BULLETIN OF MARINE SCIENCE, 69(2): 793–803, 2001

TEN YEARS AFTER THE CRIME: LASTING EFFECTS OF DAMAGE FROM A CRUISE SHIP ANCHOR ON A CORAL REEF IN ST. JOHN, U.S. VIRGIN ISLANDS

Caroline S. Rogers and Virginia H. Garrison

ABSTRACT

In October 1988, a cruise ship dropped its anchor on a coral reef in Virgin Islands National Park, St. John, creating a distinct scar roughly 128 m long and 3 m wide from a depth of 22 m to a depth of 6 m. The anchor pulverized coral colonies and smashed part of the reef framework. In April 1991, nine permanent quadrats (1 m^2) were established inside the scar over a depth range of 9 m to 12.5 m. At that time, average coral cover inside the scar was less than 1%. These quadrats were surveyed again in 1992, 1993, 1994, 1995 and 1998. Recruits of 19 coral species have been observed, with *Agaricia agaricites* and *Porites* spp. the most abundant. Quadrats surveyed outside the scar in June 1994 over the same depth range had a higher percent coral cover (mean = 7.4%, SD = 4.5) and greater average size (maximum length) of coral colonies than in quadrats inside the damaged area. Although coral recruits settle into the scar in high densities, live coral cover has not increased significantly in the last 10 yrs, reflecting poor survival and growth of newly settled corals. The relatively planar aspect of the scar may increase the vulnerability of the recruits to abrasion and mortality from shifting sediments. Ten years after the anchor damage occurred, live coral cover in the still-visible scar (mean = 2.6%, SD = 2.7) remains well below the cover found in the adjacent, undamaged reef.

Concern over deterioration of coral reefs from a variety of human activities is increasing. Although sedimentation and eutrophication represent the most pervasive chronic stresses to reefs in many locations, severe localized damage associated with cruise ships and other vessels is becoming more and more of a problem with the dramatic increases in ship-based tourism. Unfortunately, national parks and other marine protected areas established to protect coral reefs and other marine ecosystems often end up concentrating recreational uses because of the growing interest in scuba diving, 'eco-tourism', and boating.

Damage from anchors and vessels grounding on reefs now represents the most immediate threat to reefs in some locations, e.g., in the Florida Keys and U.S. Virgin Islands. Early published reports of reef destruction from anchors and groundings include those by Davis (1977), Gittings et al. (1988), S. H. Smith (1988) and S. R. Smith (1985).

In a 1985 survey, people from ten Caribbean islands (or island groups) out of a total of 26 reported anchor damage or boat groundings as causes of reef decline (Rogers, 1985). People from 20 islands out of this initial group of 26 responded to a follow-up questionnaire in 1996, and all of them listed boat damage as a problem on their reefs. Anchor damage was the most frequently cited cause of reef degradation overall (R. Dunsmore, pers. comm.)

Here we describe damage caused by a cruise ship anchor to a reef in Virgin Islands National Park in October 1988 and the failure of the anchor scar to recover after a decade. This case was the first involving vessel damage to a reef to go to court. It eventually settled out of court, and the cruise line was ordered to pay $350,000 to the U.S. Government.

Few long-term studies of coral recruitment following natural or human disturbances have been conducted (Hughes and Connell, 1999). To our knowledge, this is the longest study of recolonization following anchor damage on a Caribbean reef.

Materials and Methods

The location of this study was selected by the 120-m long cruise ship Windspirit on October 9, 1988, when it dropped an anchor weighing about 1 t on a coral reef north of St. John, within the boundaries of Virgin Islands National Park. The reef is a bank reef which rises from a depth of 22 m to 6 m. Corals and gorgonians are more abundant on the portion of the reef that slopes steeply into deeper water than on the more gradually sloping upper portions above 12 m. These shallower portions are representative of the predominant reef communities around St. John, gorgonian-dominated hard bottoms with limited stony coral development. At least 14 species of gorgonians and 21 species of sponges are found on this reef (Gladfelter, 1995). Few branching corals are present, and the most abundant coral species are *Agaricia agaricites* and *Montastraea cavernosa*. Water temperature measured with a Ryan Industries thermistor at 13 m ranged from 24.7–29.3ºC (from October 1990–October 1997).

