4-1-1998

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Recommended Citation

Banks, Kenneth, Richard E. Dodge, Lou Fisher, David Stout, and Walter Jaap. "Florida coral reef damage from nuclear submarine grounding and proposed restoration." In Journal of Coastal Research 26: pp. 64-71. 1998.

Journal of Coastal Research	SI	26	64–71	Royal Palm Beach, Florida	Spring 1998

Florida Coral Reef Damage from Nuclear Submarine Grounding and Proposed Restoration

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ABSTRACT

BANKS, K.; DODGE., R.E.; FISHER, L.; STOUT, D., and JAAP, W., 1998. Florida Coral Reef Damage from Nuclear Submarine Grounding and Proposed Restoration. *Journal of Coastal Research*, SI(26), 64–71. Royal Palm Beach (Florida), ISSN 0749-0208.

The United States submarine Memphis grounded in approximately 10 m water depth on a tropical coral reef off southeast Florida in February, 1993. The grounding caused extensive physical and biological damage to the reef substrate and to the coral community. As part of a claim by the State of Florida against the United States, the impact of the grounding was assessed, and the area of damage was determined through field and photographic studies. A recovery rate for the reef was assigned from literature estimates. The NOAA Habitat Equivalency Model (HEM) was used to calculate the reef area needed to be replaced in order to compensate for damages. A plan devised to restore the reef included: removal of loose rubble generated from the grounding; stabilization of reef faces in danger of collapse; emplacement of six different types of artificial reefs; transplantation of reef-building corals (15% of the number damaged) to bare damaged substrate and to the artificial reefs; and a 20 year monitoring period to assess restoration plan efficacy. Settlement of the claim in April, 1997 resulted in an award of $750,000 to the Ecosystem Management Trust Fund of the State of Florida. Utilization of this fund necessitates a revised plan to restore the damaged reef within economic constraints. This plan will involve rubble removal/stabilization, artificial reef emplacement, stony coral transplantation, and monitoring.

ADDITIONAL INDEX WORDS: *Coral reef, coral reef restoration, coral reef assessment, ship grounding.*

INTRODUCTION

The submarine USS Memphis ran aground on a shallow (d=7 m) reef area offshore of Dania Beach, Florida (Figure 1) on February 25, 1993, at 5:50 a.m., EST. Attempts to free the submarine included blowing ballast tanks and reversal of engines. These efforts were successful after approximately 90 minutes, and the submarine subsequently proceeded to the base at King's Bay, Georgia, for damage evaluation.

Representatives from the Broward County Department of Natural Resource Protection (DNRP) visited the site on the following day to perform a preliminary damage evaluation. Weather conditions and poor visibility made determination of the areal extent and nature of damage difficult, but results of the initial reconnaissance indicated that further survey work was necessary. Subsequent underwater mapping of the site by DNRP staff provided information on the areal extent of damage and the characteristics of reef impacts. Biological characterization of adjacent non-impacted reef provided data for extrapolation to the grounding site, allowing an estimate of biological impacts.

The reef where the grounding occurred is commonly called the second reef line or terrace. Generally, there are three parallel, sequentially deeper, north-south trending reef lines (first, second, and third reefs) offshore of Broward County, all within two miles of the shoreline. GOLDBERG (1973) and DODGE *et al.* (1991, 1992) described the biological features of portions of these reefs. The second reef is 6–8 m deep and dominated by octo-corals and sponges, although 30 species of stony corals are also present and locally abundant. The geology of these reefs have been reported in prior inspections and datings of portions of the reef track (DUANE and MEISBURGER, 1969; LIGHTY *et al.*, 1972; LIGHTY, 1977; RAYMOND, 1972). RAYMOND (1972) studied the geology of Broward's second reef. Geological investigations of the third reef along this coast have been conducted by LIGHTY *et al.* (1972) and LIGHTY (1977) who investigated the internal reef composition and structure exposed by an excavated pipeline trench perpendicular to the reef axis. Radiocarbon dates of the corals indicated that this reef is Holocene in age with no reef framework growth over the past 6000 years.

