TECHNICAL REPORT 2065
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ADMINISTRATIVE INFORMATION

The work described in this report was performed for Naval Facilities Engineering Command Southeast (NAVFAC SE) by the Environmental Sciences Branch (Code 71750), Space and Naval Warfare Systems Center Pacific (SSC Pacific), San Diego, California, and Naval Facilities Engineering Command Expeditionary Warfare Center (NAVFAC EXWC), Jacksonville, Florida.

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SB

EXECUTIVE SUMMARY

The National Marine Fisheries Service considers the near-shore coral reefs at Naval Station Guantánamo Bay, Cuba (GTMO) as a reference for comparison to other Caribbean near-shore coral reef habitats due to their relatively good condition. These reefs were affected by Hurricane Sandy, which impacted GTMO on October 25, 2012. Subsequently, a marine ecologist from Space and Naval Warfare Systems Center Pacific (SSC Pacific) and a marine ecologist from Naval Facilities Engineering Command Expeditionary Warfare Center (NAVFAC EXWC) conducted a survey to assess the extent and severity of impact from the hurricane.

The team chose a state-of-the-art method known as photomosaicing to complete objectives of this survey. This technology provides superior image clarity in a mosaic-landscape map. It provides an archival database to overlay other methods such as line point intercept method (LPIM) or belt transects (BT). Another advantage is the ability to obtain quantitative data at a later date such as coral colony size or tracking patterns of change over time.

We analyzed coral and algal assemblages at eight sites using both qualitative and quantitative methods, as well as a qualitative analysis of reef health and impact. After mosaics were created, a damage assessment analysis was performed based on category levels ranging from no damage to extreme coral and high reef damage. In addition, we deployed temperature and light data loggers.

Overall, damage from Hurricane Sandy was patchy with no clear or wide paths of subsurface destruction. GTMO coral reefs appeared to sustain remarkably little impact, with most areas classified as experiencing only minor coral damage (Damage Level of 1 on the impact assessment scale) and three areas exhibiting only moderate damage (Damage Level of 2). Most of the damage to coral colonies was partial. No areas experienced high, severe, or extreme coral damage, and no colonies appeared to be completely, or even severely, damaged. There was some uniformity in the relatively minimal amount of damage.

Survey results showed increased disease and decreased biodiversity. Specifically, all colonies of *Montastrea cavernosa* within the mosaics exhibited disease, and species such as *Agaricia tenuifolia*, *Copophyllia natans*, *Dichocenia stokesii*, *Diploria strigosa*, and other *Porites* species, which were previously recorded at the Cuzco control site, were not observed in the Cuzco mosaic. Of further concern is the decrease in average coral cover at several of these areas. GTMO requires more frequent surveys analysts to understand the dynamics and status of the coral ecosystem there, and to obtain accurate and consistent results. Given recent studies showing increased stressors such as nutrient loads and higher sea surface temperatures, a long-term health-status program should be established. Even if a consistent monitoring program is established at GTMO, it will take many years to fully understand the extent of impact multiple stressors are placing on coral and whether these reefs are resilient enough to maintain acceptable biodiversity and percent coverage at sustainable levels.

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ACRONYMS AND ABBREVIATIONS

#	number
%	percentage
2D	two-dimensional
BT	Belt transect
cm	centimeter
CNRSE	Commander Navy Region Southeast
CPCe	Coral Point Count with Excel Extensions
D	Simpson Index of Diversity
DoN	Department of the Navy
fsw	Feet of Sea Water
GBRMPA	Great Barrier Reef Marine Park Authority
GIS	Geographic Information Systems
GPS	Global Positioning System
GTMO	Guantánamo Bay
GUI	Graphic-user interface
H	Shannon–Weaver Diversity Index
JTF	Joint Task Force
km	kilometer
km/h	kilometer/hour
LPIM	Line Point Intersect Method
m^2	square meters
mph	miles per hour
N	North
NE	Northeast
N/A	Not Applicable
NASA	National Aeronautical and Space Administration
NAVFAC EXWC SDS	Naval Facilities Engineering Command Expeditionary Warfare Center Scientific Diving Services
NAVFAC SE	Naval Facilities Engineering Command Southeast
NCLDV	Nucleocytoplasmic large DNA virus sequences
NHC	National Hurricane Center
NW	Northwest
°	degree Celsius
S	Species Richness
SCSDV	Single-stranded DNA viruses and their associated satellites
SE	Southeast
sp.	Species
SSC Pacific	Space and Naval Warfare Systems Center Pacific
SW	Southwest
UTC	Coordinated Universal Time or Zulu
W	West

1. INTRODUCTION

The National Marine Fisheries Service considers the near-shore coral reefs at Naval Station Guantánamo Bay, Cuba (GTMO) as a reference for comparison to other Caribbean near-shore coral reef habitats due to their relatively good condition. These reefs were affected by Hurricane Sandy, which impacted GTMO on October 25, 2012. This report presents a post-hurricane assessment of impacts to the reefs conducted by a marine ecologist from Space and Naval Warfare Systems Center Pacific (SSC Pacific) and a marine ecologist from Naval Facilities Engineering Command Expeditionary Warfare Center (NAVFAC EXWC) to assess the extent and severity of impact from the hurricane.

1.1 BACKGROUND AND TRACK OF HURRICANE SANDY

According to the National Aeronautics and Space Administration (NASA) Hurricanes/Tropical Cyclones and the National Weather Service's National Hurricane Service, Hurricane Sandy began as a low-pressure system that developed sufficient organized convection for classification as a tropical depression on October 22, 2012, south of Kingston, Jamaica. It moved slowly at first due to a ridge to the north. Low wind shear and warm waters allowed for strengthening, and the system was named Tropical Storm Sandy late on October 22. Early on October 24, an eye began developing, and it began moving steadily northward due to an approaching low-pressure trough. Later that day, the National Hurricane Center (NHC) upgraded Sandy to hurricane status about 65 miles (105 km) south of Kingston, Jamaica. At about 1900 UTC that day, Sandy made landfall near Kingston with winds of about 80 mph (130 km/h). Just offshore Cuba, Sandy rapidly intensified to winds of 110 mph (175 km/h), and at that intensity it made landfall just west of Santiago de Cuba at 0525 UTC on October 25. The storm traveled directly over GTMO (Figure 1). Some personnel stationed there made anecdotal observations of the after-effects while diving and have commented that several areas that contained coral were damaged and algal growth had already occurred. Hurricanes of extreme intensity are predicted to occur more frequently under a changing climate (Knutson and Tuleya, 2004; Knutson et al., 2010; Webster, Holland, Curry, and Chang, 2005).

Cuba, however, is no stranger to hurricanes and other storms. Since 1950, 19 storms (hurricanes and other tropical storms) have hit Cuba (See Table 1).

1.1.1 Need for Assessment

Several factors have underscored the importance of the post-Sandy impact assessment. Based on recent studies in 2011 and 2012 (Marx et al., 2012), multiple stressors may be affecting the GTMO coral reef ecosystem. The source of those stressors has not been pinpointed, but it is important to differentiate between what may be anthropogenic and natural stressors. Examples of human-induced stressors include coastal development, overfishing, and vessel groundings. Natural stressors include storms, biota competing for space, and predation. Hughes and Connell (1999) state that to understand the effects of multiple stressors on coral reef ecosystems, long-term monitoring is necessary.

Further, there may be political and international ramifications if the Navy did not properly assess and document post-Sandy impacts. The Navy could be improperly identified as the cause of impacts from anthropogenic stressors when those impacts may have occurred outside of the GTMO installation or were actually the result of natural stressors, such as Hurricane Sandy.

1.2 IMPLEMENTATION OF NEW METHODS TO ASSESS REEF CONDITION

The marine biologist team from SSC Pacific and NAVFAC EXWC conducted a state-of-the-art method known as photomosaicing to complete objectives of this survey. This technology provides superior image clarity in a mosaic-landscape map. It provides an archival database that can overlay other methods such as line point intercept (LPIM) or belt transects. Another advantage is the ability to obtain quantitative data such as coral colony size or tracking patterns of change over time later.

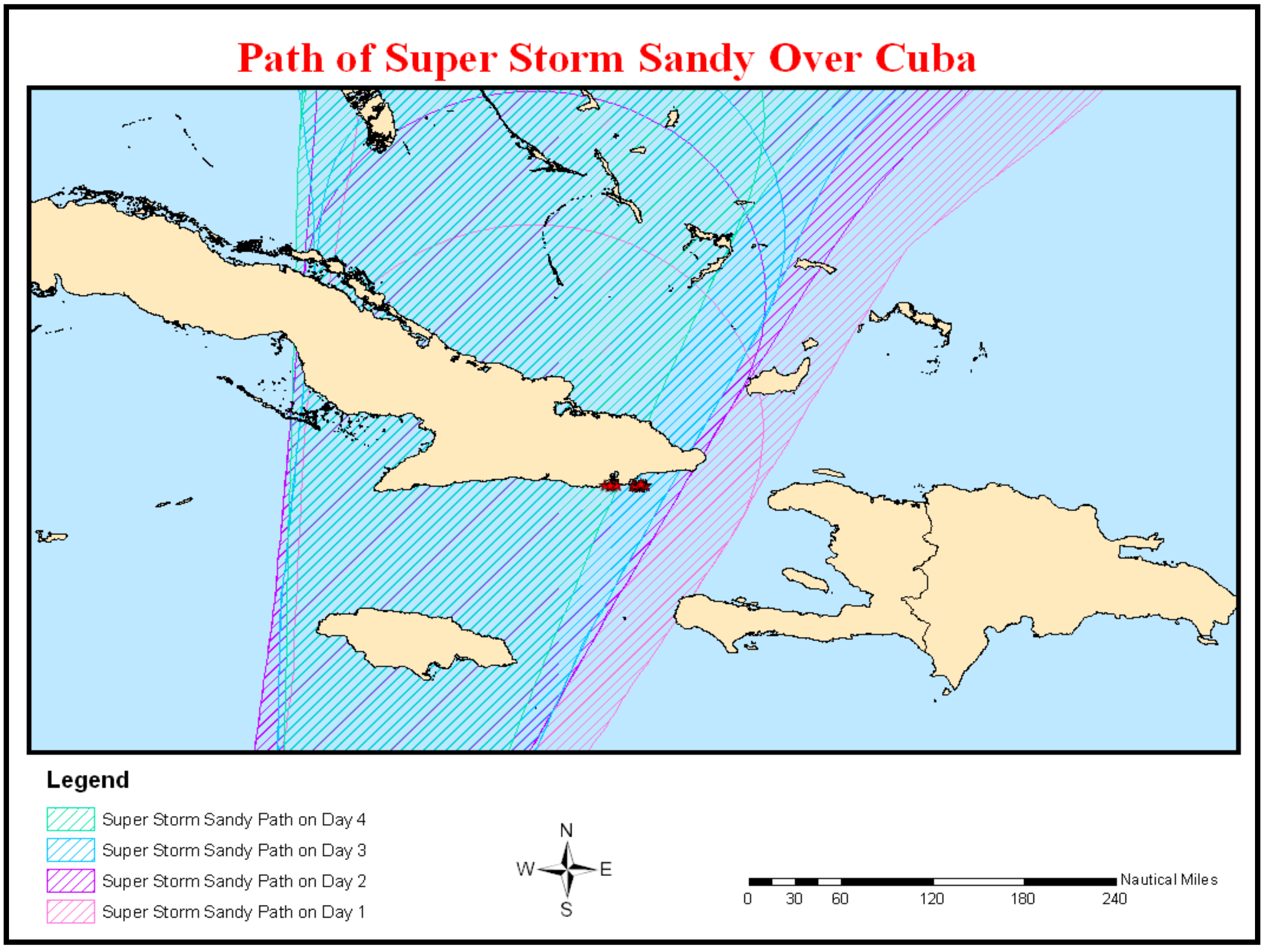

Figure 1. Map depicting the path of Hurricane Sandy over Guantánamo Bay (ArcGIS® Desktop: Release 10.1. 2012. Environmental Systems Research Institute (ESRI), Redlands, CA).

Table 1. Storm history of Cuba.

Storm Name	Year	Storm Name	Year	Storm Name	Year
Sandy	2012	Ivan	2004	Allen	1980
Paloma	2008	Charley	2004	Kate	1985
Ike	2008	Lili	2002	Frederic	1979
Gustav	2008	Isidore	2002	Camille	1969
Noel	2007	Michelle	2001	Inez	1966
Wilma	2005	Irene	1999	Cleo	1964
Dennis	2005	Georges	1998	Flora	1963

2. METHODS

The marine biologist team used both qualitative and quantitative methods to analyze the coral and algal assemblages at all sites.

Tropical algae are often placed into one of three functional groups: turf algae, crustose coralline algae, and macroalgae. Turf algae, as used in this assessment, are defined as the multi-species assemblage of diminutive, generally filamentous algal species with heights of less than 10 cm. The crustose coralline group contains species are heavily calcified and have encrusting and/or hard lumpy growth patterns. Macroalgae includes all remaining species, including heavily calcified upright branching genera, like the green algae, *Halimeda* sp.

We recorded observations of algae by functional group. The (apparent) dominant functional group and/or genera of algae were denoted on all mosaics analyzed. We estimated dominance based on the percentage of the seafloor occupied by various algal groups.

During the mosaic analysis, and to the extent possible, we listed corals to the lowest taxonomic classification. The analysis also included observations of corals to assess the colonies for the following factors:

- Physical damage (e.g., cracks and broken branches)
- Complete or partial mortality of individual colonies
- Mucus production
- Disease
- Predation
- Bleaching

Physical damage can be the result of natural phenomena or anthropogenic effects. We made a careful effort to distinguish between the two. Partial mortality as used in this assessment referred to surface lesions/dead areas on stony corals. Hughes and Jackson (1980), Riegl (1995), and others have shown that partial mortality on the surface of stony corals can be effective indicators of stress. Stony coral mucus production is another indicator of stress from pollutants, sedimentation, etc. (Stafford-Smith and Ormond, 1992; Stafford-Smith, 1993; Wild, Woyt, and Huettel, 2005). Bruno, Petes, Harvell and Hettinger (2003) and Sutherland, Porter, and Torre (2004) have shown that corals are more susceptible to disease when they are stressed by changes in the environment. We recorded all apparent visual evidence of disease. The assessment of predation on corals focused on action by parrotfishes and macro-bioeroders (e.g., boring sponges). Cooper et al. (2008) correlated high densities of macro-bioeroders with diminished water quality. Bleaching refers to the loss or reduction of symbiotic zooxanthellae that reside within the coral polyps. This results in the coral appearing lighter in color, mottled or white.

2.1 REEF HEALTH AND IMPACT ASSESSMENT QUALITATIVE ANALYSIS

As of the date of the field survey work, 10 months had elapsed since the hurricane passed over GTMO. Readers may wish to read Precht (2006) and the Great Barrier Reef Marine Park Authority (GBRMPA, 2011) to gain a more complete understanding of the level of detail required to assess impacts from storms. Figure 2 details the types of qualitative data collected at each site and are based on a form used by scientists during their post-cyclone Yasi assessment (GBRMPA, 2011).

Reef Health and Impact Survey Reporting Form

Observers Name:		**Date:**	
Site Name:		**Habitat:**	
Air Temp:		**% Macroalgae:**	
Water Temp:		**% Live coral:**	
Water Depth:		**% Recently dead coral:**	
Visbility:		**% Live coral rock:**	
Tide at time of survey:		**% Coral Rubble:**	
		% Sand:	
			100%

MACROALGAE OBSERVATIONS	**Present: Y / N**			**Photos Taken: Y / N**	
	Slime	**Entangled/Mat-like**	**Filamentous**	**Leafy/Fleshy**	**Tree/Bush-like**
Proportion of the total macroalgale cover	%	%	%	%	%

CORAL OBSERVATIONS	**Present: Y / N**						**Photos Taken: Y / N**	
	Soft coral	**Branching**	**Bushy**	**Plate**	**Vase/Foliose**	**Encrusting**	**Massive**	**Mushroom**
No damage (live coral cover)	%	%	%	%	%	%	%	%
Damage to tips/edges	%	%	%	%	%	%	%	%
Damage to Branches/parts	%	%	%	%	%	%	%	%
Damage to Colonies	%	%	%	%	%	%	%	%
Portion of live coral that is bleached	%	%	%	%	%	%	%	%
Proportion of live coral affected by :								
Black band disease	%	%	%	%	%	%	%	%
Brown band disease	%	%	%	%	%	%	%	%
White syndromes	%	%	%	%	%	%	%	%
Other disease/tumors	%	%	%	%	%	%	%	%

RUBBISH OBSERVATIONS		**Present: Y / N**		**Photos Taken: Y / N**	
	Fishing line	**Plastic**	**Netting**	**Rope**	**Wood Debris**
# of pieces of rubbish					

Figure 2. Example Reef Impact Data Form completed by mosaicing analyst (from GBRMPA, 2011).

2.2 PHOTOMOSAICING

The marine biologist team chose the photomosaicing method because of its state-of-the-art capability in providing an archival database to document the coral reef community at various sites as well as superior image clarity. Mosaics (Figure 3) provide both landscape-level maps and high-resolution (sub-millimeter) images of individual coral colonies (mesoscale). Scientists can collect imagery at both landscape and colony-levels for areas of several hundred square meters in reduced diving time, creating mosaic products that provide increased information on coral colony health and small-scale competitive interactions. Landscape mosaics address several limitations of traditional, diver-based, coral reef monitoring techniques:

- Mosaics provide a landscape view of coral reefs that has previously been unobtainable.
- Mosaics are efficient tools for tracking patterns of change over time.
- Mosaics have high spatial accuracy and precision.

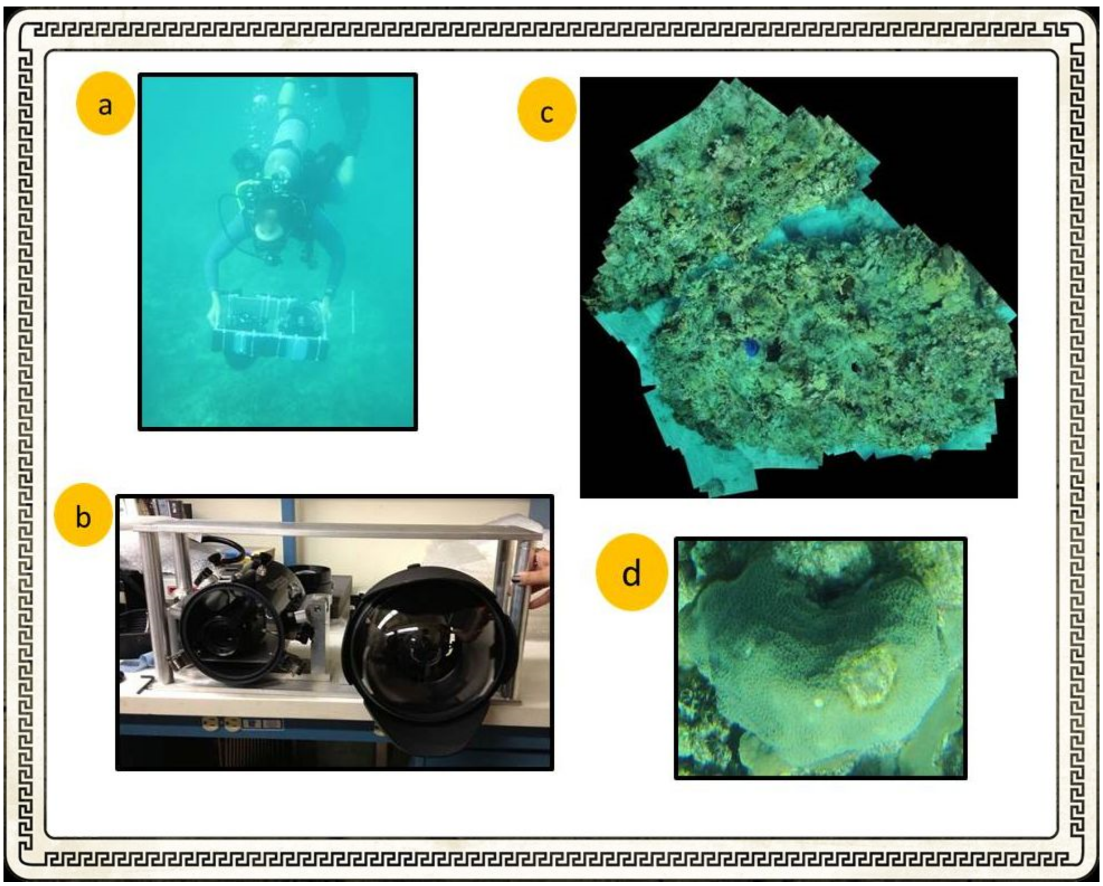

Figure 3. Mosaic Overview: (a) imagery acquired by a diver, (b) camera set-up, (c) mosaic taken at Joint Task Force Guantánamo (JTF-GTMO) covering a large area (230 square meters at JTF-GTMO), and (d) identification of disease (diseased area Is 38.43 cm).

Metrics that we extracted from mosaics for this assessment include:

- Algae
    - % Cover
    - Algal species ID classified as functional groups (turf algae, crustose coralline algae and macroalgae)
    - Species richness
- Coral
    - % Cover
    - Coral species ID
    - % Bleached
    - % Diseased
    - % New and old mortality*
    - Species richness
    - Species diversity (Shannon–Weaver index/Simpson Index)

**For this study, old mortality is defined as a demise of coral function caused directly by Hurricane Sandy or other stressors.*

2.2.1 Photomosaicing Site Selection

The authors attempted to use the photomosaicing method on as many sites as possible. Time and budget constraints dictated the number of sites visited. We chose sites based on revisiting established photomosaicing and photoquadrat sites surveyed in 2011 and 2012. Eight sites were successfully photomosaiced (Figure 4). These sites and their respective quantitative areas covered include:

- Hidden Beach: 156.96 square meters
- Leeward Point: 126.74 square meters
- Girl Scout Beach (replacement for Glass Beach): 186.20 square meters
- Blue Beach (replacement for Windward Point Point): 135.96 square meters.
- Cuzco: 186.14 square meters
- Windmill Beach: 444.20 square meters.
- Joint Task Force Camp (JTF): 229.95 square meters.
- Kittery Beach: 163.19 square meters

We also attempted photomosaics at Chapman Beach, Mid-Bay, and Phillips, but poor visibility at these locations prevented successful analysis of the images.

Traditional methods used to assess coral reef health do not analyze near as much area of the reefscape as the mosaics do. Line Point Intersect Method analyzes 200 meters of coral (100 meters at two different depths); the Point-Center Quarter Method analyzes 1 meter of coral and a Belt Transect analyzes 10 meters of coral. In general, these methods cover much less total area than the photomosaicing technique, which allows for the assessment on average of 100 square meters of coral.

Table 2 shows sites mosaiced along with Global Positioning System (GPS) coordinates, date, and any pertinent notes about the site where the photomosaic were taken and data loggers were installed.

