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LONG-TERM TRENDS ON CORAL PATCH REEFS OF SAN SALVADOR, BAHAMAS

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ABSTRACT

Long-term monitoring of coral reefs has only recently begun in a number of regions. Since 1992, near-shore coral patch reefs around San Salvador Island, Bahamas have been monitored three times a year with the aid of Earthwatch volunteers. During each monitoring visit, permanent belt transects have been surveyed for new damage to scleractinian corals, the fate of areas damaged in the past, and physical parameters such as temperature, salinity, pH, and visibility. Transects have been hand-mapped and photographed annually, with each coral colony drawn to scale and identified to species. Haphazard Point Intercept data have been collected to monitor substrate types. The rugosity of the reefs, their relative height off the bottom, and depth below the ocean surface have also been monitored. During the monitoring period, two bleaching events, a course of gorgonian *Aspergillosis*, and several coral disease outbreaks have occurred. Use of the monitoring protocols along with episode-specific survey techniques has provided an opportunity to note variations in courses, outcomes and possible causes of these periodic phenomena. The picture emerging is one of relative stability in spite of the increasing intensity of stresses and environmental assaults on these systems. While algal cover is increasing at times at some sites, most hard corals and gorgonians are maintaining their coverage or becoming more abundant. Despite warmer-than-normal SSTs in some years, the eight-year trend shows only minor variation from historical temperatures. The 1998 bleaching event and some diseases have affected the reefs noticeably in the short term, but in recovery, the overall diversity and health of the systems appears to remain stable. New development near at least one of the monitored reefs will provide information on the impact of beachfront construction on near-shore patch reef systems. Long-term monitoring provides an excellent measure of the dynamics and stability of coral patch reefs.

INTRODUCTION

Coral reefs around the world have experienced declines since the early 1980s. These declines have been attributed to such events as the loss of significant populations of some organisms on the reefs such as *Diadema* sp. and to coral bleaching events (Grigg and Dollar 1990, Cook *et al.* 1988, D'Elia *et al.* 1991, Goreau 1990, Porter and Meier 1992, Smith and Buddemeier 1992). The extent of the declines has been hard to gage since few long-term monitoring efforts have been in place throughout the period (Lang *et al.* 1992).

Similar declines appear to have affected the reefs of the Bahamas. Patch reefs make up a major portion of the reefal structure important to the Bahamas in a variety of ways. The patch reefs in the Bahamas are often in very shallow water (Buchan 2000). While influences on patch reefs in close proximity may appear to be similar, the reefs may change over time in strikingly different ways (H.A. Curran, pers, comm.).

In the early 1990s it was suggested that patch reefs around San Salvador Island, Bahamas had experienced decline as well (H.A. Curran and D. Gerace, pers. comm.). In order to characterize the reefs and follow future changes in these systems, three coral patch reefs around San Salvador Island have been monitored three times each year

(McGrath 1992, McGrath *et al.* 1994, McGrath and Smith 1999). During this period two major bleaching events and outbreaks of diseases on hard coral and gorgonians have occurred (McGrath and Smith 1998, McGrath and Smith 2001 [in press], Smith *et al.* 1996, Richarson *et al.* 1998). Eight years of data make it possible to observe trends in the parameters being monitored on these reefs and to compare these trends with those seen or suspected elsewhere around the world.

METHODS

Three near-shore patch reefs around San Salvador Island, Bahamas have been monitored three times a year in February, July, and November, with the aid of Earthwatch volunteers. During each monitoring visit, permanent ten meter by one meter transects have been surveyed for new damage to scleractinian corals, the fate of previously damaged areas, and physical parameters such as temperature, salinity, pH, and visibility. Transects have been hand-mapped and photographed annually, with each coral colony drawn to scale and identified to species. Haphazard Point Intercept data have been collected to monitor substrate types. The rugosity of the reefs, their relative height off the bottom, and depth below the ocean surface have also been monitored. The specific methods used in monitoring and in following episodes of bleaching and disease have been previously reported in detail (McGrath 1992, McGrath, *et al.* 1994, McGrath and Smith 1998, McGrath and Smith 1999, McGrath and Smith 2001, Wells 1995).

RESULTS

Salinities around the transects have averaged 38 o/oo (std. = 0.1) throughout the period. While salinities reached 40 o/oo during some summers in the warmest years, this variation was not statistically significant (ANOVA $P > 0.1$).

