HIGH DENSITY OF *DIPLORIA STRIGOSA* INCREASES PREVALENCE OF BLACK BAND DISEASE IN CORAL REEFS OF NORTHERN BERMUDA

Sarah Carpenter
Department of Biology, Clark University, Worcester, MA 01610
(SCarpenter@clarku.edu)

Abstract Black Band Disease (BBD) is one of the most widespread and destructive coral infectious diseases. The disease moves down the infected coral leaving complete coral tissue degradation in its wake. This coral disease is caused by a group of coexisting bacteria; however, the main causative agent is *Phormidium corallyticum*. The objective of this study was to determine how BBD prominence is affected by the density of *D. strigosa*, a common reef building coral found along Bermuda coasts. Quadrats were randomly placed on the reefs at Whalebone Bay and Tobacco Bay and then density and percent infection were recorded and calculated. The results from the observations showed a significant, positive correlation between coral density and percent infection by BBD. This provides evidence that BBD is a water borne infection and that transmission can occur at distances up to 1m. Information about BBD is still scant, but in order to prevent future damage, details pertaining to transmission methods and patterns will be necessary.

Key Words: *Black Band Disease,* Diploria strigosa*, density*

Introduction

Coral pathogens are a relatively new area of study, with the first reports and descriptions made in the 1970's. Today, more than thirty coral diseases have been reported, each threatening the resilience of coral communities (Green and Bruckner 2000). The earliest identified infection was characterized by a dark band, which separated the healthy coral from the dead coral. It was first reported on the reefs of Belize by A. Antonius in 1972 and is now known as the Black Band Disease (BBD). By the 1980's, studies were being conducted to identify the bacteria that constituted the BBD. Rutzler et al. 1983 demonstrated that many different bacteria co-existed as the causative agents, the cyanobacterium *Phormidium corallyticum* being the most prominent. Recent studies have been focused on the methods by which BBD is transmitted from one coral to another.

Environmental stressors such as increasing water temperatures, changes in salinity, pollution, sedimentation, and eutrophication are the cause of increasing disease outbreaks (Sekar 2008, Voss and Richardson 2006). Many of these changes are due to anthropogenic climate change and pollution. As these trends persist, it becomes increasingly important for the science community to be able to isolate or slow the spread of BBD. BBD is a water-borne disease that is also capable of spreading by vectors such as fireworms (Zvuloni et al. 2009). BBD is one of the most widespread coral infections and it is becoming increasingly prominent. Porter et al. 2001 studied coral reefs in the Florida Keys in 1996 and again in 2001, they found that the number of locations exhibiting disease increased by 40%. This study exemplifies the severity of coral infections and demonstrates the need for immediate action.

This study was designed to determine if there is a correlation between the density of *D. strigosa* and percent of infected individuals by Black Band Disease. Because the means of transmission were known to be water-borne, I hypothesized that density of coral and percent of corals infected would have a positive correlation. Information from this study and similar studies in the future could help to determine the distances over which BBD can spread through the water, which could lead to a plan to reverse the increasing damage.

Materials and Methods

Diploria strigosa, commonly known as symmetrical brain coral or simply brain coral, is found in the Caribbean, the Gulf of Mexico, the Bahamas, Bermuda, and off the coast of Florida. It is most commonly found in shallow waters between 1m and 30m. *D. strigosa* rely on their relationship with zooxanthella therefore light must be able to penetrate the water above the coral. Zooxanthellae *Symbiodinium* provide products of photosynthesis to the host and receive inorganic nutrients in return (Baker 2003). *D. strigosa* grow in domes up to 1.8m in diameter. The surface of this coral is covered in convoluted valleys, giving it the appearance of a brain. This pattern can be seen in the uninfected regions of the coral pictured in Fig 1. The color of the *D. strigosa*, which ranges from yellow to blueish gray to greenish brown, is provided by the zooxanthella. *D. strigosa* is a prominent coral in so many reefs because it acts as the foundation on which other corals flourish. The coral skeleton makes up the majority of the colony with the living tissue just forming a thin layer on top.

Figure 1: An image taken at Whalebone Bay of *D. strigosa* infected by Black Band Disease. A thin black line can be seen around the outskirts of the revealed coral skeleton.

D. strigosa is one the 42 corals that are commonly infected by Black Band Disease. The disease arranges itself in a band that can range from 1mm to 1cm in thickness, can be seen in Fig 1. This band is horizontal and moves along the surfaces of the coral leaving behind a bare coral skeleton (Richardson 1996). BBD is capable of moving across the coral at a rate of 1cm each day, faster than the infected corals can grow, making it impossible for the coral to outgrow the infection (Richardson 1996). The dominant species in BBD is the cynobacterium, *Phormidium corallyticum*. This cynobacterium is accompanied by heterotrophic bacteria, fungi, and *Beggiatoa*, a sulfide oxidizing bacterium (Richardson 1996). Transmission occurs by direct contact, water-borne transmission, and possibly by disease vectors such as fireworms or snails (Zvuloni 2009). BBD is found throughout the Caribbean and Indo-Pacific. BBD is becoming increasingly significant in coral reefs worldwide as anthropogenic activity is increasing its rate of transmission.

The sites of this observational study were Tobacco Bay and Whalebone Bay, both located on the north side of Bermuda near the town of St. Georges. Both bays were relatively shielded from ocean disturbances. The data were collected in early October when the water temperatures are still warm from the summer months. When studying BBD, time of year is significant as infection rate nearly disappears during the coldest months (Edmunds 1991).

