Coral Health and Water Quality Evaluations at Waiopae Tide Pools, Kapoho, Big Island of Hawai'i

by Cheresa Coles

Abstract

The Waiopae tide pools contain several reef communities that have recently been designated as a Marine Life Conservation District (MLCD). Patches of coral are scattered throughout the A'a and Pa'hoe'hoe lava substrate that make up this unique ecosystem. A continuously and rapidly expanding community is being built around the tide pools. All of the dwellings have cesspools or septic systems. These sewage systems allow raw residential sewage to leak directly into the underground water table that flows into the tide pools. As a consequence, excess nutrients are leached into the coral communities that live in the Waiopae tide pools. Coral ecosystems are easily affected by inputs of nutrients that can change the conditions of the marine environment needed for survival. Field experiments were conducted in Kapoho, Hawai'i, USA, (latitude: 19.5195, Longitude: -154.8135) to determine the amount of bacteria in several locations of the MLCD, as well as in areas outside of the MLCD. A total of eight locations were monitored weekly over an eight month period. Bacterial levels were quantified using the fecal indicator bacteria *Escherichia coli* and *Enterobacter aerogenes* by using Coliscan® tests. It was found that the Waiopae tide pool ecosystem contained levels of the fecal indicator bacteria *E.coli* and total bacteria coliforms in excessive levels according to EPA and state guidelines. Due to the excess nutrients and sewage inputs into the Waiopae tide pools, the coral communities in the tide pools may be at great risks from these anthropogenic stresses.

Introduction

Coral ecosystems in the Waiopae tide pools consist of many marine species. Corals are a keystone species that defines an ecosystem and provides its basic three-dimensional structure (Birkeland, 2004). The phylum Cnidaria consists of many orders of coral. The stony corals are in phylum Cnidaria, class Anthozoa, subclass Hexacorrallia, and order Scleractinia. These corals have anemone like polyps that secrete calcium carbonate skeletons and live in benthic colonies. Corals can reproduce both sexually and asexually. In Hawai'i, there are about 50 species of shallow-water corals in 17 genera (Hoover, 1998). In the Waiopae tide pools there are about five dominate species of coral.

Corals are sessile benthic animals. This organism's survival is completely dependent on the quality of their environment. Scientific evidence has indicated that coral reefs are deteriorating rapidly around the world (NOAA, 2005). Some causes of the coral's deterioration are pollution, natural weather patterns, global warming and trampling by observers. The increasing threats to coral, coincides with an expanding population along the coastlines around the world. Although, reefs have been degraded by human activities, evidence shows that they will recover, provided remedial measures are implemented on land to restore water and substrate conditions Wolanski et al., 2004). Reefs are especially important to protect because they contribute to our world economy by providing food, tourism, jobs, recreation and protection from storms and tidal surges (Cesar et al. 2004).

Steady environmental conditions must exist for coral communities to develop and survive. These necessary stable conditions are: water movement, water temperature, and clear water. Wave action provides the water movement that is necessary to supply the corals with oxygen and prevents sediments from collecting on them, since they are sessile organisms. This is a process that is controlled by natural ocean currents and the geomorphology of the coral reef (Smith, 2004). Some scientists have suggested that exposure to severe wave action may limit coral development and abundance (Maragos, et al. 2004). Waves naturally keep the surrounding water clean and circulated.

Corals need a constant water temperature that is approximately 31º C for optimal health. Some researchers have suggested that temperature extremes may contribute to decline of coral species and abundance (Maragos, et al. 2004). In lagoons and tide pools like the Waiopae tide pools, water temperatures may also fluctuate with tidal variation and weather.

Corals need to have clear water so the symbiotic algae called zooxanthellae, located within their cells, can photosynthesize. Most reefs have developed in areas where the water quality is adequate for their survival. If the surrounding water is affected by nutrient run off it has the potential to cause and algal bloom. An algal bloom will cause the ocean water to have an opaque or cloudy appearance. This is detrimental to coral which need clear water. In turn, eutrophication of the coral reef may occur after an algal bloom.

The Waiopae tide pools are located on the island of Hawai'i's east coast. Part of this unique marine area was established as a Marine Life Conservation District (MLCD) in 2003 (DLNR, 2004), and the other part was left as an unrestricted public use area. In the MLCD zone of the tide pools no commercial activities, fishing, or aquarium collection is allowed.

The Waiopae tide pools are situated in a distinctive area of the eastern coastline on the Big Island of Hawai'i. This area of the coastline was created by the 1950's lava flow and consists of several tide pools that vary in size and depth. The tide pools are connected to the underground water table and are a mix of fresh and marine water.

