Coral Disease in Chumbe Island Coral Park: A baseline survey of the prevalence of coral disease and other afflictions within Chumbe Marine Protected Area

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Coral Disease in Chumbe Island Coral Park
A baseline survey of the prevalence of coral disease and other afflictions within Chumbe Marine Protected Area

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Abstract

Coral mortality from disease and other afflictions is a rising concern for reefs around the world. The aim of this study was to provide to a baseline for the prevalence of coral disease and other afflictions, which indicate compromised coral health, in Chumbe Island Coral Park, Zanzibar, Tanzania. Chumbe's reef experienced a widespread bleaching event earlier this year and this baseline study will provide a starting point to see how the bleaching event affected the prevalence of disease and other afflictions within the reef. A baseline study will also allow the park to investigate if their current monitoring procedures are effective in protecting the coral from disease and other afflictions. Results based mostly on signs of compromised reef health indicate that the north is the unhealthiest region of the reef, while the south is the healthiest. Infectious disease is currently at relatively low numbers on the reef, but if the other afflictions are not addressed the numbers could rise drastically in the near future.
1.0 Introduction

1.1 Beginning of Coral Disease Research

Coral disease first came to the world's attention in the early 1970's, when scientists noticed an outbreak of white band disease affecting coral in the Caribbean Sea. Since then the Caribbean has become known as the global 'hot spot' for coral disease, as diseases have been responsible for declines of 80% of coral cover in the Caribbean Sea in the past two decades (Gardner, Cote, Gill, Grant, Watkinson, 2003). Although a new field has developed to study coral disease, there is still much unknown about the causes, effects, and paths of these diseases. Problems persist in identification, as nomenclature of diseases is not consistent. Yet, recent progress has been made with the publication of the Coral Disease Handbook by the Coral Reef Targeted Research (CRTR) Program.

1.2 Importance of Coral Reefs

Coral reefs play a critically important environmental role should not be downplayed. Reefs offer shoreline protection by dissipating wave energy, reducing routine erosion, and lessening floods and wave damage caused by storms (Burke, Reytar, Spalding, & Perry, 2011). Although coral reefs cover less than one quarter of 1 percent of the entire marine environment, they are home to 25% of marine life (World Wide Fund). Coral reefs are also important nurseries for hundreds of fish species (Richmond, 2011). It has also been discovered that many corals can be used to develop medicines to treat a number of diseases including cancer, HIV, and malaria. And, corals have the potential to provide for many more applications (Burke et al., 2011).

Coral reefs are not only important for their environmental benefits. They have economic importance. In 2008, it was estimated that the total global net benefit of coral reefs, mangroves, and sea grasses was $29.8 billion dollars. Tourism and recreation accounted for as much as $9.6 billion dollars. Tanzania has 3580km² of coral reefs and it was calculated
that the net welfare loss from ecological damage to reefs in Zanzibar was $22.0-$154.0 million (Conservation International, 2008). CHICOP is a privately run organization that depends on tourists to survive. Without the revenue generated from tourists who visit the park, there would be no park. The revenue generated from tourism is what pays the staff, and allows for the funding of conservation and education programs. If the coral reef were to be damaged beyond repair, CHICOP would not successfully function

1.3 Need for Baseline Studies

Baseline studies are created with the purpose of future comparison. In the case of one conducted in a marine protected area such as CHICOP, a baseline study will also allow the park to investigate if their current monitoring procedures are effective in protecting the coral from disease and other afflictions. As CHICOP underwent an 80% bleaching event earlier this year, this study will also allow for the park to monitor how this bleaching event affected the incidence of coral afflictions within the reef.

This baseline study also introduces a new methodology to visually represent coral coverage within a reef. The methodology consists of creating top-down visual representations of sample areas, which allows for one to see the differences in coral coverage, coral genus, and the distribution of afflictions within the area. This methodology will also allow for the park to repeatedly monitor not only the same sample area but also the same colony of coral over a long period of time. Using this visual representation as a base future researchers can also witness the change in coral coverage and genera over extended periods of time.

1.4 Biological and Anthropological Impacts on Coral Reefs

With the concern of the spread of coral disease and coral mortality from disease, there is a question of biological and anthropological impacts on coral disease. There is evidence of rising disease prevalence following bleaching events, as high sea surface temperatures have
also shown to increase the frequency of coral disease (William, Knapp, Work, Conklin, 2011). It is estimated that 4,000 to 6,000 metric tons of sunscreen from swimmers enters oceans worldwide annually; sunscreen has been proven to cause coral bleaching by
promoting viral infections (Danovaro et al., 2008). Over the past decades there has been a
rise in the number of recreational SCUBA and snorkelers visiting the world's reefs, and these
tourists have been shown to have negative impacts on coral reefs. Numerous studies
conducted in different locations have shown that areas with high SCUBA activity have lower
coral cover, significantly higher numbers of broken and damaged corals, especially branching
corals, and increased rates of sediments on the reef (Zakai, Chadwick-Furman, 2002) (Hasler,
Ott, 2008). In addition to this it has been shown that coral tissue damaged associated with
damage by predators, such as the Drupella cornus snail and other agents on branching stony
corals are much higher at heavily dived sites (Guzner, Novplansky, Shalit, Chadwick, 2010).
Although SCUBA diving is not allowed at Chumbe Island Coral Park, the question of the
damage caused by the snorkelers should not be ignored.