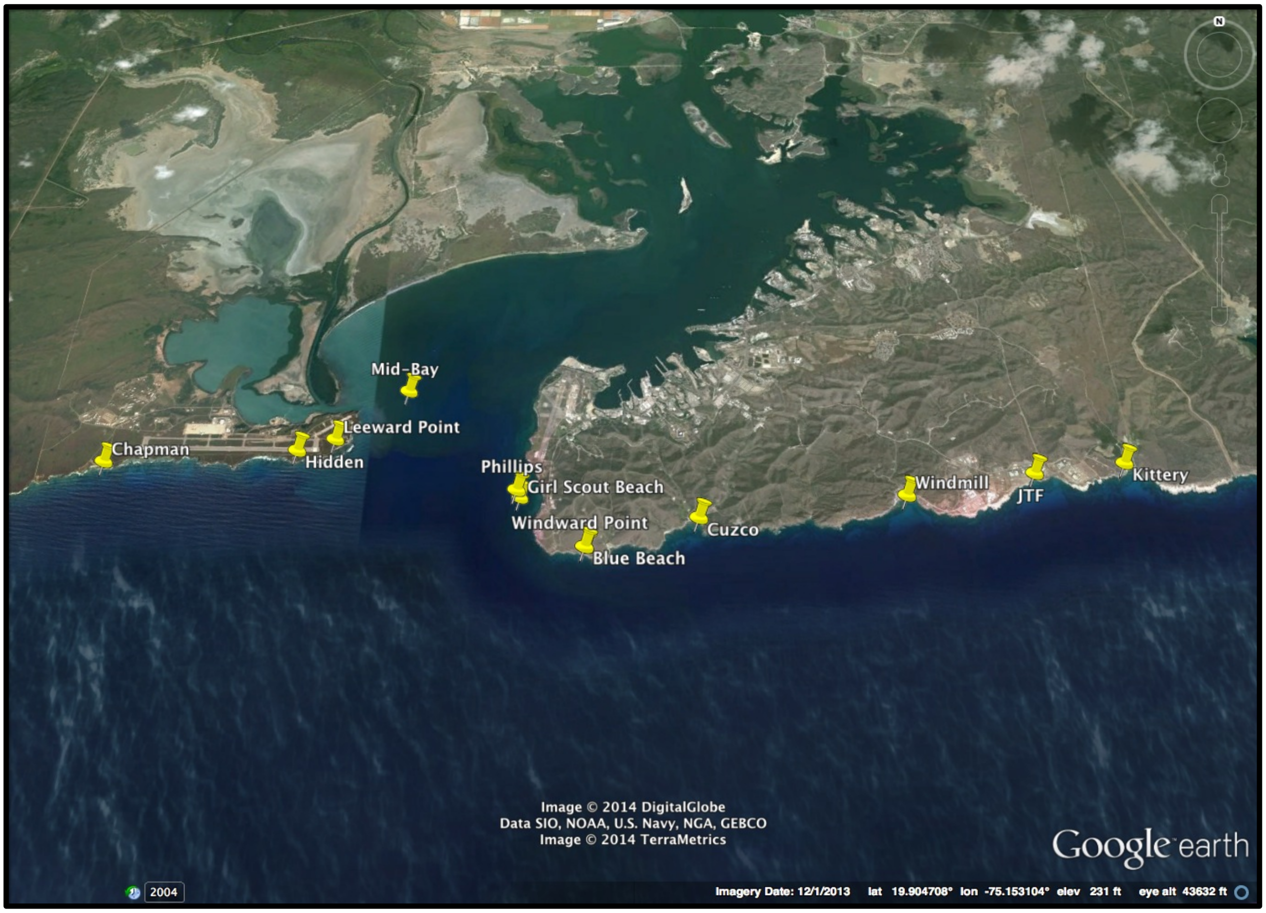

Figure 4. Sites where photomosaicing was attempted. Map date: ©2014 Google. ©2014 Digital Globe.

Table 2. Site locations where all photomosaic were acquired and all data loggers were installed (fsw = feet of seawater).

Site Name	Photomosaic Coordinates (Date and Depth)		Data Logger Coordinates (Date and Depth)	Notes
Chapman	19.903100 -75.223917° 19.903000 -75.223883° 19.902967 -75.223983° 19.903067 -75.224000° 14AUG2013 21FSW	Chapman-NE Chapman-SE Chapman-SW Chapman-NW	19.90283° -75.22358° 12AUG2013 28FSW	Logger placed in between two boulders with *Porites asteroides* species Photomosaics were not successfully analyzed due to poor visibility.
Hidden	19.903700 -75.198417° 19.903667 -75.198367° 19.903750 -75.198450° 19.903767 -75.198367°	Hidden-SW Hidden-SE Hidden-NW Hidden-NE	N/A	None
Leeward Point	19.903917 -75.192134° 19.903940 -75.192144° 19.903976 -75.192227° 19.903934 -75.192196° 15AUG2013 29FSW	Leeward Point-SE Leeward Point-NE Leeward Point-NW Leeward Point-SW	19.90569° -75.19346° 15AUG2013 29FSW	Logger placed on left edge of spur facing the shore. *Porites asteroides*, *Agaricia agaricites*, *Siderastrea siderea* & *Montastrea annularis* next to it.

Table 2. Site locations where all photomosaic were acquired and all data loggers were installed (fsw = feet of seawater). (Continued)

Site Name	Photomosaic Coordinates (Date and Depth)	Data Logger Coordinates (Date and Depth)	Notes
Mid-Bay	19.912683 -75.184317°	N/A	Imagery and video were not taken here due to the poor visibility.
Glass	19.91064373 -75.16828097°	N/A	Imagery and video were not taken here due to the poor visibility. Girl Scout Beach was the replacement for this site.
Girl Scout Beach	19.903333 -75.166917° Girl Scout Beach-NW 19.903283 -75.166867° Girl Scout Beach-NE 19.903200 -75.166917° Girl Scout Beach-SE 19.903267 -75.166983° Girl Scout Beach-SW 17AUG2013 10FSW	N/A	1Mx1M metal debris outside of the corner of this quadrat
Phillips	19.897583 -75.168500° Phillips-NW 19.897517 -75.168533° Phillips-SW 19.897467 -75.168467° Phillips-SE 19.897533 -75.168417° Phillips-NE 17AUG2013 Depth of spur mosaic was taken ranges from 20 to 32FSW.	19.89842° -75.16905° 12AUG2013 30FSW	Mosaic is over photoquad pin. Logger placed in proximity to 2nd buoy + in from mouth of bay, adjacent to *Montastrea annularis*, *Montastrea cavernosa*, *Dichocoenia strokesi*, *Siderastrea sidere*a and two unknown species of plate coral. Photomosaics were not successfully analyzed due to poor visibility.
Windward Point	19.8907885 -75.160121°	19.89079° -75.16012° 12AUG2013 40FSW	Logger on small patch reef 3M x 3M. 1 *Dichocoenia strokesi, Siderastrea siderea*, and 1 *Montastrea annularis* Most of this patch reef has MANN with some Dictyota. Imagery and video were not taken here due to the poor visibility. Blue Beach was the replacement site for Windward Point.
Cuzco	19.894350 -75.145833° Cuzco-NW 19.894267 -75.145783° Cuzco-SW 19.894283 -75.145683° Cuzco-SE 19.894367 -75.145733° Cuzco-NE 14AUG2013 21FSW	N/A	None
Blue Beach	19.895200 -75.130233° Blue-NE 19.895167 -75.130300° Blue-NW 19.895083 -75.130300° Blue-SE 19.895117 -75.130217° Blue-SW 15AUG2013 30FSW	N/A	None
Windmill	19.896867 -75.119450° Windmill-NE 19.896867 -75.119550° Windmill-NW 19.896767 -75.119533° Windmill-SW 19.896783 -75.119467° Windmill-SE 13AUG2013 10FSW	N/A	There was an enormous amount of trash and debris on the surface at this site. We had a camera equipment malfunction on 13AUG2013 at this site.

Table 2. site locations where all photomosaic were acquired and all data loggers were installed (fsw = feet of seawater). (Continued)

Site Name	Photomosaic Coordinates (Date and Depth)	Data Logger Coordinates (Date and Depth)	Notes
JTF	19.899700 -75.101067° JTF-NE 19.899617 -75.101033° JTF-SE 19.899600 -75.101133° JTF-SW 19.899667 -75.101167° JTF-NW 16AUG2013 25FSW	N/A	There was an enormous amount of trash and debris on the surface at this site. We had a camera equipment malfunction on 13AUG2013 at this site so this was the second mosaic.
Kittery	19.900567 -75.088650° Kittery-NE 19.900550 -75.088733° Kittery-NW 19.900467 -75.088717° Kittery-SW 19.900517 -75.088633° Kittery-SE 16AUG2013 27FSW	19.90139° -75.08917° 13AUG2013	We had a camera equipment malfunction on 13AUG2013 at this site so this was the second mosaic.
Radio Point*	N/A	19.916178° -75.168850° 15 to 20 FSW	Water is extremely hot along shoreline & thermocline pockets exist. Logger was placed by coral and picture taken but visibility was too poor to see the coral colony in the picture.
Ferry Landing*	N/A	19.920432° -75.148960° 20 to 25 FSW	Logger was placed by coral and picture taken but visibility was too poor to see the coral colony in the picture.
St. Nicolas*	N/A	Three feet from Buoy 1 ⁺. Depth –30 to 35 FSW	Logger was placed by coral and picture taken but visibility was too poor to see the coral colony in the picture.
TOTAL SITES	11 (8 successful)	8	

** Visibility was too poor to locate coral during timeframe that other data loggers were deployed. Contingency plan was to deploy data loggers during winter 2013 when visibility improve and photographs could be taken of coral adjacent to logger installment site. Loggers were actually deployed in February 2014.*
⁺ These buoys are known to move so using them as exact markers to locate a mosaic or logger could be problematic.

2.2.1.1 Mosaic Acquisition

The first step of data acquisition was to conduct a landscape mosaic survey of each chosen site. The team placed temporary markers on the seabed surrounding the site to ensure that the entire area was covered. We placed colored quadrats and half-meter sticks at the corners and along the edges of the area of interest to provide a visual border of the area for mosaic surveys and to enable size scale of the pixels in the final mosaic to meters. Areas of 10 meters by 10 meters were covered by each mosaic and can be equated to 18 to 28 minutes of dive time.

During the survey, divers swam in a double “lawn mower” pattern (Figure 5) over the survey area with the cameras pointing as vertically down as possible. The rule of thumb for this procedure was to swim 1.5 to 2 times the height of the largest object in the survey area; for example, if relief was less than 0.5 meters and the overall depth was only about 2 meters, data collected close to the surface was best. We determined exact heights by the conditions we encountered at each site.

The swim pattern consisted of parallel transects followed by a second set of “tie lines.” The parallel transects in the primary direction had substantial side-to-side overlap (60 to 80%). The tie lines in the other direction did not require much side-to-side overlap.

At the end of each day in the field, we backed up the images acquired and prepared the cameras for the next day’s dives (batteries charged, housings cleaned, etc.).

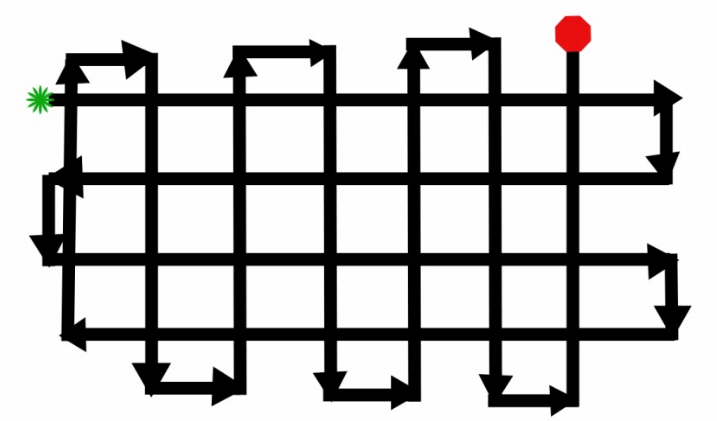

Figure 5. Sketch of the pattern to swim while acquiring data for mosaics. The camera remains in one orientation during the entire acquisition period. All changes in direction area accomplished by divers only.

2.2.1.2 GPS Data Acquisition

The team placed colored quadrats (used to demarcate the corners of the mosaic) and half-meter sticks (used to outline the boundary connecting the quadrats) at the corners and along the edges of the area of interest to provide a visual border of the area for the mosaic surveys and to enable scaling the size of the pixels in the final mosaic to meters. GPS points were then acquired using a Magellan® eXplorist® 200 encased in a waterproof Dry-Pak® pouch. The GPS satellite signals were triangulated while on the boat and passed off to the snorkeler thereafter. Triangulation was accomplished by aligning 12 out of the 14 satellites to get a three-dimensional (3D) position fix at each site with an accuracy of 3 meters. All points were taken in latitude and longitude (map datum: WGS84; north reference: magnetic north), and elevations were recorded in feet. Because visibility was so poor at these sites, the snorkeler had to free-dive down to get closer to the sites. From there, the snorkelers positioned themselves above the colored quadrats (which were used to indicate a corner of the mosaiced area), and took the GPS point. They then repeated the process for all corners at each site. The process was then repeated at the sites where the HOBO® data loggers were installed as well.

We downloaded the track logs from the GPS to a portable field laptop at the end of every day and demarcated data for each site in the text file downloaded off the GPS. We then converted the GPS track logs into Microsoft® Excel® and brought them into ArcGIS® 10.1 as a database table and mapped as point features. The points defined the vertices of the polygon bounding the mosaics. GPS points were also acquired for piers and other known structures near the GTMO dive locker and Port Ops buildings for accuracy confirmation.

2.2.1.3 GIS Data Integration

The team used ArcCatalog® 10.1 to georeference each mosaic, and then imported in ArcMap® 10.1 as a georeferenced image. All data brought into ArcGIS® had a datum of WGS 1984 and geographic coordinate system of NAD 1983/UTM Zone/17N, which is the most suitable one to be used for areas of North America between 84°W and 78°W. It is a Cartesian, two-dimensional (2D) coordinate system with axes of easting and northing; orientations of east and north; and units of measure in meters. We then determined the area of each mosaic from the polygon and compared it to the mosaic information extracted using the MATLAB® Mosaic Info Graphic User Interface (GUI). Data extracted from "Coral Point Count with Excel® extension" (CPCe) and the Reef Health & Impact Survey Reporting forms were converted from Microsoft® Excel® and brought into ArcGIS® 10.1 as database tables. We then made shapefile/layer and layer package files from the database tables. Damage levels were projected over the storm path (provided by NASA's Hurricanes/Tropical Cyclones and the National Weather Service's National Hurricane Service page) for the 4 days that the storm impacted Guantánamo Bay, Cuba. The team added all data to the GTMO Storm Impact Assessment geodatabase for final submission. All GIS data (georeferenced mosaics: tabular Geographic Information System (GIS) data files, metadata, geodatabases, and any figures used in the report) were structured according to *Commander Navy Region Southeast (CNRSE) Standards for Geographic Information System (GIS) Deliveries*.

2.2.1.4 Mosaic Creation

The team used mosaicing software to assemble landscape mosaics from the raw data. We executed mosaic creation in strict adherence with processes and procedures laid out in the Mosaicing Creation Manual (Reid, 2010).

After the mosaics were created, the team extracted metrics (Table 3). Analysis was performed using CPCe (Kohler and Gill, 2006), a freeware program, and the mosaic viewer software created in RC-1333. The mosaic viewer software integrates the final mosaic with a "point and click" interface that brings up the corresponding still images when a point is clicked in the mosaic. CPCe is the primary program used to extract benthic cover and to identify coral species richness from the mosaics. The mosaic viewer, however, was used to "zoom in" on the still images acquired during the survey to aid in species identification, as necessary.

CPCe allows for the analysis of large amounts of data with equivalent or less time in the water compared to other methods. This program is an efficient way to extract quantitative data such as percent cover and enables coral reef scientists to monitor large areas. CPCe can utilize up to 500 random points on an image for analysis. Because the main objective of this survey was to assess damage from the hurricane, and due to time and budget contraints, 400 points were randomly placed on each mosaic image, with the understanding that more points are required to characterize reefs with lower cover and more homogeneously distributed coral colonies, as presented by Pante and Dustan in 2011. This number provides accuracy and can be used for comparisons to future mosaics acquired at the same areas. Statistical robustness of the number of points per mosaic should be considered when mosaic comparisons are made in the future. An advantage of photomosaicing is that one can go back and utilize the maximum points in the software if a more robust analysis is chosen to compare updated mosaics with this archival data baseline.

Analysts identified corals to species, determined if colonies were bleached, determined presence or absence of disease, estimated the amount of bleaching, and estimated old and new mortality affecting the colony at that time. Analysts used the same visual references for estimating % bleaching, % new mortality, and % old mortality as they did in the field.

Table 3.Coral size and condition metrics and the measurements to be made from each mosaic.

Metric	Data Measurement from Mosaic	Method of measurement
2.3 Benthic cover	Percentage cover of live coral, turf algae, macroalgae, crustose coralline algae, milleporans, gorgonians, zoanthids, and sponges measured from mosaics using random point counts.	CPCe and Mosiac Viewer
Coral species richness & diversity	Number of coral species as counted from mosaics using random point counts and image inspection.	CPCe and Mosaic Viewer
Percentage of corals diseased	Analyst estimate of the % of each colony that is diseased	Mosaic Viewer
Percentage of corals bleached	Analyst estimate of the % of each colony that is bleached	Mosaic Viewer
Recent coral mortality	Analyst estimate of the % of each colony that is new coral mortality	Mosaic Viewer
Old coral mortality	Analyst estimate of the % of each colony that is old coral mortality	Mosaic Viewer
Juvenile coral density	Number of juvenile corals (< 4 cm maximum length) as counted from mosaics using inspection of random subquadrats.	CPCe and Mosiac Viewer

Simpson's Diversity Index (D) is a measure of diversity and it is often used to quantify the biodiversity of a habitat. It takes into account the number of species present, as well as the abundance of each species. Simpson's Index gives more weight to the more abundant species in a sample. The value of D ranges between 0 and 1, with 0 being infinite diversity and 1 being no diversity.

The Shannon–Weaver Index (H) is a diversity index and is the measure of species diversity in a given community. It is different from species richness in that unlike richness it also shows community composition and considers the relative abundance of species that are present in the community. The Shannon–Weaver Index is a commonly used diversity index that takes into account both abundance and evenness of species present in the community. Here, a high value of H would be a representative of a diverse and equally distributed community and lower values represent less diverse community. A value of 0 would represent a community with just one species.

Species richness (S) is the number of species per sample. The more species present in a sample, the "richer" the samples. Species richness as a measure on its own takes no account of the number of individuals of each species present. It gives as much weight to those species that have very few individuals as to those which have many individuals**.**

2.4 TEMPERATURE AND LIGHT DATA LOGGERS

We deployed Onset® HOBO® data loggers during and after the mosaic surveys (Figure 6). These loggers acquire data on temperature and ambient light. This information is important in determining if stressors are present over time, such as increased ocean temperatures, increased nutrient loads, and if macroalgae dominance resulting in decreased light to the symbiotic zooxanthellae algae of coral are occurring. Figure 7 depicts a logger attached to two 10-pound weights. The weights ensure that the loggers will remain in place on the seafloor.

The GTMO Navy dive locker assisted in lowering clumps to mark accurate GPS coordinate location for deployment and retrieval. The dive team ensured that the loggers with weights were lowered slowly and that the scientific diver chose the appropriate site adjacent to coral colonies.

Table 2 shows site selection, GPS coordinates, date, and depth of logger installation. At Radio Point, Ferry Landing, and St. Nichols, visibility was too poor to locate coral during mosaic surveys and when other data loggers were deployed. The team's contingency plan was to deploy data loggers during winter 2013 when visibility improved and we could take photographs of coral adjacent to logger installment site.

Figure 6. Physical locations of where the HOBO® data loggers were installed. Map date: ©2014 Google. ©2014 Digital Globe.

Figure 7. HOBO® data logger attached to 10-pound weight so that it did not move with the currents.

2.5 DAMAGE ASSESSMENT ANALYSIS

After the mosaics were created, the team performed an impact analysis. This is composed of a rapid assessment of mosaics to ascertain severity, extent, and spatial pattern of damage inflicted upon GTMO coral reefs by Hurricane Sandy. The final impact analysis metrics included evidence of scour, presence of rubble, presence of disease, and physical evidence of damage to colonies, tips, edges, and branches. Scouring is defined as recently-created bare areas formed by high energy currents and waves generated by the destructive winds of Hurricane Sandy. While it is natural to have some bare areas in GTMO spur and groove coral reefs, the bare areas analyzed in the mosaics were more than likely created due to hurricane impact.

These metrics were based on qualitative analysis of the mosaics that included macroalgae characterization, percent coral cover, types and severity of coral damage, and current stressor indicators on coral that were apparent from viewing the mosaics, such as bleaching or disease.

The team documented the coral colony damage levels tied to increasingly severe impacts from the hurricane to the underlying substrate. Extensive rubble fields of live and dead coral fragments, scoured areas of substrate, displacement of large coral colonies, and impact craters in large coral colonies indicated sites showing structural/reef framework damage. We correlated these characteristics with the combined extent and severity of coral colony damage scores used to define the damage levels described in this assessment. Our analysis was modeled after the Hurricane Yasi study at the Great Barrier Reef (GBRMPA, 2011). The level of damage incurred by individual corals was captured under Levels 1 to 5 and the level of damage that was severe enough to affect the reef as a whole was captured under Levels 3 to 5 (See Table 4).

We used the survey results to estimate the extent and severity of hurricane damage to the total reef area within the Navy installation boundaries. The proportion of each level of hurricane damage observed within each mosaiced area was extrapolated to the known reef area within the Navy's boundaries.

Table 4. Example of hurricane damage levels and reef area affected (GBRMPA, 2011).

Damage Level	Damage Categories
Level 0	No Damage
Level 1	Minor Coral Damage
Level 2	Moderate Coral Damage
Level 3	High Coral Damage and Minor Reef Damage
Level 4	Severe Coral Damage and Moderate Reef Damage
Level 5	Extreme Coral Damage and High Reef Damage

3. RESULTS

Figure 8 (Hidden), Figure 11 (Leeward Point), Figure 12 (Girl Scout Beach), Figure 14 (Blue Beach), Figure 16 (Cuzco), Figure 18 (Windmill), Figure 20 (JTF) and Figure 21 (Kittery) are very-low resolution versions of the final photomosaics made at each site. Due to file compression, these images do not accurately represent the full quality of the photomosaics. Please see DVD for full-resolution imagery.

3.1 REEF HEALTH AND IMPACT ASSESSMENT QUALITATIVE ANALYSIS

As described in Section 2.1, the reef health and impact assessment consisted of a qualitative assessment of the storm damage over the area of the mosaic. We characterized both the extent and severity of the coral damage in each mosaic and included detailed assessments of coral colony damage at the tip, branch, and whole colony levels.

3.1.1 Hidden

This site was co-dominated by macroalgae (20%) and coral rubble (20%). Macroalgae was a more dominant feature at Hidden Beach than at the other reef sites assessed. This reef is inundated by the river plume on a falling tide, delivering relatively high amounts of terrestrial nutrients for algae growth. Only 10% bare rock was present and 5% live coral. This area appeared to have been affected by some stressor(s) (hurricane, nutrient loads, sediment, etc.) because it exhibited a vast amount of bare areas or areas with rubble. The small amount of corals here were little colonies or juveniles. Most damage to massive/mound and encrusting colonies at this site and other sites are probably from sedimentation (sediment settling on the colonies) and not from the hurricane.

