2015 Monitoring Report for Emergency Restoration following the *LNG-C Matthew* grounding in 2009 Guayanilla, Puerto Rico

Corals reattached during Emergency Restoration at the *LNG-C Matthew* site.

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Introduction

On December 15, 2009 at approximately 0605 the 920’ Norwegian-flagged Liquefied Natural Gas Carrier (LNG-C) *Matthew* grounded near Guayanilla, Puerto Rico while en route to the Eco-Electrica power plant. The starboard bow of the ship ran aground on coral reef on the south side of Cayo Maria Langa (Lat. 17.577° N, Long 066.454° W; Fig. 1). In an effort to free the tanker the bow of the vessel was pushed side to side, inflicting additional damage to the reef structure.

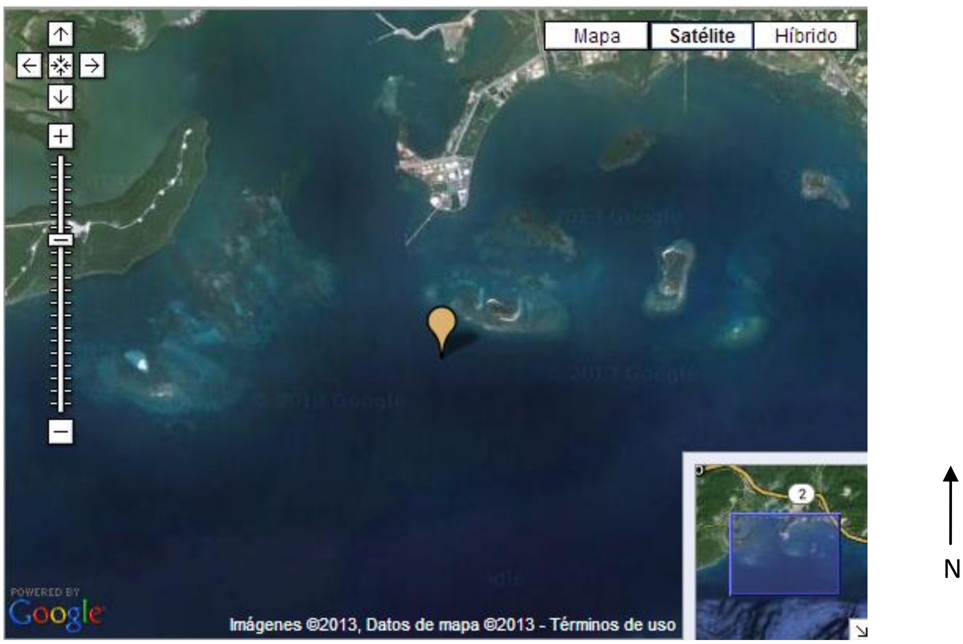

Figure 1. *LNG-C Matthew* grounding site map. Marker shows site where Matthews ran aground, (Lat. 17.57.7N, Long 066.45.4W) south of Cayo Maria Langa.

Damage to the reef included fractured and crushed scleractinian (hard) corals, dislodged octocorals (soft corals), and scraped and pulverized sea floor. The United States Coast Guard notified the National Oceanic and Atmospheric Administration (NOAA), and NOAA sent a restoration response team to quantify the total damage to the reef structure. Between the initial grounding and removal efforts, a total of 3,200 m^2 of the reef structure was damaged at a depth ranging between 7 and 13 meters (21-40 feet) (Fig. 2). In December 2009, live corals were salvaged from the rubble and cached in an effort to keep them alive until they could be permanently reattached. During the emergency restoration that took place in 2010, approximately 7,000 corals were reattached over the course of several months. Corals were reattached to the damaged substrate using cement. In order to help restore the rugosity, or topographic complexity, of the most damaged area that was flattened by the grounding, rubble

was used to form structures where the corals could be attached. Rugosity is an important reef feature which can be destroyed by a ship grounding in shallow waters. The reestablishment of this topographic complexity by rebuilding the reef plays a key role in increasing survivorship of corals, stabilizing the substrate and restoring lost ecological function.

