Effects of Nitrate/Nitrites on coral bleaching: Coral Reef health around the Hawaiian Islands

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Coral reefs are not only beautiful, but also enrich the underwater environment and provide a home to many species of marine life. Coral reefs bring in $1billion (US) annually in tourism, attracting coral reef enthusiasts. In addition, research scientists are interested in the medicinal properties of various corals. Recent studies show that coral reefs, such as the Great Barrier Reef, are dying off at alarming rates due to stresses associated with rising temperatures and acidification of the oceans. Water quality, including nitrates, is directly influenced by human activity on land, and can determine the rate of coral reef survival. Nitrogen is a controllable input by humans, further studies of nitrogen input into the waters surrounding the Hawaiian water is necessary to prevent further deterioration of Hawaii's corals. A main source of nitrates into water is from farming ad agriculture practices. By consistent study and measurement of nitrates, the government can implement changes necessary to adjust agricultural practices before the coral reefs are adversely affected.

This study involved collecting images and water samples from various locations around Hawaii's main islands. Images were collected around the Big Island (Hawaii) and Molokini Crater for visual comparison of coral health. Water samples were collected to measure nitrogen levels from various locations including some freshwater samples taken from Oahu. Data from images and water samples were then compared to determine overall coral health.Results of this study showed that nitrogen levels were low in all saltwater locations, and corals had a low percentage of bleaching

Abstract

The extensive biodiversity of coral reefs is biologically important to both humans and marine ecosystem. Over 15% of the world's population lives within 100 km of coral reef ecosystems, deriving critical economic benefits through tourism and fishing (Hoegh-Guldberg 1999). Unfortunately, corals are under threat from rising temperatures and frequent bleaching events causing stress on a sensitive ecosystem. By controlling nutrient levels such as nitrogen input coral reefs have a higher chance of recovery after bleaching events. Coral reefs in Hawaii sustained minimal bleaching previous years in comparison to other reefs such as the Great Barrier Reef (GBR) (Parsons 2008).

The hypothesis that corals in Hawaii are more resilient to bleaching because of lower nitrate levels in the surrounding waters was tested. In this study, an analysis of nitrates was used to compare the water quality at various ranges of locations around the main Islands of Hawaiian. To test this, nitrate concentrations were compared across different environments to determine if lower levels correlate with lower percentage of coral bleaching. Saltwater samples were taken from bays populated with coral reefs, both in popular tourist location such as Molokini, and rural areas like the Big Island of Hawaii. Samples were also taken from the open ocean far from the islands to measure the background levels of nitrates. On the island of Oahu, one freshwater sample was taken from the Anahulu River to quantify the contribution of nitrates from human activity. In addition to water samples, photographic images were gathered and analyzed using imager analysis software. Images collected data quantifying number and relative frequency of bleached corals within general coral coverage of the area. For all saltwater samples, the amount of measured nitrogen is less than half of the critical levels, 1.0 um, determined by Global Coral Reef Alliance. Percentages of bleached corals were also low, less than 2% at the island of Hawaii. When compared to values of other coral reefs throughout the world, Hawaii's corals are healthier than many of those found globally including the Great Barrier Reef (Parsons 2008, Fabricus 2005).

Introduction

Coral reefs are known as the rainforests of the sea, home to numerous species of marine animals. Diversity of the reefs gives economic benefits to surrounding coastal towns such as tourism, fishing, and protection from rough waves. Approximately 15% of the world's population lives within 100 km of coral reefs, with their livelihood depending on the funds generated by them (Hoegh-Guldberg 1999). The Great Barrier Reef (GBR) brings in approximately $US1 billion annually in tourism. Coral reefs also provide approximately 25% of fish caught in developing countries, providing employment of millions of people (Hoegh-Guldberg 1999, Fabricius 2005). The loss of these reefs would be devastating to coastal populations and have broad negative global impacts.

Coral reefs exist because of a tight symbiotic relationship between the invertebrate and the dinoflagellate microalgae, known as zooxanthellae (Hoegh-Guldberg 1999). The invertebrate provides structure and hosts the zooxanthellae, in return for up to 95% of the needed nutrients. Nutrients are obtained through photosynthesis within the zooxanthellae (Hoegh-Guldberg 1999). The delicate and tight symbiotic relationship between the zooxanthellae and the coral invertebrates is regulated by limited nutrient flow including nitrogen. Lower nutrients available in the water allow for a tighter relationship between the coral invertebrate and the zooxanthellae, allowing for maximum growth (Hoegh-Guldberg 1999). If too much nutrients are in the ecosystem, the zooxanthellae become overstimulated and can leave the host, leaving it vulnerable to diseases and eventual death if the zooxanthellae do not return (Hoegh-Guldberg 1999, Fabricius 2005). This necessary symbiotic relationship is highly influenced by surrounding physical and biological factors. This continuous growth of corals is central for the framework in reef systems (Hoegh-Guldberg 1999).

