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19 August 2022

# **Coral Mitigation for Pier Construction at the Atlantic Undersea Test and Evaluation Center**

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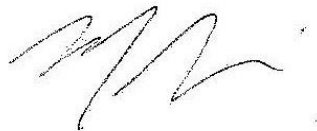
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## PREFACE

According to the Environmental Final Governing Standards (FGS) for the Bahamas, proper protection, enhancement, and management is required for any species declared endangered or threatened by either U.S. or the host nation government. A number of protected coral species were identified on the pier at the Naval Undersea Warfare Center Detachment Atlantic Undersea and Test Evaluation Center (AUTEC) installation on Andros Island, Bahamas. The mitigation required to offset the adverse effects to coral from planned construction of the AUTEC pier was translocation. A team of Navy divers and scientists performed the coral mitigation between April 19–29, 2022 at AUTEC. This report describes these mitigation efforts and provides an initial assessment of the translocated protected coral species and relocation sites.

The information within this report has been reviewed by Tara E. Moll (Code 1023), Nikki M. Baade (Code 00L) (Naval Undersea Warfare Center Division, Newport), and Susan Findlay (Naval Undersea Warfare Center Detachment AUTEC).

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## **EXECUTIVE SUMMARY**

According to the Environmental Final Governing Standards for the Bahamas, proper protection, enhancement, and management is required for any species declared endangered or threatened by either United States or the host nation government. A number of protected coral species were identified on the pier at the Naval Undersea Warfare Center Detachment Atlantic Undersea and Test Evaluation Center (AUTEC) installation on Andros Islands, Bahamas. The mitigation recommended to offset the adverse effects to coral from planned construction of the AUTEC Pier was translocation. A team of Navy divers and scientists performed the coral mitigation between April 19-29, 2022 at AUTEC. This report describes these mitigation efforts and provides an initial assessment of the translocated protected coral species and relocation sites.

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## TABLE OF CONTENTS

Section	Page
<b>EXECUTIVE SUMMARY</b> .....	ES-1
<b>LIST OF TABLES</b> .....	ii
<b>LIST OF ABBREVIATIONS AND ACRONYMS</b> .....	ii
<b>1 INTRODUCTION</b> .....	1-1
<b>2 CORAL MITIGATION METHODOLOGY</b> .....	2-1
2.1 Project Area.....	2-1
2.1.1 AUTEC Pier.....	2-1
2.1.2 Relocation Site .....	2-4
2.2 Coral Removal .....	2-6
2.2.1 Mountainous Star Coral ( <i>Orbicella faveolata</i> ) .....	2-8
2.2.2 Lobed Star Coral ( <i>Dichocoenia stokesii</i> ) .....	2-9
2.2.3 Elliptical Star Coral ( <i>Dichocoenia stokesii</i> ) .....	2-9
2.3 Coral Translocation .....	2-10
2.4 Data Collection .....	2-12
<b>3 RESULTS</b> .....	3-1
3.1 Translocated Coral .....	3-1
3.1.1 Hog Fish Reef.....	3-1
3.1.2 Dallas Point.....	3-1
3.2 Water Quality.....	3-2
<b>4 DISCUSSION</b> .....	4-1
4.1 Initial Coral Translocation Assessment .....	4-1
4.2 Monitoring .....	4-3
<b>5 REFERENCES</b> .....	5-1
<b>APPENDIX–PHOTOS OF TRANSLOCATED CORAL COLONIES</b> .....	A-1

## LIST OF ILLUSTRATIONS

Figure	Page
2-1 AUTEC Pier (left) and South Dolphin Mooring (right) .....	2-1
2-2 Location of the AUTEC Pier and Coral Relocation Sites .....	2-3
2-3 Hog Fish Reef Underwater Relocation Site .....	2-5
2-4 Dallas Point Underwater Relocation Site .....	2-6
2-5 <i>D. stokesii</i> (left) and <i>O. faveolata</i> (right) on the AUTEC Pier, and <i>O. annularis</i> (bottom) at a Relocation Site .....	2-7
2-6 Navy Divers with Recovered Coral from the AUTEC Pier (Left) and Removed Corals Ready for Translocation (Right).....	2-8
2-7 Harvested <i>O. faveolata</i> colony .....	2-8
2-8 Harvested <i>O. annularis</i> colony.....	2-9

## LIST OF ILLUSTRATIONS (Continued)

<b>Figure</b>		<b>Page</b>
2-9	Harvested <i>D. stokesii</i> colony .....	2-10
2-10	Divers Securing Coral to the Seafloor .....	2-10
2-11	Recently Translocated Coral with Tag.....	2-11
2-12	Transect at the Dallas Point Site Showing Recently Translocated Coral (red arrows).....	2-11
2-13	Diver Recording Data on Recently Translocated Corals .....	2-12
2-14	Water Quality Data Logger Setup (left) and Deployment at Relocation Site (right) .....	2-13
3-1	Tempature Data Collected at the AUTEC Pier and Relocation Site .....	3-3
3-2	Temperature Variation between the AUTEC Pier and Relocation Site.....	3-3
3-3	Light Data Collected at the AUTEC Pier and Relocation Site .....	3-4

## LIST OF TABLES

<b>Table</b>		<b>Page</b>
1-1	Coral Species Designated as Rare or Threatened by the IUCN.....	1-1
3-1	Translocated Coral at the Hog Fish Reef Relocation Site.....	3-1
3-2	Translocated Coral at the Dallas Point Relocation Site.....	3-2

## LIST OF ABBREVIATIONS AND ACRONYMS

<b>Acronym</b>	<b>Definition</b>
AGRRA	Atlantic Gulf Rapid Reef Assessment
AUTEC	Atlantic Undersea and Test Evaluation Center
°C	Degrees Celsius
cm	centimeter(s)
CTD	Conductivity Temperature Depth
DLA	Defense Logistics Agency
DoD	Department of Defense
ESA	Endangered Species Act
°F	Degrees Fahrenheit
FGS	Final Governing Standards
in	inch(es)
IUCN	International Union for the Conservation of Nature
JBW	Junction Box West
km	kilometer(s)
m	meter(s)
mi	mile(s)
min	minute(s)
°N	Degrees North

NIWC	Naval Information Warfare Center
NOAA	National Oceanic and Atmospheric Administration
NUWC	Naval Undersea Warfare Center
OHDT	Ocean Haul-Down Tower
PSU	Practical Salinity Units
U.S.	United States

## 1. INTRODUCTION

According to the Environmental Final Governing Standards (FGS) for the Bahamas (Department of the Navy 2016), reasonable protection, enhancement, and management is required for any species declared endangered or threatened by either United States (U.S.) or the host nation government. Repairs of the pier located at the Naval Undersea Warfare Center (NUWC) Atlantic Undersea and Test Evaluation Center (AUTEC) installation is planned for 2022 by the Naval Facilities Engineering Command. Proposed repairs to the AUTEC Pier include replacement, removal, and repairs to structures that would detrimentally affect the survival of corals that have grown on the underwater pier structures over decades.

The FGS (2016) lists the coral species in Table 1-1 as rare and threatened, as designated by the International Union for the Conservation of Nature (IUCN). Analysis of images and videos from June 2020 and March 2022 surveys by AUTEC divers revealed multiple coral species on the main Pier, some of which were designated as rare or threatened by the IUCN, and therefore, required protection in accordance with the Environmental FGS for the Bahamas. Mitigation was recommended to offset the adverse effects to IUCN protected coral from construction at the AUTEC Pier, in accordance with the FGS (2016). The mitigation recommended to offset the adverse effects to coral from planned construction of the pier was translocation, which is the direct removal of existing coral colonies and transporting them to a suitable nearby site with similar environmental characteristics. This report describes these mitigation efforts and provides an assessment of the initial translocated protected coral species and relocation sites.

**Table 1-1. Coral Species Designated as Rare or Threatened by the IUCN**

Common Name	Scientific Name
Boulder star coral*	<i>Orbicella franksi</i>
Lobed star coral*	<i>Orbicella annularis</i> <sup>†</sup>
Elkhorn coral*	<i>Acropora palmata</i>
Elliptical star coral	<i>Dichocoenia stokesii</i>
Lamarck's sheet coral	<i>Agaricia lamarcki</i>
Large ivory coral	<i>Oculina varicosa</i>
Mountainous star coral*	<i>Orbicella faveolata</i>
Pillar coral*	<i>Dendrogyra cylindrus</i>
Rough cactus coral*	<i>Mycetophyllia ferox</i>
Staghorn coral*	<i>Acropora cervicornis</i>
<p>* Also listed as threatened under the U.S. Endangered Species Act list.  <sup>†</sup> Listed as boulder star coral in the FGS (Department of the Navy 2016), but recognized as lobed star coral by the National Marine Fisheries Service.</p>	

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## 2. Coral Mitigation Methodology

Mitigation efforts were conducted between 19–29 April, 2022 at AUTEC. The team was comprised of a small group of Navy divers from the Naval Information Warfare Center (NIWC) Pacific Littoral Dive Unit, Navy scientific divers from NIWC Pacific and NUWC Division Newport, and NUWC marine and environmental scientists. The mitigation effort was carried out in four stages as described in detail below: 1) relocation site survey, assessment, and location marking; 2) inspection of the AUTEC Pier; 3) coral removal from the pier and translocation to the selected relocation sites; and 4) initial monitoring and data collection.

### 2.1 Project Area

#### 2.1.1 AUTEC Pier

AUTEC Pier is located on the AUTEC installation on Andros Island, the largest island in the Bahamas, located between the extensive Bahamas Bank to the west and the Tongue of the Ocean to the east (Figures 2-1 and 2-2). The pier primarily supports berthing of range vessels for test operations and associated range users. Proposed pier repairs include replacement and repairs to structures.



