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We Are All Alive: Understanding Connections between People and Coral Reefs in Samoa

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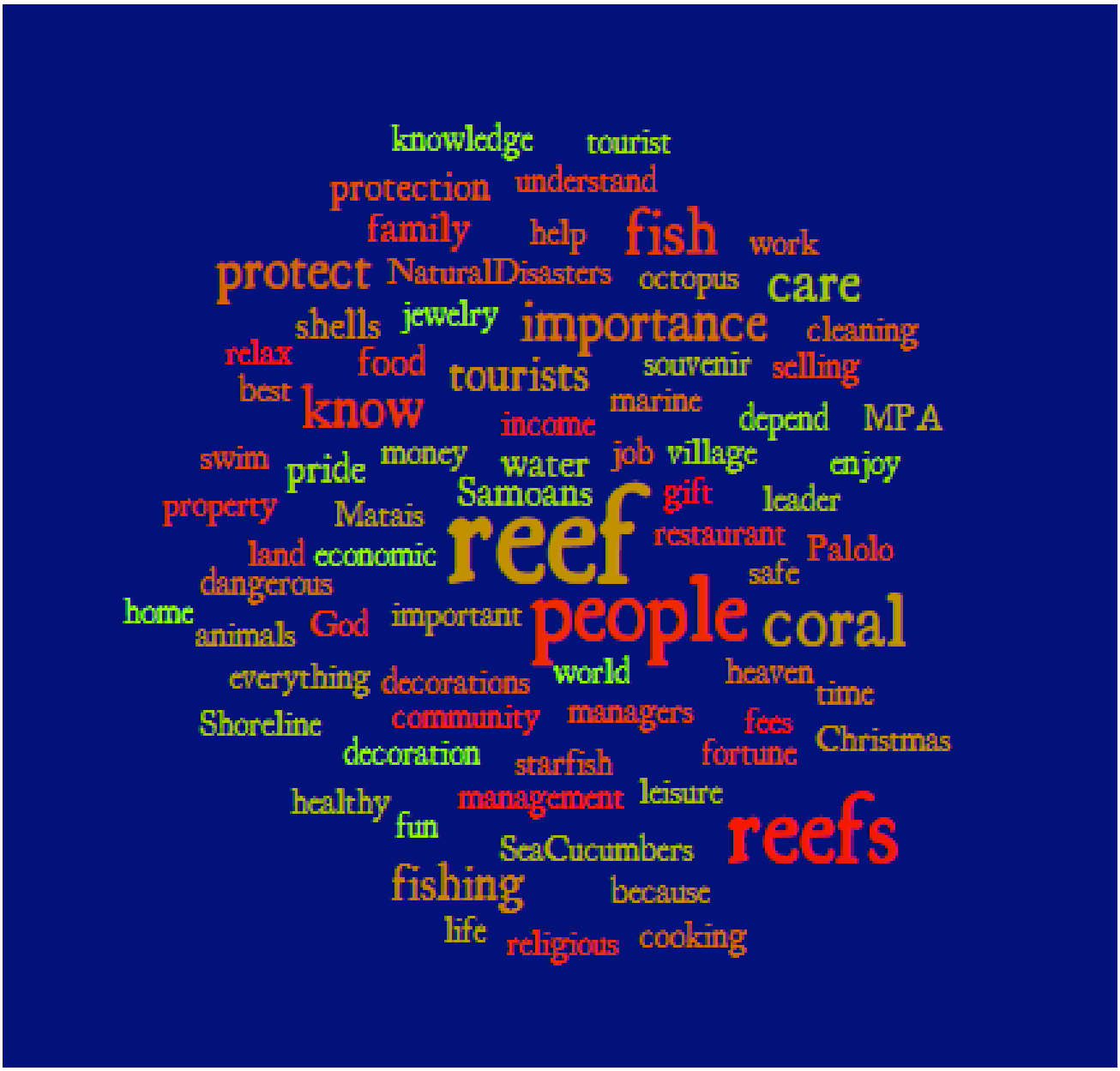
Completed with the advice of Dr. Patila Amosa



We are All Alive

Abstract

This work seeks to incorporate ecological research methods, socioeconomic data analysis, and local story collection into one understanding of coral reefs on the island of Upolu in Samoa. Data collection utilized transects and timed dives to assess four reef health indicators, and socio-economic indicators were sourced from the Samoa Bureau of Statistics. Interviews were also conducted to gain Samoan perspectives on the importance of coral reefs. Findings include patterns between the socioeconomic factors of population demographics, unemployment rates, education, and improved water, waste, and sanitation facilities and the environmental indicators of prevalence of plastic, percentage cover of living coral, parrotfish population size, and fish species richness. The ecological assessment showed that Palolo Deep was by far the healthiest reef. Interview responses indicate that Samoans care about coral reefs for a variety of reasons, which may be part of what makes certain reefs healthier, connecting people and reefs into one codependent system.

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Introduction and Background

Samoa is classified as being both highly dependent on reefs, and as a place where reefs are highly threatened; however, it is also identified as having a high adaptive capacity (Burke, Reytar, Spalding, & Perry, 2011, p. 22). Yet, there is very little academic work about how that "adaptive capacity" manifests itself in 2019 through comparative reef studies. This study seeks to fill that gap by connecting regional socioeconomic data, environmental reef assessment data, and local stories on the importance of coral reefs in Samoa.

The report *Revisiting Reefs at Risk* (2011) is one of the largest global reports to understand the connections between scientific data, economic activity, and the reality of the importance of reefs (Burke, Reytar, Spalding, & Perry, 2011). The project was able to create a global map of the world's reefs by threat level, as well as identify the four greatest local threats to reefs as coastal development, watershed-based pollution, marine-based pollution, and overfishing. In addition, the report identified the two greatest global threats as thermal stress and ocean acidification (Burke, Reytar, Spalding, & Perry, 2011, p. 16). These findings are corroborated by the Healthy Reefs for Healthy People project (McFeild & Kramer, 2007) and other studies which have demonstrated similar findings (Pendleton & Edwards, 2017). In recent years, special focus has been added to climate-driven stressors (Beyer, et al., 2018).

Previous work has also identified measures of the global reliance on reefs. Small island nations are the most reliant on coral reefs (Donner & Potere, 2007). Reliance on coral reefs takes many forms, from the 93 global countries that have economies that include reef tourism to the 150,000 km of global shoreline that is protected because of coral reefs. For many countries, their food security, exports, tourism, shoreline protection, and general livelihood are all dependent on coral reefs (Burke, Reytar, Spalding, & Perry, 2011, p. 21). This economic dependence is true for

some of the poorest people in the world, as 415 million people worldwide live in areas within 100 km of reefs with annual GDP per-capitas less than $5,000 USD (Donner & Potere, 2007). Many of these people live in the Pacific (Ibid).

Global studies lack consistency, and are actually pieced together regional studies which may imply homogeneity when none exists (Pendleton & Edwards, 2017, p. 13). Thus, regional and local studies may be able to provide a clearer understanding of the true biology and importance of coral reefs. In the Pacific region, coral reefs directly offer resources for food, medical products, industrial products, and leisure activities in addition to other indirect services, ecological values, and social values which create a pressure to protect them (Lal, 2005, p. 61). However, that does not mean that individuals voice these values in the same way (Lal, 2005, p. 63).