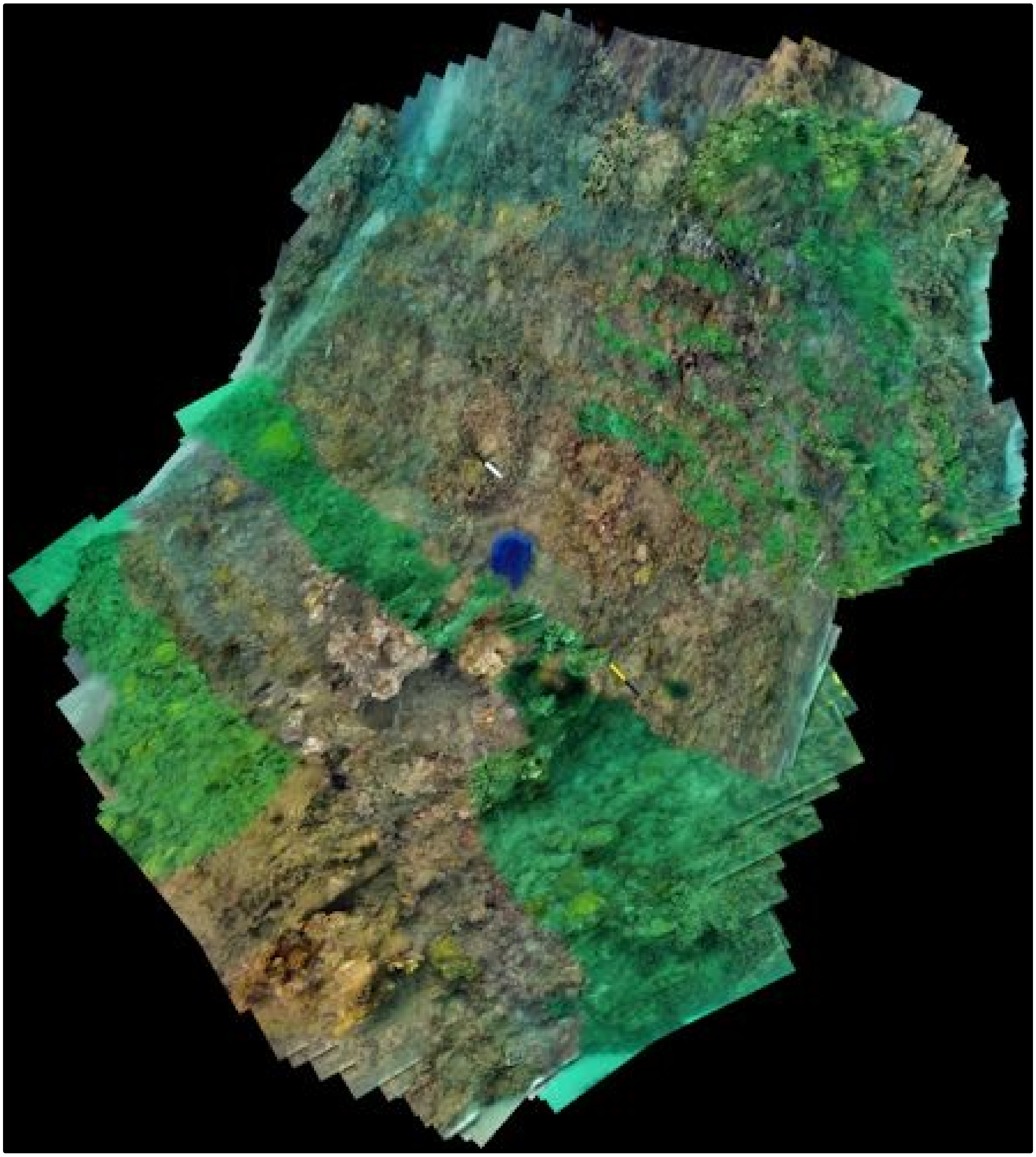

Figure 8. Mosaic of the reef community at Hidden (due to file compression, this image does not represent accurately the full quality of the photomosaics. Please see DVD for full-resolution imagery).

3.1.2 Leeward Point

This site was dominated by bare rock (50%). There was very little live coral (10%), old mortality coral (2%), and macroalgae (4%). We observed the rare coral *Mussa angulosa* here, but they did not appear healthy (Figure 9). This colony was not bleached, but was pale and presented little color. There was a *Montastrea cavernosa* colony that appeared to have some disease affecting it. Most damage to massive/mound and encrusting colonies at this site and other sites were probably from sedimentation (sediment settling on the colonies) and not from the hurricane (Figure 10**).**

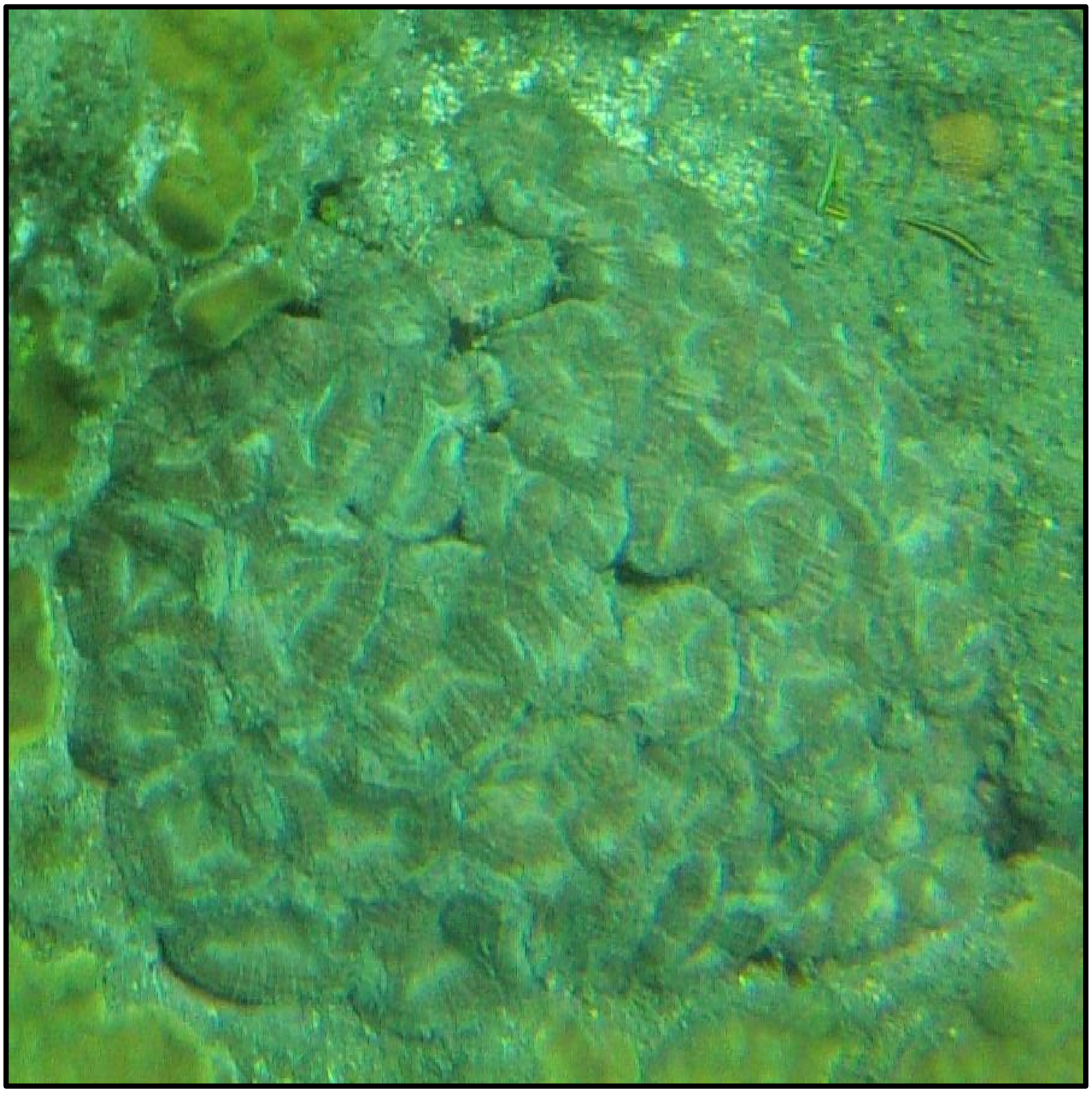

Figure 9. *Mussa angulosa* at the Leeward Point site.

Figure 10. Example of sedimentation at the Leeward Point site.

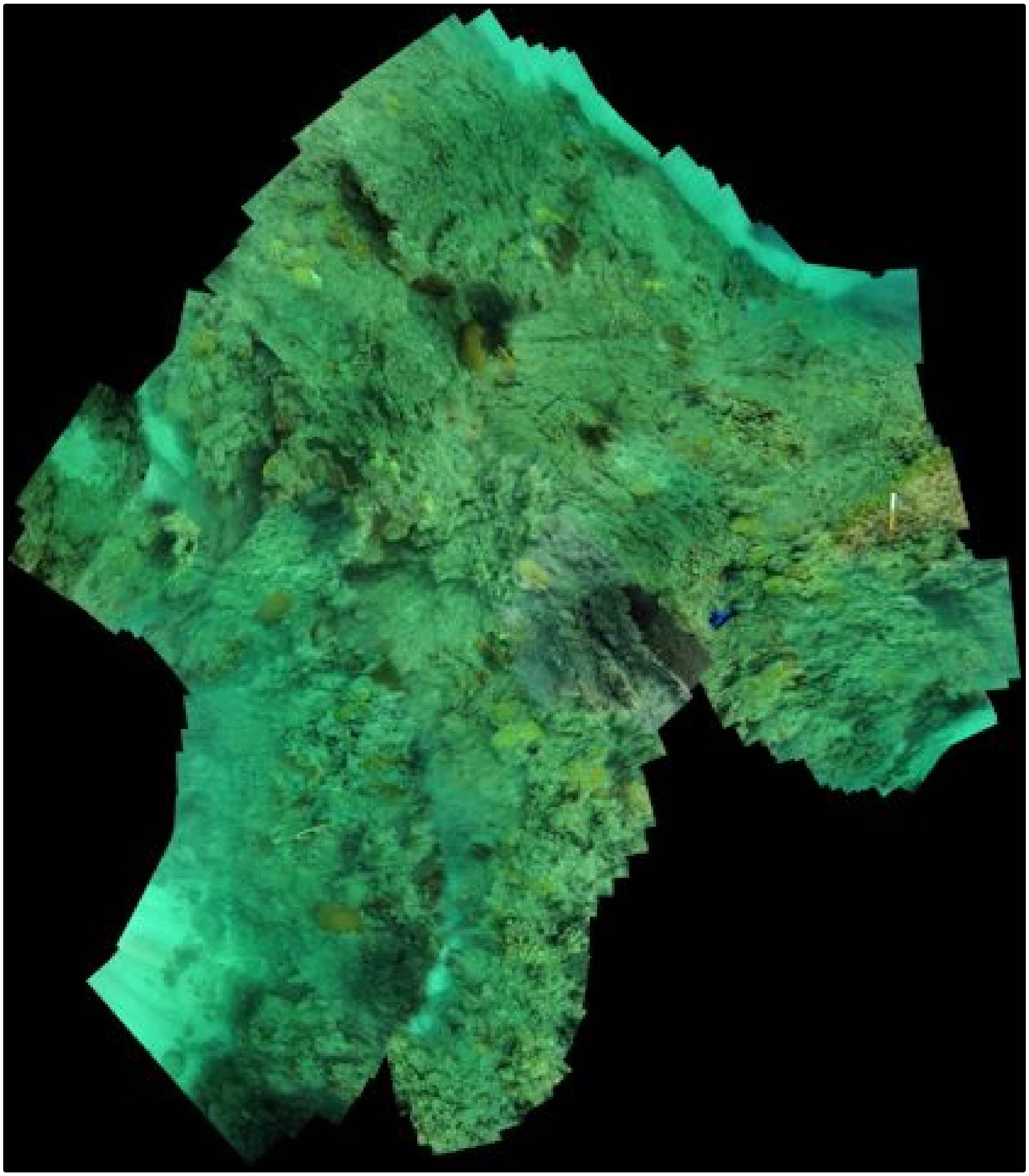

Figure 11. Mosaic of the reef community at Leeward (due to file compression, this image does not represent accurately the full quality of the photomosaics. Please see the DVD for full-resolution imagery).

3.1.3 Girl Scout Beach

This site replaced Glass Beach since visibility was poor at Glass Beach due to the arrival of turbid upper bay waters on a falling tide. The Girl Scout Beach reef was dominated by live coral (20%) followed by old mortality coral (10%). There was 10% coral rubble present with very little macroalgae (3%), and bare rock (5%). There was evidence of slight scour on *Montastrea annularis* colonies. There was much more presence of sponge species here than at Blue Beach or Cuzco, and probably other areas outside of the bay. No big coral colonies are present at this site. Coral appeared to be growing back or competing with sponge, algae, etc. Most damage to massive/mound and encrusting colonies at this site and other sites were probably from sedimentation (sediment settling on the colonies) and not from the hurricane.

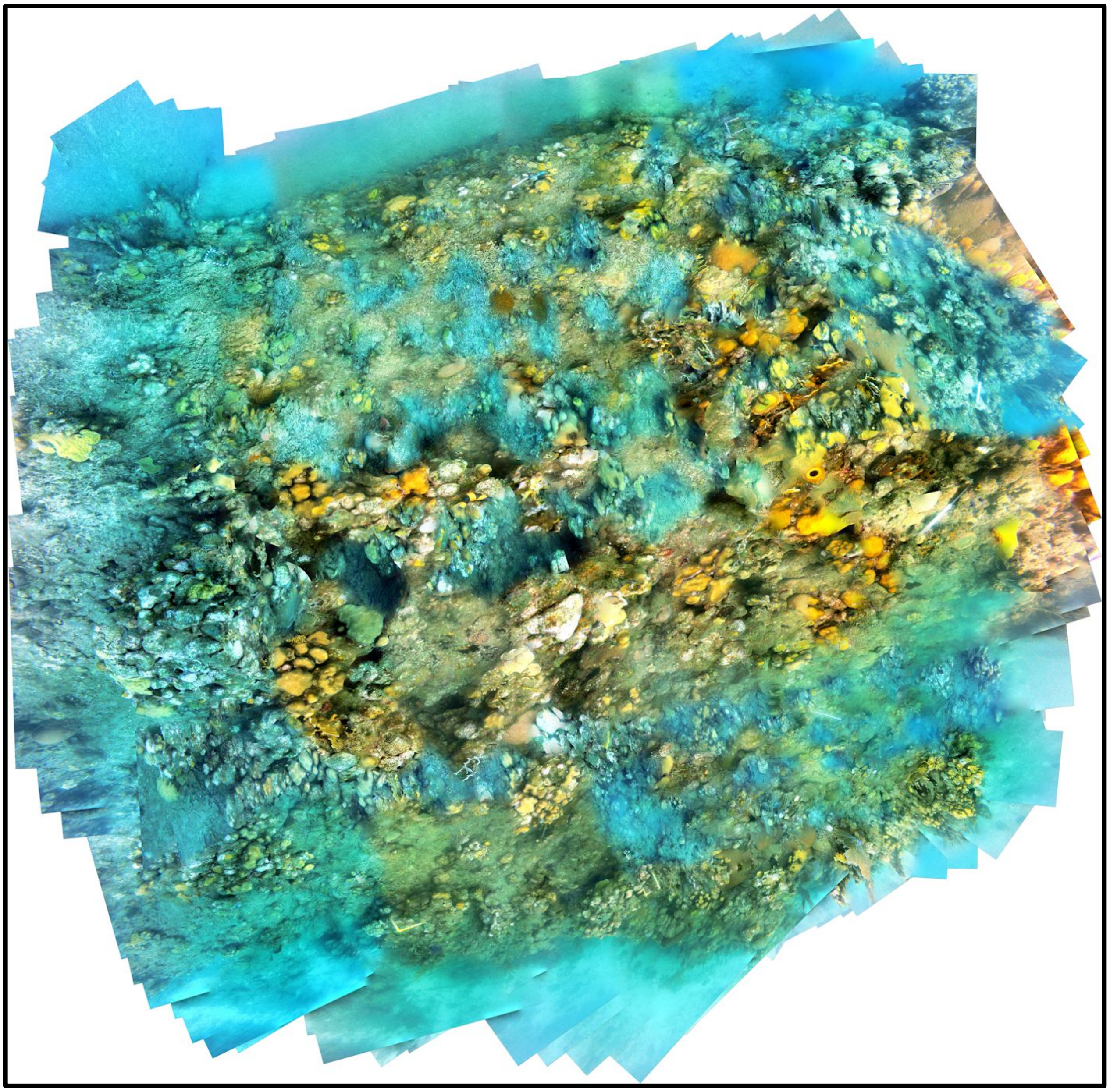

Figure 12. Mosaic of the reef community at Girl Scout Beach (due to file compression, this image does not represent accurately the full quality of the photomosaics. Please see DVD for full-resolution imagery).

3.1.4 Blue Beach

This site is dominated by live coral (30%), followed by old mortality coral (20%). There was 15% macroalgae and 15% sand with little bare rock (5%) and coral rubble (2%). Three small fish were seen. A small portion of what could have been scouring from hurricane (about 15%) (Figure 13) was also visible. Old mortality (5%) was from small branching coral, and was probably not caused by hurricane impact because remnants of branches would probably have been washed away. *Montastrea annularis* colonies appeared to be growing back on bare substrate adjacent to live colonies. Most macroalgae appeared to be *Dictyota* sp. (Figure 13). Most damage to massive/mound and encrusting colonies at this site and other sites were probably from sedimentation (sediment settling on the colonies) and not from the hurricane. We base this conclusion on the wave exposure at this site, natural dynamics leading to the settling of sediment, and possible run-off. The latter would need further research to confirm.

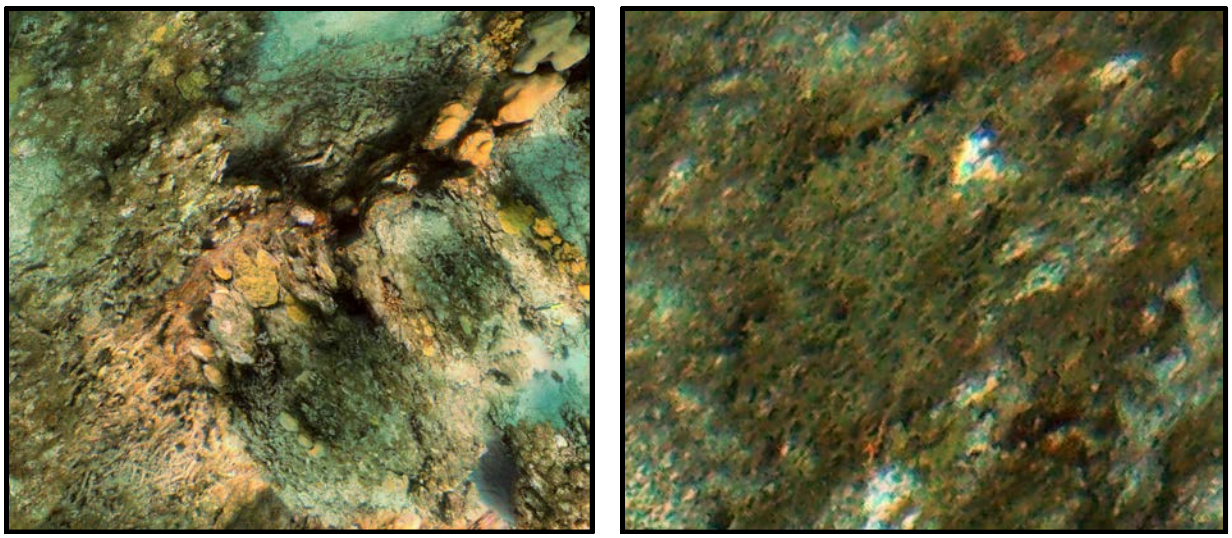

Figure 13. Evidence of scour and *Dictyota sp.* present at the Blue Beach site.

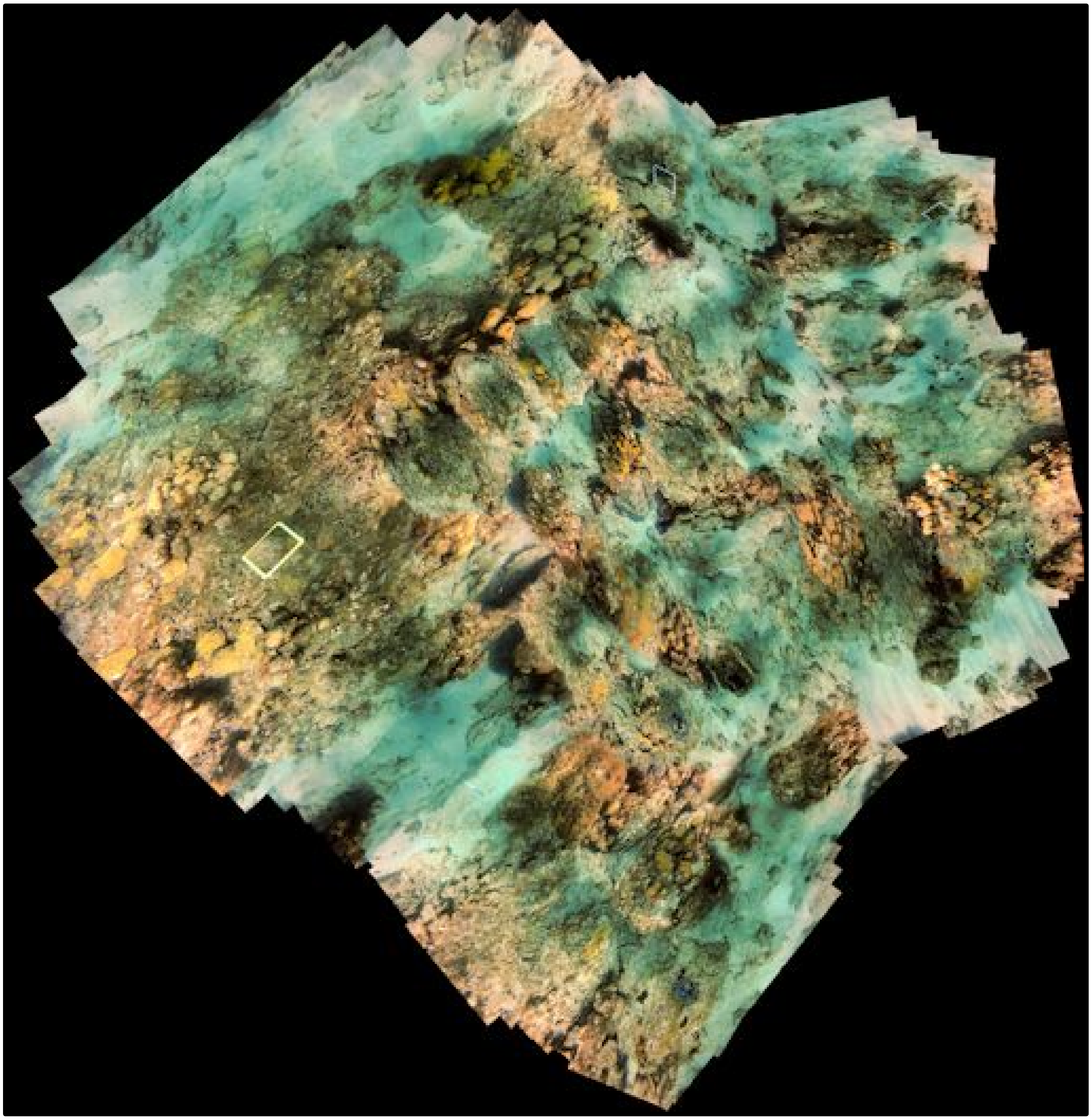

Figure 14. Mosaic of the reef community at Blue Beach (due to file compression, this image does not represent accurately the full quality of the photomosaics. Please see DVD for full-resolution imagery).

