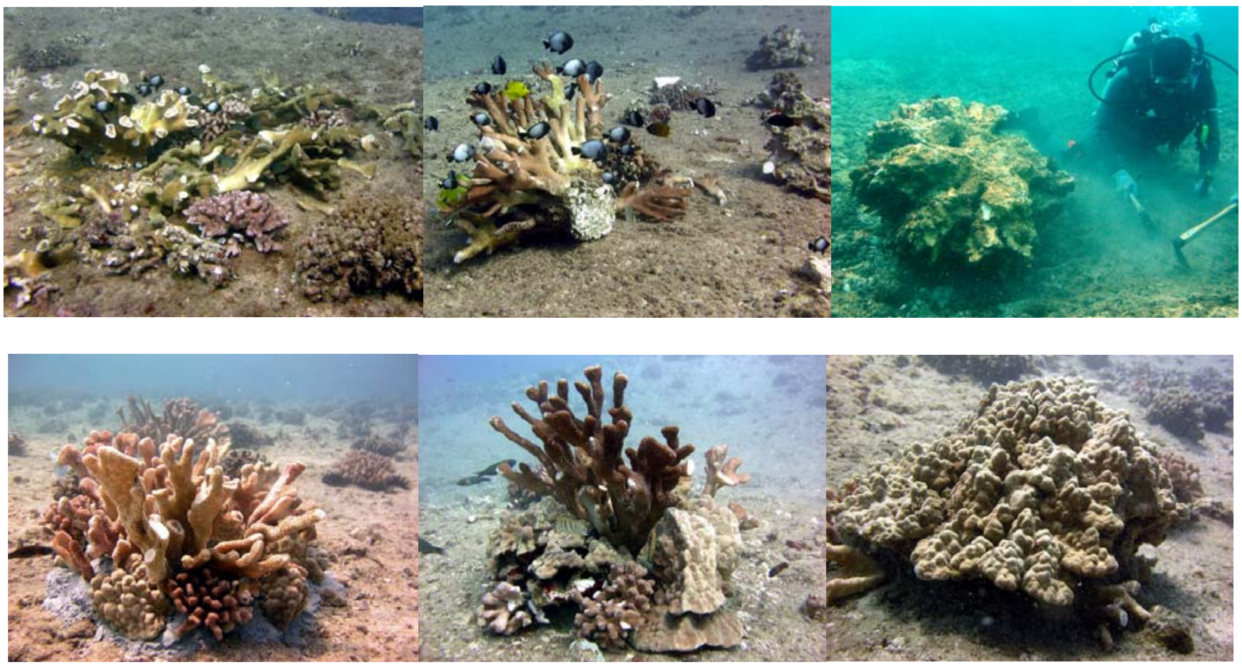
Emergency Restoration of Reef Habitat and Resources Damaged in the Grounding and Removal of the *M/V Cape Flattery*, Barbers Point, Oahu, Hawaii, 2005



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Summary

An emergency reef restoration, implemented south of Barbers Point Harbor, Oahu, Hawaii following the 2005 grounding and removal of the *M/V Cape Flattery*, resulted in 825 damaged corals being stabilized in 105 single and multi-colony cement aggregations and over 400 additional corals being righted at depths of 9 to 16 m (28 to 54 ft.). Seven species of scleractinian corals, ranging from 0.5 cm to > 2.5 m in greatest diameter, were affected by restoration efforts. *Pocillopora eydouxi* and large lobate *Porites* were selected as focal species for cement stabilization. Cement aggregate areas totaled 34 m^2 and included a majority of known, large, significant habitat forming colonies that were found detached in the impact area. The project was estimated to have stabilized/restored approximately 660 m^2 of reef area; this accounts for, at best, 1 % of the area damaged by the grounding and ship removal activities. Righted colonies not stabilized in cement foundations are exposed to displacement by high wave energy events that frequently occur in the area. Cemented colonies are threatened by extreme wave energy and associated movement of remaining reef debris, boat anchoring, and biological activities including collisions by turtles and predation by coral eating invertebrates. Long-term monitoring of cemented and nearby reference corals (189 colonies selected and measured) is recommended annually for a five year period to determine the ecological success of the emergency restoration.

