Coral Disease and Community Structure throughout the Northwestern Hawaiian Islands

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May 6th, 2016

Abstract

In the last decade there has been a major increase of coral disease found worldwide due to increased anthropogenic impacts like overfishing, pollution and climate change. To understand coral disease fully, knowing how much disease is found normally in an ecosystem must be quantified. Papahānaumokuākea Marine National Monument encompasses the Northwestern Hawaiian Islands (NWHI) is known to be one of the last largest pristine coral reef ecosystems. In the Hawaiian archipelago there is a range of latitude of 10 degrees (19.5–29.5 N. Latitude) from Hawaiʻi Island to Kure Atoll. Going northwest up the NWHI archipelago is the "Darwin Point" leading to a weaker coral ecosystem, furthermore coral cover on each island should therefore decrease with increasing latitude within the island chain. NOAA's Reef Assessment and Monitoring Program (RAMP) conducts ecological benthic coral scuba surveys every year in the NWHI. During summer of 2015, I participated as coral scuba diver on a 30-day research cruise to seven of the ten islands. This research summarizes RAMP data from 2007-2012, to determine coral cover and diversity throughout the archipelago and how disease prevalence is associated with cover and diversity. Species richness varied from 40 species at French Frigate to 26 species. at Kure atoll. Coral cover and diversity showed a significant change at each island, submerged bank, reef and atoll. Prevalence and severity of disease is found to be associated with diversity. The significance between coral cover, diversity and disease may be due to each island, submerged bank, reef and atoll have other contributing factors occurring such as currents and geographic location that allow each location to have a unique coral ecosystem.

Introduction

Coral reefs are some of the most diverse and valuable ecosystems on Earth. Providing structure and habitat to thousands of marine species. Coral reefs support more species per unit area than any other marine environment. Coral disease is a growing problem on coral reefs found worldwide (Goldberg and Wilkins 2004). The increase of disease and number of corals being affect and distribution of diseases, have shown an increase within the last decade (Abey 2006). The increase of anthropogenic stressors such as nutrients, overfishing and climate change have all linked to coral diseases (Abey 2006; Abey et al 2011; Friedlander et al. 2005;). In understanding coral disease fully, it is important to have a baseline of how much disease is found normally in a healthy ecosystem.

The Hawaiian archipelago consist of an inhabited main Hawaiian Islands and a remote northwestern Hawaiian islands (NWHI). Papahānaumokuākea Marine National Monument is the single largest U.S. conservation, was established on June 15, 2006. It encompasses 139,797 square miles of the Pacific Ocean. Within the monument lies the northwestern Hawaiian Islands consisting of islands, atolls submerged banks and reefs (Figure 1). Due to the geographical isolation and federal protection of the monument, islands and atolls located within this monument have coral reefs that are only exposed to global impacts and very little anthropogenic impacts (Friedlander et al 2005). The Hawaiian archipelago consist of a chain of volcanic islands, coral islands and atolls, which are slowly subsiding and gradually drifting due to seafloor spreading to the northwest from tropical into subtropical latitudes and cooler waters (Griggs 1982) (figure 1).

Reef Building corals at high latitude with cooler temperatures aren't in right physical condition and good health to create reef. The growth rate of reef building corals surrounding the islands should therefore decrease with increasing latitude within the island chain. At one point the growth of corals should no longer support and sustain atolls at sea level. This point defines a threshold for atoll development also known as the Darwin Point theory. The second voyage of HMS Beagle sailed between the years of 1831-1836. Charles Darwin kept a dairy of his experiences on this voyage. As the HMS Beagle travels through out Tahiti and Moorea on April 12th, 1836, Darwin made a journal entry about "coral islands". This theory suggest as islands eroded and subside with is left is a circular coral reef with a lagoon. This hypothesis was tested with research that was conducted between 1978-1981in the MHI and NWHI (Griggs 1982). Rates of gross production of $CaCO_3$ per unit area were measured from the first island of Hawaii to the last island in the Hawaiian Archipelago, Kure Atoll. An range of latitude of about 10 degrees (19.5–29.5 N. Latitude). In this research, Griggs found that corals at Kure Atoll (threshold point) could not keep pace with sea-level rise (Griggs 1982).