Pacific peoples have voiced concerns about reefs in a variety of ways. One theme is negative, that Marine Protective Areas sometimes represent a "livelihood failure" by severely limiting the resources available to indigenous communities in Palau and elsewhere (Lal, 2005, p. 66). This does not mean that Pacific Islanders don't believe in protecting reefs, as these concerns were voiced by islanders in many ways, including newspaper articles in Samoa (Maiava, 2018), Fiji (Ross, 2018), and Tahiti (Tahiti News, 2019) among other places. There is just a discrepancy between what is perceived as conducive to economic stability and what is conducive to reef management. An important piece of the solution to this problem may be in using indigenous terminology in place of "MPA", as was exhibited by the success of the Ra'uis of the Cook Islands (Hoffman, 2002, p. 401).

Since local management strategies are the political manifestation of the significance of reefs to people, it is important to consider the research that has been done on the effectiveness of these

strategies. This issue is often viewed through the lens of food security in the region. Pacific islanders rely on marine resources for the majority of their dietary protein (Bell, et al., 2009, p. 64). However, population growth, resource mismanagement, and climate change (the same issues driving coral reef degradation) has made this level of fish consumption likely to be impossible by 2035 (Bell, et al., 2015, p. 99). Other literature looks at the critical protection reefs provide for coastlines, and the social and economic importance of this ecosystem service to coastal-dwelling people (Wilson & Forsyth, 2018).

Limited research has been published in academic journals on the reefs within Samoa. Most recently, in 2016 during the Tara expedition, researchers found Samoan coral reefs to have low percentages of live coral cover, with a minimum of 1%, an average of 10%, and higher percentages present in select Marine Protected Areas (MPAs) (Ziegler, et al., 2018, p. 392). The same study also found that fish in Samoa are smaller than on neighboring islands. These are different results than the researchers expected, because most of the reefs are further removed from urban centers than is present on other islands (Ziegler, et al., 2018, p. 392). Other notable research that connects the reef to human activities includes a 1994 study by Zann which identified that Samoa's reefs are under more pressure than Fiji's or Tonga's reefs due to the relatively limited size of Samoa's coral reefs compared to its rapidly increasing population coupled with the large reliance of Samoa on subsistence activities (Zann, 1994, p. 52). More research has been done in the American Samoa, including work that contributed to the decision to monitor parrotfish populations in this study (Heenan & Williams, 2013). Nevertheless, the overall lack of publications on the coastal marine biology of Samoa is surprising, creating a unique space for this assessment.

Other work has been done within the MNRE and Fisheries on some of the sites studied. These include a 2007 study which deemed Palolo Deep to be 'healthy' (Ward, Asotasi, Penaia, Sooaemalelagi, & Ifopo, 2007, p. 8). At this time, 25.41% of the surveyed area contained live coral and 11.03% contained dead coral (Ward, Asotasi, Penaia, Sooaemalelagi, & Ifopo, 2007, p. 6). Amaile is part of the Aleipata district Marine Protected Area. As a whole, the reefs of Aleipata were considered "moderately healthy" (Satya M. , Ward, Kwan, & Fatima, 2015, p. 18). The villages of Aleipata also published a management plan which included coverage of many of the socioeconomic factors touched on in this project, including education (Villages of Aleipata, 2008, p. 14). Specific to Amaile within Aleipata, 35.92% of substrate cover was found to have living corals (Satya M. , Ward, Kwan, & Fatima, 2015, p. 14). The fisheries study on Savaia identified that much of the coral is alive, however bleaching and crown of thorns sea stars pose great threats (Tanielu E., 2017, p. 8).

Non-site specific work includes an evaluation by the MNRE in 2015 which determined that in Samoa the damage caused by the 2015 coral bleaching threat was low, however the damage caused by crown of thorns sea stars was high (Satya M. , Ward, Kwan, & Faitua, 2015, p. 10). The proposed solutions for the crown of thorns sea stars include removal by communities (Sataya, Junie, Kwan, & Jeffrey, 2016, p. 8). Other non-site-specific research includes work on Palolo abundance by fisheries (Tanielu, Palolo Rising Report, 2017). Palolo is an edible delicacy in the South Pacific; scientifically, it is the collected by-product during the spawning of marine annelids (Palolo worms) (Ibid, p. 2).

The department of fisheries has also produced a report on the importance of reefs to Samoan communities through fishing. The Samoa Socioeconomic Fisheries Survey Report (Titii, Sharp, & Ah-Leong, 2014) identified several relevant details:

- 79% of Samoans live within 1 km of the shoreline (Ibid, p.12).
- According to the most recent data (2009), 65% of fish caught were for in-home consumption. Only 3% of fish were sold; 32% were for mixed consumption and sales (Ibid, p. 16).
- 72% of fishing occurred in-shore (Ibid, p. 16).
- Both men and women perform fishing activities, and both focus on reef fishing. However, more men use boats for fishing activities (Ibid, p. 24).
- With regards to invertebrate fishing, women tend to target soft-bottom species and men tend to target species that require diving, boats or night collection (Ibid, p. 24).
- The average Samoan consumes 2.7 fish per week (Ibid, p. 25).

The following paper fills a gap in the available materials on Samoa's reefs. To the best knowledge of the researcher, no previous work has been done at the Aga Reef Resort. Also, to the best knowledge of the researcher, this is the first time that a transect-based study on plastic abundance on reefs has been conducted in Samoa. In addition, this is the first known completed reef assessment of Samoa of any variety in 2019, and offers an important update to other reports. Furthermore, this project adds to the growing yet limited knowledge base that connects people to coral reefs around the world, especially in the Pacific region.

Methods

Site selection

The four sites were selected according to the economic factors at play surrounding tourism and the subsistence economy in their respective areas. Palolo Deep was chosen as a location because of its location near Apia Harbor. Lefaga Bay (also called Savaia) was chosen for its community management principles which emphasize ecological well-being for the benefit of tourists (Lefaga bay was gifted giant clams by the Samoan government as a reward for their good management techniques). The Aga Reef Resort was chosen because it has had a luxury hotel built on top of the reef, creating a cove that is somewhat separate from the *moana* (ocean). Finally, the fish reserve at Amaile was chosen for its location in a traditional Samoan village largely engaged in subsistence food production. By selecting reefs that differed in this way, the reefs also differed according to other socio-economic factors and in the environmental factors. At all four sites, there was some form of protection whether this was put in place by the government or the resort.

Data Collection

Socio-economic data was compiled from the Samoa Socio-Economic Atlas of 2011 (Samoa Bureau of Statistics, 2011). The following variables were chosen as potential factors that may influence the way a region interacts with its local reef:

- Population
- Population density
- Population growth rate
- Percentage of population actively engaged in labor force participation
- Unemployment rate
- Secondary school attendance rate
- Post-secondary school attendance rate
- Percentage of the population with knowledge of traditional fishing
- Percentage of the population with Samoan citizenship
- Percentage of the population with improved drinking water
- Percentage of the population with improved sanitation
- Percentage of the population with improved waste disposal facilities

The coral reef assessment was conducted using different techniques compiled from recommendations made by the American Smithsonian (McFeild & Kramer, 2007), the Australian Institute for Marine Science (Hill & Wilkinson, 2004), researchers in the American Samoa (Heenan & Williams, 2013), and other scientific sources. These techniques were utilized together to create a simple scheme to evaluate a real threat to coral reefs through the plastic problem (Lamb, et al., 2018), a test of species richness to learn something of the biodiversity present on each reef (Knowlton, et al., 2010), and measures of population health for the keystone species groups of hermatypic corals (Hill & Wilkinson, 2004) and parrotfish (Heenan & Williams, 2013). This was done by first creating a grid over each reef with nine numbered sections. Then, five locations were selected randomly as sites to count the number of pieces of plastic, the

number of living coral heads and the number of dead coral heads along a ten meter transect at a depth of one to two meters. The apparent number of species of fish (species richness) at each of these sites observed within two minutes was also counted. Parrotfish population health was evaluated by randomly selecting an additional three sections of the reef to count the number of parrotfish visible within ten minutes. For further information, the reef assessment rubric is available in part (iii) of the Appendix.

