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# The effects of the 1995/1996 Western Atlantic coral bleaching event on the patch reefs around San Salvador Island, Bahamas

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**Abstract:** In October 1995, a mass bleaching event was reported in the Western Atlantic, including areas such as Belize, where little bleaching damage had been recorded previously. Reports based on remote sensing data suggested that sea temperatures in the region were warmer than normal during early October. In November, a monitoring team found that bleaching was well above background levels on the patch reefs around San Salvador Island, Bahamas, a location well out of the main influences of the wider Caribbean. These San Salvador patch reefs have been studied in a long-term monitoring project since 1991. The team found that the overall bleaching level in November was 14% of all coral colonies counted on the three monitored reefs. Bleaching affected the various coral species differently. *Agaricia sp.* were the most affected, as measured both by the number of colonies affected and by the total coral surface area bleached; however, *Agaracia* was not the most abundant species on any of the sampled reefs. Of those corals colonies affected, the percent of surface area bleached differed from reef to reef. On Lindsay's Reef, an average of 42.2% of the surface area of the bleached corals was affected, while at Rice Bay, the average was 31.3%, and at French Bay, the average was 15.2%. Sea temperatures taken at each reef during the census were normal for this time period. Seven corals were marked and photographed at Lindsay's Reef for future analysis. In addition, samples of the surface mucopolysaccharide layer (SML) from bleached and non-bleached *Agaricia* sp. were taken for microbiological analysis. The survey and microbiological sampling were repeated in February. One of the marked coral colonies had 100% of its surface bleached in November; by February, it was well on the way to complete recovery. Metabolic comparisons of bacteria from the SMLs showed that the normal microbiota, which had changed during bleaching, returned to a normal distribution in recovery. The February 1996 census showed that bleaching patterns had remained the same, but that the extent and severity of the bleaching had returned to background levels. Sea temperatures at this time were almost 1°C below normal for the time period. By July of 1996, most corals affected by the bleaching event had recovered, with the number damaged or dead representing <1% of the total hard coral cover on these reefs. While the extent of this bleaching event was significant, the long-term impact was negligible.

**Key Words:** Coral, reef, bleaching, surface Microbiota, zooxanthellae.

Corals under stress will expel zooxanthellae from their endodermal cells, slough endodermal cells, or show a decline in the chlorophyll content of their zooxanthellae. Any of these responses will make the white coral skeleton visible through clear, mostly colorless animal tissue. This is termed "bleaching" (Brown and Ogden 1993). Coral bleaching has been reported increasingly around the world since the early 1980s. Several mass bleaching events, bleaching not attributable to local factors and simultaneously occurring over a wide geographic region, have been documented during this time (Atwood *et al.* 1992, Williams and Bunkley-Williams 1990). In the Pacific, mass bleaching events have been linked to *El Niño* warming events (Glynn 1984, 1988). Some have suggested that many mass bleaching events may have been caused by higher than tolerable sea temperatures (Cook *et al.* 1990), which may result from global climate change (Goreau 1990, D'Elia *et al.* 1991, Miller 1991). Others have suggested that UV irradiance increased beyond tolerable levels due to calmer-than-usual seas, either alone or in combination with other factors, may be a cause of these events (Lesser *et al.* 1990, Gleason and Wellington 1993, Drollet *et al.* 1995). Bleaching can slow the deposition of skeletal calcium carbonate in corals (Goreau and McFarlane 1989). Some mass bleaching events have led to significant declines in the coral reefs affected, including the loss of a species (Glynn and de Weerdt 1991, Goenaga *et al.* 1989).

In October and November of 1995, a mass bleaching event was reported to be under way in the Western Atlantic and Caribbean region. In some areas, sea temperatures 1°C higher than the last decade average for that time of year as reported by NOAA from satellite data (Schweitzer 1993) were reported. This bleaching event encompassed areas that had not been affected during previous mass bleaching events in the region, notably Belize (Lang 1995, McField 1995, Ware 1995, Rodríguez 1996, Burke 1997). Among the places it was in evidence were the patch reefs around San Salvador Island, Bahamas, as found by an expedition under the auspices of Earthwatch, during the third week of November 1995. Teams characterized this event and have followed it through its course.

