THE M/V WELLWOOD AND OTHER LARGE VESSEL GROUNDINGS: CORAL REEF DAMAGE AND RECOVERY

Stephen R. Gittings[1], Thomas J. Bright[2] and Derek K. Hagman[2]

[1] Flower Garden Banks National Marine Sanctuary, 1716 Briarcrest Dr., Suite 702, Bryan, Texas, 77802
[2] Texas A&M Sea Grant College Program, 1716 Briarcrest Dr., Suite 702, Bryan, Texas, 77802

ABSTRACT

The characteristics of reef community damage caused by three large vessel groundings in the Florida Keys were investigated between 1984 and 1991. Damage at each site included impact to living resources, framework alteration and fracturing, reef rock displacement, and sediment production. These were caused by vessel contact with the bottom, by propwash and cable dragging during attempts by operators and/or salvagers to refloat the ships, and by subsequent movement of destabilized substrates. None of the groundings were accompanied by significant cargo or fuel spills. Coral community recovery was followed for five years on Molasses Reef after the grounding of a 122 m freighter. Repetitive and random photographic methods, and diver counts were used to assess coral populations, cover, recruitment, and the fate of damaged coral colonies. Substantial population recovery occurred in the five years following the grounding, but colonies remained small. Hard coral recruitment was dominated by species that brood larvae. These species were also numerical dominants in undamaged communities nearby. Though, in time, complete recovery would occur naturally, transplantation could be used to increase the relative abundance of species found only rarely as recruits. These include primarily the large massive corals conspicuous in mature reef communities. Most are broadcast spawners, and have long planktonic stages, low recruitment rates, and low relative abundances in mature communities. Following large vessel groundings that cause extensive flattening of portions of the reef surface, transplantation could also serve to restore lost habitat complexity, and enhance the rate of development of associated invertebrate and reef fish assemblages.

INTRODUCTION

On August 4, 1984, the 122 m freighter M/V WELLWOOD ran aground on Molasses Reef, in the Key Largo National Marine Sanctuary (Fig. 1). Damage occurred where the vessel made contact with corals along its inbound path, at the site where the vessel was hard aground, and during ship salvage efforts (Bright and Andryszak [1984]; Curtis [1985]; Gittings and Bright [1988]). In the area of initial contact (approximately 8 meters depth), large corals were abraded, toppled or fractured (within and seaward of Area BS in Fig. 1). The final resting site (6-8 m depth) was the most heavily impacted portion of the reef. Under the bow and amidships (Area BB in Fig. 1), the broad tops of forereef spurs were ground flat by the ship hull, and linear piles of boulders were formed by the plowing of the port side of the ship as it pivoted on the reef. Nearly all corals were destroyed in the 1500 m^2 flattened area. Corals in some depressions survived, but were shaded during the 12 days the ship remained aground, and lost zooxanthellae. This also occurred in toppled colonies. Substantial tissue loss occurred on colonies with severe bleaching. During ship salvage, many corals and large barrel sponges seaward of the grounding site were damaged by tug cables used to haul the vessel off the reef.

Damage assessments were also conducted at two other ship grounding sites in the Sanctuary. On October 25, 1989, the 47 m oil field supply vessel M/V ALEC OWEN MAITLAND ran aground in a reef coral community in 2-3 meters of water approximately 2.5 km southwest of Carysfort Light (Gittings, 1991a). Along the 156 m grounding track, at least two community types were affected, one of high relief and dominated by gorgonians and the hydrozoan Millepora spp., and the other a low relief hard bottom with lower coral abundance. Damage on the 88 m inbound path included toppling, fracturing, and crushing of coral colonies. At the end of and perpendicular to the inbound path, was an area 64 m in length where the vessel apparently turned during initial freeing efforts. Damage there consisted of grinding by the ship's hull, removal and overturning of corals, and excavations caused by propwash. The final resting site measured 68 m in length, contained two large excavations totaling over 25 m in length, the remains of detacted corals, and rubble and sediment accumulations. The two excavation (or blowout) craters were formed by propwash during attempts by the crew to free the vessel.