Interviews were conducted by asking one local man and woman at each site a single question: "What does this reef mean to you?". From there, the conversation was allowed to flow naturally on the subject of the local reefs, allowing points of interest to arise according their importance to the correspondent. Interviews were also conducted with experts from the Samoa Ministry of Natural Resources and Environment (MNRE) and the Department of Fisheries to further frame the local knowledge and the patterns identified during the first stage of the project.

Ethics

No damage was done to any coral reefs or study participants. The utmost care was taken by the researcher to not crush or pull any coral in the field. Furthermore, oral consent was always recorded during all interviews, and participants had the full ability to deny participation. The anonymity of all participants will be preserved, as no names will be attached to any participants at any point in the study. The recorded interviews are password protected and will be deleted no later than two weeks after the conclusion of the study.

Statistical Analysis Techniques

The initial exploratory statistical method was to calculate Pearson's correlation coefficient for all pairs of socioeconomic indicators and reef health indicators. Then, a few composite variables were constructed for more holistic analysis of multiple factors. The formulas for these are below.

Reef Health Number = (# parrotfish* # species *(% living coral^2)) - (0.5*# plastic)

Formal education = secondary school attendance rate * % population with post-secondary education

Clean= % improved sanitation* % improved H2O * % improved waste

Single-variable regression models were also constructed for the most notable patterns, and tested for statistical significance using f-tests (for linear models) and t-tests/Akaike Information Criterion (AIC) values (for logistic and exponential models). In addition, analysis of variance (ANOVA) tests will be conducted to look for true differences between reef sites. All calculations were completed in R version 3.5.1 "Feather Spray".

Paradigm Statement

For comprehensive evaluation, the positivist paradigm was used to unite socioeconomic data, environmental data, and local voices into a single truth on the sustainability of coral reefs.

Results

The four environmental indicators were combined into the single variable “reef health”. As shown in Figure 1, Palolo Deep is significantly healthier than the other reefs.

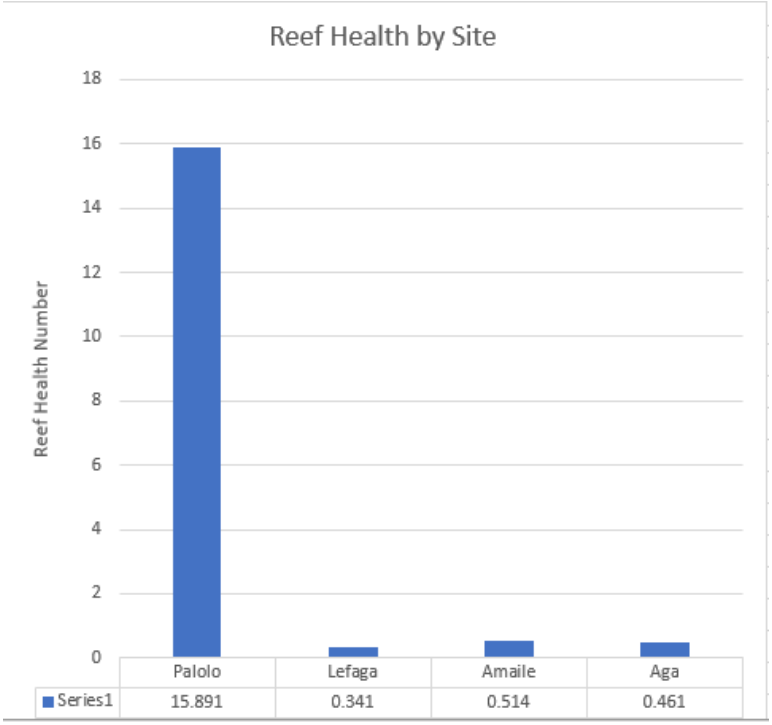

Figure 1: Reef Health by location name. Below the horizontal axis, the reef health numbers are also written below each site.

Pearson’s correlation coefficient calculations revealed many strong correlative patterns. High abundance of marine plastic was correlated with high population growth rates, high prevalence of traditional fishing knowledge, and high percentages of Samoan citizenship. High abundance of marine plastic was also correlated with areas with low population, low population density, low secondary and post-secondary participation rates, and low rates of improved water, sanitation, and waste disposal facilities. High percentages of living coral were correlated with large local populations, high rates of population density, and high rates of post-secondary participation as well as low population growth rates, low prevalence of traditional fishing knowledge, and low

percentages of Samoan citizenship. Larger parrotfish populations were correlated with improved water, sanitation, and waste disposal facilities as well as low unemployment rates. High species richness was correlated with high populations, high population density, and post-secondary school participation rates. High species richness was also correlated with low population growth rates, low prevalence of traditional fishing knowledge, and low percentages of Samoan citizenship.

Table 1: Pearson's Correlation Coefficients (r) for strength of relationship between socioeconomic indicators (left) and reef health indicators (top). Strong correlations ($|r| < 0.69$) are bolded for easy comprehension. "Species" refers to species richness, the observed number of species of fish.

	plastic	% living coral	parrotfish	species
total population	**-0.78**	**0.81**	0.43	**0.77**
population growth rate	**0.93**	**-0.81**	-0.40	**-0.79**
population density	**-0.81**	**0.90**	0.27	**0.89**
% labor participation	-0.59	0.48	0.65	0.43
% unemployed	0.03	0.53	**-0.78**	0.58
Secondary School Attendance rate	**-0.99**	0.51	0.57	0.50
Post-secondary School participation	**-0.94**	**0.79**	0.44	**0.77**
Prevalence of Traditional Fishing knowledge	**0.93**	**-0.80**	-0.43	**-0.78**
% Samoan citizen	**0.92**	**-0.75**	-0.52	**-0.72**
% improved water	**-0.90**	0.16	**0.70**	0.15
% improved sanitation	**-0.87**	0.05	**0.86**	0.02
% improved waste disposal	**-0.79**	0.28	**0.89**	0.23

In further analysis, some of these correlations were found to be mostly due to the statistical anomaly of Apia as a city where Palolo Deep (with its significantly healthier reef) is located. For example, there was no apparent pattern in the rest of the Samoan citizenship data, but the relatively lower percentage of citizens in Apia combined with the unusually good health of

Palolo Deep created the high correlations (Table 1). This was also true about the prevalence of traditional Samoan fishing knowledge. Some of these factors may reveal patterns if the data set were larger to better combat outlier effects.

However, some notable patterns were observed for different categories of socioeconomic indicators. These are detailed below.

Population Demographics

No notable patterns were identified for any kind of composite population variable on either the individual reef health indicators or the composite reef health indicator, because population growth rate often had an opposite effect on reef health as total population or population density. However, the data did suggest that the prevalence of reef plastic increased as the population growth rate increased (figure 2). The percentage of living coral and species richness also seem to increase as population density increased (figures 3 and 4).

