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Pre-Assessment Report of Injury to Coral Reef Resources and Habitat in Association with the Grounding and Removal of the *M/V Cape Flattery*, Barbers Point, Oahu

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Contents

List of Figures

List of Tables

Foreword and Acknowledgements

This pre-assessment of injury associated with the grounding of the *M/V Cape Flattery* and response at Barbers Point Harbor, Oahu, Hawaii was conducted by a multi-agency Trustee team of biologists from the State of Hawaii Department of Land and Natural Resources (DLNR), National Marine Fisheries Service Pacific Islands Regional Office (NOAA PIRO) and the U.S. Fish and Wildlife Service (FWS). The Trustees did invite representatives of the Responsible Party (RP) to participate in this pre-assessment; however, the RP declined. Five general categories of coral reef community composition were measured, including scleractinian corals (Steven Kolinski, NOAA PIRO; David Gulko, DLNR), major non-coral macro-invertebrates (Kevin Foster, FWS), algae (Ryan Okano, DLNR), fish and substrate topographic complexity (Matthew Parry, NOAA PIRO; Gordon Smith, FWS; Paul Murakawa, DLNR). The methods utilized limited the assessment of injury to gross impacts.

A number of Trustee representatives participated in supporting the pre-assessment activities, including but not limited to John Cubit, Doug Helton, Katherine Pease, Patrick Rutten, Robert Ricker, Steve Thur, Mark Curry, Lindsay Yates (NOAA Damage Assessment Remediation and Restoration Program), Chuck McKinley, Roger Helm, Karen Rosa (FWS), Kathy Ho (State of Hawaii Attorney Generals Office), Robert O'Conner, John Naughton, Alan Everson and Gerry Davis (NOAA PIRO). Randy Cates and his crew (Cates International) provided boat support. Underwater photographs of coral reef community sites and injury at Barbers Point were captured and provided by Steven Kolinski. Information, ideas, support and discussions with Polaris Applied Sciences, Inc. were and continue to be appreciated.

Executive Summary

A pre-assessment (referred to here after as assessment) of injury to coral reef habitat and resources associated with the February 2 to 11, 2005 grounding of the 555 ft bulk carrier *M/V Cape Flattery* and response near the entrance channel to Barbers Point Harbor, west Oahu, Hawaii, was conducted between September 6 and November 30, 2005 by biologists from the State of Hawaii Department of Land and Natural Resources, National Marine Fisheries Service Pacific Islands Regional Office, and the U.S. Fish and Wildlife Service. Responsible Party representatives were invited to participate but declined. Injuries to habitat and resources were estimated to have occurred across 79,085 m^2 (19.5 acres) of coral reef. Five habitat zones, including steep outer reef escarpment slope (45 to 80 ft depths), escarpment top (crest, top and protruding ridges, 45 to 55 ft depths), gradually sloping shelf pavement (25 to 45 ft depths), natural reef depressions (25 to 40 ft depths), and an inshore lobate *Porites* aggregate area (25 to 35 ft depths) were surveyed. Injury to deep rock and seagrass habitat, located offshore of the escarpment (80 to > 120 ft depths), was not assessed due to diving time and depth limitations.

The assessment was designed to ascertain gross impacts to major constituents (substrate topography, scleractinian corals, non-coral macroinvertebrates, algae and fish) of the coral reef community in the incident area. The data also serve as baseline for defining injury as it relates to natural temporal community trends and for monitoring further site degradation and/or recovery. Relevant information on community structure prior to the grounding was not available. Severe crushing, breakage and displacement of reef habitat and organisms limited the ability to directly assess injury. This assessment was therefore based on community comparisons between impact and reference habitats.

Inference in comparing impact and reference habitats is complicated for unplanned incidents such as ship groundings by an inability to replicate and randomly assign impact treatments (i.e. multiple ship groundings) for measurement and analysis. Although unbiased selection of reference and impact sites occurred, the inability to randomly assign impact treatments increases the risk of spatial confounding. There are no direct methods to determine spatial confounding for this event. However, the incident area was large, encompassed multiple habitat zones, and heterogeneity was observed in remnant communities and debris distributions. Assessment of multiple reference areas was conducted, which enhanced the probability of representing pre-incident communities fairly by accounting for system heterogeneity. Observations of remnant impact communities, debris distributions and areas directly bordering zones of impact provided no reason to believe that reference areas inadequately represented incident impacted habitats. No prior impacts resulting in habitat degradation specific to this incident location were known.

Sample sites were selected by drawing multiple points on area photo maps within and outside suspected regions of incident related impact, and then randomly selecting a set of points for impact and reference area sampling for each habitat zone (with the exception of impact slope sample sites which were fixed). Reference selection included sites north and south of the incident. The location of injury in the shelf pavement zone was differentiated into hull- and non-hull impact areas for sampling and analyses. Five general categories of coral reef community composition, including topographic complexity, scleractinian corals, non-coral macro-invertebrates, algae, and fish, were measured at impact and reference locations. Measurements of rugosity were used to infer topographic complexity along four 10 m transects at replicate sites in escarpment top, shelf pavement and *Porites* zone habitats. Site numbers and size categories of

live coral fragments and attached colonies were assessed for individual species along with numbers of individuals of select groups of Mollusca, Crustacea and Echindermata within multiple 10 m^2 transects in escarpment slope, top, shelf pavement and *Porites* zones and throughout paired reef depressions at replicate sites. Major coral species were grouped by genus, functional habitat form and growth rate into the following categories: *Montipora* encrusting, *Pocillopora meandrina*/cauliflower, *Pocillopora eydouxi* and *Porites* lobate groups. These categories were analyzed with statistics being applied to colony size categories of $<$ or $\geq$ 10 cm greatest diameter. Select species of macroinvertebrates were grouped and analyzed as mobile urchin, boring urchin and guard crab functional groups. Algal cover was assessed within three 0.25 m^2 quadrats along established 10 m transects. In reef depressions two quadrats along the bottom and one on north and south sides of depression walls were measured. Algae were grouped as turf, macro, coralline crustose and invasive species for analyses. Fish numbers and sizes were visually surveyed along two 25 m transects at each site (except slope habitat) or throughout individual reef depressions. Fish were grouped by mobility class (Friedlander and Parrish 1998) for analyses. Separate estimates of injury/loss were determined for corals, macroinvertebrates and coralline crustose algae based on significant differences between reference and impact areas using an α of 0.10 (to account for small sample sizes in a heterogeneous environment) by multiplying the difference in mean densities by estimated area of injury in each habitat zone. Modified injury values and power analysis results were provided when P-values ranged between 0.100 and 0.050. Corals with injury/loss estimates were further differentiated into their original size categories for estimating the length of time needed for coral population recovery, which is not included in this report.

Over 1 million corals, 150,000 macro-invertebrates and 5,000 m^2 of coralline crustose algae were estimated to have been lost/injured as a result of the grounding and response and removal activities of the *M/V Cape Flattery*. Seventy-one percent of corals were $<$ 10 cm in greatest diameter. Estimated losses were greatest for *Montipora* encrusting and *Porites* lobate species but occurred in all groups. Other community functional groups tended to support ecological loss associated with a large-scale impact. Levels of turf and/or macroalgae tended to be higher in impact compared to reference areas, which supported observations of successional colonization of physically altered substrate. Average fish numbers tended to be lower at impact sites, with statistically significant displacement evident in the shelf pavement region. All habitat zones in the impact area displayed significantly higher live fragment levels than at similar reference sites. In some of these zones, live fragment data suggested injury had occurred to measured species groups, even though it may not have been resolved through statistical analysis of the attached coral community comparisons.

These methods, in particularly the sample sizes, limited the ability to fully account for injury. Fish losses were not projected in this assessment due to difficulties in discerning levels of fish displacement from actual loss. Pulverized fish were observed in impacted areas soon after ship removal. Many of the macro-invertebrate species naturally occur at low densities. Impacts to organisms at low densities are difficult to assess without large numbers of sample replicates or replicate surveys of large spatial areas. Dead attached corals, which provide habitat, were not assessed. Rugosity measurements incorporated the presence of unconsolidated reef debris, which may ultimately shift to reef depressions and/or down the escarpment slope. Communities injured by the anchor and chain in deep rock and seagrass habitats below the escarpment slope, as well as communities at the base of the slope where debris had and will continue to accumulate, were not surveyed in this assessment due to depth, dive time and safety reasons.

In addition, the sampling was not designed to adequately assess the presence of predators at levels useful for applying statistically appropriate comparative analyses. However, measured averages and anecdotal observations suggested larger mean numbers of the coral eating starfish *Acanthaster planci* and *Culcita novaeguinaeae* occurred in impact compared to reference areas in slope and escarpment habitats. *Drupella* sp., a coral eating mollusk not measured in this assessment, was also recently observed (Kolinski, pers. obs.) to be seriously impacting injured and restored Pocilloporid corals in areas disturbed by response efforts. Potential latent effects to corals in the impacted community may have and continue to occur as a result of predator attraction to injured corals resulting from the incident. Additional assessments specific to detecting and comparing predator abundances are recommended for this and future grounding incidents that occur in Hawaii.

Scleractinian corals and coralline crustose algae create and consolidate habitat framework utilized by other sessile and mobile coral reef animals. Herbivorous fish and urchins may facilitate habitat recovery by continuous predation on colonizing fleshy algae, which compete for open space with corals and coralline crustose algae. Although initial projections on recovery rates of corals and coralline crustose algae can be made using current data from the site and the literature, recovery levels and rates of the impacted reef will likely depend on the recruitment, growth and activities of multiple coral reef community constituents, including macro-invertebrates and fish. Hull-impact areas in the shelf pavement zone may be vulnerable to reduced rates and/or overall limited recovery due to the current absence of adequate shelter for herbivores. In addition, the potential for wave induced movement of incident related reef debris poses a threat to remaining coral reef resources and area recruits, which continue to be exposed to potential scouring, collision and burial impacts. Initial efforts have been undertaken by the RP to remove large loose reef debris to reduce threats of further injury, and limited habitat structure has been restored in a portion of the shelf pavement area impacted by the ship's hull. Rapid assessment of the efficacy of these efforts is warranted, as opportunities for resource and recovery benefits from such activities may be reduced with time.

1. Introduction

On February 2, 2005, the 555 ft bulk carrier *M/V Cape Flattery* grounded on coral reef habitat outside the entrance channel to Barbers Point Harbor, Oahu, Hawaii (Figure 1). The U.S. Coast Guard, State of Hawaii and Responsible Parties (RP) developed a Salvage Operations Oil Spill Contingency Plan as part of an Incident Action Plan to provide direction due to a substantial threat of a discharge of oil as the result of the grounding and subsequent response operations. Over the following days, fuel and cement cargo were offloaded, and various tugs and other vessels attempted to remove the vessel. The *Flattery* was towed from the reef on February 11, 2005. Although cement cargo had entered the water during offloading, substantial discharge of oil to the environment had been avoided.

The natural resource trustees for the *M/V Cape Flattery* grounding are the State of Hawaii Department of Land and Natural Resources (DLNR), the State of Hawaii Department of Health, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Fish and Wildlife Service (FWS) (collectively "Trustees" or Natural Resource Trustees). The Trustees have authority to pursue natural resource damage assessment (NRDA) activities pursuant to state and federal statutes and regulations, including but not limited to the Oil Pollution Act of 1990, 33 U.S.C. §§ 2701 *et seq*.; the Oil Pollution Act NRDA Regulations, 15 C.F.R. Part 990; the National Contingency Plan, 40 C.F.R. Part 300, Subpart G; Executive Order 12777; Chapter 128D HRS; and 11-451 Hawaii Administrative Rules. The Natural Resource Trustees and the RP biologists began pre-assessment evaluations on February 11, 2005, collecting direct physical evidence, photo documentation, area measurements and recording observations, to determine whether physical injury to natural resources, including coral reef habitat and its associated community, had occurred as a result of the grounding and response operations. The collective evidence and observations from the these activities confirmed that physical injury to coral reef habitats and resources resulting from *M/V Cape Flattery* stabilization and response activities

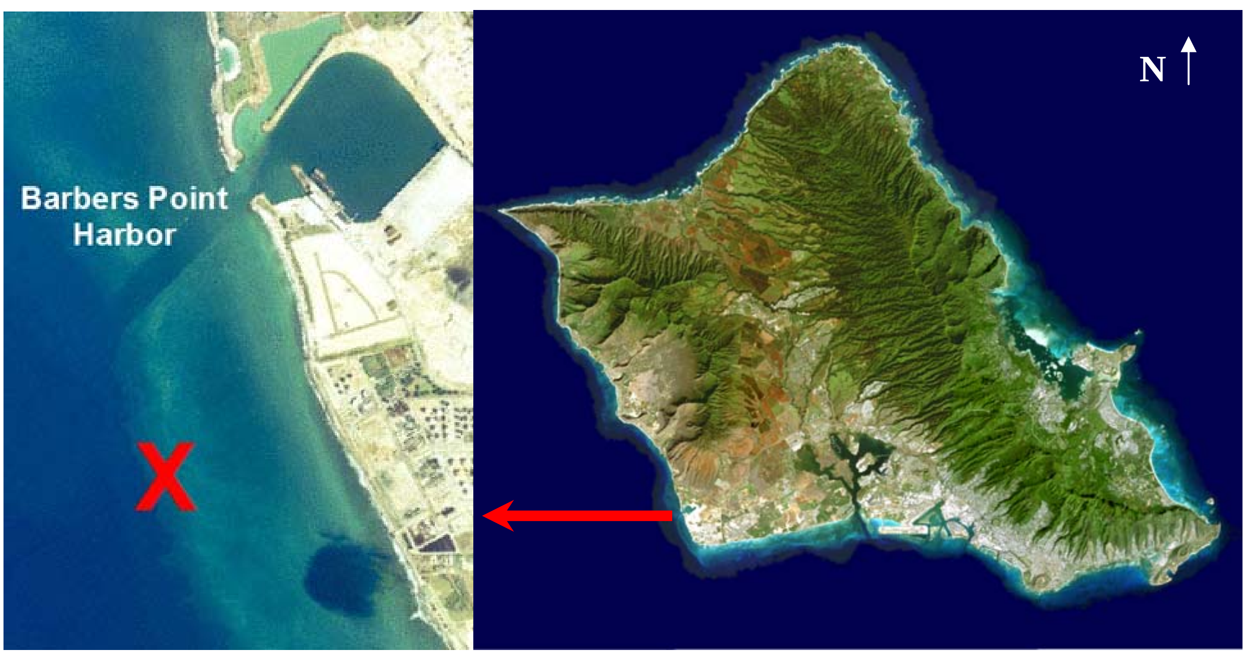

Figure 1. Barbers Point Harbor (left; NOAA Center for Coastal Monitoring and Assessment), Oahu, Hawaii (right; U.S. Geological Survey, Earth Resources Observation Systems Data Center). X = area of *M/V Cape Flattery* incident.

was widespread (Kenyon 2005, Kolinski 2005a and b, Polaris Applied Sciences, Inc. 2005). The Trustees determined that additional actions to quantify and further document injury were necessary.

Initial injury quantification efforts (geo-referenced towed-diver photo documentation surveys) were conducted by the Trustees on February 15, 2005 and reported (Kenyon 2005). This report discusses the additional pre-assessment (here after referred to as assessment) activities and analyses that refine the area estimates and further quantify injury to coral reef habitat and resources.

2. General Methods

This assessment to quantitatively evaluate *M/V Cape Flattery* related injury to coral reef habitat and resources was conducted between 6 September and 30 November 2005 at Barbers Point, Oahu, Hawaii by Trustee biologists. The Trustees invited representatives of the RP to participate in this assessment, which would have enhanced on-site opportunity for cooperative site selection and application of methodologies. However, the RP declined to participate.

The surveys and accompanying analyses focused on refining the quantification of injured area, habitat and resources through measurement and comparison of injured and multiple reference areas. Such comparisons are considered an indirect means of measuring and quantifying injury, but are commonly used as detailed, time-relevant, area specific information on habitat structure and natural resource composition is typically lacking prior to unplanned impacts such as ship groundings for direct comparison (Wiens and Parker 1995, Glasby and Underwood 1996, Underwood et al. 2003, Hudson and Goodwin 2003). Nearby areas that were not impacted during the incident can be considered reasonable pre-incident proxies if multiple locations within habitat zones similar to those injured are sampled, and sample sites are selected blindly to avoid bias. Coral reef communities are heterogeneous across a spectrum of commonly measured spatial and temporal scales (Connell et al. 1997). The use of multiple nearby areas for reference is a suggested approach for enhancing the probability of representing pre-incident communities fairly by accounting for system heterogeneity and reducing potential for spatial confounding (Underwood 1992).

Six habitat zones were observed to have sustained injury as a result of the *Cape Flattery* grounding and response activities (Trustees 2005). These included:

1. **Deep rock and seagrass** –sand, accumulated rock and pavement habitat seaward of the escarpment slope that gradually descends from 80 to > 120 foot (limits of observation) depths. Sand areas appear to be fairly heavily colonized by the seagrass *Halophila decipiens* (a known forage species for Hawaiian green turtles, *Chelonia mydas*; Russell et al. 2003), *Caulerpa* sp, algae, and the non-indigenous algae *Avrainvillea amadelpha*. Accumulated rock debris supports various live corals and macroinvertebrates. This area sustained injury through deployment and removal of the ship's anchor and chain, and is the general recipient of downward moving incident related reef debris.
2. **Escarpment slope - s**ubmerged historical shoreline forming a nearly vertical (in many areas) seaward face of the reef extending from the escarpment top (≈ 45 feet deep) downwards to deep rock and seagrass habitat (≈ 80 feet deep). This slope develops north and south of the Barbers Point Harbor channel and is mainly characterized by small to mid-sized lobate, encrusting and branching corals, various macroinvertebrate species, high coralline crustose, turf and macroalgae

cover, resident and semi-vagile fish species, and caves and crevices utilized by sea turtles and sharks as resting habitat. Various areas of this habitat sustained injury associated with deployment and removal of the ship's anchor and chain and or movement of incident generated reef debris.
3. **Escarpment top area** - including the escarpment crest, protruding ridges and areas within approximately 20 m shoreward of the crest at 45 to 55 foot depths. Much of this pavement based habitat is characterized by heavily colonization by lobate and branching corals, various macroinvertebrates, fairly high turf, macro- and coralline crustose algae cover, and high fish numbers and biomass (relative to the other examined habitat zones). Escarpment top habitat was injured by towlines, cables, anchor chain and movement of incident generated reef debris.
4. **Shelf pavement** – hard reef pavement gradually sloping from roughly 25 foot depth to the escarpment top area at approximately 45 foot depth. The distribution of corals in this habitat is varied, but is mainly characterized by encrusting, lobate and branching species that reach fairly large (> 80 cm diameter) sizes. The community includes various macroinvertebrates, fairly high macro, turf and coralline crustose algae cover and a variety of resident and semi-vagile fish species. Green sea turtles are commonly sited in the area. The shelf pavement community sustained direct impact by the ship's hull, deposition of cement during offloading, and injury from towlines, cables, anchor chain and movement of incident generated reef debris.
5. **Reef depressions -** natural depressions of various sizes and depths scattered throughout the shelf pavement area. These depressions support a variety of coral, macoinvertebrate, algae and resident and semi-vagile fish species, and appear to act as common resting habitat for Hawaiian green turtles. Reef depression communities sustained injury from movement of the ship's hull, towlines, cables and incident related accumulations of sediment and reef debris.
6. ***Porites* zone** – a shoreward extension of shelf pavement at 25 to 35 foot depths characterized by large (> 160 cm diameter) lobate *Porites* coral aggregates, various other coral, macroinvertebrate, algae and resident and semi-vagile fish species. This community sustained injury from towlines and cables during ship stabilization and response activities.

Methods for estimating areas and quantifying injury to natural resources in all but the deep rock and seagrass zone (which was not surveyed in this assessment due to depth related safety and time concerns) are described below.

2.1 Area of Injury

A variety of data and methods were used to document injured areas. Polaris Applied Sciences, Inc. utilized an AquaMap DGPS-linked sonar system in February 2005 to outline injury boundaries and quickly provided an initial graphic for reference (Polaris Applied Sciences, Inc. 2005). Towed-diver surveys, which included six digital photo and video transects across injured habitats at different depths, were conducted by the Trustees on 15 February 2005 and provided gross injury boundaries (Kenyon 2005) as well as geo-referenced images for fine scale injury area analyses. Trustee agencies measured lengths of injured coral reef along 63 line transects that radiated from geo-referenced locations, tracking bearings and noting gross injury types between 21 February and 14 April 2005. Emergency restoration stations, areas where large, incident related broken corals were re-cemented to benthic substrate between 14 February and 22 April (Kolinski 2005b), were geo-referenced as were observed aggregations of large, broken *Pocillopora eydouxi* identified for potential restoration in limited surface tow-transects by

Trustee and Polaris Applied Sciences, Inc. representatives. Trustees also documented geo-referenced sites of injury in conducting natural resource damage assessments between 6 September and 30 November 2005 (Figure 2).

Within the shelf pavement and reef depressions zones, areas were delineated by general injury type including that which appeared to have resulted from impact by the ship's hull (hull-impact) and that from placement and/or movement of towlines, chains, anchors and reef debris (non-hull-impact). Towed-diver videotapes were analyzed and all data relating to geo-referenced locations of injury were combined to estimate injured coral reef area within each of the six designated habitat zones for extrapolation and determination of *M/V Cape Flattery* related resource loss/injury (Figure 3, Table 1). ArcGIS software was used to plot spatial data, draw polygons and calculate areas. The total area of reef depressions was estimated by independent measures of average depression frequency and size (planar area of an ellipse) along nine 50 m transects run throughout the shelf pavement area of injury. Injury extrapolation for reef depressions was limited to an area inclusive and adjacent to hull-impact scarring due to limited and focused sampling within that region. A larger estimate of total reef depression area throughout the shelf pavement zone was subtracted prior to shelf pavement area estimates and analyses.

Table 1. Estimated areas of coral reef habitats injured by non-hull- and hull-impacts associated with the grounding and removal of the *M/V Cape Flattery* at Barbers Point, Oahu.

	Injury Type		
Habitat Zone	**Non-Hull-Impact (m^2)**	**Hull-Impact (m^2)**	**Total (m^2)**
Deep	1,067		1,067
Escarpment Slope	150		150
Escarpment Area	10,971		10,971
Shelf Pavement	41,513	7,243	48,756
Reef Depressions	5,019	2,597	7,616
Porites	10,525		10,525
Total	**69,245**	**9,840**	**79,085**

2.2 Assessment Methods

Surveys were conducted between 6 September and 30 November 2005. Survey sites within injured areas were, with the exception of slope habitat, selected by drawing multiple points on area photo maps within and/or in close proximity to the initial RP AquaMap and Trustee towed-diver based injury polygons, and then randomly selecting (point numbers drawn from a bag) a set of points for sampling within each habitat zone. The shelf pavement injury area was subdivided into non-hull- and hull-impact zones for sampling (specific boundaries of cement deposition were unclear but appeared to overlap the hull-impact area; thus, cement related impacts were not assessed separately). The escarpment area was surveyed in block design fashion with two sites each representing crest, protruding ridge and top. Injured slope sites were considered fixed and were specifically selected for assessment. Similar random based methods were used to select reference sites, although in a manner that ensured sites both north and south of the injury were represented (i.e., if two or three south sites were selected, the last site would be randomly chosen from points north of the injury). Uncertainty regarding overall injury boundaries in the shelf pavement zone prior to and at the time of surveying required having precautionary spatial buffers for reference site selection. This resulted in sites north of the Barbers Point Harbor entrance channel being considered for shelf pavement and reef depression sampling. Sites north of the

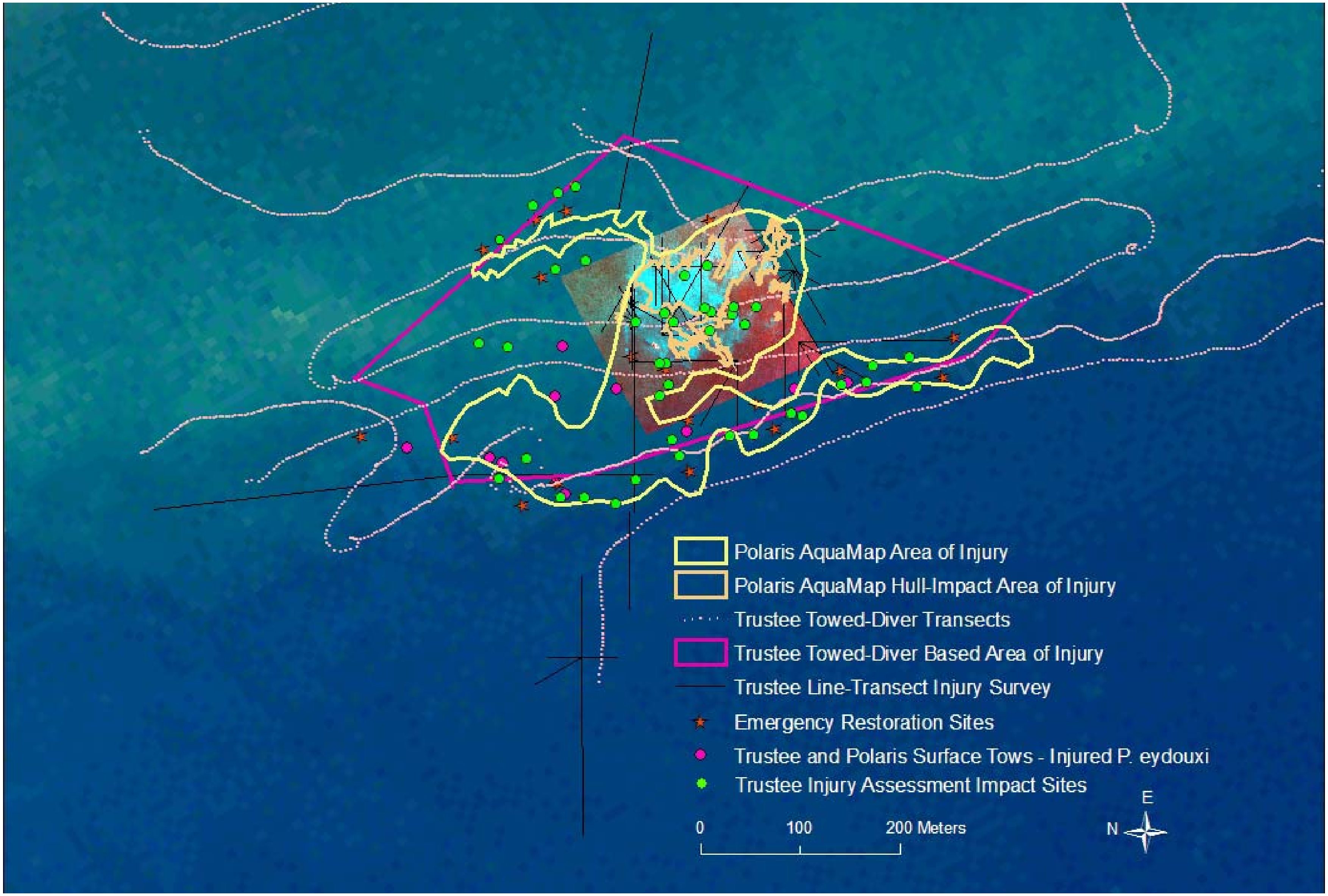

Figure 2. Geo-referenced locations of injury and initial injury polygon projections.

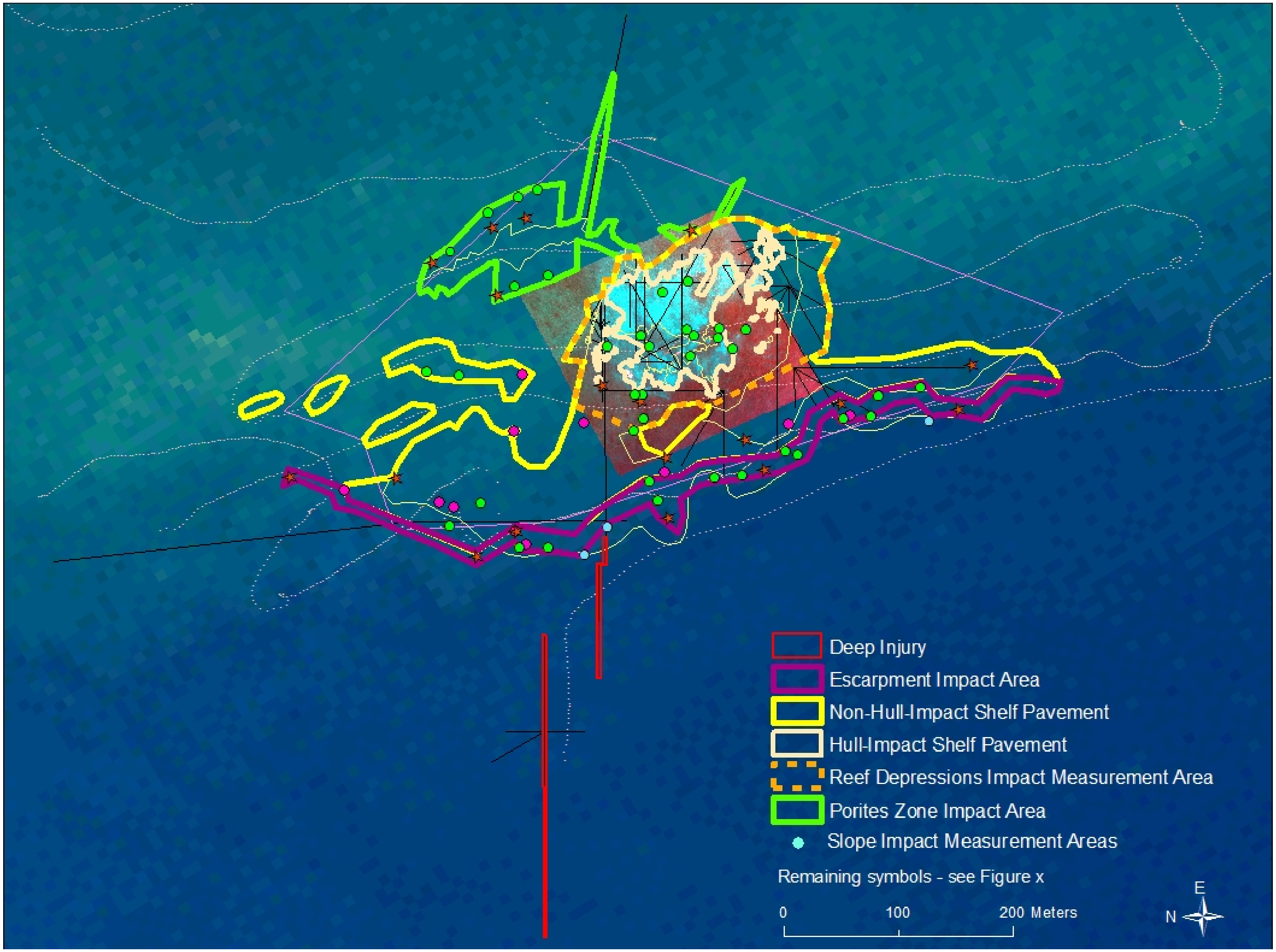

Figure 3. Area of *M/V Cape Flattery* incident related injury delineated by general habitat zone.

harbor channel were also considered as reference habitat for slope and escarpment surveys as the escarpment naturally tapered directly north of the injured area but redeveloped north of the channel. Sample point error (in many cases due to drift of the boat and or divers in strong currents away from selected sites and sub-habitats) was resolved by swimming to and deploying in the nearest area representing the targeted habitat zone.

In slope habitats, fish teams surveyed a single visual transect from reef crest to escarpment slope bottom. Two 10 m transects were then deployed and surveyed by the benthic team, one approximately midway down the slope and one just above slope bottom parallel to the escarpment (slope crest measurements were considered separately in escarpment area surveys). At escarpment area, shelf pavement and *Porites* zone sites, fish biologists deployed two 25 m linear transects parallel to shore and/or the escarpment crest while conducting fish assessments. In shelf pavement areas, reef depressions were avoided for separate surveys. Benthic survey team members entered the water to assess coral, macro-invertebrate and algae community composition along the 10 m ends of each 25 m transect (i.e., only the 0 to 10 m and 15 to 25 m sections of each transect were sampled) following completion of fish assessments along the first 25 m transect. Reef depressions were selected based on size (> 2.5 m length) and depth (> 0.5 m) at each site. Two neighboring depressions were surveyed at all but one site (where the ability to pair with an additional depression was limited by diver air consumption and available time). Planar areas (ellipse, determined from longest length and perpendicular width measures) and depth were measured for each depression. Fish and benthic organisms were assessed within each full depression. Rugosity (ratio of the length of 1 cm linked chain draped to conform to substrate under each 10 m end section of transect to 10 m) was measured by fish team members at all but the slope and reef depression sites, where it was thought difficulties with consistent deployment and down-slope chain slippage would increase sampling error. Digital photos of communities and substrate were collected every 0.5 m along the 10 m ends of each transect. These photos were taken from 0.5 m distance directly above imaged substrate. Photos were similarly taken midway down depression walls as well as along the lips of each depression. General area and habitat photos were collected along the length of each surveyed 10 m of transect and depression.

Corals, macro-invertebrates, algae and fish were surveyed as follows to clarify incident related impacts to major constituents of the coral reef community.

Corals: All visible live corals within 0.5 m of each side of the 10 m ends of each 25 m transect were identified to species, categorized by size (longest linear dimension; size categories = 0 to < 2 cm, 2 to < 5 cm, 5 to < 10 cm, 10 to < 20 cm, 20 to < 40 cm, 40 to < 80 cm, 80 to < 160 cm, and 160 + cm) and recorded. Living fragments and detached colonies were enumerated, sized and noted, as were colonies that appeared to have been completely parted by fission. In slope habitats each 10 m transect was assessed. Corals were assessed throughout surveyed reef depressions, including an outer 0.5 m rim bordering the inner lip of each depression. Select species were grouped by genus, functional habitat form and growth rate into *Montipora* encrusting, *Pocillopora meandrina*/cauliflower, *Pocillopora eydouxi*, and *Porites* lobate groups for analyses. Remaining species were not grouped for analysis due to low site representation. Data were averaged across all transect subsections at each site for analyses.

Macro-Invertebrates: Individuals from the phyla Mollusca (snails, bivalves, and octopus), Crustacea (guard crabs) and Echinodermata (asteroids, echinoids, and holothuroids) within 0.5 m of each side of the 10 m ends of each 25 m transect were identified to species (when possible), enumerated and recorded. In slope habitats the full 10 m transects were assessed, as were surveyed reef depressions. Select species were consolidated into three functional groups (mobile urchins, boring urchins and guard crabs) for analysis based on their relative abundance, critical functional capacity and susceptibility to incident related injury. Data were averaged across all transect subsections at each site for analyses.

Algae: Algal cover was assessed within three 0.25 m^2 quadrats placed at the zero, 5 m and 10 m marks of surveyed 10 m sections of each transect. In reef depressions, two quadrats were surveyed on the depression bottoms on the north and south sides, and two quadrats were surveyed midway down depression walls on sides facing east and west. Each quadrat was divided by lines crossed to give 49 evenly spaced points. Twenty points were randomly selected prior to site entry for point intercept identification. Alga or substrate beneath each of the 20 points was identified to species or genus level when possible, or was categorized by functional group (i.e., turf algae, coralline crustose algae). Turf algae consisted of all unidentifiable upright algal species < 1 cm in height (including diatoms but not blue-green algae). Non-indigenous species listed in Smith et al. 2002 were considered invasive. Proportional cover was determined for each species or functional group by dividing total number of relevant points by the total for each 10 m section of transect or depression. These data were consolidated by general functional group (macroalgae, coralline crustose algae, turf algae and invasive algae) for analysis. Data were averaged across all transect subsections at each site for analyses.