**Figure 2-1. AUTEC Pier (left) and South Dolphin Mooring (right)**

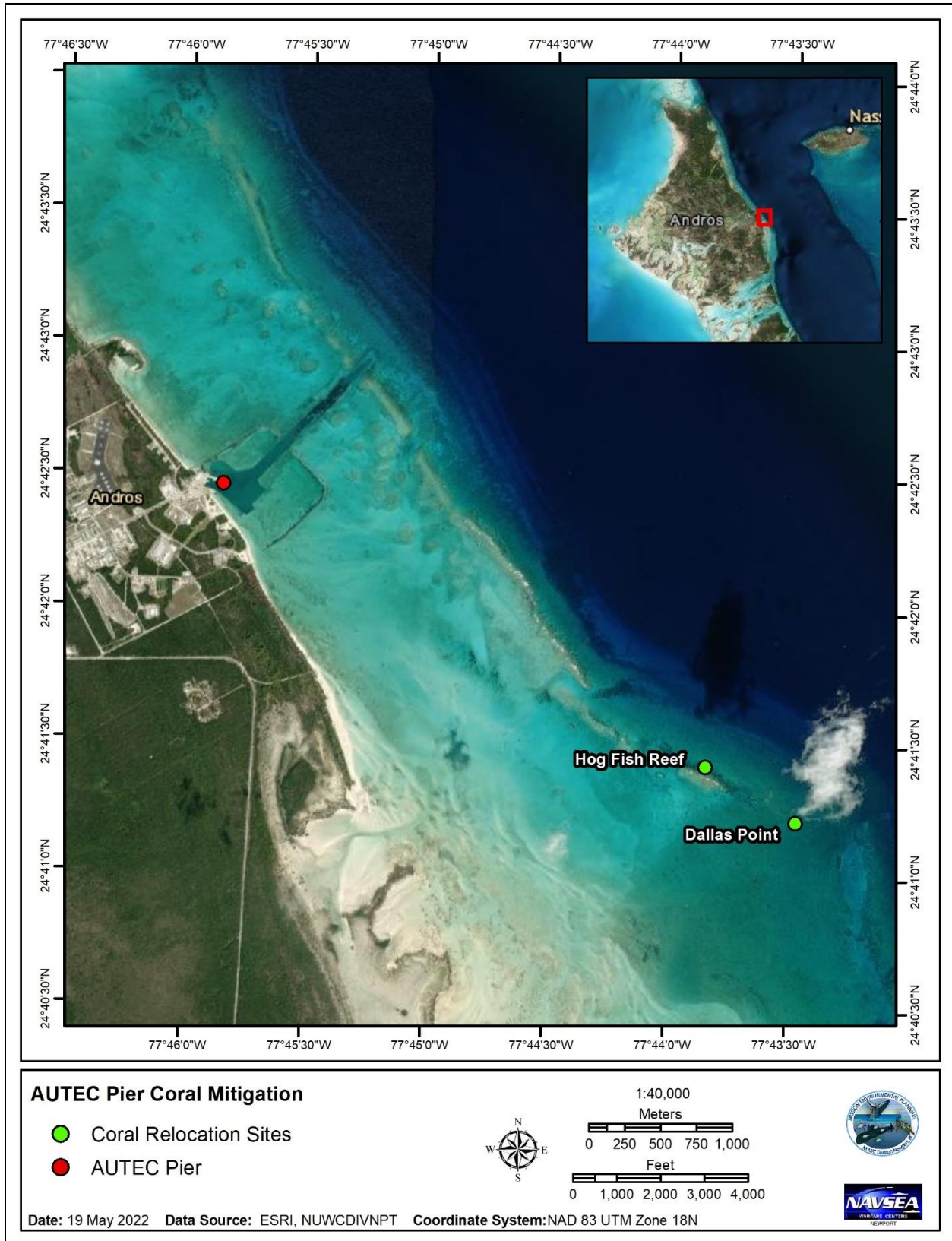


Figure 2-2. Location of the AUTEC Pier and Coral Relocation Sites

### 2.1.2 Relocation Sites

Multiple candidate relocation sites along the Andros Barrier Reef, the third largest fringing barrier reef in the world, were evaluated by the team in order to select one or more suitable sites to support coral translocation. Coral reefs, particularly fringing reefs, are extremely important in the protection of shorelines and infrastructure. Based on the selection criteria listed below and the time allotted to execute the mitigation effort, scientists determined, that of the available relocation sites, the two most suitable sites were at Hog Fish Reef and Dallas Point (Figures 2-2 through 2-4). Multiple relocation sites were used as a means to reduce risk in case one site is more heavily impacted by a particular hazard (e.g., storm) or more susceptible to an unrecognized hazard (e.g., unknown pollutant discharge). Additionally, if one site proves to be much more successful for coral survival and growth, that site may be selected for future mitigation efforts.

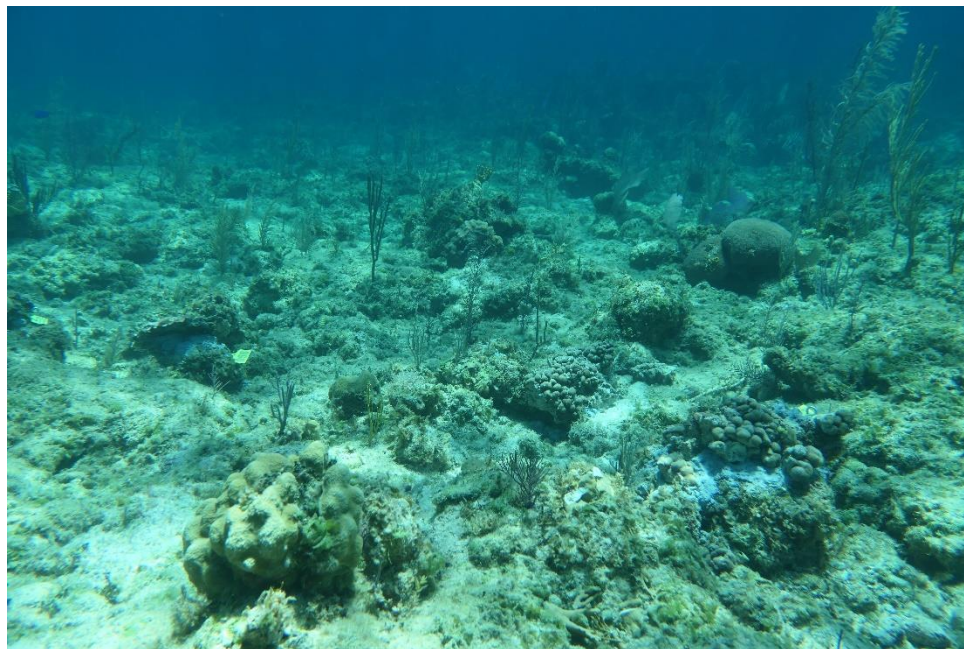
As described in more detail below, sites were selected based on criteria such as proximity to the pier, available natural hard substrate, similar surrounding viable coral, water quality, vessel traffic, and absence of natural predators. Both sites were less than 2.9 miles (mi; 4.6 kilometers [km]) from the pier. While an ideal relocation site would meet all the criteria listed below, the most suitable site was chosen based on meeting as many criteria as possible from the sites available along the reef.

Site selection criteria consisted of the following:

- Area should be accessible for logistics and monitoring
- Evidence of existing, viable coral colonies at the relocation site is desirable
- Suitable water quality, including similar visibility (clear water), current or water flow, low sediment settling, and stable water temperatures
- Low macroalgae cover
- Crustose coralline cover
- Presence of damselfish, surgeonfish, and *Diadema* sp. (sea urchins) to maintain macroalgae population (Note - too many of these species can have the opposite effect)
- Absence of predators such as parrotfish, snails or other harmful corallivores
- Solid/fixed substrate (no rubble or unconsolidated sediment)
- Area free of vessel traffic to avoid prop wash or other potential adverse impacts from training and operations

#### 2.1.2.1 Hog Fish Reef

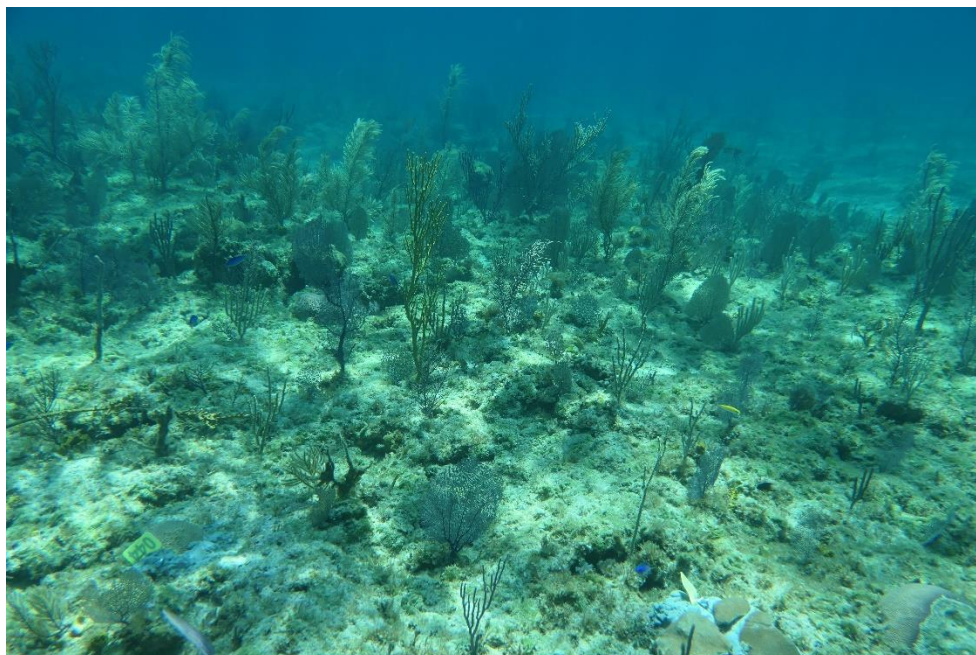
Hog Fish Reef is located 2.4 mi (3.9 km) from the AUTEC Pier. Hog Fish Reef has a maximum depth of 13 feet (ft; 4.0 meters [m]), with an average depth of 11 ft (3.6 m). During the translocation effort, water temperature at this site recorded from divers remained consistent at 78.8 degrees Fahrenheit (°F; 26 degrees Celsius [°C]) on the surface and on the bottom. The site was dominated by a limestone hard bottom covered by algal turf, and interspersed with small pockets of sand (Figure 2-3). This site also was interspersed with octocorals, including Gorgonians and sponges. There were multiple species of sporadic stony coral that were very healthy and sizable, including great star coral (*Montastraea cavernosa*), mountainous star coral (*Orbicella faveolata*), elliptical star coral (*Dichocoenia stokesii*), mustard hill coral (*Porites astreoides*), and *Agaricia* spp., as well as hydrocorals including branching fire coral (*Millepora alcicornis*). A small community of various fish species was observed here as well, including bluehead wrasse (*Thalassoma bifasciatum*), juvenile slippery dick (*Halichoeres bivittatus*), and juvenile rainbow wrasse (*Halichoeres pictus*).