1.5 Effectiveness of Marine Protected Areas

The effectiveness of Marine Protected Areas (MPAs) in combatting the prevalence of
coral disease is questionable. There is an argument that MPAs could promote the spread of
coral disease because of the increased coral host density in MPAs (Hein, Lamb, Scot, Willis,
2015). This is why a baseline coral reef study is important in an MPA like Chumbe. A
baseline study will allow the park to understand if the methods that they are currently
implementing are effective in combatting coral disease. A baseline study helps them to
understand what needs to be changed in their management plan and provides a guide for
future studies in the area.

This study had four main goals. The first was to create a new working methodology to
give future researchers and CHICOP a way to visually represent coral coverage and the
distributions of coral afflictions. The second goal was to provide CHICOP disease data for areas of the reef that had not been previously studied and that were vastly different from their already established points. The third goal was to provide a general assessment of the health of the whole reef through timed swims. The fourth and final goal was to provide data for afflictions that had not previously been recorded by the park.
2.0 Study Area

35 km off the mainland of Tanzania, Zanzibar consists of two islands, Unguja and Pemba. About 8 km from the southwest coast of Unguja is Chumbe Island Coral Park (CHICOP). Established in 1991, CHICOP was the first marine park in Zanzibar, and is currently the only privately managed Marine Park (MPA) in East Africa. The protected reef comprises a thirty-three hectare area and is 1.3 km long. The reef on the eastern side of the island is unprotected and fisherman regularly fish there. Over 200 species of coral, or 90% of East Africa’s hard coral species, can be found within the fringing reef of CHICOP (Chumbe). While Chumbe boasts one of the richest and healthiest reefs in the area, earlier this year the park experienced a mass-bleaching event, during which 80% bleaching was observed across the reef (Chumbe).

Figure 1: Map of Zanzibar with Chumbe Highlighted
Figure 2: Topographic Map of Chumbe Island with Nine Sample Points Marked
*The locations of the nine points are estimations as GPS coordinates could not be taken.
3.0 Background

3.1 Coral & Coral Bleaching

Coral reefs are multidimensional ecosystems comprising of a variety of plants and animals. Corals are the backbone of this ecosystem. Part of the phylum family, Cnidaria, coral polyps are living organisms. Colonies form when several polyps join together. A unique characteristic of coral is the symbiotic relationship they have with a single-celled algae called zooxanthellae. The zooxanthellae provides the coral with food and in the case of hard corals the calcium carbonate needed for skeletal growth (Richmond, 2011). Coral bleaching occurs when corals expel their zooxanthellae due to high water temperatures.

3.2 Definitions of Coral Diseases and other Afflictions

Disease is defined as an abnormal condition of an organism that impairs organism functions, associated with specific symptoms and signs (ICRI/UNEP-WCMC, 2010). More specific definitions for each disease can also be found, for example pigmentation response is defined as multifocal or diffuse areas of pink, purple or blue brightly colored tissue discoloration (Raymundo et al., 2008). Pigmentation response (PR) can be caused by a number of factors, including but not limited to fish bites, competitors, and algal abrasion, and is therefore a type of "inflammatory" response by the coral. Pigmentation response is not a disease itself but rather a symptom of compromised health (Beeden, Willis, Raymundo, Page, Weil, 2008).

White syndrome (WS) is a syndrome that describes diffuse patterns of tissue loss exposing irregular bands or patches of white skeleton on Indo-Pacific Corals. Known to be one of the most destructive diseases on coral reefs, studies have shown that there is a high prevalence of the *Vibrio* bacteria species associated with white syndrome signs in diseased colonies sampled from WS outbreaks (Sussman, Willis, Victor, Bourne, 2008). A study conducted at the Christmas and Cocos Islands in the Indian ocean found that WS was found
almost exclusively in *Acropora* plate corals, and that WS was not only host-specific but also spatially variable and positively correlated with host density (Hobbs, Frisch, 2010). These findings were consistent with studies done in the Pacific Ocean, which demonstrated a positive correlation between temperature anomalies, high coral cover, and raised prevalence of white syndrome (Hoff, 2007).

*Porites* ulcerative white spot (PUWS) is defined as multifocal patterns of tissue loss exposing small circular areas of bare white skeleton (Bourne, Ainsworth, Pollock, Willis, 2015). Lesions tend to be less than one centimeter in diameter. A slow killer, the rate of tissue loss associated with PUWS is much slower than that that has been reported for other diseases. PUWS is also associated with a slow onset and rare recovery rate (Raymundo, Harvell, Reynolds, 2003). Believed to be caused by *Vibrio* bacteria, PUWS has been found to be transmissible (Arboleda, Reichardt, 2010).