The pH has also remained consistent over the period at 8.2 (std. = 0.1). No differences among the three patch reefs being monitored were found in either salinity or pH (ANOVA $P > 0.5$).

Visibilities, a relative measure of particulate content in the water column, showed seasonal variation on all three patch reefs being monitored with July most often having the highest visibility measurements. Many times there were noticeable differences between transects on the same reef in this parameter during a single monitoring visit suggesting that current and sedimentation rates may differ from one area of a patch reef to another. No significant trends in visibility were seen over the period. All of these elements can be seen in the representative data from Lindsay's Reef in Figure 1.

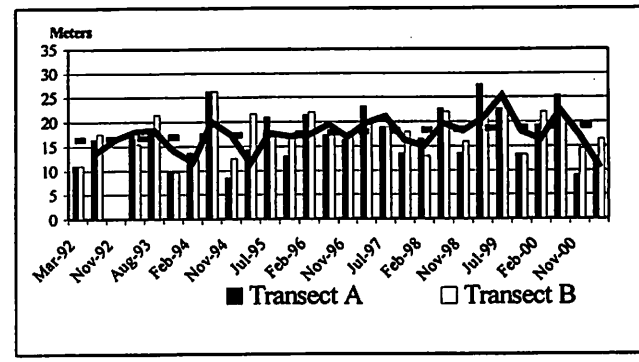

Figure 1. Mean visibility measurements for the transects on Lindsay's Reef show marked seasonality, variation between transects in some seasons, and no clear change or trend over the period of monitoring.

Sea temperatures on the transects showed marked seasonality. There were no differences among transects on a single reef in this parameter during any monitoring visit. While mean temperatures among the reefs were remarkably similar during each visit, Rice Bay sea temperatures remained slightly lower than those seen at Rocky Point and Lindsay's Reef as seen in Figure 2. This variation was not significant, however (ANOVA $P > 0.05$). Surprisingly there has been a trend toward lower temperatures on the transects over the period. This is counter to widely reported SST warming globally (Atwood *et al.* 1992, Strong *et al.* 2000).

Comparing mean transect temperatures by season with mean SSTs reported for the 1980s by NOAA (Schweizer 1993) from the closest monitoring buoy (24°N 75°W) showed that summer

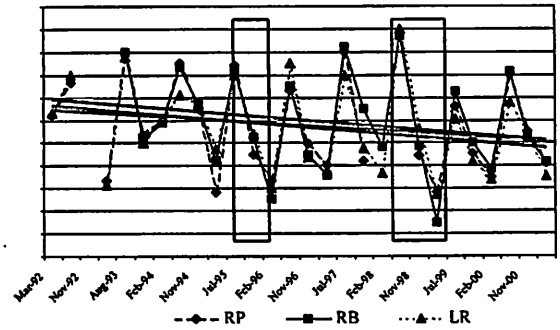

Figure 2. Mean sea temperatures within 0.5 m of the transects for the three monitored reefs. Temperatures show strong seasonal variation and a lowering trend. The regions set off in rectangles show the periods of coral bleaching in 1995 and 1998.

temperatures in the 1990s were higher than those in the 1980s while November temperatures in the 1990s were lower. February temperatures appeared similar in both decades.

Measurements of reef height off the bottom can detect changes in sand accumulation around the base of the reef. Only two regions showed changes in this parameter over the period, the south face of Lindsay's Reef and the North face of Rocky Point Reef. While both of these reefs are on the west side of the Island, they are apparently under the influences of slightly different currents which affect the sand accumulation on those faces of the reef exhibiting change. All other reef faces showed no significant changes in sand accumulation over the period in spite of three hurricane events directly affecting the Island, Bertha, Lily, and Floyd.

Rugosity is a measure of the three dimensionality of a reef. Lindsay's Reef and Rocky Point Reef both showed an increasing rugosity over the period while Rice Bay Reef showed no increase in its three dimensional character.

