

**Figure 1.** AGRRA survey sites at San Salvador Island, Bahamas.

**ASSESSMENT OF CORAL REEFS OFF SAN SALVADOR ISLAND, BAHAMAS  
(STONY CORALS, ALGAE AND FISH POPULATIONS)**

BY

PAULETTE M. PECKOL,<sup>1</sup> H. ALLEN CURRAN,<sup>2</sup> BENJAMIN J. GREENSTEIN,<sup>3</sup>  
EMILY Y. FLOYD,<sup>4</sup> and MARTHA L. ROBBART<sup>1,5</sup>

**ABSTRACT**

During assessments at 11 shallow reef sites on San Salvador Island, Bahamas in June 1998 we found low prevalence of disease, bleaching, and recent partial-colony mortality among stony corals (10 cm minimum diameter). Old partial-colony mortality was >50% in *Acropora palmata*; however, recent tissue losses were low and it had recruits at several sites. Total (recent + old) partial-colony mortality of the *Montastraea annularis* species complex exceeded 30% on leeward patch reefs and back reefs. Groupers (serranids), snappers (lutjanids), and grunts (haemulids) were rare. Parrotfishes (scarids) were uncommon at most sites and surgeonfishes (acanthurids) were the dominant herbivores. Macroalgae, particularly browns that are seldom grazed by surgeonfishes, were the dominant algal functional group. The green macroalga *Microdictyon marinum* was extremely abundant and overgrowing *Porites porites* on leeward patch reefs. To facilitate their conservation, San Salvador Island's reef resources should be designated as a marine reserve.

**INTRODUCTION**

The condition of coral reefs worldwide is in decline (Wilkinson, 2000) and the reefs of the greater Caribbean region have emerged as one area of particular concern (Ginsburg, 1994). Reductions in coral cover and diversity, with concomitant increases in macroalgal abundances in the Western Atlantic, have been related to the well-documented mass mortality of the herbivorous sea urchin *Diadema antillarum*

---

<sup>1</sup>Department of Biological Sciences, Smith College, Northampton, MA 01063.  
Email: ppeckol@email.smith.edu

<sup>2</sup>Department of Geology, Smith College, Northampton, MA 01063.  
Email: acurran@email.smith.edu

<sup>3</sup> Department of Geology, Cornell College, Mt. Vernon, IA 52314.  
Email: bgreenstein@cornell-iowa.edu

<sup>4</sup> Department of Biology, San Diego State University, San Diego, CA 92182.

<sup>5</sup> Caribbean Coral Reef Ecosystem Program, Smithsonian Institution, Washington, DC 20560.

(Lessios, 1988; Hughes et al., 1999), to increases in coral diseases (Bruckner and Bruckner, 1997; Santavy and Peters, 1997), to overfishing (Hughes, 1994; Koslow et al., 1994), and to widespread elevated sea surface temperatures resulting in coral bleaching (Brown, 1997; Wilkinson et al., 1999). While the greatest degradation of Caribbean reefs is associated with large human populations (Hughes, 1994; Causey et al., 2000), fewer studies document the condition of coral reefs in areas experiencing less human disturbance as has been until quite recently the case off San Salvador, Bahamas.

San Salvador Island (24°N, 74°30'W), located 600 km ESE of Miami on an isolated carbonate platform (Fig. 1), is bordered by a narrow shelf with an abrupt shelf-edge break leading to a very steep slope. Marine water quality is excellent with deep water close offshore and no immediate sources of concentrated pollutants. Its eastern and southeastern coasts typically are windward to the prevailing trade winds. A well-developed, *Acropora palmata*-dominated, bank-barrier reef lies off the northern coast and smaller bank-barrier reefs occur along the southeast and southern coasts. Hundreds of small patch reefs dot the island's eastern shelf; larger patch reefs occur in the broad coastal embayments on the leeward western shelf.

Relatively little has been published on the ecological health and short-term changes to San Salvador's coral reefs. Curran et al. (1994) assessed stony coral cover and diversity at two leeward patch reefs between 1984 and 1992. At Telephone Pole Reef, rapidly growing colonies of *Porites porites* were replacing dead and broken branches of *Acropora cervicornis* which had been a spatial dominant until decimated by white-band disease (Aronson and Precht, 1997) during the early 1980s. During the same interval, the percent of live stony coral cover on nearby Snapshot Reef exhibited no significant change; however, there was an overall increase in the sizes of monitored coral heads and noticeably less macroalgae than seen at present. Similarly, Meyer et al. (1991) reported slight increases in the population densities of two species of the crinoid *Nemaster* residing in large colonies of the *Montastraea annularis* species complex at Snapshot Reef. More recently, stony coral cover, seaward of Snapshot Reef at the 10 m CARICOMP monitoring site, experienced a slight decline and macroalgae had a twofold increase between 1994 and 1998 (Woodley et al., 1997, 2000; Gerace et al., 1998).

In the Bahamas, the major commercial fishery is the spiny lobster, *Panulirus argus*, followed by snappers and groupers. Reports of overfishing are widespread (Woodley et al., 2000). The queen conch (*Strombus gigas*) provides another important, but smaller-scale (usually subsistence level), fishery although densities are declining (Stoner, 1996). Fishing regulations now prohibit the taking of nonlipped queen conch and the use of scuba gear for any kind of fishing. However, few data exist regarding the status of the marine fisheries off San Salvador Island.

Until recently San Salvador has experienced little pressure from human activities. Now the island is rapidly becoming a more popular tourist destination with impetus from the opening of a large Club Med in October 1992 and recent expansion of airport facilities, including extension of the runway to permit landing of intercontinental jet aircraft. Currently, several dive boats operate primarily off the western (leeward) coast bringing up to 200 snorkel and scuba divers per day to the reefs (Kevin Collin, personal communication). With San Salvador in a state of flux with respect to human impact, the Atlantic and Gulf Rapid Reef Assessment (AGRRA) surveys reported here provide an

important baseline for the current condition of San Salvador's coral reefs as well as the status of its finfish populations.

## METHODS

Our assessment of reef-building corals, algae, and fish populations was focused on three areas of San Salvador Island (Fig. 1). Three shallow (1-4 m) fore-reef sites on the exposed northern bank-barrier at Gaulin's Reef have low (<3 m) spur formations extending seaward from the reef crest to a carbonate pavement dominated by sea fans and *Millepora* spp. (*Acropora palmata* is the dominant coral of the reef crest.) Three sites at 2-8 m on the Gaulin's back reef are characterized by large (1-4 m tall) colonies of the *Montastraea annularis* complex along with *Millepora* spp. and *A. palmata*. Three leeward patch reefs in Fernandez Bay (Snapshot, Telephone Pole, Lindsay) are each in water depths of 3-7 m. Snapshot Reef (~200 m offshore) consists of an aggregation of individual coral colonies dominated by the *M. annularis* complex. Telephone Pole Reef (~250 m offshore) is dominated by large colonies of the *M. annularis* complex interspersed with *Porites porites* growing on dead *A. cervicornis*. Lindsay Reef extends out from a sandy beach and experiences a relatively high sediment load. Two windward patch reefs, at depths of approximately 3-5 m and shoreward of a well-developed reef crest in French Bay, are dominated by dead *A. palmata* and *Agaricia agaricites*. These 11 survey sites were selected to be representative of the majority of reef types and exposure conditions occurring off San Salvador. We also considered Telephone Pole and Snapshot Reefs to be "strategic sites" because of earlier survey data (Curran et al., 1994) and their popularity as tourist dive sites.

Stony coral and algal populations were assayed during June 1998 by five-six divers/survey. AGRRA Version 1 benthic protocols (see Appendix One, this volume) were used with the following modifications: stony corals  $\geq 10$  cm in diameter were included in the surveys; coral diameter and height were measured to the nearest cm for smaller corals (10-25 cm in diameter) and to the nearest 5 cm for larger (>25 cm) colonies. The *Montastraea annularis* complex was treated as a single species. Sediment deposits in the algal quadrats were removed by hand before estimating the abundance of crustose coralline algae. *Diadema antillarum*, being rare, was not counted. Training sessions were conducted with all divers censusing "practice" transects at the leeward patch reefs; species identifications, percent cover estimates, and coral disease and bleaching assessments were compared to ensure sampling consistency. We used Humann's (1993) reef coral guide for most coral species identifications.

A stationary visual census technique (Bohnsack and Bannerot, 1986) was employed by two divers to survey the fish populations. All sampling occurred between 10:00 a.m. and 3:00 p.m. At each sampling point, all species belonging to eight families (Acanthuridae, Chaetodontidae, Haemulidae, Labridae, Lutjanidae, Pomacentridae, Scaridae, Serranidae) observed in five minutes within a 7.5 m radius cylinder were recorded. Each census was begun three minutes after laying a measuring tape on the substratum by counting all individuals of all species observed in the pre-set radius within the initial field of view. New sectors of fields of view were then scanned by rotating in one direction. Abundances of species moving in schools were taken when first observed

in the sampling cylinder (it was important to count fishes moving in schools immediately because they were unlikely to remain in the sampling area). When very large schools were present it was sometimes necessary to estimate numbers in 10s or 50s. Fish lengths were estimated in cm using a T-shaped tool marked every 5 cm to help avoid underwater magnification problems (Bohnsack and Bannerot, 1986). We recorded the number of individuals, plus the minimum, maximum, and mean estimated lengths for each of the eight fish families. We used Humann's (1994) reef fish guide for species identifications. Littler and Littler (2000) was later consulted for macroalgae.

