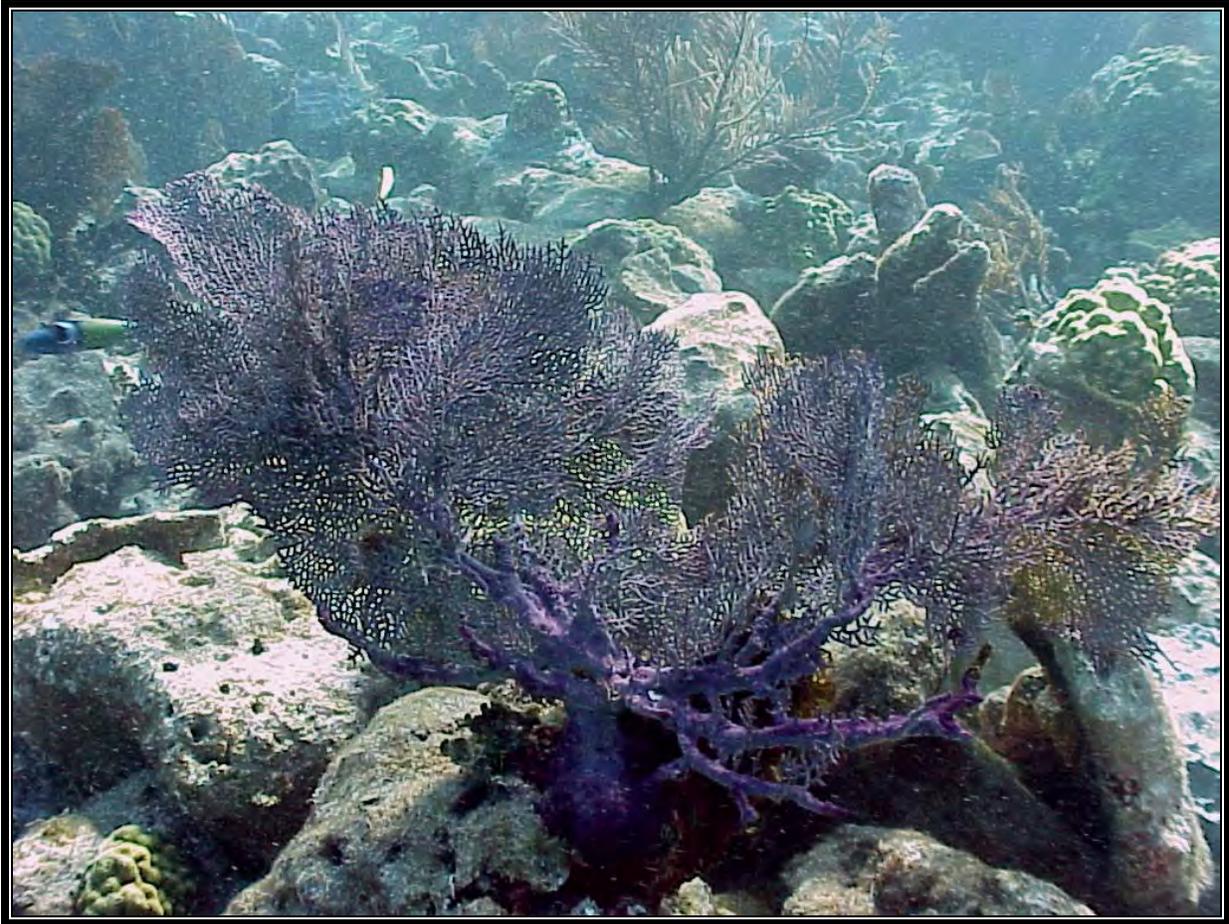


Habitat Restoration Conducted at *ADARO* Grounding Site: Florida Keys National Marine Sanctuary

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INTRODUCTION

This report presents results of habitat restoration activities conducted at the *ADARO* grounding site on Grecian Rocks Reef, within the boundaries of Florida Keys National Marine Sanctuary (FKNMS). Restoration activities were conducted 3 September 2003 through 23 February 2004. The grounding site is located approximately 5.5 nautical miles east of Largo Sound, Key Largo, Florida at 25°06.66 N latitude and 80°18.28 W longitude (**Figure 1**). The *ADARO*, a 21-m (68-ft) sport fishing vessel, was reportedly under its own power and heading in an easterly direction when it grounded in a water depth of approximately 1 m (3 ft) on the reef crest on 2 August 2003. The *ADARO* was removed from the site on the day following the grounding event.

The impacted habitat is characterized as a moderately developed outer bank reef. The shallow-water reef crest is a relatively flat platform of dead and encrusted elkhorn coral (*Acropora palmata*) (see **Image 1 Appendix**). The structural framework of the reef crest is variably reticulated due to the settlement position of the branching elkhorn coral and density of lithified calcareous rubble/sediment within the internal voids. Visually dominant epibiota associated with the impacted reef crest are the mustard-hill coral (*Porites astreoides*) (see **Image 2 Appendix**), purple sea fan (*Gorgonia ventalina*), fire coral (*Millepora* spp.), white encrusting zoanthid (*Palythoa caribaeorum*), and sea rods (Plexauridae).

