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A DECADE OF DECLINE OF MASSIVE CORALS IN FLORIDA PATCH REEFS

BY

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ABSTRACT

Patch reefs are the most common reef type in the Florida Reef Tract, which represents the largest tropical reef area in the conterminous United States. Clusters of large massive corals of the *Montastraea* group form the backbone of these reefs and are of paramount importance as they provide habitat for a large variety of invertebrates and fish. Significant increases in dead surface area in clusters from 51% in 1995 to 67% in 2005 on average along the reef tract were observed during this long-term study. Even though the causes of decline are not entirely clear, the results are alarming because patch reefs are considered to be the reef type, which suffered the least decline in Florida in recent time.

INTRODUCTION

The declines of tropical coral reefs have been recognized for almost two decades both on a global scale (Brown, 1987; Hodgson, 1999; Pandolfi et al., 2003; Jones et al., 2004), in the Caribbean realm (Hughes, 1994; Bellwood et al., 2004; Gardner et al., 2003; Jackson, 1997), and in south Florida (Dustan and Halas, 1987; Porter and Meier, 1992; Chiappone and Sullivan, 1997; Wheaton et al.; 2001). With more than 6,000 patch reefs and some 25 shelf margin reefs, the Florida Reef Tract extends 350 km from Miami to Key West and farther to the west reaching the Dry Tortugas (Fig. 1). Reefs are most common off the Upper and Lower Keys, and they are rare in the Middle Keys. This preferential development of reefs is believed to be the result of the continuous islands off the Upper and Lower Keys that block the outflow of cold and/or nutrient-rich waters from Florida Bay (Roberts et al., 1982; Porter et al., 1999) and the Gulf of Mexico (Smith 1994), which are believed to be deleterious for reef growth. Reefs are therefore rather rare offshore of the widely scattered Middle Keys (Ginsburg and Shinn, 1964).

Florida patch reefs are most numerous on the shelf offshore the Upper Keys (Jones, 1977; Marszalek et al., 1977; Jaap, 1984). Most patch reefs range in dimensions from several meters up to 700 m in diameter and reach to the low-tide level (Jones, 1977; Jaap, 1984). Whereas shelf margin reefs are predominated by branched *Acropora* sp., patch reefs are formed mainly by massive corals, especially species of the *Montastraea* group (Weil and Knowlton, 1994) (Fig. 2). Within patch reefs, these corals form

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accumulations of large (>1 m diameter) colonies, which were termed clusters (Ginsburg et al., 2001). Rarely, other large massive corals such as *Siderastrea siderea*, *Colpophyllia natans*, and *Diploria* sp. are observed in clusters. Clusters are 1-5 m in diameter, and are of paramount significance as they form the core of many patch reefs, and provide habitats for fish and a large number of invertebrates.