Furthermore, the tide pools are surrounded by a rapidly expanding residential community and all of the dwellings are on cesspool or septic systems. The naturally occurring water table is close to the surface throughout the community that surrounds the tide pools. Therefore, when a large hole or cesspool is dug, water fills the hole. A septic system is a cement or plastic tub that is placed into the hole; this type of septic system holds solid material but allows liquid to be released into the surroundings. Both of these sewage disposal systems allow for raw sewage to be released into the Waiopae tide pools. Raw sewage that is released into the tide pools will eventually be dispersed throughout the entire tide pool ecosystem.

There are two guidelines or standards that are commonly used in the U.S. to determine recreational water quality are: the fecal limit of 100 *E. coli* colony forming units (CFU)/100mL and a total coliform limit of 1000 CFU/100mL (Cabelli et al., 1983). The U.S. EPA acknowledges that *Escherichia coli*, the most commonly used a fecal indicator bacteria, is the best indicator of potential health risks to humans (EPA website, 2005). It has been well documented that *E. coli* cannot survive for long in marine ecosystems after it's introduction; therefore, most e. coli that is found in the marine environment comes from a recent source (Perez-Rosas and Hazen, 1987). One study has determined that exposure to solar radiation completely eliminated all *E. coli* in their water sample after two days and *E. aerogenes* still remained after three days (McCambridge and McMeekin, 1981). Total coliforms alone are not adequate as a health risk indicator because there can be many contributors, like other warm blooded animals (Cabelli et al., 1983). The above guidelines were mandated because it has been estimated that when the bacteria limits are exceeded that approximately 8 per 1,000 individuals may experience some type of gastrointestinal illness, flu like symptoms, or respiratory irritations (Francy et al., year).

In this water quality assessment of Waiopae tide pools it is expected that the tide pools close to shore will have higher levels of fecal indicator bacteria than the tide pools farther away from shore. Due to the development of the shoreline it is predicted to see high quantities of both *E. coli* and total coliforms in the marine waters. By determining the amount of fecal indicator bacteria in the tide pools, we can assume the coral communities may be experiencing anthropogenic stresses due to excess nutrient influxes from residential sewage.

Materials and Methods

Field experiments were conducted in Kapoho, Hawai'i located on the Big Islands east coast, USA latitude: 19.5195, Longitude: -154.8135), shown below.

Figure 1 Waiopae Tide pools are located on the east coast of the Big Island indicated by the arrow

Water samples were collected weekly from eight locations throughout the Waiopae tide pools during a variety of recorded tidal and weather conditions.

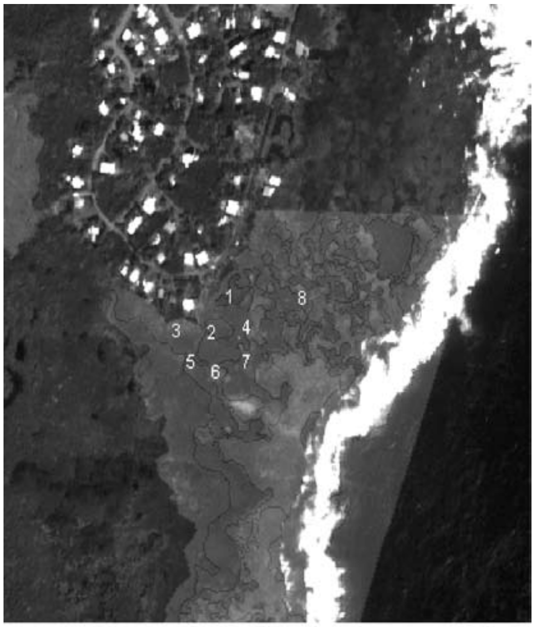

Figure 2 This aerial satellite picture shows where the eight tide pool monitoring sites were located. The residential subdivision can be seen behind the tide pools.

Samples were collected in sterile bottles and analyzed within one hour of collection. The eight tide pool locations were chosen haphazardly for this analysis. Every one of the tide pools were similar in size and depth. All of the locations were within the MLCD except for one location which was located in the non-MLCD zone. The salinity of the water samples was determined using a refractometer. The water samples were analyzed for bacteria using Coliscan® tests. The Coliscan® method of bacteria analysis allowed *Escherichia coli* and *Enterobacter aerogenes* bacteria to be identified by color and easily quantified in units of colony forming units per 100 milliliters (CFU/100mL).

For each analysis, 2mL of the water sample was mixed with the Coliscan® easy gel media and placed in a pre-treated Coliscan® Petri dish. In addition, a replicate Petri dish was also prepared for each water sample using a 4mL of the water sample mixed to the easy gel.