There are two distinct areas of impact associated with the grounding event which include the grounding and the outbound tracks (**Figure 2**). Impact along the grounding track was the result of vessel momentum. The grounding track is characterized by three zones of impact and are designated from shoreward to seaward (i.e., west to east) as 1) the shoreward slope, 2) trenches, and 3) final resting site (**Figure 2**). Noted impact along the shoreward slope was burial of epibiota and minor disruption of unconsolidated substrate. Shoreward slope impact was caused predominantly by framework rubble ejected behind the grounding vessel as it came in contact with the shallow reef crest along the trenches (i.e., seaward of the slope). The primary impact feature along the grounding track was the trenches formed by breaking, compressing, and displacing the structural framework of the reef crest (see **Image 3 Appendix**). The depth of the trenches below ambient grade was estimated to range from 0.3 to 1 m (1 to 3 ft). Impact at the final resting site of the grounded vessel was characterized by breakage and minor compression of a relatively thin surficial substrate overlying consolidated reef bedrock. Impact along the outbound track was the result of salvage operations and removal of the vessel from the final resting site following the grounding event. Impact along the outbound track was similar to impact observed at the final resting site.

Marine Resources, Inc. (MRI) was contracted by McIntosh Marine, Inc. to conduct restoration activities at the *ADARO* grounding site that included emergency triage, aerial photography, coral reattachment, and stabilization of natural and artificial substrates. The objectives of the habitat restoration project were

- 1) to restore lost habitat topography and structure,
- 2) to salvage and reattach displaced corals,
- 3) to stabilize reef substrate along the impact track, and
- 4) to document general conditions of the grounding/restoration site.

This report presents the scope of work and results of restoration activities and includes a brief description of the impact areas, an overview for current status for each activity, a description of methodologies, and a summary listing of the reattached corals.

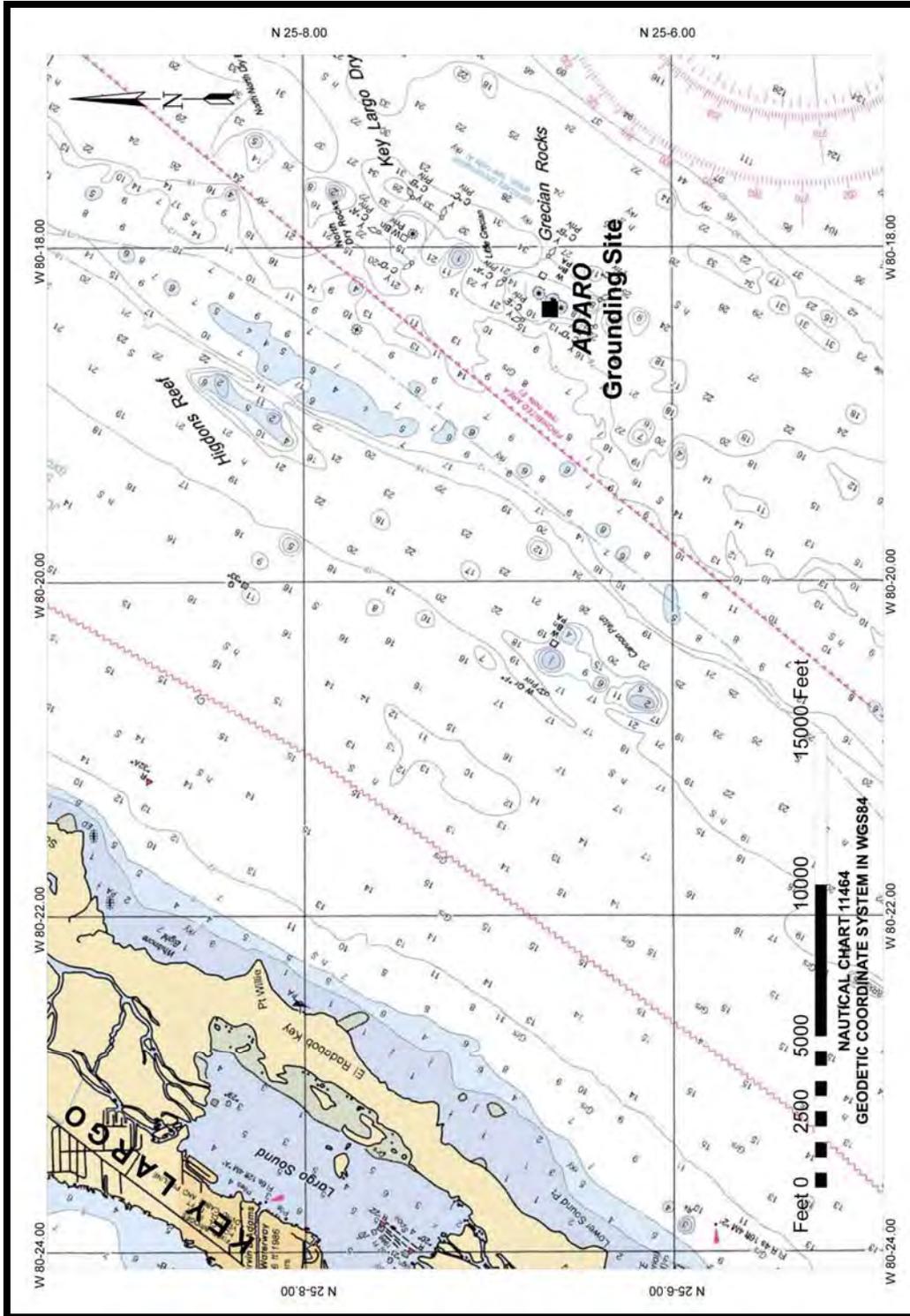


Figure 1. Approximate location of the ADARO grounding site relative to Largo Sound, Key Largo, Florida.