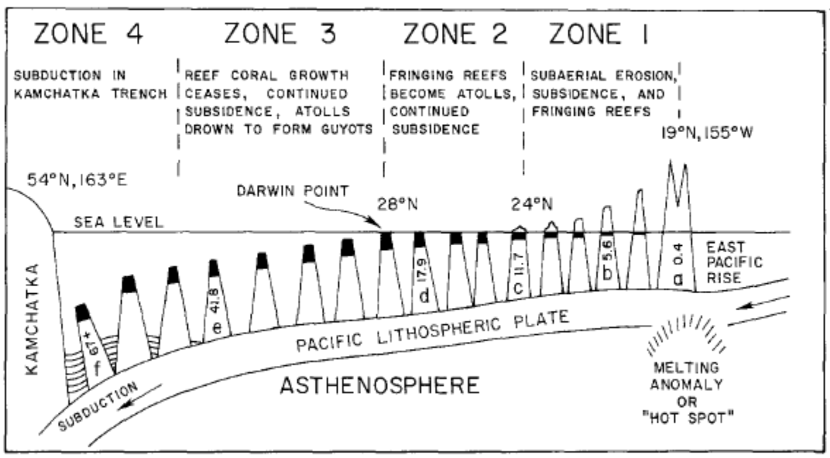

Figure 1. A visual representation of evolutionary history of the Hawaiian Archipelago showing location of the Darwin Point (Kure Atoll) separating between zone two and three (Griggs, 1982).

The NOAA's Coral Reef Ecosystem Division (CRED) leads the Pacific Reef Assessment and Monitoring Program (RAMP), providing scientific information that supports ecosystem approaches to management and conservation of coral reefs. For the last 15 years, RAMP has conducted scuba surveys for coral health and disease. These researches will assess a three-year period of that long-term data to make connections between coral disease and community structure in relation to latitude. The first hypothesis is that with increasing latitude there will be a decrease in species diversity and coral cover. The second, disease severity will be associated with diversity and coral cover. This research will focus on years of 2007-2010 across the main 7 islands, atolls, reefs and banks.

Methods

Study Site

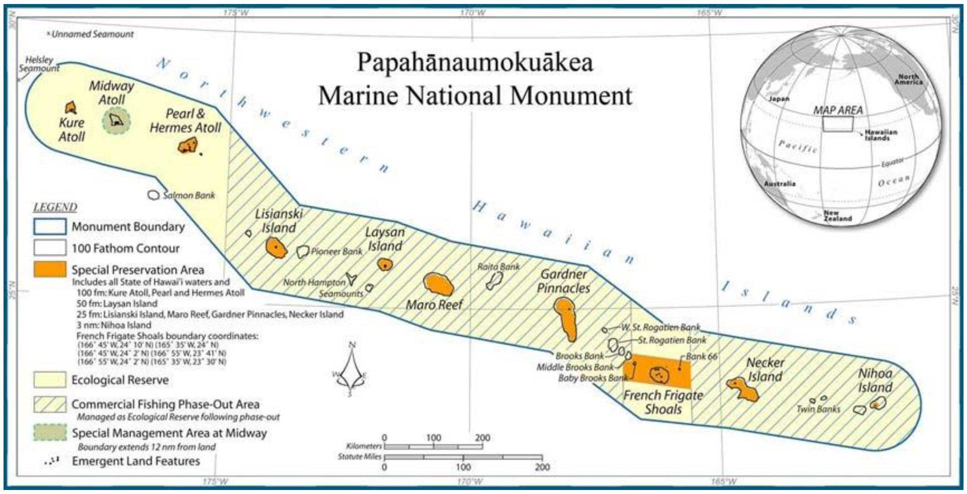

Figure 2. Names and Location of the 10 islands and atolls of the Papahānaumokuākea Marine National Monument.

