BENTHIC COMPOSITION OF CORAL REEFS OF TOBAGO IN 2019 AND SUMMARY REPORT 2010-2019

PREPARED BY

DR ANJANI GANASE
CORAL REEF ECOLOGIST

October 2020

HILLTOP LANE, CHAGUARAMAS
P. O. BOX 3160, CARENAGE POST OFFICE, TRINIDAD & TOBAGO, W.I.
TEL: (868) 634-4291-4; FAX: (868) 634-4433; E-MAIL: imadirector@ima.gov.tt
Website: www.ima.gov.tt
A Statutory body established by Act of Parliament, No. 15 of 1976

© 2020 by The Institute of Marine Affairs (IMA)

Benthic Composition of Coral Reefs of Tobago in 2019 and Summary Report 2010-2019 © 2020 by The Institute of Marine Affairs is licensed under Attribution-Noncommercial-No Derivatives 4.0 International. This license allows users to copy and distribute the information in any medium or format in a non-adapted form only, for non-commercial purposes, and only so long as attribution is given to the Institute of Marine Affairs. To view a copy of this license, visit http://creativecommons.org/licenses/by-nc-nd/4.0/

No part of this research report may be reproduced or translated in any form or by any means, whether for sale or noncommercial distribution, without the permission in writing to the Director of the Institute of Marine Affairs (IMA). For more information of this report please contact the Director:

Director
Institute of Marine Affairs Hilltop
Lane, Chaguaramas
P.O. Box 3160, Carenage
Republic of Trinidad and Tobago
Tel: 1-868-634-4291
Fax: 1-868-634-4433
E-mail: director@ima.gov.tt
Website: www.ima.gov.tt

The Institute encourages fair use of this document and proper citation is requested. This publication may be cited as:

Ganase, Anjani. Benthic Composition of Coral Reefs of Tobago in 2019 and Summary Report 2010-2019. Chaguaramas: Institute of Marine Affairs, 2020.

IMA Library Cataloguing-in-Publication Data

Ganase, Anjani

Benthic Composition of Coral Reefs of Tobago in 2019 and Summary Report 2010-2019. Chaguaramas: Institute of Marine Affairs, 2020.

30 p.; ill.; 22 cm.

Includes references.

ISBN 978-976-8311-15-3

1. Coral reefs. 2. Benthic animals. 3. Trinidad and Tobago. I. Institute of Marine Affairs. II. Title

© Copyright: illustrations and photographs all IMA, except where specified

ACKNOWLEDGEMENTS

Special thanks to the field survey team - Jonathan Gomez, Farahnaz Solomon, Addison Titus and Rachael Amoroso – for their support in the field. Additional thanks to Jonathan Gomez for assistance in the data processing for the automated identification of benthic categories.

ABSTRACT

In 2019, ten coral reefs sites in Tobago were surveyed as part of the Baseline Assessment of Tobago's Coral Reefs Project carried out by the Institute of Marine Affairs (IMA) and compared to the IMA's long-term coral reef monitoring dataset (2010 - 2018). The aim of long-term monitoring is to provide data to observe spatial and temporal trends in coral reef composition and to advise on specific efforts, such as marine spatial planning and ecosystem based management to conserve marine biodiversity. The ten sites were surveyed and analysed for spatial trends in benthic cover, as well as assessed for temporal changes in the benthic composition. Collected images were analysed using a deep-learning framework, which allowed annotators to carry out coral point count analyses guided by machines trained to identify benthic categories using manually analysed datasets. While turf algae dominated all monitoring sites, some sites continued to show prevalence in hard coral cover including Angel Reef and Buccoo Outer Reef. Octocoral communities were more prominent at Buccoo West Reef, Culloden East and Castara, and sponge communities were prominent on Blackjack Hole and Flying Reef. There were significant spatial differences among reef sites with Blackjack Hole being the most dissimilar reef community with regard to benthic composition. Conversely, neighbouring Caribbean reef sites – Castara, Culloden East and West, and Plymouth reefs were the most similar with regard to community composition. Long-term trends show a decline in hard coral cover across sites because of the 2010 coral-bleaching event, with no significant change, further degradation or recovery in the following nine years.

Keywords: coral reef, monitoring, Tobago, benthic analysis, community composition, deep-learning framework

TABLE OF CONTENTS

Page #

1.0 INTRODUCTION 1

2.0 METHODOLOGY 3

2.1 SURVEY SITES 3

2.2 DATA COLLECTION 4

2.3 SEMI-AUTOMATED IMAGE ANNOTATION 4

2.4 DATA ANALYSIS 4

3.0 RESULTS 5

3.1 BENTHIC FUNCTIONAL GROUP DISTRIBUTION 5

3.2 HARD CORAL SPECIES 7

3.3 BENTHIC SPECIES RICHNESS 9

3.4 COMMUNITY ANALYSIS 10

3.5 LONG-TERM TRENDS 12

4.0 DISCUSSION 14

5.0 CONCLUSION 17

6.0 REFERENCES 18

7.0 APPENDIX 22

LIST OF FIGURES

Page #

FIGURE 1: MAP OF CORAL REEF BASELINE ASSESSMENT LOCATIONS AROUND TOBAGO - CORAL REEF MONITORING SITES 2010 - 2019 2

FIGURE 2: BENTHIC COVERS OF MAIN FUNCTIONAL GROUPS FOR TEN MONITORING SITES AROUND TOBAGO SURVEYED IN 2019 6

FIGURE 3: PERCENTAGE COVER OF MAIN FUNCTIONAL GROUPS 7

FIGURE 4: THE TEN MOST PROMINENT HARD CORAL SPECIES PRESENT AT MONITORING SITES IN 2019 8

FIGURE 5: MEAN SPECIES RICHNESS (+/- STANDARD ERROR OF MEAN) OF BENTHIC COMPONENTS PER CORAL REEF MONITORING SITE, TOBAGO 9

FIGURE 6: CLUSTER ANALYSIS OF BENTHIC COMMUNITIES FOUND AT TEN MONITORING SITES ACROSS TOBAGO 11

FIGURE 7: NMDS ORDINATION PLOT FOR MONITORING SITES ACROSS TOBAGO 12

FIGURE 8: NINE YEARS' TRENDS IN CORAL REEF FUNCTIONAL GROUPS FOR TEN MONITORING SITES IN TOBAGO 13

LIST OF TABLES

Page #

TABLE 1: LOCATION OF CORAL REEFS MONITORING SITES IN TOBAGO 3

1.0 INTRODUCTION

While coral reefs of Tobago and the Caribbean have significant cultural and economic value, they also have a long history of chronic and acute disturbances, including overfishing, disease, hurricanes and climate change (Hughes, 1994; Jackson, 1997; Aronson and Precht, 2001; Lessios, 2003; Eakin *et al*., 2010; Alemu I and Clement, 2014). Many Caribbean reefs have also shown limited recovery following disturbance events, which includes hurricane and coral bleaching events, as a result of chronic pressures, such as land-based sources of pollution and overfishing, that cripple the reef ecological functions that facilitate reef resilience to disturbances (Nyström and Folke, 2001; Gardner *et al*., 2005; Steneck *et al*., 2019). Furthermore, with persistent disturbances without recovery, coral reefs with less than 10 % hard coral cover are thought to be too little to support a net accreting condition and function as a habitat provider (Perry *et al*., 2013). As Tobago's coral reefs are a fundamental part of Tobago's island ecology and economy - an estimated US$33 million annually in shoreline protection and supporting approximately 30,000 jobs - it is essential to fully understand the current state of Tobago's reefs in order prescribe the measures needed to boost reef recovery and resilience (Burke *et al*. 2008). Dominant chronic drivers of coral reef degradation in Tobago and throughout the Caribbean, include land based sources of pollution (Lapointe *et al*., 2010), coastal land clearing that leads to sedimentation and smothering of corals, and long-term over exploitation of fish species (Burke *et al*., 2004; Mora, 2008; Mallela *et al*., 2010). While the intensity of local pressures vary at a smaller geographic scale, anthropogenic driven climate change that drives thermal stress events and coral bleaching has a more widespread impact at the country or regional scale (Eakin *et al*., 2010; Alemu I and Clement, 2014)

The Institute Marine Affairs (IMA) has been monitoring permanent reef sites around Tobago over the last ten years to assess the spatial and temporal changes in coral reef health throughout Tobago, in order to advise on specific management efforts to curb biodiversity loss. The monitored reef sites cover a range of environmental conditions that may influence the level of coral degradation, the recovery ability of the reef, as well as changes in the community composition (Figure 1). Previous monitoring results have revealed significant declines in hard coral cover, mainly as a result of the 2010 regional coral bleaching event that impacted most monitoring sites (Alemu I and Clement, 2014; Amoroso, 2017). Corresponding with a significant drop in coral cover, other benthic community types such as macroalgae have showed an increase in dominance in the following years (IMA, 2016). Since the 2010 bleaching event, hard coral

cover appears to have remained stable or shown minor declines at some survey sites, but no recovery (Buglass et al 2016, Amoroso, 2017).