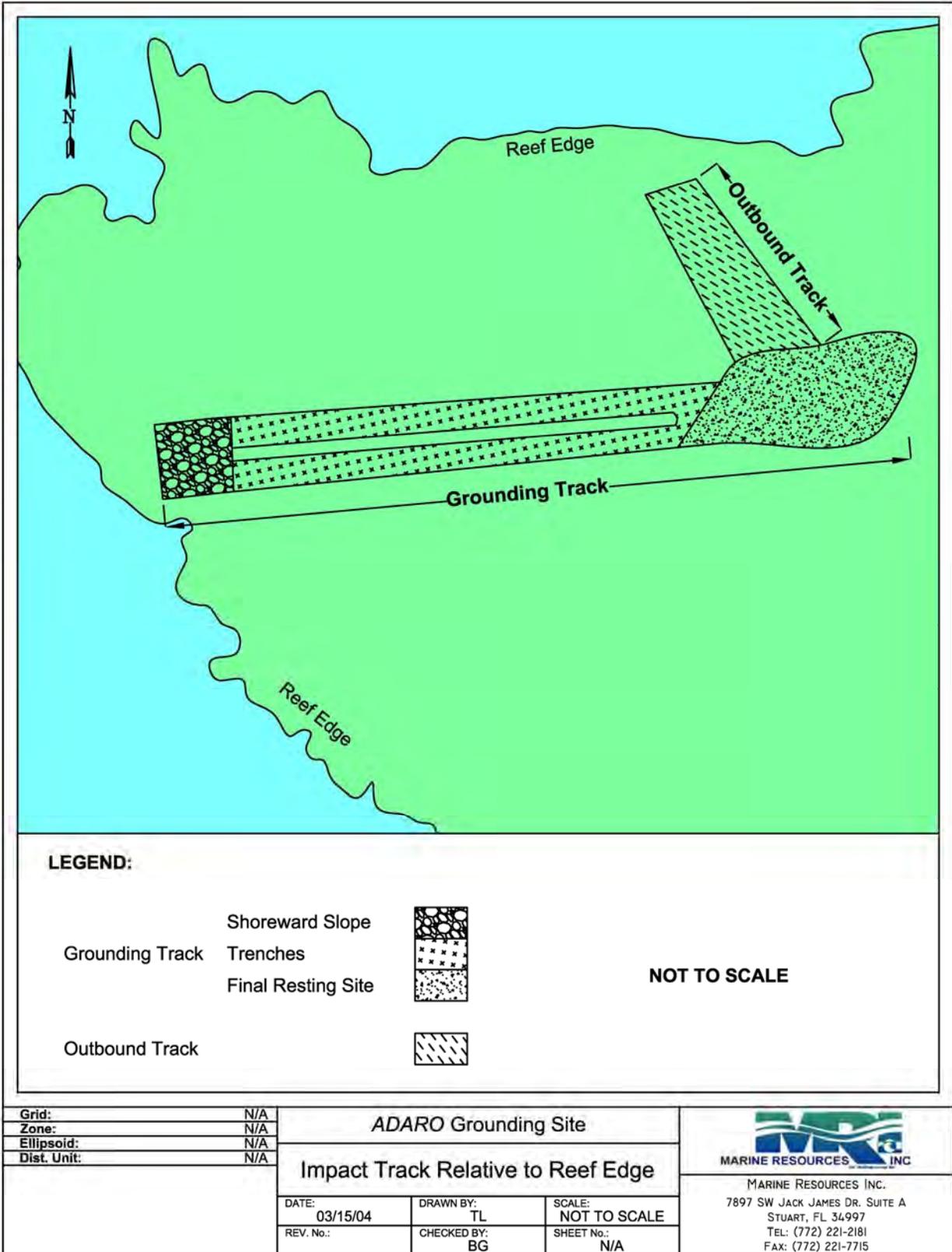


Figure 2. Areas of impact associated with the *ADARO* grounding event.

RESTORATION ACTIVITIES: CURRENT STATUS

Emergency Triage included righting, caching, and measuring of displaced corals and was conducted by MRI and FKNMS representatives during 3 – 4 September 2003. Triage efforts were applied to a total of 790 displaced corals. Mustard-hill coral (*Porites astreoides*) comprised over 80% of the cached corals. Approximately 30 coral colonies/fragments considered in very poor condition remain cached in a fiberglass holding bin and may be available for reattachment prior to subsequent monitoring.