Special attention was given to the staghorn coral (*Acropora cervicornis*) due to its listing as threatened under the Endangered Species Act since 2005. In 2011 and 2012, *A. cervicornis* colonies were outplanted to the grounding site.

This report describes the monitoring efforts carried out following the restoration to evaluate its success.

Figure 2. Damage to the reef structure caused by the *LNG-C Matthew* grounding. Light areas show exposed calcareous skeleton where corals were broken from the reef.

Methodology

After the restoration was completed, monitoring activities took place in 2012, 2013 and 2015. The restored area of the grounding site was divided into three major zones for monitoring (Fig. 3). Two reference sites were established to the east and west of the grounding site.

Reattachment success

In each of the three restored zones, 10 structures and 25 reattached corals were tagged so they could be followed over time. In the reference areas, a total of 25 corals were tagged in order to compare survivorship between reattached and naturally-occurring, undamaged corals. Structures

were evaluated for success in terms of their presence, stability and scouring. Corals were evaluated for reattachment success by observing presence, stability and partial mortality. Kruskal-Wallis ANOVAs were used to test for differences in survivorship between reattached scleractinians and octocorals, and between reference corals and reattached corals.

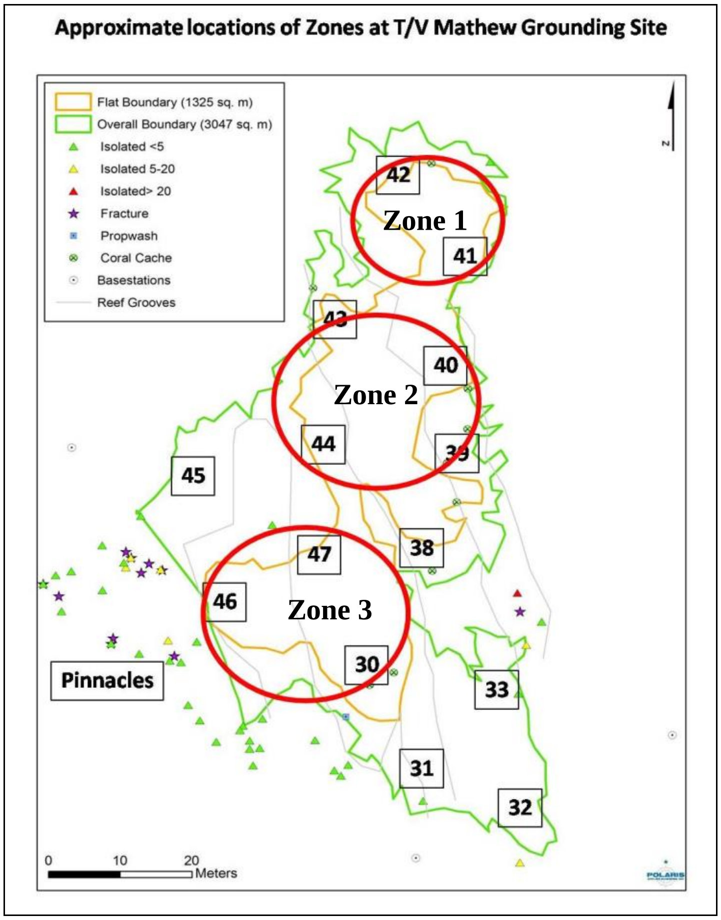

Figure 3. Map showing the impacted site where monitoring efforts took place.

Acropora cervicornis

24 of the original *A. cervicornis* colonies outplanted in 2011 were tagged. Presence, stability, fusion to the substrate, colony size and partial mortality were observed in each sampling period to evaluate the success of the outplanting.

Coral Recruitment

Coral recruitment was monitored in three different areas: the restored area within the grounding site, the unrestored area within the grounding site, and the reference area nearby but outside the grounding site. In each of the three areas, 15 permanent quadrats (25 cm x 25 cm) were established for observation of coral recruits. Recruitment rates in each area were calculated as

new recruits/m^2. Kruskal-Wallis ANOVAs were used to test for differences in recruitment rates between areas, years and coral types.