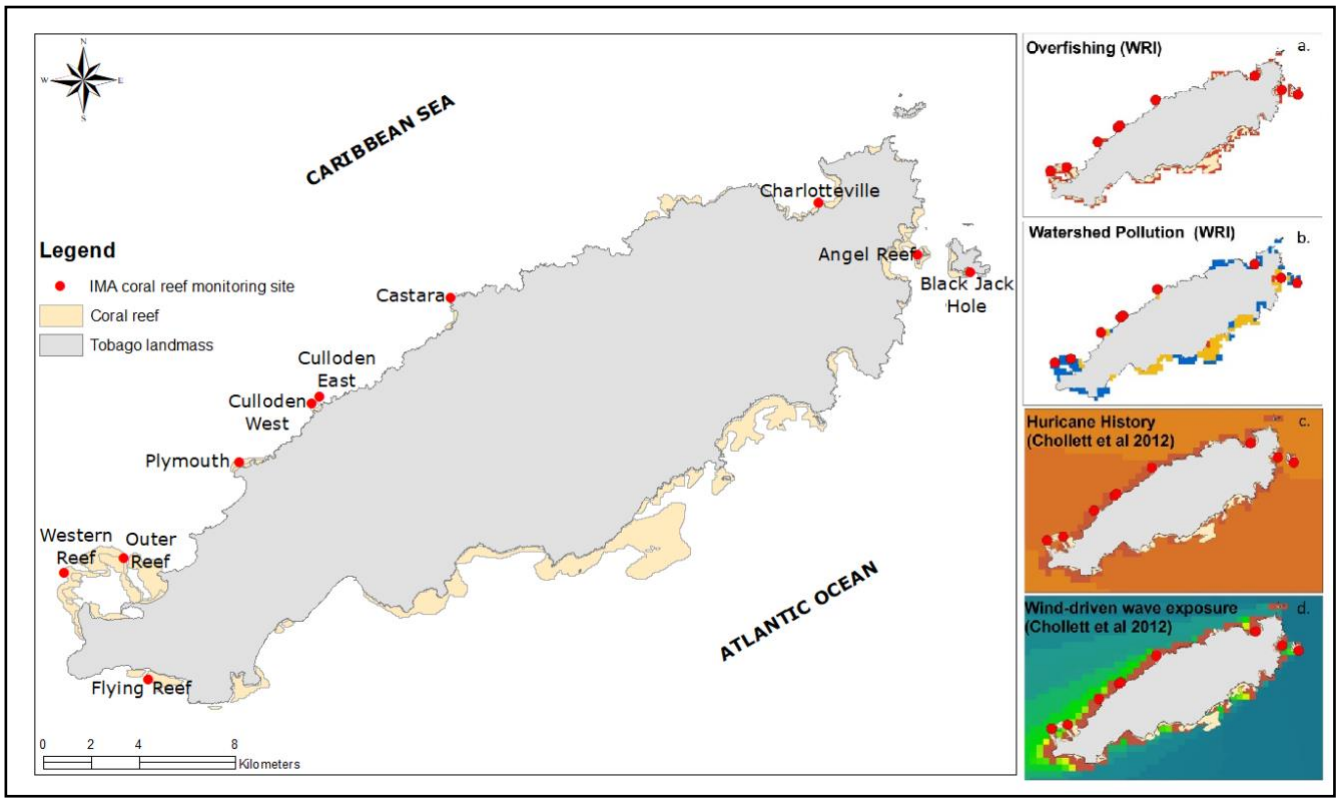


FIGURE 1: MAP OF CORAL REEF BASELINE ASSESSMENT LOCATIONS AROUND TOBAGO. CORAL REEF MONITORING SITES 2010 – 2019

Side panel showing some of the environmental conditions experienced across different locations. Right Panel: a. Overfishing and b. Watershed pollution intensity increasing from blue to red derived from modelled based threat analysis (Burke and Maidens 2005); c. Hurricane history (number of hurricane with 50 km over the last 157 years) increases from yellow to orange; d. Wind driven wave exposure increases in intensity from green to blue (red shows no data) (Chollett *et al*. 2012).

The Baseline Assessment of Coral Reefs of Tobago Project carried out in 2019 by the IMA, is a comprehensive assessment of the environmental, ecological and structural states of coral reefs around Tobago. As part of the ecological component of the project, benthic monitoring was done in conjunction with fish surveys and measurements of structural complexity of coral reef site to characterise the biodiversity and habitat potentials of sites across Tobago. The analysis of the benthic component of the project is the focus of this report. While the Baseline Assessment project adopts the survey methods of the IMA's long-term coral reef monitoring programme, it seeks to standardize and fast track the image annotation phase of the benthic assessment with the use of a semi-automated analysis tools (Beijbom *et*

al., 2015). The aim of this report is to provide a data output on the benthic state of coral reefs in 2019 to guide the understanding of the ecological conditions of the reefs to support management and planning.

2.0 METHODOLOGY

2.1 SURVEY SITES

The IMA's long-term coral reef monitoring programme has permanent monitoring transects at ten locations around Tobago. Figure 1 shows a map of the monitoring stations as well as modelled environmental conditions (wave exposure, hurricane history (Chollett *et al*., 2012); overfishing, watershed pollution derived from modelled based threat analysis (Burke and Maidens 2005) at various locations in Tobago. Monitoring sites represent developed hard coral reefs that are typical along the Caribbean coastline, northeast and southwest coastline (Table 1). Four locations were established in 2010: Buccoo Reef (outer and western reef) and Culloden Reef (east and west). Angel Reef was added in 2014 and Blackjack Hole in 2015. Castara, Plymouth and Charlotteville were added in 2016. Flying Reef was added as the tenth survey site in 2019. In 2019, all sites were monitored for spatial and temporal changes in benthic cover, fish and invertebrate composition and coral structural complexity. The focus of this report will be on the results of benthic surveys.

TABLE 1: LOCATION OF CORAL REEFS MONITORING SITES IN TOBAGO

Site #	Common Name	Latitude (UTM WGS84 m)	Longitude (UTM WGS84 m)	Depth Profile	Coastline Profile
1	Buccoo Western Reef	735175	1237188	3m – 15m	Sandy Bay
2	Buccoo Outer Reef	737665	1237811	10m – 30m	Sandy Bay
3	Culloden Western Reef	745493	1244256	3m – 15m	Sandy Bay
4	Culloden Eastern Reef	745822	1244533	3m – 15m	Sandy Bay
5	Castara	751274	1248667	3m – 30m	Sandy Bay
6	Plymouth	742463	1241814	3m -15m	Rocky Shore
7	Charlotteville	766598	1252635	3m – 30m	Sandy Bay
8	Angel Reef	770732	1250446	3m – 20m	Sandy/Rocky Shore
9	Blackjack Hole	772912	1249743	15m – 40m	Rocky Shore
10	Flying Reef	738659	1232756	3m – 20m	Rocky Shore

2.2 DATA COLLECTION

Surveys were carried out during the last two weeks of July in 2019. One site was surveyed for benthic composition per day. At every site, photo-transects were taken along the entire length of the ten established permanent 10 m transects. Each image included a reef area of 1 m^2 defined using a one metre-squared quadrat. This methodology is consistent with the long-term monitoring programme of the IMA and is derived from methods described in Hill and Wilkinson (2004).

2.3 SEMI-AUTOMATED IMAGE ANNOTATION

Image annotations were done using the CoralNet Platform (https://coralnet.ucsd.edu) and the details of the training process for semi-automated image analysis is explained in 7.0 Appendix – CoralNet semi-automated annotation. CoralNet is an online benthic image analysis tool that employs the use of a deep-learning framework (also known as neural networks) to automate the process of image annotations in a standardized and accurate manner (Beijbom *et al*., 2015). CoralNet is trained using previous Coral Point Count (CPC) annotations and images from IMA's long-term monitoring dataset (2010 to 2017) (7.0 Appendix). The 2019 images were then uploaded to CoralNet and annotated manually with recommendations from the deep-learning framework based on the training data provided by previous datasets (7.0 Appendix). The annotation process on CoralNet uses a similar interface as the CPC method. Each image was annotated using 60 random points within the 1 m^2 quadrat area to determine percentage cover.

2.4 DATA ANALYSIS

Community Analysis

Diversity of all benthic taxa present at the survey site was measured using species richness among survey sites. The benthic community composition at species level was compared across sites using Bray-Curtis dissimilarity function of the percentage covers. A similarity profile permutations test (SIMPROF) was also run to determine significant clusters based on Group Average using PRIMER statistical software v. 6 (1000 permutations, 999 to generate null distribution for statistical calculations). A non-metric multidimensional scaling (nMDS) was also carried out to visualise the distributions of the survey sites on a two dimensional space, where spacing is governed by the cluster analysis (PRIMER v. 6). The percentage cover of benthic species was transformed for this process using square root transformation as part of the statistical methodology. A one-way ANOSIM (PRIMER v. 6, 999 permutation, pair-wise

comparisons) was carried out to determine if there were significant differences among monitoring sites with respect to the benthic community composition. Outputs of the ANOSIM provide an R value (values range between -1 and 1, a value close to + 1 indicates high separation between samples, while R value close to 0 indicate no separation) and a P value (the significance value is set at 1 in 1000 or $P<0.001$, or $p<0.1$ %).

Long-Term Data Analysis (2010 – 2019)

Sites were compared for changes in hard coral percentage cover using a Generalised Least Squared analysis for repeated measures between sites and across years (R; non-linear mixed effect (nlme) package, significant P-value < 0.05). The transect number was represented in the model as a random variable and Year variable was included for autocorrelation structure analysis. Model residuals assessed for normality and homogenous variance (Zuur *et al*., 2010). To determine whether there was any continued decline in hard coral cover in the years (2011 – 2019) following the 2010 bleaching event, the same Generalised Least Squared analysis for repeated measures between sites and across years was carried out without 2010 data.

3.0 RESULTS

3.1 BENTHIC FUNCTIONAL GROUP DISTRIBUTION

Hard coral (hc) and octocorals (octo) were the main the contributors to the 3D matrix of most coral reefs sites in Tobago. Hard coral communities were most prominent at Angel Reef (~19.8 ± 3.3 %) and Buccoo Outer Reef (18.8 ± 3.4 %), while octocoral communities were more prominent at Buccoo West Reef (28.1 ± 2.6 %), Culloden East (29.4 ± 2.3 %) and Castara (29.2 ± 3.5 %) (Figure 2). The majority of the reefs have mixed hard coral and octocoral assemblages, including Culloden West (hc – 16.3 ± 3.5 %, octo – 15.0 ± 3.8 %), Plymouth (hc – 14.1 ± 1.4 %, octo – 20.2 ± 2.0 %) and Booby Island (hc – 16.2 ± 2.2 %, octo – 17. 6 ± 3.0 %) (Figure 2). Blackjack Hole and Flying Reef were the only reefs to have a prevalent cover of sponge communities compared to the other sites (16.1 ± 1.9 % and 7.6 ± 0.5 % respectively) and the lowest hard coral cover compared to the reef of the sites (7.4 ± 1.4 % and 4.8 ± 0.8 % respectively) (Figure 2).