Distinctive by irregular circular patches that are lighter in color and raised above the surface of the healthy coral, tumors are considered a growth anomaly (Raymundo, et al., 2008). They begin as single polyps. Although there are two types of tumors, hyperplasia and neoplasia, we have not identified them separately, as consistent with the current CHICOP monitoring plan. The reason for this is because the rangers are not sure of the specific identification between the two types. Neoplasia is identified as white, globular masses raised above the surface of the coral skeleton with polyp structures that are not easily discernable and Hyperplasia is identified by remaining polyp structure and pigmented tissue (Tyler, 2008).

Chumbe white splotch (CWS) is an unusual bleaching pattern that is seen as an area of white coral, with corallites still intact, of varying sizes (Tyler, 2008) seen in this study as various sizes of "non-focal" bleaching patterns. CWS is not yet identified and may not be
classified as a disease. This name has been used by the park in its current monitoring program and will continue to be used until it is identified.

Although coral diseases are important causes of coral mortality, corals can also be afflicted with a number of other factors that not only cause mortality but may also lead to a higher prevalence of coral disease. *Drupella cornus* are snails that vary in color from pink to dark red with shells that can grow up to 5cm (Beeden, et al. 2008)(Reef Resilience). Coral predators *Drupella* eat the live coral tissue by stripping the tissue from the coral skeleton, leaving easily identifiable feeding scars. Night feeders, the snails are typically found during the day hiding in the bases of branching colonies near their feeding scars. Feeding scars often become overgrown with algae and can have devastating effects on coral colonies. A study conducted on the Great Barrier Reef directly correlated the transmission of brown band disease with the *Drupella* feeding activity; the disease was clearly seen to begin from the feeding scar and rapidly progress (Nicolet, Hoogenboom, Gardiner, Pratchett, Willis, 2013). Abundance of *Drupella* has also been correlated with the other diseases, including white syndromes and skeletal eroding band. It is unknown, however, if the corallivorous snails are directly transporting diseases between colonies or indirectly causing diseases by creating an entry wound for pathogens in their feeding scars.

Sedimentation occurs when a layer of sediment is deposited on coral colonies. Sedimentation negatively impact corals in a number of ways: it blocks light, thereby inhibiting photosynthesis; can directly smother and abrade coral; and triggers increase in macro algae (U.S. Geological Survey). Moreover, sedimentation has been directly linked to a higher prevalence of coral disease. A study conducted in Western Australia showed how sedimentation and turbidity were drivers of coral disease as researchers found a two-fold higher disease prevalence in areas that had high sediment plume exposure. This two-fold increase was mostly driven by a 2.5 fold increase in White Syndromes, however there was
also an elevated prevalence of Pigmentation Response at high exposure sites (Pollock et al., 2014).
4.0 Methodology

4.1 Timed Swims

To assess the general health of the whole reef, nine timed swims, three in each area of the reef, were conducted. Each timed swim was thirty minutes long. To accurately represent the total area of the reef each timed swim was conducted with a focus on different sections of the reef within the larger area: the edge, the middle, and the shallow regions of the reef. During each timed swims observations were made on the types and sizes of organisms seen, as well as the types and health of corals. All of the timed swims but two in the north were swum going from south to north; two in the north were swum going from north to south.

4.2 Establishing Sample Points

Nine sample points distributed evenly at three areas of the reef (north, middle, and south) were established. The points were chosen with the help of Chumbe's head ranger, Omari Nyange, to ensure that the points did not conflict with the areas already monitored in Chumbe's established monitoring program. Each point was marked on the surface by a plastic bottle attached to fishing line tied to a piece of dead coral. The dead coral that the fishing line was tied to was treated as the sample point. The sample area consisted of a five-meter radius around each of the nine sample points on the reef. Southern and middle points were labeled from south to north, so South-1 was the most south while South-3 was the most north. While northern points were labeled from north to south, so North-1 was the most north while North-3 was the most south.

After the nine points were established, top-down photos of the total area of the nine points were taken using a GoPro Hero4+. These images were later stitched together on Adobe Photoshop to create a top-down visual representation of the coral cover of the sample area. At three of the points, one from each area, each infected colony was marked on the top-down visual image to show the distribution of diseases in the sample areas.
4.3 Disease Observations

When observing disease prevalence in the sample area, two tape measures were laid out in a cross to make it easy to identify the total sample area. Consistent with Chumbe's monitoring plan, only live colonies larger than 10cm were counted. After the number of colonies within the area was counted, the observers swam around the sample area to identify the afflicted colonies. The type of affliction and the genus of each colony was recorded on a diving slate and photos were taken of the afflicted colonies.
5.0 Results

5.1 Southern Timed Swims

Two hawksbill turtles (Eretmochelys imbricate) were seen on two timed swims. Large schools of pickhandle barracuda (Sphyraena jello) were observed in the edge of the reef, while a small sea urchin was seen buried in the rubble in the shallow regions. A 25cm spider conch (Lambis lambis) was observed in the shallow part of the reef. Many large healthy colonies of Porites, Fungia (mushroom), Platygyra (brain), Montipora, and Acropora were seen in the edge of the reef. In the middle and shallow regions of the reef Montipora colonies were most common and healthy. Bleached sea anemones were observed with healthy anemone as well. Large expanses of dead Acropora branching colonies with small live and growing colonies on the edge of the dead colony were seen in the middle region.