## MATERIALS AND METHODS

The patch reefs surrounding San Salvador Island, Bahamas have been monitored with the aid of Earthwatch volunteers since the early 1990s (McGrath 1992, McGrath *et al.*1994, McGrath and Smith 1997 in press). Patch reefs form a major reefal system in the Bahamas and are used by the resident population in a number of economically important ways. San Salvador lies on an isolated limestone platform on the Eastern edge of the archipelago in the Western Atlantic. This region lies outside many of the influences of the wider Caribbean based on NOAA current maps.

Initial free swimming visual surveys of several patch reefs around San Salvador conducted at the beginning of the third week of November, 1995 confirmed that bleaching above normal background level (>5% of the hard coral surface) was underway. Three patch reefs on different sides of the Island were selected for surveys. Rice Bay Reef on the north east corner of the Island is a patch reef within 30 m of shore. It has been highly compromised in the last decade and a half, presumably by siltation, as the protective fringing reef has collapsed. Lindsay's Reef is an inshore patch reef in moderate health at the south end of a protected bay on the west side of the Island. French Bay Reef is in a bay on the south coast and, while close to shore, is connected to the fringing reef.

Bleaching surveys were conducted on each of the selected reefs: two 30 m lines marked at 1 m intervals were extended along the reef surface. Pairs of snorkelers were trained to recognize bleaching and to identify a small number of hard coral species (2-5 species/pair of observers) and then assigned to count the colonies of these corals within one meter on either side of these lines. As they swam along the line, they assigned each coral colony to one of five categories based on the estimated amount of the colony's surface area that exhibited bleaching. A coral colony was defined as a discrete coral mass with no visible tissue connection to other coral masses of the same species. Bleaching was defined as a white area of an otherwise colored coral surface with live polyps still in place. Blanching was defined as coral tissue which was almost white but retaining a minimum of the color of surrounding healthy tissue. The amount of each coral head's surface area bleaching was estimated and assigned to one of the following 5 categories: no bleaching; 1 - 25% bleached; 26 -50%

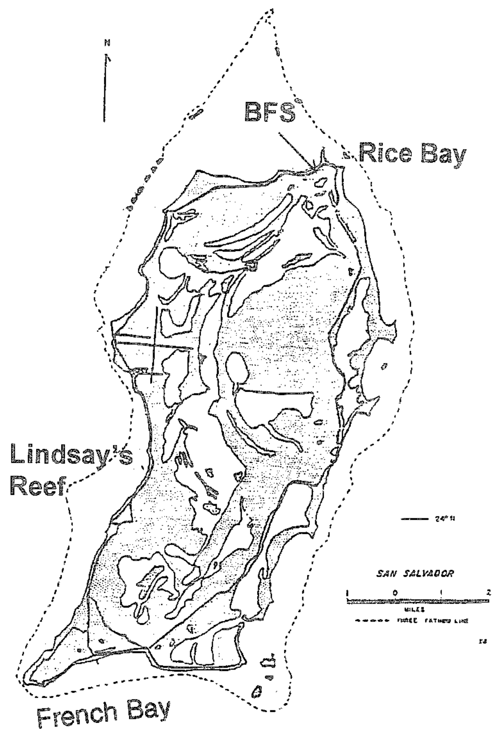


Fig. 1. San Salvador Island, Bahamas showing Rice Bay Reef, Lindsay's Reef and French Bay Reef

bleached; 51 -75% bleached; and 76 - 100% bleached. Frequent surface dives were performed in order to be certain that the corals along reef edges, in crevices, and at depth were noted. These surveys were conducted in November 1995, February 1996, and July 1996.

It was noted that Lindsay's Reef was being affected to a greater degree than the other two reefs. The surveys revealed that *Agaricia sp.* exhibited both greater numbers of coral heads with bleaching and also a greater percentage of their surface area bleached than any other coral species. Reports from Bonaire and Belize indicated that *Montastraea annularis* had been most affected (McField 1995, Ware 1995). Five heads of *A. agaricites* and two heads of *M. annularis* on Lindsay's Reef were selected to be followed photographically and were designated using weighted markers. All of these coral heads were within 1.5 m of the surface. These coral heads were photographed in November and again in February and July.