3.1.5 Cuzco

Live coral (30%) dominated this site; only 10% old mortality coral was present. There was evidence of slight scour on *Montastrea annularis* colonies. A colony of *Montastrea faveolata* may have some disease at this site, and other colonies of the same species have what appear to be parrotfish bites (Figure 15). Disease was present on one colony of *Montastrea annularis* with spots of bleaching as well. Many colonies at this site appeared to have boring holes from snail predators. Many juvenile corals were growing here. Most damage to massive/mound and encrusting colonies at this site and other sites were probably from sedimentation (sediment settling on the colonies) and not from the hurricane.

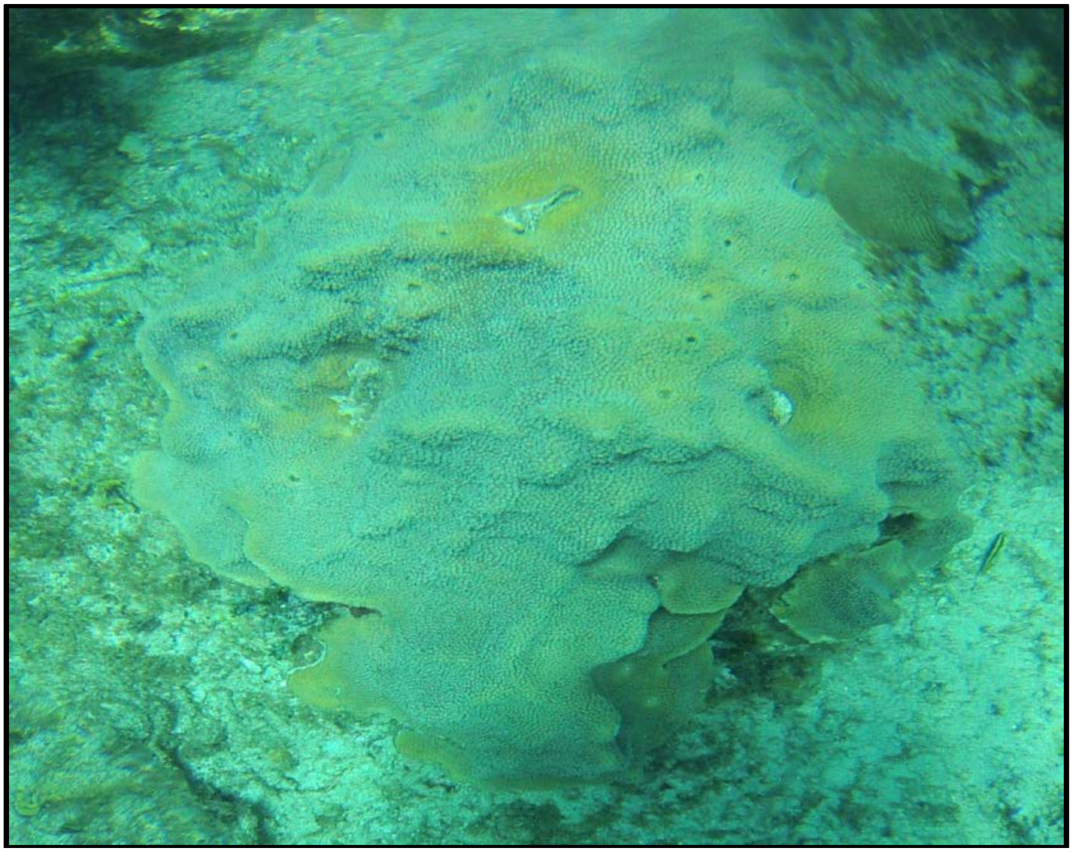

Figure 15. Evidence of disease and fish bites on *Montastrea faveolata* located at Cuzco.

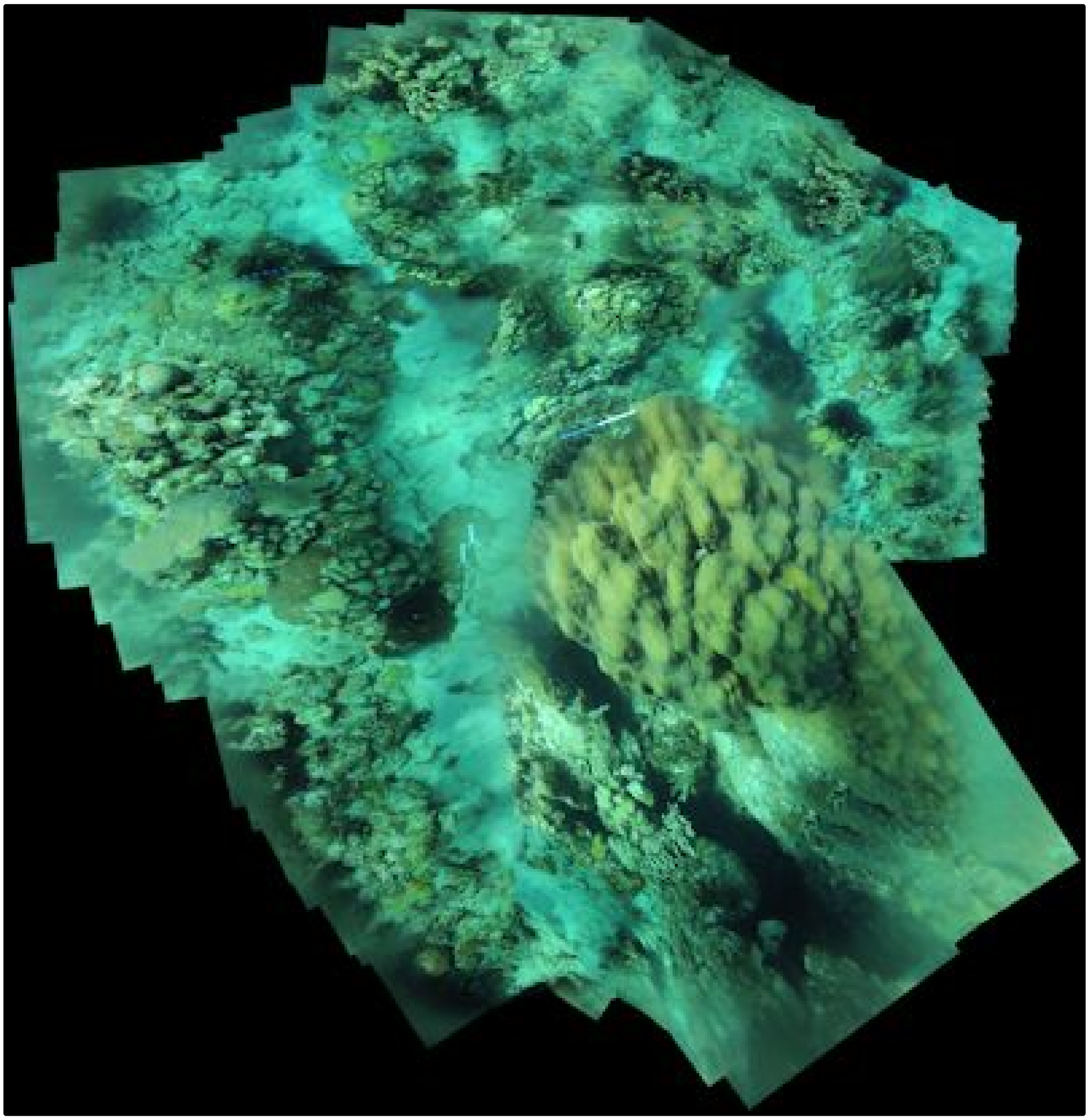

Figure 16. Mosaic of the reef community at Cuzco (due to file compression, this image does not represent accurately the full quality of the photomosaics. Please see DVD for full-resolution imagery).

3.1.6 Windmill

This site was dominated by live coral (40%) with 20% old mortality coral. There was little sand (8%), bare rock (5%), macroalgae (2%), and coral rubble (2%). Evidence in this mosaic of rubble and dead *A. cervicornis* indicates at least one whole colony at Windmill was completely wiped out by the hurricane. There was evidence of disease on the *Montastrea faveolata* colony located at the bottom of the mosaic. Compared to all other sites, the biggest colony of *Montastrea faveolata* was present at this site. We observed a few fish as well. A small colony of *Montastrea annularis*, with *Millipora complanata* to the right of it, appeared to have a blue ring (must zoom in to see) on it, indicating disease. Further research would need to be conducted to determine the type of disease. There was a 1% damage classification due to the tops of *Montastrea annularis* exhibiting scouring from the hurricane. Some rubble and dead coral was identified as *Acropora cervicornis*, which appeared to be evidence of hurricane damage.

Over all sites, fish populations were sparse. We also saw a brown "matted-like" sponge (Figure 17).

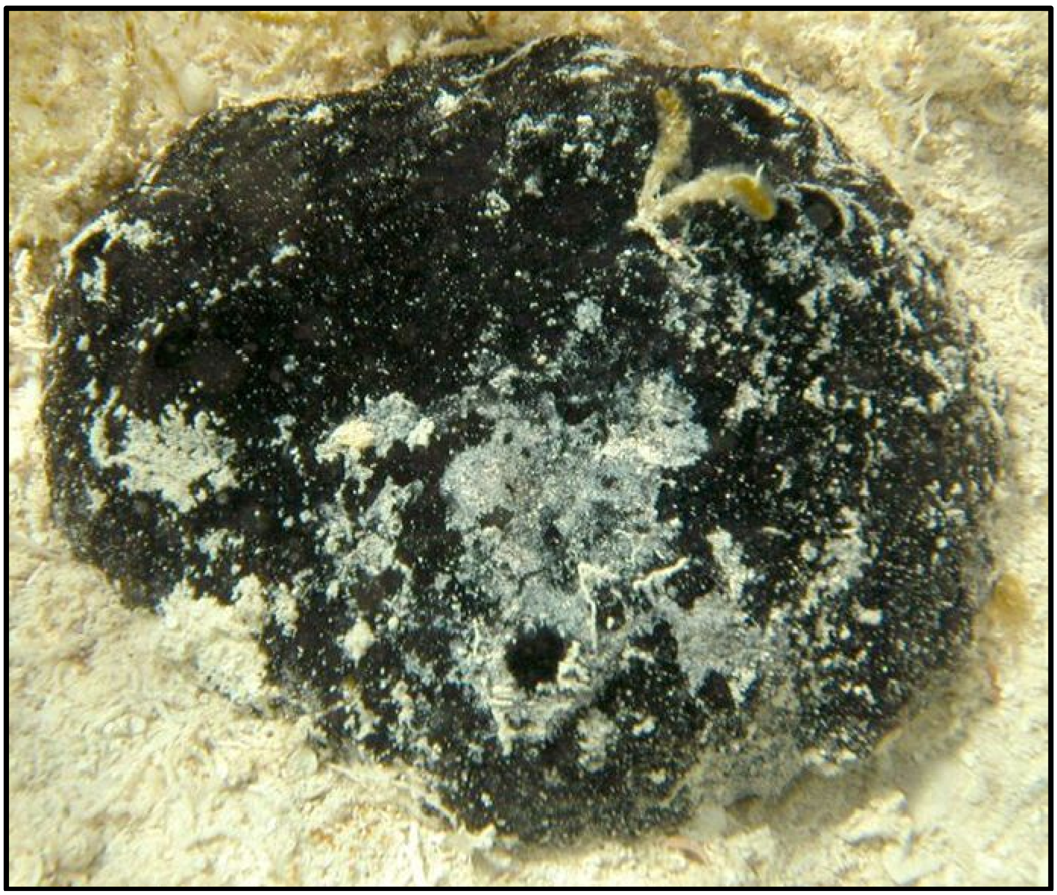

Figure 17. Matted-like sponge seen at all sites.

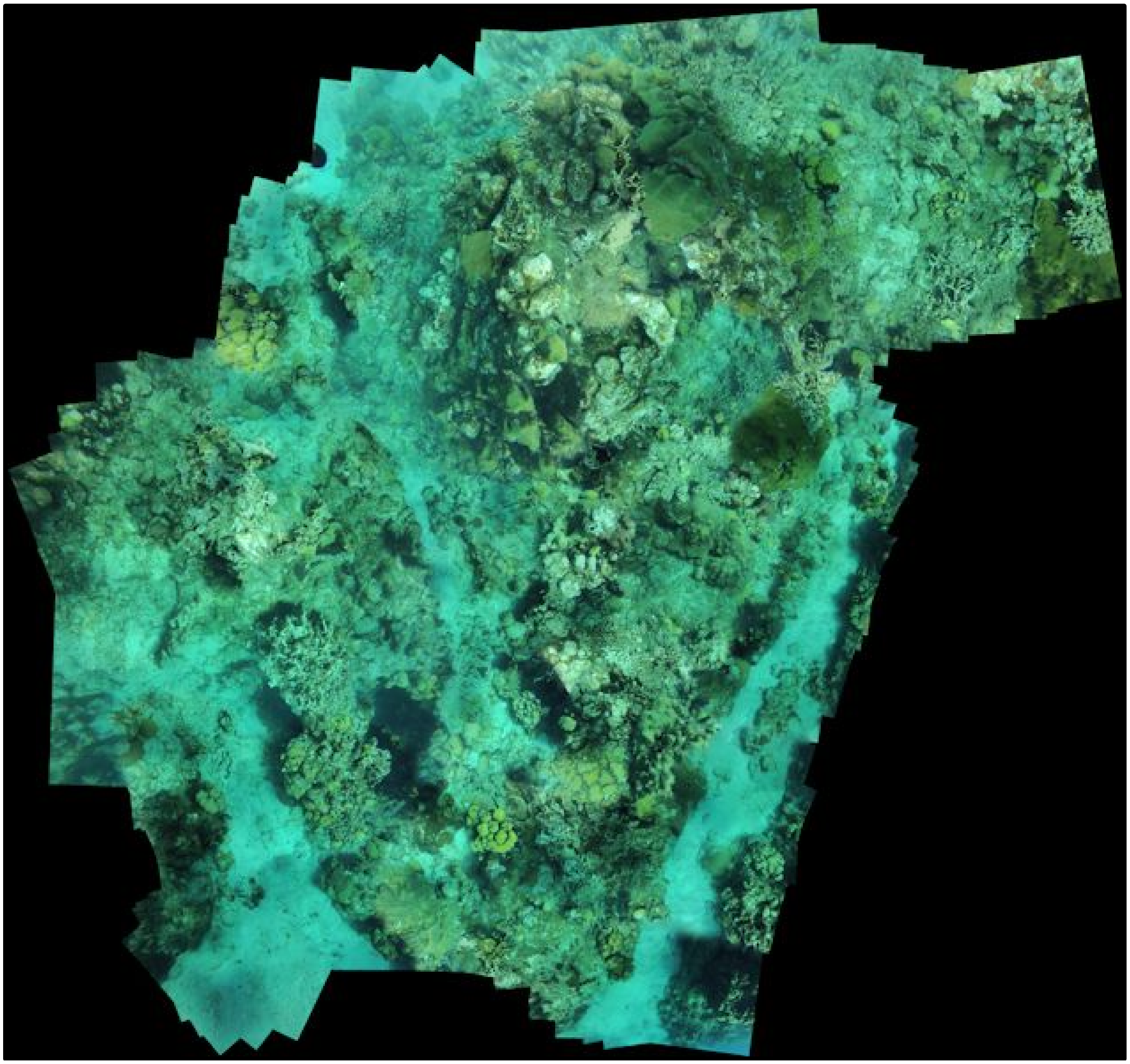

Figure 18. Mosaic of the reef community at Windmill (due to file compression, this image does not represent accurately the full quality of the photomosaics. Please see DVD for full-resolution imagery).

3.1.7 Joint Task Force (JTF)

There was 40% live coral and 15% percent bare rock present at this site. Minimal coral rubble (2%), and sand (5%) were also visible. No macroalgae was present. Small evidence of slight scour was present at this site. At least two large colonies of *Montastrea cavernosa* were present that indicated disease. Assess which disease was present was difficult without further study, but the indications pointed toward possible yellow-band disease. One colony of *Acropora palmata* appeared to have some disease as well (Figure 19). Most damage to massive/mound and encrusting colonies at this site and other sites was probably from sedimentation (sediment settling on the colonies) and not from the hurricane.

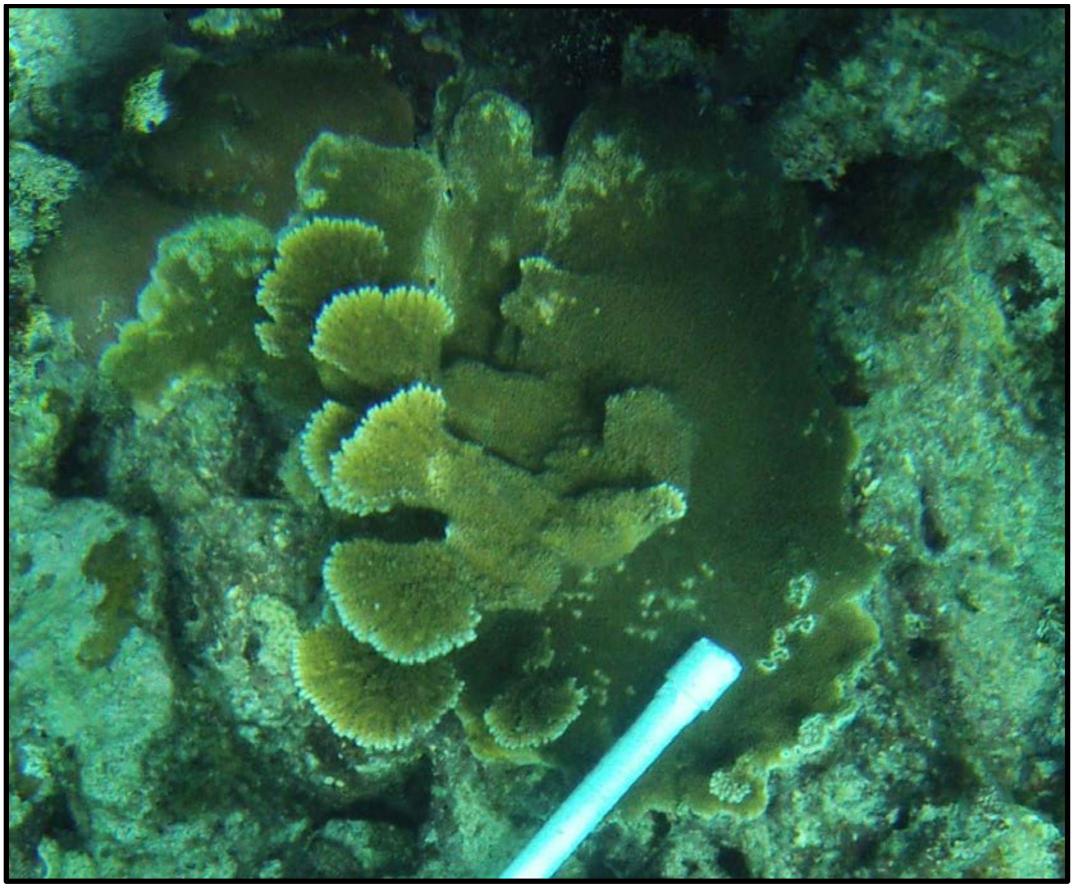

Figure 19. Diseased *Acropora palmata* at JTF.

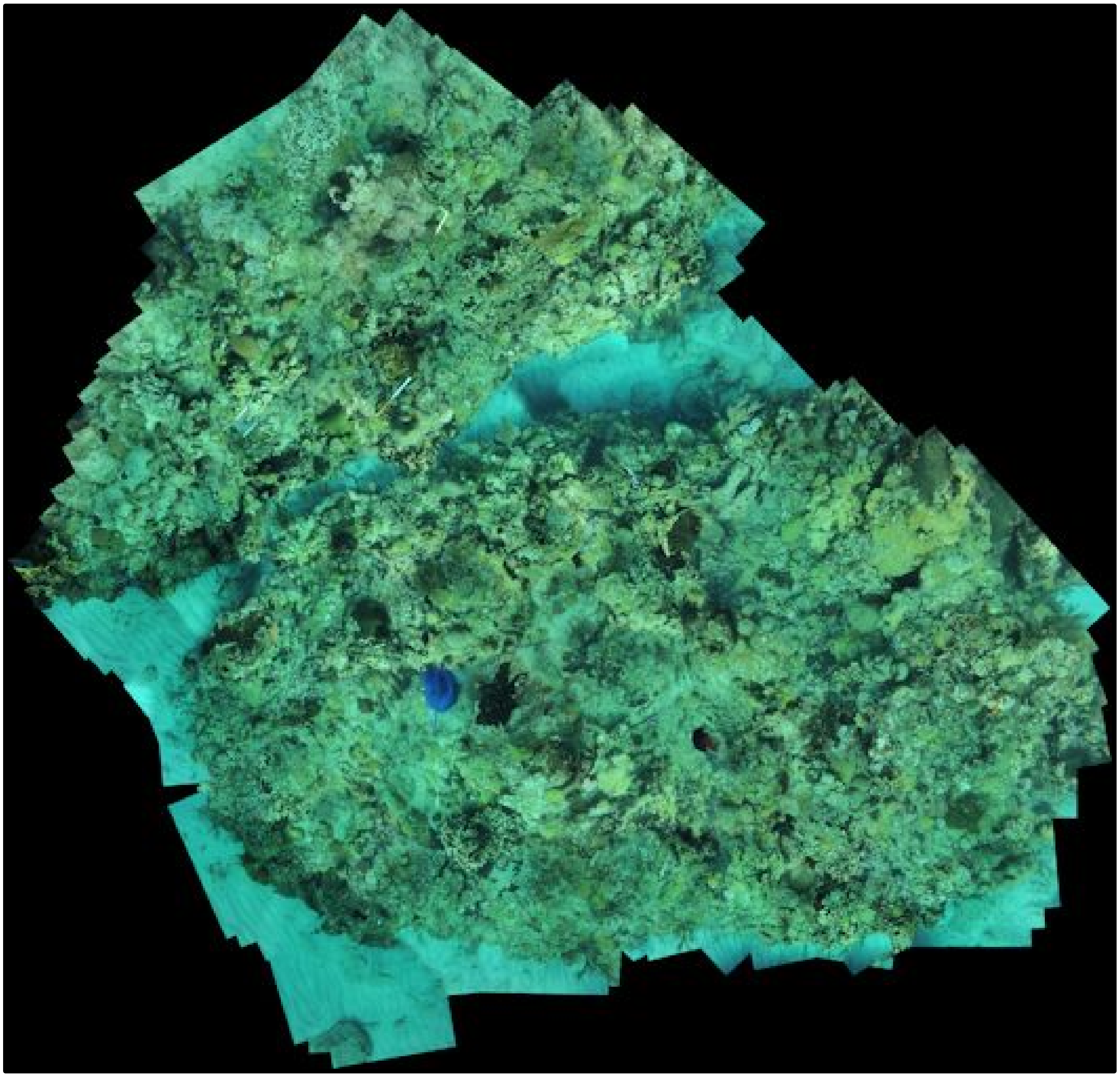

Figure 20. Mosaic of the reef community at JTF (due to file compression, this image does not represent accurately the full quality of the photomosaics. Please see DVD for full-resolution imagery).