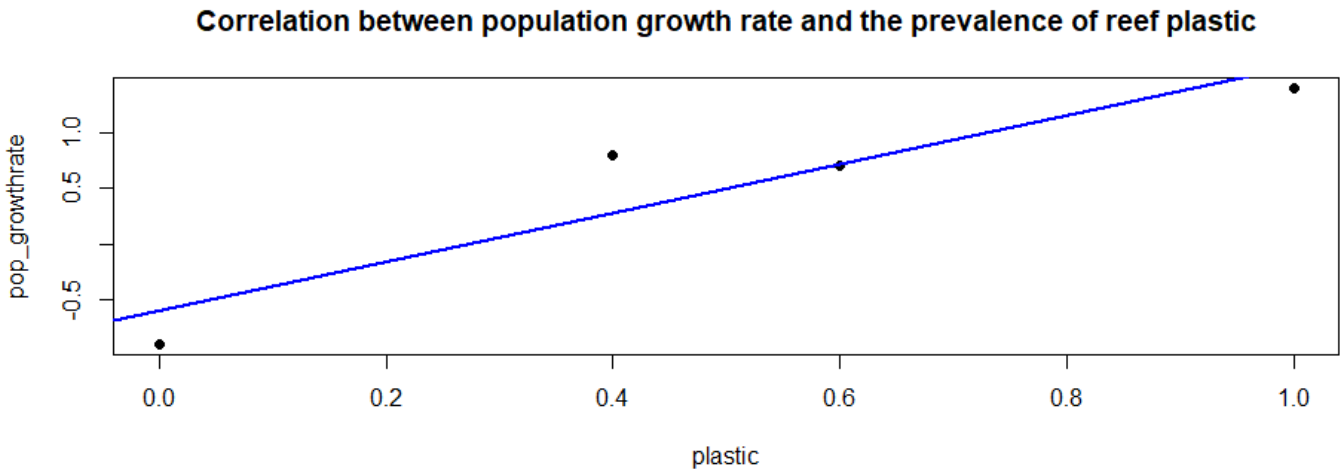

Figure 2. Simple regression model for the linear predictive ability of the variable population growth rate for the prevalence of plastic on coral reefs. With an f-statistic of 12.47 and a p-value of 0.072, this relationship is statistically significant at the less conservative $\alpha = 0.1$ level but not at the standard $\alpha = 0.05$ level.

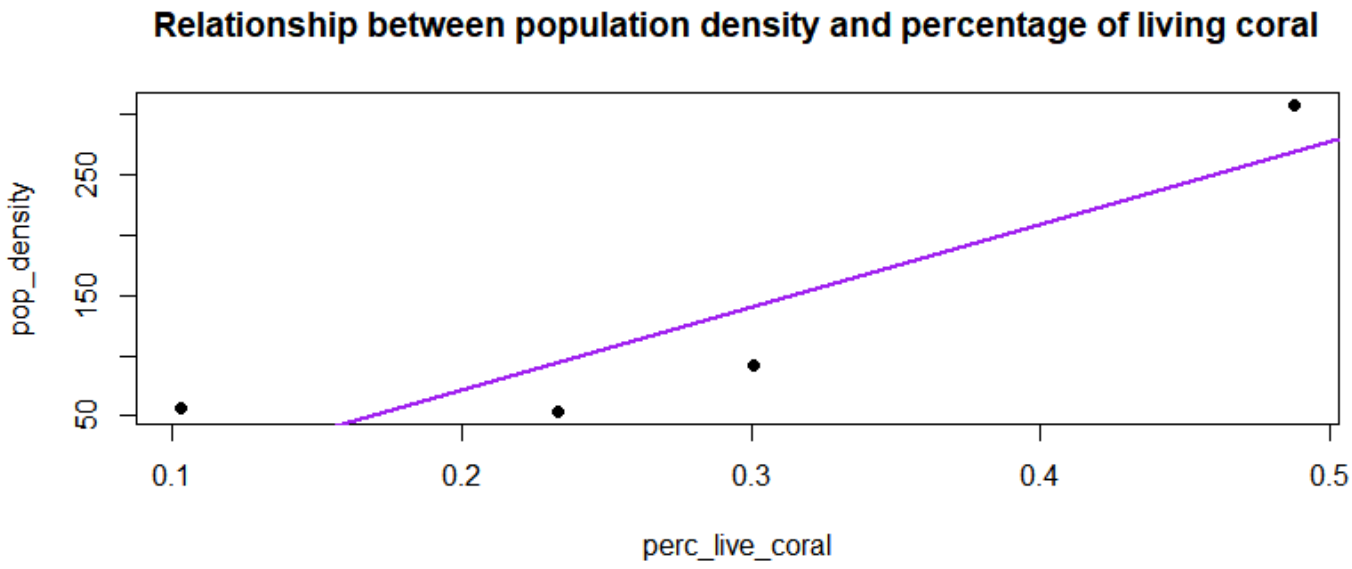

Figure 3. Simple regression model for the linear predictive ability of the variable population growth rate for the percentage of living coral. With an f-statistic of 8.59 and a p-value of 0.0959, this relationship is statistically significant at the less conservative $\alpha = 0.1$ level but not at the standard $\alpha = 0.05$ level.

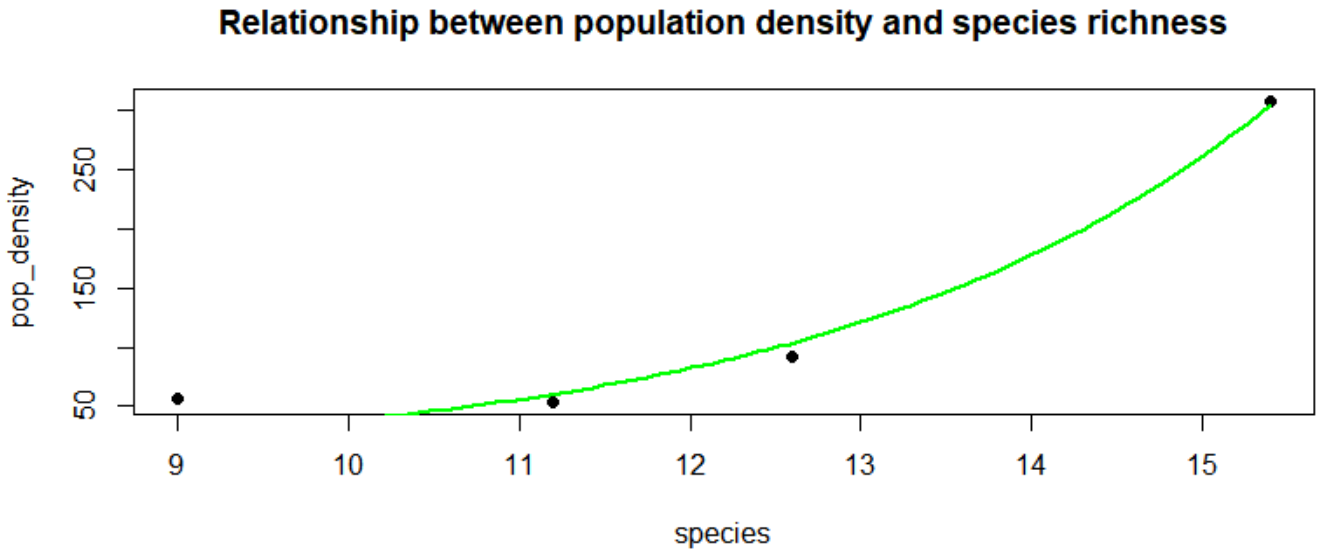

Figure 4. Simple regression model for the exponential predictive ability of the variable population growth rate for species richness. The AIC is 48.437, the t-statistic is 2.697 and the p-value is 0.114 which is not statistically significant at either the $\alpha = 0.1$ or $\alpha = 0.05$ level of significance. Nevertheless, the data suggest a clear pattern where denser populations are correlated with higher numbers of species that is moving towards statistical significance.

