EFFECTS OF CORAL DISEASE ON EXOSYMBIOTIC INVERTEBRATE ASSEMBLAGE

EXAMINING EXO-SYMBIONT ASSEMBLAGE ON HEALTHY AND DISEASED PORITES SPECIES THROUGHOUT SHALLOW WATER REEF SYSTEMS ON HAWAI'I ISLAND

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Abstract –

Pōhaku puna (*Porites lobata* Dana, 1846) is a foundational coral species found throughout coral reef systems in Hawaiʻi, that is of cultural and ecological importance. Local and global anthropogenic impacts to coastal environment make *pōhaku puna (Porites lobata)* and other coral species vulnerable to diseases and other afflictions. Growth anomaly (GA) is a disease that has been identified on other coral species as abnormal tissue growth that increases mortality and hinders biological functions such as growth, digestion, defense, and feeding which results in reduced fecundity. This study developed a morphological definition of the GA disease found on *pōhaku puna* colonies, in comparison to unafflicted (UA) and healthy (H) coral tissue, based on the difference in mean polyp density (H=4.1 polyp/cm^2, UA = 3.2 polyp/cm^2, GA=2.9 polyp/cm^2), mean individual polyp diameter (H=1.2mm, UA=1.6mm, GA=1.8mm), and mean distance between coral polyps (H=2.0mm, UA=1.6mm, GA=2.7mm). Of these parameters, the distance between coral polyps was the only parameter that showed significant difference between GA, UA, and H coral tissue. Additionally, 12 *pōhaku puna* colonies were examined over six months to determine any differences in exosymbiont species assemblage between GA afflicted and unafflicted *pōhaku puna* colonies. No significant differences were found in exosymbiont species diversity (p-value > 0.05) and density (p-value > 0.05) between GA afflicted and unafflicted *pōhaku puna* colonies suggesting that the presence of GA afflictions on *pōhaku puna* does not impact exosymbiont assemblage. These results imply that there is little impact to exosymbiotic community assemblage from this disease, and the relationships amongst these host corals and their exosymbiont invertebrates are resilient to this disease. The size of the individual colonies and the proportion of the coral surface area occupied by GA could be a factor also and can be further investigated in future studies. It is important to note that this disease could potentially impact whole reef ecosystem structure by negatively effecting coral physiological processes and biological functions. To further elucidate the effects of coral GAs to whole ecosystem health and productivity future studies need to be more longitudinal and must examine the impacts to the physiological and ecological processes at the ecosystem level.

Table of Content –

Chapter 1 - Introduction

Hanau ka ʻUku-koʻakoʻa, hanau kana, he ʻAkoʻakoʻa, puka

Born was the coral polyp, born was the coral, came forth
(Beckwith, 1951)

Cultural and Ecological Context for Present Research –

In Hawaiian culture, practice, and identity there is a deep connection and understanding of place and origin that has been perpetuated throughout generations. The interconnected relationship between people and the environment is recognized in many different contexts in Hawaiian practice and can elude to ecological function, productivity, and health of our natural resources. The Hawaiian creation chant, *The Kumulipo*, is a *mele ko'ihonua* and is the remembrance from the *lipo* of our deep past to the *lipo* of our unknown future (Kanahele 1997). It reveals the connections of the sky and earth, the ocean and land, the land and man, the man and gods and recognizes the interconnected relationships among all things (Kanahele 1997). The fifteenth line of *The Kumulipo* introduces the coral polyp and the emergence of coral from the slimy darkness (Queen Lili'uokalani 1897, Beckwith 1951). In the Hawaiian belief system, the coral polyp is the beginning of creation that emerges from the slime of the Earth in the darkness of night from the depths of our oceans (Queen Lili'uokalani 1897, Beckwith 1951). Following this emergence are the births of foundational invertebrate species connected to these coral colonies such as *nā ina* (rock-boring urchins), *nā hawaʻe* (collector urchins), *nā wana* (long-spined urchins), *nā leho* (cowry shell), and *nā kūpeʻe* (*Nerita polita*). *The Kumulipo* continues to speak of the births of ocean fish, seaweed, and plants and identify their relationships with land plants, trees, and organisms. Through this connection and understanding, the coral polyp that creates the coral colony, which creates the coral reef system, is recognized as the foundation of life both culturally and ecologically (Queen Lili'uokalani 1897, Beckwith 1951).

The relationships identified in *The Kumulipo* elude to the ecological connection these organisms have with one another and the importance of coral species as foundational organisms that create our Hawaiʻi reef systems. Coral species from the family Poritidae are recognized as *Pōhaku puna* in Hawaiian culture and are identified as key coral species that contribute to the composition of our Hawaiian coral reef environments. *Porites* species are found throughout coral reef habitats from shallow coastal regions to the deeper regions of the photic zone. Small *Porites* colonies can be found in regions of strong wave action with larger colonies inhabiting deeper and more protected ocean areas (Dollar 1982, Edinger et al. 2000, Lough & Barnes 2000). The large reef-building coral colonies from the genus *Porites* contribute to the construction of such coral reef systems providing many invertebrate and fish species with protected habitats abundant with food (Stella 2010, Idjadi 2016, Yoshioka et al. 2016). Their lobular and branching morphologies create ideal habitats for other marine organisms and their tissues provide food for corallivorous marine consumers (Gothfeld 1997, Stimson 2011, Idjadi 2016, Tortolero-Langarica 2016) These characteristics create diverse symbiotic relationships between *Pōhaku puna* colonies and exosymbiont marine invertebrates (Stella 2010, Aeby et al. 2011, Idjadi 2016). These relationships contribute to the health and productivity of Hawaiʻi coral reef habitats and can potentially be negatively impacted by coral disease, which may lead to a change in exosymbiont community structure. As the health of our global oceans continuously changes due to climate change and other anthropogenic practices the health and productivity of our Hawaiʻi coral reef systems are perpetually impacted (Aeby 2011, Aeby 2016, and Williams 2017). To best understand how coral disease impacts coral reef ecosystems at the community level we must first understand the different relationships had amongst host coral colonies and their exosymbionts. Understanding these relationships, identifying any changes in these relationships, and correlating these changes with reoccurring climate change events and other anthropogenic stresses can provide stronger insight to the health and productivity of these systems and how to design management strategies best suited for them.

Throughout the Hawaiian archipelago and other regions of the Pacific, coral reef habitats surround many island communities, providing food and cultural significance**.** Persistent impacts to coral reef habitats from human use practices and changing environmental conditions pose threats to these systems. Community assemblages are particularly vulnerable due to the role each species has on the function and productivity of coral reef environments. Loss or diminishment of coral reef species can cause extreme shifts in ecosystem function (Edinger 2000, Takabayashi et al. 2008, Stella 2010, Chollett et al. 2014,). Many studies on coral reef ecosystems have examined the effects of anthropogenic impacts and changing environmental conditions on invertebrate species, such as foundational coral colonies, have found varying responses from these organisms. Studies conducted in Moorea and Indonesia showed increased linear growth of *Porites* colonies under increased temperature over time, suggesting that *Porites* colonies can withstand warmer temperatures (Bessat 2001, Kaczmarsky 2006). Studies addressing the impacts from ocean temperatures and thermal stress to coral reef systems show there to be a positive correlation between increasing temperatures and coral disease outbreaks (Bruno et al. 2007). Findings from a study conducted in Puakō, Hawaiʻi showed increased nutrient loads throughout coastal marine habitats from sewage pollution resulted in the increased presence of growth anomalies on *Porites lobata* colonies (Yoshikoka 2016). Results from these studies show the varied responses invertebrate organisms have to changing environmental conditions, increasing anthropogenic impacts, and the onset of disease occurrences.

Exosymbiont relationships

Pōhaku puna (Porites species) are one of the most predominant coral taxa found throughout coral reef communities in Hawaiʻi that provide a variety of exosymbiont invertebrates with protected habitat and food resources (Stella 2010, Idjadi 2016,). The diverse relationships between *Pōhaku puna* colonies and their exosymbiotic invertebrates can be characterized as mutualistic, commensal or parasitic, and can impact the health and productivity of the individual coral colony and the larger coral reef community (Gochfeld 1997, Mikkelson 2001). Mutualistic symbiotic relationships between hosts and their inhabitant organisms benefit both organisms **(**Apprill 2007). The mutualistic relationship between coral species and *Symbiodinium* benefits both host and symbiont through the acquisition of needed food resources for the coral through photosynthesis and protected habitat for their symbionts (LaJeunesse et al. 2004, Apprill 2007). The predatory and specialist relationship had between corallivorous nudibranchs from the genus *Phestilla* and *Porites* species is seen through their interdependent relationship. The nudibranch *Phestilla minor* relies on different chemical cues from *Porites lobata* species for larval metamorphosis (Ritson-Williams et al. 2003).

The relationship between *Porites lobata* species and *Phestilla minor* can also be seen as parasitic being that the grazing of the corallivorous nudibranch can cause harm to the large *Porites lobata* colonies and yet predation on *Phestilla minor* from larger predators tends to control their grazing rate (Aeby 1997, Ritson-Williams 2003). Commensal symbiotic relationships benefit the inhabitant with little to no impact to the host organism (Shima et al. 2010)**.** The commensal relationship between *pōhaku puna* colonies and *nā kio* (christmas tree worms) benefits *nā kio* populations with little harm to the *pōhaku puna* colonies as the polychaete worms burrow into the calcareous skeleton of the *pōhaku puna* colonies, using their rough surface and deep tissue mass for protection against predation (Shima et al. 2010).

The extensive research studying the epifaunal communities of four different branching coral species conducted by Stella et al. (2010) sought to examine the differences and similarities in community assemblage amongst these four coral species. The intent was to identify the diverse epifaunal communities closely associated with coral hosts that would be impacted by the reduction in population densities of their coral host. This study found there to be a total of 2,481 individuals from 12 different phyla associated with the four coral hosts that would be directly impacted from the reduced abundance of their coral host due changing environmental conditions derived from anthropogenic impacts and climate change events (Stella 2010). Idjadi (2006) studied the relationship between macro-invertebrate communities and their scleractinian coral hosts to assess how coral traits (coral diversity, percentage cover of live coral, and the topographic complexity created by coral skeletons) facilitated invertebrate community diversity. The results of this study showed how the difference in the examined coral traits drove invertebrate community diversity, which further supported the positive relationship had between invertebrate community diversity and coral reef health and productivity (Idjadi 2006). Collectively these two studies exemplify the closely tied relationship between invertebrate communities and coral hosts that can be negatively impacted by reoccurring events such as coral disease outbreaks and changing ocean conditions. Thus, it is important to examine how coral diseases such as the growth anomaly disease impacts invertebrate community structure as it can provide insight as to how these outbreaks influence coral reef ecosystem structure and productivity.

