Project No. 106-3817

May 8, 2009

Mr. Mark Curry, Principal
Industrial Economics, Inc.
2067 Massachusetts Avenue
Henderson Carriage Building, 4th Floor
Cambridge, MA 02140

SUBJECT: ***T/V Margara*** **Grounding Incident Site Restoration Alternatives for Biological Recovery**

Dear Mr. Curry:

As requested by you and staff of the National Oceanic and Atmospheric Administration (NOAA), following are my opinions regarding the potential for natural recovery and biological restoration at the *T/V Margara* grounding site. My opinions are based on observations that I made during a site visit with NOAA personnel in January 2009, combined with personal knowledge and experience with benthic marine communities, including corals; and the recovery of marine habitats at other vessel grounding sites in Florida and Puerto Rico. Mr. Charles Callaway P.E. has also been retained to assist NOAA in this effort. His selection as a team member is based on the government's recognition of his significant experience in the field of reef restoration design. Mr. Callaway and I have collaborated on the development of our respective project deliverables and our recommendations while prepared separately, support our determination that further site restoration is needed. It is my understanding that Mr. Callaway will present his findings and design considerations to the NOAA restoration team in the near future.

Introduction

Physical damage sustained by a reef environment from a ship grounding event commonly consists of scarring, substrate and biota displacement/fragmentation, fracturing, and pulverization of reef components. Restoration is defined as "*the return of an ecosystem to a close approximation of its condition prior to disturbance*" (Precht 2006). Emergency restoration efforts conducted at the *T/V Margara* site were an attempt to stabilize discrete segments of the reef including key reef species, and prevent further deterioration of the reef community. However, additional restoration efforts identified prior to, and during, the January 2009 survey focused on the need to address the two remaining areas of concern:

1) the significant areas of unconsolidated rubble; and
2) the loss of structural complexity.

While emergency restoration efforts have experienced varying levels of success, they only addressed a small portion of the overall restoration needed at the site. Emergency restoration efforts at the site include numerous cement pours with imbedded substrate and benthos (hard and soft corals) incorporated into the individual installations or small modules. Based on information provided by NOAA; these installations are comprised of varying lengths of rebar driven into the generally unconsolidated substrate as an anchoring method with dislodged framework and corals attached using a cement mixture. While the installations seem to be stable, there were indications that rubble has been removed from under the modules by currents or wave action, in effect, suspending the installation above the reef structure. I have a concern that further scour and collapse of the individual modules could result in mortality of scleractinian corals and other benthic organisms attached to the installations.

Currently, several areas at the grounding site are characterized by rubble, primarily relic *Acropora cervicornis* fragments that were exposed when the reef framework was compromised during the incident. The primary concern in these areas as expressed by NOAA personnel, and observed during the January 2009 reconnaissance investigation, is the mobile nature of the rubble, lack of rugosity, and low survival rates of recruiting biota observed since the incident. Mapping by NOAA personnel indicates that several discrete rubble dominated areas comprise approximately 2600 square meters of the overall injury site. Based on previous experience at similar sites; without stabilization of the rubble, natural biological recovery of the reef will not occur or will be significantly slower. Considering the nature and extent of the injury sites, additional erosion / scour of the sites is possible, further limiting natural recovery. Experience at the *R/V Columbus Iselin* Grounding Site at Looe Key in the Florida Keys National Marine Sanctuary clearly demonstrates the need for structural stabilization of the reef after an incident.

In 1994, the *R/V Columbus Iselin* ran aground and injured four spur features at Looe Key with substantial mortality of benthic fauna and displacement of mobile fauna. Damage at the site was calculated during a 1997 survey and determined to affect approximately 3,750 square feet of reef area with a volumetric displacement of approximately 7,500 cubic feet of material from the reef structure (CPE 2000). During the 1997 field investigations, we observed virtually no benthic invertebrate recovery within the areas of severe damage, assumed to be due to the lack of stable substrate to support recolonization. In 1998, after the passage of Hurricane Georges, the Looe Key site was resurveyed to determine the nature and extent of additional impact resulting from storm generated waves. The effect of the hurricane was to scour and excavate additional reef materials from within the damage site and further destabilize the structure. It was determined that Hurricane Georges resulted in a significant increase in the surface area of the damage combined with a doubling of the pre-storm volumetric loss of reef material by an additional 7,500 cubic feet. Considering that the *R/V Columbus Iselin* site has similar characteristics to the *T/V Margara* site, stabilization of the reef structure is critical to site restoration. In my opinion, significant benthic community recovery is not likely to occur within the rubble dominated areas of the impact site without human intervention and site stabilization.

