INVESTIGATING REEF RECOVERY FOLLOWING A FREIGHTER GROUNDING IN THE KEY LARGO NATIONAL MARINE SANCTUARY, (Florida Keys, USA)

ETUDE DU RETABLISSEMENT D'UN RECIF CORALLIEN APRES L'ECHOUAGE D'UN CARGO DANS LA RESERVE MARINE NATIONALE DE KEY LARGO (Etats-Unis)

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ABSTRACT

On August 4, 1984, a 400-foot Cypriot-registered freighter ran aground on Molasses Reef in the Key Largo National Marine Sanctuary, Florida, USA and remained aground for 12 days. While the ship sustained only minor physical damage and no hazardous wastes were spilled, the grounding and associated salvage efforts caused substantial damage to benthic marine populations on the forereef. Haystack-sized colonies of Montastrea annularis were abraded, fractured or overturned when struck by the ship as it approached the grounding site. Where the ship grounded, at the seaward end of the spur and groove track, the reef formation was crushed and now resembles a graded roadbed covered with a veneer of coralline debris. Additional damages were caused by cable drag, propwash scour and shading.

The recovery of Molasses Reef following the ship grounding is now the subject of a large scale, multidisciplined research program sponsored by the National Oceanic and Atmospheric Administration which manages the Key Largo National Marine Sanctuary. A research plan has been developed in an effort to direct the multi-investigator program and inform the public of the research activities and results. An assessment of the immediate impact of the grounding on algal, coral and fish populations has been completed, and viable coral colonies have been rehabilitated. Reef population recovery studies have begun, and experimental studies are being conducted to identify factors that promote or inhibit reef recovery. Aerial photography has been obtained and a photomosaic is being produced for groundtruth mapping and monitoring purposes. The results of these investigations will be synthesized into a management document that discusses the extent of damages associated with the ship grounding and identifies strategies, if any, that would be effective in enhancing or hastening reef recovery following such a disturbance.

RESUME

Le 4 août 1984, un cargo chypriote s'échoua sur le récif de Molasses dans la réserve marine nationale de Key Largo, aux Etats Unis, et y resta pendant 12 jours. Alors que le navire ne souffrit que de dommages mineurs, et qu'aucun produit dangereux ne se répandit, l'échouage lui-même, ainsi que tous les efforts de sauvetage, causèrent des dégâts considérables aux populations benthiques de l'avant-récif. Des colonies de Montrastrea annularis atteignant la hauteur d'une meule de foin furent abîmées, brisées ou renversées lors de l'échouage du navire. Quant à l'endroit même de l'impact, au niveau des éperons-sillons de la pente externe, le récif a été écrasé. Il ressemble aujourd'hui à une route passée au rouleau compresseur qui serait comme recouverte d'une couche de débris coralliens. Les espèces mobiles furent tuées ou déplacées lors de la destruction du récif. D'autres dommages furent causés par le frottement des câbles, le tourbillon des hélices, le décapage et l'ombre portée dûs à la présence du navire. La restauration du récif de Molasses consécutive à l'échouage du navire est maintenant le sujet d'un programme de recherche multidisciplinaire de grande envergure, subventionné par le "National Oceanic and Atmospheric Administration" qui assure la gestion de la Réserve Maritime Nationale de Key Largo. Un projet de recherche a été développé dans le but de diriger ce programme multidisciplinaire et d'informer le public des activités et des résultats de ces recherches. L'évaluation de l'impact immédiat de l'échouage sur les populations d'algues, de coraux et de poissons est achevée et les colonies de coraux viables se sont rétablies. L'étude du rétablissement des peuplements du récif a commencé, et on cherche à identifier, à l'aide d'expériences, les facteurs qui favorisent ou inhibent ce rétablissement. Des photos aériennes et une carte photographique devront permettre de vérifier les données sur le terrain et de surveiller efficacement la recolonisation du récif. Les résultats de ces enquêtes seront synthétisées dans un document où l'étendue des dommages dûs à l'échouage du navire sera examinée et les stratégies identifiées, afin de définir celles qui pourraient être favorables à l'accroissement du récif, ou à un rétablissement plus rapide de celui-ci après une telle perturbation.

