Proceedings of the 6th International Coral Reef Symposium, Australia, 1988, Vol. 2

THE IMPACT OF A SHIP GROUNDING ON THE REEF FISH ASSEMBLAGE AT MOLASSES REEF, KEY LARGO NATIONAL MARINE SANCTUARY, FLORIDA

GEORGE D. DENNIS[1] and THOMAS J. BRIGHT[2]

[1]Dept of Marine Sciences, University of Puerto Rico, Mayagüez, PR USA 00709-5000
[2]Dept of Oceanography, Texas A&M University, College Station, TX, USA 77843

ABSTRACT

Reef fish recolonization of a coral reef area damaged by a ship grounding was monitored by diver visual census for two years (November 1984 to November 1986). During this time impacted and control areas tended to become more similar, though they still differed detectably in species composition, community structure, and biomass as late as two years after the grounding. These differences can be attributable to damage from the grounding and not just spatial variability, as control areas were never significantly different. Further recovery of the epifaunal assemblage and an increase in spatial complexity, especially in the severely impacted area, may be necessary for the reef fish assemblage to recover to pre-impact levels. This may take several more years based on epifauna recovery rates of corals and alcyonarians.

INTRODUCTION

The number of reef fish species and reef fish diversity are known to be directly related to substrate complexity in the form of vertical relief as well as number of interstices (Risk 1972, Luckhurst & Luckhurst 1978, Molles 1978, Talbot et al. 1978). Substrate rugosity plays an important role in determining shelter from predation, spawning sites, and foraging areas for reef fishes.

Although not as well documented, epifauna influence reef fish composition more subtly by providing additional shelter and a greater variety of food resources (Gladfelter & Gladfelter 1978, Carpenter et al. 1981, Bell & Galzin 1983). The occurrence of epifauna adds both structural complexity and food resources to any given reef area (Dahl 1973). Predominant reef epifaunal taxa such as corals, alcyonarians, and sponges are not themselves primary food sources for reef fishes, but provide special habitat for an array of crustaceans, mollusks, echinoderms and other invertebrates fed on by fishes. Thus epifauna enhance the quality of a reef area for fishes beyond just structural complexity alone.

The grounding of a ship can cause severe impact to a coral reef through mechanical damage from abrasion of the ship's hull on the bottom, subsequent break up of the ship, and discharge of cargo into surrounding waters. Ship groundings primarily cause a loss of substrate complexity by the crushing and compacting effect of the ship's hull. This damage is usually restricted in area. Debris swept about by surge may cause damage in a larger area than just the grounding site. If a ship grounding causes a reduction in the amount of vertical relief and number of interstices, this suggests there should be a concomitant reduction in reef fish diversity.

The 122-m freighter M/V WELLWOOD ran hard aground on Molasses Reef in the Key Largo National Marine Sanctuary on the night of 3 August 1984. The ship was finally refloated by offloading the cargo (chicken feed) and removed from the reef on 16 August 1984. As there was little loss of cargo into surrounding waters and the hull remained intact, the impact to the reef was restricted to physical abrasion. The grounding and subsequent removal of the ship from the reef caused substantial damage to both substrate and epifauna. Few studies have examined the impact of the ship wrecks on the coral reef community (e.g., Hatcher 1984), thus, this grounding, in an otherwise protected area, provided an excellent opportunity to study the impact of ship grounding on the reef fish assemblage.

Description of the Grounding Area

The grounding of the WELLWOOD occurred in the area most heavily utilized by sport divers in the Key Largo National Marine Sanctuary, approximately 0.5 km due east of the Molasses Reef lighthouse. Molasses Reef is a prominent shelf-edge feature of the Florida reef tract (Jaap 1985). The particular area of the grounding lies within the forereef face directly below the spur and groove formation, at depths of 6 to 11 m where there is a well-developed alcyonarian community. The area is relatively flat reef rock covered with alcyonarians and small coral colonies. This alcyonarian zone incurred the greatest damage from the grounding. Undisturbed areas to the west of the grounding site include a poorly developed *Acropora palmata* zone characteristic of Molasses Reef. No significant damage was incurred within the Palmata zone.

