

Population Study Survey of *Acanthaster planci*, the Crown-of-Thorns starfish on the Northwest Coast Moorea, French Polynesia

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Abstract: Outbreaks of *Acanthaster planci*, the Crown-of-Thorns starfish, have been known to cause considerable amounts of damage to coral reef systems. Surveys of *A. planci* populations in Moorea, French Polynesia in 2004 indicated the island was experiencing the beginning stages of an outbreak. The goal of the present study was to survey the population densities of these sea stars at 3 sites on the north coast of the island in November 2006. Average densities inside the island's lagoon were found to be 566 *A. planci*/ km², while densities on the outer slope were found to be 1352 *A. planci*/km². These numbers were well above both the outbreak threshold of 30-40 *A. planci*/km², as well as the population densities measured in the 2004 survey. Data were analyzed to look for a correlation between population densities inside and outside of the reef crest at all 3 study sites. Only the interaction between study site and side of the reef crest was found to be statistically significant. In addition, studies were conducted into the average size and local population density of *Acanthaster* inside the lagoon as a function of distance from the reef crest. A marginally significant positive correlation was observed for question of average size with distance from the crest. Any measured trend in local population density was determined to be statistically insignificant.

Introduction:

The Crown-of-Thorns starfish (*Acanthaster planci*) is ravenous corallivore whose presence in large numbers can be extremely detrimental to the coral reef ecosystem. Like most other sea stars, the Crown-of-Thorns extrudes its gastric folds to digest its prey externally. This feeding method allows these stars to affect very large areas of coral over relatively short time spans. A bleach white feeding scar is all that remains once a coral has been preyed upon by *A. planci*. These feeding scars will never recover and in most cases become overgrown with algae. This can powerfully alter the ecosystem by reducing the species diversity and species richness of the corals and providing more space for algae to establish (PORTER, 1972). This in turn decreases habitat for most coral reef species and negatively alters a coral reef system.

Acanthaster planci feeds primarily upon scleractinian or reef-building corals, often choosing first to prey upon faster growing species such as *Acropora spp.* and *Montipora* (DE'ATH and MORAN, 1997). While *A. planci* individuals have been

recorded preying upon *Pocillopora spp.*, this is not nearly as common a prey item as many other corals of similar size and rugosity. This is due largely to invertebrate symbionts which will defend the coral head from *A. planci* grazing (PRATCHETT, 2001). A 2001 study conducted by Morgan Pratchett found that trapeziid crabs, usually *Trapezia* and *Tetralia* species, were effective enough in the defense of these corals that *A. planci* would move on to other, often less preferred corals to avoid being harmed. As soon as these coral symbionts were removed, however, *A. planci* was observed to eat the coral without hesitation (PRATCHETT, 2001).

In response to the extensive damage already inflicted on the Great Barrier Reef (GBR) by *A. planci*, much research has been conducted in an attempt to better understand the life cycle of these stars. It has been determined that *A. planci* has a pelagic larval duration of around 3 weeks. Larvae settle on shallow reefs, where they make the change into a pre-juvenile stage and move down to deeper waters. The next portion of their life takes place at depths greater than 80m, where these pre-juveniles feed almost solely upon algal matter (MADL, 2002). They may remain at these depths for up to 3 years as very small stars, measuring less than 5 cm (FAURE, 1989). When Crown-of-Thorns enter their juvenile stage, they ascend to depths of approximately 20m, and begin their lives as corallivores. At this point, monitoring is logistically feasible and damage done to the reef becomes easily visible. As adults, *A. planci* can measure 25-35 cm across their disk. This ample body size allows these stars to consume large volumes of corals, amounting to roughly 5-6 m² of coral tissue destroyed per year (MORAN, 1990). For this reason, during a large outbreak, it is possible for an entire reef system to be decimated.