National oceanic and atmospheric administration (NOAA) research vessel the Hiʻialakai was used to travel from main Hawaiian Islands through out the monument in order to conduct scientific scuba surveys at each location. NOAA small boats were deployed from the Hiʻialakai at 8:00 am on diving days for dive teams to conduct surveys. Roughly 4 to 5 sites were done per dive day. Depending on depth and abundance of coral, a dive could range around 45-75 minute bottom time.

Survey Methods

Sampling Design

Sample sites are randomly stratified sorted by three different depth zones. The three depths zone are shallow (0-19ft), moderate (20-59ft), deep (60-100ft). Upon arrival at the sample site, divers are to determine whether the benthic habitat at the survey location is reef habitat. If the sample site is a reef habitat at the right depth zone, then surveys can be completed at that site. At each sample site, two transects are deploy to 18m. Divers characterize the site by habitat type, and record maximum and minimum depth of both transects. Furthermore the adult and juvenile corals surveys can be started.

Coral Colonies Surveys

Adult coral colonies (≥ 5cm) are surveyed within four (1.0 x 2.5m) segments on each transects. Colonies are identified to the lowest possible taxonomic level. Empirical measurements, estimates and evaluations of each colony include morphology, size, partial mortality, condition along with extent and severity. *Juvenile coral colonies* are (<5cm) are surveyed within three (1.0 x 1.0m) segments on each transect (3m^2 per transect; 6m^2 per site). Each colony is identified to lowest taxonomic level possible, morphology is noted and size is measured using two measurements (maximum and perpendicular diameter). No disease or condition data is recorded on juvenile surveys. Coral disease data will be sorted and most prevalent disease will be determined for each atoll, island or reef. An example of the data sheet and summary of diseases and health conditions can been seen in Figure 3 and 4.

BENTHIC CORAL DATA SHEET							Observer:				Date:		
Location/Habitat:						Site Notes:							
Site:						Depth T1 (min/max):				Depth T2 (min/max):			
Col	T	Seg	Taxon	Morph	L (cm)	W (cm)	%Dead	%Recent	RD cause	Condition	Ex	Sv	Comment
1													
2													
3													

Figure 3. Example of the layout and data collected on each site.

Recent dead cause

general	**Disease**	**DZGN**
specific	Disease - general	DZGN
	Cyanophyte infection	CYA
	Banded Fungal Infection	BFI
	Black band disease	BBD
	Brown band disease	BRD
	Porites ulcerative white spot	PUS
	Sub-acute tissue loss	TLS
	Acute tissue loss - White syndrome	WSY
	Other	OTH
general	**Predation**	**PRED**
specific	Predation - general	PRED
	Crown of thorns	COTS
	Fish predation	FISH
	Gastropod predation	GAST
general	**Overgrowth**	**OVRG**
specific	Overgrowth - general	OVRG
	Algae general	ALGA
	Macroalgae	MACA
	Encrusting algae	ENCA
	Turf algae	TRFA
	Crustose coralline algae	CRCA
	Sponge	SPON
	Octocoral	OCTO
	Zoanthid	ZOAN
	Tunicate	TUNI
	Stony coral-(Scler&Millp)	CORA
general	**Sediment**	**SEDI**
specific	Sediment necrosis	SEDI
general	**Damage - Abrasion**	**DAMA**
general	**Damage - Broken**	**DAMB**
general	**Damage - Dislodged (loose)**	**DAMD**
general	**Damage - Toppled**	**DAMT**
specific (all damage)		
	Anchor	ANCH
	Rope	ROPE
	Chain	CHAN
	Line	LINE
	Net	FNET
	Other	OTHR
	Unknown	UNKN
general	**Other**	**OTHR**
general	**Unknown**	**UNKN**

