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MONITORING THE CORAL PATCH REEFS OF SAN SALVADOR ISLAND, BAHAMAS

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ABSTRACT

Reports of decline in coral reefs have increased since the early 1980s. Among these reports are those specifically noting the decline on the reefs around San Salvador, Bahamas during the same time period. A long-term monitoring study of the patch reefs around this island was initiated in 1991.

Physical and biological parameters have been monitored since that time using mapping, point intercept analysis, general survey methods and photography. Physical parameters have remained within expected range until July 1998 when sea temperatures were found above normal and salinities were raised. A bleaching event ensued and some corals were lost. While hard-coral cover and species diversity have remained relatively constant over most of the period, there has been an approximately 10% flux in coral colonies per year on the study transects. This represents less than 10% of the coral cover affected by these changes, since the vast majority of change occurs in coral colonies under 5 cm in surface diameter. A background level of damage occurs on these transects, with fewer than 5% of the coral colonies affected and then usually only at minimal levels. Generally this background bleaching does not result in permanent damage to the colonies affected. One primary cause of this background level of damage is abrasion by algae or gorgonians. While algae cover fluctuates seasonally, it appears to have increased over the time of the study. Algae cover fell dramatically following Hurricane Lili in October 1996.

Continuing to track the scoured reefs will help determine whether algae, scleractinian corals or other biota will be the primary re-colonizers of the reefs. Continued monitoring will elucidate normal cycles and patterns of change caused by stress and disease.

INTRODUCTION

Coral reef degradation has been a growing concern worldwide since the early 1980s (Atwood, *et al.*, 1992; Grigg and Dollar, 1990; Wilkenson, 1992; Williams, 1991). What appear to be increasing incidences of bleaching, involving the loss of zooxanthellae or the loss of chlorophyll from these dinoflagellate endosymbionts, have been of major concern (Brown and Ogden, 1993). Some researchers have proposed that increasing sea temperatures, possibly related to global climate change, have driven these events (Cook, *et al.*, 1988; D=Elia, *et al.* 1991; Goreau, 1990; Smith and Buddemeier, 1992). In some regions of the world, the use of dynamite and toxins, including bleach, for fishing has contributed significantly to reef degradation. Numerous local natural and anthropogenic conditions have led to reef decline (Grigg and Dollar, 1990). The majority of reports of reef decline are based on short-term observations of acute changes on the reefs. Few long-term monitoring studies have been conducted to track normal conditions on reefs and to follow changes over time (Lang, *et al.*, 1992).

The reefs of San Salvador, Bahamas have suffered some decline in recent years (Curran, PC; Gerace, PC). This decline has thus far been poorly quantified, and the causes of the decline are obscure. A long-term monitoring study of patch reefs around San Salvador was begun in 1991 (McGrath, 1992; McGrath, *et al.*, 1994). Patch reefs were selected for monitoring since this reef type comprises a significant portion of the reefal structure in the Bahamas, particularly those areas that are heavily used by the resident population and by visitors.

METHODS

As previously described (McGrath, *et al*, 1994), three patch reef sites around San Salvador, Bahamas were selected for study. Ten meter permanent transects (Chiappone and Sullivan, 1991; Loya, 1978; Ohlhorst, *et al.*, 1988) were established at each site, three at Rocky Point (Gerace Reef), and two each at Rice Bay and Lindsay's Reef.

These sites have been monitored three times a year, in February, July and November, with the aid of trained Earthwatch volunteers (Wells, 1995). Monitoring includes measurements for pH, temperature, salinity (refraction), visibility in the water column, and recording observations of new damage, as defined by newly whitened, live hard-coral surfaces. Each July, the transects are belt-quadrat mapped and photographed (Dodge, *et al.* 1982; McGrath, *et al.*, 1994). Digital temperature loggers (HOBOTEMP) have been in place sporadically over the monitoring period, recording temperatures at one or more of these sites at 1.2-hour intervals. Unfortunately, weather and human intervention have conspired to remove one or more loggers at various times, leaving the record they provide incomplete. Point intercept analyses (Brown, 1988; Loya, 1978) have been conducted haphazardly at regular intervals around the transect sites. The purpose of this is to ascertain that the transects continue to reflect the reef area as a whole, with respect to hard-coral cover, and to track changes in surface cover of algae, gorgonians, sponges, sand and rock, both seasonally and over longer time periods.

