Vieques Artificial Reef Research Project

Final Report

Contract No. DG133C06SE5400

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Prepared for:
National Oceanic and Atmospheric Administration (NOAA)
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EXECUTIVE SUMMARY

The National Oceanic and Atmospheric Administration (NOAA) contracted Dial Cordy and Associates to test various materials (concrete, ceramic, natural limerock, coral rubble, etc.) and three artificial reef structural designs in the preferential success of coral settlement and growth (juvenile recruitment and success), survival of donor corals transplanted to these structures, and habitat for other benthic (sponges, octocorals, crustose coralline algae, etc.) and mobile reef organisms (fish, urchins, lobster, etc.).

Artificial reef units constructed and deployed off Blue Beach, Vieques, PR on 23 August 2007 included four replicates (units) of three types: 1) Eco-Reef ceramic units (ER); 2) concrete units with quarried limestone boulders (QR); and 3) concrete units with locally collected coral rubble (LR). Following deployment of these units, corals of opportunity were collected from the adjacent reef and attached to half of the units (with transplants (WT) or no transplants (NT)). For transplantation of other corals, "corals of opportunity," including *Acropora cervicornis and A. palmata,* were collected from donor sites around the project area in the waters off Vieques.

Artificial reefs were colonized by algae during the two-year monitoring period. No new coral recruits were documented on any artificial reef type, with or without transplants, during the monitoring period 2007-2009. Monitoring results documented the survival of most of the 56 transplanted corals, except *Acropora palmata* and *A. cervicornis* colonies. Colonies of *A. palmata* and *A. cervicornis* attached to the ERs were removed from the structures or *A. palmata* transplants on the quarried and live rock modules experienced partial mortality during the monitoring period. Missing acroporid colonies were first documented in October 2008, and may have been removed by wave action associated with tropical storm Hanna, which affected the south coast of Vieques in the summer of 2008. Other corals attached to ERs such as *Porites porites* and *Porites astreoides* were living and attached during the last monitoring event. No disease was documented on any corals during the monitoring period. No coral recruits were documented during the two years of monitoring on any type of reef module.

Fish populations were concentrated around the larger modules (QR and LR) (with and without transplants), and were noticeably fewer surrounding ERs. Fish were documented using the artificial reefs as habitat throughout the monitoring events. Fish species included mostly herbivorous juvenile reef fish. Artificial reefs with holes and overhangs may be desirable for providing habitat for cryptic species. Green morays and a rock hind were documented on consecutive monitoring events using all types of artificial reefs.

Module performance was compared across four success criteria categories: pioneering colonizers (e.g. algae); coral recruitment; transplant survival; fish habitat. No coral recruits were documented during the monitoring period on any module type, all artificial reefs were colonized similarly by algae during the monitoring period, regardless of type. Coral transplants survived similarly on LR and QR reef types, while transplants on ERs were removed, presumably by wave action. Acroporids on LR and QR modules experienced partial mortality during the monitoring period. Fish populations typical of back reef habitats (juvenile herbivorous and omnivorous fish) utilized all artificial reef types, but were more abudant and diverse surrounding the LR and QR module types, while fewer fish representative of fewer groups were found on ERs

Recommendations from this study include: 1) the placement of artificial reefs in areas suitable for coral reef habitat (i.e. sufficiently shallow sediment and lack of detrital material); 2) if ERs are used, they should be deployed as they were designed, with multiple units joined together to create a larger reef structure; 3) artificial reefs placed in areas where coral recruitment is low, as is the case throughout much of the Caribbean, should include transplanted corals of opportunity in order to enhance the potential for coral recruitment of these artificial habitats.

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

1.0 INTRODUCTION

Dial Cordy and Associates Inc. (DC&A) was contracted by the Office of Response and Restoration (OR&R), NOAA to perform an artificial reef demonstration project off the Island of Vieques, Puerto Rico, through contract # **DG133C06SE5400**. The goal of this research project funded by the National Oceanic and Atmospheric Administration (NOAA) was to test various materials (concrete, ceramic, natural limerock, coral rubble, etc.) and three artificial reef structural designs in the preferential success of coral settlement and growth (juvenile recruitment and success), survival of donor corals transplanted to these structures, and habitat for other benthic (sponges, octocorals, crustose coralline algae, etc.) and mobile reef organisms (fish, urchins, lobster, etc.).

The project site is located off of Blue Beach at Vieques National Wildlife Refuge (VNWR), Vieques, Puerto Rico (Figure 1). The study area is located in the sandy nearshore, therefore not impacting the natural reef. The study plots consisted of 0.72-acre, with the artificial reef structures occupying only 0.006-acre (Figure 2).

The information obtained in this study regarding settlement and transplant success, specifically of *Acropora palmata* and *Acropora cervicornis,* on artificial structures will be used in guiding future reef restoration initiatives on Vieques by NOAA. In addition, with the listing of these acroporids as threatened on the Endangered Species Act (ESA), the information gleaned from this study may forge new and valuable techniques that could assist in the recovery of these corals throughout their extant range.

2.0 METHODS

Three (3) common and readily available artificial reef restoration module types were constructed and deployed in this study. Required permits were received from the Puerto Rico Department of Natural Resources (PRDNR) and the United States Army Corps of Engineers (USACE) (Appendix A). Four replicate units of each structural type were used; two of each type to test coral settlement and settlement of other sessile benthic organisms and two to test the success of coral transplants. For transplantation of other corals, "corals of opportunity," including *Acropora cervicornis and A. palmata,* were collected from donor sites around the project area in the waters off Vieques.

Following receipt of necessary permits from the PRDNR and USACE, artificial reef units were constructed and deployed off Blue Beach, Vieques, PR on 23 August 2007. They included four replicates (units) of three types: 1) Eco-Reef ceramic units (ER); 2) concrete units with quarried limestone boulders (QR); and 3) concrete units with locally collected coral rubble (LR). Following deployment of these units, corals of opportunity were collected from the adjacent reef and attached to half of the units (with transplants (WT) or no transplants (NT)).

Eco-Reef Units (ER) were constructed on-board the dive vessel and anchored to the bottom using cement and rebar rods.

