Effects Of Marine Protected Areas On The Population Of ACANTHASTER PLANCI In Moorea, French Polynesia

Park, Albert

2008-12-01

EFFECTS OF MARINE PROTECTED AREAS ON THE POPULATION OF ACANTHASTER PLANCI IN MOOREA, FRENCH POLYNESIA

ALBERT PARK

Environmental Science Policy and Management, University of California, Berkeley, California 94720 USA

Abstract. Since the 1960's the crown-of-thorns starfish, Acanthaster planci¸ has devastated coral reefs. There are many competing theories about the causes for these outbreaks of A. planci. One of the leading theories is that it is an anthropogenic cause. As a result, Marine Protected Areas (MPA) may be a way to protect coral reefs from outbreaks of A. planci by removing anthropogenic effects and allowing the reef to protect itself. Coral reef health was assessed using fish population diversity, percent live coral reef coverage and density of *A. planci*. Lowest live coral reef coverage was 42.97% with 80.70% the highest. Highest Simpson's 1-D diversity index value was 0.47 for outside of a MPA with 0.82 the highest index value for a site inside an MPA. Density of *A. planci* were found to be 12.5 per hectare, which is below outbreak densities. No significant differences were found in any metrics for inside or outside MPAs.

Key words: echinoderms; Acanthaster planci; *outbreak; no-take-zones; Moorea, French Polynesia; population; fish diversity; coral reef health*

INTRODUCTION

The crown-of-thorns seastar, *Acanthaster planci* Linnaeus 1758, is a predator of scleractinian corals. In coral reef ecosystems *A. planci* occur naturally in low densities (<1 per ha) and have a negligible effect on the populations on scleractinian corals (Zann et al. 1990). *A. planci* is an important organism to study because of its ability to decimate coral reef systems during outbreaks by killing up to 90% of scleractinian corals (Chesher 1969).

Widespread outbreaks have only recently been recorded starting in the 1960's with the 1962 outbreak at Green Island off of Cairns (Barnes 1966). However, this is a potentially skewed trend since recreational diving only started since 1943 when Jacques Cousteau and Emile Gagnan started to sell the first SCUBA system commercially, the AQUA-LUNG.

There have been many theories regarding the cause of boom and bust cycles of *A. planci* populations from natural processes (Moore 1978) to anthropogenic predator removal (Potts 1981). Currently, there exist multiple non-exclusive theories on the *A. planci* population cycle. The first is that agricultural runoff increases phytoplankton which increases survivability of *A. planci* larvae. A second theory is that anthropogenic effects on predator fish population decrease the predatory stress on the larvae and juvenile stages of *A. planci* (Sweatman, 2008).

Studies have shown a negative relationship between outbreaks and predator populations (Ormond 1990; Dulvy 2004). As a result marine protected areas (MPAs) have been suggested to be able to reduce outbreaks (ISRS 2004). However, an MPA can only effectively protect against outbreaks if they are effective at protecting the coral reef ecosystem.

There is also the theory that what we are observing are natural boom and bust cycles of *A. planci*. A female *A. planci* can potentially produce a billion eggs during a lifetime (Babcock 1992). As a result, even small percent changes in survivorship of the larvae stage can result in exponential population growth.

Naturally occurring localized climate changes such as the El-Nino-Southern Oscillation (ENSO) can create dramatic localized changes in salinity, temperature and availability of planktonic food (McPhaden 1999).

Healthy reef systems are considered to be able to sustain a population density of *A. planci* up to 20-30 full sized adults per hectare (Moran 1992). A healthy coral reef system for the purpose of this study is defined as 40-50% live coral cover (Moran 1992). Even after an outbreak decimates a reef, total reef recovery is possible given a time frame of 10-15 years (Salvat 2008).

The distribution of *A. planci* may also be affected by the distribution of corals. A base feeding preference has been determined for *A. planci* which starts with the greatest preference for the branching forms of *Acropora* and the lowest for massive heads of *Porites* (Pratchett, 2007). This could determine the distribution of *A. planci* if they are going where their preferred food is.