5.2 Middle Timed Swims

A blacktip reef shark (Carcharhinus melanopterus) was seen on the edge of the reef. Three sea urchins were also observed on the edge of the reef. Two lobsters were seen on two of the timed swims on the edge and shallow regions. On the edge of the reef the most dominant type of coral was Acropora, however in the shallower regions the most common colonies were Porites and Montipora. Evidence of bleaching was observed on the top of many Porites colonies. A bleached detached sea anemone was seen floating in the shallow region. Large expanses of dead Acropora colonies were observed towards the northern section of the middle of the reef.

5.3 Northern Timed Swims

A crown-of-thorns starfish (Acanthaster planci) and a mantis shrimp (Odontodactylus scyllarus) were observed on the edge of the reef. Singular blackspot emperor (Lethrinus harak) were the largest species of fish observed. Smaller reef fish such as the black-saddle toby (Canthigaser valentini), skunk anemonefish (Amphiprion aallopisos), and zebra humbug
(Dascyllus aruanus) were the most commonly seen and in the shallower region a few other species were observed. In the northern most section of the reef there was no clear drop off as in the south and middle regions, instead there was a gradual sandy slope. Only about ten minutes into the timed swim in the north was the drop off reached. There was a clear distinction in the number of colonies and genus of colonies between the slope region and the drop off. During the middle timed swim 233 sea urchins were counted. Broken sea urchin spines were also observed. Multiple large expanses of dead Acropora colonies were seen, however the most common type of live coral were Porites.

5.4 Affliction Prevalence in the South

Six of the seven afflictions were observed in the three southern sample areas. 603 coral colonies were counted in the three sample areas. The only cases of Tumors were observed in two of the three southern sample areas. In South-1 three of the four cases of pigmentation response were observed within one quadrant of the sample area. As shown in Graph 1 afflicted colonies accounted for 6.14% of all colonies in the South. Pigmentation response was the most common affliction affecting 3.48% of the colonies. Drupella snails afflicted 1.16%, sedimentation 0.66%, white syndrome and tumors afflicted 0.33%, and finally Chumbe White Splotch afflicted 0.17% of the coral colonies. The distribution of the afflictions in sample area South-2 is shown in Figure 3, and the images of the coral coverage for the other two southern points may be found in the appendix.
Graph 1: Percent Affliction in the South

Graph 2: Affliction Percentages in the South
Figure 3: Distribution of Afflictions at point South-2
5.5 Affliction Prevalence in the Middle

Four of the seven afflictions were observed in the three middle sample areas. 510 colonies were counted in the sample areas. As shown in Graph 3 afflicted colonies accounted for 8.63% of total colonies in the sample areas. Pigmentation response was the most common affliction, affecting 6.27% of all colonies. Sedimentation affected 1.57%, Drupella affected 0.59%, and Chumbe white splotch accounted for 0.20%. The distribution of afflictions in sample area Middle-3 is shown in Figure 4 and as the figure shows sedimentation was observed with pigmentation response in three of four cases. The images for coral cover of the other two middle points can be found in the appendix.
Figure 4: Distribution of Afflictions at Middle-3
5.6 Affliction Prevalence in the North

Six of the seven afflictions were observed in the three northern sample points. 266 coral colonies were counted in the three points. The only cases of Porites ulcerative white spots was observed in North-1; in one of these cases pigmentation response was also observed on the colony. As shown in Graph 5 afflicted colonies accounted for 22.56% of colonies in the sample areas. Pigmentation response was the most common affliction, affecting 16.92% of all colonies. Sedimentation affected 2.26%, Drupella affected 1.13%, and finally Porites ulcerative white spots, Chumbe white splotch, and white syndrome affected 0.75%. The distribution of afflictions in sample area North-3 is shown in Figure 5, and the images for coral cover of the other two northern points can be found in the appendix.
Figure 5: Distribution of Afflictions at point North-3

Key
- ▲ Pigmentation Response
- ● Sedimentation
- ▲ Chumbe White Splotch
- ★ White Syndrome
5.7 Comparisons of Affliction Prevalence of the whole Reef

The most common affliction was pigmentation response, which was observed 98 times. Pigmentation response was the only affliction observed in all nine sample areas. Sedimentation and *Drupella cornus* were the next most common afflictions affecting 18 and 13 colonies, respectively. Sedimentation was observed in eight of the sample areas, while *Drupella* snails were observed in five of the sample areas. There were four cases of white syndrome and Chumbe white splotch. White syndrome was observed in three of the sample areas. Chumbe white splotch was observed in four of the sample areas. There were two cases of tumors and *Porites* ulcerative white spots. Tumors were observed in two of the sample areas. *Porites* ulcerative white spots were observed in one sample area. Graph 7 displays the distribution of each of the afflictions per region. While Graph 8 summarizes the percent of afflicted coral per region.
5.8 Afflicted Coral Genera