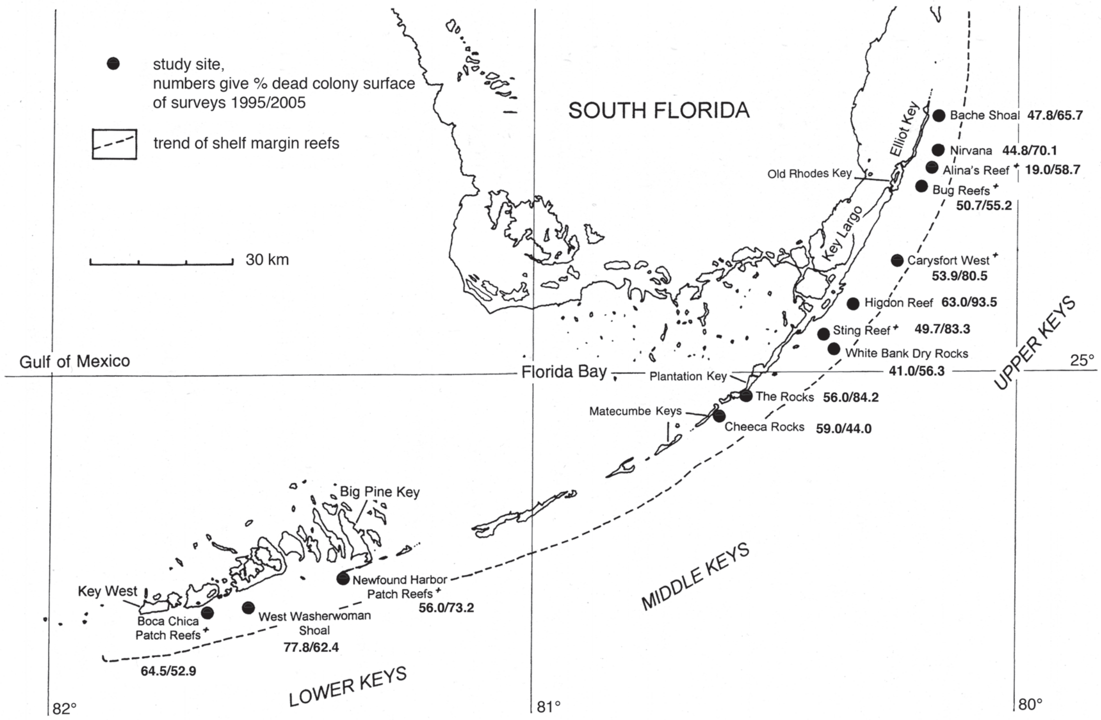

Figure 1. Map of the study area including reef sites. Numbers are comparisons of mean percentages of dead colony surface area between the 1995 and 2005 surveys. Asterisks mark reefs that are not named on nautical charts, and which were given names by the authors.

METHODS

In a previous study, the condition of 65 clusters was studied in 17 randomly selected reef sites along the Florida Reef Tract in the summer of 1995 (Ginsburg et al., 2001). In the summer of 2005 we revisited 51 clusters at 13 sites (Fig. 1, Tab. 1). From all individual clusters investigated in 1995, 16 could be positively reidentified and 35 could not be relocated probably due to inaccurate GPS readings 10 years ago (Tab. 1). Like in the 1995 study, we used a modified line point intercept method (Loya, 1978), which is a rapid and straightforward approach of assessing coral condition. We draped 6 m long nylon lines marked in 25 cm distances over *Montastraea* clusters and noted the condition under each mark in the five categories: dead, alive, rubble, substrate, and corals other than *Montastraea*. Lines were rotated over the approximate center of the cluster at 45° in order to have 4 transects with a total of some 100 points per cluster. During this study, each cluster was assessed twice by different assessors, and averages were calculated for individual clusters and for the 13 locations. The standard deviation between assessors on individual clusters was 4.84% on average with a range between 0.71-19.09%. For comparison, the variation in the 1995 study ranged from 0.82-14.7% (Ginsburg et al., 2001).

