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Coral Yellow Band Disease; current status in the Caribbean, and links to new Indo-Pacific outbreaks

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Abstract
Yellow band disease (YBD) has had severe impacts on major reef-building corals throughout the Caribbean. Recent data from Bonaire indicates that this disease remains in epizootic phase showing similar rates of infection as compared to the late 1990s. Ten-meter line transects at five, 10 and 15m depths revealed a high frequency of yellow band lesions on *Montastraea* spp. colonies. At 5m depth, yellow band lesions were positively identified on an average of 9.4 (87%) colonies per transect. At 10m depth an average of 8.3 (88%) colonies and at 15m an average of 2.6 (83%) colonies were found affected by YBD per 10m transect. Video transects from 1997 of the same research site confirm that YBD has advanced across the surface of many colonies leaving greatly increased areas of denuded skeleton. These observations coincide with recent severe outbreaks in the Indo-Pacific where similar lesions were found on *Diploastrea heliopora*, *Herpolitha* spp. and *Fungia* spp. YBD continues to be in an infectious stage in the Caribbean and appears to be spreading in Pacific coral genera.

Key Words: Yellow band disease, *Montastraea* spp., zooxanthellae, symbiosis

Introduction

The severity of Yellow band/blotch disease (YBD) affecting reef-building scleractinian corals has been widely documented in the Caribbean (Goreau et al. 1998; Santavy et al. 1999; Cervino et al. 2001; Bruno et al. 2003; Weil et al. 2006), and Indo-Pacific (Cervino et al. 2008) and has been linked to *Vibrio* pathogens that are genetically related to *V. alginolyticus* and *V. harveyi* (Cervino et al. 2004b, 2008). YBD targets *Montastraea* spp. throughout the Caribbean and *Fungia* spp., *Herpolitha* spp., and *Diploastraea heliopora* in numerous locations in the Indo-Pacific (Cervino et al. 2008). *Vibrios* have previously been implicated in coral disease: Kushmaro *et al*., (1996), suggested that vibrionic bacterial bleaching is caused by a temperature-influenced infection by *Vibrio shiloi* (Ben-Haim and Rosenberg 2002). *Vibrio corallilyticus* was also shown to cause bleaching and tissue lysis in the Indo-Pacific coral *Pocillopora damicornis* (Ben-Haim et al. 2003). YBD is having an adverse effect on these species, as rates of infection are reportedly high and widespread.

Two separate teams conducted research in Bonaire, approximately ten years apart. Research from 1997 to 1998 showed that 91% of *Montastraea* spp. corals at ten research sites were affected by YBD (Cervino et al. 2001). Line transects counted from 2007 to 2008 at the research site Karpata reveal that 86% of *Montastraea* spp. corals are currently affected. Analysis of video transects taken in 1997 by T.J. Goreau, confirms that both research teams covered the same territory at Karpata.

Yellow Band Disease begins as a small lesion (or blotch) about 1-2 cm in diameter. Polyps in the lesion acquire a somewhat irregular and swollen appearance, and pigmentation is lost, giving the affected area a lighter color than the surrounding healthy tissue. The disease spreads at a rate of about 0.5 cm to 1 cm per month. Gradually, the tissue in the center of the lesion dies, often becomes overgrown with algae, and expands into a yellow ring (or band) with healthy tissue surrounding it. The virulence of YBD is greatly enhanced by warmer seawater temperatures (Cervino et al. 2004b). Taken in the context of global climate

The authors would like to alert readers that the present version of this paper differs from that in the printed proceedings. An old version was erroneously printed which is corrected here. Authors and editors apologize for any confusion this may cause.

change, this could mean coral colonies will die faster than they can recover or reproduce (Colwell 1996; Goreau et al. 1998; Harvell et al. 1999; Van Veghel and Bak 1994).

Materials and methods

Bonaire is home to a large population of *Montastraea* spp. corals and boasts one of the most successful Marine Protected Areas (MPAs) in the Caribbean. These attributes make Bonaire an ideal research site to gauge the status of the health of these corals, as it is protected from overfishing, boat anchors, rampant coastal overdevelopment and other common stressors in the Caribbean. The study site, Karpata, is a very popular dive site on the northwest coast of the island and has a particularly abundant and densely packed population of *Montastraea* spp. colonies (Bak et al. 2005).

Surveys were conducted in August of 2007 and January of 2008. Occurrence of YBD was determined from line transect counts using SCUBA. An average of ten transects each (100 linear meters) at depths of 5 meters, 10 meters, and 15 meters were counted. North and south directions from the site's buoy were covered and there was no overlap in transects from 2007 and 2008 in order to survey as much of the site as possible.