Unemployment

Only a single reef health indicator (parrotfish population) was strongly correlated with unemployment rates (Table 1). The data suggest that as unemployment decreases, parrotfish populations increase (Figure 5).

Figure 5. Simple regression model for the linear predictive ability of the percent of residents in each region that are unemployed for the abundance of parrotfish in that region. With an f-statistic of 3.156 and a p-value of 0.218, this pattern is not statistically significant at either the $\alpha = 0.1$ or $\alpha = 0.05$ level of significance. Nevertheless, the data suggest a clear pattern where higher unemployment rates are correlated with fewer parrotfish which is moving towards statistical significance.

Education

With two socioeconomic factors (secondary education attendance rate and post-secondary education participation rate) and three reef health indicators that were all strongly correlated (Table 1), the composite variable "formal education" was used to predict the composite variable "reef health". The data suggest that as the prevalence of formal education increases, reef health also increases (Figure 6).

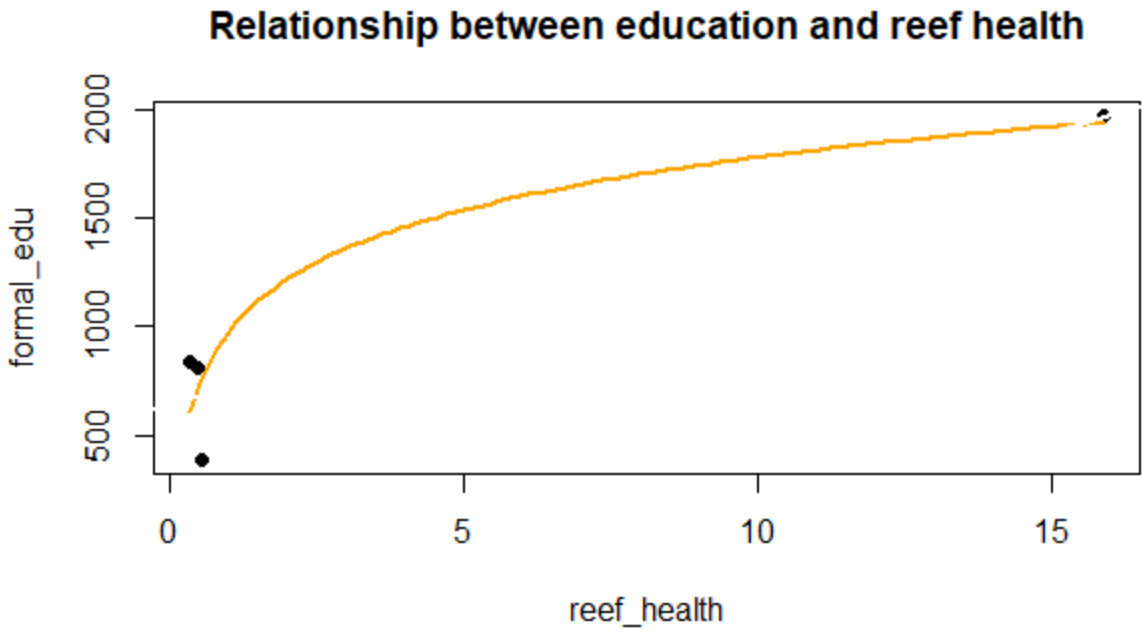

Figure 6. Simple logistic regression model for the logistic predictive ability of the variable formal education and reef health. With an AIC of 23.201, a t-value of 4.33 and a p-value of 0.049, this relationship is statistically significant at the standard $\alpha = 0.05$ level of significance.

Improved waste, water, and sanitation facilities

Because these factors are similar in nature, they were combined into the composite "clean". These variables were only strongly correlated with the factors of marine plastic abundance and improved waste disposal, and not the overall reef health or the other environmental indicators (Table 1). This composite clean demonstrated a clear negative trend with marine plastic abundance, however the single predictor "improved waste disposal" was a better predictor of parrotfish population data. The data suggest that in areas with lower quality waste, water, and sanitation facilities, there is more plastic on the reefs (Figure 7). The data also suggest that in areas with improved waste disposal there are larger parrotfish populations (Figure 8).

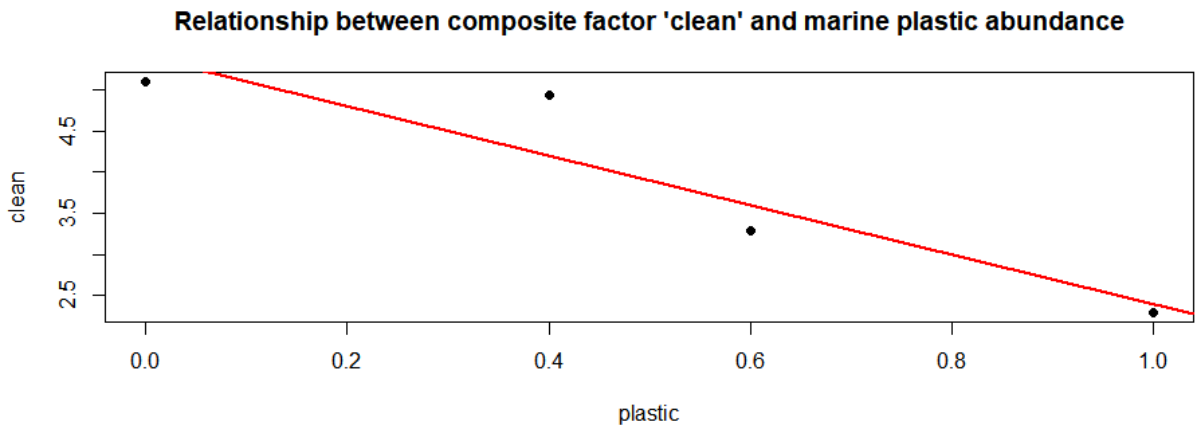

Figure 7. Simple regression model for the linear predictive ability of the composite "clean" for marine plastic abundance. With an f-statistic of 12.78 and a p-value of 0.070, this relationship is statistically significant at the less conservative $\alpha = 0.1$ level but not at the standard $\alpha = 0.05$ level.

