The Motion of the Ocean at Puakō, Hawaiʻi:
A Relationship Between Water Motion and Coral Health

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ABSTRACT:

Increasing anthropogenic stressors, such as sewage pollution, are a major contribution to reef degradation. The amount of water motion within a reef system regulates the mixing of excess nutrients around coral colonies. Water motion supplies the corals with oxygen and removes metabolites across the coral membrane. This research project aims to measure the amount of water motion around coral colonies at 12 previously studied sites on the reef in Puakō, Hawaiʻi. Clod cards were used as the method of measurement, but no data were collected due to a large swell during the study period. The dissolution rate due to water motion would have been calculated and compared between sites. I would have also tested to see if there is a relationship between the water motion data and coral health surveys conducted by The Nature Conservancy. I hypothesized that at the stations where there is less water motion, that the coral will be in worse health. Subsequently, there is no data and therefore no results.

INTRODUCTION:

Coral reefs require specific environmental characteristics for coral establishment and growth. The most vital characteristics include: warm water, ample sunlight, low dissolved nutrient concentrations, and vigorous water motion. Corals are oligotrophic organisms, meaning that they thrive in low nutrient environments. Water motion is important for coral health because it controls the rate of exchange between the coral membrane and the surrounding water. Generally, corals favor vigorous water motion, but differ among species (Jokiel, 1978). More water movement flushes nutrients and sediment, while balancing temperature, dissolved oxygen concentration, and salinity. These factors affect calcification, photosynthesis, and respiration of the corals (Dennison & Barnes, 1988). On the other hand, algae favor conditions with high nutrient concentrations and also high water motion (Doty, 1971). Furthermore, coral growth anomalies, an epizootic coral disease, is strongly negatively related to water motion (Burns *et al*., 2011). Areas with lower water motion are areas where nutrients and bacteria are more concentrated, which leads to an increase in percent and severity of coral disease (Bruno *et al.*, 2013).

A simple and effective way to measure water motion is the clod card method (Doty, 1971). Clod cards are small, dissolvable blocks made of patching compound and resin glue. When anchored to the reef, the varying amount of water agitation will dissolve the cards at different rates, thereby revealing areas of slower or faster water movement. Different parts of the patching compound and resin glue make for either a fast-dissolving (F-type) formula, used for lower wave action, or a slow-dissolving (S-type) formula, used for higher wave action locations.

The Puakō-Mauna Lani reef system, located on the west side of Hawaiʻi island, is known as one of the most productive reefs in the state due to the high diversity of corals, invertebrates, and fishes that make up this fringing reef ecosystem (Wiggins, 2012). The Puakō reef is not only a food source for humans, but also an economic resource from tourism. The Hawaiʻi Department of Aquatic Resources reports a 35% loss in coral cover, along with a 43%-69% decline in fish abundance from 1979-2008 in the South Kohala District, where the Puakō reef lies (Walsh, 2011). In 2007, the residents in the shoreline community reached out to The Nature Conservancy (TNC) to research the causes for the depletion of this vital natural resource. A combination of water quality samples and benthic surveys help to determine the source of nutrients and its effect on the corals. The Nature Conservancy conducts benthic surveys by measuring the health of a single coral colony by recording the percent cover of growth anomalies, tissue loss, bleaching (tissue present), algal cover, discoloration, and trematodiasis (a parasitic, burrowing worm). These conditions of coral health are all signs of stress on the organism. Depending on the percent of each condition per each colony, the overall health of the reef can be measured. For example, high rates of algal cover on a coral reef most likely indicates high rates of coral mortality in that area.

Anthropogenic stressors, such as nutrient enrichment from sewage or fertilizers, weaken the immune system of the corals, thereby increasing the rate of coral disease and mortality (Lesser, 2007). Not only does nutrient enrichment increase coral mortality, but it also stimulates algal growth (Pedersen & Borum, 1996). On the Puakō reef, the added nutrients in the water from sewage effluent may be a significant driver of the rise in loss of coral cover, which may lead to the possible shift of a coral dominated reef to an algal dominated one.