Throughout the Pacific, studies have taken place for many years in an effort to monitor exactly how and why outbreaks occur. On some portions of the GBR, outbreaks have been known to last anywhere from 2-3 years. In other more extreme cases, such as the Ryuku Islands of Japan, outbreaks have been reported to have lasted for more than 20 years (MORAN, 1988). A population of Crown-of-Thorns is said to approach outbreak status in a system such as the one found in Moorea when numbers reach 30-40 individuals/km² (FAURE, 1989). Studies conducted in Guam and the GBR found that after extensive damage by Crown-of-Thorns, it took 12-15 years for most reefs to return back to pre-outbreak conditions (MORAN, 1988).

Core samples of coral reefs have been found to contain evidence of *Acanthaster* outbreaks, which have occurred with relative regularity over thousands of years (PANDOLFI, 1992). Now, however, there are worries that these outbreaks are becoming larger and more persistent. It is believed that the depletion of natural predators, mainly the Triton Snail (*Charonia tritonis*), and the Humphead Wrasse (*Cheilinus undulatus*), may play a large part in the frequency and severity of outbreaks that are seen today. The snail, which can grow very large, is collected for its highly prized shell and is now rarely observed in sizes larger than a few centimeters. The wrasse has been heavily over-fished, and individuals large enough to effectively prey upon *A. planci* are extremely rare. A recent study focusing on the cascade effects of coral reefs found a significant relationship between predator removal by fishing exploitation and *Acanthaster* densities on several relatively pristine reef systems found near Fiji. Across these islands a 61% decrease in large predator density was accompanied with a 35% decrease in scleractinian coral cover due to *A. planci* predation (DULVY et al, 2004). Heavy terrestrial runoff is also believed to play a part in outbreaks, as the nutrients that wash into the ocean have been known to cause phytoplankton blooms. These blooms in turn provide food for many *A. planci* larvae and help them grow to adulthood, boosting populations and causing widespread outbreaks (FAURE, 1989).

In 1989, Gérard Faure published a report on the last large outbreak in Moorea from 1982-1986. His study focused on the degradation on Moorea's coral reefs as a result of the outbreak and found that in some locations, such as near Taotoi pass more than 35% of living substrates were destroyed. During his timed searches for *A. planci*, over the course of 20 minutes, between 30-50 stars were counted giving a density of 3 to 4 starfish/m² (FAURE, 1989). Densities of this magnitude indicate population levels that are well above the outbreak threshold and severe damage to the reef is likely. In 2004, students from UC Santa Cruz conducted a study on the population of *A. planci* in response to an increase in sightings of the stars since 2002. Their study found an average 306 starfish/km² except for a particularly dense area, which contained an estimated 4,000 starfish/km² (KRUPA & REEVES, 2004). This large spike in density demonstrates the patchy distribution of *A. planci* populations. This makes obtaining large scale density estimates very difficult without complete sampling of the area in question.

The purpose of this study was to investigate the current state of *A. planci* populations on the northwest coast of Moorea during November 2006, with the intent of uncovering whether or not an outbreak was occurring. In order to do this, a base population survey was conducted with three questions in mind:

1. What is the average density of *Acanthaster* populations at each of the three study sites, both on the inside and the outside of the reef crest?
2. Is there a correlation between the population densities on the outer slope and the densities of a corresponding location within the lagoon?
3. Is there a relationship between the size of *A. planci* individuals and their distance from the reef crest inside the lagoon?

Currently, it is believed that the results of this study will indicate that Moorea is undergoing an outbreak of Crown-of-Thorns starfish. By investigating this further, the study expects to find a correlation between the densities of stars on the inside and outside of the reef crest as well a significant trend in the size of individuals as a function of distance from the crest within the lagoon.