As time permitted on the leeward patch reefs, two divers measured herbivorous fish grazing rates following the AGRRA methodology given in Appendix One. All grazing rate measurements were made between 10:00 a.m. and 2:00 p.m. during the peak time for grazing activity (Lewis, 1986).

## RESULTS

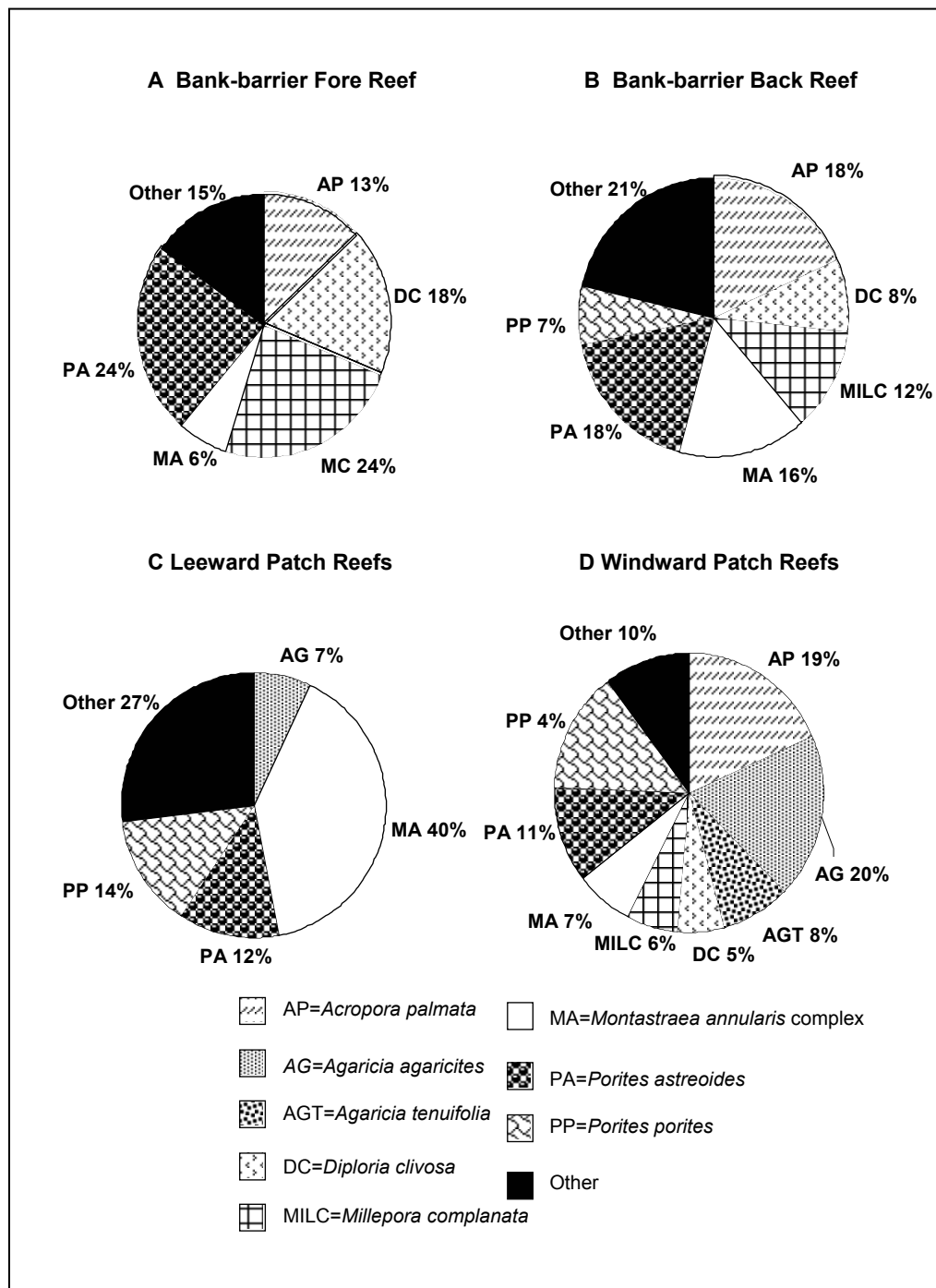
### Stony Corals

*Species composition.* At each site, we censused at least 10 transects with each transect sampling ~9-12 stony corals that were  $\geq 10$  cm in diameter (Table 1). In terms of numerical abundance, *Acropora palmata* was fairly important (means of 13-19%) along the Gaulin's bank-barrier reef and on the windward patch reefs at French Bay (Fig. 2A, B,D). While  $>50\%$  of the upper surfaces of the *A. palmata* colonies were long dead (means for the six Gaulin's sites ranged from 42-78%; mean of 65% at French Bay), very little ( $<2\%$ ) recent partial mortality of colony surfaces (hereafter recent mortality) was evident for this species.

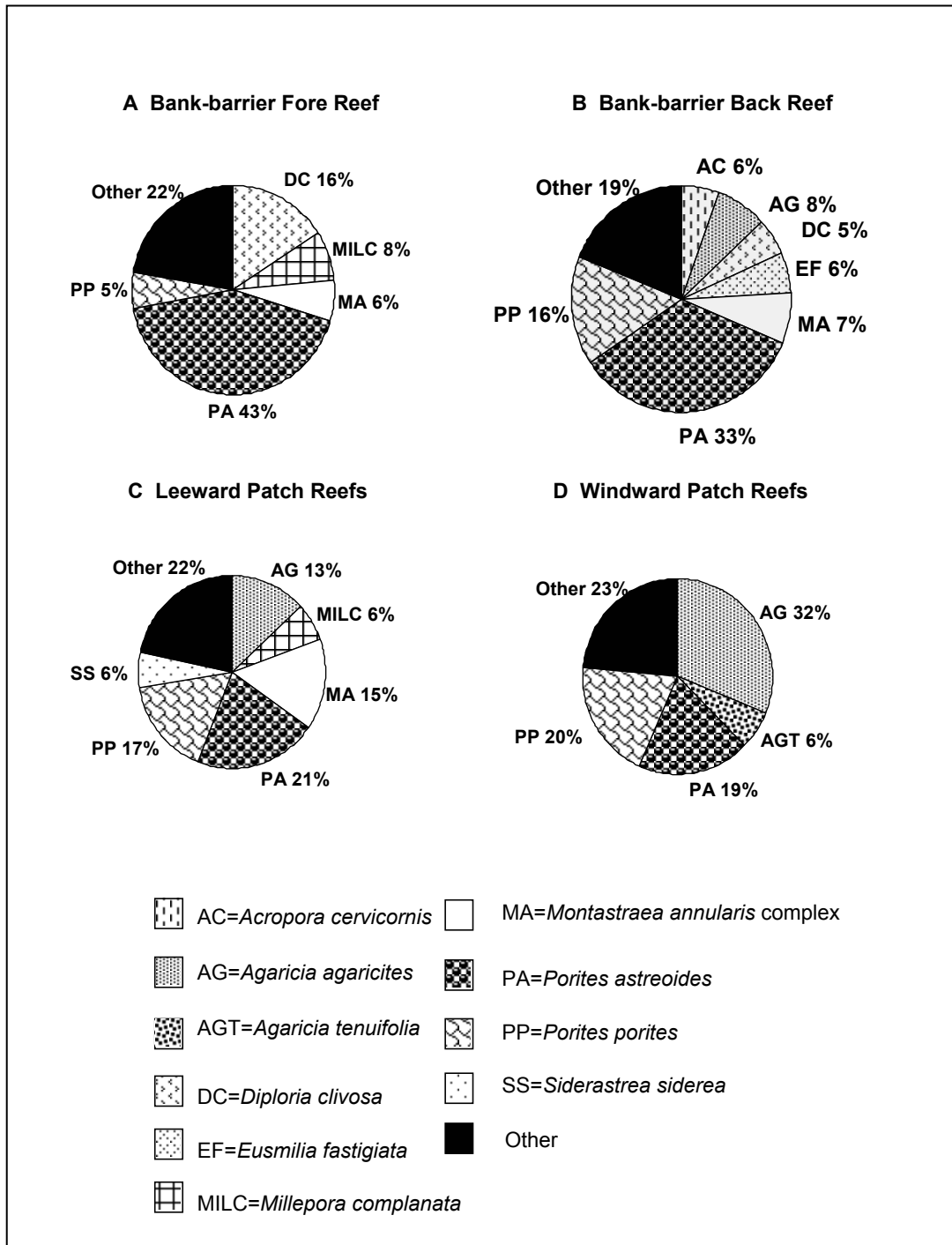
The *Montastraea annularis* complex dominated (mean 40% of all colonies) the leeward patch reefs in Fernandez Bay (Fig. 2C). Recent mortality here was fairly low ( $<4\%$  of their upper surfaces), while nearly 40% (range 30-48% for three leeward patch reefs) of the corresponding surfaces were long dead. The *Montastraea annularis* complex and *Diploria clivosa* together contributed about 25% of the colonies in Gaulin's back reef (Fig. 2B). Approximately 35% of the upper surfaces of colonies of *M. annularis* complex on the back reef were long dead.