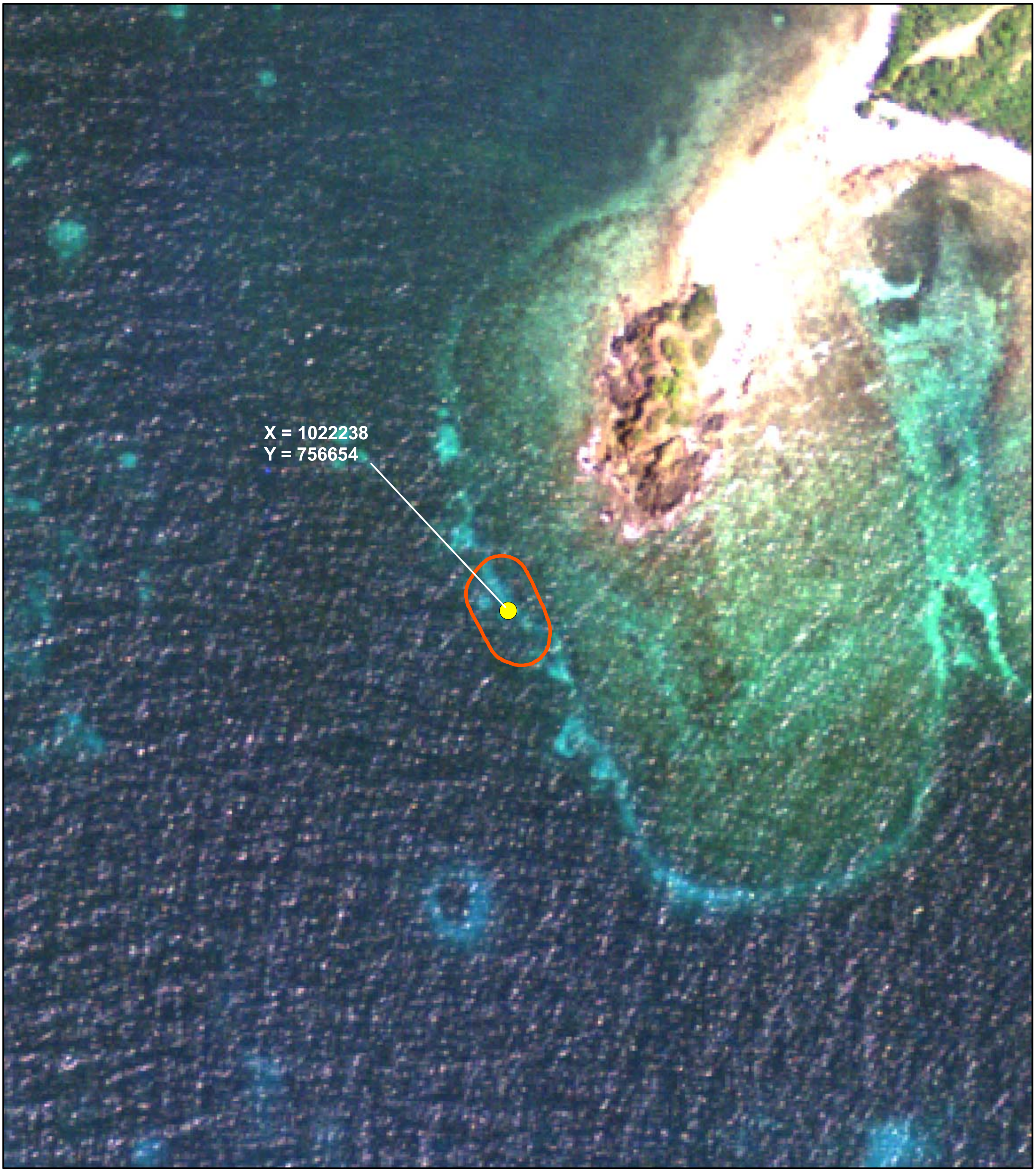
Concrete and quarried limestone rock units (QR) (>1.27 m diameter) were constructed with cement and reinforced with 3/8" rebar. Six cinderblocks were secured to the top of the

Legend

Approximate Location of Artificial Reef

0 50 100 200 300 400 500 Meters

Location Map, Blue Beach, Isle de Vieques, PR	
Artificial Reef Restoration Area Vieques, Puerto Rico	
Scale: as shown	Drawn By: MDR
Date: April 2011	Approved By: MLR
DIAL CORDY AND ASSOCIATES INC Environmental Consultants	J06-986
	Figure 1



Legend

Approximate Location of Artificial Reef

GPS Location

0 20 40 80 120 160 Meters

Artificial Reef Restoration Site	
Artificial Reef Restoration Area Vieques, Puerto Rico	
Scale: as shown	Drawn By: MDR
Date: April 2011	Approved By: MLR
DIAL CORDY AND ASSOCIATES INC Environmental Consultants	J06-986
	Figure 2

module with cement. The blocks were set in pairs on approximately 120 degree axes, with the holes of the blocks oriented horizontally towards the outer edge of the module. Limestone rubble harvested locally was then placed on top of the module and attached at contact points using cement.

Plastic pools (1.27 m diameter and 30.5 cm deep) and were used as molds for the concrete units and were removed from the outer edge of the module prior to their deployment. Each of the units was constructed with approximately ten 50-pound bags of Type 2 concrete. Taking into account the weight of the aggregate mixed with the cement, the weight of the blocks, and the stone attached to the modules, it is estimated that each weighed between 2,000 and 2,500 pounds.

The concrete units were constructed on-board the retired Navy landing craft (LC) owned and operated by Astillero de Puerto Rico, Inc. for marine construction. The eight concrete units were lifted from the LC deck and deployed within a narrow sand pass between the adjacent reef and seagrass beds off Blue Beach.

Concrete and coral rubble units (LR) (>1.27 m in diameter) were constructed by pouring a shallow rebar (3/8") reinforced base of cement several inches thick and letting it set enough to support cinderblocks. Three cinderblocks were placed on top of the base in a spoke-like pattern with the holes of the block oriented vertically. The unit was then filled with cement to a point level with the top of the blocks. The holes in the cinderblocks were left open to provide additional microhabitat for marine fauna. Nylon zip ties were inserted in the top surface of the concrete to facilitate attachment of coral rubble to the module. Coral rubble was collected locally and attached to the surface of the unit with zip-ties, once the modules were placed on the seafloor. The coral rocks were then secured with cement placed at contact points to ensure the longevity of the units.

2.1 Quarterly Monitoring

Quarterly monitoring began in December 2007 and was conducted for two years until October 2009 (Table 1). Unfortunately, during the October 2009 monitoring event, the camera flooded underwater, so photos and coral data for the final monitoring event are not available. The final quarterly monitoring results reported for coral data are July 2009, fish data for October 2009 are reported. For the three artificial structures used to test coral settlement, monitoring included *in-situ*, photo and video data collection methods (Table 1). *In-situ* data included the identification of corals at least to genus, size of recruits, percent mortality, and documentation of other sessile organisms that settled on the structures. Photographic and video data collection served as a record for the project and were used to document coral settlement and growth for recruits, as well as the number and type of species dead versus the total number transplanted to the structures to determine survivorship. Fish population data were collected using a modified Bohnsack and Bannerot (1986) cylinder method.

Table 1. Quarterly monitoring schedule and types of data recorded for each event.

Quarterly Monitoring Event	*In Situ* Data	Video Data	Photo Data	Fish Population Data
December 2007	X		X	
April 2008	X	X	X	X
July 2008	X	X	X	X
October 2008	X	X	X	X
January 2009	X	X	X	X
April 2009	X	X	X	X
July 2009	X	X	X	X
October 2009*		X*	X*	X

*Camera was broken during this event, photographs were lost.

3.0 RESULTS

All of the artificial reef structures installed off of Blue Beach were intact after two years of quarterly monitoring; although, two of the large round modules were tilted in October 2008, possibly by storms that affected the area in the summer of 2008 (notably tropical storm Hanna). Several arms of the ERs were broken during the monitoring period.

Fifty-six hard corals were transplanted to six modules, two of each type, ER, LR, and QR artificial reef types. Data were collected during quarterly monitoring events and results for each year of coral data are attached as Appendix B. Appendix C includes photographs of each module for each monitoring event.

Monitoring results documented the survival of most of the 57 transplanted corals, except *Acropora palmata* and *A. cervicornis* colonies (Table 2). Fifty-one out of 57 coral colonies were alive in October 2009. Four colonies were physically missing from the structures, while 2 experienced mortality during the monitoring period. Colonies of *A. palmata* and *A. cervicornis* attached to the ERs experienced partial mortality and were removed from the structures, presumably by wave action during the monitoring period. *A. palmata* transplants on the quarried and live rock modules experienced partial mortality during the monitoring period. A single *A. cervicornis* colony was missing in July 2008. Multiple *acroporid* colonies were documented as missing in October 2008, and may have been removed by wave action associated with tropical storm Hanna, which affected the south coast of Vieques in August of 2008. All acroporids were missing from ERs as of April 2009. Other corals attached to ERs such as *Porites porites* and *Porites astreoides* were still living and attached during the last monitoring event. No disease was documented on any corals during the monitoring period. No coral recruits were documented during the two years of monitoring on any type of reef module. Fish populations were concentrated around the larger modules (with and without transplants), and were noticeably fewer surrounding ERs. Figures 3 through 23 show individual modules (8ERWT, 6QRWT, 9LRWT) at each monitoring event from December 2007 through July 2009. Photographs for all modules are included in Appendix C.