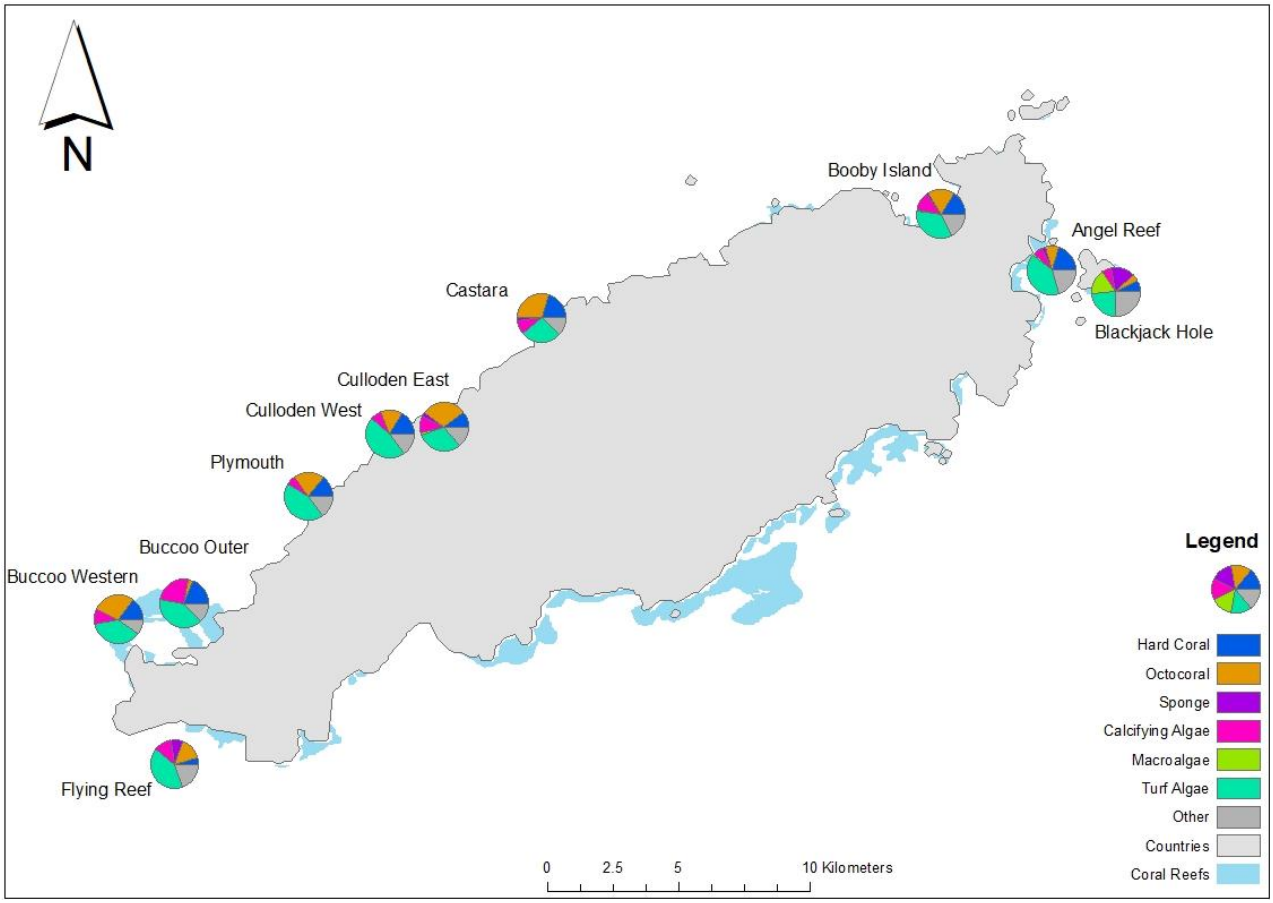


FIGURE 2: BENTHIC COVERS OF MAIN FUNCTIONAL GROUPS FOR TEN MONITORING SITES AROUND TOBAGO SURVEYED IN 2019

All monitoring sites across Tobago were dominated by turf algae as the largest functional component, making up to 46 % cover of the reefscape (Figure 3). Calcifying algae cover was highest at Buccoo Outer reef (25.3 ± 4.5 %), while at the other sites, calcifying algae ranges between 6 – 12 % (Figure 3). Macroalgae were only prevalent at Blackjack Hole (16.6 ± 2.8 %), while at other sites they are generally lower than 2 % (Figure 3). Soft substrate also made up a significant portion of benthos at Blackjack Hole (12.9 ± 5.3 %) (Figure 3). The presence of other groups, such as zoanthids, appeared to be more common on Caribbean Sea reefs, namely Castara, Culloden and Plymouth (Figure 3).

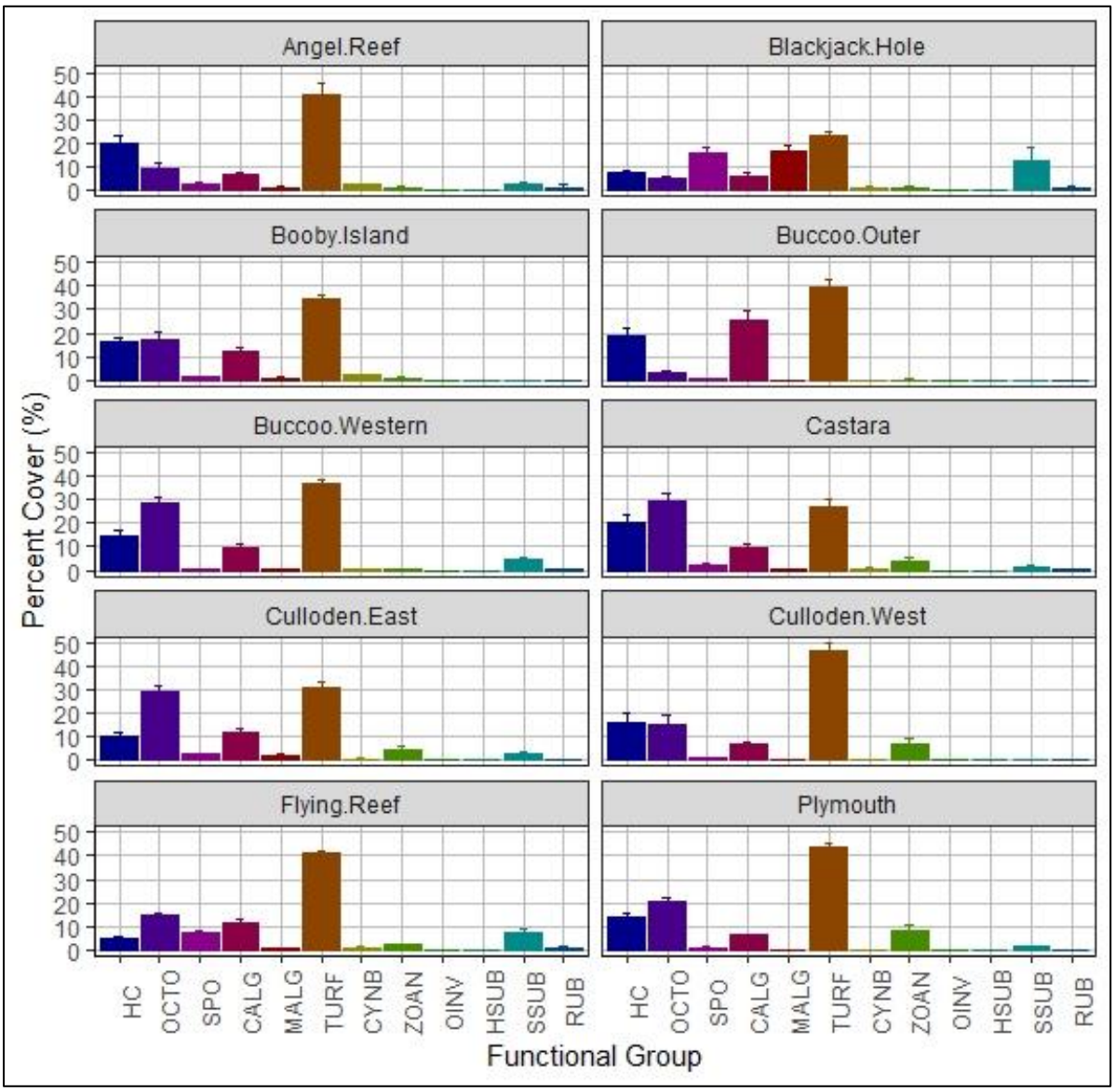


FIGURE 3: PERCENTAGE COVER OF MAIN FUNCTIONAL GROUPS

Hard Coral (Hc), Octocoral (Octo), Sponge (Spo), Calcifying Algae (Calg), Macroalgae (Malg), Turf Algae (Turf), Cyanobacteria (Cyan), Other Invertebrates (Oinv), Hard Substrate (Hsub), Soft Substrate (Ssub), Rubble (Rub) For Ten Monitoring Sites Across Tobago In 2019

3.2 HARD CORAL SPECIES

Orbicella faveolata is the dominant coral species present on most of the surveyed reefs, with the exception of Blackjack Hole and Flying Reef where hard coral cover is low in general. The largest *Orbicella faveolata* cover can be found at Buccoo Outer Reef (12.1 ± 2.9 %). *Orbicella annularis*, another major reef builder for the Caribbean, however is less common at survey sites and only occurs on Angel Reef (2.6 ± 1.7 %). Other prominent hard coral species include *Colpophyllia natans*,

Pseudodiploria strigosa, *Montastraea cavernosa* and *Siderastrea siderea*, which are all massive boulder growth forms. Finger and branching morphologies of hard corals, such as *Madracis mirabilis*, *Porites porites* and *Dendrogyra cylindrus* are hardly captured on monitoring sites. *Madracis mirabilis* are only found on Atlantic sites – Angel Reef and Blackjack Hole at the survey depth (Figure 4).

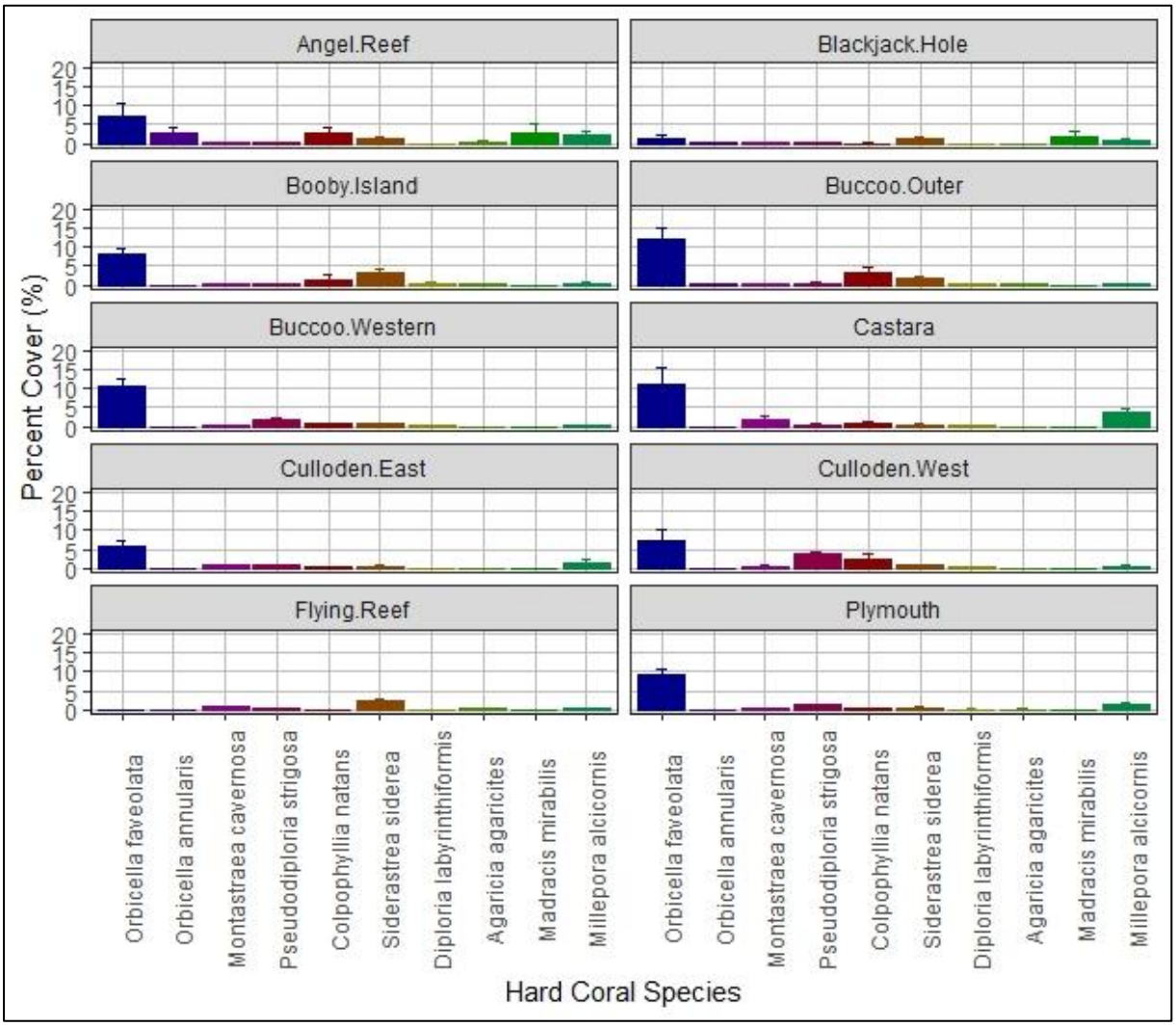


FIGURE 4: THE TEN MOST PROMINENT HARD CORAL SPECIES PRESENT AT MONITORING SITES IN 2019

3.3 BENTHIC SPECIES RICHNESS

The highest mean species richness of the benthic taxa occurs at the two northeast Atlantic sites – Angel Reef and Blackjack Hole (26.6 ± 1.8 and 27.6 ± 1.3 species respectively), and 26.8 ± 0.7 species at Culloden East along the Caribbean coast (Figure 5). Buccoo Outer Reef had the lowest species richness (15.7 ± 0.8), while the remainder of the sites have a species richness range between 20 – 25 species (Figure 5). Higher species richness is associated with greater environmental heterogeneity and ecosystem health (Stein *et al.*, 2014).

