PROCEEDINGS

OF THE

FOURTH SYMPOSIUM

ON THE

NATURAL HISTORY OF THE BAHAMAS

Edited by
W. Hardy Eshbaugh

Conference Organizer
Donald T. Gerace

Bahamian Field Station, Ltd.
San Salvador, Bahamas
1992

Printed in USA by Don Heuer

ISBN 0-935909-41-9

LONG-TERM STUDY OF CORAL BLEACHING EVENTS ON REEFS OF SAN SALVADOR ISLAND, BAHAMAS

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THE BIOLOGY OF CORAL BLEACHING

Many cnidarians and sponges harbor endodermal symbiotic algae termed zooanthellae. Symbiodinium microadriaticum is the zooanthellate alga found in Caribbean scleractinian corals. While it has been suggested that there are several species that inhabit the variety of coral hosts found throughout Caribbean reef systems (Sandeman, 1988), the more commonly held view is that this one species exists in a variety of strains physiologically adapted to each host (Schoenberg and Trench, 1981). These symbionts contribute to the nutrition of their hosts by translocating photosynthetically fixed carbon to host tissue (Muscatine and Porter, 1977) and in return receive nitrogen and other essential nutients from the host. It is not yet clear how these endosymbionts are passed into newly produced cells (Gladfelter, 1988).

Corals and sponges have been known to expell their zooanthellae in response to various environmental stresses such as significant salinity changes (Goreau, 1964; Reimer, 1971), siltation (Acevedo, et al.,1989), increased irradiance (Harriott, 1985; Lesser, et al., 1990), and periods of either unusually high or low water temperature (Brown and Suharsono, 1990; Cook, et al., 1990; Gates, 1990). This expulsion of zooanthellae is termed "bleaching" because the animal lightens in color as algae are lost and the skeletal elements become visible through the transparent body of the organism. The suseptibility to bleaching in response to each of the above factors appears to be related to the position of the particular member of each coral species on the reef (Savina, 1989) and to the latitude of that reef (Cook, et al., 1990). Deep water corals seem to be more suseptible to such factors as thermal stress than are shallow water corals of the same species on the same reef system. Corals in the higher latitudes such as Bermuda appear to be less suseptible to thermal stresses than are the same species of coral south of the Bahamas. It is not known whether these apparent variations in suseptibility are due to selection of site adatpted larvae or adaptation of the organism after larval recruitment.

Species vary in their suseptibility to bleaching. This is likley due to variations in the metabolic relationships between each coral species and its strain of zooanthella (Schoenberg and Trench, 1981). Whenever bleaching occurs, it is most probably due to the high production of free radicals by oxygen liberated from the zooanthellae which cannot be depleted quickly enough by the host tissue (Lesser, et al., 1990). This metabolic disruption is compensated for by the removal of the source of free oxygen, thus reducing the problem even though other problems are created.

Reef building stony corals have been shown to have their ability to lay down skeletal materials reduced by a substantial reduction in their zooanthellae, thus reducing their growth rates and jeopardizing their long term survival (Goreau and McFarlane, 1990; Harriott, 1985). Further, the feeding success of coral polyps is drastically reduced in such instances. Such bleached animals may be more suseptible to other stresses, to diseases, and to algal overgrowth or to interspecific competition for space on the reef (Kleppel, Dodge and Reese, 1989).

Recovery from bleaching is possible. When conditions return for the proper host/alga interaction to be reestablished, zooanthellae can be found in ever increasing numbers in the host tissue as residual members of the original association reproduce in the host tissue. Recovery can be rather rapid, beginning within a day or two following the bleaching episode. Recovered corals are as healthy as unbleached corals (Hayes and Bush, 1990). However, the longer corals remain bleached, the less likely they are to recover (Ghiold and Smith, 1990; Gladfelter, 1988). Polonged periods of bleaching without recovery lead to the death of the coral. The most common occurance following coral death on a reef is overgrowth by filamentous algae, making it impossible for other corals to establish a colony to replace the one that was lost (Ghiold and Smith, 1990). Results of the long-term and drastic modification of the reef environment include the loss of the reef's structural integrity as carbonate productivity ceases. The short and long-term ecological effects of bleaching have been summarized and are presented in Table 1.

RECENT BLEACHING EVENTS

Until recently, bleaching has been seen as primarily local events. Wide-spread bleaching did occur in the Pacific following the 1982-83 El Niño, Southern Oscillation event (Brown and Suharsono, 1990; Glynn, 1984; Glynn, 1988). It was correlated with extraordinarily high water temperatures brought about by this event. Some residual effects were noticed in Atlantic reefs but they were not extensive or long lived (Williams and Bunkley-Williams, 1990). Recovery from this bleaching was good in the Pacific.