Fish: Fish ≥ 10 cm were identified to species, sized (visual estimate of total length), and enumerated within 2 m of each side and above two 25 m transects during transect deployment in escarpment, shelf pavement and *Porites* zone areas, with subsequent measures of fish < 10 cm (including cryptic fish) occurring within 1 m of transects during secondary swims following individual transect deployment. In slope habitats, divers deployed and surveyed a single transect. Two divers progressed abreast of each other and counted fish on their respective transect sides in roughly the same visual zone. Reef depressions were visually divided, and all fish were surveyed by divers in their respective depression halves. Visual fish census methods are commonly applied in Hawaiian coral reef habitats as they are non-destructive (Brock 1954, Godwin and Kosaki 1989, Friedlander and Parrish 1998, Friedlander et al. 2003); however, sampling error may be enhanced if potential for multiple counts of individual fish is realized. Care was taken to ensure that fish were not recounted when they moved from one side of a transect to the other, and fish observed to cross transect halves were assumed to have been previously counted.

Fish densities along 25 m transects were calculated by dividing recorded numbers by 100 m^2 for fish ≥ 10 cm, 50 m^2 for fish < 10 cm, with slope areas (denominators) modified based on transect length, and planar ellipse areas (denominators) used for reef depressions. Fish numbers m^{-2} were transformed into numbers ha^{-1}, with lengths used to calculate biomass as tons ha^{-1} using published length to weight conversions. Fish species were categorized into site fidelity groups (mobility classes) based on Friedlander and Parrish (1998). These groups include R (Resident, species with limited movement and well defined home ranges), S1 (Semi-vagile, species that are semi-vagile with daily movements on the order of tens of meters), S2 (Semi-vagile, species that have daily movements on the order of hundreds of meters), and T (Transient, species that move over greater distances). Number and biomass of individuals in each mobility class were summed over each transect, and the means of the two transects per site were used in analyses. Only fishes that were grouped into the two lowest mobility groups (highest site fidelity) were used for statistical analyses. The rationale was that the higher mobility and transient fishes were not likely to have been impacted by incident related effects that only represent a small portion of their total home ranges, and these groups are unevenly sampled with this type of transect method. Conversely, less mobile fishes, with greater site fidelity, would be more likely impacted by the incident which probably represents either all or the majority of their home ranges.

2.3 Statistics and Injury Projections

Injury to a variety of coral reef resources had been observed and documented in pre-assessment activities. The purpose of this assessment was to quantify injury, not determine whether it had occurred. Statistical hypotheses thus tended, for most functional groups, to be one sided. A priori, numbers of attached corals were hypothesized to be less dense in injured areas while fragment numbers were predicted to be higher; urchin and guard crab functional groups were hypothesized to be lower in injured compared to reference areas; coralline crustose algae was hypothesized to be lower, while turf algae was predicted to be higher (a reflection of successional colonization of newly opened substrate) in impact compared to reference areas (predictions on macro- and invasive algae functional groups were uncertain); fish numbers were predicted to be lower in areas devoid of habitat structure (hull-impact area), although uncertainty existed about an ability to determine effects in areas where structure, whether or not attached, remained. When multiple factors (coral sizes, fish mobility classes) or impact types (non-hull- and hull-impacts) were considered, two-sided ANOVAs (one-way, factorial, block) with contrasts were used. If test assumptions could not be met, factors were independently evaluated with appropriate one- or two-sided tests. In all other cases one-sided tests were used. In most cases, transformations (square-root, log, arcsine square-root) were used to meet model assumptions.

Although multiple transects and transect sections or depressions were assessed at each site, they lacked broader spatial independence and were considered sub-samples that were averaged for analysis. The advantage of sub-sampling and averaging is better site representation (Underwood 1997). Size and extent of injury, time, depth, availability of people and boats, and weather conditions limited overall sampling for each habitat zone, therefore numbers of site replicates for analyses were low. In addition, the sampling design was most conducive to the use of 2-sided statistical procedures (which questions difference without a priori expectation) whereas the a priori expectation in most analyses was 1-sided (most community parameters were hypothesized a priori to be lower in impacted compared to reference regions). To counteract the likelihood of type II statistical error (probability of accepting the null hypothesis of no difference when one truly exists) as a result of low replicate numbers and 2-sided test limitations, α was conservatively set at 0.100 (Wiens and Parker 1995, Mapstone 1995, 1996). However, modified injury values and power analysis results were provided when P-values ranged between 0.100 and 0.050.

Functional groups were analyzed separately. Attached corals and fragments were also analyzed separately, with attached individuals consolidated into small (0 to < 10 cm) and large ($\geq$ 10 cm) size categories within each functional group. These groupings allowed standard parametric tests to be applied despite the relatively small numbers of site replicates, and were biologically based on relative habitat contribution, age and suspected susceptibility to injury. Projections of total loss/injury were calculated for coral, macro-invertebrate and coralline crustose algae functional groups. When statistical comparisons demonstrated significantly lower numbers in impact compared to reference areas, mean differences were multiplied by relevant areas of injury (Table 1). When relevant, small and large coral categories were subdivided into constituent size groups for proportioning extrapolations based on mean proportional distributions of colony sizes in the reference area. This proportioning provides a necessary component for estimating the temporal aspects of injury from a coral recovery perspective, but assumes equivalent loss/injury proportional to constituent size representation within small and large size categories, a conditional limitation of the analysis.

3. Assessment Descriptions and Results

3.1 Slope Area

Six 50 m^2 slope habitat sites were assessed (Figure 4) within the *M/V Cape Flattery* removal and nearby reference areas at 53 to 73 ft depths between 19 September and 15 November 2005. Slope impact sites were selected based on habitat degradation associated with deployment and/or retrieval of the *M/V Cape Flattery* anchor chain and movement of detached escarpment top corals down-slope (Figure 5). Reference areas were randomly chosen from multiple points distributed on a map both north and south of the area of presumed impact. Site selection from these points was based on identification of the closest slope habitat area with similar grade and depth to that observed at sites of impact (slope topography tapered and was characterized by shallower depths north of the impact area but redeveloped north of the channel; Figure 4). Fish were assessed from slope top to bottom in a transect run perpendicular down-slope. Fish data were analyzed using a factorial ANOVA. A 10 m transect was deployed parallel to the escarpment at mid and deep slope depths for benthic resource assessments (i.e., two 10 m transects per site). Data were blocked by depth and analyzed using block design factorial

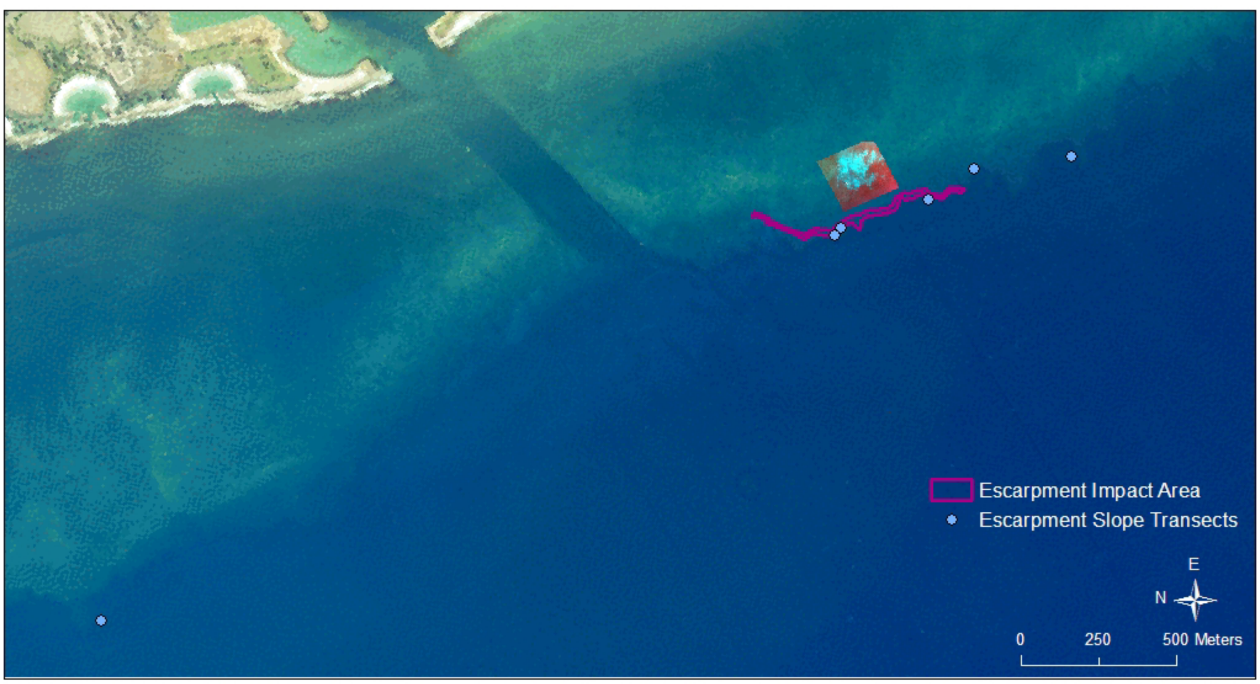

Figure 4. Escarpment slope impact and reference sites relative to where the ship grounded (each point represents the approximate beginning of two parallel 10 m transects placed at different depths).

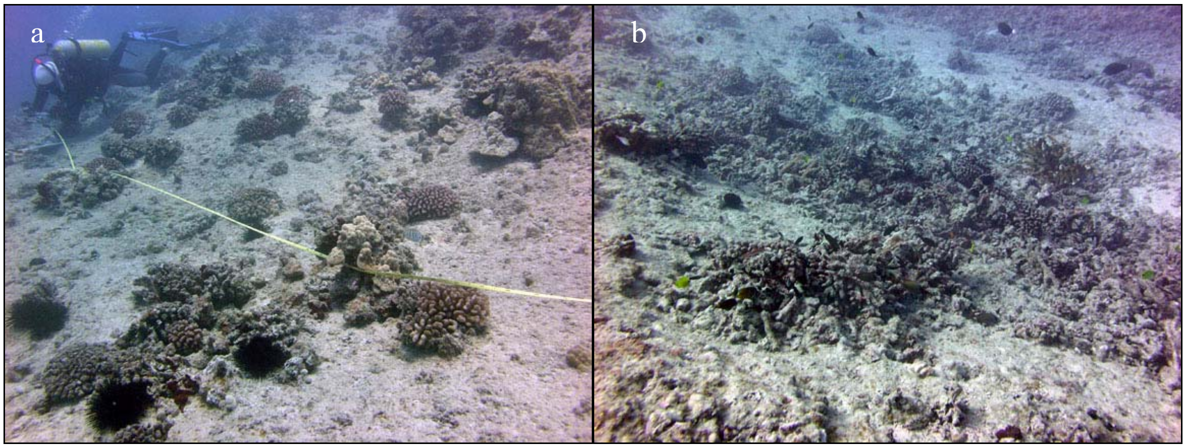

Figure 5. (a) Mid-slope reference site. (b) Down-slope view at an impact site showing broken, accumulated, mainly dead/dying coral debris.

ANOVAs followed by Tukeys HDS comparisons or T-test contrasts. Data not conforming to model assumptions were analyzed using appropriate one-sided T-tests. Extrapolations were confined to 10 m x 5 m areas from just below the slope crest to slope bottom, and were limited to species-functional groups and, for corals, colony sizes (categorized as small and large for initial analyses), for which average densities or proportional cover were demonstrated to be significantly different ($\alpha = 0.10$). Although injury was evident outside the areas assessed, impact sites were considered fixed; thus, community differences were not extrapolated over broader areas for projections of potential injury/loss. Rugosity was not measured along mid and deep slope transects due to difficulties with chain slippage down-slope.

3.1.1 Scleractinian Corals

A total 1,353 scleractinian corals (86 %) and coral fragments (14 %) representing 12 species were identified along transects established in the operational (impact) area of *M/V Cape Flattery* removal and reference areas along mid and deep sections of escarpment slope (Figure 6). Twenty-seven percent of attached corals and 89 % of fragments were identified in the area of impact. Seven (58 %) of the species were grouped by genus, functional habitat form and growth rate into *Montipora* encrusting (*M. capitata*, *M. patula*), *Pocillopora meandrina*, *Pocillopora eydouxi*, and *Porites* lobate (*P. brighami*, *P. evermanni*, *P. lobata*) groups for analyses. Species representatives of these four groups were observed as injured (detached, fragmented, tissue and/or skeletal loss) in the operational area of *M/V Cape Flattery* removal (Figure 7). *Fungia granulosa*, *F. scutaria*, *Leptastrea purpurea*, *Pavona duerdeni* and *Porites compressa* were present along transects but not analyzed due to low site representation.

3.1.1.1 Attached Coral Analyses

Average values (± S.E.) of small (0 to < 10 cm greatest diameter) and large (10 to > 160 cm) attached colony size categorizations for species groups are shown in Table 2 and Figure 8. The *Porites* lobate and *Montipora* encrusting groups dominated relative abundance at reference and impact sites. Small colonies tended to be more abundant than large. Comparative analyses of individual species groups showed significantly lower numbers of small attached *Montipora* encrusting and small and large *Pocillopora meandrina* at impact sites (Table 3). *Pocillopora* *eydouxi* and *Porites* lobate colonies showed similar mean trends; however, significant differences were not apparent with the low sample size.

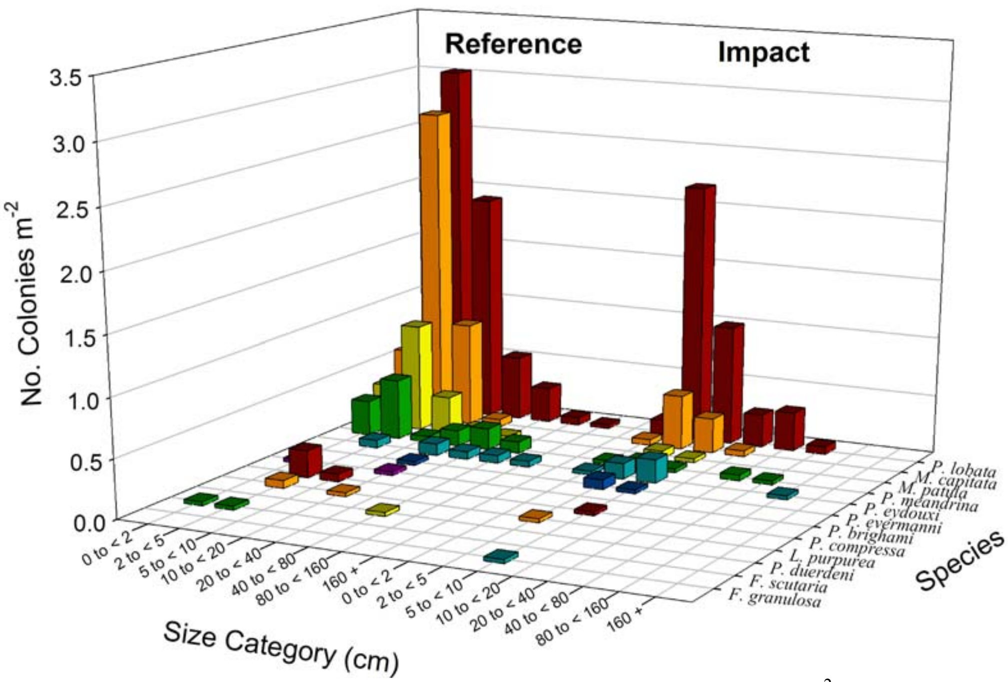

Figure 6. Coral community composition represented as average no. attached colonies m^{-2} in reference and impact areas of the escarpment slope.

Figure 7. (a) Broken, detached *Pocillopora meandrina*. (b) Broken, overturned *P. eydouxi*. (c). Overturned *Porites lobata*. No photos available of injured *Montipora* encrusting species.

Table 2. Average (± S.E.) attached colony numbers m^{-2} of species group size data for small (< 10 cm) and large (≥ 10 cm) colonies (n = 3 mid and 3 deep slope surveys).

Species Group	n	Size Group	Reference	Impact
Montipora encrusting	6	small	5.850 ± 1.766	0.850 ± 0.305
	6	large	0.083 ± 0.065	0.050 ± 0.022
Pocillopora meandrina	6	small	0.867 ± 0.220	0.100 ± 0.063
	6	large	0.367 ± 0.115	0.083 ± 0.048
Pocillopora eydouxi	6	small	1.150 ± 1.150	0.083 ± 0.065
	6	large	0.217 ± 0.178	0.117 ± 0.060
Porites lobate	6	small	4.433 ± 1.133	3.450 ± 0.389
	6	large	0.917 ± 0.263	0.483 ± 0.185

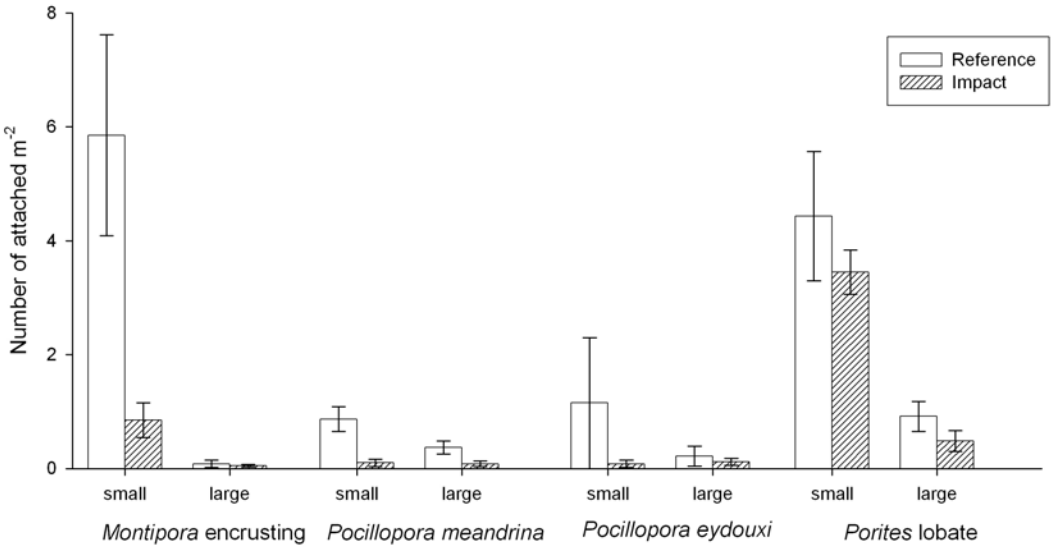

Figure 8. Average (± S.E.) attached colony numbers m^{-2} of species group size data for small (< 10 cm) and large (≥ 10 cm) colonies.

Table 3. Block design factorial ANOVAs with Tukey HSD comparisons of Location mean attached colonies m^{-2} and T-test contrasts for Intxn terms for species groups in reference (Ref) and impact (Imp) areas (data square-root transformed to conform to model assumptions). Depth (Block) = mid-slope, deep slope. L = large colonies; S = small colonies; nsd = no significant difference.

Source	**DF**	**SS**	**MS**	**F**	**P**	
***Montipora* encrusting**						
Depth	1	0.358	0.358			
Location (A)	1	3.054	3.054	12.00	0.003	
Size (B)	1	11.880	11.880	46.69	0.000	
Intxn (A × B)	1	3.054	3.054	12.00	0.003	L Ref L Imp nsd
Error	19	4.834	0.254			S Ref > S Imp
Total	23	23.181				
Pocillopora meandrina						
Depth	1	0.042	0.042			
Location (A)	1	1.509	1.509	17.64	0.001	Ref > Imp
Size (B)	1	0.198	0.199	2.32	0.144	
Intxn (A × B)	1	0.169	0.169	1.97	0.176	
Error	19	1.625	0.086			
Total	23	3.543				
Pocillopora eydouxi						
Depth	1	0.072	0.072			
Location (A)	1	0.158	0.158	0.42	0.527	
Size (B)	1	0.010	0.010	0.03	0.875	
Intxn (A × B)	1	0.083	0.083	0.22	0.646	
Error	19	7.225	0.380			
Total	23	7.547				
***Porites* lobate**						
Depth	1	2.542	2.542			
Location (A)	1	0.263	0.263	1.72	0.206	
Size (B)	1	8.103	8.103	53.02	0.000	
Intxn (A × B)	1	0.050	0.049	0.32	0.576	
Error	19	2.904	0.153			
Total	23	13.861				

Indirect quantification of potential colony loss/injury through examination of differences between reference and impact site mean colony numbers m^{-2} is shown in Table 4. Mean differences were extrapolated only within the surveyed impact sites (three 10 m x 5 m sites) to estimate potential colony loss/injury for species groups that displayed significant differences. Subdivision of small and large categories into constituent size groups (based on mean proportional distributions of colony sizes at reference sites) provides a necessary component for estimating the temporal aspects of injury from a recovery perspective (Table 5). This method assumes equivalent loss/injury proportional to constituent size representation within small and large size categories, a conditional limitation of the analysis. A total 908 *Montipora* encrusting and *Pocillopora* meandrina colonies were projected as injured through coral community comparisons, with 95 % < 10 cm (small) and 5 % ≥ 10 cm (large).

Table 4. Potential colony loss/injury (area with injury = 150 m^2; n = 3 mid and 3 deep slope surveys).

Species Group	n	Size Group	Diff. in Mean Colonies m^{-2}	Potential Loss/Injury (colonies)
Montipora encrusting	6	small	5.000	750
Pocillopora meandrina	6	small	0.767	115
	6	large	0.284	43

Table 5. Percentage of coral colony sizes constituting small and large categories and associated estimates of potential loss/injury (% of Total × Table 4 Potential Loss/Injury).

	Colony Size Category						
	Small Colonies			Large Colonies			
	1 to < 2 cm	2 to < 5 cm	5 to < 10 cm	10 to < 20 cm	20 to < 40 cm	40 to < 80 cm	Total
***Montipora* encrusting**							
Percent of Total (Ref)	24.58	53.83	21.59	na	na	na	
Potential Loss/Injury	184	404	162				750
Pocillopora meandrina							
Percent of Total (Ref)	38.39	55.06	6.55	3.33	80.30	16.36	
Potential Loss/Injury	44	63	8	1	35	7	158

3.1.1.2 Fragment Analyses

Average live (at the time of surveys) fragment numbers and proportions (live fragments/all colonies within a species group) m^{-2} appeared highest at fixed impact sites and were dominated by *Porites* lobate corals (Table 6, Figure 9). Only the *Porites* lobate species group displayed significantly higher numbers and proportions of fragments m^{-2} at impact compared to reference sites (Table 7); *Pocillopora meandrina* had significantly higher fragment m^{-2} numbers (one-sided T-test that mean impact > 0, the average value for reference sites, df = 2, T = 2.00, P = 0.092; Power = 0.384 at α = 0.050) but not proportions (one-sided T-test that arcsine square-root mean impact > 0, the average value for reference sites, df = 2, T = 1.46, P = 0.141).

Table 6. Average (± S.E.) numbers and proportions of live fragments m^{-2} (n = 3 mid and 3 deep slope surveys).

		Numbers		Proportions	
Species Group	n	Reference	Impact	Reference	Impact
Montipora encrusting	6	0.017 ± 0.017	0.033 ± 0.021	0.001 ± 0.001	0.035 ± 0.027
Pocillopora meandrina	6	0 ± 0	0.033 ± 0.021	0 ± 0	0.200 ± 0.163
Pocillopora eydouxi	6	0.033 ± 0.021	0.133 ± 0.072	0.085 ± 0.083	0.352 ± 0.178
Porites lobate	6	0.317 ± 0.182	2.617 ± 0.719	0.059 ± 0.034	0.375 ± 0.063

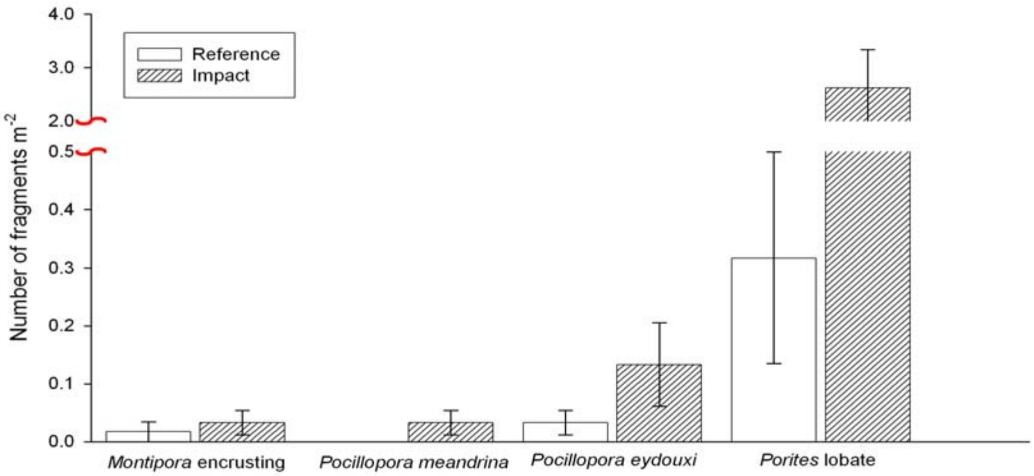

Figure 9. Average (± S.E.) numbers of live fragments m^{-2} for species groups in reference and impact areas.

Table 7. Block design ANOVAs with Tukey HSD comparisons of numbers and proportions of live fragments m^{-2} for species groups in reference (Ref) and impact (Imp) areas (number data square-root transformed and proportion data arcsine square-root transformed to conform to model assumptions). Depth (Block) = mid-slope, deep-slope.

Source	DF	SS	MS	F	P	
***Montipora* encrusting**						
number						
Depth	1	0.008	0.008			
Location	1	0.008	0.008	0.36	0.563	
Error	9	0.208	0.023			
Total	11	0.225				
proportion						
Depth	1	0.008	0.008			
Location	1	0.024	0.024	1.40	0.267	
Error	9	0.154	0.017			
Total	11	0.186				
Pocillopora eydouxi						
number						
Depth	1	0.005	0.004			
Location	1	0.062	0.062	1.01	0.342	
Error	9	0.556	0.062			
Total	11	0.622				
proportion						
Depth	1	0.140	0.140			
Location	1	0.468	0.468	1.64	0.232	
Error	9	2.561	0.285			
Total	11	3.169				
***Porites* lobate**						
number						
Depth	1	0.155	0.155			
Location	1	3.533	3.533	15.91	0.003	Imp > Ref
Error	9	1.998	0.222			
Total	11	5.686				
proportion						
Depth	1	0.080	0.080			
Location	1	0.628	0.628	27.68	0.001	Imp > Ref
Error	9	0.204	0.023			
Total	11	0.912				

Fragments tend to slide from steep slope habitats; thus, their contribution to quantifying injury in this zone is very limited. Numbers also may be partially biased by fragment movement from the escarpment crest. Only surviving fragments (those retaining live coral tissue) were surveyed, beginning approximately seven months following the incident. These factors need be considered in interpreting extrapolated projections of injury based on fragments (Table 8).

Table 8. Percentage of live fragment sizes constituting the fragment category and associated estimates of total live fragment numbers (% × 150 m^2 × mean diff. Tot. Frag. No. m^{-2} from Table 6). n.d. = not determinable at α = 0.050.

	Fragment Size Category							
	1 to < 2 cm	**2 to < 5 cm**	**5 to < 10 cm**	**10 to < 20 cm**	**20 to < 40 cm**	**40 to < 80 cm**	**80 to < 160 cm**	**Total**
Pocillopora meandrina								
Percent of Total (Imp)	0	50	0	0	50	0		
Projected No. Frag.		2 (n.d)			2 (n.d)			4 (n.d.)
***Porites* lobate**								
Percent of Total (Imp)	0	15.73	29.64	31.80	16.33	6.50	0	
Projected No. Frag.		54	102	110	56	22		344

3.1.2 Macro-Invertebrates

Fourteen species of select macro-invertebrates were identified along transects surveyed at reference and impact sites (Table 9). Five (36 %) of these were consolidated into three functional groups for analysis based on their relative abundance, critical functional capacity and susceptibility to incident related injury.

Table 9. Macro-invertebrate community represented as average no. organisms m^{-2} in reference and impact areas of the escarpment slope.

Species	Functional Group	Reference	Impact
Mollusca			
Cypraea tigris		0.017	0
Pinctada radiata		0.050	0
Crustacea			
Hymenocera picta		0	0.017
Stenopus hispidus		0	0.050
Scyllarides squammosus		0.017	0
Echinodermata-Asteroids			
Acanthaster planci		0.033	0
Unidentified Brittle Star		0.350	0.350
Echinodermata-Echinoids			
Eucidaris metularia	Mobile Urchin	0.733	0.333
Echinothrix calamaris	Mobile Urchin	0.283	0.200
Tripneustes gratilla	Mobile Urchin	0.083	0.050
Echinostrephus acciculatus	Boring Urchin	2.580	0.967
Echinometra mathaei	Boring Urchin	0.733	0.067
Echinodermata-Holothuroids			
Holothuria hilla		0	0.017
H. whitmaei		0	0.017

3.1.2.1 Macro-Invertebrate Analyses

Average densities (± S.E.) of select macro-invertebrate functional groups are shown in Table 10 and Figure 10. No guard crabs were identified within transects. Significantly lower densities of mobile urchins were identified at impact compared to reference sites (Table 11; Power ≈ 0.44 at α = 0.050). No difference in boring urchins was detected.

Table 10. Average (±S.E.) number m^{-2} of macro-invertebrates by functional group (n = 3 mid and 3 deep slope surveys).

Functional Group	n	Reference	Impact
Boring Urchins	6	3.31 ± 1.37	1.03 ± 0.50
Mobile Urchins	6	1.10 ± 0.19	0.583 ± 0.147
Guard Crabs	6	0 ± 0	0 ± 0

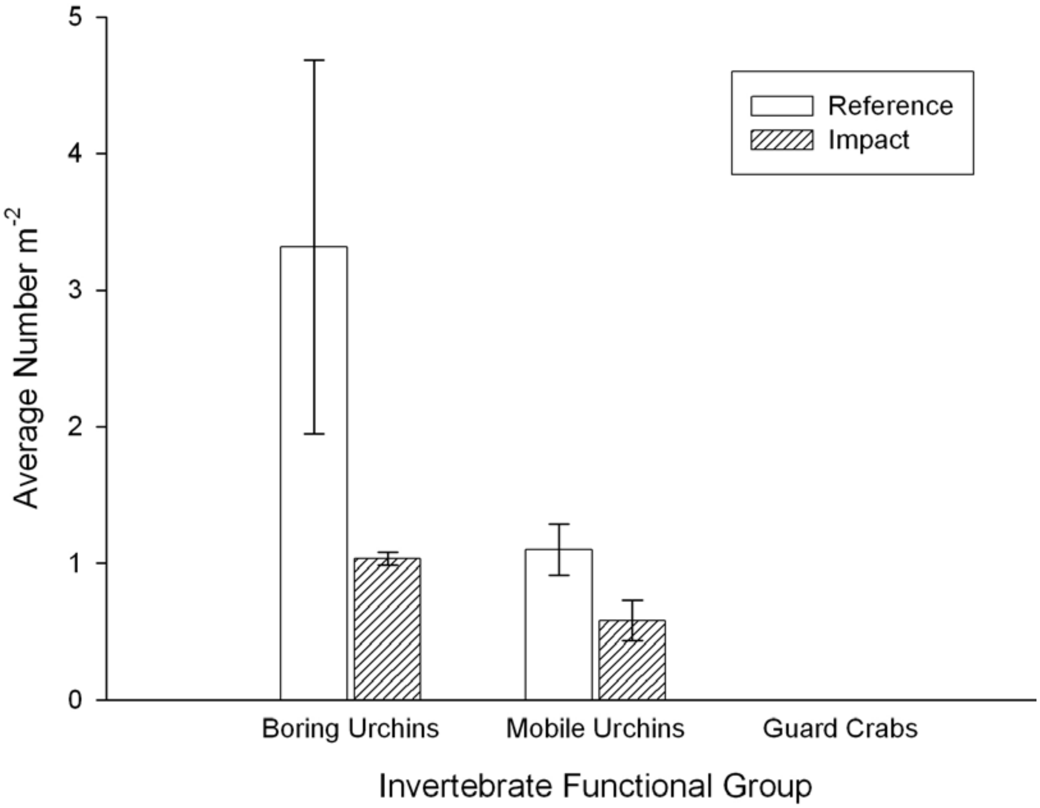

Figure 10. Average (±S.E.) number m^{-2} of macro-invertebrates by functional group.

Table 11. Block design ANOVA with Tukey HSD comparison of Location urchin densities m^{-2} (Ref = reference, Imp = impact). Depth (Block) = mid-slope, deep-slope. Data square-root transformed to meet model assumptions. Note, at α = 0.05, differences in mobile urchin densities would be considered not determinable with given methods.

Source	DF	SS	MS	F	P	
Boring Urchins						
Depth	1	0.275	0.275			
Location	1	1.852	1.852	2.13	0.179	
Error	9	7.843	0.871			
Total	11	9.969				
Mobile Urchins						
Depth	1	0.001	0.001			
Location	1	0.801	0.801	4.22	0.070	Ref > Imp
Error	9	1.708	0.190			
Total	11	2.509				

Indirect quantification of mobile urchin loss through examination of mean density differences at reference and impact sites (0.517 mobile urchins m^{-2}) suggested a potential loss of 78 individuals when extrapolated over the slope impact area (150 m^2) at $\alpha = 0.100$. The potential loss could not be determined at $\alpha = 0.050$.

3.1.3 Algae

Eleven species of macroalgae were identified along with crustose coralline and turf algae in impact and reference areas (Table 12). Algae covered 73 % of the benthic substrate in sampled quadrats at impact sites and 77 % at reference sites. Algal data were consolidated by functional group (macroalgae, coralline crustose algae, turf algae and invasive algae) for evaluation and analysis. The macroalgae were mainly represented by species from the order Gelidiales, *Amansia glomerata* and *Dictyota sp.* (Table 12).

Table 12. Algae community represented as average percent cover at reference and impact sites of the escarpment slope.

Species within Functional Groups	Reference (% cover)	Impact (% cover)
Macroalgae	**23.33**	**11.67**
Amansia glomerata	6.39	0.83
Cladophoropsis herpestica	0	0.28
Dictyota sp.	4.44	5.56
Dictyota friabilis	0.28	0
Gelid.	10.28	3.61
Haloplegma duperreyi	0.28	0
Neomeris annulata	0	0.56
Padina sp.	0.56	0
Ralfsia sp.	0	0.56
Sargassum sp.	0.56	0.28
Tolypiocladia glomerulata	0.56	0
Coralline Crustose Algae	**29.17**	**17.78**
Turf Algae	**24.17**	**42.78**

3.1.3.1 Algae Analyses

Average percent coverage values (± S.E.) of algae functional groups are shown in Table 13 and Figure 11. Of the algae functional groups, coralline crustose algae had the highest cover at reference sites and turf algae had the highest cover at impact sites. Invasive algae were not observed within measured quadrats.

Table 13. Average (± S.E.) percent cover algal functional groups (n = 3 mid and 3 deep slope surveys)..