Introduction

On 2 February 2005, the 555 ft. bulk carrier *M/V Cape Flattery* grounded on fringing reef outside and adjacent to the Barbers Point Harbor entrance channel on the west side of Oahu, Hawaii (N21°18′; W158°07′; Figure 1). A substantial threat of oil discharge was declared (United States Coast Guard 2005). Fuel and large quantities of bulk granular cement cargo were removed in an effort to lighten the vessel and reduce oil release risks. Repeated efforts at towing occurred. On 11 February 2005, the *M/V Cape Flattery* was towed off the reef.

Preliminary assessments of damage to natural resources in the area were conducted by representatives of the National Marine Fisheries Service, Pacific Islands Regional Office (PIRO; Kolinski 2005a), the U.S. Fish & Wildlife Service (FWS), the State of Hawaii Department of Land and Natural Resources (DLNR), Polaris Applied Sciences, Inc. (RP biologists; Polaris Applied Sciences, Inc. 2005), with assistance from the National Marine Fisheries Service, Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division (CRED; Kenyon 2005). Impacts to reef resources were identified to have occurred as a result of both grounding and ship removal activities and affected six general habitat zones, including, from shore to sea:

1. A ***Porites* Zone,** characterized by large lobate *Porites lobata* and *P. evermannii* corals that were broken, detached and overturned by towlines and propeller wash (approximately 7 to 9 m depth, 23 to 30 ft.);
2. An **Intermediate Shelf Pavement Zone,** where scattered *Pocillopora meandrina* corals and related organisms were pulverized by the ship (approximately 7 to 9 m depth, 23 to 30 ft.);
3. **Reef Depressions,** large deep holes utilized by corals, related organisms and resting sea turtles, some of which filled in with reef debris created by the grounding and removal activities (approximately 9 to 15 m depth, 30 to 50 ft);