Table 2. Organisms recorded by reef module from south to north.

Number	Module Name	Organism	Number	Size (cm)	July 2008 % mortality	July 2009 % mortality
1	ERNT	*Dictyota* sp. algae	several			
		Turf algae	several			
2	LRNT	*Siderastraea radians*	1	3	0	*
		Branching gorgonian	1	10	0	0
3	LRWT	*Siderastraea radians*	1	3	0	0
		Siderastraea radians	1	3	0	0
		Siderastraea radians	1	3	0	0
		Diploria strigosa	1	8	0	0
4	ERNT	*Schizothrix* sp. algae	several			
		Dictyota sp. algae	several			
		Orange encrusting algae	several			
		Turf algae	several			
5	QRNT	*Schizothrix* sp. algae	several			
		Dictyota sp. algae	several			
		Tunicate	single			
		Turf algae	several			
6	QRWT	*Porites porites*	1	10	0	0
		Porites porites	1	10	0	0
		Porites porites	1	10	0	0
		Porites porites	1	15	0	0
		Porites astreoides	1	7	0	0
		Siderastraea siderea	1	10	0	0
		Dichoncoenia stokesii	1	5	0	*
		Diploria strigosa	1	8	0	*
		Diploria strigosa	1	8	0	0
		Montastraea annularis	1	4	0	0
		Acropora palmata	1	10	75	100
		Acropora palmata	1	5	50	50
		Acropora palmata	1	5	50	50
		Agaricia agaricites	1	10	0	0
		Agaricia agaricites	1	5	50	50
		Eusmilia fastigiata	1	10	0	0
		Madracis decactis	1	8	0	0
		Udotea sp. algae	few			
7	QRNT	*Schizothrix* sp. algae	several			
		Dictyota sp. algae	several			
		Orange encrusting sponge	several			
		Turf algae	several			

Table 2, continued:						
Number	**Module Name**	**Organism**	**Number**	**Size (cm)**	**July 2008 % mortality**	**July 2009 % mortality**
8	ERWT	*Porites porites*	1	15	0	0
		Acropora palmata	1	10	0	**
		Acropora palmata	1	15	0	**
		Acropora palmata	1	20	0	**
		Porites astreoides	1	12	0	0
9	LRWT	*Diploria strigosa*	1	10	0	0
		Diploria strigosa	1	10	0	0
		Acropora palmata	1	12	100	100
		Eusmilia fastigiata	1	10	0	0
		Porites porites	1	8	0	0
		Porites porites	1	8	0	0
		Porites porites	1	10	50	50
		Porites astreoides	1	10	0	0
		Porites astreoides	1	15	0	0
		Dichocoenia stokesii	1	8	0	0
		Porites astreoides	1	3	0	0
		Siderastraea radians	1	2	0	0
		Schizothrix sp. algae	several			
		Udotea sp. algae	few			
		Blue sponge	single		0	*
10	QRWT	*Siderastraea siderea*	1	8	0	0
		Siderastraea siderea	1	8	0	0
		Porites porites	1	25	0	0
		Porites porites	1	5	0	0
		Porites porites	1	5	0	0
		Eusmilia fastigiata	1	15	0	0
		Eusmilia fastigiata	1	10	0	0
		Meandrina meandrites	1	10	0	0
		Montastraea annularis	1	5	0	0
		Diploria strigosa	1	10	0	0
		Millepora alcicornis	1	10	0	0
		Acropora palmata	1	10	50	50
		Acropora palmata	1	10	50	50
		Madracis decactis	1	10	0	0
		Porites astreoides	1	10	0	0
		Schizothrix sp. Algae	several			
		Turf algae	several			
		Orange encrusting sponge	several			
Table 2, concluded:						

Number	**Module Name**	**Organism**	**Number**	**Size (cm)**	**July 2008 % mortality**	**July 2009 % mortality**
11	LRNT	*Schizothrix* sp. Algae	several			
		Halimeda sp. Algae	several			
		Rope sponge	1	15	0	0
		orange anemone	1	5	0	0
12	ERWT	*Porites porites*	1	20	0	0
		Porites porites	1	25	0	0
		Acropora cervicornis	1	15	**	**
		Orange encrusting sponge	several			
		Schizothrix sp. Algae	several			

Data include number of organisms, size (cm) and percent mortality.
Data collected in July 2009.
* denotes that a colony was not photographed during the current sampling,
** denotes colony was missing. ER= EcoReef, LR = Live Rock, QR = Quarried Rock, WT = With transplants, NT = No transplants.

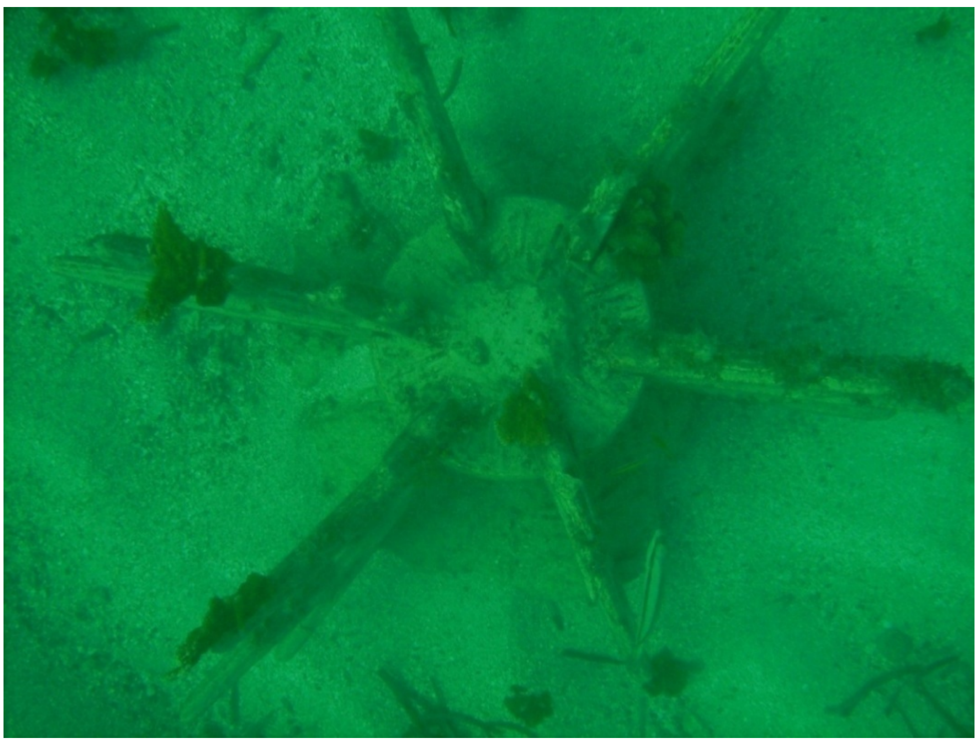


Figure 3. ERWT8 (EcoReef with transplant) in December 2007

Figure 4. ERWT8 in April 2008 with several colonies of *Acropora palmata* and *Porites porites*