Finally, parasitic symbiotic relationships benefit the symbiont while diminishing the health of the host organism (Shima, 2014). The predatory relationship between *pōhaku puna* colonies and corallivorous snails result in severe coral tissue loss that create pathways for coral diseases to inhabit these large colonies and disturb normal ecological functions (Work, 2016). The vermetid gastropod *Dendropoma maximum* uses mucus nets to suspension feed that smothers the surrounding coral tissue resulting in the decrease in tissue loss and coral density (Shima, 2014). These examples show the different roles of associate invertebrates as it relates to coral health and function. The need to continue studying ecosystem relationships of species and their environment is significant to better identify the onset of coral disease events and develop most appropriate management and monitoring efforts to mitigate for these impacts.

Coral diseases

Coral disease is presented in many forms and can be stimulated by parasitic relationships between host and inhabitant, human use changes within ocean habitats and surrounding land resources, or environmental shifts caused by global climate change (Edinger et al. 2000, Bruno et al. 2007, Harvell 2007, Aeby 2016, Raymundo 2016). Scleractinian corals such as montiporids, pocilloporids and poritids have been particularly vulnerable to disease being that they are large primary reef building corals with large densities and distribution throughout coral reef habitats (Work et al. 2008, Williams et al. 2010, Burns et al. 2016). Much work has been conducted to address coral disease and the potential driving factors of disease. Studies conducted on montiporids, pocilloporids, pavonids, and poritids have found the prevalence of coral disease is related to changing environmental conditions and impacts from anthropogenic changes (Raymundo et al. 2005, Takabayashi et al. 2008, Aeby et al. 2011). Coral bleaching events and other disease occurrences such as white and black band disease, white pox, trematodiasis, and growth anomalies have been examined globally with studies being conducted in the Western Atlantic, Caribbean, Philippines, and throughout the South Pacific (Raymundo 2004, Harvell 2007, Work 2008, Aeby 2010, Burns et al. 2015). Many abiotic and biotic factors potentially driving disease and pathogen distribution have also been examined such as increasing ocean temperatures, increasing turbidity, and changes in predator interactions (Raymundo 2005, Bruno 2007, Work 2008, Aeby 2011). Collectively these studies have provided significant information relating to coral disease yet further ecological studies need to be conducted to better understand how the relationships between and among coral species and their exosymbionts are affected by the onset of disease events.

Coral disease events are often triggered by environmental changes coupled with anthropogenic impacts. Changing environmental conditions such as increasing ocean temperatures can trigger the onset of coral bleaching events and decreasing calcification (Bruno et al. 2007). Increasing nutrient loads from terrestrial sediment runoff and sewage pollution can cause algal blooms and disease outbreaks that can lead to increased coral mortality (Harvell 2007, Vroom 2009, Yoshioka 2016). Many diseases lead to morphological deformations of large stony coral colonies that can potentially cause changes in associate invertebrate assemblages simply through the loss of inhabitable space. Decreased coral cover from coral disease also impacts community assemblage at the ecosystem level again by simply reducing the inhabitable space and niches available for coral exosymbionts (Aeby 2011). On large *Porites* colonies, there are many associated invertebrates that inhabit these colonies or feed upon them. The corallivorous nudibranchs from the genus *Phestilla* graze on *Porites* tissue sequestering their toxins for their own defense, and the burrowing Christmas tree worms, *Spirobranchus corniculatus*, use the large calcareous mass of *Porites* colonies to burrow into and inhabit for protection (Bailey-Brock 1976, Williams et al. 2010). Loss of large portions of these colonies from disease can reduce the amount of food and inhabitable space for these associate invertebrates. This loss of food and habitat source leads to changes in community structure and function. The need to continue studying the types of coral diseases afflictions found on different types of coral colonies and the impacts from these diseases to coral reef ecosystem function is important in understanding how they occur and influence coral reef community structure.

Coral growth anomaly

Growth anomalies are a type of coral disease found on large *Porites* colonies that can often be mistaken for natural tissue growth. This disease is seen in the morphological deformation of tissue and skeleton on massive *Porites* colonies that results in decreased polyp density, reduced corallite diameter, and increased distance between corallites (Pihana 2017). The bulbous masses protrude from the surrounding healthy tissue area and appear to be swollen and thick. Studies have been conducted to define these anomalies on *Porites compressa* as well as other reef building corals such as the large plating montiporid and branching acroporid species yet few studies have examined their presence on *Porites* spp. (Takabayashi et al. 2008, Work et al. 2008, Aeby et al. 2011, Stimson 2011). Growth anomalies on *Porites compressa* were identified by their bulbous appearance, closely packed calices, increased numbers of septa and hypertrophied polyps. These morphological parameters are key markers for such tumorous growth anomalies (Stimson 2011). Burns et al. (2011) identified two types of growth anomalies (GA) on montiporid species using key morphological differences amongst anomalies. Type A growth anomalies exhibited reduced polyp density and enlarged fused tuberculae that resulted in a nodular appearance and Type B growth anomalies exhibited the complete absence of polyps and smoother more bulbous appearance.

Finally, the work conducted by Work et al. (2008) and Aeby et al. (2011) aimed to define growth anomalies on acroporid coral species. Work et al. (2008) identified the reduction of polyp and zooxanthellae density as well as the reduction in mesenterial filaments and gonad abundance and significant necrosis as key characteristics of acroporid growth anomalies (Work et al. 2008). Aeby et al. (2011) described growth anomalies on both acroporid and poritid species as easily distinguishable protuberant masses that results in reduced colony growth, partial coral mortality, and decreased reproduction (Aeby et al. 2011). Burns et al. (2011) growth anomaly study om *Montipora capitata* colonies found two distinct morphological types of growth anomalies that resulted in the reduction or complete loss of coral polyps. Comprehensively, these studies have provided much information relating to the presence and morphology of growth anomalies on many scleractinian corals as well as the environmental factors that may stimulate the presence of these growths, yet little ecological analysis has been conducted to assess the impact from such disease types at an ecosystem level.

Effects of coral growth anomalies on exosymbiotic invertebrate assemblages should be more closely examined because these and other corals function as shelter and symbiotic hosts to a myriad of other species. Thus, a decline in coral health will affect all its symbioses and potentially the entire ecosystem. To comprehensively assess associate invertebrate assemblages on and among *Porites lobata* colonies, clearly defined morphological parameters need to be created for growth anomalies found on *Porites lobata.* A quantitative definition has to be developed in order to pursue identification of growth anomalies on *Porites lobata* so that the growth anomalies can be distinctly differentiated from natural tissue growth. Upon development of such definition, a comprehensive assessment can be conducted to identify key associate invertebrates that may have the potential to elude to the presence of such a disease. Because of the type of relationships associate invertebrates have with *Porites* colonies they have the potential to indicate the presence or absence of disease as well as have the potential to facilitate disease. In order to comprehensively address the potential of associate invertebrates to be indicative of disease such as growth anomalies a baseline assessment must be conducted to determine what invertebrates are present, the type of relationship invertebrates have with *Porites* colonies, and if that relationship can be indicative of health. This study aimed to develop a morphological definition for growth anomalies found on *Porites lobata*, assess the invertebrate diversity and abundance found on the selected healthy and unhealthy *Porties lobata* colonies, and determine if there is a difference in invertebrate assemblage amonst the selected healthy and unhealthy *Porites lobata* colonies studied.

Objectives & Hypothesis –

1) Develop a field definition for growth anomaly (GA) disease afflictions found on pohaku puna (Porites lobata) coral colonies
2) Examine the differences in exosymbiotic invertebrate assemblage on GA afflicted and unafflicted coral colonies
3) Create community-driven monitoring efforts

Chapter 2 - Materials & Methods

Defining growth anomalies –

A field definition for growth anomalies found on *Porites lobata* species was created to better identify the disease presence on the *Porites lobata* coral colonies found within the study site. Physical parameters were used to create the definition, identify the disease presence, and select the healthy and unhealthy *Porites lobata* colonies. The morphological characteristics of coral growth anomalies found on *Porites lobata* species were defined using the difference in coral polyp composition between healthy and unhealthy coral tissue. The field definition created for growth anomalies found on *Porites lobata* colonies was based on the difference in coral polyp density, individual polyp diameter (mm), and distance between individual polyps (mm) within a given area between healthy and unhealthy coral tissue.

Magnified images were taken of presumed unhealthy and healthy coral tissue using a Sea&Sea underwater camera with an attached macro lens. A 30.5cm ruler was included in all images for coral polyp size calibration. Images were then uploaded to the Coral Point Count (CPCe) program for PC computers where measurements were taken for individual polyp diameter, distance between individual polyps, and overall polyp density within a 0.50cm^2 area. Individual coral polyp diameter measurements were taken horizontally across the middle of the coral polyp. Distance measurements between individual coral polyps were taken from the outer edge of one corallite to the outer edge of a neighboring corallite. Finally, to determine coral polyp density an area of 0.50cm^2 was selected within the image on both healthy and unhealthy coral tissue and coral polyp density was counted within that given area. Upon completion of data collection, the data were analyzed using Minitab 17 to determine the statistical differences for each parameter.

Mapping selected coral colonies –

Twelve *Porites lobata* colonies were haphazardly selected within the study site and later mapped using the ArcGIS mapping program. A team of snorkelers swam the area of the study site to identify and select six healthy and six unhealthy *Porites lobata* colonies. The selection of unhealthy *Porites lobata* coral colonies was based on the growth anomaly field definition created at the onset of this research study, with all selected colonies being more than 1m in distance from one another. Upon completion of coral selection, a mapped pathway through the study site was created to enable long term monitoring of each selected coral colony. The mapped pathway began at the shoreline of the study site and weaved through all twelve selected coral colonies. Two snorkelers shot degree bearings using underwater compasses from selected markers beginning from the shoreline and throughout the study site. The bearing data obtained from this process was then inputted into the ArcGIS mapping program for PC computers where a GIS map of the study site was generated.