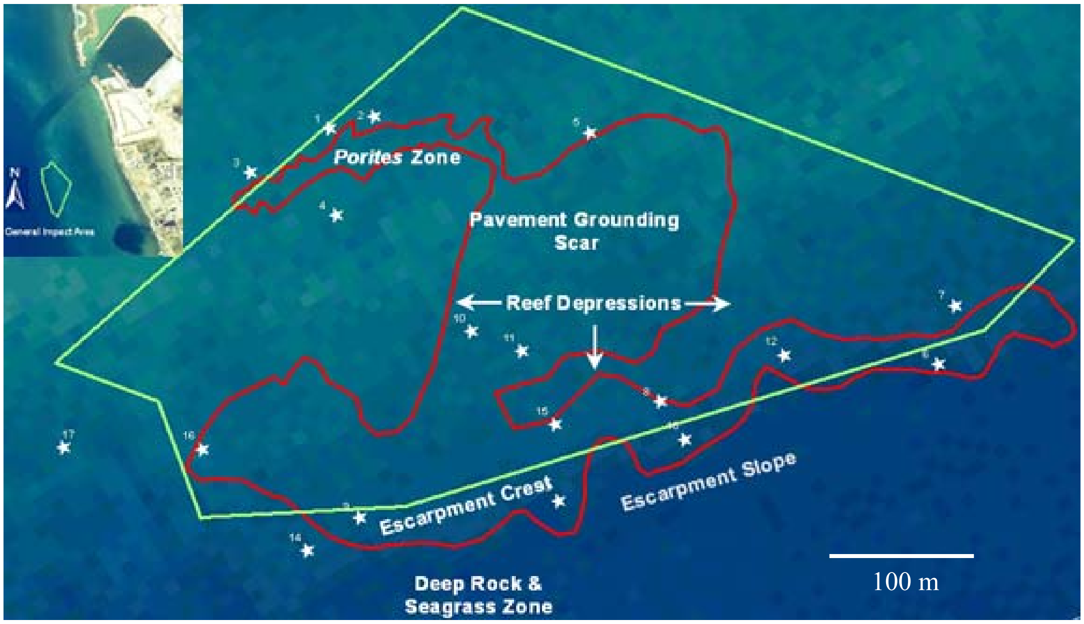

Figure 1. General habitat zones south of Barbers Point Harbor where damage occurred as a result of the grounding and removal of the *M/V Cape Flattery*. Measured areas of impact: red = Polaris Applied Sciences, Inc. 2005; green = Kenyon 2005; white star = emergency reef restoration station.

4. The **Escarpment Crest**, a region with relatively high coral cover and topographic complexity where corals were sheared and broken by towlines and anchor chain and many detached colonies remained (approximately 12 to 17 m depth, 40 to 55 ft);
5. The **Escarpment Slope**, a relatively high coral cover and topographically complex area impacted by the ships anchor chain, towlines and detached corals (approximately 12 to 24 m, 40 to 80 ft), and;
6. A **Deep Rock and Seagrass Zone**, disturbed by deployment and movement of the ships anchor (21 to > 30 m depth, 70 to > 100 ft; Kolinski 2005b, Figure 1).

Damage occurred at depths of 7 to > 30 m (23 to > 100 ft.). Estimates of total reef area within which damage occurred presently range between 6.3 ha (15.4 acres; Polaris Applied Sciences, Inc. 2005) and 13.7 ha (33.8 acres; Kenyon 2005).

An emergency reef restoration plan was developed and implemented (with field modifications) between 14 February and 22 April 2005 with the intention of mitigating damage to injured live coral habitat and associated organisms, and preventing secondary impacts to non-injured resources as a result of wave induced movement of large, incident generated reef debris (Kolinski 2005c). The emergency restoration objectives included:

1. Stabilizing large reef boulders and coral colonies
    a. To provide opportunity for individual colony recovery
    b. To prevent wave induced bulldozing by large, loose reef aggregates
2. Stabilizing large habitat forming corals
    a. To restore significant three-dimensional habitat for fish and invertebrates
    b. To maintain reproductive potential of significant habitat forming colonies
3. Righting overturned colonies to enhance their survival potential (Kolinski 2005d).

Oahu's west coast frequently experiences high wave energy events (National Oceanographic Data Center 1998, www.surforecasts.com/hawaii); thus, emergency restoration was necessary as reef habitat and surviving resources were immediately susceptible to further, wave enhanced, degradation.

This report summarizes the first phase, including the development, implementation and initial measurements, of the emergency reef restoration. Future reports will present information on the extent of long-term success of this restoration effort.

Materials and Methods

The emergency restoration initially focused on two mechanisms of coral colony stabilization: righting and cementing large detached *Porites* and *Pocillopora* colonies to hard substrates, and; simple righting of detached colonies (Kolinski 2005c). The locations selected for restoration were identified and recorded during towed-diver surveys (Kenyon 2005) and throughout the period of preliminary assessment and emergency restoration.

Cementing and Measuring Corals

Sites with detached, boulder-sized *Porites lobata*, *P. evermannii* and rock, and areas with aggregations of large, living fragments from multiple *Pocillopora eydouxi* colonies were selected for cementing activities. These species and sizes were the focus of restoration efforts due to their high habitat forming value, potential to cause secondary, wave induced, collision impacts to other remaining benthic resources, and their relatively extensive natural replacement times. When feasible, detached corals and fragments were carried to a central location at each site by divers using SCUBA. Multiple 0.6 m (2 ft.) diameter circular areas of pavement scarred by grounding related activities and/or pavement free of macro-invertebrates and macro-algae were scraped clean and wire brushed, as where the broken ends and bases of the detached corals and fragments to enhance cement bonding (Figure 2). A Hawaiian Cement mix (Portland type II cement mixed with seawater and liquid Molding Plaster) prepared on surface craft in 19 l (5 gal) plastic buckets was delivered using snorkel or SCUBA to awaiting divers. A thick, putty-like, cement patty (approximately 8 l [2 gal]), 10 cm in height) was deposited from an individual