The impacted area can be divided into two subareas: (1), the forward section of the grounding area (Area BB, Figure 1) where the ship's hull "bulldozed" the reef substrate, reducing relief substantially and removing most epifauna; and (2) the stern area (Area BS, Figure 1), where the ship damaged only elevated coral heads, leaving the major structural element of the reef intact. Area BS was further impacted by the removal process as the propeller wash from the WELLWOOD selectively destroyed most erect alcyonarians (Gittings et al. 1988). Two nearby control areas were visually selected to match relief found in the impacted areas. Area XBE was selected as a control for BB as both had approximately similar, low relief substrate structure. The area XBW was selected for similarity to area BS. Preliminary sampling

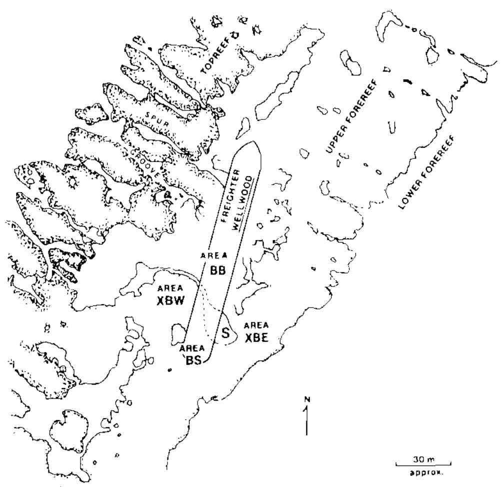


Figure 1. Map of the WELLWOOD grounding site and sampling areas. BB and BS are impacted areas; XBE and XBW are control areas.

within these two control areas indicated possible differences in reef fish abundance and community parameters. Four sampling areas were felt necessary to control natural among-area differences, as the impacted area lies along a transition zone between the two control areas. Control areas selected were at least 10 m away from the impacted area. This reduced the influence of ship damage while standardizing habitat and hydrographic conditions.

METHODS

Almost 3.5 hours of video recording were made by U.S. Department of Commerce National Oceanic and Atmospheric Administration (NOAA) of the grounding site in a haphazard manner while the ship was aground and immediately following its removal from the reef. These tapes were reviewed to ascertain initial effects of the grounding on the reef fish assemblage and also to qualitatively compare results of the grounded ship stage to the period immediately following ship removal. Within two weeks of the ship removal (27-29 August 1984), a site survey and preliminary damage assessment was carried out by the authors. Monthly surveys were carried out between November 1984 and November 1985 (Year 1) and quarterly until November 1986 (Year 2). Surveys were taken on the same moon phase (full moon) each month to reduce the effects of any lunar periodicity on fish activity.

A modified point-count census technique was used by diver to enumerate reef fishes present in the area impacted by the WELLWOOD grounding (Bohnsack and Bannerot 1986). An imaginary 6-m diameter cylinder with a 2-m off-bottom height was used as the sampling unit and represents the largest size feasible under visibility conditions and reef fish abundances encountered. Within this unit all species were identified to their lowest taxonomic level, enumerated, and assigned to one of three size categories: juvenile, intermediate, and adult. Counts were recorded on underwater paper. A single observer (senior author) collected all point-count census samples.

Each survey consisted of 24 point-count census replicates divided equally among the two impacted (BB and BS) and two control (XBW and XBE) sites (Figure 1). All census replicates were haphazardly placed within each area and were taken completely within each area such that the radius of the sampling area did not intersect the boundaries of the area, thus reducing the chance of an "edge" effect. In addition all replicates were restricted to hard bottom. The order in which the areas were to be sampled was randomly selected so as not to bias the census by conducting them in the same sequence each sampling period. All counts were carried out between the hours 0945 and 1530. The group of fishes censused by this method can be best described as the suprabenthic fish assemblage (Smith and Tyler 1973).

Average fish length within each size category was estimated using a ruler held at arm length. Average weight for each size category was calculated from estimated length and the appropriate length-weight relationships. Data on length-weight relationships of reef fishes were gathered from published sources. Biomass was estimated from the number of individuals multiplied by the average weight for each species size category.