INTRODUCTION

Statistics on boat groundings on Florida reefs (i.e., frequency, vessel size and area of impact) have increased in recent years to the growing alarm of resource managers and the general public. Most groundings involve small pleasure and commercial boats of <12 m in length; however, since 1980, a disproportionate number of larger vessels (15-30 m in length) have run aground on Florida reefs. Groundings are attributed to several factors, including increased boating activities, inexperience, negligence and "Acts of God." In addition, the close proximity of Florida reefs to heavily trafficked ocean shipping lanes poses the threat of major shipgroundings. In 1984, this threat became a reality when a 122 m freighter, the M/V WELLWOOD, ran aground on Molasses Reef, a Caribbean-type bank reef on the margin of the Florida reef tract, resulting in extensive damages to the reef and complex law suits.

Molasses Reef is located in the southeasternmost corner of the Key Largo National Marine Sanctuary which was established by the United States Department of Commerce in 1975 to protect and preserve a 259 sq. km area of bank reef, patch reef, hardground, sand flat and seagrass habitats beyond the State of Florida's territorial boundary (Fig. 1). Molasses Reef is located approximately 8.4 km from shore (25°00.7'N, 80°22.4'W) and is comprised of several distinct biological zones, including an extensive reef flat area with prominent rubble horns, a narrow Acropora palmata reef top, a spur-and-grove system dominated by alcyonarians (sea plumes, sea fans, sea rods) with a sizeable population of scleractinian head corals, a buttress zone with haystack-sized colonies of M. annularis, measuring 2-3 m in height and between 200-400 years in age (Hudson 1981) and a deep reef (15-20 m water depth) with low relief spur-and-groove formations, large aborescent gorgonians, barrel sponges, and star and brain corals.

Molasses Reef is by far the most popular reef in the Sanctuary. Its spectacular shallow-water coral formations, abundant fish life and excellent underwater visibility attract SCUBA and snorkel diving, hook-and-line fishing and glass bottom boat tours. Sanctuary regulations prohibit spearfishing, specimen collecting, anchoring on coral and other activities that could possibly diminish the value of the reef as an ecological, recreational, research and aesthetic resource.

Shortly after midnight on August 4, 1984, the Cypriot-registered freighter M/V WELLWOOD grounded on Molasses Reef. The freighter had been travelling north in the Florida Current, with a cargo of pelletized animal feed, when it strayed off course and ran aground (Fig. 2). Attempts to remove the ship took place at every (diurnal) high water for 12 days using a combination of the ship's backing propulsion, five tugboats and two 4000-ton beaching anchors. Only after all of the fuel and 750 tons of cargo were lightered was the ship pulled free.

The M/V WELLWOOD was not damaged and completed its voyage after the episode. However, the reef sustained considerable damage. The United States through the Department of Justice has filed a claim against the ship and the ship's owners, operators and master, and the Department of Commerce, which manages the Sanctuary, has initiated a major research effort to support the litigation and the development of management strategies to promote reef recovery. A review of the literature at the time of the grounding revealed reports of catastrophic damage to coral reefs from natural causes, such as hurricanes, typhoons, volcanism, Acanthaster, meteorological phenomena, and from human perturbations, including pollution, dredging, dynamiting, coastal development [see review by Coles (1984)], but no reports of shipgroundings. Consequently, a research plan was designed to obtain information that was lacking on the impact of the shipgrounding, the processes in reef recovery and the management of the damaged ecosystem. In this paper, the research agenda is described and the preliminary research results are discussed.

METHODS

Aerial Photography and Groundtruth Mapping

Aerial reconnaissance was conducted immediately after the grounding to document the ship's presence on the reef and, after the ship was removed, to accurately locate the grounding site in relation to the entire Molasses Reef complex. Low altitude color photography (1:2400 scale) was obtained for constructing a mosaic of the reef from which the major physiographic features of the coral reef will be scribed onto a clear acetate overlay. Biotic zonation will be interpreted from the photography based on textural and color contrasts and groundtruthing by reef ecologists. Photo enlargements of the grounding site will be made for use in monitoring large scale recovery processes.