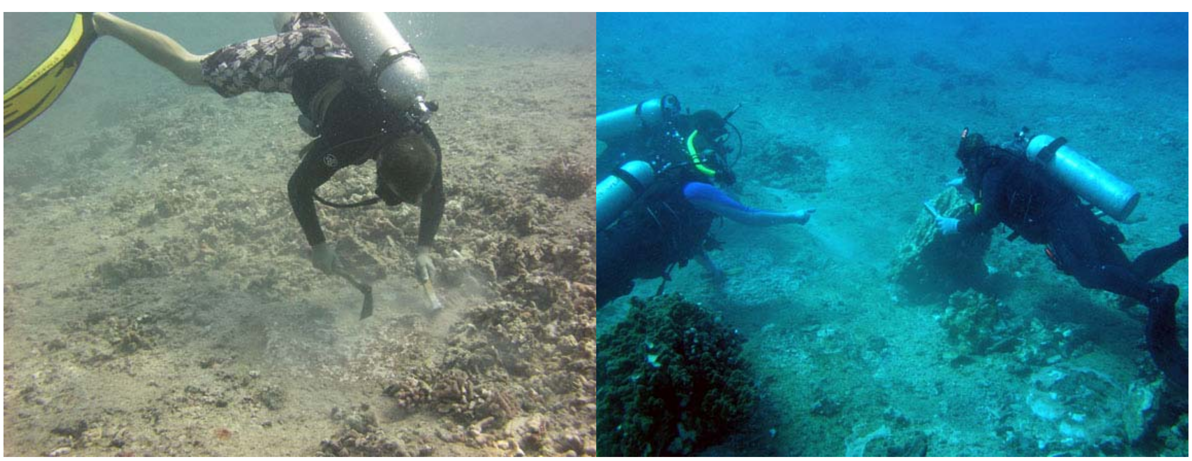

Figure 2. Preparation of substrate and detached corals for cement bonding.

bucket onto each cleaned pavement surface (multiple patties were adjacently placed for cementing large lobate corals). Collected corals were arranged and pressed firmly in the cement to form single or multi-colony aggregates. In forming multi-colony aggregates, small colonies of *Pocillopora meandrina* and *Porites* were cemented on the aggregate edges to keep the larger branches of *Pocillopora eydouxi* upright while the cement hardened (Figure 3). Four to seven people were utilized in boat support and diving in each cementing operation. Divers and duties were staggered to maximize bottom-time at each restoration site, particularly at depths exceeding 12 m (40 ft.). The cement operations lasted 13 days and occurred between 17 February and 23 March 2005. Cementing activities were conducted at depths of 9 to16 m (28 to 54 ft.).

Figure 3. Forming multi-colony aggregates (*Porites lobata*, *Pocillopora eydouxi* and *P. meandrina*).

Aggregations and their individual colony components were mapped, identified to species and measured between 17 February and 22 April 2005 by Steven P. Kolinski, Ph.D. (Coral Ecologist, PIRO) and Evelyn F. Cox, Ph.D. (Coral Ecologist, Hawaii Institute of Marine Biology). A flexible measuring tape was used to determine the longest linear length, perpendicular width and height of each aggregation and colony (with the exception of some small epiphytic corals, which were identified to species and noted). Projected areas of colonies and aggregations were calculated as πab (area of an ellipse; a = ½ greatest diameter; b = ½ perpendicular width). Gross percent of colony mortality/damage was visually estimated in the field. Similar measurements and maps were made for reference corals that remained attached at each restoration site, including those recovering from damage as well as colonies that appeared free of impact. Reference corals were selected based on their species, attachment, size, general appearance, recovery potential (if damaged), availability and proximity. Growth and survival measurements of the reference corals will be used to comparatively determine the success of the colony stabilization efforts over time. Cement aggregates and reference corals were photographed using an Olympus digital camera (5050).