The following community parameters were calculated and were used to determine differences between control and impacted areas: a) species richness, S (number of species), b) total abundance (number of individuals), c) Shannon-Wiener diversity index $H' = -\Sigma p_i \ln p_i$, d) Pielou's evenness (Pielou 1975) $J' = H'/\ln S$, and e) total biomass. The first year's sampling periods were analyzed for monthly trends, and both year's sampling periods were analyzed for quarterly trends. Sampling periods and areas were compared in a two-way ANOVA (5% significance level) (Sokal & Rohlf 1981). If interaction was not present then one-way ANOVA was carried out on each factor. Parameters were transformed to reduce the dependence of the variance on the mean and to make the error terms additive. Duncan's multiple range test was used to identify significant differences among sampling periods and areas (Snedecor & Cochran 1967). Abundances of the five most numerous species were analyzed by two-way ANOVA to determine significant differences among areas and sampling periods. In addition all species with more than 20 individuals were compared with a chi-square goodness of fit test for equal abundance among areas. The Bray-Curtis similarity coefficient was used to evaluate similarity among areas (Gauch 1983). Abundance data summed over each year were root-root transformed to form the Bray-Curtis similarity matrix. The unweighted paired group mean (UPGMA) clustering algorithm, using an agglomerative hierarchial strategy, was employed to form dendrograms depicting similarity among areas (Boesch 1977).

RESULTS

Based on video tape analysis, several species of fish exhibited unusually high abundance in the grounding area while the ship was aground. The initial sample taken on 6 August 1984 showed a large number of Haemulon aurolineatum associated with the stern section of the hull. This species was not observed in the impacted area during the next two years of sampling. In sand passages under the hull Lutjanus griseus aggregated. In general there were few species associated with the hull. By August 9th large numbers of Chromis multilineatus had become associated with the sides of the hull. On 10 August large schools of atherinids (Atherinomorus stipes) were first observed in association with the hull. This species is common at Molasses Reef Lighthouse about 0.5 km away but was not usually found over the forereef area where the grounding occurred. Two species that are typically abundant in the Palmata zone, Mulloidichthys martinicus and Haemulon chrysargyreum, were exceptionally abundant in the sand channels under the hull.

Once the ship was removed from the reef, major shifts occurred in reef fish abundance. Chromis multilineatus, H. aurolineatum, H. chrysargyreum, L. griseus, and atherinids disappeared from the grounding area (BB), while Stegastes partitus became the most abundant species. Few fish were observed in the impacted area once the ship was removed.

Community Parameters

Both months and areas showed highly significant differences (P<0.01) in number of taxa during the first year and the lack of interaction led to comparisons by months and areas. Four months had significant differences among areas. In both April 1985 and August 1985 area BB had significantly (P<0.01) fewer taxa than the other areas. In June-July 1985 and October 1985, area XBE showed a significant (P<0.05) lower number of taxa. Areas BS and XBW were never significantly different. In the quarterly analysis of both years there remained significant differences in both sampling periods and areas. In March 1986 XBE had a significantly lower number of taxa than area BS and was significantly lower than all other areas in November 1986. Area BB was significantly lower in taxa than areas XBW and BS in August 1986.

Reef fish abundance also showed significant differences in both months and areas. November 1984, April 1985, and May 1985 showed significantly lower abundance in area BB (P<0.05). Area XBE was significantly lower in June-July 1985. The quarterly analysis of abundance exhibited significant interaction; no further analysis was attempted. Major interaction is evident in November 1985 where area BS increased substantially while other areas decreased (Figure 2). A similar response in abundance can be found in August 1986 and November 1986. There is also an increasing trend in abundance from August 1985 to November 1986 in area BB.

Quarterly analysis of diversity showed significant differences in both sampling periods and areas. Area XBE was significantly lower in diversity than other areas in November 1984 and lower than BS and XBW in November 1986. Area BB was significantly lower than all other areas in August 1986 and lower than BS in November 1986. No significant differences were found among areas or months for evenness.

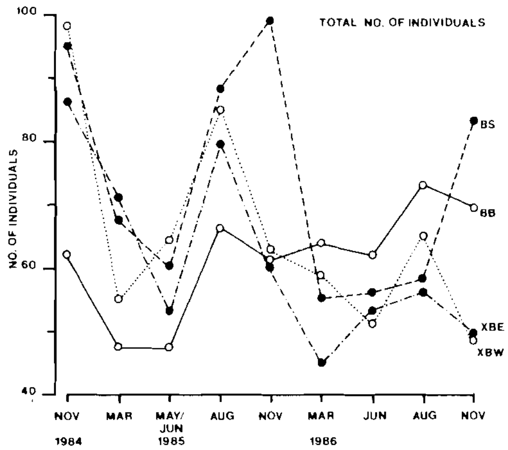


Figure 2. Quarterly mean abundance by area.