The aim of this project is two-fold; to determine if MPAs affect the distribution of *A. planci*, and to determine if MPAs are effective in positively affecting the health of the coral reef ecosystem. Health will be determined using coral distribution and fish diversity indices.

METHODS

Study sites

Study sites were the following four MPAs:

AMP de Pihaena - This is the protected area on the north side of Mo'orea, outside of cook's bay, on the west side of the pass.

AMP de Tetaiuo - This is the protected area on the northwest corner of Mo'orea, south of Motu Fareone, north of AMP de Taotaha.

AMP de Taotaha - This is the protected area on the northwest corner of Mo'orea, north of Ha'apiti, south of AMP de Tetaiuo.

AMP de Nuarei - This is the protected area south of Temae airport on the Northeast corner of Mo'orea.

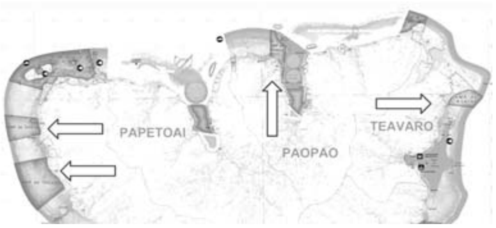

FIG 1. Study sites labeled with arrows.

Transects

At each site, two base transects 200 meters from the edge of the MPA were setup - one inside the MPA and one outside. These were paired sites for the purpose of comparing reef health and *A. planci* distribution in and out of the MPA. Each base transect was aligned perpendicular to the shoreline.

Start locations along the base transect were randomly chosen by using a random number generator to find three numbers between 0-10 to be used as start points for transects for each 10 meter segment of the base transect. I also used a random number generation of 0-1 to determine directionality of transect off the base transect.

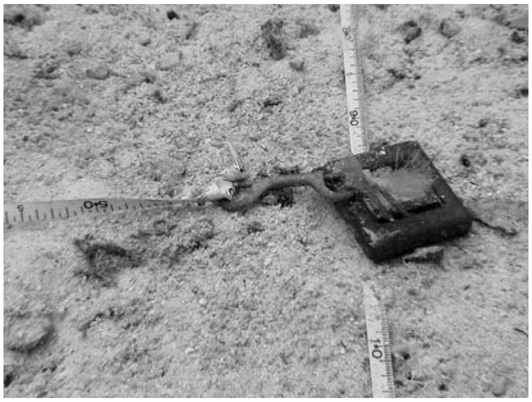

FIG 2. Transect off the base transect.

These transects were 30 meters in length and parallel to the shore. Once the start point was established, a GPS reading was taken as well a bearing for the direction of the transect.

The subsequent fish, coral and *A. planci* surveys were repeated for the remaining two transects off the base, and for the other base transect. For the MPAs Tetaiuo and Taotaha which have two suitable borders I used the northern borders of the MPAs.

All sites were surveyed between October 27th of 2008 and November 13th of 2008. All surveys were conducted between the hours of 1330 and 1630 hours with the exception of AMP de Nuarei which was conducted between 730 and 1100 hours.

Photographs of *A. planci* and coral heads were taken for use as vouchers. Video footage was preserved for later identification, fish counts, as well as for use as vouchers.

Fish Surveys

I started videotaping while swimming away from the base transect, parallel to the shore, as I played out a 30 meter transect. Taping ended once I reached 30 meters. Once the end of the transect was anchored using a 2lb. dive weight, I returned to the base transect.

FIG. 3. End of transect anchored.

Videos were later analyzed to species when possible, but to genus or family when field markings were indistinguishable. Fish were identified using a key consisting of fish commonly found in Moorea (Brooks 2001).

Only fish which passed through a vertical line drawn through middle of the video were counted. Fish which left the frame of the video and returned were counted as a new fish.

Coral Surveys

Starting at the base transect, I headed out along the transect and performed an intercept transect for coral. Length of intercept was recorded to the centimeter. Categories recorded were live coral, dead coral, and substrate. For live coral intercepts, corals were identified to genus. Photographs of unknown coral were taken for later identification.