The ship's anchor apparently bounced along in the deeper portion of the reef causing intermittent damage and then gouged out a linear track up to the shallower part of the reef. The anchor completely pulverized much of the coral that had been present, as evidenced by the plume of calcareous sediment visible at the surface off the ship's stern shortly after the anchor was dropped.

The U.S. Virgin Islands have been hit by several hurricanes during the course of our study; however, no conspicuous damage to corals from these storms was seen at or near the Windspirit anchor damage site. We saw no evidence of further damage from other anchors.

A variety of different methods was used to document the damage created by the anchor and to monitor the growth of organisms within the scar, with primary emphasis on detailed monitoring of organisms within permanent quadrats to assess recovery on a small scale. Soon after the incident, biologists dived on the site and observed that the anchor scar began at a depth of 21.6 m at the base of the reef slope and ended in about 9.1 m. The 128 m scar averaged about 3 m wide. No stabilization of loose coral heads or framework was attempted. Five days after the incident, a videotape was made of the scar and adjacent reef to further document the damage. A few preliminary quadrats (1 m^2) were surveyed to get estimates of cover inside and outside the scar**.** (These were deliberately placed in an effort to sample the existing variation in cover inside and outside the scar.) Coral cover near the scar over a depth range of 7.6–19.8 m varied greatly, ranging from 1.8 to 79.8% (mean = 24.6, SD = 26.4, n = 7) with the highest cover in the deeper reef. Coral cover within the scar, over a depth range of 9–19.8 m, varied from 0.7 to 3.9% (mean = 1.8, SD = 1.5, n = 4).

Monitoring of Cover and Coral Density.—Only the first 18 m of the 128 m scar were deeper than 12.5 m. We decided to monitor recolonization of the scar at the shallower depths (≤12.5 m) because this area was the most representative of the extensive anchor damage and because of safety considerations and time limitations for scuba diving in deeper water. Nine permanent 1 m^2 quadrats were established in April 1991 within the scar at depths of 9 to 12.5 m. Some quadrats were entirely scoured, while others contained corals or fragments of corals that escaped destruction or which had rolled into the scar. All coral species were identified to genus or species (when possible), and cover by corals, gorgonians, and sponges was recorded. (*Agaricia*, *Siderastrea*, and *Scolymia* species were lumped. Most of the *Agaricia* colonies were *A. agaricites*). The percent cover of these organisms plus algae and other substrate was subsequently recorded in June and December 1992, June 1993, June 1994, August 1995 and December 1998. When recording corals within the quadrats, all corals evident in planar view were listed. The observer also looked for corals that were obscured by macroalgae or growing on the edges (non-horizontal and vertical planes) of the substrate. Only corals (or portions of corals) in planar view were used to estimate coral cover, but all corals were totaled for density calculations (number of corals m^{-2}). Each quadrat within the scar took 45 to over

90 min to survey. In June/July 1994, we also surveyed cover and coral density within 27 1-m^2 quadrats outside the scar at depths of 8 to 12.5 m.

LIMITATIONS OF THE QUADRAT METHOD.—Efforts were made to carefully record all visible components within each quadrat, including sand, rubble, coralline algae, and dead coral with turf algae growing on it. In practice, it is sometimes difficult to differentiate among some of these—e.g., while a piece of coral rubble which appeared to be bare would clearly be recorded as 'rubble', a piece of coral which had some turf algae intermixed with coralline algae could not readily be assigned to any one category. Another difficulty is that macroscopic algae or other organisms can mask small coral recruits. Macroscopic algal cover is very variable. Macroalgae are usually found growing on sand or on areas otherwise occupied by algal turf. We found the on-site determination of benthic reef components far superior to attempts to document quadrat cover using close-up photography because of the small size of most of the recruits (many only a few millimeters across) and the overgrowth of macroalgae (see also Edmunds et al., 1998). It is also more difficult to differentiate among the more problematic substrate categories with photographs than when making observations in situ. Neither in situ quadrats or photoquadrats adequately represent gorgonian corals.

CORAL COLONY MEASUREMENTS.—Starting in June 1994, maximum lengths of all coral colonies within quadrats inside the scar were measured during each sampling period to provide data on size frequency distributions over time. Measurements of all colonies in quadrats sampled outside the scar in June 1994 were compared to those inside the scar both in June 1994 and in December 1998, the last sampling period.