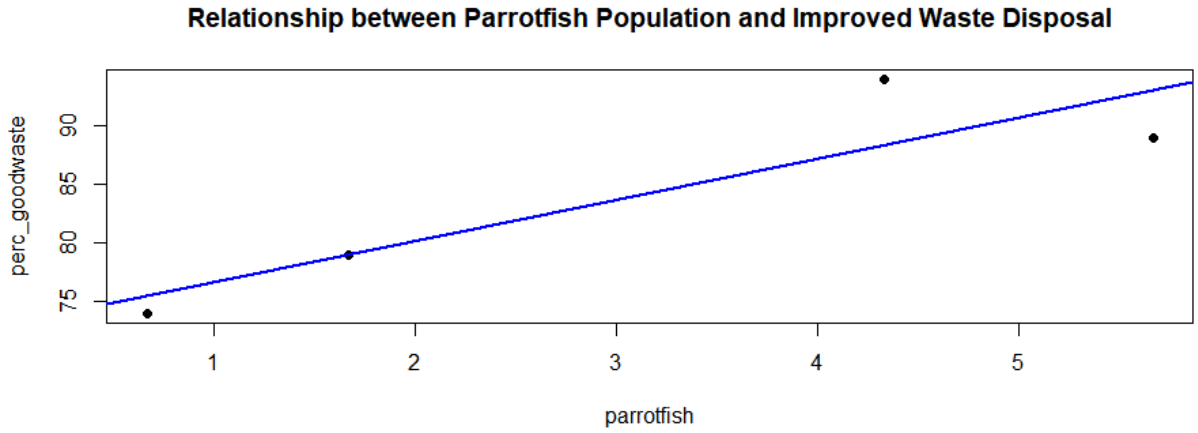

Figure 8. Simple regression model for the linear predictive ability of the variable improved waste disposal for parrotfish population. With an f-statistic of 7.909 and a t-statistic of 0.107, this relationship is not statistically significant at either the $\alpha = 0.1$ level or the $\alpha = 0.05$ level. However, the plot shows a clear positive trend that may be statistically significant if more data was available.

Other Statistical Results

In addition to the analysis of the relationship between socioeconomic factors and reef health indicators, one-way ANOVA tests were completed to look for true differences between site plastic, coral, and species richness indicators. No statistically significant difference ($p = 0.489$) was noted between sites for plastic, suggesting that perhaps in the future more transects should

be completed at each site to verify this variable. However, sites varied significantly in species richness ($p= 0.074$) at the less conservative $\alpha=0.1$ level of significance and for the percent of living coral ($p= 0.001$) at the standard $\alpha=0.05$ level of significance. Because all of these variables are continuous resulting in decreased potential differences between data, none were omitted. These differences between sites as distinct entities may have interesting implications for the type of site each data set was collected at. This information is summarized in Table 2 below.

Table 2. Summary of site-comparison data, with ANOVA. Data for "plastic", "% living coral", "parrotfish" and "species richness" all represent site averages.

	Plastic	% living coral	parrotfish	species richness	Economic Classification/Location
Palolo	0	0.488	4.333	15.4	located in the capital city (Apia)
Lefaga	0.4	0.103	5.67	9	located in an "ecotourism" area
Amaile	1	0.233	1.667	11.2	located in a traditional village
Aga	0.6	0.301	0.667	12.6	located within a luxury resort
	ANOVA	ANOVA	ANOVA	ANOVA	
	f= 0.846	f=9.41	f= 1.45	f= 2.80	
	df= 19	df= 19	df=11	df= 19	
	p= 0.489	p= 0.001	p= 0.299	p= 0.074	

Field Interview Results

Participants varied in association with the reef, location, and gender to compile a variety of perspectives. Professions included owners/managers of reef sites (2), an employee of a reef resort (1), an employee of a restaurant close to the reef (1), a guest (individual using reef shoreline for leisure time) (1), one *matai* (village chief) (1), and other local inhabitants of villages near reefs (2).

Some participants emphasized their knowledge of the reef. Quotations of this nature include "We swim in the water, we fish in the water, I know everything... I know which place is dangerous, which place is safe for people" from Palolo Deep. Another quotation was "protect the coral reef because they know, we all know" from Amaile.

At three sites (Palolo, Amaile, and Lefaga), participants vocalized something about family or community management of the reef. At Palolo, one man described to me killing the crown of thorns sea star because they do damage as "devils" to the reef; this, as well as general cleaning, is completed by the extended family. In Amaile, one village leader said that the Matais "protect and care the coral reef because… all the fish depend [on the coral reef]". The result of this "care" is that the reef in Amaile was the second healthiest reef in the study (Figure 1). In Lefaga, a young man also said that "we try to take care of it and protect it" (it being the MPA in Lefaga). Nothing to this nature was vocalized at Aga.

Both of the reef managers/owners vocalized a lot of pride in their reefs. One man said "This is the best place in the world"; he was very proud that people come all the way from Europe to his reef.

Participants also vocalized the economic importance of coral reefs. One woman emphasized this more than others. She said "all of the peoples are going and fishing", followed by a description of cooking fish. She described the importance of shells too, "selling for the people… like the shells to have a souvenir." Other people also discussed this theme, and reefs were also brought up as a place for food and "decoration" in Amaile by both participants there. This includes some people breaking coral off the reef to use for jewelry and Christmas decorations for both Samoans and tourists. Tourism was also referenced as a money-making property of reefs. One man referenced income from tourist fees saying "I'm going to make a fortune". Another woman referenced tourists coming from the reef to the restaurant she works at, but this answer was given in a sort of "brush off" way.

Two of the participants described some harmful fishing techniques (such as ripping up coral with a crowbar to get the fish) in the past tense, however, both of these women also made the

distinction that “they don’t do it for fun”, that the fishing is done for food. The same two people talked about other marine animals “like the octopus” or sea cucumbers as reasons to protect reefs.

Some themes only arose in one interview. For example, only one person vocalized a religious importance of reefs. This man vocalized that the reef was God’s gift to him, and it is his job to take care of it “before [he] goes to [his] father in heaven”. Shoreline protection was also brought up as a factor that make reefs important by only one woman. She vocalized frustration that this component is not discussed frequently enough, saying “We have the protection against natural disasters and stuff, but Samoans, they don’t seem to understand”. Another participant vocalized something about reefs as a place for leisure time. One man said “A land where people come to relax and enjoy”.

Many people also stated something about the general importance of reefs. These answers varied from coral reefs are “a home for fish” to “reefs help me”. One man even went so far as to answer “[this reef] is my life”.

MNRE Interview response

An employee of the marine sector of the Ministry of Natural Resources and Environment was able to provide many details about how current projects in Samoa are shaping the observed connections between people and reefs on Upolu. She discussed education, waste management, tourism, and community management amongst other topics.

She said that the MNRE has been able to incorporate ecology and other coursework about coral reefs into the local secondary education curriculum, but mainly for years 12 and 13. She also said that they had partnerships with the National University of Samoa. Not only the MNRE, but she

also knew that SPREP and various travelling research vessels have also partnered with local schools. These partnerships include classroom work and field work, even taking kids snorkeling so it is "not only the theory".

On the topic of waste management, she discussed the recent plastic ban and how it may help to keep plastics off of reefs in Samoa. She also said that the MNRE is working to evaluate the extent that microplastics are present in local fish through dissections of fish from the market. As an immediate fix to waste-related issues, the MNRE also does occasional reef clean-ups in partnership with the South Pacific Regional Environmental Programme (SPREP).

The MNRE perspective on tourism is mostly positive; "Ecotourism is one opportunity we look at when we promote these marine protected areas". They uphold Palolo Deep and Lefaga as areas that are doing this well, even better because it is a way that can help local communities. However, she does discuss the need for "rules" for the tourists, such as no stepping on the coral and no sunscreen. Yet, she does consider a sunscreen ban like that in Hawaii (State of Hawaii Department of Health, 2019) as too far in the future for Samoa.

This correspondent does feel that, on the whole, Samoans care about coral reefs. She notes that it is more common for villages or communities to come to the MNRE seeking to establish protections for their reefs rather than the other way around. If not the MNRE, then the United Nations Development Plan (UNDP), where many communities find funding to establish protected areas. "Lots of people they do get it… they require the sustainability of the coral reefs". The MNRE has observed that community management strategies are so successful because the *matais* enforce rules such as a ban on destructive fishing practices. Another key factor to reef health is management of crown of thorns sea stars. Communities that actively go and kill these sea stars, like Palolo Deep, are healthier.