Colony Measurements -

All twelve selected coral colonies were measured for area by obtaining data for the length, width, and height of each individual coral colony. The length, width, and height data were taken at the longest, widest, and highest areas of each coral colony. Data was logged to be used during statistical analysis.

Invertebrate assemblage data collection -

Invertebrate assemblage data was collected using a team of two snorkelers. One snorkeler was the data collector and the second snorkeler was the invertebrate species identifier and counter. The counter would identify and count all invertebrate species found in or on the coral colony in a counter clockwise rotation and relay the information to the data logger. To reduce the potential for overlap the counter would circle the coral colony in a counterclockwise motion visually dividing the sides of the colony into countable sections.

Results –

Statistical results for the growth anomaly physical definition showed there to be no significan difference in corallite density (H=4.1polyp/cm^2, UA = 3.2 polyp/cm, GA=2.9polyp/cm^2) and mean individual polyp diameter (H=1.2mm, UA=1.6mm, GA=1.8mm) (fig 2 & fig 4). It was also found that the mean distance between coral polyps (H=2.0mm, UA=1.6mm, GA=2.7mm) was significantly different so this parameter was used to select the coral coloines (fig 6). Results for the exosymbiotic community assemblage was characterized by a number of parameters such as the number of species, total number of individuals, and SW diversity index. The collected data relating to these parameters were examined using the Shannon-Wiener diversity index and the two sample t-test to identify any differences in exosymbiotic invertebrate assemblage as it related to the presence of growth anomalies. The results from the two sample t-test showed there to be no significant difference (p-value = 0.438) in exosymbiotic invertebrate assemblage between healthy *pōhaku puna* colonies and *pōhaku puna* colonies with growth anomalies (fig 10).These results suggest that the presence of growth anomalies found on *pōhaku puna* do not affect or reduce the capacity to host exosymbiotic invertebrates.

Also, when statistically examining the correlation between the invertebrate species assemblage and the volume of the individual coral colonies the results showed there to be no significant correlations (p-value = 0.139) between the two parameters suggesting that volume does not influence exosymbiotic invertebrate assemblage (fig 11). Further examination of the data also showed there to be a difference in individual species abundance between the healthy and disease afflicted colonies with three documented invertebrates being found on either the healthy or disease afflicted coral colony but not both. The *nahawale* (*Isognomon perna*) and the *punohu* (*Heterocentrotus mamillatus*) were found on the healthy coral colonies and an orange sponge species was found on the disease afflicted colonies.

Further examination of the data also showed there to be a difference in individual species abundance between the healthy and disease afflicted colonies with three documented invertebrates being found on either the healthy or disease afflicted coral colony but not both. The *nahawale* (*Isognomon perna*) and the *punohu* (*Heterocentrotus mamillatus*) were found on the healthy coral colonies and an orange sponge species was found on the disease afflicted colonies. Given the nature of these organisms it was an interesting find because the filter feeding *nahawale* tend to inhabit crevices within the coral colony and the *punohu* are often found at the base of a large *pōhaku puna* colony or inside the colony itself. The orange sponge species documented during this study are known to be weedy organisms that are able to live in extreme evironments and were found on the coral colony (Hoover,1999). Thus, this was an interesting find that gives rise to further research into these relationships to identify if any of these exosymbiotic invertebrates could elude to coral health as it relates to the presence of growth anomalies.

Growth Anomalies Definition -

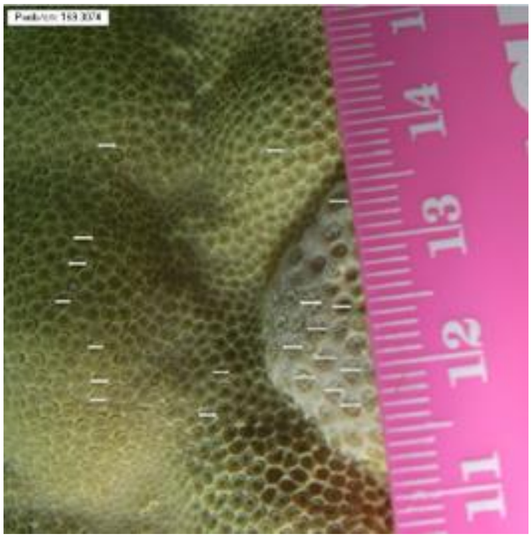


Fig. 1. – diameter of individual corallites on unafflicted (UA) coral tissue and growth anomaly (GA) tissue

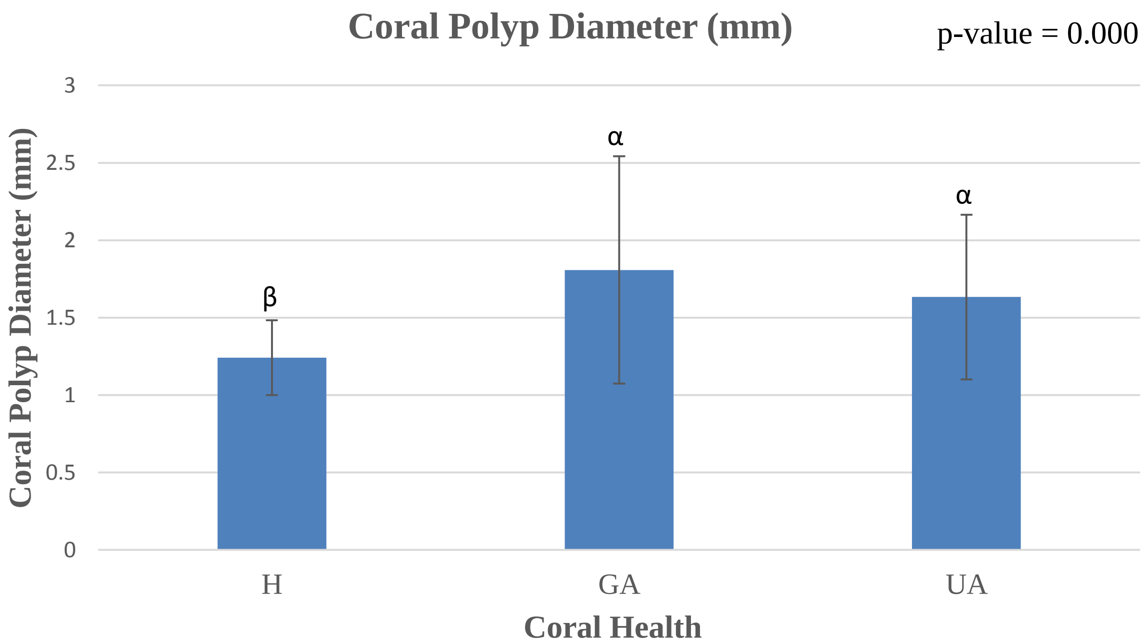


Fig. 2: difference in individual polyp diameter on healthy (H), unafflicted (UA), and growth anomaly (GA) tissue is significantly different

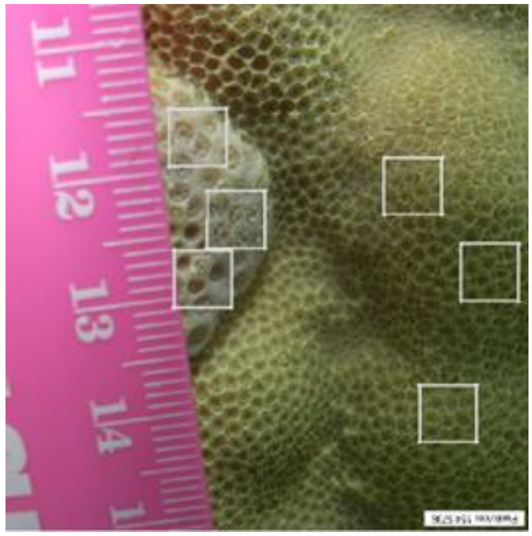


Fig. 3: Polyp density in a given area on unafflicted (UA) coral tissue and growth anomaly (GA) tissue; CPCe image

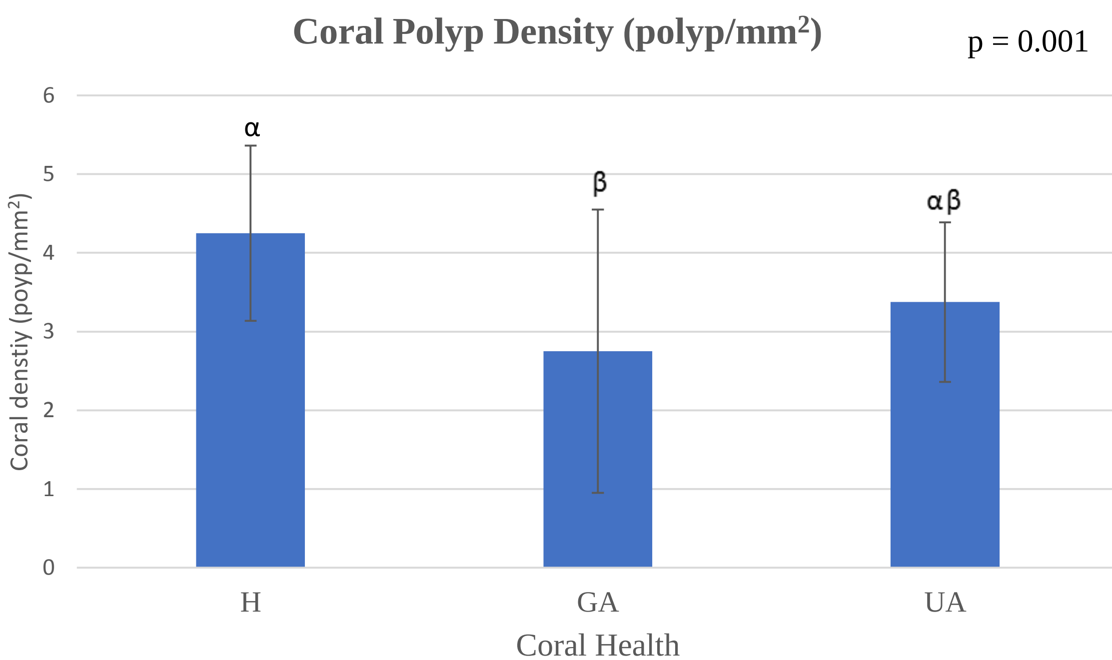


Fig. 4: polyp density on healthy (H), unafflicted (UA), and growth anomaly (GA) tissue is significantly different