Total biomass had significant differences in both months and areas. Three months, May 1985, June-July 1985, and August 1985, exhibited significant differences in biomass among areas. In all three cases area BB was significantly lower in biomass. The second year's data also shows significantly lower biomass in area BB as late as August 1986. Total biomass averaged over all areas ranged from 412 to 1297 kg/ha ($\bar{X}$ = 722.7) on a monthly basis.

Individual Species

One hundred and fifty species were observed in the area of the grounding during two years of study. The top 20 species comprised 96.2% of the total number of individuals observed and the top ten species 87.4%. In general there were few differences in the rank order of abundant species among areas. The top five species overall, Stegastes partitus, Thalassoma bifasciatum, Sparisoma aurofrenatum, Halichoeres garnoti, and Acanthurus bahianus were analyzed by ANOVA to determine differences among areas. Of these, three, S. partitus, A. bahianus, and H. garnoti in particular showed effects of the grounding.

Stegastes partitus had highly significant differences among areas and months (P<0.01) but significant interaction precluded further analysis. A plot of the data suggests area BB to be lower in abundance during the first six months but thereafter area XBE was lowest (Figure 3). Quarterly analysis also has a significant interaction term. Area BB tended to continue increasing in abundance from March 1986 to August 1986 as other areas tended to decrease in abundance.

Acanthurus bahianus had both area and month differences in abundance. For the first three months (Nov. 1984 - Feb. 1985) area BB had significantly higher numbers of A. bahianus. By April 1985 area BB was not significantly different from at least one control area and by June-July 1985 no significant difference was detected among areas. In general, control areas had significantly fewer A. bahianus. Analysis by quarters shows

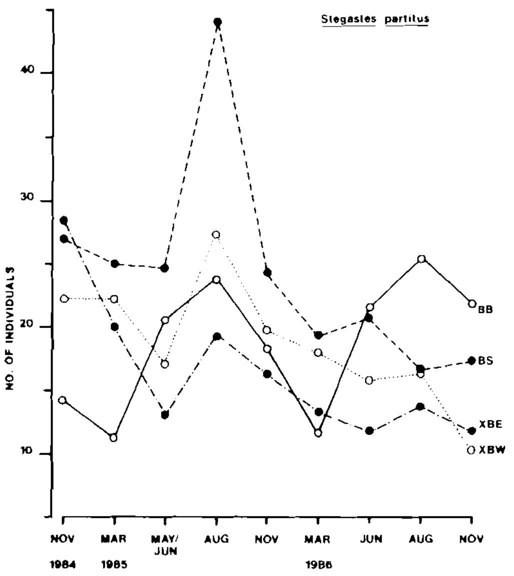


Figure 3. Quarterly mean abundance of S. partitus by area.

significant differences only among areas. Area BB has significantly higher numbers of A. bahianus than the other areas.

Halichoeres garnoti was significantly lower in abundance in the impacted areas and remained in lower abundance in area BS after two years.

The chi-square analysis of the remaining species showed that seven species were significantly more abundant in area BB and thirteen species were significantly less abundant (Table 1). Area BS possessed the greatest number of higher abundance species; nineteen species were significantly more abundant in BS than other areas (Table 1). Only three species were significantly less abundant in BS. Area XBW had six species that were significantly more abundant and three species were significantly less abundant (Table 1). Area XBE was characterized by only three species in greater abundance than other areas. XBE had the greatest number of species in significantly lower abundance than other areas (Table 1).

The analysis of similarity (Figure 4) showed that areas BS and XBW were the most similar while XBE was quite similar to XBW. Area BB was the least similar to the other three but not substantially so. During the second year area BB became even less similar to the other areas, whereas the other three areas became more similar to each other (Figure 4).

DISCUSSION

Video tape data of the ship aground provided useful insight into the initial effect of the grounding. The ship's hull provided an "artificial reef" effect at the site (sensu Klima & Wickham 1972) causing the aggregation of several species not typically found in the area. Haemulon aurolineatum, C. multilineatus, and atherinids were aggregated in the water column at the grounding area in direct response to the presence of the hull. Also, Lutjanus griseus, H. chrysargyreum, and M. martinicus made use of the new relief of the hull to congregate under the hull. After the ship was removed all these species were absent from the impacted area.