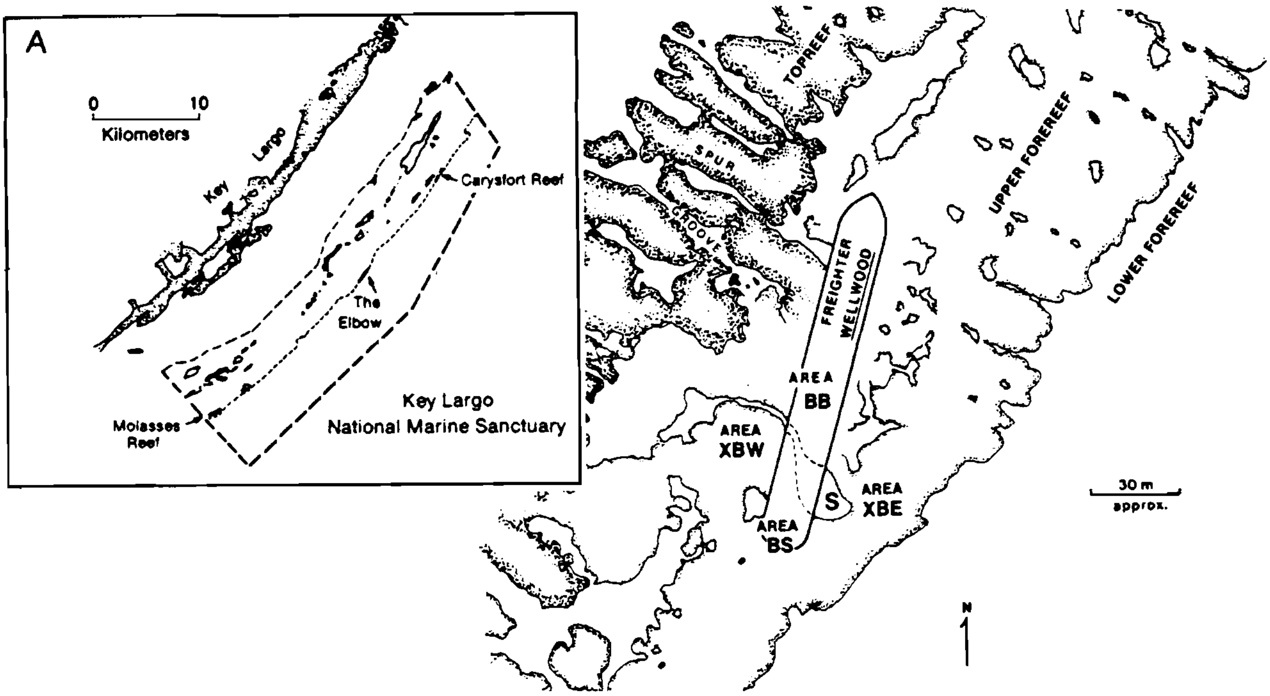

Figure 1. Study areas at the grounding site of the M/V WELLWOOD. Inset (A) shows the locations of reefs in the Key Largo National Marine Sanctuary near the grounding sites discussed here.

On November 11, 1989, the 143 m freighter M/V ELPIS ran aground in a reef coral community in 8.5-10.0 meters of water 0.5 km northeast of the Elbow Reef Light. This vessel caused over 3,000 m^2 of damage. It produced intermittent damage over nearly 100 m of reef before coming to rest and flattening an area nearly 40 m in length. Propwash apparently caused by forward and reverse thrust resulted in craters 18 m and 11 m in diameter, respectively, each 2-3 m deep. After coming to rest, the vessel pivoted 230° and drifted into shallower water, flattening roughly 700 m^2 of additional sea bottom over an 80 m length. Upon removal, vessel propwash produced a 75 m long trench that, together with rubble accumulations, covered over 1400 m^2 (Gittings, 1991b).