CONDITION

Code	Disease description
NDZ	No Disease
ALG	Algal infection
PDS	Porites Discolored Swelling
SGA	Skeletal growth anomalies
PTR	Porites trematodiasis
PRS	Hyperpigmented response
PRS	Pigmentation Response
PRS	Pink line/spot syndrome
BIN	Barnacle infestation
TIN	Tube worm infestation
OTH	Other
AND	Alcyonarian necrotizing disease
BLE	Bleaching
BLP	Patchy bleaching
DIS	Discolorations other than bleaching
CCD	Coralline cyanobacterial disease
CFD	Coralline fungal disease
CLD	Coralline lethal disease (aka Coralline White Band Syndrome)
CLOD	Coralline lethal orange disease
CRS	Coralline ring syndrome
DAMA	physical damage - abrasion
DAMB	physical damage - broken
DAMD	physical damage - dislodged (loose)
DAMT	damage - toppled

Figure 4. Summary of coral health conditions and disease with codes.

Statistical analysis

Coral survey data will be organized for atoll, island or reef using the coral demographics, species and disease or condition type. Species richness will be calculated for each island by summing up the number of each species for each island or atoll. Species diversity was calculated using the Shannon-Weiner Diversity Index Equation. Statistical Program R was used into other test for significant between general linear models and mixed effect models between each Island. Statistical it is correct to analyze each island separately through mixed effect models. Account for each islands differences within severity, coral cover and diversity. Therefore allowing each island to have separate linear regressions. In order to calculate the % coral cover for each island. Each area of the coral colonies is found then divided by the amount of area covered through out each segment of each transect.

Results

Species Richness was variable through out the northwestern Hawaiian Island (Figure 1). Total number of each species or species richness ranged from 24 to 40 species quantified for each island. Pearl and Hermes atoll had the highest about of species with a total of 40 different species. Laysan Island came in with the lowest amount of species at 24 species. The high latitude atolls of Kure and Midway had low species richness with totals of 25 and 26 species.

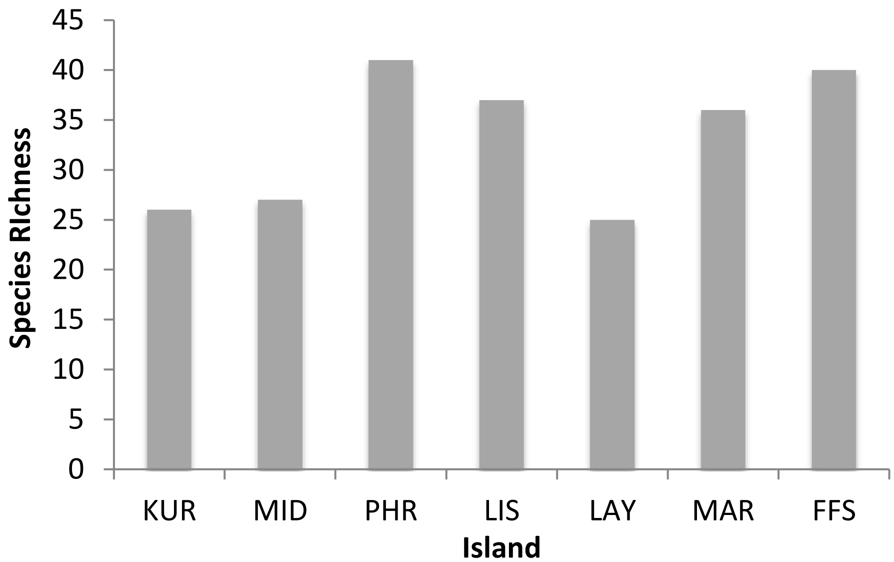

Figure 1. Number of total species found at each study site from the years of 2007-2012.