The State of Florida, utilizing the Broward County DNRP Reef Community Impact Assessment (1993) and performing an economic impact analysis of the grounding (DEP, 1994), filed a damage claim against the United States for approximately $2.4 million. The Federal government disputed the amount of the claim. Litigation activities proceeded until a settlement of $750,000 was reached.

98031 received and accepted in revision 10 March 1998.

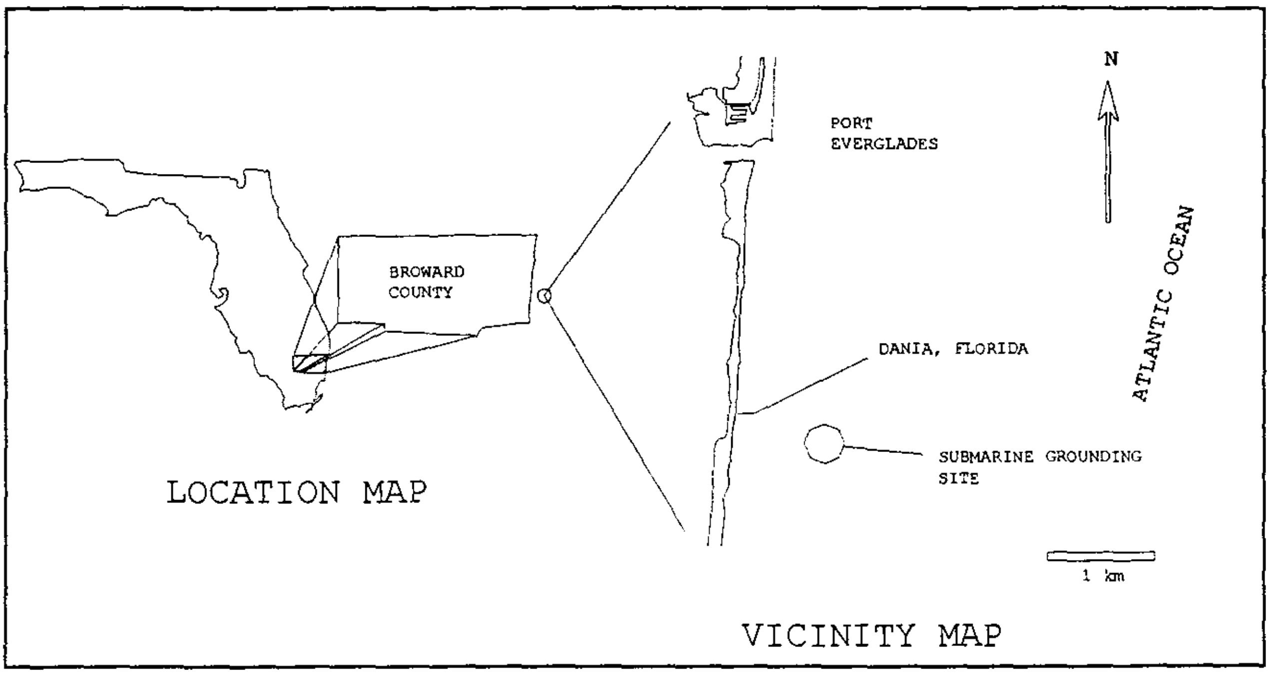

Figure 1. Location and Vicinity Maps of the submarine grounding site.

The notoriety of ship groundings within the context of resource damage has increased dramatically in the last 14 years. Previously, a ship grounding incident was viewed more as a loss of property and/or life. As awareness of natural resources has increased, however, this viewpoint has broadened and, presently, in the waters of the State of Florida any vessel grounding may result in the levying of fines or claims for damage caused to the resource. Table 1 summarizes recent, large vessel groundings in waters off south Florida. It is interesting to note that the primary cause of these groundings was navigational negligence (JAAP, in press).

While it may not be possible for the resource manager or scientist to prevent ships from grounding on sensitive marine habitat, case studies such as this help the uninitiated profit from the experience of others and provide a springboard for critical review of methods.

