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# Comparisons of the 1995 and 1998 coral bleaching events on the patch reefs of San Salvador Island, Bahamas

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**Abstract:** Coral patch reefs around San Salvador Island, Bahamas have been monitored with the aid of Earthwatch volunteers three times a year since 1992. During that period two significant mass bleaching events occurred: autumn 1995, and late summer 1998. Elsewhere in 1995, bleaching was caused by higher-than-normal summer sea temperatures; in San Salvador, however, temperatures were normal. In 1998 a prolonged period of higher-than-normal sea temperatures preceded bleaching on San Salvador and worldwide. During the 1995 event, one of the monitored reefs had twice the percentage of coral colonies bleached as the other two. Bleaching was more evenly distributed among the reefs during the 1998 event. In 1995 *Agaricia agaricites* was significantly more affected than other coral species, with almost 50% of all its colonies showing bleaching. Bleaching was more evenly spread among coral species in 1998, with five species showing bleaching on more than 40% of their colonies. Bleaching began on *Millepora* as early as August during the 1998 event and progressed to other species through the remainder of the autumn. In 1995 bleaching was not seen until late autumn and appeared to impact all affected species at about the same time. Recovery from the 1995 event was complete: no coral death or damage above normal background levels were seen. In the 1998 event, all *Acropora cervicornis* on the monitored reefs died and *A. palmata* was severely damaged. *Millepora* sp. lost almost half of their live tissue, and *Montastraea* sp. showed significant tissue damage following this event. Phototransect analysis suggests that more than 20% of total live tissue on affected species died during the 1998 event. *A. cervicornis* has demonstrated no re-growth from 1998 to 2000 on monitored reefs. Monitoring has suggested significant differences in causes and courses in these two events.

**Key words:** Coral bleaching, patch reefs, sea temperatures, Bahamas.

A severe mass bleaching event occurred in 1995, primarily in October and November, following a period of years in the early 1990s when little coral bleaching was reported in the Western Atlantic. In some areas NOAA satellite-recorded sea temperatures were higher than the last decadal average for the summer (Schweitzer 1993) as seen on the NOAA SST website. This bleaching event encompassed areas that had not been affected during previous mass bleaching events in the region, notably Belize (Lang *et al.* 1992, McField 1995, Ware 1995, Rodriguez 1996, Burke 1997) and the patch reefs of San Salvador Island, Bahamas (McGrath and Smith 1998). While local bleaching events occurred in intervening years, the next mass event took place in 1998. This latter event has been proclaimed the worst bleaching event on record worldwide (Normile 2000). The 1998 bleaching once again affected the reefs around San Salvador Island.

Monitoring of patch reefs around this island has been underway since 1992. Monitoring

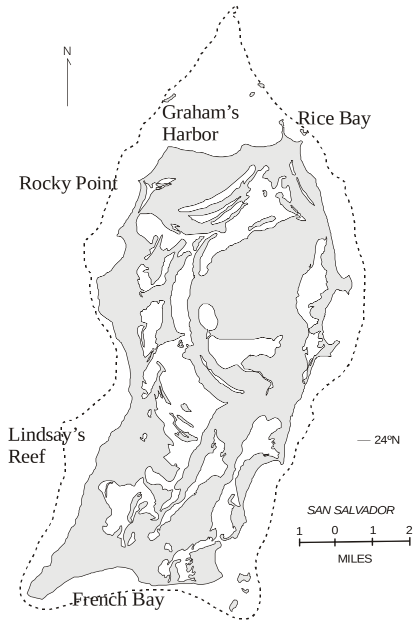


Fig. 1. San Salvador Island, Bahamas, showing Lindsay's Reef, Rocky Point Reef, Rice Bay Reef, and French Bay Reef.

has allowed for both events to be well characterized and tracked through resolution on these patch reefs. Comparisons can now be made between these two events regarding causes, courses, and impact on the reefs.

