Re-attachment and monitoring of broken fragments of *Acropora palmata* following a ship grounding in Puerto Rico

South-east coast of Mona Island, Puerto Rico, USA – 1997-2008

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Project in collaboration with the Puerto Rico Department of Natural and Environmental Resources, the Center for Field Studies/Earthwatch and the NOAA Damage Assessment, Remediation and Restoration Program.

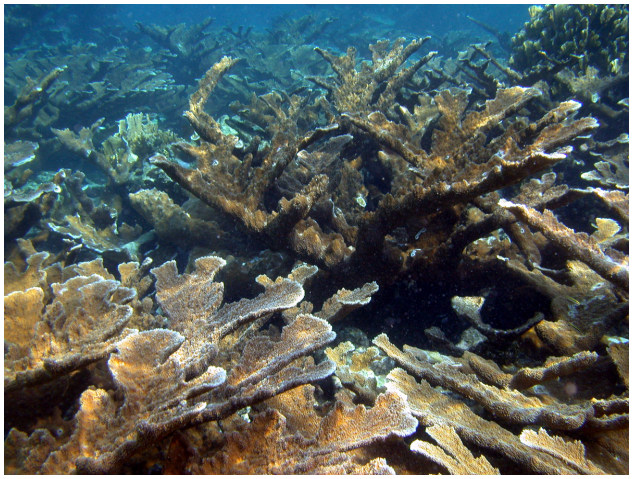

Figure 1: *Acropora palmata* stand adjacent to the *Fortuna Reefer* grounding site in 1997 (Photo: A. Bruckner).

Background

The grounding of the 99-m freighter M/V *Fortuna Reefer* on 24 July 1997 and its subsequent removal impacted 2.75 ha of shallow *Acropora palmata* forereef habitat (Figure 1). At the impact site on the south-east coast of Mona Island (Figure 2) there was total coral destruction along an area up to 30 m wide, that extended from the reef crest about 300 m seaward at 1–4 m depth (Figures 3 and 4). Colony breakage occurred over a much larger area, to about 7 m depth, in part due to the steel cables used to extract the vessel that dragged across the reef. Entire colonies of *A. palmata*, many several metres in diameter, were crushed or dislodged and fractured by the ship, and in addition the cable sheared off hundreds of branches. Restoration was undertaken as part of a Natural Resource Damage Assessment (NRDA) settlement with the party responsible for the ship grounding. Under the OiI Pollution Act, the US government is responsible for restoring trust resources and compensating the public for lost use of natural resources; the National Oceanic and Atmospheric Administration (NOAA) was therefore able to pursue damages due to the threat of release of oil posed by the ship grounding, although no oil was spilt.

Objectives

To re-attach fragments of *A. palmata* (Elkhorn coral), a species listed on the US Endangered Species Act, to recreate the reef habitat and its structural relief that had been damaged by the grounding, and to reduce the mortality of broken coral fragments.

Methods used

Restoration was undertaken 3 months after the grounding, during September and October 1997. A total of 1857 fragments of *A. palmata* were collected on the grounding site in depths of 1–6 m and varying in length from 15-340 cm. Some were attached to stainless steel nails that were epoxied into holes drilled into the relict reef substrate using stainless steel wire wrapped over fragments and around the nails. Others were attached to dead standing *A. palmata* skeletons using stainless steel wire. In a few cases, plastic cable ties were used but these loosened quickly in heavy surge so this technique was abandoned in favour of wire. SCUBA and free diving were used, and lift bags were used to reposition heavy fragments. No fragments were removed from the water.

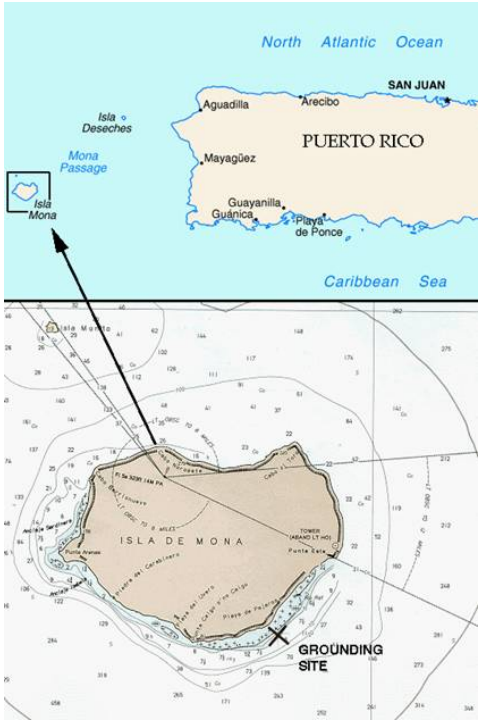

Figure 2: Location of the *Fortuna Reefer* grounding site in Puerto Rico.

Due to considerable corrosion and breakage of the original wires after about 3 years, surviving fragments were further stabilized (Figure 5) in July 2000 using a more durable copper-nickel alloy wire (Monel 400) with, in some cases, Portland cement, particularly where fragments were located shallow, in heavy surge.

