bleaching event. Proc. 11th Int. Coral Reef Symp, 2008. 738-741.

HASSANALI, K. 2009. Coastal Conservation Project: An Assessment of the Coral Reefs of Tobago. *Research Report for the Institute of Marine Affairs, Trinidad and Tobago*.

HILL, J. & WILKINSON, C. 2004. Methods for ecological monitoring of coral reefs. *Australian Institute of Marine Science, Townsville,* 117.

HOEGH-GULDBERG, O., MUMBY, P. J., HOOTEN, A. J., STENECK, R. S., GREENFIELD, P., GOMEZ, E., HARVELL, C. D., SALE, P. F., EDWARDS, A. J., CALDEIRA, K., KNOWLTON, N., EAKIN, C. M., IGLESIAS-PRIETO, R., MUTHIGA, N., BRADBURY, R. H., DUBI, A. & HATZIOLOS, M. E. 2007. Coral reefs under rapid climate change and ocean acidification. *Science,* 318**,** 1737.

HOFFMAYER, E. R., DRIGGERS, W. B., GRUBBS, R. D., GIRESI, M. M., GELSLEICHTER, J. & LATOUR, R. 2014. Length/weight relationships and life history data for *Mustelus canis* off of the Atlantic coast of the US.

HU, C., MONTGOMERY, E. T., SCHMITT, R. W. & MULLER-KARGER, F. E. 2004. The dispersal of the Amazon and Orinoco River water in the tropical Atlantic and Caribbean Sea: Observation from space and S-PALACE floats. *Deep Sea Research Part II: Topical Studies in Oceanography,* 51**,** 1151-1171.

HUGHES, T. P. 1994. Catastrophes, Phase-Shifts, and Large-Scale Degradation of a Caribbean Coral-Reef. *Science,* 265**,** 1547-1551.

HUGHES, T. P., RODRIGUES, M. J., BELLWOOD, D. R., CECCARELLI, D., HOEGH-GULDBERG, O., MCCOOK, L., MOLTSCHANIWSKYJ, N., PRATCHETT, M. S., STENECK, R. S. & WILLIS, B. 2007. Phase shifts, herbivory, and the resilience of coral reefs to climate change. *Current Biology,* 17**,** 360-365.

IMA 2016. State of the Marine Environment, Trinidad & Tobago 2016. *A Publication of the Institute of Marine Affairs*.

JACKSON, J., DONOVAN, M., CRAMER, K. & LAM, V. 2014. Status and trends of Caribbean coral reefs: 1970-2012. Washington, D.C.

KLOMP, K. D., CLARKE, K., MARKS, K. & MILLER, M. Condition of reef fish on Jamaica's north coast signals late stages of overezploitation. *In:* CRESWELL, R. L., ed. 54th Annual Meeting of the Gulf-and-Caribbean-Fisheries-Institute, Nov 12-17 2001 Turks & Caicos Isl, W Ind Assoc St. Gulf Caribbean Fisheries Inst Gcfi, 592-608.

KUFFNER, I. B., WALTERS, L. J., BECERRO, M. A., PAUL, V. J., RITSON-WILLIAMS, R. & BEACH, K. S. 2006. Inhibition of coral recruitment by macroalgae and cyanobacteria. *Marine Ecology Progress Series,* 323**,** 107-117.

LAPOINTE, B. E., LANGTON, R., BEDFORD, B. J., POTTS, A. C., DAY, O. & HU, C. 2010. Land-based nutrient enrichment of the Buccoo Reef Complex and fringing coral reefs of Tobago, West Indies. *Marine Pollution Bulletin,* 60**,** 334-343.

LAPOINTE, B. E., LANGTON, R., DAY, O. & POTTS, A. C. 2003. Integrated water quality and coral reef monitoring on fringing reefs of Tobago: Chemical and ecological evidence of sewage-driven eutrophication in the Buccoo reef complex. *Proc 54th Annual Gulf and Caribbean Fisheries Institute***,** 457–472.

LAYDOO, R. 1984. Inference of a white-band epidemic in the elkhorn coral, A. palmata, populations in Tobago, West Indies. *Proceedings of the Association of Island Marine Laboratories in the Caribbean,* 18**,** 12.

LAYDOO, R. S. 1985a. Coral reefs at Man-O-War, Tobago. *Chaguaramas: Institute of Marine Affairs.* .

LAYDOO, R. S. 1985b. In-situ observations on stages of *Diadema antillarium* mass mortality in Tobago, West Indies. *Carenage: Institute of Marine Affairs.*

MALJKOVIĆ, A., VAN LEEUWEN, T. & COVE, S. 2008. Predation on the invasive red lionfish, *Pterois volitans* (Pisces: Scorpaenidae), by native groupers in the Bahamas. *Coral Reefs,* 27**,** 501-501.

MALLELA, J. & CRABBE, M. J. C. 2009. Hurricanes and coral bleaching linked to changes in coral recruitment in Tobago. *Marine Environmental Research,* 68**,** 158-162.