Functional Group	n	Reference	Impact
Macroalgae	6	23.33 ± 6.90	11.67 ± 4.77
Crustose Coralline Algae	6	29.17 ± 5.16	17.78 ± 6.44
Turf Algae	6	24.17 ± 6.05	42.78 ± 6.63
Invasive Algae	6	0	0

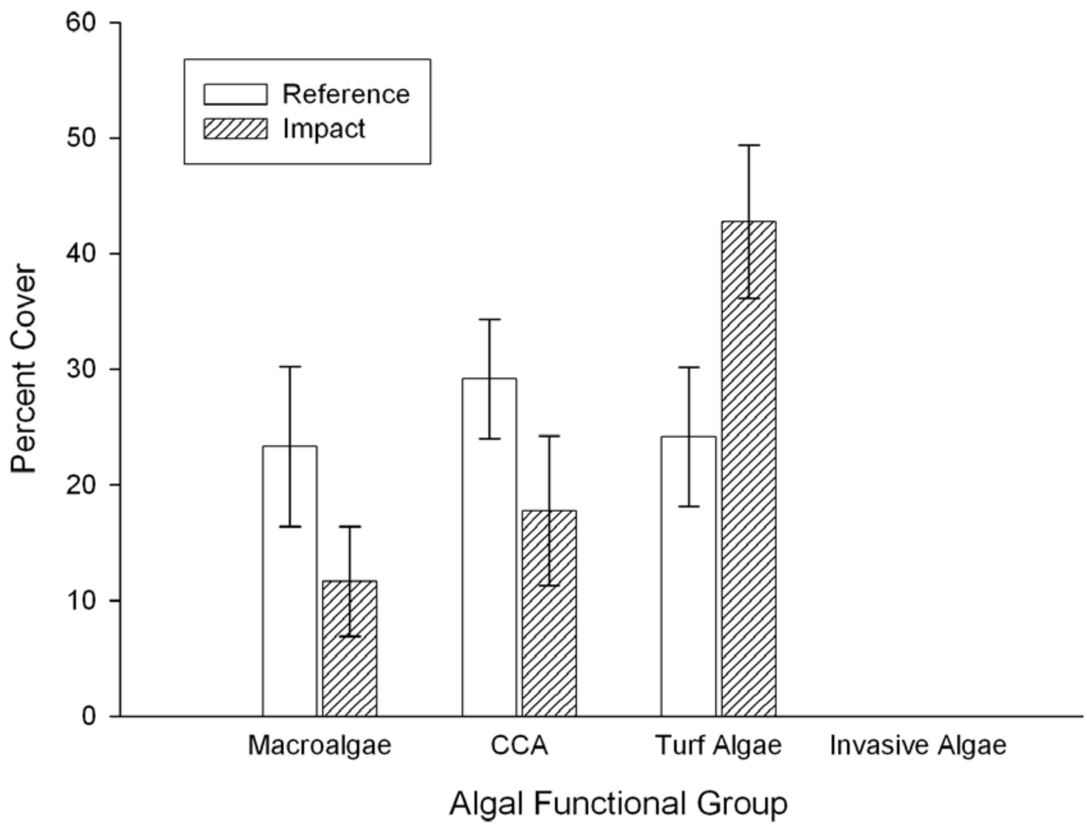

Figure 11. Percent cover (± S.E.) of algal functional groups (CCA = coralline crustose algae).

Turf algae was the only algae functional group that displayed significantly different proportional cover between reference and impact areas (Table 14; Power ≈ 0.429 at $\alpha = 0.050$). The higher cover of turf algae in the impact area is consistent with successional colonization of substrate altered through injury.

Table 14. Block design factorial ANOVAs with Tukey HSD comparisons of Location mean percent cover. Data analyzed as arcsine square-root transformed proportions to conform to model assumptions. Ref = reference sites; Imp = impact sites; nsd=no significant difference; Depth (Block) = mid-slope, deep slope. Note, at $\alpha = 0.05$, differences in turf algae would be considered not determinable.

Source	**DF**	**SS**	**MS**	**F**	**P**	
Macroalgae						
Depth	1	0.047	0.047			
Location	1	0.123	0.123	2.53	0.147	
Error	9	0.439	0.049			
Total	11	0.609				
Coralline Crustose Algae						
Depth	1	0.013	0.013			
Location	1	0.126	0.126	2.22	0.170	
Error	9	0.510	0.057			
Total	11	0.649				
Turf Algae						
Depth	1	0.002	0.002			
Location	1	0.133	0.133	3.98	0.077	Imp > Ref
Error	9	0.300	0.033			
Total	11	0.434				

3.1.4 Fish

A total of 55 species was found along transects in the slope zone. A list of species, by mean abundance in the reference sites, is shown in Table 15. Fifty-two percent of all fish were classified as R mobility (resident species), 43% as S1 mobility (semi-vagile, small area), and 5% as S2 mobility (semi-vagile, larger area). No transient species (T mobility class) were observed.

Table 15. Fish species average abundance (numbers ha^{-1}) at reference (Ref.) and impact (Imp.) areas of the escarpment slope (Mob. = mobility class).

Species	**Mob.**	**Ref.**	**Imp.**	**Species** (cont.)	**Mob.**	**Ref.**	**Imp.**
Chromis vanderbilti	R	3333	6200	*Halichoeres ornatissimus*	S1	133	0
Acanthurus nigrofuscus	S1	3167	600	*Ptereleotris heteroptera*	S1	133	0
Thalassoma duperrey	S1	2467	1433	*Acanthurus olivaceus*	S2	100	0
Apogon kallopterus	R	2200	633	*Coris gaimard*	S1	100	100
Chromis hanui	R	1767	3900	*Plectroglyphidodon imparipennis*	R	100	66.7
Parupeneus multifasciatus	S1	1200	367	*Stethojulis balteata*	S1	100	100
Paracirrhites arcatus	R	1067	400	*Acanthurus triostegus*	S2	66.7	0
Dascyllus albisella	S1	667	0	*Canthigaster coronata*	S1	66.7	0
Pseudocheilinus octotaenia	S1	633	333	*Chaetodon kleinii*	S1	66.7	100
Sargocentron xantherythrum	R	600	0	*Cirrhitops fasciatus*	R	66.7	0
Sufflamen bursa	S1	500	433	*Monotaxis grandoculis*	S2	66.7	0
Canthigaster jactator	S1	400	400	*Paracirrhites forsteri*	R	66.7	0
Macropharyngodon geoffroy	S1	367	100	*Stegastes fasciolatus*	R	66.7	66.7
Parupeneus cyclostomus	S2	333	0	*Sufflamen fraenatus*	S2	66.7	33.3
Zebrasoma flavescens	S1	333	267	*Exallias brevis*	R	33.3	0
Centropyge potteri	R	267	133	*Labroides phthirophagus*	R	33.3	0
Chaetodon ornatissimus	S1	267	200	*Naso lituratus*	S2	33.3	0
Chlorurus sordidus	S2	267	133	*Synodus binotatus*	S2	33.3	0
Melichthys vidua	S1	267	133	*Abudefduf abdominalis*	S1	0	200
Coris venusta	S1	233	267	*Anampses chrysocephalus*	S1	0	100
Chaetodon auriga	S1	200	0	*Chromis agilis*	R	0	66.7
Chaetodon multicinctus	S1	200	267	*Forcipiger flavissimus*	S1	0	66.7
Parapercis schauinslandi	S1	200	0	*Pervagor spilosoma*	S1	0	66.7
Plectroglyphidodon johnstonianus	R	200	0	*Plagiotremus ewaensis*	R	0	100
Lutjanus kasmira	S2	167	833	*Pseudojuloides cerasinus*	S1	0	133
Sargocentron spiniferum	R	167	0	*Pseudocheilinus tetrataenia*	S1	0	200
Ctenochaetus strigosus	S1	133	33.3	*Xanthichthys auromarginatus*	S1	0	33.3
Gomphosus varius	S1	133	133				

3.1.4.1 Fish Analyses

Average number ha^{-1} and biomass by mobility class are shown in Table 16 and Figure 12. Only S1 numbers ha^{-1} were shown to be significantly lower in impact compared to reference sites (Table 17). There were no significant differences between the reference and impact zones in fish biomass (t ha^{-1}) (ANOVA on square-root of biomass: df 1,8, $F = 1.00$, $P = 0.347$). *Dacyllus albisella* and *Sargocentron xantherythum*, two species that often shelter within the branches of large *Pocillopora eydouxi* colonies, were not enumerated in the impact zones.

Table 16. Average number and biomass (± S.E.) of fish by mobility class in reference and impact areas of the escarpment slope.

		Number ha^{-1}		Biomass (t ha^{-1})	
Mobility class	**n**	**Reference**	**Impact**	**Reference**	**Impact**
R	3	9,967 ± 1,922	11,567 ± 1,478	0.093 ± 0.032	0.065 ± 0.014
S1	3	11,967 ± 1,220	6,067 ± 448	0.450 ± 0.234	0.234 ± 0.057
S2	3	1,133 ± 167	1,000 ± 500	0.203 ± 0.184	0.063 ± 0.033
T	3	0 ± 0	0 ± 0	0 ± 0	0 ± 0

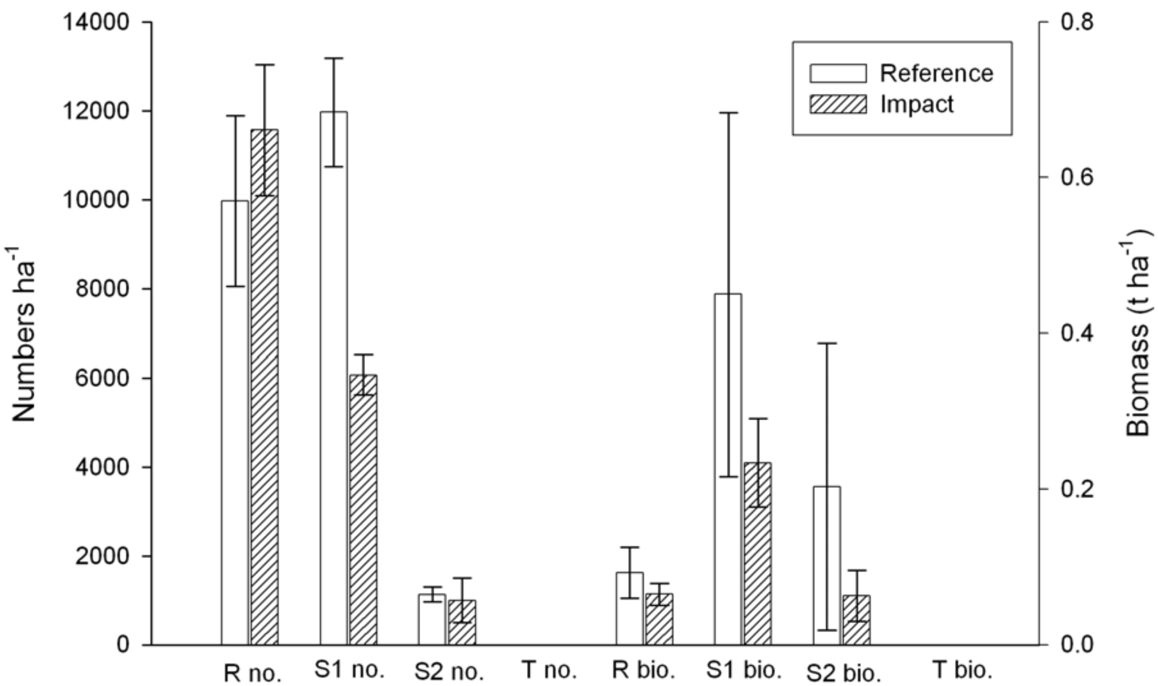

Figure 12. Average number and biomass (± S.E.) of fish by mobility class in reference and impact areas of the escarpment slope.

Table 17. ANOVA for numbers ha^{-1} (square root transformed data) with T-test contrasts for reference (Ref) and impact (Imp) areas (nsd = no significant difference).

Source	**DF**	**SS**	**MS**	**F**	**P**	
Location (A)	1	403.67	403.67	3.09	0.117	
Mobility (B)	1	275.69	275.69	2.11	0.184	
Intxn (A × B)	1	1167.96	1167.96	8.94	0.017	R Ref R Imp nsd
Error	8	1045.03	130.63			S1 Ref > S1 Imp
Total	11	2892.34				

3.2 Escarpment Area

Coral reef community comparisons were conducted at six impact and six reference sites along the top and crest of a submerged escarpment (Figure 13) at 45 to 55 ft. depths between 6 September and 30 November 2005. Injury to habitat and resources in this region appeared to have resulted from the placement and movement of cables, towlines and anchor chain during *M/V Cape Flattery* response events (Figure 14). Three sub-habitats along the escarpment top were sampled, including 10 m to 20 m inshore of the escarpment edge, the escarpment crest and the tops of protruding ridges. Sites were randomly chosen from multiple points distributed on a map within, north and south of the area of presumed impact. Site selection from these points was based on identification of the closest target sub-habitat area with topography and depth similar to that observed at sites of impact (note: escarpment topography tapered and was characterized by shallower depths towards the channel entrance but redeveloped north of the channel). Sub-habitat transects were run perpendicular to the escarpment edge. Data were blocked by sub-habitat and analyzed using block design factorial ANOVAs followed by Tukeys HDS comparisons or T-test contrasts. The area of injury used to extrapolate potential habitat and resource loss/injury based on average community differences between reference and impact sites was 10,971 m^2. Extrapolations were limited to species-functional groups and, for corals, colony sizes (categorized as small and large for initial analyses), for which average densities or proportional cover between reference and impact sites were demonstrated to be significantly different (α = 0.10). Topographic complexity, as grossly measured by rugosity averaged across sub-habitats, was 1.18 ± 0.05 S.E. at reference and 1.11 ± 0.04 S.E in impact areas. These values did not differ significantly (block design ANOVA, df = 11, F = 1.58, P = 0.244). Differences were noted; however, between individual reference and impact sub-habitats, with significantly lower rugosity in impact escarpment top (one-sided two-sample T-test, df = 2, T = 5.58, P = 0.015) and point areas (one-sided two-sample T-test, df = 2, T = 3.05, P = 0.046), but no difference noted for the escarpment crest (one-sided two-sample T-test, df = 2, T = 0.51, P = 0.671) where debris appeared to partially accumulate.

3.2.1 Scleractinian Corals

A total 10,574 scleractinian corals (88 %) and coral fragments (12 %) representing 18 species were identified along transects established in the operational (impact) area of *M/V Cape Flattery* removal and reference areas (Figure 15). Forty-one percent of attached corals and 95 % of fragments were identified in the area of impact. Eight (44 %) of the species were grouped by

Figure 13. Escarpment impact area and transect locations relative to where the ship grounded (each point represents the approximate beginning of a 25 m fish transect, the 10 m ends on which benthic organisms were surveyed).

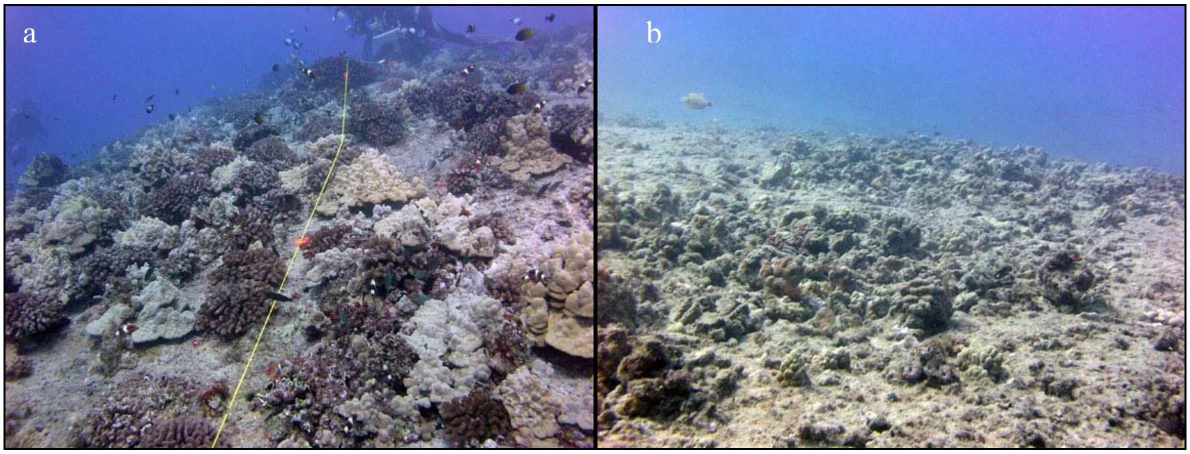

Figure 14. (a) Escarpment reference site. (b) Escarpment impact area with broken, detached, mainly dead/dying coral debris.

genus, functional habitat form and growth rate into *Montipora* encrusting (*M. capitata*, *M. patula*), *Pocillopora meandrina*, *Pocillopora eydouxi*, and *Porites* lobate (*P. brighami*, *P. evermanni*, *P. lobata*) groups for analyses. Species representatives of these four groups were observed as injured (detached, fragmented, tissue and/or skeletal loss) in the operational area of *M/V Cape Flattery* removal (Figure 16). *Cyphastrea ocellina*, *Cycloseris vaughani*, *Cycloseris* sp., *Diaseris* sp., *Fungia scutaria*, *Leptastrea purpurea*, *Pavona duerdeni, P. varians, Pocillopora damicornis*, *Porites compressa*, and *Psammacora* sp. were present along transects but not analyzed due to low site representation.

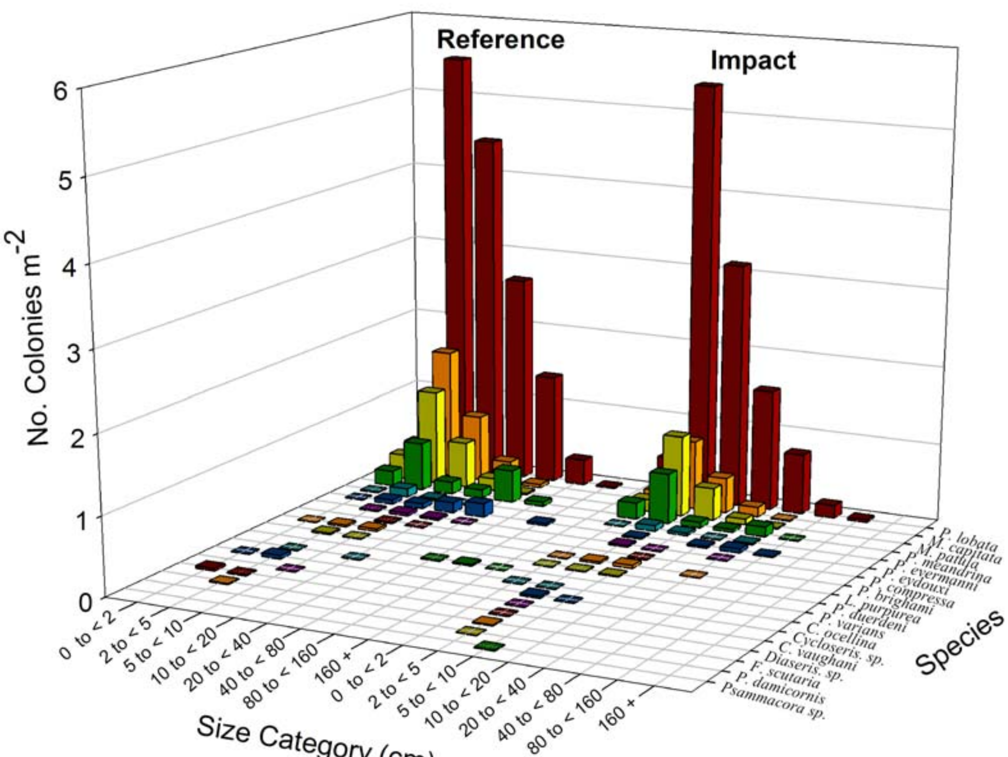

Figure 15. Coral community composition represented as average no. attached colonies m^{-2} at reference and impact sites in the escarpment area.

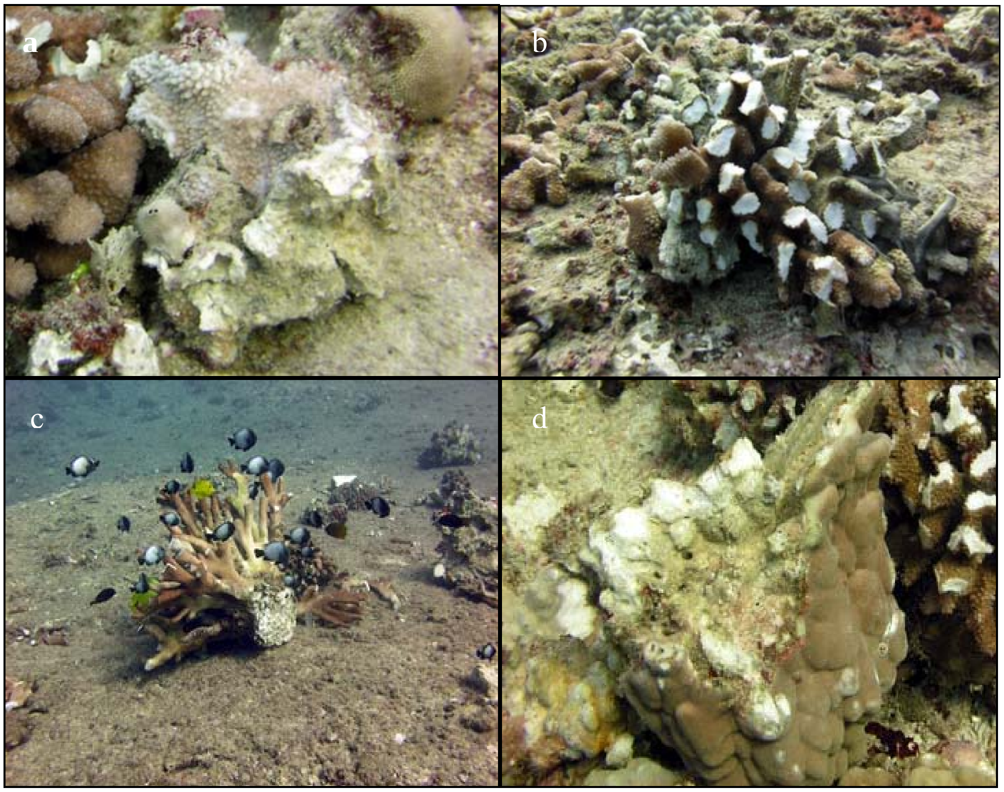

Figure 16. (a) Broken and detached *Montipora capitata*. (b) Shattered *Pocillopora meandrina*. (c) Broken and detached *Pocillopora eydouxi*. (d) Overturned *Porites lobata*.

3.2.1.1 Attached Coral Analyses

Average values (± S.E.) of species group size data of small (0 to < 10 cm greatest diameter) and large (10 to > 160 cm) colony categorizations are shown in Table 18 and Figure 17. The *Porites* lobate and *Montipora* encrusting species groups dominated relative abundance in reference and impact areas, followed by *Pocillopora meandrina* and *Pocillopora eydouxi*. Small colonies tended to be more abundant than large, except in *Pocillopora eydouxi*. Comparative analyses of the average number of attached colonies m^{-2} between reference and impact areas showed significantly lower numbers of attached *Montipora* encrusting, *Pocillopora eydouxi* and *Porites* lobate (Power ≈ 0.477 at $\alpha = 0.050$**)** colonies in the impact area across size groups, and significantly lower numbers of large attached *Pocillopora meandrina* colonies in the impact area (Table 19).

Table 18. Average (± S.E.) attached colony numbers m^{-2} of species group size data for small (< 10 cm) and large (≥ 10 cm) colonies.

Species Group	n	Size Group	Reference	Impact
Montipora encrusting	6	small	5.183 ± 0.761	3.146 ± 0.391
	6	large	0.525 ± 0.116	0.246 ± 0.071
Pocillopora meandrina	6	small	0.975 ± 0.149	0.896 ± 0.152
	6	large	0.583 ± 0.151	0.163 ± 0.046
Pocillopora eydouxi	6	small	0.500 ± 0.356	0.017 ± 0.011
	6	large	0.788 ± 0.371	0.092 ± 0.024
Porites lobate	6	small	10.204 ± 1.456	8.550 ± 0.903
	6	large	4.013 ± 1.032	2.475 ± 0.800

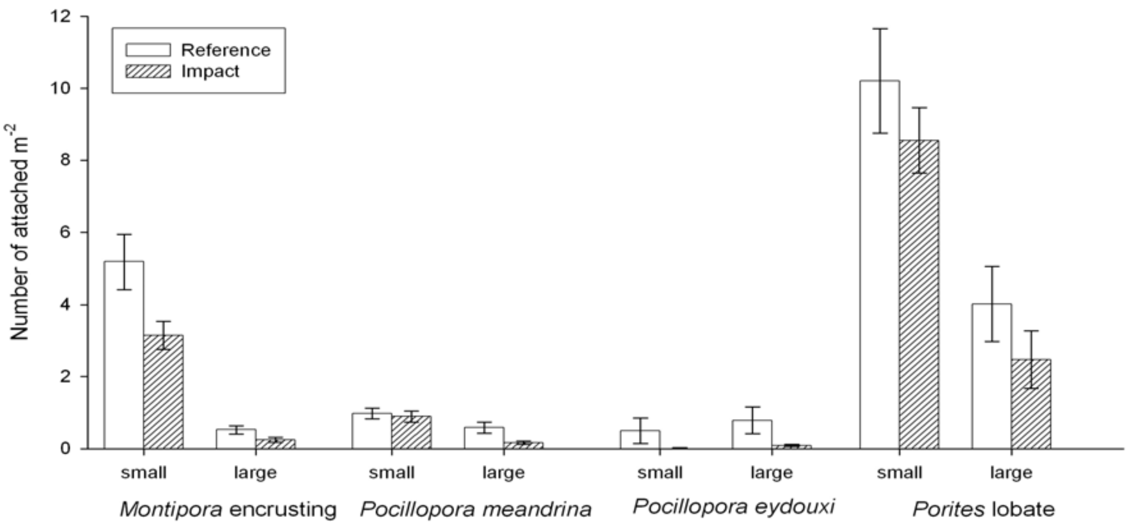

Figure 17. Average (± S.E.) attached colony numbers m^{-2} of species group size data for small (< 10 cm) and large (≥ 10 cm) colonies.

Table 19. Block design factorial ANOVA with Tukey HSD comparison of Location mean attached colonies m^{-2} and T-test contrasts for Intxn terms for species groups in reference (Ref) and impact (Imp) areas (data square-root transformed to conform to model assumptions). Sub-habitat (Block) = escarpment top, escarpment crest and escarpment ridge. L = large colonies; S = small colonies; nsd = no significant difference. Note, at α = 0.050, *Pocillopora meandrina* would be considered significantly lower for L and S colonies at Imp areas, and differences in *Porites lobata* would be considered not determinable.

Source	**DF**	**SS**	**MS**	**F**	**P**	
***Montipora* encrusting**						
Sub-habitat	2	0.513	0.256			
Location (A)	1	0.771	0.771	15.18	0.001	Ref > Imp
Size (B)	1	12.001	12.001	236.42	0.000	
Intxn (A × B)	1	0.101	0.101	2.00	0.175	
Error	18	0.914	0.051			
Total	23	14.300				
Pocillopora meandrina						
Sub-habitat	2	0.120	0.060			
Location (A)	1	0.234	0.234	6.36	0.021	
Size (B)	1	0.949	0.949	25.80	0.000	
Intxn (A × B)	1	0.148	0.148	4.03	0.060	L Ref > L Imp
Error	18	0.662	0.037			S Ref S Imp nsd
Total	23	2.113				
Pocillopora eydouxi						
Sub-habitat	2	0.336	0.168			
Location (A)	1	1.451	1.451	13.56	0.002	Ref > Imp
Size (B)	1	0.297	0.297	2.78	0.113	
Intxn (A × B)	1	0.001	0.001	0.01	0.939	
Error	18	1.925	0.107			
Total	23	4.010				
***Porites* lobate** (no transformation required)						
Sub-habitat	2	71.083	35.541			
Location (A)	1	15.280	15.280	4.04	0.060	Ref > Imp
Size (B)	1	225.707	225.707	59.70	0.000	
Intxn (A × B)	1	0.020	0.020	0.01	0.942	
Error	18	68.056	3.781			
Total	23	380.146				

Indirect quantification of potential colony loss/injury through examination of differences in reference and impact area average colony numbers m^{-2} is shown in Table 20. Mean differences were extrapolated over the escarpment area portion of the injury polygon to estimate potential colony loss/injury. Subdivision of small and large categories into constituent size groups (based on mean proportional distributions of colony sizes in the reference area) provides a necessary component for estimating the temporal aspects of injury from a recovery perspective (Table 21). This method assumes equivalent loss/injury proportional to constituent size representation within small and large size categories, a conditional limitation of the analysis. A total 77,971 coral colonies were projected as injured through coral community comparisons, with 59 % < 10 cm (small) and 41 % ≥ 10 cm (large).

Table 20. Potential colony loss/injury (area with injury = 10,971 m^2). Values in parentheses reflect estimate changes at α = 0.050. n.d. = not determinable.

Species Group	n	Size Group	Diff. in Mean Colonies m^{-2}	Potential Loss/Injury (colonies)
Montipora encrusting	6	small	2.037	22,348
	6	large	0.279	3,061
Pocillopora meandrina	6	small	0.079	(867 at α = 0.05)
	6	large	0.420	4,608
Pocillopora eydouxi	6	small	0.483	5,299
	6	large	0.696	7,636
Porites lobate	6	small	1.654	18,146 (n.d. at α = 0.05)
	6	large	1.538	16,873 (n.d. at α = 0.05)

Table 21. Percentage of coral colony sizes constituting small and large categories and associated estimates of potential loss/injury (% × Table 20 Potential Loss/Injury). Values in parentheses reflect estimates at α = 0.050 when estimates differ. n.d. = not determinable.

	Colony Size Category							
	Small Colonies			Large Colonies				
	1 to < 2 cm	2 to < 5 cm	5 to < 10 cm	10 to < 20 cm	20 to < 40 cm	40 to < 80 cm	80 to < 160 cm	Total
***Montipora* encrusting**								
Percent of Total (Ref)	13.57	59.29	27.14	86.78	13.22	0	0	
Potential Loss/Injury	3,033	13,250	6,065	2,656	405			25,409
Pocillopora meandrina								
Percent of Total (Ref)	20.74	60.22	19.03	19.26	72.77	7.97		
Potential Loss/Injury	(180)	(522)	(165)	888	3,353	367		4,608 (5,475)
Pocillopora eydouxi								
Percent of Total (Ref)	2.82	40.00	57.18	36.53	45.11	10.08	8.28	
Potential Loss/Injury	149	2,120	3,030	2,789	3,445	770	632	12,935
***Porites* lobate**								
Percent of Total (Ref)	5.11	53.42	41.47	65.96	27.64	6.22	0.18	
Potential Loss/Injury	927 (n.d.)	9,694 (n.d.)	7,525 (n.d.)	11,130 (n.d.)	4,664 (n.d.)	1,049 (n.d.)	30 (n.d.)	35,019 (n.d.)

3.2.1.2 Fragment Analyses

Average live (at the time of surveys) fragment numbers m^{-2} appeared highest within the impact area and were dominated by *Porites* lobate corals (Table 22, Figure 18). *Montipora* encrusting, *Pocillopora meandrina*, *Pocillopora eydouxi* and *Porites* lobate species groups all displayed significantly higher numbers and proportions (live fragments/all colonies within a species group) of fragments m^{-2} in the impact area compared to reference areas (Table 23).

Table 22. Average (± S.E.) numbers and proportions of live fragments m^{-2}.

		Numbers		Proportions	
Species Group	**n**	**Reference**	**Impact**	**Reference**	**Impact**
Montipora encrusting	6	0.017 ± 0.008	0.163 ± 0.038	0.003 ± 0.002	0.050 ± 0.014
Pocillopora meandrina	6	0.013 ± 0.013	0.625 ± 0.113	0.008 ± 0.008	0.380 ± 0.070
Pocillopora eydouxi	6	0.042 ± 0.024	0.338 ± 0.108	0.032 ± 0.016	0.642 ± 0.111
Porites lobate	6	0.158 ± 0.047	3.671 ± 0.898	0.011 ± 0.040	0.235 ± 0.043

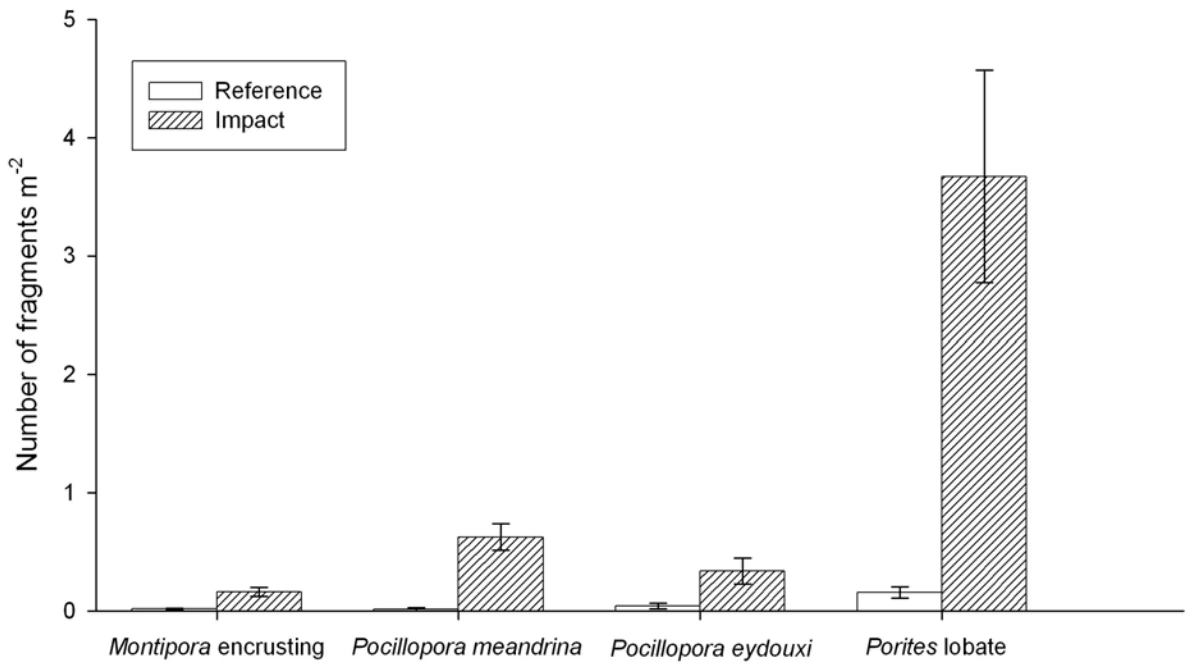

Figure 18. Average (± S.E.) numbers of live fragments m^{-2} for species groups in reference and impact areas.

Extrapolation of fragment numbers across the escarpment area provides a limited basis for accounting for injury to these species groups. Proportional subdivision of mean differences into constituent size classes allows total fragment number estimates by size (Table 24). These numbers presumably underestimate actual injury to coral resources as surveys were limited to live remaining fragments. However, fragments, particularly branches, do not necessarily represent whole colony losses on a one fragment to one colony basis.

Table 23. Block design ANOVAs with Tukey HSD comparisons of numbers and proportions of live fragments m^{-2} for species groups in reference (Ref) and impact (Imp) areas (number data square-root transformed and proportion data arcsine square-root transformed to conform to model assumptions). Sub-habitat (Block) = escarpment top, escarpment crest and escarpment ridge.