GROUNDING DAMAGE ASSESSMENT METHODOLOGY

Physical Damage Mapping

Reconnaissance inspection of the Memphis grounding site occurred on February 26, 1993. Underwater visibility at the site was limited by sea conditions which included wave heights of 1.5 to 2 m.

Detailed mapping of the site took place on March 2 and 8,

Table 1. *Some recent major ship groundings in Florida.*

Ship Name	Year	Location	Damage Area (m^2)	Trustee	Settlement
M/V Wellwood	1984	FL Keys	1,282	NOAA	$6 mil.
M/V Mini Laurel	1984	FL Keys	N/A	N/A	N/A
M/V Mavro Vetranic	1989	FL Keys	15,800	State of Florida	$3.3 mil.
M/V Elpis	1989	FL Keys	>3,000	NOAA	$2.75 mil.
Dredge Long Island	1988	Dade County	>6,006	State of Florida	$1.1 mil.
USS Memphis	1993	Broward County	1,205	State of Florida	$750,000
R/V Columbus Iselin	1994	FL Keys	338	NOAA	$3.7 mill.
M/V Firat	1994	Broward County	>1,000	State of Florida	N/A
M/V Sealand Atlantic	1994	Broward County	500–1,000	State of Florida	N/A
M/V Igloo Moon	1996	Biscayne National Park	N/A	US Dept. of Interior	in litigation
M/V Houston	1997	FL Keys	N/A	NOAA, FKNMS, State of Florida	$6 mil.
M/V Fortuna Reefer	1997	Puerto Rico	7,500	NOAA and PR	$1.25 mil.
M/V Pacific Mako	1998	Ft. Lauderdale	N/A	State of Florida	not settled

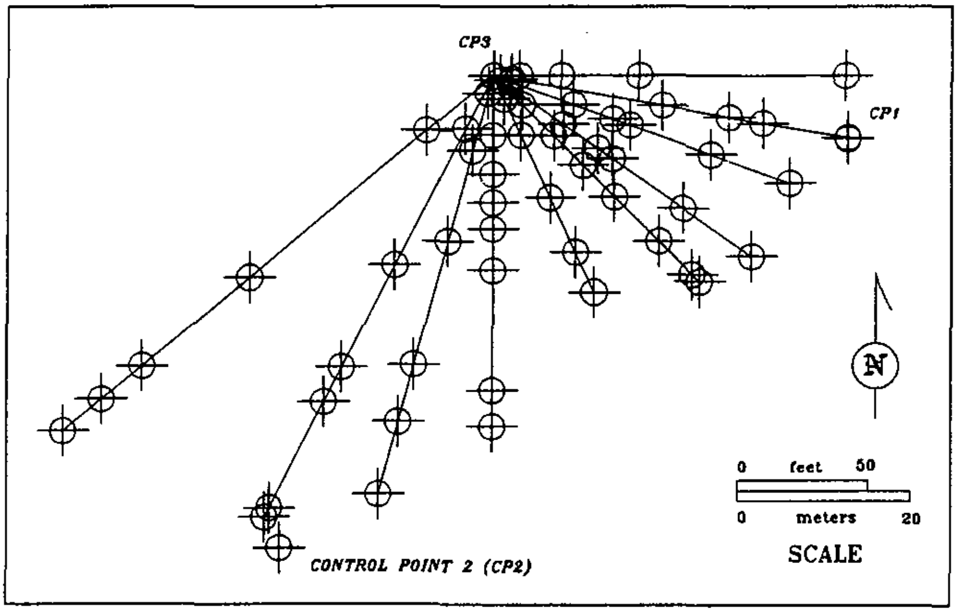

Figure 2. Circular strip mapping technique with CP-3 as the start point. Points along each transect line are distance measurements to points where impact categories change. This technique was also used at CP-1 and CP-2 (from DNRP, 1993).