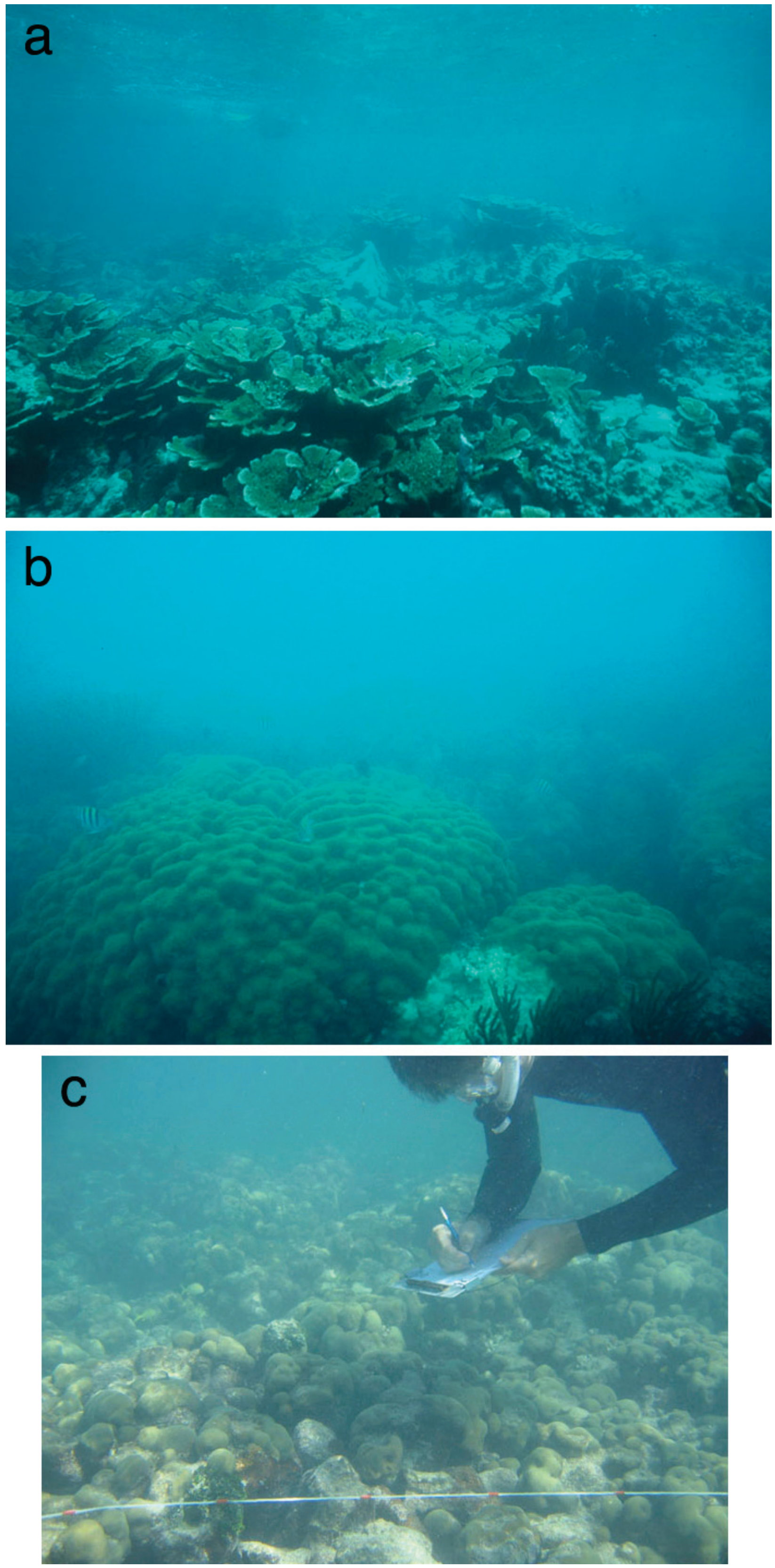

Figure 2. (a) Shelf margin reef with *Acropora palmata*. Horseshoe Reef off Key Largo. (b) Typical cluster of large *Montastraea* species. Mosquito Bank. (c) Author swimming along marked transect line recording coral condition. Newfound Harbor patch reefs.

RESULTS

Comparison of the results from 2005 with those of 1995 show a decline in the condition of large *Montastraea* sp. clusters. This can be seen when comparing the 1995 and 2005 data for individual clusters and for all clusters taken together. Among reef sites, a decline in coral condition is visible in most of the examples, however, it is statistically significant in only three sites. The large majority of clusters investigated showed no signs of recent death, i.e., diseases or infections, bleaching, or overgrowth by other organisms. Only in two examples (Bache Shoal, West Washerwoman Shoal) colony breakage by recent boat groundings were identified. Also, clusters surveyed in Biscayne National Park often exhibited entangled fishing line, which in several cases scraped colony surfaces while being moved with the current. In summary, most dead surface areas on clusters appeared as being dead for longer time periods (at least several months) and/or being expansions of earlier dead spots.