New recruits from each sampling period were followed to the next sampling period in order to determine recruit survivorship rates. Differences in recruit survivorship between areas and coral types were explored with Kruskal-Wallis ANOVAs.

Benthic Cover

The coral recruitment quadrats were also used to measure benthic cover in the three areas.

Results and Discussion

Reattachment success

No differences in survivorship of reattached corals was observed between zones, so zones were pooled. Not all tagged structures and colonies were found in 2015. Of the 30 structures originally tagged, 21 tags were found. Of the 75 corals originally tagged in the restored area, 48 (30 scleractinians and 18 octocorals) were found, and of the 25 in the reference area 24 (all scleractinians) were found. Reasons structures or colonies might not have been found include detachment or overgrowth of tags by benthic organsims, inexact mapping and lack of time due to the limitations of SCUBA. Only structures and corals with tags that were identified were used in the analysis.

In 2015, all structures were stable. Average scouring was very light and ranged from none (for the majority) to moderate.

Overall survivorship of reattached corals decreased over time. Total mortality was due to a combination of detachment and colony death. Scleractinians that were reattached during the restoration had significantly higher survivorship than octocorals that had been reattached (Kruskal-Wallis $p = 0.0006$; Fig. 4). Survivorship of scleractinians was slightly lower for reattached corals than for reference corals but the difference was not significant (Fig. 5).

In 2015, 44% of reattached octocorals and 10% of reattached scleractinian colonies were missing meaning that they had detached from the substrate. However, the only species of scleractinian that detached was *A. cervicornis*. Wave action and storms surge likely contributed to the detachment of octocorals and branching *A. cervicornis* colonies while lower-profile plating and mounding scleractinians were not affected. All colonies that were still present were stable. Of these stable colonies, 3% of scleractinians and 33% of octocorals had suffered complete mortality. In 2015 in the restored area, surviving octocorals had an average of <1% partial tissue mortality and surviving scleractinians had and average of 6% partial tissue mortality compared to 10% for reference scleractinians.

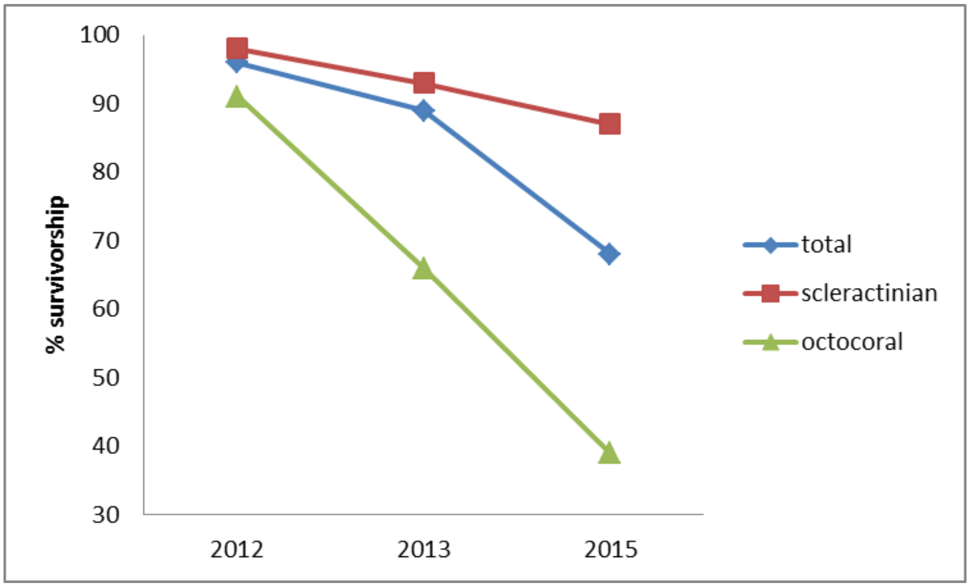

Figure 4: Survivorship of reattached octocorals and scleractinian corals over time.