MALLELA, J., HETZINGER, S. & HALFAR, J. 2016. Thermal stress markers in *Colpophyllia natans* provide an archive of site-specific bleaching events. *Coral Reefs,* 35**,** 181-186.

MALLELA, J., PARKINSON, R. & DAY, O. 2010. An assessment of coral reefs in Tobago. *Caribbean Journal of Science,* 46**,** 83-87.

MATTOS, S. M. G., BROADHURST, M., HAZIN, F. H. V. & JONNES, D. M. 2001. Reproductive biology of the Caribbean sharpnose shark, Rhizoprionodon porosus, from northern Brazil. *Marine and Freshwater Research,* 52**,** 745-752.

MAYNARD, J., VAN HOOIDONK, R., EAKIN, C. M., PUOTINEN, M., GARREN, M., WILLIAMS, G., HERON, S. F., LAMB, J., WEIL, E. & WILLIS, B. 2015. Projections of climate conditions that increase coral disease susceptibility and pathogen abundance and virulence. *Nature Climate Change,* 5**,** 688.

MCFIELD, M. & KRAMER, P., R 2007. Healthy Reefs for Healthy People: A Guide to Indicators of Reef Health and Social Well-being in the Mesoamerican Reef Region. *The Smithsonian Institution, Washington, D.C., USA.*

MCGANN, J. & CREARY, M. Coral reef monitoring for the Organization of Eastern Caribbean states (OECS) and Tobago. Proceedings of the 11th International Coral Reef Symposium, Ft Lauderdale, Florida. Session, 2008.

MOSES, C. S. & SWART, P. K. Stable isotope and growth records in corals from the island of Tobago: Not simply a record of the Orinoco. Proc 10th Int Coral Reef Symp, 2006. 580-587.

MOTTA, F. S., GADIG, O. B., NAMORA, R. C. & BRAGA, F. M. 2005. Size and sex compositions, length–weight relationship, and occurrence of the Brazilian sharpnose shark, *Rhizoprionodon lalandii*, caught by artisanal fishery from southeastern Brazil. *Fisheries Research,* 74**,** 116-126.

MUMBY, P. J., HASTINGS, A. & EDWARDS, H. J. 2007. Thresholds and the resilience of Caribbean coral reefs. *Nature,* 450**,** 98.

MUMBY, P. J., HEDLEY, J. D., ZYCHALUK, K., HARBORNE, A. R. & BLACKWELL, P. G. 2006. Revisiting the catastrophic die-off of the urchin *Diadema antillarum* on Caribbean coral reefs: fresh insights on resilience from a simulation model. *Ecological Modelling,* 196**,** 131-148.

NASH, K. L., GRAHAM, N. A. J., WILSON, S. K. & BELLWOOD, D. R. 2013. Cross-scale Habitat Structure Drives Fish Body Size Distributions on Coral Reefs. *Ecosystems,* 16**,** 478-490.

NEGRI, A. P., WEBSTER, N. S., HILL, R. T. & HEYWARD, A. J. 2001. Metamorphosis of broadcast spawning corals in response to bacteria isolated from crustose algae. *Marine Ecology Progress Series,* 223**,** 121-131.

NORSTRÖM, A. V., NYSTRÖM, M., LOKRANTZ, J. & FOLKE, C. 2009. Alternative states on coral reefs: beyond coral-macroalgal phase shifts. *Mar Ecol Prog Ser,* 376**,** 295-306.

NYSTRÖM, M. 2006. Redundancy and Response Diversity of Functional Groups: Implications for the Resilience of Coral Reefs. *AMBIO: A Journal of the Human Environment,* 35**,** 30-35.

O'FARRELL, S. & DAY, O. 2005. Report On The 2005 Mass Coral Bleaching Event In Tobago. *Part I. Results From Phase 1. Coral Cay Conservation*.

POLLOCK, F. J., LAMB, J. B., FIELD, S. N., HERON, S. F., SCHAFFELKE, B., SHEDRAWI, G., BOURNE, D. G. & WILLIS, B. L. 2014. Sediment and turbidity associated with offshore dredging increase coral disease prevalence on nearby reefs. *PLOS one,* 9**,** e102498.

VAN BOCHOVE, J. & MCVEE, M. 2012. Tobago Coastal Ecosystems Mapping Project Final Report - Results of Community and Scientific Work. *Coral Cay Conservation*.