**Figure 2-3. Hog Fish Reef Underwater Relocation Site**

#### **2.1.2.2 Dallas Point**

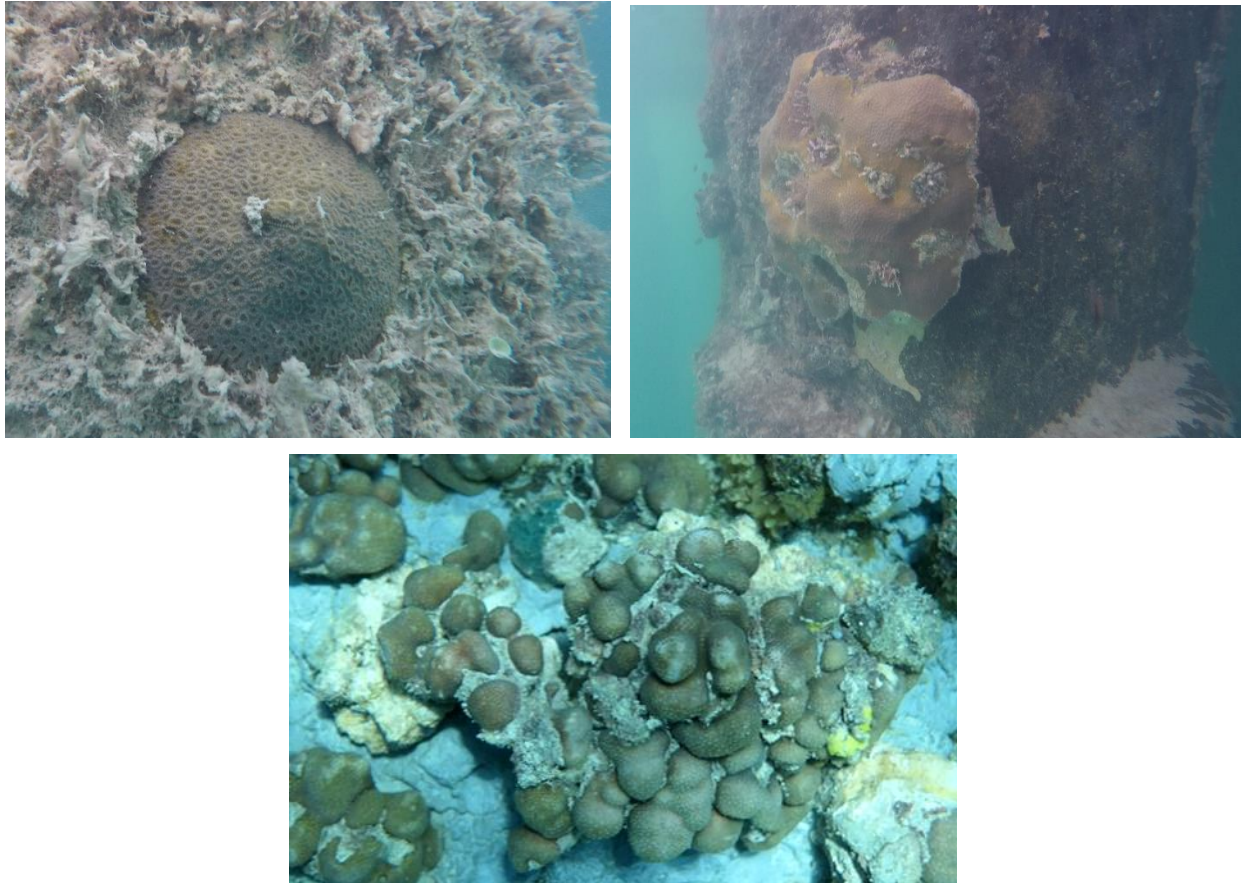
Dallas Point, named after the USS DALLAS (SSN 700), which ran aground in this area in the 1980s, is located 2.9 mi (4.6 km) from the AUTEC Pier just seaward of the fringe and barrier reefs. The maximum depth at Dallas Point is 12 ft (3.7 m), with an average depth of 10 ft (3.0 m). During the translocation effort, water temperature recorded from divers at this site remained consistent at 26 °C (78.8 °F) at the surface and on the bottom. The bottom type was very similar to Hog Fish Reef, with a dominate limestone hard bottom covered by algal turf and interspersed with small pockets of sand (Figure 2-4). There were multiple species of sporadic soft and stony coral that were very healthy and sizable. Stony coral species included *M. cavernosa*, mountainous star coral, grooved brain coral (*Diploria labyrinthiformis*), elliptical star coral, mustard hill coral, branching fire coral, massive starlet coral (*Siderastrea siderea*), and *Agaricia* spp. As with Hog Fish Reef, a small community of various fish species were observed, including bluehead wrasse, juvenile slippery dick, and juvenile rainbow wrasse.



**Figure 2-4. Dallas Point Underwater Relocation Site**

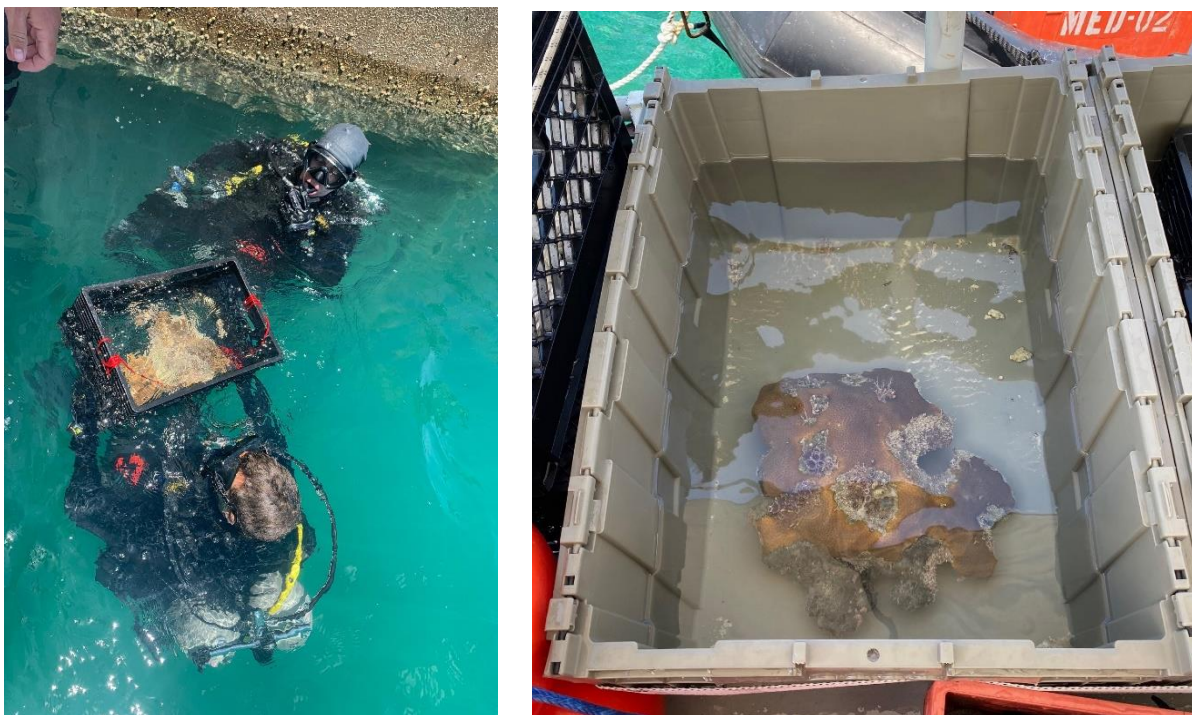
## 2.2 Coral Removal

Once the relocation sites were determined, the pilings and structures making up the AUTEC Pier were inspected to locate and identify rare or threatened coral species. The three protected species identified to be present on the pier structures were mountainous star coral (*O. faveolata*), lobed star coral (*O. annularis*), and elliptical star coral (*D. stokesii*) (see sections 2.2.1 through 2.2.3 for species descriptions). *O. faveolata* was found only in encrusting sheet morphology, while the *D. stokesii* was in dome form (Figure 2-5). *O. annularis* was found in irregular divided colonies of small mounds of lumps. It is recommended that candidate coral for relocation be healthy and greater than approximately 2–4 inches (in; 5–10 centimeters [cm]) in size (S. Smith, personal communication, 2020; U.S. Coral Reef Task Force 2016). However, the size best suited for increased likelihood of survivability can vary based on species and reproductive type (e.g., fragmenting). All but one coral colony was greater than 10 cm (4 in) in size, and with the exception of very small areas of mortality in a few corals due to algae, they were observed to be in good health.