Sewage is entering Puakō Bay through submarine groundwater discharge (S. Colbert, pers. comm.). Submarine groundwater discharge can be described as the movement of subterranean water towards the ocean. Although groundwater naturally has a high nutrient content, it is also the vector for dissolved nutrients from sewage to enter the marine environment. Sewage effluent seeps into the groundwater from sewage systems such as cesspools, and then makes its way to the ocean via submarine groundwater discharge. In 2013, the spatial distribution of the sewage pollution was mapped in Puakō by measuring the amount of isotopic nitrogen in the macroalgae *Ulva fasciata*. The form of nitrogen, ^{15}N, which is associated with fecal matter, was recorded in high concentration near shore (Yoshioka *et al.*, 2016). Not only were high levels of ^{15}N found in the water, but large numbers of the microbe enterococci, a fecal indicator bacteria (FIB) in the family *Enterococcus*, were also found. Mapping the enterococci concentrations and the levels of ^{15}N together show that the highest concentrations of nutrients and bacteria were north of the Puakō boat ramp (Yoshioka *et al.*, 2016) (see Figure 1 for reference). According to benthic surveys by TNC and other affiliates, poor coral health was associated in the locations with high bacteria and nutrient levels (Schweitzer, 2016).

Even though we know that sewage is entering Puakō Bay, we do not know how well the contaminated water is mixing into the surrounding waters. In the areas where Yoshioka *et al.* 2016 recorded the highest concentrations of ^{15}N and enterococci counts, is the sewage indication higher at that site because there may be lack of water motion in that area? Where the water motion is slow, nutrients and bacteria are not thoroughly mixing, and therefore are more concentrated. In those areas, the added nutrients from sewage are causes for not only poor coral health, but potentially mortality. The groundwater carrying the fecal matter will either flush out of the bay via a current, or it will gradually decrease with offshore mixing. Which prompts the question: Does the water motion vary around the corals within the Puakō reef?

The purpose of this research project was to measure the amount of water motion around coral colonies on the reef in Puakō, Hawai‘i. The first research question was, is there a difference in water motion between sites along the Puakō coastline? The second research question was, is there a relationship between water motion and coral health? To address these research questions, I intended to run statistical analyses using my data and benthic surveys of coral health conducted by The Nature Conservancy. Further objectives were to map spatial distribution of water motion. I hypothesized a strong relationship between poor coral health and less water motion on the Puakō reef.

METHODS:

Study Site

The study location was the Puakō reef, located on the west side of Hawai‘i Island. Below the water, Puakō is a fringing reef ecosystem, meaning the reef lies directly along the shoreline.

Along the shelf of this fringing reef, there are 12 study sites that range in depth from 1-3 m. The range of these sites stretch about 3.5 km. These 12 sites are known as The Nature Conservancy coral health survey sites. Of the 12 sites, 7 are situated on the north side of the reef, while the other 5 are situated on the south side. The site that is just north of the Puakō boat ramp is the northernmost site, while southernmost site is in front of the Mauna Lani Bay Hotel. There is a golf course that is owned by the Mauna Lani Bay Hotel, and is situated on the property at the south end of the study area. A residential neighborhood begins north of the Mauna Lani and continues north to the boat ramp. Below the water, many of the sites have collapsed lava tubes in the shelf that create archways and deeper sections. Right off of the shelf, the depth drops to about 10 m and gradually declines into the pelagic zone. All sites are dominated by the coral species, *Porites lobata*, except for the boat ramp which is dominated by broken *Porites compressa* beds.