WILKINSON, C. E. 2008. Status of Coral Reefs of the World. *Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville, Australia.*

2.10. Appendices

Appendix 2.10a Peer-reviewed literature on coral reef communities of the NETMPA

Author(s)/ Source	Title
Alemu 2014	Fish assemblages on fringing reefs in the southern Caribbean: biodiversity, biomass and feeding types
Alemu 2016	The status and management of the lionfish, *Pterois* sp. in Trinidad and Tobago
Alemu and Clement 2014	Mass Coral Bleaching in 2010 in the Southern Caribbean
Buglass et al. 2016	A study on the recovery of Tobago's coral reefs following the 2010 mass bleaching event
Chan et al. 1991	Cembrane and pseudopterane diterpenoids of the octocoral *Pseudopterogorgia acerosa.*
Crabbe 2012	The Influence of Extreme Climate Events on Models of Coral Colony Recruitment and Survival in the Caribbean
Esteban et al. 2002	Institutional arrangements for Caribbean MPAs and opportunities for pro-poor management.
Guppy and Bythell 2006	Environmental effects on bacterial diversity in the surface mucus layer of the reef coral *Montastraea faveolata*
Hayes and Trimm 2008	Distributional ecology of the anemone shrimp *Periclimenes rathbunae* associating with the sea anemone *Stichodactyla helianthus* at Tobago, West Indies
Hayes et al. 1998.	Selection by two decapod crabs (*Percnon gibbesi* and *Stenorhynchus seticornis*) associating with an urchin (*Diadema antillarum*) at Tobago, west indies
Hu et al. 2007	The dispersal of the Amazon and Orinoco River water in the tropical Atlantic and Caribbean Sea: Observation from space and S-PALACE floats
Kumarsingh et al. 1998	Historic records of phosphorus levels in the reef-building coral *Montastrea annularis* from Tobago, West Indies
Lapointe et al, 2003.	Integrated water quality and coral reef monitoring on fringing reefs of Tobago- Chemical and ecological evidence of sewage-driven eutrophication in the Buccoo
Lapointe et al. 2010	Land-based nutrient enrichment of the Buccoo Reef Complex and fringing coral reefs of Tobago, West Indies
Laydoo 1990	The shallow water scleractinians (stony corals) of Tobago, West Indies
Mallela and Crabbe 2009	Hurricanes and coral bleaching linked to changes in coral recruitment in Tobago
Mallela and Harrod 2008	D13c and D15n reveal significant differences in the coastal foodwebs of the seas surrounding the islands of Trinidad and Tobago.
Mallela and Parkinson 2008	Coral disease succession in Tobago: from yellow band to black band disease
Mallela et al. 2007.	Fine-scale phosphorus distribution in coral skeletons- combining X-ray mapping by electronprobe microanalysis and LA-ICP-MS
Mallela et al. 2010	An assessment of coral reefs in Tobago
Mallela et al. 2016	Thermal stress markers in *Colpophyllia natans* provide an archive of site-specific bleaching events
McCue 2015	Piloting the integration of coastal zone management and climate change adaptation in Tobago (tt-t1034)
Mohammed et al. 2016	Performance Evaluation of CRW Reef-Scale and Broad-Scale SST-Based Coral Monitoring Products in Fringing Reef Systems of Tobago
Odriozola et al. 2007.	On the absorption of light in the Orinoco River plume
Potts 2004	The coral reefs of Tobago-status and management
Soma 2003	How to involve stakeholders in fisheries management—a country case study in Trinidad and Tobago

Table 2.10b Other literature on coral reef communities of the NETMPA

Author(s)/ Source	Title
Alemu and Armstrong 2013	Case studies of social-ecological resilience in island systems
Alemu and Clement 2010	Status of Coral reefs of Tobago 2010. Institute of Marine Affairs. Chaguaramas
Alemu and Clement 2011	Status of Coral reefs of Tobago 2011. Institute of Marine Affairs. Chaguaramas
Alemu and Clement 2012	Status of Coral reefs of Tobago 2011. Institute of Marine Affairs. Chaguaramas
Ali 2011	Understanding the Lionfish Invasion in Bonaire to Develop the Best Strategy for Trinidad and Tobago
Armstrong et al. 2009	Speyside Marine Area Community-based Management Project
Bouchon et al. 2008	Status of coral reefs of the Lesser Antilles: The French West Indies, The Netherlands Antilles, Anguilla, Antigua, Grenada, Trinidad and Tobago
Burke 2008	Coastal Capital- Economic Valuation of Coral Reefs in Tobago and St. Lucia
Creary 2008	Coral Reef Monitoring for the Organisation of Eastern Carribean States and Tobago Year 1 - Status of Coral Reef in 2007. Caribbean Community Climate Change Centre - Mainstreaming Adaptation to Climate Change (MACC) Project.
Creary 2009	Coral Reef Monitoring for the-Organisation of Easter Carribean States and Tobago Year 2 - Status of Coral Reef in 2008. Caribbean Community Climate Change Centre - Mainstreaming Adaptation to Climate Change (MACC) Project.
D' abadie 2011	Marine Protected Areas - Zoning for Conservation and Rehabilitation of Coral Reefs in Data Poor Areas - A Case Study of North-Eastern Tobago
Flower 2010	Tobagan fishers' livelihood security and attitudes to coastal management in the context of declining catches
Harding et al. 2008	Continued degradation of Tobago's coral reefs linked to the prevalence of coral disease following the 2005 mass coral bleaching event.
Hassanali 2009	Coastal Conservation Project: An Assessment of the Coral Reefs of Tobago.
Hendee et al. 2016	Expansion of the Coral Reef Early Warning System (CREWS) Network Throughout the Caribbean. Proceedings of the 13th International Coral Reef Symposium, Honolulu: 517-522
Hoetjes et al. 2002	Status of coral reefs in the eastern Caribbean: the OECS, Trinidad and Tobago, Barbados and the Netherlands Antilles. In *Status of coral reefs of the world*
ICRI 2002	Regional Workshop for the Tropical Americas
IMA 2016	State of the Marine Environment – Trinidad and Tobago 2016
Kenny 1976	A preliminary study of the Buccoo Reef/Bon Accord Complex with special reference to development and management. Unpublished report. Department of Biological Sciences, University of the West Indies, St Augustine: 123
Lapointe 2003	Impacts on Land-based Nutrient Pollution on Coral Reefs of Tobago
Laydoo	Status of CARICOM coral reefs and their management
Laydoo 1984	Inference of a white-band epidemic in the elkhorn coral, A. palmata, populations in Tobago, West Indies
Laydoo 1985	In-situ observations of Diadema antillarium mass mortality in Tobago, West Indies. Chaguaramas: Institute of Marine Affairs
Laydoo 1985	Coral reefs at Man-O-War, Tobago. Chaguaramas: Institute of Marine Affairs.
Laydoo 1985	The coral reefs at Speyside, Tobago
Laydoo 1991	A guide to the coral reefs of Tobago
Mallela	Coral Reefs and Reef Research in Tobago
Mallela 2011	Coral reef and catchment management in Tobago: monitoring reefs for the future
Mallela 2011	Tobago: A Sustainable Future for Buccoo Reef
Mallela et al. 2010	Tobago brain coral provides a long-term archive of south American river runoff, tropical climate variability and shifts in coral growth