## MATERIALS AND METHODS

Three patch reefs (Fig. 1) around San Salvador Island, Bahamas-Lindsay's Reef, Rice Bay Reef, and Rocky Point (Gerace) Reef - have been monitored with assistance from Earthwatch volunteers three times a year since the early 1990s (McGrath 1992, McGrath *et al*. 1994, McGrath and Smith 1999). French Bay Reef has been monitored periodically during this period and has been used as a surrogate for Rocky Point Reef when weather did not allow data collection there due to the similarity of the two reefs in scleractinian coral density and species composition (McGrath and Smith 1998).

Ten meter by one meter belt transects have been permanently established at the three primary monitoring sites using galvanized spikes anchored into the reef at five-meter intervals. Species area curves on all reefs in this study become asymptotic well under ten meters. Two permanent transects have been established at each of the smaller patch reefs Lindsay's Reef (1 185 $m^2$) and Rice Bay (792 $m^2$) while three transects have been established at Rocky Point (2 705 $m^2$) (McGrath and Smith 1999).

Monitoring has involved collecting temperature, pH, salinity, visibility data, coral species diversity and density on permanent transects, as well as substrate cover by type, depth of the reef from the water surface, height of the reef from the ocean floor, and rugosity on the reef as a whole using haphazard surveys. Weather permitting; these data are collected three times each year, in February, July, and November. Mapping and sequential photography of the permanent transects have been conducted annually (McGrath *et al*. 1994, McGrath and Smith 1999).

During bleaching events, in addition to the standard monitoring activities, haphazard surveys were also conducted on each of the selected reefs, using two 30 m lines marked at 1 m intervals. These were extended haphazardly along the reef surface within 20 m of the permanent transects. All scleractinian corals within 1 m of each side of the line were identified to species and noted as healthy or bleached. Those that were seen to be bleaching were recorded in one of four categories according to the percentage of live tissue affected: <25%, 25% to 50%, 50% to 75%, or >75% (McGrath and Smith 1998). Since Acroporid corals are widely spaced and minimally represented on these reefs, systematic surveys of each reef area were conducted to determine the presence and health of these coral species. Additionally, coral heads of species that exhibited significant bleaching were marked and followed photographically during and after the event. Seven such corals were tracked from the 1995 event, and ten were followed in 1998; all were outside the transects on Lindsay's Reef.

## RESULTS

Bleaching was first noted by one of us (Smith) in November 1995. In 1998, bleaching was first reported occurring on *Millepora*

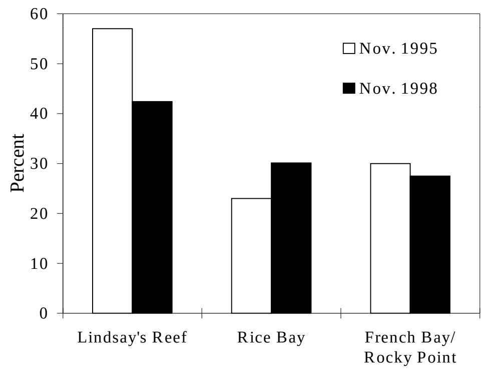


Fig. 2. The percent of colonies bleaching on each reef in November during the 1995 and 1998 events.

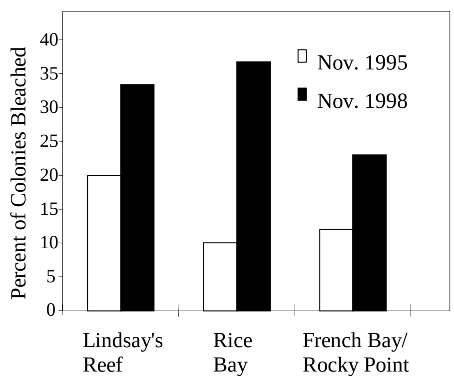


Fig. 3. Percent of all bleached corals counted on all reefs each year.

species in August. By November 1998, numerous other species also were bleaching. November appeared to be the peak bleaching month during both events.

