THE DISTRIBUTION OF FIRE CORAL, *MILLEPORA PLATYPHYLLA*, WITH REGARD TO THE REEF COMPLEX IN MOOREA, FRENCH POLYNESIA

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Abstract. The fringing coral reefs of the island of Moorea have been subjected to a variety of natural and human disturbances over the past twenty-five years. Efforts are increasing to monitor coral reef systems and advance knowledge that would enable forecasts of the behavior of coral reef ecosystems to environmental factors. The present study sought to establish a zonal pattern for the population distribution of *Millepora platyphylla,* commonly referred to as fire coral, on the island of Moorea. Line transects were used to study the distribution and clod cards were used to examine the effects of water motion on the abundance of *Millepora,* as much available literature suggested that *Millepora* spp. were common in areas of strong water motion. The tolerance of *Millepora platyphylla* over time was assessed with the use of MCR LTER data sets spanning 2005 to 2013, with particular interest in the relative abundance of coral genera before and after the crown of thorns outbreak in 2006-2009. The distribution of *Millepora* at the Gump Station site was related to proximity from the reef crest, as water current is generally highest at the reef crest in fringing reefs and decreases with movement towards the shore. The distribution of *Millepora* at the Temae Beach site was not related with proximity to the reef crest, but high measurements of water current as far as 230 meters for the reef crest provided additional support that high *Millepora* cover is correlated with high water current. A lack of significant reduction in *Millepora* cover in response to the 2006-2009 Crown of Thorns outbreak on the island of Moorea, in addition to relative tolerance to severe physical conditions, suggests that *Millepora* may become a more prominent player in the reef complex should scleractinian coral cover continue to decline.

Key words: Fire coral; Millepora platyphylla; *distribution; water current; tolerance; Moorea, French Polynesia*

INTRODUCTION

Coral reefs have been a focus of conservation efforts for many years, as they cover less than 0.1% of the oceans; yet harbor the greatest richness of species among marine shallow water communities (Spaulding *et. al* 2001). In addition to their crucial ecological role, they also encompass one of the world's most fragile and endangered ecosystems. It has been estimated that the world has lost 19% of productive reef area with another 15% under immediate threat of loss (Chin *et. al* 2001). Changes in coral reef cover are driven by interactions between many environmental and human factors such as overfishing, sedimentation, and pollution. In addition to direct human encroachment, environmental disturbance in the form of worldwide temperature increases are predicted to be a major source of continued stress on coral communities (Parmesan 2006, Hoegh-Guldberg 1999).

Recent studies have found that the reefs of the Pacific are faring better than reefs in other parts of the world (Chin *et. al* 2001). However, due to threats posed by climate change, the long-term outlook for the coral reefs of the Pacific is considered to be poor (Chin *et. al* 2001). On the island of Moorea, coral reefs have been subject to a variety of disturbances between 1979 and 2009, including outbreaks of crown of thorns seastars most recently in 2006-2009, cyclones in 1983, 1991, and 2009, and coral bleaching in 1983, 1987, 1991, 1997, 2002, and 2003 (Adjeroud *et. al* 2009, Trapon *et. al* 2011). While coral recovery after disturbance has occurred, there are signs of long-term changes in the coral community composition, for example a decline in *Acropora* species and increased dominance of *Pocillopora* and *Porites* corals (Gleason 1993, Trapon *et. al* 2011). Furthermore, live scleractinian coral cover decline has been documented between 1979 and 2003 on Tiahura Reef in French Polynesia, with additional evidence indicating a shift in community structure from *Acropora* being the dominant genus to *Pocillopora* becoming the most abundant coral (Berumen and Pratchett 2006). As the frequency and intensity of natural and human disturbances increase over time, the community structure and relative abundance of coral genera in reef communities is projected to change, with some coral genera declining in abundance, some showing no change, and a few increasing in abundance (Adjeroud *et. al* 2014, Brown and Edmunds 2013).