Source	DF	SS	MS	F	P	
***Montipora* encrusting**						
number						
Sub-habitat	2	0.063	0.032			
Location	1	0.268	0.268	37.78	0.000	Imp > Ref
Error	8	0.057	0.007			
Total	11	0.388				
proportion						
Sub-habitat	2	0.021	0.010			
Location	1	0.090	0.090	35.26	0.000	Imp > Ref
Error	8	0.021	0.003			
Total	11	0.132				
Pocillopora meandrina						
number						
Sub-habitat	2	0.117	0.058			
Location	1	1.591	1.591	124.94	0.000	Imp > Ref
Error	8	0.102	0.013			
Total	11	1.810				
proportion						
Sub-habitat	2	0.116	0.058			
Location	1	1.157	1.157	108.52	0.000	Imp > Ref
Error	8	0.085	0.011			
Total	11	1.359				
Pocillopora eydouxi						
number						
Sub-habitat	2	0.047	0.023			
Location	1	0.470	0.470	9.52	0.015	Imp > Ref
Error	8	0.395	0.049			
Total	11	0.912				
proportion						
Sub-habitat	2	0.078	0.039			
Location	1	2.073	2.073	31.15	0.001	Imp > Ref
Error	8	0.532	0.067			
Total	11	2.684				
***Porites* lobate**						
number						
Sub-habitat	2	0.643	0.321			
Location	1	6.442	6.442	29.60	0.001	Imp > Ref
Error	8	1.741	0.218			
Total	11	8.826				
proportion						
Sub-habitat	2	0.020	0.010			
Location	1	0.488	0.488	48.97	0.000	Imp > Ref
Error	8	0.080	0.010			
Total	11	0.588				

Table 24. Percentage of live fragment sizes constituting the fragment category and associated estimates of total live fragment numbers (% × 10,971 m^2 × mean diff. Tot. Frag. No. m^{-2} from Table 22).

	Fragment Size Category							
	1 to < 2 cm	**2 to < 5 cm**	**5 to < 10 cm**	**10 to < 20 cm**	**20 to < 40 cm**	**40 to < 80 cm**	**80 to < 160 cm**	**Total**
***Montipora* encrusting**								
Percent of Total (Imp)	12.78	42.22	36.67	0	8.33	0	0	
Projected No. Frag.	205	676	587		133			1,601
Pocillopora meandrina								
Percent of Total (Imp)	4.99	49.13	27.46	12.44	5.98	0		
Projected No. Frag.	335	3,299	1,844	835	401			6,714
Pocillopora eydouxi								
Percent of Total (Imp)	6.41	39.31	18.67	8.23	23.21	4.17	0	
Projected No. Frag.	208	1,277	606	267	754	135		3,247
***Porites* lobate**								
Percent of Total (Imp)	0.77	27.12	27.45	24.47	15.37	4.74	0.08	
Projected No. Frag.	297	10,452	10,579	9,431	5,924	1,827	31	38,541

3.2.2 Macro-Invertebrates

Twenty species of macro-invertebrates were identified along transects surveyed at reference and impact sites (Table 25). Five (36 %) of these were consolidated into three functional groups for analysis based on their relative abundance, critical functional capacity and susceptibility to incident related injury.

Table 25. Macro-invertebrate community represented as average no. organisms m^{-2} at reference and impact sites in the escarpment area.

Species	Functional Group	Reference	Impact
Mollusca			
Pinctada radiata		0.046	0.012
Octopus sp		0.008	0.004
Crustacea			
Stenopus hispidus		0.004	0
Trapezia ferruginea	Guard Crab	0.021	0.117
Trapezia flavopunctata	Guard Crab	0.117	0.079
Trapezia intermedia	Guard Crab	0.021	0.029
Trapezia tigrina	Guard Crab	0.088	0.108
Echinodermata-Asteroids			
Acanthaster planci		0.012	0.004
Culcita novaeguineae		0.012	0
Unidentified Brittle Star		0.183	0.379
Echinodermata-Echinoids			
Eucidaris metularia	Mobile Urchin	0.317	0.208
Echinothrix calamaris	Mobile Urchin	0.292	0.767
E. diadema	Mobile Urchin	0.058	0.033
Tripneustes gratilla	Mobile Urchin	0.088	0.054
Echinostrephus acciculatus	Boring Urchin	1.11	2.23
Echinometra mathaei	Boring Urchin	0.542	1.07
Heterocentrotus mammillatus	Mobile Urchin	0.004	0
Echinodermata-Holothuroids			
Holothuria atra		0.004	0
H. hilla		0.004	0
H. whitmaei		0.008	0.004

3.2.2.1 Macro-Invertebrate Analyses

Average densities (± S.E.) of macro-invertebrate functional groups are shown in Table 26 and Figure 19. Boring urchins were significantly higher in impact compared to reference sites. Mobile urchins and guard crabs did not differ significantly between sites, although average values were slightly higher in impact areas (Table 27). Injury to macro-invertebrates could not be quantified in the escarpment area with these methodologies.

Table 26. Average (±S.E.) number m^{-2} of macro-invertebrates by functional group.

Functional Group	n	Reference	Impact
Boring Urchins	6	1.650 ± 0.393	3.304 ± 0.554
Mobile Urchins	6	0.758 ± 0.159	1.063 ± 0.340
Guard Crabs	6	0.246 ± 0.095	0.333 ± 0.059

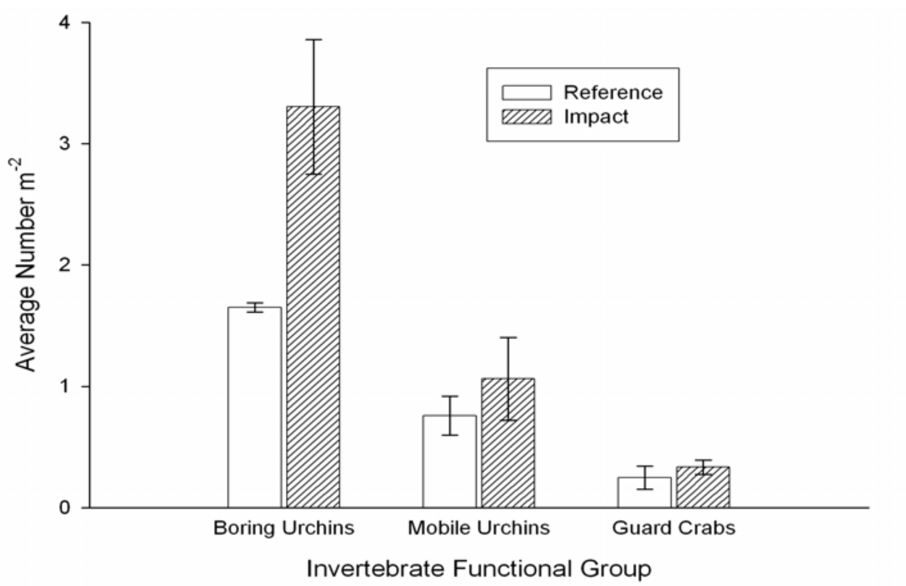

Figure 19. Average (±S.E.) number m^{-2} of macro-invertebrates by functional group.

Table 27. Block design ANOVA with Tukey HSD comparison of Location urchin and guard crab densities m^{-2} (Ref = reference, Imp = impact). Sub-habitat (Block) = escarpment top, escarpment crest and escarpment ridge. Data transformations were not required to meet model assumptions.

Source	DF	SS	MS	F	P	
Boring Urchins						
Sub-habitat	2	2.975	1.488			
Location	1	8.209	8.209	6.05	0.039	Ref < Imp
Error	8	10.860	1.358			
Total	11	22.044				
Mobile Urchins						
Sub-habitat	2	2.163	1.081			
Location	1	0.278	0.278	1.08	0.330	
Error	8	2.063	0.258			
Total	11	4.503				
Guard Crabs						
Sub-habitat	2	0.100	0.050			
Location	1	0.023	0.023	0.66	0.439	
Error	8	0.278	0.035			
Total	11	0.401				

3.2.3 Algae

Twenty-three species of macroalgae, including the invasive species *Avrainvillea amadelpha,* were identified along with crustose coralline and turf algae in impact and reference areas (Table 28). Algae covered 82 % of the benthic substrate in sampled quadrats at impact sites and 70 % at reference sites. Algal data were consolidated by functional group (macroalgae, coralline crustose algae, turf algae and invasive algae) for evaluation and analysis. The macroalgae were mainly represented by species from the order Gelidiales, *Amansia glomerata* and *Dictyota sp.* (Table 28).

Table 28. Algae community represented as average percent cover at reference and impact sites in the escarpment area.

Species within Functional Groups	Reference (% cover)	Impact (% cover)
Macroalgae	**22.08**	**24.17**
Amansia glomerata	4.44	3.96
Cladophoropsis herpestica	0.14	1.53
Caulerpa taxifolia	0.14	0
Cladophoropsis herpestica	0.14	0.28
Crouania sp.	0.07	0.49
Dictyosphaeria cavernosa	0	0.07
Dictyota sp.	4.31	5.21
Dictyota friabilis	0.42	0.14
Gelid.	8.13	7.08
Gibsmithia hawaiiensis	0.07	0
Halimeda discodea	0.21	0
Herposiphonia sp.	0	0.69
Jania sp.	0.35	0
Laurencia sp.	0	0.49
Neomeris annulata	0.49	0.21
Padina sp.	0.28	0.14
Padina melemele	0	0.07
Ralfsia sp.	0.49	0.28
Sargassum sp.	0.21	0.21
Spirocladia hodgsoniae	0	0.07
Spyridia filamentosa	1.74	3.13
Tolypiocladia glomerulata	0.49	0.14
Coralline Crustose Algae	**19.65**	**21.81**
Turf Algae	**26.88**	**36.18**
Invasive Algae	**0.90**	**0.07**
Avrainvillea amadelpha	0.90	0.07

3.2.3.1 Algae Analyses

Average percent coverage values (± S.E.) of algae functional groups are shown in Table 29 and Figure 20. Turf algae were the dominant algae functional group in both reference and impact areas, followed by macroalgae, coralline crustose algae and invasive algae. The turf algae group was the only algae functional group that displayed significantly different proportional cover between reference and impact sites (Table 30). The higher cover of turf algae in the impact area is consistent with successional colonization of substrate altered through injury.

Table 29. Average (± S.E.) percent cover of algal functional groups.

Functional Group	n	Reference	Impact
Macroalgae	6	22.08 ± 6.02	24.17 ± 8.18
Coralline Crustose Algae	6	19.65 ± 2.27	21.81 ± 3.27
Turf Algae	6	26.88 ± 3.63	36.18 ± 5.39
Invasive Algae	6	0.90 ± 0.82	0.07 ± 0.07

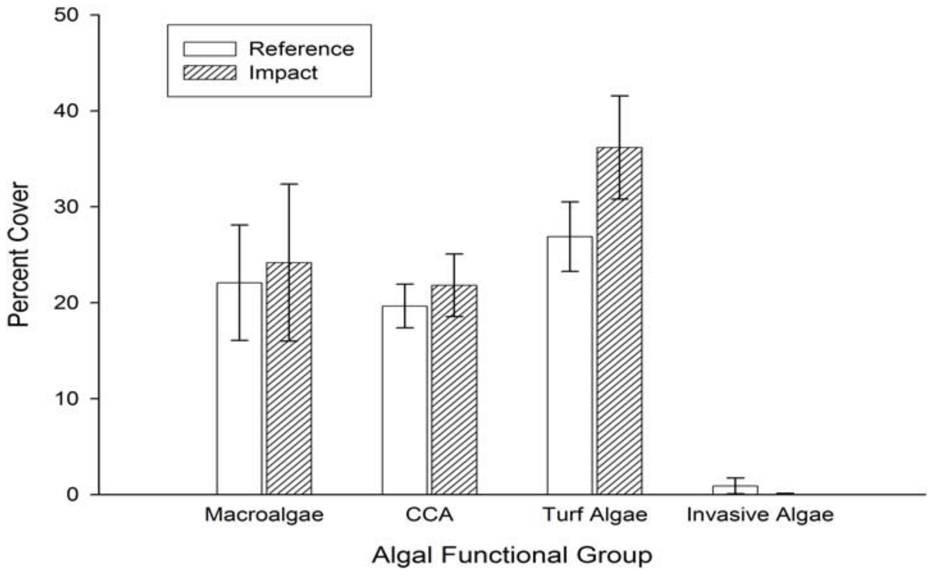

Figure 20. Average percent cover (± S.E.) of algal functional groups (CCA = coralline crustose algae).

Table 30. Block design factorial ANOVAs. Data analyzed as arcsine square-root transformed proportions to conform to model assumptions. Ref = reference sites; Imp = impact sites; Sub-habitat (Block) = escarpment top, escarpment crest and escarpment ridge.

Source	DF	SS	MS	F	P	
Macroalgae						
Depth	2	0.487	0.243			
Location	1	0.000	0.000	0.00	0.964	
Error	8	0.154	0.019			
Total	11	0.641				
Coralline Crustose Algae						
Depth	2	0.058	0.029			
Location	1	0.002	0.002	0.71	0.425	
Error	8	0.020	0.003			
Total	11	0.079				
Turf Algae						
Depth	2	0.100	0.050			
Location	1	0.031	0.031	5.50	0.047	Ref < Imp
Error	8	0.044	0.006			
Total	11	0.175				
Alien Invasive Algae						
Depth	2	0.012	0.006			
Location	1	0.004	0.004	1.03	0.340	
Error	8	0.033	0.004			
Total	11	0.049				

3.2.4 Fish

A total of 68 species was counted along transects in the escarpment area. A list of the species, by abundance in the reference sites, is shown in Table 31. Sixty percent of the individuals were in R class (resident species) and 37 % in the S1 class (semi-vagile, small area). Only 2% of the individuals were in the S2 class (semi-vagile, large area), and 1% belonged to the T class (transient species).

Table 31. Fish species average abundance (numbers ha^{-1}) at reference (Ref.) and impact (Imp.) sites in the escarpment area. Mob. = mobility class.

Species	**Mob.**	**Ref.**	**Imp.**	**Species** (cont.)	**Mob.**	**Ref.**	**Imp.**
Chromis vanderbilti	R	12358	7542	*Rhinecanthus rectangulus*	S1	33	0
Thallasoma duperrey	S1	1783	2250	*Halichoeres ornatissimus*	S1	25	17
Parapeneus multifasciatus	S1	1392	617	*Naso lituratus*	S2	25	17
Acanthurus nigrofuscus	S1	1058	1017	*Plectroglyphidodon imparipennis*	R	25	33
Chaetodon auriga	S1	750	0	*Chromis hanui*	R	17	17
Chaetodon kleinii	S1	550	208	*Chaetodon miliaris*	S1	17	0
Dascyllus albisella	S1	483	58	*Chaetodon unimaculatus*	S1	17	0
Paracirrhites arcatus	R	408	342	*Coris venusta*	S1	17	17
Chaetodon multicintus	S1	258	267	*Mulloidichthys vanicolensis*	S1	17	0
Ctenochaetus strigosus	S1	217	142	*Ostracio meleagris*	S1	17	0
Sufflamen bursa	S1	200	375	*Oxycheilinus bimaculatus*	S1	17	67
Canthigaster jactator	S1	183	167	*Pervagor spilosoma*	S1	17	17
Hemitaurichthyls thompsoni	S1	167	0	*Pseudojuloides cerasinus*	S1	17	83
Pseudocheilinus octotaenia	S1	167	108	*Stethojulis balteata*	S1	17	75
Chaetodon ornatissimus	S1	142	175	*Cheilio inermis*	S2	8	8
Melichthys niger	S1	125	0	*Chlorurus sordidus*	S2	8	17
Naso unicornis	S2	108	108	*Gomphosus varius*	S1	8	75
Forcipiger flavissimus	S1	100	0	*Gymnothorax flavimarginatus*	R	8	0
Plectroglyphidodon johnstonianus	R	100	33	*Macropharyngodon geoffroy*	S1	8	0
Zebrasoma flavescens	S1	92	117	*Melichthys vidua*	S1	8	58
Acanthurus olivaceous	S2	83	58	*Parupeneus cyclostomus*	S2	8	0
Chaetodon lunulatus	S1	83	0	*Scomberoides lysan*	T	8	67
Sargocentron spiniferum	R	83	0	*Scarus psittacus*	S2	8	167
Labroides phthirophagus	R	67	0	*Sufflamen fraenatus*	S2	8	8
Bodianus bilunulatus	S2	58	0	*Xanthichthys auromarginatus*	S1	8	8
Cirrhitops fasciatus	R	58	50	*Anampses chrysocephalus*	S1	0	17
Chaetodon quadrimaculatus	S1	50	0	*Apogon kallopterus*	R	0	1133
Plectoglyphidon sindonis	R	50	33	*Canthigaster coronata*	S1	0	50
Pseudocheilinus tetrataenia	S1	50	33	*Cantherhines sandwichiensis*	S1	0	8
Chromis agilis	R	42	0	*Centropyge potteri*	R	0	33
Chromis ovalis	R	42	250	*Coris gaimard*	S1	0	8
Parapeneus pleurostigma	S1	42	8	*Elagatis bipinnulata*	T	0	208
Plagiotremus ewaensis	R	42	92	*Paracirrhites forsteri*	R	0	25
Cephalopholis argus	S1	33	0	*Parapercis schauinslandi*	S1	0	33

3.2.4.1 Fish Analyses

Average number ha^{-1} and biomass by mobility class are shown in Table 32 and Figure 21. There were no significant differences in number ha^{-1} or biomass for reference and impact sites (blocked ANOVA with sub-habitats as blocks for square-root transformed number ha^{-1}, df 1, 14, $F = 0.80$, $P = 0.38$; blocked ANOVA with sub-habitats as blocks for square-root transformed biomass, df 1, 14, $F = 1.18$, $P = 0.30$). Although there was injury to corals documented at impact sites, structure that remained (both attached and detached) appeared to provide some three dimensional relief for fish use. However, small sample sizes may have precluded detection of statistically significant differences between impact and reference areas. It should be noted that *Dascyllus albisella*, a species that typically shelters in large *Pocillopora eydouxi* colonies, was reduced in abundance at the impacted sites.

Table 32. Average number and biomass (± S.E.) of fish by mobility class at reference and impact sites of the escarpment area.

		Number ha^{-1}		Biomass (t ha^{-1})	
Mobility Class	**n**	**Reference**	**Impact**	**Reference**	**Impact**
R	6	13,300 ± 3,972	9,583 ± 3,133	0.062 ± 0.013	0.048 ± 0.013
S1	6	8,167 ± 1,734	6,075 ± 1,783	0.281 ± 0.109	0.160 ± 0.052
S2	6	317 ± 100	383 ± 162	0.052 ± 0.034	0.016 ± 0.005
T	6	8.3 ± 8.3	275 ± 275	0.0003 ± 0.0003	0.130 ± 0.130

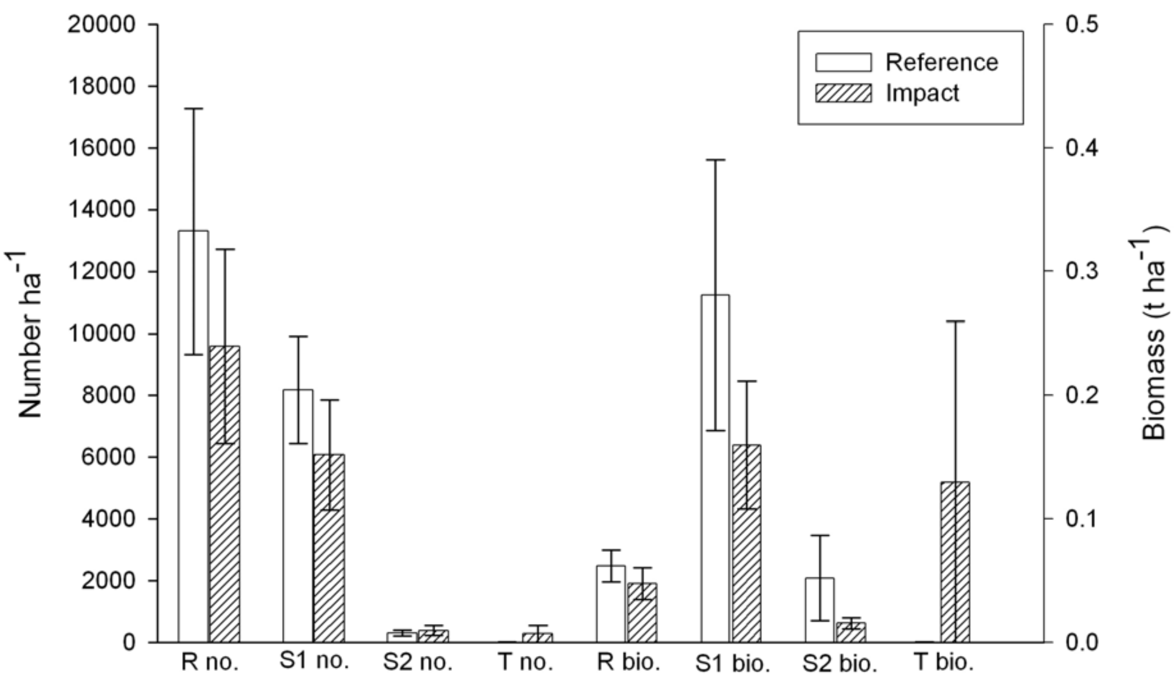

Figure 21. Average number and biomass (± S.E.) of fish by mobility class at reference and impact sites in the escarpment area.

3.3 Shelf Pavement

Seven impact and four reference sites were assessed along coral reef shelf pavement at 26 to 43 ft. depths between 7 September and 21 November 2005 (Figure 22). Impacts to habitat and resources appeared to have resulted from the placement and movement of the ship's hull, cables, towlines and anchor chain, and cement deposition during *M/V Cape Flattery* grounding and response activities (Figure 23). Sampling of the area of injury was divided into non-hull-impact and hull-impact regions based on initial RP and towed-diver survey injury polygons. Sites were randomly chosen from multiple points distributed on a map within hull-impact, non-hull-impact, and both north and south of the presumed impact area. Transects were positioned roughly parallel to the shoreline along individual depth gradients. Reef depressions were intentionally avoided for separate measurement. Transects at one of the measurement areas crossed both non-hull- and hull-impact type regions. The individual transects were separated and assigned accordingly to the appropriate impact type (one fish transect, 2 benthic sections to each impact region).

Data were analyzed using factorial ANOVAs followed by Tukey's HDS comparisons or T-test contrasts. Data not conforming to model assumptions were analyzed using appropriate one-sided one- and two-sample T-tests. The area of impact used to extrapolate potential habitat and resource loss/injury based on average community differences between reference and impact sites was 41,513 m^2 for the non-hull-impact area and 7,243 m^2 for the hull-impact area (estimated reef depression areas within these zones were subtracted prior to shelf pavement injury area determinations). Extrapolations were limited to species-functional groups and, for corals, colony sizes (categorized as small and large for initial analyses), for which average densities or proportional cover between reference and impact sites were demonstrated to be significantly different ($\alpha = 0.10$). Topographic complexity as grossly measured by rugosity averaged 1.09 ± 0.03 S.E. at reference, 1.003 ± 0.003 S.E. in non-hull impact and 1.00 ± 0.00 S.E. in hull-impact areas. Rugosity was significantly lower in non-hull-impact (one-sided two-sample T-test for unequal variance, df = 3.1, T = 3.37, P = 0.021) and hull-impact areas (T-test that mean reference area rugosity > 1.00, the mean value for hull-impact sites, df = 3, T = 3.48, P = 0.020) compared to reference sites.

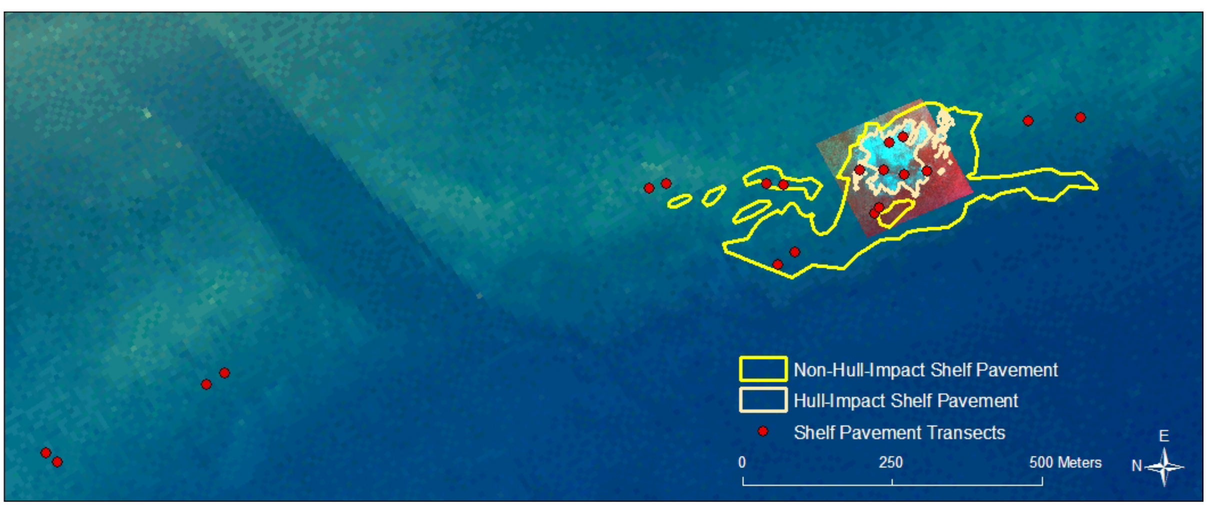

Figure 22. Shelf pavement non-hull-impact and hull-impact areas and transect locations relative to where the ship grounded (each point represents the approximate beginning of a 25 m fish transect, the 10 m ends on which benthic organisms were surveyed).

Figure 23. (a) Shelf pavement reference site. (b) Non-hull-impact site. (c) Hull-impact site.

3.3.1 Scleractinian Corals

A total 6,333 scleractinian corals (94 %) and live coral fragments (6 %) representing 17 species were identified along transects established in the grounding and operational area of *M/V Cape Flattery* removal and reference sites on shelf pavement (Figure 24). Twenty-five percent of attached corals and 93 % of fragments were identified in areas of impact (hull and non-hull). Nine (53 %) of the species were grouped by genus, functional habitat form and growth rate into *Montipora* encrusting (*M. capitata*, *M. patula, M. studeri*), *Pocillopora* cauliflower (*P. ligulata, P. meandrina*), *Pocillopora eydouxi*, and *Porites* lobate (*P. brighami*, *P. evermanni*, *P. lobata*) groups for analyses. Species representatives of these four groups were observed as injured (detached, fragmented, tissue and/or skeletal loss) in the operational area of *M/V Cape Flattery* grounding and removal (Figure 25). *Cycloseris vaughani*, *Cycloseris* sp., *Diaseris* sp., *Leptastrea purpurea*, *Pavona duerdeni, P. varians, Pocillopora damicornis* and *Porites compressa* were present along transects but not analyzed due to low site representation.

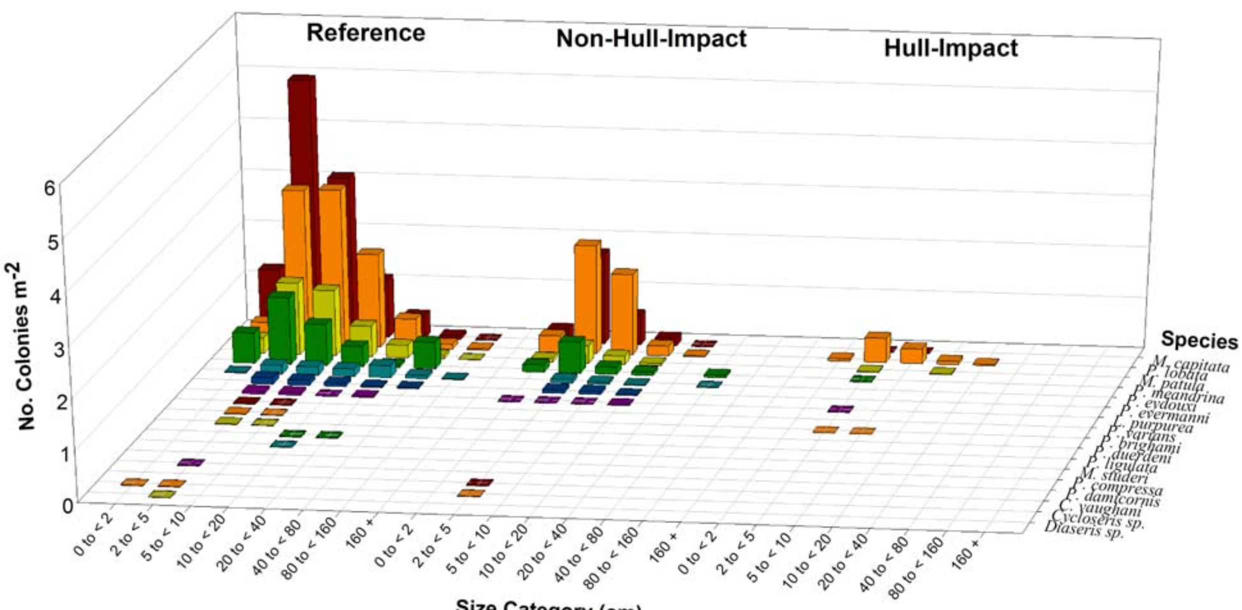

Figure 24. Coral community composition represented as average no. attached colonies m^{-2} in reference, non-hull- and hull-impact areas of the shelf pavement zone.

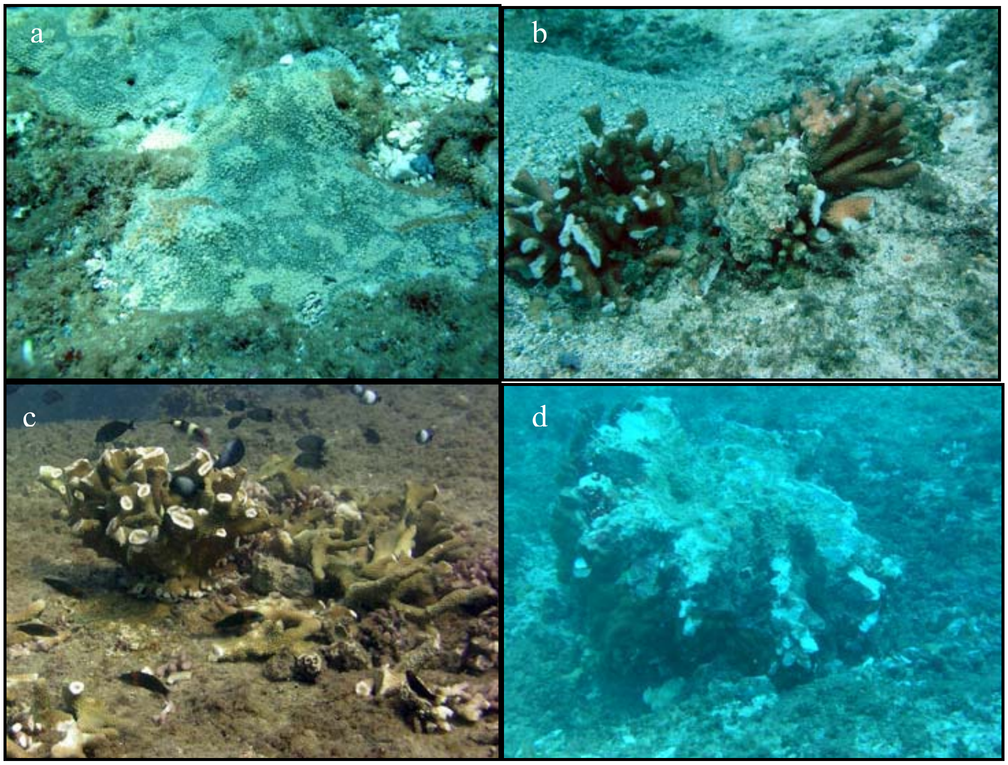

Figure 25. (a) Cement related tissue necrosis, *Montipora capitata.* (b) Broken and detached *Pocillopora meandrina*. (c) Broken and detached *P. eydouxi*. (d). Overturned *Porites evermanni*.

3.3.1.1 Attached Coral Analyses

Average values (± S.E.) of species group size data of small (0 to < 10 cm greatest diameter) and large (10 to > 160 cm) colony categorizations are shown in Table 33 and Figure 26. *Montipora* encrusting and *Porites* lobate species dominated relative abundance in reference, non-hull- and hull-impact areas. Small colonies tended to be more abundant than large, except in *Pocillopora eydouxi*. Figure 26 suggests a trend of declining colony numbers m^{-2} from reference to non-hull-impact to hull-impact areas. Multiple analyses were conducted for *Montipora* encrusting colonies to meet test assumptions of variance homogeneity. A factorial ANOVA demonstrated significantly lower numbers of attached *Montipora* encrusting m^{-2} in non-hull-impact compared to reference sites (Table 34). Separate two-sample T-tests (one-sided for unequal variance, data square-root transformed) for large and small colonies showed mean numbers of attached

Table 33. Average (± S.E.) attached colony numbers m^{-2} of species group size data for small (< 10 cm) and large (≥ 10 cm) colonies. (n = 4 for reference and non-hull-impact areas; n = 3 for hull-impact area).

Species Group	Size Group	Reference	Non-Hull-Impact	Hull-Impact
Montipora encrusting	small	12.369 ± 3.797	3.288 ± 1.591	0.033 ± 0.033
	large	2.588 ± 1.121	0.244 ± 0.129	0.017 ± 0.017
Pocillopora cauliflower	small	2.338 ± 0.459	0.906 ± 0.266	0.008 ± 0.008
	large	0.425 ± 0.130	0.200 ± 0.096	0 ± 0
Pocillopora eydouxi	small	0.356 ± 0.115	0.056 ± 0.041	0 ± 0
	large	0.463 ± 0.043	0.019 ± 0.012	0 ± 0
Porites lobate	small	6.769 ± 1.642	4.169 ± 0.985	1.017 ± 0.227
	large	2.631 ± 0.706	0.225 ± 0.052	0.117 ± 0.046

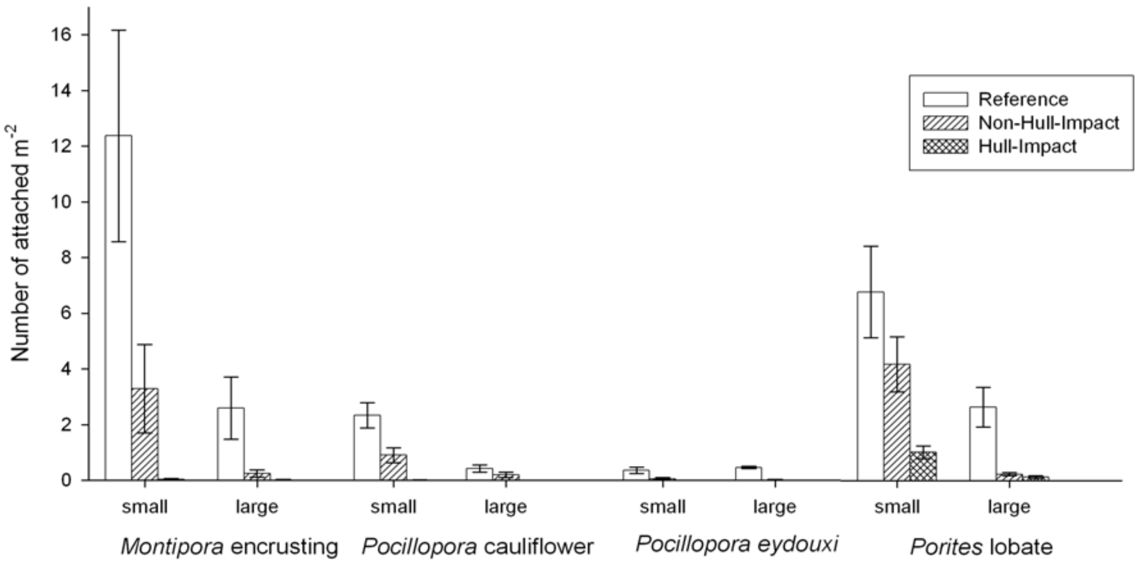

Figure 26. Average (± S.E.) attached colony numbers m^{-2} of species group size data for small (< 10 cm) and large (≥ 10 cm) colonies.