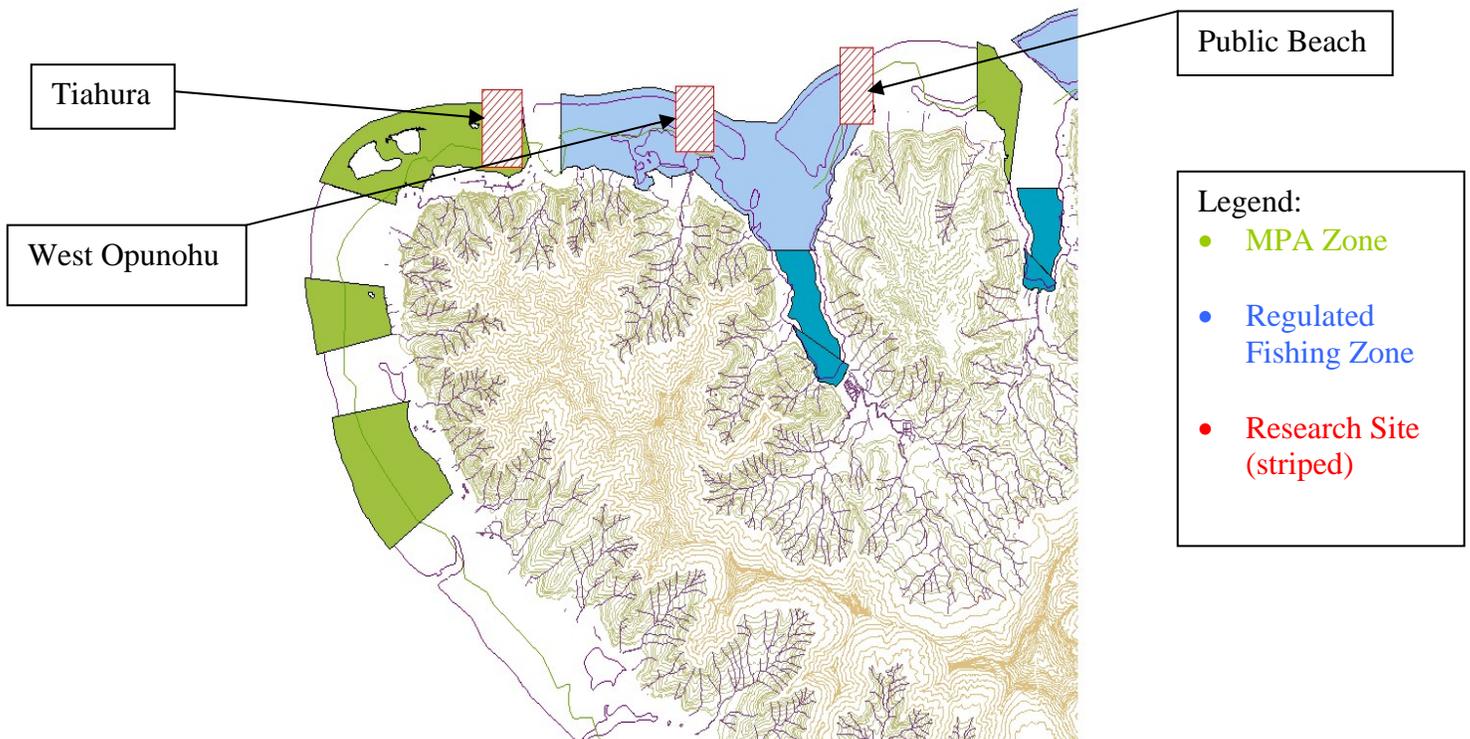
Materials and Methods:

Study Sites:

The island of Moorea is located in the Society Islands of French Polynesia, and is surrounded by a barrier reef which forms an inshore lagoon. Studies were conducted at three sites, both inside and outside of the lagoon; the sites chosen were Public Beach, West Opunohu, and Tiahura. Outside of the crest, studies were conducted on SCUBA from a depth of 21.3 meters (70ft) to the top of the crest. The topography of the outer slope was made up of a series of spurs and grooves, and the substrate consisted almost entirely of a wide variety of living corals, with coral rubble and dead coral making up the remainder of the slope. *Acanthaster planci* individuals were not observed on the island's fringing reef during multiple outings, nor were there any reports of individuals by researchers working in these areas. Thus, inside the lagoon, the area sampled was the region of the barrier reef between the boat channel and the reef crest. The depth of the

lagoon ranged from ~ 3.0 meters (10 ft) to ~ 0.5 meters (1.5 ft). Data for this portion of the study was collected entirely by skin diving. The substrate inside the lagoon was mainly sand and coral rubble, with the presence of live increasing with proximity to the crest. All sites were located on the north shore of the island as shown by the map below.