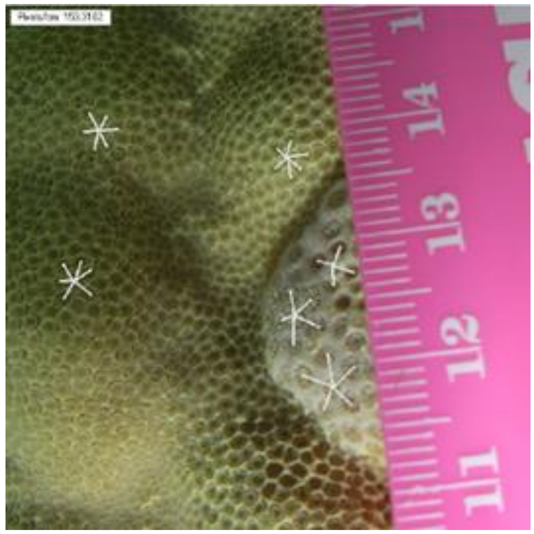


Fig. 5: distance between corallites on unafflicted (UA) coral tissue and growth anomaly (GA) tissue; CPCe image

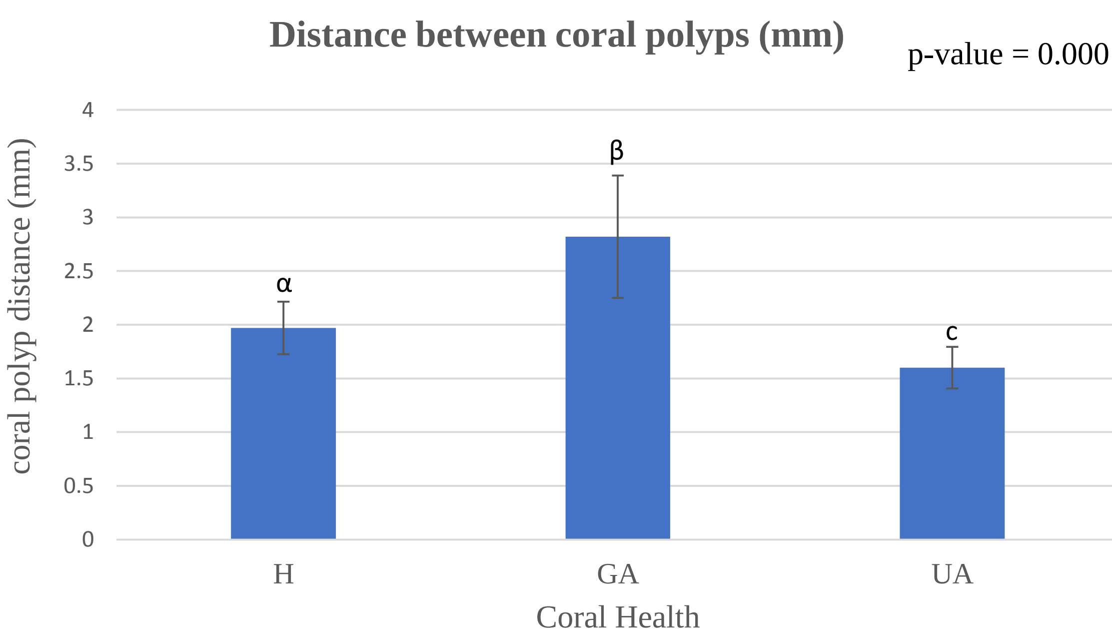


Fig. 6: the distance between coral polyps is significantly different amongst healthy coral tissue, unafflicted coral tissue, and coral tissue with GA.

Coral colony mapping -

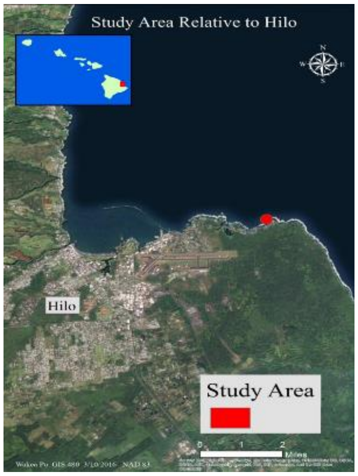


Fig. 7 – GIS map of Hilo Bay

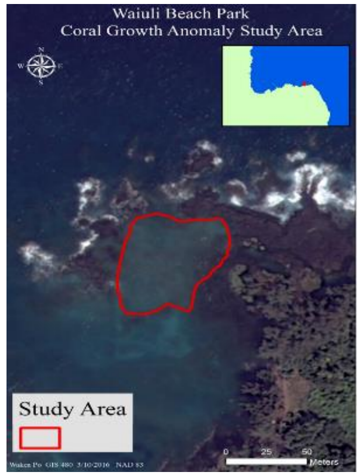


Fig. 8 – GIS map of Waiuli study site

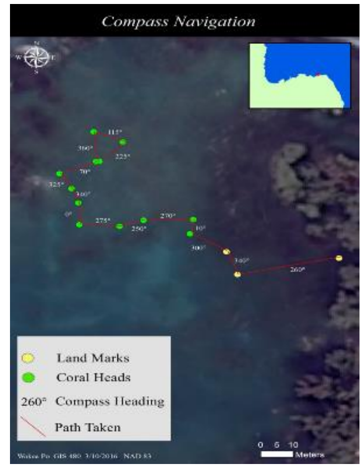


Fig. 9 – GIS map of coral colonies with degree bearings

Invertebrate assemblage data collection

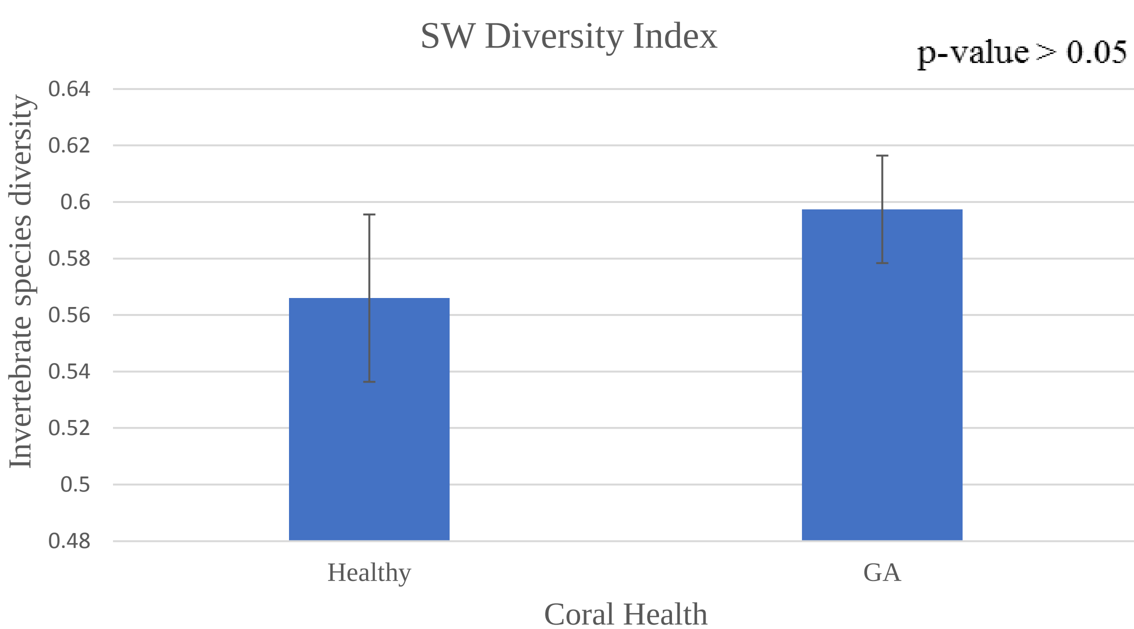


Fig 10: Shannon Weiner species diversity index; there is no significant difference in exosymbiotic invertebrate species diversity amongst healthy *pōhaku puna* colonies and *pōhaku puna* colonies with GA.

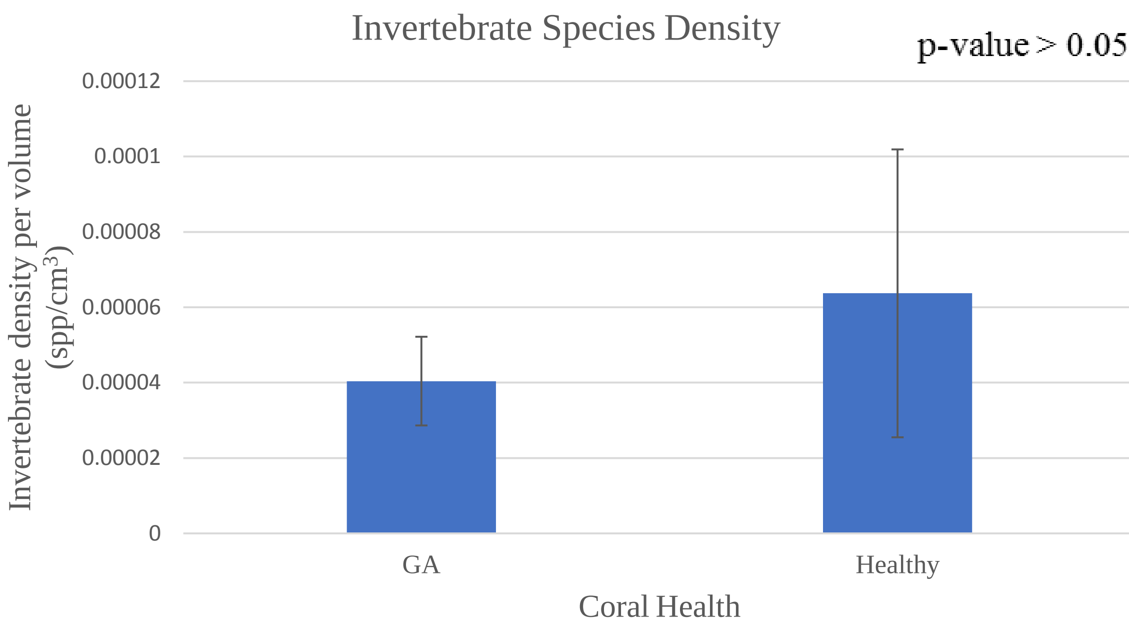


Fig 11: no significant difference in invertebrate species diversity between healthy *pōhaku puna* colonies and *pōhaku puna* colonies with GA.