The 1998 event was significantly more severe than the 1995 event ($X^2$, p < 0.01). Over twice the percentage of colonies were affected overall in 1998 (501 out of 1 646 or 30.4%) compared to 1995 (155 out of 1 076 or 14.4%). Lindsay's Reef was significantly more affected than the other two reefs in 1995 ($X^2$, p < 0.01) with over twice the percentage of its corals affected than were affected on either of the other two reefs even though the total number of coral colonies within transects was nearly equal on Lindsay's Reef and Rocky Point Reef, 430 and 389 respectively. Rice Bay Reef transects had approximately half the

TABLE 1

*Total number of corals counted on each reef during each survey*

| Survey Date | Lindsay's Reef | Rocky/ French | Rice Bay |
|---|---|---|---|
| November 1995 | 430 | 389 | 257 |
| February 1996 | 711 | 1113 | 277 |
| November 1998 | 635 | 599 | 412 |
| February 1999 | 848 | 673 | 515 |

number of colonies (257) on it as either of the other two reefs (Table 1). The reefs appeared to have been more equally affected in 1998 (Figs. 2, 3).

While summer 1995 sea surface temperatures in some areas of the world remained higher than the average temperatures of the previous decade for extended periods, this was not the case around San Salvador, as can be seen in Figs. 4a and 4b. Mean sea temperatures for each monitoring expedition are seen in Fig. 4a, while electronic temperature logger data from Lindsay's Reef for 1995 are seen in Fig. 4b. The 1995 temperatures in this area have been corroborated with the aid of NOAA satellite data from Alan Strong (pers. Comm. 1999).

Mean summer sea surface temperatures were higher than the normal mean (29$^{o}$C) in 1998 as seen in Fig. 4a and remained high for an extended period as is seen in the electronic temperature logger data from Lindsay's Reef in Fig. 5.

Data collected on surveys revealed variation in the percentage of bleaching by species. Table 2 lists the twenty-one coral species found in the haphazard bleaching surveys.

For comparative purposes, only those coral species represented by more than 20 colonies in the haphazard surveys in 1995 have been included in Figures 6 and 10. During the 1995 event, *Agaricia agaricites* and *Favia fragum* were significantly more affected by bleaching than other species on the reefs ($X^2$, p < 0.01), with close to 40% of the colonies of each of these species exhibiting bleaching. *A. agaricites* made up 16% of the total coral colonies on the

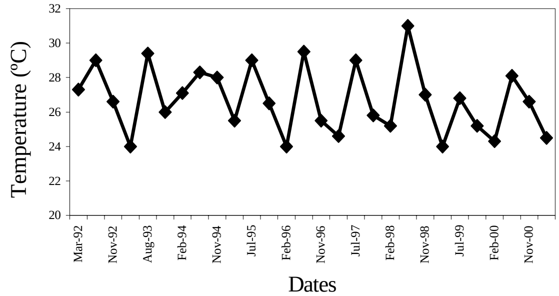


Fig. 4a. Mean temperatures on monitored reefs at approximately 1 m depth for each monitoring session.

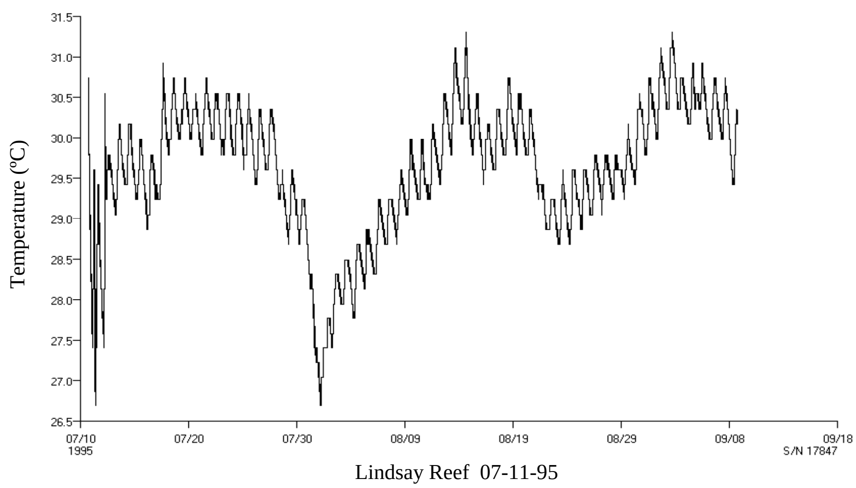


Fig. 4b. Electronic temperature data logger from Lindsay's Reef at 3 m depth from July through November 1995.