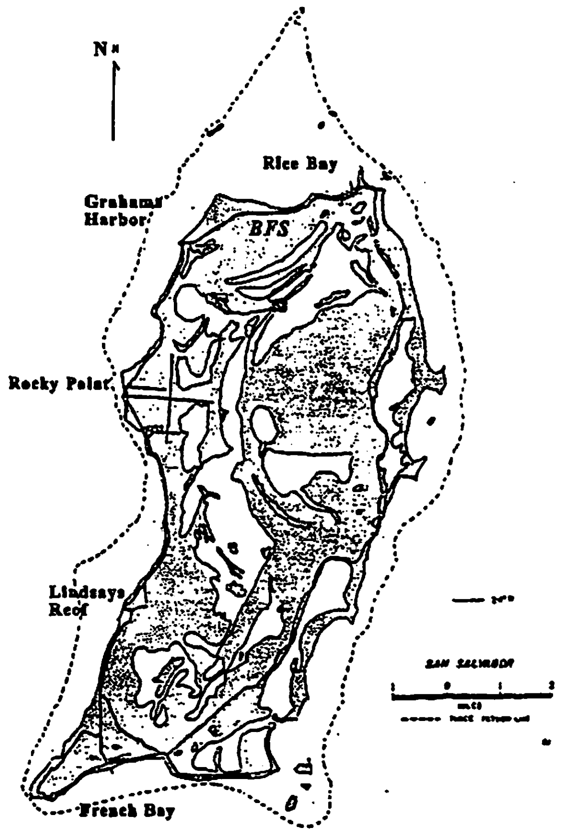

Figure 1. San Salvador, Locating Study Sites

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The surface areas of the reefs being studied have been measured. The perimeter has been defined as a quadrilateral, and a 30m line marked at 1m intervals was used to measure it. The height of the reefs off the sandy bottom immediately surrounding them has been measured by dropping a weighted line marked in 0.5m intervals from the water surface to the sandy bottom, and then reading from the line, swimming to reach parallax. The depth of the water on each edge of the reef was also measured at the same time by determining the point of contact with the line at the water/air interface. Each of these measurements has been done a minimum of 10 times haphazardly along each edge of each reef and repeated at both high and low tides.

Relative three-dimensional relief (rugosity) in each reef is measured by stretching a weighted 5m line over the surface of the reef and then laying a 5m chain along the bottom contour of the reef directly beneath it. The point at which the chain ends is recorded by swimming over the stretched line and looking directly down to site the end of the chain. The run of the chain/5m provides a relative measure of rugosity, where a measurement of 1.0 = a totally flat surface and a measurement of 0.0 = a vertical 5m surface. These measurements are taken numerous times haphazardly around each transect and again several times on each transect.

RESULTS

Physical Conditions

Over the course of the monitoring project, salinity has remained at 37.5 o/oo, with a standard error of <0.01 until July 1998, when it rose to 39.0 (SE = 0.02). The pH has remained at 8.2 (SE < 0.01). Visibility has varied from 7.8m at Rice Bay following a storm at sea in November 1993 to over 23m at Lindsay's Reef and Rocky Point in February of 1996. Visibility has not been consistently low or high for any one reef site, nor has it been consistently low or high at all three reefs sites during each monitoring period. It appears that this measurement fluctuates with the prevailing wind and weather. Since no specific weather data have been obtained over the period of this monitoring, correlation to weather cannot be corroborated statistically.

Since HOBOTEMP logger data has not been consistently available over the monitoring period, a summary of these data is not possible. However, the loggers are yielding some revealing Asnapshots≅ of specific events at the reef sites. One remarkable data set is available from Lindsay's Reef, recorded at 3m depth over the period of elevated temperatures from July to October of 1998. This prolonged elevation in sea temperatures is the most probable cause of a mass bleaching event that began in the fall of 1998 and is still being tracked.