Table 34. Factorial ANOVAs with Tukey HSD comparisons or T-test contrasts for Location and Intxn terms for species groups in reference (Ref), non-hull-impact (NHI) and hull-impact (HI) areas (data square-root transformed to conform to model assumptions). L = large colonies; S = small colonies; nsd = no significant difference.

Source	**DF**	**SS**	**MS**	**F**	**P**	
***Montipora* encrusting** (comparison of Ref vs. NHI only)						
Location (A)	1	0.709	0.709	10.30	0.008	Ref > NHI
Size (B)	1	2.071	2.071	30.10	0.000	
Intxn (A × B)	1	0.107	0.107	1.56	0.236	
Error	12	0.826	0.069			
Total	15	3.712				
***Pocillopora* cauliflower**						
Location (A)	2	3.722	1.861	35.35	0.000	
Size (B)	1	1.335	1.335	25.36	0.000	
Intxn (A × B)	2	0.592	0.296	5.63	0.014	L Ref L NHI nsd
Error	16	0.842	0.053			L Ref > L HI
Total	21	6.491				S Ref > S NHI
						S Ref > S HI
Pocillopora eydouxi (comparison of Ref vs. NHI only)						
Location (A)	1	0.981	0.981	38.59	0.000	Ref > NHI
Size (B)	1	0.002	0.002	0.08	0.785	
Intxn (A × B)	1	0.031	0.031	1.20	0.295	
Error	12	0.305	0.025			
Total	15	1.318				
***Porites* lobate**						
Location (A)	2	7.040	3.520	22.02	0.000	Ref > NHI, Ref > HI
Size (B)	1	6.069	6.069	37.97	0.000	
Intxn (A × B)	2	0.679	0.340	2.13	0.152	
Error	16	2.557	0.160			
Total	21	16.345				

Montipora encrusting m^{-2} to be significantly lower at hull-impact than reference sites (Large, df = 3.2, T = 3.79, P = 0.014; Small, df = 3.2, T = 5.44, P = 0.005). Significantly lower numbers of attached *Pocillopora* cauliflower and *P. eydouxi* colonies m^{-2} were identified in non-hull-impact areas with the exception of large *Pocillopora* cauliflower, the numbers of which were not shown to differ significantly (Table 34). A factorial ANOVA demonstrated significantly lower numbers of attached *P. eydouxi* in the non-hull-impact compared to reference areas (Table 34). Separate one-sample T-tests (one-sided, data square-root transformed) for large and small colonies showed mean reference numbers of attached *P. eydouxi* m^{-2} to be significantly greater than zero, the mean value for the hull-impact area (Large, df = 3, T = 21.84, P = 0.000; Small, df = 3, T = 5.40, P = 0.006). Significantly lower attached *Porites* lobate numbers were observed in non-hull and hull-impact sites compared to reference areas (Table 34).

Indirect quantification of potential colony loss/injury through examination of differences in reference and impact area mean colony numbers m^{-2} is shown in Table 35. Mean differences were extrapolated over non-hull and hull-impact portions of the shelf pavement injury polygon to estimate potential colony loss/injury (estimated reef depression areas were removed prior to extrapolation). Subdivision of small and large categories into constituent size groups (based on mean proportional distributions of colony sizes in the reference area) provides a necessary component for estimating the temporal aspects of injury from a recovery perspective (Table 36). This method assumes equivalent loss/injury proportional to constituent size representation within small and large size categories, a conditional limitation of the analysis. A total 966,161

Table 35. Potential colony loss/injury (non-hull-impact area = 41,513 m^2; hull-impact area = 7,243 m^2).

Species Group	Size Group	Non-Hull-Impact Diff. in Mean Colonies m^{-2}	Potential Loss/Injury (colonies)	Hull-Impact Diff. in Mean Colonies m^{-2}	Potential Loss/Injury (colonies)
Montipora encrusting	small	9.081	376,980	12.336	89,350
	large	2.344	97,306	2.571	18,622
Pocillopora cauliflower	small	1.432	59,447	2.330	16,876
	large	na	na	0.425	3,078
Pocillopora eydouxi	small	0.300	12,454	0.356	2,579
	large	0.444	18,432	0.463	3,354
Porites lobate	small	2.600	107,934	5.752	41,662
	large	2.406	99,880	2.514	18,209

Table 36. Percentage of coral colony sizes constituting small and large categories and associated estimates of potential loss/injury (% of Total × Table 35 Potential Loss/Injury; NHI = non-hull-impact; HI = hull-impact).

	Colony Size Category							
	Small Colonies			Large Colonies				
	1to < 2 cm	2 to < 5 cm	5 to < 10 cm	10 to < 20 cm	20 to < 40 cm	40 to < 80 cm	80 to < 160 cm	Total
***Montipora* encrusting**								
Percent of Total (Ref)	13.72	53.64	32.64	71.85	25.37	2.56	0.23	
Projected Injury/Loss NHI	51,727	202,219	123,034	69,913	24,686	2,487	221	474,286
Projected Injury/Loss HI	12,260	47,929	29,161	13,379	4,724	476	42	107,971
***Pocillopora* cauliflower**								
Percent of Total (Ref)	24.50	56.71	18.79	35.96	59.73	4.31		
Projected Injury/Loss NHI	14,562	33,715	11,169	na	na	na		59,447
Projected Injury/Loss HI	4,134	9,571	3,171	1,107	1,839	133		19,954
Pocillopora eydouxi								
Percent of Total (Ref)	3.57	40.42	56.00	30.81	51.85	14.56	2.79	
Projected Injury/Loss NHI	445	5,034	6,975	5,678	9,556	2,684	514	30,886
Projected Injury/Loss HI	92	1,042	1,444	1,033	1,739	488	93	5,932
***Porites* lobate**								
Percent of Total (Ref)	6.21	47.46	46.33	75.16	20.55	3.57	0.71	
Projected Injury/Loss NHI	6,699	51,226	50,008	75,071	20,530	3,566	713	207,814
Projected Injury/Loss HI	2,586	19,773	19,303	13,686	3,743	650	130	59,871

colonies were projected as injured through coral community comparisons. Seventy-three percent of these colonies were < 10 cm (small) and 27 % were ≥ 10 cm (large).

3.3.1.2 Fragment Analyses

Average live fragment numbers m^{-2} appeared highest within the non-hull-impact area and were dominated by *Pocillopora* cauliflower and *Porites* lobate corals (Table 37, Figure 27). Only limited numbers of fragments were identified along transects within the hull-impact area, possibly due to colony and fragment pulverization by movement of the ship's hull. All species groups displayed significantly higher mean fragment numbers and proportions (live fragments/all colonies within a species group) m^{-2} in non-hull-impact compared to reference areas (Table 38). No significant differences in species group mean numbers m^{-2} between reference and hull-impact areas were displayed (Table 38; including an one-sided one-sample T-test that reference < 0, the hull-impact area average, for square-root transformed *Montipora* encrusting, df = 3, T = 1.00, P = 0.805). Significantly higher proportions (arcsine square-root transformed) of fragments m^{-2} in hull-impact versus reference areas were displayed by *Pocillopora* cauliflower (Table 38) and

Table 37. Average (± S.E.) numbers and proportions of live fragments m^{-2} (n = 4 for reference and non-hull-impact areas; n = 3 for the hull-impact area).

Species Group	Numbers			Proportions		
	Reference	Non-Hull Impact	Hull-Impact	Reference	Non-Hull Impact	Hull-Impact
Montipora encrusting	0.006 ± 0.006	0.188 ± 0.065	0 ± 0	0.001 ± 0.001	0.095 ± 0.036	0 ± 0
Pocillopora cauliflower	0.031 ± 0.019	1.250 ± 0.281	0.025 ± 0.014	0.012 ± 0.009	0.548 ± 0.102	0.750 ± 0.250
Pocillopora eydouxi	0.044 ± 0.036	0.244 ± 0.059	0.050 ± 0.014	0.045 ± 0.031	0.846 ± 0.094	1.000 ± 0.000
Porites lobate	0.056 ± 0.028	0.456 ± 0.122	0.050 ± 0.029	0.006 ± 0.003	0.109 ± 0.045	0.033 ± 0.018

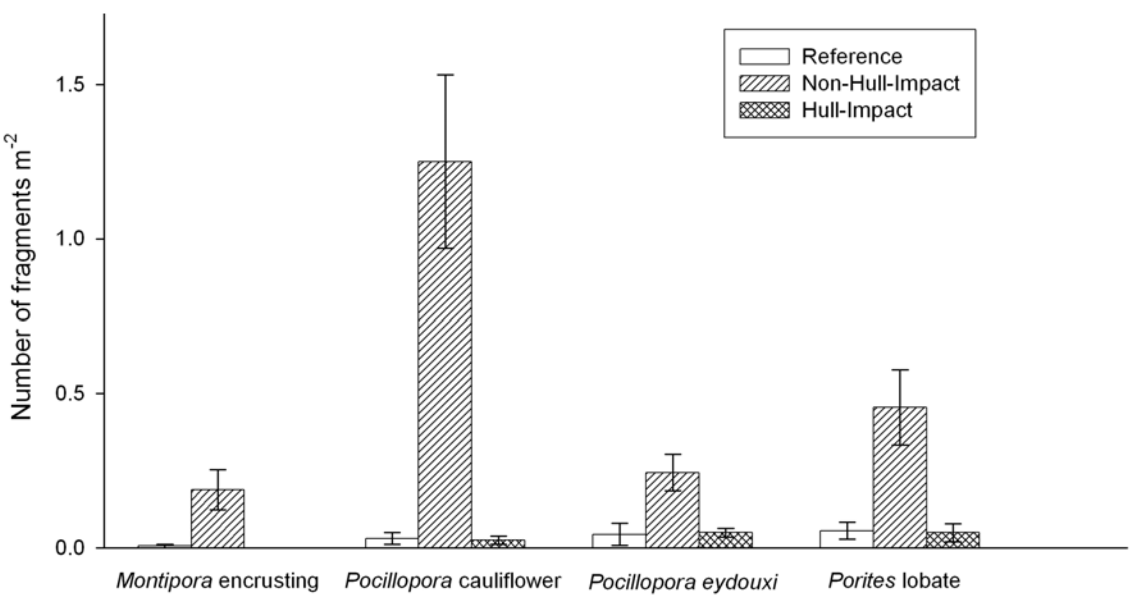

Figure 27. Average (± S.E.) numbers of live fragments m^{-2} for species groups in reference, non-hull- and hull-impact areas.

Table 38. One-way ANOVAs with Tukey HSD comparisons or T-test contrasts for numbers and proportions of live fragments m^{-2} for species groups in reference (Ref), non-hull-impact (NHI) and hull-impact (HI) areas (number data square-root transformed and proportion data arcsine square-root transformed to conform to model assumptions). nsd = no significant difference.

Source	DF	SS	MS	F	P	
***Montipora* encrusting** (comparison of Ref vs. NHI only)						
number						
Location	1	0.276	0.276	17.6	0.006	Ref < NHI
Error	6	0.094	0.016			
Total	7	0.369				
Proportion						
Location	1	0.152	0.152	16.6	0.007	Ref < NHI
Error	6	0.055	0.009			
Total	7	0.207				
***Pocillopora* cauliflower**						
number						
Location	2	2.397	1.198	33.6	0.000	Ref < NHI
Error	8	0.285	0.036			Ref HI nsd
Total	10	2.682				
proportion						
Location	2	1.988	0.994	14.9	0.003	Ref < NHI
Error	7	0.468	0.067			Ref < HI
Total	9	2.456				
Pocillopora eydouxi						
number						
Location	2	0.251	0.126	6.04	0.025	Ref < NHI
Error	8	0.166	0.021			Ref HI nsd
Total	10	0.418				
proportion (comparison of Ref vs. NHI only)						
Location	1	2.550	2.550	33.6	0.001	Ref < NHI
Error	6	0.455	0.076			
Total	7	3.005				
***Porites* lobate**						
number						
Location	2	0.554	0.277	9.64	0.007	Ref < NHI
Error	8	0.230	0.029			Ref HI nsd
Total	10	0.783				
proportion						
Location	2	0.137	0.068	5.81	0.028	Ref < NHI
Error	8	0.094	0.012			Ref HI nsd
Total	10	0.231				

Pocillopora eydouxi (one-sided T-test that reference < 1.00, the hull-impact area value, df = 3, T = 9.38, P = 0.001), but not *Montipora* encrusting (one-sided T-test that reference < 0, the hull-impact area value, df = 3, T = 1.00, P = 0.805) or *Porites* lobate (Table 38) species groups.

Extrapolation of fragment numbers across the shelf pavement zone provides a limited basis for accounting for injury in the non-hull-impact area. Proportional subdivision of mean differences into constituent size classes allows total fragment number estimates by size (Table 39). These numbers presumably underestimate actual injury to coral resources as surveys were limited to live remaining fragments; however, fragments, particularly branches, do not necessarily represent whole colony losses on a one fragment to one colony basis. Fragments ≥ 80 cm in largest diameter were not observed along transects. Potential insights on injury from extrapolation of fragment numbers in the hull-impact area are limited due to a general absence of fragments.

Table 39. Percentage of live fragment sizes constituting the fragment category and associated estimates of total live fragment numbers at NHI (% × 41,513 m^2 × mean diff. Tot. Frag. No. m^{-2} calculated from Table 37).

	Fragment Size Category						
	1to < 2 cm	**2 to < 5 cm**	**5 to < 10 cm**	**10 to < 20 cm**	**20to < 40 cm**	**40to < 80 cm**	**Total**
***Montipora* encrusting**							
Percent of Total (Imp)	31.35	59.09	9.56	0	0	0	
Projected No. Frag.	2,368	4,464	723				7,555
***Pocillopora* cauliflower**							
Percent of Total (Imp)	1.51	47.86	41.03	5.64	3.96	0	
Projected No. Frag.	764	24,218	20,765	2,852	2,005		50,604
Pocillopora eydouxi							
Percent of Total (Imp)	0	41.15	34.49	20.51	3.85	0	
Projected No. Frag.		3,417	2,863	1,703	319		8,302
***Porites* lobate**							
Percent of Total (Imp)	14.71	61.15	21.15	0.89	0	2.08	
Projected No. Frag.	2,443	10,155	3,513	148		346	16,605

3.3.2 Macro-Invertebrates

Fifteen species of macro-invertebrates were identified along transects surveyed at reference and impact sites (Table 40). Ten (67 %) of these were consolidated into three functional groups for analysis based on their relative abundance, critical functional capacity and susceptibility to incident related injury.

Table 40. Macro-invertebrate community represented as average no. organisms m^{-2} in reference, non-hull-impact and hull-impact areas of the shelf pavement zone.

Species	Functional Group	Reference	Non-Hull-Impact	Hull-Impact
Mollusca				
Pinctada radiata		0.006	0.025	0
Octopus sp		0.025	0	0
Crustacea				
Hymenocera picta		0	0.006	0
Stenopus hispidus		0.006	0	0
Trapezia ferruginea	Guard Crab	0.200	0.031	0
Trapezia flavopunctata	Guard Crab	0.125	0	0
Trapezia intermedia	Guard Crab	0.069	0	0
Trapezia tigrina	Guard Crab	0.106	0.056	0
Echinodermata-Asteroids				
Unidentified Brittle Star		0.394	0.038	0
Echinodermata-Echinoids				
Eucidaris metularia	Mobile Urchin	0.156	0	0
Echinothrix calamaris	Mobile Urchin	0.088	0	0.017
Tripneustes gratilla	Mobile Urchin	0.138	0.044	0.017
Echinostrephus acciculatus	Boring Urchin	0.712	0.206	0.008
Echinometra mathaei	Boring Urchin	0.944	0.156	0
Echinodermata-Holothuroids				
Euapta godeffroyi		0.012	0	0

3.3.2.1 Macro-Invertebrate Analyses

Average densities (± S.E.) of macro-invertebrate functional groups are shown in Table 41 and Figure 28. Boring and mobile urchins displayed significantly lower mean densities in non-hull and hull-impact areas compared to reference areas (Table 42). Guard crabs mean densities were also significantly lower at non-hull-impact compared to reference sites (one-sided two-sample t-test of square-root transformed data, df = 6, T =3.38, P = 0.007). No guard crabs were identified at hull-impact sites; however, reference site densities were significantly greater than zero (one-sided one-sample t-test that reference > 0, df = 3, T = 9.05, P = 0.001).

Table 41. Average (±S.E.) number m^{-2} of macro-invertebrates by functional group.

Functional Group	n	Reference	Non-hull Impact	n	Hull-Impact
Boring Urchins	4	1.656 ± 0.817	0.362 ± 0.322	3	0.008 ± 0.008
Mobile Urchins	4	0.381 ± 0.143	0.044 ± 0.044	3	0.033 ± 0.008
Guard Crabs	4	0.500 ± 0.109	0.088 ± 0.054	3	0 ± 0

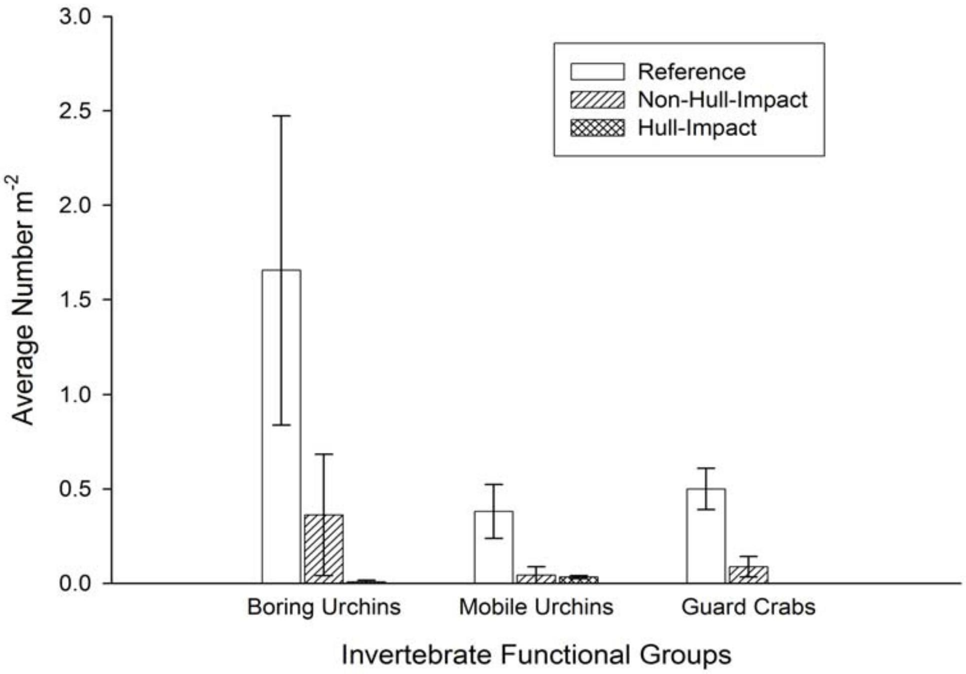

Figure 28. Average (±S.E.) number m^{-2} of macro-invertebrates by functional group.

Table 42. One-way ANOVAs of urchin functional group densities with T-test contrasts for Location (Ref = reference, NHI = non-hull-impact; HI = hull-impact). All data square-root transformed to conform to model assumptions.

Source	DF	SS	MS	F	P	
Boring Urchins						
Location	2	2.314	1.157	4.58	0.047	Ref > NHI; Ref > HI
Error	8	2.020	0.253			
Total	10	4.335				
Mobile Urchins						
Location	2	0.529	0.264	7.72	0.013	Ref > NHI; Ref > HI
Error	8	0.274	0.034			
Total	10	0.803				

Indirect quantification of functional group loss through examination of mean density differences at reference and impact sites is shown in Table 43. Mean differences were extrapolated over non-hull-impact (41,513 m^2) and hull-impact (7,243 m^2) areas to estimate the potential loss of individuals in the shelf pavement zone.

Table 43. Differences in functional group densities and potential loss of individuals within the shelf pavement zone (NHI = non-hull-impact; HI = hull-impact).

Functional Group	Difference in density: Reference – NHI	Potential Loss	Difference in density: Reference – HI	Potential Loss
Boring Urchins	1.294	53,718	1.648	11,936
Mobile Urchins	0.337	13,990	0.348	2,521
Guard Crabs	0.412	17,103	0.500	3,622

3.3.3 Algae

Twenty-nine species of macroalgae, including the invasive species *Avrainvillea amadelpha,* were identified along with crustose coralline and turf algae in impact and reference areas (Table 44). Algae covered 83 % of the benthic substrate in sampled quadrats at non-hull-impact sites, 55 % at hull-impact and 76 % at reference areas. Algal data were consolidated by functional group (macroalgae, coralline crustose algae, turf algae and invasive algae) for evaluation and analysis. The macroalgae were mainly represented by *Amansia glomerata*, species from the order Gelidiales, and *Dictyota sp.* (Table 44). The presence of *Udotea* sp., a green calicified algae, is the first noted record in shallow Hawaiian waters. *Udotea* sp. has only recently been discovered in deep Hawaiian habitats.

Table 44. Algae community represented as percent cover at reference, non-hull- and hull-impact sites within the shelf pavement zone.

Species within Functional Groups	Reference (% cover)	Non-Hull-Impact (% cover)	Hull-Impact (% cover)
Macroalgae	**37.19**	**48.44**	**12.92**
Amansia glomerata	8.85	18.13	0.42
Asparagopsis taxiformis	0.21	1.67	0
Champia sp.	0	0.31	0
Chondria sp.	0.10	0	0
Cladophoropsis herpestica	0.31	1.67	0
Dasya iridescens	0	0	0.14
Dictyota sp.	4.27	5.21	4.44
Dictyota friabilis	0.21	0	0
Gelid.	13.33	10.42	1.25
Griffithsia sp.	0.21	0	0
Halimeda discodea	0.73	0.63	0.14
Herposiphonia sp.	1.25	0.83	0.28
Heterosiphonia crispella	0	0.63	0.14
Jania sp.	0.10	0.21	0
Laurencia sp.	2.60	0.42	0.14
Martensia fragilis	0.10	0.10	0
Microdictyon setchellianum	0	0.42	0.28
Neomartensia flabelliformis	0	0.10	0
Padina sp.	0.21	1.25	2.64
Padina melemele	0.21	0.00	0.69

(Table 44 cont.)

Species within Functional Groups	Reference (% cover)	Non-Hull-Impact (% cover)	Hull-Impact (% cover)
Peyssonnelia sp.	0.00	0.10	0
Portieria hornemannii	0.10	0	0
Ralfsia sp.	0.10	0	0.69
Sargassum sp.	0.94	0	0.00
Spirocladia hodgsoniae	0.42	1.15	0.56
Spyridia filamentosa	2.08	5.00	0.97
Tolypiocladia glomerulata	0.73	0.21	0.14
Udotea sp.	0.10	0	0
Coralline Crustose Algae	**16.35**	**8.02**	**3.06**
Turf Algae	**20.31**	**23.23**	**38.89**
Invasive Algae	**1.77**	**2.92**	**0.56**
Avrainvillea amadelpha	1.77	2.92	0.56

3.3.3.1 Algae Analyses

Average percent coverage values (± S.E.) of algae functional groups are shown in Table 45 and Figure 29. Of the four algae functional groups, macroalgae displayed the highest percent cover at reference and non-hull-impact sites, while turf-algae had the highest cover at hull-impact sites.

Table 45. Average (± S.E.) percent cover of algal functional groups.

Functional Group	n	Reference	Non-Hull-Impact	n	Hull-Impact
Macroalgae	4	37.19 ± 9.69	48.44 ± 10.18	3	12.91 ± 0.42
Coralline Crustose Algae	4	16.36 ± 3.26	8.02 ± 1.74	3	3.05 ± 0.77
Turf Algae	4	20.31 ± 5.75	23.23 ± 2.96	3	38.89 ± 3.10
Invasive Algae	4	1.77 ± 1.77	2.92 ± 1.68	3	0.56 ± 0.56

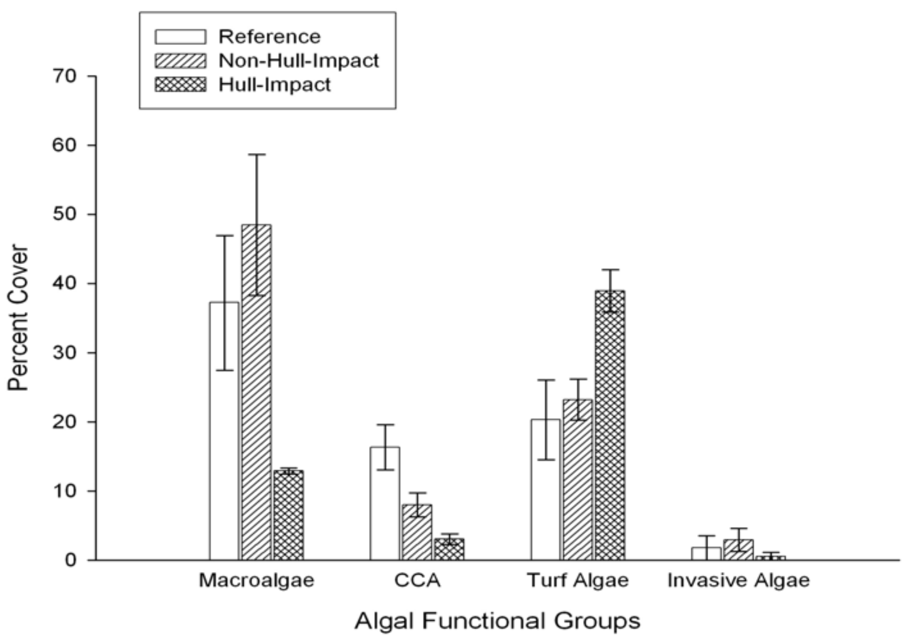

Figure 29. Average percent cover (± S.E.) of algal functional groups (CCA = coralline crustose algae).

Multiple analyses were conducted for the macroalgae to meet test assumptions of variance homogeneity. Average proportional macroalgae cover was significantly higher in reference compared to hull-impact sites (two-sided two-sample T-test for unequal variance of arcsine square-root transformed proportion data, df = 3.0, T = 2.50, P = 0.044), but did not differ between reference and non-hull-impact areas (two-sided two-sample T-test of arcsine square-root transformed proportion data, df = 6, T = 0.80, P = 0.773). Significantly lower coralline crustose algae cover was detected at non-hull- and hull-impact compared to reference sites (Table 46). A comparison of turf algae cover showed significantly higher coverage at hull-impact sites compared to the reference sites, but no difference existed between non-hull-impact and reference sites. No differences with invasive algae were shown. The demonstrated differences in coralline crustose and turf algae groups are consistent with substrate alteration and successional colonization as a result of injury.

Table 46. Crustose Coralline Algae one-way ANOVAs with T-test contrasts for Location; Turf and Invasive Algae one-way ANOVAs applied to Kruskal-Wallis ranks followed by all-pairwise comparisons for Location. Ref = reference, NHI = non-hull-impact; HI = hull-impact; nsd = no significant difference. Data analyzed as arcsine square-root transformed proportions to conform to model assumptions.

Source	**DF**	**SS**	**MS**	**F**	**P**	
Coralline Crustose Algae						
Location	2	0.032	0.016	7.68	0.014	Ref > NHI
Error	8	0.017	0.002			Ref > HI
Total	10	0.049				
Turf Algae (Parametric ANOVA applied to Kruskal-Wallis ranks; multiple comparison)						
Location	2	61.583	30.792	5.09	0.038	Ref NHI nsd
Error	8	48.417	6.052			Ref < HI
Total	10	110.000				
Invasive Algae (Parametric ANOVA applied to Kruskal-Wallis ranks; multiple comparison)						
Location	2	28.396	14.198	1.60	0.261	
Error	8	71.104	8.888			
Total	10	99.500				

Potential loss/injury of reef binding coralline crustose algae through examination of differences in mean percent cover between reference and impact areas suggests an injury related loss of 8.33% cover at non-hull- and 13.30% cover at hull-impact sites. Extrapolating respective percent differences over 41,513 m^2 (non-hull-impact area) and 7,243 m^2 (hull-impact area) equates to a total loss/injury of 4,421 m^2.

3.3.4 Fish

A total of 41 species was found along transects in the shelf pavement zone. The list of the species, by abundance in the reference sites, is shown in Table 47. Forty-seven percent of the individuals belonged to the R mobility class (resident species), and 50% were in the S1 class (semi-vagile, small area). Only 3% of the individuals were classified as S2 (semi-vagile, large area). No T class individuals (transient species) were counted along transects.

Table 47. Fish species average abundance (numbers ha^{-1}) at reference (Ref.), non-hull-impact (NHI) and hull-impact (HI) sites within the shelf pavement zone. Mob. = mobility class.

Species	Mob.	Ref.	NHI	HI	Species	Mob.	Ref.	NHI	HI
Chromis vanderbilti	R	4038	575	200	*Bodianus bilunulatus*	S2	38	0	0
Thallasoma duperrey	S1	2450	250	0	*Coris gaimard*	S1	38	25	0
Dascyllus albisella	S1	438	0	0	*Zebrasoma flavescens*	S1	38	0	0
Paracirrhites arcatus	R	400	162	0	*Acanthurus olivaceous*	S2	25	0	0
Acanthurus nigrofuscus	S1	362	50	100	*Caracanthus typicus*	R	25	0	0
Plectroglyphidodon johnstonianus	R	350	25	0	*Chromis ovalis*	R	25	0	0
Sufflamen bursa	S1	238	50	200	*Chlorurus sordidus*	S2	25	0	0
Plectroglyphidodon imparipennis	R	225	25	0	*Cirrhitops fasciatus*	R	25	25	0
Canthigaster jactator	S1	188	262	0	*Macropharyngodon geoffroy*	S1	25	0	0
Chaetodon miliaris	S1	188	0	0	*Naso hexacanthus*	S1	25	0	0
Parapeneus multifasciatus	S1	175	125	0	*Ostracion meleagris*	S1	25	0	17
Plagiotremus goslinei	R	138	0	0	*Paracirrhites forsteri*	R	25	0	0
Chaetodon quadrimaculatus	S1	112	0	0	*Echidna nebulosa*	S1	12	0	0
Scarus psittacus	S2	88	50	0	*Gomphosus varius*	S1	12	0	0
Chaetodon ornatissimus	S1	75	0	0	*Canthigaster coronata*	S1	0	25	0
Halichoeres ornatissimus	S1	75	0	0	*Cantherhines dumerilii*	S1	0	25	17
Coris venusta	S1	50	75	100	*Melichthys vidua*	S1	0	0	17
Parapercis schauinslandi	S1	50	100	317	*Naso unicornis*	S2	0	50	67
Pseudocheilinus octotaenia	S1	50	0	0	*Oxycheilinus unifasciatus*	S1	0	0	17
Pseudocheilinus tetrataenia	S1	50	0	0	*Sufflamen fraenatus*	S2	0	62.5	0
Rhinecanthus rectangulus	S1	50	38	267					

3.3.4.1 Fish Analyses

Average number and biomass (± S.E.) of fish by mobility class are shown in Table 48 and Figure 30. The means of number ha^{-1} for fishes in the two high site fidelity groups (R and S1) were significantly lower in the two categories of impact sites compared to the reference sites (Table 49). Biomass of R mobility class fish was also significantly lower in non-hull- and hull-impact areas compared to reference sites. Biomass of S1 mobility class fish was significantly lower in non-hull-impact compared to reference sites, but was not shown to differ significantly between reference and hull-impact areas. The differences in fish abundance and biomass would be expected as there was significant loss of three dimensional fish habitat in these impact areas. In addition, the lack of *Dacyllus albisella*, a fish species that commonly inhabits large *Pocillopora eydouxi* colonies, in the non-hull- and hull-impact sites corroborates the loss of these large colonies within these zones. Several other species that are obligate coral dwellers or corallivores were not found in the hull-impact sites although were present in the reference sites, including *Paracirrhites arcatus*, *Paracirrhites forsteri*, and *Cirrhitops fasciatus* (3 coral dwellers) and *Plectroglyphidodon johnstonianus*, *Chaetodon quadrimaculatus*, and *Chaetodon ornatissimus* (3 corallivores). Two species were more abundant at the hull-impact sites, *Parapercis schauinslandi* and *Rhinecanthus rectangulus*, both common inhabitants of rubble areas.

Table 48. Average (± S.E.) number ha^{-1} and biomass ($t\ ha^{-1}$) by mobility class at sites in the shelf pavement zone.

Mobility Class	n	Reference	Non-Hull-Impact	n	Hull-Impact
Number ha^{-1}					
R	4	5250 ± 2184	812 ± 396	3	200 ± 200
S1	4	4725 ± 843	1025 ± 284	3	1050 ± 350
S2	4	175 ± 43	162 ± 99	3	67 ± 67
T	4	0 ± 0	0 ± 0	3	0 ± 0
Biomass ($t\ ha^{-1}$)					
R	4	0.032 ± 0.010	0.009 ± 0.005	3	0.0006 ± 0.0006
S1	4	0.140 ± 0.061	0.030 ± 0.017	3	0.106 ± 0.076
S2	4	0.008 ± 0.007	0.003 ± 0.002	3	0.001 ± 0.001
T	4	0 ± 0	0 ± 0	3	0 ± 0

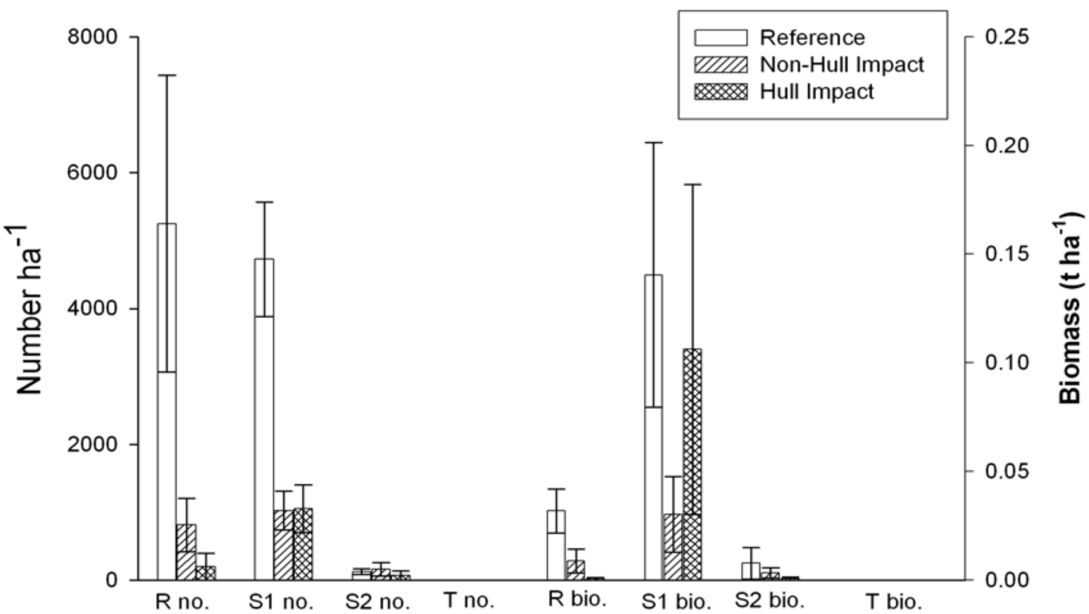

Figure 30. Average (± S.E.) number ha^{-1} and biomass ($t\ ha^{-1}$) of fish by mobility class at shelf pavement sites.