Figure 5. ERWT8 in July 2008

Figure 6. ERWT8 October 2008, notice missing corals – *P.porites* (left arm) and *A. palmata* (center)

Figure 7. ERWT8 in January 2009

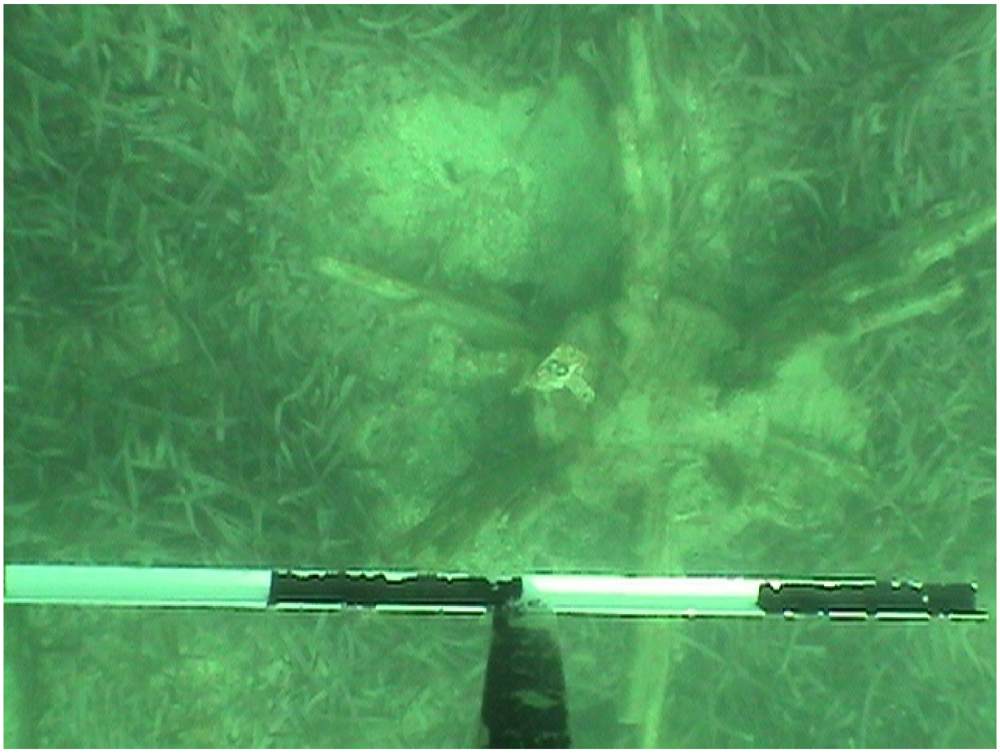


Figure 8. ERWT8 in April 2009, No *Acropora* colonies remain on arms

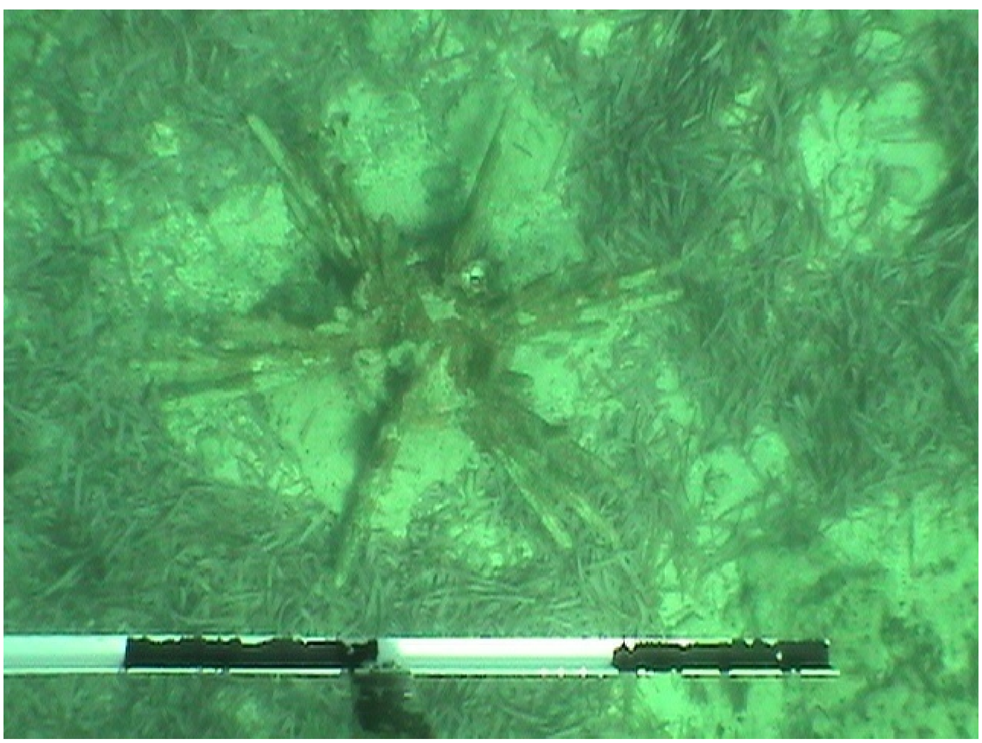