1993. Initially, three horizontal control points (CP's) were installed as benchmarks. The CP's consisted of #3 steel reinforcing rods (9.5 mm, diameter) driven into hardbottom at the northeastern, southwestern, and northwestern boundaries of the grounding impact site. The points were buoyed with a minimal scope buoy line and XY positions were determined using a shore-based Hydro-1® laser range-azimuth positioning system (accurate to 2 m). During the survey, five types of reef impact were categorized: (1) trench, gouge, or surface scrape of the reef framework; (2) scour of sand away from buried hardbottom or buried portions of hardbottom; (3) dense rubble, consisting of displaced reef framework, previously buried rock and coral; (4) sparse grounding generated rubble; and (5) sand cover of previously exposed areas, presumably from sediment suspended as the submarine attempted to free itself from the reef.

Underwater mapping of the site was accomplished by SCUBA divers using a circular strip mapping technique described by HALUSKY (1982). Figure 2 illustrates the technique.

A physical damage map was created for the grounding site using the AUTOCAD® computer-aided drafting program. Input consisted of locations of control points and transect lines as well as the stop and start point of each damage category on each transect line. AUTOCAD® was used to interpolate the points of common category areas along each transect line to form contour lines. The area inquiry function in AUTOCAD® was used to determine impact category areas, some of which were overlapping.

In order to gain a three dimensional perspective of the site a bathymetric survey was carried out. Fifty survey lines were used, twenty-seven oriented on a north/south axis, twenty-three east/west (perpendicular to reef) with 6 m line spacing. Survey data was processed and corrected for tide and sea state. Contouring was performed and bathymetric contour plots were generated.

Low level aerial photographs were taken (1″=150′) to image the grounding site and assist in further delineation of the areal extent of damage. Reference targets for the air photographs were secured by minimal scope mooring lines to the three (one target each) control points. This provided horizontal scale for the photographs and allowed for rectification of the images.

An additional physical damage assessment was conducted on April 5, 1993. We used a single transect line originating at CP-1 and traversing westward, following the center of the large gouge and trench for a distance of 52 m. This survey was conducted to measure the area subjected to 100 percent loss of reef organisms from the grounding. Divers recorded the distance north and south of the transect, perpendicular to the line at two meter intervals, where all live reef organisms were either missing or covered by rubble. The transect dimensions and location were plotted on the map, using references to CP's.

Biological Damage Assessment

Quantifying the damage to the stony coral community at the grounding site was done by determining coral population characteristics at adjacent, non-impact areas. The Modified Belt-Transect Method (DODGE et al., 1982) was used to determine the abundance and distribution of stony corals. To judge if these data were representative they were compared to data identically collected from other, same depth, reef areas of Broward County and the Florida Keys (DNRP, 1993).

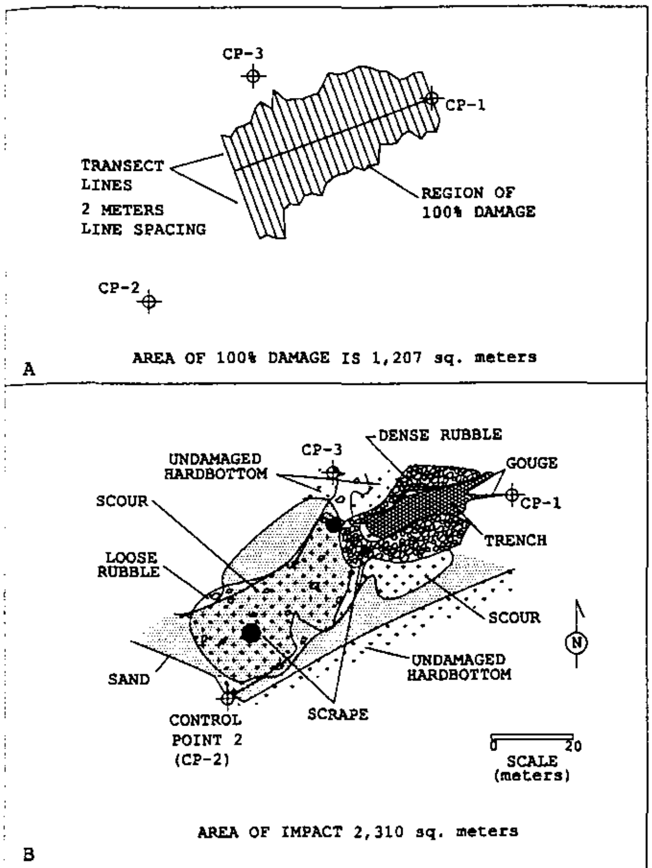

Figure 3. (A) Map showing areal extent of 100 percent damage region of Memphis grounding site. (B) AUTOCAD digitized map of grounding impact regions, created from circular strip mapping of the submarine grounding site.