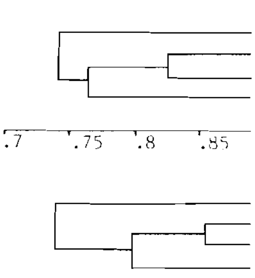
Initial colonization of the impacted area after removal of the ship was probably by planktivorous species such as S. partitus and T. bifasciatum which are mobile enough to have moved in from nearby undamaged areas. Similar initial colonization was observed by Gundermann and Popper (1975) in an area impacted by poisoning from a pesticide spill on a reef off Eilat (Red Sea).

By the time of the preliminary fish survey at Molasses Reef, two weeks after removal of the ship, herbivorous fishes had become abundant in the impacted area, due to the filamentous algal turf that had grown there. The development of a filamentous algal turf is a typical successional stage of disturbed reef areas (Glynn et al. 1964, Walsh, 1983) and was important in establishing the

Table 1. Species significantly more ↑ or less ↓ abundant than in other areas based on chi-square test of equal abundance among areas based on total abundance over two years from point-count census.

	IMPACT		CONTROL	
	BB	BS	XBE	XBW
Abudefduf saxatilis	0 ↓	47 ↑	1 ↓	32
Acanthurus coeruleus	53 ↓	121 ↑	56	89
Amblycirrhitus pinos	0	19 ↑	0	2
Canthigaster rostrata	4 ↓	81 ↑	28	56
Caranx ruber	14 ↓	34	52	105 ↑
Chromis cyaneus	21 ↓	190 ↑	78	62
Chromis multilineatus	0	26 ↑	0	0
Clepticus parrai	0 ↓	374 ↑	33 ↓	96
Haemulon chrysargyreum	0	20 ↑	0	3
Haemulon flavolineatum	28	99 ↑	9 ↓	50
Haemulon plumieri	6 ↓	19	54 ↑	9
Haemulon sciurus	1	19 ↑	3	5
Haemulon striatum	17	27	5 ↓	97 ↑
Halichoeres bivittatus	326 ↑	13 ↓	57 ↓	19
Halichoeres maculipinna	219	175 ↓	317 ↑	247
Halichoeres radiatus	26 ↑	8	1 ↓	7

	IMPACT		CONTROL	
	BB	BS	XBE	XBW
Holacanthus tricolor	6	33 ↑	11	15
Holocentrus rufus	5 ↓	13	0 ↓	47 ↑
Hypoplectrus gemma	4	27 ↑	6	9
Hypoplectrus unicolor	1	16	13	27 ↑
Malacanthus plumieri	31 ↑	2	1	0 ↓
Microspathodon chrysurus	0 ↓	50 ↑	4 ↓	15
Ocyurus chrysurus	35 ↓	41	46	115 ↑
Scarus spp. (juveniles)	157	161 ↑	72 ↓	101
Scarus croicensis	177 ↑	2 ↑	69 ↓	118
Scarus taeniopterus	11	25 ↑	0 ↓	15
Serranus baldwini	68 ↑	19	12	5 ↓
Sparisoma atomarium	38	8 ↓	50 ↑	17
Sparisoma viride	37 ↓	129 ↑	37 ↓	64
Stegastes diencaeus	3	38 ↑	1 ↓	6
Stegastes planifrons	3 ↓	68 ↑	2 ↓	29



YEAR I

AREA	BS	XBW	XBE
BB	.726	.766	.750
BS		.823	.726
XBW			.790
XBE			1.000

YEAR II

AREA	BS	XBW	XBE
BB	.722	.739	.744
BS		.852	.765
XBW			.838
XBE			1.000

Figure 4. Bray-Curtis among-area similarity matrix based on root-root transformed abundance data and UPGMA clustering.

initial dominance of herbivorous fish in the impacted area. Throughout the study there was an exceptional abundance of juvenile herbivores (e.g., *Scarus* spp. and *A. bahianus*) in the impacted area. Filamentous algae provide food resources not previously available to herbivorous fishes. In addition the low relief of the impacted area reduces the number of adult herbivores venturing into the area (Randall 1965) allowing the algal resources to be exploited by the juvenile stages.

The impacted area typically exhibited lower community parameter values than did control areas (i.e., number of taxa, abundance, and biomass). By the end of the first year, however, the impacted area, especially area BB, was more similar (i.e., fewer significant differences) to the control areas than at the beginning of the study. During several periods area BB was significantly lower in number of taxa and biomass than areas XBW and BS in the second year. As late as August 1986, two years after the grounding, significant differences remained in total biomass between area BB and the control areas. The lower biomass is a result of smaller size classes of fishes found in area BB. Marked seasonality in most community parameters must be taken into account before results from different times of the year can be compared. These results indicate that after two years the impacted area had recovered somewhat but not completely compared to control conditions. Although the control areas were visually different there were few significant differences in community parameters.