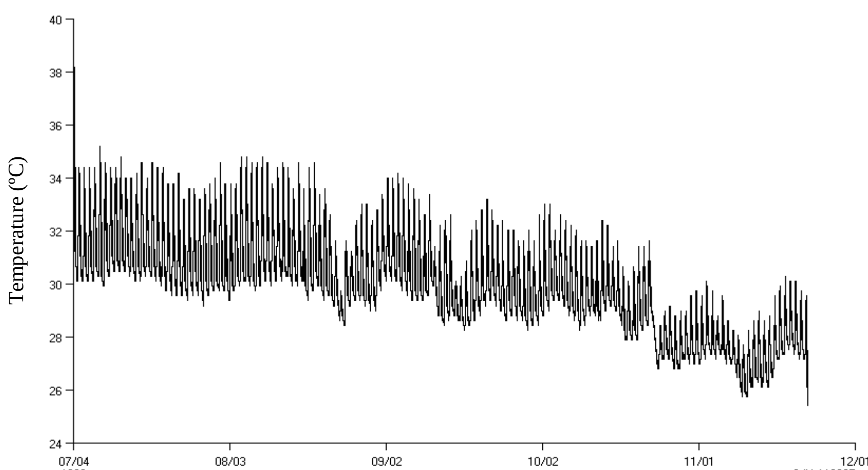


Fig. 5. Electronic temperature data logger from Lindsay's Reef at 3 m depth from July through November 1998.

TABLE 2

*Coral species present on haphazard bleaching survey transects*

| Species | Lindsay's Reef | Rocky/ French | Rice Bay |
|---|---|---|---|
| *Agaricia agaricites* | +/* | +/* | +/* |
| *Dichocoenia stokesii* | +/* | o/* | +/* |
| *Diploria clivosa* | | o/O | o/O |
| *D. labrynthiformis* | * | O | |
| *D. strigosa* | + | +/* | o/* |
| *Eusmilia fastigiata* | O | | |
| *Favia fragum* | +/* | +/* | +/* |
| *Isophylia sinuosa* | o/* | O | |
| *Manicinia areolata* | o/* | +/* | +/* |
| *Millepora alcicornis* | o/* | * | o/* |
| *M. complanata* | o/* | o/* | + |
| *Montastraea annularis* | o/* | o/* | o/* |
| *M. cavernosa* | o/* | | + |
| *Mycetophillia lamarkiana* | O | * | |
| *Porites asteroides* | o/* | o/* | o/* |
| *P. furcata* | * | o/* | o/* |
| *P. divaricata* | O | | O |
| *P. porites* | * | +/* | +/* |
| *Siderastrea radians* | +/* | o/* | +/O |
| *S. siderea* | +/* | o/O | + |
| *Scolymia lacera* | * | * | |

+ = present and exhibited bleaching in 1995 o = present and remained healthy in 1995
* = present and exhibited bleaching in 1998 O = present and remained healthy in 1998
Blank cells indicate absence from the site

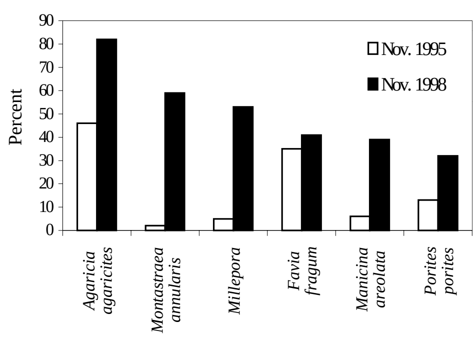


Fig. 6. Percent of all colonies counted in November 1995 and 1998 exhibiting bleaching, for the species having more than 20 colonies in the haphazard surveys exhibiting more than 25% of their colonies bleaching in November 1998.