3.1.8 Kittery

Sand (30%) dominated this site. There was 15% macroalgae and 15% bare rock, respectively. Few live coral (10%) and coral rubble (2%) were present. The amount of suitable substrate for coral to settle or grow on at this site was limited. Most damage to massive/mound and encrusting colonies at this site and other sites were probably from sedimentation (sediment settling on the colonies) and not from the hurricane.

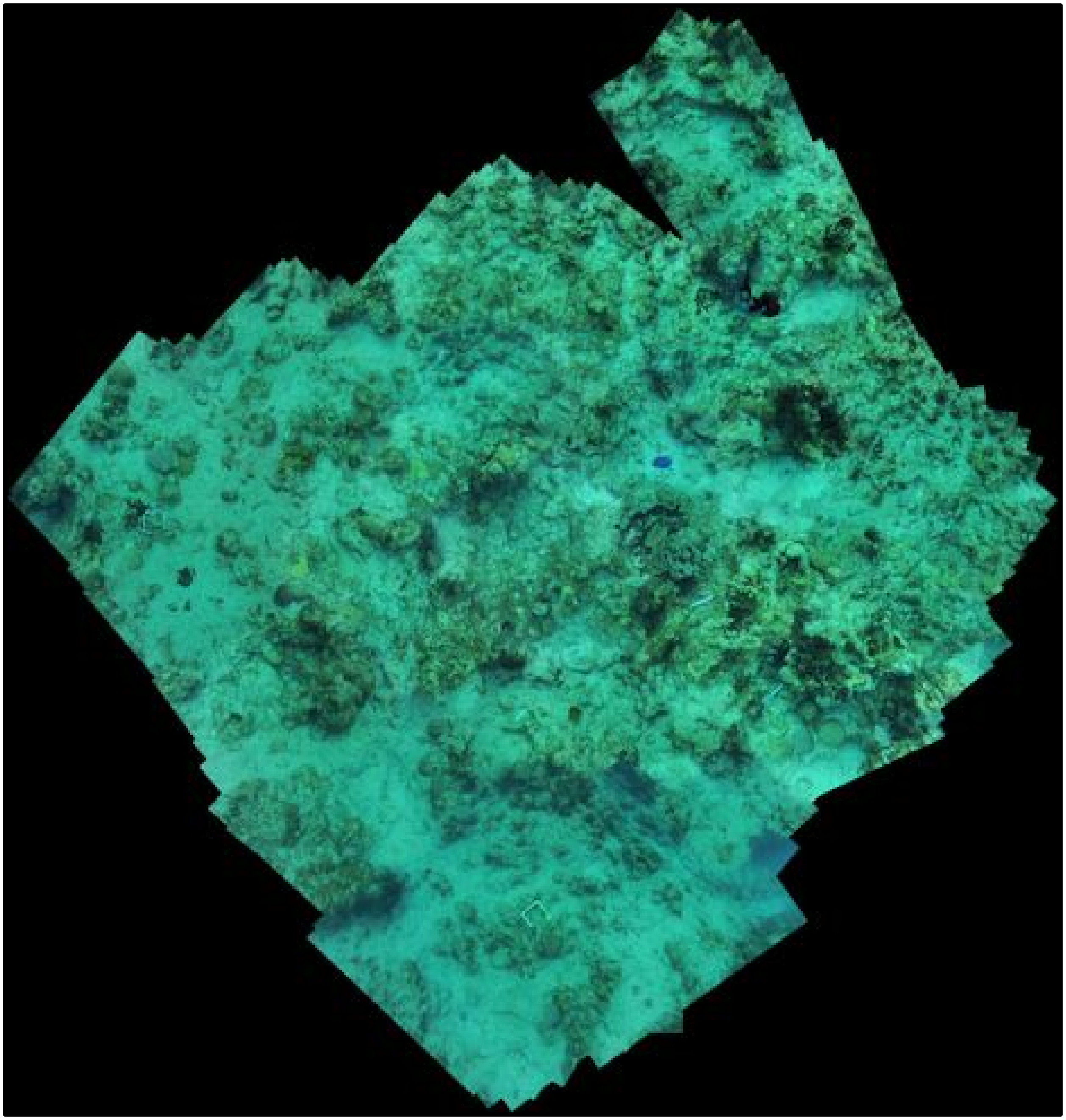

Figure 21. Mosaic of the reef community at Kittery (due to file compression, this image does not represent accurately the full quality of the photomosaics. Please see DVD for full-resolution imagery).

3.2 CPCe QUANTITATIVE ANALYSIS

As described in Section 2.2.1.4, we used the Coral Point Count with Microsft® Excel® extensions (CPCe) software to analyze each mosaic and extract the pertinent metrics (See Table 4). CPCe is a program that provides features for determining the coral cover using transect photographs. The program was used for image calibration and area analysis of benthic options. It calculated coverage statistics that were automatically sent to Microsoft® Excel® spreadsheets.

3.2.1 Hidden

Sand, pavement, and rubble (90.8%) dominated this site. This site had macroalgae (4.6%) and coral (3.8%) present, as shown in Figure 22. There were only small amount of dead coal with algae (0.4%) and sponges (0.4%).

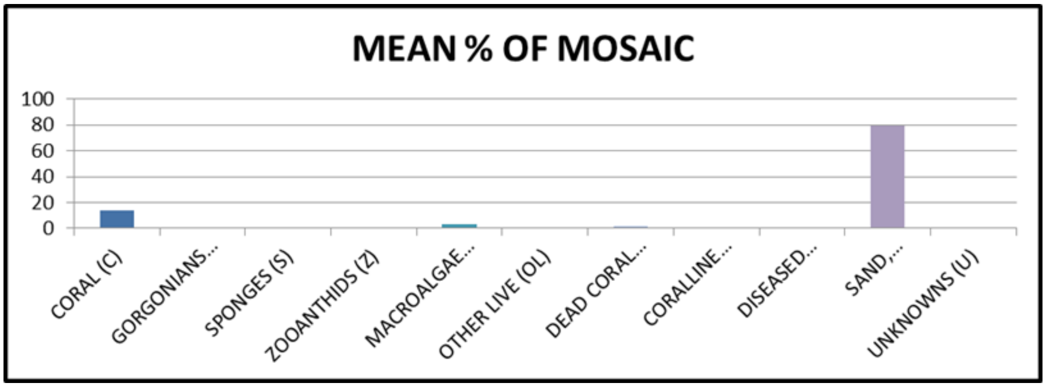

Figure 22. Benthic cover of major functional classes present at Hidden site.

The dominant coral species at this site was *Porities asteroides* (3.5%), followed by *Montastrea faveolata* (0.5%) and *Siderastrea siderea* (0.5%), as shown in Figure 23. The only algal group identified was macroalgae (5.5%).

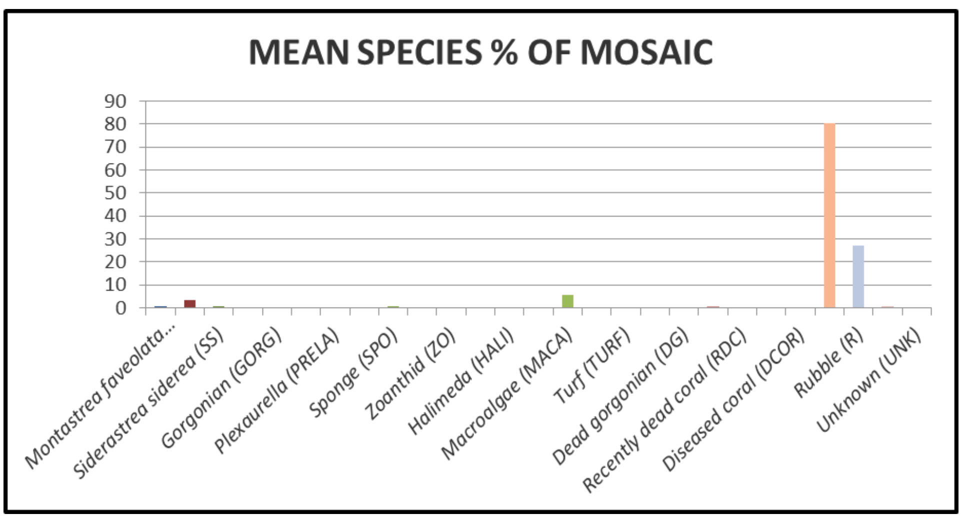

Figure 23.Species-level assessment of benthic cover of major functional classes present at Hidden site.

This site had one of the lowest coral species richness value (3) of all the sites, and was not very diverse (H = 0.39; D = 0.17). This site had the lowest algal species richness (1) of all the sites.

3.2.2 Leeward Point

This site was dominated by sand, pavement, and rubble (79.7%), as shown in Figure 24.There was 13.6% live coral with 1.2% dead coral with algae (old mortality). Macroalgae was present (3.3%) along with small portions of sponge (1%), gorgonians (0.8%), and zoonathids (0.3%).

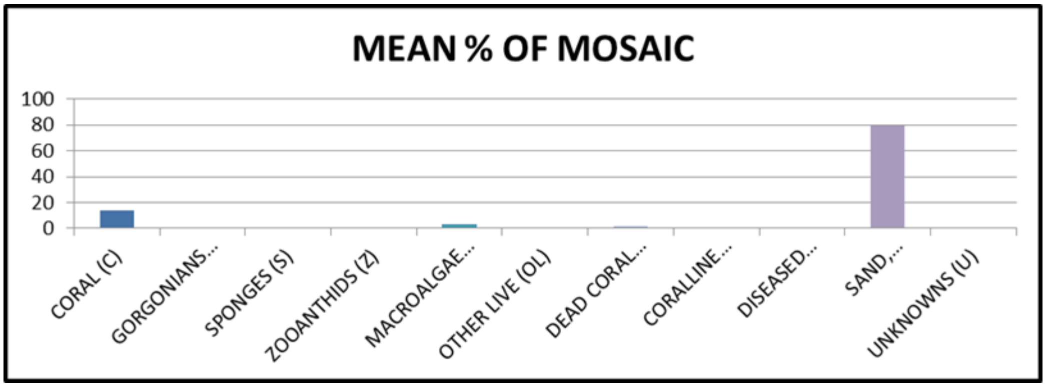

Figure 24. Benthic cover of major functional classes present at Leeward Point.

An Algal community of Halimeda are located at the Leeward Point site. We observed a few old dead coral (1%) here, along with some recently dead coral (0.5%). The dominant algal species at this site was macroalgae (2.5%), followed by *Halimeda* (1%) (Figure 25), Styptopodium (0.5%), and turf algae (0.5%). The coral species present at this site was *Porites asteroides* (9%), followed by *Siderastrea siderea* (2.5%), *Agaricia fragilis* (2%), *Millipora complanata* (1%), *Montastrea faveolata* (0.5%), *Mussa angulosa* (0.5%), and *Diplora strigosa* (0.5%), as shown in Figure 26.

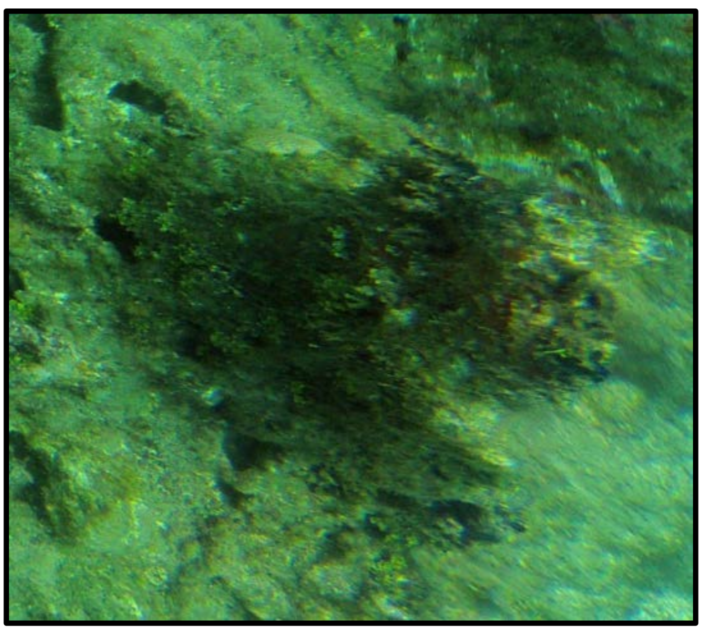

Figure 25. Algal community of *Halimeda* present at the Leeward point site.

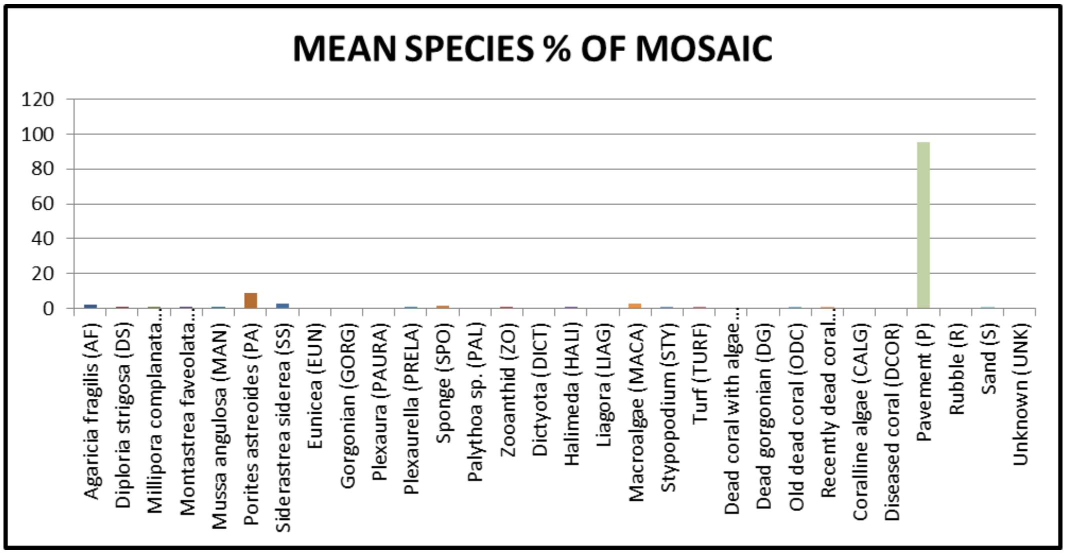

Figure 26. Species-level assessment of benthic cover of major functional classes present at Leeward Point.

This site had a coral species richness value of 7 and was moderately diverse (H=0.70; D=0.34). This site had high algal species richness (4).

3.2.3 Girl Scout Beach

Sand, pavement, and rubble (66.2%) dominated this site, as shown in Figure 27. This site has slightly more dead coral with algae (old mortality) (16.3%) than coral (14.5%). There were minimal amounts of macroalgae (0.8%), sponge (0.8%), and gorgonians (0.3%) at this site.

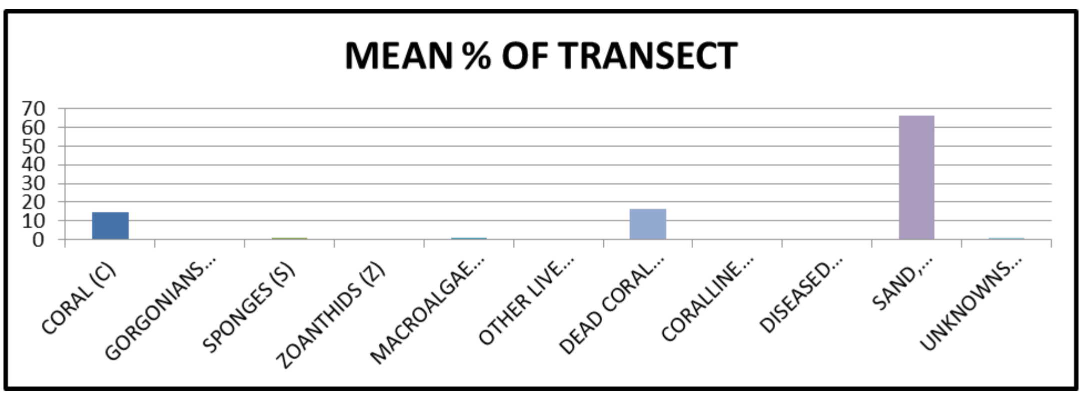

Figure 27. Benthic cover of major functional classes present at Girl Scout Beach.

The dominant coral species at this site was *Montastrea annularis* (13.5%), followed by *Milliipora complanata* (2.5%), Siderastrea siderea(1.5%), *Montastrea cavernosa* (1.5%), PA (1%), *Montastrea faveolata* (0.5%), and *Diplora strigosa* (0.5%), as shown in Figure 28. This site had evidence of recently dead coral (0.5%) and old dead coral (24%). This site had low amounts of *Dictyota* and macroalagae (0.5% for each).

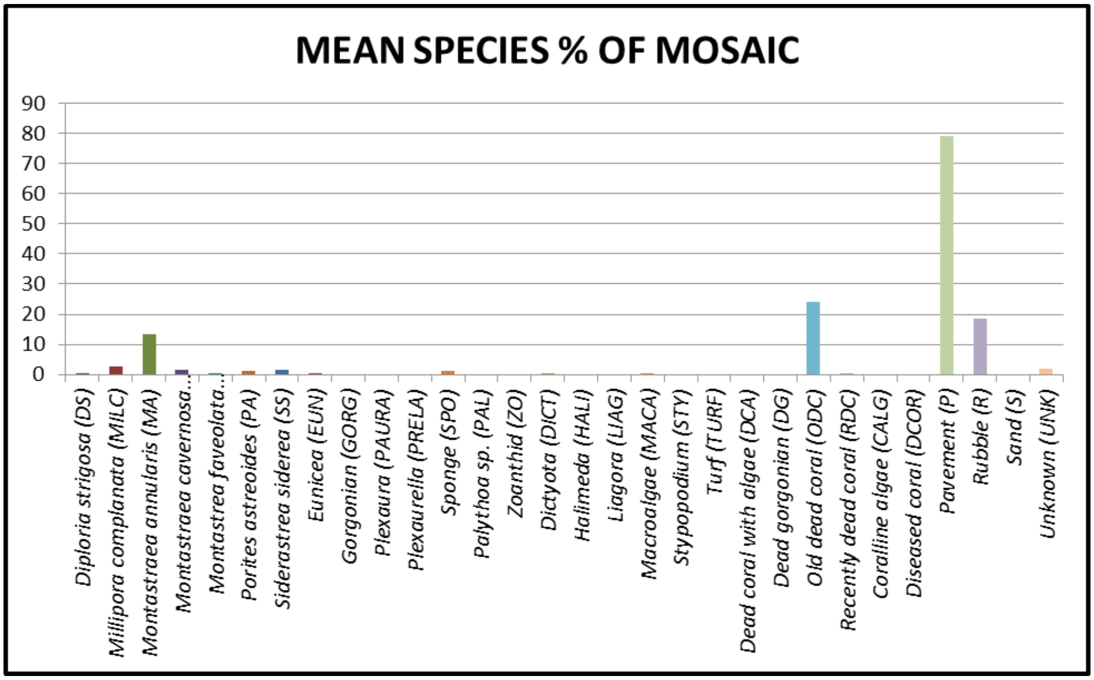

Figure 28. Species-level assessment of benthic cover of major functional classes present at Girl Scout Beach.

This site had a coral species richness value of 7 and was highly diverse (H = 0.97; D = 0.51). This site had low algal species richness (2).

3.2.4 Blue Beach

Sand, pavement, and rubble (68.8%) dominates this site, as shown in Figure 29. It had low amounts of live coral (12.9%) and macroalgae (11.3%). We observed only a few dead coral with algae (old mortality) (4.9%) and sponges (2%).

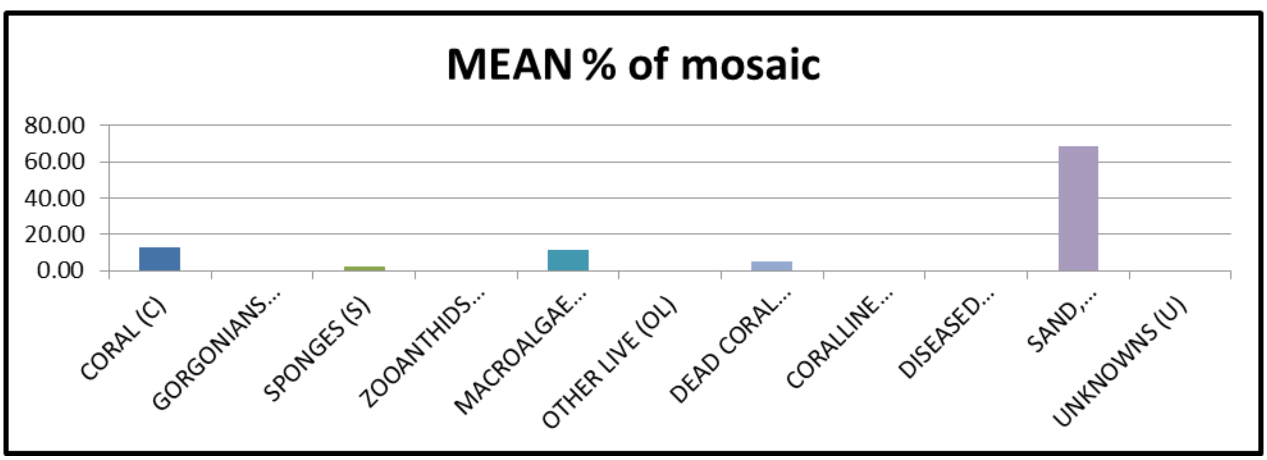

Figure 29. Benthic cover of major functional classes present at Blue Beach.

The dominant coral species at this site were *Montastrea annularis* (7.5%), *Porites asteroides* (6.5%), and *Montastrea faveolata* (2.5%).

The dominant algal species at this site were turf algae (10.5%), followed by macroalgae (2.5%) and then by Dictyota (1.5%), as shown in Figure 30.