**Figure 2-5. *D. stokesii* (left) and *O. faveolata* (right) on the AUTEC Pier, and *O. annularis* (bottom) at a Relocation Site.**

Using standard methodology by scientists to translocate corals (Frias-Torres et al. 2018, Smith and Hughes 1999; Yap and Molina 2003; Lirman et al. 2010), corals were systematically removed from the pier by divers using chisels and hammers. Removed coral was gently placed in plastic crates, allowing the coral to remain in seawater until ready to be transferred to the range vessel (Figure 2-6). Harvested colonies were placed in totes filled with seawater and secured on the boat during transport (Figure 2-7). The tubs were kept shaded by the vessel canopy and tote lids if necessary so that the colonies could remain completely submerged in water with a constant temperature and frequent water replenishment to increase the chances of survivability. Colonies were placed at depths similar to their origination.



**Figure 2-6. Navy Divers with Recovered Coral from the AUTEC Pier (Left) and Removed Corals Ready for Translocation (Right)**

### **2.2.1 Mountainous star coral (*Orbicella faveolata*)**

Mountainous star coral (*Orbicella faveolata*) has small, round polyps with exsert (protruding) walls in mounds with flanging edges or thick plates. They may fluoresce, and their color may vary to include brown, grey, or green. Colonies have been observed as wide and tall as 15 ft (4.6 m) (Lang and Marks, 2013). Their surfaces can be smooth, ridged, or with bumps aligned in vertical rows. *Orbicella* spp. can be the predominant coral species on fore reef slopes between 20 and 75 ft (6.1 and 22.9 m) and of the three species, *O. faveolata* is generally the most common (Humann and Deloach, 2013). A harvested colony of *O. faveolata* is shown in Figure 2-7.



**Figure 2-7. Harvested *O. faveolata* colony**

### 2.2.2 Lobed star coral (*Orbicella annularis*)

Lobed star coral (*Orbicella annularis*) has small, round, exsert polyps and can be light brown or yellow-brown, with shades of green or gray. Colonies have clusters of long, thick columns with enlarged dome-like tops, or it can grow in irregular mounds and encrustations with scattered lumps (Humann and Deloach, 2013). Thick plates can form at the colony sides or bases under low light conditions. This species differs from *O. faveolata* in that they subdivide to form columns with basal plates. *Orbicella* species, including lobed star coral, occur in most reef habitat types, although less commonly on the reef flat and in the shallow zones formerly dominated by elkhorn coral (Brainard et al., 2011; Goreau, 1959; National Oceanic and Atmospheric Administration, 2012b). *Orbicella* species are key reef-builders. A harvested fragmented colony of *O. annularis* is shown in Figure 2-8.



Figure 2-8. Harvested *O. annularis* colony

### 2.2.3 Elliptical star coral (*Dichocoenia stokesii*)

Elliptical star coral (*Dichocoenia stokesii*) has very exsert, Y-shaped polyps that vary from round to elliptical or elongate. The septa on vertical walls of a colony are more distinct. This species most commonly forms rounded domes and flattened plates (Humann and Deloach, 2013). Color can vary, including cream, yellow, or brown. There was one brown specimen that was translocated; the remaining *D. Stokesii* were yellow. Colonies can grow to 18 in (45.7 cm) (Lang and Marks, 2013). This species can be found at depths between 12 and 225 ft (3.7 and 68.6 m) (Humann and Deloach, 2013). A harvested colony of *D. Stokesii* is shown in Figure 2-9.



**Figure 2-9. Harvested *D. stokesii* colony**

### **2.3 Coral Translocation**

Coral was temporarily stored in open plastic totes with seawater aboard a 36 ft (11 m) range craft while transported to the relocation sites on the reef. Using the proven method demonstrated by Unsworth et al. (2020), coral was adhered to the hard substrate on the seafloor with a combination of 10 parts Portland Type I/II cement to 1 part silica fume. This ratio was tested on shore prior to deploying on the range craft to ensure its effectiveness. Fresh water was added to the cement mixture in buckets on the dive boat. The cement mixture was then poured into plastic grout bags and lowered to the seafloor in a crate along with the coral and an identifying tag (Figure 2-10). Divers squeezed the cement mix onto the seafloor substrate and gently affixed the coral to the seafloor. Numbered tags were placed in the cement adjacent to each colony and photo-documented for ease of identification during monitoring efforts (Figure 2-11).



**Figure 2-10. Divers Securing Coral to the Seafloor**



**Figure 2-11. Recently Translocated Coral with Tag**

One 32 ft (10 m) transect line was strategically laid out at Dallas Point, and a 36 ft (11 m) transect at Hog Fish Reef was laid. In order to deploy the transect tapes appropriately, a clump with a buoy at the surface was placed at the start and end of the transect. The transect tape was connected to the start buoy clump and unwound to the 10-m mark. The end buoy clump then was placed at the 10-m mark, slack was taken out, and the tape was secured to that clump. This ensured that the transect tape would stay in place and decrease potential movement of the tape by current. Each transect line marked 10 individual coral colonies at 1 m (3.4 ft) increments. By this design, 10 coral colonies were located at the Hog Fish Reef site and 11 at the Dallas Point site, for a total of 21 (Figure 2-12). The compass heading for the Hog Fish Reef transect was 90° east, while the heading for the Dallas Point transect was 007° north.



**Figure 2-12. Transect at the Dallas Point Site Showing Recently Translocated Coral (red arrows)**

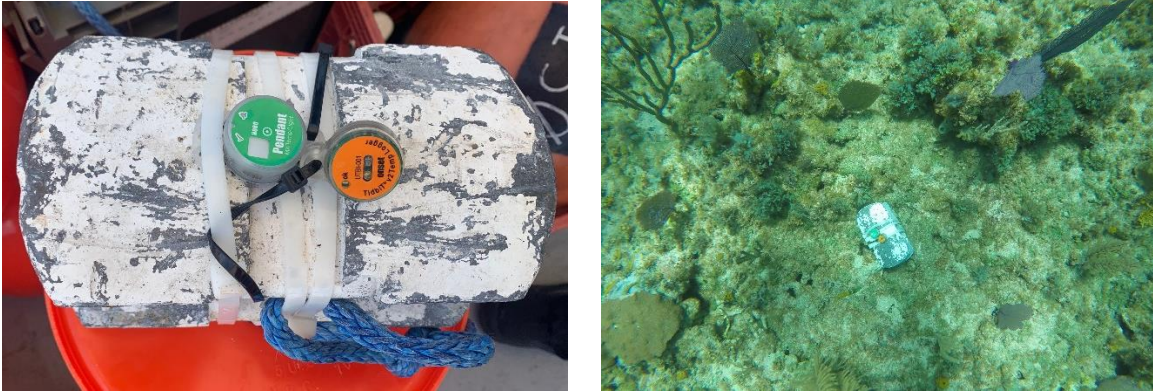
## 2.4 Data Collection

Detailed documentation of translocated coral colonies was obtained for the purposes of potential follow-on monitoring (Figure 2-13). Data collected included species, health (i.e., disease or bleaching), size (two longest dimensions of length and width), date of coral removal from the AUTEC Pier, and translocation information (e.g., depth, relocation site, substrate type [e.g., natural rock bottom], and environmental conditions [e.g., depth, visibility, current] at the time of placement).



**Figure 2-13. Diver Recording Data on Recently Translocated Corals**

Water quality measurements (e.g., temperature and light) were taken with HOBO® temperature and light data loggers (HOBO Pendant® MX Temperature/Light Data Logger) at the pier within the AUTEC harbor, as well as at the relocation sites. Measurements were obtained to assure similarities in the conditions at the removal site and relocation sites, as well as probability of success at the relocation sites. Data loggers were deployed at the seaward end of the main pier at a depth of 12 ft (3.7 m) from 21–26 April. Data loggers were attached to a 70-pound clump weight and deployed on the seafloor at approximately 12 ft (3.7 m) depth at Hog Fish Reef from 27–28 April and Dallas Point from 26–28 April (Figure 2-14). Due to malfunction of the data loggers at Dallas Point, data was not available at this relocation site. However, given the close proximity of this site to Hog Fish Reef (0.6 mi [0.7 km]) and the similar depth, conditions would be expected to be similar and would reflect the environmental conditions at the time of the translocation effort.



**Figure 2-14. Water Quality Data Logger Setup (left) and Deployment at Relocation Site (right)**

### 3. Results

#### 3.1 Translocated Coral

The team was able to remove practically all protected coral species from the pier structures (i.e., concrete pilings). There were only a few small colonies of *O. faveolata* remaining; however, the configuration in which the coral adhered to the structures precluded any successful removal. A total of 11 corals were moved to the Hog Fish Reef relocation site and 10 to the Dallas Point relocation site, for a total of 21 corals, as described in the following sections. All corals were harvested and translocated on the same day. Representative images of each translocated coral are provided in the Appendix.

##### 3.1.1 Hog Fish Reef

Data collected for corals translocated to the Hog Fish Reef site are provided in Table 3-1. Health status is given for the initial assessment at the time of translocation. All coral species were healthy, with only one coral (*O. faveolata*) showing very minimal signs of bleaching (one percent) and no indications of disease. Slight paling was observed on five corals. Five harvested corals (*O. faveolata* and *D. stokesii*) also exhibited some degree of mortality ranging from 1 percent to 25 percent (Tags 51, 56, 58, 60, and 61). A slight algal cover was visible on small portions of two *O. annularis* colonies and one *O. faveolata* colony (Tags 54, 55, and 57). Some corals were colonized by tubeworms and sponges. Half of the coral were translocated as one fully intact colony; however, due to their morphology and difficulty in removing them from the pier, the remaining five corals (*O. faveolata* and *O. annularis*) were fragmented and all fragments for each coral were translocated together (see Appendix).