While coral communities affected by ship groundings vary considerably, the collective characteristics of damage identified at the three sites discussed here distinguish large vessel grounding damage from other forms of human or natural impact. This paper focuses on the characteristics of mechanical damage caused by ship groundings. We also discuss the physical and biological processes affected by groundings that, in turn, affect reef community recovery. Finally, implications for mitigation and recovery enhancement efforts are discussed.

METHODS

At the shallow water grounding site of the ALEC OWEN MAITLAND, damage occurred in more than one coral community type. The probable pre-grounding boundaries between different communities were determined using post-grounding aerial photography and ground truthing. Probable pre-grounding coral population levels at the site were determined using underwater video, and quantitative photographic and survey techniques in undamaged areas. The extent of destruction to the coral community was then assumed to be the difference between the existing populations at the site and population levels in similar, but undamaged communities nearby.

Similar techniques were used at the two deeper sites as well, but aerial photography was not as heavily relied upon. Divers surveyed the grounding sites and determined, based on topography, depth, and observed reef zonation, the probable pre-grounding community types at each grounding site.

Damage assessments required between three and seven days at each site using two to three dive teams. Field sampling at the WELLWOOD site, where coral community recovery was monitored, was conducted quarterly between August 1984 and November 1986, then again in September 1988 and August 1989. Each sampling trip lasted four to five days.

Similar quantification techniques were used at all sites. Random photographic techniques were used to assess hard coral and gorgonian abundance and distribution in damaged and undamaged (control) areas (Gittings et al., 1990). Randomly located photos were taken in each area, each providing coverage of either 0.5 m^2 or 1.0 m^2, depending on the nature of the coral community (e.g., average size and abundance). They were analyzed to determine sizes and numbers of scleractinians, gorgonaceans, hydrozoans, and zoanthideans by species for each area. Percent cover was considered the vertical projection of a colony onto the substrate (like canopy cover in terrestrial ecosystems) and was calculated for scleractinians using a digital planimeter. For upright gorgonians, relative size was determined ("small" being 0-10 cm height, "medium" 10-30 cm, and "large" over 30 cm). Gorgonian canopy cover at the WELLWOOD site, and all coral cover at the other sites was measured using the random point-intercept method. Clear acetate overlays containing 100 randomly located points were laid over photos, and cover was estimated by counting points covering each coral species.

At the WELLWOOD site, recruitment was assessed from random photographic data, and underwater counts of juvenile corals in the area of greatest destruction (Area BB). Numerical abundances on random photographs were compared between sampling periods. Recruitment rates were determined in terms of net increases in individual groups (gorgonians, scleractinians, and hydrozoans) and species, where possible. In November 1986, September 1988, and August 1989, underwater counts in eighteen 1 m^2 quadrats were made in Area BB to determine the population of scleractinians, gorgonians, hydrozoans, zoanthideans, and selected associated invertebrates in the area. Samples were spaced approximately 1 m apart on a line from the southernmost to the northernmost portion of Area BB. This visual method was employed because many juvenile corals are found predominantly on the undersides or sides of reef surfaces, and may not be accounted for using down-looking photographic techniques.

Another technique used to evaluate population changes (recruitment and loss) was repetitive photography of three 15 m x 0.5 m transects. For two of the three transects (107 and 110), half of each was located in Area BB and half in areas beyond the direct impact of the ship hull. For the third transect (102), the impacted half was in an area only partially damaged by the vessel (i.e., adult colonies and considerable topographic relief remained).

Lateral coral growth on damaged and undamaged Montastrea annularis colonies at the WELLWOOD site was measured using repetitive photographic techniques described by Gittings et al., (1988). Eighty-four permanent stations were established and photographed from 1984 to 1989. Tissue growth and retreat rates were compared to determine the fate of damaged colonies and the influence of colony displacement (e.g. damaged colonies displaced into sand vs. those remaining on the reef following fracture).