Exosymbiotic invertebrates – unique cases; invertebrate species was found on either the healthy (H) *pōhaku puna* or the *pōhaku puna* colonies with GA.

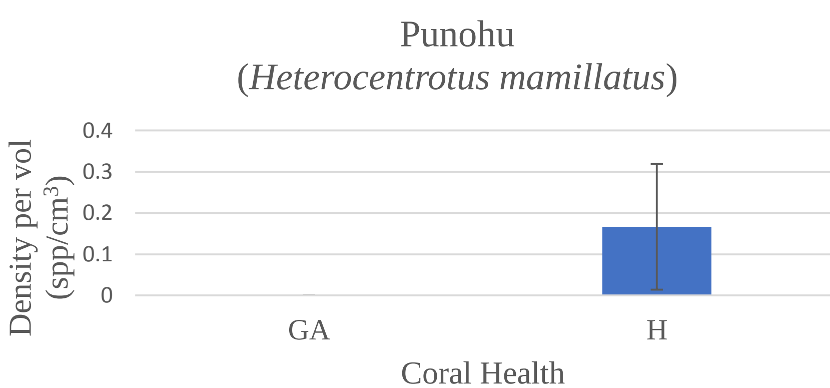


Fig. 12: difference in Punohu (*Heterocentrotus mamillatus)* found on healthy and unhealthy pohaku puna colonies

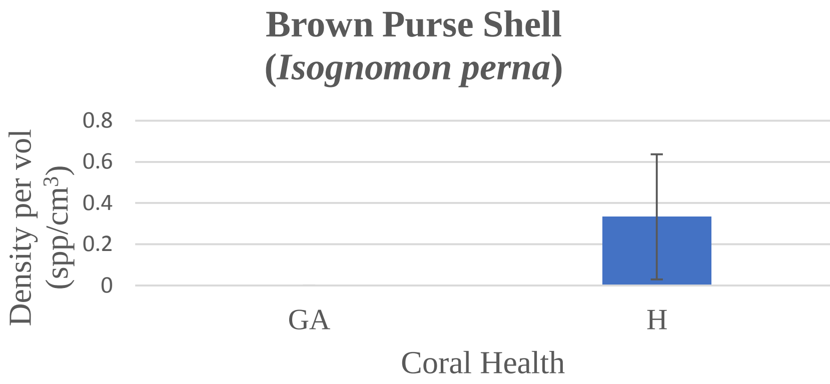


Fig. 13: difference in Brown purse shell (*Isognomon perna*) found on healthy and unhealthy pohaku puna colonies

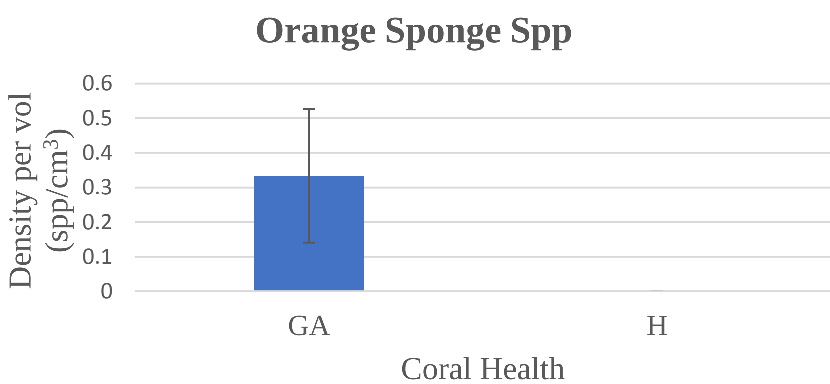


Fig. 14: difference in Orange sponge spp. found on healthy and unhealthy pohaku puna colonies

Chapter 3 - Native Hawaiian Science Methods

The application of an integrated research approach was applied during this study, which combined Western and Native Hawaiian science research methods. This approach provided researchers with a more detailed and intimate understanding of the selected study site as well as the community closely tied to these ocean resources. Components of the Native Hawaiian scientific and cultural practices highlighted in this study related to conducting Native Hawaiian field protocol, documenting environmental observations, interpreting Wahi Pana (place names), and researching Hawaiian chants, stories, and proverbs. The collective information provided from these resources and practices enhanced the scientific rigor of the study showing the interconnected relationship between both knowledge systems.

(4a) ***Nā Oli Ka Hea a me Ka Pani –***

Native Hawaiian cultural protocol was conducted at the beginning and end of each field study site visit. The purpose of conducting Native Hawaiian cultural protocol was to strengthen our relationship with place and perpetuate the practices of our ancestors. Nā oli ka hea are entrance chants that are conducted before entering a place to request entrance and knowledge in preparation for the work. E Hō Mai and Aia ke kama o Hilo were chanted at the beginning of the field data collection days to prepare for the work set for that day. Upon completion of the field data collection day Nā oli mahalo were conducted to recognize the knowledge attained during the field day and to close the day‘s research. Mele Mahalo and ‘O Kau ‘Ola were the closing chants used to end the field research days.

(4b) ***Nā Kilo Moana –***

The practice of *nā kilo ʻāina*, environmental observations, was applied throughout the duration of the project, conducted during each field site visit to develop a stronger sense of place. At the onset of project development and throughout the duration of the project, environmental observations were conducted to familiarize self with place and understand the key characteristics and ecological processes of the selected study site. Environmental observations were made at the beginning of each field visit upon completion of opening cultural protocol and again at the end of the field site visit before closing cultural protocol. At the beginning of the field visits researchers would document their environmental observations individually. Each researcher would take ten minutes alone to spend time making and documenting the environmental observations. Upon completion of data collection researchers would group together to complete the group environmental observation piece that enabled all researchers to share the environmental observations they observed during field data collection. Collectively this component of the research methods provided important quantitative information that could be compared to the qualitative data collected to gain a more detailed understanding of the ecological processes occurring in the study site.

(4c) ***Nā Wahi Pana –***

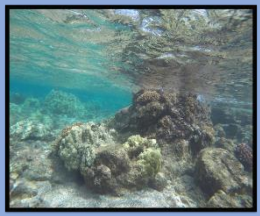
The *wahi pana* component of the research examined the Hawaiian place names associated with the selected study site. Researchers would gather information about the Hawaiian places names given to the land division and community where the site was located and all of the Hawaiian place names given to the site itself and the surrounding sites closely connected to the study site. All collected Hawaiian names were literally interpreted and then broken down to identify other Hawaiian words nested in the original words that eluded to the *kauna* or hidden meaning of the original place name. Upon completion of interpretation, the meanings where then compared to the environmental conditions and research data collected to further identify relationships amongst the qualitative and quantitative data sets.

(4d) *Nā Oli, Nā ʻŌlelo Nōʻeau, a me Nā Mo'olelo Hawaiʻi –*

Hawaiian chants, proverbs, and stories relating to the marine environment and the Hawaiian place names of the study site were examined to identify longitudinal environmental observations and key characteristics data documented historically. These resources were selected based on the information gathered from Native Hawaiian community members, the UHH Hawaiian Studies Program, and Published peer-reviewed research papers relating to the subject from accredited publishing agencies. All resources were reviewed in detail to identify documented environmental relationships, occurrences, and characteristics of the study site and surrounding community. This information was then compared to the environmental observation data collected for this study and other current research studies applying similar methods to identify environmental occurrences that may have changed or remained constant over time.

Nā Kilo Moana –
Table 1 – environmental observations conducted during the Ka Wā: Hoʻoilo (Winter Season 2016)

Nā Lewa & Nā Mahina **(the levels & months)**	**Iulai (July)**	**ʻAukake (August)**	**Kepakemapa (September)**
Ka Halawai **(horizon)**			

Ka ʻae kai **(intertidal)**			
Ka papa ʻākoʻa **(coral reef)**			

Nā Wahi Pana –

Table 2 – breakdown and interpretation of Hawaiian place names

***Nā Wahi Pana* (place names)**	**Definitions (http://wehewehe.org)**
Hilo	**to twist, braid, spin** **Name of a famous navigator** **First phase of the new moon**
hi (hī)	to cast or troll; to flow, hiss; to purge
lo (lō)	a black insect, earwig front half of the skull lord a line of Oʻahu chiefs
Keaukaha	**Place name of the coastal district in Hilo** **the cutting/slicing current**
kaha	to scratch, mark, check, draw, sketch, cut, cut open or slice lengthwise, as fish or animal place (often followed by a qualifier, as kahakai, kahaone, kahawai) to swoop, as a kite; to be poised, soar, as a bird; to go by, pass by, to turn and go on; to surf, body surf tage of a foetus in which limbs begin to develop; A kind of tapa.
au	period of time, age, era, epoch, cycle, the passing of time currents; era, cycle, or period movement, eddy, tide, motion; to move, drift, float, walk, hurry, stir; succession or train, as of thought, trend. to rub, massage, polish to set, as a net or fish trap a native shrub
aukaha	desolate, dreary, nonproductive
kea	white, clear; fair (skin); breast milk variety of sugar cane, among Hawaiians one of the best-known and most-used canes, especially in medicine
uka	inland, upland, towards the mountain, shoreward (if at sea); shore, uplands
aha	why? what? for what reason? meeting, assembly, gathering, convention, court, party design supposed to resemble the continuing track of a duck, carved on tapa beaters
ha (same as haʻa) (hā)	***haʻa*** low; dwarf; to lower; humble; a dance with bent knees

	short variety of banana ***hā*** to breathe, exhale; to breathe upon stalk that supports the leaf and enfolds the stem of certain plants trough, ditch, sluice; to form a ditch or trough stick or furrowed stone used as a sinker, with hooks attached A native tree
Waiuli	**Name of a wind, Honolua, Maui**
wai	Water, liquid or liquor of any kind other than sea water Place names beginning with Wai-, river, stream Grain in stone to retain, place, leave, remain, earn, deposit
uli	Any dark color, including the deep blue of the sea, the ordinary green of vegetation, and the dark of black clouds name of a goddess of sorcery early stage in the development of a foetus, as the body begins to form to steer; steersman short for ʻōuli, omen
li ***(lī)***	***lī*** Chills; to have chills; to tremble with cold Lace, as of shoes; to lace or tie To hang, gird; to furl or reef, as a sail
ai ***(ʻai)***	***ai*** Coition; to have sexual relations, cohabit same as wai linking or anaphoric part ***ʻai*** food or food plant to eat, destroy or consume as by fire; to erode; to taste, bite, take a hook, grasp, hold on to; edible dancing style or type stroke or hold in lua fighting; spear thrust stone used in the kimo game other than the stone that is tossed and caught
Iu ***(ʻiu)***	***ʻiu*** lofty, sacred, revered, consecrated; such a place taboo isolating menstruating women in a special hut

