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NOTE

Temporal dynamics of black band disease affecting pillar coral (*Dendrogyra cylindrus*) following two consecutive hyperthermal events on the Florida Reef Tract

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Abstract Black band disease (BBD) affects many coral species worldwide and is considered a major contributor to the decline of reef-building coral. On the Florida Reef Tract BBD is most prevalent during summer and early fall when water temperatures exceed 29 °C. BBD is rarely reported in pillar coral (*Dendrogyra cylindrus*) throughout the Caribbean, and here we document for the first time the appearance of the disease in this species on Florida reefs. The highest monthly BBD prevalence in the *D. cylindrus* population were 4.7% in 2014 and 6.8% in 2015. In each year, BBD appeared immediately following a hyperthermal bleaching event, which raises concern as hyperthermal seawater anomalies become more frequent.

Keywords Black band disease · Coral bleaching · *Dendrogyra cylindrus* · Florida Reef Tract

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Introduction

The increase in coral diseases in recent decades has largely been attributed to environmental stressors, especially increasing sea temperatures associated with climate change (Croquer and Weil 2009; Harvell et al. 2009; McLeod et al. 2010; Hoegh-Guldberg 2012; Randall and van Woesik 2015). One such coral disease, black band disease (BBD), is now found worldwide, affecting 42 coral species (Sutherland et al. 2004). In the Greater Caribbean, 19 scleractinian species, in particular massive reef-building forms, and six octocoral species are known to be susceptible (Weil et al. 2006). The background prevalence of BBD throughout the Caribbean is typically between 1 and 4% at the community level but can be higher for individual species (Kuta and Richardson 1996; Bruckner and Bruckner 1997; Croquer and Weil 2009).

BBD is a complex polymicrobial disease dominated by cyanobacteria and is characterized by a migrating mat or dark band that moves across infected corals at rates 3–10 mm d^{-1} (Rützler and Santavy 1983). Sulfide produced within the band acts synergistically with the cyanotoxin microcystin to cause lysis of coral tissue (Viehman et al. 2006; Richardson et al. 2009). Environmental factors, including elevated temperatures, nutrients, and light intensity, affect the rate of BBD progression (Kaczmarsky et al. 2005; Voss and Richardson 2006; Boyett et al. 2007). Although it can persist year round in some areas of the Caribbean (Edmunds 1991; Kuta and Richardson 1996), on Florida reefs, BBD tends to be seasonal and most active during the warmer summer and early fall months, especially once temperatures exceed 29 °C (Rützler and Santavy 1983; Kushmaro et al. 1997; Ben-Haim et al. 2003; Richardson and Kuta 2003).

In 2014 and 2015 the Florida Reef Tract (FRT) experienced sustained hyperthermal sea temperatures that exceeded the FRT bleaching index of 30.5 °C (Manzello et al. 2007) for 8 and 11 weeks, respectively (Fig. 1). Mean monthly temperatures during these two events exceeded the 10-yr mean monthly temperatures (±1 SD) recorded at Molasses Reef (MLRF-1) from 2003 to 2013. NOAA's Coral Reef Watch sea surface temperature models reported five degree heating weeks for the summers of 2014 and 2015 on reefs of the Florida Keys (http://coralreefwatch.noaa.gov). Both hyperthermal anomalies resulted in consecutive bleaching events (Precht et al. 2016), severely affecting many species of coral along the FRT, including the pillar coral *Dendrogyra cylindrus* (Ehrenburg, 1834).

Dendrogyra cylindrus is a slow-growing gonochoric broadcast spawner typically found in low abundance throughout its Caribbean range. While this species is rarely considered an important reef builder, its unique columnar growth form provides important vertical structure and habitat complexity. It was categorized as 'vulnerable' in 2008 under the IUCN Red List criteria because of its susceptibility to bleaching, disease (especially white plague), and habitat degradation (Aronson et al. 2008). *Dendrogyra cylindrus* was federally listed in the US as 'threatened' in 2014 (NOAA Fisheries 2014) due to its rare occurrence and rapidly declining, critically fragmented population. Surveys of the *D. cylindrus* population along the FRT in 2013–2014 documented fewer than 600 live colonies at 106 sites, with two-thirds of these sites consisting of single colonies, often separated by tens of kilometers, contributing to low recruitment success. *Dendrogyra cylindrus* was once anecdotally reported to have BBD throughout its Caribbean range (Ward et al. 2006). Here we document for the first time the occurrence of BBD in *D. cylindrus* along the FRT in the context of the hyperthermal bleaching events of 2014 and 2015.