Recent events in the Western Atlantic have been more severe. A massive and wide-spread bleaching event began in the area from Florida to Columbia during the summer of 1987 and continued into 1988. Later tracking of the event showed that it was evidenced world-wide and not confined to the wider Caribbean (Roberts, 1987; Roberts, 1988; Williams and Bunkley-Williams, 1990). Recovery from this event was poor in many instances (Ghiold and Smith, 1990; Gonega, Vicente, and Armstrong, 1989; Gonega, 1991; Goreau and McFarlane, 1990).

This massive and wide-spread event was followed by lesser events in 1988-89 and in 1989-90. The most severe and extensive bleaching ever reported in the Western Atlantic occurred in 1990 (Miller, 1991). Fire coral mortality was significant at the beginning of the event. The Bahamas and other northern regions were the most severely affected. Bleaching of significant proportion was also reported from parts of the Pacific such as in Hawaii and Fiji during this time. Recovery is reported to be underway, although much mortality has occured (Williams, 1991).

Initial study of the 1987-88 event showed that bleaching had followed a prolonged period of higher than usual summer sea surface temperatures in the region (>30°C) and extraordinary water clarity due to a period of gentler than average trade winds. These factors are thought to have worked synergistically and in some regions may have been exacerbated by pollution stresses heightening the extent of the effect. Bleaching has begun in the summer months and has continued well into the winter months, with little sign of recovery in some cases (Gates, 1990; Goreau and McFarlane, 1990; Ogden and Wicklund, 1988; Williams and Bunkley-Williams, 1990).

The 1987 event has received much attention from both the scientific community, from politicians, and from the popular press. During the 1987 event, Ernest Williams set up a reporting scheme for tracking bleaching throughout the region through the Marine Ecological Disturbance Information Center at the University of Puerto Rico, Lajas, which is also keeping records on Diadema mortality and recovery as well as turtle tumors, fish mortality, and marine mammal strandings.

Senator Lowell Weiker (Republican, Connecticut), a long time supporter of the National Oceanic and Atmospheric Administration Undersea Research Program (NURP), suggested in 1987 that steps be taken to do something about the bleaching problem (Palca, 1987). NOAA sponsored a conference in 1988 (Ogden and Wickland, 1988). The result was a call for more study and monitoring of the problem in the region. Recently Senator Al Gore (Democrat, Tennessee) asked scientists to report on coral reef deterioration and its possible link to global climate change (Miller, 1991).

Subsequent studies of the 1987 event and the events that followed have suggested that bleaching in these instances may be related to thermal stress and high irradiance (Goneaga, 1991; Roberts, 1988). Further it has been proposed that these

Table 1

Ecological Effects of Bleaching

Short-term Effects--
* immediately increases the vulnerability of coral reefs to other stresses
* reduces coral growth rates
* increases coral mortality
* emigration of coralivores occurs
* predator concentrations decrease
* bioerosion increases
* decreased coral recruitment
* microbial loading of sediments changes
* disease susceptibility of corals increases
* zooplankton in water column changes

Long-Term Effects
* loss of reef framework
* alteration of food webs
* decreased coral recruitment
* decreased fish recruitment
* loss of shoreline protection
* loss of species - genetic bank
* loss of seagrasses and mangroves
* loss of sand supply

Additional Impact
* decreased tourism
* loss of educational benefit
* decline in fisheries

After Ogden and Wicklund, 1988

factors may be indicators of global warming trends (Goreau, 1990; Miller, 1991). Others have noted that patterns of bleaching are not easily correlated with temperature and irradiance and assigning these factors as proximal causes may be premature (Ghiold and Smith, 1990). It also has been suggested that perhaps a microbial or viral agent is involved and may prove to be as elusive as the causitive agent of Diadema antillarum mortality earlier this decade (Garriet Smith, PC). Etiology may be further confused by such things as white band and black band disease, conditions caused by microbial invasion that bring about whitening of coral tissue, most often, but not always, with clearly defined borders or even blackened edges in the case of black band disease (Dustan, 1986). These whitened areas can be confused with bleaching brought about by environmental changes. Even more importantly, there seems to be a normal background bleaching level which has been reported (Williams and Bunkley-Williams, 1990).