Using the Shannon-Weiner diversity index species richness and species abundance was used to calculate how evenly distributed species are at each island. Species diversity was found to be lowest at high latitude islands Kure and Midway showing a diversity value at Kure of 1.21 and Midway of 1.26 (Figure 2). Lisianski showed to have the highest diversity or most evenly distributed with a diversity value of 1.79.

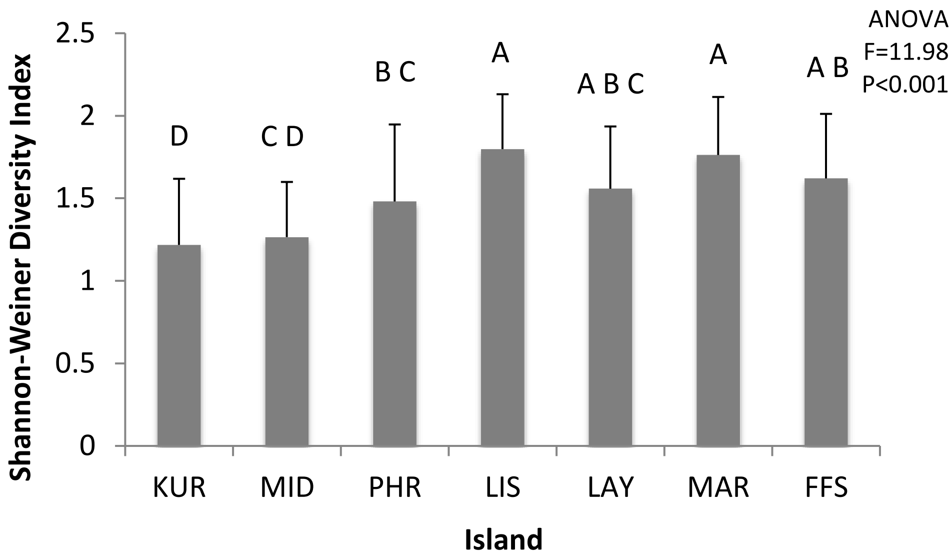

Figure 2. Shannon-Weiner diversity index using species richness and abundance of each species to calculate how evenly distributed species are at each study site.

Disease severity is rated on a scale of 0-5. For example on a bleached colony 0 (normal) coral has a good amount of color, to 5 (severe) coral is stark white. Overall disease severity in the NWHI is very low with a severity of 0.5 (Figure 3). Islands with low amount of species diversity found to be highest in severity. Generally there is a trend of increasing severity with latitude. Each island to be significantly different from each other.

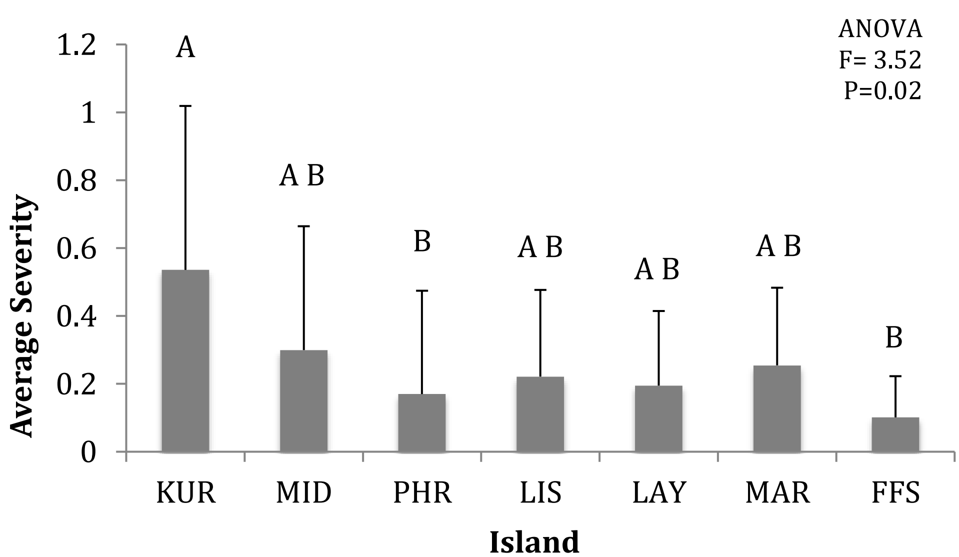

Figure 3. Average disease severity of each site study. Overall disease severity is low through out the NWHI, high latitude atolls showing highest amounts of severity.