Materials and methods

Between April 2014 and April 2016, 163 *D. cylindrus* colonies at 28 sites located along the FRT (Fig. 2) were assessed tri-annually (April/September/January) for health status. Data loggers (Onset HOBO Inc., Bourne, MA, USA) were secured at each assessment site to record hourly temperatures. During the monitoring period, two hyperthermal bleaching events occurred (August/September 2014 and 2015). After the 2014 event, 64 of the 163 colonies were selected from three of the 28 geographically stratified sites (Pickles, Coffins, and Marker 32; Fig. 2) to document the dynamics of bleaching recovery. Recovery monitoring was carried out in October, November, and December (2014 and 2015) and March 2015 to quantitatively track bleaching, disease, and recovery. Assessments tracked individual *D. cylindrus* colonies for bleaching and recovery using the CoralWatch Coral Health Chart (Siebeck et al. 2006). Disease presence and progression were also documented for each colony. The presence of bleaching and disease were noted, but not quantified, for other coral species at each site. Mean daily and monthly water temperatures and number of days per month that mean daily sea temperatures exceeded 29.0 and 30.5 °C were calculated for each site. Archived temperature data for 2004–2013 at Molasses Reef C-MAN station

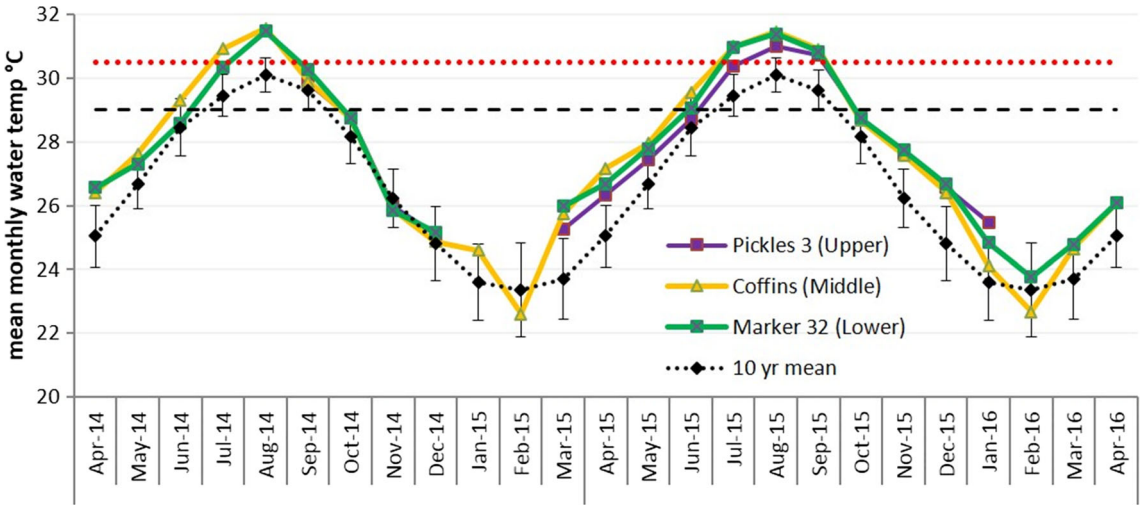

Fig. 1 Mean monthly sea temperature profiles from April 2014 to April 2016 at three sites: Pickles, Coffins, and Marker 32. *Dotted black line* represents mean monthly water temperatures (±SD) recorded at Molasses Reef 2003–2013 (National Data Buoy Center, MLRF1). *Dotted red line* indicates bleaching threshold for the Florida Reef Tract (30.5 °C). *Dashed black line* indicates optimal temperature for black band disease microbial community (29.0 °C). Gaps in data are due to lost or broken HOBO data loggers