*Millepora complanata*, which forms extensive thickets on the spurs, contributed nearly a quarter (24%) to the total abundance of stony corals at Gaulin's fore reef (Fig. 2A). Colonies of *Agaricia* spp. were important on the windward patch reefs and *Porites* spp. were numerically abundant at most sites (Fig. 2).

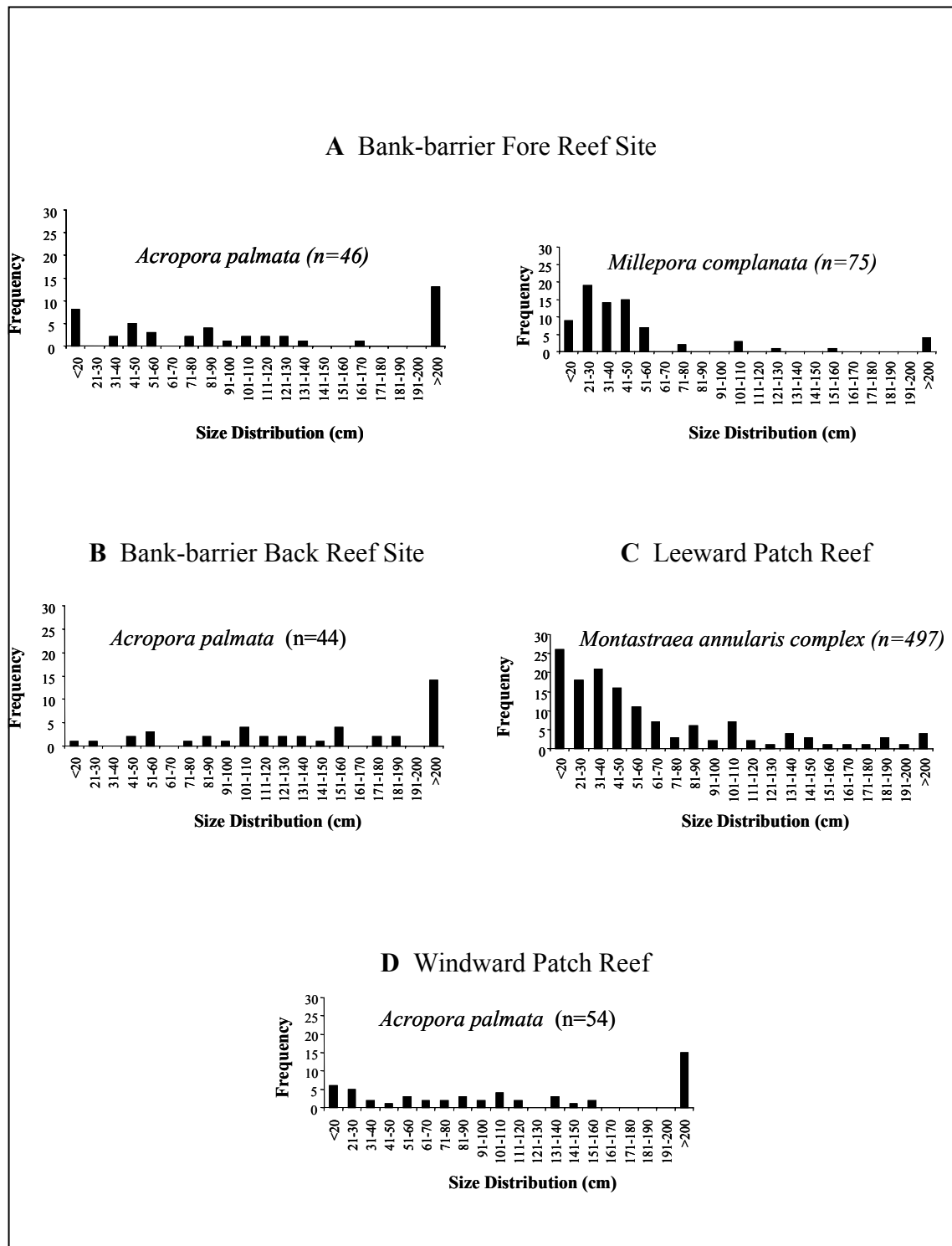
*Recruits.* The composition of recruits (Fig. 3) was largely dominated by *Porites astreoides* (especially on the bank-barrier reef), *P. porites* (all patch reefs, Gaulin's back reef) and *Agaricia agaricites* (especially on windward patch reefs). Collectively, poritids and agariciids contributed 45-70% of the recruit densities. Although 15% of the recruits were of the *Montastraea annularis* complex on the leeward patch reefs and accounted for  $<10\%$  of the recruits on the bank-barrier reef, none were found on the windward patch reefs. At all four habitat types, *Acropora palmata* represented  $<5\%$  of the recruits.



**Figure 2.** Species composition and mean relative abundance of the most abundant stony corals ( $\geq 10$  cm diameter) at (A) bank-barrier fore reef ( $n=319$ ), (B) bank-barrier back reef ( $n=232$ ), (C) leeward patch reefs ( $n=344$ ), (D) windward patch reefs ( $n=249$ ), off San Salvador Island, Bahamas. Other category = combined coral species, each with  $<5\%$  abundance of occurrence.

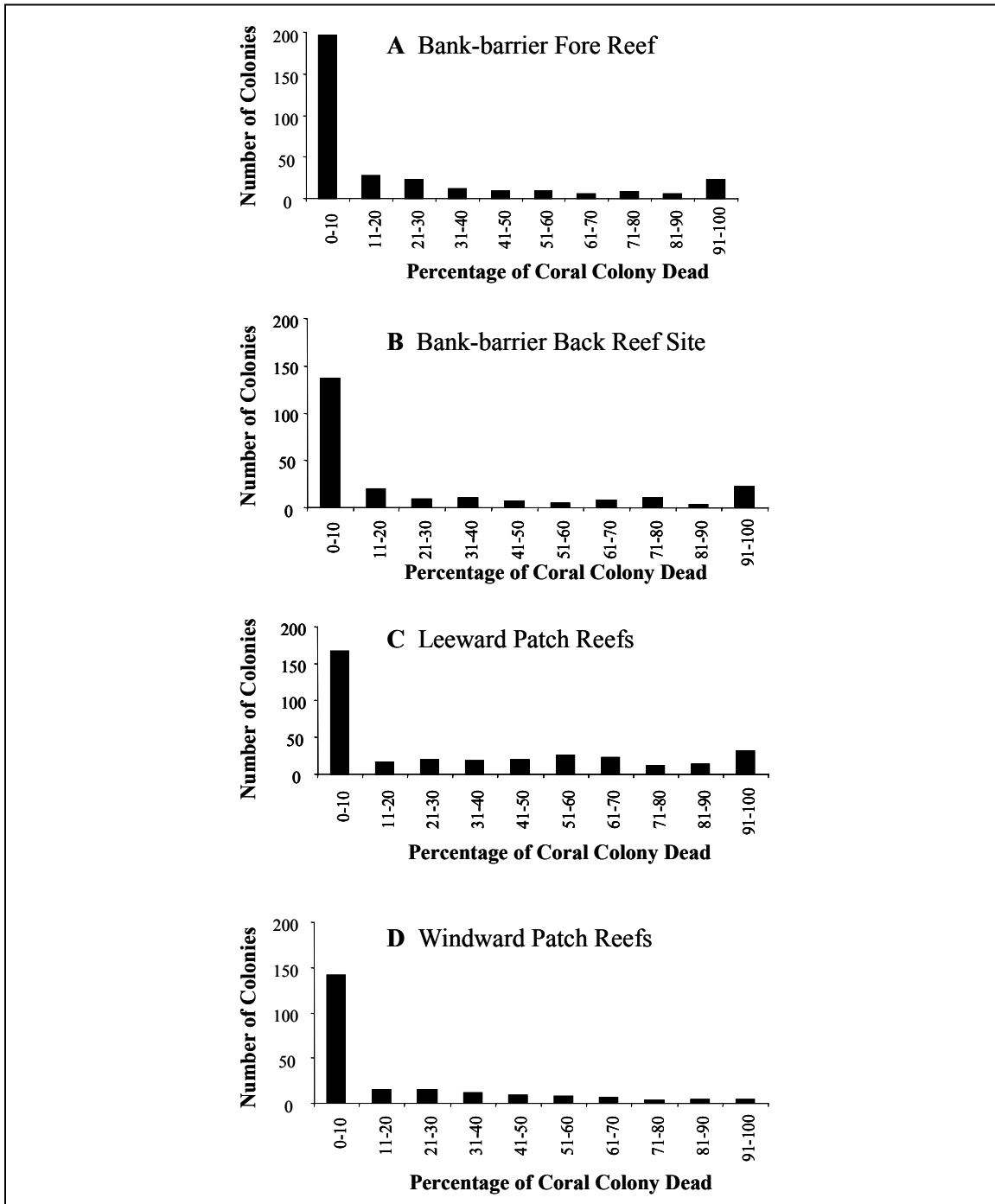


**Figure 3.** Species composition and mean relative abundance of all stony coral recruits ( $\leq 2$  cm diameter) at (A) bank-barrier fore reef (n=64), (B) bank-barrier back reef (n=52), (C) leeward patch reefs (n=96), (D) windward patch reefs (n=65), off San Salvador Island, Bahamas.