The most severely impacted area (BB) also had significantly fewer of the most abundant species, with only *A. bahianus* found in greater abundance than in other areas. A high number of juvenile *A. bahianus* in area BB accounts for the difference among areas. Area BB had several species unique to the area and attributable to the ship's damage. *Ioglossus calliurus*, *Malacanthus plumieri*, *Opistognathus aurifrons*, and *Opistognathus maxillosus*, all burrowing species, made use of habitat formed from the rubble generated during the ship grounding. *Halichoeres bivittatus*, a wrasse typical of rocky-rubble non-reef areas, was particularly abundant in area BB. This species was absent in the preliminary sampling period in August 1984 (after removal of the ship); it colonized the area in great numbers by November 1984 and remained the most common *Halichoeres* species in the impacted area throughout the remainder of the study.

Area BS possessed the greatest species richness due to its position abutting the Palmata zone. The cavernous relief of this area, developed from the cementing together of *Acropora palmata* rubble, formed habitat for several species unique to the area. The low number of living alcyonarians in area BS, an impact of the grounding, had no obvious effect on community parameters or species composition.

Area XBW derived some of its diversity from the presence of two large groups of coral heads (*Montastraea annularis*) in the sampling area. This particular coral head group was not included in any sampling, but drifting schools of fishes, such as *Lutjanus griseus*, *L. mahogoni*, *L. synagris*, and *Mulloidichthys martinicus* associated with them were sometimes encountered in the point-count census. Area XBW was also the site of numerous cleaning stations (both *Gobiosoma oceanops* and *Periclimenes pedersoni*, Peterson's cleaning shrimp), which increased the number of typically transient pelagic species, *C. ruber* and *O. chrysurus*, in the counts and also may have contributed to greater species richness in this area. These species waited near bottom for their turn at the cleaning stations making their inclusion in counts more common than in other areas. Cleaning stations tend to be areas of higher diversity due to the congregation of species awaiting cleaning. Cleaning behavior was used to explain the great variation in point diversity of reef fishes on Red Sea reefs (Slobodkin and Fishelson 1974).

Area XBE was chosen because of its similarity in relief to area BB (i.e., low flat relief) but tended to have an unusual assemblage of species. The low abundance of *Haemulon* spp. and *Scarus* spp. and greater abundance of *Sparisoma* spp. was particularly characteristic of this zone. The uniqueness of its assemblage may be ascribed to its separation from the Palmata zone. The relative lack of *A. saxatilis*, *M. chrysurus* and *S. planifrons*, species typical of the Palmata zone, most impressively illustrates this point.

Similarity comparisons of species composition using Bray-Curtis similarity and cluster analysis shows clearly that area BB is the least similar area among the four and that XBE was also dissimilar from XBW and BS. The same pattern of similarity was observed in both the first and second year's data. It would be expected that the impacted areas would become more similar to the control areas with time as recovery progressed. Interestingly area BB became more dissimilar to the other areas in the second year; while the other areas became more similar to each other. This suggests that whatever recovery took place in the second year did not increase the similarity of species composition in area BB in comparison to the controls. One potential cause for the decrease in similarity during the second year could be Hurricane Kate, which passed nearby in November 1985. The hurricane removed much of the rubble from area BB, thus destroying any recovery of epifauna to that point and disrupting the fish assemblage. Hurricanes are known to cause major disturbances to Caribbean reefs (Stoddart 1963, Glynn et al. 1964), but impacts on reef fish ranges from negligible (Springer & McErlean 1962, Glynn et al. 1964) to castastrophic (Robins 1957, Walsh 1983). In this case there was no major change in the reef fish assemblage, but hurricane damage may have slowed recovery.

Although severely impacted area BB was most similar to control area XBE, once completely recovered (or at least some type of equilibrum is reached) final species composition of area BB should be most similar to areas XBW and BS due to the fact that all three areas border on the Palmata zone and are greatly influenced by the species composition of that zone. Whether or not the impacted areas return to near their original conditions or an alternative stable state remains to be determined once the epifauna has fully recovered. This recovery may take several more years based on the recovery rate of corals and alcyonarians.

REFERENCES

Bell, J.D. & Galzin, R. 1984. Influence of live coral cover on coral-reef fish communities. Mar. Ecol. Prog. Ser. 15:265-274.

Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. EPA Publ. EPA-600/3-77-0033. 114 pp.

Bohnsack, J.A. & Bannerot, S.P. 1986. A stationary visual census technique of quantitatively assessing community structure of coral reef fishes. NOAA Tech. Rep. NMFS 41, 15 pp.

Carpenter, K.E., Miclat, R.I., Albaladejo, V.D., & Corpuz, V.T. 1981. The influence of substrate structure on the local abundance and diversity of Philippine reef fishes. Proc. 4th Inter. Coral Reef Symp. Manila, 2:497-502.

Dahl, A.L. 1973. Surface area in ecological analysis: quantification of benthic coral-reef algae. Mar. Biol. 23:239-249.

Gauch, H.G. 1982. Multivariate analysis in community ecology. Cambridge Univ. Press, Cambridge, 298 pp.

Gittings, S.R., Bright, T.J., Choi, A., & Barnett, R.R. 1988. The recovery process in a mechanically damaged coral reef community: Recruitment and growth. Proc. 6th Inter. Coral Reef Symp. Townsville, in press.

Gladfelter, W.B. & Gladfelter, E.H. 1978. Fish community structure as a function of habitat structure on West Indian patch reefs. Rev. Biol. Trop. 26(Suppl. 1):65-84.

Glynn, P.W., Almodovar, L.R., & Gonzalez, J.G. 1964. Effects of hurricane Edith on marine life in La Parguera, Puerto Rico. Carib. J. Sci. 4:335-345.

Gundermann, N. & Popper, D. 1975. Some aspects of recolonization of coral rocks in Eilat (Gulf of Aqaba) by fish populations after poisoning. Mar. Biol. 33:109-117.

Hatcher, B.G. 1984. A maritime accident provides evidence for alternative stable states in benthic communities on coral reefs. Coral Reefs 3:199-204.

Jaap, W.C. 1984. The ecology of the south Florida coral reefs: a community profile. U.S. Fish Wildl. Serv. FWS/OBS-82/08. 138 pp.

Klima, E.F. & Wickham, D.A. 1971. Attraction of coastal pelagic fishes with artificial structures. Trans. Amer. Fish. Soc. 100:86-99.

Luckhurst, B.E. & Luckhurst, K. 1978. Analysis of the influence of substrate variables on coral reef fish communities. Mar. Biol. 49:317-323.

Molles, M.C. 1978. Fish species on model and natural reef patches: experimental insular biogeography. Ecol. Monogr. 48:289-306.

Pielou, E.C. 1975. Ecological diversity. John Wiley, New York, 165 pp.

Randall, J.E. 1965. Grazing effects on seagrasses by herbivorous reef fishes in the West Indies. Ecology 46:255-260.

Risk, M.J. 1972. Fish diversity on a coral reef in the Virgin Islands. Atoll Res. Bull. 153:1-6.

Robins, C.R. 1957. Effects of storms on the shallow-water fish fauna of southern Florida with new records of fishes from Florida. Bull. Mar. Sci. Gulf Carib. 7:266-275.

Slobodkin, L.B. & Fishelson, L. 1974. The effect of the cleaner-fish Labroides dimidiatus on the point diversity of fishes on the reef front at Eilat. Amer. Nat. 108:369-376.

Smith, C.L. & Tyler, J.C. 1973. Population ecology of a Bahamian suprabenthic shore fish assemblage. Amer. Mus. Nov. No. 2528, 38pp.

Snedecor, G.W. & Cochran, W.G. 1967. Statistical methods. 6th ed. Iowa State Univ. Press, Ames, 593 pp.

Sokal, R.R. & Rohlf, F.J. 1981. Biometry. 2nd ed. W.H. Freeman & Co. San Francisco, 859 pp.

Springer, V.G. & McErlean, A.J. 1962. A study of the behavior of some tagged south Florida coral reef fishes. Amer. Midl. Nat. 67:386-397.

Stoddart, D.R. 1963. Effects of hurricane Hattie on the British Honduras reefs and cay, October 30-31, 1961. Atoll Res. Bull. 95:1-142.

Talbot, F.H., Russell, B.C., & Anderson, G.R.V. 1978. Coral reef fish communities: unstable high-diversity systems? Ecol. Monogr. 48:425-440.

Walsh, W.J. 1983. Stability of a coral reef fish community following a catastrophic storm. Coral Reefs 2:49-63.