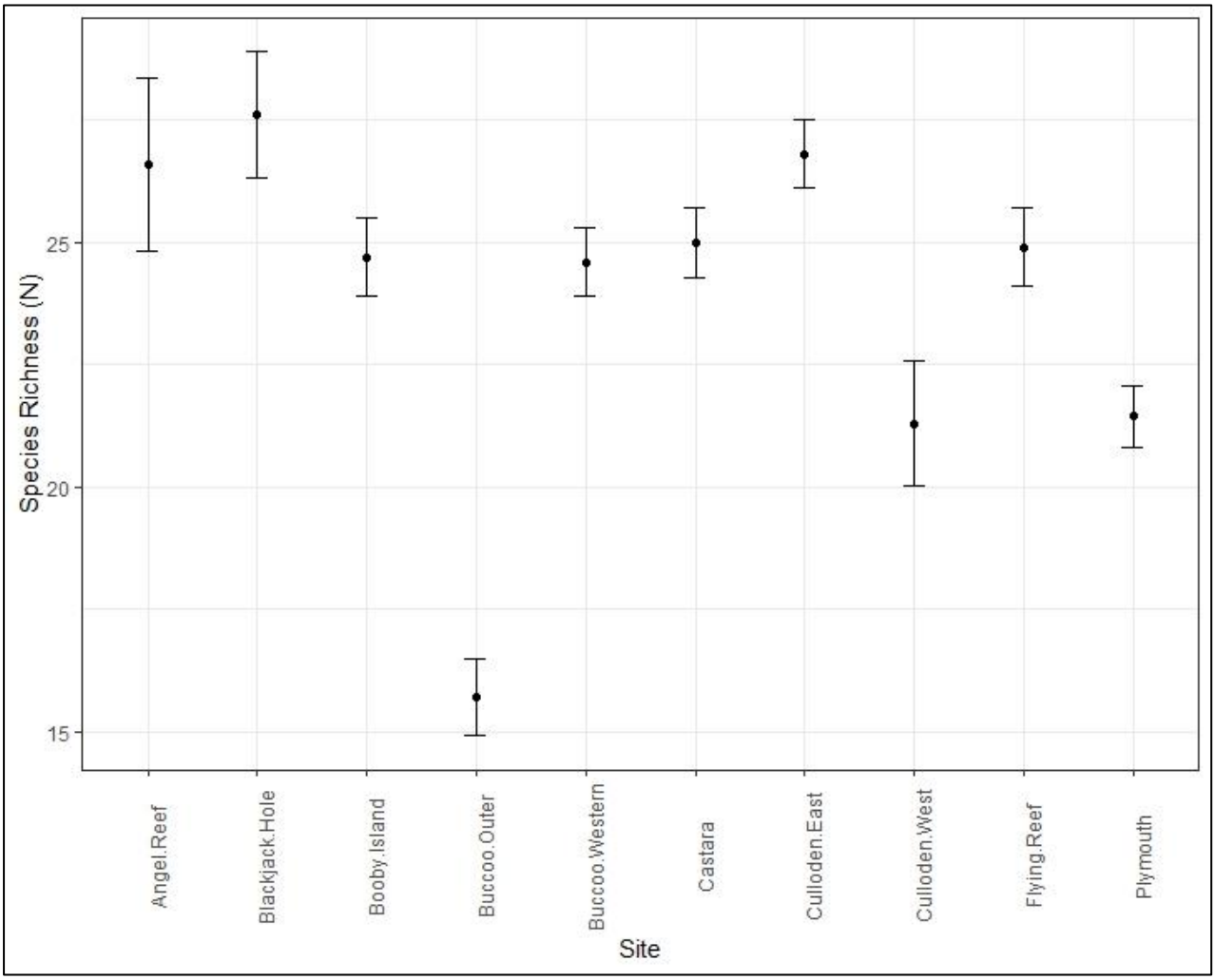


FIGURE 5: MEAN SPECIES RICHNESS (+/- STANDARD ERROR OF MEAN) OF BENTHIC COMPONENTS PER CORAL REEF MONITORING SITE, TOBAGO

3.4 COMMUNITY ANALYSIS

The Bray-Curtis similarity cluster analysis identified significant distinctions among the monitoring sites where reef communities in close proximity tend to cluster together. Survey sites in Speyside, Blackjack Hole and Angel Reef, showed the most distinction in benthic composition compared to all other monitoring sites and to each other (Figure 6). The distinctions in the benthic compositions for Blackjack Hole includes high covers in sponge, soft substrate and macroalgae and therefore shows only ~ 50 % similarity with the rest of the sites (Figure 6). Angel Reef is another unique reef site with species of hard corals found on no other site and shows ~ 55 % similarity with other sites (Figure 6). Even within Angel reef there is considerable variation in benthic composition. Conversely, the following sites cluster together around 65 % similarity (Figure 6):

1. Sites along the Caribbean coast that are in close proximity – Culloden, Castara and Plymouth
2. Buccoo Western Reef and Flying Reef
3. Buccoo Outer Reef and Booby Island

Higher similarities can be found among transects within sites. The non-metric multi-dimensional scaling (MDS) ordination displays similar separation of sites based on community composition (Figure 7).

Results of the one-way ANOSIM confirm that there were significant differences in the community composition among sites ($R = 0.816$, $p < 0.1$ %). Pairwise comparisons revealed that there is significant variability in species composition among most sites. Blackjack Hole had the highest dissimilarities with most other sites ($R > 0.9$), except for Angel Reef ($R = 0.693$). The sites that show the greatest similarities are Plymouth and Culloden West ($R = 0.418$), Castara and Culloden East ($R = 0.319$), and Angel Reef and Booby Island ($R = 0.494$), yet all comparisons still show that differences as significant ($p < 0.1$ %).

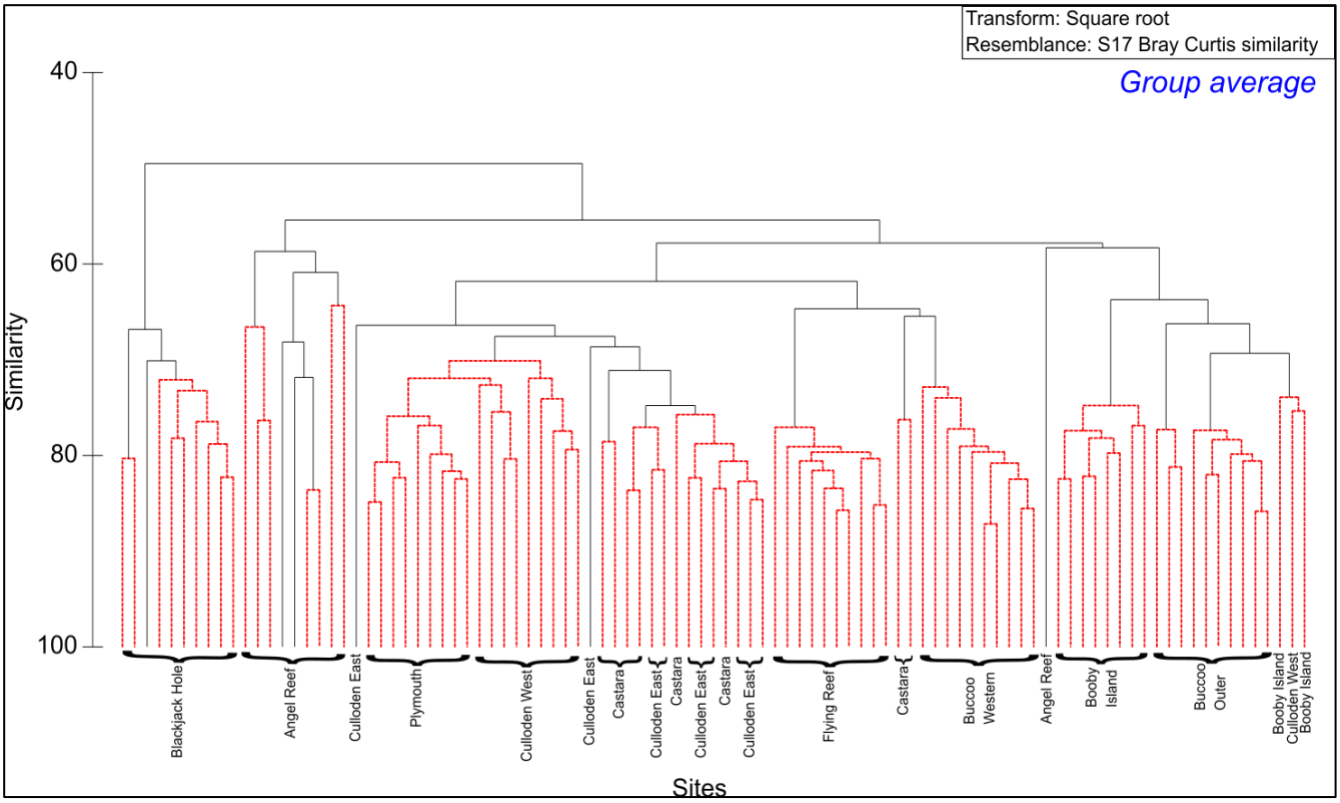


FIGURE 6: CLUSTER ANALYSIS OF BENTHIC COMMUNITIES FOUND AT TEN MONITORING SITES ACROSS TOBAGO

Bray Curtis similarity method for clustering using Group Average. Significant clusters are identified by black lines using the SIMPROF test