Reconnaissance Investigation

From January 12 through January 15, 2009, I participated in a field investigation of the *T/V Margara* grounding site with representatives of the NOAA restoration team. The goal of this effort was to identify primary restoration alternatives and to observe discrete segments of the injury site where loss of rugosity, compromised structural stability, and highly mobile rubble are affecting benthic recruitment. Specifically areas where loose rubble, low rugosity, and low recruitment exist were targeted for further evaluation during the January 2009 reconnaissance investigations. Video and still photography was also collected at select sites. Field notes from these investigations have been included as an attachment at the end of this document.

Dives at the site included both affected and unaffected reef sites that allowed the researchers an opportunity to comparatively evaluate the issues of stability and benthic community composition. Naturally occurring rubble (predominantly relic *Acropora* fragments) was present in low lying areas of the unaffected reef structure. A limited natural occurrence of rubble has functional value in providing foraging and refuge for smaller species, and may serve as a transitional environment that contributes to the biological community diversity as a whole. The grounding incident converted large expanses of formerly stable reef structure to rubble dominated features with a significant loss of rugosity.

Rubble thickness, as measured by driving rebar to refusal, is highly variable throughout the sites. The quantity of available rubble that could be transported offsite by natural forces (waves & currents) is therefore assumed to be significant. The risk of additional scour and collateral damage from rubble movement away from the damage sites is also high under the right wave and current conditions most frequently associated with hurricane events. As an example, a natural cut (groove) in the southeast portion of Site 131 was reportedly void of rubble immediately after the vessel grounding. This feature was subsequently filled with rubble from the adjacent injury site during several storm events. Based on rough calculations, the amount of rubble deposited in this area is estimated to be approximately 25 cy. The material at this site appeared to be generally smaller 2.5 to 7.6 cm (1 to 3 in) than that observed at other sites (5 to 12.7 cm [2 to 5 in]), but clearly demonstrated the mobile nature of the rubble at the injury sites.

Discussions following the reconnaissance surveys determined that restoration alternatives which involve structural stabilization and restoration of site rugosity will require detailed design criteria and stability analyses. Rubble overlying portions of the grounding site is of variable thickness and will require innovative methods for structural stabilization. A regional analysis of the area's wave climate was conducted and it was determined that a 40 year return storm event will generate the most extreme conditions at the site. A smaller storm will have smaller associated waves, and a larger storm will generate waves that will break offshore of the site due to depth limitations. Design considerations will be dependent upon physical and biological characteristics, as well as fiscal determinations. Additionally, the affected sites generally represent topographic highs on the reef structure, and any restoration will depend upon installation weight and possibly subsurface anchoring techniques for stabilization.

Benthic Community Recovery

As described previously, the recovery of benthic communities at the grounding sites is critically dependent upon site stabilization and restoration of rugosity. Monitoring events conducted at the *T/V Margara* rubble fields revealed numerous coral recruits, a majority of which were soft corals. Corals are capable of settling and recruiting onto unconsolidated pieces of rubble. Their growth and survival, however, is significantly reduced as the loose rubble they are attached to become mobile and are buried or overturned thereby smothering and consequently killing coral recruits.

The most common species of corals recruiting on the rubble belonged to the soft coral genus, *Pseudopterogorgia*. The presence and abundance of these corals may indicate that a possible "phase shift" may have occurred at the site. Highly disturbed or injured sites commonly undergo a shift which is characterized by a lack of relief and rugosity, an abundance of soft corals and macroalgae, and an absence of hard corals, more specifically large reef building coral species (Fox 2003).

Soft coral colonies recruiting onto the unconsolidated rubble can reduce the amount of available substrate for hard coral recruitment. In addition, soft corals may overshadow existing hard coral recruits, inhibiting their growth and survival consequently contributing to the phase shift. Large hard corals species are essential in establishing rugosity and providing food and shelter for numerous key reef organisms. A phase shift may disturb trophic interactions, reducing the abundance and diversity of local reef species.