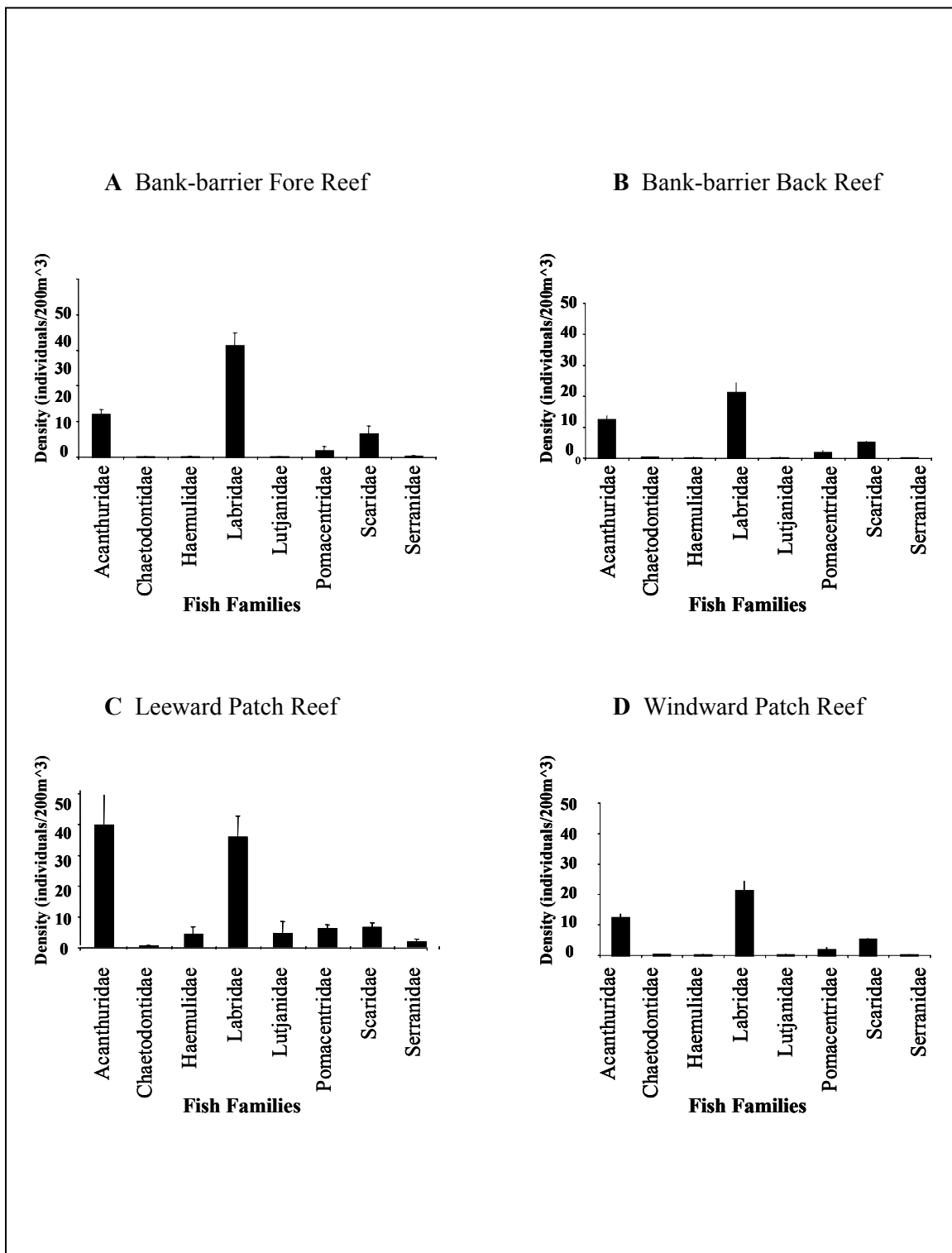


**Figure 4.** Size-frequency distribution as % of dominant stony corals ( $\geq 10$  cm diameter) at (A) bank-barrier fore reef, (B) bank-barrier back reef, (C) leeward patch reefs, (D) windward patch reefs, off San Salvador Island, Bahamas.





**Figure 5.** Frequency distribution of total (recent + old) partial colony mortality of all stony corals ( $\geq 10$  cm diameter) at (A) bank-barrier fore reef, (B) bank-barrier back reef, (C) leeward patch reefs, (D) windward patch reefs, off San Salvador Island, Bahamas.



**Figure 6.** Mean fish abundance (no. individuals/200 m<sup>3</sup>) at (A) bank-barrier fore reef, (B) bank-barrier back reef, (C) leeward patch reefs, (D) windward patch reefs, off San Salvador Island, Bahamas.

*Coral size.* The mean size of surveyed corals ( $\geq 10$  cm in diameter) ranged from 21 cm (at Lindsay Reef) to 85 cm (at Gaulin's A). However, mean colony sizes were remarkably similar among habitat types ranging from ~40 cm on the leeward patch reefs to ~53 cm in the bank-barrier back reef (Table 2). Size-frequency distributions of the major reef-building stony corals at each habitat type are shown in Figure 4. Wherever *Acorpora palmata* occurred a high proportion of colonies were very large ( $>200$  cm), emphasizing its importance as a major frame-builder. *Millepora complanata* also showed a relatively broad size range with colonies of  $<20$  cm to  $>200$  cm in diameter at the bank-barrier fore reef. While the *Montastraea annularis* complex only exceeded 100 cm in diameter on the leeward patch reefs, its massive growth forms provided substantial relief at most sites.

*Coral condition.* We observed evidence of coral disease in 2% or less of the censused colonies at most (8/11) sites (Table 2). Signs of disease were higher at one windward (3%) and two of the leeward patch reefs (4% at Telephone Pole; 8% at Snapshot). The coral diseases observed were black-band disease and yellow-blotch disease (both mainly on the *M. annularis* complex) and white-band disease (on *A. palmata*). The percentage of colonies that were bleached was low in all habitat types (from 1.3% in Fernandez Bay to 2.6% in Gaulin's fore and back reefs). Recent mortality was also very low at most sites (Table 2). The higher percentages of recent mortality at Snapshot (4%) and Telephone Pole (4.7%) were largely associated with the *Montastraea annularis* complex and *Porites porites*, respectively. The decline of *P. porites* was due in large part to overgrowth by the macroalga *Microdictyon marinum* and crustose coralline algae.

Although old partial-colony mortality (hereafter old mortality) exceeded 30% at three sites (Gaulin's back reef A, Snapshot, Telephone Pole), it largely was confined to the locally dominant coral species (Table 2). Total (recent + old) partial-colony mortality (hereafter total mortality) was lowest overall in the bank-barrier fore reef (~20%) and highest at Snapshot (~35%, where total mortality of the *M. annularis* complex was nearly 55%), Gaulin's A (~38%, where *A. palmata* and the *M. annularis* complex together contributed 65% of the colonies measured) and Telephone Pole (~42%, with *P. porites* exhibiting about 44% total mortality).

Because recent mortality was never greater than 5% of the upper surface of coral colonies, we plotted frequency distributions of total mortality for the four reef habitat types (Fig. 5A-D). In all areas the vast majority of corals had  $<10\%$  total mortality. However, there was a clear signature (~5-10% of stony corals measured) of colonies showing  $>90\%$  total mortality at all sites except the windward patch reefs.