Figure 3: *Fortuna Reefer* site one week after the grounding in 1997 showing where the keel struck the reef (Photo: J. Morlock).

Monitoring

The fragments were monitored 1-3 times a year for the first 6 years, and then annually until the tenth year. The following data were collected: fragments present or missing; maximum length to nearest cm; orientation of attachment (up or down, with respect to orientation prior to grounding); location of attachment (relict reef substrate or dead standing *A. palmata* skeletons); condition (live or dead). Fragment condition was assessed through estimates of tissue loss, and causes of mortality were identified as named diseases, predation (*Coralliophila abbreviata* snails or parrotfish) overgrowth by sponge (*Cliona*) or algae, or other factors. Coral growth over the wire, fusion with the substrate, and the amount of new growth was also noted. Fish abundance and species composition within the grounding site and in surrounding areas was also monitored using 15-20 30-m belt transects per survey.

Figure 4: Reef framework and large *Diploria strigosa* colonies crushed by the impact of the *Fortuna Reefer* (Photo: A. Bruckner).

Ecological outcomes

In general, there were high rates of early mortality due to wire breakage and removal of fragments during winter storms, overgrowth by bioeroding (*Cliona)* sponges, disease and predation by gastropods (*Coralliophila*). After 2 years, 57% of the fragments had survived, 26% were dead, and 17% had become detached and had disappeared from the site. The largest number of fragments died from *Cliona*, primarily because fragments were attached directly on top of this sponge.

After 3 years (i.e. by 2000), a further 8.3% of fragments had disappeared from the site, making a total of 25% loss of reattached fragments as a result of wire corrosion and breakage. The wire was also a significant cause of partial mortality, as the high surge at the shallow site loosened it and then abraded coral tissue that was in contact with it. However, there were some instances where the tissue overgrew the wire where it remained tight. Algae or *Millepora* also overgrew the wire dividing tissue into smaller patches that slowly died. The fragments exhibited a limited ability to fuse to the substrate and only about 17% of the survivors at 3 years showed tissue growth onto the substrate.

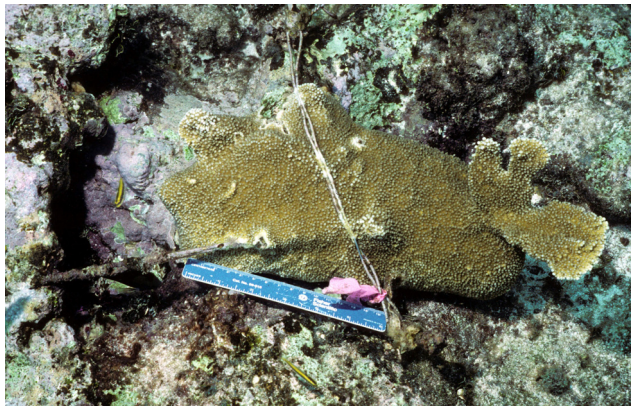

Figure 5: Approximately 60 cm long fragment of Elkhorn coral, *Acropora palmata*, broken off during the grounding which has been secured to nails in the reef with stainless steel wire during the restoration. Both original wire (overgrown) and new wire added during mid-course correction are visible (Photo: A. Bruckner).

At 5 years, coral tissue was overgrowing the new wire used to stabilize the fragments in 2000, and there was very little initial breakage. However, after a further 4 years (9 years after the initial restoration) the new wire began to break and fragments detached, partly due to numerous storms, and partly because the dead skeletons to which many larger fragments had been attached were collapsing from bio-erosion and the weight of growth of the reattached fragments.

After 10 years (2008), just under 6% (104) of the fragments were still alive, although only a small proportion of these were securely fused to their attachment sites; 26% had become detached or were missing, and 68% had died in place (Figure 6). About half of the survivors resembled adult colonies with tissue covering the upper skeletal surfaces, extensive branching (mean = 5 branches, 89 cm in length), and a substantial increase in height (mean 39 cm tall). The highest survival was in fragments of 20–80 cm length attached to the relict

reef substrate. Overgrowth by *Cliona* was one of the most significant stressors, with about 22% of the fragments dying due to this. Ongoing sources of mortality include sponge overgrowth (6%), snail predation (8%), and disease (6%).

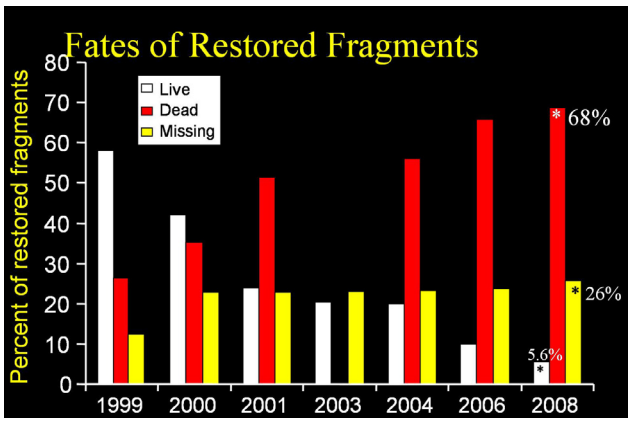

Figure 6: Fates of attached *Acropora palmata* fragments between 1999 and 2008 (Bruckner et al. 2009).