Nā Inoa –
Table 3 – breakdown and inerpretation of Hawaiian names

Nā Inoa (names)	Definitions
ʻākoʻakoʻa	**to assemble; collected, heaped, assembled**
ʻā	ʻā – firey, to burn; to glitter/sparkle; in the nature of (hina – white; ʻāhina – grey)
koʻa	koʻa – coral, fishing grounds, shrine
koʻakoʻa	koʻakoʻa – coral, scarred; rough scar, well-supplied rich, to stay or live in one place
Pōhaku puna	***rock coral***
pōhaku	rock, stone, mineral, tablet; sinker thunder; rocky, stony
pō	night, darkness, obscurity; the realm of the gods; pertaining to or of the gods, chaos, or hell; dark, obscure, benighted; formerly the period of 24 hours beginning with nightfall
haku	lord, master, overseer, employer, owner, possessor, proprietor to compose, invent, put in order, arrange; to braid, as a lei, or plait, as feathers Core, lump, as of poi; stone, coconut sponge
poha ***(pohā)***	***pohā*** to burst, crack, break forth, crash, pop, bang; to ferment (of poi); bursting, cracking, as of explosives or of a whip; flashing of light, breaking of bubbles
ku ***(kū)***	***kū*** to stand, stop, halt, anchor, moor; to rise, as dust; to hit, strike, jab in a state of, resembling, like; To appear, show, reveal; to start, go to achieve; to change into, transform; beginning, appearance; arrival to run in schools, as fish; numerous, as octopus in season
oha	Spreading, as vines; thriving; to grow lush affection, love, greeting; to greet, show joyous affection or friendship, joy
puna	Spring (of water); coral, lime, plaster, mortar, whitewash, calcium; coral container, as for dye, coral rubber; Short for kupuna as a term of address
pu ***(pū)***	***pū*** Tree, cluster of several stalks head of octopus or squid; canoe endpiece coil of hair, topknot of hair; rope or line, as attached to sticks in an ʻōpelu net

	together, entirely, completely, also with, together with
na	by, for, belonging to
una* *(var. of une)	Shell of turtle or tortoise to urge, disturb, harass (*une*) To send, transmit, send on an errand, command, put to work (*hoʻouna*)

Chapter 4 – Discussion:

Summary –

The main objective of this study was to understand how the growth anomalies (GA) impacted *pōhaku puna* (*Porites lobata*) species at the community level by examining the difference in exosymbiotic invertebrate assemblage between healthy *pōhaku puna* colonies and those with growth anomalies. Because coral is of both cultural and ecological importance in Hawaiʻi, the potential impacts from coral disease must continue to be examined to best understand how to mitigate these occurrences. Culturally, from a Native Hawaiian worldview, coral is recognized as our foundation and ancestor. Ecologically it is recognized as the trophic foundation of our coral reef systems that provide sustenance and habitat for other organisms. Collectively these roles exemplify its nature as a foundational organisms. As coral diseases have the potential to negatively impact corals, it is important to understand how those impacts affect the symbiotic communities associated with them. For example, the sybiodimium species closely dependent to corals are directly impacted by coral disease due to the loss of inhabitable space (Harvell 2007, Burns 2011, Aeby 2016) . The mutualistic relationship between the two organisms is fundamental to the health, wellness, and productivity of corals and coral reef ecosystems overall so loss of inhabitable space from coral disease can potentially lead to changes in the ecosystem structure of coral reef environments (Kempf 1986, Harvell 2007, Burns 2011). Because growth anomalies is a prominent disease in Hawaiʻi it is important to understand its impact at the individual, population, and community level. Therefore, it is important to examine the impacts of GA on exosymbiotic communties to better how it is impacting coral reef habitats at the ecosystem level. The integrated methodology applied in this study combined indigenous and institutional sciences with the intent to gain a more comprehensive understanding of how coral disease impacts coral reef ecosystems in Hawai’i both culturally and ecologically. In a

Native Hawaiian worldview, there is a strong cultural connection to our natural resources and it is recognized that the health and wellness of our communities are closely tied to the health and wellness of our natural resources. Thus, the integrated methodology implemented in this study was important to apply as it provided researchers with a deeper understanding of how coral disease impacts the cultural and ecological health and wellness of our coral reef systems.

Growth Anomaly (GA) Morphological Definition –

To initiate the study a morphological definition for the growth anomaly found on *pōhaku puna* had to be established. Studies have examined the morphological characteristics of the growth anomaly on many different scleractinian corals and other *Porites* species yet a morphological definition has not been established for *pōhaku puna* colonies. Research conducted on *Porites compressa* colonies defined the morphology of the growth anomaly disease as bulbous in appearance with closely packed calices, some with an increased number of septa (Stimson 2011). Burns et al. (2011) examined the growth anomalies found on *Montipora capitata*, identifying two distinct types of growth anomalies; type A and type B. This study showed the growth anomaly disease type A to have reduced polyp density and type B to have no discernable calices or polyps and fused protuberant coenosteum. Finally, a study examining the relationship between coral bleaching and growth anomalies found on *Porites spp.* found that the growth anomalies had larger calices with less distance between calices and some calices had higher than normal numbers of septa (McClanahan 2009). Collectively these studies recognize the varied appearances of growth anomalies found on scleractinian corals with some defining characteristics being tissue swelling, changes in calices, and reduction in or loss of individual polyps. For this study, healthy (H), unafflicted (UA), and growth anomaly (GA) coral tissue was examined to identify the morphological parameter that could be used to define GA found on *pōhaku puna*. The selected parameters for developing the morphological definition for growth anomalies found on *pōhaku puna* were the distance between corallites, the diameter of an individual corallite, and the density of corallites within a given area. Statistical results showed there to be no significan difference in corallite density (H=4.1polyp/cm^2, UA = 3.2 polyp/cm, GA=2.9polyp/cm^2) and mean individual polyp diameter (H=1.2mm, UA=1.6mm, GA=1.8mm). It was also found that the mean distance between coral polyps (H=2.0mm, UA=1.6mm, GA=2.7mm) was significantly different so this parameter was used to select the coral coloines.

When comparing the morphological findings with other studies examining growth anomalies observed on other coral species one can identify general similarities of the disease on the different coral species as well as distinct differences in the disease morphology amongst the varied coral species. The morphological expression of this disease on *Montipora capitata* is reflected in the reduction in polyp density, undisernable calices, and fused proturbent coenostrum (Burns 2011). The appearence of the growth anomaly disease found on the branching coral species *Turbinaria mesenterina* were described as being small, circular or irregular shaped with indistinct edges, and rugose in texture (Hussain 2016). This study also identified similar morphologies described in other coral growth anomaly research such as the reduction in polyps, tissue loss, and discoloration (Hussain 2016). Finally, when looking at how the growth anomaly disease appears on the different poritid species similarities and differences can be recognized amongst the coral species. The growth anomaly disease found on the *Porites compressa* species eminated distinct charateristics such as bulbous or mushroom-top shape, orientation of growth, larger sized calices, discoloration, and extension of polyps (Stimson 2011). The study looking at the growth anomaly disease on *Porites spp.* showed larger calices with less distance between calices and some calices with higher than normal numbers of septa as key characteristics of the growth anomaly disease (McClanahan 2009). This study identified the distance between calices as being a key morphological characteristic of the growth anomaly disease found on *pōhaku puna*. Although the other parameters showed a significant difference in polyp density and individual polyp diameter these differences were more closely associated with the difference between individual coral colonies rather than the presence of the growth anomaly disease. Overall these studies identified the general characteristics of the growth anomaly disease found on different coral species with specific differences being reflected amongst the individual coral species.

The importance of establishing a morphological definition for growth anomalies found on *pōhaku puna* was to enable researchers to differentiate GA tissue from healthy tissue growth. Because of the mounding and globular nature of *pōhaku puna* it is difficult to differentiate abnormal tissue growth from normal tissue growth so to accurately address the main objective of the study a well-defined morphological definition had to be created for the growth anomaly disease found on *pōhaku puna*. In addition to identifying the morphological parameter to define the growth anomaly disease found on *pōhaku puna* field observations recognized other characteristics of the growth anomaly disease that should be further investigated. The observations made throughout the study recognized that the growth anomalies found on the selected unhealthy coral colonies tended to be localized and slow growing suggesting their impact at the morphological level to be benign. When observed over time, it appeared that the growth anomalies found on the selected unhealthy coral colonies did not spread or enlarge rather they remained the same size and in the same location. Also, throughout the duration of the study new growth anomalies were not observed nor documented also suggesting these growth anomalies to be a slow growing disease. Collectively these two finds pose interesting questions relating to the growth rate of the growth anomaly disease and its ability to spread across individual colonies and larger *pōhaku puna* (*Porites lobata*) populations.

Exosymbiotic Invertebrate Assemblage –

Upon completion of the descriptive piece of this study relating to the development of a morphological definition for the growth anomaly disease found on *pōhaku puna* colonies the main component of the study was addressed; there are difference in exosymbiotic invertebrate assemblage amongst healthy *pōhaku puna* and *pōhaku puna* colonies afflicted with the growth anomaly disease. Because coral disease is known to influence biological functions and physiological processes it was assumed that there would be impacts from the disease at the community and ecosystem level (McClanahan 2009, Burns 2011, Stimson 2011, Hussain 2016). Studies examining the relationship between exosymbiotic invertebrates and the host coral colonies have found that the diversity in exosymbiotic community assemblage associated with the coral host can elude to the health and productivity of the coral reef system (Idjadi 2006, Stella 2010).