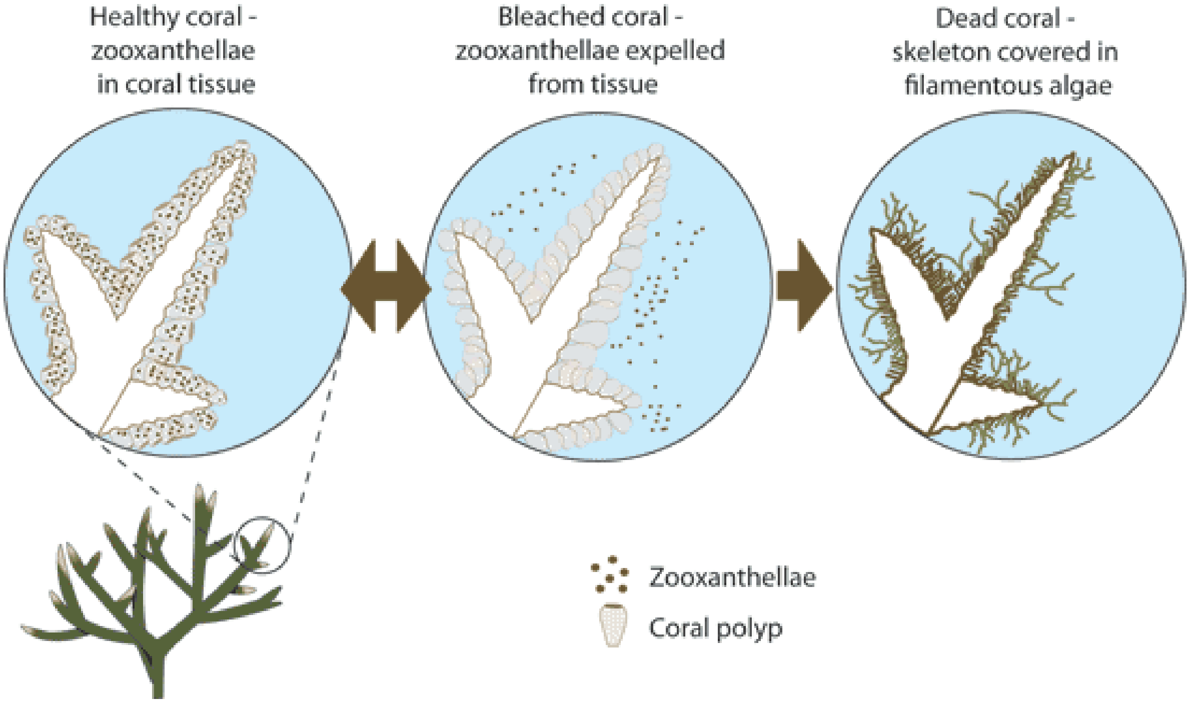

Figure 1 Picture representing the relationship between zooxanthellae and invertebrate structure. When bleaching occurs, the zooxanthellae leave the invertebrate tissue leaving the coral vulnerable to death. (***Image from Australian Government)***

Coral reefs are very successful in stable environments; locations where amount of sunlight, salinity and temperature change ver little year round. Coral reefs are very successful in equatorial locations, where seasonal and diurnal changes are small. When stability is interrupted, this can cause chronic stress upon corals, visible by a response called bleaching can occur (Hoegh-Guldberg 1999, Wooldridge 2009, Fabricius 2005). When changes to the environment are introduced suddenly, the zooxanthellae can leave its host, a visible response where corals become a bright white, thus called ‘bleaching’ (Hoegh-Guldberg 1999, Goreau 1994). Bleaching can occur as a response to any changes of the surrounding environment. Increases in seawater temperature, sediment flow, changes in salinity, decrease in available light, and increased nutrient flow, including nitrates, can all contribute to reasons of chronic stressing that can trigger coral bleaching (Wooldridge 2009). Bleaching events occur on both small local scales with few corals, and/or globally involving large reef systems.

Studies show that over 70% of coral bleaching has been associated with warmer than normal temperatures (Hoegh-Guldberg 1999, Fabricius 2005). Corals cannot evolve their physiological performance quickly enough to keep up with the temperature changes. If corals cannot evolve quickly enough to warming temperatures, this valuable habitat will be vulnerable to destruction. Coral reefs have infinite lives, older reefs have been around for over 1000 years, and some have recently been reported with massive coral deaths (Wooldridge 2009). Models show oceans continuously increasing in temperature, leaving scientists to assume that coral reefs will continue to die off at increasing rates. However, observations of surviving reefs show a correlation between low nutrients and a higher threshold against bleaching due to rising sea temperatures (Hoegh-Guldberg 1999, Wagner 2010).

Poor water quality conditions that impact corals include high concentrations of nitrates (NO_3) and nitrites (NO_2). Two main sources of nitrates/nitrites effect coral reefs, sediment run-off from fertilizers and upwelling from deep ocean sources (Wooldridge 2009). With growing global population, sediment run-off has increased, about six times as much since 1960 (Fabricius 2005). During summer months nitrates are elevated in rivers that contain sediment run-off from fertilized areas such as sugarcane fields that are located near the coast (Wooldridge 2009). High concentrations of nitrates can also directly affect the salinity of water near fresh water plumes (Wooldridge 2009). Gathering freshwater samples is necessary to find the source of nitrogen entering the oceans due to human activity. If a link between nitrogen levels in seawater and resilience in corals to bleaching can predict future health risks to coral health, it could enable preventative action by coastal governments (Wooldridge 2009). Monitoring the nitrogen levels in rivers and discharge bays provides crucial information to human activity. Small changes to agriculture policies can be made in advance to allow farmers time to adjust farming practices at a more cost efficient rate.

Materials and methods

Images and Boat Personell

The method of image collection and analysis was adapted from Kenyon et al. (2006) during their tow dive surveys. A zodiac boat was deployed from the R/V Thompson with a crew of at least four to obtain images and water samples: a coxswain to drive the boat, additional crew to maneuver and maintain boat safety, along with science crew to assist in deploying Niskin bottles, imager equipment, and record time and location of video recording start and end.