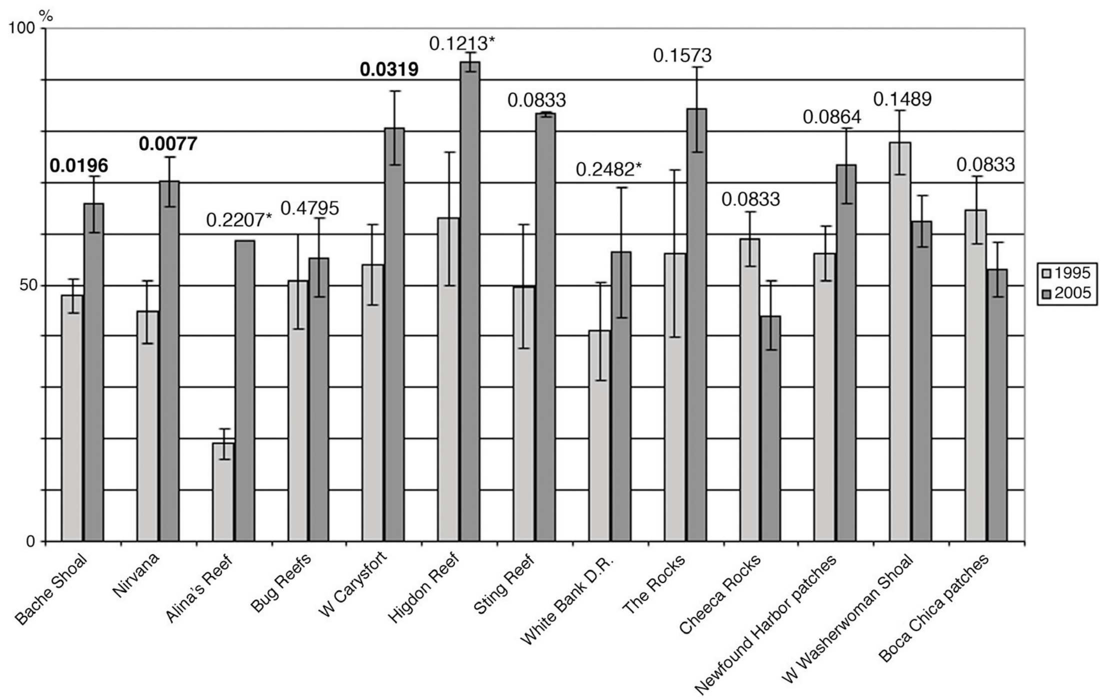

Figure 3. Comparison of dead colony surface in the 1995 and 2005 surveys per reef site. Numbers are average values calculated from individual clusters; bars show standard error. Numbers on top of columns are Chi-Square approximations of a Wilcoxon/Kruskal-Wallis test (statistical significance at $p \leq 0.05$). Statistically significant differences are marked bold. Sites in which <3 clusters were sampled are marked with an asterisk. Non-parametric statistics were used because data are not distributed normally. Sites are plotted from north (left) to south (right).

Individual Clusters

Among the 16 individual clusters identified in both surveys, 14 clusters showed declines between 5.9-79.9%, and only 2 clusters exhibited an improvement, i.e. decrease in dead tissue area, by 5.8-20.9% (Tab. 1).

Reef Sites

In 10 reef sites, dead surface area increased between 4.5-39.7% on average (Fig. 1; Tab. 2). In eight locations this change was significant in that error bars of the 1995 and 2005 data did not overlap (Fig. 3). Three sites in the Lower and Middle Keys exhibit a decrease in dead colony surface area, i.e., an increase in tissue area, which ranges from 11.6-15.4%. In these sites the changes are significant as seen by non-overlapping error bars. According to the Wilcoxon/Kruskal-Wallis test, statistically significant differences ($p<0.05$) between the 1995 and 2005 data sets occur between three sites (Bache, Nirvana, Carysfort) in the northern reef tract (Fig. 3). In four sites (Sting, Cheeca, Newfound Harbor, Boca Chica) the change is close to significant (p-values around 0.08). In the remaining six sites, differences between the 1995 and 2005 data sets are statistically insignificant ($p>0.12$), however, in three of these sites (Alina's, Higdon, White Bank) the number of clusters analyzed (<3) is probably too low to make a reliable judgement. A sign test was applied in order to test whether or not a significant majority of sites showed a decline. The resulting p-level amounts to 0.096 and is only close to significant ($p<0.05$).