SPATIAL RELIEF (RUGOSITY).—The topographical relief (rugosity) of the undisturbed reef adjacent to the scar was estimated in April and August 1995. For each measurement, a 10 m tape was extended across the bottom and then a lightweight chain was positioned under the tape and conformed to the substrate. The ratio of the length of chain to the length of tape gave an estimate of topographical relief. Rugosity measurements were also taken inside the scar in August 1995. All inside and outside rugosity measurements were made over a depth range of 9 to 12.5 m, corresponding to the depths of the permanent quadrats.

STATISTICAL ANALYSES

CHANGES IN PERCENT COVER OF CORALS AND OTHER ORGANISMS OVER TIME—Frequently scientists have used ANOVA to analyze data from permanent transects or quadrats surveyed over time. According to some statisticians, such analyses are not strictly appropriate when sampling units have been selected haphazardly rather than randomly. Consequently, a general linear mixed model was used to analyze the data. The mixed model assumed (1) coral cover varied with sampling period with no directionality, and (2) coral cover varied randomly among quadrats.

COMPARISON OF CORAL COVER, COLONY DENSITY AND COLONY SIZES OUTSIDE AND INSIDE THE SCAR.—Randomization testing (Manly, 1991) was used to test whether colony density within the scar changed over time and if the coral cover within quadrats outside the scar in June 1994 differed from quadrats within the scar for June 1994 and for December 1998. Randomization testing measures the 'strength of evidence' against the null hypothesis (e.g., cover inside and outside the scar is the same) and indicates how likely it is that chance explains the pattern observed in the data.

To test whether the distribution of maximum coral lengths differed between the disturbed and undisturbed areas, the non-parametric Kruskal-Wallis rank sum test was used (Zar, 1984).

RESULTS

COVER AND CORAL DENSITY.—Over the course of the study, average coral cover ranged from 1.0% (SD = 0.9) to 2.6% (SD = 2.7) within the permanent quadrats (Fig. 1). The inference from the statistical model used to test the 63 observations on the nine perma-

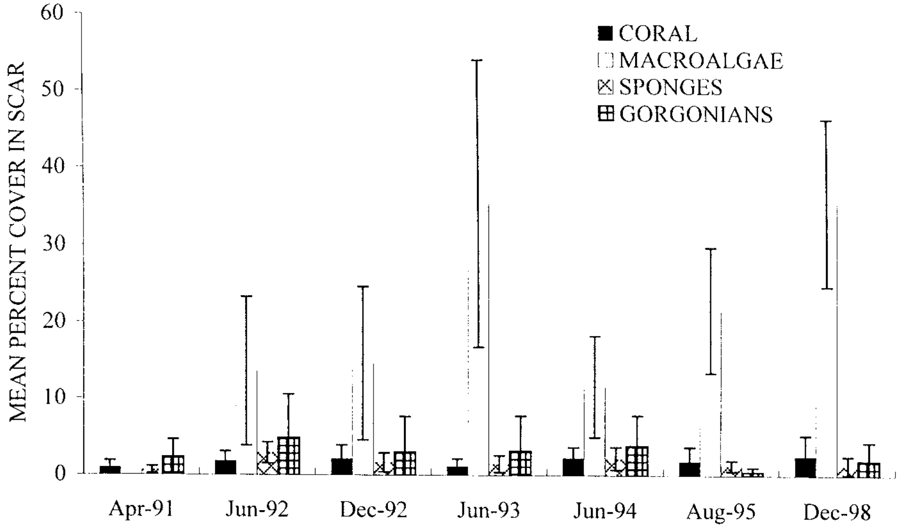

Figure 1. Mean percent cover of coral, gorgonians, sponges and macroalgae in quadrats inside the WINDSPIRIT scar for all sampling periods. Error bars represent standard deviation.