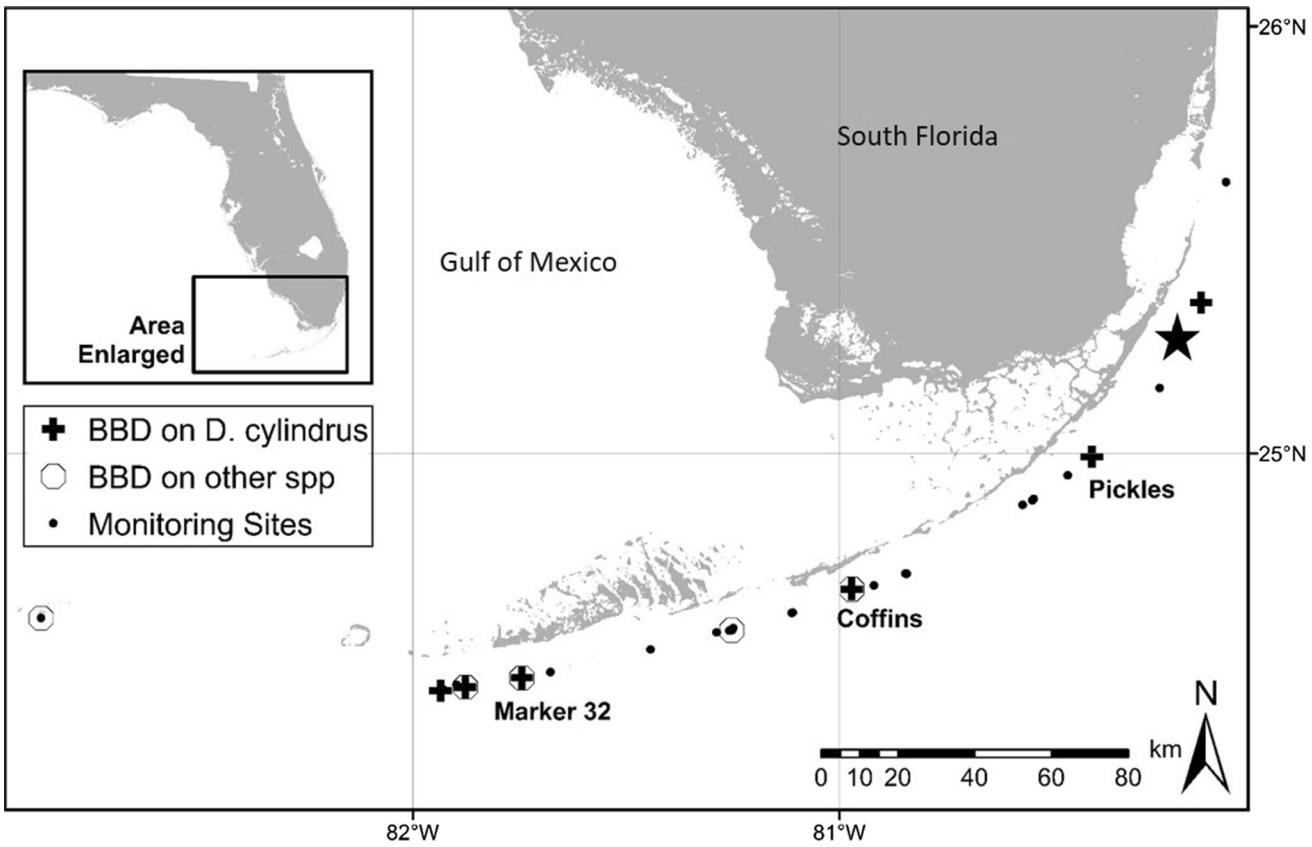

Fig. 2 *Dendrogyra cylindrus* tri-annual assessment sites along the Florida Reef Tract. *Black dots*: *D. cylindrus* sites with no observations of black band disease (BBD). *Black star*; site where BBD was first observed in *D. cylindrus*. *Black crosses*: all other sites where BBD was observed on *D. cylindrus* between April 2014 and April 2016 (includes three bleaching recovery sites: Marker 32, Coffins, and Pickles). *Open circles*: sites where BBD was observed on other coral species at *D. cylindrus* assessment sites

MLRF1 (25.012 N 80.376 W; NOAA National Data Buoy Center; http://www.ndbc.noaa.gov/station_page.php?station=mlrf1) were used to calculate 10-yr mean monthly sea temperatures.

Results and discussion

Active BBD was first observed on a single *D. cylindrus* colony at an Upper Florida Keys site in August 2014 (marked with a star in Fig. 2). During the September tri-annual survey, we observed three additional colonies with BBD among the 28 sites. Subsequent, repeated monitoring in 2014 and 2015 documented increased BBD prevalence in both years (Fig. 3), with maximum values of 4.7% (7 of 163 colonies) in 2014 and 6.7% (11 of 163 colonies) in 2015. BBD was observed to progress 15 cm in five weeks (October to November 2014) on one closely monitored colony (Fig. 4). Monitoring also revealed that nearly all 163 *D. cylindrus* colonies were severely bleached in 2014, scoring C1 on the Coral Watch Coral Health Chart, while in 2015, 64% of colonies were severely bleached and the remainder were partially bleached or pale. Bleaching events occurred during each year, in both cases two weeks after the temperature maximum for that year was reached (Fig. 1). During the larger tri-annual assessment conducted in January 2015, active BBD was no longer evident on any *D. cylindrus* colony; however, one *Montastraea cavernosa* colony at Coffins remained infected. BBD was not observed in *D. cylindrus* or any other susceptible species in March, April, May or December 2015.