Hand-held temperature data show little fluctuation from year to year at each season and remain within the values expected for this region based on historical temperature data for 24° N/70° W from the last decade (Schweitzer, 1993). The sole exceptions are the temperatures from July 1998.

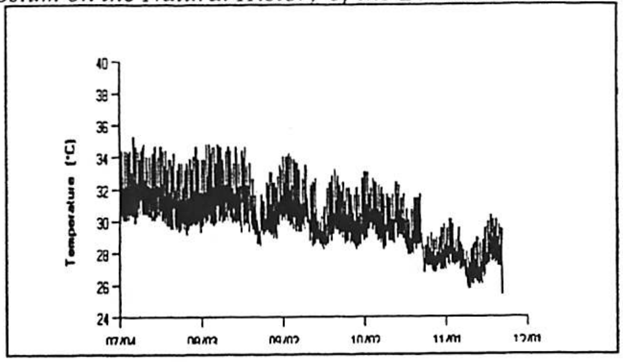


Figure 2. Temperatures at Lindsay's Reef 1998

Reef Measurements

Each reef site is defined as a quadrilateral, and the area of the reef surface represented by the monitoring transects has been measured. The reef surface areas, as measured in July 1995, are as follow:

Rocky Point	2,705m^2
Lindsay's Reef	1,185m^2
Rice Bay Reef	792m^2.

The results of reef relief three-dimensional measurements are presented in Table 1.

Table 1. Relative Relief (Three-Dimensionality)

Reefs	Rocky Point	Lindsay=s Reef	Rice Bay
Haphazard [SE] (N)	0.86 [0.01] (31)	0.71 [0.03] (11)	0.63 [0.06] (15)
Transects	0.66	0.56	0.62

Table 2. Height/Depth in Meters [ ] = SE

Reef Sites	Lindsay=s North	Lindsay=s South	Rocky East	Rocky North	Rocky West	Rice Bay East	Rice Bay West
Mean Height	2.4[0.1]	1.6[0.2]	2.5[0.1]	3.2[0.1]	2.1[0.1]	2.3[0.1]	1.2[0.1]
Mean Depth	3.5[0.1]	2.7[0.2]	3.9[0.1	4.4[0.1]	3.5[0.1]	3.7[0.1]	2.5[0.1]

The mean tide range for 25° 5N 77° 21W, as measured by NOAA is 0.8m (NOAA Tide Tables for November 1996). The following measurements of water depth around the reefs and reef heights off the sand bottom were taken during the summer of 1995 at low tide.

Biological Characteristics

As shown in Table 3, seven species of scleractinian corals are common to all three reef sites, and seven species are found on only one of the three reef sites. The species richness for these reefs shows no significant differences among the reefs (X^2 test, p > 0.4).

Table 3. Stony Corals on theTransects (X = present) RP=Rocky Point; LR=Lindsay=s Reef; RB=Rice Bay

Coral Species	RP	LR	RB
Millepora alcicornis Ml	X		
M. complanata Mc	X		X
Acropora cervicornis Ac	X		
Agaricia agaricites Aa	X	X	
Siderastrea radians Sr	X	X	X
S. siderea Ss		X	
Porites asteroides Pa	X	X	X
P. porities Pp	X	X	X
P. furcata Pf		X	
P. divaricata Pd		X	X
Diploria clivosa Dc	X		
D. labyrinthiformis Dl	X		X
D. strigosa Dst	X		X
Favia fragum Ff	X	X	X
Manicina areolata Mar		X	X
Montastrea annularis Man	X	X	X
M. cavernosa Mcv		X	
Dichocoenia stokesi Ds	X	X	X
Mycetophylia lamarkiana Ml	X	X	X
Scolymia lacera Sl		X	
Eusmilia fastigiata Ef	X	X	

Both photographs and transect maps show that the most abundant corals by colony count are not always the species that account for the greatest hard-coral cover. At Rocky Point, *P. asteroides* and *M. annularis* make up the most significant portion of the hard-coral cover by area (>30%). At Lindsay=s Reef, *Porites* species have the greatest coral cover. At Rice Bay, *M. annularis* accounts for the greatest coral cover. While the colony count of other species is often high, it is clear that many of the coral colonies counted on all of these reefs are quite small.