## Algae

Macroalgae dominated the benthic algae in three habitats (Gaulin's fore and back reefs, leeward patch reefs) and was the predominant component of the algal assemblages at all but three sites (Table 3). On leeward patch reefs, where their abundance was highest (about 50 to 70%), the fleshy green *Microdictyon marinum* was the dominant species. For example, at Telephone Pole Reef it commonly was completely overgrowing *Porites porites* resulting in total colony mortality. Elsewhere, brown algae, including *Dictyota*

*divaricata*, *D. bartayresii*, *Lobophora variegata*, *Padina sanctae-crucis*, *Turbinaria turbinata* and *Styopodium zonale*, predominated. Green calcareous *Halimeda* spp. were extremely rare at all reef sites. Mean macroalgal height was generally lowest (~2 cm) at the windward sites (fore reef and patch reefs) but reached nearly 3 cm at Telephone Pole Reef. Mean macroalgal indices (absolute abundance of macroalgae x macroalgal height) varied from about 43 on the windward patch reefs to 150 on the leeward patches. Turf algae were more abundant at two sites (Gaulin's fore reef 1, French Bay 2) while crustose coralline algae were predominant at only a single site (French Bay 1).

## Fishes

Mean fish densities (Table 1) were highest at the leeward patch reefs, ranging from ~50 (Lindsay Reef) to 177 individuals/ 200 m<sup>3</sup> (Snapshot Reef). Fish abundances were relatively similar at the other sites varying between ~43 (windward patch reefs and bank-barrier back reef) and 53 individuals /200 m<sup>3</sup> (bank-barrier fore reef).

All reef habitats showed a dominance of wrasses (Labridae) and surgeonfishes (Acanthuridae) which collectively represented 76% of the total fish abundance on the leeward and windward patch reefs and over 90% on the bank-barrier reefs (Fig. 6A-D). Parrotfish (Scaridae) densities were low at all sites except Lindsay Reef where acanthurids were scarce (Table 4), yet the highest abundances of surgeonfishes occurred at the two other leeward patch reefs (Snapshot and Telephone Pole).

Groupers and other seabasses (Serranidae), snappers (Lutjanidae) and grunts (Haemulidae) were absent altogether on the Gaulin's back reef, present in extremely low densities on the Gaulin's fore reef and the windward patch reefs, and slightly more abundant on the leeward patch reefs (Fig. 6; Table 4). Considered together, these three families represented ~12% of total abundance in the eight censused fish families at Snapshot and Telephone Pole Reefs.

The size-frequency distributions for two major guilds (herbivores–parrotfishes, surgeonfishes, the yellowtail damselfish *Microspathodon chrysurus*; carnivores–grouper, snapper) at each of the four reef types are shown in Figure 7. Notably, no groupers or snappers were censused on the bank-barrier back-reef. Relatively low abundances of carnivores elsewhere make length comparisons among sites difficult. For all reef types, 40-50% of the herbivores fell within the 11-20 cm length category; generally, <10% were larger than 20 cm.

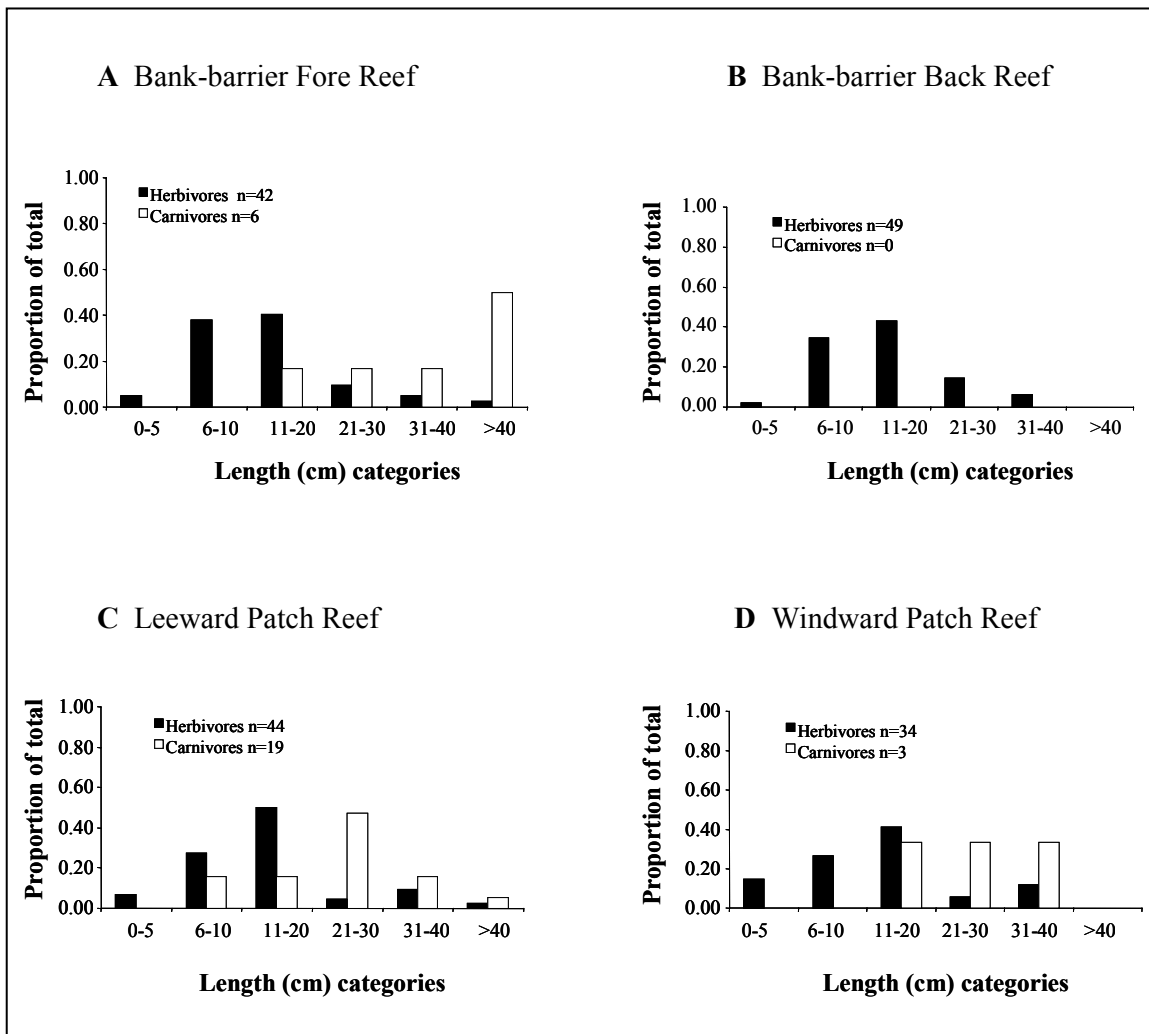
We found no relationship between herbivorous fish density and macroalgal index (Fig. 8). Grazing rates were nearly identical at Telephone Pole (mean=3.1 bites/minute, se =0.9, n=8) and Snapshot (3.5 bites/minute, se=1.1, n=12) Reefs, respectively. The grazing rate at Lindsay Reef was nearly three times those values (mean=11.1bites/minute, se=0.4, n=5). Ninety percent of the grazing at Lindsay Reef was due to parrotfishes, whereas surgeonfishes were the dominant herbivores at the other two patch reefs.

## DISCUSSION

The stony corals at 11 evaluated sites of the reef system off San Salvador Island, Bahamas, are in reasonably good condition. Total (recent + old) partial-colony mortality

of upper surfaces (colonies  $\geq 10$  cm diameter) ranged from 15-42% and was particularly low ( $\sim 20\%$ ) on the bank-barrier fore reef. Interestingly, these estimates of old (and total) mortality were lowest ( $\sim 15-16.5\%$ ) at the sites on the fore reef and back reef that are nearest to land. These two sites experience higher wave surge and mixing than elsewhere on Gaulin's bank-barrier reef which perhaps provides a more favorable environment for coral survival. Similar to other Caribbean reefs, *Acropora palmata*, formerly a dominant in shallow windward zones, showed high ( $>50\%$ ) total colony mortality; nevertheless, we found evidence of its recruitment at several sites.