Background prevalence of BBD throughout the Caribbean is typically <4% in susceptible species and is normally present during the warmer months of each year (Kuta and Richardson 1996; Bruckner and Bruckner 1997; Croquer and Weil 2009). Because BBD is rarely, if ever, reported in *D. cylindrus* throughout the wider Caribbean (Ward et al. 2006), this species may be relatively resistant to BBD. BBD was not observed in *D. cylindrus* during the initial fieldwork to locate live colonies at 106 sites on the FRT leading up to this monitoring effort (summer 2013 to spring 2014). 2013 was a non-bleaching year on these reefs. The quantitative documentation of zero BBD signs on the 163 *D. cylindrus* colonies identified in 2013,

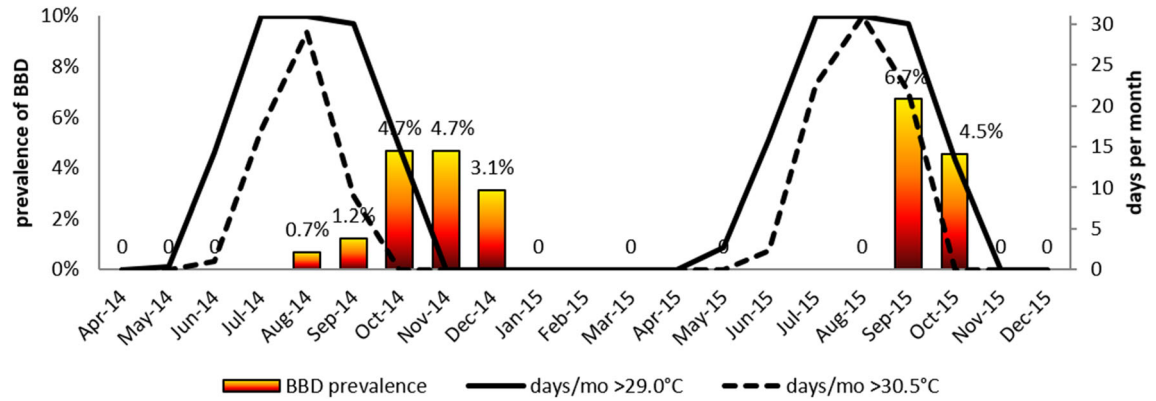

Fig. 3 Prevalence of black band disease (BBD) in *Dendrogyra cylindrus* on the Florida Reef Tract (FRT) from April 2014 to December 2015. Tri-annual assessments (*) occurred in April/May, September 2014, and January, April/May and September 2015. Additional assessments at three sites occurred in October, November, December 2014 and March, October, November, December 2015 to document the dynamics of bleaching recovery after the hyperthermal events in August/September 2014 and 2015. *Solid black line*: number of days per month that mean daily sea temperatures exceeded 29.0 °C, the optimal temperature for active BBD. *Dashed black line*: number of days per month that mean daily sea temperatures exceeded 30.5 °C, the bleaching threshold for the FRT