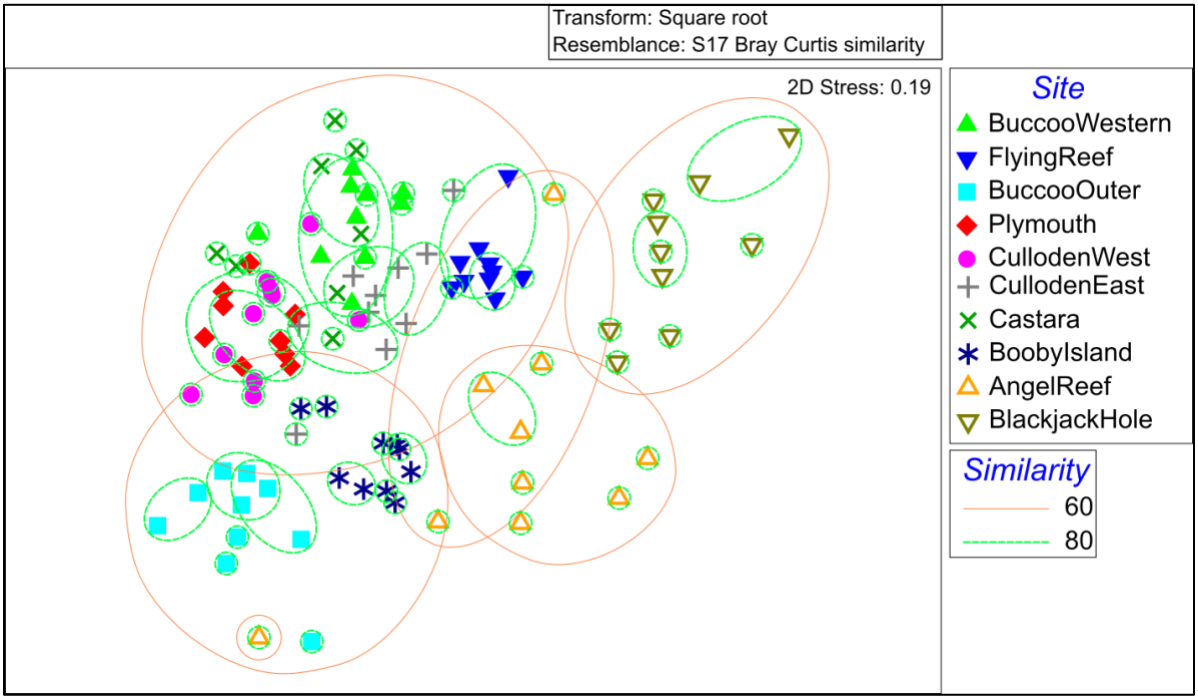


FIGURE 7: NMDS ORDINATION PLOT FOR MONITORING SITES ACROSS TOBAGO

Orange (60 % similarity) and green lines (80 % similarity) group sites based on the Bray-Curtis Similarity among sites

3.5 LONG-TERM TRENDS

Overall, the Generalised Least Squared analysis showed a significant decline in hard coral cover over time across all sites (t-value = -2.24, p-value = 0.0255) (Figure 8). However, following the 2010 decline in hard coral cover because of the 2010 bleaching event, there was no significant change in hard coral cover between 2011 and 2019 (t-value = -1.77, p-value = 0.0765). While the results show that there have been no major disturbance event to hard corals since 2010, it also implies that no recovery of hard corals at any of the sites has occurred since the major 2010 bleaching event. The only significant difference in hard coral cover was found among the survey sites (ANOVA: chi-squared = 169.11, P-value < 2e-16), where Angel Reef had highest hard coral cover compared to the rest of the sites, while Blackjack Hole had the lowest. Corresponding with the hard-coral cover decline from 2010 to 2011 is the steady increase in turf algae cover in 2011 (Figure 8). Calcifying algae also showed a decline after 2010 in Culloden (both sites) and Buccoo Western reefs. However calcifying algae is appearing to be more prevalent on Buccoo Outer Reef (Figure 8). Buccoo West showed an increase in octocoral community cover from 2014 – 2019 (Figure 8).

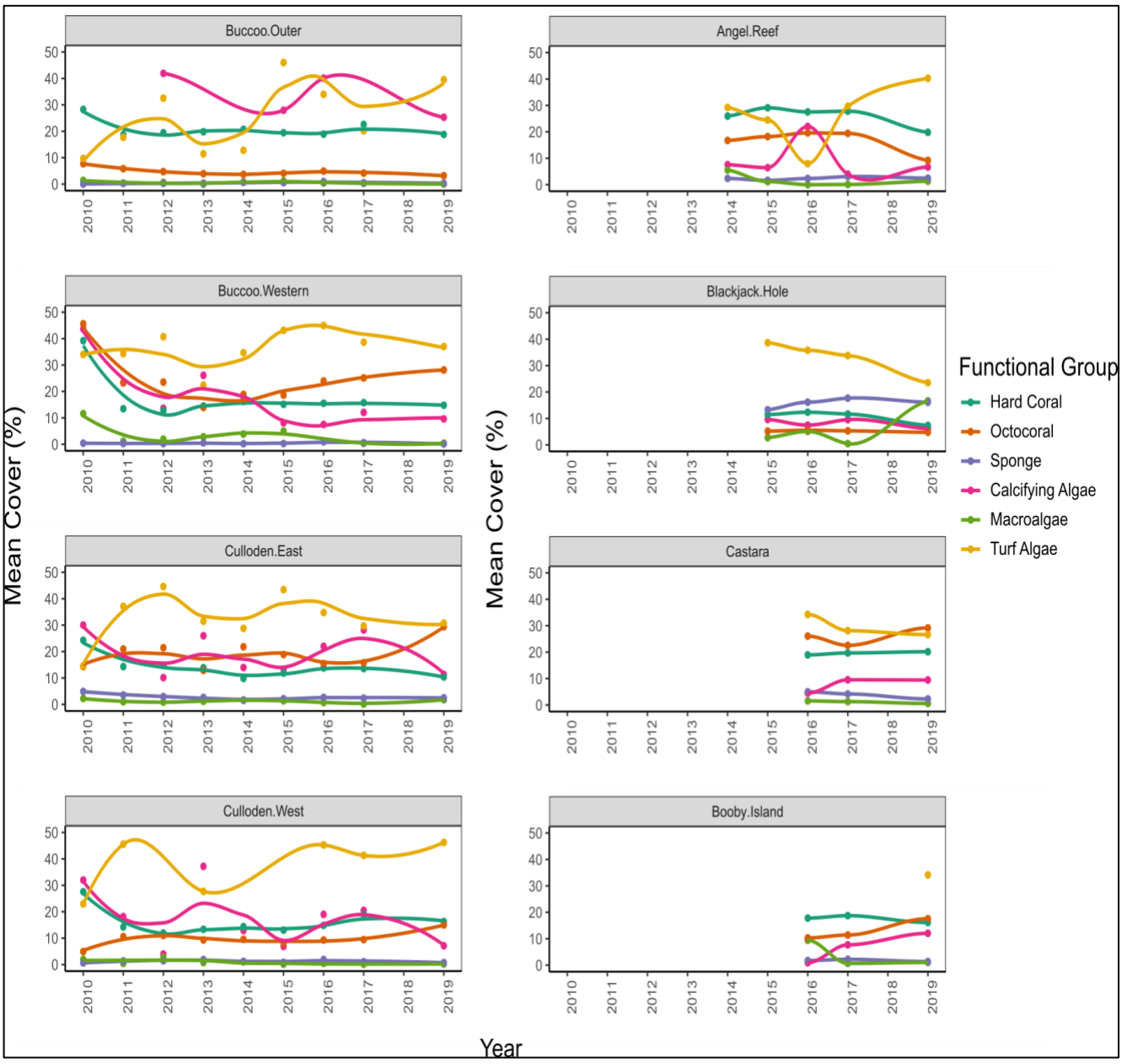


FIGURE 8: NINE YEARS' TRENDS IN CORAL REEF FUNCTIONAL GROUPS FOR TEN MONITORING SITES IN TOBAGO

Graphs on the left represent sites monitored since 2010. While graphs on the right show sites that were added in the years after. The trend in Flying Reef was not included since it was only surveyed once in 2019.

Of the more recently established sites, Angel Reef has shown consistent dominance in hard coral cover from 2014 to 2017, but a decline in 2019 that corresponded with an increase in turf algae (Figure 8). Octocoral communities also declined in cover in 2019, compared to previous years at Angel Reef (Figure 8). Throughout the years, Blackjack Hole is the only reef to show a prominent sponge community, being

the dominant community apart from turf algae. From 2017 to 2019, there appears to have been a sudden increase in macroalgae cover at Blackjack Hole and a corresponding decline in turf algae (Figure 8). Castara Reef shows a consistent benthic cover from 2016 to 2019, dominant in octocorals, followed by hard corals throughout the years. Booby Island also shows consistent benthic cover from 2016 to 2019 with hard coral cover being the most prominent, with the exception of calcifying algae steadily increasing (Figure 8).

4.0 DISCUSSION

All sites surveyed were dominant in turf algae (up to 46 %), while hard coral cover ranged between 7.6 - 19.8 %. Octocoral communities were also prevalent on many of the survey sites (up to 29.4 % cover). Of the hard coral species, *Orbicella faveolata*, makes up a significant portion of the reef composition followed by massive growth forms, such as *Colpophyllia natans* and *Pseudodiploria strigosa*. A few sites, such as Blackjack Hole and Flying Reef, had high sponge and macroalgae cover and correspondingly low hard coral cover. Cluster analysis revealed dissimilar reef community types, where Atlantic reef sites, Angel Reef and Blackjack Hole, were distinct from the rest of the survey sites. Conversely, greatest similarities were found in neighbouring Caribbean reefs – Plymouth, Castara and Culloden Reefs. Long-term trends confirm a significant decline in hard coral cover as a result of the 2010 bleaching event, but no significant changes in the hard coral covers in the following nine years. There were significant variations in the hard coral cover composition among sites for the surveyed years.

The changes in benthic composition on reefs across Tobago are indicative of the trajectory of coral health and imply changes in their functional integrity. With regard to the hard coral community composition, O*rbicella faveolata*, a known major coral reef builder on Caribbean coral reefs, was the dominant contributor to hard coral cover. *O. faveolata* tend to dominate on fore reef slope environments between 8 – 15 m, but can occur shallower or deeper areas depending on water conditions (Geister, 1977). Other prominent hard corals are the massive, brain corals – *Colpophyllia natans* and *Pseudodiploria strigosa*, which are stress tolerant corals common to reefs of Tobago (Darling *et al.*, 2012). Hard corals are ecosystem engineers; they contribute the structural complexity and integrity of the reef that can, in turn, be utilised as habitats supporting marine biodiversity. While octocorals and sponges also contribute to

the three-dimensional space, they are only established on an existing reef infrastructure. Higher coral cover and diversity (species richness) can support a higher biodiversity of fish and invertebrate populations and is associated with greater environmental heterogeneity and ecosystem health (Komyakova *et al.*, 2013). Therefore, sites such as Angel Reef and Castara Reef may house higher biodiversity compared to other sites and additional fish and invertebrate surveys should confirm this. However, as benthic cover continues to shift away from hard coral dominance towards non-reef builders, such as soft corals, sponges and algae, the limited accretion of hard coral skeleton may result in a net erosion of the reef framework (Perry *et al*., 2013), and may get worse with ocean acidification. Unfortunately, some of the monitoring sites may already be at risk of net reef erosion owing to the low hard coral cover, including Blackjack Hole and Flying Reef. As Flying Reef was only added to the monitoring sites in 2019, it is not certain whether Flying Reef had higher coral cover in previous years or whether it has always been low in hard corals and therefore a non-net accreting reef system.

With regard to other substrate types, the main indicators of coral health are substrates that encourage hard coral settlement and growth, such as crustose coralline algae, where certain species encourage coral recruitment. However, some species of calcifying algae may also inhibit coral recruitment through direct overgrowth by aggressive and chemical defended species, such as Peyssonnelia algal crust (PAC) species (Edmunds *et al*., 2019). Calcifying algae cover is highest at Buccoo Outer Reef (25 %) implying that it has great potential for coral recruitment, while at the other sites, calcifying algae ranges between 6 – 12 %. Further investigation should be done to determine the dominant species of calcifying algae present at Buccoo Outer Reef and other sites and assess whether they do, in fact, promote coral recruitment and growth.