Three reef sites around San Salvador – Rocky Point (Gerace Reef), Lindsay's Reef and Rice Bay Reef – have been monitored at permanent transects since 1991. These transects have been mapped and photographed each year in July. The condition of all coral heads on these is noted during each of three monitoring visits in November, February and July of each year (McGrath, *et al.* 1994, McGrath and Smith 1997 in press). Bleached coral colonies on these permanent sites were also noted and followed through the resolution of this event. Water temperatures, pH, salinity, and visibility are monitored during each visit to these sites (McGrath, *et al.* 1994).

It has been suggested that the surface microbiotic community structure of corals changes during bleaching (G. Smith, personal communication). To test this the surface mucopolysaccharide layers of marked, bleached and unbleached colonies of *A. agaricites* from Lindsay's Reef were sampled in November 1995 using 3.0cc syringes. Marked recovered colonies were resampled in February and July 1996. Contents of syringes were transferred to 1.5ml vials and kept cold until laboratory processing. In the laboratory, 0.1and 0.001ml subsamples were spread-plated on a glycerol artificial seawater nutrient medium (Smith and Hayasaka 1982) and colonies arising on the surface of the medium were streaked onto fresh plates until pure cultures were obtained. Each pure culture was aseptically removed from plates and suspended in sterile 3.2% seawater. The cell concentration was adjusted to a standard absorbance at 600nm. Each suspension (approx. 890 isolates) was distributed into Biolog GN microtiter plates (Bochner 1989). Each plate contained 96 microwells, each containing a different carbon source, except for the A1 microwell which contained no carbon source. All microwells included mineral salts and tetrazolium violet (to indicate metabolic activity). Plates were incubated for three days at 30'C, after which the absorbance at 490nm was read in each microwell on an automated plate reader. Data were then entered into a database where they were compared with data from known and previously isolated coral bacteria.

## RESULTS

The results of the two 30 m line surveys demonstrated that one reef was more affected than the other two in both the number of coral heads exhibiting bleaching and in the extent of bleaching on those coral heads. It was also shown that one species, *A. agaricites,* was more affected than any other species. Table 1 shows

TABLE 1

*Total corals and percent bleached at three reef sites, November 1995*

| Reef Site | Total Heads | Percent showing bleaching |
|---|---|---|
| French Bay Reef | 389 | 12 |
| Rice Bay | 257 | 10 |
| Lindsay's Reef | 430 | 20 |
| Total for 3 sites | 1 076 | 14 |

that 14% of all corals counted at the three sites showed bleaching in November 1995. At Lindsay's Reef, the number of corals exhibiting bleaching was almost twice that seen on the other two reefs.

Table 2 shows the number and percent of the five most abundant coral species exhibiting bleaching on each of the three reefs in November 1995.

While the greatest percentage of *F. fragum* colonies showed bleaching, these were both low in number and small in size when compared to *A. agaricites.*

Table 3 shows the reported levels of bleaching in all of the affected colonies at each site in November 1995.

*A. agaricites* showed the greatest extent of surface bleaching among the five species most affected. When all coral species at each site were considered, and the levels of bleaching in each species was multiplied by the total number of coral heads affected in November 1995, it was estimated that the bleached surface area of corals at Lindsay's Reef was 42.2%; at Rice Bay, 31.3% and at French Bay, 15.2%.Clearly,

TABLE 2

*Number and percent of the five most abundant species of corals at three reef sites, November 1995*

| Species | French Bay total number | French Bay percent bleached | RiceBay total number | Rice Bay percent bleached | Lindsay's Reef total number | Lindsay's Reef percent bleached |
|---|---|---|---|---|---|---|
| *P. porites* | 122 | 6% | 14 | 7% | 79 | 33% |
| *A. agaricites* | 96 | 14% | 29 | 14% | 73 | 62% |
| *F. fragum* | 33 | 61% | 50 | 16% | 11 | 80% |
| *M. annularis* | 0 | - | 0 | - | 44 | 2% |
| *D. clivosa* | 26 | 4% | 3 | 0% | 1 | 0% |