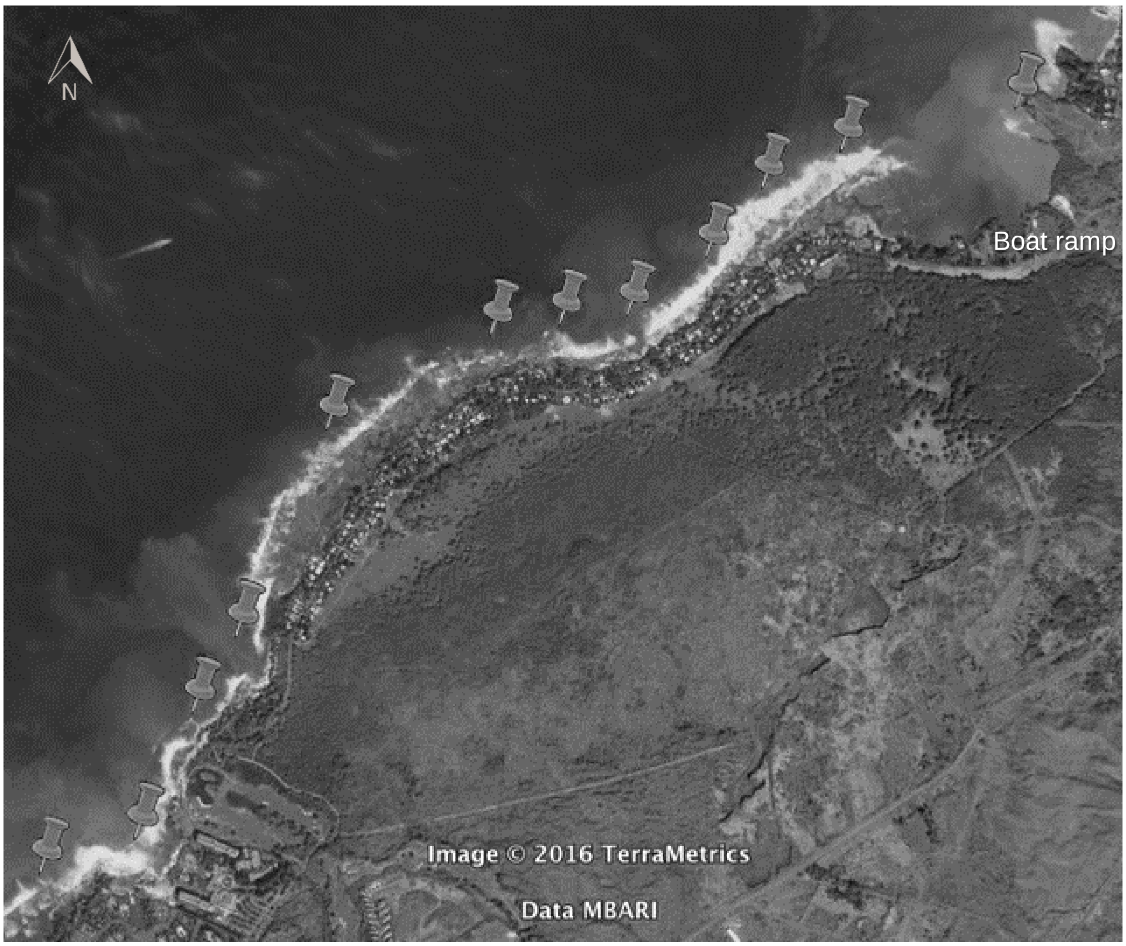

Figure 1. The GPS locations of the 12 study sites are represented by the tacks. The place of entry and exit to the sites is marked on the map with “boat ramp”.

Clod Card Construction

The first step to measuring water motion is the construction of the clod cards. The clod card design I used had never been used before. In order to suspend the card over the benthos, a wire “T” was attached to each card. A float and three 2 oz fishing weights were attached on either side of the wire ends. This design inverted the card in the water column, in between the weights and a float (making the “T” sideways). To make the metal “T”, galvanized steel 12 GA wire was cut into 25.5 cm lengths, bent in half, then twisted a couple times at the closed end to create an elongated loop. The two wire ends were then bent in a straight line, perpendicular to the loop, giving a “T” shape. Both wire ends were then formed to have two small eyelet loops. White electrical tape was used to label each card using a number between 1-70. The weight of each wire was recorded. Floats for each card were created by cutting 5 cm pieces of foam pool noodles. Then, to make the actual cards, I used an S-type formula that consisted of 1 part Weldwood plastic resin glue, 10.1 parts Fix-it-all Patching compound, and 5.2 parts tap water (Grovhoug, 1978). The formula was poured into 5 ml plastic cups. A wire “T” was then submerged into each cup while the formula was still wet. The cards were dried in an air-conditioned room for three weeks. During the last week of drying, the cards were removed from the cups and continued to dry in the air-conditioner. The day before deployment, each card was weighed. This weight was recorded as the initial weight.