An underwater reel with ten meters of measured nylon line was stretched horizontally along the reef and held in place by two divers who monitored depth and tension of the transect line. The survey was conducted along the transect line and all colonies that crossed the line were counted. The underwater topography at 10 and 15 meters depth is a near vertical wall, therefore colonies that fell into the line of sight *behind* the transect line on the wall were counted, while at five meters depth the transect line was stretched above the flat reef, and all colonies that lie in line of sight *under* the transect line were counted.

Montastraea spp. colonies with visible signs of YBD were counted as infected. Colonies devoid of visible signs of blotches or bands and those that showed signs of disease but could not be positively attributed to YBD were *not* counted. A series of photos were taken along transects at all depths using an underwater Sony W5 digital camera in August 2007.

Average water temperatures were measured at each transect using a Suunto Vyper diving computer. In August of 2007, temperatures ranged from an average of 29° C at five and ten meters depth to an average of 28° C at fifteen meters depth. In January of 2008 temperatures averaged 26° C at all depths. Only minor bleaching was observed.

Results

The indices of YBD were very high (86%) in 2007/2008 (Fig. 1), similar to the findings in 1997/98 (91%) (Cervino et al. 2001).

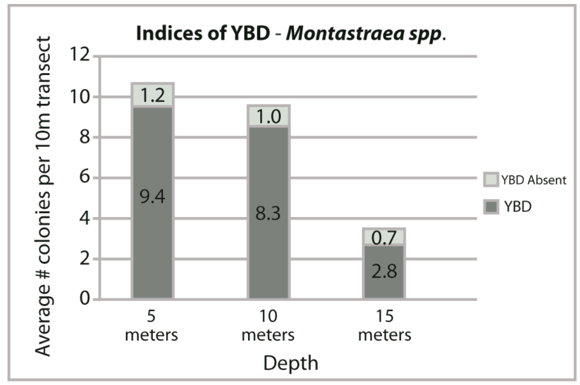

Figure 1: YBD transect results 2007 & 2008 in Bonaire showed high occurrence of disease.

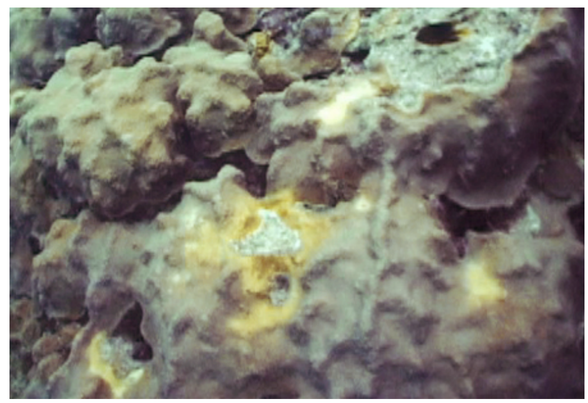

Figure 2: Video still of YBD infection on *Montastraea faveolata* colony in 1997.

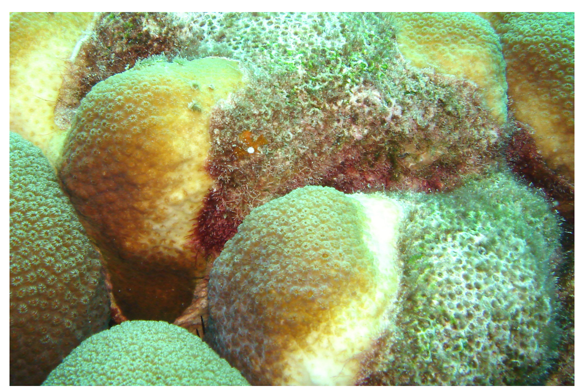

Figure 3: Montastraea annularis with signs typical of YBD infection in 2007. Photo: A. Donà

The video transects reveal a greater amount of live coral tissue in 1997 as compared to 2007/2008. Many of the colonies observed in the '90s had numerous large YBD rings, whereas today much of that coral tissue is dead and covered with algae, and what remains of the live tissue has smaller and less conspicuous lesions. In the late '90s, there was more coral tissue to infect than now, and it was common to find many large YBD rings on one colony or group of closely positioned colonies (Fig. 2). Those large rings have expanded over the years and have since broken off into smaller lesions affecting separate lobes or patches of the coral colonies (Fig. 3).

At five meters depth, an average of 9.4 *Montastraea* spp. colonies per ten-meter line transect were infected with YBD, as opposed to an average of 1.2 colonies, which appeared free of the disease. At the top of the reef, in the five-meter range, many colonies are lobate *Montastraea annularis* or relatively small colonies of *Montastraea faveolata*. There remains a higher relative abundance of live coral cover at this depth when compared to the deeper transects, though the majority (87%) of colonies show signs of infection (Fig. 4).