Damage Assessment

Within hours of the grounding and over the course of 19 days, Sanctuary personnel using SCUBA surveyed Molasses Reef to measure and map areas of damage and to characterize resource conditions. Survey stakes were driven into bedrock along the inbound path of the ship and a grid system was set up at and adjacent to the grounding site. A combination of visual inspections, overlapping 35 mm photography, and video photography was utilized to document substrate type and condition. Direction was determined by shipboard and underwater compass and distance was measured using metered transect lines strung between permanent stakes. The grounding site was closed to visitors while surveys were in progress. Later, after the reef was reopened, additional area-intensive surveys were conducted using photographic transects after Littler (1980) and Bright et al. (1984) to quantitatively assess the effect of the grounding on the composition, distribution and abundance of algal and coral populations, and a reef-plate damage survey was conducted to document the location and extent of reef-plate fracturing and to ascertain a practical method for stabilizing damaged substrate to aid in the recolonization of hard and soft corals (H. Hudson, pers. comm.).

Restoration and Monitoring of Surviving Coral Colonies

An immediate concern at the time of the grounding was over the fate of large coral colonies, such as Montastrea annularis, that were fractured, detached, overturned, bleached or buried by the shipgrounding but were still alive, and a decision was made to rehabilitate those colonies that appeared to have a good chance of surviving. Consequently, shattered heads of stony corals were pieced back together, living fragments were rescued from the rubble and overturned colonies were righted using mechanical and air-bag devices. Detached alyconarians were restored to an upright position by wedging holdfasts into crevices.

Reef Recovery Studies

Investigations are in progress to study the major processes of reef recovery that will be operating at the M/V WELLWOOD grounding site (i.e., regeneration and repair of surviving scleractinian and alcyonarian coral colonies and recruitment and establishment of corals and other colonizing organisms). The fate of surviving macrobenthos is being monitored through field observations, photography and systematic studies. Haystack colonies of M. annularis, which were variously injured when struck by the ship as it approached the grounding site, are being monitored using a quadrat grid method and macrophotography to document whole colony survivorship. To study tissue regeneration capacity in this coral species, stainless steel spikes have been driven into the surface of freshly exposed coral skeleton near the border of living tissue. Stations are monitored quarterly using close-up photography to measure tissue advance or retreat and the nature of colonizing organisms. Control colonies have been established for analyzing natural changes at living tissue borders. A limited photographic survey of the recovery of the vase sponge Xestospongia muta in deep reef areas is also being performed.

To quantitatively monitor successional algal and coral community reestablishment and development, permanent transects have been established so as to intercept both damaged and undamaged portions of the reef at the grounding site (Fig. 3) and the photogrammetric quadrat techniques of Bright et al. (1984) and Littler (1980) are being used to sample transects (weekly for the first two months and monthly thereafter for algae and quarterly for corals). In addition, randomly placed transects are being photo-surveyed quarterly to monitor changing patterns of the reef biota in disturbed and undisturbed areas. Underwater tape recorded and written field notes, sketches of quadrat plots and limited voucher collections supplement photography.

To study the effects of season on recovery processes and to identify organisms that may be sensitive to recruitment conditions, selected quadrats were established for treatment by scraping and wire brushing to delay the initiation of recruitment. Because the treatments are staggered over the course of a year, alternate climax communities may result in study plots.

To assess coral spat recruitment and other epibenthic growth, permanent photostations were established on the horizontal and vertical surfaces of bare M. annularis skeleton which was exposed due to splitting of coral heads by the M/V WELLWOOD upon grounding. Photography is examined microscopically and quantitative comparisons are made quarterly to reveal seasonal coral recruitment and mortality patterns and to assess aspects of competition with other colonizing organisms and disturbance by grazers and territorial fish. Recruitment racks containing natural (clam shell) and artificial (plexiglass) settling plates were established for similar analyses, although the frequency of sampling also includes monthly samples.

A coral transplantation experiment is being planned to assess the feasibility of artificially restoring scleractinian and alcyonarian coral populations to approximately their pre-grounding distribution and abundance.