Other substrates, such as algae, including thick turf algal mats and macroalgae, sponges and soft corals are competitors of hard coral for space and can limit recruitment through settlement and recruitment prevention or by directly smothering coral recruits through overgrowth (Birrell *et al.*, 2005; Box and Mumby, 2007). High macroalgae cover and turf algae are a result of a combined influence of high nutrient conditions and/or low grazing pressure (Vermeij *et al*., 2010). Solutions, such as the protection of herbivorous fish will be crucial to curb the blooming impacts of algae on the reefs, especially during periods of higher nutrient influx, which is more likely during the wet season. Macroalgae was only prevalent at Blackjack Hole (16.6 %), which posits Blackjack Hole as a unique site. Further investigation

is needed to determine what drives high macroalgae at Blackjack Hole, including nutrient loads, fishing pressures or another unknown type of influence.

Octocorals appear to inhibit coral growth through direct overshadowing and sweeping of hard coral surfaces (personal observation). Damage to the coral tissue exposes the coral to disease infection (Aeby and Santavy, 2006). Sponge communities are prevalent in the Caribbean (Wilkinson and Cheshire, 1990) and especially on Tobago's reefs, likely because of Tobago's proximity to the Orinoco Delta, but also potentially as a result of high local nutrient deposits. Sponges can filter out and regulate the nutrient conditions of the reef (Maldonado *et al*., 2012). Again, Blackjack Hole showed significant amounts of sponge communities and further investigations should determine the environmental conditions that encourage macroalgae and sponge growth as opposed to turf algae growth and other community members at this site. Insights into the potential drivers of the unique community patterns at Blackjack Hole may be revealed when the benthic data is assessed with prominent environment conditions and/or localised disturbances. Further investigations will be done through the Coral Reef Baseline Assessment Project.

The 2010 coral-bleaching event was a major disturbance event that significantly reduced the hard coral cover at all monitoring sites and resulted in the shift in the benthic community composition toward higher turf algae, sponge and octocoral cover. In the nine years after, coral reefs of Tobago have not experienced other significant disasters that would have resulted in further mass coral death, including mass coral bleaching or hurricane impacts. However, the results highlighted that there has been little to no recovery of hard coral cover over the last ten years. Sites need to continue to be assessed individually to determine why hard coral cover recovery is being inhibited – be it competition with algae or limited coral recruitment, or nutrient pollution (Buglass et al 2016). Restoration methods can then focus on improving the environmental conditions to support hard coral recruitment and survival.

5.0 CONCLUSION

While most coral reefs of Tobago today are dominated by turf algae, there are still components of the benthic community that contribute to important ecological functions on the reef sites. Cluster analysis revealed that the coral reefs of Speyside – Angel Reef and Blackjack Hole are distinct from all other survey sites, as well as from each other. Conversely, sites along the Caribbean coast - Culloden, Castara and Plymouth – are the most similar in community composition. Most reefs, with the exception of Blackjack Hole and Flying Reef, are dominated by *Orbicella spp*. as an important reef builder in the Caribbean. Unfortunately, hard coral cover has continued to show no recovery in 2019 following the major bleaching event in 2010, as well as continued to display a gradual decline in coral cover over the last nine years. Outputs of the benthic analyses provide insights for the recommended research steps including further exploration in discretizing the type of calcifying algae that are prominent on certain reefs and the potential for coral recruitment. This will allow viable sites for passive and active coral reef restoration to be identified.

As the patterns in benthic composition of Tobago's coral reefs are reflective of reefs in the Caribbean that are impaired with regard to their ecological recovery potential, Tobago's reefs require management strategies that encourage hard coral recruitment, growth and survival. These include the protection of important reef grazers, such as parrotfish and sea urchin species, as well as managing land-based sources of pollution that encourage algal blooms. In addition to these strategies, assessments in hard coral recruitment may reveal the need for active forms of coral restoration, such as coral farming and propagation (Mumby *et al*. 2014).

The benthic data assessed in this report will be evaluated along with additional dataset collected, such as structural complexity and fish community data to discretize the spatial patterns with prominent environmental drivers. Comparisons of the spatial patterns of the benthic communities and the structural complexity should be reflective of the fish communities that utilise the reef habitat within different environments.

6.0 REFERENCES

Aeby GS, Santavy DL (2006). Factors affecting susceptibility of the coral Montastraea faveolata to black-band disease. Mar Ecol Prog Ser 318:103–110

Alemu I JB, Clement Y (2014). Mass coral bleaching in 2010 in the Southern Caribbean. PLoS One 9:

Amoroso R (2017) Coral Reef Monitoring For Tobago. Institute of Marine Affairs

Aronson RB, Precht WF (2001). White-band disease and the changing face of Caribbean coral reefs Richard. Hydrobiologia 460:25–38

Beijbom O, Edmunds PJ, Roelfsema C, Smith J, Kline DI, Neal BP, Dunlap MJ, Moriarty V, Fan T-Y, Tan C-J (2015). Towards automated annotation of benthic survey images: Variability of human experts and operational modes of automation. PLoS One 10:e0130312

Birrell CL, McCook LJ, Willis BL (2005). Effects of algal turfs and sediment on coral settlement. Mar Pollut Bull 51:408–414

Box SJ, Mumby PJ (2007). Effect of macroalgal competition on growth and survival of juvenile Caribbean corals. Mar Ecol Prog Ser 342:139–149

Buglass S, Donner SD, Alemu I JB (2016). A study on the recovery of Tobago's coral reefs following the 2010 mass bleaching event. Mar Pollut Bull 104:198–206

Burke L, Greenhalgh S, Prager D, Cooper E, Lucia S (2008). Coastal Capital – Economic Valuation of Coral Reefs in Tobago and St. Lucia. World Resour Inst

Burke L, Maidens J (2005). Technical notes on the Reefs at Risk in Belize threat analysis. World Resour Institute, Washingt DC

Burke LM, Maidens J, Spalding M, Kramer P, Green E (2004). Reefs at Risk in the Caribbean.

Chollett I, Mumby PJ, Müller-Karger FE, Hu C (2012). Physical environments of the Caribbean Sea. Limnol Oceanogr 57:1233–1244

Darling ES, Alvarez-Filip L, Oliver TA, McClanahan TR, Côté IM (2012). Evaluating life-history strategies of reef corals from species traits. Ecol Lett 15:1378–1386

Eakin CM, Morgan JA, Heron SF, Smith TB, Liu G, Alvarez-Filip L, Baca B, Bartels E, Bastidas C, Bouchon C, Brandt M, Bruckner AW, Bunkley-Williams L, Cameron A, Causey BD, Chiappone M, Christensen TRL, Crabbe MJC, Day O, de la Guardia E, Díaz-Pulido G, DiResta D, Gil-Agudelo DL, Gilliam DS, Ginsburg RN, Gore S, Guzmán HM, Hendee JC, Hernández-Delgado EA, Husain E, Jeffrey CFG, Jones RJ, Jordán-Dahlgren E, Kaufman LS, Kline DI, Kramer PA, Lang JC, Lirman D, Mallela J, Manfrino C, Maréchal JP, Marks K, Mihaly J, Miller WJ, Mueller EM, Muller EM, Toro CAO, Oxenford HA, Ponce-Taylor D, Quinn N, Ritchie KB, Rodríguez S, Ramírez AR, Romano S, Samhouri JF, Sánchez JA, Schmahl GP, Shank B V., Skirving WJ, Steiner SCC, Villamizar E, Walsh SM, Walter C, Weil E, Williams EH, Roberson KW, Yusuf Y (2010) Caribbean corals in crisis: Record thermal stress, bleaching, and mortality in 2005. PLoS One 5:

Edmunds P, Zimmermann S, Bramanti L (2019). A spatially aggressive peyssonnelid algal crust (PAC) threatens shallow coral reefs in St. John, US Virgin Islands. Coral Reefs

Gardner TA, Côté IM, Gill JA, Grant A, Watkinson AR (2005). Hurricanes and Caribbean Coral Reefs: Impacts, Recovery Patterns, and Role in Long-Term Decline. Ecology 86:174–184

Geister J (1977). The influence of wave exposure on the ecological zonation of Caribbean coral reefs Proceedings of the 3rd International Coral Reef Symposum.

Hill J, Wilkinson C (2004). Methods for ecological monitoring of coral reefs. Aust Inst Mar Sci Townsv 117:

Hughes TP (1994). Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. Science (80-) 265:1547–1551

IMA (2016). State of the Marine Environment, Trinidad and Tobago - 2016. Institute of Marine Affairs

Jackson JBC (1997). Reefs since columbus. Coral reefs 16:S23–S32

Jia Y, Shelhamer E, Donahue J, Karayev S, Long J, Girshick R, Guadarrama S, Darrell T (2014). Caffe: Convolutional architecture for fast feature embedding. 675–678

Komyakova V, Munday PL, Jones GP (2013). Relative importance of coral cover, habitat complexity and diversity in determining the structure of reef fish communities. PLoS One 8:

Lapointe BE, Langton R, Bedford BJ, Potts AC, Day O, Hu C (2010). Land-based nutrient enrichment of the Buccoo Reef Complex and fringing coral reefs of Tobago, West Indies. Mar Pollut Bull 60:334–343

Lessios HA (2003). Mass Mortality of Diadema Antillarum in the Caribbean: What Have We Learned? Annu Rev Ecol Syst 19:371–393

Maldonado M, Ribes M, van Duyl FC (2012). Nutrient fluxes through sponges: biology, budgets, and ecological implications. Advances in Marine Biology. Elsevier, pp 113–182

Mallela J, Crabbe MJC (2009). Hurricanes and coral bleaching linked to changes in coral recruitment in Tobago. Mar Environ Res 68:158–162

Mallela J, Parkinson R, Day O (2010). An assessment of coral reefs in Tobago. Caribb J Sci 46:83–87

Mora C (2008). A clear human footprint in the coral reefs of the Caribbean. Proc R Soc B Biol Sci 275:767–773

Nyström M, Folke C (2001). Spatial resilience of coral reefs. Ecosystems 4:406–417

Perry CT, Murphy GN, Kench PS, Smithers SG, Edinger EN, Steneck RS, Mumby PJ (2013). Caribbean-wide decline in carbonate production threatens coral reef growth. Nat Commun 4:1402

Mumby PJ, Flower J, Chollett I, Box SJ, Bozec YM, Fitzsimmons C, Forster J, Gill D, Griffith-Mumby R, Oxenford HA, Peterson AM, Stead SM, Turner RA, Townsley P, vanBeukering PJH, Booker F, Brocke HJ, Cabañillas-Terán N, Canty SWJ, Carricart-Ganivet JP, Charlery J, Dryden C, vanDuyl FC, Enríquez S, denHaan J, Iglesias-Prieto R, Kennedy EV, Mahon R, Mueller B, Newman SP, Nugues MM, CortésNúñez J, Nurse L, Osinga R, Paris CB, Petersen D, Polunin NVC, Sánchez C, Schep S, Stevens JR, Vallès H, Vermeij MJA, Visser PM, Whittingham E, Williams SM (2014). Towards Reef Resilience and Sustainable Livelihoods: A handbook for Caribbean coral reef managers.

