LONG-TERM IMPLICATIONS OF CORAL USE IN THE CONSTRUCTION OF ROYAL COASTAL MARAE ON MOOREA, FRENCH POLYNESIA

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Abstract. Early Polynesians created monumental structures called *marae*, using coral as a major element in the construction of the *ahu*. This study will analyze the relative frequency of coral genera found in the *ahu* of three different royal coastal *marae* sites on Mo'orea and evaluate its correspondence to the composition of adjacent coral communities. Volumetric measurements of the *ahu* and its constituent coral genera composition were calculated. Transects were performed in both the fringing and barrier reefs surrounding the *marae* sites in order to record size and frequency of the coral genera present there. Some *marae* site survey results revealed a strong correlation between the usage of coral as a major element of construction in *marae*, and modern coral genera distribution and abundance in the surrounding fringing reef. The barrier reef environment suffered minimal impact resulting from *marae* construction. When all coral genera were combined, there was a significant difference in coral composition between *marae* site reefs and control site reefs. Additionally, coral measurements revealed a positive correlation of increased coral diameter with increased distance from shore. Using coral head size as a proxy for age, the presence of younger coral communities closer to shore may be the long-term result of older, larger corals being collected nearer to shore for use in the constructing of *marae*.

Key words: marae; ahu; coral; Pocillopora; Acropora, Porites; Mo'orea; French Polynesia

INTRODUCTION

The Society Islands possess a rich cultural history, illustrated by earliest European depictions from the late 18th century, and a vast collection of archaeological findings (Hooper, 2006). These materials have allowed modern historians and archaeologists to envision the fundamental components of Polynesian life ways in antiquity. Much of this work has been conducted on the island of Mo'orea. There, the territorial base of political and social units was geographically stratified. The commoners, or *manahune*, occupied the interior valley areas while the upper class, or *ari'i* consisting of political and religious figureheads, exclusively inhabited the coastal lowlands. In addition to supporting the elite members of society, coastal zones also contained important architectural structures, called *marae*. *Marae* are the major stone remains in the Society Islands and have been investigated by archaeologists for 80 years (Emory, 1933; Wallin, 2004). Chiefs were the proprietors of the royal *marae* where many life rite, sacrificial, and religious rituals were carried out. (Sahlins, 1958).

The *marae* of the Leeward Islands are megalithic, composed of large cut-and-dressed blocks. In contrast, the more

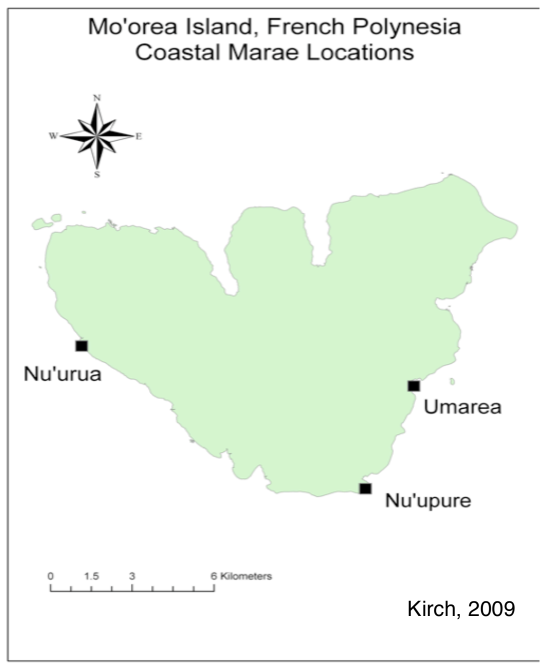


FIG. 1. Study sites where *marae* surveys and coral reef transects were performed. Each plot on the map represents the location of both a *marae* and control site, situated opposite each other on two points at the mouth of a bay, at each of the three sites.