Figure 9. ERWT8 in July 2009

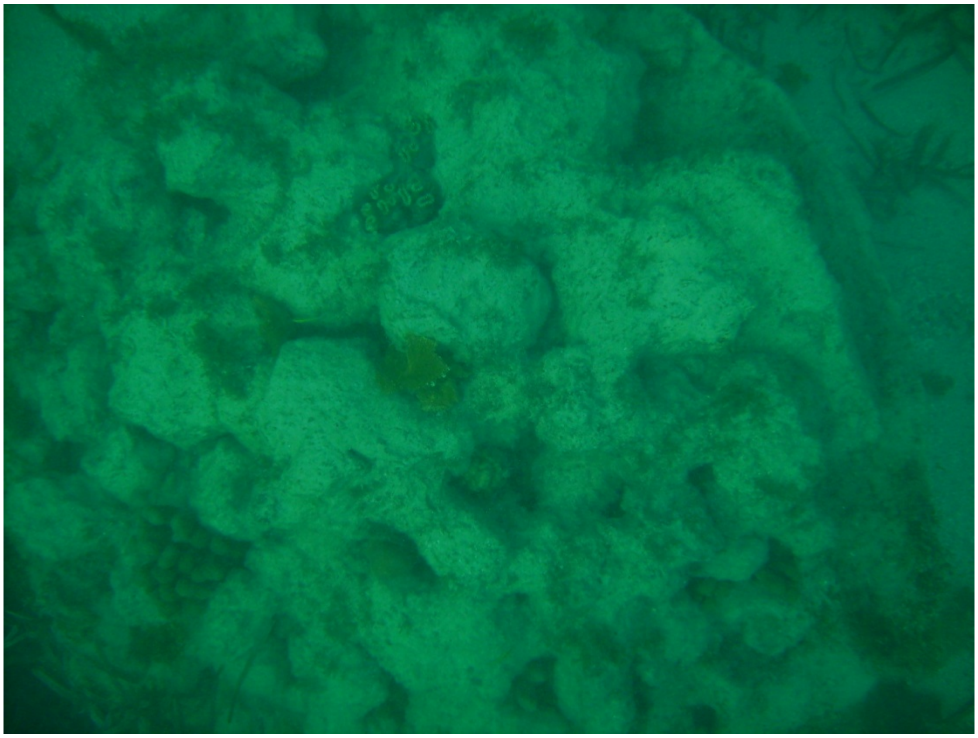


Figure 10. QRWT6 (quarried rock with transplant) in December 2007

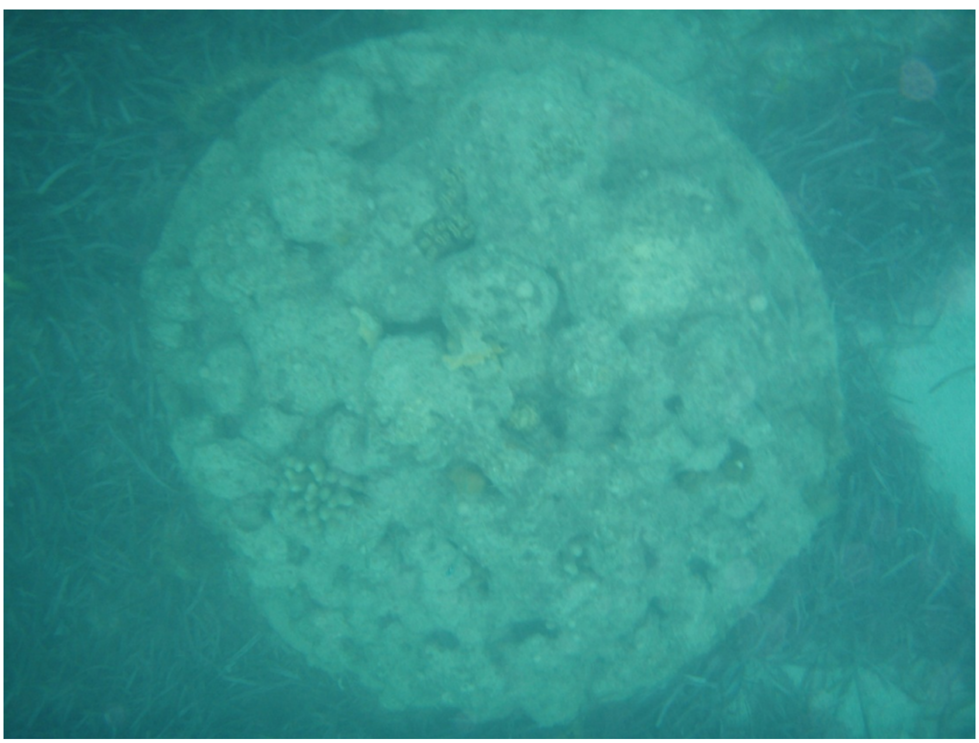


Figure 11. QRWT6 in April 2008

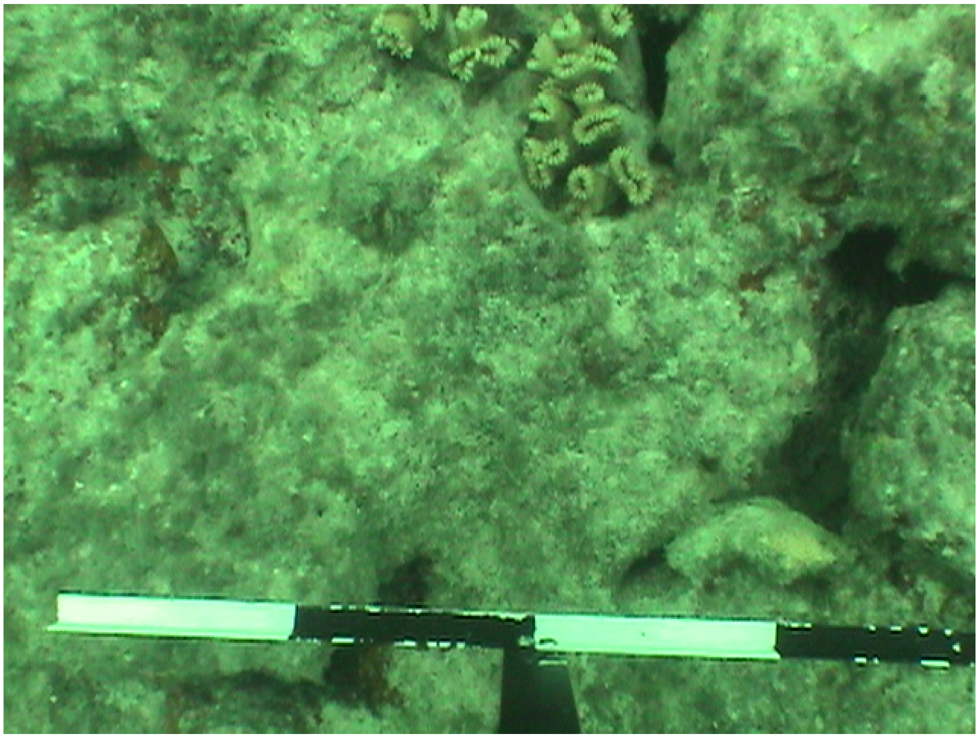


Figure 12. QRWT6 in July 2008, close up of *Eusmilia fastigiata* coral transplant.