Much has been made of the reported increase in macroalgae cover on reefs with degradation. Most reports have suggested a

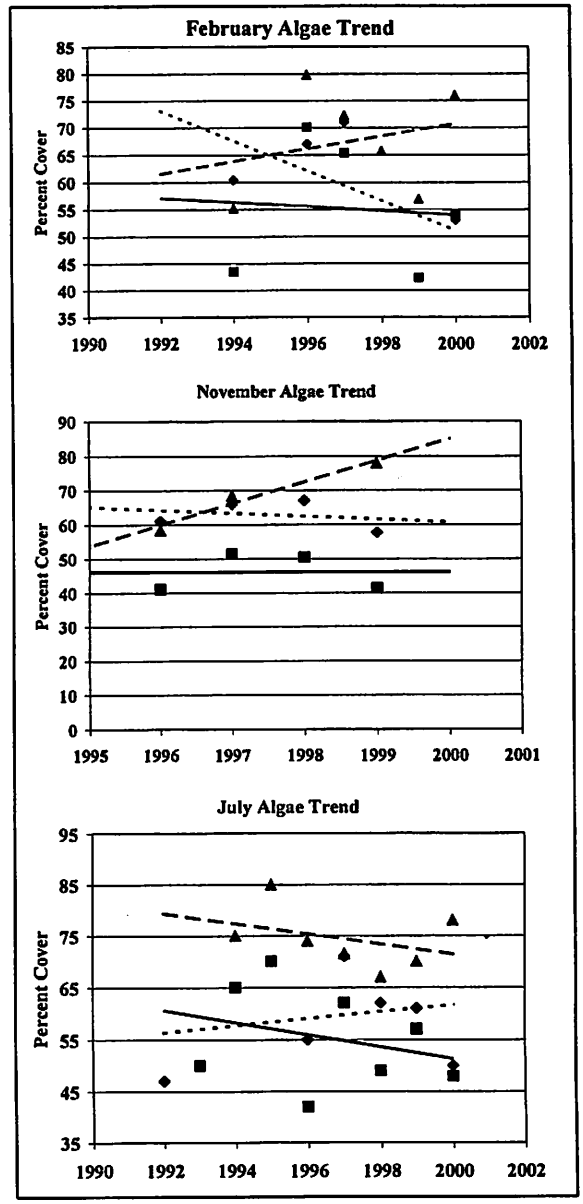

Figure 3. Trends in algae cover. Changes in algae cover seem to occur in different ways and at different times among the reefs.

Lindsay's Reef ◆ .....
Rocky Point ——
Rice Bay Reef. Δ ——

striking and linear increase in algae as reefs become compromised by bleaching, diseases, loss of algae grazers, and over nutrification (CRMP team 2001, Porter and Meier 1992, Normile 2000, Ostrander *et al.* 2000). Data on these patch reefs suggest a more complicated picture.

Algae growth is clearly seasonal with February being the time of the greatest algae cover (Figure 3). Rice Bay Reef showed the least variation in algae cover seasonally, however. Algae cover there remained high throughout each year. This is a highly compromised reef with low coral cover.

Changes in algae cover differ by reef as well as by season suggesting a complex dynamic affecting this parameter at each site. Rice Bay Reef showed increasing algae cover during the November and February monitoring visits but a decreasing algae cover in the summer months over the period. Lindsay's Reef showed a significant decreasing trend in algae cover in February. Rocky Point Reef appeared to be the most stable reef in all seasons with respect to algae cover. Differences in algae species composition have been noted among the reefs and are now being quantified.

Gorgonians appear to be increasing on all three reefs in spite of a major outbreak of sea fan *Aspergillosis* and increasing incidences of other gorgonian diseases (Figure 4).

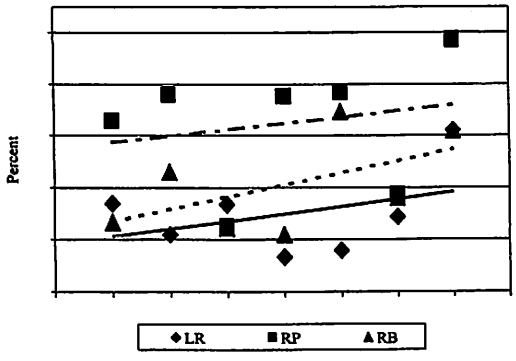

Figure 4. Mean gorgonian cover on the three reefs. Gorgonian abundance appears to be increasing.

Mean hermatypic scleractinian coral cover for the three reefs is;

Lindsay's Reef	8.6% (std. = 0.2)
Rocky Point Reef	9.1 % (std. = 0.2)
Rice Bay Reef	4.3 % (std. = 0.1)

The mean coral cover values at Lindsay's Reef and Rocky Point are not significantly different from one another (ANOVA Tukey $P > 0.05$). Rice Bay reef coral cover is siginficantly different from both Lindsay's Reef and Rocky Point Reef, however (ANOVA Tukey $P \leq 0.05$).