RESULTS

Gittings et al. (1990) reported the results of five years (1984-1989) of population studies at the WELLWOOD grounding site. Coral populations had increased by 1989 from virtually 0% in an area of major impact to 65% and 78% of supposed pre-impact populations for hard corals and gorgonians, respectively. They also found that recruitment rates increased with time, and estimated that population levels could approach pre-grounding levels after six years of recovery. But coral cover, particularly for scleractinians, had not increased as fast as populations levels. Gorgonian cover increased from virtually 0% of that in the control area (Area XBE in Fig. 1) to approximately 40% of cover in the control area by 1989. Hard coral cover increased from an average of 12.4% of cover in the control area during the first two years after the grounding to 22.1% in 1988 and 1989.

Diver counts in square meter quadrats in Area BB indicated that coral populations in 1989 were roughly 20 m^{-2} (less than 4 m^{-2} existed in the first counts in 1986). Gorgonians and scleractinians had approximately equal populations (nearly 10 m^{-2} each), and accounted for 95% of all corals. Millepora spp. represented 5% of the hard coral population in the area.

Coral recruitment on repetitive transects was dominated by gorgonian corals (45% of all recruits), followed by scleractinians (36%) and Millepora spp. (19%). Gorgonian recruitment was dominated by Pseudopterogorgia spp. (75%), Gorgonia ventalina (14%) and Briareum asbestinum (7%). Scleractinian recruitment was dominated by Favia fragum (38%), Agaricia agaricites (32%), and Porites sp. (10%). Though these taxa accounted for over 90% of all corals in the Area BB by 1989, richness (the number of coral taxa) increased gradually, primarily due to an increase in the number of scleractinian species.

Massive corals such as Montastrea spp., Diploria spp., and Dichocoenia stokesi, which were conspicuous in surrounding habitats, were only rarely encountered in Area BB. Their relative abundances, however, were similar in both areas. Though conspicuous due to their larger size in undisturbed habitats, these corals did not represent numerically dominant species in any area.

Fig. 2 shows cumulative coral recruitment on the impacted portions of repetitive transects between 1984 and 1989. Gittings (1988) showed that recruitment on Transect 102 (in the partially damaged area) was significantly higher than that on the other transects through 1986. In fact most recruitment on Transect 102 occurred in the first two years after the grounding; most recruitment on Transects 107 and 110 (in the heavily damaged area) occurred after 1986. Recruitment on the undamaged portions of the transects was similar between 1984 and 1989 (Gittings and Bright, 1990).

Gittings et al. (1988) and Gittings and Bright (1990) showed that coral colonies displaced into sandy habitats during or after the grounding had greater tissue retreat rates than those not displaced from the reef. Between 1988 and 1989, however, stations in sand and on the reef had virtually identical rates of advance and retreat. Fig. 3 compares growth at stations on three coral colonies, one damaged and displaced into sand (Head S; 10 stations), one damaged but not displaced (Head D; 8 stations), and an undamaged colony (Head C; 12 stations). The ternary diagrams show the proportions of marginal tissue growing, retreating, and remaining stable between sample periods. Prior to 1988 (Periods A-I), data indicated that damaged colonies displaced into sand had comparatively high proportions of retreating margins. Damaged colonies that remained on the reef exhibited high retreat only during the first three months following the grounding (Period A). In 1989, all colonies had proportions of advancing margins of at least 50%.

DISCUSSION

Damage Characteristics

The principal forms of damage observed at all three grounding sites can be divided into four categories: impacts to living resources, framework fracturing, reef rock displacement, and sediment production. Impacts to living resources included obliteration, fracture, or abrasion of coral colonies (and associated reef invertebrates), displacement of colonies, and bleaching (primarily at the WELLWOOD site, where the vessel remained aground for nearly two weeks). Unique to the WELLWOOD site was the shearing of many corals and sponges over a large area seaward of the grounding site by cables used to remove the vessel from the reef. This damage could have been avoided by keeping the cables off the bottom.