architecturally sophisticated *marae* found on the Windward Islands, such as Mo'orea, are composed of many small stones and corals that were individually shaped by experts (Goldman, 1970). Recent Uranium dating put the final construction phases of these *marae* in the range from A.D. 1740-1760 (P. V. Kirch, pers. comm., Dec. 12, 2009). Typically, a stonewall lined the perimeter of the *marae* court. The focal substructure of the *marae* court is the *ahu*, a large platform-like altar. The *ahu* is the area of interest for this research, as it is composed largely of coral in royal coastal *marae*. The steps of the *ahu* are representative of the societal hierarchy. The largest *marae* recorded was on the island of Tahiti. The *ahu* base measured 81 by 22 meters, and the height, consisting of ten steps, was between 13.5 and 15.5 meters. Unfortunately, like many other *marae* in the Societies, this remarkable structure did not survive the arrival of Christian missionaries, who sought to destroy these monumental symbols of Polynesian culture and religion (Bellwood, 1987). However, several royal coastal *marae* still survive around the perimeter of Mo'orea, today.

Although Polynesian prehistory has been studied and reconstructed through archaeological remains for decades, only recently have scientists begun to utilize archaeology as a discipline through which to better understand the co-evolution of man and environment. "Polynesian culture is largely reef-oriented in terms of knowledge, traditions and resources. Nowhere are culture and nature considering coral reefs so intimately associated" (Di Castri and Belaji, 2002). As an integral aspect of Polynesian life, the ocean and its natural resources have been strained by human exploitation for centuries. The royal coastal *marae* of Mo'orea are a prime example of this relationship. These prodigious structures were built chiefly from coral heads collected from the island's reef complexes. Additionally, on a smaller scale, coral was extracted for use in the construction of domestic settlements, to create curbing and elevated floors (Handy, 1932). Coral was not only used as a functional building material, but also as a secondary element in Polynesian artwork, such as sculpture (Barrow, 1973).

Mo'orea's encircling reefs, from which a large volume of corals were collected, support a diverse population of marine organisms. Corals are the foundation of these communities and promote the biodiversity of their dependant inhabitants. However, these calcareous living structures are relatively fragile, require specific environmental conditions for survival, and are restricted by extremely slow growth rates. At maximum output, a square meter of coral can only calcify up to 10kg of carbonate per year, dependant on environmental conditions and species (Dicastri, *et al*, 2002). Due to these life history characteristics, coral reefs are a highly vulnerable ecosystem. Such severe anthropogenic disturbances to a coral community may lead to long term or permanent damage (Berumen and Pratchett, 2006).

In this study, I analyzed the relative frequency of coral genera found in *ahu* and evaluated its correspondence to the generic-level composition of adjacent coral communities. These data were used to determine whether the usage of coral as a major element of *ahu* construction, had a long-term effect on contemporary coral distribution and abundance in the adjacent reef. This study seeks to test for a discernable correlation between coral population and the presence of a *marae* site. By analyzing historical marine communities through material culture, we can improve our understanding of contemporary environmental conditions and the extent to which indigenous populations have influenced them (Hooper, 2006). This will allow us to better develop precautionary measures to conserve and protect coral reefs worldwide, by being able to predict the long-term implications of anthropogenic influence.

METHODS

Study site

This study was conducted at three separate *marae* sites located on the East, South-East, and West coasts of the island of Mo'orea. Mo'orea is part of the Society Island Archipelago, in French Polynesia, located at 17° 52' S latitude, 149° 56' W longitude. Sites were selected on the basis of their close proximity to shore and use of coral as a major building component in the construction of the *ahu*. All sites were situated on points at the mouth of a bay. The opposite point was selected as the control site. A stream providing freshwater influx bisects each bay. All control and *marae* site reefs possess similar geomorphology and oceanographic characteristics. The analysis of reef composition was performed on adjacent fringing reefs, as well as barrier reefs located directly across the channel from the *marae* and control sites.