While coral cover at both Lindsay's Reef and Rocky Point Reef has declined over the period, Rice Bay Reef coral cover has remained steady (Figure 5).

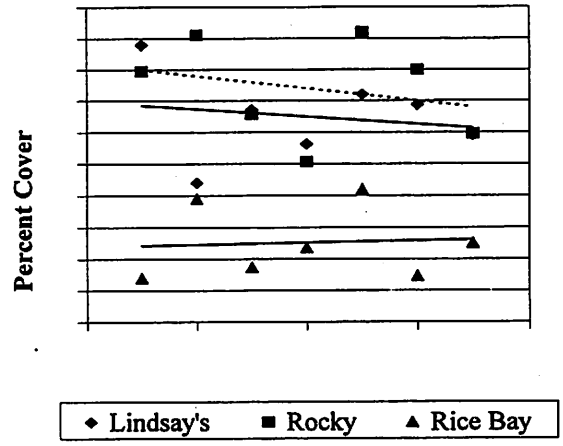

Figure 5. Trends in hard coral cover on the three monitored reefs.

It was suspected that changes in coral cover may have been due to one or both major bleaching events that occurred during the monitoring period. Therefore coral cover on each reef before and after bleaching commenced in 1995 was compared. While lower coral cover numbers after bleaching were seen at Lindsay's Reef and Rocky Point in these comparisons, no statistically significant differences were found (paired *t* test $P > 0.05$).

Since the 1998 event was the more significant of the two bleaching events, hard coral colony numbers were compared on the reefs before and after this event. Again Lindsay's Reef and Rocky Point appeared to

show some decrease in numbers but once again no significant differences were found on any reef (*t* test $P > 0.05$).

Shannon-Wiener Diversity Indices for hard corals were calculated for the three reefs. The index is a measure of species diversity. A value of 4.6 indicates maximum diversity and 0.0 indicates a monoculture. The indices were;

Lindsay's Reef	2.4
Rocky Point Reef	2.8
Rice Bay Reef	2.9

These represent moderate diversity on all three reefs with little difference in diversity among them.

When the percentage of total hard coral colonies making up each of the five most abundant coral species on each of the three reefs was analyzed, it was apparent that species distributions differed among the reefs. As seen in Figure 6, the most abundant species on Lindsay's Reef are *Agaricia agaricites* complex and *Manicinia areolata*, while Rocky Point Reef is dominated by *Porites asteroides*. Rice Bay has a more even distribution among species. These distribution patterns were maintained throughout the monitoring period.

Comparisons of species distributions among the reefs were made by calculating the coefficients of community (CC). These calculations were made on the basis of the consistent appearance of species from year to year.

CC for LR/RP = 0.56
CC for LR/RB = 0.78
CC for RP/RB = 0.72

Lindsay's Reef and Rocky Point Reef are most different from one another in terms of community structure, while both of those reefs are more similar to Rice Bay.