Reef framework damage varied with the size of the vessel, the nature of the grounding, and the configuration of the reef surface on which the grounding occurred. At each site, however, some portion of the reef surface was flattened (ranging from several to over 1500 m^2) and large cracks in the reef surface appeared, particularly where the ship's hull rested on the bottom.

Reef rock displacement at each site was caused by movement of loose material either by the ship hull (i.e., plowing, which formed a long pile of rubble along the west side of the WELLWOOD site; Curtis, 1985), by propwash during attempts of remove the vessel from the reef, or by storms following the grounding. Rubble movement caused by propwash and storms was exacerbated in areas with reef framework damage. The large craters at each site attest to the destructive power of propwash in mechanically damaged habitats. In each case, fallout from propwash caused the burial of corals in the vicinity of the craters, as well as abrasions on surviving colonies. "Secondary" damage was documented on repetitive transects at the WELLWOOD site, where storm-tossed rubble, generated by the grounding, damaged and destroyed a number of colonies adjacent to the grounding site during Hurricane Kate in 1985 (Gittings, 1988).

At each site, areas flattened by the ship hull also contained fine sediments that formed as the vessel pulverized corals and rock on the reef top. These sediments were generally found packed by the weight of the vessel into depressions on the reef surface. Removal required storms at the deeper grounding sites, or less energetic events at the shallower water site.

The effect of the generation of both loose material and sediments is to inhibit recruitment or survival of benthic fauna and flora (e.g., Bak and Engel, 1979). Data at the WELLWOOD site substantiated this effect; recruitment was low in the first year following the grounding in Area BB compared to less damaged areas, and increased significantly thereafter.

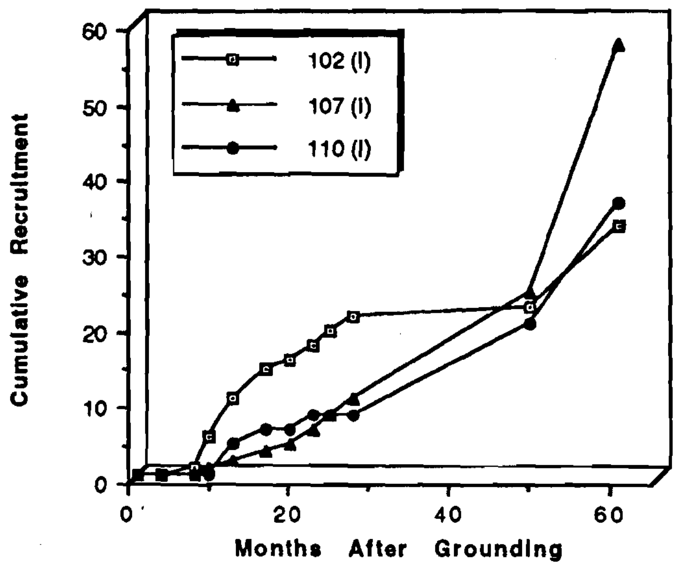

Figure 2. Cumulative coral recruitment (all species combined) on the impacted portions of repetitive transects 102, 107 and 110 between 1984 and 1989.