A simple camera mount was pieced together using plywood, weights and a piece of metal rail to suspend and mount a Sony Cybershot 4.0 megapixel DSC-P9 camera in it's underwater housing. A simple LED light was attached to the side of the camera. The tow line was rope connected and easily adjusted the length and depth of images collected. Two ten minute recordings were collected at each of the two sites, Molokini Crater and the shore north of Kona on Hawai'i. Between recordings the video was checked on a laptop on the zodiac to ensure equipment functionality and quality of coral images collected.

The zodiac traveled an average speed of 1-1.2 knots/hour, traveling about 0.45 nm total distance at each location. A handheld GPS unit was used to record the longitude and latitude at the beginning and end of each transect.

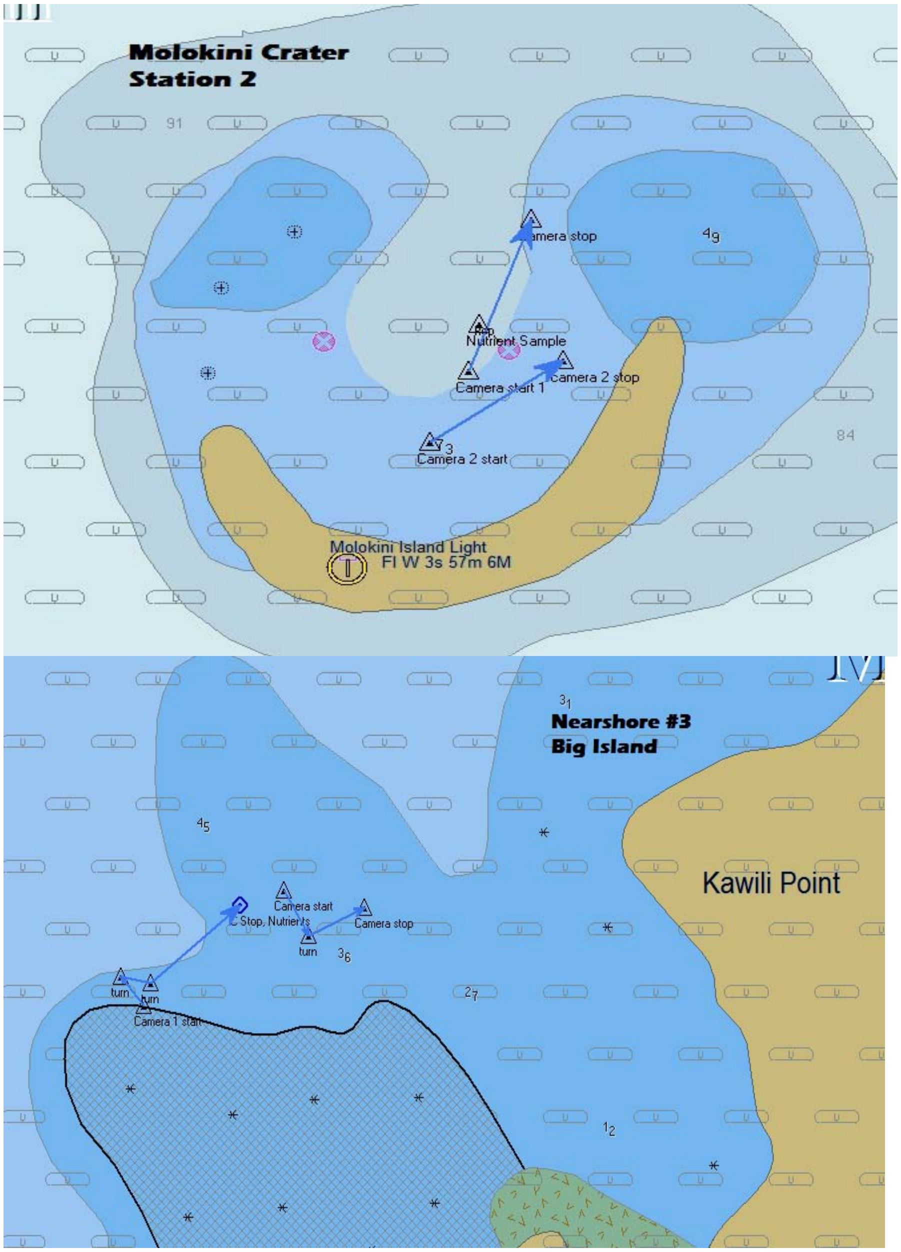

Figure 2 Map of transects taken to collect video recordings. TOP: MolokiniCrater BOTTOM: Nearshore off the island of Hawai'i. Location of water samples taken between the transects.

Image Processing

Using an open source program called Avidemux program (http://fixounet.free.fr/avidemux/), the video was split into still frames. Blurry, or unusable frames due to boat tow speed were manually removed from the data set. From the remaining images, a random frame from every five second interval was chosen for analysis. A total of 220 frames at each location were used. Following the methods of Kenyon et al. (2006) selected frames were then transferred into SigmaScan Pro, software that allows pixel analysis of selected areas. Images were analyzed twice, once for general coral coverage, and a second time for bleached corals. Selected areas were manually traced and input into a spreadsheet on SigmaScan Pro, and later transferred to Microsoft Excel for further calculation. Using Excel, formulas were input to calculate percentage of coral coverage. Once the amount of coral coverage was determined, the percentage of bleached coral was then calculated from the coral coverage.