Reef Fish Recolonization

Underwater fish surveys are being conducted monthly using a modified version of the Bohnsack & Bannerot (1983) random point-count census to assess reef fish abundance, biomass and trophic structure at the grounding site and in adjacent undamaged areas. Fish species are graded into three classes (i.e., juvenile, intermediate, adult) based on coloration and size in order to make inferences about the distribution of biomass within the community and the timing of recruitment events. Trophic categories are based on observed and reported food habits. For each point-count replicate, substate complexity is estimated following the chain link method of Risk (1972) and abundances of major epifaunal groups (scleractinians, alcyonarians, hydrocorals and sponges) are determined. An overall species list for each monthly sampling trip is compiled using Jones & Thompson (1978) rapid visual technique, and time lapse photography is obtained in damaged and control areas to study aspects of reef fish behavior. Several fractured M. annularis heads are monitored visually to determine frequency and type of use (e.g., feeding, spawning or territory) by reef fish.

RESULTS

Damages to Molasses Reef are extensive but variable with location, depth, and afflicted taxa; however, three distinct zones of damage are evident (Fig. 4): the inbound path of the ship as it traveled over the buttress zone on its approach to the grounding site (Area A); the grounding site, which is the seabed at and adjacent to where the ship grounded and remained for 12 days (Area B); and the deep reef area which was unavoidably damaged during efforts to remove the ship (Area C).

The M/V WELLWOOD was travelling northeast, almost parallel to the forereef but on a slightly converging course, when it entered the Sanctuary waters and contacted large M. annularis coral heads in Area A which protrude several meters above the reef substrate in water depths averaging 8 m. At least 12 colonies of M. annularis were variously overturned, crushed, fractured or abraded by the ship. Other corals damaged or destroyed in this zone included Millepora complanata, Acorpora cervicornis, A. palmata, Agaricia agaricites, Colphophilia natans, Porites porites, Favia fragum, Siderastrea siderea, Gorgonia ventalia, and a variety of gorgonians.

The ultimate grounding occurred when the ship contacted the lower end of coral spurs in approximately 6 m of water (Area B). The ship's hull cut deep into the limestone outcroppings when it grounded and then pivoted, bow to port and stern to starboard, to its final resting position. The lateral movement flattened the broad tops of spur formations, obliterating nearly all epibenthic life in the area of contact and creating large amounts of rubble and debris. In addition to the species listed for Area A, others variously impacted by the grounding included M. cavernosa, Dichocoenia stokesii, Meandrina meandrites and P. astreoides. In sand channels between the spurs, beneath the ship, mortality was less than total, although marine life was distinctly affected by shading, prop wash scour and rubble fill.

The quantitative data from algal and coral transects indicate that the M/V WELLWOOD grounded in a transition zone between the shallow upper forereef (just seaward of the A. palmata reef top), which is dominated by the scleractinian Agaricia agaricites, Pseudopterogorgia spp. (sea fans) and long-lived perrenial algal species, and a deeper forereef zone which is dominated by large head corals and alcyonarians other than Psuedopterogorgia spp. (i.e., sea rods and sea plumes). The data show substantially lower populations of scleractinian and alcyonarian corals and macroalgae in the grounding area (Area B in Fig. 4) than in adjacent areas extending to the east and west, and as expected, there are greater numbers of dead alcyonarian skeletons in the area beneath the ship than in the adjacent control areas. No scleractinians, few hydrocorals and only one alcyonarian were detected alive at the hull site immediately after the grounding. All but wiry and stony forms of algae were sheared away by prop wash and scleractinians were variously affected by shading and rubble scour.

Statistical evidence indicates that the impacts of the grounding on coral populations may have differed depending on the coral's growth form, size and systematic affiliation. Small scleractinian head corals suffered little mortality beneath the ship where the hull did not touch the bottom. However, populations of alcyonarians in general, and sea plumes in particular were significantly diminished in these areas. In addition, prop wash caused significant mortality of alcyonarians beneath the stern of the ship, and transported their skeletal remains out of the immediate area and into surrounding depressions. Colonies of M. annularis experienced substantial loss of zooxanthellae where they were in the shade of the ship for 12 days; other scleractinian corals did not suffer as great a degree of zooxanthellae loss.