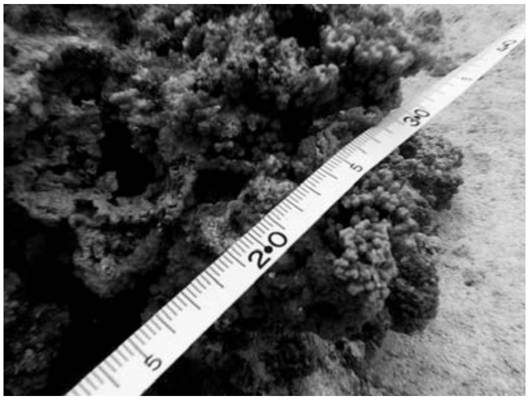

FIG. 4. An example coral intercept.

A. planci *Surveys*

For each 10 meter portion of the base transect, an exhaustive search for *A. planci* was conducted in a 60m x 10m area, centered on the base transect. Each search area was paired to a set of fish and coral transects. The area searched is considered to be 600m^2. The area underneath shelf and branching coral formations were also searched, not just what was visible from above.

Statistical Analysis

Fish survey results for the three transects per base transect were aggregated. The Shannon's and Simpson's 1-D biodiversity indexes were run on the aggregated survey counts.

The biodiversity values for the paired sites for the three of the four study areas were compared using a t-test for paired means with two degrees of freedom. The fish survey data for AMP de Tetaiuo was lost to data corruption, and as a result was left out of the analysis.

Coral intercept data was processed by generating a percentage of live versus dead coral, less substrate. The percentage of live coral per paired sites for the four study areas were compared using a t-test for paired means with three degrees of freedom.

All statistical analyses were computed using JMP version 8.0 by SAS Institute Inc.

RESULTS

Fish Surveys

Using the Simpson's 1-D Index of Diversity to analyze returned values above 0.75 for Nuarei and Taotaha, with diversity index values of .45 to .55 for Pihaena. These are of a scale where 1.0 is the most diversity possible.

The lowest difference of the diversity index scores for a paired site was .004 for Naurei. The highest difference between insie and outside the MPA was .087 for Pihaena.

A t-test for paired means comparing the Simpson's 1-D Index of Diversity values for the three study areas, inside versus out yielded a p-value of 0.5464 with two degrees of freedom and a standard error of 0.0327. The differences in the Simpson's 1-D diversity index values for the three study sites were not statistically significant.

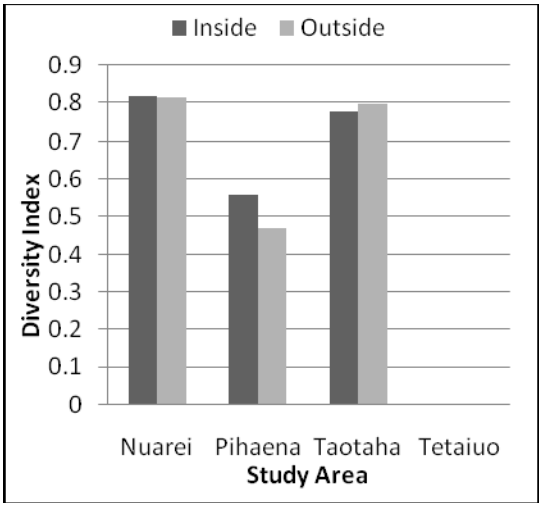

FIG. 5. Simpson's 1-D Diversity Index

Shannon's Index of Diversity returned values as high as 1.85 for outside Nuarei to as low as 0.71 for outside Taotaha. This is on a scale where the maximum value is *ln*S where S is the species richness.

The lowest difference between paired sites was 0.10 for Nuarei. The highest difference was 0.94 for Taotaha.

A t-test for paired means comparing the Shannon Index of Diversity for the three study areas, inside versus out, yielded a p-value of 0.3568 with two degrees of freedom and a standard error of 0.30527. The differences in index values for the three study sites were not statistically significant.