Fox (2003) established that low survival rates in rubble fields were due to post-settlement mortality and not recruitment limitations. Moderate or high recruitment on rubble fields is therefore not an accurate measurement of recovery success. Raymundo (2007) reported a mean survival rate of 6% of recruits in rubble fields compared to a 63.4% survival rate in reference areas during an assessment of a rubble field created by blast fishing events. Further analysis revealed that recruits in reference areas displayed significant growth compared to recruits settled onto unconsolidated rubble, which displayed signs of abrasion or partial mortality. It is highly unlikely that corals recruiting onto loose rubble will demonstrate significant growth. Consequently, coral cover and abundance are not expected to increase due to these limitations, and the biological function of the affected reef system will not be restored.

In 2003, Fox also reported that the highest recruitment in rubble fields occurred in areas with low currents and low frequency of severe storm action; while low recruitment rates were observed in areas with high current action and where storms are common. Unconsolidated rubble can be detrimental to small coral recruits and other biota as it is highly dynamic and will move as a result of wave actions or currents. In addition, unstable crushed rubble can increase the amount of suspended particles in the water column. Increased turbidity may retard recovery and reduce post recruitment survival of coral recruits (Jaap, 2000). Additionally, decreased water quality in the area can damage and/or increase mortality of otherwise healthy biota in surrounding areas.

Hard corals (scleractinians) are among the slowest growing components of a biological reef community and are critical for providing structural framework and integrity to the reef. For the most part, large reef building coral species are broadcast spawners. Broadcast spawners release their gametes into the water column and fertilization occurs externally. Once fertilization occurs, the larvae will settle and recruit assuming suitable substrate is available. Broadcast spawners, are characterized by their large size, low recruitment rates, and low mortality.

Most soft coral species are brooders. Brooding species undergo internal fertilization and release the planulae into the water column for settlement. Brooders display high recruitment rates, are often characterized by small sizes, early sexual maturation, and high adult mortality. As a result of their high recruitment rates and their ability to reproduce several times throughout the year, populations of brooding species are more likely to recover faster in disturbed and unstable habitats than broadcast spawner populations (Szmant, 1986; Smith, 1992).

Massive hard corals provide valuable habitat for numerous sessile and mobile species. Research shows that reef fish species richness and abundance are directly related to substrate and habitat complexity (Luckhurst and Luckhurst, 1978; Dennis and Bright, 1988).

The negative effects of ship groundings on ichthyofauna (fish) are not a result of impacts to fish populations, but a result of a loss of refuge that corals and the reef community provide for fish. Spieler et al. (2001) summarizes several studies that found a positive correlation between reef complexity (refuge) and fish diversity and abundance. Ebersole (2001) looked at patterns of species composition at three grounding sites in the Florida Keys National Marine Sanctuary. He concluded that regardless of the initial reef complexity, fish diversity and abundance was low post-impact, similar to species composition found on low relief hardbottom habitats. However, it is unclear whether damage to the reef limits fish food resources (Spieler et al., 2001).

Ebersole (2001) found a difference in species composition between low relief hardbottom and impact (grounding) site assemblages, and spur and groove assemblages. This was found to be a result of a preference of habitat by some species, as well as species richness and abundance on the spur and groove formations. Ebersole (2001) also determined that impacts from groundings are localized, but could have a greater impact on fish assemblages if there is slow recovery of the reef community and/or if fragmentation of the reef framework affects keystone species essential to reef structure and function. As a result, short-term, minor adverse impacts to the fish community are expected to be confined to the injury site.

Precht et al. (2001) found that without the restoration of topographically complex sites (e.g. spur and groove formations) the community structure will shift to a community similar to low relief hardbottom areas (e.g. *M/V Wellwood*). However, for sites that are characterized as low relief hardbottom communities before the incident, recovery may occur and no statistical difference is evident when compared to adjacent hardbottom communities (e.g. *M/V Elpis*) (Precht et al., 2001). Several of the areas identified for restoration at the *T/V Margara* site had relative relief characteristics in the pre-incident condition that could be classified as moderate to high when considering overall reef topography. Therefore, a loss in relief at this site has resulted in a community transition. Site stabilization and restoration of rugosity is essential if the benthic community is expected to return to pre-incident conditions.