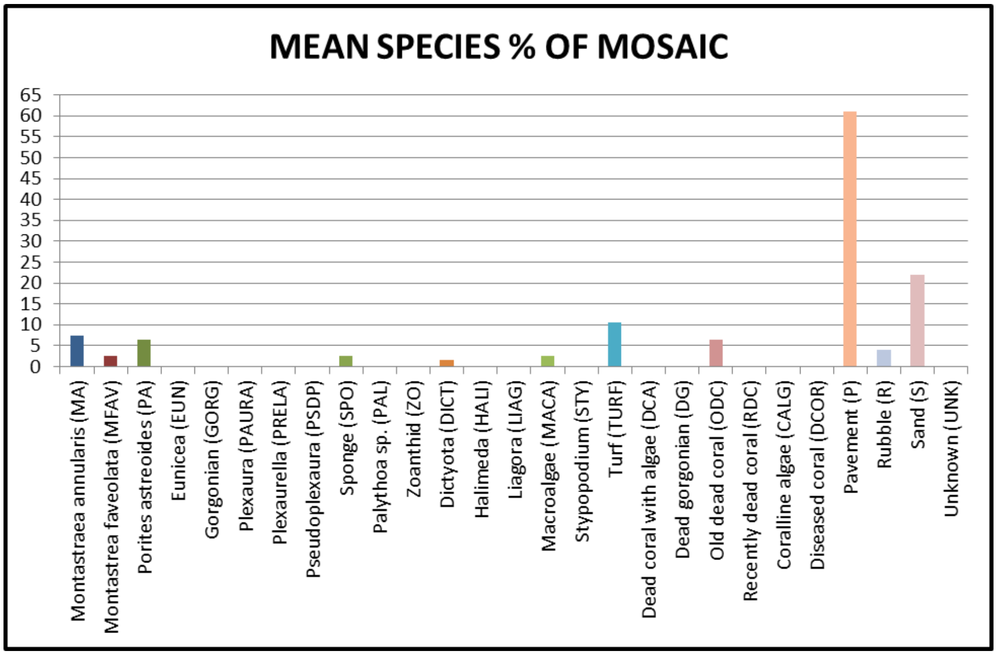

Figure 30. Species-level assessment of benthic cover of major functional classes present at Blue Beach.

This site had one of the lowest coral species richness values (3) of all the sites, but was highly diverse (H = 0.97; D = 0.49). This site had moderate algal species richness (3).

3.2.5 Cuzco

Sand, pavement, and rubble (54.5%) dominated this site, as shown in Figure 31. Live coral was present (31.3%), with 8.6% dead coral with algae (old mortality). There were minimal amounts of macroalgae (3.0%), gorgonians (1.2%), and sponges (0.7%) at this site.

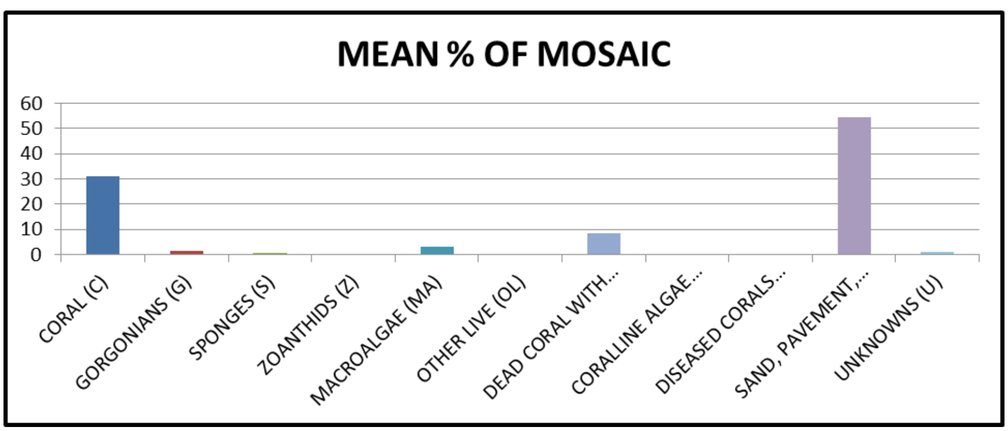

Figure 31. Benthic cover of major functional classes present at Cuzco.

The dominant coral species at this site was *Montastrea faveolata* (38%), followed by *Porites asteroides* (8%), *Montastrea annularis* (5%), *Siderastrea siderea* (2.5%), and *Millipora complanata* (0.5%), as shown in Figure 32. The algal community was represented by macroalgae (2.5%) and turf algae (2%).

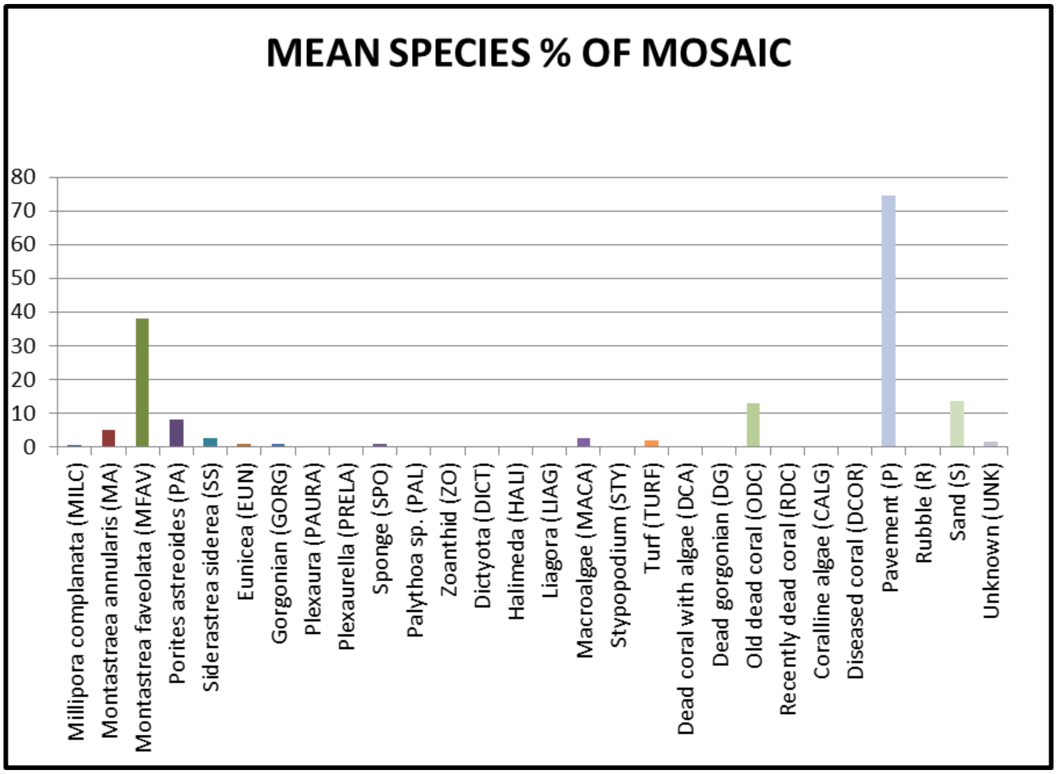

Figure 32. Species-level assessment of benthic cover of major functional classes present at Cuzco.

This site had a coral species richness value of 5 and was highly diverse (H = 1.08; D = 0.57). This site had low algal species richness (2).

3.2.6 Windmill

Sand, pavement, and rubble (60%) dominated this site, as shown in Figure 33. Live coral was present at 25.5%, with 6.4% dead coral with algae (old mortality). Macroalgae was also present (5.6%), and we observed zooanthids (1.2%), as shown in Figure 34, and sponges (0.9%) at this site.

The coral species present at this site were *Montastrea faveolata* (15%), followed by *Montastrea annularis* (9%), *Porties asteroides* (3%), Montastrea franksi (1%), *Agaricia tenuifolia* (0.5%), *Millipora complanata* (0.5%), *Porites porites* (0.5%), and *Siderastrea siderea* (0.5%), as shown in Figure 35. The dominant algal species at this site was macroalgae (2.5%), followed by Dictyota (2%), turf algae (1.5%), and Liagora (0.5%).

This site had the second highest level of coral species richness (8) and was highly diverse (H = 1.08; D = 0.56). This site had high algal species richness (4).

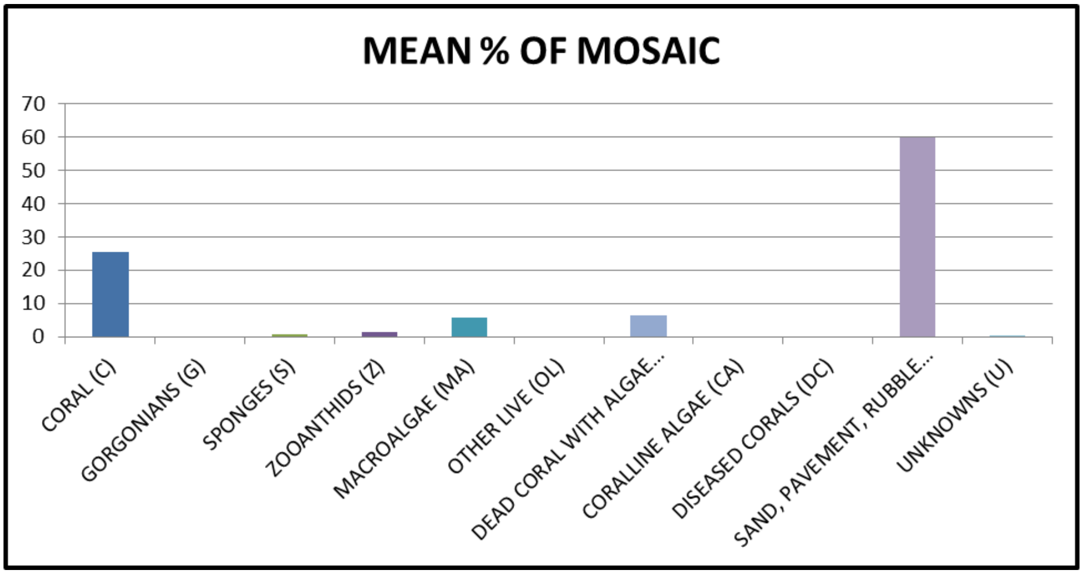

Figure 33. Benthic cover of major functional classes present at Windmill.

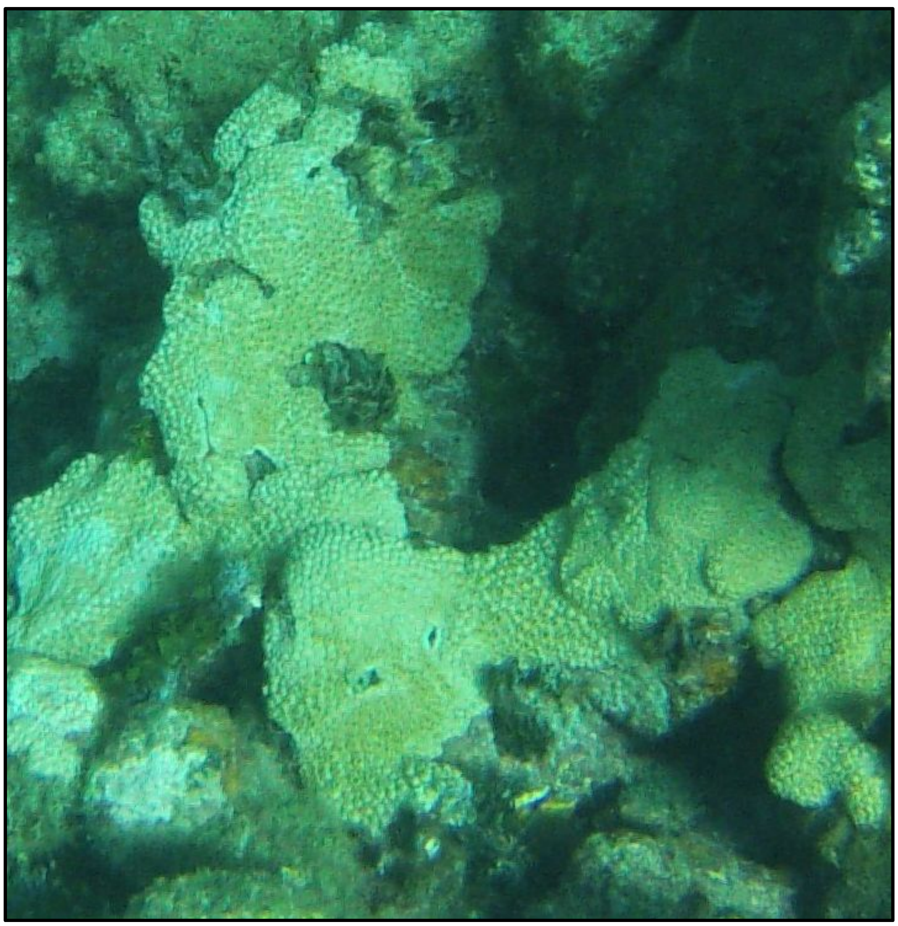

Figure 34. Typical zoonathid seen at several of the surveyed sites.

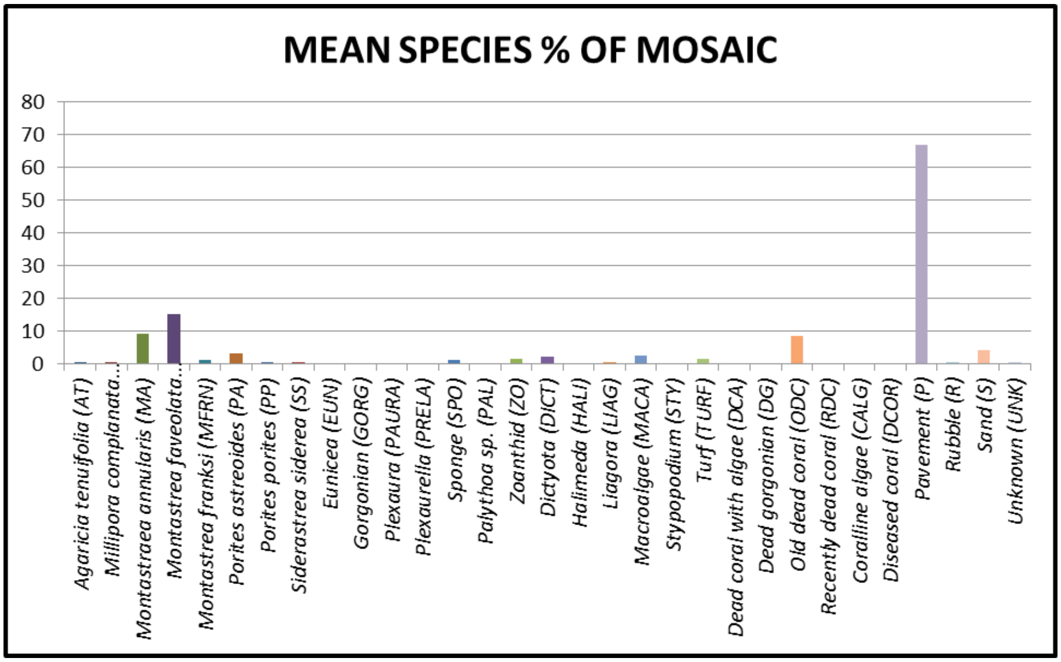

Figure 35. Species-level assessment of benthic cover of major functional classes present at Windmill.

This site had the second highest level of coral species richness (8) and was highly diverse (H = 1.08; D = 0.56). This site had high algal species richness (4).

3.2.7 JTF

Sand, pavement, and rubble (65%) dominated this site, as shown in Figure 36. This site had 21.5% coral with 3% dead coral with algae (old mortality). Zooanthids were present (5.6%) at this site, along with gorgonians (2.3%), sponges (1.6%), and macroalgae (1.1%).

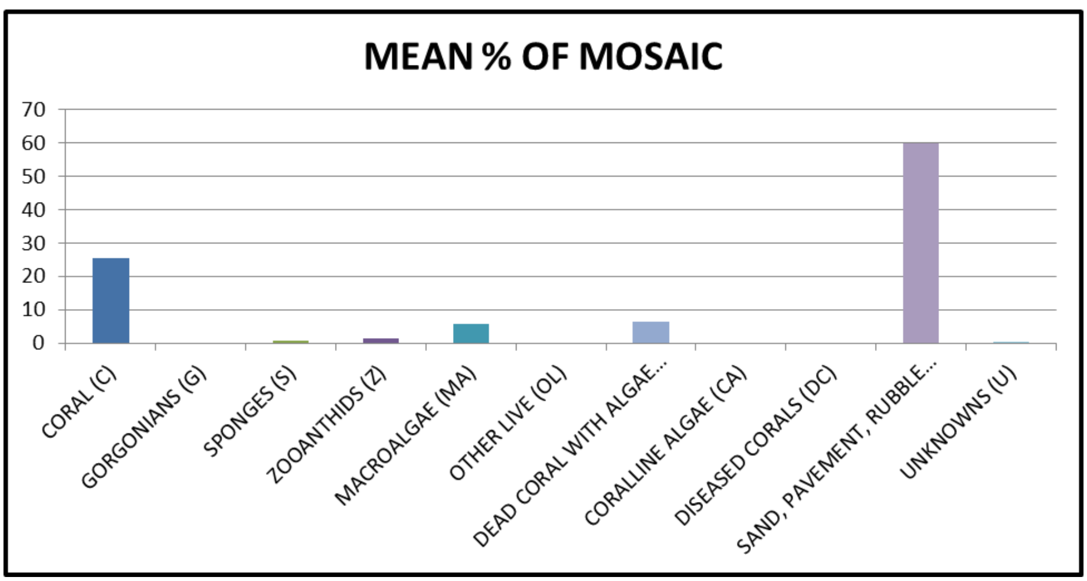

Figure 36. Benthic cover of major functional classes present at JTF.

The dominant coral species was *Porites asteroides* (14%), followed by *Agaracia tenufolia* (2.5%), *Montastrea franksi* (2.5%), *Diplora strigosa* (2%), *Acropora* palmata (1.5%), Montastrea annularis (1.5%), *Montastrea faveoloata* (1.5%), *Sideastrea siderea* (1.5%), *Diploria labyrinthiformis* (0.5%), and *Millipora complanata* (0.5%), as shown in Figure 37. The algae present at this site were turf algae (1%) and macroalgae (0.5%).

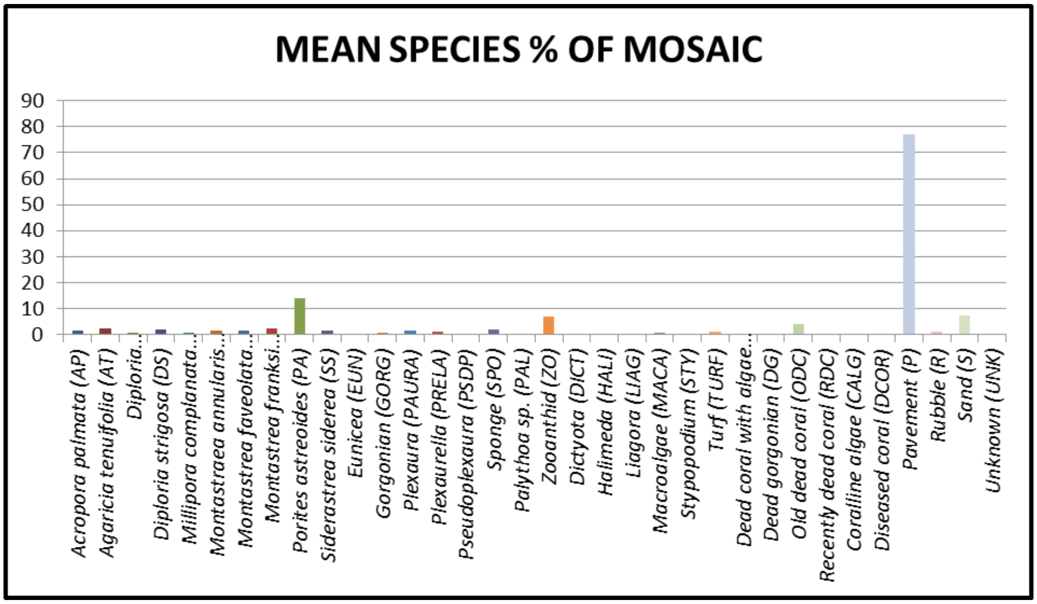

Figure 37. Species-level assessment of benthic cover of major functional classes present at JTF.

This site had the highest coral species richness value (10) of all the sites and was very diverse (H = 1.04; D = 0.57). This site had low algal species richness (2).

3.2.8 Kittery

Sand, pavement, and rubble (81.7%) dominated this site. This site had coral (7.5%) and macroalgae (7.4%) present, as shown in Figure 38. There was 1.2% dead coral, with algae present at this site. There were a few species of sponge present (2.3%).

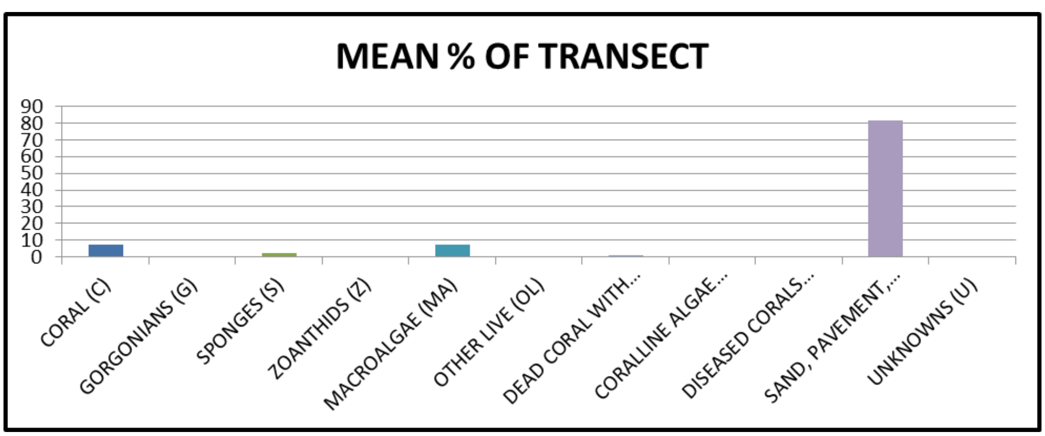

Figure 38. Benthic cover of major functional classes present at Kittery.

The coral species present at this site were *Montastrea annularis* (1.5%), *Siderastrea siderea* (1.5%), *Porites asteroides* (1%), and *Diplora strigosa* (0.5%), as shown in Figure 39. The dominant algal species at this site was macroalgae (2.5%), followed by Styptopodium (0.5%), and turf algae (0.5%).