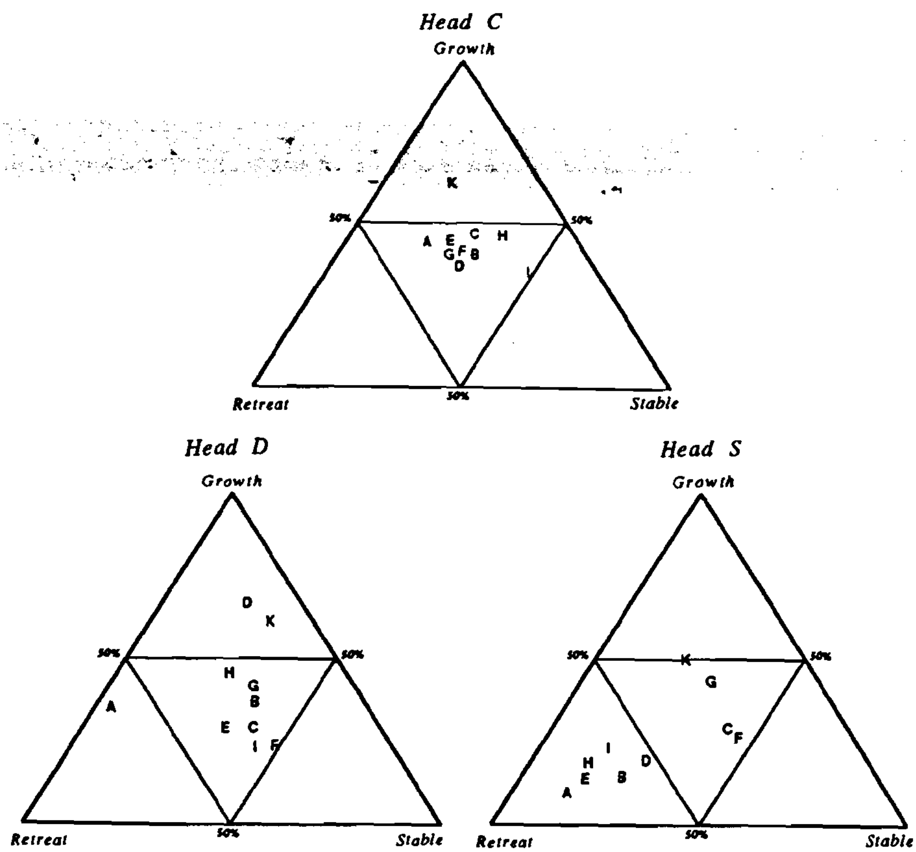

Figure 3. Ternary diagram showing the proportions of growing, retreating, and stable coral margins during each sample period on three different coral heads. Letters indicate sample period as follows: A=Aug 84-Nov 84, B=Nov 84-Mar 85, C=Mar 85-May 85, D=May 85-Aug 85, E=Aug 85-Dec 85, F=Dec 85-Mar 86, G=Mar 86-Jun 86, H=Jun 86-Aug 86, I=Aug 86-Nov 86, J=Nov 86-Sep 88 (no data), K=Sep 88-Aug 89.

Coral Community Recovery

Recovery of a reef coral community requires the replenishment of populations as well as the restoration of age-class structure. Recovery of the reef habitat must also include the regeneration of pre-existing three-dimensional structure. The disparity between the increases in population levels and coral cover at the WELLWOOD site in the first five post-grounding years is attributable to the lack of large colonies in the recovering community. This reflects the lack of age-class structure recovery.

As suggested by the percent cover estimates at the WELLWOOD site, gorgonian corals, which grow much faster in area than stony corals, contributed most significantly to the increase in coral cover at the site. Gittings et al. (1990) predicted that gorgonian cover would approach control levels much faster than stony coral cover. Extrapolation of best fit curves on percent cover data suggested that control community percent cover could be reached in Area BB at approximately seven years for gorgonians (r^2=0.965; second order polynomial), and over 12 years for hard corals (r^2=0.192).

Nevertheless, complete community recovery would still require the development of species diversity, age-class structure and three-dimensional habitat structure in the area comparable to that in control areas, and development of a diverse community of associated reef algae, invertebrates and fishes.

Species dominating the recovery community in Area BB were those dominating mature communities in control areas, but relative abundances changed considerably over the course of the study. The scleractinian coral species dominating Area BB (F. fragum, Porites sp., and A. agaricites) were described by van Moorsel (1983) and Szmant (1986) as larval brooders. Planulae released from brooding adults are able to settle soon after release and may colonize areas near parent colonies. Generally, these species produce small colonies, have multiple reproductive cycles per year, have high recruitment rates, and are often found in unstable habitats. They are analogous to r-selected, opportunistic species in some respects (Pianka, 1970), especially in their ability to colonize substrates made available through removal of other organisms, as occurs during ship groundings. Thus, a high relative abundance of these species in the early recovery community should be expected.