The types of coral genus afflicted by disease varied per disease, however the most afflicted genus were *Porites* with *Porites* colonies afflicted with five of the seven afflictions. As *Porites* Ulcerative White Spots only affects *Porites* colonies, this affliction has not been taken into account when counting the number of afflictions that effect different genera. All four cases of Chumbe White Splotch were observed in *Porites*, while 96 cases of pigmentation response were *Porites*. The other two instances of pigmentation response were found on *Fungia* (mushroom) coral. Two cases of tumors were recorded on the reef, one on a *Porites*, and the other on an *Astreopora*.

Sedimentation affected the widest range of coral genera, affecting five different genera. 72% or 13 cases, of Sedimentation were observed on *Porites*, and two cases were observed on *Galaxea*. One case was observed on *Diploastrea*, *Platygyra*, and *Oulophyllia* corals and for these genera. Sedimentation was the only affliction that was observed on them.
Four cases of White Syndrome were observed over the nine sample areas. Three of the cases affected Acropora corals, while one case was observed on a Galaxea. Acropora corals were also the most afflicted with Drupella cornus snails, 11 or 85% of Drupella afflictions were observed on Acropora corals. The other two cases of Drupella were observed on Montipora.
6.0 Discussion

6.1 Improvements to Methodology

Improvements need to be made to the way that points are marked. Over the course of the study South 2, South 3, Middle 2, and North 1 had to be reestablished once, while Middle 3 had to be reestablished twice. This was because the plastic bottles disappeared, and without the bottles the researcher had no way of locating the points. When these points were reestablished the locations were changed from the original established location, as it was too time consuming to try to find the original locations on the reef. Points were not randomly established. Instead Omari Nyange, based on his experiences on the reef, chose the points where he knew that coral disease more prevalent. The location of the points was also limited by the fact that the areas could not overlap with the points already established by the park. The park's transect follows the edges of the reef in the three section, which is the most diverse and healthy part of the reef as shown by the timed swims. Due to this, many of the sample points in this study, especially the three in the north, were placed in shallower regions and therefore unhealthier and less diverse regions of the reef.

Originally the plastic bottles used were small soda and juice bottles, however throughout the course of the study a lot of time was wasted in the water trying to locate the points while swimming. Therefore, after one week the small bottles were replaced with larger 1.5L water bottles that had been stuffed with yellow construction paper. It was found that having the bright paper in the larger bottles made the bottles not only more visible for a swimmer in the water, but the bottles could also be seen from the island. This meant that it was easier to check if the bottles were still there or not, an important factor because they tended to disappear.

Considerations should also be taken when trying to figure out what camera to use to take the top-down images to create the visual of the greater coral cover. The GoPro camera is
helpful in that it is a small camera that is easy to carry along with the other equipment when one is swimming alone. But there are also many disadvantages to using the GoPro, the main one being that the wide-angle of the camera creates a distortion on the edge of the image. This means that it takes longer to stitch together the images on Photoshop because the distortion must be taken into account when trying to blend and merge images. In fact the visuals of each sample area created for this study are comprised of about 30-40 images. It is recommended that future researchers whom try to replicate this image method that a camera that uses a normal, rather than a wide-angle lens, as this will save much time in the image processing. The other major disadvantage of using a GoPro is that the camera has no view screen, so one does not know what they are taking an image of and therefore many more images need to be taken, which adds time out of the water for processing. This could have been easily avoided by purchasing the additional screen attachment that GoPro offers.

6.2 General Reef Health from Timed Swims

The observations made in the timed swims support the general consensus by the Chumbe staff and long-term guests that the north is the least healthy region of the reef and that the south is the healthiest. Hawksbill turtles and blacktip reef sharks are important indicator species of a healthy reef; a profusion of sea urchins and the presence of the crown-of-thorns starfish are indicators of an unhealthy reef. It should be noted, however, that crown-of-thorns are native to the Western Indian Ocean, only when they are in an outbreak are they a true indicator of poor reef health. The differences between average size of fish and types of fish seen on the timed swims, with the larger and more diverse schools of fish observed in the south, versus the smaller and more common reef fish seen in the north also show the difference in health between the different areas of the reef. Although dead coral colonies were observed in all areas of the reef, there was a sharp contrast between the prevalence of dead colonies between the south, middle, and north. In the north and middle regions multiple
large expanses of dead Acropora colonies with no live colonies in the same vicinity are a clear indication that the colonies were not able to bounce back from the bleaching event that occurred earlier in the year. In the south the dead Acropora colonies were attached to healthy, growing Acropora colonies. The presences of these healthy colonies are an indication that some of the colonies were able to recover from the bleaching event. Throughout every region of the reef the healthiest and most diverse corals were observed at the edge of the reef, in the deeper waters. Porites and Montipora colonies dominated the shallow areas in every region of the reef.