Stein A, Gerstner K, Kreft H (2014). Environmental heterogeneity as a universal driver of species richness across taxa, biomes and spatial scales. Ecol Lett 17:866–880

Steneck RS, Arnold SN, Boenish R, de León R, Mumby PJ, Rasher DB, Wilson MW (2019). Managing Recovery Resilience in Coral Reefs Against Climate-Induced Bleaching and Hurricanes: A 15 Year Case Study From Bonaire, Dutch Caribbean. Front Mar Sci 6:265

Vermeij MJA, Van Moorselaar I, Engelhard S, Hörnlein C, Vonk SM, Visser PM (2010). The effects of nutrient enrichment and herbivore abundance on the ability of turf algae to overgrow coral in the Caribbean. PLoS One 5:

Wilkinson CR, Cheshire AC (1990). Comparisons of sponge populations across the Barrier Reefs of Australia and Belize: Evidence for higher productivity in the Caribbean. Mar Ecol Prog Ser Oldend 67:285–294

Zuur AF, Ieno EN, Elphick CS (2010). A protocol for data exploration to avoid common statistical problems. Methods Ecol Evol 1:3–14

7.0 APPENDIX

CORALNET SEMI-AUTOMATED ANNOTATION

In the age of rapid assessments where underwater surveys have drastically improved with the use of underwater photography in high resolution along with the use of Autonomous Underwater Vehicles (AUVs) and diver propulsion vehicles (DPVs) to cover larger areas, coral reef scientists continue to be bottle necked in the process of reef monitoring by the manual task of image annotation. In addition to this, there is very little standardization with regard to observer variability and the labels used in the identification process between and within monitoring datasets. CoralNet (https://coralnet.ucsd.edu/source/) is an online platform that provides automated image analysis in a standardized, accurate and efficient manner. The technology behind CoralNet is the use of a Caffe deep learning framework (https://caffe.berkeleyvision.org), a type of neural network that utilises multiple layers of an image on a hierarchy of visual representation for classification of image features (Jia *et al*. 2014). For each data point in image analysis, the software extracts colour and textural information and detected features of the image by region-based convolution; the layers are then pooled and a pixel prediction for the data point is returned. The output is the probability of certain labels occurring per data point per image. The most probable label is selected and then the percentage cover for that label is calculated (Beijbom *et al*. 2015). In Beijbom *et al*. (2015), a semi-automated annotation mode is recommended to speed up the image annotation, while maintaining accuracy of more obscure and rare features in the benthic community. More specifically, image data points that are labelled by the framework with a higher confidence value of accuracy will be automatically automated, so that the annotator can manually annotate less identifiable data points with lower confidence label values.

For the benthic analysis, CoralNet was trained using the data from the IMA's long-term coral reef monitoring programme (2014, 2015, 2016) with images that were manually annotated. This training set was assessed for accuracy at the *label* level and the *functional group* level. The training set was then used to assist in the analysis of 2019 data set.

Methodology -*Training Data*

A total of 3231 digital images and their Coral Point Count data from previous coral reef benthic surveys carried out in 2014, 2015 and 2016 were imported into CoralNet for training. The Coral Point Count method used 60 random points per image. All the images were analysed using the standard AGRRA (Atlantic and Gulf Rapid Reef Assessment) Labelset. As the AGRRA labelset was altered over the survey years, where generalised non-coral labels, such as sponge and octocoral groups, were being specified to species and genus, the final CoralNet labelset comprised of all the Labels used in previous surveys for the training (**TABLE A 1**). The same labelset was used for the 2019 data. All the data from previous years were input for training and then assessed for accuracy at the *label* and *functional group* level with the use of confusion matrices produced by CoralNet. As part of CoralNet's diagnostic tools, the robotic performance accuracy is assessed with confusion matrices at the *label* and *functional group* level. It must be noted that the accuracy of the robot is highly dependent on the accuracy of the expert observers used to manually annotate the training dataset. Therefore, discrepancies among observers will be reflected in a lower accuracy. CoralN*et al*so provides a confidence threshold sweep to show the changes in the accuracy in annotation output when different robot confidence thresholds (The percentage confidence of the robotic annotations) are used (Figure A 2).

"Plot is created by trying hundreds of confidence thresholds on the validation-set. For each threshold, all annotations for which the classifier confidence is lower then the threshold are discarded. Then accuracy is then calculated for the remaining annotations both on the level of individual levels and the functional group level. This is plotted along with the fraction of points above the threshold" – CoralNet

This is used to guide future annotations using a semi-automated analysis mode including the 2019 dataset.

Results of CoralNet automated annotation test

At the *label* level the fully automated annotation test by CoralNet had an overall accuracy of 61.8 %, where the highest accuracies are related to hard coral species, including *Orbicella faveolata* (78 %), *Colpophyllia natans* (73 %), Madracis mirabilis (70 %). The higher accuracies are associated with more common and easily identifiable species and groups found on the permanent transects. Conversely, higher confusion was found among the 'Turf Algae' label and most other labels owing the overgrowing nature of turf algae on other benthic organisms. Other cases of confusion were found among broader group labels and species names, for example, there was high confusion between the family "*Gorgonia spp*." label and genus "*Pseudopterogorgia sp.*" label. Other confusions likely contributing to the lower accuracies/ higher confusion among labels are the variations in the label choices made among manual annotators in the previous years.

The accuracy of fully automated annotation test by CoralNet was higher at the *functional group* level (76.9 %). 'Algae' had the most accuracy with 93 % of the data points being correctly identified as Algae and this is likely because of the high prevalence of algae on the sites (Figure A 1), where algae labelled data points (n=10,810) were ten-fold greater than any other labels. Additionally, a large percentage of the other functional group labels were misidentified as 'Algae', 39 % of 'Other Invertebrates' and 20 % of 'Hard Corals' (Figure A 1). The 'Hard Coral' functional group also had a high accuracy of 71 % (Figure A 1). The accuracy of the functional groups are similar to the findings of the Beijbom *et al*. (2015), who also assessed the variability in the machine-learning framework at the functional group level. Beijbom *et al*. (2015) found the functional group with the least confusion were the hard coral but higher confusions were found among Algae groups, such macroalgae and crustose coralline algae. This is reflective of the fact that the accuracy of coral reef experts, in general, varies among benthic categories, where hard corals are more identifiable in images compared to algae and other obscure reef components. The fully automated annotation carried out by Beijbom *et al* (2015) had accuracies of 63 % for hard coral functional groups and 48 % for macroalgae. When the semi-automated analysis mode (where data points < 50 % uncertainty was referred to manual annotations) was implemented in Beijbom *et al* (2015), this resulted in the improvement in the accuracy of labels and functional groups, to similar accuracies to that of the expert annotations (Hard Coral – 90 %, Macroalgae – 71 %, CCA – 51 %, Turf Algae 62 %; Beijbom *et al* 2015). The speed of assessment was still faster than manual annotations.

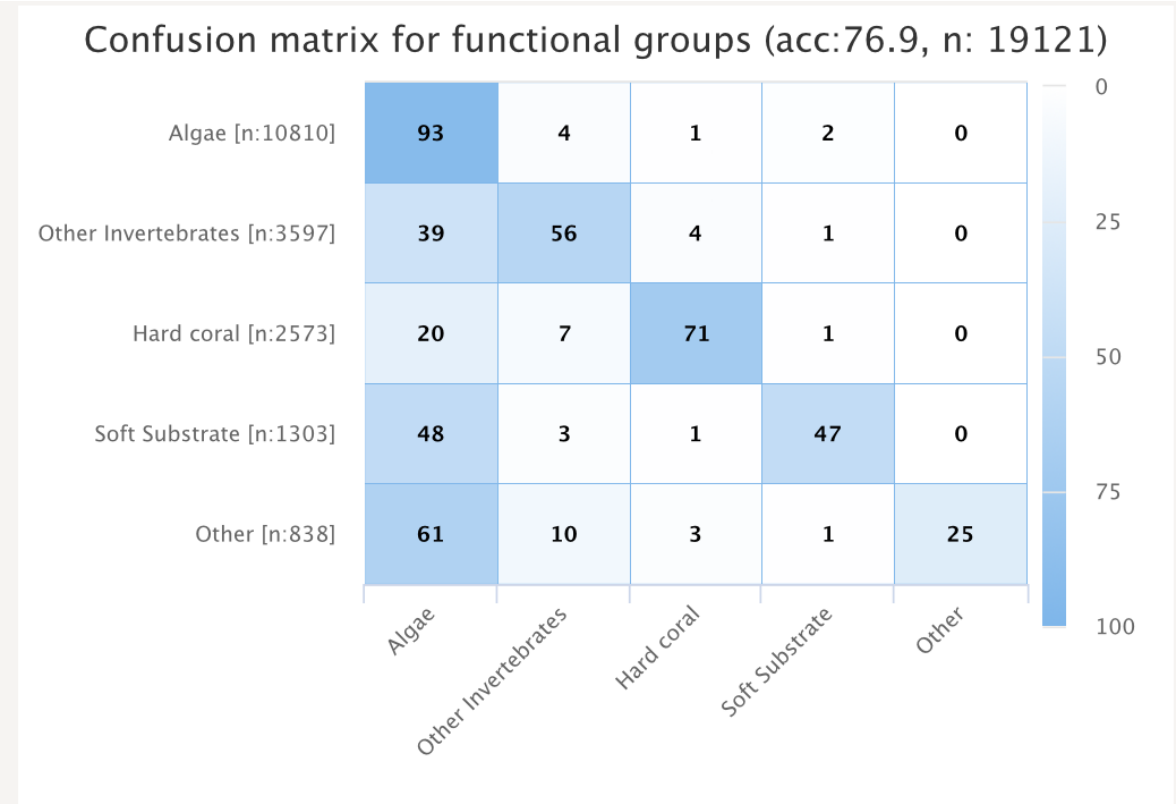


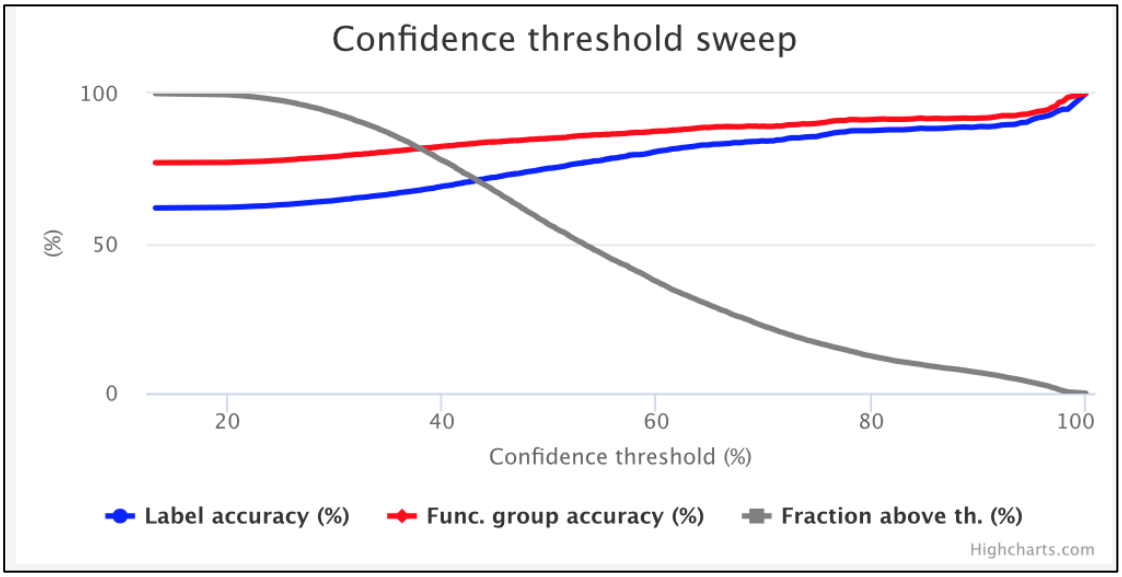
FIGURE A 1: CONFUSION MATRIX FOR ACCURATE IDENTIFICATION OF FUNCTIONAL GROUPS USING A CONFIDENCE THRESHOLD OF 0 % (FULLY AUTOMATED ANNOTATION). GRAPH SOURCED FROM CORALNET