Author(s)/ Source	Title
McGann and Creary 2008.	Coral Reef Monitoring for the Organization of Eastern Caribbean States (OECS) and Tobago
Moses and Swart	Stable isotope and growth records in corals from the island of Tobago: Not simply a record of the Orinoco
Mukhida 2003	Opportunities and Constraints of Co-Management- cases of the Buccoo Reef Marine Park and the Speyside Reefs Marine Park, Tobago.
O'Farrell and Day 2006	Report on the 2005 mass coral bleaching event in tobago: part i. Results from phase 1 survey
Ramsaroop 1982	A preliminary survey of the coral reefs in Man-o-War Bay, Tobago
Risk et al. 1992	Sclerochronology of Tobago corals: a record of the Orinoco
Steinberg et al.	Co-Management and the Bucco Reef Management Committee
Tomkins et al. 2002	Trade off analysis for participatory coral reef management
van Bochove and McVee 2012	Tobago coastal ecosystems mapping project - final report- results of community and scientific work
Wilkinson and Brodie 2011	Catchment Management and Coral Reef Conservation: a practical guide for coastal resource managers to reduce damage from catchment areas based on best practice case studies.
Wothke	Final Report of the Marine Protected Area Specialist Team for the Project: IFPAMTT
Wothke 2013	Improving forest and protected area management in trinidad and tobago
Wothke 2014	Marine Protected Area Co-Management Capacity Building in North East (NE) Tobago
Wothke 2015	Final Report Marine Protected Area Monitoring and Co-Management Capacity Building

Appendix 2.10c Fisheries landing questionnaire

Date	Interviewer	Location

INTERVIEWEE

Name of person being interviewed	Are you the Owner ☐ Captain ☐	Do you fish Part-time ☐ Full-time ☐
Age/date of birth		

VESSEL

Name of boat	Type of boat?	Type of hull wood ☐ fibreglass ☐ steel ☐
Length (ft):	Type of engine inboard ☐ outboard ☐	# of engines Horsepower
Where do you moor your boat?	Where do you usually bring your catch ashore?	
Where else do you bring your catch ashore?		

FISHING GEAR

What kind of fishing do you do?
How many of this type of gears do you use in each trip?

FISHING OPERATIONS

What days of the week do you fish? M T W T F S S
What months of the year do you fish? J F M A M J J A S O N D
What are the high fishing months? J F M A M J J A S O N D

What time do you usually leave to go fishing? And to come back? Do you fish on your own or with other people?
FISH CATCHES/LANDINGS
What types of fish do you catch, in order of most to least? How much fish do you usually catch in one trip (lbs per species)? How often do you catch grouper? How often do you catch snapper? How oftern do you catch shark? How often do you catch parrotfish (for spearfishermen alone) Are any of these fish seasonal? Are you aware of any breeding or spawning seasons for these species? Where do you go to fish for these species and other species? Species specific Are there any boundaries on where you can fish?
Do you throw any fish back? What price do you get for your fish per lb ($)?
How have your catches changed over the years in the amount of fish you catch? Species specific
Impact on Fishery
What are the most important threats or impacts to fishing in this area? What should be done to address these impacts? Are there any restrictions from the THA on what you catch? Do you think fishermen should have restrictions on what they catch, where or how they catch it? Do you think protecting some areas from fishing would improve your catch Where? Do you think other fishermen from this village or from another village outside affect your catch? Do you think foreign fishing boats affect your catch? How? Do you think any development on land affect your catch? How? Do you think there are other ways to improve your catch? What are they? How important is conservation of the marine environment to you? Do you have a fishing association, are you part of it and if not then why? Is fishing your only job? If you had a choice, would you prefer to be a fisherman or have a different job? What do you think the THA should do to help manage the fishing or help the fishermen?
Is there anything else that this questionnaire should be asking?