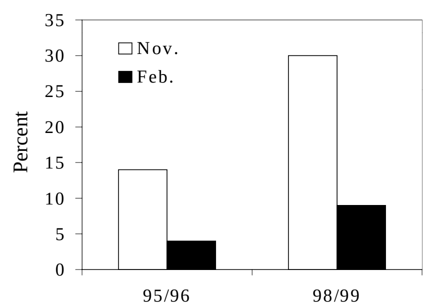


Fig. 7. Comparison of the percent of coral colonies bleaching in November and February of the two bleaching episodes.

transects in 1995 and *F. fragum* comprised 19%. In 1998, five species showed bleaching on 40% or more of their colonies. *A. agaricites* was again the most severely affected, with over 80% of its colonies bleaching. The percent of bleaching in these species was significantly greater in 1998 than in 1995 ($t$ = 9.4, $p < 0.02$). Acroporids were not bleached in 1995. In November 1998, all Acroporids observed on monitored reefs were dead and beginning to be overgrown with algae.

By February 1996 and 1999, the percentage of all colonies showing bleaching during surveys decreased by more than half (Fig. 7). The

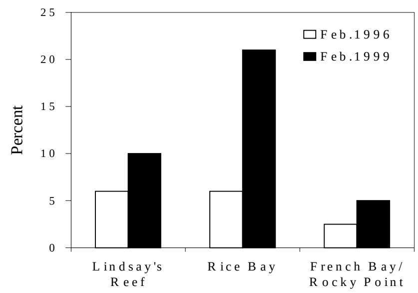


Fig. 8. Percent of corals bleaching in February 1996 and 1999.

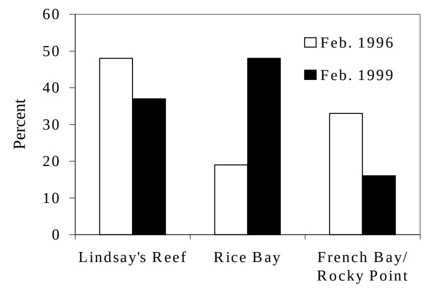


Fig. 9. Percentage of all bleached corals at each reef in February 1996 and February 1999.

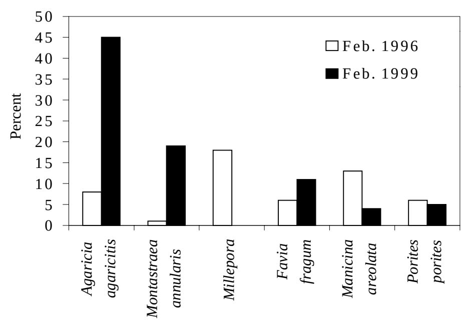


Fig. 10. The bleaching pattern among species in February 1996 and February 1999.

reduction in the percentage of colonies bleaching was significant in each case ($X^2$, $p < 0.05$ for 1995/96; $X^2$, $p < 0.01$ for 1998/99).

In February 1996 the percentage of colonies exhibiting bleaching fell into the range of normal background bleaching seen during non-bleaching seasons (McGrath and Smith 1999).

In February of 1996 and 1999, the pattern of bleaching among the reefs was changing. Bleaching was more evenly distributed among the reefs in 1996, while Rice Bay was significantly ($X^2$, $p < 0.01$) more affected in 1999 (Fig. 8).

The distribution of bleached colonies among the reefs in February of each event can be seen in Fig. 9.