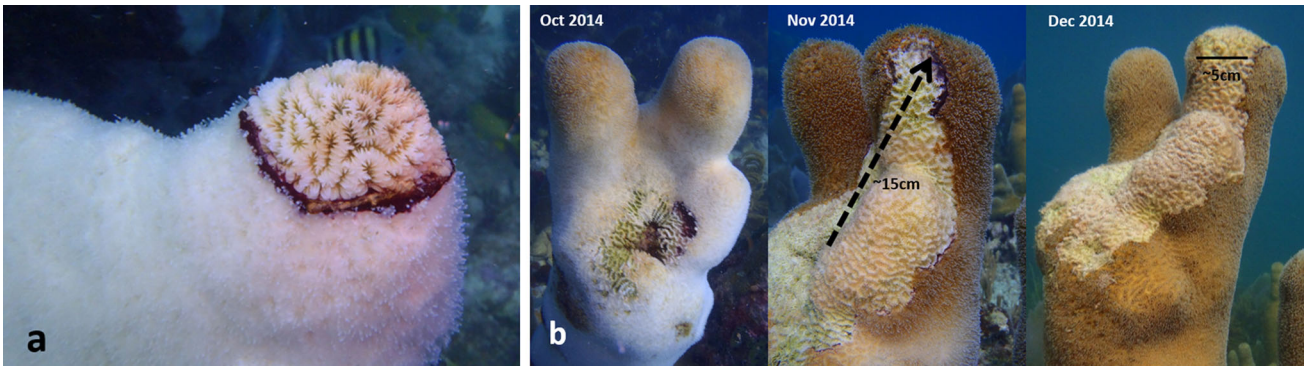

Fig. 4 Black band disease (BBD) in *Dendrogyra cylindrus*. **a** BBD on bleached *D. cylindrus* demonstrating the characteristic dark band and adjacent freshly denuded coral skeleton. **b** Progression of BBD on a single *D. cylindrus* pillar—BBD was not observed on this colony in September 2014, although the colony was severely bleached, but first appeared in October 2014, displaying a BBD lesion approximately 2 cm in diameter. By November 2014, the active band had progressed upwards approximately 15 cm and expanded laterally (calculated 0.5 cm d^{-1}). Four weeks later, the active band had slowly progressed approximately 5 cm to the top of the pillar. Active BBD was no longer visible in January 2015 but reoccurred on the same pillar in September 2015

together with the fact that prior to 2014 there were no reports of BBD on *D. cylindrus* on these reefs while BBD was reported in other species, may serve as a tentative baseline for BBD in this species on the FRT. Furthermore, the increase from zero BBD in the *D. cylindrus* population in 2013 compared to BBD prevalence values of 4.7% and 6.7% in the following years, immediately after two hyperthermal events, suggests a relationship between anomalously elevated water temperatures (and associated thermal stress), bleaching, and disease for *D. cylindrus*. Differences in other water quality parameters at each site, not measured in this study, may also be driving the apparent susceptibility to BBD of *D. cylindrus*. Additionally, coral animal genotypes, the *D. cylindrus* microbiome, and the microbiota in the surrounding environment may play roles in differential BBD susceptibility and/or resistance.

The impacts of bleaching are known to include a nutritionally compromised health status of the affected corals due to the loss of their *Symbiodinium*-derived nutrients (Muscatine and Porter 1977; Muller et al. 2009). Potential synergy of thermal and nutritional stress may have contributed to the vulnerability of *D. cylindrus* to BBD pathogens (Croquer and Weil 2009; Rogers et al. 2009; Kuehl et al. 2011). However, it was not possible to separately address these stressors in a natural setting. Additionally, prolonged elevated sea temperatures may have increased the pathogenicity of the polymicrobial community associated with BBD. Enhanced pathogenicity occurs in these and many other marine microbes at

temperatures exceeding 29 °C (Rützler and Santavy 1983; Kushmaro et al. 1997; Ben-Haim et al. 2003; Richardson and Kuta 2003).

BBD has rarely been reported in *D. cylindrus,* perhaps due to the relatively low abundance of this little-studied species throughout its Caribbean range or perhaps also due to its relative resistance to this particular disease. This study presents the results of the first quantitative monitoring of *D. cylindrus* on the FRT for health, bleaching status, and disease, and includes the first report of BBD for this species in this region. This data set is the first step in potential management of this recently listed threatened species. The observed persistent advance of BBD (progressing up to 0.5 cm d^{-1}; Fig. 4) on this slow-growing coral, the pattern of increased BBD prevalence following two consecutive hyperthermal events, and escalating environmental stressors due to predicted climate change, all suggest that BBD may play a more prominent role in the decline of *D. cylindrus* and other susceptible reef-building species, lending urgency for management and restoration efforts.

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References

Aronson R, Bruckner A, Moore J, Precht B, Weil E (2008) *Dendrogyra cylindrus*. The IUCN red list of threatened species 2008. http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T133124A3582471.en

Ben-Haim Y, Zicherman-Keren M, Rosenberg E (2003) Temperature-regulated bleaching and lysis of the coral *Pocillopora damicornis* by the novel pathogen *Vibrio coralliilyticus*. Appl Environ Microbiol 69:4236–4242

Boyett HV, Bourne DG, Willis BL (2007) Elevated temperature and light enhance progression and spread of black band disease on staghorn corals of the Great Barrier Reef. Mar Biol 151:1711–1720

Bruckner A, Bruckner R (1997) Outbreak of coral disease in Puerto Rico. Coral Reefs 16:919–928

Croquer A, Weil E (2009) Changes in Caribbean coral disease prevalence after the 2005 bleaching event. Dis Aquat Organ 87:33–43