Terrestrial Survey Techniques

Determination of *ahu* composition was estimated by performing five randomly placed transects across the structure. Each transect spanned the width of the *ahu*. Once the transect line was laid, the genera and diameter of coral heads that it intersected were recorded. Identification of coral genera from aged, eroded coral rubble with no living tissue found in the *ahu* was achieved by comparing size, shape, and micro pore structure to modern taxonomic references and living type specimens. Location of individual coral heads in the *ahu* was also taken by recording the meter mark at which it was found, in effort to determine a composition differentiation across the marae width.

The total volume of each *ahu* was calculated by referencing Emory's illustrations labeled with dimensions from 1933, when the *ahus* were somewhat closer to the form that was created in antiquity. Umarea site 92 exhibited an atypical two-tiered *ahu* with an off-centered second tier. The volume of the base was calculated, excluding areas of the property where fallen rubble had been accumulated into piles by modern anthropogenic influence. The original length of the *ahu* was distinguished from fallen rubble, by large cut-and-dressed coral blocks serving as markers of *ahu* corners. The top tier was excluded from the volume calculation, as it was composed entirely of basalt. At Nuupure site 91, I was provided a description of the number of steps by Emory, and sequentially subtracted two meters from the length and width of each step, assuming that each step was one meter wide. The volumes of the four individual tiers were calculated and added together to find the total *ahu* volume. Where the *ahu* was reduced to a shapeless mound, as in the case of Nuurua site 82, I used Emory's provided dimensions to approximate the volume with the formula for a trapezoidal prism.

The intended purpose of volumetric *ahu* measurements was to estimate the volume of each material used in the ahu. Furthermore, a volume of each individual coral genus composition in the *ahu* was determined from these data by establishing a ratio of percent composition of each genera recorded in *ahu* transects, to total volume of the *ahu*. This enabled us to estimate an approximate volume of each genus harvested from the reef in the *ahu* construction process. The estimated volume for each genus was then compared to its frequencies in the correlating fringing and barrier reef complexes do determine level of long-term impact.

Marine Survey Techniques

Three evenly spaced coral reef transects were performed on both the fringing and barrier reefs adjacent to the *marae* and paired control sites. Total coral abundance between the three study site reefs was compared using a one-way analysis of variance statistical test (ANOVA). The same test was similarly run three times comparing abundance of each of the three individual genera present at control site reefs and *marae* site reefs. Fringing reef transects extended the entire length of the fringing reef, from the shoreline to the lagoon channel. Barrier reef transects extended from the start of the back reef, to as far seaward as wave action permitted at each site, which was commonly around 15m. Abundance and genera of coral in study site reefs were quantified by recording all coral heads located within 1m to each side of the transect line. Genus, diameter, distance from shore, and health of corals were all recorded while swimming the length of the transect. After graphing the abundance of each coral genera found at control site reefs and *marae* site reefs, visually apparent trends in individual genera distribution were further investigated by one-way analysis of variance (ANOVA) testing, to determine statistical significance. Using size as a proxy for age, coral heads less than 20cm in diameter were excluded from the survey on the basis that they were too young to be relevant in this study concerning coral from approximately two centuries ago. With all coral data combined within each study site, a χ^2 test was performed comparing the coral genera present between control and *marae* site reefs. An analysis of co-variation (ANCOVA) statistical test was run for the effect of site, *marae* reef or control reef, on coral diameter, with distance from shore as a covariate.