**Table 3-1. Translocated Coral at the Hog Fish Reef Relocation Site**

Transect	Tag	Species Code	Max Length (cm)	Max Width (cm)	Percent Bleached (%)	Diseased (Y/N)	Fragment <sup>4</sup> (Y/N)	Substrate Type	Depth (ft)
1	51	OFAV <sup>1</sup>	40	34	0	N	Y	Natural	11
	52	OFAV	45	28	1	N	Y	Natural	11
	53	DSTO <sup>2</sup>	15	14	0	N	N	Natural	11
	54	OANN <sup>3</sup>	46	41	0	N	Y	Natural	11
	55	OANN	40	31	0	N	Y	Natural	11
	56	OFAV	32	28	0	N	N	Natural	11
	57	OFAV	40	32	0	N	N	Natural	11
	58	DSTO	12	12	0	N	N	Natural	11
	59	OFAV	21	9	0	N	N	Natural	11
	60	OFAV	33	25	0	N	N	Natural	11
	61	OFAV	36	26	0	N	Y	Natural	11

<sup>1</sup> OFAV = *Orbicella faveolata*

<sup>2</sup> DSTO = *Dichocoenia stokesii*

<sup>3</sup> OANN = *Orbicella annularis*

<sup>4</sup> Indicates whether coral was fully intact when removed off the pier or if it was fragmented with all fragments translocated together

##### 3.1.2 Dallas Point

Data collected for corals translocated to the Dallas Point site is provided in Table 3-2. All coral species were healthy, with very minimal signs of bleaching on two corals (less than one percent) and no indications of disease. One coral (*D. stokesii*) exhibited signs of paling, while four corals (Tags 45, 47, 48,

and 50) had minimal mortality (less than two percent). Seven corals (*O. faveolata*) were translocated as fragments due to difficulty in removing these coral colonies from the pier.

**Table 3-2. Translocated Coral at the Dallas Point Relocation Site**

Transect	Tag	Species Code	Max Length (cm)	Max Width (cm)	Percent Bleached (%)	Diseased (Y/N)	Fragment <sup>3</sup> (Y/N)	Substrate Type	Depth (ft)
1	41	OFAV <sup>1</sup>	35	24	0	N	N	Natural	12
	42	OFAV	23	20	0	N	Y	Natural	12
	43	OFAV	31	23	0	N	Y	Natural	12
	44	DSTO <sup>2</sup>	13	11	0	N	N	Natural	12
	45	OFAV	43	35	0	N	N	Natural	12
	46	OFAV	36	33	0	N	Y	Natural	12
	47	OFAV	28	28	0	N	Y	Natural	12
	48	OFAV	34	22	2	N	Y	Natural	12
	49	OFAV	23	22	0	N	Y	Natural	12
	50	OFAV	24	32	1	N	Y	Natural	12

<sup>1</sup> OFAV = *Orbicella faveolata*

<sup>2</sup> DSTO = *Dichocoenia stokesii*

<sup>3</sup> Indicates whether coral was fully intact when removed off the pier or if it was fragmented with all fragments translocated together

### 3.2 Water Quality

The most recently available water quality data at AUTEC is shown in Figures 3-1 through 3-3. During the data collection period in April 2022, water temperatures within the AUTEC harbor ranged from 24.5 to 26.5 °C (76.1 to 79.7 °F), with an average of 25.6 °C (78.1 °F) (Figure 3-1). Temperature at the Hog Fish Reef relocation site ranged from 25.6 to 28.7 °C (78.1 to 83.7 °F), with an average of 26.3 °C (79.3 F) during this period. There was substantial overlap between the two sites, with night time temperatures generally similar, and daytime temperatures slightly warmer at Hog Fish Reef (Figure 3-2).

Light was very different between the sites, with peak irradiance of approximately 45,000 lux at the 12 ft (3.7 m) depth of the AUTEC Pier, and over 131,000 lux at the same depth at the Hog Fish Reef relocation site (Figure 3-3). Average daytime irradiance also differed by approximately an order of magnitude, at about 26,700 lux for Hog Fish Reef and 2,040 lux at the AUTEC Pier.