Appendix 2.10.1 AGGRA fish species list

Common name	**Family/Species**
Surgeonfishes	***Acanthuridae***
Doctorfish	*Acanthurus chirurgus*
Blue tang	*Acanthurus coeruleus*
Ocean surgeonfish	*Acanthurus bahianus*
Butterflyfishes	***Chaetodontidae***
Foureye butterflyfish	*Chaetodon capistratus*
Spotfin butterflyfish	*Chaetodon ocellatus*
Reef butterflyfish	*Chaetodon sedentarius*
Banded butterflyfish	*Chaetodon striatus*
Longsnout butterflyfish	*Prognathodes aculeatus*
Grunts	***Haemulidae***
Black Margate	*A. surinamensis*
Porkfish	*Anisotremus virginicus*
White Margate	*Haemulon album*

Common name	**Family/Species**
Tomtate	*Haemulon aurolineatum*
Caesar grunt	*Haemulon carbonarium*
Smallmouth grunt	*H. chrysargyreum*
French grunt	*Haemulon flavolineatum*
Spanish grunt	*H. macrostomum*
Cottonwick	*Haemulon melanurum*
Sailor's choice	*Haemulon parra*
White grunt	*Haemulon plumierii*
Bluestriped grunt	*Haemulon sciurus*
Snappers	***Lutjanidae***
Mutton snapper	*Lutjanus analis*
Schoolmaster	*Lutjanus apodus*
Cubera snapper	*Lutjanus cyanopterus*
Grey snapper	*Lutjanus griseus*

Common name	Family/Species
Dog snapper	*Lutjanus jocu*
Mahogany snapper	*Lutjanus mahogoni*
Lane snapper	*Lutjanus synagris*
Yellowtail snapper	*Ocyurus chrysurus*
Angelfishes	***Pomacanthidae***
Queen angelfish	*Holacanthus ciliaris*
Rock Beauty	*Holacanthus tricolor*
Grey angelfish	*Pomacanthus arcuatus*
French angelfish	*Pomacanthus paru*
Parrotfish	***Scaridae***
Midnight parrotfish	*Scarus coelestinus*
Blue parrotfish	*Scarus coeruleus*
Rainbow parrotfish	*Scarus guacamaia*
Striped parrotfish	*Scarus iseri*
Princess parrotfish	*Scarus taeniopterus*
Queen parrotfish	*Scarus vetula*
Greenblotch parrotfish	*Sparisoma atomarium*
Redband parrotfish	*S. aurofrenatum*
Redtail parrotfish	*S. chrysopterum*
Yellowtail parrotfish	*Sparisoma rubripinne*
Stoplight parrotfish	*Sparisoma viride*
Groupers	***Serranidae***
Coney	*Cephalopholis fulva*
Graysby	*C. cruentata*
Rock Hind	*E. adscensionis*
Red hind	*Epinephelus guttatus*
Nassau grouper	*Epinephelus striatus*
Black grouper	*Mycteroperca bonaci*
Yellowmouth grouper	*M. interstitialis*
Tiger grouper	*Mycteroperca tigris*
Yellowfin grouper	*Mycteroperca venenosa*
Triggerfishes	***Balistidae***

Common name	Family/Species
Queen Triggerfish	*Balistes vetula*
Ocean Triggerfish	*Canthidermis sufflamen*
Black Durgon	*Melichthys niger*
Sargassum Triggerfish	*Xanthichthys ringens*
Moray Eels	***Muraenidae***
Add species as seen	
Wrasses	***Labridae***
Spanish Hogfish	*Bodianus rufus*
Slippery Dick	*Halichoeres bivittatus*
Yellowhead Wrasse	*Halichoeres garnoti*
Puddingwife	*Halichoeres radiatus*
Hogfish	*Lachnolaimus maximus*
Pufferfish	***Diodontidae***
Ballonfish	*Diodon holocanthus*
Porcupinefish	*Diodon hystrix*
Filefishes	***Monacanthidae***
Scrawled Filefish	*Aluterus scriptus*
Whitespotted Filefish	*C. macrocerus*
Orangespotted Filefish	*Cantherhines pullus*
Porgies	***Sparidae***
Jolthead Porgy	*Calamus bajonado*
Saucereye Porgy	*Calamus calamus*
Sheepshead Porgy	*Calamus penna*
Pluma Porgy	*Calamus pennatula*
	Other Fishes
Bar Jack	*Caranx ruber*
Bermuda Chub	*Kyphosus* spp.
Spotted Trunkfish	*Lactophrys bicaudalis*
Yellowtail Damselfish	*Microspathodon chrysurus*
Lionfish	*Pterois* spp.
Bandtail Pufferfish	*Sphoeroides spengleri*
Great Barracuda	*Sphyraena barracuda*