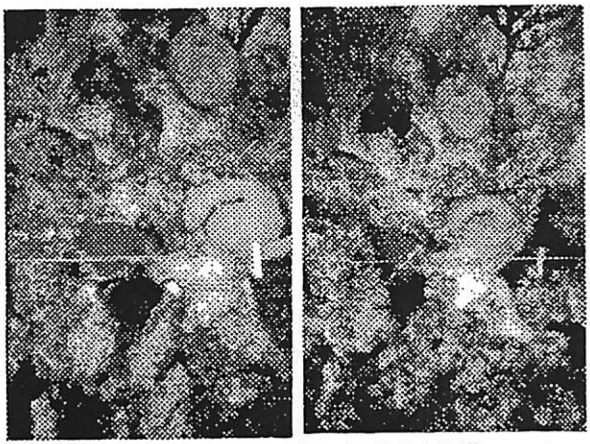
As shown in Table 4, the three reefs differ not only in numbers of corals but also in the species that are most abundant. This table reflects coral counts that were done in July 1996 on the established transects.

Table 4. Total Coral Colonies andMost Abundant Species on Transects

Reefs	Rocky Point	Lindsay's Reef	Rice Bay
Total coral colonies	256	298	100
Most abundant species	*Pa* 123 *Sr* 45 *Aa* 29 *Ff* 28	*Ma* 57 *Pp* 56 *Aa* 45 *Ff* 36	*Ff* 24 *Pp* 17 *Sr* 12 *Ma* 11
Most abundant / total	88%	65%	64%

The abundant *Favia fragum* do not achieve a size of over 6cm in any given colony. However, specimens of the other species found on these reefs can be found in varying sizes.

Point intercept (PI) data from areas surrounding the transect sites have provided quite variable data for coral cover. For example, PIs for Rocky Point in July 1995 indicated a hard-coral cover of 11.1% (N = 1248), while the same procedure performed over the same area in 1996 indicated only 7.6% (N = 1000) hard-coral cover. In comparative photographs and maps of the transects from July 1995 and 1996, no such changes were seen. It would seem then, that PI techniques may not be the best way to evaluate hard-coral cover on these sites.


Rocky Point C Transect
July 1995

Rocky Point C Transect
July 1996

Figure 5. Photos on Rocky Point C Transect

Hard-coral cover was determined from transect maps using a grid system to determine the percent cover in each 0.5 x 1m quadrat along each transect to the nearest 5%. The mean of these areas was then determined.

Table 5. Percent Hard-Coral Cover on Transects

Reefs	Rocky Point	Lindsay's Reef	Rice Bay Reef
1995	9.2	10.6	5.5
1996	9.6	9.9	4.2
1997	9.2	8.9	4.2
1998	9.9	9.5	4.5

The variations from 1995 to 1996 represent less than 10% of the hard-coral cover for both Rocky Point and Lindsay=s Reef. While the change noted for Rice Bay is higher, two factors may account for this. First, Rice Bay Reef is highly compromised and was originally chosen for study for this reason. Second, the relatively low correlation between the 1995 and 1996 maps for one of the transects on this site suggests that either major damage had been done to the site or something had caused change at the site, perhaps a storm or visitors.

The yearly loss and gain of coral colonies on these transects has been followed.

The gains in corals over the period represent recruitment, and all were small colonies. Over 60% of the colonies lost were also quite small, less than 5cm in diameter. No species were extirpated from any of the transects, nor were any new species added in the turnover.

Table 6. Coral Species Lost and Gained from 1995 to 1996

Transect sites	Species	Colonies Lost	Colonies Gained
Rocky Point	*Aa*	5	5
	Dc	0	1
	Ds	2	0
	Ff	11	4
	Man	0	1
	Mar	1	0
	Pa	3	19
	Sr	3	16
Lindsay's Reef	*Aa*	12	4
	Ds	2	0
	Ef	1	0
	Ff	1	1
	Man	1	0
	Mar	2	6
	Ml	1	1
	Pa	4	8
	Pp	3	0
	Sr	6	3

Figure

Note: The abbreviations used here are defined in Table 3.