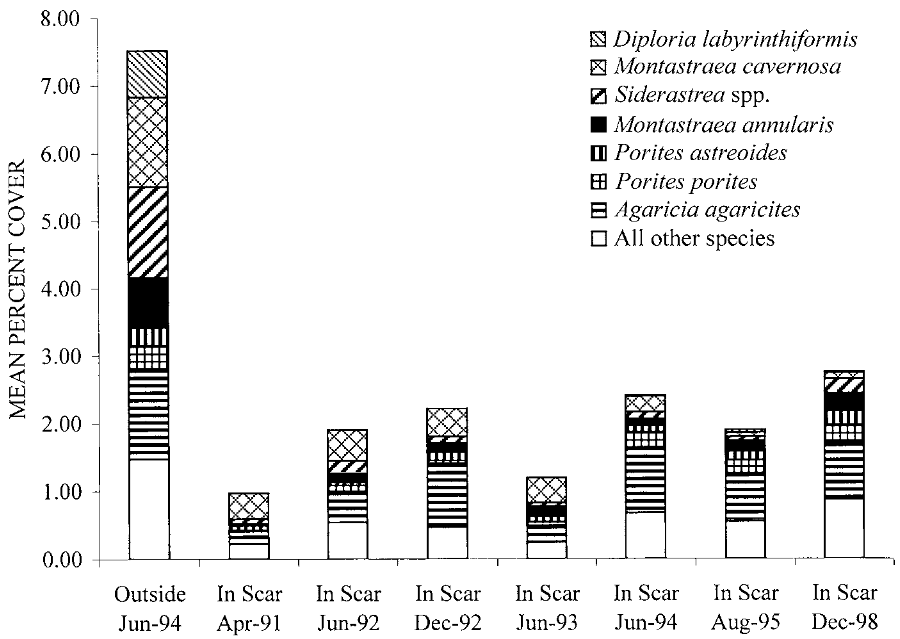

Figure 2. Mean percent cover of coral species in quadrats inside the WINDSPIRIT scar for all sampling periods and outside the scar in June 1994. Only coral species with a cover of ≥0.25% in at least one of the sampling periods are shown individually.

nent quadrats is that there was no trend in coral cover within the scar. The estimate of slope was nearly equal to standard error in the linear regression model, indicating no trend.

Agaricia spp. were the most abundant in terms of both cover (Fig. 2) and density (reaching a maximum of 16.3 ± 20.7 colonies m^{-2}). The only coral species which made up greater than 1% of the cover within a quadrat for any given survey period were *Agaricia* spp., *Montastraea annularis*, *Stephanocoenia michelinii, Siderastrea* spp., *Porites astreoides*, and *M. cavernosa* (a single colony which was partially damaged by the anchor).

The number of coral species inside the scar for each sampling period ranged from 12 to 19. Twenty-five coral species (scleractinians and *Millepora* spp.) were found outside the scar and 24 inside over the course of the study, with the following species absent from the scar but present in low abundance on the adjacent reef: *Diploria clivosa*, *Dendrogyra cylindrus*, *Mycetophyllia ferox* (Table 1).

Algae, both turf and macroscopic species (primarily *Dictyota* spp.), consistently made up the largest component in each permanent quadrat. Average macroalgae cover (mostly

Table 1. Stony coral species found outside and inside the anchor scar created by the cruise ship WINDSPIRIT, St. John, U.S. Virgin Islands.

Coral Species	Outside Scar	Inside Scar
Order Scleractinia		
Stephanocoenia michelinii	X	X
Madracis decactis	X	X
M. mirabilis	X	X
Acropora cervicornis		X
Agaricia agaricites	X	X
Leptoseris cucullata	X	X
Siderastrea spp.	X	X
Porites astreoides	X	X
P. divaricata		X
P. porites	X	X
Favia fragum	X	X
Diploria clivosa	X	
D. labyrinthiformis	X	X
D. strigosa	X	X
Colpophyllia natans	X	X
Montastraea annularis	X	X
M. cavernosa	X	X
Meandrina meandrites	X	X
Dichocoenia stokesi	X	X
Dendrogyra cylindrus	X	
Mussa angulosa	X	X
Scolymia spp.	X	X
Isophyllia sinuosa	X	X
Mycetophyllia ferox	X	
Eusmilia fastigiata	X	X
Order Milleporina		
Millepora alcicornis	X	X
Millepora squarrosa	X	X