TABLE 3

*Number of bleached corals and degree of bleaching, by species, at each study site, November 1995*

| Species | <25% | c 50% | c 75% | > 75% |
|---|---|---|---|---|
| *P. porites* | 5FB, 12LR | 2FB, 1RB, 8LR | 3LR | 1LR |
| *A. agaricites* | 11FB, 3RB, 22LR | 2FB, 15LR | 1RB, 8LR | |
| *F. fragum* | 18FB, 8RB, 3LR | 2FB, 3LR | 2LR | |
| *M. annularis* | 1LR | | | |
| *D. clivosa* | 1FB | | | |

FB = French Bay, LR = Lindsay's Reef, RB = Rice Bay

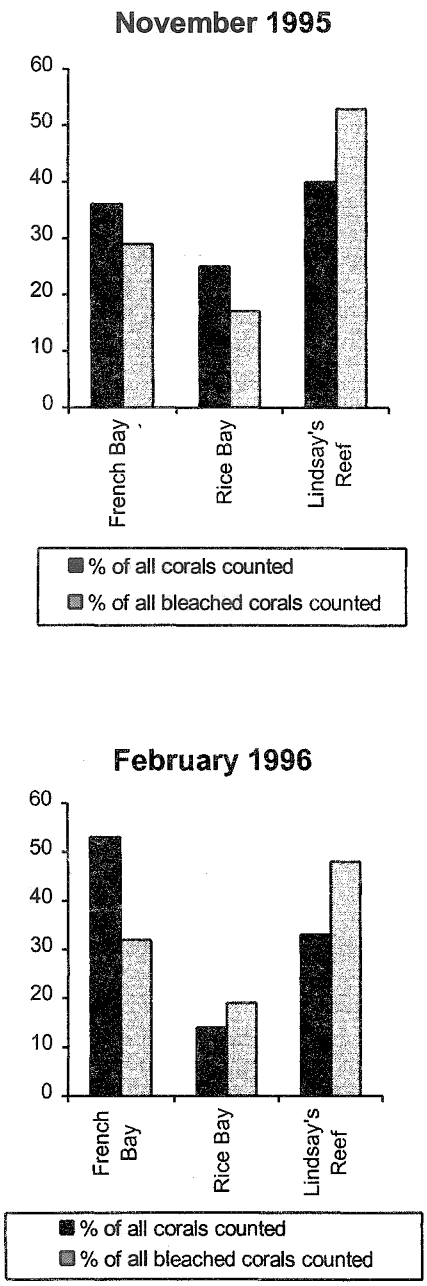


Fig. 2. Percent of all bleached coral heads found on three reef survey sites in November 1995 and February 1996.

the corals at all three reef sites were affected at a level far greater than background bleaching. It was also notable that Lindsay's Reef had more coral surface affected than either of the other two reefs.

However, in the following February, only 4% of all coral heads counted on the three sites were categorized as showing bleaching. Seventy-five percent of those categorized as showing bleaching were marked at a <25% bleaching level. It appeared that the bleaching event was moving toward resolution. As can be seen from Fig. 2, the same pattern of bleaching remained for the three reef sites with the greatest number of coral heads bleaching at Lindsay's Reef. Of all of the bleached corals, *A. agaricites* was still the species showing the greatest number of all coral heads bleached, comprising 29% of all the reported bleached colonies.

While the data above describe the nature and course of the event, they do not indicate the fate of the corals that were bleached in November. Photographs and observation of the marked coral heads at Linsday's Reef suggest that the corals colonies which were bleached in November had most likely recovered or begun recovery by February.

No necrosis or permanent damage has been seen as a result of the November bleaching on any of these marked corals. None of the coral heads which were healthy in November showed any signs of bleaching later in the course of this event.

Further corroboration of the recovery of bleached corals during this event is evident in data from permanent transect maps on three reef sites, two of which were represented in the surveys above.