PIs may be useful in evaluating algae cover changes. Quantitative measures of algae cover noted over the time of this monitoring reflect the changes noted both qualitatively and by photographs of the study sites. Values for algae cover during summer months when algae cover is at its annual lowest level are shown in Figure 6.

PIs consistently showed nearly 70% algae cover on each of the reef sites during the winter months. However, after Hurricane Lili brought 100+ miles-per-hour winds directly over the reefs in October 1996, PI data collected in November 1996 showed that the algae cover on the reefs was well below usual readings, with 41% (N = 355) algae cover on Rocky Point, 61% (N = 607) on Lindsay=s Reef, and 58% (N = 550) on Rice Bay Reef.

New damage on the transects was assessed during each monitoring visit.

Table 7. Number of Corals Showing New Damage, by Season

	1995			1996		
Reef Site	Feb	Jul	Nov	Feb	Jul	Nov
Rocky Point	6	16	11	14	2	9
Lindsay=s Reef	9	21	9	8	0	1
Rice Bay	8	10	4	1	0	3

In all cases, the total hard-coral surface showing new damage was less than 5% of the total hard-coral surface area present. In most cases it was less than 1%. Since new damage seems to occur in all seasons with no consistent variation, it can be considered normal background damage. In virtually every case in which corals were abraded, nearby algae and gorgonians were in positions where wave action regularly caused them to brush against the corals. This would appear to be the most common causative condition.

DISCUSSION

The pH measured during these monitoring studies is within the expected range for this region, according to Field Station records (Gerace, PC). Salinities are similar to those found in the COADS data sets available through the Internet. Since visibility measurements seem to vary with weather patterns, following weather patterns and correlating them to visibility measurements on the reef sites seems appropriate.

Temperature data from hand-held measurements during monitoring visits are very similar to HOBOTEMP measurements where these are available and time frames overlap. Considering the potential quality of the data obtained from these instruments and the ability to obtain readings over time periods when investigators are not on site, it is imperative that a solution be found to the loss of these instruments.

Numerous labs reported higher-than-normal sea-surface temperatures for the entire Western Atlantic in the fall of 1995 and again in the summer and fall of 1998. The 1995 period was one where temperature data became unavailable to this project due to instrument loss. When sea temperatures were recorded during the July and November 1995 monitoring visits, they were within the normal range for that time of year. This was not the case for 1998, however. July temperatures were above the mean for that time of year, and subsequent scrutiny of NOAA SST data confirmed that sea temperatures remained elevated through October. In 1998, a bleaching event occurred. The 1995 event appears to be idiopathic, while the 1998 event is clearly correlated with prolonged elevation of sea surface temperatures.

While the three dimensionality of the transects at Rocky Point and Lindsay=s Reef are somewhat different from those determined for the reef as a whole by haphazard measurements, this should not affect the validity of coral species density and diversity data from these reefs.

While height/depth measurements indicate that the top of the reef should be wet at all tide levels, it has been observed at all three sites that during spring tides where there is significant wave action, areas of the reef may be emergent. Emergence of *Millepora* sp. has occurred in calm waters during spring tides as this coral grows vertically beyond the displacement of maximum spring tides. Gorgonians, particularly *Gorgonia* sp., are also emergent at these times. The emergent tips of both genera have been seen to become necrotic, as a result.

Species present on the transects reflect the most common species at each reef site. While not all species seen at each site by investigators are represented on the transects, species area curves suggest that sampling includes the most abundant populations on these reefs (Loya, 1978).

The rate of hard-coral-colony turnover on the reefs is surprising. When large coral colonies (older and established) are measured, however, they show little change from year to year. Small colonies representing new or young recruits seem much more susceptible to loss. Buddemeier and Fautin (1993) have suggested that loss of coral colonies and recruitment of new colonies may be adaptive in the long term. In spite of the numbers of colonies lost and gained between 1995 and 1996, species diversity and hard-coral density on the transects has been maintained, suggesting a stable coral community structure.