The Petri dishes were incubated at room temperature 30-37ºC for 48 hours. The *E.coli* turned a dark blue color colonies and the total coliforms formed red colonies. Next, *E. coli* colonies were quantified and then recorded in CFU/100mL. Total bacteria coliforms were calculated using the total of red and blue colonies in the Petri dish and then recorded as CFU per 100ml. This process was conducted over eight months for all eight tide pool monitoring sites.

Four out of the eight tide pools were chosen for monitoring saturation percent of dissolved oxygen and temperature. To collect this data a YSI meter was used and these tide pools were monitored weekly for 3 months.

Results

Several water quality conditions were discovered in the Waiopae tide pools. The Coliscan® analyses determined that most of the tide pools had excessive levels of *E. coli*, according to Hawai'i Department of Health (DOH) recreational water standards of 100cfu/100ml water. The *E. coli* levels decreased when the tide pool distance from shore increased. Figure 3 shows how the abundance of *E.coli* decreased to lower levels in the outer tide pools.

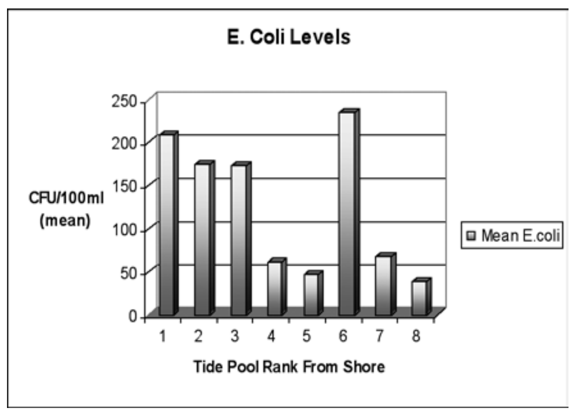

Figure 3 *E. coli* **levels tend to decrease as the tide pool distance from shore increases.**

Total coliform analyses found that most of the tide pools exceed the 1000cfu/100ml safe guidelines indicated by the DOH. Some of the inner tide pools had higher cfu/100ml counts but there was no general trend that indicated the inner tide pools always had higher total coliforms than the outer tide pools.

The majority of the tide pools were in excess of the 1000cfu/100ml safe levels for recreational waters. Only two tide pools that were located away from shore had total coliform levels that met the DOH recreational water quality standards (Fig. 4).

Interestingly, the salinity values of the tide pools were found to be low in the near shore tide pools and increased in the outer tide pools to salinity values of pure seawater which is 33-36 ‰ (Fig. 5).

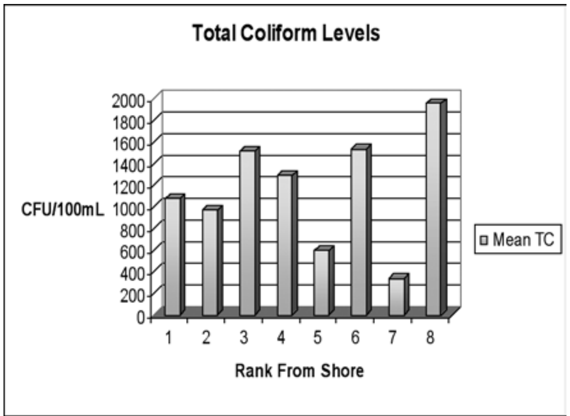

Figure 4 Total coliform levels (cfu/100ml) in tide pools when distance from shore is ranked. Tide pools one is closest to shore.

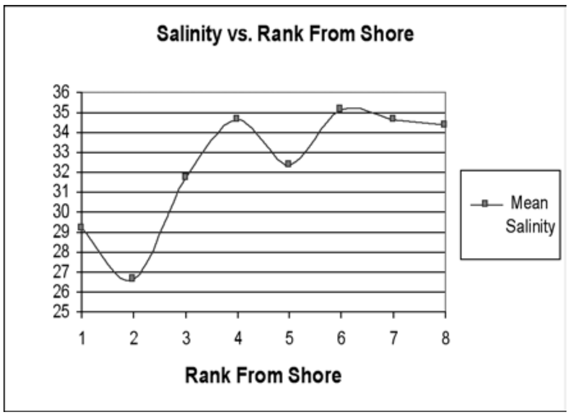

Figure 5 Salinity (0/00) values for the ranked tide pools

Furthermore, the fecal indicator bacteria levels were found to be highest in the inner tide pools that also had the lowest mean salinities (Fig. 6 and 7).