Water Nutrient Sampling

During transects, a handheld Niskin bottle was used to collect water samples from the surface and from 5 m depth. Water samples were collected in accordance with the methods recommended by Kathy Krogslund at the Marine Chemistry Laboratory at the University of Washington. Aboard the ship, water samples were stored in a freezer until returned to the University of Washington for analysis. Nutrient measurement was done by Kathy Krogslund. Analyses of nitrate/nitrite levels involve passing the water sample through a Cd column that reduces NO3 to NO2. The sample then passes through a 15mm flowcell and absorbance is measured at 540 nm. For analyses of nitrite slight modifications are required, the Cd column is unnecessary and a 50 mm flowcell is used (Krogslund). A detailed protocol can be found at http://water.washington.edu/Protocols/watersamples.html.

Results

Coral Imaging

Video transects were 0.45 nm long for each location. Images from both areas revealed a mix of sand, rocks, and marine organisms. At Molokini Crater, the camera was 2-3 m from the bottom throughout transects. This camera depth allowed for more area to be covered in a single image. Molokini Crater was covered with rocks and coral and very little sand. Corals seemed to be smaller and less defined in shape. Bleaching was difficult to identify within the condensed coral reef, small amounts were obvious and calculated to be less than 0.5% for the area. Coral coverage was high, at 70%.

Near the shore of Kona, Hawaii transects were taken in the afternoon allowing for maximum sun light. The camera was closer to the bottom, staying about 1 m above the sea floor. Less area was covered but clearer images were captured, not covering the same visual image that Molokini had. Corals were spread out, and surrounded by sand and marine organisms such as sea urchins (Fig 3d). The coral coverage was considerably lower, less than 5%, and bleached coral was higher, 1.7% than found at Molokini Crater (Fig 2).

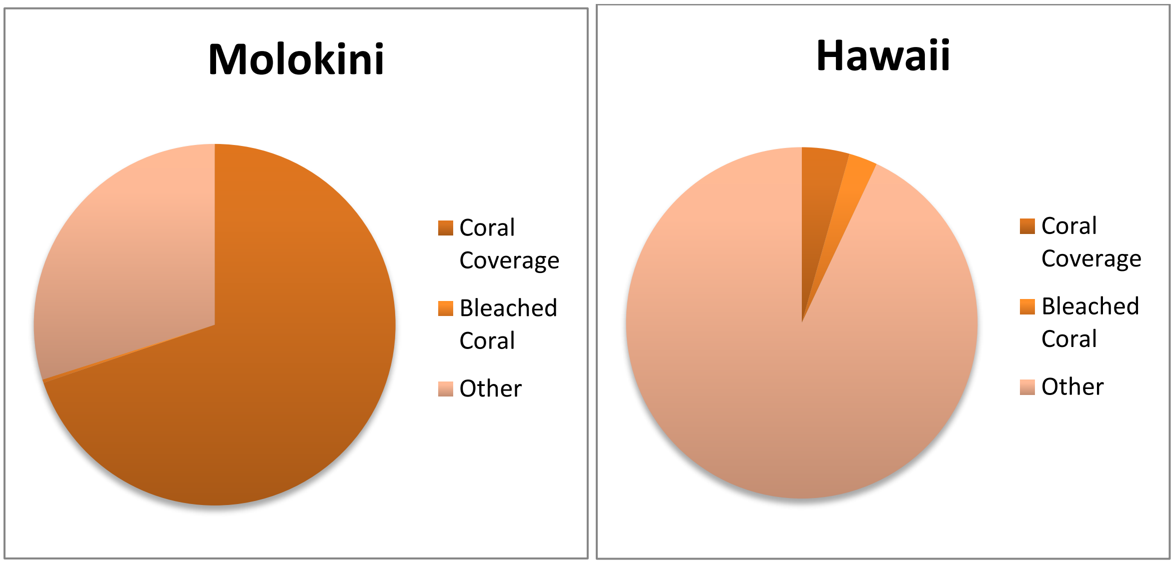

Figure 3Coral coverage based on image analysis. Molokini had greater coral coverage, and Hawaii had higher percentage of bleached corals. Other included sand and rock and occasional marine organisms.