Appendix 2.10.2.1. Mean hard coral cover (% benthic cover ± SE), total species richness (in a $60m^2$ area) and mean species diversity (Shannon-Weiner Index ± SE) in $10m^2$ transects

Site	Region	Mean Coral Cover (%)	Species Richness	Species Diversity
Sanger Rock	Caribbean	37.0±4.0	13	1.17±0.07
Sisters Deep	Caribbean	29.8±3.9	17	1.79±0.08
St Giles	Caribbean	29.7±5.3	11	1.4±0.08
Angel Reef	Speyside	27.8±4.8	20	1.28±0.24
Sleeper	Speyside	25.6±3.7	17	1.57±0.16
Englishman's Bay	Caribbean	17.6±1.6	14	1.69±0.12
Sisters South	Caribbean	16.8±2.6	16	1.67±0.11
Runway	Speyside	15.1±3.7	9	0.81±0.23
Queens Bay	Atlantic	12.0±1.1	15	1.4±0.18
King's Bay	Atlantic	10.3±1.6	11	1.6±0.07
Landslide	Caribbean	8.3±0.7	17	1.75±0.12
Spiny Colony	Speyside	5.7±1.5	13	1.24±0.18
Coral Gardens	Speyside	5.3±0.7	13	1.21±0.13
Belmont Bay	Speyside	2.05±0.5	9	0.9±0.21

Appendix. 2.10.2.2. Coral recruit density (individuals/m^2) for two size classes across sites in the NETMPA

Site	Density	
	<2cm	**2-4cm**
Angel Reef	41.1±9.1	12.9±1.5
Belmont Bay	10.4±3.7	3.1±0.9
Coral Gardens	4.9±1.5	3.1±1.1
Englishman's Bay	9.2±2.8	5.8±2.4
King's Bay	10.1±2.4	2.8±1.3
Landslide	11.3±2.4	4±2.1
Queen's Bay	9.7±3.1	3.2±1.7
Sanger Rock	5.4±1	3.4±1.2
Sisters Deep	11±3.4	4.6±0.7
Sisters South	3.4±2.8	1.4±0.9
Sleeper	10.5±2.8	3±0.8
Spiny Colony	10±6	2±2
St. Giles	3.4±1.8	2.5±1.1

Appendix. 2.10.3. Sponge cover (% benthic cover) averaged across transects at each site in the NETMPA.

Site	AR	BB	CG	EB	SG	KB	LS	QB	SC	SD	SR	SS	SL	RU
Agelas citrina	1.07±0.21	0.13±0.1	3.53±0.88	0.02±0.02	0±0	0.02±0.02	0.02±0.02	1.16±0.54	0±0	0.16±0.13	0.02±0.02	0.02±0.02	0.48±0.13	0.05±0.02
Agelas clathrodes	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0.02±0.02	0±0	0±0	0±0	0.01±0.01	0±0
Agelas conifera	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0
Agelas tubulata	0±0	0±0	0.29±0.22	0±0	0.55±0.36	0±0	0.13±0.06	0.16±0.16	0±0	0±0	0±0	0.5±0.34	0.09±0.09	0.07±0.07
Agelas wiedenmyeri	0±0	0±0	0±0	0±0	0±0	0±0	0.08±0.08	0±0	0±0	0±0	0±0	0±0	0±0	0±0
Amphimedon compressa	0.02±0.02	0±0	2.88±1.31	0±0	0.33±0.19	0±0	0.05±0.05	0.5±0.34	0±0	0±0	0±0	0.19±0.06	0±0	0±0
Aplysina caluiformis	0.14±0.11	0.13±0.07	3.97±1.15	0.27±0.15	2.19±0.74	0.41±0.16	0.86±0.29	0.16±0.16	0.05±0.05	0±0	0±0	0.55±0.31	0.21±0.08	0.22±0.08
Aplysina fistularis	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0
Aplysina fulva	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0.01±0.01	0±0
Callyspongia vaginalis	0±0	0±0	0±0	0±0	0.38±0.2	0±0	0.08±0.05	0±0	0.02±0.02	0±0	0±0	0±0	0±0	0±0
Clathria raraechelae	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0
Clathria sp.	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0
Cliona caribbaea	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0
Cliona delitrix	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0.16±0.16	0±0	0±0	0±0	0±0	0±0	0±0
Cliona varians	0±0	0±0	0.02±0.02	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0
Desmapsamma anchorata	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0
Dipstrella megastellata	0.19±0.12	0.3±0.13	1.08±0.61	0.05±0.05	0±0	0.11±0.07	0.05±0.05	0±0	0.08±0.03	0.02±0.02	0.02±0.02	0.02±0.02	0±0	0.14±0.08
Dipstrella sp.	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0.5±0.22	0±0	0±0	0±0	0±0	0±0	0±0
Ectyoplasia ferox	2.55±0.95	0.8±0.2	4.73±0.87	0±0	0.02±0.02	1.05±0.35	0±0	0.83±0.4	0.02±0.02	0±0	0±0	0.19±0.1	0.27±0.2	0.01±0.01
Iotrohota birotulata	0±0	0±0	1.44±0.77	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0.05±0.05	2.3±0.55	0±0	1.18±0.24
Ircinia campana	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0
Ircinia strobilina	0±0	0±0	0±0	0.02±0.02	0.02±0.02	0.02±0.02	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0
Monanchora arbuscula	0±0	0±0	0.02±0.02	0±0	0.05±0.03	0.11±0.08	0.41±0.27	0±0	0.02±0.02	0±0	0±0	0±0	0.09±0.09	0.01±0.01
Mycale laevis	0±0	0±0	0.02±0.02	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0
Niphates erecta	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0
Phorbas amaranthus	0.02±0.02	0±0	0.08±0.08	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0