Efforts to remove the M/V WELLWOOD caused damages to epiflora and fauna that could not be avoided. In the area adjacent to the hull grounding site, colonies of M. annularis, C. natans and Dendrogyra cylindrus were overturned, fractured or abraded, and in the deep reef area (Area C in Fig. 4) hundreds of colonies of Xestospongia muta, M. annularis and other stony corals and alcyonarians were damaged or destroyed during salvage operations.

Motile invertebrates and reef fish inhabiting the grounding site were killed by the impact or fled the scene when the grounding occurred. While the ship was on the reef, opportunistic predatory fish (snook, bar jack, snappers and groupers) roamed the reef in search of displaced prey. Three weeks after the grounding, less than one half of the 123 species of fish previously reported for Molasses Reef had returned to the grounding site, and most of these were of a single size class, indicating recruitment from larvae or immigration from other parts of the reef. Exposed surfaces of M. annularis were observed to be used for algal gardens by three spot damselfish, spawning patches by sargent majors and feeding areas by blueheads and ocean surgeons.

At the time of this writing (i.e., 7 months after the grounding), there are very few results to report for those studies that are time dependent. Opportunistic successional species of microfilamentous yellow-turf algae have shown dramatic increases in disturbed areas. Recruitment of coralline and other algae and other epifauna to the surface of freshly exposed reef rock, coral skeletons and unconsolidated sediments is significant throughout the damaged areas. No change in the nature of random and permanent coral transects has been detected (i.e., a significant difference in scleractinian and alcyonarian populations between disturbed and undisturbed areas still exists), except for evidence of movement of unconsolidated sediments. No coral planulae have settled on M. annularis recruitment stations; however, one artificial settling plate out of 60 examined for the period between November 1984 and March 1985 yielded a single coral recruit. The results of encrusting growth studies are variable; in some instances, living tissue along fracture edges regressed due to mortality and disintegration for several months following the grounding but stablized prior to the November 1984 sampling and in other cases, living tissue has made some advance across the fracture surface. For many of the coral colonies that suffered from zooxanthellae loss, there was subsequent mortality of afflicted tissue, yet seven months after the grounding, surviving colonies had stabilized and the tissue that did not die had regained zooxanthellae. The hull site continues to differ from control areas in the number of reef fish species and number of individuals and there is preliminary evidence that season affects these numbers, especially late winter when all areas exhibited a decrease in abundance. Xestospongia muta in deep reef areas appear to be regenerating lost tissue.

DISCUSSION

The damages caused by the grounding of the M/V WELLWOOD are significant, and preliminary results indicate that the processes involved in recovery are variable and the rates are slow. Recovery will depend upon a complex interaction of geological, biological and ecological processes, some of which may be aided by reef managers. Whether Molasses Reef recovers to pregrounding conditions remains to be seen. Unlike recovery from hurricanes in the Florida Keys, which is rapid because of widespread scattering of live coral fragments, such as Acropora cervicornis and A. palmata (Shinn, 1976), asexual propogation by fragmentation is not likely to be significant at the M/V WELLWOOD grounding site because few fragments of reef-building corals and alcyonarians survived the grounding. The timing of recovery in this area is uncertain because before the barren substrate is rendered suitable for colonization, the reef plate must be stabilized and rubble and debris must be consolidated and undergo a period of biological conditioning (see Schuhmacher, 1977 for a description of the phases of colonization prior to coral recruitment). Because of the high mortality rate for coral larvae and juveniles and the low priority of sexual reproduction in many of the coral species impacted by the grounding (e.g., M. annularis) (Highsmith, 1982) recruitment potential is uncertain. The recovery potential of injured corals is also variable. Whether colonies regenerate lesions completely or partly or are totally destroyed by continued retreat of living borders or invaded by disease will depend upon colony type, fragment size and regenerative capacity as well as the kind and degree of fouling