RESULTS

Marae Composition

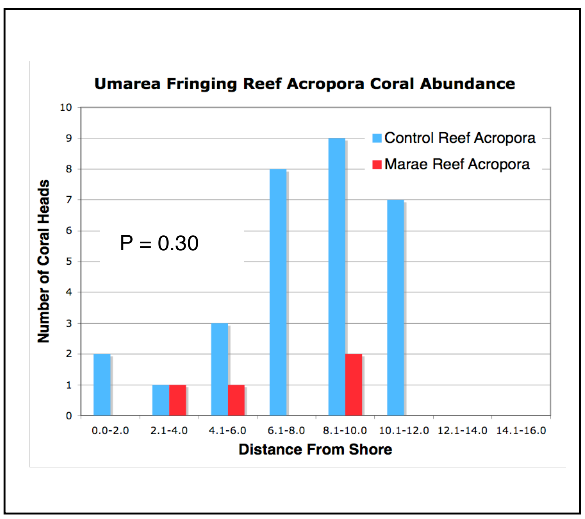
Study Site	**Porites**	**Acropora**	**Basalt**	**Other**
Umarea	15%	41%	24%	20%
Nuupure	86%	11%	3%	0%
Nuurua	61%	2%	17%	20%

TABLE 1. Percent composition of each material used in *ahu* specified by site.

Study Site	**Porites**	**Acropora**	**Basalt**	**Other**
Umarea	3,553 m^3	9,712 m^3	5,685 m^3	4,738 m^3
Nuupure	16,151 m^3	2,065 m^3	563 m^3	0 m^3
Nuurua	21,537 m^3	706 m^3	6,002 m^3	7,061 m^3

TABLE 2. Percent composition of each material present in the *ahu*, converted to volume.

Fringing Reef Composition



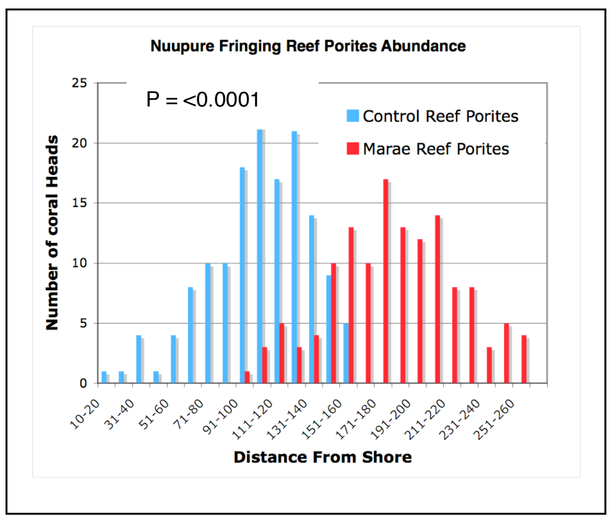


FIG. 2. The light blue bars (left) represent the abundance of coral genus Acropora with increasing distance from shore at the control fringing reef at Site 92, Umarea. The red bars (right) represent Acropora abundance at the *marae* fringing reef at site 92, Umarea.

FIG. 3. The light blue bars (left) represent the abundance of coral genus Porites at the control fringing reef Site 91, Nuupure, with increasing distance from shore. The red bars (right) represent Porites at the *marae* fringing reef Site 91, Nuupure, with increasing distance from shore.

