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THE RELATIONSHIP BETWEEN ENVIRONMENTAL FACTORS AND CORAL BLEACHING AT LEE STOCKING ISLAND, BAHAMAS IN 1990

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ABSTRACT

Following the Caribbean-wide bleaching event of 1987 we instituted monitoring of environmental factors that might contribute to stress on coral reefs at our marine laboratory in the Bahamas. Once again in 1990 extensive bleaching occurred from shallow water to 33 m. Elevated water temperatures were closely associated with the start of this bleaching. Periods of calm wind with little rain and high insolation in the summer preceded these elevated water temperatures. The extensive nature of the bleaching in 1990 may be attributable to the long duration of elevated temperatures, atypical for this site. Density cascading of warm hypersaline water on to the shelf in the summer may be an additional stress on deeper reefs at this location.

INTRODUCTION

The apparent decline of coral reefs worldwide has prompted the Caribbean Marine Research Center (CMRC) to establish a long-term study of reefs in the Exuma Cays, Bahamas. During the fall of 1987 scientists observed bleached hard and soft corals, sponges, and anemones from shallow water to 95 m (Lang et al., 1988). This Caribbean-wide bleaching event of 1987 was believed to be associated with elevated water temperatures but we could find no long-term in-situ seawater temperature data set anywhere in the Caribbean to address this question. At that time CMRC started monitoring more closely environmental conditions on reefs near our marine laboratory at Lee Stocking Island (LSI), Bahamas. The site is particularly interesting because: 1) coral reefs are well monitored, thus the timing of bleaching can be well documented, 2) there is little anthropogenic contribution to environmental stress (e.g., sewer discharge, heavy metal, or pesticide pollution), 3) turbidity stress is very low due to the lack of river runoff, and 4) a range of depths and habitats are in close proximity to the laboratory facilitating the study and comparison of reef systems. Other unique physical characteristics of the site include: 1) extreme temperature range experienced by shallow-water coral reefs in the Bahamas (18-32°C), and 2) reefs are situated on the edge of a large shallow-water bank that rapidly responds to local meteorological conditions and generates density currents (masses of warm saline water) that might affect deeper reefs on the shelf.

Lang et al. (1988) hypothesized that elevated water temperature in 1987 resulted in coral bleaching and that the cause of this warm water was local calm wind conditions. Other contributing factors proposed include density cascading of warm saline water off the bank and clear skies resulting in synergistic light-related effects. Following the 1987 coral bleaching event, CMRC instituted continuous water temperature monitoring and measurement of meteorological parameters might that influence water temperature. Elevated water temperatures at our site could be due to a regional rise in temperature (i.e., an ENSO event) or simply localized conditions such as calm winds and clear skies or a combination of the two. Past events in the Florida Keys (Jaap, 1979; 1985) and locally (Lang et al., 1988) have suggested that doldrum periods contribute to warm water events resulting in bleaching. Duration of the thermal stress also may be a factor in determining the magnitude of a bleaching event. Here we address the hypothesis that elevated water temperature resulted in the coral bleaching event of 1990 in the Bahamas and identify the potential cause of thermal-related stress on corals.

METHODS

Visual observations on coral reefs were made by divers on a weekly basis and more frequently after the start of bleaching. Three locations were monitored: Rainbow Garden (on the bank), Perry Reef (shallow fringing reef, 20 m), and Adderley Dropoff (shelf-edge reef, 33 m) (Figure 1). Thermographs, recording water temperature every 30 min, were deployed at several locations on the bank, as well as, at Perry reef and the shelf edge off Adderley Cut (Figure 1)(see Wicklund et al., 1993 for other locations). A General Oceanic current meter with conductivity probe was used to determine salinity in Adderley Cut (1990) and at Adderley Dropoff (1992). A Campbell Scientific meteorological station summarized hourly measurements of air temperature, relative humidity, insolation (pyranometer, cal/cm^2), rainfall, wind speed and direction from 1990-1992.