Stella et al. (2010) research examining the differences and similarities in community assemblage amongst these four coral species found there to be a total of 2,481 individuals from 12 different phyla associated with the four coral hosts that would be directly impacted from the reduced abundance of their coral host. The studied relationships between macro-invertebrate communities and their scleractinian coral hosts assessed how coral traits (coral diversity, percentage cover of live coral, and the topographic complexity created by coral skeletons) facilitated invertebrate community diversity(Idjadi 2006). Results showed different coral traits drove invertebrate community diversity, further supporting the positive relationship had between invertebrate community diversity and coral reef health and productivity (Idjadi 2006). Collectively these two studies exemplify the closely tied relationship between invertebrate communities and coral hosts that can be negatively impacted by reoccurring events such as coral disease outbreaks and changing ocean conditions. Thus, it is important to examine how coral diseases such as the growth anomaly disease impacts invertebrate community structure as it can provide insight as to how these outbreaks influence coral reef ecosystem structure and productivity.

At the onset of the study it was hypothesized that there would be a difference in the exosymbiotic invertebrate assemblage between healthy *pōhaku puna* colonies and *pōhaku puna* colonies with growth anomalies. It was assumed that *pōhaku puna* colonies without GA would have greater exosymbiotic invertebrate diversity and abundance than the healthy *pōhaku puna* colonies because of the lack of disease presence. The results from this study found there to be no difference in exosymbiotic species assebmage between healthy and unhealthy *pōhaku puna* colonies. This find raises more questions relating to the resilience of the exosymbiotic invertebrate communities to coral disease and the severity of the disease to the coral host. Furthermore, undocumented personal field observations showed exosymbiotic invertebrates that were found on *pōhaku puna* colonies with growth anomalies tended to inhabit areas of the colonies with healthy tissue. Researchers did not observe exosymbiotic invertebrates inhabiting areas on or near the growth anomalies. Thus, stimulating more curiosity to the behavioral adaptations of exosymbiotic invertebrates as it relates to the presence and distribution of growth anomalies found on *pōhaku puna* colonies.

Also, it was recognized at the beginning of the study that the volume of the *pōhaku puna* colonies needed to be accounted for to accurately assess the distribution of the exosymbiotic invertebrate assemblages found on the individual colonies as it related to the presence of growth anomalies. It was assumed that there would be a correlation between the volume of the coral colony and the distribution of the exosymbiotic invertebrates because of the greater availability of space. Being that many invertebrates inhabit different areas of the *pōkahu puna* colonies it was important to account for the volume to attain an accurate understanding of invertebrate species distribution.Yet, when statistically examining the correlation between the invertebrate species assemblage and the volume of the individual coral colonies the results showed there to be no significant correlations (p-value = 0.139) between the two parameters suggesting that volume does not influence exosymbiotic invertebrate assemblage. The volume of the healthy *pōhaku puna* colonies (0.19m^3) and the *pōhaku puna* colonies with growth anomalies (0.15m^3) also did not differ (p-value = 0.509) which was to be expected as colonies of similar size were selected. Although there was no statistical correlation between coral volume and exosymbiotic invertebrate assemblage, researchers observed there to be enough inhabitable space on, in, and around the base of the coral colonies not affected by growth anomalies to support exosymbiotic invertebrates. The three-dimensional morphology of *pōhaku puna* colonies enables diverse exosymbiotic invertebrates to inhabit it yet the relationships amongst the host *pōhaku puna* colonies and the exosymbiotic invertebrates vary with some exosymbiotic invertebrates being more dependent on the host coral colony than others. The relationship amongst the host *pōhaku puna* colonies and the exosymbiotic invertebrates found on the surface area were more dependent than those found within or around the base of the colony. Collectively, these findings raise more interesting questions as to how exosymbiotic invertebrates distribute themselves throughout the coral colony and how their distribution is affected by growth anomalies and other coral diseases. They also pose interesting questions as to how coral tissue health, coral colony surface area, and species interaction play a role in exosymbiotic invertebrates assemblage and distribution in the presence of growth anomalies.

Although the results showed that there was no statistical difference in exosymbiotic invertebrate assemblage between healthy *pōhaku puna* colonies and *pōhaku puna* colonies with growth anomalies it was interesting to examine the difference in the number of individuals of certain taxa between the healthy *pōhaku puna* colonies and the *pōhaku puna* colonies with the growth anomalies because it could provide more information about the relationships had between the host coral colonies and the exosymbiotic invertebrate assemblage as it relates to the presence of growth anomalies. If the exosymbiotic invertebrate assemblage on *pōhaku puna* colonies with growth anomalies contains more predatory or parasitic invertebrates compared to that of the healthy *pōhaku puna* colonies then perhaps that could also elude to the health of the individual coral colony. If more commensal and mutualistic exosymbiontic invertebrates are found on healthy *pōhaku puna* colonies compared to *pōhaku puna* colonies with growth anomalies this too could elude to the health of the individual coral colony.

For example, The total number of cone snails individuals was greater on the unhealthy coral colonies compared to that of the healthy coral colonies (UH = 24; H =10). This is an interesting find because of the predatory nature of cone shell species on *pōhaku puna* (Williams 2005, Raymundo 2016). Another interesting find was the difference in the number *nā ina* (*Echinometra mathaei; Echinometra oblonga*) between the healthy colonies and the colonies with the growth anomaly disease. Given the rock-boring nature of *nā ina*, during the study, they were often found in the crevices of the coral structure or burrowed on the side of a large colony. Finally, the number of individual *kauna'oa* (*Serpulorbis variabilis*) differed between the healthy colonies and the colonies with the growth anomaly disease (H=47; UH=116) which was interesting given the boring nature of these organisms. The *kauna'oa* may have either burrowed through the coral tissue or the coral tissue may have built around the *kauna'oa* as the colony grows. Their burrowing nature into the coral tissue may elude to the higher number of individuals found on the *pōhaku puna* colonies with the growth anomaly disease compared to that of the number of individuals found on the healthy *pōhaku puna* colonies. In summary when examining the data to further identify relationships amongst exosymbiotic invertebrates and *pōhaku puna* hosts more questions can be posed as to how the growth anomaly coral disease influences community structure and interaction between the exosymbiotic invertebrate organism and their coral host.

Many studies have examined the prevelance of coral disease within a coral reef environment and its impact on the abundance and diversity of scleractinion coral species. Indirectly these studies address the impact to exosymbiontic invertebrate communities based on the loss of coral percent cover and diversity within a given system yet no studies have specifically examined the impact of coral disease to exosymbiotic invertebrate community assemblage. Stella et al. (2010) examined the variation in the structure of invertebrate assemblage associated with four branching coral species to better understand the morphological attributes that influence invertebrate assemblage. The main predictors (living space, live tissue, and coral species) of this study were found to influence the variation in invertebrate assemblage amongst the four branching coral species as it related to species richness and abundance (Stella 2010). Although this study only examined the relationship between invertebrate species richness and abundance and coral morphology it provided significant information about the variation and number of invertebrates found amongst the four branching coral species studied. Collectively, this study found there to be over 178 species from 76 families and 12 phyla that inhabit these four branching coral species. When comparing the findings from both studies one can deduce that the morphological structure of individual coral colonies influences invertebrate assemblage and may potentially aid in protecting the associate invertebrates from coral disease as this current study found no significant differences in exosymbiotic invertebrate assemblage between healthy *pōhaku puna* colonies and *pōhaku puna* colonies with the growth anomalies. Yet, the impact from coral disease occurrences at the coral species population level could be more severe simply because a greater amount of individual coral species affected by coral disease thus reducing the overall abundance of coral hosts for the exosymbiotic invertebrates (Stella 2010).

Other studies examining the relationship between coral disease and invertebrate associates commonly look at the specific relationship between the invertebrate organism and coral host to identify potential drivers for coral disease outbreaks (Idjadi 2006, Raymundo 2016, and Williams 2005). The studies conducted by Williams (2005) and Raymundo (2016) looked at the relationship between corallivorous snail and their host coral species to understand how their consumption of coral tissue triggered disease events. Raymundo et al. (2016) found that the grazing rate of the corallivorous snails reduced the integrity of the coral skeleton making it more susceptible to coral disease outbreaks and secondary inhabitance by invasive algae. Williams (2005) looked at the corallivorous snails as potential facilitators of coral disease via their consumption of health and unhealth coral tissue. Both studies examined a specific relationship had between a predatory snail and its coral prey that identified potential drivers for coral disease. This current study documented the presence of cone snails on both healthy *pōhaku puna* colonies and *pōhaku puna* colonies with the growth anomalies and although there was no significant difference in their abundance it was recognized that there were more cone snails found on the *pōhaku puna* colonies with the growth anomalies than on the healthy *pōhaku puna* colonies. Thus, it would be interesting to further examine the exosymbiotic invertebrate assemblage found on healthy *pōhaku puna* colonies and *pōhaku puna* colonies with the growth anomalies to see if there are more predatory and parasitic invertebrates found in the exosymbiotic invertebrate assemblage on *pōhaku puna* colonies with the growth anomalies or other coral diseases as compared to healthy *pōhaku puna* colonies. Collectively the results of this study combined with the knowledge gained through the application of Native Hawaiian science provide more information to the collective knowledge of how coral diseases like the growth anomalies influence coral reef ecosystem health and wellbeing.

Native Hawaiian Science –

The Kumulipo, our Native Hawaiian geneology chant, speaks to the *mokukūauhau* (geneology) of the *pae‘āina o Hawai‘i nei* (all of Hawai‘i) recognizing the relationships and genealogical ties had amongst organisms, including *nā kanaka maoli* (Native Hawaiians), spanning from the depths of our oceans to the summits of our mountains and into our heavens and cosmos. This foundational relationship establishes our Native Hawaiian identity, culture, practice, and indigenous knowledge systems. From a Native Hawaiian worldview, our natural resources are recognized as our ancestors and the communities closely tied to them are recognized as *nā konohiki* (stewards/caretakers) who care for and tend to the resources (Louis 2007, Kurashima 2017, Pascua 2017). *Nā konohiki* are the Native Hawaiian scientists of their communities that understand the ecology and biology of their natural resources. *Nā konohiki* also carry the generational knowledge of the place that cannot be attained by the research scientist who comes into communities to conduct research within a short period of time. The Western (institutional) science approach to research conducted in Hawai’i and throughout Polynesia excludes *nā konohiki* and the communities closely tied to the resources from the practice. It is this paradigm that we are working to shift through the inclusion and application of Native Hawaiian science.