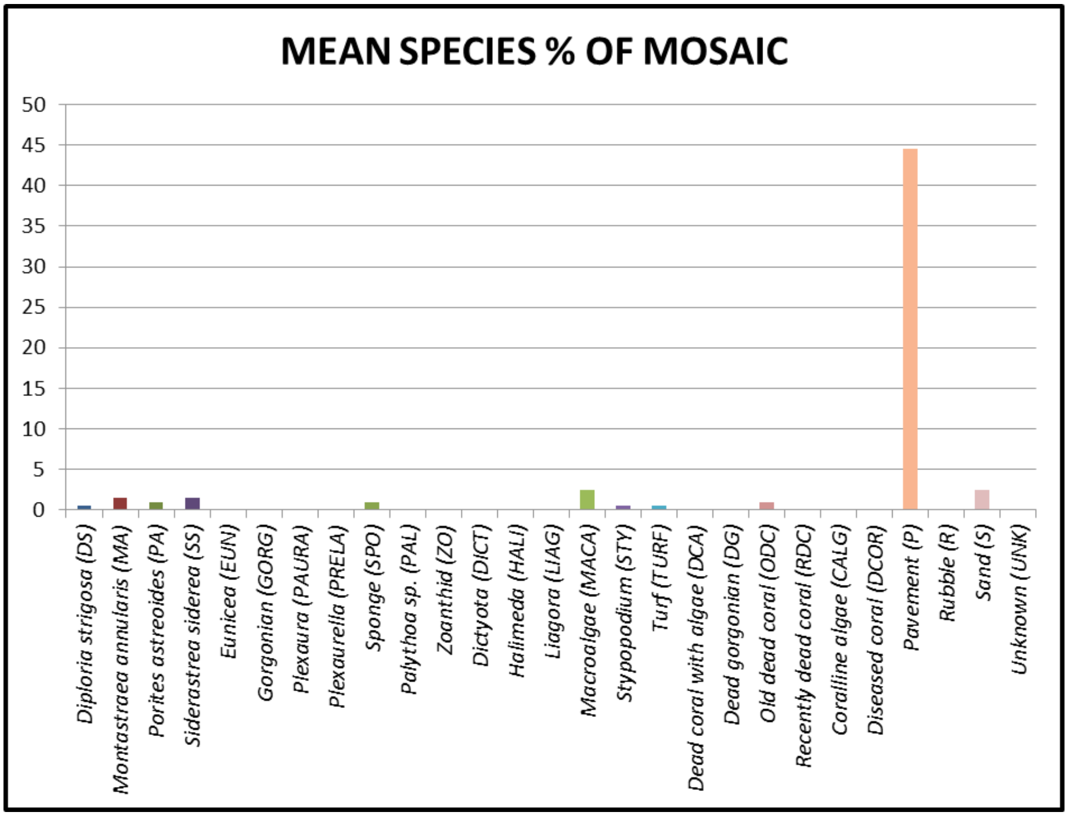

Figure 39. Species-level assessment of benthic cover of major functional classes present at Kittery.

This site had one of the lowest coral species richness value (4) of all the sites, but was moderately diverse (H = 0.67; D = 0.32). This site had moderate algal species richness (3).

3.3 DATA LOGGER RESULTS

In August 2013, the team only installed five loggers due to poor visibility. The GTMO dive locker deployed the three remaining loggers in February 2014. Due to the deadline for publication and submittal to Naval Facilities Command Southeast (NAVFACSE), results of the data loggers were not included in this report.

3.4 DAMAGE ASSESSMENT ANALYSIS

Characterizations of damage ranged from minor to moderate (see Table 5) for a description of the characterizations). Minor was defined as a small percentage of partial coral damage, broken tips, branches, or plate edges. Moderate damage was defined as a slightly higher percentage of partial coral damage, fragile colonies with tips or edges broken, and/or some branches missing or large rubble fragments.

This assessment is based upon multiple indicators such as rubble, evidence of scouring resulting in bare substrate or settling of sediment preventing coral larvae settlement or coral growth, fresh or old coral mortality, and physical damage to coral. One of these indicators alone does not necessarily constitute damage by the hurricane. No site was categorized as having high, severe, or extreme damage, and no site was classified as having no damage whatsoever. Table 5 shows a summary of damage levels and categories assigned to each area based on mosaic analysis.

Table 5. Damage assessments summary.

Site Name	Damage Level	Damage Category	Damage Indicators
Hidden	1	Minor Coral Damage	20% rubble, >1% dead coral, 10% bare substrate, no physical damage observed.
Leeward Point	**1**	Minor Coral Damage	2% old mortality, 50% bare substrate, 1% damage to massive/mound/encrusting coral
Girl Scout Beach	**2**	Moderate Coral Damage	16.3% dead coral, 10% rubble, 5% bare substrate, 1% damage to massive/mound coral+
Blue Beach	2	Moderate Coral Damage	2% rubble, 20% dead coral (15% probably from scouring), 5% bare substrate.
Cuzco	1	Minor Coral Damage*	1% rubble, 10% dead coral, 15% bare substrate, 1% damage to coral colonies due to scouring.
Windmill	2	Moderate Coral Damage	20% dead coral (mostly *Acropora cervicornis* and *Montastrea annularis*.s), 5% bare substrate, 1% damage to massive/mound coral from scouring
JTF	1	Minor Coral Damage	2.97% dead coral, 2% rubble, 15% bare substrate (evidence of scouring),
Kittery	1	Minor Coral	1% dead coral, 2% rubble, 15% bare substrate

**This is based on an area where a mosaic was created and did not include branching coral such as Acropora palmata. It is understood that Acropora palmata resides outside of this mosaic area and were damaged from the hurricane. Further comparisons and an expanded survey of the Cuzco site would more than likely elevate this to a higher damage level.*

+Damage from tops/tips of massive/mound corals due to impact.

4. DISCUSSION

This section analyzes algal and coral metrics generated by the hurricane impact study and compares them with historic data.

4.1 HIDDEN

This area was categorized as having minor coral damage. Damage indicators included 20% rubble and 10% bare substrate. However, we observed no physical damage such as broken tips or sheared tops of colonies.

Table 6 summarizes all the historic data for this site. Previous surveys of Hidden occurred in 2011 and 2012. Percent coral cover has declined from 31.0% in 2011 to 29.0% in 2012 to 3.8% in 2013. This could be partially attributed to method differences between the 2012 use of LPIMs and belt transect and our use of CPCe in the 2013 study. This was a dramatic decrease and further monitoring of this area with a consistent methodology would be needed to confirm this decline and assess recovery. The low amounts of coral analyzed in the mosaic were small colonies or juveniles.

No data on S and H' for this area were provided in previous studies so no comparisons are made here.

Table 6. Summary of historic coral and algae data for Hidden.

Functional Class	2011 % Cover	2012 % Cover	2013 % Cover	2013 Shannon-Weaver Index (H)	2013 Simpson Index (D)	2013 Species Richness (S)
Coral (C)	31.0	29.0	3.8	0.4	0.2	3.0
Coralline Algae (CA)	N/A	4.2	0.0	N/A	N/A	N/A
Macroalgae (MA)	46.7	44.4	4.6	N/A	N/A	N/A
Gorgonian (G)	4.3	2.9	0.0	N/A	N/A	N/A
Zooanthid (Z)	1.4	0.6	0.0	N/A	N/A	N/A
Sand, Rock/Pavement, Rubble (SPR)	4.0	3.9	90.8	N/A	N/A	N/A
Sponge (S)	0.9	1.8	0.4	N/A	N/A	N/A

4.2 LEEWARD POINT

Leeward Point also had minor coral damage. Damage indicators here included 2% old coral mortality, 50% bare substrate, and 1% damage to massive/mound/encrusting coral. Most damage to these latter coral was probably due to sedimentation. This is not necessarily a result of the hurricane impact.

The rare coral *Mussa angulosa* was observed here, but it did not appear healthy. While not bleached, this colony was very pale and presented little color. *M. cavernosa* was also present, but exhibited disease.

Table 7 summarizes all the historic data for this site. Previous surveys of Leeward Point occurred in 2011 and 2012. Percent coral cover has declined from 15.6% in 2011 and 17.8% in 2012 to 13.6 in 2013. This could be partially attributed to method differences between the 2012 use of LPIMs, and belt transect and our use of CPCe in the 2013 study. This decrease requires further monitoring of this area with a consistent methodology to confirm this decline and assess recovery. The low amounts of coral analyzed in the mosaic were small colonies or juveniles.

Previous studies provided no data on S and H' for this area, so no comparisons are made here.

Table 7. Summary of historic coral and algae data for Leeward Point.

Functional Class	2011 % Cover	2012 % Cover	2013 % Cover
Coral (C)	15.6	17.8	13.6
Coralline Algae (CA)	N/A	5.8	0.0
Macroalgae (MA)	75.6	51.1	3.3
Gorgonian (G)	0.4	1.3	0.8
Zooanthid (Z)	0.0	0.0	0.3
Sand, Rock/Pavement, Rubble (SPR)	5.0	3.8	79.7
Sponge (S)	0.4	0.2	1.0

4.3 GIRL SCOUT BEACH

The team categorized this area as having moderate coral damage. Discernible differences in stressor impacts from nutrient loads and Hurricane Sandy at the area known as Girl Scout Beach inside Guantánamo Bay are questionable. The moderate coral damage category assigned to this area could be a combined result from both stressors. No previous surveys of Girl Scout Beach have been conducted, so no comparisons can be made here.

Damage indicators included 10% old coral mortality, 10% rubble, 5% bare substrate, and 1% damage to massive/mound coral. The latter consisted of damage to the tops or tips of these massive/mound corals due to impact.

Table 8 summarizes all the historic data for this site. No surveys at this site were conducted in previous years. Consequently, there are no data on average coral cover percentage, *S* and *H'*, to make comparisons.

Table 8. Summary of historic coral and algae data for Girl Scout Beach.

Functional Class	2011 % Cover	2012 % Cover	2013 % Cover	2013 Shannon-Weaver Index (H)	2013 Simpson Index (D)	2013 Species Richness (S)
Coral (C)	25.6	17.8	14.5	1.0	0.5	7.0
Coralline Algae (CA)	N/A	2.7	0.0	N/A	N/A	N/A
Macroalgae (MA)	50.0	51.1	0.8	N/A	N/A	N/A
Gorgonian (G)	1.2	1.8	0.3	N/A	N/A	N/A
Zooanthid (Z)	0.1	0.1	0.0	N/A	N/A	N/A
Sand, Rock/Pavement, Rubble (SPR)	13.9	8.8	66.2	N/A	N/A	N/A
Sponge (S)	4.6	3.4	0.8	N/A	N/A	N/A

4.4 BLUE BEACH

Table 9 summarizes all the historic data for this site. Survey methods differed between surveys, but percent coral cover at the Blue Beach reef has shown a pattern of decline since 2003. Percent coral cover, as assessed in this study, was lower than the values determined in 2003, 2007, and 2011. Interestingly, species diversity is not substantially different in our study (1.0) than it was in the 2012 study (1.1). Species richness is significantly lower in our study [3] than the 2012 study [26]. This could be partially attributed to method differences between the 2012 use of photoquads, line-point intersect method (LPIM), and belt transects (BTs) and our use of CPCe in the 2013 study. This is a big fluxuation and further studies utilizing the same method is recommended for future surveys to obtain accurate and consistent results (See Section 5 for discussion).

Table 9. Summary of historic coral and algae data for Blue Beach.

Functional Class	2003 % Cover	2007 % Cover	2011 % Cover	2012 % Cover	2012 Shannon-Weaver Index (H)	2012 Species Richness (S)	2013 % Cover	2013 Shannon-Weaver Index (H)	2013-Simpson Index (D)	2013 Species Richness (S)
Coral (C)	32.0	14.8	20.0	N/A	1.1	26.0	12.9	1.0	0.5	3.0
Coralline Algae (CA)	N/A	N/A	N/A	N/A	N/A	N/A	0.0	N/A	N/A	N/A
Macroalgae (MA)	N/A	N/A	60.0	N/A	N/A	N/A	11.3	N/A	N/A	N/A
Gorgonian (G)	N/A	N/A	1.0	N/A	N/A	N/A	0.0	N/A	N/A	N/A
Zooanthid (Z)	N/A	N/A	0.1	N/A	N/A	N/A	0.0	N/A	N/A	N/A
Sponge (S)	N/A	N/A	0.5	N/A	N/A	N/A	2.0	N/A	N/A	N/A
Sand, Rock/Pavement, Rubble (SPR)	N/A	N/A	0.1	N/A	N/A	N/A	68.8	N/A	N/A	N/A

4.5 CUZCO

The area known as Cuzco was one of the original sites surveyed when baseline data was obtained in 2003 and follow up surveys were conducted in 2007 (DoN, 2005; DoN, 2007). Cuzco is considered a “control” site because it has historically exhibited a healthy reef community, compared to some other sites at GTMO that were thought to have been dominated by algae.

The mosaic analysis of this area showed only minor coral damage. This was based on an area where the mosaic was created and did not include branching coral such as *A. palmata*. It is possible that any branching *Acropora* sp. that may have occupied the area within the mosaic before Hurricane Sandy could have been wiped out, but there were no indicators of this during mosaic analysis. It is known from prior studies and anecdotal observations after the hurricane that *A. palmata* colonies reside outside of the mosaic area and were damaged from the hurricane. Further comparison and an expanded survey of the Cuzco site would more than likely elevate this to a higher damage level.

Damage indicators for this area included 1% rubble, 10% old mortality of coral, 15% bare substrate, and 1% damage to coral colonies due to scouring. A colony of *M. faveoloata* appeared to have some disease. We do not know if the hurricane impact initiated this or led to the propensity of this symptom.

Table 10 summarizes all the historical data for this site. Survey methods and exact survey locations on the Cuzco reef differed between surveys, but average coral cover ranged from 17% to 37% based on five separate assessments since 2003. Average coral cover was 37.0% in 2003, 26.5% in 2007, 20.0% in 2011, 17.0% in 2012, and 31.1% in 2013. Species diversity was not notably different between our study (1.5) and the 2012 study (1.1). Species richness was substantially lower in our study (S = 5) than the 2012 (S = 14) and 2007 (S = 23) studies. This could be partially attributed to method differences between the 2012 use of LPIMs and belt transect in 2012 and our use of CPCe in the 2013 study. This is a drastic reduction in species diversity since 2007, although different methodologies were used to express this over the years. This could also be the result of impact from the hurricane; however, further studies utilizing the same methodology are recommended to confirm this as the only stressor resulting in adverse impact. On the positive side there are many juvenile corals growing here so a recovery may be occurring.

Table 10. Summary of historic coral and algae data for Cuzco.

Functional Class	2003 % Cover	2007 % Cover	2007 Shannon-Weaver Index (H)	2007 Species Richness (S)	2011 % Cover	2012 % Cover	2012 Shannon-Weaver Index (H)	2012 Species Richness (S)	2013 % Cover	2013 Shannon-Weaver Index (H)	2013 Simpson Index (D)	2013 Species Richness (S)
Coral (C)	37.0	26.5	0.9	23.0	20.0	17.0	1.5	14.0	31.1	1.1	0.6	5.0
Coralline Algae (CA)	N/A	N/A	N/A	N/A	N/A	2.9	N/A	N/A	0.0	N/A	N/A	N/A
Macroalgae (MA)	N/A	N/A	N/A	N/A	54.4	40.0	N/A	N/A	3.0	N/A	N/A	N/A
Gorgonian (G)	N/A	N/A	N/A	N/A	2.2	0.6	N/A	N/A	1.2	N/A	N/A	N/A
Zooanthid (Z)	N/A	N/A	N/A	N/A	0.1	0.4	N/A	N/A	0.0	N/A	N/A	N/A
Sponge (S)	N/A	N/A	N/A	N/A	15.0	11.9	N/A	N/A	54.4	N/A	N/A	N/A
Sand, Rock/Pavement, Rubble (SPR)	N/A	N/A	N/A	N/A	2.1	4.3	N/A	N/A	0.7	N/A	N/A	N/A

4.6 WINDMILL

Windmill had moderate coral damage. Damage indicators included 20% old coral mortality (mostly *A. cervicornis* and *M. annularis*), 2% rubble, 5% bare substrate, and 1% damage to massive/mound coral from scouring.

Table 11 summarizes all the historic data for this site. Results from the 2003 survey showed an average coral cover here of 52%. It declined substantially in 2007 to 19.8% and has varied slightly since then (21.1% in 2011, 17.8% in 2012, and 25.5 in 2013). Species richness (*S)* has declined from 23 in 2007, and 2012 to 8 in 2013. Coral species diversity (*H')* was 0.9 in 2007, 1.5 in 2012 to 0.6 in 2013. This could be partially attributed to method differences between the 2012 use of LPIMs and belt transect and our use of CPCe in the 2013 study. This decrease requires further monitoring of this area with a consistent methodology to confirm this decline and assess recovery.

Table 11. Summary of historic coral and algae data for Windmill.

Functional Class	2003 % Cover	2007 % Cover	2007 Shannon-Weaver Index (H)	2007 Species Richness (S)	2011 % Cover	2012 % Cover	2012 Shannon-Weaver Index (H)	2012 Species Richness (S)	2013 % Cover	2013 Shannon-Weaver Index (H)	2013 Simpson Index (D)	2013 Species Richness (S)
Coral (C)	52.0	19.8	0.9	23.0	21.1	17.8	1.5	23.0	25.5	1.1	0.6	8.0
Coralline Algae (CA)	N/A	N/A	N/A	N/A	N/A	2.7	N/A	N/A	**0.0**	N/A	N/A	N/A
Macroalgae (MA)	N/A	N/A	N/A	N/A	48.9	44.4	N/A	N/A	**5.6**	N/A	N/A	N/A
Gorgonian (G)	N/A	N/A	N/A	N/A	1.7	1.7	N/A	N/A	**0.0**	N/A	N/A	N/A
Zooanthid (Z)	N/A	N/A	N/A	N/A	0.6	0.4	N/A	N/A	**1.2**	N/A	N/A	N/A
Sand, Rock/Pavement, Rubble (SPR)	N/A	N/A	N/A	N/A	10.0	7.5	N/A	N/A	**59.9**	N/A	N/A	N/A
Sponge (S)	N/A	N/A	N/A	N/A	3.2	3.2	N/A	N/A	**0.9**	N/A	N/A	N/A

4.7 JTF

The area known as JTF was assigned the minor coral damage category. Damage indicators included 2% rubble and 15% bare substrate with evidence of scouring.

Table 12 summarizes all the historic data for this site. The average coral cover at JTF was holding steady from 21.1% in 2011, 21.1% in 2012, and 21.5% in 2013. No data on S and H' for this area were provided in previous studies, so no comparisons were made.

Two colonies of *M. cavernosa* appeared to have what is tentatively identified as yellow-band disease. A colony of *A. plamata* also appeared to exhibit disease. So while this area appears to have not lost any coral cover, there are indications that it was experiencing stressors.

Table 12. Summary of historic coral and algae data for JTF.

Functional Class	2011 % Cover	2012 % Cover	2013 % Cover
Coral (C)	21.1	21.1	21.5
Coralline Algae (CA)	N/A	1.0	0.0
Macroalgae (MA)	55.6	25.6	1.1
Gorgonian (G)	3.3	1.8	2.3
Zooanthid (Z)	1.0	0.3	5.6
Sand, Rock/Pavement, Rubble (SPR)	7.5	5.6	65.0
Sponge (S)	2.5	2.5	1.6

4.8 KITTERY

This area was assigned the minor coral damage category. Damage indicators included 1% old coral mortality, 2% rubble, and 15% bare substrate.

Table 13 summarizes all the historic data for this site. Previous surveys of Hidden occurred in 2011 and 2012. Percent coral cover has declined from 17.8% in 2011 and 2012 to 7.5 in 2013. This could be partially attributed to method differences between the 2012 use of LPIMs, and belt transects and our use of CPCe in the 2013 study. This was a dramatic decrease and further monitoring of this area with a consistent methodology would be needed to confirm this decline and assess recovery. The low amounts of coral analyzed in the mosaic were small colonies or juveniles.

No data on S and H' for this area were provided in previous studies, so no comparisons are made here.

Table 13. Summary of historic coral and algae data for Kittery.

Functional Class	2011 % Cover	2012 % Cover	2013 % Cover
Coral (C)	17.8	17.8	7.5
Coralline Algae (CA)	N/A	5.2	0.0
Macroalgae (MA)	45.6	28.9	7.4
Gorgonian (G)	3.1	3.5	0.0
Zooanthid (Z)	0.0	0.1	0.0
Sand, Rock/Pavement, Rubble (SPR)	7.6	7.5	81.7
Sponge (S)	2.5	2.5	2.3

4.9 REEFSCAPE ANALYSIS

Note that physical assessments of damages from Hurricane Sandy in this region continue, and much work needs completion before a full understanding of the impacts and their implications are achieved. From a coastal perspective, areas like Delaware Bay, coastal New Jersey, Hudson-Raritan Estuary of New Jersey, and the Long Island Sound and Jamaica Bay areas of New York show much worse impacts from Hurricane Sandy than GTMO (The American Littoral Society, 2012).

The team took the photomosaics 10 months after Hurricane Sandy hit GTMO. As presented in this study, it was still possible to identify and discern storm damage characterization such as scoured tops of *M. annularis*, broken tips/edges/branches, rubble, and scoured areas of substrate. However, expediting surveys as soon as possible after the hurricane would have provided more accurate data and enabled researchers to better identify storm impacts (Goff and Austin Jr., 2013).

Furthermore, every methodology has its limitations. For example, photoquadrats or photomosaics may not produce desired results if conditions such as turbidity, low light levels, and poor visibility are factors. LPIM, LIM, or belt transects should be considered as additional methods or replacement of the aforementioned methods, especially inside the bay.

4.9.1 Functional Damage to Reef Communities:

Overall, damage from Hurricane Sandy was patchy with no clear or wide paths of subsurface destruction. GTMO coral reefs appeared to sustain remarkably little impact, with most areas classified as experiencing only minor coral damage (Damage Level of 1 on the impact assessment scale), and three areas exhibiting only moderate damage (Damage Level of 2). Most of the damage to coral colonies was partial. No areas experienced high, severe, or extreme coral damage, and no colonies appeared to be completely or even severely damaged. There was some uniformity in the relatively minimal amount of damage.

All of the colonies of *M. cavernosa* analyzed in the mosaics exhibited coral disease (Figure 40, Figure 41, and Figure 42). An extreme warming phenomenon occurred in 2005, which increased disease. Based on the history of this species experiencing disease, it is likely that these species showed symptoms of disease before Hurricane Sandy hit the area, and that the hurricane may have exacerbated their condition by causing additional stress, resulting in further spread of disease. The surveys in 2011 and 2012 did not include detailed research on disease at the time but opportunistic observations made by Marx showed only small amounts of disease (Marx et al., 2012). Existing documentation shows that hurricanes add nutrients temporarily to the ocean environment by runoff from agricultural areas (Zhang, Kelbe, Fischer, and Moore, 2009). As stated by Risk, Burchell, Brunton, and McCord, 2014), “Of all the worldwide sources in which land-based sources of pollution have impacted reefs, [GTMO] may well be the most intractable. The US Navy has jurisdiction over the reefs, with the obligation to protect them, yet the threat comes from down the river in Cuba.”

Biodiversity appears to have decreased dramatically since 2003. Species, such as *Agaricia tenuifolia*, *Copophyllia natans*, *Dichocenia stokesii*, *Diploria strigosa*, and other Porites species, which were previously recorded at the Cuzco control site, may no longer be present according to this most recent survey. It is possible that these species may reside outside of the mosaic areas. However, the number of species recorded overall during the mosaic analysis and previous studies has significantly decreased. Marx et al. (2012) recorded 39 coral species. Only 10 species were recorded in the current photomosaic analysis.