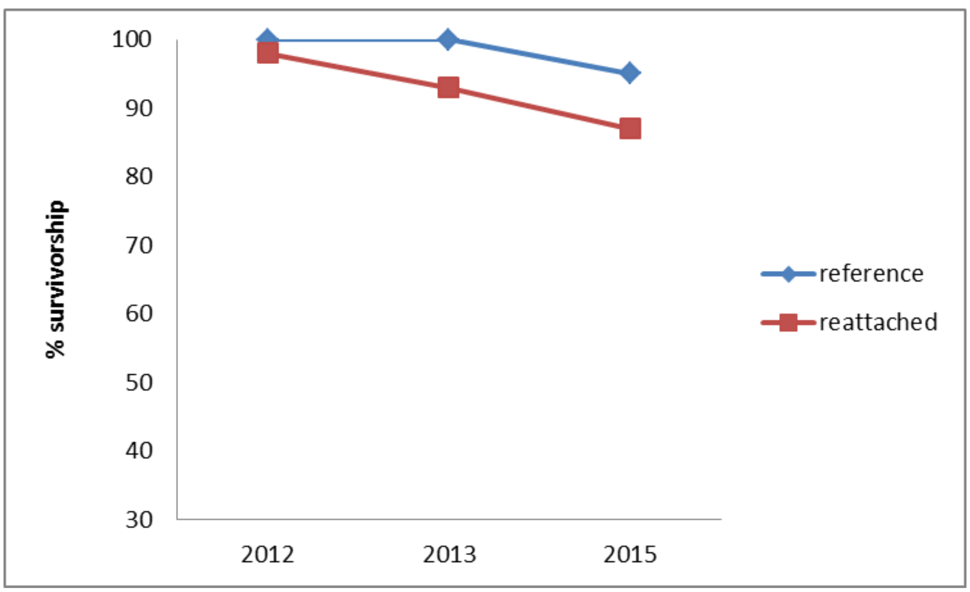

Figure 5: Survivorship of reattached and reference scleractinian corals over time.

Acropora cervicornis

50% of the original 24 tagged colonies of *A. cervicornis* that were outplanted in 2011 were missing in 2013. Most of the remaining colonies have formed into clusters or small thickets

making it difficult to identify individual colonies and measure size. Only 2 of the original colonies can still be considered solitary colonies. The others have fused with at least one other colony creating 3 clusters or small thickets. One is unstable and 40% have fused to the substrate. The average partial tissue mortality of surviving colonies was 31%. Since the original colonies were planted together into clusters, monitoring in 2011 should have included measurements for the dimensions of the clusters to determine growth or reduction in the size of the clusters. Subsequent outplanting and natural storm based fragmentation likely also added to the size of these clusters.

Recruitment

Coral recruitment varied significantly over area (Kruskal-Wallis p =.0439), coral type (Kruskal-Wallis p =.0180) and sampling period (Kruskal-Wallis p =.0002). In 2011 and 2012 recruitment was higher in the reference area than in the grounding area (restored or unrestored). 2013 had low recruitment in all areas and in 2015 recruitment was significantly higher in the restored areas than in either unrestored and reference areas (Kruskal-Wallis p =.0001; Fig. 6).

Recruit survivorship also varied between coral type, area and sampling period (Fig. 7), although differences were not significant likely due to the small numbers of recruits observed. Future monitoring efforts should consider using 50cm x 50cm quadrats to increase the number of recruits being tracked.