Table 49. Factorial ANOVA with T-test contrasts for Location for square root transformed number and biomass of fish by mobility class in the reference (Ref), non-hull-impact (NHI), and hull-impact (HI) areas (nsd = no significant difference). Note, at α = 0.050, biomass would be considered significantly lower for R and S1 at NHI and HI areas.

Source	DF	SS	MS	F	P	
Number						
Location (A)	2	9572.30	4786.15	15.71	0.000	Ref > NHI, Ref > HI
Mobility (B)	1	535.72	535.72	1.76	0.203	
Intxn (A × B)	2	468.05	234.03	0.77	0.480	
Error	16	4873.61	304.60			
Total	21	15449.68				
Biomass						
Location (A)	2	0.174	0.087	5.11	0.019	
Mobility (B)	1	0.286	0.286	16.86	0.001	
Intxn (A × B)	2	0.093	0.046	2.73	0.096	Ref > NHI for R and S1
Error	16	0.272	0.017			Ref > HI for R, nsd for S1
Total	21	0.825				

3.4 Reef Depressions

Four reference, two non-hull-impact and three hull-impact reef depression sites were assessed within the shelf pavement zone (Figure 31) at 30 to 41 ft. depths between 28 September and 30 November 2005. Impacts to reef depression habitat and resources appeared to have resulted from the placement and movement of the ship's hull, cables, towlines and cement deposition during *M/V Cape Flattery* grounding and response activities, as well as collision, burial and smothering through movement of incident generated reef debris (Figures 32, 34). Sampling of the area of injury was divided into non-hull-impact and hull-impact regions based on RP and towed-diver survey injury polygons. Sites were randomly chosen from multiple points distributed on a map in and around the hull-impact area and both north and south of the collective area of impact. Depressions were selected based on size (> 2.5 m length) and depth (> 0.5 m) at each site. Two neighboring depressions were surveyed at all but one site (where time and air considerations limited ability to survey a neighboring depression), with values averaged for each site prior to analysis.

All visible fish, corals and macro-invertebrates were assessed within each depression. Algae were assessed through quadrat sampling. Coral surveys extended 0.5 m beyond each depression lip in an effort to capture community richness associated with edge effects not sampled in shelf pavement zone surveys. Non-proportional data for each depression were standardized by projected area using the formula for an ellipse (area = $\pi \times 0.5$ length $\times 0.5$ width). Data were analyzed using factorial ANOVAs followed by Tukey's HDS comparisons or T-test contrasts. Data not conforming to model assumptions were analyzed using appropriate one-sided one- and two-sample T-tests. The area of impact used to project potential habitat and resource loss/injury was determined by independent measures of average depression frequency (3.56 depressions/500 m^2, ± 0.77 S.E.) and size (37.11 m^2 ± 9.56 S.E.) within five meters to either side of nine 50 m transects run throughout the shelf pavement area of injury. These values were extrapolated over the sampled reef depression impact assessment area (Figure 31; 28,859 m^2), resulting in total depression area estimates of 5,019 m^2 and 2,597 m^2 for non-hull- and hull-impact regions. Estimates of potential resource loss/injury in affected reef depressions were limited to species-functional groups and, for corals, colony sizes (categorized as small and large

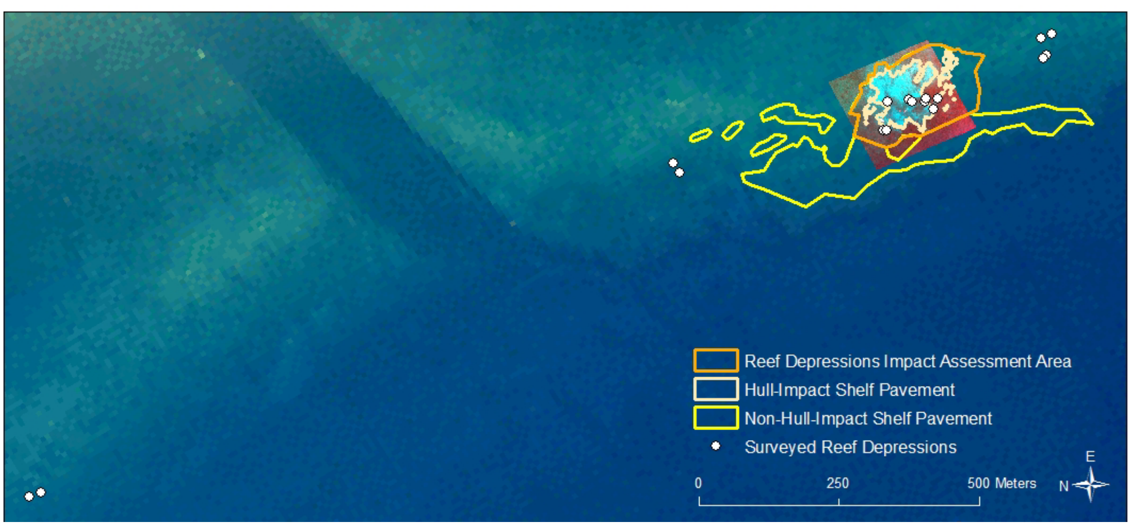

Figure 31. Surveyed reef depressions in non-hull-impact, hull-impact and reference areas. The reef depression impact assessment area is that within which community differences were extrapolated.

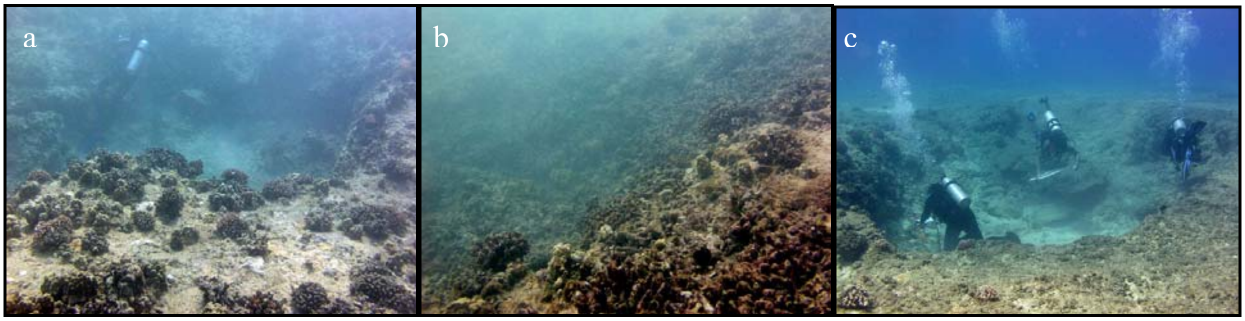

Figure 32. (a) Reference reef depression. (b) Non-hull-impact reef depression. (c) Hull-impact reef depression.

for initial analyses), for which average densities or proportional cover between reference and impact sites were demonstrated to be significantly different ($\alpha = 0.10$). Rugosity was not measured within reef depressions as no decision on how to adequately measure it was made.

3.4.1 Scleractinian Corals

A total 9,751 scleractinian corals (95 %) and coral fragments (5 %) representing 19 species were identified in surveyed reef depressions in the operational area of *M/V Cape Flattery* removal and reference sites along shelf pavement (Figure 33). Twenty-three percent of attached corals and 84 % of fragments were identified in non-hull- and hull-impact area depressions. Nine (47 %) of the species were grouped by genus, functional habitat form and growth rate into *Montipora* encrusting (*M. capitata*, *M. patula, M. studeri*), *Pocillopora* cauliflower (*P. ligulata, P. meandrina*), *Pocillopora eydouxi*, and *Porites* lobate (*P. brighami*, *P. evermanni*, *P. lobata*) groups for analyses. Species representatives of these four groups were observed as injured (detached, fragmented, tissue and/or skeletal loss) in the operational area of *M/V Cape Flattery* removal (Figure 34). *Cycloseris vaughani*, *Diaseris* sp., *Fungia scutaria*, *Leptastrea bottae*, *L. pruinosa*, *L. purpurea*, *Pavona duerdeni, P. varians, Porites compressa* and *Psammocora* sp. were present along transects but not analyzed due to low site representation.

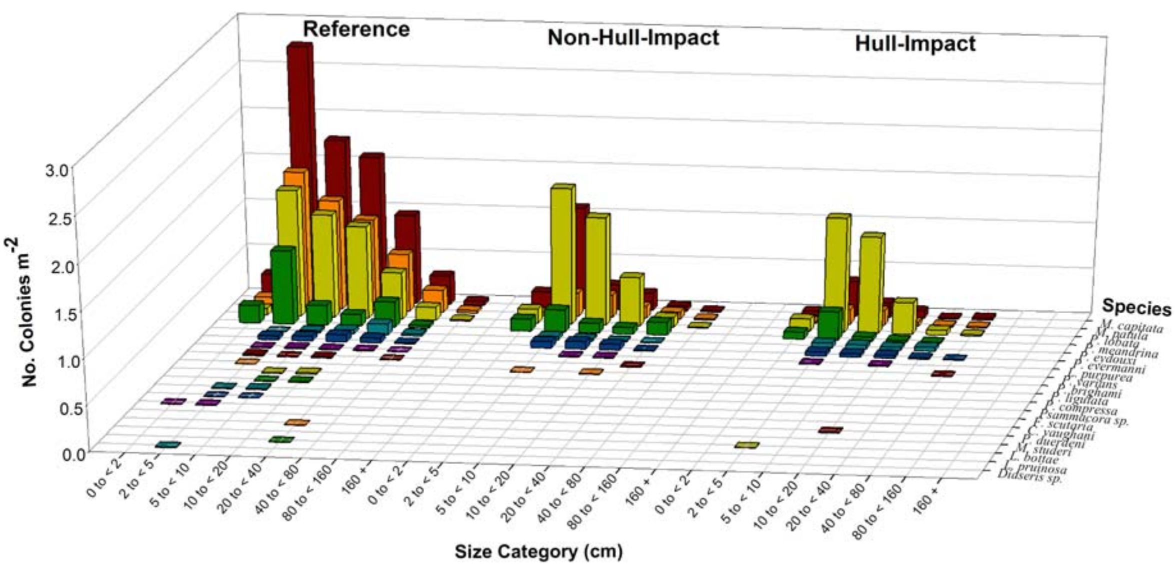

Figure 33. Coral community composition represented as average no. attached colonies m^{-2} in reference, non-hull-impact and hull-impact shelf pavement reef depressions.

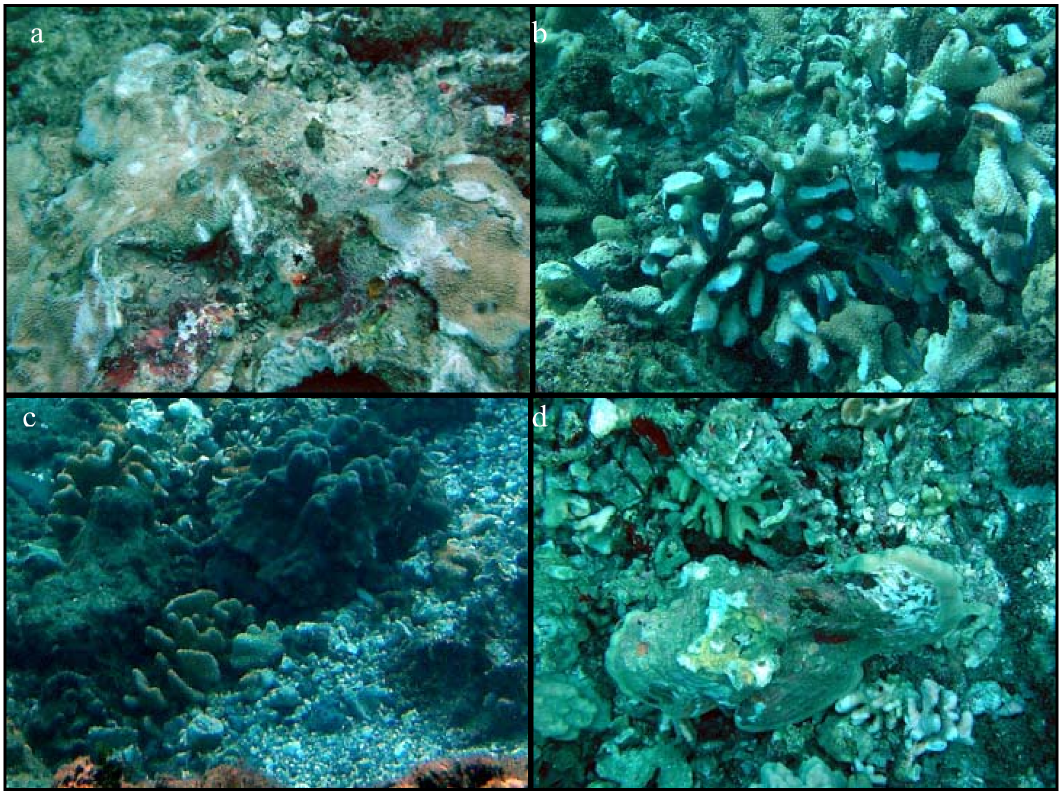

Figure 34. (a) *Montipora capitata* impact injuries. (b) Broken and detached *Pocillopora meandrina*. (c) Broken and partially buried *Pocillopora eydouxi*. (d) Overturned *Porites lobata*.

3.4.1.1 Attached Coral Analyses

Average values (± S.E.) of species group size data of small (0 to < 10 cm greatest diameter) and large (10 to > 160 cm) colony categorizations are shown in Table 50 and Figure 35. *Montipora* encrusting and *Porites* lobate species dominated relative abundance in reference, non-hull- and hull-impact depressions. Small colonies tended to be more abundant than large, except in *Pocillopora eydouxi*. Average numbers of attached colonies m^{-2} were significantly lower in both non-hull-impact and hull-impact depressions compared to reference depressions for *Montipora* encrusting and *Pocillopora* cauliflower corals (Table 51). Large *Porites* lobate colonies displayed a declining trend from reference to non-hull- to hull-impact depressions; however, no significant difference was shown, possibly due to limited sample size.

Table 50. Average (± S.E.) attached colony numbers m^{-2} of species group size data for small (< 10 cm) and large (≥ 10 cm) colonies (n = 4 for reference; n = 2 for non-hull-impact and n = 3 for hull-impact depressions).

Species Group	Size Group	Reference	Non-Hull-Impact	Hull-Impact
Montipora encrusting	small	8.398 ± 0.797	2.241 ± 0.851	1.853 ± 1.569
	large	5.107 ± 1.827	0.506 ± 0.236	0.376 ± 0.312
Pocillopora cauliflower	small	1.369 ± 0.318	0.507 ± 0.100	0.644 ±0.378
	large	0.524 ± 0.129	0.228 ± 0.105	0.048 ± 0.032
Pocillopora eydouxi	small	0.034 ± 0.029	0.069 ± 0.049	0.069 ± 0.069
	large	0.178 ± 0.096	0.018 ± 0.018	0.050 ± 0.050
Porites lobate	small	3.024 ± 0.647	3.139 ± 0.763	3.090 ± 1.191
	large	1.921 ± 0.502	0.747 ± 0.186	0.612 ± 0.109

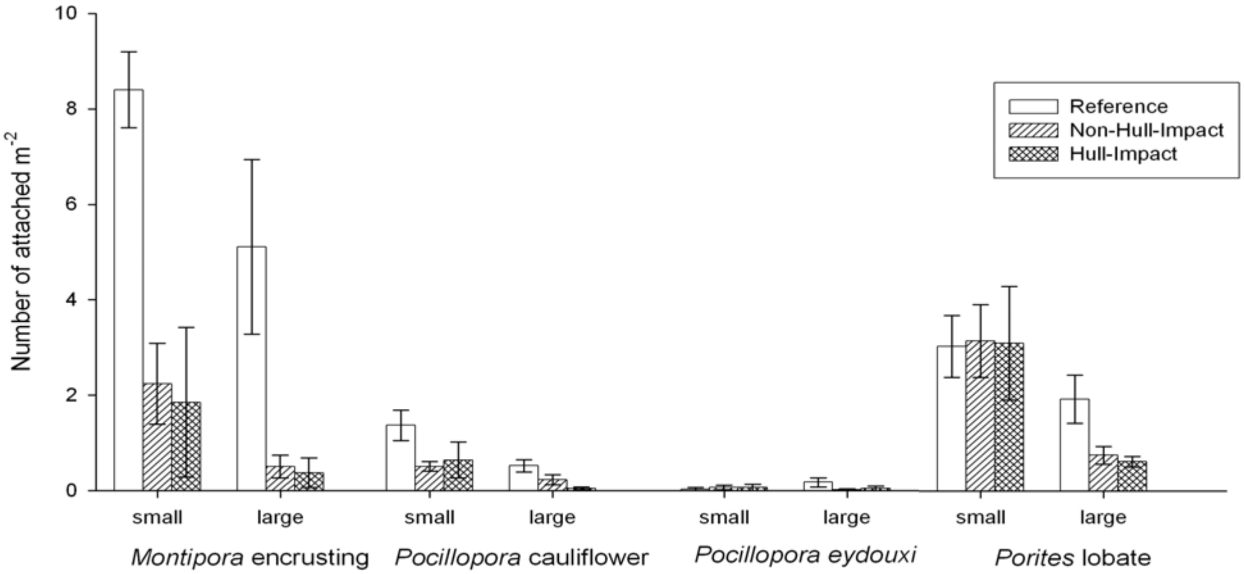

Figure 35. Average (± S.E.) attached colony numbers m^{-2} of species group size data for small (< 10 cm) and large (≥ 10 cm) colonies.

Table 51. Factorial ANOVAs with T-test contrasts for species groups in reference (Ref), non-hull-impact (NHI) and hull-impact (HI) depressions (data square-root transformed to conform to model assumptions).

Source	DF	SS	MS	F	P	
***Montipora* encrusting**						
Location (A)	2	12.267	6.134	12.60	0.001	Ref > NHI, Ref > HI
Size (B)	1	2.000	2.000	4.11	0.066	
Intxn (A × B)	2	0.049	0.024	0.05	0.951	
Error	12	5.842	0.487			
Total	17	20.158				
***Pocillopora* cauliflower**						
Location (A)	2	0.788	0.394	5.91	0.016	Ref > NHI, Ref > HI
Size (B)	1	0.677	0.677	10.14	0.008	
Intxn (A × B)	2	0.051	0.025	0.38	0.692	
Error	12	0.801	0.067			
Total	17	2.317				
Pocillopora eydouxi						
Location (A)	2	0.025	0.013	0.26	0.778	
Size (B)	1	0.001	0.001	0.02	0.888	
Intxn (A × B)	2	0.103	0.052	1.00	0.398	
Error	12	0.621	0.052			
Total	17	0.750				
***Porites* lobate**						
Location (A)	2	0.320	0.160	1.20	0.336	
Size (B)	1	2.199	2.199	16.47	0.002	
Intxn (A × B)	2	0.343	0.172	1.28	0.312	
Error	12	1.602	0.134			
Total	17	4.464				

Indirect quantification of potential colony loss/injury through examination of differences in reference and impact area mean colony numbers m^{-2} is shown in Table 52. Mean differences were extrapolated for estimated non-hull- and hull-impact depressions within the reef depressions impact assessment area of the shelf pavement injury polygon (Figure 31) to determine potential colony loss/injury. Subdivision of small and large categories into constituent size groups (based on mean proportional distributions of colony sizes in the reference area) provides a necessary component for estimating the temporal aspects of injury from a recovery perspective (Table 53). This method assumes equivalent loss/injury proportional to constituent size representation within small and large size categories, a conditional limitation of the analysis. A total 92,209 *Montipora* encrusting and *Pocillopora* cauliflower colonies were projected as injured through coral community comparisons, with 59 % < 10 cm (small) and 41 % ≥ 10 cm (large).

Table 52. Potential colony loss/injury (non-hull-impact area = 5,019 m^2; hull-impact area = 2,597 m^2).

Species Group	Size Group	Non-Hull-Impact Diff. in Mean Colonies m^{-2}	Potential Loss/Injury (colonies)	Hull-Impact Diff. in Mean Colonies m^{-2}	Potential Loss/Injury (colonies)
Montipora encrusting	small	6.157	30,902	6.545	16,997
	large	4.601	23,092	4.731	12,286
Pocillopora cauliflower	small	0.862	4,326	0.725	1,883
	large	0.296	1,486	0.476	1,236

Table 53. Percentage of coral colony sizes constituting small and large categories and associated estimates of potential loss/injury (% of Total × Table 52 Potential Loss/Injury; NHI = non-hull-impact; HI = hull-impact).

	Colony Size Category							
	Small Colonies			Large Colonies				
	1 to < 2 cm	2 to < 5 cm	5 to < 10 cm	10 to < 20 cm	20 to < 40 cm	40 to < 80 cm	80 to < 160 cm	Total
***Montipora* encrusting**								
Percent of Total (Ref)	6.92	55.02	38.06	57.27	31.76	9.95	1.03	
Projected Injury/Loss NHI	2,137	17,003	11,762	13,224	7,334	2,297	237	53,994
Projected Injury/Loss HI	1,176	9,352	6,470	7,036	3,902	1,222	126	29,284
***Pocillopora* cauliflower**								
Percent of Total (Ref)	14.43	67.89	17.68	29.86	65.61	4.53		
Projected Injury/Loss NHI	624	2,937	765	444	975	67		5,812
Projected Injury/Loss HI	272	1,278	333	369	811	56		3,119

3.4.1.2 Fragment Analyses

Average live (at time of surveys) fragment numbers m^{-2} appeared highest within the non-hull-impact depressions and were dominated by *Porites* lobate and *Pocillopora* cauliflower corals (Table 54, Figure 36). Live fragments of *Montipora* encrusting species were not identified in surveyed hull-impact depressions, prohibiting inclusion in one-way ANOVAs. No significant differences in mean *Montipora* encrusting fragment numbers m^{-2} (square-root transformed) between reference and non-hull-impact (one-sided two-sample T-Test, df = 4, T = 0.62, P = 0.285) and reference and hull-impact (one-sample T-Test that reference < 0, the mean value for hull-impact depressions, df = 3, T = 1.58, P = 0.894) depressions were displayed. However, significantly higher proportions (live/fragments/all colonies within a species group; arcsine square-root transformed) of *Montipora* encrusting fragments m^{-2} occurred in non-hull-impact depressions (one-sided two-sample T-Test, df = 4, T = 2.46, P = 0.035), but not hull-impact depressions (one-sample T-Test that reference < 0, the mean value for hull-impact depressions, df = 3, T = 1.73, P = 0.909). Significantly higher proportions, but not numbers, of *Pocillopora* cauliflower fragments m^{-2} occurred in non-hull- and hull-impact compared to reference depressions (Table 55). *Pocillopora eydouxi* had significantly higher fragment numbers (Table

55; Power = 0.542 at α = 0.050) and proportions m^{-2} (variance heterogeneity led to use of one-sided two-sample T-tests; reference vs. non-hull-impact, df = 4, T = 12.08, P = 0.000; reference vs. hull-impact, test for unequal variance, df = 2.2, T = 5.04, P = 0.015) in non-hull- and hull-impact areas. Significantly higher mean fragment numbers and proportions of *Porites* lobate corals occurred in non-hull-impact compared to reference areas. Hull-impact areas had higher proportions but not numbers of *Porites* lobate fragments m^{-2} (Table 55).

Table 54. Average (± S.E.) numbers and proportions of live fragments m^{-2} (n = 4 for reference; n = 2 for non-hull-impact; n = 3 for hull-impact depressions).

Species Group	Numbers			Proportions		
	Reference	Non-Hull Impact	Hull-Impact	Reference	Non-Hull Impact	Hull-Impact
Montipora encrusting	0.023 ± 0.014	0.030 ± 0.017	0 ± 0	0.002 ± 0.001	0.010 ± 0.002	0 ± 0
Pocillopora cauliflower	0.156 ± 0.069	0.416 ± 0.138	0.346 ± 0.190	0.070 ± 0.023	0.370 ± 0.142	0.372 ± 0.131
Pocillopora eydouxi	0.005 ± 0.005	0.301 ± 0.242	0.198 ± 0.119	0.012 ± 0.012	0.765 ± 0.015	0.849 ± 0.151
Porites lobate	0.099 ± 0.043	0.781 ± 0.035	0.195 ± 0.041	0.021 ± 0.007	0.173 ± 0.029	0.054 ± 0.006

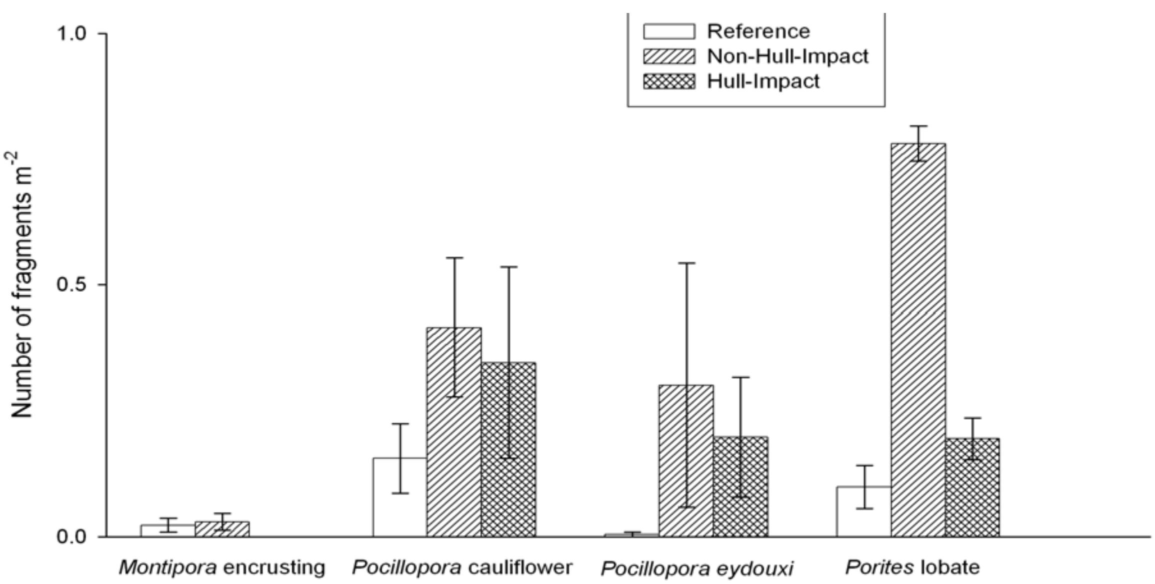

Figure 36. Average (± S.E.) numbers of live fragments m^{-2} for species groups in reference, non-hull-impact and hull-impact area depressions.

Extrapolation of fragment numbers across depressions within the reef depression impact assessment area of the shelf pavement zone provides a limited basis for accounting for injury. Proportional subdivision of mean differences into constituent size classes allows total live fragment number estimates across size groups. Projected numbers for species demonstrating significantly higher mean live fragment numbers and/or proportions m^{-2} in impact compared to reference areas are shown in Table 56. These numbers presumably underestimate actual injury to coral resources as surveys were limited to live (at the time of assessment) remaining fragments; however, fragments, particularly branches, do not necessarily represent whole colony losses on a one fragment to one colony basis. Fragments occurring in depressions may also partially

Table 55. One-way ANOVAs with T-test contrasts of numbers and proportions of live fragments m^{-2} for species groups in reference (Ref), non-hull-impact (NHI) and hull-impact (HI) depressions (number data square-root transformed and proportion data arcsine square-root transformed to conform to model assumptions). nsd = no significant difference. Note, at $\alpha = 0.05$, differences in number of *Pocillopora eydouxi* fragments would be considered not determinable.

Source	DF	SS	MS	F	P	
***Pocillopora* cauliflower**						
number						
Location	2	0.121	0.060	1.25	0.353	
Error	6	0.291	0.048			
Total	8	0.412				
proportion						
Location	2	0.343	0.171	5.39	0.046	Ref < NHI
Error	6	0.191	0.032			Ref < HI
Total	8	0.534				
Pocillopora eydouxi						
number						
Location	2	0.369	0.184	4.59	0.062	Ref < NHI
Error	6	0.241	0.040			Ref < HI
Total	8	0.610				
***Porites* lobate**						
number (no transformation applied)						
Location	2	0.654	0.327	55.9	0.000	Ref < NHI
Error	6	0.035	0.006			Ref HI nsd
Total	8	0.689				
proportion						
Location	2	0.121	0.060	14.1	0.005	Ref < NHI
Error	6	0.026	0.004			Ref < HI
Total	8	0.147				

represent broken colonies displaced from surrounding shelf pavement. Fragments ≥ 80 cm in largest diameter were not observed in surveyed reef depressions.

Table 56. Percentage of live fragments for size groups constituting the fragment category and associated estimates of total live fragment numbers (% of Tot. × impact area × diff. of Tot. mean Frag. No. m^{-2} calculated from Table 54). NHI = non-hull-impact; HI = hull-impact. NHI depression area = 5019 m^2; HI depression area = 2,597 m^2.

	Fragment Size Category						
	1 to < 2 cm	**2 to < 5 cm**	**5 to < 10 cm**	**10 to < 20 cm**	**20 to < 40 cm**	**40 to < 80 cm**	**Total**
***Montipora* encrusting**							
Percent of Total (NHI)	25.00	37.50	37.50	0	0	0	
Projected No. Frag. (NHI)	9	13	13				35
***Pocillopora* cauliflower**							
Percent of Total (NHI)	0.59	22.90	40.79	18.34	17.38	0	
Projected No. Frag. (NHI)	8	299	532	239	227		1,305
Percent of Total (HI)	0	11.93	56.39	19.74	11.95	0	
Projected No. Frag. (HI)		59	278	97	59		493
Pocillopora eydouxi							
Percent of Total (NHI)	0	14.13	31.76	26.45	22.10	5.56	
Projected No. Frag. (NHI)		210	472	393	328	83	1,486
Percent of Total (HI)	0	15.22	47.87	32.57	4.35	0	
Projected No. Frag. (HI)		76	240	163	22		501
***Porites* lobate**							
Percent of Total (NHI)	0	26.42	47.29	23.50	2.79	0	
Projected No. Frag. (NHI)		904	1,619	805	95		3,423
Percent of Total (HI)	0	27.43	35.29	16.68	11.79	8.81	
Projected No. Frag. (HI)		68	88	42	29	22	249

3.4.2 Macro-Invertebrates

Fourteen species of macro-invertebrates were identified along transects surveyed at reference and impact sites (Table 57). Nine (64 %) of these were consolidated into three functional groups for analysis based on their relative abundance, critical functional capacity and susceptibility to incident related injury.

Table 57. Macro-invertebrate community represented as average no. organisms m^{-2} in reference, non-hull- and hull-impact reef depressions.

Species	Functional Group	Reference	Non-Hull-Impact	Hull-Impact
Mollusca				
Conus leopardus		0	0	0.003
Pinctada radiata		0.033	0.008	0.028
Crustacea				
Saron marmoratus		0.106	0	0
Stenopus hispidus		0.031	0	0.022
Trapezia ferruginea	Guard Crab	0.113	0.059	0.0082
Trapezia flavopunctata	Guard Crab	0.148	0.035	0
Trapezia tigrina	Guard Crab	0.094	0.035	0
Echinodermata-Asteroids				
Unidentified Brittle Star		0.259	0.057	0.077
Echinodermata-Echinoids				
Eucidaris metularia	Mobile Urchin	0.238	0.044	0.024
Echinothrix calamaris	Mobile Urchin	0.219	0.096	0.062
E. diadema	Mobile Urchin	0.004	0	0
Tripneustes gratilla	Mobile Urchin	0.133	0.073	0.157
Echinostrephus acciculatus	Boring Urchin	1.242	0.547	0.132
Echinometra mathaei	Boring Urchin	0.509	0.262	0.065

3.4.2.1 Macro-Invertebrate Analyses

Average densities (± S.E.) of the macro-invertebrate functional groups are shown in Table 58 and Figure 37. Mean densities tended to display a declining trend from reference to non-hull to hull-impact areas. Variation in boring urchin densities in reference depressions was high. Significantly lower densities of mobile urchins were identified in impacted depressions (Table 59; Power = 0.452 at $\alpha = 0.050$). Guard crabs densities were significantly lower in hull-impact compared to reference depressions, but did not display differences between non-hull impact and reference depressions (Power = 0.511 at $\alpha = 0.050$). This lack of difference may have resulted from an inadequate sample number of non-hull-impact depressions and the use of the two-sided ANOVA for analysis.

Indirect quantification of functional group loss through examination of mean density differences at reference and impact sites is shown in Table 60. Mean differences were extrapolated over non-hull- (5,019 m^2) and hull-impact (2,597 m^2) depression areas of injury to estimate potential loss of individuals.

Table 58. Average (±S.E.) densities of macro-invertebrates by functional group at reference, non-hull- and hull-impact sites in reef depressions.

Functional Group	n	Reference	n	Non-Hull Impact	n	Hull-Impact
Boring Urchins	4	1.75 ± 0.895	2	0.809 ± 0.343	3	0.197 ± 0.082
Mobile Urchins	4	0.597 ± 0.123	2	0.213 ± 0.040	3	0.242 ± 0.101
Guard Crabs	4	0.356 ± 0.146	2	0.130 ± 0.130	3	0.0082 ± 0.0082

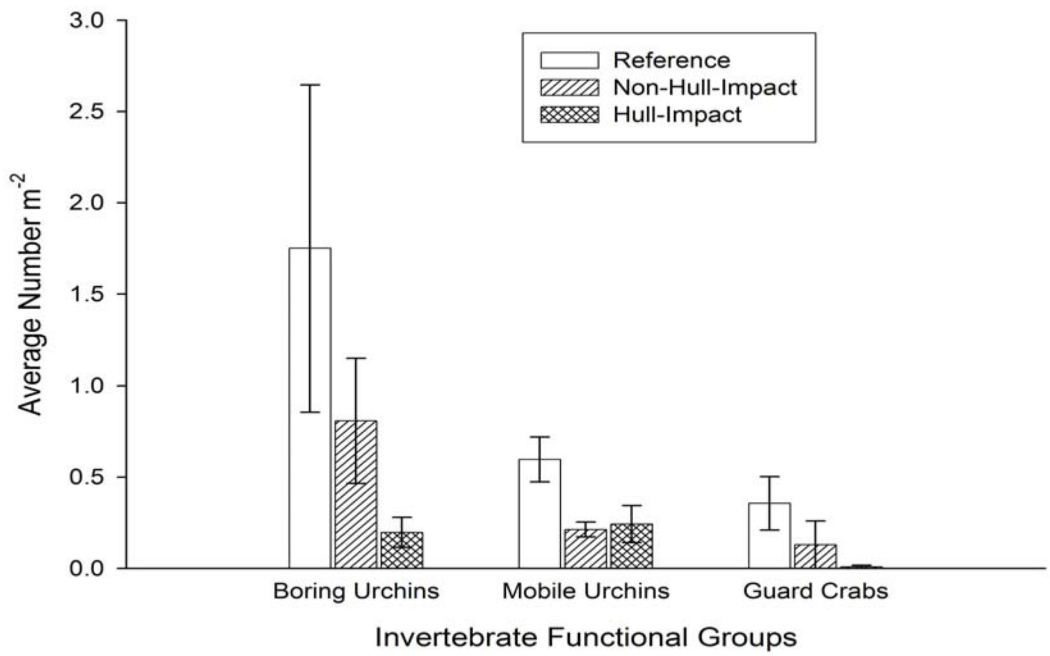

Figure 37. Average (±S.E.) densities of macro-invertebrates by functional group at reference, non-hull- and hull-impact sites in reef depressions.