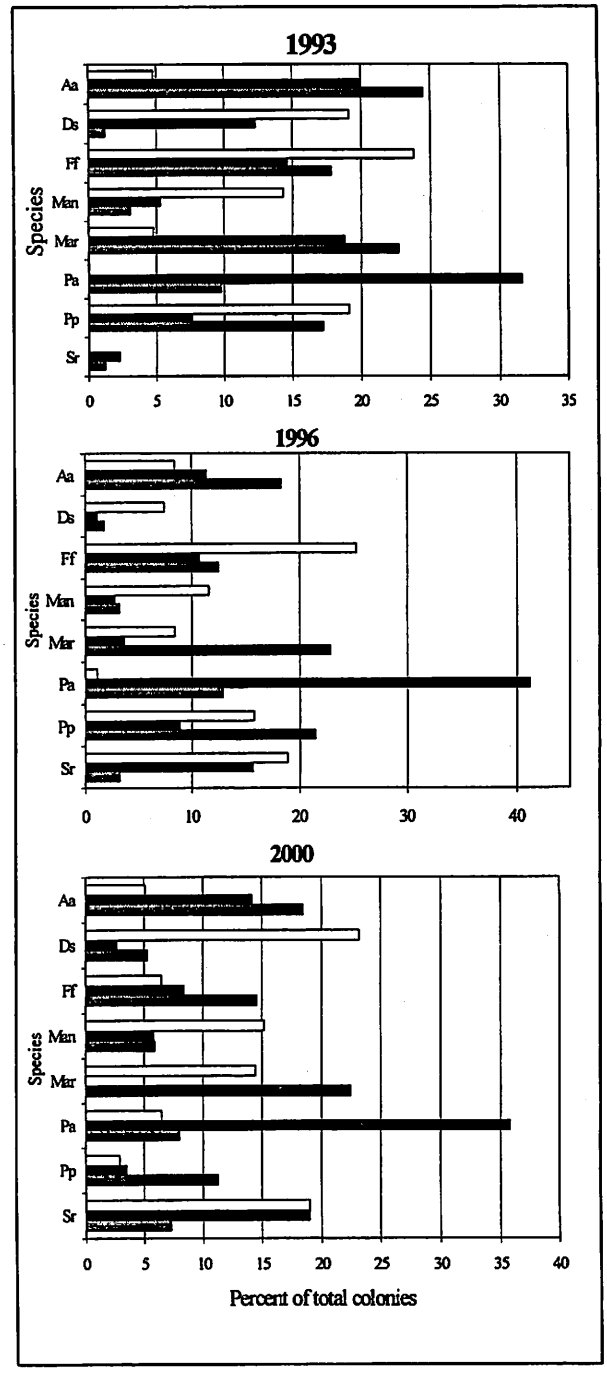

Figure 6. Comparing the percent of total colonies of the most abundant species on each reef in three different years, early in the study, 1993, mid-study, 1996, and 2000.
Gray bars – Lindsay's Reef
Black bars – Rocky Point
White bars – Rice Bay

DISCUSSION

Declines in reef-building coral populations have been widely reported in the Western Atlantic and Caribbean. Often these declines appear to have been accompanied by the subsequent overgrowth of the newly available substrates by macroalgae. Reasons for the reported declines vary and include bleaching damage, disease epidemics, algae grazer die-offs, weather events, and sedimentation and over nutrification from coastal development (Brown 1988). Anecdotal reports suggest that such declines in coral cover affected reefs around San Salvador Island in the Bahamas in the 1980s as well. With monitoring efforts not beginning until 1992 on the patch reefs around this island, the fact that a decline did occur and the exact nature of such a decline can not be determined. Over the past decade, however, monitoring has provided a picture of a dynamic system demonstrating remarkable stability in the face of events possibly equivalent to those that may have brought about significant change in the previous decade.

The physical parameters of pH and salinity have shown little variation throughout the decade. With little in the region to affect these parameters this finding was expected.

Since sand transport in near shore systems is toward the open ocean in higher energy periods, and toward the beach in lower energy periods, the seasonality observed in the visibility data were also expected. Clearer summer waters over the reefs reflect the deposition of sand from the water column in that season. Visibilities varying markedly among transects on the same reef during the same season suggest significantly different patterns of current and sand movement on reefs within a few tens of meters. These current variations are now being studied on these reefs.

It is surprising to note no trend in visibilities over the period in spite of anecdotal reports of an increased number of storms in the region during the rainy season and possible lower than average winds in the late dry season.

Temperatures on the reefs have been measured with hand-held thermometers during every monitoring visit and sporadically using electronic temperature loggers (Stowaway by HOBO temp®). Technical problems with electronic loggers prevented a more continuous record from but when their data were available they did corroborate and amplify the hand-held data.

With global warming and the subsequent rise in SSTs receiving much attention, it was surprising to note the declining trend in local sea temperatures recorded on the reefs. This suggests that while overall trends may occur in the biosphere, communities may vary in how they are affected by these changes. Comparing these local data to region-wide and world-wide data will provide a better picture of the complexity of global changes.

Height and depth measurements have revealed no significant changes in these parameters on the reefs over the decade. Changes in these measurements may occur over periods of time too great or they may be too small to be detected by the methods used.

The three dimensional character of a reef may change over time as new growth and bioerosion affect its surfaces. In a highly compromised reef system, these elements may not work as quickly or as effectively if at all. This seems to be the case with these reefs. Rocky Point and Lindsay's Reef have a greater coral cover and a seemingly healthier assemblage of biota than Rice Bay. Consequently, the factors affecting increased rugosity may be more at work on these reefs than on the more compromised Rice Bay Reef.