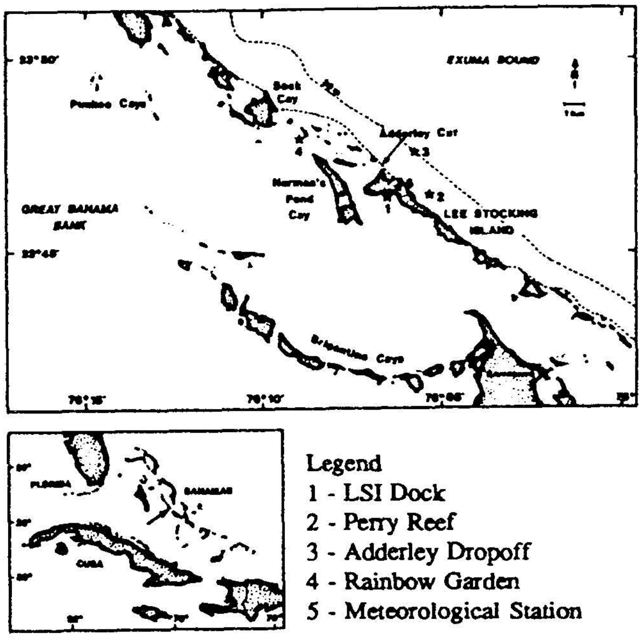

Figure 1. Map of Lee Stocking Island and Sampling Locations.

RESULTS

Bleaching Observations

Following the massive bleaching event of 1987, little bleaching was observed in 1988 and 1989 and cannot be attributed to any specific environmental cause. Widespread bleaching was again observed in mid-August 1990 at 20-25 m on the shelf-edge fringing reef and involved 1-2% of the reef. By mid-September bleaching was observed in a depth range of 2-46 m. Bleaching at 20 m consisted of about 25% of the reef. Bleached organisms included stony coral, gorgonians, and sponges (see Table 1 for list of species). Bleaching continued to increase in number of colonies affected through the first week of October. Several colonies of *A. cervicornis* and *P. porites* that bleached and survived in 1987 died in 1990. One loggerhead sponge (*Spheciospongia vesparia*) at 35 m, reduced in size through tissue loss in 1987, bleached again in 1990. No further bleaching was observed in 1991 or 1992.

Table 1. List of species bleached in 1990 at Lee Stocking Island.

Porifera (sponge)	Scleractinia (hard coral)	Gorgonacea (soft coral)
Aplysina spp.	*Acropora cervicornis*	several unidentified species
Spheciospongia vesparia	*Agaricia agaricites*	
Xestospongia muta	*Diploria strigosa*	
	Montastrea annularis	
Hydrozoa (fire coral)	*Montastrea cavernosa*	
Millepora alcicornis	*Porites porites*	

Hydrographic.— Bank (3 m)

Coral bleaching occurred at Lee Stocking Island following a short period (18 days) of daily average water temperatures above 30.5°C on the bank in July-August 1990 followed by another temperature peak in mid-September (Figure 2). A maximum temperature of 32.5 was reached on 23 September 1990. The July monthly average for 1990 did not differ from surrounding years, but August and September were significantly warmer in 1990 (Table 2). The 5-yr record at the LSI dock distinctly shows a longer-term maxima in 1990 (Figure 3); this trend needs to be substantiated.

We examined two trends in water temperature in detail. One hypothesis was that a more rapid rate of warming in the spring might result in a pool of warm water upon which singular events in the summer could react. Spring water temperature increase is relatively linear from April through June, so we compared the rate of spring temperature rise for 1988-1992 (Table 3). In 1990 the rate of spring water temperature increase was not exceptional, in fact in most years the temperature rose more rapidly than in 1990.

Typically by the end of August water temperature starts its annual decline. Examination of plots of the yearly data suggest that the warm period was prolonged in 1990 (Figure 2). To test this hypothesis we examined the temperature trends from July through September. Our hypothesis of prolonged warming would be confirmed if the slope of the trend was significantly less than in other years. For bank waters 1990 was the only year with a significant positive slope for this period confirming the prolonged warming period in 1990 (Table 3).