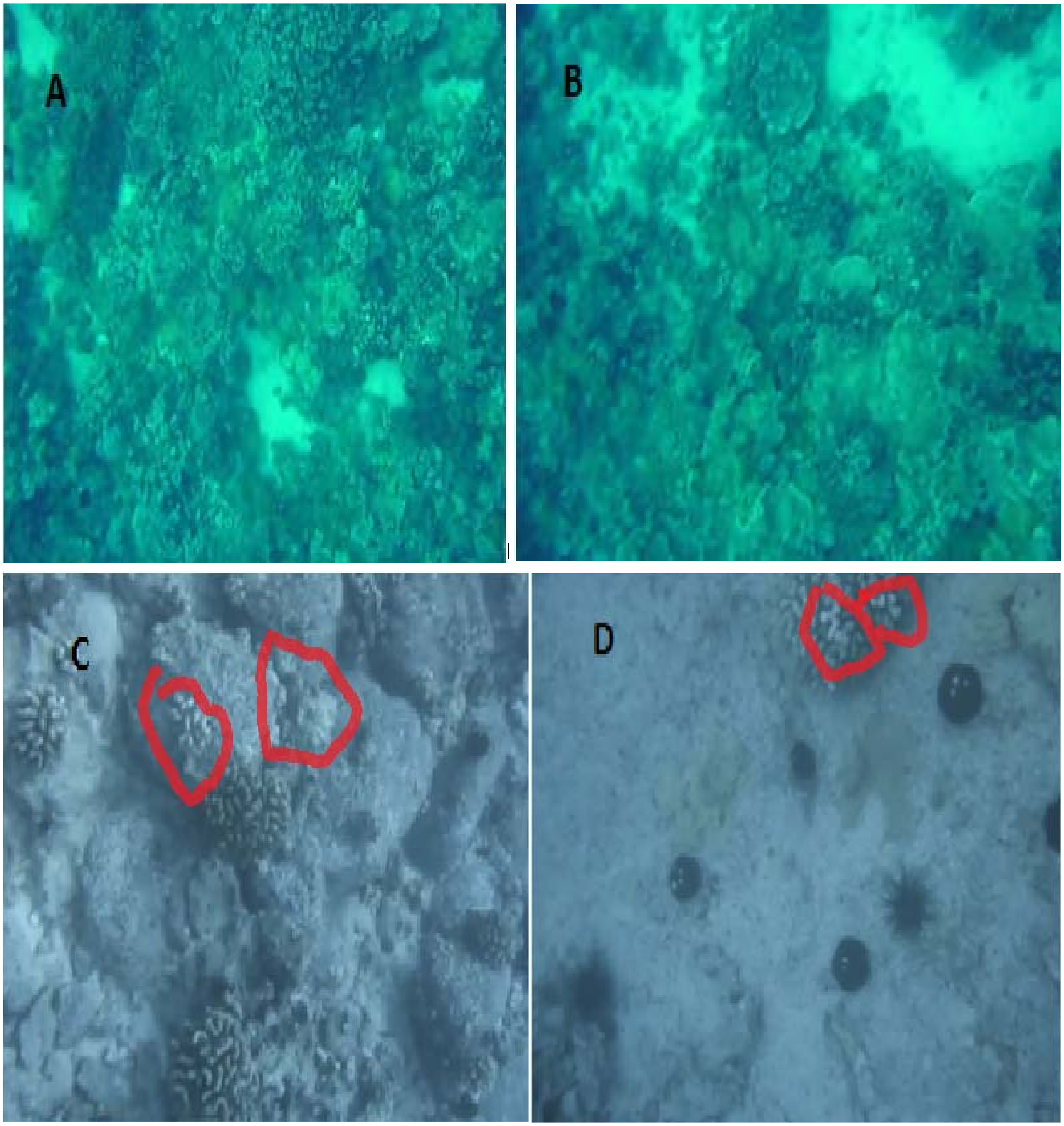

Figure 4Samples of images taken from Molokini (A and B) and north of Kona on Hawaii (C and D) Molokini had higher % of coverage, corals were tightly grouped making it difficult to separate dead coral and rock. Coral images taken from Hawaii were distinct in grouping and bleaching. Areas of coral bleaching have been circled to easier identify.

Nitrates and Nitrites

Molokini Crater was furthest from any main island activity, and had the lowest nitrogen readings. Higher nitrogen measurements were found at the site closest to Kona on the island of Hawaii (Fig 4).

Similar nitrogen measurements were found at Hale'iwa Bay and Anahulu River. Only a few hundred meters separated these two locations.