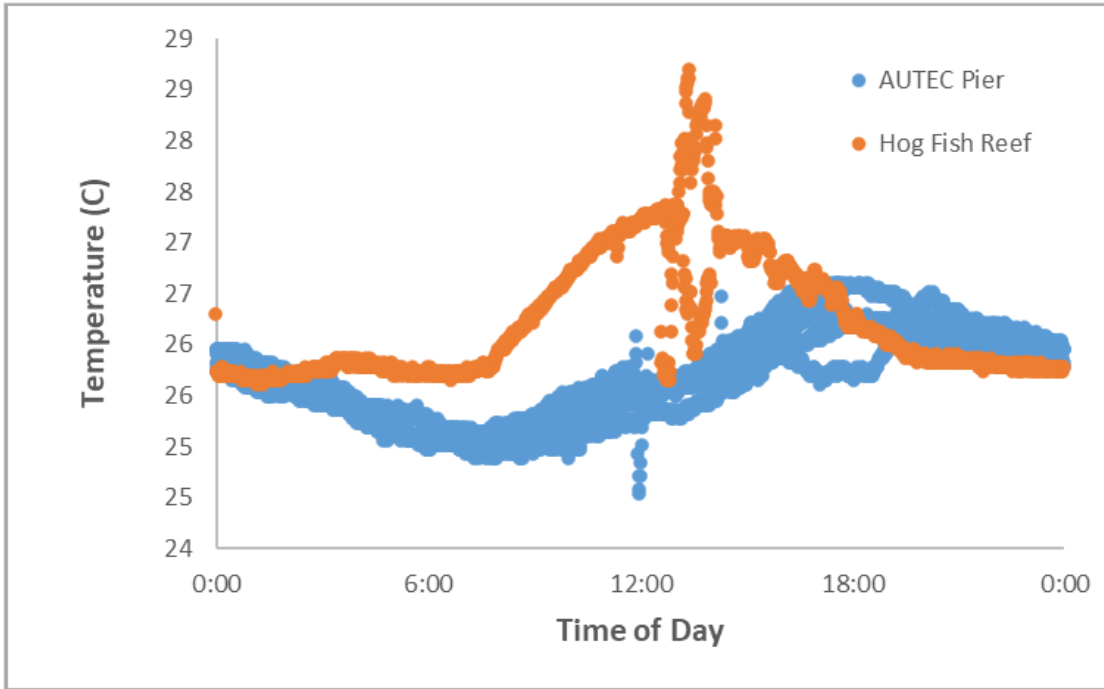


Figure 3-1. Temperature Data Collected at the AUTEC Pier and Relocation Site

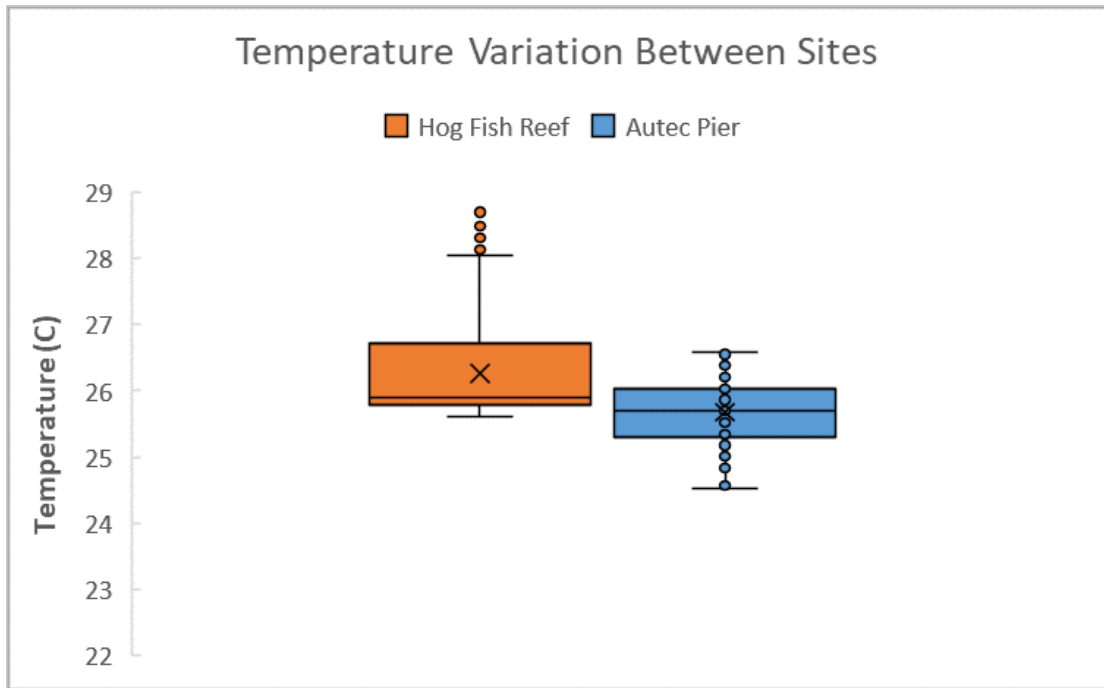


Figure 3-2. Temperature Variation between the AUTEC Pier and Relocation Site

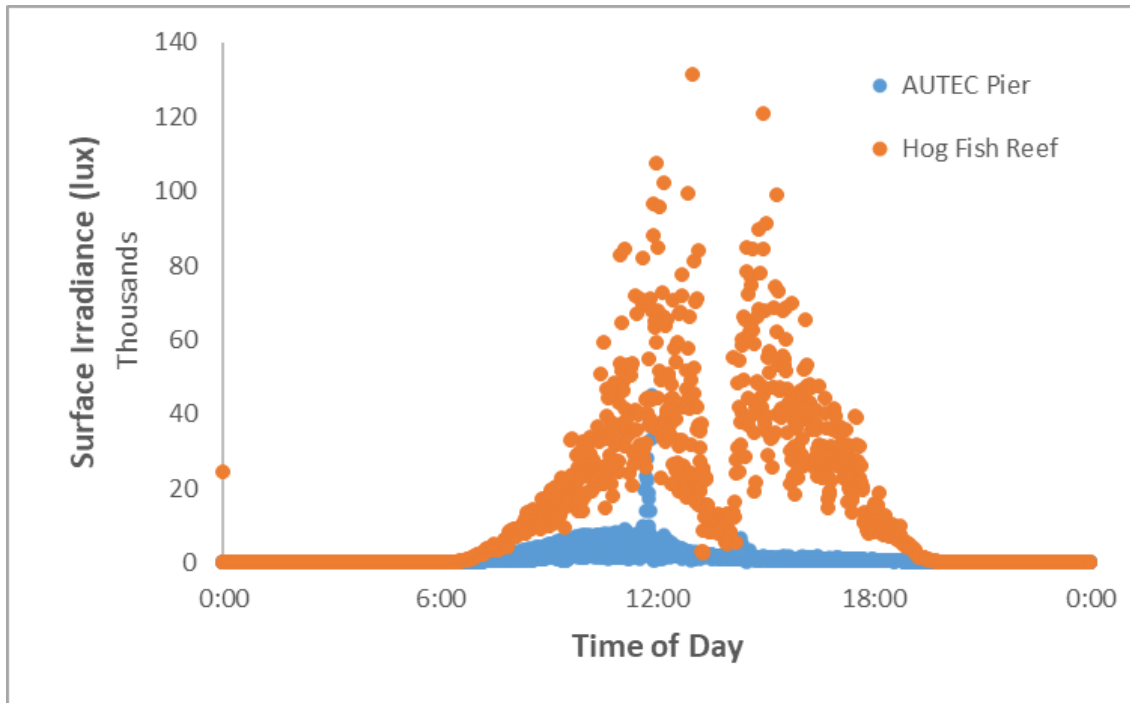


Figure 3-3. Light Data Collected at the AUTEC Pier and Relocation Site

## 4. Discussion

### 4.1 Initial Coral Translocation Assessment

Three species of protected corals (*O. faveolata* in encrusting sheet form, *O. annularis* in irregular divided mound form, and *D. stokesii* in dome form) were identified on the AUTEC Pier and successfully translocated to two relocation sites during the coral mitigation effort at AUTEC. All the corals translocated during this effort were attached to the natural substratum at the relocation sites along the barrier reef which has shown to increase survival compared to fragmented corals that have not been secured to the substratum (Forrester et al. 2011). Success rates vary between different coral morphologies, and more time is generally required to monitor slow-growing species to determine their long-term success. For example, several studies on translocated species have shown that branching corals have good success rates in the short term, particularly when the fragments are 1.4 in (3.5 cm) or greater (Forrester et al. 2011; D. Lirman pers comm.). Furthermore, branching corals, such as staghorn coral (*Acropora cervicornis*), are fast-growing and can provide data on success rates early on compared to slow-growing species. Other research has shown that dome or boulder species, such as *Porites asteriodes*, have thrived long-term after translocation.

All coral colonies translocated as part of the AUTEC pier mitigation project were over 4 in (10 cm) in size with the exception of one healthy, intact *O. faveolata* colony at Hog Fish Reef that had a maximum width of 3.5 cm (9 cm). Though research is ongoing to ascertain the minimum size class criteria for stony coral relocation projects, the general consensus among coral researchers and within the regulatory community is that stony corals greater than 4 in (10 cm) in diameter can be successfully relocated (U.S. Coral Reef Task Force (2016)). The size of relocatable corals, however, can vary across sites and reproductive type (e.g., fragmenting) and can be considerably smaller for certain species.

Corals with encrusting morphologies are generally difficult to remove, which can result in low success rates. While some of the colonies of *O. faveolata* and one large colony of *O. annularis* were difficult to remove from the pier structures due to their morphologies, if they fragmented during the removal process, the fragments were translocated together at the relocation site. Page et al. (2018) have shown fragments of *O. faveolata* can be successfully translocated if predation does not overcome the coral. Slow-growing, massive corals like *O. faveolata* also can be resilient to climate change. *O. annularis* is a slow-growing species as well, and its populations have been reduced by more than 50 percent during the past 30 years throughout its range and up to 95 percent in some areas (Aronson et al. 2008, NOAA 2014).

In addition to the parameters outlined in the methods section of this report, the health and chances of survival of translocated coral depend on a number of conditions, including erosion and sedimentation, bleaching, disease, storms and anthropogenic effects. With the exception of three corals that showed minimal bleaching, all translocated corals were healthy and showed no indications of disease. Any existing mortality observed on the corals were primarily due to the presence of algae. Translocating healthy corals is critical to the success of a mitigation effort. Not only is there a reduced chance of survival if diseased corals are translocated, but their placement among healthy coral can spread disease to other corals in the area. Survivorship and vitality of translocated coral may not be the only measure of a successful translocation effort. Success criteria can include structural and functional aspects of coral reef restoration as well as a framework for monitoring (Thayer et al., 2003).

Macroalgae can compete and overgrow coral reefs. Increased nutrients and the reduction of herbivores, such as certain fish and sea urchins, can lead to an overabundance of algae growth. During the translocation process, coral colonies were “groomed.” This is the process of manually removing any algae that were currently growing on the colonies. Overfishing has resulted in reduced populations of fish species that feed on algae as part of their diet including species of parrotfish, surgeonfish, and *Diadema* spp. of sea urchins. As part of the management of the coral ecosystem and follow-on monitoring efforts, it is recommended that the grooming process be implemented to maintain or increase chances of survival of the translocated coral. This should be done in a meticulous manner so that the coral is not damaged during the process. While this can be beneficial, there are associated risks if not done correctly. While Ceccarelli et al. (2018) has noted that this ecological intervention has had little research to quantify success in the monitoring process, there is some research that suggest this is beneficial. In their research, Smith et al. (2021) has shown that removal of macroalgae from degraded reefs enhances coral recruitment. Forrester et al. (2011) had observed improved growth of transplanted elkhorn coral (*A. palmata*) fragments with macroalgae grooming after the first year. Subsequently, data collected in follow-on monitoring efforts may provide valuable information on this replacement for the natural grooming from herbivores that have declined to a point where it is detrimental to the balance of the coral reef ecosystem.

Success rates can vary depending on species. Success rates between 60 and 100 percent were reported in studies at the M/V Wave Walker grounding reef restoration site (Franklin et al. (2005) and HDR, CSA and SSC PAC (2019)). Here, reattached coral included fragments from *O. annularis*, *Diploria labyrinthiformis*, *Colpophyllia natans* and *Porites astreoides*. The branching coral *A. cervicornis* has shown up to a 97 percent success rate (CSI, 2016). In contrast, some species may be more susceptible to disease. *Pseudodiploria strigosa* and *Meandrina meandrites* suffered from white-plague disease, but the initial cause of their mortality was thought to be from sediment burial due to ongoing dredging (Precht et al., 2019). Lack of long-term monitoring also can influence reported success and recovery rates of translocated coral. Furthermore, there may be biases toward publishing successes rather than failures (Bayraktarov et al., 2016). Restoration techniques require additional independent scientific publications with solid temporal data to validate survival and growth rates of colonies (Meesters et al., 2015).

Two relocation sites were used to reduce risk in the event that one site is more susceptible to a particular hazard. Utilizing two sites also allows for a comparison to determine which site may be more suitable for future translocation. The Reef Resilience Network (2020) suggests the use of as many sites as feasible to spread out the impact to populations and increase the potential for higher genetic diversity. Both the Hog Fish Reef and Dallas Point relocation sites exhibited similar existing healthy reef communities, with octocorals, stony corals, and various reef fish species suggesting these sites will be suitable for the continued growth of the translocated corals. As previously mentioned, there is a global reduction in herbivores, including in the Bahamas. *Diadema* spp. can be important in maintaining the balance between algae and coral. Unfortunately, no sea urchins were observed during the translocation process at the relocation sites, however they were observed in the surrounding areas. Additionally, little to no herbivorous fish, such as damselfish and surgeonfish, were seen at these site. A balance of herbivorous fish and those species that consume algae as part of their diet (e.g., parrot fish) is essential to reef health, however too many parrot fish can impact reef health as they do also consume coral. These important contributors to the ecosystem can help to maintain viable conditions necessary for coral communities to recover after acute disturbances, such as storms or bleaching events (Reef Resilience Network, 2022).

While ideal shallow water relocation sites in the Bahamas are limited, of the available translocation sites along the reef, Hog Fish Reef and Dallas Point were utilized based on meeting the most selection criteria

compared to other sites surveyed. Because the relocation sites currently support coral growth, it can be assumed that environmental conditions at the relocation sites were most conducive to coral success. Water quality conditions (e.g., temperature) were similar at both the removal site within the harbor and Hog Fish Reef and Dallas Point relocations sites, which will increase the probability of success of the corals at the relocation sites. The light measurements were not collected on the same days, so it is possible that weather patterns (e.g., cloud cover) played a role in the difference observed between the AUTEC Pier and the Hog Fish Reef relocation site. However, the difference was more likely due to periodic shading caused by the pier pilings and structures, which do not exist at the open water Hog Fish Reef site. Dissolved oxygen and salinity measurements, which were not obtained during this effort, should be obtained during future monitoring events to more accurately compare conditions within the harbor and at the relocation sites.

#### **4.2 Monitoring**

Monitoring of the translocated coral colonies will be undertaken to the extent funding or other constraints allow. If monitoring opportunities arise, the translocated corals should be revisited, photographed, and assessed as practicable within the first year for the following information: 1) survival; 2) measurement of growth/recession of coral tissue; 3) condition of structural attachment (has coral attached to the substrate); and 4) qualitative description of health. During monitoring, careful grooming of colonies may be required to remove macroalgae, but this process should not result in damage to the coral. Removal of turf algae or other biota that may negatively impact the colonies should be avoided. Monitoring and grooming should be conducted by coral reef scientists or divers trained to conduct the Atlantic Gulf Rapid Reef Assessment (AGRRA) or similar monitoring protocol to ensure accurate data collection. Bleaching, a regional disease-spreading phenomena, or physical impacts due to storms or anthropogenic effects may occur, and it is important to obtain data revealing the effects of these occurrences. Water quality measurements should be taken periodically to aid in coral monitoring. Lastly, monitoring of both relocation sites will aid in determining which site may be more suitable and successful for future coral mitigation efforts.