High-Resolution Aerial Photography was conducted of the grounding site and adjacent habitat on 16 January 2004. Weather and sea conditions were excellent during aerial photography providing clear visibility of six initially designated visual targets in the images. Geo-rectification of the aerial photographs is not completed and may require additional on-site visual targets.

Coral Reattachment utilizing Portland cement was conducted for 829 hard and soft corals and “live rock” fragments. Seven-hundred and ninety-one coral colonies comprising 11 taxa and 38 “live rock” fragments (i.e., multiple coral taxa attached to reef substrate) were reattached along the grounding track, the outbound track (created during salvage operations), and along the shoreward fringe of the reef adjacent to the cached coral area. The mustard-hill coral, *Porites astreoides*, was far the most abundant taxa, accounting for 74% of all reattached corals/ “live rock” fragments.

Stabilization of Natural and Artificial Substrates was conducted utilizing over nine tons of concrete. Approximately six tons of natural reef substrate was incorporated into the restoration site and included on-site rubble compressed during the grounding event and off-site loose substrate devoid of attached corals. Approximately seven and one half tons of artificial substrate (i.e., quarried limestone boulders) was utilized to augment natural substrates in order to adequately grade the impact areas.

SCOPE OF WORK

VESSELS AND NAVIGATION

Restoration activities were conducted utilizing a 9-m (30-ft) MAKO[®] and a 7.6-m (25-ft) PARKER[®], both with sufficient deck space to accommodate SCUBA and construction equipment. On-board navigation during transit to and from the grounding site was achieved using a Garmin[®] differential global positioning system (DGPS).

Navigational positioning data associated with high-resolution aerial photography was collected utilizing a Leica[®] MX421B DGPS with the antennae mounted on a diver-positioned catamaran (**Figure 3**). The United States Coast Guard DGPS beacon in Miami, Florida was utilized to provide positioning correctional data. The catamaran mounted DGPS antenna was tethered to the receiver with a 150-ft floating antennae cable. Deployed on-bottom markers and on-site permanent features were utilized as visual targets to provide guidance for positioning the DGPS antenna. The catamaran mounted DGPS antenna was deployed and positioned over visual targets utilizing a diver. The on-board navigator recorded navigational coordinates once the DGPS was positioned directly over the visual target.