Once physical restoration of the selected sites is complete, biological restoration activities and transplantation of available biota should be conducted. Based on the reconnaissance investigations conducted in January 2009, a substantial number of scleractinian and soft coral recruits (less than 10 cm [4 in]) are present at the site. Recovery and stabilization of these colonies will decrease individual mortality and encourage biological recovery. Other candidates for transplantation include dislodged colonies from surrounding sites; those that were reattached to rebar supported modules during the emergency restoration activities and which are now in jeopardy of becoming unstable due to site erosion; or nursery reared (*A. cervicornis*) colonies that are of sufficient size and health to be viable. Transplantation of available biota is an appropriate and critical component of the comprehensive restoration plan for the *T/V Margara* site.

Site Stabilization & Restoration of Rugosity

Secondary damage caused by unconsolidated rubble because of storm activity is of major concern when considering the necessity of restoration alternatives. The *T/V Margara* site is located in an area where storm activity is common. Hurricane Dean passed approximately 200 miles south of Puerto Rico on August 18, 2007. Although the storm path was not in proximity to the grounding site, the storm had critical impacts on the restored site as described previously in reference to the filling of a groove feature at Site 131.

Restoration activities are imperative to minimizing secondary damages to the reef and its surrounding areas, and to recovery of the reef's biological functions. Restoration that addresses rubble focuses on the removal or stabilization of loose substrate, to the extent practical, to decrease additional damage to adjacent habitats. Rubble stabilization onsite is a common method used in vessel grounding restorations.

Substrate rubble considered prone to movement during high-energy events may be relocated to another area onsite that is determined to be more stable (i.e., low energy environment). Concrete may also be used in areas with an abundance of rubble to stabilize the substrate. The concrete can be incorporated into the piles of rubble in such a manner that binds them into one cohesive unit that can be anchored securely to the substrate through mechanical means or by the weight of the installation itself. Additional loose pieces of rubble may be affixed to the concrete surface, maximizing natural surface area exposure and minimizing exposed concrete. Rubble with substantial biological recruitment will likely be cached and subsequently replaced on the surface of constructed concrete rubble mounds.

Destabilization of the reef structural matrix increases vulnerability of the compromised reef framework and may accelerate natural erosional processes. Studies have indicated that once destabilization of the reef framework occurs, complete recovery is not likely without mitigative actions to stabilize the site (Miller et al., 1993; Jaap, 2000; Hudson and Goodwin, 2001).

Some natural recovery of the reef substrate is expected, and may include the shifting and settling of displaced substrate that could stabilize the impact area and provide settlement opportunities for organisms. If the natural recovery rate is slower than the erosion rate, then net erosion will occur. However, natural processes will likely change the grounding site into a permanently altered coral community (Tilmant et al., 2003), thereby resulting in conditions that do not resemble pre-grounding topography, structure, and function. Neither alternative will lead to a fully functioning coral reef community with the same topographic complexity and structure to that which existed prior to the injury. Additionally, erosional processes from high energy storm events and currents could further damage and enlarge the impact area if no action is taken to restore the reef framework.

Common restoration activities aimed at restoring substantial framework loss include the use of quarried limestone boulders. Lost habitat topography and structure may also be restored using quarried limestone boulders, with or without a bonding agent such as cement, to stabilize the boulders within the habitat. Individual boulders must be of sufficient size and weight to avoid shifting or movement during storm events. Large boulders can be deployed to provide topographic relief and to help stabilize underlying substrate rubble. Assembled units must be either individually stable based on their weight characteristics, or anchored using mechanical means to assure no movement of the installation up to the design storm conditions. Once stabilized, unconsolidated sediment and organisms will settle in the voids and crevasses of the repaired reef, assisting in further stabilization of the reef substrate.