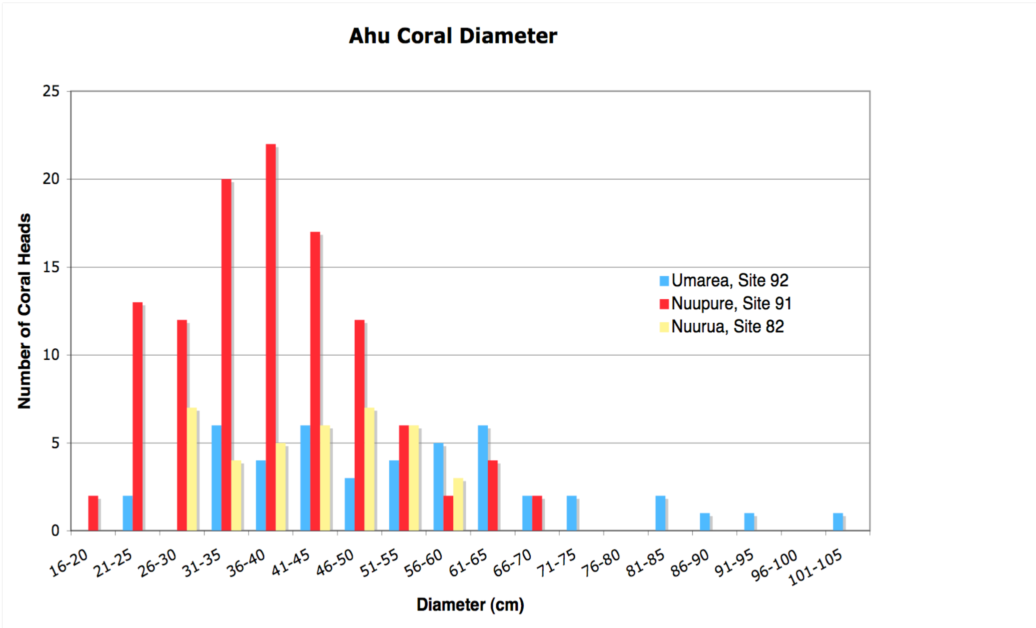


FIG. 4. Coral head diameters from the three, study site *ahus*. Blue (left) represents corals from Site 92, Umarea. Red (middle) represents corals from Site 91, Nuupure. Yellow (right) represents corals from site 82, Nuurua.

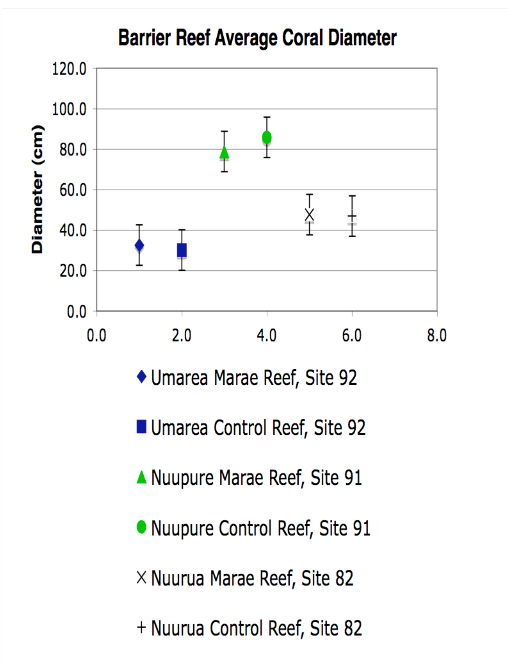


FIG. 5. Average coral head diameter from the control and *marae* barrier reefs at each site, with error bars indicating one standard deviation from the mean (±10).

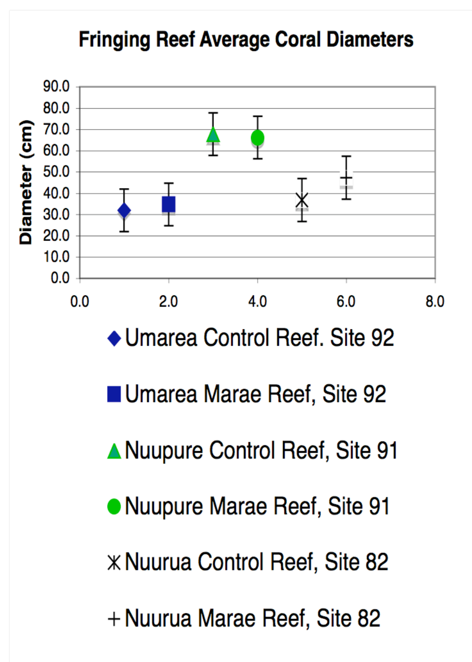


FIG. 6. Average coral head diameter from the control and *marae* fringing reefs at each site, with error bars indicating one standard deviation from the mean (±10).