Total coral colony area had been quantified for each transect then averaged for each island. At the high latitude atolls of Kure, Midway and Pearl and Hermes showed the lowest percentages of coral cover (Figure 4). A significant differences between each island. All high latitude atolls showed to be in the same Tukeys grouping. Lisianski and French Frigate Shoals had the highest coral cover percentages at 47% and 44%.

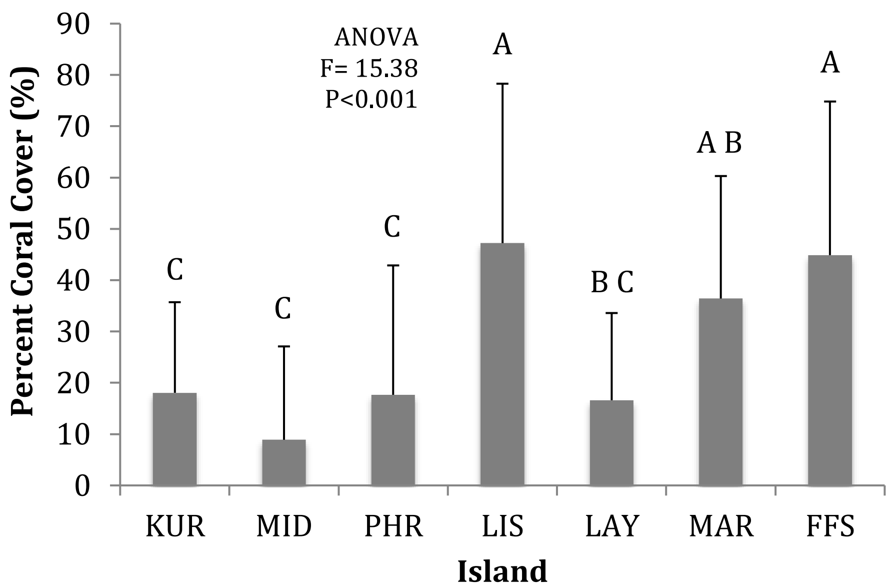

Figure 4. Percent coral cover for each study site. High latitude atolls found to in same tukeys grouping and resulting in lowest amounts of coral cover.

Disease severity and diversity and coral cover data was nested into pool for each island. To account for each islands differences in severity, diversity and coral cover. Mixed effect models were generated to create linear regressions for each island. Severity and diversity found significance with a p-value of ____. Overall average severity is very low, with highest value at 0.5 at Kure (Figure 5). The models for diversity and severity showed that there is no similar linear trend happening for each island. Therefore these islands can't be grouped together for statistical analysis and are very unique. The high latitude islands of Kure, Midway and Pearl & Hermes show the highest amount of severity.