The majority of studies on this phenomenon have relied on sea surface temperature readings gathered by NOAA at 3 meter depths from fixed sites around the region or from similar temperature monitoring devises at the paticipating laboratory (Cook, et al., 1990; Gates, 1990; Ogden and

Wicklund, 1988). The assumption is that there is insignificant or no temperature differences in the water column between the surface and 20 M or more of depth in the wider Caribbean. Few temperature readings have been taken at depth and on site. This reliance on data collected at a distance from the disturbance fails to take into account highly local meso-habitat variations which may exist. Further, studies have often begun after the bleaching event is underway and the character of the environment prior to bleaching has only been infered (Williams and Bunkley-Williams, 1990). No currently published accounts indicate that a microbial or viral origin for the problem is being studied, although there are individuals working along these lines (Garriet Smith, PC). Finally, most studies of bleaching have been rather short term, lasting only a period of weeks or a few months and then with rather infrequent visits to the sites for data collection.

PROJECT PROPOSAL

A unique opportunity for studying the phenomenon of coral bleaching exists on San Salvador. Dustan (1986) made some preliminary observations on the vitality of reef corals around the island prior to the bleaching events. The recent bleaching events have severely affected the reefs of San Salvador and the corals that seem to be most affected during bleaching in other regions are well represented in the shallow reef environments here (Gerace, 1980; William and Bunkley-Williams, 1990). Affected reef systems around San Salvador are easily reached from shore and observed by skindivers without the aid of SCUBA equipment. Over 70 institutions bring students to the Field Station each year and there is a continual influx of visiting scientists. The purpose of this proposed study is to use the human resources visiting the Field Station and the unique character of the Island's reefs to study coral bleaching.

Reefs chosen for this study will be ones where previous bleaching events have been noticed as recommended by Lang in Ogden and Wicklund (1988) and which can be easily reached by students and scientists visiting the island who may chose to take part in the study. Transect study sites (Loya, 1972) will be established along constant depth profiles between 1 and 3 meters depth using 5-15 meter lines. Transects will be established at depth along each side of chosen reefs. The lines will be marked at intervals for the positioning of a portable frame. The frame will be moved to each set position on the line in a manner similar to the Belt Quadrat method (Dodge, 1982). Once the frame is positioned, it will be photographed using a Nikonos camera with a 28mm wide-angle lens with ISO 200 Ektachrome film and available light or flash if needed (Dodge, 1982). A color chart will be included in each frame for later color comparison (Lang, PC). Coral species will be identified in each frame to the lowest taxonomic group possible. Each colony will be measured for area of coverage. Each colony will be scored for color using a system previously developed by Judith Lang (Ogden and Wicklund, 1988), Ghiold and Smith (1990), or by Gates (1990). Temperatures will be taken along the transect at depth using a hand-held thermometer. Water samples will be taken along the transect at depth and tested for ph.salinity and dissolved oxygen content. Irradiance will be measured and correlated to UV A and UV B penetration (Lesser, et al., 1990). Samples from both affected and unaffected corals will be taken for microbiological evaluation by Garriet Smith.

Should photographic surveys prove impossible, the study will proceed using the protocols set down by Gates (1990), Lang (Ogden and Wicklund, 1988), or Ghiold and Smith (1990) while still collecting data for the other physical and biological paramenters. In either case, easily followed, very simple protocols will be written so that volunteers willing to collect data from one or more of the established study sites will be able to do so with a minimum of variablity. Volunteers for data collection will be solicited from any group or person visiting the Field Station and will be supplied with the materials and any prliminary instruction necessary by the Field Station personell (Gerace, PC).

Analysis of the collected data will be undertaken at Corning Community College, University of South Carolina at Aiken, and the Bahamian Field Station. Volunteers will be kept informed about the progress of the study through a newsletter which will be sent to them upon request. These methods of data collection and analysis will provide several benefits for this study.

* Data can be collected year around (most frequently from December though June) allowing the establishment of a long baseline of information.

* All data will be collected from the site being studied.

* Bleaching episodes can be detected as they begin and sites most effected targeted for closer scrutiny.

* The progress, recovery or death, of the species affected can be charted more closely and for a longer period both before and after the onset of the event than is possible with conventional methods of study.

* Such information as coral growth rates, coral recruitment, macrofloral and macroafaunal changes on the reef, storm damage, and other parameters may be monitored should there be significant changes worth noting at the study sites.

* Photographic analysis will provide a permanent record of the events in the study areas.

* Undergraduates and visitors will have the opportunity to have first-hand experience with collecting data and seeing the resultant analysis of it.

Continual monitoring will lead to further understanding of the dynamics of San Salvador's reefs and most importantly will contribute to the understanding of the causes and ultimate course of coral bleaching here and in the wider Caribbean.

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