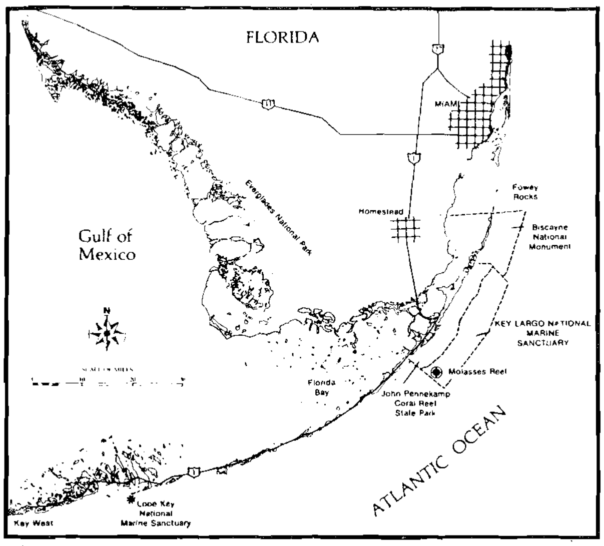

Figure 1 : Location map.
Key Largo National Marine Sanctuary.

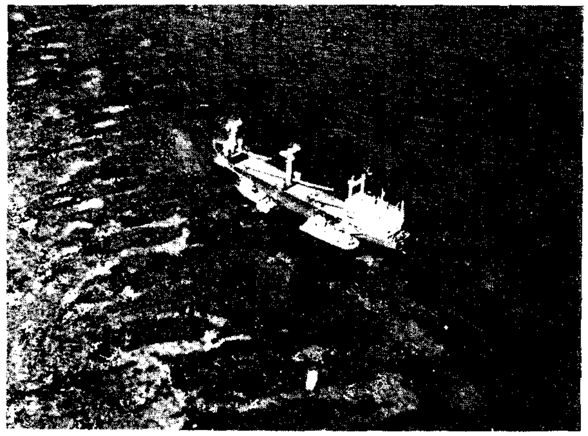

Figure 2 : M/V WELLWOOD grounded on Molasses Reef Key Largo National Marine Sanctuary.

Figure 3 : Algal transect in Area B. Note flattened reef platform which is reminiscent of a freshly graded road bed.

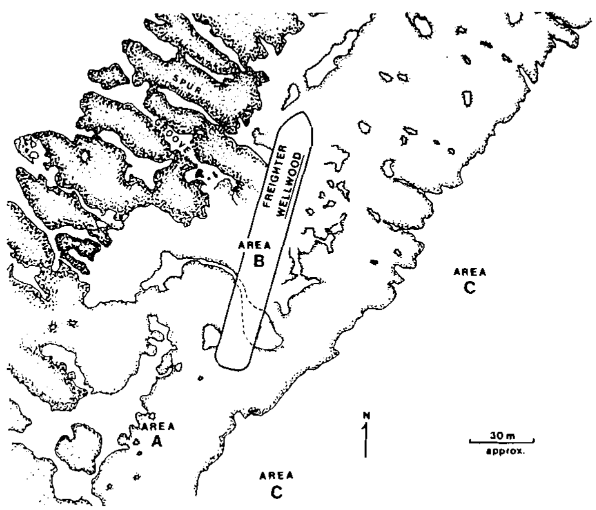

Figure 4 : Grounding site of the freighter WELLWOOD. Showing is the path of the ship during the initial grounding (Area A), the major grounding site and environs (Area B), and the deep reef salvage-damaged areas (Area C).

of exposed skeleton at tissue borders and the competitive ability of surviving colonies, new recruits and other colonizing organisms. (Bak, Brouns & Heyes, 1977; Bak & Steward-Van Es, 1980). Interestingly, M. annularis which is the most severly affected coral species, is well-adapted to regenerating lesions, but produces very few juveniles, whereas A. agaricites, also impacted, has a high rate of recruitment, but the regeneration of lesions is poor (Bak & Engel, 1979). Organisms with minor injuries will probably survive, while those with extensive tissue necrosis, bleaching or major skeletal damage will be more prone to disease, overgrowth and death. Stochastic events may lead to alternate successional communities which inhibit the recruitment or regrowth of desirable species, and recovery may be prolonged or prevented altogether by chronic low-level disturbances, such as damages due to anchors, storms or additional groundings.

The grounding of the M/V WELLWOOD has refocused attention on a problem that has persisted in the Florida Keys since the time of the Spanish explorers. Managers may not be able to stop all groundings but they may succeed in lowering the statistics through a variety of management strategies aimed at educating the boating public and protecting fragile resources (e.g., mooring buoys). And they may be able to mitigate damages by applying some of the lessons learned from the M/V WELLWOOD.

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