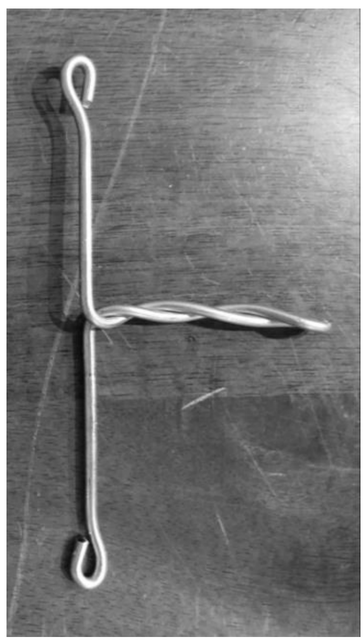

Figure 2. This image shows the “T” shape made from galvanized steel wire.

Figure 3. This image shows the final product just prior to deployment.
This clod card design inverts the cards in the water column.

Deployment

Deployment took place on 3/4/17. For this procedure, I used a total of 52 clod cards. This number was derived by deploying 4 test cards per 12 sites, plus 4 control cards. The cards were transported from Hilo to Puakō in a cooler with numerous gel ice packs to wick moisture. The 12 study sites were accessed by boat, an 18’ Larson, property of the University of Hawaiʻi at Hilo. The boat was operated by Captain Stephen Kennedy. The study sites were located using a handheld Garmin GPS device. Cards were deployed to the substrate by free-diving. In transit to each site, 4 cards were removed from the cooler, then for each card, the float and weights were attached using zip-ties through the eyelet loops at each end of the wire. The four card numbers and time of deployment were recorded for each site. Meanwhile, on land, four control cards were submerged into four separate Sterelite 70 qt clear buckets filled with seawater from the Puakō shoreline. These large buckets were used for the control cards in order to not to oversaturate the water in the bucket. If the water were to become oversaturated, then the card would stop dissolving. Conversely, increased heat speeds up the rate of dissolution. To prevent the sunlight from heating the seawater in the control buckets, the buckets were placed in the shade.

Both the test cards and the control cards were supposed to be deployed for a length of 24 hours. A 24-hr time period is used to include diurnal and tidal changes.

Retrieval

During the 24-hour deployment period, the swell turned from 0-1 ft during initial deployment, to 6-8 ft during the first attempted retrieval. Due to the high surf and lack of safety, I was unable to access any of the sites during the first attempted retrieval. Four days after deployment when the swell died down, on 3/8/17, I was able to attempt retrieval for a second time. Of the 48 cards that were deployed, 28 were recovered. Unfortunately, no mass of any card was left, therefore, no data was able to be collected. If there had been any mass left of the clod cards at the time of retrieval, then I would have put each test card into a separate plastic bag, and brought them back to Hilo. I would have also needed to redo the control cards to have them submerged in the water for four days, just like the test cards. Once the cards arrived back in Hilo, all of the cards would have been removed from the plastic bags and each placed onto its own drying tin and set into the air-conditioner once again. After the remains of the cards were completely dry, I would have weighed each of the cards again. This value would be recorded as the final weight.

Dissolution Rate Calculations

For data analysis, if I had any data, the dissolution rate for each clod card (D_c) would be calculated by the final weight (W_f) minus the initial weight (W_i), divided by the initial weight ($D_c = \frac{W_f - W_i}{W_i}$). Then, the dissolution rate due to water motion (D_w) would have been calculated by subtracting the mean dissolution rate of the control cards (D_m) from the individual test clod card dissolution rate ($D_w = D_c - D_m$).

Statistical Analysis

To determine if there was a difference in water motion between sites, a One-Way Analysis of Variance (ANOVA) would have been run using Minitab Statistical Software. Then using the data collected during benthic coral health surveys conducted by the TNC, I would have run a linear regression comparing the percent of algal cover per colony to the amount of water motion. I would have also run another linear regression between percent of bleaching and water motion.