Acanthaster Surveys 2006



Between the three sites, there was a significant difference in live coral cover. With the exception of one location, data for percent live coral cover were obtained from surveys conducted in 2004-05 by Yannick Chancerelle. No data were available for the inside of the lagoon at the West Opunohu site. Thus, a transect was run to determine the percent coral cover at this site. At Public Beach, the live coral cover on the outer slope was 43.6 %, and cover in the lagoon was 30.0%. At the West Opunohu site, the coral cover on the outside of the crest was 30.0%. Inside the lagoon, it was measured to be 28.5 %. Finally, at the Tiahura transects, the coral cover was 51.0 % on the outer slope,

and 40.0% inside the lagoon. These variations may have accounted for some of the differences in the numbers of *Acanthaster* individuals between the three study sites.

In addition to the coral cover, the composition and structure of the coral in the lagoon were very different between the sites. At Tiahura and West Opunohu, the coral in the lagoon consisted mainly of *Porites* species. These corals grow in large, massive bommies which were separated by areas of sand and rubble. The coral at Public Beach was largely comprised of *Montipora* and *Acropora* species. Here, the coral cover was much more contiguous throughout the reef.

On the outer slope, the rugosity and steepness of the terrain varied greatly between the three study sites. At Tiahura, the slope was very shallow and neither spurs nor the grooves were very pronounced. West Opunohu's slope was slightly steeper with more prominent spurs and grooves. The outer slope at Public beach was quite steep, with taller spurs and deeper grooves.

Population Density Surveys:

Between the 10th and the 23rd of November, four transects were run at each of the three sites to measure the density of *Acanthaster* populations: two on the outside of the crest and two in the lagoon. All transects were 30 meters wide and were swum by two observers. Each skin diver was responsible for surveying 15 meters on one side of a transect. On the outer slope, the transects began at 21.3m and continued up the slope as close to the crest as currents and wave action would safely allow. GPS markers were taken at the beginning of each transect, then compared to a map in GIS to find the length of the area covered. Inside the lagoon, the transects were swum from the outer boat channel to the reef crest, again using a 30m swath and GPS to calculate the size of the sampled area. Each observer counted the number of *Acanthaster* individuals found on their half of the transect. Numbers of *A. planci* per transect were calculated by adding the total counts of the two observers. The resulting totals were then divided by the area of the transect to give a density of individuals/km². In addition, size, behavior, and food sources were recorded for observed individuals.

Size and Local Population Density as a Function of Distance from the Crest:

Inside of the lagoon at the Public Beach site, approximately 50 meters from the reef crest, nine identical transects were laid out and marked with buoys. These transects ran parallel to the crest and were spaced 10 meters apart from one another. All transects were 100 meters in length. On the 16th and 21st of November 2006, the transects were run by two skin divers, each monitoring 5 meters to either the left or the right of the transect midline. This allowed for complete coverage of a 100 X 100 meter area. Divers recorded both the size of any *Acanthaster* individuals encountered, as well as their distance from the reef crest. Size and local population density of individuals was then analyzed with respect to their distance from the crest in hopes of discovering a significant trend.

Results:

Acanthaster population densities were calculated for each of the 3 sites. To begin, the GPS coordinates of every transect were compared to a map to find the total area of each transect. The areas of the transects were as follows:

Transect	Area
Public Beach Inside 1	4900 m ²
Public Beach Inside 2	4900 m ²
Public Beach Outside 1	4800 m ²
Public Beach Outside 2	4800 m ²
West Opunohu Inside 1	5400 m ²
West Opunohu Inside 2	5400 m ²
West Opunohu Outside 1	4200 m ²
West Opunohu Outside 2	4200 m ²
Tiahura Inside 1	8400 m ²
Tiahura Inside 2	8400 m ²
Tiahura Outside 1	5100 m ²
Tiahura Outside 2	5100 m ²

For the most part, the areas sampled were roughly the same size, except for the site inside the reef crest at Tiahura, where the lagoon is much larger. These data were then compared to the number of *Acanthaster* individuals observed on each transect to find a density of stars for each study site. The results can be seen below and are represented in Figure 1:

Site	Density
Public Beach Inside	1531 <i>A. planci</i> /km ²
Public Beach Outside	938 <i>A. planci</i> /km ²
West Opunohu Inside	96 <i>A. planci</i> /km ²
West Opunohu Outside	1548 <i>A. planci</i> /km ²
Tiahura Inside	71 <i>A. planci</i> /km ²
Tiahura Outside	1569 <i>A. planci</i> /km ²

Observations made on the population density transects were used to analyze the behavior of *A. planci* individuals counted. Of the 54 stars encountered, 31 (57.4%) were recorded as resting, 22 (40.7%) eating, 1 (1.9%) moving, and 0 spawning. The stars were observed feeding upon 5 genera of corals: *Acropora* (36.4%), *Montipora* (27.3%), *Montastrea* (18.2%), *Fungia* (13.6%), and *Pocillopora* (4.5%). Crown-of-Thorns were not observed actively feeding on any other genera of corals, however a species of *Gardinoseris* was found bleached in one of the *Acanthaster* feeding scars.

Analysis of the population survey data indicated that there was a statistically significant interaction ($P < 0.001$) between location and density of *Acanthaster planci*; this interaction was found to be between both the study site and the side of the reef crest (inside or outside) on which the star was observed. This data is unadjusted for the live coral cover at each location. At the Tiahura and West Opunohu study sites, there were far fewer individuals observed inside the lagoon than on the outer slope. At Public Beach, however, this trend was reversed and more stars were located inside the lagoon. This relationship can be seen in Figure 2. The data was then adjusted to take into account the coral cover at each site by adding “Percent Coral Cover” as a covariate. Again, the interaction was found to be equally significant ($P < 0.001$), and the results were left nearly unchanged.

The size of *Acanthaster* individuals recorded was then analyzed by a 2-way ANOVA test of square root transformed data to see if there was any correlation between the size of individuals and the site or side of the crest (inside vs. outside) on which they were encountered. Both of these relationships were found to be statistically insignificant ($P = 0.483$ for site and $P = 0.182$ for side of the crest), demonstrating that there was no trend in size distribution between either the sites or side of the crest. The interaction between site and side was found to be insignificant as well ($P = 0.714$).

Data from the 100 x 100 meter square was analyzed to investigate whether the average size of *Acanthaster* individuals varies with distance from the reef crest. A 2-way ANOVA test using log transformed data found that there was a marginally significant relationship ($P = 0.095$) between the average size of individuals and their distance from the crest. This relationship indicates that as distance from the crest increases, the average size of Crown-of-Thorns individuals increases as well. Figure 3 illustrates this trend.

The same data was used to test whether the density of *Acanthaster* individuals varied as a function of distance from the crest. This data was analyzed using a Pearson Chi-square approach. First, it was divided into two subsets: close to the crest (45 meters and lower) and far from the crest (greater than 45 meters). Because the data was collected on two separate days, the variable “Day” was included to detect any difference between the two dates sampled. The Pearson Chi-square test indicated the possibility of a weak effect ($P = 0.148$). However, this appears to be a false positive, as the pattern that presented itself on the first day of sampling was reversed on the second day. Thus, the data provided no evidence that the distance from the crest was related to the abundance of *A. planci*.

Discussion and Conclusion:

Population densities of *Acanthaster planci* in Moorea have been relatively unknown in recent years. The findings of this study indicate that the island is in fact undergoing an outbreak. Currently the population levels of Crown-of-Thorns starfish are much higher than previous counts performed in 2004, and appear to be on the rise. Data from the 2004 study by Krupa and Reeves showed an average density of 160 *A.*

plancki/km² at two sites within the lagoon (KRUPA and REEVES, 2004). Observations of the same two sites used in this study yielded an average density of 814 *A. plancki*/ km², while data from all three sites sampled gave a density of 566 *A. plancki*/ km². The 2004 report did not provide data for the density of *Acanthaster* populations on the outside, but noted the populations were not at obvious infestation levels of 30-40 *A. plancki*/km², a number taken from Faure's 1989 report (FAURE, 1989). Population surveys of the outer slope conducted in this study yielded an average 1352 *A. plancki*/km². These numbers are well above the threshold set forth by Faure and indicate Moorea's coral reefs are potentially in danger of destruction by a large outbreak.