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## APPENDIX PHOTOS OF TRANSLOCATED CORAL COLONIES

### A.1 Hog Fish Reef Relocation Site



**Figure A-1. Translocated Coral #51 (fragments of *O. faveolata*). Minimal signs of mortality (1%).**



**Figure A-2. Translocated Coral #52 (fragments of *O. faveolata*). Sponges and tubeworms present, with minimal bleaching (1%).**



Figure A-3. Translocated Coral #53 (three separate colonies of *D. stokesii*).

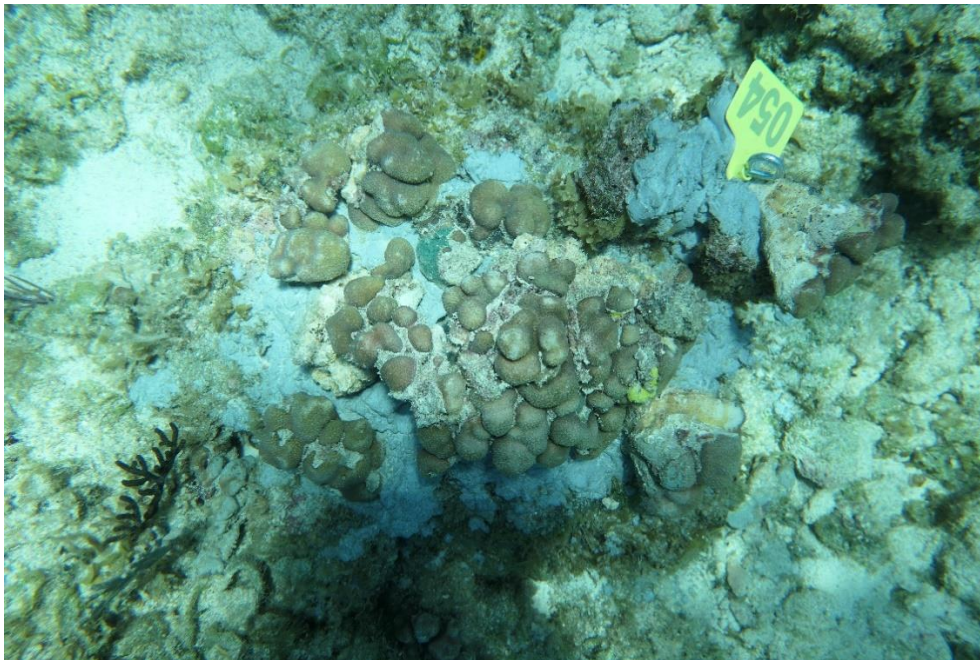


Figure A-4. Translocated Coral #54 (fragments of *O. annularis*).  
Algae and sponges present, with some paling.



**Figure A-5. Translocated Coral #55 (fragments of *O. annularis*).  
Algae and sponges present, with some paling of the coral.**



**Figure A-6. Translocated Coral #56 (*O. faveolata*).  
Some paling present, with 25% mortality.**



**Figure A-7. Translocated Coral #57 (*O. faveolata*).  
Tubeworms and algae present, with some paling of the coral.**



**Figure A-8. Translocated Coral #58 (*D. stokesii*).  
Some paling, with minimal mortality (1%).**

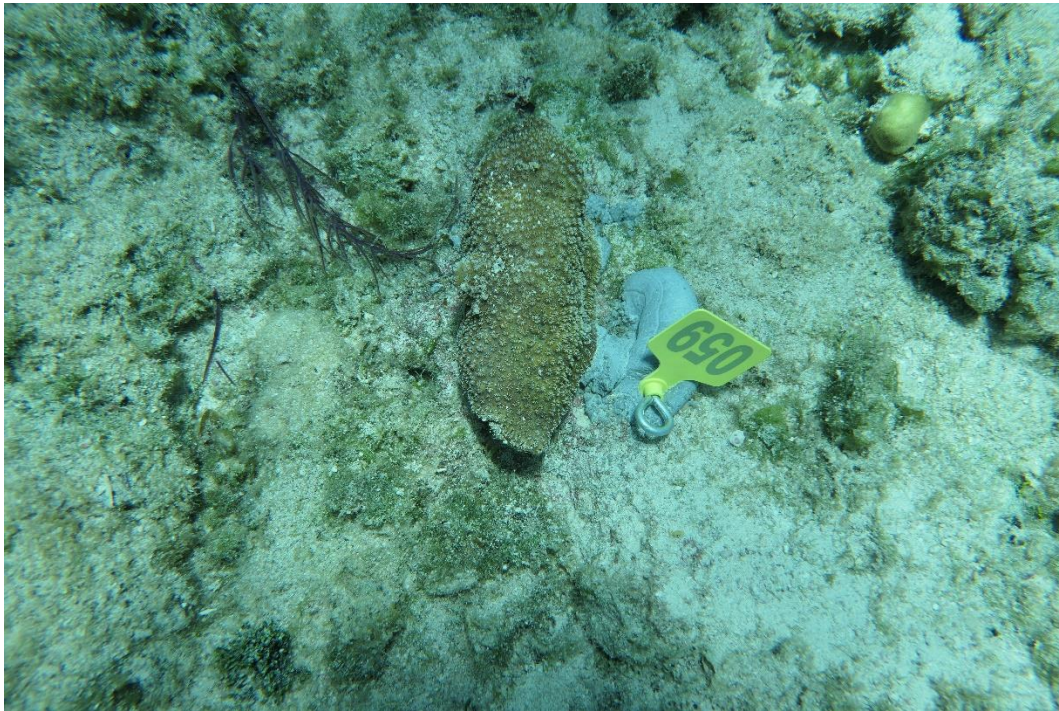


Figure A-9. Translocated Coral #59 (*O. faveolata*). Some pinched polyps present.

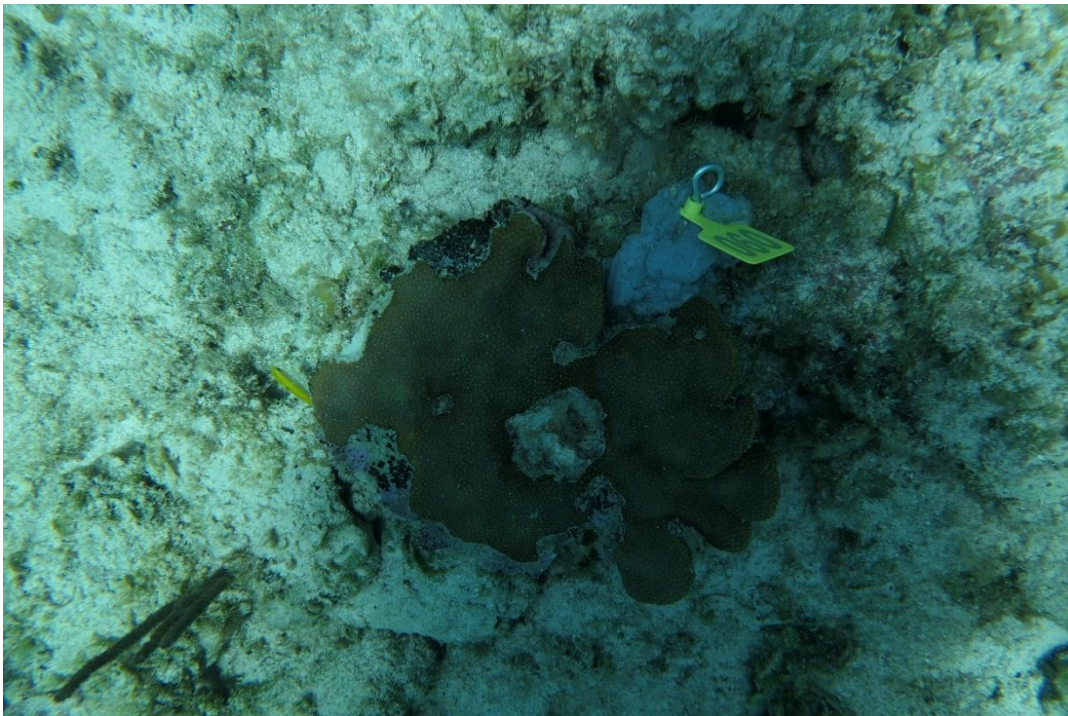
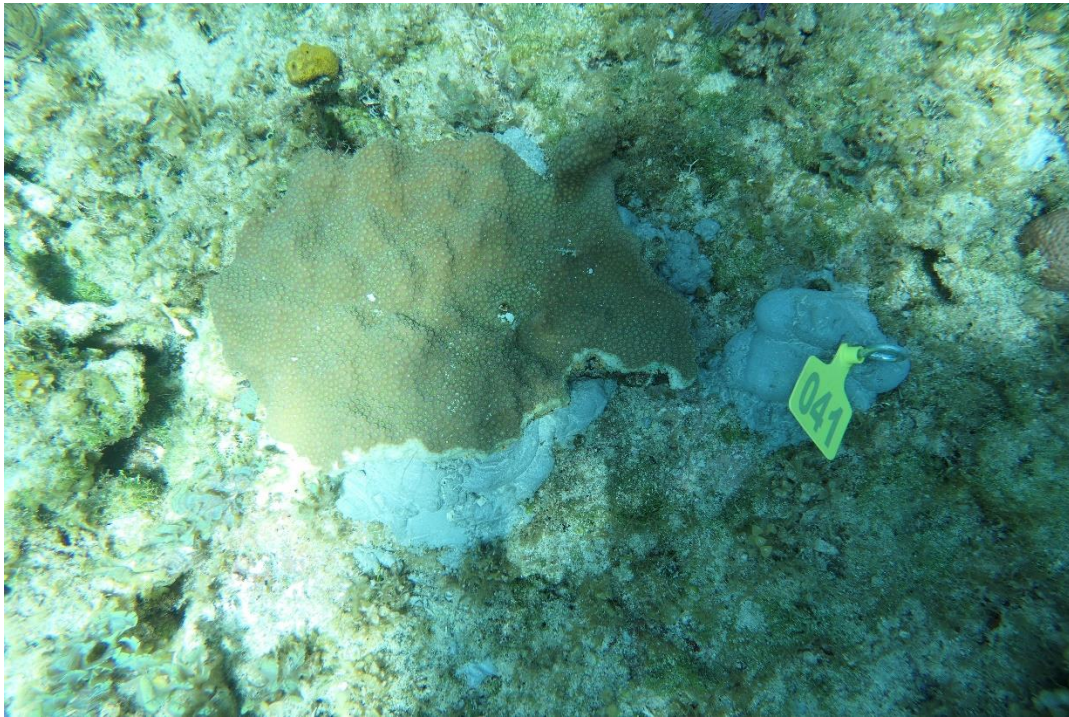


Figure A-10. Translocated Coral #60 (*O. faveolata*). Minimal mortality (3%) present.