RESULTS:

If data had been collected, the results would have shown a table of dissolution rate calculation. Then, the statistical tests would be displayed. The results from the One-Way ANOVA would show if there was a difference in water motion between sites. If results showed a significant difference in water motion between sites, then I would have mapped the amount of water motion along the 12 sites using ArcGIS software. Both of the linear regression tests address my hypothesis that where there is less water motion, the coral is in worse health. If my hypothesis were to be correct, the results would show that there was an increased percent algal cover or bleaching per colony with a decreased amount of water motion.

CONCLUSION:

Even though I was not able to obtain any data and continue my project, I was able to make some observations. The first observation was about the pool noodle floats that I used. Upon retrieval of the cards, the air pockets in the foam of the float had condensed to about half the size of the original girth. This tells me that the floats may not have been doing the job that I suspected they would, possibly allowing the cards to drag against the substrate.

The second observation that I made was that there was a significant amount of microalgae that had grown onto floats at certain sites. Not every single site had the same amount of algae recruitment, and some sites had none visible to the naked eye. The site that had the most significant amount of algal overgrowth on the floats was the site north of the boat ramp. Seeing the amount of microalgal recruitment and growth during the four days that they were deployed was surprising considering the high surf warning for the area during the period. This algal growth may be an indicator of an unbalance in the ecosystem since excess nutrients in a system may stimulate rapid algal growth. The algal recruitment and growth on the floats is what happens to the corals once they are bleached since bleached corals act as a surface for algal recruitment, similar to the floats. This highlights the threat of the synergistic effects between coral bleaching and excess nutrients as an efficient catalyst to the demise of the reef as a whole. Unfortunately, the corals that have a significant amount of algal overgrowth are considered to be dead and cannot rebound.

Although the high surf event was rare for the Puakō area, I was able to see the full range of water motion possible in the area. Seeing the waves roll through the site north of the boat ramp, made me assume that that is why the *Porites compress* bed is substantially broken. During the high wave action, I was also aware of the decline in water clarity around the boat ramp site as compared to the other sites due to the visual difference in water color. In the paper conducted by Yoshioka *et al.* 2016, they recorded the highest concentrations of ^{15}N and counts of enterococci at this site. It may be suggested that this is why the site north of the boat ramp had the most significant algal-covered floats, since poor water visibility usually indicates high nutrient concentrations.

Besides the observations I made, I am able to take away a few key lessons. The first lesson learned was that I should not solely rely on tracking GPS points on a boat to find the cards underwater. Besides the accuracy of being on a moving platform, many of the sites I had to jump out and swim to since it was too shallow for the boat to make it to the site location. From the original places I had set the cards, all were pushed closer to shore and were usually caught in crevices. Even though all of the cards moved from the original places I had set them, if I found one at a site, I was able to find all four, or none where found at the site. So, if I had a marker in the water column that rose just above the coral heads, and one deployed at each site in the area of the clod cards, the cards would then be conspicuous when going for retrieval.

I also learned that I should always incessantly check the surf report and cancel if there is any sign of swell, even if I think it wouldn't pick up until after my test period. Even though conditions were flat on the deployment day, Puakō is an exposed coastline and therefore the swell can pick up quickly. The other half to this lesson is giving myself enough time to collect data, in the event that I am prevented from collecting it the first two scheduled days, I should have a third back-up date scheduled.

Lastly, and perhaps the biggest lesson learned, is that non-ecofriendly materials should not be deployed into the ocean. Not only as a marine scientist, but as a conservationist, I do not want to contribute to the problem of plastic debris in the oceans. If I were to do the clod card method again, I would use the same model shape, but exchange the materials I used. Instead of the plastic zip-ties used to attach the weights and floats to the cards, I would use biodegradable monofilament fishing line, for example, Bioline by Eagle Claw. To replace the Styrofoam pool noodle floats, I could use coconut shells that have the husks removed. Two holes would be drilled into the coconut next to each other. Then, using the Bioline, I would string the line through the holes and attach them to the card. At depth, the coconut shells could be filled with air using a SCUBA set up or a smaller, handheld pony bottle. More weight would most likely need to be added to each card to compensate for the coconut float. By using eco-friendly materials, there would be little to no environmental risk of using this method.

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