Table 59. One-way ANOVAs of urchin and guard crab densities with T-test contrasts for Location (Ref = reference, NHI = non-hull-impact; HI = hull-impact; nsd = no significant difference). Data square-root transformed to conform to model assumptions. Note, at α = 0.05, differences in mobile urchin and guard crab densities would be considered not determinable.

Source	DF	SS	MS	F	P	
Boring Urchins						
Location	2	0.995	0.498	1.82	0.241	
Error	6	1.638	0.273			
Total	8	2.633				
Mobile Urchins (no transformation required)						
Location	2	0.300	0.150	3.67	0.091	Ref > NHI
Error	6	0.245	0.041			Ref > HI
Total	8	0.545				
Guard Crabs						
Location	2	0.453	0.226	4.26	0.071	Ref NHI nsd
Error	6	0.319	0.053			Ref > HI
Total	8	0.772				

Table 60. Differences in functional group densities and potential loss of individuals in reef depressions. (n.d.) = not determinable at α = 0.050.

Functional Group	Non-Hull Impact Density Difference	Potential Loss	Hull Impact Density Difference	Potential Loss
Mobile Urchins	0.384	1,927 (n.d.)	0.355	922 (n.d.)
Guard Crabs			0.348	903 (n.d.)

3.4.3 Algae

Twenty-four species of macroalgae, including the invasive algae *Avrainvillea amadelpha*, were identified along with coralline crustose and turf algae in impact and reference reef depressions (Table 61). Algae covered 64% of the benthic substrate in reference depressions, 80% in non-hull-impact and 47 % in hull-impact depressions. Algal data were consolidated by functional group (macroalgae, coralline crustose algae, turf algae and invasive algae) for evaluation and analysis. Macroalgae were mainly represented by *Amansia glomerata* and *Dictyota spp.* Species of the order Gelidiales also displayed high relative abundance (Table 61).

Table 61. Algae community represented as average percent cover in reference and impact (NHI = non-hull-impact; HI = hull-impact) reef depressions.

Species within Functional Groups	Reference (% cover)	NHI (% cover)	HI (% cover)
Macroalgae	**24.69**	**21.25**	**17.08**
Amansia glomerata	7.81	5.00	2.29
Asparagopsis taxiformis	0.31	0.00	0.00
Caulerpa racemosa	0.00	0.00	0.42
Caulerpa webbiana	0.16	0.00	0.00
Champia sp.	0.16	0.00	0.00
Cladophoropsis herpestica	0.31	1.88	0.21
Crouania sp.	0.63	0.00	0.21
Dictyota sp.	5.47	7.19	3.75
Dictyota friabilis	0.31	0.00	0.83
Gelid.	3.91	2.50	4.58
Halimeda discodea	0.31	0.63	0.42
Halimeda opuntia	0.16	0.00	0.00
Herposiphonia sp.	0.94	0.31	0.21
Jania sp.	0.31	0.31	0.21
Laurencia parvipapillata	0.16	0.00	0.00
Laurencia sp.	0.47	0.63	0.42
Microdictyon setchellianum	0.00	0.00	0.21
Neomeris annulata	0.00	0.00	0.63
Padina sp.	0.00	0.00	0.21
Spirocladia hodgsoniae	1.09	0.31	0.63
Spyridia filamentosa	1.56	1.88	1.88
Tolypiocladia glomerulata	0.47	0.63	0.00
Ventricaria ventricosa	0.16	0.00	0.00
Coralline Crustose Algae	**13.44**	**12.19**	**6.25**
Turf Algae	**25.63**	**41.56**	**23.54**
Invasive Algae	**0.16**	**5.00**	**0.42**
Avrainvillea amadelpha	0.16	5.00	0.42

3.4.3.1 Algae Analyses

Average percent coverage values (± S.E.) of algae functional groups are shown in Table 62 and Figure 38. Macro- and turf algae dominated percent algae cover in reference depressions. Turf algae displayed the highest cover in non-hull and hull-impact depressions (Table 4A).

Comparative analyses demonstrated significantly higher proportional cover of coralline crustose algae in reference compared to hull-impact depressions, and greater invasive algae cover (Power = 0.440 at $\alpha = 0.050$) in non-hull-impact compared to reference depressions (Table 63). No other differences were detected. The difference in coralline crustose algae cover in reef depressions is consistent with substrate alteration as a result of injury.

Table 62. Average (± S.E.) percent cover of algal functional groups (n = 4 for reference; n = 2 for non-hull-impact and n = 3 for hull-impact depressions).

Functional Group	**Reference**	**Non-Hull-Impact**	**Hull-Impact**
Macroalgae	24.69 ± 5.02	21.25 ± 10.63	17.09 ± 6.10
Coralline Crustose Algae	13.44 ± 0.94	12.19 ± 0.94	6.25 ± 0.96
Turf Algae	25.63 ± 4.23	41.57 ± 9.07	23.54 ± 3.47
Invasive Algae	0.16 ± 0.16	5.01 ± 4.38	0.42 ± 0.21

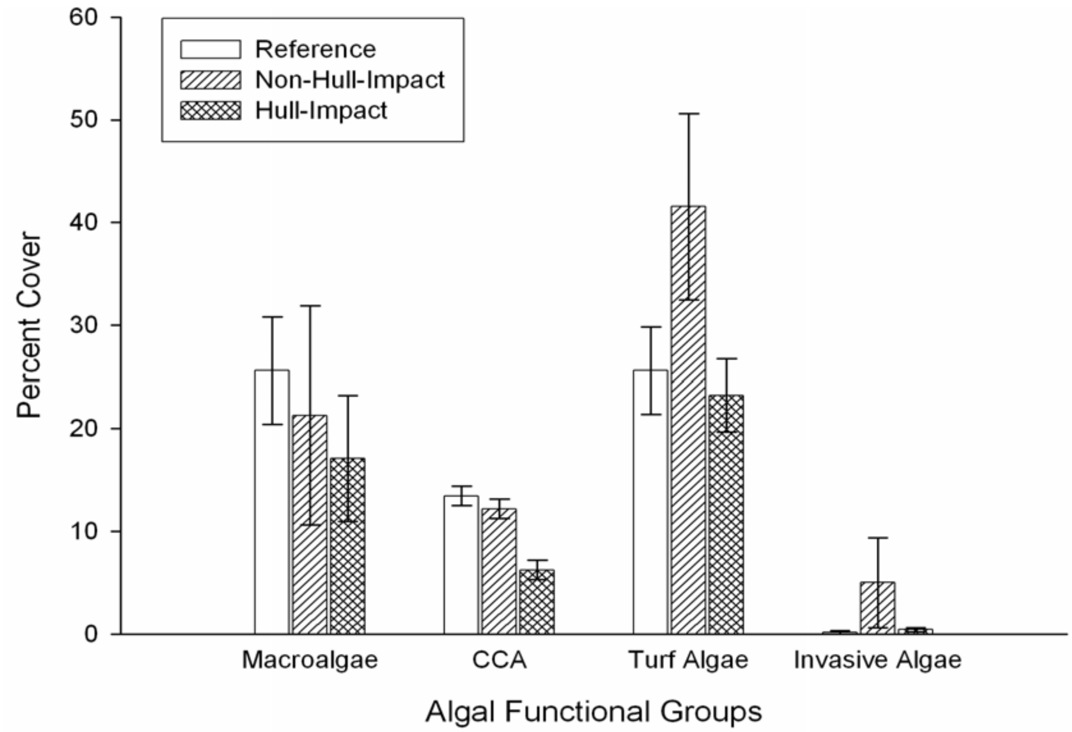

Figure 38. Percent cover (± S.E.) of algal functional groups (CCA = coralline crustose algae).

Table 63. Macroalgae, Crustose Coralline Algae, Turf, and Invasive Algae one-way ANOVAs with T-test contrasts for Location. Ref = reference, NHI = non-hull-impact; HI = hull-impact; nsd = no significant difference. Data analyzed as arcsine square-root transformed proportions to conform to model assumptions. Note, at α = 0.05, differences in invasive algae would be considered not determinable.

Source	**DF**	**SS**	**MS**	**F**	**P**	
Macroalgae						
Location	2	0.016	0.008	0.40	0.688	
Error	6	0.123	0.021			
Total	8	0.139				
Coralline Crustose Algae						
Location	2	0.028	0.014	16.9	0.003	Ref NHI nsd
Error	6	0.005	0.001			Ref > HI
Total	8	0.033				
Turf Algae						
Location	2	0.052	0.026	2.75	0.142	
Error	6	0.057	0.010			
Total	8	0.110				
Invasive Algae						
Location	2	0.042	0.021	3.55	0.096	Ref < NHI
Error	6	0.036	0.006			Ref HI nsd
Total	8	0.078				

Potential loss/injury of reef binding coralline crustose algae through examination of differences in mean percent cover between reference and the hull-impact area suggests an injury related reduction of 7.19 %. Extrapolating the percent difference over 2,597 m^2 equates to a total loss/injury of 187 m^2.

3.4.4 Fish

A total of 49 species were found within surveyed reef depressions. A list of species, arranged by abundance in impact sites, is shown in Table 64. Fifty-five percent of the individuals belonged to the R mobility class (resident species) and 37% in the S1 mobility class (semi-vagile, small area). Only 8 % were in the S2 mobility class (semi-vagile, large area). No transient species (T mobility class) were enumerated.

Table 64. Average abundance (numbers ha^{-1}) of fish species in surveyed reef depressions (no distinction between non-hull and hull-impact depressions was made). Mob. = mobility class; Ref. = reference; Imp. = impact.

Species	**Mob.**	**Ref.**	**Imp.**	**Species**	**Mob.**	**Ref.**	**Imp.**
Chromis vanderbilti	R	3716	11325	*Oxycheilinus bimaculatus*	S1	51	0
Acanthurus nigrofuscus	S1	622	2157	*Parapeneus multifasciatus*	S1	48	65
Acanthurus olivaceus	S2	617	499	*Hemitaurichthys thompsoni*	S1	47	0
Thalassoma duperrey	S1	532	2295	*Monotaxis gradoculis*	S2	47	0
Zebrasoma flavescens	S1	379	0	*Plectroglyphidodon imparipennis*	R	41	117
Sufflamen bursa	S1	334	288	*Pseudocheilinus tetrataenia*	S1	40	48
Halichoeres ornatissimus	S1	231	201	*Coris venusta*	S1	27	837
Chlorurus sordidus	S2	223	47	*Gymothorax flavimarginatus*	R	27	17
Paracirrhites arcatus	R	201	178	*Pseduocheilinus evandius*	S1	27	0
Ctenchaetus strigosus	S1	189	27	*Scarus psittacus*	S2	24	62
Pseudochilineus octotaenia	S1	176	254	*Anampses chrysocephalus*	S1	0	119
Plectroglyphidodon johnstonianus	R	167	90	*Bodianus bilunulatus*	S2	0	28
Chaetodon ornatissimus	S1	163	55	*Cephalopholus argus*	S1	0	39
Cirrhitops fasciatus	R	133	200	*Chaetodon multicintus*	S1	0	24
Canthigaster jactator	S1	129	248	*Cirrhitus pinnulatus*	R	0	17
Naso literatus	S2	119	41	*Coris gaimard*	S1	0	129
Acanthurus blochii	S2	95	0	*Melichthys niger*	S1	0	48
Rhinecanthus rectangulus	S1	93	375	*Novaculichthys taeniourus*	S1	0	152
Melichthys vidua	S1	88	325	*Ostracion meleagris*	S1	0	55
Macropharyngodon geoffroy	S1	81	0	*Parapeneus bifasciatus*	S1	0	44
Plagiotremus goslinei	R	75	104	*Pervagor spilosoma*	S1	0	27
Gymnothorax meleagris	R	75	0	*Plagiotremus ewaensis*	R	0	24
Apogon kallopterus	R	68	295	*Stethojulis balteata*	S1	0	55
Naso unicornis	S2	54	55	*Sufflamen fraenatus*	S2	0	172
Chaetodon quadrimaculatus	S1	51	103				

3.4.4.1 Fish Analyses

Average number and biomass (± S.E.) of coral reef fish by mobility group are shown in Table 65 and Figure 39. No distinction between non-hull and hull-impact depressions was made due to low overall sample size, organism mobility potential, sampling focus in the hull-impact vicinity, and questions of overall community effects in relation to displacement from injured habitat as opposed to calculations of fish loss. Significantly higher numbers of resident (R) and semi-vagile, small area (S1) fish were identified in impact compared to reference depressions (Table 66; Power = 0.51 at $\alpha = 0.050$). Biomass of S1, but not R fishes, was also found to be significantly higher in impacted depressions. Such increase is consistent with displacement of coral reef fishes from lost shelf pavement habitat as depressions, in accumulating incident related reef debris, may have represented best available remaining shelter in the shelf pavement zone following the grounding and removal of the *M/V Cape Flattery*.

Table 65. Average (± S.E.) number ha^{-1} and biomass ($t\ ha^{-1}$) by of coral reef fish by mobility class in reef depressions.

		Numbers ha^{-1}		Biomass ($t\ ha^{-1}$)	
Mobility Class	**n**	**Reference**	**Impact**	**Reference**	**Impact**
R	4	4,502 ± 1,641	12,369 ± 4,996	0.043 ± 0.016	0.062 ± 0.025
S1	4	3,310 ± 923	7,968 ± 1,174	0.142 ± 0.058	0.697 ± 0.244
S2	4	1,180 ± 578	904 ± 211	0.212 ± 0.183	0.298 ± 0.118
T	4	0 ± 0	0 ± 0	0 ± 0	0 ± 0

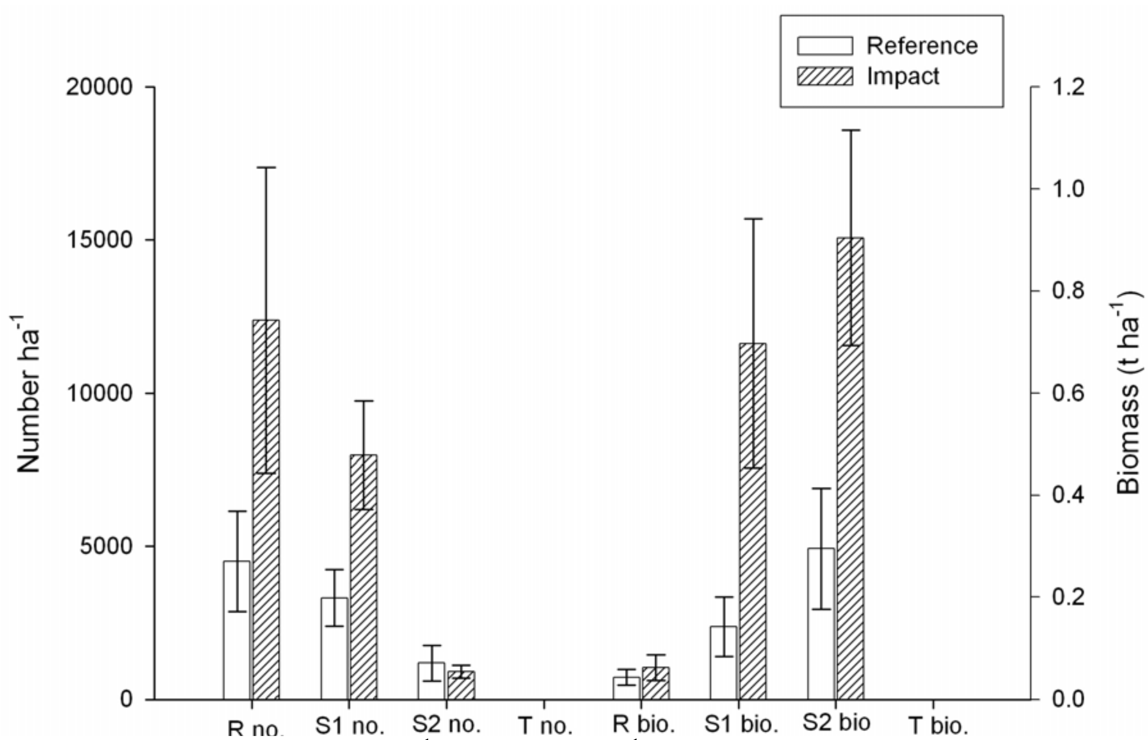

Figure 39. Average (± S.E.) number ha^{-1} and biomass ($t\ ha^{-1}$) of coral reef fish in reference and impact reef depressions.

Table 66. Factorial ANOVA comparisons of mean number ha^{-1} and biomass (t ha^{-1}) for mobility classes R and S1 in the reference and impact reef depressions (data square-root transformed). Tukeys HSD and T-test contrasts used. Imp = impact; Ref = reference, nsd = no significant difference. Note, at α = 0.050, fish number would be considered not detectable and biomass would be considered significantly lower for R and S1 at Imp areas.

Source	DF	SS	MS	F	P	
number						
Location (A)	1	5822.1	5822.08	4.66	0.051	Imp > Ref
Mobility Class (B)	1	291.9	291.90	0.23	0.638	
Intxn (A × B)	1	147.2	147.20	0.12	0.737	
Error	12	14992.2	249.35			
Total	15	21253.4				
biomass						
Location (A)	1	0.228	0.228	5.88	0.032	
Mobility Class (B)	1	0.539	0.539	13.91	0.003	
Intxn (A × B)	1	0.142	0.142	3.66	0.080	R Imp Ref nsd
Error	12	0.465	0.039			S1 Imp > Ref
Total	15	1.372				

3.5 *Porites* Zone

Areas inshore of the ship grounding were assessed within the *Porites* zone between 12 September and 21 November 2005 at 29 to 34 ft. depths and included three impact and nearby reference sites (Figure 40). Injury to coral reef habitat and resources in this region appeared to have resulted mainly from the placement and movement of cables and towlines during *M/V Cape Flattery* response events (Figure 41). Sites east of the grounding were randomly chosen from multiple points distributed on a map in the vicinity of the injury polygon provided by RP representatives, and both north and south of the general area based on the initial injury polygon determined from towed-diver surveys. Data were analyzed using factorial ANOVAs with Tukey HDS comparisons and one- or two-sided two-sample T-tests. The area of injury used to extrapolate potential loss/injury based on average community differences between reference and impact sites was 10,525 m^2. Extrapolations were limited to species-functional groups and, for corals, colony sizes (categorized as small and large for initial analyses), for which average densities or proportional cover between reference and impact sites were demonstrated to be significantly different (α = 0.10). Topographic complexity as grossly measured by rugosity averaged 1.14 ± 0.07 S.E. at reference and 1.05 ± 0.02 S.E. at impact sites. These values did not differ significantly (one-sided two-sample T-test, df = 4, T = 1.31, P = 0.131). The rugosity measure does not discriminate between firm and detached substrate.

3.5.1 Scleractinian Corals

A total 2,751 scleractinian corals (94 %) and coral fragments (6 %) representing 10 species were identified along transects established in the operational area of *M/V Cape Flattery* removal (impact area) and reference areas in the *Porites* zone (Figure 42). Forty-six percent of attached corals and 95 % of fragments were identified in the area of impact. Seven of the species (70 %) were grouped by genus, functional habitat form and growth rate into *Montipora* encrusting (*M. capitata*, *M. patula*), *Pocillopora* cauliflower (*P. ligulata*, *P. meandrina*), *Pocillopora eydouxi*, and *Porites* lobate (*P. evermanni*, *P. lobata*) groups for analyses. Species representatives of these four groups were observed as injured (detached, fragmented, tissue and/or skeletal loss) in the

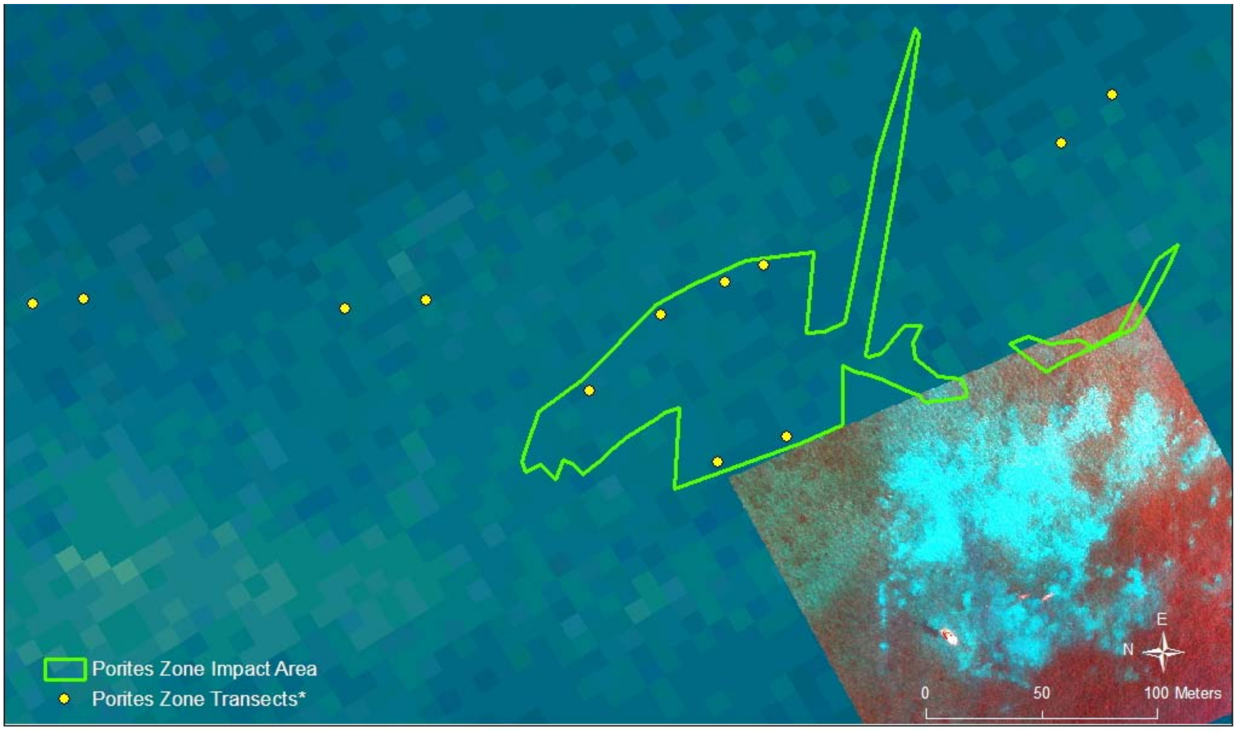

Figure 40. *Porites* zone impact area and transect locations relative to where the ship grounded (each point represents the approximate beginning of a 25 m fish transect, the 10 m ends on which benthic organisms were surveyed).

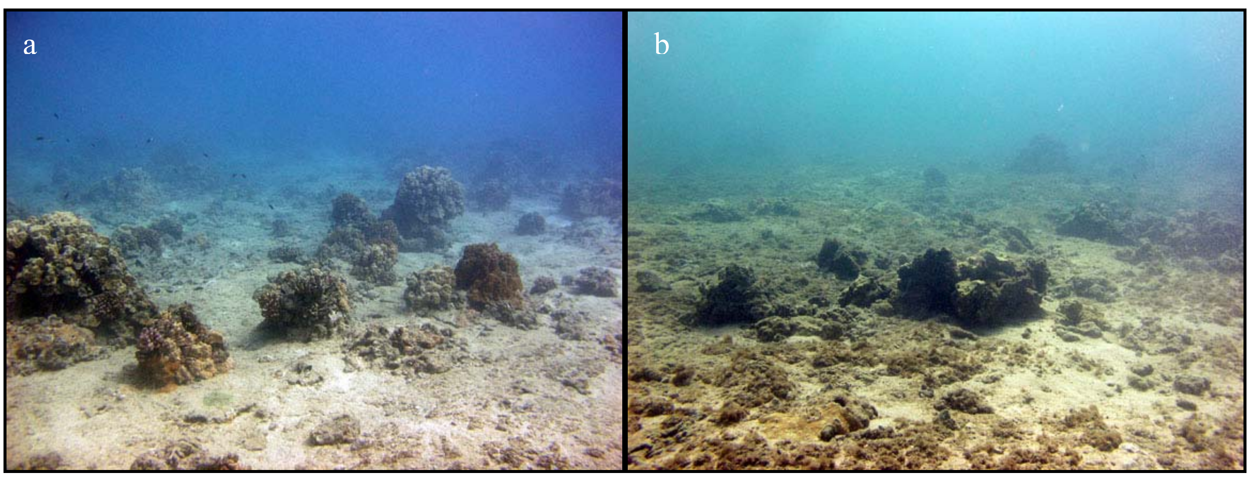

Figure 41. (a) *Porites* zone reference site. (b) *Porites* zone impact site with broken overturned coral debris.

operational area of *M/V Cape Flattery* removal (Figure 43). *Leptastrea purpurea*, *Pavona duerdeni* and *P. varians* were present along transects but not analyzed due to low site representation.

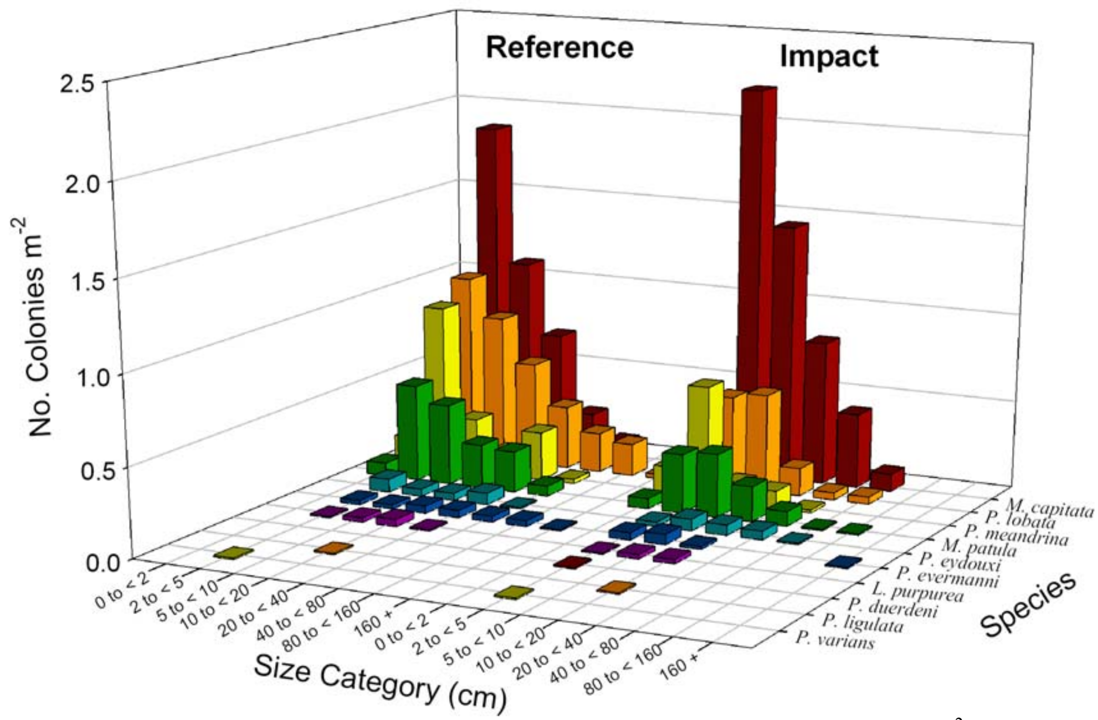

Figure 42. Coral community composition represented as average no. attached colonies m^{-2} in reference and impact areas of the *Porites* zone.

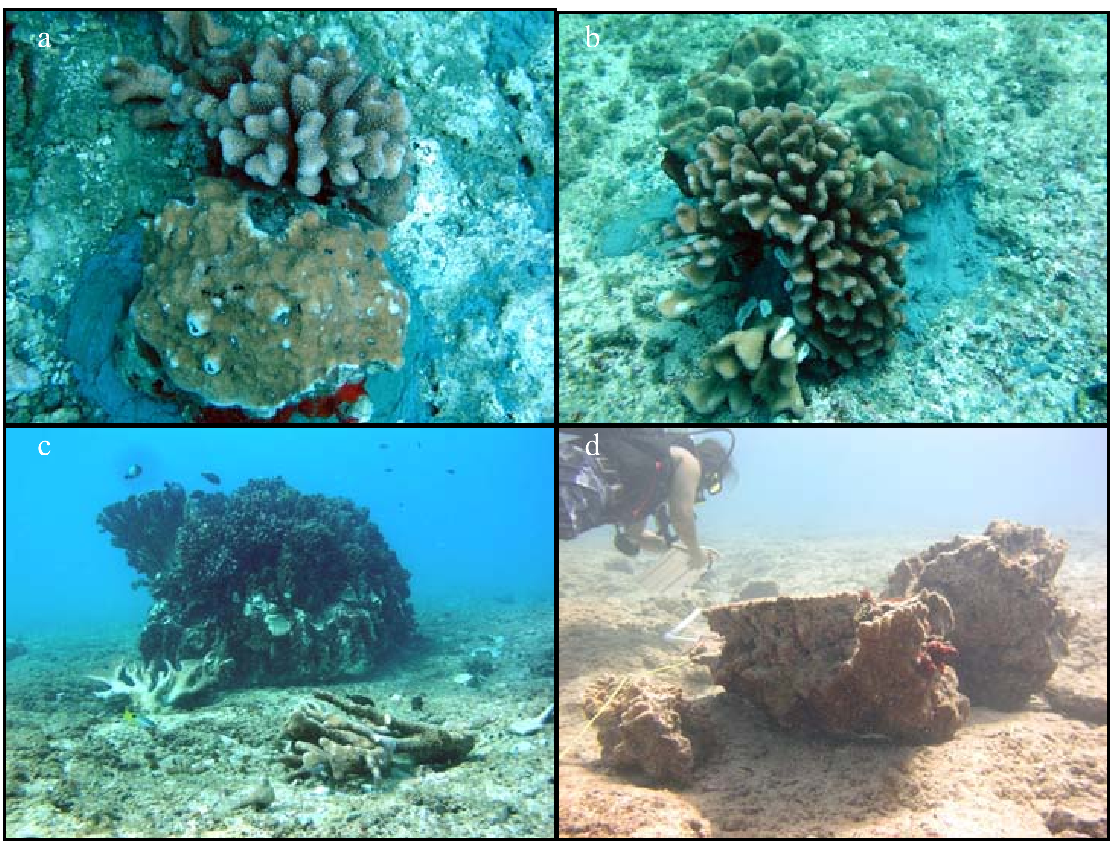

Figure 43. (a) Cemented *Montipora patula* and *Pocillopora meandrina*. (b) Cemented *P. meandrina*. (c) Large broken and detached *Pocillopora eydouxi* and *Porites evermanni*. (d) Overturned *P. lobata*.

3.5.1.1 Attached Coral Analyses

Average values (± S.E.) of species group size data of small (0 to < 10 cm greatest diameter) and large (10 to > 160 cm) colony categorizations are shown in Table 67 and Figure 44. The *Montipora* encrusting species group dominated relative abundance in reference and impact areas, followed by *Porites* lobate, *Pocillopora* cauliflower and *Pocillopora eydouxi*. Small colonies appeared more abundant than large. Comparative analyses of the average number of attached colonies m^{-2} between reference and impact areas showed no significant difference between areas for *Montipora* encrusting and *Pocillopora eydouxi* species groups, but significantly lower numbers of attached *Pocillopora* cauliflower and *Porites* lobate colonies in the impact area (Table 68).

Table 67. Average (± S.E.) attached colony numbers m^{-2} of species group size data for small (< 10 cm) and large (≥ 10 cm) colonies.

Species Group	n	Size Group	Reference	Impact
Montipora encrusting	3	small	4.267 ± 0.887	4.833 ± 0.504
	3	large	1.633 ± 0.659	1.442 ± 0.282
Pocillopora cauliflower	3	small	1.408 ± 0.298	0.942 ± 0.250
	3	large	0.450 ± 0.125	0.125 ± 0.000
Pocillopora eydouxi	3	small	0.117 ± 0.073	0.092 ± 0.030
	3	large	0.117 ± 0.073	0.117 ± 0.068
Porites lobate	3	small	2.058 ± 0.338	1.442 ± 0.418
	3	large	1.533 ± 0.108	0.825 ± 0.188

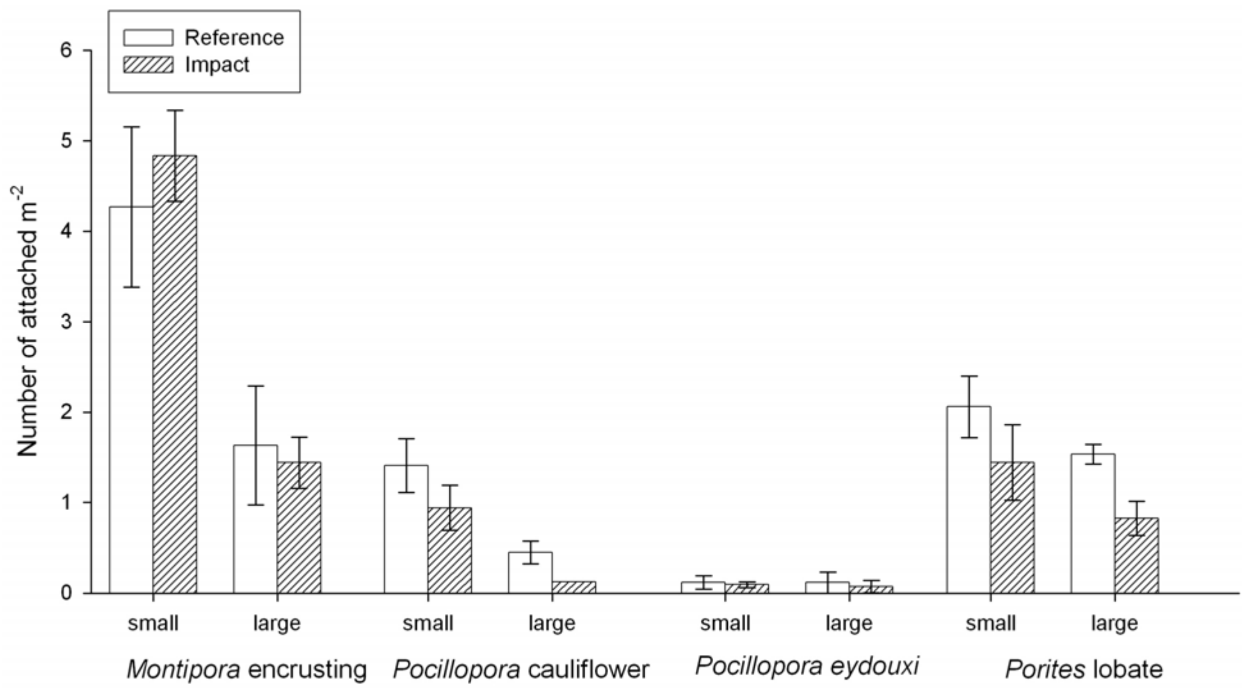

Figure 44. Average (± S.E.) attached colony numbers m^{-2} of species group size data for small (< 10 cm) and large (≥ 10 cm) colonies.