Reef areas enclosed by cement aggregates at a site were measured using a flexible transect tape and were estimated using area formulas that best represented the geometric distribution of a sites cement aggregates. Such areas were determined as a proxy for estimating the area of reef restored.

Righting Corals

Initial efforts at simply righting detached corals along the Escarpment Crest were conducted on 17 and 18 February 2005 by representatives of PIRO, CRED, DLNR, FWS and the University of Hawaii (UH). All corals within 5 m of either side of a transect laid parallel to the escarpment edge were righted in every other 20 m sector to allow for analysis of the long term efficacy of the method (Kolinski 2005c). Each coral was stabilized when possible in a righted position by pressing or wedging it into available substrate. Corals were identified to species, assigned to a size category (greatest diameter ≤ 5cm, > 5 and ≤ 10, > 10 and ≤ 20, > 20 and ≤ 40, > 40 and ≤ 80, > 80 and ≤ 160, > 160), and visually assessed for percent damage. These efforts were eventually abandoned due to problems with implementation under harsh environmental conditions (strong currents), a general absence of unconsolidated substrate within which to stabilize righted corals, and a need to divert diver efforts towards concrete stabilization of corals and continued damage pre-assessment. However, throughout the period of emergency restoration and pre-assessment, large isolated lobate *Porites* and *Pocillopora eydouxi* corals were righted when encountered. Only general attributes of the coral righting information (species, minimum number of righted colonies/fragments, and the size range encompassing all righted corals) were amenable to analysis.

Results

Cemented Corals

A total of 825 corals representing seven species were cemented in 105 individual aggregations at 18 stations in areas impacted by *M/V Cape Flattery* grounding and removal activities (Table 1, Figure 1). Ninety-three of the aggregates included multiple corals and 12 consisted of large, single colonies (Figure 4). One-hundred-thirty-eight (17 %) of the corals were categorized as epiphytes. *Pocillopora meandrina* colonies were the most abundant of the species cemented (48 %), followed by *P. eydouxi* (22 %) and *Porites lobata* (22 %); however, *Pocillopora eydouxi* accounted for half of the cumulative species projected area. Colony sizes ranged from 0.5 cm (coral epiphyte) to 112 cm in greatest diameter and varied between species. The largest colonies were represented by *Porites evermannii*, *P. lobata* and *Pocillopora eydouxi* (Table 1).

Table 1. *M/V Cape Flattery* emergency coral restoration summary data for cemented corals.

Species	Total No. Colonies	No. Epiphytes	No. Measured	Mean Diameter (cm)	Diameter Range (cm)	Mean % Live Tissue	Total Projected Area (m^2)
Montipora capitata	14	14	7	7.3	2 to 19	99.3	0.03
M. patula	47	46	15	14.8	2 to 49	99.3	0.26
Pocillopora eydouxi	184	0	184	38.5	8 to 94	88.9	20.15
P. meandrina	396	33	389	19.1	1 to 52	88.1	9.65
Porites brighami	2	0	2	11.0	10 to 12	97	0.01
P. evermannii	4	0	4	91.3	77 to 112	65.0	2.11
P. lobata	178	45	141	23.9	0.5 to 100	77.1	7.87
Total	**825**	**138**	**742**	**25.0**	**0.5 to 112**	**86.5**	**40.08**

Cumulative projected area of the cement coral aggregations totaled 34 m^2, predictably less than the collective estimate for all aggregate colonies (Table 1, which does not account for adjacent colony overlap). Approximately 660 m^2 of reef was enclosed by the individual site aggregations. If this measure is used as a proxy for reef area restored, then at best, 1 % of the area damaged by grounding and ship removal activities might be considered to have received repair. Although not quantified, the cementing efforts did address the majority of known, large, significant habitat forming colonies that remained detached in the impact area (Kolinski, pers. obs.).

Figure 4. Examples of single (*Porites evermannii*) and multi-colony (*Pocillopora eydouxi, P. meandrina*) aggregates.