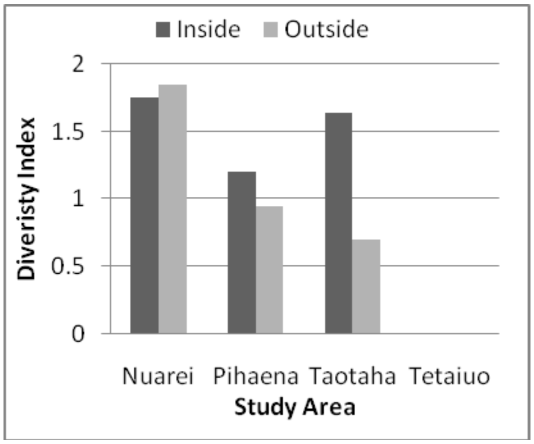

FIG. 6. Shannon's Index of Diversity

Coral Surveys

Coral intercept transects showed a higher percent of live coral in three of the four study areas. The greatest difference in percentage of live coral was 29.95% which was found at Tetaiuo, with more live coral found inside the MPA. The smallest difference in percentage of live coral was 6.20% which was found at Taotaha, with more live coral found outside of the MPA.

A t-test for paired means comparing the percent of live coral found inside versus outside the MPAs yielded a p-value of 0.1608 with three degrees of freedom and a standard error of 8.0709. The differences in live coral cover for the four study sites were not statistically significant.

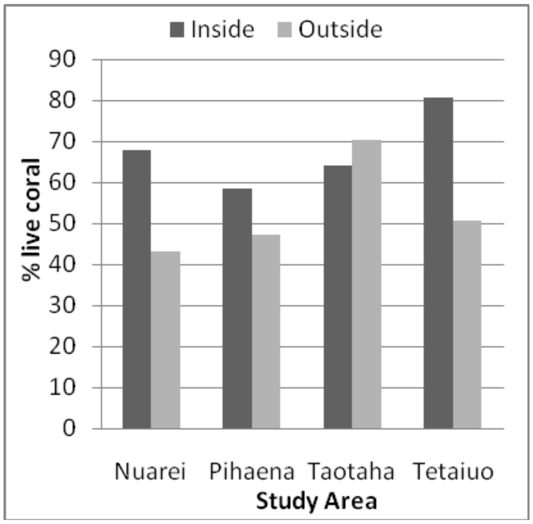

FIG. 7. Live coral cover, aggregate.

A. planci *Surveys*

Given area surveys for *A. planci* revealed a total of six *A. planci* for all study areas. This resulted in a density estimation of 12.5 per hectare. The greatest number of *A. planci* found was three adults found inside the MPA at Pihaena. The fewest found was zero at Tetaiuo.

A t-test for paired means comparing the numbers of *A. planci* found inside versus outside the MPAs yielded a p-value of 0.6638 with three degrees of freedom and a standard error of 1.04083. The difference in *A. planci* found was not statistically significant.

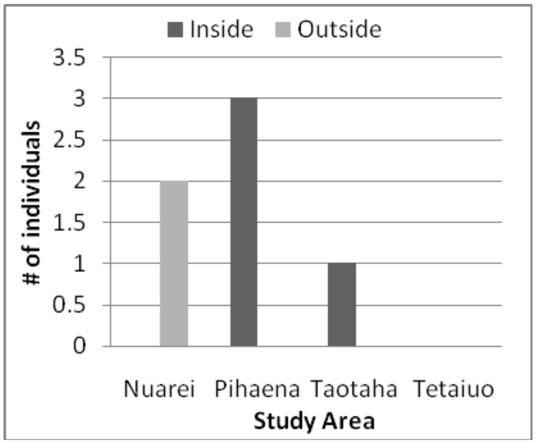

FIG. 8. *A. planci* distribution.

DISCUSSION

Fish Surveys

Using diversity indices allowed us to assess the makeup of the fish populations at each sample site. The index values allowed us to create a way to compare these very different populations. Two indices were used to allow for different theories as to what makes a diverse fish ecosystem.