Site	AR	BB	CG	EB	SG	KB	LS	QB	SC	SD	SR	SS	SL	RU
Plakortis angulospicculaus	0±0	0±0	0.02±0.02	0±0	0.02±0.02	0±0	0.05±0.03	0.33±0.21	0±0	0±0	0±0	0±0	0.07±0.05	0±0
Ptilocaulis walpersi	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0
Scopalina ruetzleri	0.02±0.02	0±0	0.6±0.11	0.11±0.08	0.08±0.03	0.27±0.12	0.02±0.02	0.83±0.47	0.05±0.03	0.05±0.03	0±0	0±0	1.22±0.55	0.03±0.02
Spirastrella hartmani	0±0	0±0	0±0	0±0	0±0	0±0	0±0	3.66±1.58	0±0	0±0	0±0	0±0	0.05±0.05	0±0
Unidentified	0.14±0.09	1.66±0.78	2.08±0.64	0.13±0.06	1.25±0.27	0.08±0.03	0.3±0.13	0±0	0.19±0.09	0.02±0.02	0.11±0.07	0.27±0.11	0.33±0.33	0.09±0.04
Xestospongia muta	0.19±0.19	3.11±1.11	5.72±1.4	0.05±0.03	5.11±0.4	0.5±0.33	3.41±1.13	0±0	0.75±0.23	4.03±1.33	5.35±1.61	3.41±0.41	8.43±2.26	2.64±0.3

EB=Englishman's Bay SR=Sanger Rock AR=Angel Rock KB=King's Bay
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Appendix 2.10.4. Large (2-4cm) coral recruit density (ind./m^2) ± SE at sites in the NETMPA.

Species	AR	BB	CG	EB	KB	LS	QB	SR	SD	SS	SL	SC	SG
Helioseris cucullata	0±0	0±0	0±0	0±0	0±0	2.6±2.6	0±0	0±0	0±0	0±0	0±0	0±0	0±0
Isophyllia rigida	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	3.2±3.2	0±0	0±0	6.4±3.9
Madracis decactis	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	5.3±3.3	0±0	0±0	0±0	0±0
Meandrina jacksoni	0±0	0±0	0±0	0±0	0±0	2.6±2.6	0±0	0±0	0±0	0±0	0±0	0±0	0±0
Meandrina meandrites	0±0	0±0	2±2	0±0	0±0	2.6±2.6	0±0	3.2±3.2	0±0	0±0	0±0	0±0	0±0
Millipora alcicornis	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	2.6±2.6	0±0	0±0	0±0	0±0
Montastraea cavernosa	0±0	0±0	4±2.6	8±5.4	2.6±2.6	5.3±3.3	0±0	3.2±3.2	5.3±5.3	6.4±3.9	2.6±2.6	0±0	0±0
Porites astreoides	16±0	0±0	4±4	2.6±2.6	5.3±3.3	10.6±7.9	5.3±3.3	0±0	0±0	3.2±3.2	2.6±2.6	0±0	0±0
Pseudodiploria strigosa	0±0	5.3±3.3	0±0	21.3±7.9	5.3±3.3	8±5.4	10.6±5.3	6.4±6.4	2.6±2.6	0±0	2.6±2.6	8±8	9.6±6.4
Scolymia cubensis	0±0	0±0	0±0	2.6±2.6	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0
Siderastrea siderea	0±0	5.3±5.3	6±4.2	8±3.5	10.6±7.9	0±0	13.3±10.4	6.4±3.9	0±0	0±0	0±0	0±0	3.2±3.2
Undaria agaricites	58.6±14.1	8±5.4	2±2	2.6±2.6	0±0	0±0	0±0	0±0	8±8	0±0	8±3.5	0±0	0±0
Undaria humilis	69.3±5.3	5.3±5.3	6±4.2	0±0	0±0	5.3±5.3	2.6±2.6	9.6±6.4	8±5.4	0±0	8±3.5	0±0	0±0

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Appendix 2.9.5. Small (<2cm) coral recruit density (ind./m^2) ± SE at sites in the NETMPA.