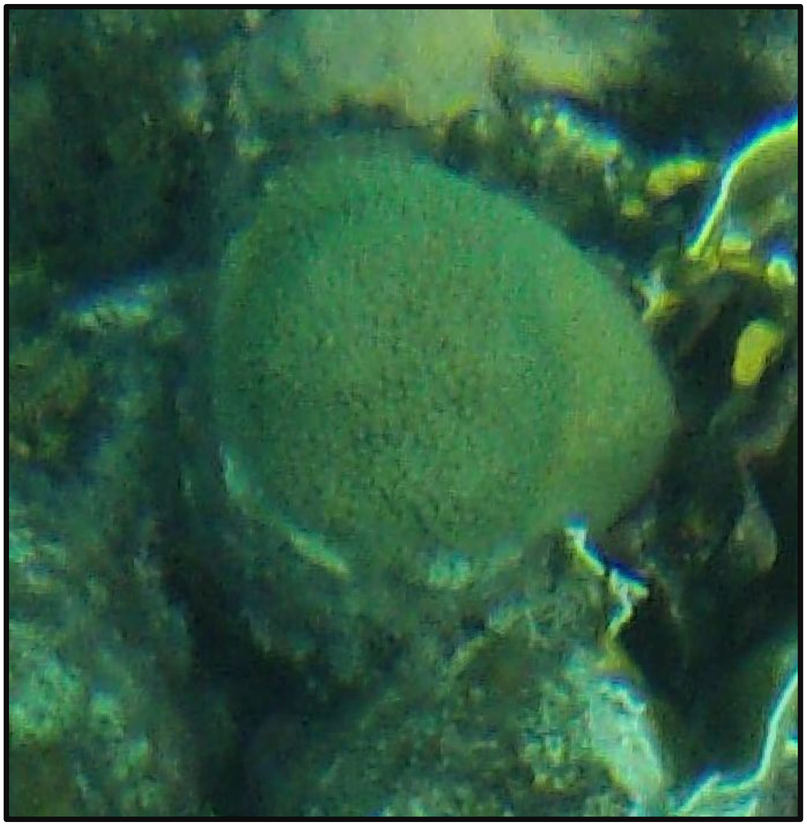

Figure 40. Evidence of disease on *Montastrea cavernosa* at the Windmill site.

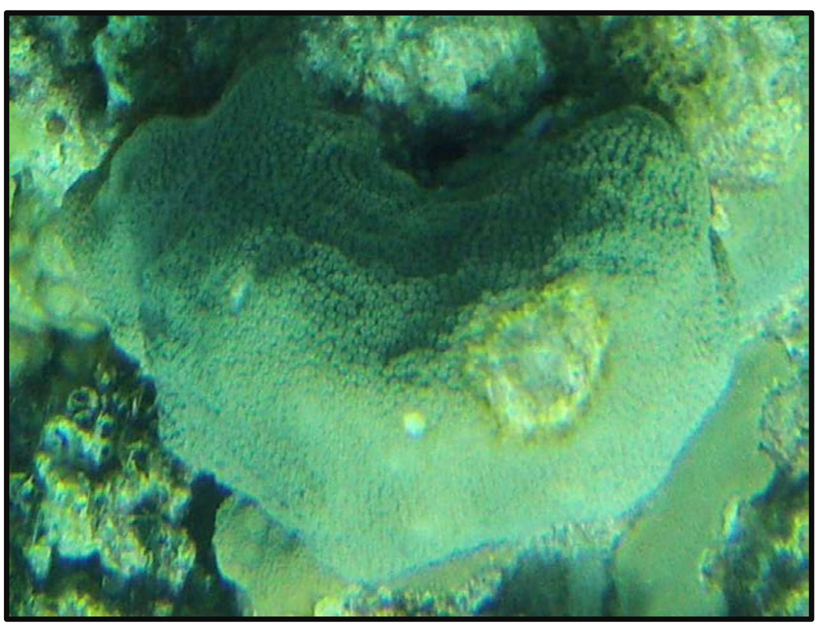

Figure 41. Evidence of disease on *Montastrea cavernosa* at the JTF site.

Figure 42. Evidence of disease on *Montastrea cavernosa* at the Leeward Point site.

Damage from hurricanes/cyclones is typically highly variable (GBRMPA, 2011). Factors determining variability include the strength of a storm, the morphology and resilience of coral species, and the physical topography in which impact occurs such as the reef slope, reef crest, or inner shelf reefs.

The GTMO spur and groove coral reef ecosystem has been considered the “gold standard” of the Caribbean (DoN, 2007; Risk et al., 2014). Based on the small amount of coral species observed in the mosaic analysis and the author’s experience conducting three other surveys at GTMO since 2007, there appears to be even less biodiversity than in previous study results. There appears to be a fluxuation in deterioration and recovery from 2003 to present. It is known, based on prior studies from 2003 to 2007, that GTMO reefs lost coral cover and habitat complexity (DoN, 2005 and DoN 2007). In the 2011 and 2012 studies, an apparent stabilization or recovery period may have been underway. However, in this most recent survey, there are indications that deterioration is occurring again. This could be caused by effects of the hurricane as well as other recent stressors that include increased nutrient loads.

Of further concern is the decrease in average coral cover at several of these areas. This includes Hidden, Kittery, and Leeward Point. Cuzco, JTF, and Windmill had higher species richness and diversity than the other sites. These sites also were the only ones that showed an increase in coral cover when compared to the 2011 and 2012 studies, suggesting that the hurricane had negligible effects on at least some portions of the reef.

4.9.2 Structural Damage to Reef Communities:

Reef structural damage appears to have been primarily outside of the mouth of the bay where direct impact from winds likely occurred (Table 14 and Figure 43). Previous post-storm surveys in other regions showed more damage in upper shelf reefs than mid or lower shelf reefs. Results in

GBRMPA (2011) showed mid-shelf reefs sustained structural damage across a wider range of latitude bans. Surveys at depths greater than 50 feet of seawater should be considered in future GTMO studies. In total, just over 7.9% of the reef areas analyzed in the mosaics were estimated to have sustained some level of coral damage (Table 14).

Table 14.Total areas of damaged reefs assessed over all sites.

Site	Reef Area Analyzed As Coral Damage (%)	Area of Reef Area Analyzed as Damaged (m^2)	Overall Site Damage Level
Blue Beach	6.5	8.8	2
Cuzco	13	24.2	1
Girl Scout Beach	24.5	45.6	2
Hidden	0.5	0.8	1
JTF	4	9.2	1
Kittery	1	0.2	1
Leeward Point	1.5	1.9	1
Windmill	8.5	37.8	2

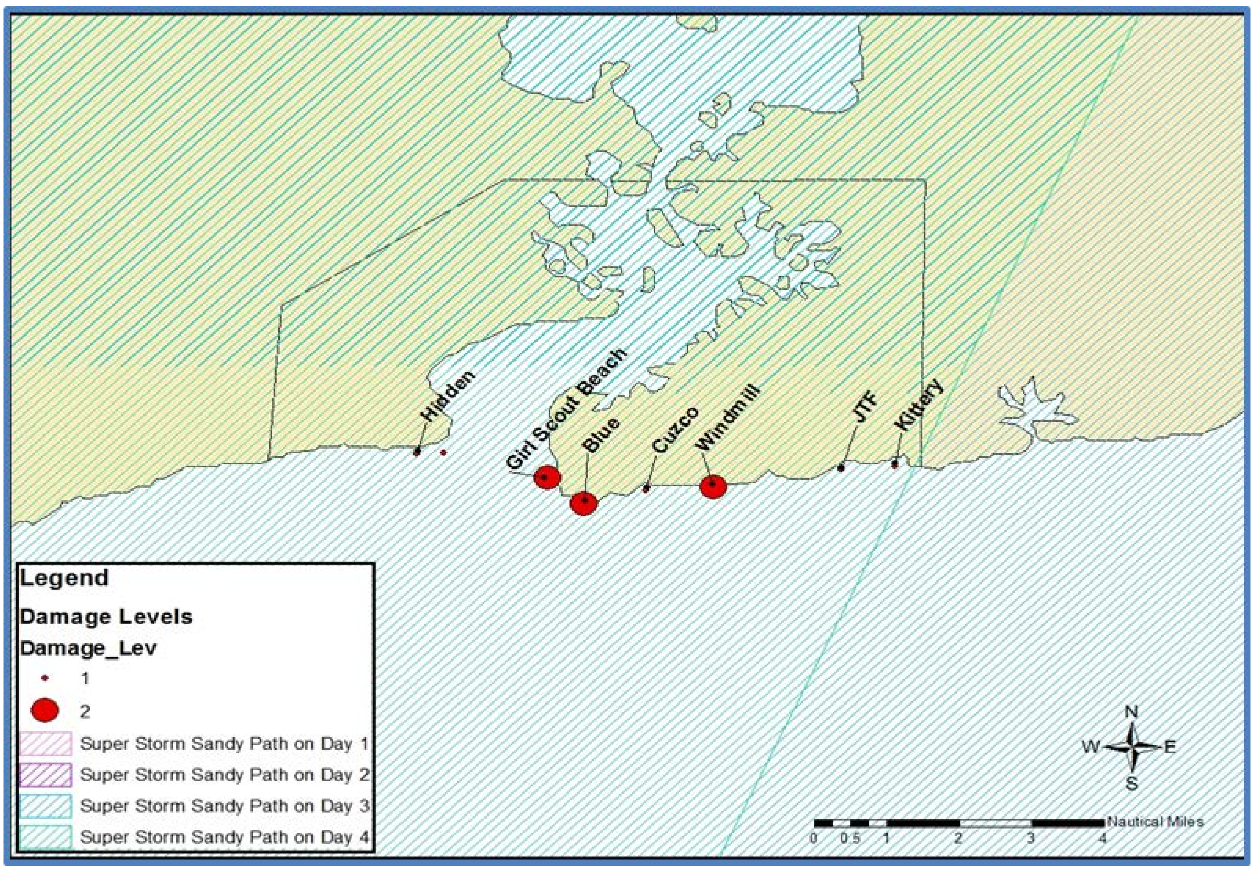

Figure 43. Graphical overlay of storm paths and damage assessment levels. ArcGIS® Desktop: Release 10.1. Environmental Systems Research Institute (ESRI). 2012. Redlands, CA.

The most structural damage from the hurricane probably occurred to the more fragile, branching corals such as *Acropora cervicornis* and *A. palmata*. Anecdotal observations immediately after the hurricane passed from personnel stationed at GTMO indicated that both species were heavily impacted with many broken branches. Evidence in the mosaic of rubble and dead *A. cervicornis* indicates at least one whole colony at Windmill was completely wiped out by the hurricane and a large percentage of the old mortality observed was from this species (Figure 44). While they may have suffered the greatest impact by Hurricane Sandy, these species reproduce by fragmentation and could possibly expand their population over time (Goreau, 1959; Stoddard, 1963; Macintyre and Glynn, 1976; Shinn et al., 1977; Lighty, 1977; Adey, 1978; and Highsmith et al. 1980), although some studies suggest that gains achieved by asexual proliferation of branching corals are likely to be offset by hurricane scour and sediment smothering of other corals and turning over of coral heads (Kruczynski and Fletcher, 2012). Remnants of living coral have the potential of accelerating recovery. These species are listed under the Endangered Species Act in the United States; assessments of their condition are an important component of coral management at GTMO. Qualitative observations made during this survey, combined with anecdotal observations reported by recreational divers immediately after the hurricane suggest these two species are susceptible to high and extreme storm damage levels due to their fragility.

The morphology of encrusting, boulder, and mound-building corals enables these species to be more resilient to storm impacts. *M. annularis* was the most impacted of all the mound-building corals. Several of the dome-like tops normally in this species morphology appeared to be slightly sheared off. In comparison, *M. annularis* in the Virgin Islands had a 40% decline in coral cover from Hurricane Hugo in 1989; no increase in coral cover was noted there as of 2002 (Riegl and Dodge, 2008). Additionally, studies in Belize show that M. annularis can be highly affected by storms, despite their resiliency to hurricane damage (McField, 2000). These studies suggest a slow recovery of this dominant species and it would be interesting to assess trends in percent cover of this species in future surveys.

The columnar species *Dendrogyra cylindrus* (a state-listed threatened species in Florida) is another fragile coral rarely observed during past surveys at GTMO. We did not observe them in the mosaics acquired during this survey. Areas near Chapman are known to have several of these colonies and it would be useful to gather information on the status of this species because it may have been impacted by the hurricane.

Individual colonies of the slow growing, encrusting *Porites astreoides* coral exhibited very little, if any, damage during the current survey.

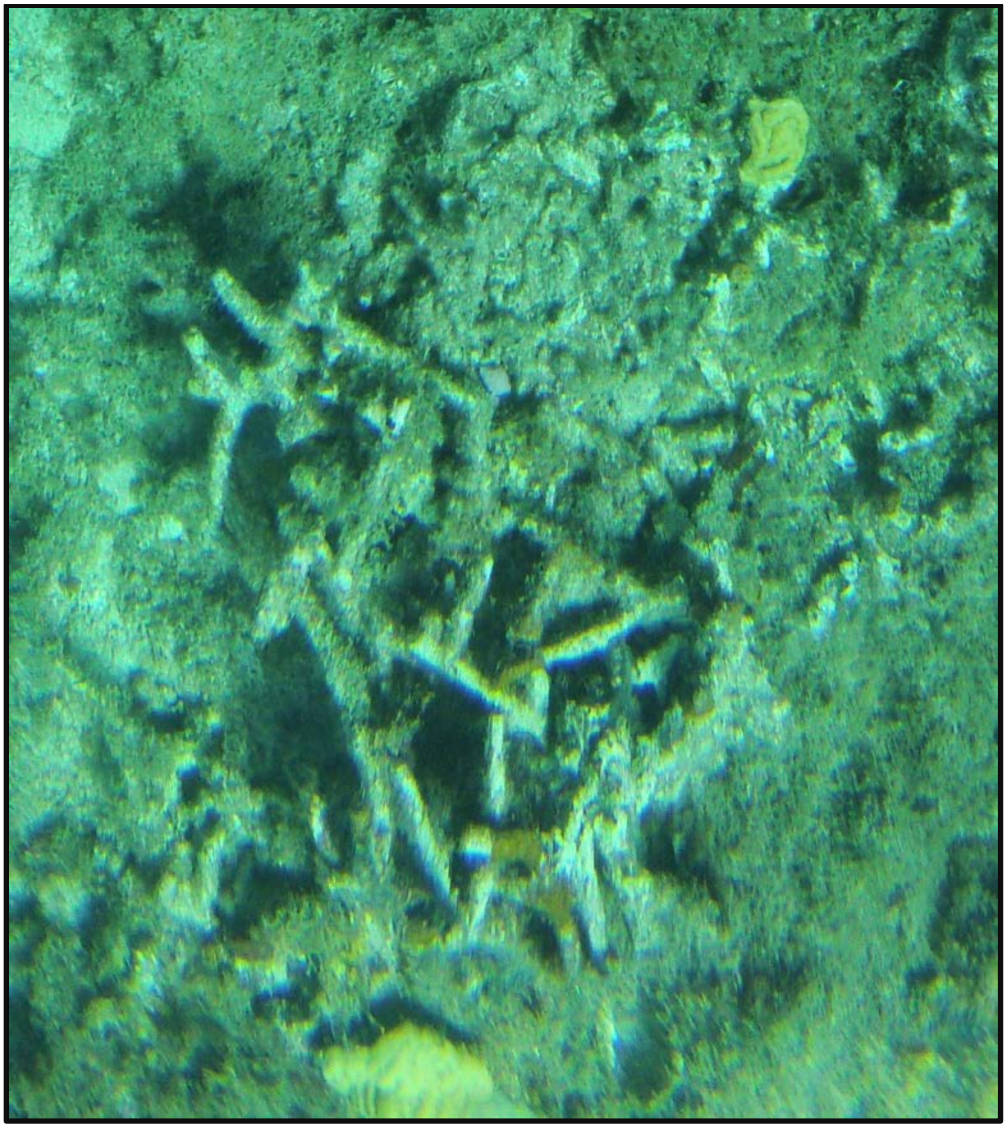

Figure 44. *Acropora cervicornis* rubble at Windmill.

5. STUDY IMPLICATONS AND RECOMMENDATIONS

GTMO coral reefs lack natural complexity and reef morphology that would be conducive to higher benthic heterogeneity in other regions (Vroom, Page, Peyton, and Kukea-Shultz, 2005; Pante et al. 2006). This suggests that GTMO may require more frequent photomosaicing surveys to understand dynamics and status of the coral ecosystem there and to obtain accurate and consistent results. Given recent studies showing increased nutrient loads, higher sea surface temperatures, sedimentation resulting from anthropogenic effects, overfishing, and ocean acidification, a long-term health-status program should be established. Furthermore, GTMO coral reefs may be losing substrate that would otherwise promote coral larvae settling, growth of juvenile coral and establishment of adult colonies. This may be from a twofold impact of sediment build-up (particularly in the bay) and algae dominance. An imbalance between available substrate, coral growth, and erosion has proven to result in reef degradation (Alvarez-Filip et al., 2009). Even if a consistent monitoring program is established at GTMO, it will take many years to fully understand the extent of impact multiple stressors are placing on coral and whether or not these reefs are resilient enough to maintain acceptable biodiversity and percent coverage at sustainable levels.

Discernible differences in stressor impacts from nutrient loads and Hurricane Sandy at the area known as Girl Scout Beach inside Guantánamo Bay are questionable. The moderate coral damage category assigned to this area could be a combined result from both stressors, especially since corals stressed from increased nutrient loading may be more vulnerable to hurricane damage. It is important to note here that abnormally high nutrient loads have been detected in GTMO bay and it is believed that the source of these high loads are coming from outside of the installation (DoN, 2012; Risk et al., 2014). In addition, there were reports of a persistent brown algae bloom in the bay following the storm. Cyclones/hurricanes can dramatically increase available nutrients as well by causing an upwelling of nutrient rich waters or re-suspension of nutrient-laden sediments by storms, as well as from decomposing organic matter such as the tissues from organisms killed during the storm (GBRMPA, 2011).

The increased presence of disease during our study is of increasing concern. Shinn et al. (2000) documented that African dust serves as a substrate for numerous species of viable spores, especially the soil fungus *Aspergillus sydowii*, which is known to cause a Caribbean-wide sea fan disease. Those authors believe that not only does the dust contain *Sphignomonas*, which causes white plague II disease in corals and *Vibrio shiloi*, which causes bleaching in *Oculina patagonica*, but that the nitrogen, phosphorous, silicon, aluminum, and iron contained within the African dust stimulate primary production, leading to additional stress and pressures on the corals from the added nutrients and with the increased algal populations developing due to the increased nutrients. White plague causes rapid tissue loss, affects many species of coral, and can cause partial or total colony mortality. Some, but not all types are associated with bacteria-some viruses. These also play a role, particularly nucleocytoplasmic large DNA viruses (NCLDVs) in bleached corals and single-stranded DNA viruses (SCSDVs) present in diseased coral tissues. Corals with white plague disease have higher viral diversity than their healthy counterparts. Increasing temperatures that stress corals and make them more vulnerable may be part of the equation, because the disease often appears to be at its worst by the end of summer. Soffer et al. (2014) states that overfishing allows more algae to grow on corals and may facilitate the spread of pathogens, as can pollution caused by sewage outflows in some marine habitats. The research noted that viral infection, by itself, does not necessarily cause major problems. Many healthy corals are infected with herpes-like viruses that are persistent but not fatal, as in many other vertebrate hosts, including humans (Soffer et al., 2014). Research on the causes of coral diseases and the ever-growing impacts they have on coral reef health is essential, as are investigating possible ways to prevent them.

Of further concern is the indication from mosaic analysis that biodiversity has declined. Several species recorded in previous studies were not observed during the mosaic analysis. Marx et al. (2012), DoN (2007), and other studies have listed species such as *Diploria clivosa*, *Dichocenia stokesi*, *Porites divaricata*, and *P. porites* as being observed in study areas that were recently mosaiced. As previously mentioned, there has never been a naturally high biodiversity rate at GTMO, but there were less than a dozen species observed in any one mosaic analyzed during this study, which is below the norm of any prior line-point or belt transect study. Since damage to the reefs from Hurricane Sandy appeared to be minimal, this lower observed diversity may have been an artifact of using the new mosaic method. The 2007, 2011, and 2012 studies used a combination of LPIMs, BTs, and photoquad methods, which covered more linear distance on the reefs when multiple transects were completed on a single stretch of reef, as was done at GTMO in 2011 to 2012 (Marx et al., 2012). One of the main disadvantages of LPIMs is that species with very low cover values, such as rare species, are often not intersected by the points and therefore are not adequately sampled. It is also difficult to detect small changes (which is a common disadvantage of many other techniques as well) and it also gives no indication of abundance of plant species across the path. Belt transects will provide the percentage cover data, which gives a good indication of how abundant certain corals are. The advantage of the photomosaic methodology is that, when acquired yearly, or at least every 2 years, data analyses of the photomosaics provide the analyst with a much more precise picture of temporal change, and the mosaic images can be catalogued for future re-assessment or new temporal comparisons. Overlaying a BT or LPIM (of known geographic location) inside the photomosaic during post-processing has demonstrated that the same analyses and metric extraction can be recreated; however that task was outside the scope of this hurricane impact study.

Hurricanes have been a violent natural stressor on coral reefs for millennia and full recovery to former healthy levels would historically be expected of coral reefs (Shinn, 1977; Shinn, Hudson, Halley, and Lidz, 1977; Highsmith, Riggs, and D'Antonnio, 1980). However, additional anthropogenic stressors to coral reefs in recent decades warrant concern about the resiliency of corals in the aftermath of an impact such as Hurricane Sandy. Coral reef ecosystems free from anthropogenic stresses show signs of recovery in 3 to 5 years after a hurricane (GBRMPA, 2011). The combination of multiple stressors this region is experiencing may decelerate recovery rate, increase disease, and cause overgrowth of algae. Due to coral's high sensitivity to the effects of climate change, shifts in the composition of crustose coralline algae-associated communities, combined with the pronounced difference in cue preferences among the different coral species, these effects could substantially influence coral community structure (Davies, Meyer, Guermond, and Matz, 2014).

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14. ABSTRACT

The National Marine Fisheries Service considers the near-shore coral reefs at Naval Station Guantánamo Bay, Cuba (GTMO) as a reference for comparison to other Caribbean near-shore coral reef habitats due to their relatively good condition. These reefs were affected by Hurricane Sandy, which impacted GTMO on October 25, 2012. This report presents a post-hurricane assessment of impacts to the reefs conducted by a marine ecologist from Space and Naval Warfare systems Center Pacific (SSC Pacific) and a marine ecologist from Naval Facilities Engineering Command Expeditionary Warfare Center (NAVFAC EXWC) to assess extent and severity of impact from the hurricane.

Survey results showed increased disease and decreased biodiversity. Specifically, all colonies of Montastrea cavernosa within the mosaics exhibited disease, and species such as Agaricia tenuifolia, Copophyllia natans, Dichocenia stokesii, Diploria strigosa, and other Porites species, which were previously recorded at the Cuzco control site, were not observed in the Cuzco mosaic. Of further concern is the decrease in average coral cover at several of these areas. GTMO requires more frequent surveys analysts to understand the dynamics and status of the coral ecosystem there, and to obtain accurate and consistent results. Given recent studies showing increased stressors such as nutrient loads and higher sea surface temperatures, a long-term health-status program should be established. Even if a consistent monitoring program is established at GTMO, it will take many years to fully understand the extent of impact multiple stressors are placing on coral and whether these reefs are resilient enough to maintain acceptable biodiversity and percent coverage at sustainable levels.

15. SUBJECT TERMS

Mission Area: Environmental Science

photomosaicing	damage assessment analysis	geographic information systems	coral reefs
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