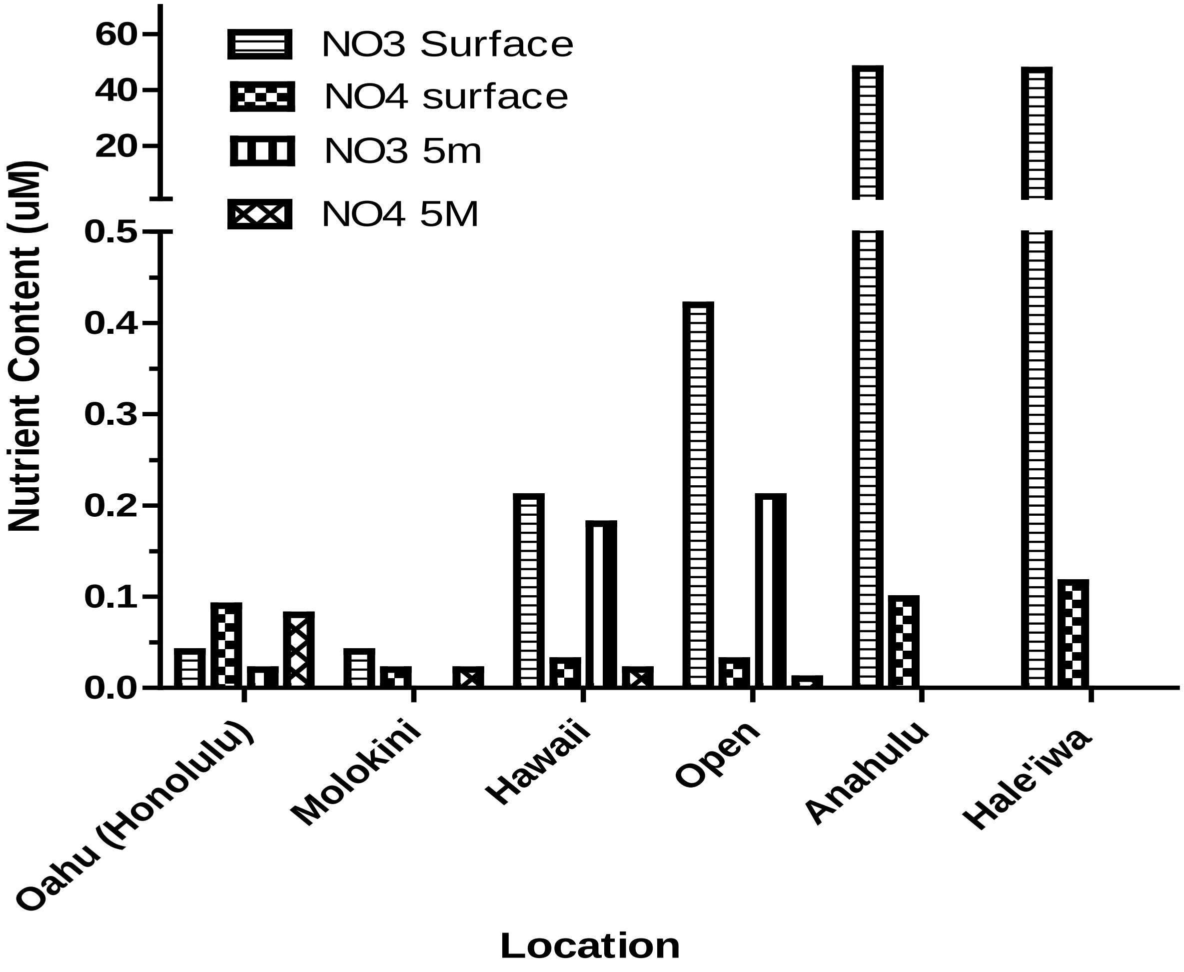

Figure 5 **Nutrient levels of water samples taken at each location. Surface and 5 m were taken at each location except at Anahulu River and Hale'iwa Bay were only surface samples were taken.**

Discussion

The water quality of Hawaii's surrounding waters is healthier in comparison to other areas of coral reefs. Studies along the Great Barrier Reef (GBR) and the Caribbean have concluded that the critical threshold of nitrate/nitrite is 1.0 µM (Lapointe 1997, Udy et al 2005, Goreau 1994). This critical level of nitrogen balances the healthy growth of corals and limits the growth of harmful aglae (Goreau 1994). When nitrate/nitrite levels rise to the critical threshold more species and larger areas of coral reefs become bleached and cannot recover as quickly from stressors in comparison to corals in lower nutrient water (Udy et al 2005, Parsons et al 2008, Wagner et al 2010). All locations sampled in Hawaii were well below this critical level, most samples were less than one-third.

The greatest impact on coral reefs is from increased sediment from land clearing and agriculture. Increasing the nutrient input into rivers and groundwater that dumps into bays and harbors containing coral reefs can be detrimental. Since 1960, fertilizer use has multiplied six times on a global basis (Fabricius 2005). Currently millions of dollars are being spent annually to try and correct a problem started over 50 years ago (Wooldridge 2009, Fabricius 2005). Hawaii has a chance to prevent the growing effects of increased nutrient input on their coral reefs.

Hawaii is thousands of miles away from any continental land, making it one of the most isolated places in the world. Human impact is small here in comparison to other coral reefs throughout the world. Hawaii is growing quickly, and land clearing is becoming more common within the islands to accommodate this rapid growth (Parsons et al 2008).

Location	Coral Coverage	Bleached Coral	Nitrate + Nitrite (um)	Date of Research	Source
Molokini Crater	**70%**	**>0.5%**	**0.06**	**Dec-10**	
Hawaii	**5%**	**1.70%**	**0.24**	**Dec-10**	
[1]Midway Atoll - NW Hawaiian Islands (Forereef)	1.60%	15%		Sep-02	Kenyon et al (2006)
[1]Midway Atoll NW Hawaiian Islands (Backreef)	11.30%	77.40%		Sep-02	Kenyon et al (2006)
[2]Kaneohe Bay (Oahu)	12.19%			1971	Hunter and Evans (1995)
[2]Kaneohe Bay (Oahu)	26.06%			1983	Hunter and Evans (1995)
[2]Kaneohe Bay (Oahu)	23.93%			1990	Hunter and Evans (1995)
[3]Kaneohe Bay (Oahu)			0.33-0.91	1976	Smith et al (1981)
[3]Kaneohe Bay (Oahu)			0.27-0.66	1979	Smith et al (1981)
[3]Honokohau Bay	37%	**0.2%	0.35	June 2004 - Aug 2005	Parsons et al (2008)
[3]Kealakekua Bay	38%	**0.5%	0.45	June 2004 - Aug 2005	Parsons et al (2008)
[4] Florida Keys		7%-57%	0.2304-0.6297	2005-2007	Wagner (2010)
[5] Great Barrier Reef			1.61-2.90	March-04	Udy et al (2005)
[6]Reunion Island, Indian Ocean	1.6%-38.86%	0-59.33%	0.24-.49	1991-1998	Charzottes et al (2002)

Table 1 Comprehensive review of several other studies regarding effects of nutrients on coral reefs. Methods within the studies differed. Information missing was left blank. ** Percentage of bleached coral did not include already dead coral.