Twice a year CHICOP experiences extreme low tides due to shifting wind patterns. Four of nine timed swims were conducted during this extreme low tide. In these cases the timed swims were conducted in 1.2 meters or less of water. The tops of many of the colonies were exposed (Appendix 3, 8). This means that when the timed swims were conducted many colonies were exposed to the sun, and the extremely shallow depth limited the path of the observer. The other timed swims were conducted in 2m to 3m of water. Although the prevalence of disease was counted during these timed swims, those results have not been included in this study. This is due to the huge variation that occurred in visibility due to the depth of water, amount of sunlight, and sediment during the different days and times that the timed swims were conducted. As the observer did not free-dive during the timed swims, there were inconsistencies in the disease prevalence counted during the timed swims with the ones conducted in the shallow water (1.2m or less) having much higher prevalence than those conducted in the deeper water.

6.3 Concentration of Diseases

In certain points the incidence of diseases, especially pigmentation response, was concentrated in one area. For example in South-1 three of the four cases of pigmentation response was observed within one quadrat. Pigmentation response was also observed in
neighboring colonies of the same genus in many cases. This high concentration of the prevalence of colonies afflicted with pigmentation response in a small area could be due to many factors. One such reason could be that originally those separate colonies were part of the same colony. A colony is distinct from another if there are no polyps joining them together- in many cases the two neighboring colonies afflicted by pigmentation response were only separated from each other by a thin row of dead coral. Another reason for the concentration of pigmentation response could be due to the nature of the inflammatory response. Since the stressors that cause pigmentation response have no bias, they could be affecting multiple colonies in the same area leading to these concentrations of pigmentation.

Aside from the spatial concentration of colonies afflicted with pigmentation response, multiple afflictions were often observed afflicting the same colony. Six colonies afflicted with sedimentation were also afflicted with pigmentation response. Again this could be because sedimentation is a known stressor of coral that can lead to higher affliction rates of pigmentation response. In two cases pigmentation response was observed with other afflictions, one with tumors and the other with *Porites* ulcerative white spots. In these cases pigmentation was observed around the other diseases, leading to the question of whether the weakened colonies were first afflicted with pigmentation that allowed for the infection from the other disease or if pigmentation as an inflammatory response occurred after the colonies were already afflicted with these diseases as a way of the colony fighting against them.

6.4 *Drupella cornus* snails

*Drupella cornus* outbreaks are defined as "any population of elevated density that causes extensive mortality of corals and persists for months or years over large areas of reef" (Cumming, 2009). *Drupella* snails were observed in five of the nine sample areas, but the levels of *Drupella* observed are not currently indicative of an outbreak. Seen in every sample area in the south, while only in one sample area each in the middle and north, the levels of
Drupella were more spatially widespread in the southern areas but more concentrated within a smaller area in the middle and the north. Drupella prefer branching colonies and are most commonly seen on Acropora and Pocillopora corals (Reef Resilience). This preferred food source could be the reason that they were seen in a more widespread area in the southern region of the reef.

As seen by the timed swims, there were large expanses of dead Acropora colonies in both the middle and northern sections of the reef, while more healthy live Acropora colonies in the southern regions. This relative difference in health of the Drupella's preferred food source over the reef area could have lead to a concentration of the Drupella in the areas where live Acropora colonies are more abundant. This argument could also be used to explain the concentration of Drupella cases within the middle and northern sample areas. The Drupella in those cases were isolated to the areas of the reef where the Acropora had survived the bleaching event. It should also be noted that in South-3 Drupella predation was observed not only on Acropora colonies but also on two Montipora colonies. These were the only cases of Drupella not on Acropora within the sample areas. This difference is significant because it represents that within Chumbe's reef the Drupella are moving from their preferred food source, healthy Acropora colonies, because of the lack of that food source within the reef.

6.5 Common Bleaching

Bleaching occurs when corals expel their zooxanthellae from the coral tissue, causing the coral to turn completely white. Without the zooxanthellae the coral loses its major food source becoming more susceptible to infectious disease (Richmond, 2011). Normally caused by rises in water temperatures, other factors can also influence coral bleaching. Chumbe Island Coral Park experienced a bleaching event earlier this year where at least 80% of the corals were bleached (Chumbe).
Dead coral colonies from this bleaching event could be seen throughout the reef; in the sample areas the number of coral colonies are much lower than the numbers of those recorded by Chumbe staff in their established sample areas. The lower number of live colonies could be due to death from this bleaching event, as dead colonies were seen scattered in every sample area. However it should be noted that the sample areas in this study were purposely laid out in the sparse coral regions of the reef, while Chumbe's monitoring points are within the dense coral areas.

Common bleaching was observed in all of the sample areas. Most commonly seen on Montipora and Porites in these areas, bleaching is widespread in the coral genera it affects. In the sample areas bleaching was commonly seen on the tops of coral colonies and was much more prevalent after the extreme low tides that occurred from November 14th to November 17th. During these days, the tops of multiple colonies were exposed to the atmosphere for multiple hours at a time. Being out of the controlled aqua environment, these colonies are susceptible to being "sun burned". It is believed that much of the bleaching that was seen in the north and middle of the reef after these extreme low tides was caused by this "sun burn" effect.