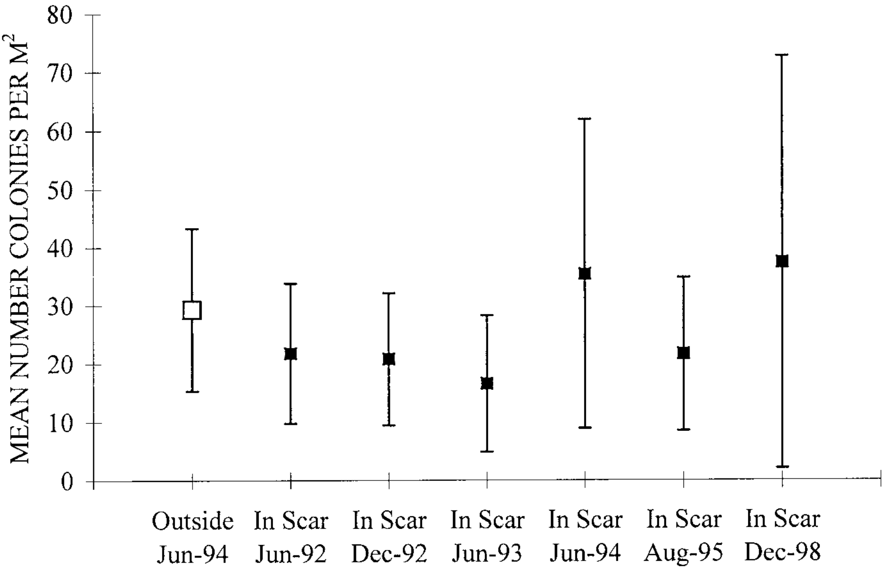

Figure 3. Mean number of coral colonies m^{-2} in quadrats inside the WINDSPIRIT scar for all sampling periods and outside the scar in June 1994. Error bars represent standard deviation.

the brown algae *Dictyota* spp.) ranged from 11.7% (SD = 6.7) to 35.6% (SD = 10.8) (Fig. 1). Mean cover by coralline algae, often difficult to separate from other categories (see Materials and Methods above), ranged from 5 to 29%, with a mean of 15 (SD = 10). Although coralline algae are known to facilitate settlement by *Agaricia* spp. (Morse et al., 1988), there was no apparent correlation between cover by *Agaricia* spp. and coralline algae.

The mean cover by sponges ranged from 0.7% (SD = 0.5) to 2.9% (SD = 1.4). Gorgonian cover ranged from 0.5% (SD = 0.6) to 4.9% (SD = 5.7) (Fig. 1).The mean cover of sand (calcareous sediments) ranged from 7.2% (SD = 8.4) to 15.6% (SD = 15.9). Within individual quadrats, sand cover ranged from nearly zero to over 50%.

The density of coral colonies varied from 16.6 (SD =11.7) to 37.4 (SD = 35.4). Mean density of coral colonies within the scar was highest in 1994 and 1998, but variability in density among quadrats was high, and there was no statistically significant change in density over time (estimated significance level mean difference = 0.1296; F-ratio: 0.2262) (Fig. 3).

Comparison of quadrats surveyed outside the scar in June 1994 with quadrats inside the scar over all time periods showed that outside quadrats had a higher percent coral cover 7.4 (SD = 4.5) (Fig. 2). In addition, these quadrats had a greater average size (maximum length) of corals (6.8 cm, SD = 10.8) than quadrats sampled inside the scar in June 1994, August 1995, and December 1998 (Fig. 4). However, the mean density of coral colonies outside the scar (29.3 m^{-2}, SD = 14.0) fell within the range reported for the inside quadrats (Fig. 3). Coral cover within the scar was significantly less than outside the scar, with the strength of evidence against the null hypothesis (coral cover inside = coral cover outside) (Table 2).

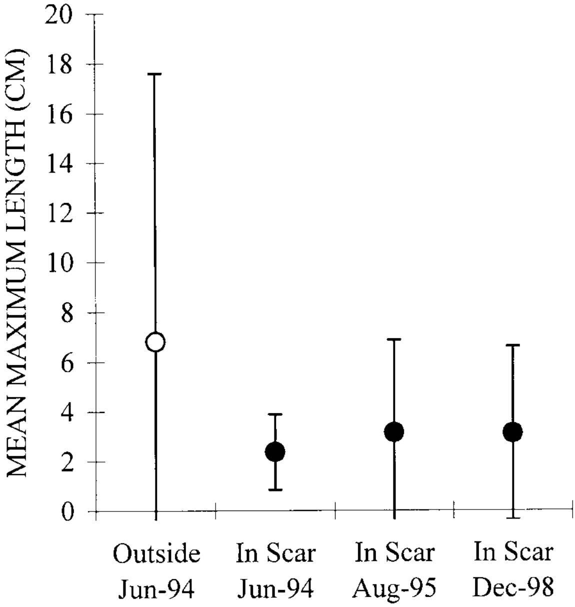

Figure 4. Mean maximum length of coral colonies in quadrats inside the WINDSPIRIT scar in June 1994, August 1995, and December 1998, and outside the scar in June 1994. Error bars represent standard deviation.