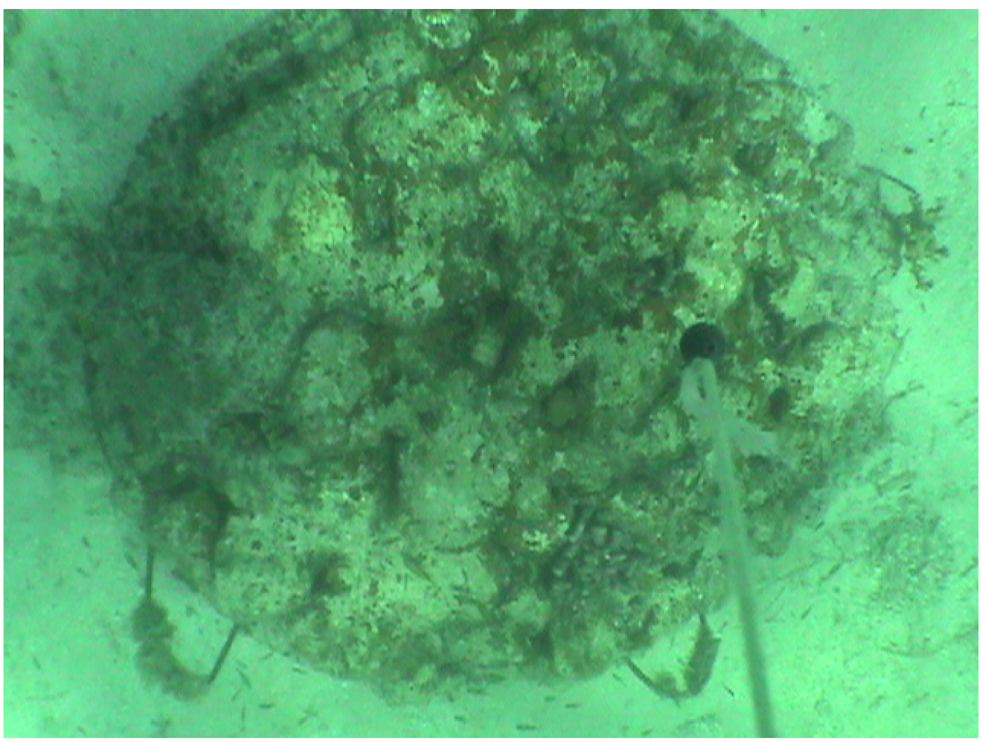


Figure 13. QRWT6 in October 2008

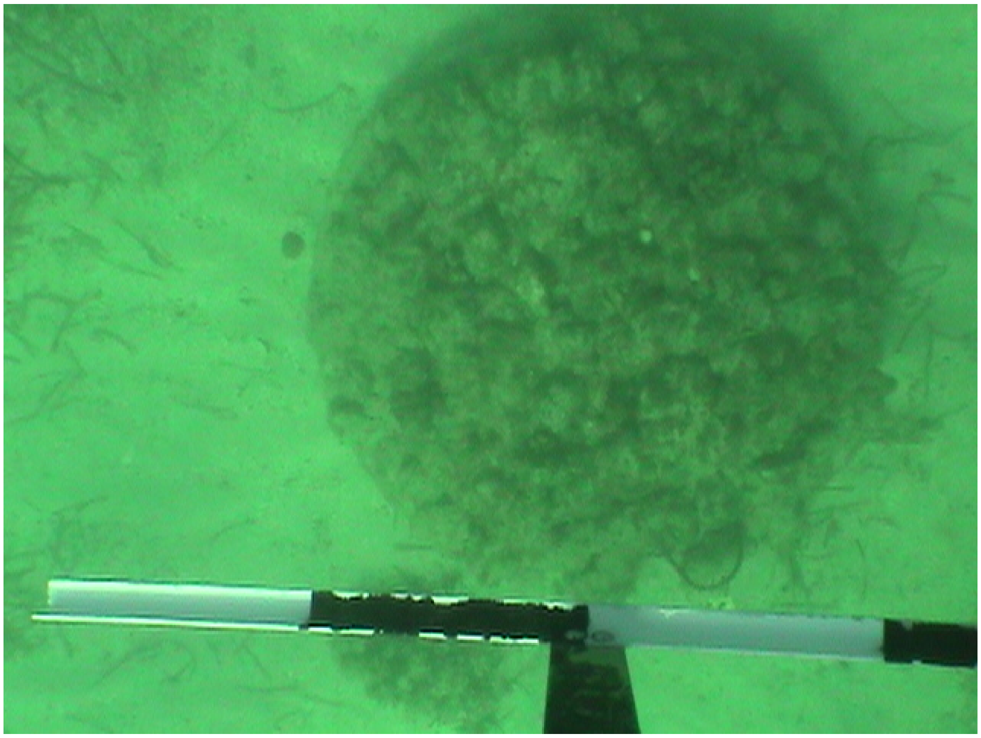


Figure 14. QRWT6 in January 2009

Figure 15. QRWT6 in April 2009

Figure 16. QRWT6 in July 2009

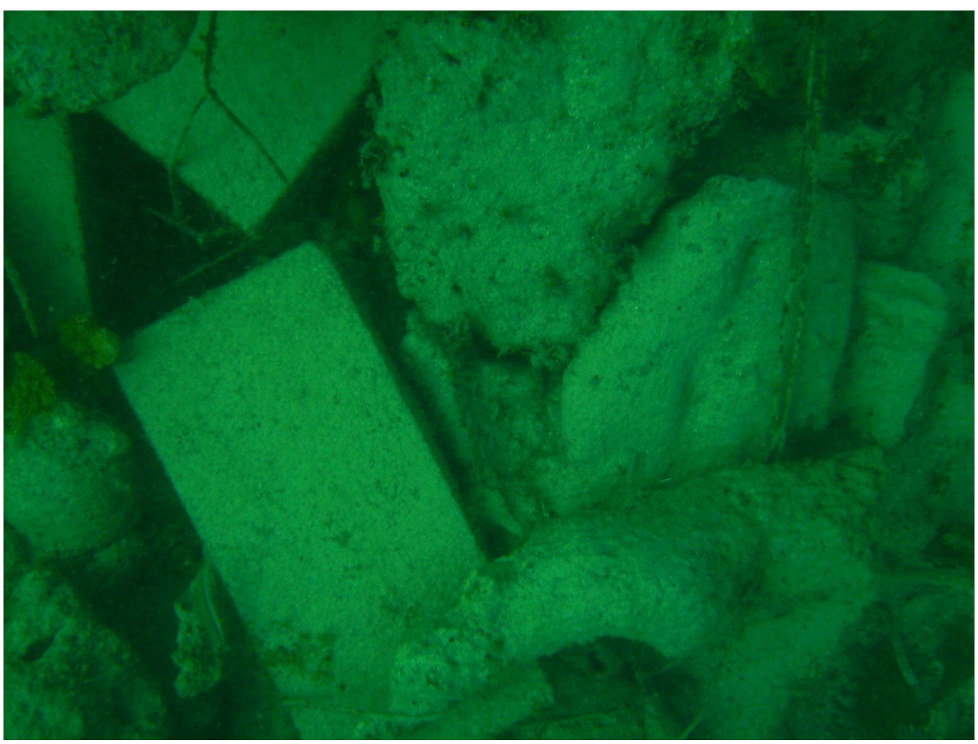


Figure 17. LRWT9 in December 2007

Figure 18. LRWT9 in April 2008

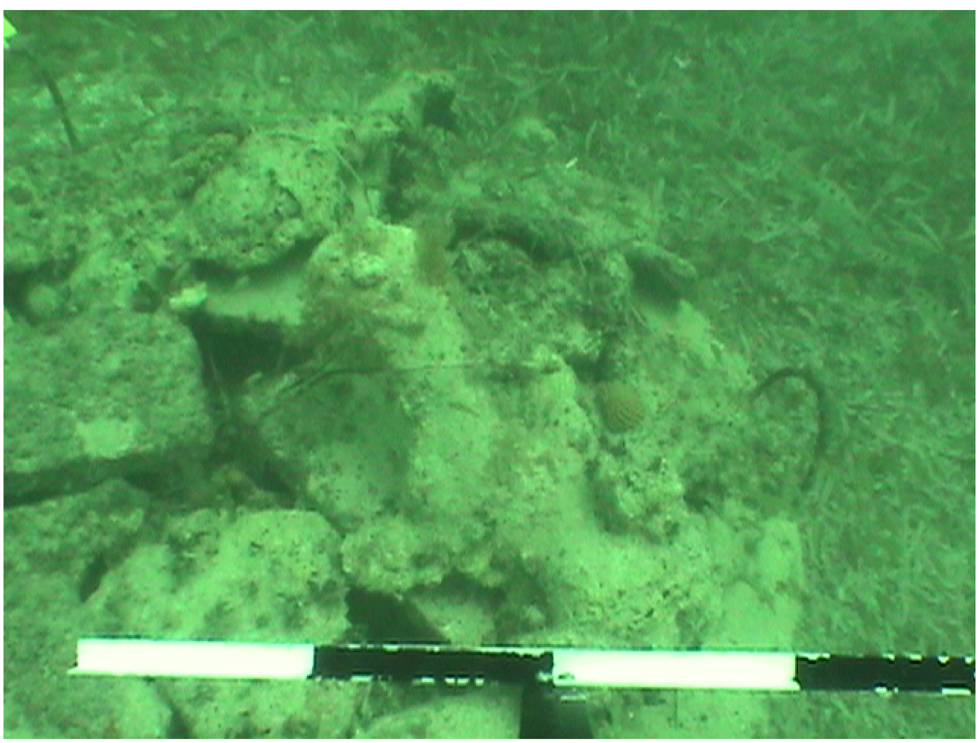


Figure 19. LRWT9 in July 2008

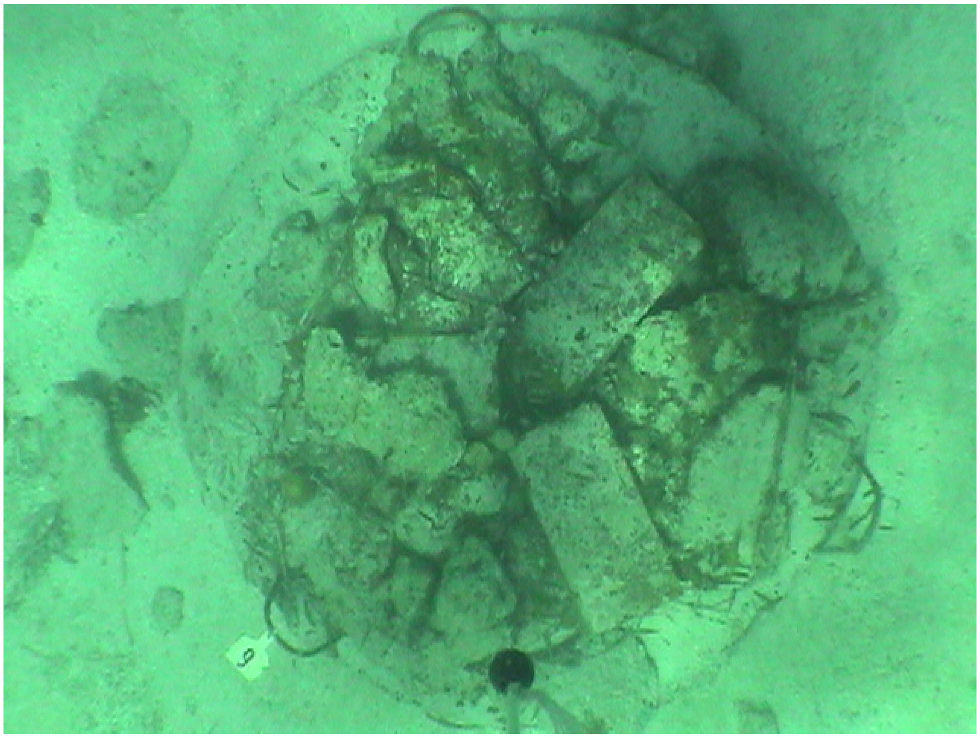


Figure 20. LRWT9 in October 2008

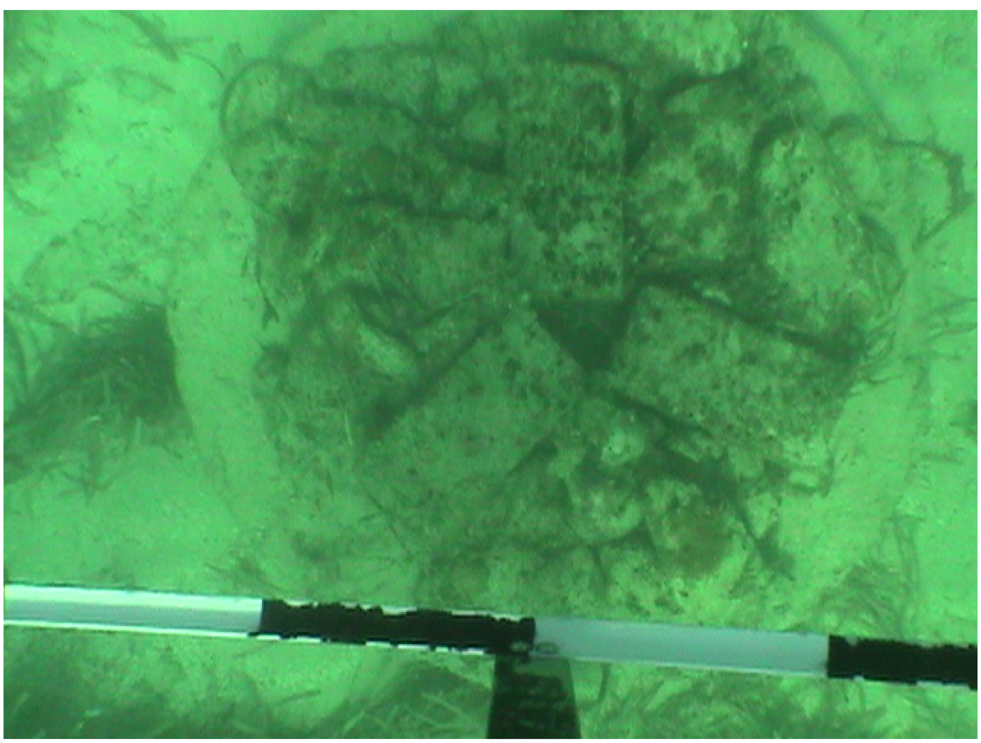


Figure 21. LRWT9 in January 2009

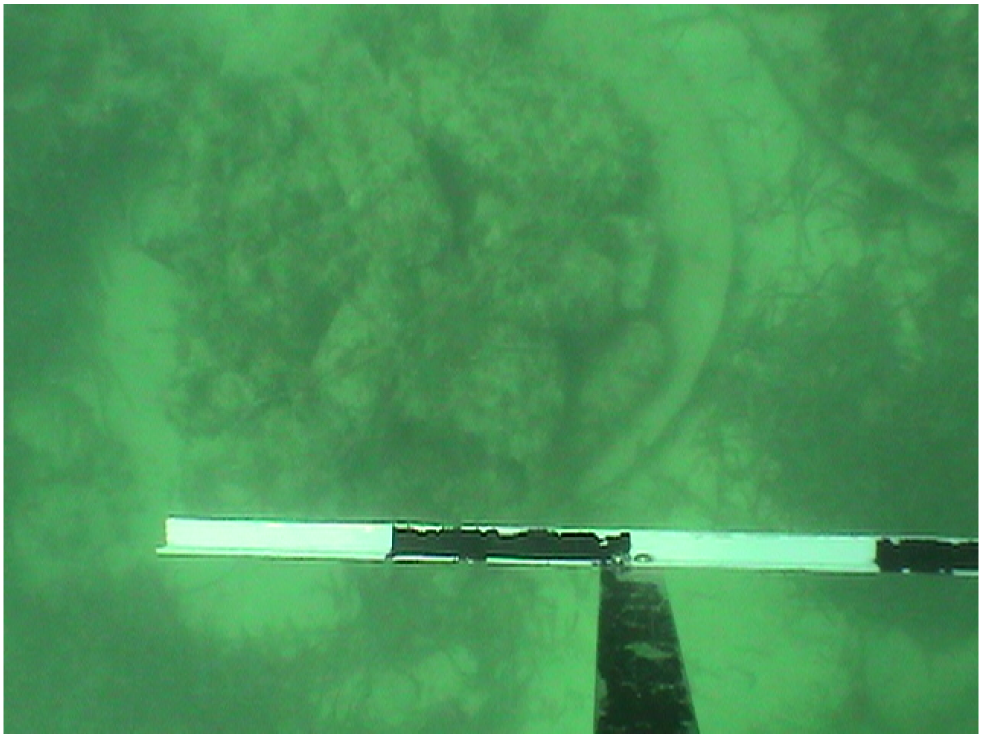


Figure 22. LRWT9 in April 2009

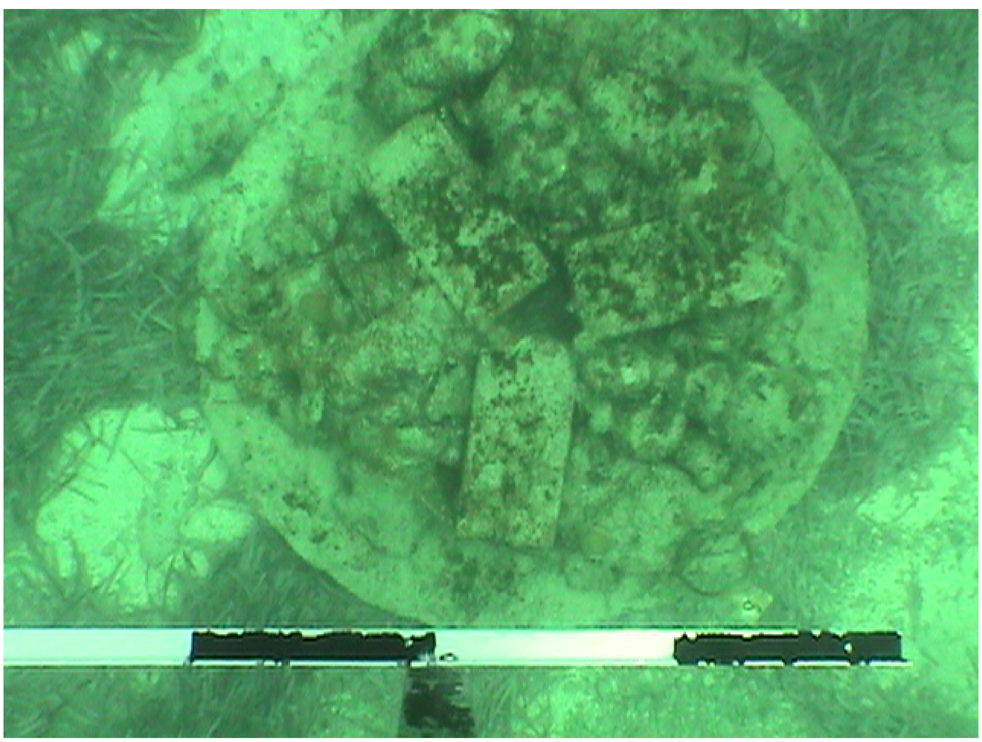


Figure 23. LRWT9 in July 2009

3.1 Fish Population

Fish were documented using the artificial reefs as habitat throughout the monitoring events. Fish species included mostly herbivorous juvenile reef fish (Table 3). Green morays were documented inhabiting the LR artificial reefs. Artificial reefs with holes and overhangs may be desirable for providing habitat for cryptic species, such as morays. A rock hind was also documented on consecutive monitoring events below ERNT1. Fish data for each monitoring event are attached as Appendix D.

ERs had lower abundance and fewer fish species surrounding them during quarterly surveys. The ERs were much smaller than the other artificial reef structures, which may account for the lower abundance and diversity of fish supported by these structures. In contrast, there was no measureable difference between fish populations surrounding LR and QR artificial reefs, with or without coral transplants. A cumulative species list, which includes all fish species documented at artificial reefs between 2007 and 2009, is provided below in Table 3.

Table 3. Fish species documented between 2007 and 2009 at the artificial reef site, Blue Beach, Vieques.

Common Name	Scientific Name
Bluehead wrasse (j, a)	*Thalassoma bifasciatum*
Princess Parrotfish (j,a)	*Scarus taeniopterus*
Striped Parrotfish (j)	*Scarus croicensis*
Stoplight Parrotfish (j,a)	*Scarus viride*
Cocoa damselfish	*Stegastes variabilis*
Beaugregory	*Stegastes leucostictus*
Threespot damselfish	*Stegastes planifrons*
Squirrel fish	*Holocentrus adscensionis*
Sharknose goby	*Gobiosoma evelynae*
Blue tang (j,a)	*Acanthurus coeruleus*
Rock hind	*Epinephelus adscensionis*
Striped grunt (j)	*Haemulon striatum*