Broadcast spawners in surrounding habitats, such as M. annularis, M. cavernosa, Diploria strigosa, Acropora spp., and Siderastrea siderea would be expected to colonize the grounding site at a slower rate and reach maximum abundance in later recovery phases. These species were found only occasionally in Area BB. As adults, they are usually larger than brooding species and have only one spawning period per year (Szmant, 1986). They become conspicuous in mature communities due to their size, and contribute substantially to coral cover and three-dimensionality on the reef, but are not numerical dominants.

Implications for Recovery Enhancement

Gittings et al. (1988) discussed potential ameliorative measures that could minimize secondary damage and enhance recovery following mechanical disturbance to reef communities. These included fine sediment removal, rubble removal or stabilization, and coral transplantation. Sediment removal could enhance recruitment by facilitating substrate conditioning (Crisp and Ryland, 1960) and by increasing habitat complexity. Rubble removal, or stabilization using cement, could reduce secondary damage caused by resuspension during storms and increase bottom stability (Endean and Stablum, 1973; Wulff, 1984). Coral transplantation may increase recruitment in denuded areas (Gittings et al. 1988), increase habitat complexity (Maragos, 1974; Gabrie et al., 1985), and has aesthetic value (Shinn, 1976).

Because corals displaced into sandy habitats by the grounding had higher tissue loss than other damaged colonies, transplantation programs should utilize these colonies. But survival of dislodged coral colonies on the reef surface is also threatened due to their instability (Hudson and Diaz, 1988). These dislodged corals could be re-secured by cementing them either in their original position or as transplants.

Coral reproductive strategies should be considered in decisions regarding transplantation. It probably would not be prudent to include most brooding species in a transplantation program. Some of these species recruit fairly rapidly in denuded habitats (Agaricia spp., F. fragum, Porites spp., and Pseudopterogorgia spp.), and recruits probably arise primarily from nearby adults.

Corals that should be considered for transplantation are those that form large, massive colonies, which on the Florida Reef Tract include M. annularis, M. cavernosa, D. strigosa, S. siderea, and possibly Acropora spp., among others. These corals generally broadcast gametes into the water column, where external fertilization takes place (Gittings et al., 1992), and dispersal is often over long distances (Szmant, 1986). Recruits are rarely observed, but survival of colonies, once a safe size is reached, can be high. As with other massive corals, these species are slow growing (except Acropora spp.). These characteristics make them good candidates for restoration programs.

It should be recognized, however, that even without transplantation, the relative abundance of these species in denuded areas at the WELLWOOD grounding site was comparable to control areas after only five years. They would, therefore, be expected to recover naturally to pre-impact age-class structure, but natural recovery time would be considerable. Transplantation of large colonies of broadcasting species offers the recovering community sexually reproductive individuals and, perhaps more importantly, provides the habitat complexity necessary for recovery of the full complement of reef invertebrates and fishes that characterize these diverse communities.

LITERATURE CITED

Bak, R.P.M. and M.S. Engel. 1979. Distribution, abundance, and survival of juvenile hermatypic corals (Scleractinia) and the importance of life history strategies in the parent coral community. Mar. Biol. 54:341-352.

Bright, T.J. and B.A. Andryszak. 1984. Coral population recovery following grounding of the freighter WELLWOOD on Molasses Reef, Key Largo National Marine Sanctuary I. Preliminary damage assessment and experimental design. Rept. of NOAA Office of Ocean and Coastal Resource Management, Sanctuary Programs Division. 35 pp.

Crisp, D.J. and J.S. Ryland. 1960. Influence of filming and surface texture on the settlement of marine organisms. Nature 185 (4706):119.