6.6 Corallivores and Disease

Every time an individual enters the water to snorkel at CHICOP, they can hear the sounds of Parrotfish (Scaridae) grazing. As such parrotfish grazing was not only observed multiple times during each timed swim, but scars from parrotfish predation were observed on coral colonies in every sample area. Parrotfish are a keystone species within a reef, whose presence are especially important after a bleaching event.

The ability of a coral reef to recover from a bleaching event depends on recruitment and survival of new corals: a process that is inhibited by macroalgae. Macroalgae are well-documented competitors of corals known to have detrimental effects on coral health (Ledlie
Parrotfish are herbivorous fishes that eat macroalgae, allowing them to play an important role in the mediation of competition between corals and macroalgae (Mumby et al., 2006). Yet even though parrotfish play this key role in allowing new corals to survive and rebuild, the scars from predation can also negatively impact the health of the coral colonies.

Fish predation is a known cause of pigmentation response (Beeden et al., 2008). This cause and effect was highlighted by the high prevalence of pigmentation that was seen on the reef around fish predation scars. Observed in six of the nine sample areas, multiple cases of fish predation were observed on the same colony as pigmentation. In many of these cases pigmentation response was just beginning and could only be seen as a small pink or purple boundary around the predation scars (Appendix 4, 14). This is interesting to note because on one hand while Chumbe depends on the abundance of parrotfish and their grazing behaviors to allow the reef to rebound from bleaching events; the very activity that allows for the reef to rebuild after bleaching seems to have a direct correlation with the elevated levels of pigmentation response within the reef. In many senses the benefits of parrotfish grazing behavior far outweigh the negative of the fish predation scars, but this correlation between fish predation and pigmentation response should be continually observed on Chumbe's reef to further understand the relationship.

Crown-of-thorns starfish (*Acanthaster planci*) are generally considered a sign of compromised reef health. Corvallivores, crown-of-thorns harm coral colonies by directly eating the live coral tissue and leaving white skeletal scars. Fast consumers crown-of-thorns are known to have devastating effects on coral coverage (Australian Institute of Marine Science). Crown-of-thorns are native to East Africa, and as such although Chumbe monitors the levels of the starfish they do not remove them unless an outbreak occurs. The only time scars from crown-of-thorns predation was observed in the reef was in sample area South-2, yet no crown-of-thorns were seen in the south during either timed swims or within the sample
areas. However, crown-of-thorns were observed in the north during timed swims and in the North-1 sample area. Although no scars from crown-of-thorns predation was observed within this sample area, it can reasonably be assumed that the presence of the crown-of-thorns will affect the corals in the area at a later date.

6.7 Implications of Affliction Prevalence

The results from the affliction observations supports the claims made from the observations in the timed swims that the north is the unhealthiest region of the reef, while the south is the healthiest region. This is clearly seen by the number of healthy colonies within the sample areas. The north had the greatest number of colonies afflicted with disease, yet it only had about 40% of the number of colonies as the south. This sharp contrast is also shown by the percent of afflicted corals within the three regions. The north had more than three times the percent of afflicted colonies than the south, and more than two times the percent of afflicted colonies than the middle. Two of the middle sample areas, Middle-2 and Middle-3, were in the southern-middle section of the reef, while Middle-1 was in the northern-middle section of the reef. Between the three points there was a noticeable difference in the number of afflicted colonies, again Middle-2 and Middle-3 had much smaller numbers than that of Middle-1. Supporting the general trend of the north being the unhealthiest region and the south being the healthiest region.

Changes in water depth could also be one of the main factors that contribute to the sharp contrast in coral health between the different reef regions. Southern sample areas could only be studied during low tide because at other times of the day, the water was simply too deep to effectively survey the area. In contrast, the north sample areas could be accessed at any time of day besides during low tide. The water was simply too shallow to be able to
safely survey the area at this time. To a certain depth, the deeper the water the wider range of coral genera that can survive.

Porites are a shallow water genus (Richmond, 2011). This means that they are commonly found in the shallower regions of reefs. In the sample areas Porites were one of the most common genera of coral. Their widespread abundance could have factored into the high levels of afflictions within the genus. In Middle-3, although the sample area was dominated by Montipora colonies, the only afflicted colonies in this area were Porites. The reason for the high affliction rates of Porites compared to other corals are not truly understood, but it could be because of the multiple stressors such as fish predation and common bleaching that seem to affect most commonly affect Porites on Chumbe's reef. As previously stated these stressors all led to weakened coral health and immunity, leaving the corals more susceptible to disease.