At 10 meters, the sloping wall has a large number of densely packed, mountainous *Montastraea faveolata* colonies which are often larger than those counted at five meters. An average of 8.3 *Montastraea* spp. colonies per ten-meter line transect showed signs of YBD while 1.0 colony did not. The number of live *Montastraea* spp. colonies is lower at ten meters than at five meters, however, the incidence of corals infected with YBD was slightly higher at eighty-eight percent (88%).

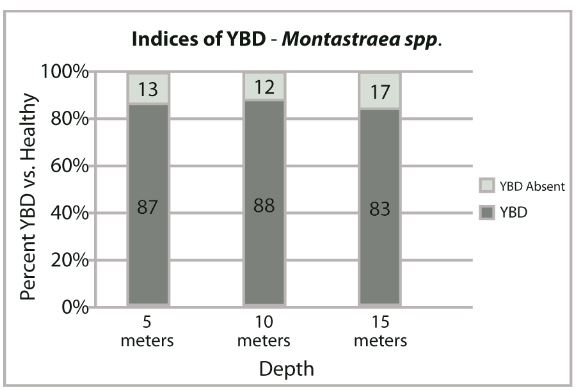

Figure 4: Percentage of YBD infected *Montastraea* spp. colonies in Bonaire, 2007 & 2008

At 15m depth, an average 2.6 *Montastraea* spp. colonies per ten-meter line transect were found to be infected with YBD and an average of 0.7 colonies were exempt from signs of the disease. The number of colonies counted at this depth was noticeably lower since most *Montastraea* spp. colonies at this depth were dead or nearly dead (more than 75% loss of live coral tissue) and were heavily overgrown with algae, sponges, tunicates and recruits of other coral species. Many of these colonies were at such advanced stages of tissue loss that it was difficult to diagnose the cause of death. Overall, eighty-three percent (83%) of *Montastraea* spp. colonies that remain at this depth were infected with YBD.

Discussion

Recent outbreaks of YBD off the fringing reefs of the west coast of Barbados (Brathwaite, pers. comm.), together with other locations where YBD has already been identified (Fig. 5) demonstrate that the disease continues to spread throughout the Caribbean. According to recent reports from scientists and divers, Vibrio-induced Yellow band lesions throughout the Caribbean have not diminished (Weil 2008, Bruckner et al. 2008) and the recent data from Karpata indicates that YBD is still active in Bonaire a decade after it was first documented. YBD lesions have moved rapidly infecting colonies adjacent to one another.

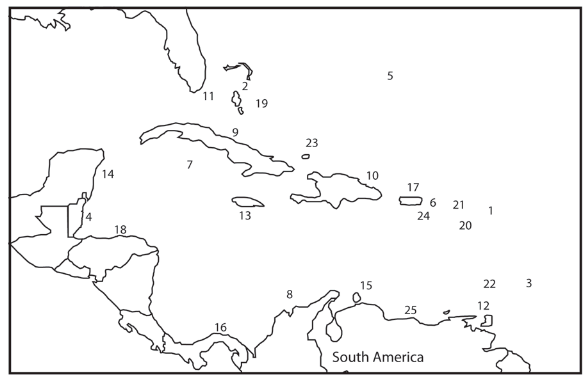

Figure 5: YBD has been documented throughout the Caribbean in; Antigua[1], Bahamas[2], Barbados[3], Belize[4], Bermuda[5], BVI[6], Cayman Islands[7], Colombia[8], Cuba[9], Dominican Republic[10], Florida[11], Grenada[12], Jamaica[13], Mexico[14], Netherlands Antilles[15], Panama[16], Puerto Rico[17], Roatan[18], San Salvador[19], St. Kitts[20], St. Maarten[21], St. Vincent and the Grenadines[22], Turks & Caicos[23], USVI[24], Venezuela[25]. (Cervino et al. 2001)

Interestingly, 15 m x 1 m belt transect counts, which were conducted at six field sites in the Wakatobi Island chain, Indonesia, in 2004 found 34 (19%) *D. heliopora* colonies infected with YBD and 531 (42%) *Fungia* spp. colonies infected with YBD (Cervino et al. 2008). These numbers reflect the dominance of *Fungia* spp. at the Wakatobi reefs and show an analogous trend to the outbreak of YBD on the primary reef-building *Montastraea* spp. colonies in Bonaire. Clearly, in 1997/1998, YBD was at a more advanced and prominent stage in Bonaire than it was in Indonesia in 2004. In the coming years it will be important to monitor the progression of YBD in the Indo Pacific as has been done in Bonaire to confirm this trend and our hypothesis that an abundance of a particular susceptible species yields high indices of

YBD infection and its spread may be density dependent.