Great Bahama Bank salinities are typically 38 ppt and can reach 43 ppt (Pitts and Smith, 1993), thus adding a synergistic stress factor to the local environment (Marcus and Thorhaug, 1981). During July and August 1990 pulses of warm (to 31.2°C) saline (to 40 ppt) water exited through island passes onto the shelf. Bank patch reefs previously studied by Lang et al. (1988) are bathed in these water masses without apparent detrimental effects.

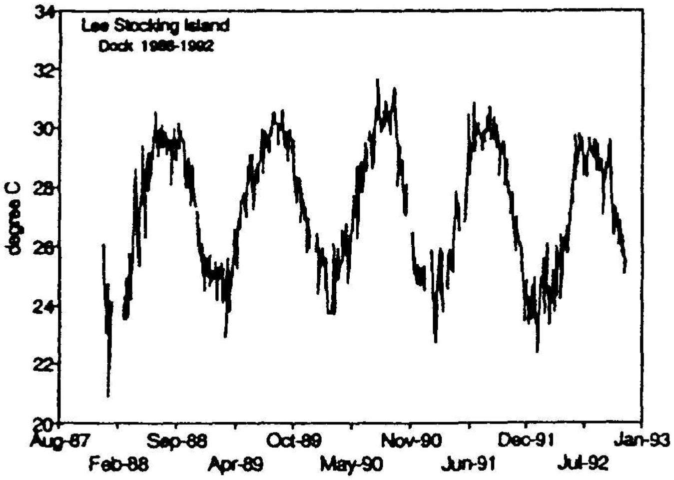

Figure 2. Five-year record of water temperature at the LSI Dock.

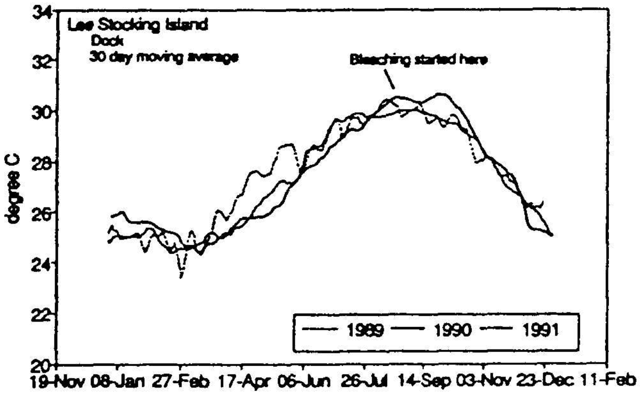

Figure 3. Annual water temperature record for 1989-1991 at the LSI Dock.

Hydrographic.— Fringing Reef (20 m)

Perry reef also exhibited two temperature peaks in July/August and at the end of September in 1990 with the second being higher. In addition the longer-term maxima in 1990 is evident. Warming by month paralleled that observed on the bank with September being significantly warmer than other years (Table 2). Increasing temperature through the summer also is evident at this location (Table 3). No salinity data is available from this area, though Perry Reef is upstream from the pass at the north end of the island. Given the prevailing currents, hypersaline waters would not be expected to reach this reef on a regular basis, though they are known to occur there.

Hydrographic.— Shelf-edge Reef (33 m)

The deepwater basin of Exuma Sound acts as a buffer to water temperature change, being warm in the winter and cooler in the summer than shallow bank waters. Instrument failure resulted in missing most of July and August 1990 for this location. Early July was no warmer than other years but by the last week in September temperature was elevated and comparable to the fringing reef (Table 2). Though our data are more fragmented at the shelf-edge reef, the longer-term trend is still evident and indicates that in 1990 water temperatures at 33 m were the highest of the 5-yr record; even at 98 m this warming was evident.

There was no conductivity recorder on the shelf in 1990, but data from a near-bottom recorder in 1992 showed that high salinity pulses can reach the bottom at this site, a mechanism for carrying warm water to the deep reefs.

Table 2. Comparison of average monthly water temperature for summer months by year. Means compared by ANOVA followed by Tukey's HSD test. Underlined years are not significantly different.