6.8 Errors in Affliction Observations

The number of coral colonies in one quadrant in South-1 is estimated to be undercounted by about 50%. This assumption is made from the total count from the other three quadrants. Therefore there should be about 30 more colonies in South-1, which would bring the total colony count of the three southern points to 633. This undercount was most likely made because this was the first point that was surveyed for afflictions and one of the observers had not counted coral colonies before. However since this change does not greatly affect the percentages of afflictions this assumed total was not used when making calculations and the counted total was used instead.

This study focused on the number of afflictions in each sample area and not the number of colonies afflicted. Therefore colonies with multiple afflictions were counted numerous times to gather the extent of afflictions within each sample area. This means that the total number of cases of affliction does not represent the total number of colonies
afflicted, however when calculating the total number of afflicted colonies each case was treated as a separate colony. Due to this double counting, the percentages of afflictions should be a little lower than what was calculated. This was assumed to not drastically affect the results and therefore has not been taken into account.
7.0 Conclusions

Knowing the rates of disease and other afflictions on coral colonies is important when creating management protocols for disease outbreak. Seven different afflictions were observed within the reef, the most common afflictions were pigmentation response, sedimentation and *Drupella cornus* snails. All three of these afflictions indicate compromised reef health and are not necessarily classified as a coral disease. Although disease seems to be at relatively low numbers currently, the concentration of signs of compromised reef health along with the bleaching event could lead to much higher concentrations of disease in the future. Nonetheless the results from the timed swims and percent afflictions of coral colonies indicate that the north is the unhealthiest region of the reef, while the south is the healthiest region. This sharp contrast was seen in the types of organisms observed, the genera and size of coral colonies, the number of live colonies, but most noticeably in the difference in percent of colonies afflicted in the north, middle, and south. The south had 6.14% afflicted colonies, the middle had 8.63%, and the north had 22.56%. To truly understand the effect of the recent coral bleaching event on the park further studies need to be conducted to see if the prevalence of coral disease and other afflictions increase.
8.0 Recommendations

Overall a great deal of knowledge is still needed to truly assess the levels of coral disease and other afflictions within Chumbe Island Coral Park. Future studies should return to the nine sample areas to assess the changes in coral coverage, the progression of the identified diseases, and to record if any new cases of afflictions are seen. Only after these studies have been done can the true effect of the bleaching event be known.

Currently the levels of *Drupella cornus* are not considered an outbreak, however their prevalence in every region of the reef indicates that the *Drupella* are widespread. The number of cases of *Drupella cornus* should be closely monitored in case an outbreak does occur and management plans should be created to address the possibility of a *Drupella* outbreak and to create procedures for how to handle one.

Education of guests is extremely important in Chumbe Island Coral Park. Although guests currently go through a pre-snorkel briefing, this briefing is solely focused on the types of fish seen. During the researchers stay on Chumbe, a presentation on the results of this study was given to three guests and staff members. The next day two guests who attended the presentation approached the researcher after the snorkeling activity and indicated that although that was their third time snorkeling on the reef it was the first time they actually looked at the coral. They said that after the presentation and visuals within it, they believed that they saw some signs of coral affliction while snorkeling. This shows that to many individuals coral disease does not cross their mind, and changing this is the first step in ensuring that people understand not only how they impact coral reefs but also how they can help to alleviate the stressors of corals. This study also did not focus on the anthropological effects of having regular snorkelers on the reef, future studies on coral afflictions within the reef should also consider looking into this relationship.
9.0 References

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Appendices
Appendix 1: Visuals of Sample Areas

Figure 1: North-1
Figure 2: North-2
Figure 3: Middle-1
Figure 4: Middle-2
Figure 5: South-1
Appendix 2: Images of Methodology

Figure 6: Improved plastic bottle buoys with bright paper

Figure 7: Establishing the sample area
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Figure 8: Exposed *Porites* and *Acropora* colonies during the extreme low tides

Figure 9: Bleaching seen on top of *Porites* in sample area North-1
Figure 10: Expanse of dead Acropora colonies in the North

Figure 11: Live Acropora branching colonies in the foreground with dead colonies seen in the background
Figure 12: Crown-of-thorns starfish (*Acanthaster planci*) observed in the North

Figure 13: Hawksbill turtle (*Eretmochelys imbricate*) seen in the South
Appendix 4: Images of Coral Disease and other Afflictions

Figure 13: Pigmentation Response affecting *Porites* colony in sample area Middle-2

Figure 14: Pigmentation Response around fish predation scars on *Porites* colony in sample area North-3.
Figure 15: White Syndrome affecting Acropora colony in sample area South-2

Figure 16: White Syndrome affecting Galaxea colony in sample area North-3
Figure 17: *Porites* ulcerative white spots observed in sample area North-1

Figure 18: Tumors affecting a *Porites* colony in sample area South-3
Figure 19: Chumbe White Splotch observed on a *Porites* colony in sample area South-2

Figure 20: Feeding scars caused by *Drupella cornus* snail on *Acropora* colony in sample area South-2.
Figure 21: *Drupella cornus* snail resting in a *Montipora* colony during the day as seen in sample area South-3

Figure 22: Sedimentation on a *Diploastrea* colony as seen in sample area South-1