Table 2. Estimated significance level of mean difference and F-ratio from randomization testing of coral cover outside and inside the WINDSPIRIT scar.

Period	Estimated significance level	Estimated significance level
	Mean difference	F-ratio
1994	0.0002	0.0055
1998	0.0001	0.0075

Frequency distribution of the maximum length of coral colonies differed significantly between inside (June 1994 and December 1998) and outside scar locations (Table 3). Size frequency distributions for quadrats in the scar (in June 1994, August 1995, and December 1998) and for quadrats outside are plotted as mean number of colonies of each maximum length vs maximum length of each coral colony in Figure 5.

Rugosity (spatial relief) outside the scar ranged from 1.1 to 3.1 with an average of 1.8 (SD = 0.6, n = 16). Inside the scar, spatial relief ranged from 1.3 to 1.5, with an average of 1.4 (SD = 0.1, n = 6).

Table 3. Kruskal-Wallis rank sum test statistics for coral colony maximum length distribution inside and outside the WINDSPIRIT scar.

Period	Kruskal-Wallis test Statistic	P
1994	131.8	<0.001
1998	85.7	<0.001

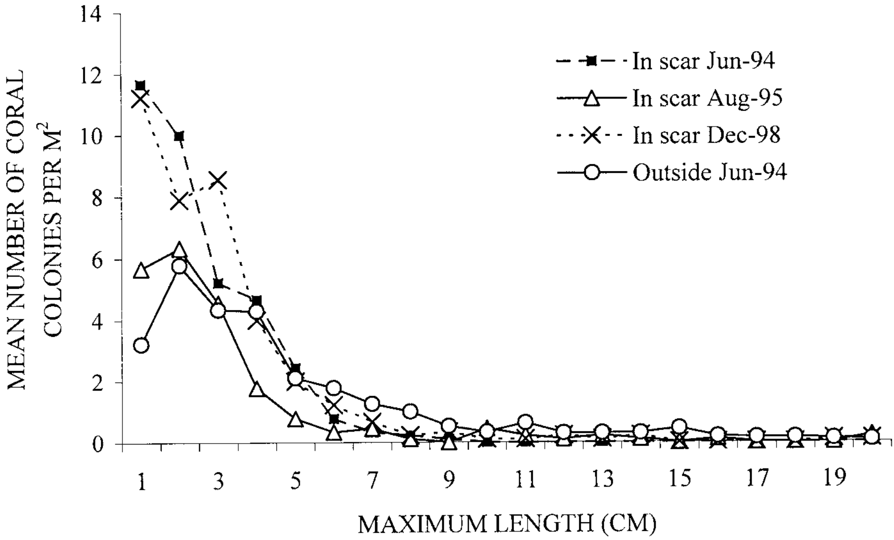

Figure 5. Size frequency distribution (maximum length vs mean number of colonies of each maximum length) in quadrats inside the WINDSPIRIT scar for June 1994, August 1995, and December 1998 and for outside the scar in June 1994.

DISCUSSION

The anchor scar created by the cruise ship WINDSPIRIT in October 1988 is still visible, over 10 yrs later. Detailed surveys within permanent quadrats inside the scar show no consistent increase in coral cover or shift to larger coral colony size categories over time. No trends in sponge or gorgonian cover were detected.

Overall, *A. agaricites* was the most abundant species in terms of cover and density inside the scar. *A. agaricites* is usually the most abundant species to settle on settling plates and within natural quadrats on Caribbean and western Atlantic reefs (e.g., Birkeland, 1977; Bak and Engel, 1979; Smith, 1997.) Given the high densities of recruits within the anchor scar, most of which were *A. agaricites*, and the growth rate of this species [reported as up to 2.4 to 2.5 cm yr^{-1} by Bak, 1976 and Hughes and Jackson, 1985] we would have expected an increase in coral cover within the scar 10 yrs after the anchor damage occurred.