Due to the physical characteristics of the site; including wide variation on a daily basis in the wave and current conditions, vessel operations involving heavy equipment will be limited by sea state. Specific precautions must be considered when selecting the preferred restoration design. Safety of the personnel and equipment, as well as protection of the reef, should be a primary consideration for the NOAA restoration team. The use of smaller (relative) vessels, with sufficient anchorage opportunities is important to the operation while allowing for mobility and rapid departure from the site if sea state conditions exceed threshold levels. Similarly, heavy equipment selected to maneuver and deliver boulders and concrete to the site should be appropriately sized to operate in adverse wave conditions to a pre-defined threshold.

Sample Grounding Restoration Sites

Grounding sites that have been restored and monitored have proven that an injured site can be restored to closely resemble pre-injury conditions. One example is the *M/V Elpis* that ran aground in the Florida Keys National Marine Sanctuary in 1989.

Mitigation for the grounding was completed in 1995. Restoration activities included the placement of quarried marine limestone formations onto the reef. The objective was to restore the reef's structural framework and reestablish biological complexity. Three monitoring events were conducted at the site during the post-restoration study period. In order to evaluate the success of restoration efforts, coral density, diversity and other population parameters such as species richness were compared between the restored site and neighboring unimpacted coral reef communities. For the purpose of monitoring restoration success, corals were divided into three groups: 1) scleractinians, 2) gorgonians, and 3) *Millepora*.

During the monitoring event that occurred nine (9) years following the completion of restoration activities, the restored area showed a greater number of scleractinian colonies (276) when compared to the reference area (185) (Hudson 2008). Species richness at the restored site was also greater. As a result of restoration efforts, the composition of the reef's biological resources closely resembled, if not exceeded, those of an unimpacted reef community.

Summary

The main goal of the proposed restoration efforts is to restore the habitat's original structural framework and complexity in order to reestablish its function and value within the ecosystem. Restoring relief in the reef system increases the amount of available habitat and foraging grounds for the reef dependent species mentioned above. Microhabitats for boring and sessile organisms will also increase if the highly mobile rubble is stabilized and rugosity is restored. Furthermore, stable substrate will be made available for future biota recruitment possibly increasing the biological complexity of the reef, and consequently restoring the reef community to its baseline conditions.

In my opinion, stabilization of the mobile rubble and restoration of the *T/V Margara* site rugosity is critical to recovery of the site from a biological community perspective. A strategic approach designed to restore rugosity and stabilize those areas most susceptible to further degradation should be implemented at the site. Specific areas within the context of the larger grounding site characterized by the NOAA restoration team as having a predominance of mobile rubble should be targeted for strategic treatment using the physical restoration techniques proposed by Mr. Callaway in his report. Once physical site restoration efforts have been completed, biological restoration activities, including the use of transplantation of available biota, should be conducted. This strategic approach would achieve NOAA's objectives for physical and biological restoration of the site from a community perspective, with consideration of the natural recovery that could occur in a more physically diverse and stable condition. Without restoration activities and human intervention, the site will not recover to its pre-incident biological functions and values in the foreseeable future, if ever.

If you have any questions about this correspondence, please contact me via e-mail at Craig.Kruempel@TtECI.com or by telephone at (561) 735-0482 ext. 201.

Sincerely,

Craig J. Kruempel

Craig J. Kruempel
Senior Scientist / Project Manager

Attachments

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FIELD OBSERVATION REPORT

Site: M/V Margara Grounding Site, Tallaboa, Puerto Rico
Date: January 12 – 15, 2009
Prepared By: Craig J. Kruempel, Senior Scientist / Project Manager TtEC
Participants: Tom Moore, Habitat Restoration Specialist, NOAA Restoration Center, St. Petersburg, FL; Charles Callaway, Callaway Marine Technologies, West Palm Beach, FL; Sean Griffin, Senior Consultant, Lighthouse Technical Consultants, Aguadilla, PR
Purpose: Site Reconnaissance for Restoration Alternative Development

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January 12, 2009: Mobilize to Ft. Lauderdale International Airport for flight to San Juan Puerto Rico (PR). Arrived in San Juan at approximately 1230. Charles Callaway and I met Tom Moore at the airport and travelled in his rental vehicle to the Copa Marina Resort in Guanica, PR at approximately 1600. Checked in the hotel and met with Tom to discuss activities and expectations for the site investigation.