Though the Tiahura and West Opunohu study sites produced very similar results, the populations at Public Beach behaved in a manner quite different from the other two sites. At the first two locations, the densities of *Acanthaster* found on the outer slope were far greater than those in the corresponding areas of the lagoon. At Public Beach, however, the density inside the lagoon was approximately 1500 *A. plancki*/km², very similar to the numbers found on the outer slope of the other two sites. In this case, the density for the area outside the reef crest was 938 *A. plancki*/km², much lower than those of the other sites.

Coral cover on the outer slope was very similar for each of the three sites, but the topography of Public Beach was very different from each of the other sites. Tall, steeply sloped spurs and deep grooves made population counts very difficult for divers, and the rugged terrain provided many locations in which the *Acanthaster* could be concealed. Therefore, the lower population density exhibited by this site was most likely an artifact of the poor sampling conditions.

A possible explanation for the discrepancies in population densities inside the lagoon may lie in the coral composition and structure of the 3 sites. The Tiahura and West Opunohu lagoon sites had relatively similar topography and corals. The coral at these two locations consisted mostly of *Porites* spp., growing in massive bommies separated from one another by areas of sand. Crown-of-Thorns have been shown to prefer fast growing hard corals such as *Acroporites* and *Montiporites*, and tend to avoid massive corals (DE'ATH and MORAN, 1997). The spatial separation of these corals may have also deterred predation by *A. plancki*. Public Beach, however, had a very

different coral composition than the other two sites. The reef in this area was for the most part contiguous, and contained a high density of *Montipora* and *Acropora* spp., both highly preferred prey of *Acanthaster*. Thus, this portion of the reef presented very favorable feeding conditions for Crown-of-Thorns, which in turn may explain the high population densities found at Public Beach.

In the height of an outbreak, these known feeding preferences of *A. planci* can have a major impact on the coral reef system. Because certain corals are preyed upon with much greater frequency, the destruction caused by a large outbreak is often patchy with some areas of reef almost completely decimated and others relatively untouched. In a relatively small reef system such as that of Moorea, this can have profound effects on the overall coral composition of the reef. This information could be potentially be used in future studies conducted in Moorea to determine the regions around the island which are most threatened by an *Acanthaster* outbreak. Eradication and removal efforts could then focus on protecting these vulnerable areas.

Another goal of this study was to determine whether or not there existed a trend in the population densities of *Acanthaster* individuals between the outer slope and the inside of the lagoon. Statistical analysis showed no trend existed from the data collected. However, this is likely an artifact of the small sample size used in this study. By having only 3 sites local differences were able to have a greater influence on the data as a whole. Thus, possible trends between side of the crest may have been masked by differences between sites. To find a pattern it would have been necessary to get more replicates by sampling more locations. The data in Figures 1 and 2 illustrate the problem encountered on this portion of this study. Without more replicates it is impossible to determine whether unusual data such as that obtained at Public Beach is simply an outlier or if no trend actually exists.

Analysis of the data obtained on the population density surveys indicates that there is no trend in the average size of *A. planci* individuals between different sites or between the two sides of the crest. This suggests that over large areas, *Acanthaster* populations were not stratified by size. Rather, both juveniles and adults could be found throughout much of the reef. This can be largely explained by the high mobility of these

starfish. Individuals are able to move with relative freedom across the reef and thus populations are mixed throughout large areas.

Over smaller scales inside the lagoon, however, there appears to be some stratification of *Acanthaster* individuals by size. Statistical analysis indicated a marginally significant correlation between the size of *A. planci* individuals and their distance from the crest. This states that inside the lagoon, as distance from the reef crest increases the average size of *Acanthaster* individuals increases as well. It is possible that the higher mobility of larger individuals allows them to venture farther into the lagoon than the smaller stars. This, in turn, would allow them to cross areas of sand and rubble to reach unexploited corals farther from the crest. In addition, predation is much more prevalent on smaller stars and they may be eaten if they move too far from the dense shelter of the coral closer to the crest. Further research into this subject could provide some insight into other explanations for this phenomenon.