There are no statistically significant spatial patterns in the data visible, i.e., there are no trends in coral condition from Upper to Lower Keys or from nearshore-to-offshore patch reefs. The latter was tested by plotting patch reef conditions from north-to-south and against distance from shore. In both cases, regression lines did not exhibit significant gradients.

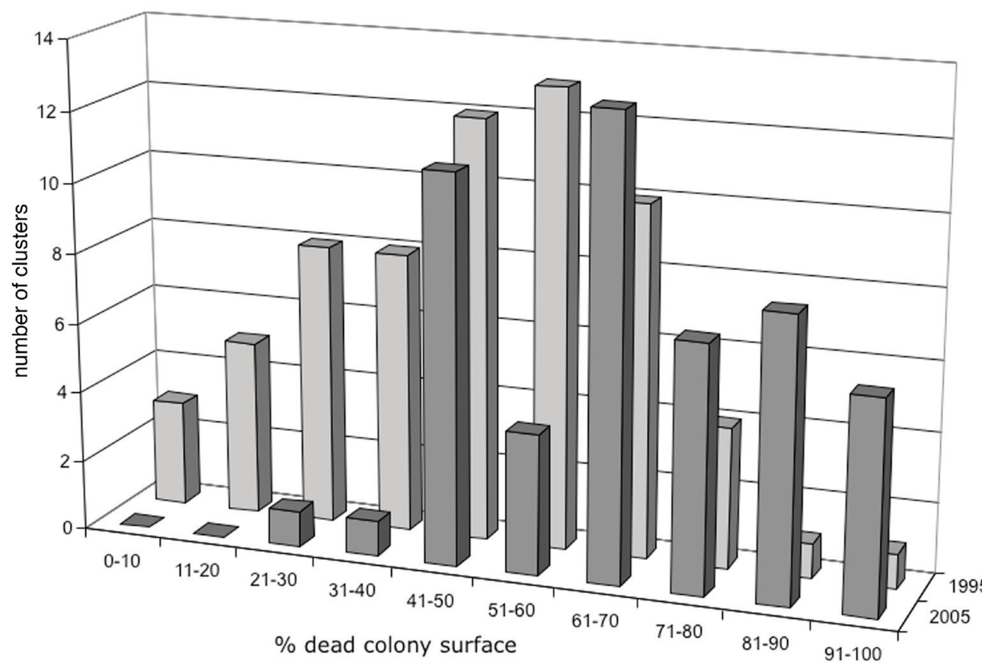

Figure 4. Comparison of dead colony surface in individual clusters per size among the 1995 (n = 65) and 2005 (n = 51) surveys.

All Clusters

The mean dead surface area of all clusters investigated increased from 51.2 ± 2.5% in 1995 to 67.2 ± 2.5% in 2005. A comparison of individual clusters also showed a prominent decline in that only 44.6% of the clusters were >50% dead in 1995, whereas in 2005, 76.5% of the clusters had >50% dead colony surfaces (Fig. 4). The Chi-Square approximation of a Wilcoxon/Kruskal-Wallis test is p=0.0196, and shows that the difference between the 1995 and 2005 data sets is statistically significant.

DISCUSSION

Data Limitations

A limitation of this study is that only about one-third of the individual clusters surveyed in 1995 could be positively identified in 2005. Because we investigated several (up to eight) clusters at each reef site, however, the condition of clusters in reef sites are representative, and comparisons of 1995 and 2005 data on reef sites are considered to be valid. Another limitation is that comparisons with results of other monitoring studies in the area (e.g., Wheaton et al., 2001) can only be made in a qualitative manner, because these and comparable studies usually investigate live coral cover per reef area and not dead surface area on corals.