Economic Impact Assessment

The economic impacts of the grounding were based on damage assessment, restoration and monitoring costs. The damage area to be restored was based on results from NOAA's Habitat Equivalency Model (HEM). The HEM model requires three inputs: the amount of damaged reef, the discount rate, and the reef recovery rate. The model generates the amount of replacement reef that is needed today to compensate for the lost use of the damaged reef over its recovery period (JULIUS *et al.*, 1994).

RESULTS OF GROUNDING SITE ASSESSMENT

Physical Damage Mapping

Figure 3 illustrates the results of the physical damage mapping by both techniques. The area of impact values for each of the five impact categories and for the area of 100 percent damage are given in Table 2. The total impacted area was calculated to be 2,310 m^2 with 1,205 m^2 destroyed. The trench was the most distinctive feature of the grounding site. The trench included a three meter deep cut in the reef framework which revealed a prominent stand of relict *Acropora palmata,* a species no longer dominant offshore of Broward County. Dense rubble, excavated from the trench by the submarine's propeller, was deposited near the trench and covered living hardbottom, killing everything under it. Scrape marks, covered with the sub's bottom paint, indicated denudation of living organisms from the reef.

Table 2. *Comparative coral community data for the second reef terrace in Broward county waters and grounding sites in the Florida keys.*

Parameter	Memphis Grounding Site[1]	Sites North of Grounding Site[2]	Sites South of Grounding Site[3]	M/V Elpis Grounding Site Key Largo (Gittings, 1991)	M/V Wellwood Grounding Site Key Largo (Gittings, 1991)
Water depth (m)	7.6	10.2	11.4	11.3	3.5
Corals/m^2	1.9	2.2	4.9	4.8	5.3
Coral areal coverage (%)	1.97	1.03	2.66	1.4	3.0
Coral species	10	10	12		

[1] All values are average from three transects adjacent to the grounding site

[2] All values are averaged from three transects offshore of John U. Lloyd State Park, approximately 2 km north of grounding site

[3] All values are averaged from two transects offshore of Hollywood and Hallandale, Florida, approximately 5 km south of grounding site

Figure 4 is a three dimensional surface plot generated from the bathymetric survey data. The trench is the only damage feature clearly visible.

Biological Damage Assessment

A comparison of coral community data from the reef area adjacent to the grounding site to similar sites in Broward County is presented in Table 3. Extrapolation of the density and coverage data from adjacent sites results in an estimate of 4,458 stony coral colonies with 45.5 m^2 of live polyp coverage destroyed at the Memphis grounding site in the area of 100 percent damage (DNRP, 1993).

Economic Impact Assessment

The area of 100 percent damage (1,205 m^2) was used as input to the HEM model. A 3 percent discount rate was assumed as the most conservative figure and one that is consistent with long term history (DEP, 1994). It was assumed that reef recovery would take, very conservatively, 35 years as extrapolated from literature estimates ranging from several to over 200 years (SHINN, 1972; GRIGG and MARAGOS, 1974; STODDART, 1974; ENDEAN, 1976; LOYA, 1976; PEARSON, 1981; and CURTIS, 1985).