	Tukey's HSD Test for Differences Among Years LOW<------------------------>HIGH					Monthly Average Temperature (°C) 1988	1989	1990	1991	1992
July										
Dock	1992	1989	1990	1988	1991	29.70	29.52	29.61	29.74	29.16
Perry Reef	1989	1990	1988	1992		28.23	27.86	28.17	---	28.78
Adderley (2-21 Jul)	1990	1988	1989	1991	1992	26.97	27.02	26.78	27.39	28.15
August										
Dock	1992	1988	1991	1989	1990	29.34	30.10	30.49	29.96	29.27
Perry Reef (21-31 Aug)	1988	1989	1992	1990	1991	28.44	28.68	29.53	29.53	28.80
September										
Dock	1992	1988	1991	1989	1990	29.56	29.74	30.59	29.62	28.48
Perry Reef	1992	1988	1989	1991	1990	28.57	28.94	29.79	29.45	28.44
Adderley (28 Sep - 10 Oct)	1992	1989	1988	1991	1990	28.72	28.71	29.65	28.99	28.65

Table 3. Comparison of water temperature trends for spring and summer at two locations. Slopes compared by ANCOVA followed by Tukey's HSD test. Underlined years are not significantly different.

Tukey's HSD Test for Differences Among Years
Trend Slope

	LOW<-------------------------				->HIGH
Spring (April-June)					
Dock	1989	1990	1988	1991	1992
Perry Reef	1991	1990	1989	1992	1988
Summer (July-September)					
Dock	1992	1988	1991	1989	1990
Perry Reef	1991	1992	1988	1989	1990

Meteorological.—

Wind data at Lee Stocking Island are available for 1990-1992; typically July-October is the calmest period of the year. There is no significant difference in number of days of low winds (≤ 3 m/s) between 1990 and 1991, but 1992 was significantly more windy (Table 4). In addition 1992 had significantly fewer days with above average insolation (Table 4). There was no difference in the number of summer days with rainfall between 1990 and 1991, though 1990 had only about 60% of the total summer rainfall of 1991.

When examined in detail the prolonged warm water period from 24 July to 3 October 1990 was the result of three rises in temperature closely related to declines in wind speed (Figure 4). Over a 14-day period in late July water temperature increased from a daily average of 28.6° to 31.7°C, concurrent with a period of low winds, little* The second small rise is related to a short period of reduced winds (28-31 Aug) and no increase in insolation (Figure 4). The final temperature rise is associated with a 12-day calm period (14-30 Sept) with an increase in insolation followed by rain and declining water and air temperature.

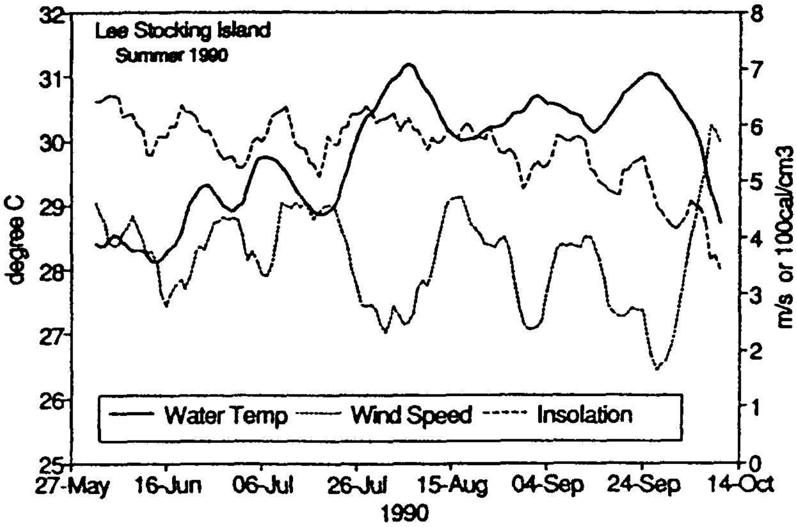

Figure 4. Daily average bank water temperature, wind speed, and insolation for the summer of 1990.

*rain, and high insolation.

temperature. Rainfall, not previously considered an important factor, can have a substantial influence on water temperature. Exposure to elevated water temperature (>31°C on the bank) in 1990 appeared to take more than a couple of days, but less than three weeks, to initiate bleaching. Prolonged elevated temperatures may be the primary contributing factor to the magnitude of the bleaching event in 1990.

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