In light of persistent ecological disturbances, efforts are increasing to monitor and evaluate coral reef communities. However, measurements of non-scleractinian invertebrates have often been missing from ecological monitoring of coral reefs. As scleractinian corals decline in abundance, the dynamics of previously rarer taxa are likely to play increasingly important roles in the community structure and function of tropical reefs (Lewis 2006). Hydrozoans from the family Milleporidae are one example of a widely distributed, non-scleractinian marine invertebrate that may be locally abundant in clumped distributions (Lewis 1996). A study in the Caribbean determined that the fluctuations in abundance of *Millepora* spp. were statistically unrelated to those of scleractinian corals, supporting the conclusion that the population dynamics of rare taxa (like *Millepora* spp.) are not predictable from the dynamics of common reef builders (Brown and Edmunds 2013). On Moorea in particular, a study examining patterns of susceptibility and short-term recovery of corals from bleaching found that while scleractinian corals were heavily damaged by a bleaching event in 1991, the *Millepora* spp. showed no evidence of bleaching (Gleason 1993). Further evidence, such as the avoidance of *Millepora* by the crown of thorns starfish, *Acanthaster planci*, also suggests that the species of *Millepora* on Moorea may be less susceptible to some disturbances that heavily impact scleratinian corals (Endean 1973).

The present study sought to assess the population distribution of *Millepora platyphylla*, commonly known as fire coral, on the island of Moorea. The first goal was to identify its habitat preference in relation to abiotic factors, particularly looking at the effects of water motion and relative distance from the reef crest on percent cover. I hypothesized that, as available literature suggested, *Millepora platyphylla* would be present in higher densities in areas of greater water motion, specifically in areas of strong current and areas closer to the reef crest, rather than the shallow, relatively calm shoreline. I predicted that Millepora cover would demonstrate a zonal pattern, as predicted by a previous study ((Moschenko 1998). The second goal was to assess the tolerance of *Millepora platyphylla* to environmental factors. Long-term ecological reef monitoring on Moorea has collected coral cover data at several reef habitats from 2005 to 2013, with surveys occurring in April of each year. Data sets were provided by the Moorea Coral Reef Ecosystem LTER, funded by the US National Science Foundation (OCE-0417412). I analyzed the changes in average *Millepora* percent cover and average stony coral percent cover over time, with particular interest in the relative abundance of genera before and after the crown of thorns outbreak in 2006-2009.

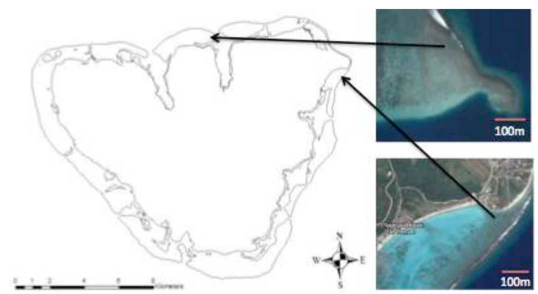

FIG. 1. Map of study sites on the island of Moorea. Top right hand image: Gump Station barrier reef (17°28′48.23″S, 149°49′38.05″W) Lower right hand image: Temae Beach, northeast shore (17°29′52.54″S, 149°45′20.40″W) Base map courtesy of the Geospatial Innovation Facility, University of California, Berkeley. Satellite images courtesy of Google Earth © 2014

METHODS

This study was conducted during October and November 2014 on the island of Moorea in French Polynesia (17°30′S, 149°50′W). Moorea is a volcanic island, located 11 km west of Tahiti, in the Society Archipelago located in the South Pacific Ocean.

Study organism

Millepora platyphylla, a hydrozoan in the family *Milleporidae*, is the only species of fire coral present on Moorea. *M. platyphylla* is found throughout the Indo-Pacific Ocean, in clumped or contagious distributions (Razak and Hoeksema 2003; Lewis 2006). The morphology varies from a bladed structure, of solid upstanding parallel or interconnected plates in areas of turbulent flow, to an encrusting growth over nearby coral fragments. *Millepora platyphylla* on Moorea is most readily characterized by its distinct yellow color that is brightest at the tips and darkest towards the base, reducing in intensity to a faded brown. (Figure 2). *Millepora* spp. are colloquially referred to as fire coral because of the presence of macrobasic mastigopore nematocysts. When their contents are discharged into bare skin, a characteristic burning sensation is produced (Garcia-Arrendondo et. al 2012).