Kaneohe Bay is the largest embayment in the Hawaiian archipelago, bordering 30.7 km of shoreline (Hunter and Evans 1995). The Kaneohe watershed covers 97 km^2, including the densely populated area of Honolulu and surrounding urban areas (Hunter and Evans 1995, Smith et al 1981). Oahu was mostly populated with military in the early 1900's, but grew rapidly after WWII. Population on Oahu increased by 450% in the two decades after the war ended, resulting in the eastern side of the island to become more neighborhood friendly, resulting in extensive urbanization (Hunter and Evans 1995).

Extensive population growth in this area also led to land being cleared, and the filling of ancient Hawaiian fishing ponds (Hunter and Evans 1995). Two highways were constructed leading from Honolulu to Kaneohe (Hunter and Evans 1995). By 1978 three sewage plants were discharging effluent into Kaneohe Bay. Observations local scientists identified green algae covering coral reefs, slowly killing off parts of the reef (Hunter and Evans 1995). The changes Kaneohe Bay were linked to nutritional changes in the water rather than intoxication as it was observed that local vegetation wasn't dying, but there were changes within the benthic community (Smith et al, 1981). Streams flowing into the bay had DIN measurements of 22 µM, while within the bay DIN was between 0.33-0.91 µM, depending on where samples were taken (refer to Table 1, Smith et al 1981).

Once the data from the scientists went public, public outcry demanded changes within government policies (Hunter and Evans, 1995). Out of the nine streams currently flowing into Kaneohe Bay, eight were diverted through ditch tunnels for agriculture and domestic purposes (Hunter and Evans 1995). This diversion decreased the nitrogen input into the bay by 60%, bringing measurements down to 0.27-0.66 µM (refer to Table 1, Smith et al 1981). Shortly after the sewage diversion away from Kaneohe bay, coral coverage increased and green algae decreased until finding a balance (Hunter and Evans 1995).

Kaneohe Bay is an example of a community coming together to save their local coral reefs. Due to sewage diversion not occurring until much of the damage had occurred and nutrient levels were high, the corals have not recovered to their original state (Parsons et al 2008, Hunter and Evans 1995). The remaining discharge pipe flowing into the bay was finally taken out in 1986 (Parsons et al 2008). Evidence of the impacts from the increased nutrients are still visible within the bay (Parsons et al 2008) and show how important constant monitoring of coral reefs is vital to ensure their survival before a negative balance allows algae to grow out of control.

Currently the island of Hawaii is growing quickly in population. For the 10 year period, 1990-2000, the population grew by 23%, and is forecasted to grow another 46% by 2020 (Parsons et al 2008). One of the areas impacted by population growth is Honokohau Bay, just south of the Kona airport. Previous expansion of the harbor was in the 1960’s, and included excavation that routed the groundwater through the walls and floor of the harbor (Parsons et al 2008). This allowed the increased nutrients in the groundwater to flow into the sea instead of directly into the harbor, minimizing damage to the local ecosystem (Parsons et al 2008). Current plans include further expansion of the boat harbor and construction of a business park in the area (Parsons et al 2008). This boom in population can lead to similar stresses and degradation of otherwise pristine coral reefs in the area.

In comparison to residency and tourism on Oahu and Maui, Hawaii has less human impact within the watersheds. The watershed within western Hawaii can process up to 5.31 million gallons per day (mgd), but on average only processes 1.35 mgd (Parsons et al 2008). According to Parsons et al (2008) research, the amount of nitrogen input into the Honokohau Harbor has increased by five times the original amount in the last 20 years. Constant monitoring of the islands nutrient input into waters is necessary to prevent irreversible damage.

The location of this study was about 10 miles north of Honokohau Bay and allows a comprehensive comparison. The research done by Parsons’ team split the Bay into sections, and for comparison we will use the northern outer edge of Honokohau Bay as it is closest in location and similar conditions.

Water samples from Parsons et al were taken over a 15 month period, and came to an average of 0.33 µM, only 0.09 µM higher than the measurement in this study. The value of nitrates and nitrites is well below the critical threshold of coral reefs, and is equal to the lower range found before the sewage diversion at Kaneohe Bay. The values of nitrogen here are a positive indicator that corals surrounding the island of Hawaii are in low nutrient water and have a higher chance of resisting bleaching due to stress factors such as global warming or ocean acidification.

Coral coverage between this study and Honokohau Bay has a negative difference of 32%. This could be due to various reasons, Honokohau Bay has more protection from rough waves. There were also limitations on how close to shore we were able to retrieve samples due to ship and boat travel distances. Honokohau Bay is a popular snorkeling location, attracting tourists from all over. The percentage of bleaching found at Honokohau Bay shows minimum impact of less than half a percent, but does not include the amount of dead coral which was calculated to be 4.3% (Parsons et al 2008). Altogether, although Honokohau Bay has higher coral coverage, it also has higher amount of bleached corals. In comparison to other coral reefs throughout the world (Table 1), the lower amount of nitrates and nitrites is comparable to the low percentage of bleached corals.

The Great Barrier Reef (GBR) is one of the largest and most extensively studied coral reefs in the world. It is also one of the most impacted with respect to coral bleaching, with 72% bleaching reported in areas during 2002 (Berkelmans et al 2004). Coral bleaching in the GBR has been attributed to increased nutrients, especially nitrates and nitrites (Wooldridge 2009, Udy et al2005). The catchment area that drains into the GBR lagoon have large areas of fertilized farms such as sugarcane fields, banana fields, and other agricultural activity such as cattle grazing (Wooldridge 2006, Udy et al 2005). In addition, increases in human population resulting in clearing of natural land, it is estimated that three to five times more sediment enters the GBR (Udy et al 2005). The GBR is being destroyed at alarmingly increasing rates every year (Wooldridge 2009, Berkelmans et al 2004). If sediment run-off from rivers can be controlled, fewer nutrients would enter the corals a fighting chance of survival. In comparison to data collected off the coast of Hawaii, the GBR has almost seven times the amount of nutrients, and considerably more coral bleaching occurring (Wooldridge 2009, Udy et al 2005, Berkelmans et al 2004).