Term	df	F	P
Control / Marae	1	26.79	0.057 *
Distance	1	1.90	< 0.0001 *
Interaction	1	9.07	< 0.0001 *

FIG. 7. One-way analysis of variance (ANOVA) between coral abundance at control and *marae* site reefs.

Site	df	F	P	n
Umarea Site 92	1	0.14	0.91	11
Nuupure Site 91	1	0.09	0.77	9
Nuurua Site 82	1	0.27	0.87	16

FIG. 8. Analysis of co-variation (ANCOVA) for the effect of study site on coral diameter with distance from shore as a covariate.

DISCUSSION

Ahu transects of all *marae* sites revealed the use of three major types of building materials. These materials included the two coral genera Porites and Acropora, as well as rock. The rock category is made up of both basalt (igneous rock) and beach rock (cemented calcium carbonate of coral skeletons). Variability of building material between *ahus* suggests that the early Polynesians who constructed these monuments were not intentionally selecting for specific coral genera, but were utilizing the resources available to them. Other than the possibility of basalt, which was intentionally carried from inland valleys to coastal zones for use in the construction of *ahu*, the randomness of *ahu* composition data within and between *maraes* does not suggest cultural or ritualistic preference of material (Emory, 1933).

However, considering all available coral genera found in the reefs surrounding Mo'orea, Acropora and Porites seem to posses certain characteristics that may have caused Polynesians to consider them ideal *ahu* building materials. For example, Acropora, at over 100, encompasses more species than any other coral genus. It is found in surface waters around the world, making it relatively abundant and accessible to primitive Polynesians, who would not have had access to deeper-living corals. Its porous skeleton grows in a tabular fashion, branched with lengthened tube-like corallites (Chesher and Faulkner, 1979).

Despite these morphological traits causing Acropora to be relatively fragile, it is also lightweight making for easier transportation from the reef to the *ahu* construction site. Its broad, flat shape is also conducive for stacking over wide surfaces. Porites is similarly easy to stack, especially in the micro-atoll form. All Porites species can be found in the Indo-Pacific, where its favored habitat is shallow waters. It too has a strong, lightweight, and porous skeleton. Like Acropora, these traits also make Porites a favored building material due to abundance, accessibility, and hardiness (Chesher and Faulkner, 1979).

Coral was the most abundant and widely used material in coastal *ahu*, but predominant genera varied slightly between *marae* sites. Acropora was the most prevalent genera used in the *ahu* at site 92, while porites made up the majority of the *ahu* at sites 91 and 82. The diameters of *ahu* coral heads varied greatly both within and between *marae* sites, ranging from 16 to 105 cm. Site 92 showed the greatest variation in coral diameter, using material of all sizes (FIG. 4). These results suggest that indigenous Polynesians were not selective towards size in the collection of coral for *ahu* construction, but rather used a wide variety of sizes that were available to them. The largest Porites coral heads were used to create the *ahu* foundation, while smaller or fragmented coral rubble pieces were used as mortar-like filler. Intact, stackable coral heads of the same size range and genera defined *ahu* terraces on the exterior. The largest of coral heads were cut-and-dressed into blocks in antiquity using an adze and chisel, and were used to delineate the face and corners of ahu steps (Barrow, 1973). Although basalt stones were similarly used, they were excluded from the diameter comparison, as this study is primarily concerned with the use of coral.

In total, Porites was the most abundant genera of coral used and was found in both spheroid and tire-like shapes. The latter is referred to as micro-atoll, and is formed as a result of shallow water growing conditions that restrict the coral's vertical growth. At both *marae* sites 91 and 82 the Porites micro-atoll corals used in the *ahu* were contingent with the surrounding shallow fringing reef conditions offshore, which would have produced coral heads of similar size and shape. The *ahu* coral composition data coupled with the absence of coral observed during these sites' fringing reef transects, suggests that environmental conditions were at one point extremely conducive to Porites micro-atoll growth. However, in the case of site 91, now only remnants of that potential past population remain. At site 82, even less Porites coral exists. Due to the presence of coral *maraes*, it is possible that these fringing reefs have been subject to a long history of anthropogenic impact, resulting in the ultimate desertification of coral in this area.