Edmunds PJ (1991) Extent and effect of black band disease on a Caribbean reef. Coral Reefs 10:161–165

Fisheries NOAA (2014) Endangered and threatened wildlife and plants: final listing. Fed Regist 79:175

Harvell D, Altizer S, Cattadori IM, Harrington L, Weil E (2009) Climate change and wildlife diseases: when does the host matter the most? Ecology 90:912–920

Hoegh-Guldberg O (2012) Coral reefs, climate change, and mass extinction. In: Hannah L (ed) Saving a million species: extinction risk from climate change. Island Press, Springer, The Netherlands, pp 261–283

Kaczmarsky LT, Draud M, Williams EH (2005) Is there a relationship between proximity to sewage effluent and the prevalence of coral disease? Caribbean Journal of Science 41:124–137

Kuehl K, Jones R, Gibbs D, Richardson L (2011) The roles of temperature and light in black band disease (BBD) progression on corals of the genus *Diploria* in Bermuda. J Invertebr Pathol 106:366–370

Kushmaro A, Rosenberg E, Fine M, Loya Y (1997) Bleaching of the coral *Oculina patagonica* by *Vibrio* AK-1. Mar Ecol Prog Ser 147:159–165

Kuta K, Richardson L (1996) Abundance and distribution of black band disease on coral reefs in the northern Florida Keys. Coral Reefs 15:219–223

Manzello DP, Berkelmans R, Hendee JC (2007) Coral bleaching indices and thresholds for the Florida reef tract, Bahamas, and St. Croix, US Virgin Islands. Mar Pollut Bull 54:1923–1931

McLeod E, Moffitt R, Timmermann A, Salm R, Menviel L, Palmer MJ, Selig ER, Casey KS, Bruno JF (2010) Warming seas in the Coral Triangle: coral reef vulnerability and management implications. Coast Manage 38:518–539

Muller EB, Kooijman SA, Edmunds PJ, Doyle FJ, Nisbet RM (2009) Dynamic energy budgets in syntrophic symbiotic relationships between heterotrophic hosts and photoautotrophic symbionts. J Theor Biol 259:44–57

Muscatine L, Porter JW (1977) Reef corals: mutualistic symbioses adapted to nutrient-poor environments. Bioscience 27:454–460

Precht WF, Gintert BE, Robbart ML, Fura R, van Woesik R (2016) Unprecedented disease-related coral mortality in southeastern Florida. Sci Rep 6:31374

Randall C, van Woesik R (2015) Contemporary white-band disease in Caribbean corals driven by climate change. Nat Clim Chang 5:375–379

Richardson LL, Kuta KG (2003) Ecological physiology of the black band disease cyanobacterium *Phormidium corallyticum*. FEMS Microbiol Ecol 43:287–298

Richardson LL, Miller AW, Broderick E, Kaczmarsky L, Gantar M, Stanic D, Sekar R (2009) Sulfide, microcystin, and the etiology of black band disease. Dis Aquat Organ 87:79–90

Rogers CS, Muller E, Spitzack T, Miller J (2009) Extensive coral mortality in the US Virgin Islands in 2005/2006: a review of the evidence for synergy among thermal stress, coral bleaching and disease. Caribbean Journal of Science 45:204–214

Rützler K, Santavy DL (1983) The black band disease of Atlantic reef corals. Mar Ecol 4:301–319

Siebeck U, Marshall N, Klüter A, Hoegh-Guldberg O (2006) Monitoring coral bleaching using a colour reference card. Coral Reefs 25:453–460

Sutherland KP, Porter JW, Torres C (2004) Disease and immunity in Caribbean and Indo-Pacific zooxanthellate corals. Mar Ecol Prog Ser 266:265–272

Viehman S, Mills D, Meichel G, Richardson L (2006) Culture and identification of *Desulfovibrio* spp. from corals infected by black band disease on Dominican and Florida Keys reefs. Dis Aquat Organ 69:119–127

Voss JD, Richardson LL (2006) Nutrient enrichment enhances black band disease progression in corals. Coral Reefs 25:569–576

Ward J, Rypien K, Bruno J, Harvell C, Jordan-Dahlgren E, Mullen K, Rodriguez-Martinez R, Sanchez J, Smith G (2006) Coral diversity and disease in Mexico. Dis Aquat Organ 69:23–31

Weil E, Smith G, Gil-Agudelo DL (2006) Status and progress in coral reef disease research. Dis Aquat Organ 69:1–7