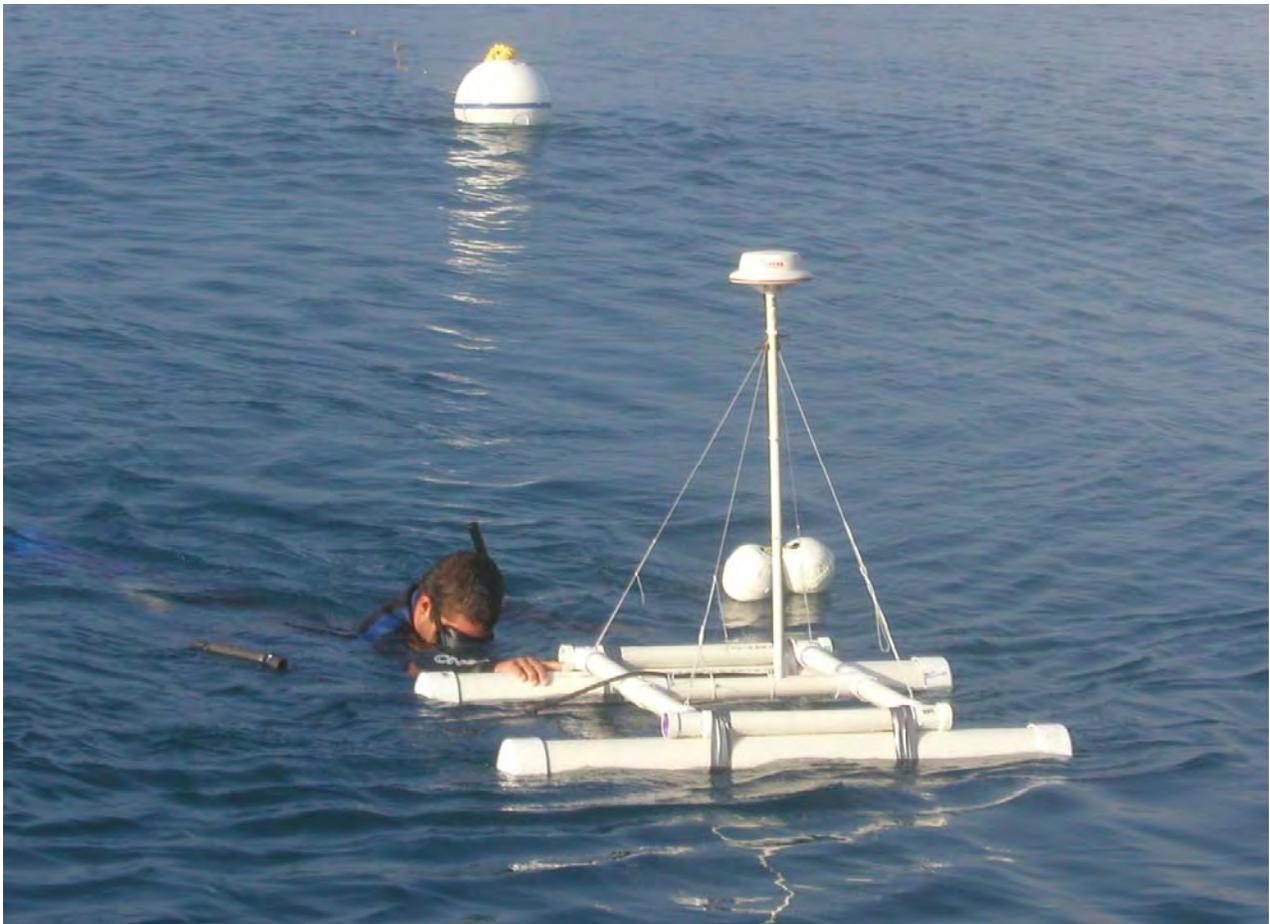


Figure 3. Catamaran mounted DGPS antenna being positioned by a diver.

EMERGENCY TRIAGE

Emergency triage efforts included repositioning, righting, caching, and measuring of displaced corals and “live rock” fragments. Displaced corals and “live rock” fragments were relocated and cached in and directly adjacent to fiberglass holding bins pending reattachment. Displaced corals and “live rock” fragments relocated and cached during emergency triage were measured to facilitate assessing the overall amount of injury associated with the grounding event. Cached corals often were comprised of substrate in association with live coral tissue. Linear measurements of the coral tissue were taken along the long-axis surface perimeter of the coral/substrate composite to account for the convex morphology of many composites.

AERIAL PHOTOGRAPHY

Aerials, Inc. located in Miami, Florida conducted high-resolution aerial photography at the *ADARO* grounding site. Photographs were taken with a Zeiss® 6” survey camera on 9” film at 1”=200’ scale. Visual targets were established within the photographic field of view to facilitate geo-rectification.

Visual targets included deployed on-bottom markers, natural permanent features of the habitat (i.e., large hard coral colonies), and permanent man-made structures (i.e., reef marker) (see **Image 4 Appendix**). Stainless steel threaded rods were permanently affixed into the substrate to anchor on-bottom markers. Measurements (i.e., distance and bearing) were collected in a south to north sequence between each of the visual targets. Navigational coordinates were collected at each of the visual targets utilizing the catamaran mounted DGPS antenna (previously described in **Vessels and Navigation**).

CORAL REATTACHMENT

Corals displaced during the grounding event were reattached at selected locations along the grounding track, the outbound track, and the shoreward reef fringe adjacent to the cached coral area. The spatial distribution of reattachment locations was similar to natural coral distribution of the habitat. The substrate and the underside of the coral colony or fragment were scraped to remove filamentous algae and other fouling organisms to provide clean surfaces to improve cement bonding. Following placement selection and preparation of reattachment surfaces, a concrete mixture of approximately 1-part Portland cement to 1-part silica sand was prepared utilizing a Gilson® 6.5 ft³ mixer. Buckets of concrete were transported by divers to coral reattachment locations. A sufficient amount of concrete was placed directly on the pre-cleaned substrate; corals to be reattached were pressed firmly into the concrete mixture and held in position until the coral was stable and secure. Reattached corals were intermittently checked during reattachment operations to ensure their stability, to address the aesthetic quality of the reattachment matrix, and to dissipate cement residue which may have settled on adjacent biota.

STABILIZATION OF NATURAL AND ARTIFICIAL SUBSTRATES

Both natural and artificial substrates were utilized during restoration. Natural substrates included on-site reef framework fragmented and compressed during the grounding event and off-site

pieces of dead elkhorn coral that were loose and devoid of attached corals. All off-site substrate was collected in the predominantly sand bottom transition area between the shoreward (i.e., west) edge of the reef formation and established beds of turtle grass (*Thalassia testudinum*). Artificial substrates included concrete (i.e., Portland cement/silica sand) and quarried limestone (i.e., calcium carbonate) boulders. Limestone boulders, acquired at White Rock Quarries in Miami, Florida, had an estimated average diameter of 0.3 m (1 ft) and a correlative weight that was safely maneuvered by a single diver. Both natural and artificial substrates were stabilized during restoration utilizing cement in the same manner as previously described for coral reattachment.

Some larger pieces of substrate, particularly at the final resting site and outbound track were not relocated prior to stabilization but attached in close proximity to their location following the grounding event. These larger substrate pieces were prepared and reattached in a similar manner as the corals but with slight modifications. Substrate pieces too large to move without aid of lift bags were stabilized to adjacent substrate at existing contact points. Contact points were prepared by cleaning and roughening the abutting surfaces utilizing a rock hammer. If appropriate, masonry nails were inserted into both surfaces at the contact points to improve cement bonding. Approximately 1 inch of the 3-inch masonry nail was exposed to increase the bonding area and provide structural reinforcement to the bonding matrix. The number of masonry nails used was dependent on the size of the substrate pieces and area of contact point(s).