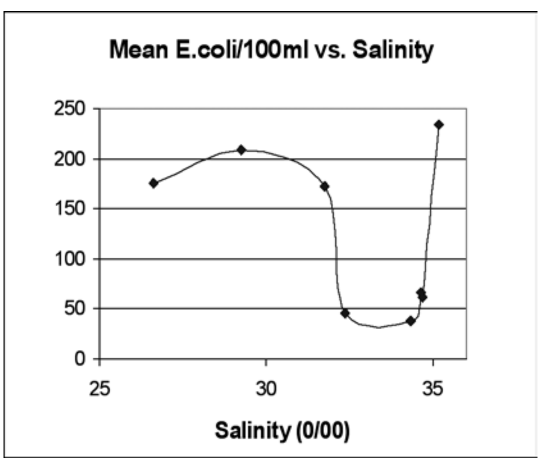

Figure 6 The effects of salinity on *E. coli* abundances in the tide pools.

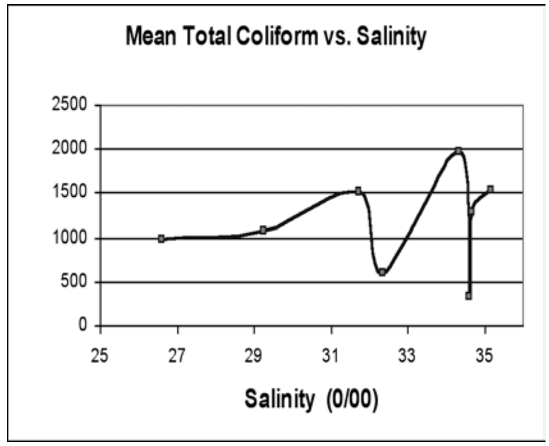

Figure 7 Total coliform per 100ml of seawater results showing the differences for tide pools with different salinities

The four tide pools that were monitored for the percent dissolved oxygen content, all had adequate levels for recreational waters as required by DOH. The dissolved oxygen levels were lower for tide pools that had low salinity values and increased exponentially when the salinity increased (Fig. 8). All tide pools exceeded the required 60% dissolved oxygen levels. Again, the inner tide pools had slightly lower dissolved oxygen levels when compared to the outer tide pools (Fig. 9).

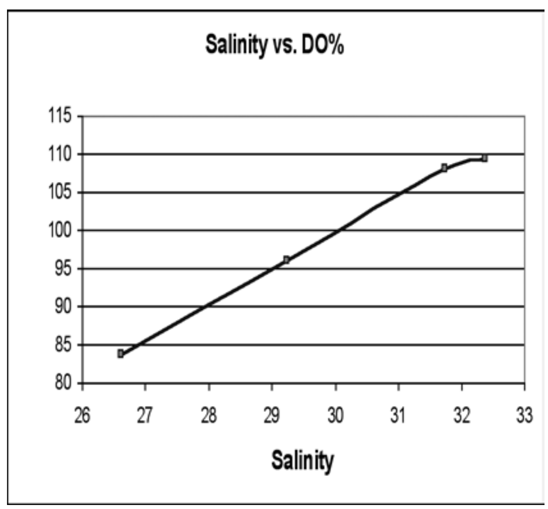

Figure 8 The dissolved oxygen percent saturation increases in tide pools with higher salinity (0/00)

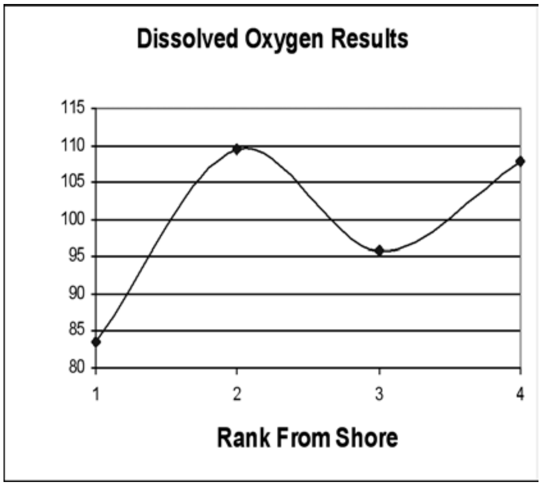

Figure 9 The results of the dissolved oxygen percent saturation in tide pools, ranked in distance from shore

Discussion

The Waiopae tide pools have only been designated a marine life conservation district for the last three years. There has not been any published data on the conditions of this unique marine ecosystem. The primary purpose of this research project was to determine the relative condition of the water quality in several areas of the Waiopae tide pool ecosystem. Several conclusions may be drawn from this eight month monitoring project.