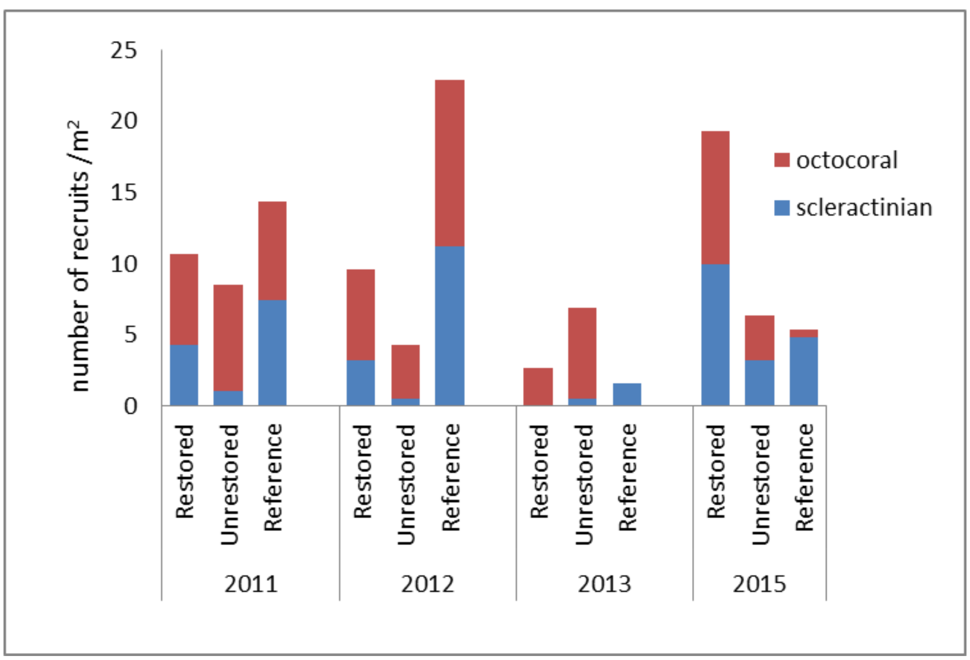

Figure 6: Number of octocoral and scleractinian coral recruits per meter squared in three areas over four sampling periods.

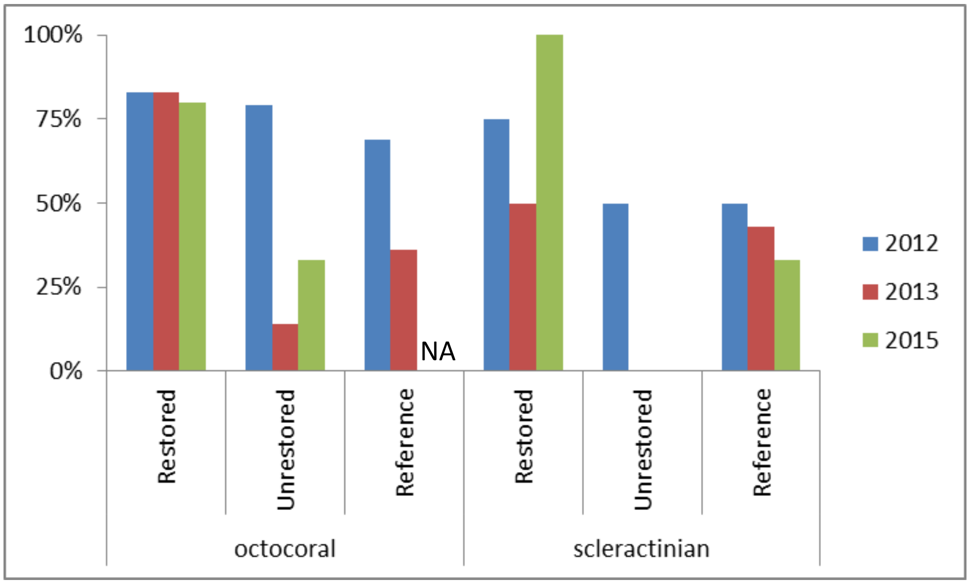

Figure 7: Percent survivorship of octocoral and scleractinian recruits from the previous sampling period in three areas.

Benthic Cover

Benthic cover varied between areas (Fig. 8). Restored areas and reference areas had similar cover of turf (53.7% and 53.4%), while turf accounted for only 35.9% of cover in unrestored areas. Unrestored areas, however, were 41.1% rubble, 14.1% bare hard substrate and 4.6% sand while restored and reference areas, the combined totals of rubble, bare hard substrate and sand were only 1.3% and 0% respectively. Reference areas had higher coral and octocoral cover (17.3%, 17.0%) compared to restored areas (10.7%, 4.7%) and unrestored areas (0.2%, 2.0%). Restored areas had significantly higher cover of CCA (18.6%) than unrestored and reference areas (0% and 0.3%, respectively). As corals are slow-growing organisms it is not surprising that coral cover in restored areas is not as high as in reference areas. CCA cover in the restored areas is promising as there is evidence that CCA provides good substrate and is favorable for coral recruitment (Erwin et al. 2008). The combined results from the benthic cover data indicate that restoration efforts made significant improvements in areas that were restored compared with unrestored areas.