While the percentages of coral heads showing bleaching on the monitored transects was lower than those seen in the more general surveys, it is clear that the pattern of bleaching was similar. Again, Lindsay's Reef was most affected. Of 25 coral heads showing some bleaching on these transects, 21 were *A. agaricites*. None that recovered showed permanent damage from the bleaching. Five relatively small (<10cm) coral heads died, representing only 0.6% of the 785 coral heads sampled on these transects.

Changes in the composition of the normal

TABLE 4

*The condition and fate of the marked corals at Lindsay's Reef*

| Species | Condition: Nov. 1995 | Condition: Feb. 1996 | Condition: July 1996 |
|---|---|---|---|
| *M. annularis* | 25% bleached | healthy | healthy |
| *A. agaricites* | >75% bleached | 50% blanched | healthy |
| *A. agaricites* | 25% bleached | healthy | healthy |
| *A. agaricites* | healthy | healthy | healthy |
| *A. agaricites* | 25% bleached | healthy | healthy |
| *A. agaricites* | healthy | healthy | healthy |
| *M. annularis* | healthy | healthy | healthy |

TABLE 5

*Results from bleached corals on transect sites at Lindsay's Reef and Rice Bay*

| Reef Site | Total Number of Corals | Total Number Bleached Corals, November 1995 | Percent Bleached Corals, November 1995 | Status of Corals, February 1996 |
|---|---|---|---|---|
| Rice Bay | 183 | 3 | 1.6 | 67% fully recovered33% dead |
| Lindsay's Reef | 313 | 17 | 5.4 | 88% fully recovered12% dead |

TABLE 6

*Percentage of* A. agaricites *associated bacteria clustering in each taxon*

| Taxon | Water Mass | Nov.'95 Normal | Nov.'95 bleached | Feb.'96 | July '96 |
|---|---|---|---|---|---|
| *Agrobacterium* | 0 | 3 | 0 | 4 | 5 |
| *Enterobacter/Klebsiella* | 3 | 8 | 5 | 4 | 5 |
| *Xanthomonas* | 3 | 4 | 8 | 6 | 4 |
| *Vibrio/Aeromonas* | 39 | 24 | 58 | 26 | 22 |
| *Alteromonas* | 23 | 8 | 8 | 10 | 6 |
| *Brucella* | 3 | 26 | 18 | 24 | 28 |
| *Deleya* | 16 | 4 | 0 | 3 | 2 |
| *Pseudomonas* | 0 | 18 | 0 | 16 | 18 |
| *Salmonella/Alcaligines* | 0 | 3 | 2 | 5 | 7 |
| No Identification | 12 | 2 | 1 | 2 | 3 |

microbiota of *A. agaricites* were observed during the bleaching event (Table 6). Most notable were the absence of the *Pseudomonas*-like taxon in the SML of beached corals. This taxon made up 16 to 18 percent of the normal (unbleached) community. Also undetectable in bleached samples were the *Agrobacterium* and *Beleya* taxons. These taxa appeared to be replaced by an increase in the percentage of the *Vibrio/Aeromonas* group in samples from bleached *A. agaricites*. The overall bacterial community changed during bleaching, but returned to a normal distribution after recovery.

## DISCUSSION

The November 1995 bleaching event was wide-spread. It was reported to be occurring across a large area of the Western Atlantic in November. There is some indication that the event may have been triggered by higher than normal sea temperatures throughout this region in early October (Lang 1995, McField 1995, Ware 1995, Burke 1997). While there are no on-site records for sea temperatures around San

Salvador in October, by the third week in November, sea temperatures were at the mean levels for the month reported for the 1980-1989 decade (Schweitzer 1993). In February, sea temperatures at the study sites were 1°C lower than the mean for that month, as reported for the last decade. In November, temperatures taken at a depth of 1 m at Rice Bay Reef and Lindsay's Reef were 26.4 °C (n=6 on each site). In February, sea temperatures at these sites were 24 °C (n=6). If high sea temperatures were a major cause of this bleaching event, there appeared to be a rapid amelioration of these conditions. The rapid return to seasonal sea temperatures and the subsequent extensive cooling may have contributed to the excellent recovery of the corals that bleached during this event.