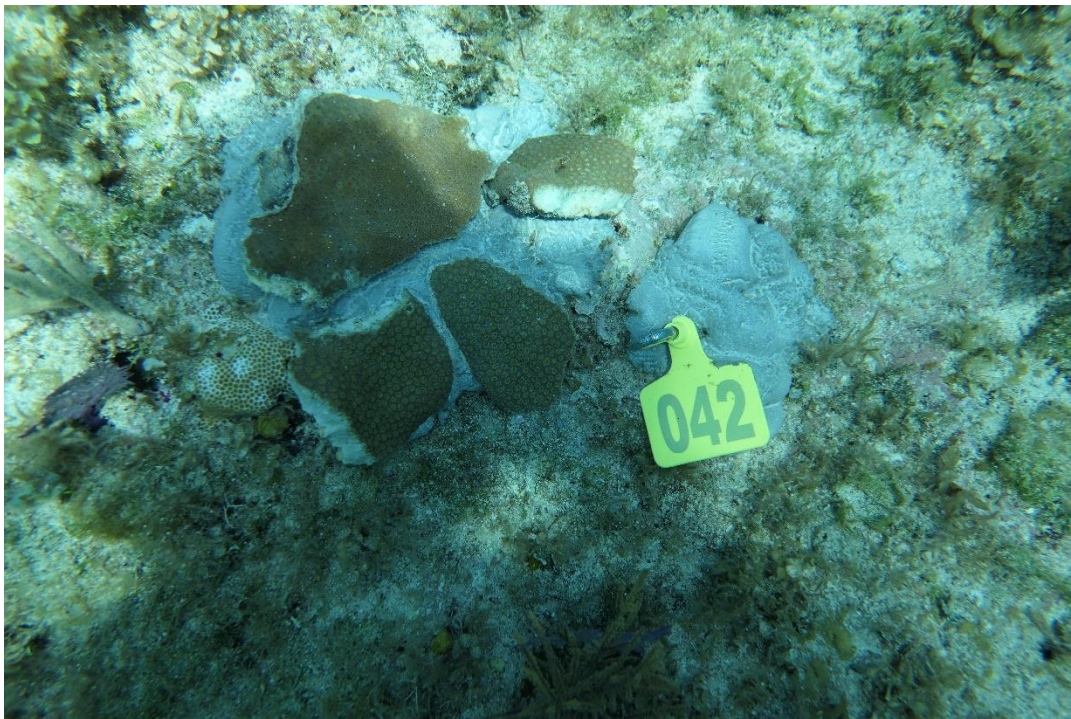


**Figure A-11. Translocated Coral #61 (fragments of *O. faveolata*). Some mortality (5%) present.**

**A.2 Dallas Point Relocation Site**



**Figure A-12. Translocated Coral #41 (*O. faveolata*)**



**Figure A-13. Translocated Coral #42 (fragments of *O. faveolata*)**



Figure A-14. Translocated Coral #43 (fragments of *O. faveolata*)



Figure A-15. Translocated Coral #44 (*D. stokesii*). Minimal paling (1%) present.

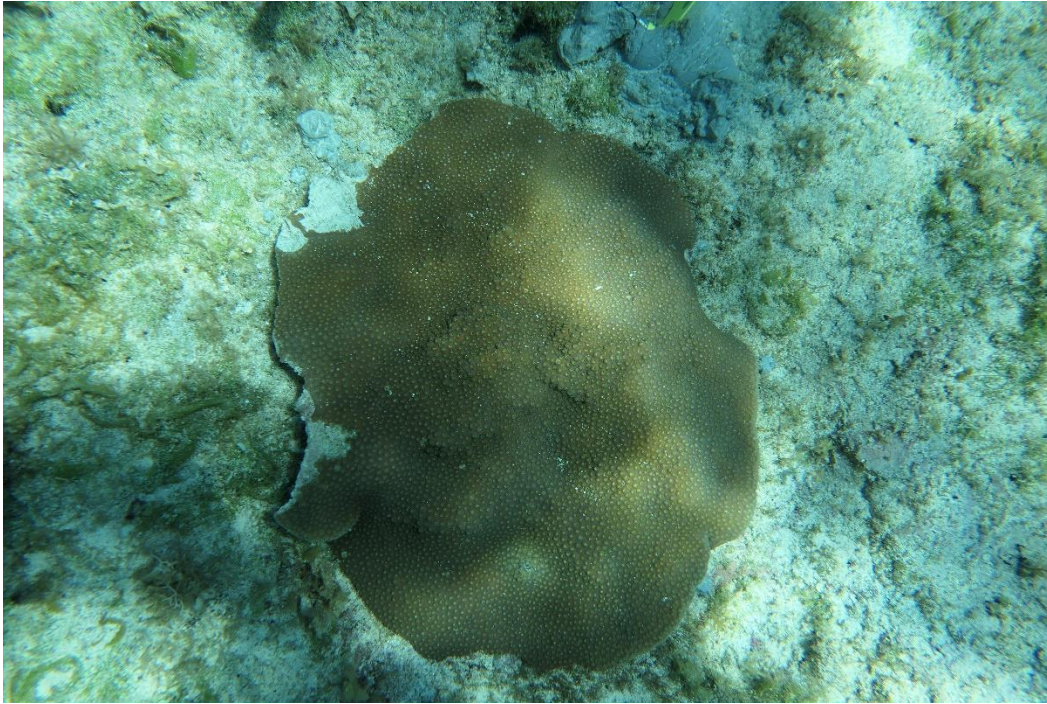


Figure A-16. Translocated Coral #45 (*O. faveolata*). Minimal mortality (1%) present.



Figure A-17. Translocated Coral #46 (fragments of *O. faveolata*)



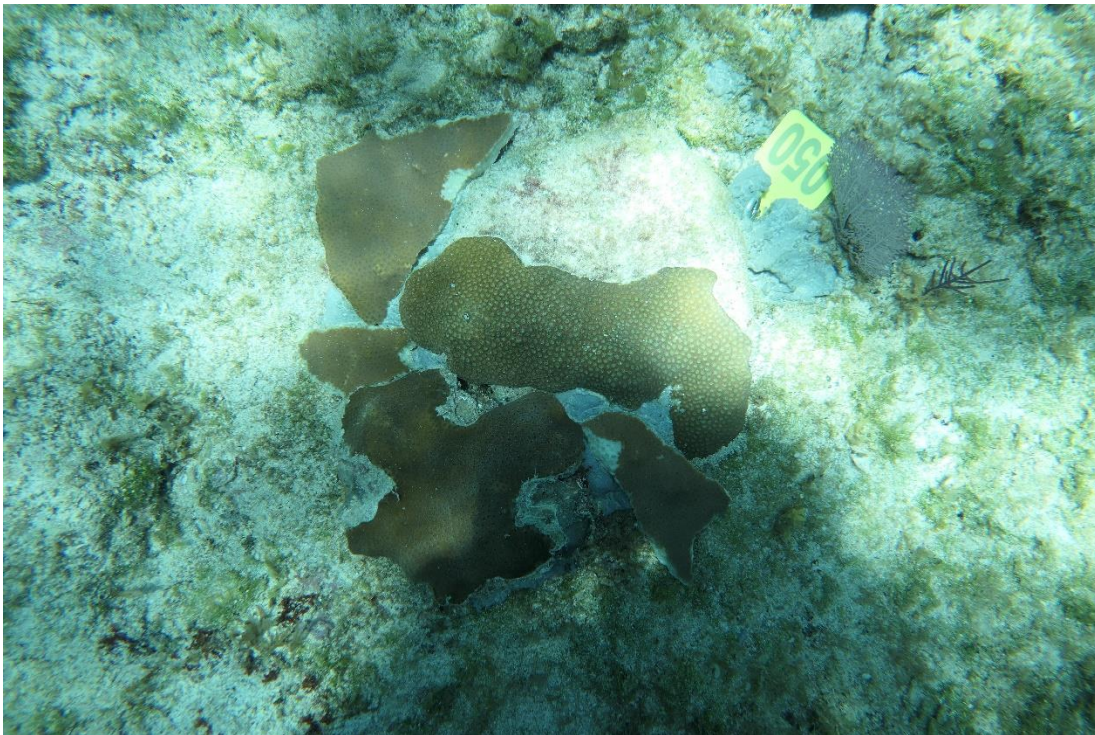
**Figure A-18. Translocated Coral #47 (fragments of *O. faveolata*). Minimal mortality (1%) present.**



**Figure A-19. Translocated Coral #48 (fragments of *O. faveolata*). Minimal bleaching (2%) and mortality (1%) present.**



**Figure A-20. Translocated Coral #49 (fragments of *O. faveolata*). Additional fragment (bottom colony) of a non-protected species (*Stephanocoenia intersepta*) also translocated.**



**Figure A-21. Translocated Coral #50 (fragments of *O. faveolata*). Minimal bleaching (1%) and mortality (2%) present.**

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