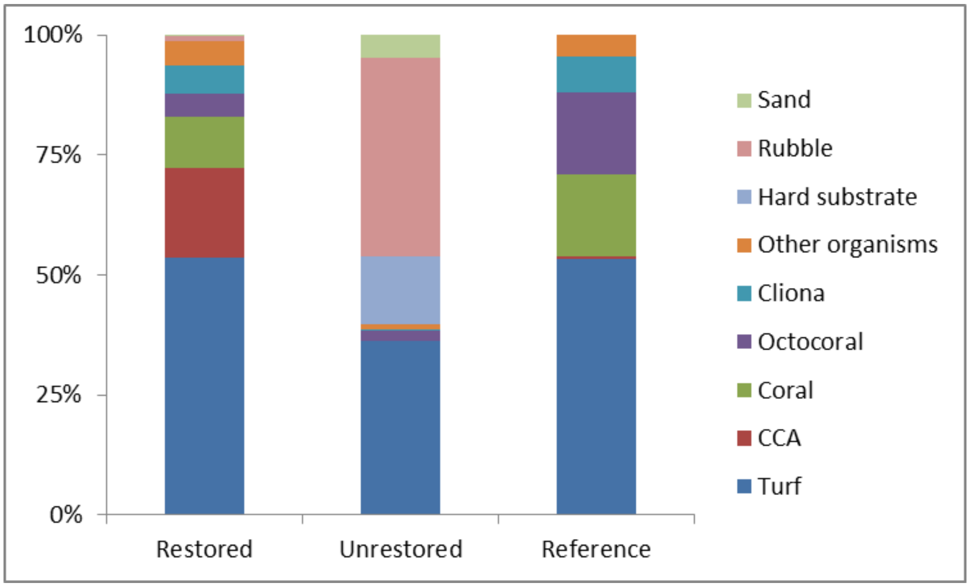

Figure 8: Percent cover of benthic organisms in three areas.

Conclusions

Reattachment of scleractinian corals in the grounding area was highly successful. This is crucial to any restoration effort since scleractinians are reef-building corals. The only species of scleractinian coral to detach at all was the branching coral *A. cervicornis*. Reattachment of octocorals was somewhat less successful. Although survivorship of reattached octocorals was not compared to reference octocorals, it is likely that the low survivorship of octocorals is due to the reattachment process. Compared to encrusting and mounding scleractinians, *A. cervicornis* and octocorals have a lot of surface area and relatively small attachment points to the substrate making them more susceptible to detachment by currents and wave action. Comparing survivorship of reattached to reference octocorals would confirm whether low survivorship is related to reattachment. Reattachment methods for octocorals need to be improved.

Although some *A. cervicornis* colonies did detach, many of the remaining colonies have grown quickly and even begun to form thickets. Encouraging this formation of thickets by outplanting colonies in clusters may increase survivorship. For monitoring, the dimensions of the original clusters should be measured to determine if the clusters or thickets have grown over time.

High survivorship of reattached scleractinian corals and evidence of higher recruitment and recruit survivorship on restoration structures compared to non-restored areas indicate that restoration efforts in areas that were restored at the *LNG Matthew* grounding site have been successful. There is still a lot of rubble present in the unrestored areas, which may account for the high levels of recruitment mortality in those areas. Future monitoring should consider using 50cm x 50cm quadrats to increase the number of recruits being monitored.

Building structures and reattaching corals has made a dramatic difference in the area damaged by the grounding. The unrestored areas are mostly rubble and turf, indicating that the substrate is not stable and corals and other benthic organisms have not been able to establish themselves. Restored areas much more closely resemble reference areas in benthic composition.

Reference

Erwin, P.M., Song, B., Szmant A.M. (2008) Settlement behavior of *Acropora palmata* planulae: Effects of biofilm age and crustose coralline algal cover. Proceedings of the 11th International Coral Reef Symposium 24:1219-1223.