Social aspects

The restoration work led to heightened awareness of the importance of coral reef resources and contributed ultimately to protection of Mona Island, which was an important destination for spear-fishermen and boaters. The involvement of the Puerto Rico Department of Natural and Environmental Resources (PRDNER) and the concomitant decline of fishery resources around the island led to changes in policy and designation of most of the shallow waters around the Island as a protected area. Mooring buoys were installed in order to reduce the use of anchors.

Resources required

Human resources: The initial assessment of damage was undertaken by a team of experts from the PRDNER and the NOAA Damage Assessment, Remediation and Restoration Programme (DARRP) with University of Puerto Rico (UPR) professors. The restoration work was undertaken by a team of 19 marine engineers and biologists. Federal staff provided the oversight and UPR staff and students and Federal staff undertook the monitoring. Volunteers were provided by the Center for Field Studies/Earthwatch for 3 years to do one to two missions of 2 weeks each annually with 3-4 days assisting in surveys at the *Fortuna Reefer* site. They were trained by the lead scientist, and their main jobs included tagging corals (temporarily and permanently), measuring length of fragments to the nearest cm with a marked PVC rod, running out transect tapes and rope to mark off the site to make sure there was no double counting of fragments. The boat for transportation was hired from a former fisherman turned conservationist.

Financial resources: The settlement for the grounding totalled US$ 1.25 million. Of this, US$ 650,000 was used for the immediate restoration, and US$100,000 went to both the Puerto Rico Department of Natural and Environmental Resources (PRDNER) and to NOAA to defray assessment costs accrued during the response. Of the Federal portion, US$3,000 was withheld by the Department of Justice to cover their involvement in the settlement. Overall, NOAA experienced a net negative balance over the course of the restoration of approximately US$62,000 that reflects unrecovered costs for Federal labor, indirect rates, overhead, travel and supplies. An additional US$400,000 was provided to PRDNER for compensatory restoration. These funds supported a new navigation light tower on Mona Island to reduce the risk of future groundings; a mid-course correction to re-secure fragments with additional, stronger wire; channel markers for the two boat landing sites; side scan sonar equipment and associated surveys of the island's reef resources; and also covered supplies, equipment installation, and transportations costs to and from the island by boat. Approximately US$2,000-5,000 per year was spent on monitoring, including volunteer housing and meals, training, equipment, boat time, and transportation to and from Puerto Rico for the principal investigators. Monitoring funds were provided by the Center for Field Studies/Earthwatch, and were in addition to settlement costs.

Time: The initial restoration in 1997 was carried out over 3 weeks. Each monitoring survey took 3-4 days using two experts to assess corals and 6-8 volunteers to assist in a range of survey tasks (photographing corals, laying out lines and transect tapes, holding measurement bars, etc.).

Lessons learnt

Despite the high cost of this project, it was felt that without intervention, a very high percentage of fragments would have died due to sand scouring, or would have been removed from the site during high wave action. After 6 years the survivorship was comparable to or higher than that on reefs following other catastrophes such as hurricanes. However, within 10 years nearly 95% of the re-attached fragments died or disappeared and only about half of the remaining fragments were in good health and resembled adult colonies. Due to the lack of studies following the fates of natural fragments over 10 years, it is not known how their fates would compare. However, areas surrounding the grounding site declined to a similar extent and there are few noticeable differences between a natural undamaged site and the restoration site at this location.

Wire alone should be avoided wherever possible as a re-attachment method, because of the problems of abrasion. It was used at this site because of the high wave exposure which made it difficult to attach corals with cement due to the amount of time required for the cement to harden. Wire may however be useful to temporarily hold a fragment in place until cement or epoxy hardens.

Tissue contact between a fragment and the substrate is essential. Attaching fragments to the tops of dead coral branches did not work as the fragments continued to grow upward but failed to resheet over the existing skeletons which eventually become weakened and broke. A possible solution would be to attach fragments to the bases of dead colonies, in a vertical position, as they would be more likely to fuse and resheet over the skeleton as they grow upward.

Any coral fragments attached on or near *Cliona* are likely to die, emphasizing the importance of finding substrate where this sponge is absent.

Medium sized *A. palmata* fragments (i.e. 20–80 cm) had the highest survival and growth, whereas very small fragments and large fragments, especially those taken from the older portions of a colony, were most likely to die.

Improvements to the method should include removal of pest species like snails (*Coralliophila*) during monitoring. Two removals were undertaken, at year 8 and 9, with fewer snails and less mortality associated with snails recorded during year 9, and even lower numbers during year 10. Other approaches that should be attempted include salvage of healthy portions of diseased colonies. A pilot experiment involving the removal of branch ends from corals with White Band Disease showed high survival of the detached fragments but complete mortality of the remaining part of the coral.

Acknowledgements

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Further information

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