HEM (DEP, 1994) output results indicated that 1,242 m^2 of living natural reef would be required to compensate for the interim lost flow of services from the 1,207 m^2 of destroyed reef. A very conservative assumption was made that plan view surface area of artificial reefs would compensate the natural reef at a ratio of 1:1. Six types of artificial reefs were used covering an area of 1,242 m^2 to calculate restoration materials costs. The total economic impact of the grounding,

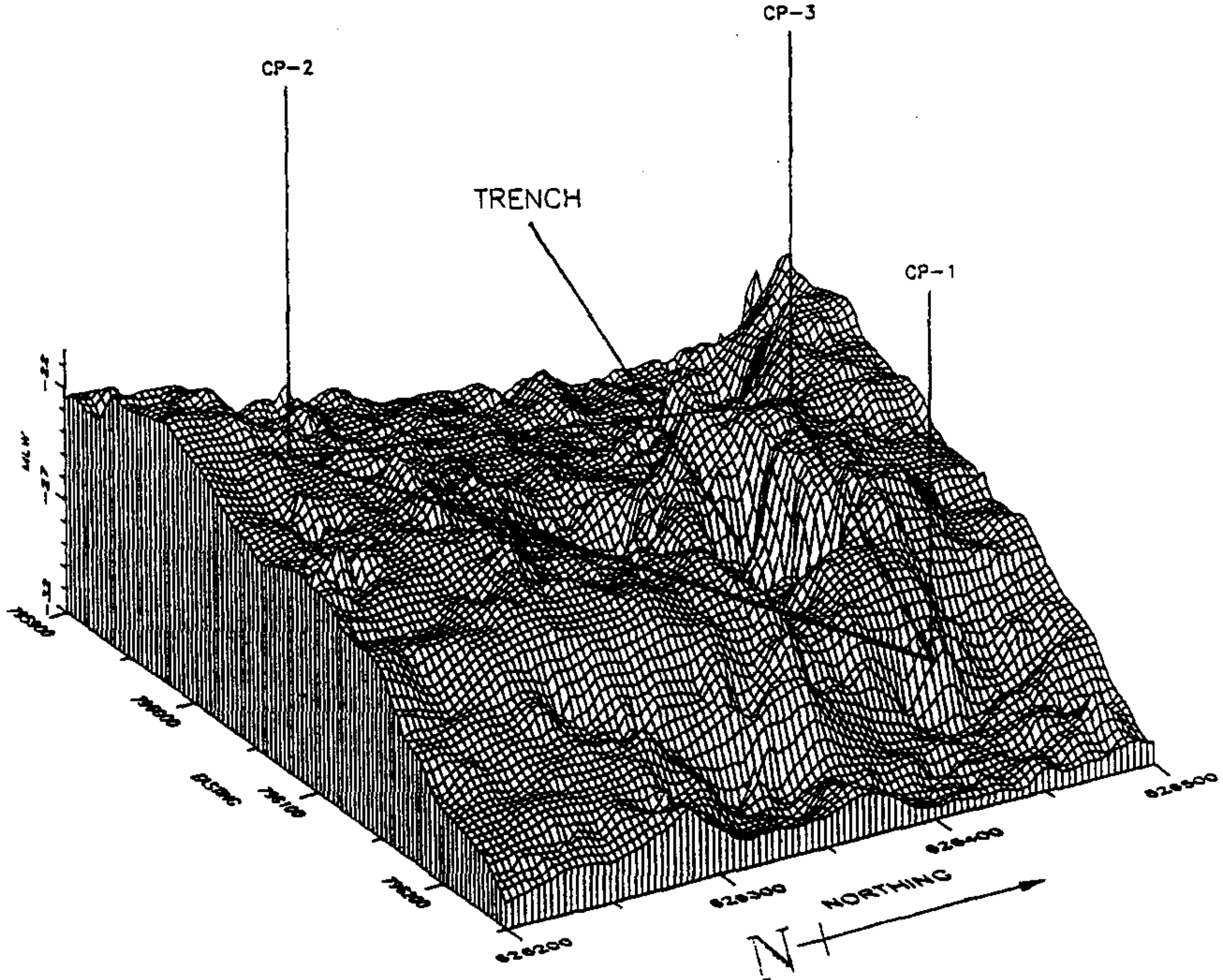

Figure 4. Three dimensional surface plot of the grounding site. The trench cut into the reef by the submarine is the depression between control points CP-1 and CP-3.

based on assessment, restoration and monitoring costs was determined to be $2,394,947 and was used as the basis of the damage claim.