As found in other studies (e.g., Rogers et al., 1986), the species composition of the stony coral recruits did not reflect the major coral-reef builders at any site. Although 15% of the recruits at the leeward patch reefs were of the *Montastraea annularis* complex, which here represented 40% of the surveyed ( $\geq 10$  cm) corals, no recruits (and

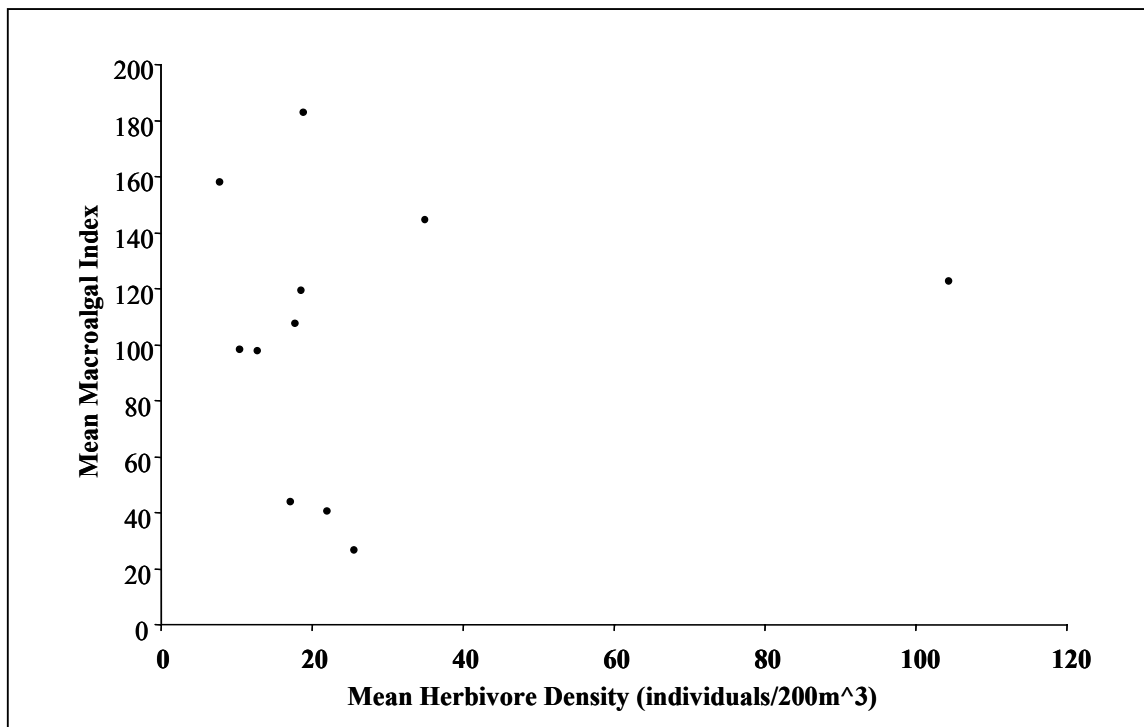


**Figure 7.** Size-frequency distribution of herbivores (all acanthurids and scarids, *Microspathodon chrysurus*) and carnivores (all lutjanids and serranids) at (A) bank-barrier fore reef, (B) bank-barrier back reef, (C) leeward patch reefs, (D) windward patch reefs, off San Salvador Island, Bahamas.

few  $\geq 10$  cm colonies) were found on the windward patch reefs. This species complex was a fairly important component (16% of  $\geq 10$  cm corals) in the bank-barrier back-reef region but it was represented by only 7% of the recruits.

Although receiving higher sediment loading from its proximity to the beach, recent and old mortality values were significantly lower at Lindsay Reef than on the other two leeward patch reefs. This apparent paradox may be an artifact of our sampling. Lindsay is a fairly “dead reef” overall; however, the live corals that remain are in good condition. The high percentages of partial mortality of the *Montastraea annularis* complex at Snapshot Reef, possibly from disease, and of *Porites porites* at Telephone Pole Reef from algal overgrowth, both occurring since Curran et al.’s (1994) assessment of these reefs, are causes for concern. The *M. annularis* complex has also suffered high rates of partial-colony mortality at other Caribbean sites. For example, two major warming events (1995, 1998) in Belize have resulted in massive coral bleaching with subsequent increased evidence of coral disease and mortality (McField, 1999; Peckol et al., this volume). Although the high incidence of diseased corals at Snapshot Reef (8% of censused colonies, 2.5% belonging to the *M. annularis* complex) in June 1998 predated the 1998 warming event that resulted in major coral bleaching worldwide (Wilkinson, 2000), San Salvador’s leeward patch reefs had previously bleached in 1995 (McGrath and Smith, 1999). However, these researchers noted that the major effect of the warming event was experienced by *Agaricia* spp. not *Montastraea*.

By June 1998, colonies of *Porites porites* were no longer expanding over the skeletons of *Acropora cervicornis* at Telephone Pole Reef. A more recent AGRRA survey during June 2000 showed that their condition had declined even further; partial-



**Figure 8.** Relationship between mean herbivore abundance (no. individuals/200 m<sup>3</sup>) and mean macroalgal index, by site in Sal Salvador.

colony mortality had risen from 44 % to >50% of the upper surfaces concomitant with an increase in macroalgal abundance from 57% to 88% (Peckol et al., unpublished). In Belize, Lewis (1986) demonstrated that macroalgae can directly overgrow and kill portions of *Porites astreoides* in herbivore exclusion treatments. Increases in macroalgae associated with declining coral cover have also been documented on other Caribbean reefs, including the San Blas Islands, Panamá (Ogden and Ogden 1994), Jamaica (Hughes 1994), and even areas remote from human impact (McClanahan et al, 1999).

High macroalgal abundances on San Salvador reefs may be related to the composition of the herbivorous fish guild where, in 1998, acanthurids (surgeonfishes) predominated at most sites. Lewis and Wainwright (1985) reported highest grazing rates for Belize in areas supporting higher parrotfish densities; similarly our highest grazing rates in Fernandez Bay were at Lindsay Reef where scarids were more common. Lewis (1985) also noted that parrotfish actively graze several genera of brown algae, including *Sargassum*, *Turbinaria*, and *Padina*, that are common at many of the San Salvador sites. Brown algae were not grazed at all by two surgeonfishes in Belize (Lewis 1985) and showed significant increases in percent cover and height (i.e., height is not a measure of abundance but rather of size/biomass) in response to experimental reduction in herbivory (Lewis, 1986). These findings may help to explain the high relative abundances of macroalgae off San Salvador reefs which are dominated by brown seaweeds at all but the leeward patch reefs. Lewis' (1985, 1986) results also may explain why there was no relationship between herbivore density (primarily acanthurids) and macroalgal index in the present study.

Absent or rare in most reef habitats, snappers, groupers and grunts were found in relatively high numbers only at Snapshot Reef in Fernandez Bay; this area may have a somewhat lower level of fishing activity than other sites. Hence, the San Salvador reefs are probably experiencing pressures from overfishing, but this conclusion cannot be stated with certainty because currently there are no comparable areas off San Salvador designated as "no-take" zones. In similar patch reefs off Belize, snapper and grouper densities and lengths are significantly greater within marine reserves and areas nearby (spillover effect) compared with sites not protected from fishing (Sedberry et al., 1992; Peckol et al., this volume).

Although we have documented partial mortalities of the major reef-building corals, *Acropora palmata* and the *Montastraea annularis* complex, that are relatively high in some habitats, the San Salvador reef system was fairly resistant to a large-scale disturbance from the passage of Hurricane Floyd. On September 13-14, 1999, this Category 4 storm passed within 20 to 30 nautical miles NE and N of the island with winds reaching 135 knots. Its greatest impact was felt on the leeward side of the island which experienced substantial coastal erosion and damage to buildings and infrastructure. However, the leeward patch reefs in Fernandez Bay showed little damage. We resurveyed the three leeward patch reefs in January 2000 and found insignificant change from June 1998 in the percent of recent or old partial mortality for the corals at these sites (compare Tables 2 and 5). As Smith and Buddemeier (1992) suggested for other reef systems, the San Salvador reefs displayed resilience in response to this large-scale natural disturbance.

Notwithstanding San Salvador's remote location, excellent marine water quality, and low human population density, the coral reefs surrounding the island are experiencing increased pressures from the combined effects of tourism and possibly

overfishing. Maintaining the integrity of San Salvador's coral reefs and adjacent marine ecosystems, and increasing the populations of fishes and invertebrates, will be important to the island's economic future. We strongly recommend the establishment of a marine reserve with an active management and regulations enforcement plan for all or a portion of San Salvador's reef system. Such designation should facilitate conservation of its critical fish and coral resources (Roberts, 1995; Nowlis and Roberts, 1997) and might contribute larval and adult fish to adjacent Bahamian insular and bank areas (Russ and Alcala, 1996; Stoner, 1996).

### ACKNOWLEDGMENTS

This research was funded by a Culpeper Foundation grant to Smith College (Curran and Peckol, coprincipal investigators), by the Smith College Summer Science Program, and by the B. Elizabeth Horner Fund. We greatly appreciate the field- and data-processing assistance provided by Smith College AGRRA team members: Lora Harris, Hali Kilbourne, Michelle Kolpin, and Shannon Ristau. We thank the Bahamian Field Station for facilities and staff support.

### REFERENCES

- Aronson, R.B., and W.F. Precht  
 1997. Stasis, biological disturbance and community structure of a Holocene coral reef. *Paleobiology* 23:326-346.
- Bohnsack, J.A., and S.P. Bannerot  
 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. *NOAA Technical Report National Fish and Wildlife Service* 41:1-15.
- Brown, B.  
 1997. Coral bleaching: causes and consequences. *Proceedings of the Eighth International Coral Reef Symposium*, Panama City, 1:65-74.
- Bruckner, A., and R. Bruckner  
 1997. Spread of a black-band disease epizootic through the coral reef system in St. Ann's Bay, Jamaica. *Bulletin of Marine Science* 61:919-928.
- Buddemeier, R.W.  
 1992. Corals, climate and conservation. *Proceedings of the Seventh International Coral Reef Symposium*, Guam 1:3-10.
- Causey, B., J. Delaney, E. Diaz, D. Dodge, J.R. Garcia, J. Higgins, W. Jaap, C.A. Matos, G.P. Schmahl, C. Rogers, M.W. Miller, and D.D. Turgeon  
 2000. Status of coral reefs in the U.S. Caribbean and Gulf of Mexico: Florida, Texas, Puerto Rico, U.S. Virgin Islands and Navassa. Pp. 261-285. In: C. Wilkinson (ed.), *Status of Coral Reefs of the World: 2000*. Australian Institute of Marine Science. Cape Ferguson, Queensland and Dampier, Western Australia.