While evidence exists that turf algae populations have been increasing over the last few

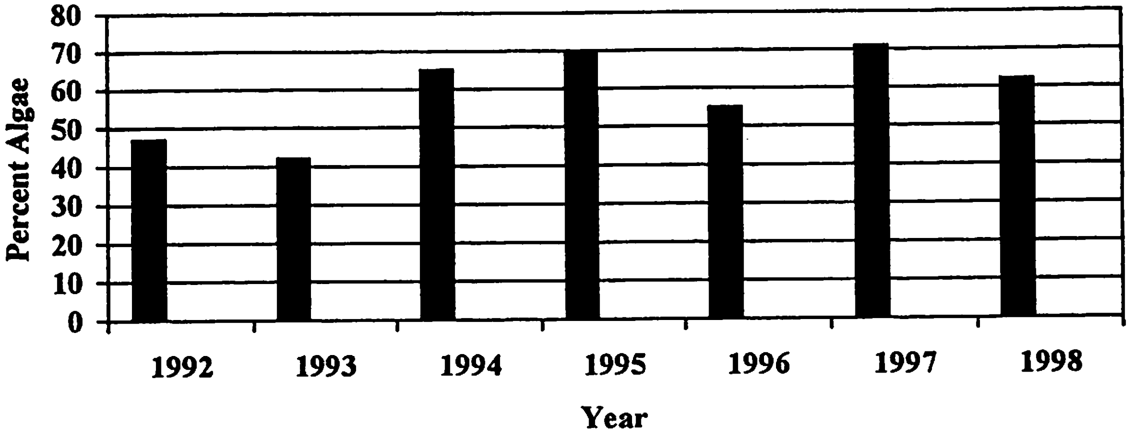


Figure 6. Percent Algae Cover, July, Lindsay's Reef

years, it is clear that major storm events, such as Hurricane Lili, can bring about significant shifts in these populations on the reefs. The decline in algae populations with the hurricane suggests a possible positive role for such events. Since the coral community was not affected directly by this storm, the scouring of algae from the reefs may provide space for future coral recruitment, thus increasing the density of reef-building corals on the sites. With permanent transects in place, research teams should be able to follow such changes.

It is clear by the recovery from the 1995 bleaching that some events have minimal impact on the reefs. It appears from early 1999 data, however, that significant decline has occurred from the 1998 bleaching event. Monitoring that employs all of the techniques used in this study will allow the variations in impact of events to be quantified.

It has been established through this study that, under normal circumstances, a small amount of damage to hard corals does occur at every time of year. While the extent of this damage may vary, the data suggest that damage of between 1% and 5% of the hard-coral surface on a reef of this type is normal for any time of year. This damage is due mainly to local factors such as abrasion by gorgonians and algae. Such normal levels of damage may need to be taken into account when evaluating events such as bleaching and disease.

CONCLUSIONS

Physical data collected by monitoring teams visiting study sites three times a year provide the most reliable data in monitoring these reefs. The data obtained by monitoring teams is consistent with data collected by remote systems where such are available.

The methods of transect mapping and photographic analysis provide the most consistent and reliable monitoring data. These methods have shown that there is a low level of turnover in the corals on these reefs, representing fewer than 5% of the coral colonies present and most commonly less than 1% of the coral surface cover in a given year. This turnover does not seem to affect the species richness or the overall hard-coral cover on the reefs.

There appears to be a normal background level of damage occurring on the hard corals. This does not seem to create significant changes on the study sites since recovery is the most common outcome. Normal background damage levels should be considered whenever damage or disease is studied on such reefs. Some bleaching events may have significant effects on the reefs. Monitoring these events will allow quantification of such effects.

As concern for the vitality of coral reefs continues to mount, the importance of monitoring changes in these ecosystems increases. Circadian, annual, and longer-term cycles undoubtedly exist in coral reef ecosystems. Permanent study sites visited regularly at different seasons can provide a framework for understanding these cycles. Only when normal conditions are known can the significance of changes such as bleaching, storm damage, disease, die-offs and anthropogenic damage be understood. Techniques that provide consistently good data for monitoring studies need to be used. While some instruments may be helpful in quantifying some environmental parameters, it is important to find methods that ensure that data sets are complete. With reliable methods, comparable data from a variety of sites and reef types can be compared, allowing for a more complete understanding of these important systems.

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