The pattern of bleaching among coral species by February in each of the two bleaching seasons (Fig. 10) was different from that seen in November (Fig. 6). Bleaching occurred in all of the same species in February 1996 as in November 1995 but to a greatly reduced level except for *Millepora* and *Manicinia areolata*, which were bleaching at somewhat higher levels. In February 1999, 45% of the *A. agaricites* colonies continued to exhibit bleaching when other species showed 20% or fewer bleached.

As the bleaching events were resolving in February 1996 and 1999, it became possible to determine how much damage each event caused to the coral populations. Since the beginning of monitoring on these sites a normal background level of death and recruitment has accounted for over 10% of the changes found in transect corals in any non-bleaching year (McGrath and Smith 1999). Table 3 shows the fate of corals on permanent transects that have been monitored annually with maps and with photographs. Table 4 shows the fate of specific coral heads marked and photographed during each bleaching cycle. Both tables suggest that the 1995 event was followed by recovery of the affected corals with little loss of colony numbers or residual tissue damage, above what would be considered normal in a non-bleaching year. During the 1998 event, damage and death of colonies was more evident. *A. cervicornis* completely died out on the monitored reefs was found during the February 1999 bleaching surveys. *A. palmata* showed significant tissue loss. *Millepora* species lost approximately half of their live coral tissue as seen in follow-up bleaching surveys in July 1999. Other species, such as *M. annularis*, lost up to 20% of their live tissue.

## DISCUSSION

Mass bleachings not attributable to local events were reported increasingly through the

TABLE 3

*The fate of corals found bleaching on permanent transects in November 1995 and 1998*

| | November | | February | |
|---|---|---|---|---|
| | # Bleaching | # Recovered | # Damaged | # Dead |
| 1995/96 | 33 | 25 | 3 | 5 |
| 1998/99 | 79 | 59 | 10 | 10 |

TABLE 4

*The fate of specific coral heads marked during November 1995 and 1998 monitored photographically through the course of the bleaching episodes*

| | November | | February | |
|---|---|---|---|---|
| | *Total #* | *# Damaged* | *# Recovered* | *# Dead* |
| 1995/96 | 7 marked<br>7 bleached | All | 0 | 0 |
| 1998/99 | 10 marked<br>10 bleached | 8 | 2 | 0 |

1980s (Williams and Bunkley-Williams 1990, Atwood *et al*. 1992). Such reports declined in number during the early 1990s, most probably due to a period of cooler-than-normal temperatures caused by particulates from the June 1991 eruption of Mt. Pinatubo in the Phillipines that blocked insolation (Kerr 1993). During the summer of 1995, NOAA reported that ocean warming in the Western Atlantic could lead to bleaching. Mass bleaching did occur in the autumn and affected many areas, some of which had not been affected significantly in past events, most notably Belize (Lang 1992, McField 1995, Ware 1995, Rodriguez 1996, Burke 1997). During surveys conducted in the summer and autumn of 1995, no such warming was found around San Salvador, but bleaching did occur. The 1998/1999 bleaching event, however, was clearly associated with prolonged higher-than-usual sea temperatures around San Salvador, as in the rest of the Caribbean. Thus the origins of these two events appear to differ.

In addition to differing in cause, the two bleaching events also differed in severity. In 1998/1999, more than twice the number of coral colonies was affected and the number of species affected was 39% greater than in 1995/96 (18 vs. 11; see Table 2). The effects among the reefs were more similar in intensity. During the 1995/1996 event, *A. agaracites* and *F. fragum* were significantly more affected than other species, and more than twice as many corals at Lindsay's Reef were affected as at the other sites. Reasons for differing intensity in bleaching among the reefs remain obscure. Variation among species in susceptibility to bleaching during a mass event has been reported (Harriott 1985, Fitt and Warner 1995). *A. tenufolia* was found to be affected most extensively in parts of the Belize barrier reef system in 1998, showing that in some areas, at least, a single or a few species can account for the majority of bleached colonies (Aronson *et al.* 2000). The reasons for a more synchronous bleaching pattern among species during the 1995 event and variations in timing and recovery among species evident in the 1998 event remain obscure. Elucidating variation among species in UV-blocking biochemicals may lead to some understanding of these differences (Gleason and Wellington 1993, Holden 2000).

