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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 an epidemic phase showing similar trends compared to the late 1990s. Ten meter belt transects taken at varied depths of *Montastraea* spp. indicate high indices of yellow band lesions. At 5m depth, yellow band rings and lesions were positively identified on an average of 9.4 (87%) colonies per transect while an average of 1.2 (13%) colonies in this depth range appeared healthy. At 10m depth an average of 1.0 (12%) healthy colonies and 8.3 (88%) colonies affected by YBD per 10m transect were counted. At 15m there were an average of 0.7 (17%) healthy colonies and 2.6 (83%) colonies affected by YBD per 10m transect. These studies coincide with recent severe outbreaks in the Indo-Pacific where similar lesions were found on *Diploastrea* spp., *Herpolitha* spp.and *Fungia* spp. Inoculation experiments of Indo-Pacific bacterial isolates under ambient temperatures cause the induction of YB lesions onto *Montastraea* spp. *in vitro*. YBD continues to be in an infectious stage in its original Caribbean hot spots and appears to be spreading in Pacific coral genera.

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

Introduction

The severity of Yellow band/blotch disease (YBD) affecting reef-building Scleractinian corals in the Caribbean (Goreau et al. 1998, Santavy et al. 1999, Cervino et al. 2000, Weil et al. 2006), and Indo-Pacific has been widely documented and has been linked to *Vibrio* pathogens that are genetically related to *V. alginolyticus* and *V. harveii (*Cervino et al. 2004*)*. Yellow band disease 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). This is not the first time that *Vibrios* have been implicated in a 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 affect on abundances of these species as rates of infection have reached epidemic proportions.

Research from 1997 to 1998 in Bonaire showed that 91% of *Montastraea* spp. corals at ten research sites were affected by YBD (Cervino et al. 2000). Ten years later, belt transects counted in Bonaire from 2007 to 2008 at the research site Karpata reveal that 86% of *Montastraea* spp. corals are currently affected. Observations of YBD at numerous other sites in Bonaire and Klein Bonaire are consistent with the transect analysis conducted at Karpata.

Yellow band/blotch disease begins as a small lesion (or blotch) about 1-2 cm in diameter. Polyps in the lesion area acquire a somewhat irregular and swollen appearance and pigmentation is lost, giving the affected area a lighter aspect than surrounding healthy tissue. The disease spreads at a rate of about 0.5 cm to 1 cm per month. Gradually, the lesion becomes a yellow ring (or band) of diseased tissue bordered by necrotic tissue often overgrown with algae within and healthy tissue surrounding it. As the diseased tissue advances the ring/band and the dead tissue and algae overgrowth area expands (Fig. 5). The virulence of YBD is greatly enhanced by warmer seawater temperatures (Cervino et al. 2004) which in the context of global climate change and El Niño events could mean that coral colonies will disappear quicker than they can recover or reproduce (Colwell, R. 1996, Goreau et al. 1998, Harvell et al. 1999, Van Veghel and Bak 1994).

Recent outbreaks of YBD off the fringing reefs of the west coast of Barbados (Brathwaite, pers. comm), together with the list of documented areas where YBD has already been identified (Fig. 1) demonstrate that the disease continues to spread throughout the Caribbean.

Figure 1: YBD has been documented throughout the Caribbean in; Antigua, Bahamas, Barbados, Belize, Bermuda, BVI, Cayman Islands, Colombia, Cuba, Dominican Republic, Florida, Grenada, Jamaica, Mexico, Netherlands Antilles, Panama, Puerto Rico, Roatan, San Salvador, St. Kitts, St. Maarten, St. Vincent and the Grenadines, Turks & Caicos, USVI, Venezuela

Recent field research in Indonesia, the Philippines and Thailand and subsequent laboratory research show that similar lesions on Indo-Pacific coral species are caused by the same pathogens that cause YBD in Caribbean coral species (Cervino et al. 2008). More research is needed in this vast geographical region to determine how widespread vibrio-induced YBD infections currently are, in order to understand the long-term impact on Indo-Pacific coral reefs.

Materials and methods

Prevalence of Yellow band/blotch disease was determined by belt transect counts using SCUBA. Surveys were conducted in August of 2007 and January of 2008. An average of ten transects each (100 linear meters) at depths of five meters, ten meters, and fifteen meters were counted. North and south directions from the site's buoy were covered to avoid overlap of transects done from August 2007 to January 2008.

Bonaire is home to a very large population of *Montastraea* spp. corals and boasts one of the most successful Marine Protected Areas (MPAs) in the Caribbean. Due to these attributes, Bonaire presented a unique opportunity to gauge the status of the region's *Montastraea* spp. health, by studying this area well protected from overfishing, boat anchors, rampant coastal overdevelopment and other stressors that plague the rest of the Caribbean. The study site, Karpata, is a very popular dive site on the northwest coast of Bonaire and has a particularly abundant and densely packed population of *Montastraea* spp. colonies (Bak et al 2005).