DISCUSSION OF ASSESSMENT METHODS

Physical Damage Mapping

The Circular Strip Mapping (HALUSKY, 1982) method for determining physical damage was selected for its ease of use and minimal preparation time needed. However, a number of problems are associated with this method. Line spacing, close together at the vertex of the radial transects (control points), increases with distance from the vertex along the transect line. This results in non-linear error over the survey field. The use of overlapping transects helps alleviate this problem. Additionally, the use of a diver's compass to determine the azimuths of the radial transect lines resulted in error because of its low resolution, ±2.5°. It is recommended that the circular strip mapping technique be used to develop a preliminary estimate of types and extent of damage, but if litigation is anticipated and resources permit, a detailed and more accurate grid map and photomosaic should be developed.

The additional damage assessment method used to determine the area of 100 percent damage (transect line along the damage length with perpendicular assessment transects) proved to be a simple, quick, and effective method. Its used might have been improved by adding a greater density of perpendicular transects and by multiple diver scientists assessing the same transect(s) to standardize observations and provide replication.

A critical factor in assessing a grounding incident is quick response. A determination of the boundaries of the impact area and re-attachment of displaced stony corals is facilitated by being undertaken as soon as possible. This is because growth of benthic organisms and, especially algae, rapidly obscures fresh surfaces making subsequent damage determinations more difficult.

Aerial Photography

Aerial photography can be useful for providing an overview of the grounding site. Water clarity, sea state, skill and equipment of the air photographer, and references for horizontal control are all important factors which determine the degree to which air photographs can be used as quantitative tools. Air photography should be done, ideally, soon after the grounding, since the growth of benthic organisms can later mask some of the damage. Subsequent air photographs may also be useful and proved so in this case.

Bathymetric Mapping

Bathymetric mapping is a useful tool for gaining a three dimensional perspective of the impacts to the reef. Overlaying contour maps and impact assessments can provide reinforcement of interpretations. At the resolution used in this study bathymetric maps had limited quantitative usefulness. Other high resolution (*e.g.*, multi-beam sonar) techniques are available for quantitative studies, but are more expensive.

Biological Assessment Methods

The biological impact assessment, extrapolating adjacent reef to the damage area, was a reasonable approach to estimating the biological extent and composition of an obliterated resource. Because the grounding of a vessel disturbs or destroys a site, it is impossible, without the availability of previously collected baseline data to know exactly what was there. A difficulty of evaluating disturbance to the reef occurs in assessing the degree of damage. Total destruction of the reef framework and denudation of all organisms represents 100% damage. This is easily discernable, but less requires a more subjective opinion on degree of damage or more time for quantitative assessment.

Economic Impact Assessment

The recovery time for coral reefs subjected to natural or man-induced impact is reported to range from a few years, several decades, to centuries (SHINN, 1972; GRIGG and MARAGOS, 1974; STODDART, 1974; ENDEAN, 1976; LOYA, 1976; PEARSON, 1981; and CURTIS, 1985). At the upper limit, there are some scientists who feel that coral reefs damaged from certain man-induced impacts will never recover. Generalizations are difficult because (a) each reef often presents a special or unique case, (b) there have been relatively few replicated studies encompassing the wide range of impacts possible, and (c) there are many and complex variables which interact ecologically to affect the "recovery" that will be finally obtained (see references as follows and references contained therein: BAK and LUCKHURST, 1980; BAK, 1978; BROWN and HOWARD, 1985; CURTIS, 1985; DOLLAR and GRIGG, 1981; ENDEAN, 1976; GITTINGS, 1991; GRASSLE, 1973; GRIGG and DOLLAR, 1990; GRIGG and MARAGOS, 1974; HATCHER *et al.*, 1989; JOHANNES, 1975; LOYA, 1976; MARAGOS, 1986; PEARSON, 1981; SHINN, 1972; SMITH, 1985; STODDART, 1969, 1974). We estimated a recovery time for the damaged reef from between 20 and 50 years and took the median, 35 years, for use in HEM and claim calculations.