A series of conference calls were conducted prior to the trip in order to acquire specific data and direction from NOAA related to their concerns and intentions for site restoration. The purpose of the trip was to identify alternatives that may be appropriate for discrete segments of the injury site where loss of rugosity and highly mobile rubble are affecting recruitment, and stability. An overview of the site characteristics and preliminary dive plan was discussed. Mobilization to the dive boat *Coqui II* was set for 0700 on the 13th for transport to the project site.

January 13, 2009: Mobilized to the dive boat at 0715 and departed at approximately 0830. Sea conditions were approximately 2 to 4 feet on average, with approximately 75 feet of visibility. Moderate wind from the SE. Two crew members and a Captain assisted with the operations.

Dive No. 1: At 0940, we moored to a previously established buoy and commenced a dive at a site adjacent to the incident that was not affected and is representative of the natural conditions in the area. Maximum depth during the dive was 45 feet, and surge conditions were present at the bottom throughout the dive. The benthic community was diverse and gorgonian dominated based on visual estimates. Scleractinian coral diversity and density was variable with some sites better than others. Naturally occurring rubble (predominantly relic *Acropora* fragments) was present in lower lying areas; an intermittent layer of fine sediment was present at the surface of the reef structure. Suspension of the sediment by natural forces was not frequently observed. Video and still photography was collected at the site. This dive was completed at 1010.

Dive No. 2: The vessel moored to buoy MB6 which is located near the large impact site. The dive commenced at 1030 and was completed at 1120. Maximum depth during the dive was 42 feet. Surface conditions had increased to 3 to 5 foot seas with an increase in wind speed from the SE. This site was characterized as having a substantial area of rubble and fractured substrate present. Restoration efforts to date included numerous cement pours with imbedded detached substrate and benthics (hard and soft corals) incorporated into the individual installations. There was evidence of rubble movement from under some of the installations that resulted in a suspended installation supported by rebar. Moved towards the east near tags 113, 130 and towards 117. Several rubble mound reattachments in the area with apparent low benthic mortality evident on the reattached organisms. Video and still photography was collected at the site.

Dive No. 3: Stayed on site at MB6 and observed area west of the buoy. Dive commenced at 1215 and was completed at 1300. Sea conditions continue to degrade and wind speed increases at the site. Rubble area at Markers 9 and 33 were evaluated and a probe (4 foot long, 3/8 inch rebar) was hammered into the rubble. No refusal was noted as the rebar was driven to greater than 3 feet at two sites. Another site near the boundary between the unaffected hardbottom and rubble area revealed that as the probe was inserted nearer the hardbottom, the depth of rubble decreased to 1.5 feet or less. Found rather large area of bottom paint (18 to 24 inches across by approximately 36 inches in length) at the site. (Sean Griffin collected this material on January 14, 2009 and transported it offsite for proper disposal.) Surface of framework variable at the site, some areas overlain by cemented relic *Acropora* fragments; other areas had a more substantial limestone composition. The *Acropora* fragments were characterized as having a porous appearance that was brittle when handled. Video and still photography was collected at the site.

Post-Dive Discussion: After returning to Copa Marina and demobilizing for the day, the team met to discuss observations and plan for the following day's activities. Certain aspects of site evaluation and restoration alternative development involved the challenges associated with sea conditions and the ability to access the site with large work platforms. Restoration alternatives that involve structural stabilization and restoration of site rugosity will require analysis of installation stability and consideration of the design criteria for the efforts. Based on storm effects experienced at the site since the incident, design storm criteria have been discussed but no formal determination has been made. These design considerations will be dependent upon physical, biological, and fiscal considerations and it is NOAA's desire to evaluate the various options before sending recommendations to the responsible party. Supplemental geotechnical investigations such as seismic sonar or core collection were discussed as potential activities that may contribute to alternative evaluation. Considering site conditions, there are questions regarding whether seismic methods have sufficient resolution to differentiate between the rubble and more stable substrate below. Core acquisition at the sites will require a larger vessel that could present challenges due to wind and wave conditions. These options will be further discussed.

January 14, 2009: Mobilized to the dive boat at 0730 and arrived at the first dive site at approximately 0840. Sea conditions were approximately 2 to 3 feet on average, with approximately 30 feet of visibility on the first dive and improved conditions as the day progressed. Moderate wind from the SE. Two crew members and a Captain assisted with the operations.