Upon analysis, data from this study appeared to indicate that inside the lagoon there was a correlation between the local population density of Crown-of-Thorns and distance from the reef crest. After further investigation, however, the trend was discovered to be an artifact of the sampling methods. Data was collected on two separate days, and though the combined data suggested an overall trend, the patterns on the two days were completely opposite one another. Thus, the data provided no evidence that the density of *A. planci* was at all stratified as a function of distance from the reef crest. During the interval between the two days on which the sampling took place, there was a major shift in weather. Wind speed, swell, and current were all greatly increased. This may have been a confounding factor as it may have caused the stars to relocate their position within the lagoon. In order to better understand if a pattern exists, it would be necessary to carry out this type of monitoring for a much longer duration.

The results of this study have led to the conclusion that Moorea is currently facing the threat of another large *Acanthaster* outbreak. The findings show a clear increase in the population density of Crown-of-Thorns, and should this trend continue it is possible it could reach levels as high as those seen in 1982. Because the vast majority of Crown-of-Thorns research has taken place on the Great Barrier Reef, relatively little is known about the behavior of the stars in this region of the Pacific. Further monitoring and future

studies investigating the habitat preferences of *Acanthaster* populations could give valuable insight into the population dynamics of an outbreak on a small island system, such as that of Moorea and the Society Islands. Such studies could eventually provide enough information to predict or possibly even prevent an outbreak of Crown-of-Thorns starfish.

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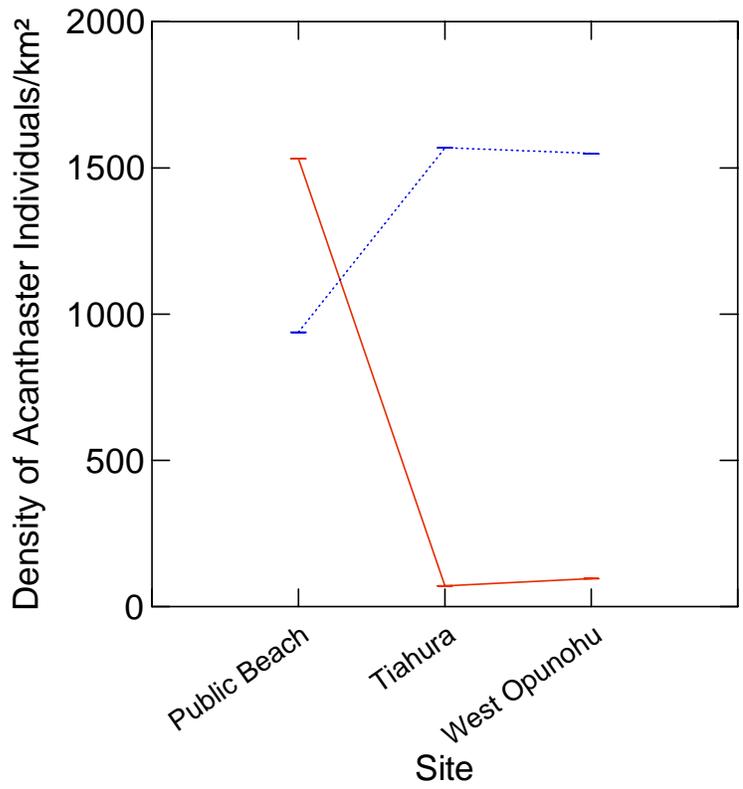