- Curran, H.A., D.P. Smith, L.C. Meigs, A.E. Pufall, and M.L. Greer  
1994. The health and short-term change of two coral patch reefs, Fernandez Bay, San Salvador Island, Bahamas. Pp. 147-153. In: R.N. Ginsburg (compiler) *Global Aspects of Coral Reefs – Health, Hazards, and History*. Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami.
- Gerace, D.T., G.K. Ostrander, and G.W. Smith  
1998. San Salvador, Bahamas. Pp. 229-245. In: B. Kjerfve (ed.), *CARICOMP- Caribbean Coral Reef, Seagrass and Mangrove Sites. Coastal region and small island papers 3*, UNESCO Paris.
- Ginsburg, R.N. (compiler)  
1994. *Proceedings of the Colloquium on Global Aspects of Coral Reefs: Health, Hazards, and History*, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami. 420 pp.
- Hughes, T.P.  
1994. Catastrophes, phase shifts and large-scale degradation of a Caribbean coral reef. *Science* 265:1547-1550.
- Hughes, T.P., A.M. Szmant, R. Steneck, R. Carpenter, and S. Miller  
1999. Algal blooms on coral reefs: what are the causes? *Limnology and Oceanography* 44:1583-1586.
- Humann, P.  
1993. *Reef Coral Identification*. New World Publications, Inc., Jacksonville, FL, 252 pp.
- Humann, P.  
1994. *Reef Fish Identification*, 2<sup>nd</sup> ed. New World Publications, Inc., Jacksonville, FL, 24 pp.
- Koslow, J.A.K. Aiken, S. Avil, and M.A. Clements  
1994. Catch and effort analysis of the reef fisheries of Jamaica and Belize. *Fisheries Bulletin*. 92:737-747.
- Lessios, H.A.  
1988. Mass mortality of *Diadema antillarum* in the Caribbean: what have we learned? *Annual Review of Ecology and Systematics* 19:371-393.
- Lewis, S.M.  
1985. Herbivory on coral reefs: algal susceptibility to herbivorous fishes. *Oecologia* 65:70-375.
- Lewis, S.M.  
1986. The role of herbivorous fishes in the organization of a Caribbean reef community. *Ecological Monographs* 56:183-200.
- Lewis, S.M., and P.C. Wainwright  
1985. Herbivore abundance and grazing on a Caribbean coral reef. *Journal of Experimental Marine Biology and Ecology* 87:215-228.
- Littler, D.S., and M.M. Littler  
2000. *Caribbean Reef Plants. An Identification Guide to the Reef Plants of the Caribbean, Bahamas, Florida and Gulf of Mexico*. Offshore Graphics, Inc., Washington, D.C. 542pp.
- McClanahan, T.R., R.B. Aronson, W.F. Precht, and N.A. Muthiga  
1999. Fleshy algae dominate remote coral reefs of Belize. *Coral Reefs* 18:61-62.

- McField, M.D.  
1999. Coral response during and after mass bleaching in Belize. *Bulletin of Marine Science* 64:155-172.
- McGrath, T.A., and G.W. Smith  
1999. Monitoring the 1995/1996 and 1998/1999 bleaching events on patch reefs around San Salvador Island, Bahamas. *International Conference on Scientific Aspects of Coral Reef Assessment, Monitoring and Restoration*, Fort Lauderdale, pp 135-136.
- Meyer, D.L., B.J. Greenstein, and G. Llywellyn  
1991. Population stability of crinoids at Snapshot Reef, San Salvador, Bahamas. Pp. 181-184. In: R.J. Bain (ed.), *Proceedings of the Fifth Symposium on the Geology of the Bahamas*, Bahamian Field Station, San Salvador.
- Nowlis, J.S., and C.M. Roberts  
1997. You can have your fish and eat it too: theoretical approaches to marine reserve design. *Proceedings of the Eighth International Coral Reef Symposium*, Panama City, 2:1907-1910.
- Ogden, J.C., and N.B. Ogden  
1993. The coral reefs of the San Blas Islands: revisited after 20 years. Pp. 267-271. In: Ginsburg R.N. (compiler), *Proceedings of the Colloquium on Global Aspects of Coral Reefs: Health, Hazards, and History*. Rosenthal School of Marine and Atmospheric Science, University of Miami.
- Roberts, C.M.  
1995. Rapid build-up of fish biomass in a Caribbean marine reserve. *Conservation Biology* 9:815-826.
- Rogers, C.S., H.C. Fritz, III, M. Gilnack, J. Beets, and J. Hardin  
1986. Scleractinian coral recruitment patterns at Salt River Submarine Canyon, St. Croix, U.S. Virgin Islands. *Coral Reefs* 3:69-76.
- Russ, G R., and A.C. Alcala  
1996. Do marine reserves export fish biomass: evidence from Apo Island, central Philippines. *Marine Ecology Progress Series* 132:1-9.
- Santavy. D.L., and E.C. Peters  
1997. Microbial pests: coral disease in the Western Atlantic. *Proceedings of the Eighth International Coral Reef Symposium*, Panama City 1:607-612.
- Sedberry, G., J. Carter, and P. Barrick  
1992. The effects of fishing and protective management on coral reefs of Belize. *Proceedings of the Gulf and Caribbean Fisheries Institute* 11:1-25.
- Smith, S.V., and R.W. Buddemeir  
1992. Global change and coral reef ecosystems. *Annual Review of Ecology and Systematics* 23:89-118.
- Stoner, A.W.  
1996. Queen conch, *Strombus gigas*, in fished and unfished locations of the Bahamas: effects of a marine fishery reserve on adults, juveniles, and larval production. *Fishery Bulletin* 94:551-565.

- Wilkinson, C., O. Linden, H. Cesar, G. Hodgson, J. Rubens, and A.E. Strong  
1999. Ecological and socioeconomic impacts of 1998 coral mortality in the Indian Ocean: an ENSO impact and a warning of future change? *Ambio* 28:188-196.
- Wilkinson, C.  
2000. Executive summary. Pp. 7-17. In: C. Wilkinson (ed.), *Status of Coral Reefs of the World: 2000*. Australian Institute of Marine Science, Cape Ferguson, Queensland and Dampier, Western Australia.
- Woodley, J.D., P. Alcolado, T. Austin, J. Barnes, R. Claro-Madruga, G. Ebanks-Petrie, R. Estrada, F. Geraldles, A. Glasspool, F. Homer, B. Luckhurst, E. Phillips, D. Shim, R. Smith, K. Sullivan-Sealy, M. Vega, J. Ward, and J. Wiener  
2000. Status of coral reefs in the northern Caribbean and western Atlantic. Pp: 261-285. In: C. Wilkinson (ed.), *Status of Coral Reefs of the World: 2000*. Australian Institute of Marine Science, Cape Ferguson, Queensland and Dampier, Western Australia.
- Woodley, J.D., K. De Meyer, P. Bush, G. Ebanks-Petrie, J. Garzón-Ferreira, E. Klein, L.P.J.J. Pors, and C.M. Wilson  
1997. Status of coral reefs in the south central Caribbean. *Proceedings of the Eighth International Coral Reef Symposium*, Panama City 1:357-362.

Table 1. Site information for AGRRA stony coral, algae and fish surveys off San Salvador Island, Bahamas, June 1998.

Site name	Reef type	Latitude (°N)	Longitude (°W)	Survey date	Depth (m)	Benthic transects (#)	≥10 cm stony corals (#/10 m)	Fish cylinders (#)	Fish species (#) <sup>1</sup>	Fish density (#/200 m <sup>3</sup> )
Gaulins 1	bank barrier fore reef	24.16	74.46	June 03 98	1-4	10	10.5	6	21	55.5
Gaulins 2	bank barrier fore reef	24.17	74.48	June 04 98	1-4	13	10	8	19	45.5
Gaulins 3	bank barrier fore reef	24.14	74.45	June 07 98	1-4	10	10	6	15	57
Gaulins A	bank barrier back reef	24.15	74.47	June 04 98	2-8	10	8.5	7	24	46
Gaulins B	bank barrier back reef	24.16	74.48	June 04 98	2-8	10	11	7	26	57
Gaulins C	bank barrier back reef	24.14	74.46	June 07 98	2-8	10	9.5	6	18	33
Snapshot	leeward patch reef	24.04	74.54	June 01 98	4-7	11	9	6	34	177
Telephone Pole	leeward patch reef	24.03	74.54	June 02 98	6-7	10	12.5	6	28	74
Lindsay	leeward patch reef	24.01	74.53	June 10 98	3-6	10	10.5	6	20	49.5
French Bay 1	windward patch reef	23.95	74.54	June 06 98	3-5	13	9.5	8	24	47.5
French Bay 2	windward patch reef	23.95	74.55	June 09 98	3-5	10	10.5	6	21	35.5

<sup>1</sup>Fish species = all species of acanthurids,, chaetodontids, haemulids, labrids, lutjanids, lomacentrids, scarids and serranids.