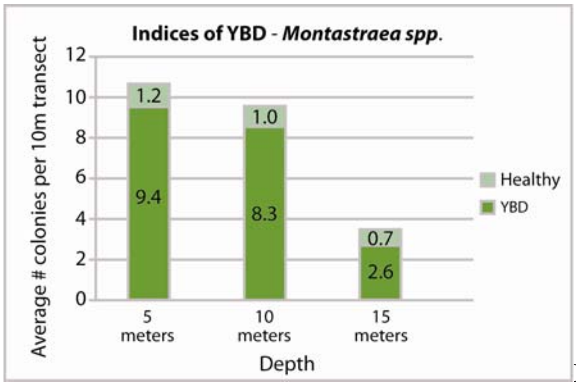
Temperatures in August of 2007 ranged from an average of 29° Centigrade at five and ten meters of depth to an average of 28° Centigrade at fifteen meters depth. In January of 2008 temperatures averaged 26° Centigrade at all depths. Only minor bleaching was observed.

An underwater reel with ten meters of measured nylon line was stretched horizontally along the reef and held in place by two divers constantly monitoring depth and tension of the transect line. The survey was conducted along the transect line and all colonies that crossed the line were counted. It should be noted that 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 *below* the transect line were counted. A series of photos was taken along transects at all depths using an underwater Sony W5 digital camera in August of 2007.

Montastraea spp. colonies with visible signs of YBD were counted as infected. Colonies devoid of visible signs of lesions/blotches or rings/bands and those that showed signs of disease that could not be positively attributed to YBD were counted as healthy. "Healthy" in the context of this paper does not mean that coral colonies were free of other diseases, it means only that Yellow band/blotch disease was not present on that particular colony.

Results and Observations

A survey of the incidence of Yellow band/blotch disease at Karpata was conducted to determine the status of *Montastraea* spp. ten years after the previous survey. Overall, the indices of YBD were very high (86%) in 2007/2008, similar to the findings in 1998 (91%) (Cervino et al. 2000).



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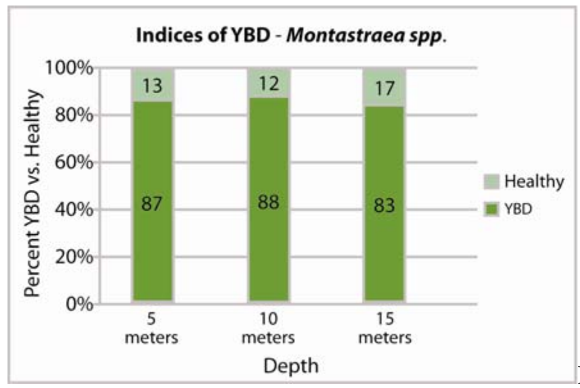
gure 2: YBD transect results 2007 & 2008 in Bonaire showed high indices of disease as compared with healthy corals.

At five meters depth, an average of 9.4 *Montastraea* spp. colonies per ten-meter belt transect were infected with YBD, as opposed to an average of 1.2 healthy colonies. At the top of the reef, in the five-meter range, many colonies are lobate *Montastraea annularis* or relatively small colonies of *Montastraea faveolata* whose morphology may explain why smaller blotches were the most observed sign of disease at this depth. There remains a relative abundance of live coral cover at this depth though the majority (87%) of colonies show signs of infection.

At ten meters, the sloping wall has a large number of densely packed, mountainous *Montastraea faveolata* colonies. These colonies are often larger than the colonies counted at five meters and the surface area of the *M. faveolata* is by and large more continuous than that of *M. annularis*, which is abundant at shallower depths. An average of 8.3 *Montastraea* spp. colonies per ten-meter belt transect showed signs of YBD while 1.0 colonies appeared to be healthy. Relative abundance 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%).

The reef at fifteen meters is topographically similar to the reef at ten meters. An average 2.6 *Montastraea* spp. colonies per 10-meter belt 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 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.

Similarly, at six field sites in the Wakatobi Island chain, Indonesia 15 m x 1 m belt transect counts were conducted which found 34 (19%) *D. heliopora* colonies infected with YBD and 531 (42%) *Fungia* spp. colonies infected with YBD. 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. It would appear, then, that an abundance of a particular susceptible species yields high indices of YBD infection and its spread may be density dependent.



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gure 3: Percentage of YBD infected *Montastraea* spp. colonies in Bonaire - transect results 2007 & 2008

Discussion

According to recent reports from scientists and divers, *Vibrio* induced Yellow band lesions throughout the Caribbean have not diminished. Nor have YBD infected colonies in Bonaire recovered since they were reported in1997. *In situ* studies and recent new outbreaks indicate that this epidemic has lasted over a decade in the Caribbean and Florida.