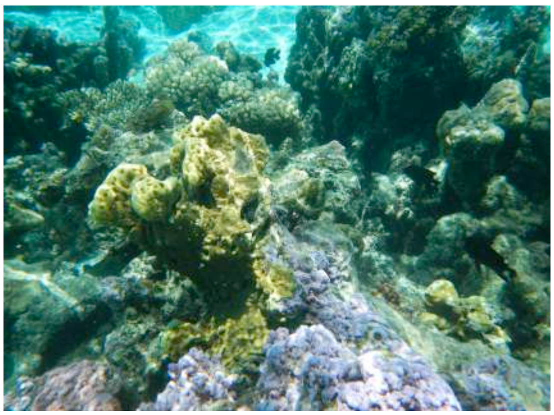

FIG. 2. *Millepora platyphylla* at Temae Beach

Preliminary survey

An initial assessment of *Millepora platyphylla* distribution and habitat was conducted by kayaking and snorkeling at several backreef sites around the island. The barrier and fringing reef at Cook's Bay were surveyed on kayak for presence of fire coral, with positive identification in both areas. The backreef lagoon habitat was surveyed by snorkeling a 700-meter transect from reef crest to shore. Various areas at the Temae Beach lagoon, extending from the conglomerate platform to the shoreline, were also assessed for the presence of fire coral by snorkeling.

Transects

Two study site locations were selected for a distribution survey: the barrier reef at the northwest mouth of Cook's Bay and the northeast side of Temae Beach (Figure 1). These locations were selected because they had biogeographical differences, but still had significant *Millepora* cover. The Gump Station site consisted of a barrier reef at the mouth of a bay, where turbidity is generally higher and live coral cover is generally lower. The Temae Beach site is largely considered to be one of the healthiest areas of the reef on the island. While *Millepora* cover was scare for the most part at Temae Beach, the area of the reef fringing the northeast shore had a noteworthy amount of fire coral cover. Five line transects, ranging in length from 50 to 70 meters were sampled at the Gump Station site. Six line transects, ranging in length from 160 to 220 meters were sampled at the Temae Beach site. Transects were run perpendicular to the reef crest heading towards the shore, in the direction of decreasing current strength. Sampling was haphazard, the beginning of each line transect was placed in a unique location as close to the reef crest as possible and each line transect was extended until *Millepora* cover became negligible. GPS coordinates were taken at the 0 meter mark and every 30 meters. A half-meter quadrat separated into 25 squares (surface area of $.01m^2$ each) was used to estimate the percent cover of *Millepora* next to the line transect at every meter marking. Percent covers of live coral, dead coral, and other substrates were also recorded.

Water current

Water current was measured at Temae Beach using a modified clod card technique (Jokiel and Morrissey 1993). Clod cards were made from a hardened mixture of Plaster of Paris and water, which dissolves into calcium and sulfate ions once placed in the field, both of which are natural components of ocean water. Two sets of ten clod cards each were placed at 30-meter intervals, beginning at the reef crest and extending to the shoreline. Time of day, depth of the placement, and GPS coordinates were noted at location of deployment for each of the clod cards. Clod cards were retrieved after 24 hours in the field and reweighed after drying for more than 48 hours. Salinity and temperature have both been shown to influence the linear rate of mass loss of the clod card. Temperature and salinity measurements were carried out at two separate events at each of the two study sites, separated by one week. However, since a calibration chamber was unable to maintain the same temperature and salinity obtained in the field, a diffusion factor was not calculated using the calibrated clod card. Instead, percent mass lost by each clod card was calculated by dividing the weight after deployment by the weight of the clod card before being placed in the field. Errors were avoided by simultaneous deployment of a set of ten clod cards in the same water mass, thus the need for a calibration clod card was circumvented.

LTER Data

Data sets were provided by the Moorea Coral Reef Ecosystem LTER, funded by the US National Science Foundation (OCE-0417412). The Moorea Coral Reef Ecosystem website was accessed on October 25, 2014 and data sets for 2005 to 2013 were obtained.