Another suggested cause of wide-spread bleaching is excess irradiation, particularly in the UV portion of the spectrum, caused by calmer than normal waters (Lesser *et al.* 1990, Gleason and Wellington 1993, Drollet *et al.* 1995). No reports of this phenomenon were found from around the region in October. During November and February monitoring visits, underwater visibility was measured for transect studies as previously described (McGrath *et al.* 1994). Visibility gives a comparative measure of light penetration and sediment load in the water column. Visibility measurements were not better at these times than during previous monitoring visits. In November, visibility ranged from 13 m to 17 m at Lindsay's Reef , and to over 20 m at one place on Rocky Point Reef. In the past, visibilities had been measured from <8 m at one point in Rice Bay in November 1993 to over 21 m at Rocky Point in February 1993. No bleaching above a background level has been correlated to high or low visibility measurements in these studies. The proximal cause of this bleaching event remains obscure.

Since temperatures and visibility as well as all other measured parameters were similar among all the reefs surveyed during this bleaching event, reasons for one reef showing greater effects than others also remain obscure although variability in recovery have been previously reported by Lang *et al.* (1992). Lindsay's Reef is on the protected Western side of the Island, away from heavy population pressure. Continued monitoring may reveal factors that have made this site more susceptible to bleaching.

In past bleaching events, certain coral species have shown particular susceptibility (Harriott 1985, Fitt and Warner 1995). *M. annularis* has been most often affected in other locations. While the most affected corals in this survey were reported as being *A. agaricites*, past surveys on these reefs have shown that *A. fragilis* and *A. tenufolia* also appeared there. While the vast majority of *Agaricia* species on these reefs is *A. agaricites*, it is possible that a small number of these other species may have been included in these data.

The bacterial community distribution in the SML of *A. agaricites* changed during bleaching but returned to a normal distribution upon recovery. The changes in the bacterial community distribution during bleaching are consistent with those previously reported (Ritchie *et al.* 1994, Ritchie and Smith 1995). In particular, the *Pseudomonas* taxon appears characteristically to decrease during bleaching, while the *Vibrio/Aeromonas* taxon increases.

No reasons for increased susceptibility by one or more species during a bleaching event have been found. Buddemier and Fautin (1993) have suggested that bleaching may be an adaptive phenomenon that allows corals to modify their zooxanthellae populations the better to fit changing environments. This theory could be corroborated if future monitoring studies show that the corals found to be bleached in this event remain healthy during the next such event. It would be of benefit to have molecular signatures, such as ribosomal subunit gene sequences, from both the corals and their zooxanthellae in order to compare those signatures before and after a bleaching event. Metabolic activity of corals and their zooxanthellae should also be considered before, during and after bleaching events such as this one.

The wide-spread bleaching event that

occurred in the Western Atlantic in October/November 1995 affected the patch reefs around San Salvador, Bahamas. Bleaching well above background levels was found in November 1995. One of three surveyed reefs, Lindsay's Reef, was significantly more affected than other reefs. *Agaricia sp.* were significantly more affected at all sites than other species. No reasons for this variation among coral species were evident. No proximal cause for this event can be suggested from the data. By February 1996, the bleaching event was close to resolution. No significant damage or loss of hard coral was sustained. The normal bacterial community associated with the SML of *A. agaricites* changed during bleaching but returned to normal distributions upon recovery. Return to pre-bleaching conditions on these reefs continued through July 1996 and have remained. Continued monitoring of these reefs for bleaching, damage, and correlated physical, chemical and biological parameters is needed in order to understand more completely the causes and consequences of such events.