Possible explanations for the decline in Florida patch reefs over the past 10 years include both natural and anthropogenic factors. Their identification is complex, however, because two data limitations must be considered. First, the Florida reef tract is situated near the margin of tropical coral-reef growth, and natural variation in coral and reef health is probably high. Second, the distribution of reefs in the Florida reef tract is not uniform, but patch reefs are concentrated in the north. As a consequence there are more study sites offshore the Upper Keys. Hence, spatial patterns in the data have to be interpreted with caution. Also, recently dead colony areas, which would allow direct identification of causes of decline, are largely lacking. Furthermore, multiple stressors such as temperature and salinity extremes, elevated turbidity, nutrient contents, and environmental contaminants are operating in concert, thereby rendering identification of single causes as well as differentiation between natural *versus* anthropogenic causes as being difficult (Hughes and Connell, 1999; Porter et al., 1999).

Possible Causes of Decline

Natural causes of decline include storms such as, e.g., Hurricane Andrew in 1991and tropical storm Gordon in 1994, which caused major damage of reefs in the northern reef tract (Lirman and Fong, 1997). Even so, except for hurricanes Georges in 1998 and Irene in 1999, no major cyclones have crossed the reef tract since the 1995 study. Also, hurricanes Georges and Irene crossed the Lower Keys, which according to this study suffered less decline than the Upper Keys. Also, storms preferentially affect branched rather than large, massive corals. Interestingly, a more severe decline in coral condition in the Upper Keys as opposed to the Lower Keys was also found in another recent study (Wheaton et al., 2001). Extreme cold fronts such as those during in the winters of 1969/70 and 1977/78 have caused widespread massive coral death as, e.g., at Hen and Chicken's patch reef located east of The Rocks in Figure 1 (Roberts et al., 1982). Comparable cold events have not been observed since then though. Ecological phase shifts may be documented in long-term studies; however, such studies are only recently increasing. For example, Davis (1982) documented the replacement of *Acropora* sp. by other corals in the Dry Tortugas by comparing reef maps of 1881 and 1976. Coral-to-Algal phase shifts have been described from Jamaica (Hughes, 1994) or from Belize (McClanahan et al., 1999). Replacement or decline of corals is often caused by disease. In *Montastraea* sp., black band infection (Kuta and Richardson, 1997) is most common and usually leads to colony death within a few weeks time. The Florida Coral Reef Monitoring Project has identified an increase in disease infections between 1996 and 2000 (Wheaton et al., 2001), however, we did not observe any *Montastraea* infected with black band disease during our revisit. Also, coral bleaching associated with abnormally elevated sea surface temperatures (Fitt et al., 2001; Hoegh-Goldberg, 1999) presumably has caused coral decline in south Florida during the 1998 worldwide bleaching event (Goreau et al., 2000), even though this event most severely affected milleporids (fire corals) in south Florida (Causey et al., 2002).

Anthropogenic causes include pollution of coastal waters, the increase of which was shown to be existent in the Florida Keys (Lapointe and Clark, 1992; Causey et al., 2002). Much of this increase may be attributed to the growing numbers of inhabitants, which amount to some 2.5 million for Miami-Dade County and 80,000 for the Florida Keys, and to the increase in tourist numbers to >3 million per year (Leeworthy and Vanasse, 1999). Even so, our 2005 data set does not support that coral condition is worse offshore than nearshore. The impact of reef tourists including snorkellers and divers is hard to assess from our data because both frequently visited reefs such as Bache Shoal, White Bank Dry Rocks, and the Newfound Harbor patch reefs, and less frequently visited locations show decline. Also, boat damage such as recently shattered coral heads was observed on the frequently visited Bache Shoal and also on the more remote West Washerwoman Shoal.