Dive No. 1: Dive commenced at Site 146, identified by NOAA as the potential point of first impact by the *Margara*. Dive started at 0855 and ended at 0948 with a maximum depth of 38 feet. Video and still photography was collected during the dive. Less rubble was noted at the site and there appeared to be a terraced configuration of the damage site with higher elevation generally to the west transitioning to lower elevations and a natural trough to the east. The grade changes at the terraces ranged from 6 to 18 inches. This site also contained a number of *Acropora* fragments that had been recovered from the site and located on wire grids and suspended from nylon line as part of NOAA's nursery. Conducted a video transect, generally from east to west from unaffected sites across the injury to natural reef. There were numerous transplanted corals and reattached rubble at the site and they installations appear to be stable. No coral mortality was observed at these 'modules'. Tom M. drove rebar into the site and found greater than 3 feet of penetration through the rubble. Rubble was excavated by hand near Tag #28 and solid substrate was found 13 inches below the rubble surface.

Dive No. 2: Dive commenced at 1035 and was completed at 1125, with a maximum depth of 44 feet. Visibility improved and a slight current was detected during the dive. Near MB7, two areas of rubble were excavated in an attempt to locate solid substrate. At the southern site (near Tag #3), located approximately 25 feet south of the MB7 mooring, a 12 inch hole was excavated and a rebar was driven to refusal at a total depth (excavation + rebar) of 3 feet. Approximately 20 feet north of the MB7 mooring another hole was excavated and again a 12 inch deep area of rubble was removed before the rebar was driven to a depth of 12 inches to refusal. Total penetration to refusal at this site was 24 inches.

Dive No. 3: This was determined to be the final dive of the day, and Site 131 was identified as a likely candidate as a test site due to area characteristics. The site is of reasonable size for practical testing of alternatives, and possesses some of the more challenging conditions present in the overall site. The dive commenced at 1245 and was completed at 1345 with a maximum depth of 39 feet. The mooring at this site will require stabilization as one of the pins had pulled free and the other had movement due to vessel attachment. A natural cut (groove) in the SE portion of this site was open after the incident, and was observed to have been filled with rubble after the passage of recent storms. Based on rough estimates, the amount of rubble deposited in this area (est. 15' x 10' x 5') was calculated to be approximately 25 cubic yards. Numerous attempts were made to drive rebar into the rubble at this site. Depth to refusal varied from less that 2 feet near the perimeter of the impact site to greater than 5 feet NE of Tag #130. Tom M. and drove a duckbill anchor approximately 18 inches into the rubble near the center of the site and were able to pull the anchor free. Although not quantified, the rubble at this site appeared to be generally smaller (1 to 3 inches) than that observed at other sites (2 to 5 inches). The site has a relatively flat top with limited berm for containment if cement is used. The east side of the site slopes downward toward the previously discussed groove. The center of the site (near Tag #131) may have sufficient berm to provide containment. Consider using rubble from site to build containment berms depending upon pour thickness and daily production volumes. It was determined that the team had sufficient observations to develop preliminary recommendations and plan for potential testing at the site.

Post-Dive Discussion: After returning to Copa Marina and demobilizing for the day, the team met to discuss observations and plan for the following day's activities. It is apparent that the rubble overlying the site is of variable thickness and will require alternative methods for structure stabilization. Considering that the affected sites generally represent topographic highs on the reef structure, any restoration will depend upon installation weight and subsurface anchoring techniques for stabilization. There may be options for the use of larger duckbill or manta-type anchors at the site, but load testing will be required to determine relative contribution of the technique to the overall stability of any structure placed at the site.

January 15, 2009: Sean arranged to visit a quarry located at Juana Diaz on our way to San Juan. The limestone at the quarry was quite dense and had limited surficial complexity to be considered as an option for use in the project. Large boulders are a by-product of the operation which normally produces aggregate for the construction industry, but the representative indicated that they would be interested in developing an estimate to provide the materials for the project. He indicated that they have another quarry located west of San Juan that may have materials that are more acceptable. Sean will investigate that quarry and others in the region and report to the team his findings.