In the Florida Keys, a direct correspondence of the nitrates and nitrites was related to a high percentage of bleached corals. In 2005 a severe bleaching episode related increased sea temperatures and higher nitrate/nitrite levels (Wagner et al 2010). Almost all the sites around the Florida Keys were affected heavily in 2005, with colonies averaging 40% of coral colonies bleached (Wagner et al 2010). Average measurements of nitrate/nitrite reached a high of 0.6207 µM, tripling the amount measured a year later (Wagner et al 2010). None of the locations around Hawaii had nitrate/nitrite amounts that reached Florida's 2005 level, and most locations except for near shore Hawaii are lower than Florida's lowest recorded measurement during the 3 year study.

Within the Hawaiian islands nutrients were low, comparable to the low % of bleaching. The island of Hawaii had the highest nutrient level, almost five times the amount found at Oahu and Molokini Crater. Coral coverage was low here in comparison to Molokini Crater, which can be contributed to other factors previously mentioned. The greatest impact of nutrient levels is from freshwater sources off of Oahu.

Located three miles from Maui, Molokini Crater has thousands of tourists visiting on hundreds of boats daily. Molokini Crater is one of the most popular diving and snorkeling locations within the Hawaiian Islands. Keeping these corals in great shape is important not only to the ecosystem but the economic income to Maui. Water quality within the crater was one of the lowest nitrate/nitrite amounts measured in this study. Average coral coverage within the Hawaiian islands is 22%, and Molokini Crater is over three times that at 70%. Images of corals at this location revealed physical damage possibly from divers and boat anchors. Nitrogen levels are low, giving corals a higher rate of recovery from physical or environmental stresses, but daily abuse can cause long term effects.

Highest levels of nitrogen were found at the freshwater input of Anahulu River on Oahu and the Hale'iwa bay. Anahulu River covers a watershed that is 17 square miles, and 27.6% of that land is used for agriculture purposes (Atlas 2008). A majority of the watershed land is protected for conservatory purposes, but unmanaged by government (Atlas 2008). The pineapple corporation, Dole, is located in the watershed area. Sugarcane fields are also located near the mouth of the river. Agriculture purposes can greatly impact nitrogen levels from fertilizers used and constant sediment run-off into rivers and bays. No coral reefs are located on the northern side of Oahu near Hale'iwa Bay. This is due to rough tidal patterns that contribute to other human activities such as surfing. Nitrates/nitrites will spread and affect coral reefs that are found south of the sample site.

Conclusion

In this current study of coral reefs in Hawaii, water quality is low and amount of bleached corals are low also. In comparison to coral reefs throughout the world, Hawaii has one of the healthiest locations with corals not responding by bleaching due to rising sea temperatures. Concerns over ongoing population growth on the island of Hawaii are valid and require continuous monitoring. Freshwater samples taken off of Oahu were high, especially when compared to Kaneohe Bay inputs of 22 um in the 1960's.

Future research on nitrogen levels should include more image data from coral reefs near other islands. More freshwater samples would also be necessary to find the difference in human influence among the islands. If rates of nitrogen continue to rise due to agriculture practices, a water treatment center may be considered near larger farming areas. Lengthening and rerouting streams can reduce the amount of nitrogen entering bays. Continuous monitoring is necessary to prevent high costs associated with fixing rather than preventing a problem. Currently the GBR is looking for funding for millions of US dollars to prevent further degradation of the world's largest coral reef (Wooldridge 2009). Action taken now by Hawaiian officials can prevent future costlier measures

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GMT Date	Local date	GMT time	Local time	Lat (start)	Long (start)	bottle #	Depth (m)	NO3	NO4	Station	Secchi Depth
27-Dec	27-Dec	0:40	1040	21 17.785	158 1.277	2297	0	0.04	0.09	Oahu nearshore	18 m (bottom)
27-Dec	27-Dec	0:40	1040	21 17.785	158 1.277	2300	5	0.02	0.08	Oahu nearshore	
28-Dec	29-Dec	21:00	700	20 38.019	156 29.758	2302	0	0.04	0.02	Molokini 1	17 m (bottom)
28-Dec	29-Dec	21:00	700	20 38.019	156 29.758	2301	5	0.00	0.02	Molokini 1	
29-Dec	29-Dec	4:11	1411	19 47.188	156 02.714	2294	0	0.21	0.03	Big Island	6 m (bottom)
29-Dec	29-Dec	4:11	1411	19 47.188	156 02.714	2293	5	0.18	0.02	Big Island	24 m (bottom)
						2256	0	0.42	0.03	Open Ocean	
						2255	5	50.59	0.04	Open Ocean	
5-Jan							0	47.57	0.11	Anahulu River	
5-Jan							0	47.87	0.09	Anahulu River	
5-Jan							0	47.22	0.11	Haleiwa bay	
5-Jan							0	47.23	0.12	Haleiwa bay	

Appendix 2 Total Data collected included Latitude and Longitude of sample points, Secchi disk reading, and time of samples.