In the field, a meter stick was swum out to the coral reef and laid down at a random location. Marker tape was tied to both ends of the meter stick to ensure that the ends of the meter sick were clearly identifiable. Video was taken at each location so that a $1m^2$ area was pictured. The video was captured on a Kodak Play Sport with a F2.8/f=3.99 lens. This process was used to collect data for 27 quadrats. To ensure that proper infection status was identified, additional close-up video was taken of the *D. strigosa* in the area.

After all the video was taken, analysis was done on the video by cropping a $1m^2$ area using the meter stick as a guide. Then the *D. strigosa* in the quadrat were counted and the infection status of each was determined using the additional close up video footage. The percent infection for each quadrat was then calculated and the data were analyzed using linear regression of *P. corallyticum* infection prevalence vs. *D. strigosa* density.

Results and Discussion

On October 10-11, 2012, I randomly placed 27 quadrats throughout Whalebone Bay and Tobacco Bay, yielding a total of 149 *D. strigosa*. The mean percent infection for the quadrats was 46.1% and the average density of D. strigosa was 5.52/ m^2. As seen in Fig 2, there is a significant positive correlation between the density of *D. strigosa* in $1m^2$ areas and percent infection within that quadrant. When only a few *D. strigosa* were in the quadrat, the graph shows much less of a trend as often all or none of them were infected. When more than five *D. strigosa* were included in a quadrat, the positive trend was more closely followed.

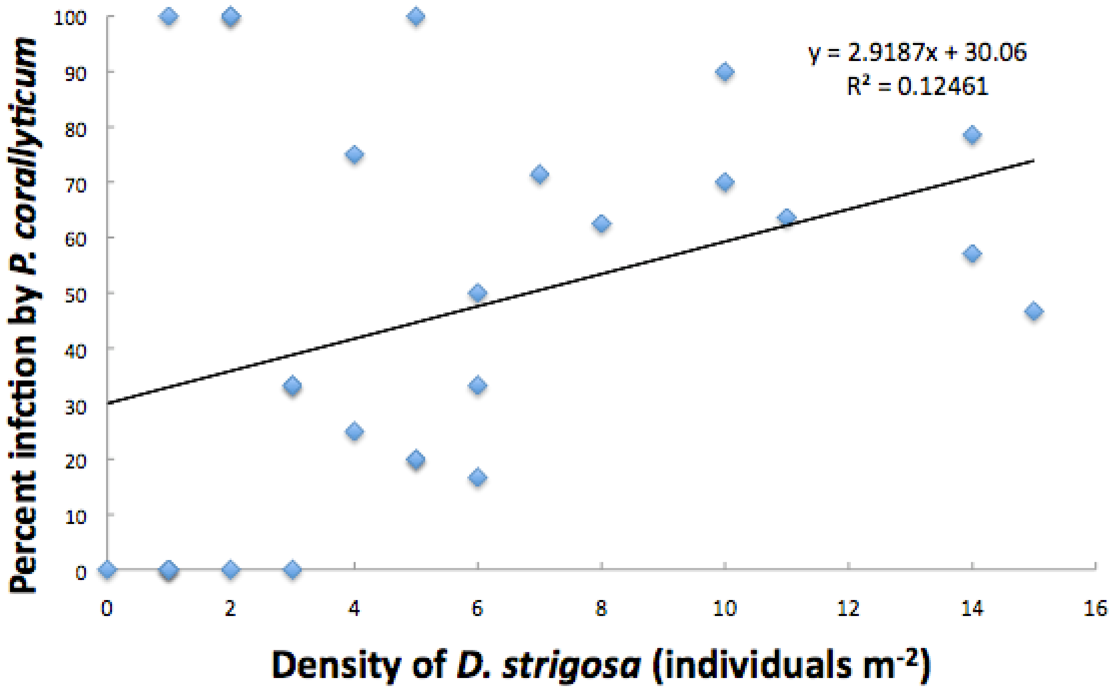

Figure 2: Percent infection of *D. strigosa* by Black Band Disease is positively correlated to the density of the coral (t_{25}=1.89, p=0.04) Quadrats were examined in October 2012 at Tobacco Bay and Whalebone Bay in Bermuda.

This result is consistent with the hypothesis that BBD is able to be transmitted though the water over distances of up to 1m. This study did not take into account any transmission by possible disease vectors snails, fireworms, ect. as there was no means to track their presence at the time of the study. This conclusion complements the findings of Zvuloni et al 2009, who found that BBD is capable of water-borne transmission over spatial scales up to 1.9m. Studies must be done to determine what makes certain *D. strigosa* more susceptible to BBD. A healthy coral can be only 2mm away from a diseased colony and not be infected, showing that BBD is not highly contagious. However, injured or weakened corals are susceptible at much larger distances away from an infected colony (Zvuloni 2009). The factors that determine the health status of a coral are still largely unknown. Although BBD is not considered highly contagious, it still infects a significant portion of our coral reefs, but the causes remain uncertain.

To obtain a better understanding of how BBD is transmitted from coral to coral, it would be worthwhile to measure the distance between uninfected corals to infected corals. This would provide information about the maximum distance BBD can spread and the mechanisms required for transmission. These observations may provide further information about the role of currents and tides on the transmission techniques. Additionally, further information needs to be gathered about alternative transmission mechanisms for BBD.

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