YBD is caused by a consortium of four novel *Vibrio* spp. together with *Vibrio alginolyticus*, a well-known shellfish pathogen (Cervino *et. al*. 2008). YBD is a disease of the symbiotic algae and not of the host coral as the microbial consortium attacks the zooxanthellae *in situ* within the gastroderm causing lysing of zooxanthellae (Cervino et al. 2004). Vacuolization and fragmentation occur and severe impairment of the thylakoid membranes cause loss of chlorophylls a and c_2, which impairs photosynthetic functionality. (Cervino et al., in prep).

Were it not for the important benefits of association with their symbiotic algae, coral hosts would be unable to lay down calcium carbonate skeleton at the same rate as they have done for centuries. Benefits of 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 unknown. However, we hypothesize that the mode of adhesion is similar to what Banin et al. *(2001)* showed when *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 (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, K.B. 2006, Gil-Agudelo, D.L. et al. 2007, Rosenberg et al. 2007).

These factors have great implications for the health and abundance of the major Caribbean reef-building *Montastraea* spp. colonies whose numbers are in decline throughout the region.

Figure 5 – Montastraea annularis with classic signs of YBD infection. Photo was taken in Bonaire, August 2007. Photo credit: Alessandro Donà.

Yellow band/blotch disease in the Indo-Pacific

YBD is currently also affecting reef-building corals in the Indo-Pacific. Field studies and laboratory experiments by Cervino et al. have shown that similar pathogens are causing similar symptoms of disease in *Fungia* spp., *Diploastraea heliopora,* and *Herpolitha* spp. colonies.

Inoculation experiments, conducted at the Mote Marine Laboratory in Summerland Key, Florida in 2007, of *Montastraea faveolata* fragments with the *Vibrio* spp. isolated from diseased Indo-Pacific corals in aquaria resulted in YBD infection (Fig. 4). Interestingly, inoculation of the *M. faveolata* fragments from the 26° and 28° C tanks resulted in infection while identically inoculated fragments in the 30° and 32° C tanks did not result in infection.

Figure 4 – M. faveolata fragments from 26° C tank, inoculated with Indo-Pacific consortium, resulted in YBD lesions.

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

Conclusion

There is still much to understand regarding the mechanism of host-alga transmission that leads to infection in YBD. That need is more compelling than ever in light of the recent Indo-Pacific outbreaks and the connection between infectivity at normal seawater temperatures and virulence with rising seawater temperatures. As Cervino et al. 2004 2008, have shown, 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. Further investigation should include laboratory analysis of the zooxanthellar clade subtypes that are affected and YBD's possible connection to aquaculture pathogens. The negative implications of a widespread infectious disease such as YBD are numerous. Besides disease, corals must deal with myriad debilitating stressors – both anthropogenic and non - such as predation, bleaching events, pollution, sedimentation and overfishing. 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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References

Antonius, A. (1977) Coral mortality in reefs: a problem for science and management. Proc. 3 Int. *Coral Reef Symp*. 2:618-623.

Antonius, A. (1981) Coral reef pathology: a review. Proc. 4th Int *Coral Reef Symp*. 2:3-6.

Bak, R.P.M., G. Nieuwland, E.H. Meesters (2005) Coral reef crisis in deep and shallow reefs: 30 years of constancy and change in reefs of Curacao and Bonaire. Coral Reefs. 24:475-479.

Banin, E., S.K. Khare, F. Naider, E. Rosenberg (2001) Proline-Rich Peptide from the Coral Pathogen *Vibrio shiloi* That Inhibits Photosynthesis of Zooxanthellae. Appl. Environ. Microb. 67:1536-1541.

Ben-Haim Y., E. Rosenberg (2002) A novel *Vibrio sp.* pathogen of the coral *Pocillopora damicornis*. Mar. Biol. 141:47-55.

Bourne, D., Y. Iida, S. Uthick, C. Smith-Keune (2007) Changes in coral-associated microbial communities during a bleaching event. ISME. Journal. 1751-7362/07:1-14.

Cervino, J., T.J. Goreau, I. Nagelkerken, G.W. Smith, R. Hayes (2001) Yellow Band and Dark Spot Syndromes in Caribbean Corals: Distribution, Rate of Spread, Cytology, and Effects on Abundance and Division Rate of Zooxanthellae. Hydrobiologia 460:53-63.

Cervino, J.M., R. Hayes, T.J. Goreau, G.W. Smith (2004) Zooxanthaellae Regulation in Yellow Blotch/Band and Other Coral Diseases Contrasted with Temperature Related Bleaching: *In Situ* Destruction vs Expulsion. Symbiosis 37:63-85.