The outcomes of the two events also differ. In the1998/1999 bleaching event, Acroporids died off. Half the Milleporids' live tissue died or was damaged early in the event. Some bleached corals of other species showed damaged areas after recovery, notably *Montastraea* sp. During the 1995/1996 event, however a pattern of recovery was evident, with affected corals returning to pre-bleaching health by February 1996. No recruitment of *A. cervicornis* has been seen on monitored reefs since the 1998 event although evidence for recruitment of this species has been found using haphazard swimming surveys in previous years. Only a few small patches of *A. palmata* have been found at Rocky Point in 2000. The collapse of *A. cervicornis* populations appears to be widespread and unprecedented on both biological and geological time scales (Greenstein *et al*. 1998).

While others have reported changes in reef community structure resulting from these events at a deeper site around San Salvador (Ostrander *et al*. 2000), monitoring at the permanent patch reef sites has shown that percent scleractinian coral cover and Shannon-Wiener species diversity indices and distribution patterns have not changed since monitoring began (unpublished data). Recruitment in subsequent seasons at the patch reef sites has brought coral cover back almost to pre-bleaching levels.

Continued monitoring of all sites is needed to track future such events and to provide data to compare with new bleaching episodes, if they occur.

## ACKNOWLEDGEMENTS

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## RESUMEN

A partir de un monitoreo a largo plazo (desde 1992) y mediante el uso de transectos permanentes (bandas de 10 X 1 m) en tres formaciones coralinas alrededor de la isla de San Salvador, Bahamas, se compara la incidencia local de dos eventos de blanqueamiento masivo global (en 1995 y en 1998) en términos de grado de severidad del fenómeno, especies afectadas, porcentajes de colonias blanqueadas de las mismas, así como sincronía del fenómeno entre los sitios de muestreo y entre las especies y, porcentajes de recuperación o muerte de corales afectados. Contrario a lo ocurrido en otras localidades a nivel global, durante el evento de 1995 no se registraron aumentos anormales de temperatura del mar en San Salvador; mientras que en 1998 un periodo prolongado de altas temperaturas anormales precedió el evento de blanqueamiento registrado. En 1995, el blanqueamiento se hizo evidente a finales del otoño (noviembre), afectando sincrónicamente a todas las especies de coral implicadas. Se presentaron diferencias de severidad entre los puntos de muestreo y entre las especies blanqueadas, siendo *Agaricia agaricites* significativamente más afectada que otras en todos los lugares de muestreo, con cerca del 50% de sus colonias blanqueadas; la recuperación de los corales afectados por el fenómeno fue completa, no registrándose daño o muerte coralina, superior al nivel considerado históricamente normal. El evento de 1998 se inició en agosto, afectando en primer término a colonias de *Millepora* sp., y extendiéndose a otras hacia el otoño. Este segundo evento se presentó más homogéneo en intensidad entre los sitios de estudio y entre las especies coralinas afectadas, con cinco de ellas (*A. agaricites*, *Montastraea annularis*, *Millepora* sp., *Favia fragum* y *Manicina areolata*) evidenciando blanqueamiento en más del 40 % de sus colonias. La recuperación en este caso fue limitada, *Millepora* sp. perdió permanentemente casi la mitad de su tejido vivo. Especies de *Montastraea* mostraron cantidades significativas de tejido dañado después de este evento; adicionalmente se registró la muerte total de *Acropora cervicornis* en todas las formaciones estudiadas y severos daños en

*A. palmata*. Análisis fotográfico de los transectos, sugiere que más del 20% del total de tejido coralino de las especies afectadas, murió durante el evento de 1998. *A. cervicornis* no ha presentado regeneración desde 1998 a 2000, dentro de las formaciones monitoreadas. El estudio sugiere diferencias significativas en cuanto a las causas y desarrollo de cada uno de estos dos eventos.

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