The *ahu* at site 92 was composed largely of Acropora coral heads. A relatively abundant level of coral exists at the fringing reef of both *marae* and control sites (TABLE 1.). Although coral abundance does not differ strongly between the two, there is a greater population of the genus Acropora at the control fringing reef than the *marae* fringing reef. This suggests that both sites possess similar growth potential for corals, and that the absence of Acropora, the major *ahu* element at site 92, is the result of the *marae* being built.

After analyzing the graphic representations of current coral distribution between the *marae* reef and the control reef for all three fringing reef sites, some trends in coral genera presence became apparent (FIG. 2 & 3). Presence of Porites coral heads between Site 91 control fringing reef and *marae* fringing reef was compared against distance from shore. There proved to be a strong statistical significance, with Porites being present at a greater distance from shore at the *marae* fringing reef than the control, where it occurred further inshore (FIG. 3.).The absence of any coral genera within the first 90m from the shoreline of *marae* site 91, suggests that the current coral scarcity is the long-term result of coral collection for *ahu* construction.

There was no decipherable difference between the Porites population at site 82 control and *marae* fringing reefs, due to lack of data at both sites. This, however, is perhaps more notable, as the Porites population was nearly non-existent at both *marae* and control fringing reefs there. As the most common component of site 82's grandiose *ahu*, it is possible that the lack of Porites in this area, and coral in general, can be attributed to its mass-harvesting for *ahu* construction. Due to increased convenience and accessibility, the corals closest to shore at the *marae* fringing reef would have been collected first and most heavily.

This hypothesis would provide a logical explanation as to the total absence of coral near to shore at the *marae* fringing reef, in contrast to the control fringing reef. Mass removal is a severe disturbance to coral communities and could lead to a long term or permanent structural shift. Shifts may be characterized as a transition in predominant organisms, for example; from hard scleractinian corals like Porites, to coralline algae (Berumen and Pratchett, 2006). Such is the case of the fringing reefs at site 82. Miniscule traces of Porites presence at site 82's fringing reef complex, is overshadowed by an incredible abundance of coralline algae, which has taken over this fringing reef habitat in the absence of coral. A phase shift like this, where stony corals are replaced by algae, can have severe implications for a reef community, because algae cannot fulfill the resource demands that coral can (McManus and Polsenburg, 2006).

When coral distribution data for site 92 fringing reef was displayed graphically, there appeared to be far greater abundance of Acropora at the control site reef than the *marae*. However, when this trend was further investigated by statistical testing, the difference in Acropora abundance between control and *marae* site fringing reefs was insignificant (FIG. 2.). In contrast to other fringing reefs, site 92 appeared to suffer minimal long-term damage as a result of coral use in the construction of the *ahu*.

Comparing the presence of the most abundant coral genera used in the *ahu*, at control and *marae* fringing reef locations, revealed varying outcomes. After testing for a statistical difference between presence of most abundant *ahu* coral genera at control and *marae* site reefs, only site 91 produced a statistically significant difference in the presence of Porites with distance from shore (ANOVA, F=35.95, P= <0.0001). However, when all coral genera data was combined within control and *marae* reefs across all study sites, there was a strong statistical difference between coral present at all *marae* fringing reefs locations and all control fringing reef locations (χ^2=21.1, df=1, P= <0.0001). The coral genus Pocillopora, however, was very rarely used in building *ahu*, which potentially contributed to it being the most prevalent coral in the surrounding reef complexes. They are also a hearty genus and are the most wide-spread reef-building coral. Pocillopora mostly inhabit shallow reef flats, with mild to considerable levels of wave action, much like the reef environments surveyed in this study.