RESULTS

The goals of restoration for the impact area of the *ADARO* grounding site were to save displaced and fragmented live coral and repair sections of reef framework fractured and destabilized during the grounding event. Significant amounts of live coral tissue were saved, time for recovery was reduced, and much of the three-dimensional habitat structure was restored by performing described restoration activities. Restoration was conducted in a manner that created substrates and topography that closely resembled existing habitat and minimized visual degradation.

EMERGENCY TRIAGE

Emergency triage for displaced coral colonies and “live rock” fragments was conducted by MRI and FKNMS representatives during 3–4 September 2003. A total of approximately 790 displaced hard and soft corals were located, righted, cached, and measured during emergency triage. The 790 corals were comprised of 10 taxa and composite “live rock”. Mustard-hill coral (*P. astreoides*) and sea fans (*Gorgonia* spp.) comprised over 90% of the cached corals. Corals and “live rock” fragments were relocated and cached within and around six fiberglass holding bins positioned along the shoreward edge of the reef crest (see **Image 5 Appendix**). Approximately 30 coral colonies/fragments considered in poor condition remain cached in a fiberglass holding bin and may be available for reattachment prior to subsequent monitoring

AERIAL PHOTOGRAPHY

A representative aerial photograph of the grounding site and adjacent habitat showing the impact and cached coral areas is presented as **Figure 3**. Four on-bottom markers were deployed as visual targets (see **Figure 3**) and in conjunction with on-site permanent features (i.e., natural features of the habitat and man-made structures) should facilitate geo-rectification of aerial photographs. Navigational coordinates for each of the visual targets are listed in **Table 1**. Aerial photography was conducted 16 January 2004 during the early stages of primary restoration. Aerial photography provides visual data concerning the general conditions of the grounding/restoration site and adjacent habitat and could provide reference for detecting potential large-scale gross changes in the structural and biological condition of the restored habitat.

Table 1. Navigational coordinates for the visual targets.

Visual Targets/Coordinates	Geographic, WGS 84 (dd mn sec)	
	Latitude N	Longitude W
On-Bottom Markers:		
Southernmost	25 06 38.868	80 18 17.268
Southwest (adjacent to Grounding Track)	25 06 39.810	80 18 17.820
Northwest (adjacent to Cached Coral Area)	25 06 40.026	80 18 17.640
Northernmost	25 06 40.488	80 18 17.154
On-Site Permanent Features:		
Large <i>Montastrea</i> sp. Colony	25 06 41.574	80 18 17.994
Reef Marker	25 06 42.750	80 18 16.902