Statistical analysis

All statistical analysis was done using RStudio Version 0.98.1074 – © 2009-2014 RStudio, Inc. The relationship between distance from the reef crest and percent cover of *Millepora* was analyzed using a zero-inflated regression model (R package "pscl", function zeroinfl). *Millepora* data was log transformed to make it normal. A Wilcoxon signed rank test was used to test the hypothesis that there was a significant difference between the percent cover of live coral and *Millepora* in each site surveyed.

Linear regression analysis was performed to analyze the relationship between distance from the reef crest and percent mass lost by the clod card, with percent mass lost by the clod cards as the response variable. The relationship between percent mass lost by the clod cards and *Millepora* cover was also analyzed for correlation, using percent *Millepora* cover as the response variable. Assumptions of normality were checked using a Shapiro-Wilk Test.

A linear regression was run using LTER data to analyze possible changes in *Millepora* cover and Stony Coral cover over time. Percent cover of *Millepora* and Stony Coral was averaged per transect site and all sites were averaged per year. Response variables were percent cover of *Millepora* and Stony Coral. Stony coral cover data was log transformed for normality. Assumptions of normality for average percent cover of *Millepora* and Stony Coral were checked using a Shapiro-Wilk Test.

RESULTS

Preliminary survey

Two study site locations were selected where a clear distribution of *Millepora platyphylla* existed: the barrier reef at the northwest mouth of Cook's Bay and the northeast side of Temae Beach (Figure 1).

Transects

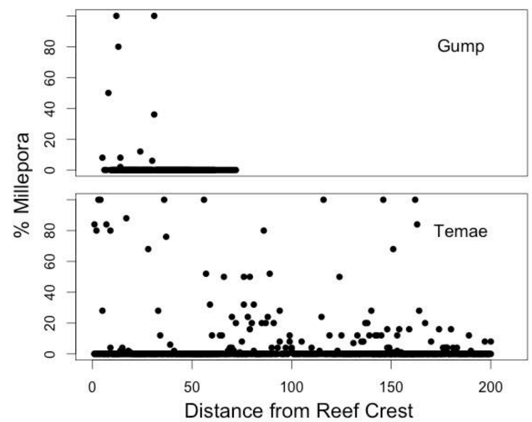

FIG. 3. Percent *Millepora* cover as distance from reef crest increases at Gump Station and Temae Beach sites.

At Temae Beach, all *Millepora* cover was found within 200 meters of the reef crest. The largest distribution was concentrated to an area of noticeably stronger current, bordering the north shore of the beach. *Millepora* cover at this site was best described as clumped or contagious. A zero inflated regression model indicated that there was no relationship between distance from the reef crest and percent *Millepora* cover (p=0.86, Figure 3). A Wilcoxon signed rank test indicated that there was a difference between the mean percent cover of *Millepora* and Live Coral (p= 0.0039). The mean percent cover of *Millepora* per quadrat was 4.37 and the mean percent cover of Live Coral Species was 4.09.

At Gump station, all Millepora cover was found within 30 meters of the reef crest. The distribution was patchier, with a lower mean percent cover of *Millepora* than found at Temae Beach. A zero inflated regression model indicated that there was a relationship between distance from the reef crest and percent cover of Millepora (p=.0031). A Wilcoxon signed rank test indicated that there was no difference between the mean percent cover of Millepora and Live Coral, likely due to an insufficient amount of data (p = 0.068). The mean percent cover of Millepora per quadrat was 2.54 and the mean percent cover of Live Coral Species was 0.44.