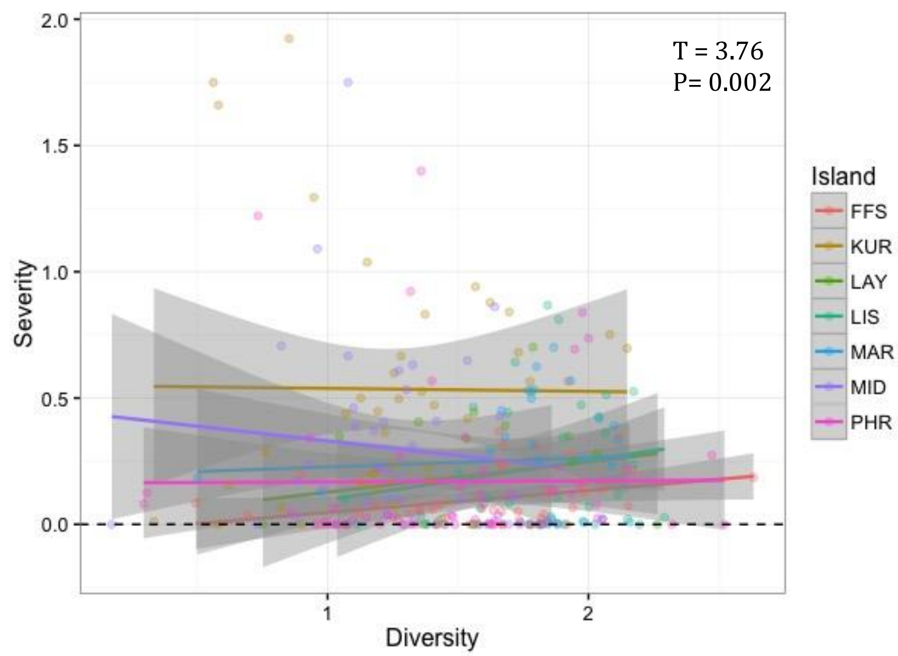

Figure 6. Mixed effect model of disease severity and diversity. Islands can be identified by color, with individual linear regressions and interval confidence.

Coral cover and severity was also found to have significance at each island. Laysan was found to have the lowest amount of coral cover at 45% (Figure). Kure showing the highest amount of severity and a negative linear relationship with percent cover. Furthermore disease severity is very low through out the northwestern Hawaiian Islands. There is not a similar linear trend between the islands.

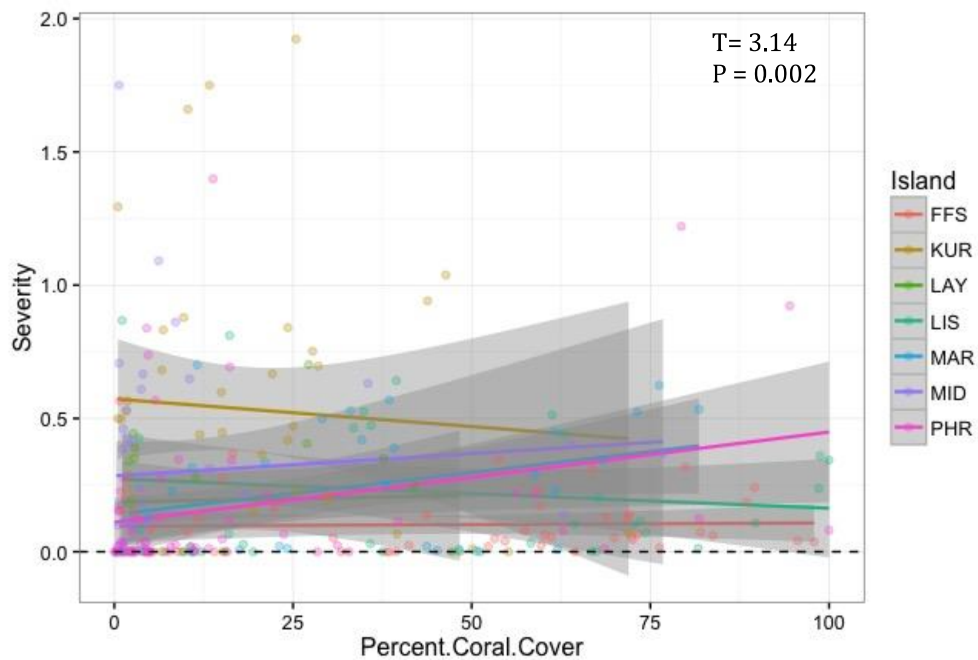

Figure 7. Mixed effect models of disease severity and percent coral cover. Significance differences were found through out the islands.