Bluestripe grunt (j)	*Haemulon sciurus*
French grunt (j)	*Haemulon flavolineatum*
Yellowtail snapper	*Ocyurus chrysurus*
Green moray	*Gymnothorax funebris*
Slippery Dick (j, a)	*Halichoeres birittas*
Filefish	*Monancanthus sp.*
Hogfish (j)	*Lachnolaimus maximus*
Foureye butterfly fish	*Chaetodon capistratus*
Spotted goatfish	*Pseudupeneus maculatus*
Long spined squirrelfish	*Holocentrus rufus*

4.0 DISCUSSION

Tropical storms and hurricanes affected the southern shore of Vieques, Puerto Rico in the summer of 2008. Locals noted that tropical storm Hanna produced large swells that stranded vessels on the land along the southern shore (Personal communication, Vieques Conservation and Histroical Trust, October 2008). During the monitoring event of October 2008, transplanted *Acropora palmata* on the ERs which had been present in July 2008 were missing. Partial mortality of *Acropora palmata* and *Agaricia agaricites* colonies on concrete modules were also documented. No other coral species revealed partial mortality, bleaching, or disease and no diseases were found on any of the remaining acroporids. No new coral recruits were visible on any of the three types of artificial reef modules. Since coral recruits may be invisible to the naked eye for as long as the first two years, additional monitoring may reveal coral recruitment.

Monitoring events in the spring and summer (April and July) documented mats of dead seagrasses, from the adjacent seagrass meadow, at the artificial reef site. Dead seagrasses accumulated in the area, surrounding all modules and burying the lower portions of the artificial reefs. The effect of the dead seagrass was not measured; however, the presence and persistence of this detrital material is not a feature of coral reef habitat. To optimize the potential for coral recruitment and artificial reef success, site selection should be considered carefully.

Module performance was compared across four success criteria categories (Table 4). While no new coral recruits were documented during the monitoring period on any module type, all artificial reefs were colonized similarly by algae during the monitoring period, regardless of type. Coral transplants survived similarly on LR and QR reef types, while transplants on ERs that remained attached (up to January 2009) survived. However, all acroporid transplants attached to ERs were missing as of