Water current

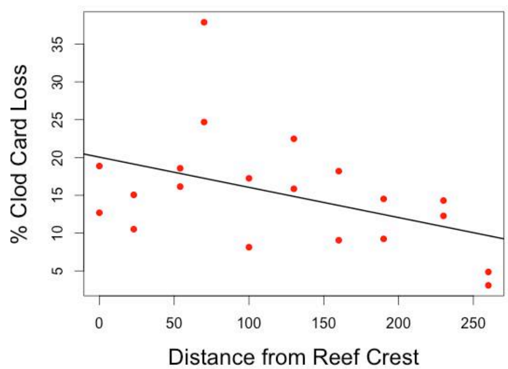

FIG. 4. Percent clod card mass lost as distance from reef crest increases at Temae Beach

Water current was measured at Temae Beach. A linear regression determined there was a significant relationship between distance from the reef crest and percent mass lost by the clod card. ($p=0.049$, $R^2=0.20$, Figure 4). An additional linear regression determined a significant relationship between percent mass lost by the clod cards and percent *Millepora* cover. ($p=0.016$, $R^2=0.28$, Figure 5). The regression was done with all percent Millepora cover on transects within 10 meters of the clod card placement.

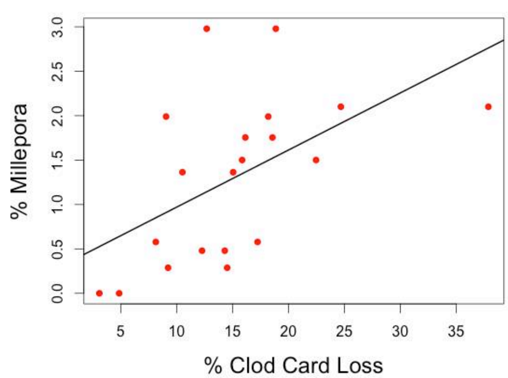

FIG. 5. Percent *Millepora* cover as a function of percent clod card loss at Temae Beach.

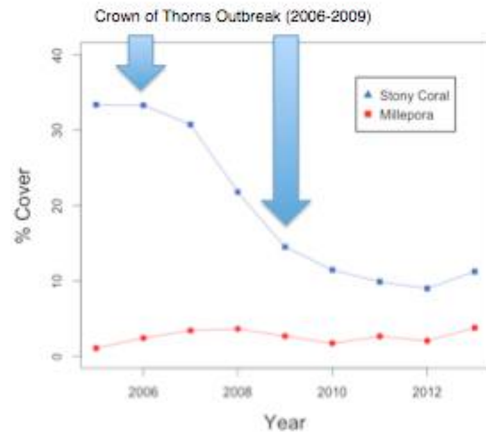

FIG. 6. Average percent cover of Stony Coral and *Millepora* over the time interval 2005-2013 at Moorea LTER sites

LTER data

A linear regression determined there was a significant relationship for average percent cover of stony coral per quadrat and year ($p=0.00018$, $R^2=0.88$, Figure 6). Average percent cover of stony coral was log transformed to meet the assumptions of normality. There was no relationship between average percent cover of *Millepora* per quadrat and year. No net change in average percent *Millepora* cover occurred over the time interval 2005 to 2013. ($p=0.41$, $R^2=0.010$, Figure 6).

FIG. 6. Map of Moorea Coral Reef Long Term Ecological Research sites surveyed. Image courtesy of Google Earth © 2014

DISCUSSION

Other studies provided some information about the ecology of *Millepora* spp. A study in South Vietnam found that

Millepora platyphylla is often found in areas where the abundance of other reef-builders is reduced, suggesting that it has a significant tolerance to environmental factors (Moschenko 1998). There, the distribution of *Millepora platyphylla* varies from contagious to random, but it exhibits a clear zonal pattern. Other literature stated that fire corals tend to form extensive outcrops on projecting parts of the reef where the tidal currents are strong. They are abundant on upper reef slopes and in lagoons, and can occur down to depths of 40 meters (Veron 1986). Based off these previous studies and personal observations, I hypothesized that the density of *Millepora platyphylla* would be greatest towards the reef crest, where currents are strongest, and that it would reduce in cover as proximity to the shoreline increases, where current is generally considered to be mild. Therefore, I expected to find a correlation between distance from the reef crest and percent cover of *Millepora*. At Gump Station, the relationship between distance from the reef crest and percent cover of *Millepora platyphylla* was significant, seeing as all *Millepora* cover was found within 30 meters of the reef crest. This finding supported my prediction of a zonal pattern for *Millepora* distribution. However, there appeared to be a lack of zonation in my preliminary distribution survey at Temae Beach. There, *Millepora* exhibited a clumped or contagious distribution, as was predicted by the literature, but also extended in cover as far as 200 meters from the reef crest.