Discussion

There are decreasing trends of coral cover and diversity going northwest in the Hawaiian archipelago. Results showed similar to Griggs study, the environmental conditions that are changing with latitude have shown to affect on general coral cover, diversity and disease severity of the islands. As coral reach high latitudes and cooler temperatures, no longer have physical strength to build reefs (Oliver & Palumbi, 2011). Although Griggs research focused on colony accretion of a dominant species of coral *Porites lobata,* this research included all species found in the NWHI. Results of decreasing coral cover was expected through the NWHI archipelago. Decrease of deposition at high latitude also do to less coral cover, Griggs did not take this into consideration. Furthermore, lowest amounts of coral cover were found at Midway and this could be do to the large amount of human impact over the last 100 years. French Frigate Shoals, Lisianski and Maro showed the highest amounts of coral cover (figure 4), research done by Friedlander showed the same results. Therefore, going towards high latitudes shows low amounts of coral cover and this research results supports this expectation.

The Hawaiian archipelago ranges in latitude about 10 degrees. High latitude coral reefs are know for being very isolated and having high amounts of endemism. Species diversity in the NWHI resulted in decrease going NW in the archipelago at the high latitude atolls. Results showed a lower species richness for Kure and Midway (Figure). This could be due to environmental conditions found at the high latitudes. Rate of subsidence and cooler temperature causing enabling species with slow growth. Islands with high amount of diversity showed to have high amounts of coral cover (Figure and). As coral cover decreases with latitude, it is expected that species diversity will decrease as weaker corals may not be able to survive as well in cooler temperatures (Abey et al 2011).

Disease prevalence has found to be located at each island but the highest at French frigate shoals and Midway in Friedlander study. This research focuses on the disease severity, and results showed to have the highest amount of severity at high latitudes. Overall disease severity is very low at the highest at Kure of 0.5 out of a scale of 5 (Figure 3). Island that were highest in diversity had the lowest amount of severity (Figure 2 and 3). This could be due to the dominant types of species found at each Island. In a study by Friedlander et al. showed that most Acropora, Montipora and Porites were the most common types of genera with disease prevalence. For example Kure was found to have a dominant species of Porites and low diversity. Porites genesis is prone to many disease that are genetically based and being a dominant species there is a large probability of having coral colonies with high disease severity. Furthermore an island being dominated by a species like Porites may also have a high disease severity vs. an island that is very diverse will have many different types of coral species which some are more resilient than others. The results of this research support our hypothesis that diversity and coral cover will be associated with disease severity. The NWHI severity, diversity and coral cover vary differently from one another, and to be studied separately. Disease severity was found to have a linear relationship between diversity and coral cover (Figure 6 and 7). These findings can assist in prioritizing areas that are most likely to succumb to disease and reduced health.

Conclusion

Within the NWHI species diversity and coral cover decreased with increasing latitude. High latitude atolls: Kure, Midway and Pearl and Hermes presented the lowest amounts of diversity and coral cover, conversely had the highest amounts of disease severity. High latitude atolls decrease in diversity, coral cover and severity may possibly being affected by the changes in environmental conditions and cooler water temperature at high latitudes. Disease severity was found to be very low through out the entire NWHI archipelago, therefore coral reefs within the NWHI can be said to be healthy.

Acknowledgments

Papahānaumokuakea Marine National Monument Dr. Steven Colbert, Dr. John Burns, Dr. Scott Godwin, Lisa Parr, Dr. Randall Kosaki, Dr. Daniel Wagner, Brain Hauk, Hadley Owen, Kanoelani Steward, NOAA Ship Hiʻialakai Crew, Marine Option Program Staff, Marine Option Program, UH Qualitative Ecological Underwater Surveying Techniques (QUEST), Marine Science Department of University of Hawaii at Hilo.

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