Even though no causes of decline could be clearly identified, the results presented here are alarming in light of the fact that among the different reef types recently monitored in south Florida, patch reefs apparently experienced the fewest losses and exhibit the highest percentages of coral cover over time (Causey et al., 2002).

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APPENDIX

Table 1. Data on dead colony surface area for individual clusters surveyed 2005. Note that 16 clusters of the 1995 study were positively identified. For detailed 1995 data see Ginsburg et al. (2001).

Cluster	**% dead 2005 ind. cluster**	**% dead 1995 ind. cluster**	**difference %**
Bache Shoal 1	65.9		
Bache Shoal 2	55.9	44.0	11.9
Bache Shoal 3	65.9		
Bache Shoal 4	87.7	48.0	39.7
Bache Shaol 6	84.0	37.0	47.0
Bache Shoal 8	65.9	60.0	5.9
Bache Shoal 10	61.4		
Bache Shoal 11	39.2	45.0	-5.8
Nirvana Proper 1	45.3	28.0	17.3
Nirvana Proper 2	81.4		
Nirvana Proper 3	70.2		
Nirvana Proper 4	72.0		
Nirvana 5	69.9		
Nirvana North 1	68.4		
Nirvana North 2	83.6		
Alinas Reef 1	58.7	16.0	42.7
Bug 1	52.7		
Bug 2	40.9		
Bug 3	77.0		
Bug 4	50.3		
Carysfort 1	81.6	63.0	18.6
Carysfort 2	49.1	70.0	-20.9
Carysfort 3	96.1	39.0	57.1
Carysfort 5	87.2		
Carysfort 6	73.5	50.0	23.5
Carysfort 6a	95.7	16.0	79.7
Higdon 2	91.6	50.0	41.6
Higdon 2a	95.3	76.0	19.3
Sting Reef 1	82.8		
Sting Reef 2	83.7		
White Bank D.R. 1	43.6	25.0	18.6
White Bank D.R. 2	68.9	40.0	28.9
The Rocks 1	80.4		
The Rocks 2	100.0		
The Rocks 3	72.2		
Cheeca Rocks 1	44.1		
Cheeca Rocks 2	48.2		
Cheeca Rocks 3	26.0		
Cheeca Rocks 4	57.9		

Cluster	% dead 2005 ind. cluster	%dead 1995 ind. cluster	difference
Newfound Harbor 1	60.6		
Newfound Harbor 2	93.5		
Newfound Harbor 3	64.6		
Newfound Harbor 4	74.3		
W Washerwoman 1	49.5		
W Washerwoman 2	65.3		
W Washerwoman 3	61.5		
W Washerwoman 4	73.1		
Boca Chica 1	48.4		
Boca Chica 2	49.0		
Boca Chica 3	45.3		

Table 2. Data on dead cluster surfaces (means) per reef sites surveyed 2005 and 1995. n = number of clusters.

location	% dead 1995	std. error	% dead 2005	std. error	% diff.	n 1995	n 2005
Bache Shoal	47.8	3.2	65.7	5.4	17.9	6	8
Nirvana	44.8	6.1	70.1	4.8	25.4	8	7
Alina's Reef	19.0	3.0	58.7	0.0	39.7	2	1
Bug Reefs	50.7	9.2	55.2	7.7	4.5	3	4
W Carysfort	53.9	7.8	80.5	7.2	26.6	7	6
Higdon Reef	63.0	13.0	93.5	1.9	30.5	2	2
Sting Reef	49.7	12.1	83.3	0.4	33.6	3	2
White Bank D.R.	41.0	9.5	56.3	12.6	15.3	3	2
The Rocks	56.0	16.3	84.2	8.3	28.2	4	3
Cheeca Rocks	59.0	5.4	44.0	6.7	-15.0	4	4
Newfound Harbor patches	56.0	5.3	73.2	7.4	17.2	5	4
W Washerwoman Shoal	77.8	6.4	62.4	4.9	-15.4	4	4
Boca Chica patches	64.5	6.6	52.9	5.4	-11.6	4	4