Table 68. Factorial ANOVAs with Tukey HSD comparisons of mean attached colonies m^{-2} for species groups in reference (Ref) and impact (Imp) areas (data square-root transformed to conform to model assumptions).

Source	DF	SS	MS	F	P	
***Montipora* encrusting**						
Location (A)	1	0.010	0.010	0.10	0.764	
Size Group (B)	1	2.508	2.508	23.06	0.001	
Intxn (A * B)	1	0.024	0.024	0.22	0.651	
Error	8	0.870	0.109			
Total	11	3.412				
***Pocillopora* cauliflower**						
Location (A)	1	0.208	0.208	7.12	0.028	Ref > Imp
Size Group (B)	1	0.933	0.933	31.98	0.001	
Intxn (A * B)	1	0.005	0.005	0.18	0.680	
Error	8	0.233	0.029			
Total	11	1.379				
Pocillopora eydouxi						
Location (A)	1	0.003	0.003	0.07	0.800	
Size Group (B)	1	0.0002	0.0002	0.00	0.948	
Intxn (A * B)	1	0.0002	0.0002	0.00	0.948	
Error	8	0.330	0.041			
Total	11	0.334				
***Porites* lobate**						
Location (A)	1	0.261	0.261	6.30	0.036	Ref > Imp
Size Group (B)	1	0.165	0.165	3.98	0.081	
Intxn (A * B)	1	0.006	0.006	0.15	0.707	
Error	8	0.332	0.041			
Total	11	0.764				

Indirect quantification of potential colony loss/injury through examination of differences in reference and impact area mean colony numbers m^{-2} is shown in Table 69. Mean differences were extrapolated over the *Porites* zone portion of the injury polygon to estimate potential colony loss/injury. Subdivision of small and large categories into constituent size groups (based on mean proportional distributions of colony sizes in the reference areas) provides a necessary component for estimating the temporal aspects of injury from a recovery perspective (Table 70). This method assumes equivalent loss/injury proportional to constituent size representation within small and large size categories, a conditional limitation of the analysis. A total 22,261 *Pocillopora* cauliflower and *Porites* lobate colonies were projected as injured through coral community comparisons in the *Porites* zone. Fifty-one percent of colonies projected as injured were < 10 cm (small) and 49 % were ≥ 10 cm (large).

Table 69. Potential colony loss/injury (area with injury = 10,525 m^2).

Species Group	n	Size Group	Diff. in Mean Colonies m^{-2}	Potential Loss/Injury (colonies)
Pocillopora cauliflower	3	small	0.466	4,905
	3	large	0.325	3,421
Porites lobate	3	small	0.616	6,483
	3	large	0.708	7,452

Table 70. Percentage of coral colony sizes constituting small and large categories and associated estimates of potential loss/injury (% × Table 69 Potential Loss/Injury). Totals slightly less than 22,261 due to rounding error.

	Colony Size Category								
	Small Colonies		Large Colonies						
	1 to < 2 cm	2 to < 5 cm	5 to < 10 cm	10 to < 20 cm	20 to < 40 cm	40 to < 80 cm	80 to < 160 cm	> 160 cm	Total
***Pocillopora* cauliflower**									
Percent of Total (Ref)	9.93	67.67	22.40	40.29	54.76	4.95			
Potential Loss/Injury	487	3,319	1,099	1,378	1,873	169			8,325
***Porites* lobate**									
Percent of Total (Ref)	5.14	51.43	43.42	40.99	25.88	16.94	14.00	2.20	
Potential Loss/Injury	333	3,334	2,815	3,054	1,929	1,262	1,043	164	13,934

3.5.1.2 Fragment Analyses

Average live (at the time of surveys) fragment numbers m^{-2} appeared highest within the impact area and were dominated by *Porites* lobate and *Pocillopora* cauliflower corals (Table 71, Figure 45). No fragments of *Montipora* encrusting species were identified at reference stations. Significantly higher numbers and proportions (live fragments/all colonies within a species group) of *Montipora* encrusting, *Pocillopora* cauliflower, *Pocillopora eydouxi* and *Porites* lobate fragments m^{-2} occurred in the impact area (Table 72).

Table 71. Average (± S.E.) numbers and proportions of live fragments m^{-2}.

		Numbers		Proportions	
Species Group	**n**	**Reference**	**Impact**	**Reference**	**Impact**
Montipora encrusting	3	0 ± 0	0.150 ± 0.052	0 ± 0	0.024 ± 0.009
Pocillopora cauliflower	3	0.008 ± 0.008	0.258 ± 0.046	0.005 ± 0.005	0.211 ± 0.063
Pocillopora eydouxi	3	0.008 ± 0.008	0.183 ± 0.046	0.022 ± 0.022	0.511 ± 0.063
Porites lobate	3	0.042 ± 0.042	0.667 ± 0.096	0.013 ± 0.013	0.247 ± 0.072

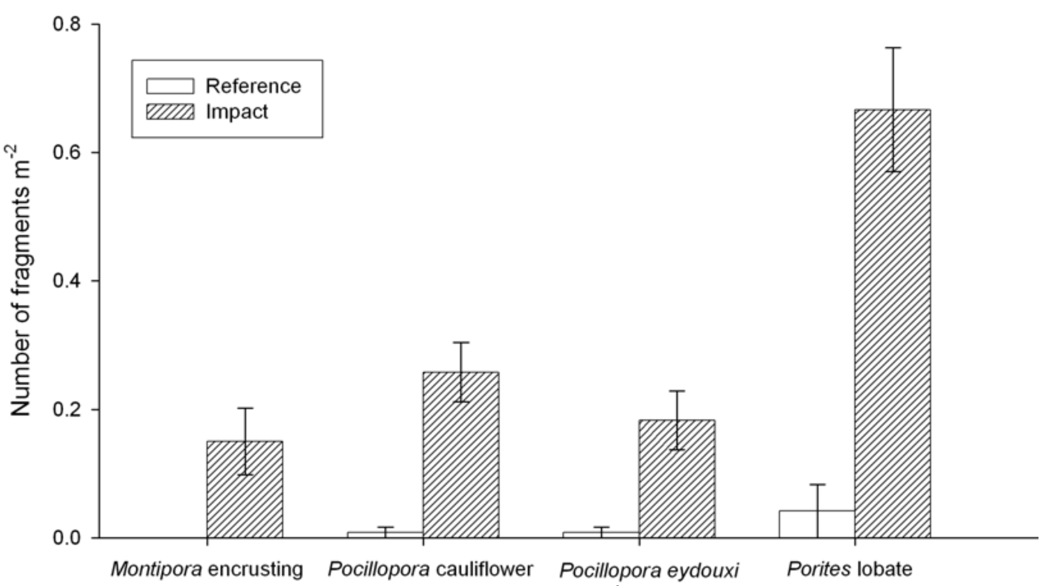

Figure 45. Average (± S.E.) numbers of live fragments m^{-2} for species groups in reference and impact areas.

Comparisons of attached corals did not account for injury to *Montipora* encrusting and *Pocillopora eydouxi* species as evidenced by photographs and fragment analyses. Extrapolation

Table 72. One-sided one-(*Montipora* encrusting) and two-sample (all others) T-tests of numbers and proportions of live fragments m^{-2} for species groups in reference (Ref) and impact (Imp) areas (number data square-root and proportion data arcsine square-root transformed to conform to model assumptions).

Species Group	Type	DF	T	P	
***Montipora* encrusting**	number	2	5.67	0.014	Imp > Ref
	proportion	2	5.07	0.018	Imp > Ref
***Pocillopora* cauliflower**	number	4	6.56	0.001	Imp > Ref
	proportion	4	4.93	0.004	Imp > Ref
Pocillopora eydouxi	number	4	4.97	0.004	Imp > Ref
	proportion	4	6.58	0.001	Imp > Ref
***Porites* lobate**	number	4	5.29	0.003	Imp > Ref
	proportion	4	4.23	0.007	Imp > Ref

of fragment numbers across the *Porites* zone provides a limited basis for accounting for injury to these species groups. Proportional subdivision of mean differences into constituent size classes allows total live fragment number estimates by size groups (Table 73). These numbers presumably underestimate actual injury to coral resources as surveys were limited to live remaining fragments; however, fragments, particularly branches, do not necessarily represent whole colony losses on a one fragment to one colony basis.

Table 73. Percentage of live fragment sizes constituting the fragment category and associated estimates of total live fragment numbers (% × 10,525 m^2 × mean diff. Tot. Frag. No. m^{-2} calculated from Table 71).

	Fragment Size Category							
	1 to < 2 cm	**2 to < 5 cm**	**5 to < 10 cm**	**10 to < 20 cm**	**20 to < 40 cm**	**40 to < 80 cm**	**80 to < 160 cm**	**Total**
***Montipora* encrusting**								
Percent of Total (Imp)	0	37.78	45.56	10.00	6.67	0	0	
Projected No. Frag.		596	719	158	105			1,578
***Pocillopora* cauliflower**								
Percent of Total (Imp)	0	43.12	41.27	13.23	2.38	0		
Projected No. Frag.		1,135	1,086	348	63	-		2,632
Pocillopora eydouxi								
Percent of Total (Imp)	0	18.28	41.01	34.65	6.06	0	0	
Projected No. Frag.		337	755	638	112	-		1,842
***Porites* lobate**								
Percent of Total (Imp)	1.59	22.09	22.07	23.17	17.06	12.43	1.59	
Projected No. Frag.	105	1,453	1,452	1,524	1,122	818	105	6,579

3.5.2 Macro-Invertebrates

Sixteen species of macro-invertebrates were identified along transects surveyed at reference and impact sites (Table 74). Eleven (69 %) of these were consolidated into three functional groups for analysis based on their relative abundance, critical functional capacity and susceptibility to incident related injury.

3.5.2.1 Macro-Invertebrate Analyses

Average densities (± S.E.) of select macro-invertebrate functional groups are shown in Table 75 and Figure 46. Significantly lower densities of boring and mobile urchins (Power = 0.416 at α =

0.050 for mobile urchins) were identified at impact compared to reference sites (Table 76). No significant difference in guard crab numbers was detected.

Table 74. Macro-invertebrate community represented as average no. organisms m^{-2} in reference and impact sites in the *Porites* zone.

Species	Functional Group	Reference	Impact
Mollusca			
Pinctada radiata		0.004	0
Octopus sp.		0.004	0.008
Crustacea			
Hymenocera picta		0	0.017
Trapezia ferruginea	Guard Crab	0.133	0
Trapezia flavopunctata	Guard Crab	0.208	0.075
Trapezia intermedia	Guard Crab	0	0.025
Trapezia tigrina	Guard Crab	0.108	0.025
Echinodermata-Asteroids			
Unidentified Brittle Star		0.400	0.167
Echinodermata-Echinoids			
Eucidaris metularia	Mobile Urchin	0.308	0.025
Echinothrix calamaris	Mobile Urchin	0.292	0.150
E. diadema	Mobile Urchin	0	0.008
Tripneustes gratilla	Mobile Urchin	0.108	0.050
Echinostrephus acciculatus	Boring Urchin	1.025	0.333
Echinometra mathaei	Boring Urchin	3.475	0.200
Heterocentrotus mammillatus	Mobile Urchin	0.042	0.008
Echinodermata-Holothuroids			
Holothuria. hilla		0	0.008

Table 75. Average (±S.E.) number m^{-2} of macro-invertebrates by functional group.

Functional Group	n	Reference	Impact
Boring Urchins	3	4.500 ± 1.428	0.533 ± 0.120
Mobile Urchins	3	0.750 ± 0.288	0.242 ± 0.139
Guard Crabs	3	0.450 ± 0.204	0.125 ± 0.066

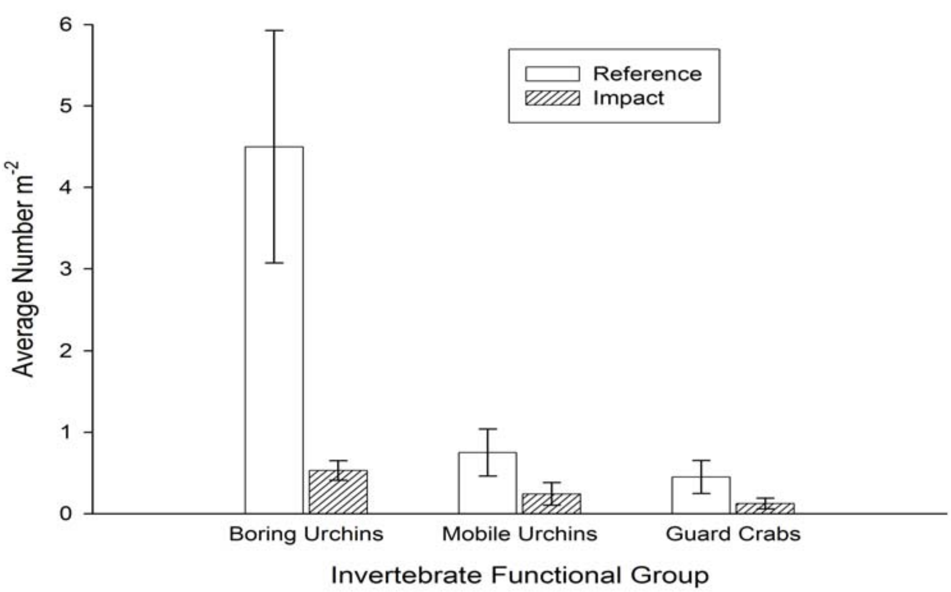

Figure 46. Average (±S.E.) number m^{-2} of macro-invertebrates by functional group.

Indirect quantification of functional group loss through examination of mean density differences at reference and impact sites is shown in Table 77. Mean differences were extrapolated over the *Porites* zone area of injury (10,525 m^2) to estimate potential loss of individuals.

Table 76. One-sided two-sample T-tests for square-root transformed average densities m^{-2} of macro-invertebrate functional groups at reference (Ref) and impact (Imp) sites. Note, at α = 0.050, difference in mobile urchin densities would be considered not determinable.

Source	DF	T	P	
Boring Urchins (test for unequal variances)	2.2	3.38	0.034	Ref > Imp
Mobile Urchins	4	1.73	0.080	Ref > Imp
Guard Crabs (transformation not used)	4	1.52	0.102	

Table 77. Differences in functional group densities and potential loss of individuals within the *Porites* zone. n.d. = not determinable. (n.d.) = not determinable at α = 0.050.

Functional Group	Difference in Density (m^{-2})	Potential Loss
Boring Urchins	3.967	41,753
Mobile Urchins	0.508	5,347 (n.d.)

3.5.3 Algae

Fifteen species of macroalgae were identified along with crustose coralline and turf algae in impact and reference areas (Table 78). Algae covered 80% of the benthic substrate in sampled quadrats at impact sites and 73% at reference sites. Algal data were consolidated by functional group (macroalgae, coralline crustose algae, turf algae and invasive algae) for evaluation and analysis. The macroalgae were mainly represented by species from the order Gelidiales and *Amansia glomerata*, but *Dictyota spp.* cover was also high at impact sites (Table 78).

Table 78. Algae community represented as percent cover at reference and impact sites in the *Porites* zone.

Species within Functional Groups	Reference (% cover)	Impact (% cover)
Macroalgae	**21.81**	**40.56**
Amansia glomerata	7.64	14.03
Caulerpa webbiana	0.14	0
Dictyosphaeria cavernosa	0.14	0
Dictyota sp.	0.97	7.64
Dictyota friabilis	0.14	0
Gelid.	11.67	17.22
Herposiphonia sp.	0	0.56
Hypnea cervicornis	0	0.14
Jania sp.	0.28	0.14
Laurencia sp.	0	0.28
Neomeris annulata	0.28	0
Padina melemele	0.28	0.28
Ralfsia sp.	0.14	0.14
Sargassum sp.	0.14	0
Tolypiocladia glomerulata	0	0.14
Coralline Crustose Algae	**26.39**	**21.81**
Turf Algae	**24.44**	**17.64**

3.5.3.1 Algae Analyses

Average percent coverage values (± S.E.) of algae functional groups are shown in Table 79 and Figure 47. Of the four algae functional groups, coralline crustose algae displayed the highest percent cover at reference sites while macroalgae had the highest cover at impact sites. *Avrainvillea amadelpha*, an invasive alga, was visually observed at two of three reference and two of the three impact sites but did not occur within measured quadrats.

Table 79. Average (± S.E.) percent cover of algal functional groups.

Functional Group	n	Reference	Impact
Macroalgae	3	21.81 ± 3.89	40.56 ± 2.70
Coralline Crustose Algae	3	26.39 ± 0.91	21.81 ± 0.84
Turf Algae	3	24.44 ± 3.49	17.64 ± 1.60
Invasive Algae	3	0	0

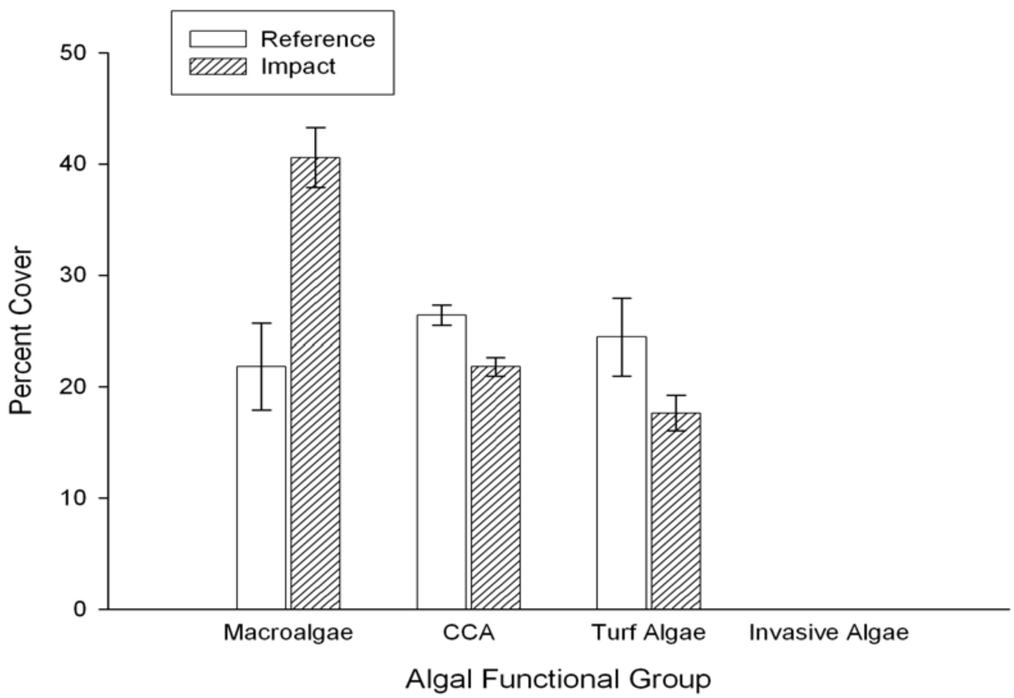

Figure 47. Average percent cover (± S.E.) of algal functional groups (CCA = coralline crustose algae).

Comparative analyses of average proportional cover of algal functional groups between reference and impact areas showed significantly greater macroalgae and significantly less coralline crustose algae at *Porites* zone sites impacted by *M/V Cape Flattery* removal (Table 80). Such differences are consistent with substrate alteration and possible successional colonization as a result of injury.

Table 80. One- and two-sided two-sample T-tests for arcsine square-root transformed mean values of proportional cover of algae at reference (Ref) and impact (Imp) sites.

Source	DF	T	P	
Macroalgae (two-sided T-test)	3	3.96	0.029	Ref < Imp
Coralline Crustose Algae (one-sided T-test; Ref > Imp)	4	3.68	0.011	Ref > Imp
Turf Algae (one-side T-test; Imp > Ref)	4	1.79	0.926	

Potential loss/injury of reef binding coralline crustose algae through examination of differences in reference and impact area mean percent cover suggests an injury related reduction of 4.58 %. Extrapolating the percent difference over 10,525 m^2 (area of injury) equates to 482 m^2 of loss/injury.

3.5.4 Fish

A total of 37 fish species were found along transects in the *Porites* zone. A list of species, by abundance in the reference sites, is shown in Table 81. Sixty-three percent of fish individuals were classified as R (resident species), 35 % as S1 (semi-vagile small area) and 2 % as S2 (semi-vagile large area). Transient fish (T) were not observed along transects in reference or impact areas.

Table 81. Fish species average abundance (number ha^{-1}) for the *Porites* Zone. Mob. = mobility class; Ref. = reference areas; Imp. = impact areas.

Species	**Mob.**	**Ref.**	**Imp.**	**Species** (cont.)	**Mob.**	**Ref.**	**Imp.**
Chromis vanderbilti	R	11100	5217	*Gomphosus varius*	S1	83	17
Acanthurus nigrofuscus	S1	1433	767	*Scarus psittacus*	S2	83	33
Thalassoma duperrey	S1	1367	2000	*Pseudochilinus tetrataenia*	S1	67	0
Coris venusta	S1	417	350	*Cirrhitops fasciatus*	R	33	67
Ctenochaetus strigosus	S1	333	0	*Melichthys niger*	S1	33	0
Canthigaster jactator	S1	217	283	*Ostracion meleagris*	S1	33	0
Macropharyngodon geoffroy	S1	200	67	*Zebrasoma flavescens*	S1	33	317
Sufflamen bursa	S1	167	67	*Parapeneus cyclostomus*	S2	33	0
Plectroglyphidodon johnstonianus	R	133	50	*Chromis ovalis*	R	33	0
Pseudocheilinus octotaenia	S1	133	33	*Cephalpholis argus*	S1	17	0
Melichthys vidua	S1	117	33	*Coris gaimard*	S1	0	100
Parapeneus multifasciatus	S1	117	50	*Novaculichthys taeniourus*	S1	0	17
Stethojulus balteata	S1	117	133	*Oxycheilinus bimaculatus*	S1	0	33
Plagiotremus goslinei	R	100	100	*Parapercis schauinslandi*	S1	0	133
Plectroglyphidodon imparipennis	R	100	50	*Ptereleotris heteroptera*	S1	0	67
Halichoeres ornatissimus	S1	100	133	*Rhinecanthus aculeatus*	S1	0	33
Rhinecanthus rectangulus	S1	100	50	*Acanthurus olivaceus*	S2	0	233
Chlorurus sordidus	S2	100	0	*Bodianus bilunulatus*	S2	0	83
Paracirrhites arcatus	R	83	217				

3.5.4.1 Fish Analyses

Average number and biomass (± S.E.) of fish by mobility group are shown in Table 82 and Figure 48. The means of number per hectare and tons per hectare for fishes in the two high site fidelity groups (R and S1) were greater in the reference sites than in the impact sites, but the differences were not statistically significant (ANOVA for natural log of fish number, df 1,8, $F = 0.45$, $P = 0.520$; ANOVA for natural log of biomass, df 1,8, $F = 2.31$, $P = 0.167$). Although there was injury to corals documented at *Porites* zone impact sites, structure that remained (both attached and detached) appeared to provide some three dimensional relief for fish use. However, small sample sizes may have precluded detection of statistically significant differences between impact and reference areas.

Table 82. Average (± S.E.) number ha^{-1} and biomass (t ha^{-1}) of fish by mobility class.

		Number ha^{-1}		**Biomass (t ha^{-1})**	
Mobility Class	**n**	**Reference**	**Impact**	**Reference**	**Impact**
R	3	11,583 ± 6,023	5,700 ± 2,139	0.049 ± 0.022	0.027 ± 0.006
S1	3	5,083 ± 2,130	4,683 ± 1,163	0.235 ± 0.121	0.082 ± 0.022
S2	3	217 ± 117	350 ± 257	0.0027 ± 0.0021	0.0091 ± 0.0049
T	3	0 ± 0	0 ± 0	0 ± 0	0 ± 0

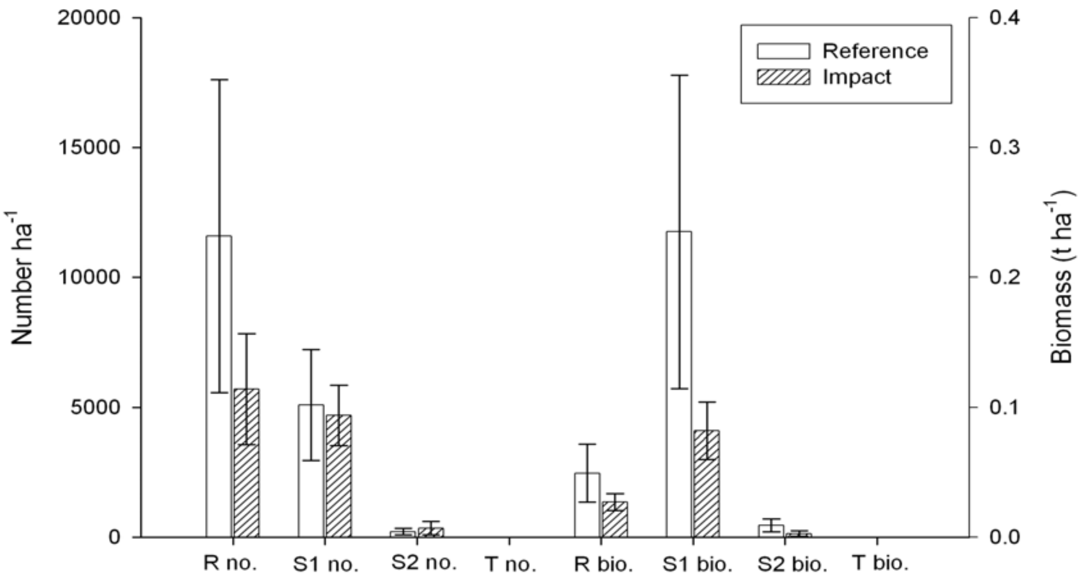

Figure 48. Average (± S.E.) number and biomass of fish by mobility class in the *Porites* zone.

4. Summary of Projected Injury and Discussion

This assessment was designed to ascertain impacts to major constituents of the coral reef community in the incident area of *M/V Cape Flattery* grounding and removal. The data can also serve as baseline information for defining injury as it relates to natural temporal community trends (Underwood 1992, 1994) and monitoring further site degradation and/or recovery. Relevant information on community structure prior to the grounding was not available. Severe crushing, breakage and displacement of reef habitat and organisms occurred across a large area (Kolinski 2005a, Kenyon 2005, Polaris Applied Sciences, Inc. 2005). The ability to directly assess injury within the site was limited; thus, this assessment was based on community comparisons between impact and reference habitats (Wiens and Parker 1995, Hudson and Goodwin 2001).

Inference in comparing impact and reference habitats is complicated for unplanned incidents such as ship groundings by an inability to replicate and randomly assign impact treatments (i.e. multiple ship groundings) for measurement and analysis (Wiens and Parker 1995, Peterson et al. 2001). Sites within the area of impact lack spatial independence despite unbiased selection. The concern is that reference and impact areas may have naturally varied prior to the incident; thus, the inability to randomly assign impact treatments increases the risk of spatial confounding. There are no direct methods to determine this for this event. However, the incident area was large, encompassed multiple habitat zones, and heterogeneity was observed in remnant communities and debris distributions. Assessment of multiple reference areas both north and south of the incident should have enhanced the probability of representing pre-incident communities fairly by accounting for system heterogeneity. Observations of remnant impact communities, debris distributions and areas directly bordering zones of impact provided no reason to believe that reference areas inadequately represented incident impacted habitats. No prior impacts resulting in habitat degradation specific to the incident location were known.

Total projected losses of live corals, macro-invertebrates and coralline crustose algae across habitat zones are summarized in Tables 83 and 84. Over 1 million corals, 150,000 macro-invertebrates and 5,000 m^2 of coralline crustose algae are estimated to have been lost/injured as a result of the grounding and response and removal activities of the *M/V Cape Flattery* using reference and impact site community comparisons. Other measured community functional groups tended to support ecological loss associated with a large-scale impact. Levels of turf and/or macroalgae tended to be higher in impact compared to reference areas, which supported observations of successional colonization of physically altered substrate. Average fish numbers tended to be lower at impact sites, with statistically significant displacement evident in the shelf pavement region.

The methods, particularly sample sizes, limited the ability to fully account for injury to fish, macroalgae, many macro-invertebrates and consolidated habitat structure. Fish losses were not projected in this assessment due to difficulties in discerning levels of fish displacement from actual loss. Pulverized fish were observed in impacted areas soon after ship removal (Kolinski 2005a). Many of the macro-invertebrate species naturally occur at low densities. Impacts to organisms at low densities are difficult to assess without large numbers of sample replicates or replicate surveys of large spatial areas, which were not employed. Dead attached corals, which provide habitat, were not assessed. Rugosity measurements incorporated the presence of unconsolidated reef debris, which may ultimately shift to reef depressions and/or down the escarpment slope. Communities injured by the anchor and chain in deep rock and seagrass habitats below the escarpment slope, as well as communities at the base of the slope where debris had and will continue to accumulate, were not surveyed in this assessment due to dive time and safety reasons.

Significant live coral differences between reference and impact areas appeared greatest for *Montipora* encrusting and *Porites* lobate species (Table 84). Injury to *Pocillopora eydouxi* corresponded to its lower prevalence within the coral community; however, its value as habitat, as large colonies, is relatively high compared to other regional species. Seventy-one percent

Table 83. Summary of projected loss/injury to coral functional groups by size category across habitat zones. Values in parentheses reflect estimates at α = 0.050 when estimates differ.

	Colony Size Category								
	Small Colonies		**Large Colonies**						
Species Group	**1 to < 2 cm**	**2 to < 5 cm**	**5 to < 10 cm**	**10 to < 20 cm**	**20 to < 40 cm**	**40 to < 80 cm**	**80 to < 160 cm**	**> 160 cm**	**Total**
Montipora encrusting	70,517	290,157	176,654	106,208	41,051	6,482	626	0	691,694
Pocillopora cauliflower	20,123 (20,303)	50,883 (51,405)	16,545 (16,710)	4,187	8,886	799	0	0	101,423 (102,290)
Pocillopora eydouxi	686	8,196	11,449	9,500	14,740	3,942	1,239	0	49,753
Porites lobate	10,545 (9,618)	84,027 (74,333)	79,651 (72,126)	102,941 (91,811)	30,866 (26,202)	6,527 (5,478)	1,916 (1,886)	164	316,637 (281,618)
Total	101,871 (101,124)	433,263 (424,091)	284,299 (276,939)	222,836 (211,706)	95,543 (90,879)	17,750 (16,701)	3,781 (3,751)	164	1,159,507 (1,125,355)
% of Total	8.79 (8.99)	37.37 (37.69)	24.52 (24.61)	19.22 (18.81)	8.24 (8.08)	1.53 (1.48)	0.33	0.01	

Table 84. Summary of projected loss/injury of select macro-invertebrate and algae functional groups across habitat zones. Values in parentheses reflect estimates at α = 0.050 when estimates differ.

Functional Group	Macro-Invertebrates	Algae (m^2)
Boring Urchins	107,407	
Mobile Urchins	24,785 (16,511)	
Guard Crabs	21,628 (20,725)	
Coralline Crustose Algae		5,090
Total	153,820 (144,643)	5,090

(819,433) of the corals were < 10 cm in greatest diameter and 29 % (340,074) were ≥ 10 cm. Differentiation into size categories provides a needed parameter for estimating the level and length of time needed for coral population recovery in impacted areas, as site specific coral growth measurements (Kolinski, unpubl. data) and relevant species growth rates in the literature can be used to grossly project the time period necessary to recover losses for coral species and forms based on their respective size categories. Recovery rates of coralline crustose algae, another reef framework builder, may also be derived from the literature and/or monitoring.

Significant differences in live coral fragment numbers suggest, that in some of the habitat zones, injury had occurred to measured species groups but it had not been resolved through attached coral community comparisons. In such cases, gross estimates of injury might be derived from live coral fragment data (Table 85) by adding fragment numbers for pertinent species groups to obtain whole colony estimates of a standardized size. The numbers of corals of the standardized size might then be used to augment recovery and compensation projections. However, live fragments represented only a small portion of the total fragment numbers within each habitat zone (dead fragments were not enumerated and sized due to dive and sampling time limitations). Surveys began approximately seven months following the incident; thus, surviving fragment numbers probably grossly underestimate those generated as a result of the incident and response. Also, probabilities of fragment production likely differ between encrusting (*Montipora*), lobate (*Porites*) and branching (*Pocillopora*) species groups. Assumptions could be made on proportional representation of live to dead fragments for deriving species group estimates. For instance, in total, live fragments represented approximately one tenth of projected colony loss/injury. To determine numbers of dead fragments not enumerated, ratios of live to dead fragments would likely need to be much less than 1:10 to provide estimates that conform to available data and anecdotal observation (Kolinski, pers. obs.).

Table 85. Summary of live fragment estimates across habitat zones. Values in parentheses reflect estimates at α = 0.050 when estimates differ.

	Fragment Size Category							
Species Group	**1 to < 2 cm**	**2 to < 5 cm**	**5 to < 10 cm**	**10 to < 20 cm**	**20 to < 40 cm**	**40 to < 80 cm**	**80 to < 160 cm**	**Total**
Montipora encrusting	2,582	5,749	2,042	158	238	0	0	10,769
Pocillopora cauliflower	1,107	29,012 (29,010)	24,505	4,371	2,757 (2,755)	0	0	61,752 (61,748)
Pocillopora eydouxi	208	5317	4,936	3164	1535	218	0	15,378
Porites lobate	2,845	23,086	17,353	12,060	7,226	3,035	136	65,741
Total	6,742	63,164 (63,162)	48,836	19,753	11,756 (11,754)	3,253	136	153,640 (153,636)
% of Total	4.39	41.11	31.79	12.86	7.65	2.12	0.09	

Although not analyzed, measured averages and anecdotal observations suggested that larger mean numbers of the coral eating starfish *Acanthaster planci* and *Culcita novaeguinaeae* occurred in impacted compared to reference areas in slope and escarpment habitats. *Drupella* sp., a coral eating mollusk not measured in this assessment, was also recently observed to be seriously impacting injured and restored *Pocilloporid* corals in areas disturbed by *M/V Cape Flattery* removal (Kolinski, pers. obs.). Unfortunately, the sampling was not designed to adequately assess predator presence at levels useful for applying statistically appropriate comparative analyses. However, latent effects to remaining corals in the impacted community may have and continue to occur as a result of predator attraction to injured corals (Ormond et al. 1973, Turner 1994, Sonoda 1993, Teruya et al. 2001, Morton et al. 2002, Kita et al. 2005). Additional assessments specific to detecting and comparing predator abundances are recommended for this and future grounding incidents that occur in Hawaii.

Scleractinian corals and coralline crustose algae create and consolidate habitat framework utilized by other sessile and mobile coral reef animals. Herbivorous fish and urchins may facilitate habitat recovery by continuous predation on colonizing fleshy algae, which compete for open space with corals and coralline crustose algae. Although initial projections on recovery rates of corals and coralline crustose algae can be made using current data from the site and the literature, recovery levels and rates of the impacted reef will likely depend on the recruitment, growth and activities of multiple coral reef community constituents, including macro-invertebrates and fish. Hull-impact areas in the shelf pavement zone may be vulnerable to reduced rates and/or overall limited recovery due to the current absence of adequate shelter for herbivores. In addition, the potential for wave induced movement of incident related reef debris poses a threat to remaining coral reef resources and area recruits, which continue to be exposed to potential scouring, collision and burial impacts. Initial efforts have been undertaken by the RP to remove large loose reef debris to reduce threats of further injury, and limited habitat structure has been restored in a portion of the shelf pavement area impacted by the ship's hull. Rapid assessment of the efficacy of these efforts is warranted, as opportunities for resource and recovery benefits from such activities may be reduced with time.

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