April 2009. This may be due to a combination of factors including the method of attachment (tie wrap) and the design of the ER module, which has a large amount of surface area exposed to wave action. Acroporids on LR and QR modules experienced partial mortality during the monitoring period. Fish populations typical of back reef habitats (juvenile herbivorous and omnivorous fish) utilized all artificial reef types. Higher abundance and diversity characterized fish populations around the LR and QR module types, and no measureable differences were noted between LR and QR module fish populations, while fewer fish representative of fewer groups were found on ERs. It should be noted that ERs were placed individually for this study. Due to the limited scope of the project only four of each type of module was deployed. With respect to ERs, these modules were designed to be deployed as interlinked groups, creating a “reef” structure. Since the project did not support this level of effort, the efficacy of ERs as reefs in these environments is unknownAlthough this is not likely a factor in their success as a coral recruitment tool, a larger structure would benefit larger and more diverse fish populations.

Table 4. Comparison of module performance across four success criteria.

Success criteria	ER	LR	QR
Pioneer colonizers	Yes	Yes	Yes
Coral recruitment	None	None	None
Transplant survival	Few	More	More
Fish habitat	Few	More	More

5.0 RECOMMENDATIONS

- Artificial reefs should be sited in areas suitable as coral reef habitat and at multiple locations to maximize the potential for the successful recruitment of corals.
- ERs should be used as they were designed, with multiple units joined together to create a larger reef structure. This would provide desired habitat for reef fish species.
- Artificial reefs placed in areas where coral recruitment is low, as is the case throughout much of the Caribbean, should include transplanted corals of opportunity in order to speed the coral recruitment of these artificial habitats.

6.0 REFERENCES

Bohnsack, J.A., and S.P. Bannerot. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Technical Report NMFS 41:1-15.

Vieques Conservation and Historical Trust. 2008. Personal Communication with Mark Martin October 2008.

APPENDIX A

Permits

APPENDIX B

Coral Data

APPENDIX C

Quarterly Monitoring Photographs
DVD

APPENDIX D

Fish Data