Reference Corals

One-hundred-eighty-nine reference corals were mapped and measured within the vicinity of the 18 cement stations (Table 2) and represented four of species cemented. Seven (4 %) of these corals were categorized as epiphytes. The number of reference colonies at a station ranged from 3 to 21 (mean = 11 colonies) and was significantly correlated to cemented colony abundance (Pearson correlation coefficient = 0.595, P = 0.009). *Pocillopora meandrina* was the most abundant reference coral selected (56%), followed by *Porites lobata* (27 %) and *Pocillopora eydouxi* (14%). General size and percent live tissue estimates are provided in Table 2.

Table 2. *M/V Cape Flattery* emergency coral restoration summary data for reference corals.

Species	**Total No. Colonies**	**No. Epiphytes**	**Mean Diameter (cm)**	**Diameter Range (cm)**	**Mean % Live Tissue**	**Total Projected Area (m^2)**
Pocillopora eydouxi	26	0	49.8	20 to 94	85.4	4.50
P. meandrina	106	7	25.7	6 to 40	91.7	4.85
Porites evermannii	6	0	39.3	24 to 59	88.0	0.67
P. lobata	51	0	28.9	8 to 90	80.3	3.63
Total	**189**	**7**	**30.3**	**6 to 94**	**87.3**	**13.65**

Righted Corals

A minimum of 409 colonies and fragments of *Pocillopora meandrina*, *P. eydouxi*, *Porites lobata*, *P. evermannii* and *Montipora patula* were righted in the *Porites* Zone, Intermediate Shelf Pavement Zone, Reef Depressions and Escarpment Crest areas. Righted corals ranged from 5 cm to > 2.5 m in greatest diameter, with a majority < 40 cm. Approximately 50 colonies of *Pocillopora meandrina* righted at 9 m (30 ft.) depth at a known location where displaced by high regional wave action and could not be relocated.

Removal of Metal Debris

A single metal cylinder lacking marine encrustations was removed from a damaged depression in the Intermediate Shelf Pavement Zone. The cylinder was approximately 1 m in length.

Discussion

Cemented Corals

Large area impacts to habitat and organisms and exposure to threats of high wave activity limited the *M/V Cape Flattery* emergency reef restoration to a triage approach. This approach placed emphasis on the long-term stabilization of corals, selected based on their size, species, habitat complexity, susceptibility to wave induced movement and large scale collision, and natural recovery potential. *Pocillopora eydouxi* and large lobate *Porites* were the focal species selected and were stabilized using cement, abundant *Pocillopora meandrina* and small sized lobate corals. Long-term stabilization efforts only occurred in areas where live focal species were numerous and/or large secondary threats existed.

Corals in multi-colony aggregates were consolidated at densities higher than that naturally occurring in the Barbers Point region, although similar densities have been observed elsewhere (Kolinski, pers. obs.). These densities were created for structural and logistic purposes, and helped maximize resource and time efficiencies. Competitive interactions may occur between species and colonies over time (Lang 1973). However, the main species restored (comprising 99 % of the non-epiphytic corals) display fairly compatible life history traits for existence in multi-species aggregations. *Pocillopora eydouxi* exhibits high vertical growth through branching, while *P. meandrina* keeps its bush-like mass close to the substrate, and *Porites lobata* remains lobate. *Pocillopora meandrina* displays signs of senescence, with rapid growth and turnover known to occur in the region (Kolinski, unpub. data). *Porites lobata* is slow growing relative to *Pocillopora*, and may be considered a more persistent and tolerant species. Dense colony aggregates should enhance individual species reproductive potential through synchrony in gamete formation, release and fertilization success (Kolinski 2004). The structural complexity of multi-colony aggregates provides habitat diversity and potential shelter for other organisms.