In general, she feels that even in the face of climate change, socio-economic factors have "a really positive impact". She noted that communities with new MPAs have notable improved reef health, including coral recruitment. These are the resilience strategies, and where they are in place corals have better been able to come back from bleaching events and other seeming disasters. In fact, the MNRE has observed that the crown of thorns starfish has been the most destructive force which causes "irreparable damage"; yet this overpopulation problem can be managed by well-informed communities.

Fisheries Interview response

When asked about unemployment, the employee of fisheries referenced the 2013 study (Titii, Sharp, & Ah-Leong, 2014). While this report describes the extent that fishing provides employment in Samoa, it does not address the relationship between general unemployment and fishing.

The MNRE also tracks abundance of parrotfish and coral cover. Parrotfish are studied with other common fish groups by site; this is because there is a "scarcity" of parrotfish. Coral cover is identified because corals provide a home for fish, "the coral is more like a safe-guard on the fisheries side".

The Department of Fisheries feels that coral reefs are mainly important for "food" reasons. They reference that corals are important hiding places for the fish and invertebrates that people eat. They reference the Palolo as an important invertebrate that they monitor as a high-value delicacy collected from reefs. As "the high delicacy for 'our' people", it has even gained some religious importance as it is given as gifts on White Sunday as gifts to pastors and other religious leaders.

The Department of Fisheries also validated my findings from the other interviews; they feel that most Samoans really care about their coral reefs. “Instead of us enforcing it, they do care”, which the Fisheries Department observes through the use of fishing committees. More than 120 villages have entered into the fisheries management program, although not all of them are especially proactive about reef management. In some of these places, “it’s low abundance of corals because they don’t even care”, although for the most part “it all depends on the village” and some villages have good management strategies.

Discussion

The findings at Amaile and Palolo Deep have similar numbers for percentages of coral cover (Table 2) as the findings of the MNRE in 2015 (Satya M. , Ward, Kwan, & Fatima, 2015) and 2007 (Ward, Asotasi, Penaia, Sooaemalelagi, & Ifopo, 2007) respectively. The findings at Lefaga differ from those of the Fisheries 2017 report, however both of the threats listed in that report (coral bleaching and crown of thorns sea stars) (Tanielu, 2017, p. 9) were qualitatively observed during data collection, potentially attributing to the lower levels of living coral found in this study.

Looking at the data, the overall reef health is much better at Palolo Deep (Figure 1). Palolo Deep had the greatest average species richness and average percentage of living coral but the lowest prevalence of plastic (Table 2). The only reef health indicator that Palolo Deep was not ranked “best” in was parrotfish population (which was greatest at Lefaga) (Table 2). There are so many reasons that this could be (both scientific and anthropogenic) that it is out of the scope of this study to attempt to isolate them. However, some potential contributing factors are discussed below through the relationships between human activity and reefs.

Some of the patterns identified were expected. For example, it makes sense that areas with higher population growth rates and less improved waste, water, and sanitation facilities would have higher prevalence of reef plastic (Figures 2 and 7). Quickly increasing population coupled with poor facilities creates a waste management problem, meaning that more mismanaged waste is likely to reach the reefs. A relationship between poor waste management and smaller parrotfish populations was also identified (Figure 8). These types of environmental stressors (fast population growth and waste management problems) associated with coastal development are also documented as destructive to reefs all over the world (Richmond, Gulbuu, & Shelton, 2019, p. 445) and as a threat to island food security (Bell, et al., 2009, p. 99). However, successful community management has also been able to ameliorate some of these problems in the Pacific region (Richmond, Gulbuu, & Shelton, 2019, p. 445). Considering the interview responses that emphasize community involvement and a general sense of care for the reefs, it makes sense that some communities have more effective management strategies for these issues creating different levels of reef health.

Another logical pattern is the relationship between parrotfish and unemployment. Places with larger unemployment rates have smaller parrotfish populations (Figure 5). The Samoa Bureau of Statistics defines the unemployment rate as the number of persons aged 15 or older who are actively participating in the job application process (Samoa Bureau of Statisitics, 2011, p. 19). Individuals who cannot find work are likely to participate in the subsistence economy of Samoa, which means more fishermen at sea. Because parrotfish are some of the larger fish found close to shore, they are a target species (Belwood, Hughes, & Hoey, 2006, p. 2434), likely reducing the parrotfish population. This is a problem that should be addressed, because parrotfish have been identified to drive reef recovery and resilience through multiple studies around the world (Brock,

1979; Belwood, Hughes, & Hoey, 2006; Heenan & Williams, 2013; Cramer, O'Dea, Clark, & Norris, 2017).

The most statistically significant relationship is the connection between formal education and reef health. The data suggest that as formal education increases, reef health also increases according to a logarithmic trend (Figure 6). After learning about all the work the MNRE (among other organizations) is doing with secondary school students in the last two years and university students, it makes sense that where more individuals complete their formal education there are healthier reefs. When considered with some of the interview responses about the (few) communities that are enrolled in the Fisheries program, but not actively managing the reef and the lack of knowledge on the coastal protection provided by reefs, these results become even more crucial. Even so, the identified positive relationship implies that these education programs are effective, and that programs that increase the percentage of the population that is formally educated at higher levels would also help coral reefs.

However, the patterns identified concerning regional population density are not intuitive. Figure 3 demonstrates that as population density increases, the data suggest that the percentage of living coral also increases. In addition, figure 4 demonstrates that as population density increases the species richness also increases according to a linear trend. This does not make sense, unless one considers the interview-collected data. The common theme that arose across all interviews is that Samoans care about their local reefs because they provide vital ecosystem services. The MNRE even said that communities usually come to the ministry seeking protection rather than the other way around. Thus, it may be hypothesized (but not proven) that in Samoa, more people in a given area may create a greater pressure to protect the local reef, resulting in earlier creation of

protections. Further analysis of this trend over many sites is needed to support this hypothesis, however data on when each reef established protections was compiled in Figure 9.

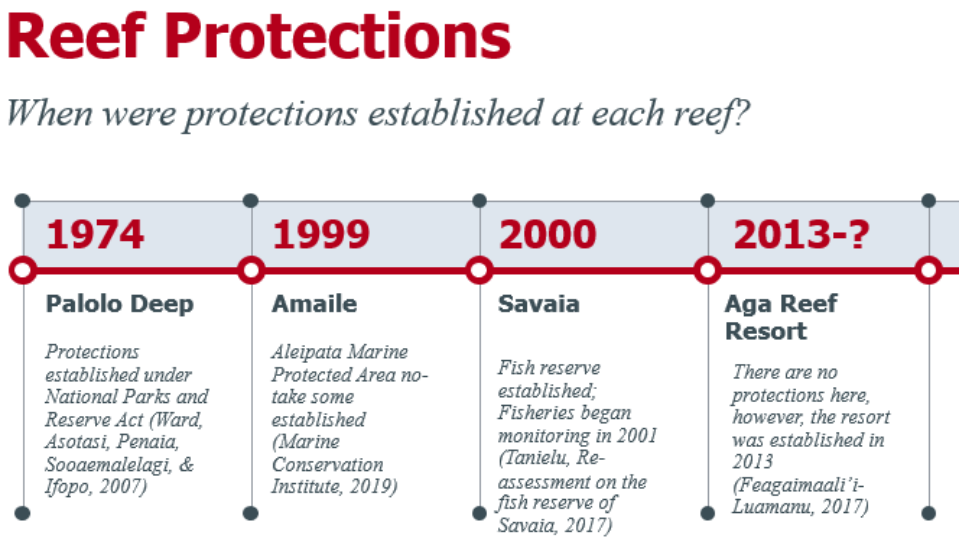

Figure 9. Timeline of when protections were established.