Yellow Band Disease is caused by a consortium of four novel *Vibrio* spp. together with *V. alginolyticus*, a well-known shellfish pathogen (Cervino et al. 2008). YBD is a disease of the symbiotic algae and not of the host coral since the microbial consortium attacks the zooxanthellae in situ within the gastroderm causing lysing of zooxanthellae (Cervino et al. 2004a). Vacuolization and fragmentation occur and severe impairment of the thylakoid membranes causes loss of chlorophylls a and c2, which impairs photosynthetic functionality (Cervino et al. 2004a).

Benefits of association between symbiotic algae and their coral hosts are well documented; photosynthesis and fixation of carbon provided by the zooxanthellae are necessary for the growth of the coral host (Muscatine and Cernichiari, 1969; T.F. Goreau et al., 1979; Muller-Parker and D'Elia 1997). Corals that are infected with YBD and other diseases experience slower growth rates, and due to a great net loss of biomass, coral colonies experience a reduction in ability to reproduce (Antonius, A. 1977, 1981, Peters 1984; Kojis and Quinn 1985; Szmant 1991; Goreau et al. 1998; Porter et al. 2001).

The exact mechanism by which the Vibrio consortium actually causes disease is still uncertain. Banin et al., (2001) proposed that *Vibrio shiloi* biosynthesized and secreted an extracellular peptide - toxin P - that impaired and inhibited photosynthesis of symbiotic zooxanthellae. The first physical barrier to infection for most corals is the mucopolysaccharide layer, which in healthy coral colonies is home to a plethora of coral associated microbes that play an important role in antibacterial activity (Hayes and Goreau 1998). Pathogenic stress, or environmental stress, such as a thermal bleaching event, can alter the microbial community commonly associated with a particular species (Ritchie et al. 1995; Frias-Lopez et al. 2002; Bourne et al. 2007). It is possible that opportunistic microbes – in this case, the YBD Vibrio consortium - repopulate the mucus layer after such events, causing disease (Knowlton and Rohwer 2003; Ritchie 2006; Gil-Agudelo et al. 2007; Rosenberg et al., 2007). There is still much to understand regarding the mechanism of host-alga transmission that leads to infection in YBD. It is important to recognize that YBD results in *in situ* destruction of the zooxanthellae rather than their expulsion, as in classic bleaching, and is therefore caused by different mechanisms (Cervino et al. 2004b).

Yellow band/blotch disease in the Indo-Pacific

Recent field research in Indonesia, as well as the Philippines and Thailand and subsequent laboratory research by Cervino *et al*., show that similar lesions on Indo-Pacific coral species - *Fungia* spp., *Diploastraea heliopora*, and *Herpolitha* spp. - are caused by the same pathogens that cause YBD in Caribbean coral species (Cervino et al. 2008). In 2007, *Montastraea faveolata* fragments were inoculated with the *Vibrio* spp. isolated from diseased Bonaire and Indo-Pacific corals in aquaria at the Mote Marine Laboratory in Summerland Key, Florida. Interestingly, the coral fragments inoculated with the Indo-Pacific isolates from the 26° and 28° C tanks resulted in infection while identically inoculated fragments in the 30° and 32° C tanks did not.

It is important to note that YBD infections were not more likely to occur in the warmer seawater temperatures. However, when infected corals from ambient temperature tanks were moved to warmer tanks the disease became more virulent. In other words, corals are apparently susceptible to infection when seawater temperatures are normal, and the disease is more likely to spread during warmer periods.

Conclusion

After 10 years, YBD infections in Bonaire remain high even though the corals they affect have steadily declined. Cervino et al. (2004b, 2008) have shown that YBD is no longer only a disease of Caribbean coral species, but it is now having a large impact on the reef-building corals of the Indo-Pacific. Comparing Caribbean and Indo-Pacific outbreaks, and the connections between infectivity at normal seawater temperatures and virulence with rising seawater temperatures is imperative if we want to understand the true impacts of global warming-induced high sea-surface temperatures on coral reefs.

Besides disease, corals are affected by a myriad of debilitating stressors – both anthropogenic and non - such as predation, bleaching events, pollution and sedimentation. The environment is quickly changing; the sum of all these ills and the accelerated timescale might be more than corals can adapt to. A strong working knowledge of the problem is essential for effective coral reef management and efforts to mitigate the damage to coral reefs around the world.

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