The cementing techniques were adapted from those commonly used to repair corals damaged by ship groundings in Florida (Jaap 2000, Marine Resources Inc. 2004, Hudson, pers. comm.). Similar techniques have also been used to secure *Pocillopora eydouxi*, *P. meandrina* and lobate *Porites* corals on a shallow American Samoa reef flat (Hudson 2000, Jeansonne 2002). Similar to corals in Florida and American Samoa, the Hawaiian corals appeared have responded well to stabilization in the cement foundations. Anecdotal observations (over the initial measurement period) suggest nearly 100 % short-term survival with evidence of individual colony growth in the form of skeletal and tissue regeneration (Figure 5). Following construction, most cement aggregates were quickly colonized by a variety of fish and/or macro-invertebrates (Figure 6). The cement aggregates presently appear as the largest, most topographically complex, stable, live coral habitat features at the majority of damaged areas where repair efforts occurred.

Figure 5. Tissue regeneration, *Pocillopora eydouxi*

Figure 6. Colonization of aggregates by fish and invertebrates.

Wave induced scour and movement of detached corals and fragments can limit their ability to survive, regenerate and grow (Smith and Hughes 1999, Dollar and Tribble 1993, Knowlton et al. 1981). Favorable environmental conditions in the Barbers Point region allowed detached corals and fragments to persist longer than initially projected (Kolinski 2005a), particularly at deeper depths. Live material deemed suitable for cementing was available for a minimum six week period, despite the presence of coral eating predators (*Acanthaster planci*, *Culcita novaeguineae*, and *Drupella* sp.). Information gained on the temporal ability of detached, injured corals to survive will be useful in planning and preparing for future emergency reef restoration events.

Although the cement stabilization appears to have been initially successful, a number of regional threats remain that can potentially impact the long-term viability of the coral aggregate formations. Thousands of corals and fragments remain detached on the reef. Wave induced movement of this reef "debris" could cause collision and partial burial of individual colonies within the aggregates. Breakage may also result directly from extreme wave energy, small boat anchors, ship groundings and removal, and fishing activities. Biological threats include collision by green turtles (*Chelonia mydas*; Figure 7), predation by coral eating invertebrates and potential overgrowth by invasive species. Multiple comparisons of cemented and reference colony survival and growth over time will be necessary to determine the long-term success of these coral stabilization efforts.

Figure 7. *Chelonia mydas* above cement aggregates.

Righted Corals

Simple righting and placement of detached corals and fragments has occurred with varied levels of success within the U.S. Affiliated Pacific Islands (Jokiel et al. in press). At Barbers Point, efforts designed to allow for long-term evaluation of this method were eventually abandoned due to strong currents, a general absence of substrate amenable to manually stabilizing righted colonies, a need to divert divers towards concrete stabilization and pre-assessment, and eventual questions about the likelihood of long-term success. The exposure of west Oahu to frequent high wave energy events significantly threatens the success of simple righting of all but the largest (> 1.5 m) coral colonies, particularly in the *M/V Cape Flattery* incident area from the *Porites* Zone to the Escarpment Crest, where hard pavement is the dominant substrate. Energy from relatively small 1.5 m (5 ft.) high waves has been notable at depths of 15 m (50 ft.) by divers on the Escarpment Crest (Kolinski, pers. obs.). Short-term monitoring of corals righted at 9 m (30 ft.) in the Intermediate Shelf Pavement Zone provided evidence of complete, wave induced loss.

Monitoring

A reassessment of the cement aggregates will occur in August and September 2005 to determine the impact of the cement processes on the restored corals. However, long-term monitoring, consisting of annual assessments over a minimum five year period, is recommended to determine restoration success over a more ecologically relevant timescale. Habitat and environmental conditions are likely to vary over a five year period at the emergency restoration site. This variability will undoubtedly include mass movement of ship generated coral reef debris (see Tsutsui et al. 1987). Annual assessments will ease the tracking of individual colonies, provide needed replication for ascertaining trends in population status, and will enhance the ability to identify sources of impacts. Colony stability, survival, growth and reproductive status (when feasible) will be measured, along with habitat utilization by fish and macro-invertebrates.

Acknowledgements

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