The intent of combining knowledge systems in scientific practice and research conducted in Hawai’i and throughout the Pacific is to shift the paradigm of research to be more driven by community need and participation. When researching in an indigenous place and space the communities connected to the resources must be involved in the conversation. The knowledge and generational ties had between the families and the resources holds much information that cannot be found in the quantitative data. Also, from an indigenous prospective it is recognized to be disrespectful to come into a community, take the knowledge from that place, and refrain from sharing the knowledge attained from place with the community tied to the resources. To engage community and share information with community not only enriches the experiences for all participants but it also enables the researcher to understand the importance of conducting research in Hawai’i and the Pacific in such a way that is respectful, humble, and considerate to the cultural identity and traditions of the place and its community.

The application of Native Hawaiian science in this study enabled researchers to contextualize the information they gathered through the practice of *nā oli kahea* and *nā oli mahalo* (protocol chants), *na kilo ʻāina* (environmental observations), interpretation of *nā wahi pana* (Hawaiian place names), and examination of *nā mo'olelo* (Hawaiian stories), *nā oli* (Hawaiian chants), and *nā ʻōlelo nōʻeau* (Hawaiian proverbs). The core question of this study focused on the relationships amongst organisms within a given environment and how these relationships may be affected by disease occurrences. Quantitative data analysis statistically addresses this question while the methods of Native Hawaiian science provide *kaʻike* (the knowledge) that contributes to *ke kauna* (the deeper meaning) of this study which is to sustain the health and wellness of our natural resources and to perpetuate the practices of our ancestors. When conducting *nā kilo ʻāina* over time a relationship with place begins to build and the researcher begins to learn more from their study site. As this practice is continued, ecological relationships begin to be recognized that lead into the creation of new *nāʻōlelo noʻeau*. The interpretation of *nā wahi pana* and the Hawaiian names given to the studied organism provides more detailed information that speaks to the identity of the place (study site) and the organism. For example, the *wahi pana*, *Keaukaha*, when translated means the cutting currents which is a key characteristic of that area that provides information about how the ocean moves along that shoreline and coastal waters. Through the practice of *nā kilo ʻāina* our ancestors recognized the shape of the coastline and how that influenced the movement of the ocean thus giving the name *Keaukaha* to the coastal community of Hilo, Hawai'i.

Furthermore, when examining the Hawaiian name given to *Porites lobata*, *pōhaku puna*, ecological and biological characteristics of this organisms recognized (table 3). Simply translated *pōhaku puna* means rock coral yet when further examining the name and breaking it down into other Hawaiian words we find that *pohaku puna* also speaks it origin as our ancestor, the realm they are found, and their diverse morphological characteristics. Finally, by examinating *nā mo'olelo* (Hawaiian stories), *nā oli* (Hawaiian chants), and *nā ʻōlelo nōʻeau* (Hawaiian proverbs) more information can be found relating to itʻs function and importance in Hawaiian culture. For example, the *ʻōlelo nōʻeau "he poʻi kai uli, kai koʻo ʻaʻole hina pūkoʻa"* translates to "though the sea be deep and rough, the coral rock remains standing" (Pukui, 1983). This *ʻōlelo noʻeau* speaks to the physical characteristics of *pōhaku puna* and ecological behavior as a stony coral species. The *ōlelo no‘eau* further speaks metaphorically to a person who reamins calm in the face of difficulty (Pukui, 1983). Thus, through deep examination and interpretation of given Hawaiian names to place and organism other characteristics of the place and species can be identified. This practice exemplifies the importance and relevance of Native Hawaiian science research methods as well as enables us as Native Hawaiians to perpetuate the practices of our ancestors in a modern context. These practices are no longer spoken of in a Historical context rather as an active and breathing pracitice that continues throughout generations.

Many studies have implemented similar methodologies recognizing the importance of these applications. Pascua et al. (2017) looked at the cultural ecosystem services (CES) from a Hawaiian placed-based perspective to identify the non-material benefits attained from applying such a methodology. This case study examined two rural communities on Kaua‘i and Hawai‘i Island that use this approach in managing their natural resources. The study identified the benefits from the reciprocal relationship had between the native communities and their natural resources and how this relationship contributed to the overall health and wellness of the resources and communities (Pascua 2017). The case study conducted by Kurashima et al. (2017) examined the benefits of using a biocultural restoration approach to manage the natural resources in Kahalu‘u, Hawai‘i. The potential benefits indentified in this study from using an integrated approach to resource management and monitoring included the increased knowledge of environmental conditions, a greater understanding of the practices that contribute to the landscape function over space and time, and the meaningful relationships built to engage community around site (Kurashima 2017). Recognizing the relevance of applying such methodologies in natural resource conservation and management in Hawai‘i contribute to the on-going efforts to care for our natural resources in a holistic and culturally sensitive way that serves the needs of the local communities as well as the natural resources (Friedlander 2008). Collectively these methods provide a deeper understanding of the study sites we work in and the purpose of perpetuating these practices. The overall benefits are seen in the relationships built between the researchers, local community, and the study site that enables a collection of ocean stewards to participate in conversation efforts that aim to care for and sustain our natural resources through the application of more holistic and culturally sensitive management approaches.

In addition to developing place-based and community-based management and monitoring efforts the development of outreach education and applied learning experiences are equally important as they contribute to the building and strengthening of our future researchers and resource managers. This component of the study aimed to perpetuate the coral disease monitoring efforts through applied learing experiences and outreach education events. The applied learning piece of the study focuses on mentored internships with undergraduate and high school students who continue monitoring the growth anomaly disease on *pōhaku puna* at Waiuli Beach Park. The outreach education piece of the study aims to educate local communities on the growth anomaly disease through hands-activities at local community events throughout Hawaiʻi Island. Both components share the integrated methodology used in this study to exemplify the purpose and function of this approach to natural resource mangement and how it aides in the understanding of coral disease.

Future studies –

The broader implications of the study suggest that at the community ecosystem level the coral growth amonaly disease has little impact to exosymbiotic invertebrate community structure and that this community structure is able to sustain itself regardless of disease presence. In order to gain a better sense of how the growth anomaly disease is impacting coral reef habitats and community structure a more longitudinal study should be conducted that examines the environmental changes over time identifing key relationships between what has been observed and what has been statistically quantified. Studies should also be conducted to further define it as a disease on *pohaku puna* by examining how this disease impacts biological functions and physiological porcesses on *pohaku puna.* Finally, a more in depth understanding of the relationships had between exosymbiotic invertebrates and their coral host needs to be developed to better understand and identify how these relationships either drive disease occurrences or are affected by these disease occurrences. By addressing these three inquiries through the application of an integrated methodology we can gain a more in depth understanding of how the growth anomaly disease influences the relationships observed within the coral reef system and the relationships had between the communities closely tied to them. Collectively this study provided insight as to how the growth anomaly disease influences exosymbiont invertebrate assemblage as well as enabled researcher to better understand the importance of applying an integrated research method that incorporate Native Hawaiian sciences and worldview in marine conservation research in Hawai‘i.

The results of this study raised more interesting questions that should be further investigated to gain a more detailed understanding about the effects of growth anomalies at the coral reef community and ecosystem levels. To thoroughly comprehend the impact from growth anomalies to *pōhaku puna* colonies and their exosymbiotic invertebrate communities a complete study must be conducted to understand how growth anomalies effect the biological functions & physiological processes of *pōhaku puna* colonies. As previous studies have identified the impacts to biological functions & physiological processes on other scleractinian coral species which has further defined it as a coral disease found on these coral species. It would be important to do the same for the growth anomalies found on *pōhaku puna*. This can soundly establish a detailed definition of the growth anomalies found on *pōhaku puna* which can then lead to further research. It would also be important to examine the type of symbiotic relationships had between the *pōhaku puna* and their exosymbiotic invertebrates to identify any correlations between the symbiotic relationships had and the presence of growth anomalies found on *pōhaku puna*. Finally, conducting community-driven longitudinal studies from the foundation established in this study will provide for a more detailed and comprehensive understanding about coral growth anomalies and other coral diseases impacting Hawai‘i coral reef systems.

Community-driven monitoring efforts –

The overarching goals of this study were to understand the impacts from the coral growth anomalies at the community level and to perpetuate the monitoring efforts established in this study through a community-driven longitudinal study. The information attained from this study laid the foundation for more research about the impacts from coral disease at the community level that can be driven by community monitoring efforts. By implementing a longitudinal study that involves community-driven monitoring efforts the amount of replicates can be increased, seasonal observation can be conducted, and other study site can be included. These efforts can contribute to the larger conversations being had about coral reef conservation that include local communities and apply methods that are scietifically rigorous and culturally rooted.

Outreach education -

In combination with the community-driven monitoring efforts, outreach education curriculums are important pieces of this study that gives more purpose to the research being conducted. Providing K-12 hands-on learning activities that engage students in marine conservation efforts is crucial in strengthening their relationships with our resources as they are the future *kiaʻa kai* (ocean stewards) of our oceans. In doing so students are introduced to research methodolgies that combine institutional and indigenous sciences to conduct meaningful and scientifically rigorous marine conservation research.

Native Hawaiian science methods training –

Finally, the development of Native Hawaiian methodology training workshops will be created that enable scientists, students, and community members to learn more about this approach and how to apply it in different communities throughout Hawaiʻi and the Pacific. One aim is to share with visiting researchers the importance of following this type of methodology while conducting research in Hawaiʻi and the Pacific as to ensure that they practice considerately and humbly as well as involve community throught all stages of their research. These workshops also aim to train local communities and students from various academic levels in this methodology so they can be more involved in the process, work with researchers, and learn how to conduct research in their community. Collectively, these workshops will enable communities and researchers to develop relationships with one another and learn how to appropriately conduct research in Hawai'i and the Pacific.

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