In many regions that have suffered coral reef declines concern has been that a die-back in coral may cause a subsequent overgrowth by macroalgae. While these data demonstrate an increase in algae growth in some seasons and on some reefs, they suggest a more complex response than has been reported. While the most compromised reef, Rice Bay, has consistently shown the highest algae cover in all seasons, it has had no significant change in that cover over the decade. Perhaps this reef, once compromised, reached a new equilibrium among taxa present

there. With Lindsay's Reef and Rocky Point showing continued increases in algae growth through the period during some seasons, it may be possible with continued monitoring to follow how this equilibrium becomes established.

Algae species composition varies among reefs as well with *Padina* sp. appearing to dominate Lindsay's Reef, while *Dyopteris* sp. appears in abundance on Rice Bay Reef and is absent from the other two reefs (J. Rollino, pers. comm.).

Algae surveys are currently underway to determine the nature and extent of these differences.

Gorgonian population increases over the monitoring period are surprising in light of the significant outbreak of sea fan *Aspergillosis* in the late 1990s. While sea fans around San Salvador fared better than those in other areas (Smith, *et al.* 1996), it appeared that the disease spread to other gorgonians in the region during this outbreak (G. Smith, pers. comm.).

While declines in scleractinian coral cover have been seen at Lindsay's Reef and Rocky Point Reef, these declines are not statistically significant for the period. Since the major declines in reef hard coral cover were reported in the 1980s, it is possible that these reefs also suffered major declines then and have since stabilized. No data are available to support this idea, however. Reaching stability in hard coral cover after a period of decline may be the norm, however, based on the data from Rice Bay Reef where hard coral cover has been consistent over the period.

The two major bleaching events during the monitoring period, one in 1995 and the more significant one in 1998, appear to have had little impact on the hard coral populations on these reefs. Comparing both overall coral cover and coral colony numbers before and after bleaching events shows that no statistically significant differences resulted (McGrath and Smith 1998, McGrath and Smith 2001). Other parts of the world reported more significant changes, particularly following the 1998 event (Wilkins 2000).

The diversity indices of these three reefs are remarkably similar for communities which seem to have such different species distributions. Coefficients of commonality show that Lindsay's Reef and Rocky Point are significantly different from one another in hard coral species distribution. While Rice Bay appears to share more species with both Lindsay's Reef and Rocky Point than those reefs share with each other, Rice Bay Reef has only half the hard coral cover of those other reefs.

Species distribution among the reefs has remained similar over the decade. When the percent of colonies of the most abundant five coral species on each of the reefs is compared, it is clear that each reef demonstrates a unique assemblage of hard corals. The patterns of species distribution among the reefs has not changed over the decade in the face of major bleaching events and hurricanes. Future monitoring may determine the longevity of this stability in coral community structure on these reefs.

Beachfront development has commenced at Lindsay's Reef during the last two years. Continued monitoring will allow detection of any impact from this development and comparisons of that impact with conditions on the other monitored reefs.

CONCLUSIONS

Salinity and pH have remained stable over the monitoring period. Visibility measurements show seasonal variation, with summer typically highest. There is variability in visibility measurements among transects within a single reef. There has been no evident trend in visibility on the reefs over the monitoring period.

Seasonal mean sea temperatures on reefs appear to be declining. 1990s decadal mean temperatures measured on reefs differ from 1980s NOAA buoy data in July and November but not in February.

Sand movement around the base of reefs does not occur evenly even when the reefs are on the same side of the Island and would be expected to be influenced by the same currents and weather.

Two reef surfaces showed a slight increase in rugosity but the most compromised of the reefs has retained a consistent rugosity over the monitoring period.

Trends in algal abundance are not simple: variation occurs across seasons and reefs.

Gorgonian abundance has increased slightly at all three sites.

Lindsay's Reef and Rocky Point have a similar percent coral cover -- both more than twice that of Rice Bay. Coral cover has declined at Lindsay's Reef and Rocky Point, but remained steady at Rice Bay.

Numbers of corals on transects declined at Lindsay's Reef and Rocky Point following the 1998 bleaching event although these declines were not statistically significant.

All three reefs show moderate coral diversity, although Rice Bay displays a slightly greater species diversity than the other two reefs.

Coral species distribution and abundance patterns differ among the reefs. These distribution patterns have remained similar throughout the monitoring period.

Monitoring data reveal that despite two major bleaching events and increased reports of coral diseases, patch reefs around San Salvador have not changed in statistically significant ways between 1992 and 2000.

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