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## RESUMEN

En octubre de 1995 ocurrió un blanqueamiento masivo en el Atlántico occidental, incluso en lugares tales como Belice, donde previamente no habían ocurrido daños de tal índole. Datos captados por medio de sensores remotos, sugieren que temperaturas marítimas más elevadas de lo normal ocurrieron durante los primeros días de octubre. En noviembre, un grupo de observadores descubrió mucho más blanqueamiento que lo normal en los arrecifes aislados–los cuales se habían observado desde 1991–cerca de la isla de San Salvador, en las Bahamas, un lugar bastante alejado de las influencias principales del Caribe. El blanqueamiento afectó distintas especies de corales en maneras distintas. *Agaricia sp.* fue la más afectada, tanto por el número de colonias afectadas como por la superficie total afectada, a pesar de que esta no fue la especie más abundante en ninguno de los arrecifes observados. En noviembre un 14% de las colonias coralinas en los tres arrecifes observados se había blanqueado. De las colonias afectadas, fueron dañados los siguientes porcentajes de las superficies: un 42.2% en Lindsay's Reef; un 31.3% en Rice Bay; y un 15.2% en French Bay. Las temperaturas del mar en cada arrecife fueron normales para esta época del año. Se marcaron y se fotografiaron siete corales en Lindsay's Reef para analizar en el futuro. Además, se sacaron muestras de las mucopolisacáridas en las superficies de *Agaricia sp.*–tanto los blanqueados como los no blanqueados–para un análisis microbiológico. En febrero de 1996 se repitió este examen y análisis de la muestra. Una colonia, cuya superficie estaba totalmente blanca en noviembre, estaba mucho más normal tres meses después. Una comparación metabólica de las bacterias dentro de las mucopolisacáridas mostró que la microbiota había vuelto a su distribución normal. En el censo de febrero 1996 se notó que los patrones de blanqueamiento fueron los mismos. Sin embargo, su extensión y grado fueron normales–es decir, fueron como los observados en años anteriores a 1995. Las temperaturas marítimas fueron casi 1° C bajo lo normal para la época. En julio de 1996 la mayor parte de los corales afectados se habían recuperado, ya que el número de aquellos muertos y dañados representaron menos del 1% de la superficie dura de corales en estos arrecifes. Aunque la extensión del blanqueamiento fue grande, el impacto a largo plazo fue insignificante.

## REFERENCES

Atwood, D.K., J.C. Hendee & A. Mendez. 1992. An assessment of global warming stress on Carribean coral reef ecosystems. Bull. Mar. Sci. 51;1: 118-130.

Bochner, B.R. 1989. Sleuthing out bacterial identities. Nature 339:157-158.

Brown, B.E. & J.C. Ogden. 1993. Coral Bleaching. Scientific American 268;1: 64-70.

Buddemeier, R.W. & D. G. Fautin. 1993. Coral bleaching as an adaptive mechanism. Biosci. 43: 320-326.

Burke, C. 1997. Abstract on Belize bleaching, 1995" January 23, 1997. Online. Coral@aoml.noaa.gov.

Cook, C.B., A. Log n, J. Ward, B. Lu khurst & C. Berg, Jr. 1990. Elevated temperature and bleaching on high latitude coral reef: the 1988 Bermuda event. Coral Reefs. 9: 45-49.

D'Elia, C.F., R.W. Buddemeier, & S.S. Smith, (eds.) 1991. Workshop on Coral Bleaching, Coral Reef Ecosystems nd Global Climate Change: Report of Proceedings. Maryl nd Sea Gr nt.

Drollet, J.H., M. Faucon & P.M.V. Martin. 1995. Elevated sea-water temperature and solar UV-B flux associated two suc essive coral mass bleaching events in Tahiti. Mar. and Freshwater Res. 46: 1153-1157.

Fitt, W.K. & M.E. Warner. 1995. Bleaching patterns of four species of Caribbe n reef corals. Biol. Bull. 189: 298-307.

Gleason, D.F. & G.M. Wellington. 1993. Ultraviolet radiation and coral bleaching. Nature 365: 836-838.

Glynn, P.W. 1984. Widespread coral mortality in the 1982/83 *El Niño* warming event. Environ. Conserv. 11: 133-146.