Figure 1
Density of Acanthaster
Individuals by Site

SIDE
 — Inside
 Outside

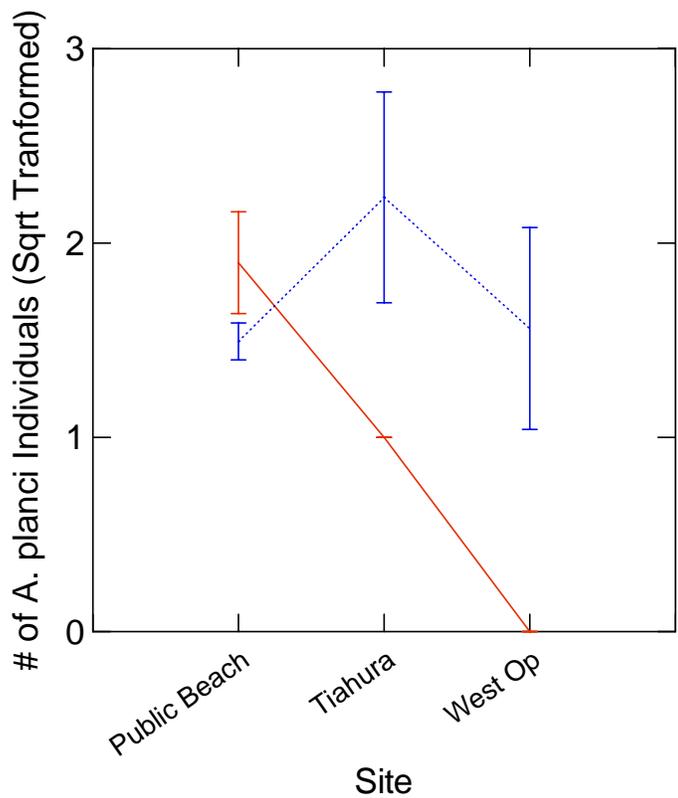


Figure 2
Number of Acanthaster
Individuals as a Function
of Study Site and Side of
Reef Crest

SIDE
 — Inside
 Outside

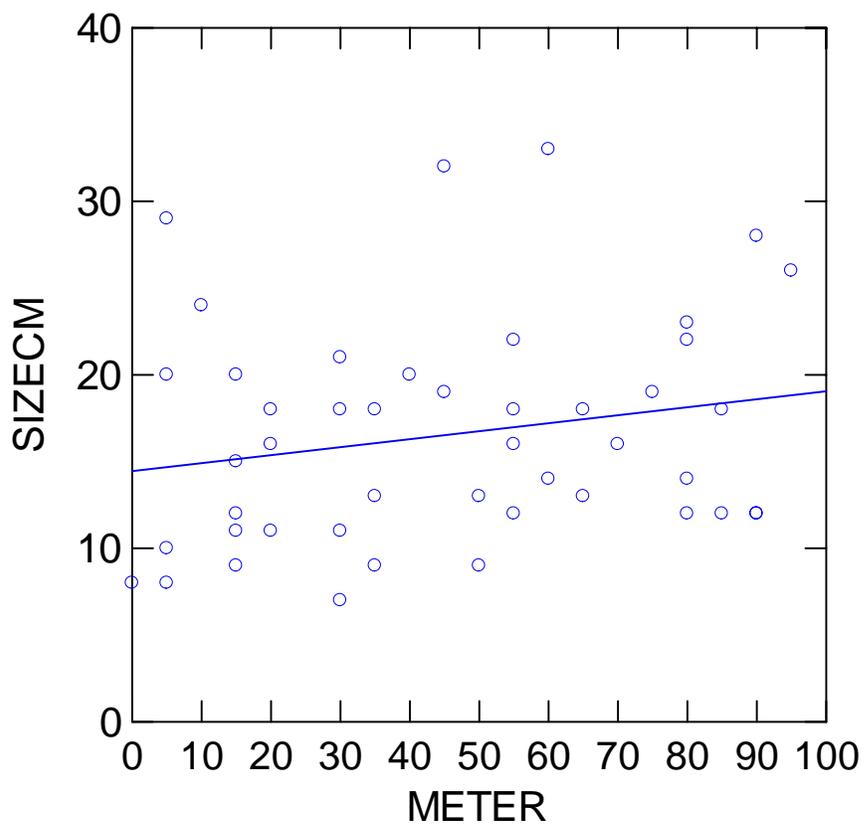


Figure 3
Average size of
Acanthaster Individuals as
a Function of Distance
from the Reef Crest

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