Curtis, C. 1985. Investigating reef recovery following freighter grounding in the Key Largo National Marine Sanctuary (Florida Keys, USA). Proc. 5th Int. Coral Reef Cong. 6:471-476.

Endean, R. and W. Stablum. 1973. The apparent extent of recovery of reefs of Australia's Great Barrier Reef devastated by the crown-of-thorns starfish (*Acanthaster planci*). Atoll Res. Bull. 168:1-26.

Gabrie, C., M. Porcher and M. Masson. 1985. Dredging in French Polynesian coral reefs: towards a general policy of resource exploitation and site development. Proc. Fifth Int. Coral Reef Symp. 4:271-277.

Gittings, S.R. 1988. The recovery process in a mechanically damaged coral reef community. Ph.D. Dissertation, Texas A&M University, Dept. of Oceanography, College Station, TX. 228 pp.

Gittings, S.R. 1991a. Coral reef destruction at the M/V ALEC OWEN MAITLAND grounding site, Key Largo National Marine Sanctuary. Rept. to U.S. Dept. of Justice, Torts Branch, Civil Division. Texas A&M Research Foundation Project No. 6795. 28 pp.

Gittings, S.R. 1991b. Reef coral destruction at the M/V ELPIS grounding site, Key Largo National Marine Sanctuary. Rept. to U.S. Dept. of Justice, Torts Branch, Civil Division. Texas A&M Research Foundation Project No. 6795. 28 pp.

Gittings, S.R. and T.J. Bright. 1988. The M/V WELLWOOD grounding: A sanctuary case study. The Science. Oceanus 31(1):35-41.

Gittings, S.R. and T.J. Bright. 1990. Coral recovery following grounding of the freighter M/V WELLWOOD on Molasses Reef, Key Largo National Marine Sanctuary. Report to NOAA Office of Ocean and Coastal Resource Management. Contract No. NA88AA-H-CZ037. 73 pp.

Gittings, S.R., T.J. Bright, and B.S. Holland. 1990. Five years of coral recovery following a freighter grounding in the Florida Keys. Proc: American Academy of Underwater Sciences, 10th Annual Symposium. pp. 89-105.

Gittings, S.R., T.J. Bright, A. Choi, and R.R. Barnett. 1988. The recovery process in a mechanically damaged coral reef community: recruitment and growth. Proc. 6th Int. Coral Reef Symp. 2:225-230.

Gittings, S.R., G.S. Boland, K.J.P. Deslarzes, C.L. Combs, B.S. Holland, and T.J. Bright. 1992. Mass spawning and reproductive viability of reef corals at the East Flower Garden Bank, northwest Gulf of Mexico. Bull. Mar. Sci. 51(3):420-428.

Hudson, J.H. and R. Diaz. 1988. Damage survey and restoration of M/V WELLWOOD grounding site, Molasses Reef, Key Largo National Marine Sanctuary, Florida. Proc. 6th Int. Coral Reef Symp. 2:231-236.

Maragos, J.E. 1974. Coral transplantation: a method to create, preserve, and manage coral reefs. Sea Grant Advisory Rep. UNIHI-SEAGRANT-AR-74-03 CORMAR-14. Univ. of Hawaii, Honolulu.

Pianka, E.R. 1970. On "r" and "K" selection. Am. Nat. 104:592-597.

Shinn, E.A. 1976. Coral reef recovery in Florida and the Persian Gulf. Env. Geol. 1:241-254.

Szmant, A.M. 1986. Reproductive ecology of Caribbean reef corals. Coral Reefs 5:43-54.

von Moorsel, G.W.N.M. 1983. Reproductive strategies in two closely related corals (*Agaricia*, Scleractinia). Mar. Ecol. Prog. Ser. 13:273-283.

Wulff, J.L. 1984. Sponge-mediated coral reef growth and rejuvenation. Coral Reefs 3:157-163.