Glynn, P.W. 1988. Coral bleaching and mortality in the tropical eastern Pacific during the 1982-83 *El Niño* warming event. *In* Ogden, J. and Wicklund, R. (Eds.) Mass Bleaching of Corals in the Caribbean: A Research Strategy. U.S. Dept. Commer., NOAA/NURP Res. Rep. 88-2.

Glynn, P.W. & W.H. de Weerdt. 1991. Elimination of two reef-building hydrocorals following the 1982-83 *El Niño* warming event. Science. 253: 69-71.

Goenaga, C.,V.P. Vincente & R.A. Armstrong. 1989. Bleaching induced mortalities in reef corals from La Parguera, Puerto Rico: a precursor of change in the community structure of coral reefs. Carib. Jour. Sci. 25:59-65.

Goreau, T.J. 1990. Coral bleaching in Jamaica. Science 343: 417.

Harriott, V.J. 1985. Mortality rates of scleractinian corals before and during a mass bleaching event. Mar. Ecol. Prog. Ser. 21: 81-85.

Lang, J.C. 1995. Yet another bleaching note.@ November 21, 1995. Online. Owner-coral-list@reef.aoml.erl.gov.

Lang, J.C., H.R. Lasker, E.H. Gladfelter, P. Hallock, W.C. Jaap, F.J. Losada & R.G. Muller. 1992. Spatial and temporal variability during periods of "recovery" after mass bleaching on Western Atlantic coral reefs. Amer. Zool. 32: 696-706.

Lesser, M.P., W.R. Stochaj, D.E. Tapley & J.M. Shick. 1990. Bleaching in coral reef nthozo ns: effects of irradi nce, ultraviolet radiation, and temperature on the activities of protective enzymes against oxygen. Coral Reefs 8: 225-232.

McField, M. 1995. Bleaching Update: Belize.@ October 27, 1995. Online. Owner-coral-list@reef.aoml.erl.gov.

McGrath, T. A. 1992. Long-term study of coral bleaching events on the reefs of San Salvador Isl nd, Bahamas. in. Proceedings of the 4th Symposium on the Natural History of the Bahamas. W. Hardy Eshbaugh, ed. Bahamian Field Station: 83-89.

McGrath, T..A., D.T. Gerace & G.W. Smith. 1994. Monitoring the patch reefs of S n Salvador, Bahamas for changes due to bleaching and dise se. Proceedings of the 26th Meeting of the Association of Marine Laboratories of the Carribean, S n Salvador, Bahamas. Compiled by Donald T. Gerace Bah mi n Field Station: 147-156.

McGrath, T.A. & G.W. Smith (in press). Monitoring the coral patch reefs of San Salvador Island, Bahamas. Proc. 7th Symp. Ntl. Hist. Bahamas.

Miller, J.A. 1991. Does coral bleaching mean global warming? Biosci. 27: 454-460.

Ritchie, K.B., J.H. Dennis, T.A. McGrath, & G.W. Smith. 1994. Bacteria associated with bleached and non-bleached areas of *Montastraea annularis*. In Kass, L. (ed.). Proceedings, 5th Symposium on the Natural History of the Bahamas. Bahamian Field Station, San Salvador, Bahamas, 75-79.

Ritchie, K.B. and G.W. Smith. 1995. Carbon source utilization patterns of coral associated marine heterotrophs. J. Mar. Biotech. 3:105-107.

Rodriguez, R.E. 1996. Re: bleachings and spawnings@. October 29, 1996. Coral@aoml.noaa.gov. October 29,

Schweitzer, P. N. 1993. Modern Average Global Sea-Surface Temperatures. U.S. Geological Survey Digital Data Series DDS-10, U.S. Dep. of the Interior.

Smith, G.W. & S.S. Hayasaka. 1982. Nitrogenase activity associated with *Halodule wrightii* roots. Appl. Environ. Microbiol. 43:1244-1248.

Ware, J. 1995 Bonaire. Bleaching.@ November 22, 1995. Online. Owner-coral-list@reef.aoml.erl.gov.

Williams, E.H. & L. Bunkley-Williams. 1990. The world-wide coral reef bleaching cycle and related sources of coral mortality. Atoll Res. Bull. 335:1-72.