Species	AR	BB	CG	EB	KB	LS	QB	SR	SD	SS	SL	SC	SG
I. rigida	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	2.6±2.6	0±0	0±0	0±0	3.2±3.2
M. auretenra	10.6±10.6	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0
M. decactis	0±0	0±0	2±2	0±0	0±0	0±0	0±0	0±0	13.3±10.4	0±0	0±0	0±0	0±0
M. meandrites	0±0	0±0	0±0	2.6±2.6	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0
M. alcicornis	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	13.3±10.4	6.4±3.9	0±0	0±0	0±0
M. cavernosa	0±0	0±0	0±0	10.6±7.9	0±0	5.3±3.3	0±0	0±0	0±0	0±0	0±0	0±0	0±0
P. astreoides	16±9.2	8±8	2±2	2.6±2.6	16±13	8±5.4	13.3±7.6	6.4±3.9	8±5.4	0±0	24±13.5	0±0	0±0
P. strigosa	0±0	18.6±10.4	0±0	13.3±4.9	37.3±8.9	53.3±10.6	37.3±12.8	9.6±9.6	0±0	3.2±3.2	5.3±3.3	56±40	19.2±11.7
S. cubensis	5.3±5.3	2.6±2.6	2±2	10.6±7.9	0±0	10.6±7.9	0±0	6.4±3.9	13.3±8.6	3.2±3.2	0±0	0±0	3.2±3.2
S. siderea	10.6±5.3	10.6±3.3	18±13.6	21.3±9.8	21.3±9.8	2.6±2.6	13.3±7.6	6.4±3.9	10.6±5.3	0±0	0±0	0±0	0±0
U. agaricites	138.6±47.4	8±8	2±2	2.6±2.6	0±0	0±0	0±0	3.2±3.2	8±3.5	12.8±12.8	5.3±3.3	0±0	3.2±3.2
U. humilis	272±33.3	34.6±16.7	16±7.4	5.3±5.3	5.3±5.3	13.3±6.4	10.6±5.3	6.4±3.9	16±10.1	16±16	53.3±15.8	0±0	0±0
Unidentified	0±0	0±0	0±0	0±0	0±0	2.6±2.6	2.6±2.6	0±0	0±0	0±0	0±0	0±0	0±0

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Appendix 2.10.6. Herbivore biomass in shallow (8-13.5m) and deep (13.5-20m) transects at sites in the NETMPA.

Sites	Biomass (kg/100m^2±SE)	
	Shallow (8-13.5m)	Deep (13.5-20m)
Angel Reef	1.19±0.5	2.64±0.94
Belmont Bay	2.99±0.8	NA
Coral Gardens	1.77±0.72	1.91±0.57
Englishman's Bay	3.31±0.43	2.07±0.36
King's Bay	3.09±0.79	3.41±1.1
Landslide	1.91±0.92	NA
Queen's Bay	1.58±0.24	3.51±1.82
Runway	6.89±0.98	7.5±1.58
Sanger Rock	3.3±0.89	5.64±2.95
Sisters Deep	NA	4.6±0.84
Sisters South	9.87±1.52	NA
Sleeper	5.66±1.66	2.15±0.41
Spiny Colony	1.83±0.94	1.65±0.85
St Giles	2.85±0.41	1.68±0.47

Appendix 2.10.7. Mean densities of *P. guttatus* and *P. argus* at sites in the NETMPA from two different survey approaches that cover a 10m^2 and 60m^2 benthic survey area. Numbers in brackets indicate number of transects. Sisters Deep and Landslide were not surveyed with the 10m^2 and 60m^2 approach respectively.

Site	Mean Density (individuals/100m^2)			
	10m^2		60m^2	
	P. guttatus	*P. argus*	*P_guttatus*	*P_argus*
Angel Reef	0.00 (7)	1.43 (7)	0 (6)	0 (6)
Belmont Bay	1.67 (6)	5.00 (6)	0.23 (8)	0.00 (8)
Coral Gardens	0.00 (6)	0.00 (6)	0.34 (7)	0.00 (7)
Englishman's Bay	0.00 (6)	0.00 (6)	0.23 (8)	0.00 (8)
King's Bay	0.00 (6)	0.00 (6)	0.45 (4)	0.15 (4)
Landslide	0.00 (6)	1.67 (6)	NA	NA
Queen's Bay	0.00 (6)	0.00 (6)	0.2 (9)	0.2 (9)
Runway	0.00 (6)	0.00 (6)	0.00 (8)	0.00 (8)
Sanger Rock	0.00 (6)	0.00 (6)	0.00 (7)	0.00 (7)
Sisters Deep	NA	NA	0.00 (5)	0.00 (5)
Sisters South	0.00 (6)	0.00 (6)	0.00 (4)	0.00 (4)
Sleeper	0.00 (6)	0.00 (6)	0.00 (8)	0.08 (8)
Spiny Colony	0.00 (7)	3.33 (7)	0.26 (7)	0.00 (7)
St Giles	0.00 (4)	0.00 (4)	0.00	0.00