2019 Analysis

Our study shows that over a 90 % average accuracy can be maintained by using a semi-automated mode where labels above a 75 % threshold certainty can be automatically annotated and data points with a lower than 75 % confidence will be annotated manually ((Graph sourced from CoralNet)

Figure A 2 & Figure A 3). These outputs exceed the accuracy of the expert annotators used in Beijbom *et al* 2015 (Note that a better comparison would be with the accuracy of the experts used in the IMA coral reef monitoring programme were not assessed in previous years). In addition to this, future assessments on CoralNet should be recorded with annotators labelled for further assessment of inter-observer variability to confirm the accuracy of the manual annotations and ensure some consistency in the annotation process between annotators and the previous years. The 2019 images were analysed directly in CoralNet by two annotators, who are experts in identifying coral reef benthos. A very conservative threshold of 90 % confidence level was use to automatically annotate labels as a precaution

until discrepancies with respect to standardising label selection are rectified and the automated annotation accuracies are improved.



(Graph sourced from CoralNet)

FIGURE A 2: CONFIDENCE THRESHOLD FOR THE USE OF AUTOMATED MACHINE LEARNING PROCESS

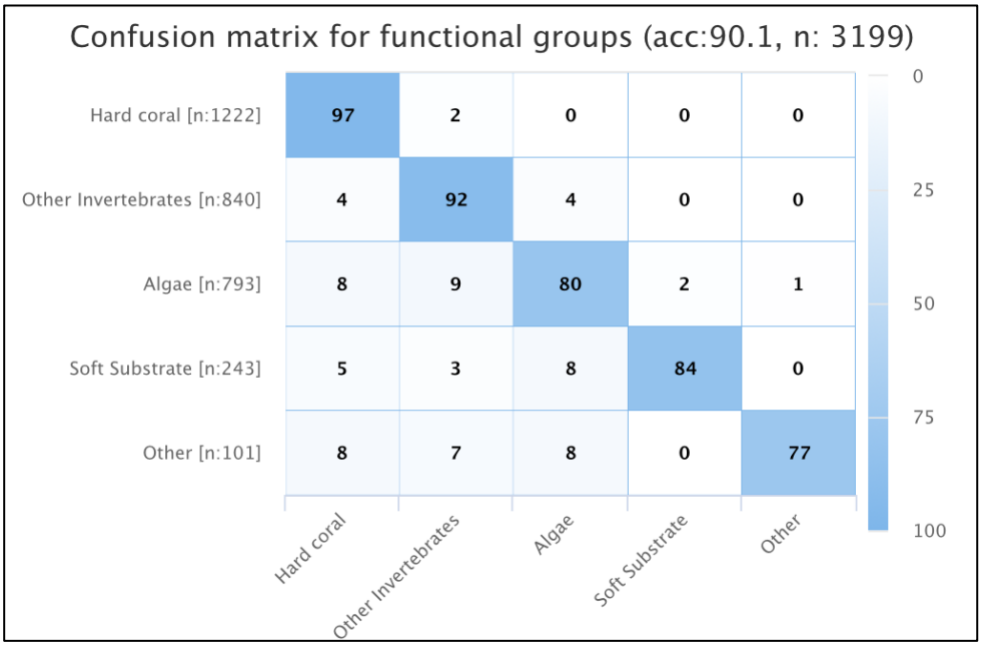


FIGURE A 3: CONFUSION MATRIX FOR THE ACCURATE IDENTIFICATION OF FUNCTIONAL GROUPS USING THE 75 % CONFIDENCE THRESHOLD (SEMI-AUTOMATED METHOD) WILL PRODUCE AN AVERAGE ACCURACY OF 90 %. GRAPH SOURCED FROM CORALNET

TABLE A 1: LABELSET USED IN CORALNET ANNOTATIONS

Name	Label	Functional Group
Agaricia agaricites	AA	Hard Coral
Acropora cervicornis	AC	Hard Coral
Agaricia fragilis	AF	Hard Coral
Agaricia grahamae	AG	Hard Coral
Agaricia humilis	AH	Hard Coral
Agaricia lamarcki	AL	Hard Coral
Acropora palmata	AP	Hard Coral
Acropora prolifera	APR	Hard Coral
Agaricia tenuifolia	AT	Hard Coral
Agaricia undata	AU	Hard Coral
Bleached Hard Coral	BL	Hard Coral
Colpophyllia breviserialis	CB	Hard Coral
Colpophyllia natans	CN	Hard Coral
Unidentified Hard Coral	CORAL	Hard Coral
Coral Juvenile	CORJU	Hard Coral
Pseudodiploria clivosa	DC	Hard Coral
Diseased Coral	DCOR	Hard Coral
Dendrogyra cylindrus	DCY	Hard Coral
Diploria labyrinthiformis	DL	Hard Coral
Pseudodiploria strigosa	DS	Hard Coral
Dichocoenia stokesi	DSO	Hard Coral
Dichocoenia stellaris	DST	Hard Coral
Eusmilia fastigiata	EF	Hard Coral
Favia fragum	FF	Hard Coral
Isophyllia rigida	IR	Hard Coral
Isophyllia sinuosa	IS	Hard Coral
Helioseris cucullata	LC	Hard Coral
Orbicella annularis	MA	Hard Coral
Mycetophyllia aliciae	MAL	Hard Coral
Mussa angulosa	MAN	Hard Coral
Manicina areolata	MAR	Hard Coral
Montastraea cavernosa	MC	Hard Coral
Madracis decactis	MD	Hard Coral
Mycetophyllia danaana	MDA	Hard Coral
Mycetophyllia ferox	MF	Hard Coral
Orbicella faveolata	MFAV	Hard Coral

Name	Label	Functional Group
Orbicella franksi	MFRN	Hard Coral
Millepora alcicornis	MILA	Hard Coral
Millepora complanata	MILC	Hard Coral
Millepora squarrosa	MIS	Hard Coral
Mycetophyllia lamarckana	ML	Hard Coral
Madracis mirabilis	MM	Hard Coral
Meandrina meandrites	MME	Hard Coral
Oculina diffusa	OD	Hard Coral
Porites astreoides	PA	Hard Coral
Porites branneri	PB	Hard Coral
Porites colonensis	PC	Hard Coral
Porites divaricata	PD	Hard Coral
Porites furcata	PF	Hard Coral
Porites porites	PP	Hard Coral
Solenastrea bournoni	SB	Hard Coral
Scolymia cubensis	SC	Hard Coral
Solenastrea hyades	SH	Hard Coral
Stephanocoenia intersepta	SI	Hard Coral
Scolymia lacera	SL	Hard Coral
Siderastrea radians	SR	Hard Coral
Siderastrea siderea	SS	Hard Coral
Tubastraea coccinea	TA	Hard Coral
Agelas conifera/tubulata	ACON	Sponge
Agelas	AECL	Sponge
Aplysina spp.	ALA	Sponge
Aplysina fulva/ cauliformis	APCA	Sponge
Sponge: Cliona	CLIO	Sponge
Ectyoplasia	ECFE	Sponge
Monanchora arbuscula	MOB	Sponge
Aka coralliphagum	SICO	Sponge
Sponge	Sponge	Sponge
Xestospongia	XEMU	Sponge
Cliona delitrix	CDE	Sponge
Briareum	BRI	Octocoral
Erythropodium (encrusting)	ERY	Octocoral
Erythropodium caribaeorum	ERYCAR	Octocoral
Eunicea spp.	EUN	Octocoral
Gorgonia spp.	GORG	Octocoral

Name	Label	Functional Group
Iciligorgia spp.	ICISPP	Octocoral
Muriceopsis spp.	MURISPP	Octocoral
Muricea spp.	MURSPP	Octocoral
Octocorallia	Octocoral	Octocoral
Pseudopterogorgia sp	PGor	Octocoral
Plexaura spp.	PLESPP	Octocoral
Plexaurella spp.	PLEXSPP	Octocoral
Pseudoplexaura spp.	PSESPP	Octocoral
Pterogorgia	PTESPP	Octocoral
Sea Fan	Seafan	Octocoral
Ascidians	ASC	Other Invertebrate
Other invertebrate	Other Inv	Other Invertebrate
Symplegma sp.	SYVI	Other Invertebrate
Tridemum solidum.	TRSO	Other Invertebrate
Tunicate	TUN	Other Invertebrate
Lebrunia spp.	LEC	Zoanthid
Palythoa	PAL	Zoanthid
Zoanthid	ZO	Zoanthid
Sand	S	Soft Substrate
Sediment	SEDI	Soft Substrate
Dead coral	ODC	Hard Substrate
Pavement	P	Hard Substrate
Cyanobacteria films	Cyanobacteria	Cyanobacteria
Blue-Green Algae	BGA	Cyanobacteria
Schizothrix	SCHIZ	Cyanobacteria
Dead coral with algae	DCA	Macroalgae
Anadyomene stellata	ANST	Macroalgae
Dictyota spp.	DICT	Macroalgae
Gracilaria spp.	GRAC	Macroalgae
Halimeda	HALI	Macroalgae
Liagora	LIAG	Macroalgae
Lobophora	LOBO	Macroalgae
Macroalgae	MACA	Macroalgae
Padina spp.	PAD	Macroalgae
Sargassum sp	SARG	Macroalgae
Stypopodium sp.	STY	Macroalgae
Turbinaria (algae)	TURB	Macroalgae
Wrangelia	WRAN	Macroalgae

Name	Label	Functional Group
Amphiroa sp.	AMP	Calcifying Algae
Crustose coralline algae	Calcifying Algae	Calcifying Algae
Crustose Coralline Algae, Diseased	CWBS	Calcifying Algae
Mesophyllum spp. Encrusting	MEME	Calcifying Algae
Peyssonnelia	PEY	Calcifying Algae
Porolithon	POR	Calcifying Algae
Dead Gorgonian	DG	Turf Algae
Turf overgrowing recently dead coral	RDC	Turf Algae
Turf Algae	Turf Algae	Turf Algae
Turf sand	TURFSA	Turf Algae
Other	O	Other
Quadrat	QUD	Other
Shadow	SHAD	Other
TAPE	TAPE	Other
Wand	WAND	Other
White band disease	WBD	Diseased
Yellow band disease	YBD	Diseased
Rubble	R	Rubble
Unknown	Unknown	Unknown

Institute of Marine Affairs
Hilltop Lane, Chaguaramas
www.ima.gov.tt

ISBN 978-976-8311-15-3