The variability between sites was statistically significant at some level for both the coral and species richness indicators (Table 2). While any number of factors could have contributed to this variability (including some of the socio-economic factors discussed above), it is also important to remember that the four sites were chosen as places with different relationships to the tourism and fishing sectors, which may account for some of the variation. Unfortunately, due to time restraints, the study could not be replicated at other sites that show similar types of economic development to expand upon these results and be able to isolate some of these "big picture" factors. However, when situated within the perspective of the MNRE, these patterns become more meaningful as the ministry believes that tourism offers an alternative to destructive fishing practices.

This study also has preliminary findings to suggest that there is a need to not only connect people to coral reefs, but also to connect religion to coral reefs. It is interesting that duty to God was raised as a reason why reefs are important during the field interviews and that the Department of Fisheries mentioned that Palolo (the delicacy) is assuming religious connotations. Arguably, the data available on Palolo populations is one of the most thorough and continuous bodies of research available on Marine resources in Samoa. If this is tied to the omnipotence of Christianity in Samoa, then the questions of how religion is currently and could possibly be tied to marine conservation should be examined in order to foster understanding of current and possible coral reef conservation projects.

In the context of the resources identified during the literature review stage of this project on the perceptions of MPAs in the Pacific, these interview responses were somewhat unexpected. The literature suggests that coral reefs and MPAs represent a livelihood failure (Lal, 2005, p. 66) especially when indigenous terminology is not incorporated (Hoffman, 2002) generating negative connotations. However, this study supports that Samoans view coral reefs in a positive way (as opposed to the lukewarm opposition suggested by various researchers). In Samoa, not only did all interviewed parties voice that coral reefs are important to them in some way or another, but both the MNRE and Fisheries suggested that communities usually lead in the creation of protected areas. While Fisheries may have said that some communities "don't care", the vast majority do. This discrepancy may be due to the need for a larger sample size or updated scholarship, however since all the MPAs of this study were already established and community-led by the end of the 20th century (Figure 9), the latter does not seem like a complete argument. Instead, the research suggests that Samoans really do care, and the success of MPAs here is explained by a positive local attitude and good community management that utilizes the

indigenous *matai* framework rather than top-down environmental agencies. Where this approach is a successful exception in the Cook Islands (Ibid), it seems to just be how Samoan reef protection operates.

Recommendations

This was a pilot study more than it was anything else. The research examined at a broad range of variables and identified the significant patterns that warrant further study. There were not enough controlled variables, nor enough sites studied. The design itself should also have more repetitions of the plastic and parrotfish environmental indicators at each site as established by the ANOVA results (Table 2). Any of the following would be a strong compliment to the study, although the possibilities are abundant considering the relatively limited amount of work done on Samoa's reefs.

For further research:

- A water chemistry study, to examine if dissolved CO_2, salinity, and temperature varies between sites explaining some of the variation not explained by socioeconomic factors.
- A water chemistry study looking for pollutants originating from sunscreens combined with a community management strategy analysis of the effectiveness of tourism-related damage.
- A study with three repetitions of each type of economic development (urban, traditional village, luxury tourism, ecotourism). This would help identify if these categories themselves create different reef health qualities, and would generate more data for the other socioeconomic indicators
- Instead of simply identifying coral as "alive" or "dead", a future study could break each coral transect into "alive" and "dead" by categorizing the apparent cause of death as algal overgrowth, coral bleaching, coral over-predation, coral disease, or other cause of death.
- Interviews that focus on each of the individual socio-economic indicators and/or religious significance in each area could be conducted to further explain the nuances of these trends.

Conclusion

By combining methodologies from different disciplines, new truths can be revealed. Reefs on the island of Upolu that differ in environmental health, and human activity may explain part of this variation. Some coral reefs on Upolu are healthier than others, with less plastic, more living coral, more fish, and more biodiversity. This study suggests that these attributes may be related as a unit or individually to population demographics, regional unemployment, education and improved facilities. These sites also differed significantly with regards to coral cover and species richness, which may have something to do with the type of economic development at each site.

With climate change as an ever-present threat, understanding which socioeconomic factors positively influence reef health through scientific verification is critical. Together with assessments of the general local attitudes towards coral reefs, this type of knowledge generation is necessary to inform community management strategies. These management strategies can sustain reef health and reefs can sustain people through ecosystem services; in Samoa, these systems are not separate. We are all alive.

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Appendix

i. Raw Environmental data (all socio-economic data can be found in the *2011 Samoa Socioeconomic Atlas*)

Table 3; all trials of data collected for number of pieces of plastic per 10 M, number of living parrotfishes observed within 10 minutes, % of living coral per 10 M transect, and number of species of fish observed within 2 minutes.

Plastics	parrotfish	% living coral	species	site
0	1	0.5	21	Palolo
0	8	0.44	15	Palolo
0	4	0.61	12	Palolo
0	[redacted]	0.63	12	Palolo
0	[redacted]	0.42	17	Palolo
0	0	0.13	12	Aga
2	0	0.17	18	Aga
1	2	0.35	12	Aga
0	[redacted]	0.56	10	Aga
0	[redacted]	0.3	11	Aga
0	12	0.31	6	Lefaga
1	3	0.05	4	Lefaga
1	2	0.11	11	Lefaga
0	[redacted]	0.03	10	Lefaga
0	[redacted]	0	14	Lefaga
1	2	0.19	12	Amaile
0	1	0.39	8	Amaile
4	2	0.07	8	Amaile
0	[redacted]	0.25	16	Amaile
0	[redacted]	0.27	12	Amaile

ii. Interview Questions

a) Field interview questions

"Why is this reef important to you?"

b) MNRE interview questions

"Do you know of any previous work done at Palolo Deep, Lefaga, Aga, or Amaile?"

"One of the trends identified in this study was a connection between formal education and reef health. Do you have any education programs in place that may help explain this pattern?"

"Do you know of any programs aimed at keeping plastic off of coral reefs?"

"What is the MNRE perspective on tourism?"

"Do you feel that Samoans care about coral reefs?"

"What do you think about the trend identified in this study between population density and coral reef health?"

"In the face of climate change, to what extent do you feel socioeconomic factors matter regarding reef health?"

c) Fisheries interview questions

"This study identified a pattern between unemployment and reduced fish populations. Have you noticed a trend in Samoa between unemployment and overfishing?"

"What resources do you have on parrotfish fishing in Samoa?"

"I heard that you manage the protected area in Lefaga/Savaia. Do you have any resources on that area?"

"What is the perspective on the ways that people and coral reefs are connected in the department of fisheries?"

"In your opinion, do most Samoan people care about coral reefs?"

"Do you have any other resources for me?"

iii. Reef Assessment Rubric

Site: _____

Indicators of Environmental Degradation

Number of pieces of plastic per 10 M transect

Average: _____

Number of dead coral heads per 10 M transect/number of healthy coral heads

Average: _____

Indicators of Environmental Health

Number of Parrotfish observed during 30-minute dive

Average: _____

Additional Notes about the size of the parrotfish _____

Total Number of species of fish observed during 5 minute dive

Average: _____