Damage Claim and Litigation

On 2/23/95, 2 years after the grounding of the USS Memphis, the State of Florida filed a claim, in Admiralty, against the US for $2.4 million for damages to the reef. If the incident had occurred within the Federal jurisdiction of the Florida Keys National Marine Sanctuary, it would be the US Government as trustee bringing suit. However, all of Broward County's reefs are within three miles of shore, are not protected by Federal sanctuaries or parks, and, thus, within State waters and jurisdiction. For this case, the US Government disputed the amount of damage; litigation activities proceeded until a settlement was reached on 4/23/97. The settlement was for $750,000 and was designated to be used for restoration of the site, reimbursement of incurred costs, and for reserve funds for other reef damage in the State.

Grounding Site Restoration Plan

A plan to restore the biological community at the site is currently under development by the Florida Department of Environmental Protection and the Broward County Department of Natural Resource Protection. Elements of the proposed plan include stabilization of loose rubble; transplanting stony corals, if feasible; deployment of artificial reef modules; and monitoring of recovery. $520,000 of the settlement, spent over five years, will be used for this effort.

The approach taken for restoration of the Memphis site differs from other recent groundings. The Firat, a Turkish freighter grounded on the reef offshore of Ft. Lauderdale in 1996, scraped and crushed many living corals, but caused little structural damage to the reef. A relatively rapid response by the ship owners and insurers resulted in re-attaching some of those displaced coral colonies which survived the grounding. This avoided litigation. A settlement of over $3 million for the grounding of the MV ELPIS on a reef in the upper Florida Keys provided funds to design and implement a restoration (BODGE, 1996).

The limited funds available from the settlement compared to the amount claimed to restore the Memphis site resulted in a need for a revised restoration plan and scrutiny in determining how the reef community would best benefit from the expenditures.

Stabilization of small rubble was considered necessary to prevent remobilization of the material during storm conditions. Grouting the rubble together in place, was rejected because of cost and the concern that organisms that had settled into the rubble would be destroyed during the grouting. The method under current consideration is the placement of porous, articulated concrete block blankets over the small rubble field. This will stabilize the site yet preserve some of the benthic recruitment that has occurred since 1993.

Coral transplantation will be used if appropriate donor sites can be identified. Initially, a feasibility study will be undertaken to evaluate the success of similar, previous, efforts; locate and evaluate donor sites; and estimate the costs for transplantation.

Installation of artificial reef modules has been chosen to replace lost reef surface area. Deployment in sand areas near the grounding site will complete the restoration activities.

Sixty modules of various design will be used. The designs will be evaluated during the monitoring phase to determine which may be more effective at recruiting benthic fauna.

Monitoring of natural reef recovery and the modules is an important part of the restoration effort. Some points of disagreement during litigation involved which type of artificial reef module was most cost effective, and how long would the recovery process take.

Reef restoration science is in its infancy and can involve subjective as well as scientific elements (PRECHT, 1998). Hence, our approach is to try to introduce hypothesis based elements into the restoration in order to further reef restoration knowledge.

SUMMARY

An assessment of the physical and biological damage caused to a high-latitude Florida coral reef by the grounding of the USS submarine, Memphis, was undertaken. A reef surface area of over 1,200 m^2 was killed. The litigation of the trustee (State of Florida) against the responsible party (US Government) was settled for $750,000. A major proportion of this settlement was designated for reef restoration. The restoration has been designed to include elements of substrate stabilization using concrete mats, replacement of reef area using artificial reef modules of various types, transplantation of living corals back to denuded reef surfaces and artificial reefs, and long-term (5 years) monitoring of restoration progress.

ACKNOWLEDGMENTS

The authors wish to acknowledge Cynthia Corbett-Elder and Joseph Ligas of the Broward County Department of Natural Resource Protection for their invaluable assistance with all aspects of field work and John Costigan and Maureen Malvern of the Florida Department of Environmental Protection for their perseverance during the long litigation.

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