Cervino, J.M., F.L. Thompson, B. Gomez-Gil, E.A. Lorence, T.J. Goreau, R.L. Hayes, K.B. Winiarski-Cervino, G.W. Smith, K. Hughen, E. Bartels (2008) The Vibrio core group induces yellow band disease in Caribbean and Indo-Pacific reef-building corals. Appl. Microbiol. [doi: 10.1111/j.1365-2672.2008.03871.x]

Colwell, R. (1996) Global climate and infectious disease: The cholera paradigm. Science 274: 2025-2031.

Frias-Lopez, J., A.L. Zerkle, G.T. Bonheyo, B.W. Fouke (2002) Partitioning of bacterial communities between seawater and healthy, black band diseased, and dead coral surfaces. Appl. Environ. Microb. 68:2214-2228.

Gil-Agudelo, D.L., D.P. Fonseca, E. Weil, J. Garzón-Ferreira, G.W. Smith (2007) Bacterial communities associated with the mucopolysaccharide layers of three coral species affected and unaffected with dark spot disease. Can J. Microbiol. 53 (4):465-71.

Goreau, T.F., N.I. Goreau, T.J. Goreau (1979) Corals and Coral Reefs. Sci. Am. p124-136.

Goreau T. J, J. Cervino, M. Goreau, R. Hayes, M. Hayes, L. Richardson, G. Smith, K. DeMeyer, I. Nagelkerken, J. Garzon-Ferrera, D. Gil, G. Garrison, E. H. Williams, L. Bunkley-Williams, C. Quirolo, K. Patterson, J. Porter, & K. Porter (1998) Rapid Spread of Caribbean Coral Reef Diseases, *Rev. Biol. Trop*, Vol. 46 Sup. (5):157-171.

Harvell, C. D., K. Kim, J.M. Burkholder, R.R. Colwell, P.R. Epstein, D.J. Grimes, E.E. Hofmann, E.K. Lipp, A.D.M.E. Osterhaus, R.M. Overstreet, J.W. Porter, G.W. Smith, G.R. Vasta (1999) Emerging marine diseases - climate links and anthropogenic factors. Science 285:505-1510.

Hayes R.L., and NI Goreau (1998) The significance of emerging diseases in the tropical coral reef ecosystem. Rivista Biologia Tropical. 46:173-185.

Knowlton, N, and F Rohwer (2003) Microbial mutualisms on coral reefs: The host as a habitat. American Naturalist. 162:S51-S62.

Kojis, B.L., and N.J. Quinn (1985) Puberty in *Goniastrea favulus*. Age or size limited? Proc. 5th Internat. Coral Reef Congr., 4:289-293.

Kushmaro, A., Y. Loya, M. Fine, E. Rosenberg (1996) Bacterial infection and coral bleaching. Nature 380:396.

Muller-Parker, G. and C. F. D'Elia (1997) Interactions between corals and their symbiotic algae. C. Birkeland, ed. Life and death of coral reefs. Chapman & Hall, New York. P96–133.

Muscatine, L. and E. Cernichiari (1969) Assimilation of Photosynthetic Products of Zooxanthellae by a Reef Coral. Biol Bull. 137:506-523.

Peters, E. (1984) A survey of cellular reactions to environmental stress and disease in Caribbean scleractinian corals. Helgol. Meeresunters. 37:113-137.

Porter, J.W., P.W. Dustan, W. Japp, K. Patterson, K. Vladimir, M. Patterson, M. Parsons (2001) Patterns of spread of coral disease in the Florida Keys. Hydrobiol. 460:1-24.

Ritchie, K.B. (2006) Regulation of microbial populations by coral surface mucus and mucus-associated bacteria. Mar. Ecol.-Prog. Ser. 322:1-14.

Rosenberg, E., O. Koren, L. Reshef, R. Efrony, I. Zilber-Rosenberg (2007) The role of microorganisms in coral health, disease and evolution. Nature. 5:355-362.

Santavy, D. L., E. C. Peters, C. Quirolo, J. W. Porter, and C. N. Bianchi (1999) Yellow blotch disease outbreak on reefs of the San Blas Islands, Panama. Coral Reefs. 18:97.

Szmant, A.M. (1991) Sexual reproduction by the Caribbean reef corals *Montastrea annularis* and *M. cavernosa*. Mar. Ecol. Prog. Ser. 74:13-25.

Van Veghel, M.L.J., R.P.M. Bak (1994) Reproductive characteristics of the polymorphic Caribbean reef building coral Montastrea annularis. III. Reproduction in damaged and regenerating colonies. Mar. Ecol. Prog. Ser. 109:229-233.

Weil, E., G.W. Smith, D.L. Gil-Agudelo. 2006. Status and progress in coral reef disease research. Dis. Aquat. Organ. [doi: 10.3354/dao069001]