The results of our study differ in some respects from that of Smith (1992) who examined recolonization in quadrats within an area heavily damaged when a freighter grounded on a reef in Bermuda. Eight years after the grounding, Smith (1992) found that the most abundant coral recruits were not *Agaricia* spp., but another brooding species, *P. astreoides*. In addition, a shift to larger size classes occurred in this species over a 3 yr period.

The density of coral colonies within the scar is similar to that found for juvenile corals on undisturbed substrate within quadrats at the same depth (9 m) at Salt River Canyon, St. Croix (13 m^{-2} on the East Wall of the submerged canyon, 33 m^{-2} on the West Wall) (Rogers et al., 1984). However, only corals less than 4 cm in diameter were included in the St. Croix counts and less space was available for settlement because adult corals and other reef organisms were more abundant than in the WINDSPIRIT scar. Edmunds et al. (1998) found recruits (<5 cm diameter) present in densities of 4.9 m^{-2} at 10 m in Lameshur Bay, off the south coast of St. John, lower than the densities found in the anchor scar, but they were examining recruitment onto undisturbed reef areas with less space available for settlement.

Why has no significant recovery occurred at the WINDSPIRIT anchor scar? Coral larvae appear to be settling in sufficient numbers, but they are not surviving and growing. We believe a combination of low habitat complexity, unconsolidated rubble and sediment, and high macroalgal cover are responsible. The cruise ship anchor changed the framework of the reef off St. John, by gouging through the structure, rather than just overturning large coral heads or scraping coral tissue off coral colonies. The resulting nearly horizontal surface and unstable substrate within the scar, with less relief than on the adjacent undisturbed reef, probably offer the worst conditions for settlement and survival of coral colonies. Coral recruits that settle may be smothered or abraded by macroalgae and sediments, both of which at least periodically covered large portions of the quadrats. Gittings et al. (1988) showed that coral recruitment was higher in less impacted areas than in totally devastated areas of the scar created by the freighter WELLWOOD when it ran aground on a reef in Key Largo National Marine Sanctuary, Florida. They suggested that loose sediments and the decrease in spatial relief of the bottom were responsible. In the St. Croix recruitment study described above (Rogers et al., 1984), over half of the juvenile corals which settled on plates at 9 m settled on vertical surfaces, which are less exposed to sediments. Of the corals that settled on horizontal plates, all but one (out of a total of 24) settled on the undersurface. Birkeland (1977) found a similar pattern for recruits settling on cement blocks at a depth of 9 m in the San Blas Islands, Panama. Hughes (1985) found that *A. agaricites* and *Leptoseris cucullata* which accounted for 90% of the larval recruitment in Jamaica at depths of 10 and 20 m showed high mortality over the course of a 6-yr study. Mortality was especially high after growth of macroalgae following the die-off of the long-spined black sea urchin *Diadema antillarum*.

CONCLUSIONS

Increasing numbers of large cruise ships are visiting Caribbean islands, and anchor damage to coral reefs will continue to be a significant concern. Although many of the stresses that are causing degradation of coral reefs worldwide appear to be beyond our control, we do have the ability to reduce physical destruction from careless operation of boats and ships. What have we learned from the failure of the WINDSPIRIT anchor scar to recover after a decade? We must increase awareness of the effects of boats and ships on coral reefs and improve the management of vessel movements near reefs. We also need to consider effective ways of responding once the damage has occurred. In recent studies, rapid stabilization of the damaged area and sediment removal have been shown to be effective (e.g., Jaap and Morelock, 1998). In some cases, transplantation of coral colonies into damaged locations and stabilization of large fragments of reef framework dislodged by anchors or groundings may be warranted. In cases where stabilization or restoration are not appropriate, financial compensation should be used to decrease the likelihood of further reef damage, for example through the installation of navigational aids. Coral reefs are already under assault from an unprecedented combination of human and natural stresses, and every effort must be made to reduce the severe and often irreversible consequences of careless and negligent vessel operation.