Nonetheless, there was a relationship between the distance from the reef crest and percent mass lost by the clod cards. Compared to water motion patterns previously measured on a reef flat, where water current decreases linearly with distance from the reef crest, the current was strong, with levels of current comparable to values obtained at the breaker zone measured up to 230 meters from the reef crest (Jokiel and Morrissey 1993). Furthermore, there was lower rate of decrease in water current as distance from the reef crest increased than expected. This corroborated personal observations that the current in this particular stretch of the reef, even at a distance from the reef crest, was stronger and more rapid than in other areas of Temae Beach. Additionally, a significant relationship between percent cover of *Millepora* present and the percent mass of the clod cards that was lost supported my hypothesis that *Millepora* cover would be greater in areas of greater water motion. *Millepora* cover disappeared before the current dropped in intensity, again providing evidence that strong currents are correlated with higher *Millepora* cover. Thus, water current strength may be able to help explain why *Millepora* cover extended further than expected from the reef crest and deviated from the zonal distribution found at the Gump Station site. This biogeographic result may possibly be due to human influence. Originally, the motu was separated from the main island by a lagoon, but was completely filled in when an airport was built in the mid 1900's. Thus, in the future, alteration of water motion patterns should be considered when construction projects encroach on coral reefs.

The tolerance of Millepora to environmental factors was also assessed in this study. At the Temae Beach site, mean *Millepora* cover per quadrat was significantly higher than mean live coral cover per quadrat, possibly indicating that *Millepora* may outcompete live coral in particularly turbulent water current conditions. Moreover, at the Gump Station site, mean *Millepora* cover per quadrat was higher than mean live coral per quadrat, further indicating that *Millepora* has perhaps found a species niche, where it's survival and growth are preferential compared to typical reef builders. At both the Temae Beach and Gump Station sites, dead coral, sand, and rubble comprised the majority of cover, indicating that *Millepora* survival and growth may be currently restricted to areas where traditional reef builders are scarce.

Analysis of the MCR LTER data supported a previous study that found that the fluctuations in abundance of *Millepora* spp. are statistically unrelated to those of scleractinian corals (Brown and Edmunds 2013). Stony coral cover decreased dramatically with the Crown of Thorns outbreak from 2006-2009 with no overall change in *Millepora* cover during the same time interval. Additionally, a cyclone in 2009 did not dramatically impact *Millepora* cover. Overall, research suggests that *Millepora* may have greater tolerance to abiotic and biotic conditions that adversely affect common reef builders on the island of Moorea. A relative tolerance to severe physical disturbance suggests that *Millepora* could become a more prominent member of the reef complex should hermatypic coral cover further decline. Thus, *Millepora* cover should continue to be monitored on Moorea.

Future studies should look at relative plankton abundance in areas of high water motion versus areas of low water motion at Temae Beach, or other areas exhibiting a distribution of *Millepora*. It has been suggested that *Millepora* spp. exhibits higher rates of zooplankton feeding, meeting a larger percentage of their metabolic needs from heterotrophic means compared to scleractinian corals, which could help explain its ability to outcompete traditional reef builders in areas of higher current (Lewis 1992). Additionally, if *Millepora* abundance on Moorea increases, expanding beyond its current restriction to areas of high current, the organisms that live in close symbiotic or commensal relationships with fire coral may experience a similar population expansion. It is probable that the fauna living on or around *Millepora platyphylla* is different that that of paired, neighboring sites, reflecting the unique morphology of this hydrozoan and its tolerance for areas of disturbance. Preliminary trials appeared to support this hypothesis. Furthermore, certain organisms are known to prey on *Millepora*, such as nudibranches from the genus *Phyllidia* and filefish from the *Aluterus* and *Cantherhines* genus (Lewis 1989). As larger populations of these species would negatively impact *Millepora* cover, the abundance of *Millepora* predators on Moorea could be surveyed in order to better forecast trends in fire coral cover.

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