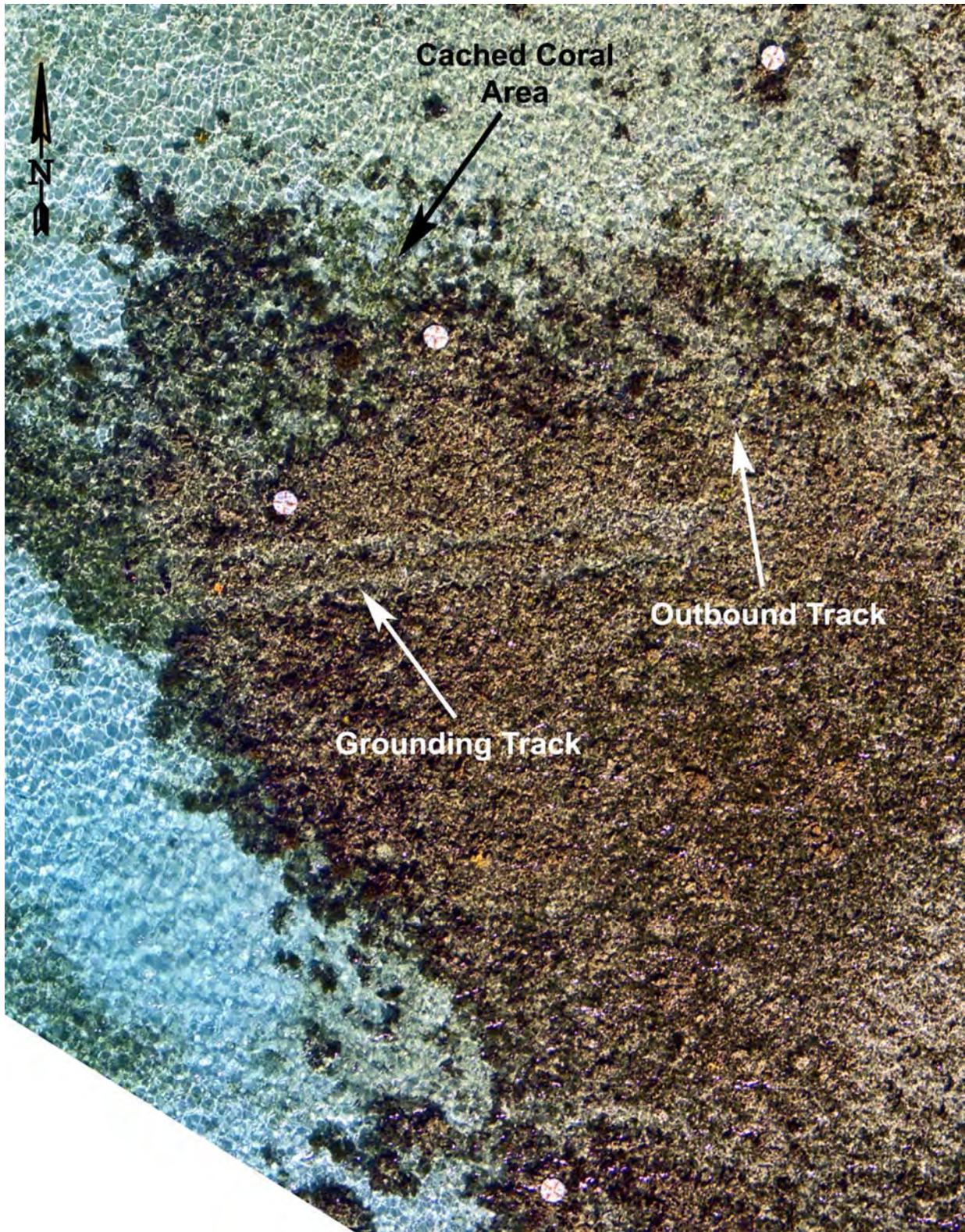


Figure 3. Representative aerial photograph of the grounding site and adjacent habitat showing the impact and cached coral areas and on-bottom markers utilized as visual targets.

CORAL REATTACHMENT

Table 2 lists taxa (including “live rock”) and number of each taxa reattached at the *ADARO* grounding site. A total of 829 corals and “live rock” fragments, comprising 11 taxa, were reattached at four general reattachment locations. The four reattachment locations include the trenches and shoreward slope along the grounding track (see **Figure 2**), the conjoint final resting site and outbound track (see **Figure 2**), and the shoreward fringe of the reef adjacent to the cached coral area (see **Figure 3**). Over 50% of the reattached corals were utilized to biologically and structurally dress the trenches of the grounding track. A disproportionately higher allocation (based on estimated areas) of reattached corals were required for the trenches which were the most prominent impact feature of the grounding site and had a complex three-dimensional restored structure unlike the other reattachment locations.

Table 2. Taxa and number of each taxa reattached at the *ADARO* grounding site. Size categories (i.e., maximum linear dimension) for the numerically dominant reattached coral *Porites astreoides* are provided.

Reattachment Location/ Taxa	Trenches	Shoreward Slope	Final Resting Site/ Outbound Track	Cache Area	Total
<i>Agaricia</i> spp.	1	x	x	x	1
<i>Diploria strigosa</i>	x	x	1	x	1
<i>Gorgonia ventalina</i>	41	22	35	x	98
<i>Millepora</i> spp.	8	x	2	x	10
<i>Montastrea annularis</i>	4	x	x	x	4
<i>Palythoa caribaeorum</i>	1	x	x	x	1
Plexauridae	16	9	6	x	31
<i>Porites astreoides</i> :<10 cm	97	6	73	52	228
10 to 15 cm	127	6	66	6	205
16 to 30 cm	100	x	66	x	166
>30 cm	18	x	x	x	18
<i>Porites porites</i>	3	x	7	1	11
<i>Pseudopterogorgia</i> spp.	4	2	x	x	6
<i>Siderastrea siderea</i>	7	1	3	x	11
Live Rock	28	5	5	x	38
Total	455	51	264	59	829

The mustard-hill coral, *Porites astreoides*, was by far the most abundant taxa, accounting for 74% of all reattached corals (see **Image 6 Appendix**). Reattached corals included displaced corals cached during emergency triage and located during restoration operations (i.e., following emergency triage). Corals cached during emergency triage accounted for the vast majority of reattached corals. Approximately 100 corals suitable for reattachment were found during restoration operations from areas within and in close proximity to the grounding site.

A primary goal of restoration for the grounding site was to salvage displaced corals. Coral rescue is considered a priority since these biotal components are the most visible and slowest growing of the impacted biological community. Reattachment of various biota was the final

aesthetic dressing of the restoration project and will significantly minimize the recovery time of the impacted areas (see **Image 7 Appendix**). Another factor favoring a timely recovery (i.e., biological recolonization) is the presence of localized healthy biological community as potential parental stock to facilitate expeditious biological conditioning for subsequent successional phases. Complete recovery to pre-grounding conditions will ultimately depend on successful recruitment, survival, and biological development to withstand natural perturbations facilitating re-establishment of pre-grounding trophic relationships.

STABILIZATION OF NATURAL AND ARTIFICIAL SUBSTRATES

Natural substrates and quarried limestone boulders in conjunction with concrete were utilized to stabilize and to elevate the grade of the *ADARO* grounding site. Approximately six tons of natural reef substrate was incorporated into the restoration site and included on-site rubble compressed during the grounding event and off-site loose substrate devoid of attached corals. Natural reef substrate was used as the primary matrix for reconstructing and aesthetically dressing the impact areas (see **Image 8 Appendix**). The natural substrate was necessary to recreate voids and crevasses characteristic of pre-impact reticulated substrate structure. Natural substrate in conjunction with reattached corals was essential for visually masking the artificial substrates utilized during restoration (see **Image 9 Appendix**).