It was unexpected to find that the inner tide pools have a mean salinity lower that the normal seawater salinity of 33-35‰. As figure 5 shows, the inner-most tide pools have much lower mean salinities. Table 1 illustrates that the salinity does fluctuate to even lower salinity values as low as 14‰ in some of the tide pools. This suggests that the tide pools have a fresh ground water source that may flush out into the tide pools near shore. The outer tide pools mean salinities were at levels of pure seawater 33-35‰, but also had low minimum salinities at some point during the monitoring project.

Interestingly, the salinity of the tide pools played a major role in amount of *E. coli* and total coliforms that resided in the water. It was surprising to find that the lower mean salinity tide pools had the highest mean amounts of *E. coli* and total coliforms CFU/100ml of water (Fig.6 and 7). It was amazing to see that the bacteria levels dropped significantly as soon as the salinity increased to 33-35‰.

The tide pools closest to shore had higher mean *E. coli* cfu/100ml than the outer pools. This is a result that was expected (Fig.1). There seemed to be no real relationship between the distance from shore and the amount of total coliforms present in the water. Figure 4 shows that there was a variety of levels in all of the tide pools with no general trend. These results may be due to survivorship of the bacteria in the water column. Perez-Rosas and Hazen suggested that *E. coli* may only survive in seawater for 12 hours due to high solar radiation (1987). The Coliscan® test gives results in *E. coli* and total coliforms per 100ml. However, many different types of Enterobacteracea colony forming bacteria may be present and show up in the total coliform results. The differences in survivorship in marine waters may be the reason no general trend was seen in the total coliform results. More specific analyses would need to be done to determine exactly what other types of bacteria are in the water column.

The four tide pools that were analyzed for percent saturation of dissolved oxygen had adequate levels. The department of health requires recreational waters to have 60% or more percent saturation of dissolved oxygen. All of the four monitored ponds exceeded these required levels. Figure 6 shows that salinity does affect the amount of dissolved oxygen in the water column. The tide pools with high salinities had the greatest amount of dissolved oxygen.

It can be concluded that the low salinity tide pools have less dissolved oxygen, but the cause of this needs to be further investigated. Several reasons may have caused these results. It seems that the outer tide pools have more water circulation than the inner pools, which may be a result of water motion caused by wave action. Also, high amounts of algae in the water column may increase the amount of dissolved oxygen in the water column.

In conclusion, Waiopae tide pools are a unique marine ecosystem composed of several coral communities of different sizes in various locations. This is a distinctive marine conservation area that has a rapidly expanding community built almost on top of the tide pools.

Coral communities require specific water quality conditions and if these conditions are not met the coral's health is at risk. Therefore, this marine life conservation district is also at risk of deteriorating.

The inner tide pools have higher levels of fecal indicator bacteria than the Hawai'i DOH recommends for recreational waters. This information indicates there is a source of sewage leaching into the near shore tide pools and some of the outer tide pools. Since the dwellings are located on the coastline very near the tide pools and they have cesspool systems, it is very likely that the residences are the source of the sewage that has been found in the tide pools.

The fecal indicator bacteria levels are an indication of excess nutrients being put into the marine life conservation district. This has the potential to affect the health of the coral communities, especially in the inner area of the tide pools.

Further research should be done on the condition of the coral communities in the protected MLCD and non-protected Waiopae tide pools for both inner and outer tide pools. In addition, more specific analyses should be done to monitor the amount of residential sewage that leaks from the cesspools of the residences closest to the coastline of the Waiopae tide pools over a long term period.

It is very important to monitor the fecal indicator bacteria because the presence of the bacteria indicates that coral health, as well as recreational marine enthusiasts, may experience negative health effects.

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Table 1 The minimum and maximum ranges of the ranked tide pools were recorded. This demonstrates that salinity fluctuates in all of the tide pools.

Salinity Ranges								
Tide pool	1	2	3	4	5	6	7	8
min	21	14	15	30	15	25	32	30
max	36	36	37	38	38	37	36	36

Table 2 Overall results for the water quality evaluations at Waiopae tide pools. Tide pools were ranked in distance form shore. Tide pools 1 is closest to shore and tide pools 8 is farthest from shore.

Tide Pool	Mean Salinity	Mean DO%	Mean DO mg/L	Mean E.coli/100ml	Mean TC /100ml
1	29	84	6	208	1073
2	27	96	7	175	967
3	32			173	1511
4	35			61	1286
5	35	108	8	67	331
6	34			39	1956
7	32	109	9	46	596
8	35			234	1533

This was a research paper for Mare 399: Marine Science, a directed studies class that focused on tropical marine research investigations at Waiopae Tide Pools.

My professor was Dr. Lisa Muehlstein, Marine Science Division.