Table 2. Size and condition (mean ± standard error) of all stony corals (≥10 cm diameter), by site off San Salvador, Bahamas.

Site name	Stony corals		Partial-colony surface mortality (%)			Corals (%)		
	(#)	Diameter (cm)	Recent	Old	Total	Standing dead	Bleached	Diseased
Gaulins 1	103	51.5 ± 7.0	2.5 ± 0.5	19.0 ± 2.8	21.5 ± 2.9	5.0 ± 3.1	6	0
Gaulins 2	131	55.5 ± 7.0	1.0 ± 0.6	24.0 ± 2.8	25.0 ± 2.8	6.5 ± 3.4	1	2
Gaulins 3	85	25.0 ± 5.0	1.5 ± 1.2	15.0 ± 3.0	16.5 ± 3.2	6.0 ± 2.5	1	1
Gaulins A	79	85.0 ± 14.0	1.5 ± 0.6	36.0 ± 4.7	37.5 ± 4.7	30.0 ± 8.4	4	1
Gaulins B	91	46.0 ± 6.0	0.5 ± 0.1	19.0 ± 3.0	20.0 ± 3.0	2.5 ± 1.7	4	1
Gaulins C	62	28.0 ± 4.0	<0.5 ± 0.1.5	15.0 ± 2.9	15.0 ± 3.0	0	0	2
Snapshot	93	61.0 ± 6.5	4.0 ± 1.3	31.0 ± 3.6	35.0 ± 3.6	5.0 ± 2.3	2	8
Telephone Pole	139	39.5 ± 4.0	4.5 ± 1.0	37.0 ± 3.1	41.5 ± 3.1	10.5 ± 3.2	4	4
Lindsay	112	21.0 ± 2.0	<0.5 ± 0.15	18.0 ± 2.6	18.0 ± 2.6	0	1	1
French Bay 1	150	63.0 ± 11.0	1.0 ± 0.5	28.5 ± 3.3	29.5 ± 3.3	28.5 ± 8.5	3	1
French Bay 2	99	36.5 ± 4.5	<0.5 ± 0.1	22.5 ± 2.8	22.5 ± 2.8	2.0 ± 1.3	0	3

Table 3. Algal characteristics and stony coral recruit abundance (mean  $\pm$  standard error) by site off San Salvador Island, Bahamas.

Site name	Quadrats (#)	Absolute abundance (%)			Macroalgal height (cm)	Macroalgal index <sup>1</sup>	Recruits (#/.0625 m <sup>2</sup> )
		Macroalgae	Turf algae	Crustose coralline algae			
Gaulins 1	70	30.5 $\pm$ 3.2	41.5 $\pm$ 2.4	28.0 $\pm$ 3.2	1.5 $\pm$ 0.2	26 $\pm$ 2.9	0.3 $\pm$ 0.1
Gaulins 2	84	51.5 $\pm$ 3.3	30.5 $\pm$ 3.0	18.0 $\pm$ 2.5	2.0 $\pm$ 0.2	107 $\pm$ 9.6	0.4 $\pm$ 0.1
Gaulins 3	54	51.0 $\pm$ 3.7	27.0 $\pm$ 3.2	21.5 $\pm$ 3.3	2.0 $\pm$ 0.1	119 $\pm$ 11.9	0.4 $\pm$ 0.1
Gaulins A	67	37.0 $\pm$ 3.8	33.5 $\pm$ 2.8	29.0 $\pm$ 2.8	2.0 $\pm$ 0.2	98 $\pm$ 11.5	0.4 $\pm$ 0.1
Gaulins B	45	49.0 $\pm$ 4.3	21.5 $\pm$ 2.8	30.0 $\pm$ 3.4	2.0 $\pm$ 0.1	98 $\pm$ 10.2	0.3 $\pm$ 0.0
Gaulins C	49	57.5 $\pm$ 4.0	19.0 $\pm$ 3.3	23.5 $\pm$ 3.4	2.5 $\pm$ 0.1	158 $\pm$ 17.0	0.4 $\pm$ 0.1
Snapshot	68	50.0 $\pm$ 4.0	27.0 $\pm$ 3.7	23.0 $\pm$ 3.1	2 $\pm$ 0.2	123 $\pm$ 15.0	0.2 $\pm$ 0.1
Telephone Pole	48	56.5 $\pm$ 3.2	21.5 $\pm$ 2.0	22.0 $\pm$ 2.5	2.5 $\pm$ 0.1	144 $\pm$ 7.7	0.4 $\pm$ 0.1
Lindsay	75	70.5 $\pm$ 4.1	24.5 $\pm$ 3.5	5.0 $\pm$ 2.7	2.5 $\pm$ 0.1	183 $\pm$ 14.3	0.7 $\pm$ 0.1
French Bay 1	90	14.5 $\pm$ 2.2	35.5 $\pm$ 2.2	50.0 $\pm$ 2.7	2.5 $\pm$ 0.4	40 $\pm$ 7.2	0.5 $\pm$ 0.2
French Bay 2	37	19.0 $\pm$ 3.8	53.5 $\pm$ 3.6	27.5 $\pm$ 3.8	2.0 $\pm$ 0.4	44 $\pm$ 10.8	0.4 $\pm$ 0.1

<sup>1</sup>Macroalgal index = absolute macroalgal abundance x macroalgal height.

Table 4. Fish abundance ( $\pm$  standard error) by site off San Salvador Island, Bahamas.

Site name	Reef type	Herbivores (#/200 m <sup>3</sup> )		Carniivores (#/200 m <sup>3</sup> )		
		Acanthuridae	Scaridae	Haemulidae	Lutjanidae	Serranidae
Gaulins 1	bank-barrier fore reef	10.4 $\pm$ 2.2	10.8 $\pm$ 7.2	0.2 $\pm$ 0.2	0.2 $\pm$ 0.2	0.6 $\pm$ 0.4
Gaulins 2	bank-barrier fore reef	11.0 $\pm$ 4.8	5.6 $\pm$ 1.6	0.3 $\pm$ 0.3	0.0 $\pm$ 0.0	0.4 $\pm$ 0.2
Gaulins 3	bank-barrier fore reef	14.8 $\pm$ 6.7	3.5 $\pm$ 0.6	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
Gaulins A	bank-barrier back reef	5.6 $\pm$ 1.1	4.1 $\pm$ 0.8	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
Gaulins B	bank-barrier back reef	6.6 $\pm$ 1.3	2.4 $\pm$ 1.1	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
Gaulins C	bank-barrier back reef	5.0 $\pm$ 0.4	1.5 $\pm$ 0.5	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
Snapshot	leeward patch reef	91.8 $\pm$ 21.5	4.2 $\pm$ 1.2	8.8 $\pm$ 4.4	12.0 $\pm$ 6.0	1.2 $\pm$ 0.3
Telephone Pole	leeward patch reef	23.3 $\pm$ 16.9	5.7 $\pm$ 1.3	3.5 $\pm$ 1.3	0.8 $\pm$ 0.7	3.3 $\pm$ 0.8
Lindsay	leeward patch reef	5.5 $\pm$ 1.0	9.7 $\pm$ 1.3	0.3 $\pm$ 0.2	0.8 $\pm$ 0.7	0.7 $\pm$ 0.2
French Bay 1	windward patch reef	13.8 $\pm$ 3.8	5.3 $\pm$ 1.9	0.25 $\pm$ 0.2	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
French Bay 2	windward patch reef	11.2 $\pm$ 2.4	4.8 $\pm$ 1.3	0.0 $\pm$ 0.0	0.33 $\pm$ 0.0	0.3 $\pm$ 0.2

Table 5. Partial-colony mortality (recent and old) of all stony corals ( $\geq 10$  cm diameter) by site at the leeward patch reefs, off San Salvador, Bahamas, in January 2000.

Site name	Stony corals (#)	Partial-colony surface mortality (% $\pm$ standard error)	
		Recent	Old
Snapshot Reef	160	0.8 $\pm$ 0.4	25.6 $\pm$ 2.6
Telephone Pole Reef	220	3.2 $\pm$ 0.8	35.1 $\pm$ 2.3
Lindsay Reef	200	1.3 $\pm$ 0.5	20.5 $\pm$ 2.1