Approximately seven and one half tons of quarried limestone boulders were utilized to augment natural substrates in order to adequately grade the impact areas. The majority of the limestone boulders were deployed and cemented as a single contiguous layer along the floor of the trenches (see **Image 10 Appendix**). The secured limestone boulders added approximately 0.3 m (1 ft) of vertical relief and were utilized as the base for stabilizing natural substrates and reattaching corals within the trenches. Limestone boulders were also deployed and cemented at topographic depression at impacted areas other than the trenches (see **Image11 Appendix**). These topographic depressions were generally characterized by accumulations of compressed and highly fragmented substrate rubble which required adequate cement to bond the rubble and overlying limestone boulder to abate substrate degradation due to erosion.

Restoration activities concerned with coral reattachment and substrate stabilization required approximately 9 tons (18,000 lb) of concrete (1 part cement: 1 part sand). The majority of concrete, approximately two-thirds, was required to stabilize the estimated 13.5 tons of substrate utilized during restoration (see **Image 12 Appendix**).

APPENDIX
VIDEO IMAGES



Image 1. The reef crest at the *ADARO* grounding site is a relatively flat platform of dead and encrusted elkhorn coral (*Acropora palmata*) with a veneer of attached biota.



Image 2. Visually dominant epibiota associated with the impacted reef crest include the mustard-hill coral (*Porites astreoides*) shown in foreground.



Image 3. Trenches were the primary impact feature of the *ADARO* grounding site.



Image 4. Reef marker utilized as a visual target to geo-rectify aerial photographs.



Image 5. Corals and “live rock” fragments were relocated and cached within and around fiberglass holding bins.



Image 6. Colony of mustard-hill coral (*Porites astreoides*) reattached along a trench.



Image 7. Corals and “live rock” fragments used to aesthetically dress impact areas.



Image 8. Natural reef substrate used to reconstruct and dress the impact areas.



Image 9. Natural substrate in conjunction with reattached corals used to visually mask the quarried limestone boulders.



Image 10. Limestone boulders deployed and cemented along the floor of a trench.



Image 11. Limestone boulders deployed and cemented at a topographic depression along the final resting site.

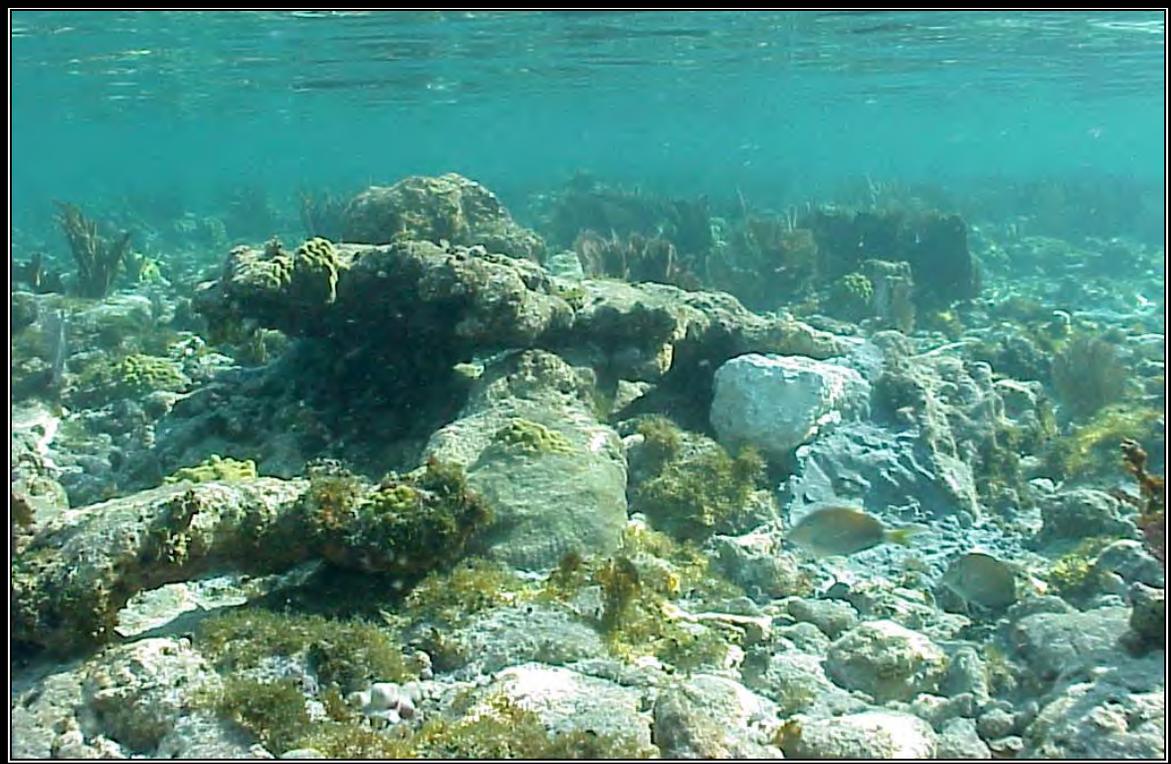


Image 12. Approximately 9 tons of concrete were utilized during habitat restoration.