Acknowledgments

Special thanks to L. McLain who notified park law enforcement rangers after noticing the plume created by the anchor of the cruise ship Windspirit when it crushed corals inside Virgin Islands National Park and who, with S. Baker, took careful measurements of the scar. Other biologists working for the National Park Service who conducted fieldwork at the site include C. Tobias, A. Friedlander, G. Beretta and R. Grober-Dunsmore. U.S. Geological Survey employees who surveyed quadrats at the site, in addition to the authors, include J. Miller, E. Link and R. Waara. J. Beets and N. Wolff helped to survey quadrats outside the scar. U.S. Geological Survey employee R. Dorazio dragged us through the statistics. We are grateful to all of these individuals who showed great patience and perseverance throughout the study. Thanks also to three almost anonymous reviewers (including W. Jaap) for their helpful suggestions for improvement.

Literature Cited

Bak, R. P. M. 1976. The growth of coral colonies and the importance of crustose coralline algae and burrowing sponges in relation with carbonate accumulation. Netherlands J. Sea Res. 10: 285–337.

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

Birkeland, C. 1977. The importance of rate of biomass accumulation in early successional stages of benthic communities to the survival of coral recruits. Proc. 3rd Int'l. Coral Reef Symp 1: 15–21.

Davis, G. E. 1977. Anchor damage to a coral reef on the coast of Florida. Biol. Conserv. 11: 29–34.

Edmunds, P. J., R. B. Aronson, D. W. Swanson, D. R. Levitan and W. J. Precht. 1998. Photographic versus visual census techniques for the quantification of juvenile corals. Bull. Mar. Sci. 62: 937–946.

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'l. Coral Reef Symp. 2: 225–230.

Gladfelter, W. B. 1995. Assessment of sponge and gorgonian community structure in anchor-damaged reef after seven years, Francis Bay, St. John, USVI. Report to the National Park Service. 11 p.

Hughes, T. P. 1985. Population dynamics and life histories of early successional corals. Proc. 5th Int'l. Coral Reef Congress 2: 101–106.

___________ and J. H. Connell. 1999. Multiple stressors on coral reefs: a long-term perspective. Limnol. Oceanogr. 44: 932–940.

___________ and J. B. C. Jackson. 1985. Populations dynamics and life histories of foliaceous corals. Ecol. Monogr. 55: 141–166

Jaap, W. C. and J. Morelock. 1998. Soto's reef restoration project. Georgetown, Grand Cayman Island, British West Indies. Tech. rpt. submitted to Holland American Line-Westours and Dept. Environment, Cayman Islands. 16 p. plus figures.

Manly, B. J. F. 1991. Randomization and Monte Carlo methods in biology. Chapman and Hall, London.

Morse, D. E., N. Hooker, A. N. C. Morse and R. A. Jensen. 1988. Control of larval metamorphosis and recruitment in sympatric agariciid corals. J. Exp. Mar. Biol. Ecol. 116: 193–217.

Rogers, C. S. 1985. Degradation of Caribbean and western Atlantic coral reefs and decline of associated fisheries. Proc. 5th Int'l. Coral Reef Symp. 6: 491–496.

Rogers, C. S., H. C. Fitz III, M. Gilnack, J. Beets and J. Hardin. 1984. Scleractinian coral recruitment patterns at Salt River Submarine Canyon, St. Croix, U.S. Virgin Islands. Coral Reefs 3: 69–76.

Smith, S. H. 1988. Cruise ships: a serious threat to coral reefs and associated organisms. Ocean Shoreline Manage. 11: 231–248.

Smith, S. R. 1985. Reef damage and recovery after ship groundings on Bermuda. Proc. 5th Int'l. Coral Reef Symp. 6: 497–502.

_________. 1992. Patterns of coral recruitment and post-settlement mortality on Bermuda's reefs: comparisons to Caribbean and Pacific reefs. Am. Zool. 32: 663–673.

_________. 1997. Patterns of coral settlement, recruitment and juvenile mortality with depth at Conch Reef, Florida. Proc. 8th Int'l. Coral Reef Symp. 2: 1197–1202.

Zar, J. H. 1984. Biostatistical analysis, 2nd ed. Prentice Hall, New Jersey. 718 p.

ADDRESSES: (C.S.R.) *U.S. Geological Survey, Biological Resources Division, Caribbean Field Station, P.O. Box 710, St. John, U.S. Virgin Islands 00830. E-mail: <caroline_rogers@usgs.gov>.* (V.H.G.) *U.S. Geological Survey, Biological Resources Division, Caribbean Field Station, P.O. Box 710, St. John, U.S. Virgin Islands 00830. E-mail: <ginger_garrison @usgs.gov>.*