In addition to assessing the presence and abundance of different coral genera, using size as a proxy for age can reveal valuable information on the population dynamics of corals (Adjeroud, *et al*, 2007). The effect of *marae* site reef versus control site reef on coral diameter, with distance from shore as a covariate was tested. Results revealed not only a significant difference of increased coral diameter at control sites (ANCOVA, F=26.79, P=0.057), but also increased coral diameter with an increasing distance from shore (ANCOVA, F=1.90, P=<0.0001). For example, barrier reef corals were much larger than those at the fringing reef. This is potentially an artifact of *marae* site fringing reef coral collection for *ahu* construction. This process would have removed the majority of coral heads, requiring total re-colonization of the fringing reef, causing the fringing reef to consist of younger, smaller corals, than the less effected barrier reef. This trend is also potentially due to environmental factors becuase the fringing and barrier reefs are two distinct habitats. All fringing reef sites were subject to freshwater influx from streams. This undoubtedly carried pollutants to the reef and caused a change in the salinity gradient. The presence of just one of these factors may have been enough to have had a detrimental influence on coral growth and survivorship in the adjacent reef. Corresponding with proximity to a freshwater source is sedimentation and alluvial deposition that can cause corals to be capped with detritus, similarly inhibiting their growth (Jones and Endean, 1973). It is possible that increased distance from the stream source, and therein the shore, could have allowed corals to achieve greater size.

Barrier reef coral composition showed no evidence of long-term impact from *marae* construction. There are two possible reasons for this, the first being that the barrier reef was simply able to recover more rapidly. The second being that due to increased difficulty in accessing and transporting coral from the barrier reef, it was not a collection site for coral. However, ancient Polynesians were experienced mariners skilled in the art of boat making. We know that they were capable of traveling extended periods of time through hundreds of miles of open-ocean to settle new territories (Sharp, 1964). Therefore, it is entirely possible that they utilized boats to travel the relatively short distance to the barrier reef to collect coral for *ahu* construction. Further investigation on the evolution and uses of ancient Polynesian vessels revealed the use two major types of outrigger canoes. The first was designed for efficient paddling and maneuverability in heavy seas, but was insufficient for shipping materials, as its carrying capacity was very small. The second model, sailing canoes, were unsuitable for carrying large loads of people or goods because of its tendency to overset with sudden wind changes (Sharp, 1964). Because of the outrigger's minimal stowage capabilities, the potential for use of boats in the job of transporting thousands of heavy coral heads was probably low.

CONCLUSIONS

Early European interpretations of the Societies describe the islands as bountiful, untouched paradises with replenish-able resources, but our historical records prove otherwise. We know that Polynesians have had a large and long-lasting impact on their island environment, through agricultural practices, and the introduction of non-native species. Until now there has been very little investigation about the possible affects of indigenous population on the marine environment (Hooper, 2006). Results from this study indicate that the fringing reef communities located near *marae* sites have undergone long-term compositional change in both abundance of coral and presence of popularly used coral genera. From coral diameters we can see that coral age increases with distance from shore. Although the coral reefs surrounding Mo'orea have historically experienced many other catastrophic events, such as severe weather, adverse environmental conditions, crown of thorns outbreaks, and mass bleaching events, it is not necessarily these natural processes that inflict long term or permanent damage. The lack of an environment's resilience to disturbances is most often attributed to anthropogenic influences. When unaffected by human impact, coral communities prove capable of recovery after withstanding acute natural disturbances (Berumen and Pratchett, 2006). It is the human exploitation of the reef ecosystem since the arrival of early Polynesians, to present, that is responsible for alterations to reef assemblages that are evident in these results. We have learned the unfortunate truth that human presence in nature can never go un-noticed, disproving the myth of a pristine environment. Every habitat on earth, both terrestrial and marine, is subject to anthropogenic influence, which may permanently alter it. Recently low coral recruitment rates and frequent reef perturbations indicate that the recovery of coral populations from this history of events will be slow (Adjeroud, *et al*, 2006).

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