The Simpson's 1-D diversity index looks for evenness in populations. Given the maximum value of 1, Nuarei and Taotaha had very high diversity index values. However, the important thing to notice is that not only are the index values high, but they're also very similar.

Pihaena had moderate fish diversity with values of 0.56 inside and 0.47 outside the MPA. Much like the other two study areas, we see that the index values are very similar.

The statistical tests showed us that the differences in the Simpson's 1-D diversity index values are not statistically significantly different from one another. This shows us that even 400 meters apart, the fish populations aren't statistically affected by the presence or absence of the MPA.

Using the Shannon diversity index showed us the same trend as with the Simpson's 1-D. We see diversity index values that are quite similar both inside and outside of a study area.

Taotaha is a little different from the other two study areas in that it seems to show a trend to have higher diversity inside the MPA. This is explained by a school of Scaridae which swam through the fish transect, but were not observed at any of the other study sites.

Even with this abundance of Scaridae, the paired t-tests failed to show a statistically significant difference between inside and outside the MPAs.

This lack of statistical significance may also be due to lack of statistical power due to a small sample size. With a larger sample size we may be able to detect a difference in the diversities of the study sites with higher sensitivity.

This may also be due to the fact that 200 meters from the edge was not far enough to reduce edge effects from the MPA. This may have resulted in surveys that are not truly separate populations, but rather two samples of the same effective population.

The fish survey also lacked information from one of the four study sites, Tetaiuo. This was due to corrupted data for this study area which precluded analysis of fish to the same level of accuracy as the other three study areas. As a result, the data was thrown out, and this site was not incorporated into the statistical analysis of the paired-sites.

Fish surveys were conducted first to avoid disturbing the fish community. This was to minimize under representing fish which were scared off. Laying out the transect tape was done concurrently to ensure the accuracy of the distance surveyed.

Due to the nature of the video equipment used and the resolution, certain fish were excluded from the fish surveys. Examples would be small prostrate fish which retreat into burrows such as *Coryphopterus neophytus* which were observed during surveys, but not observed on the video itself. Similarly, very cryptic fish such as *Synanceia verrucosa* were precluded from identification via video.

Coral Surveys

The coral surveys showed a strong trend towards higher percentages of live coral inside the MPAs versus outside. The only study area to have a higher percentage of live coral outside the MPA rather than inside was Taotaha. At Taotaha, the difference was a marginal 6.20%.

The paired t-test failed to show a statistically significant difference in the percentages of live coral, but was fairly close at 0.1608. It is very likely that with an increased sample size, and increased statistical power, a significant difference in the distribution of live corals in and out of MPAs can be seen.

Current may have affected the dataset because the amount of current was different depending on the time of day and the study site. Current affected the coral intercept transect method because it had a tendency to sweep the tape off of coral heads and make it luff in the current, instead of staying flat on the floor or on coral heads. This potentially leads to less coral intercepts and an inaccurate representation of the coral reef makeup.

There may also be an unconscious tendency for the researcher to swim towards or away from coral reef formations. Researchers were instructed to swim in a straight line once a bearing was taken, but in a patch reef system such as the study sites, the eye tends to gravitate towards coral heads instead of what may be straight ahead.

This potentially leads to higher than actual coral intercepts as the researcher bounces from coral head to coral head along the 30 meter transect.

A. planci *Surveys*

The surveys of *A. planci* did not show any sort of trend. This was mainly due to the low numbers of *A. planci* encountered during our surveys. Lack of statistical power from a small sample size is a possible cause for the lack of statistical significance.

Statistically there was no difference in the numbers of *A. planci* observed inside or outside the MPAs. This may be due to simply a low population of *A. planci* in the area. The aggregated area surveyed for *A. planci* was 4800 m^2. This gives us a density of 12.5 adults per hectare which is below the threshold value of 20-30 adults per hectare for an outbreak situation (Moran 1992).

The paired t-test showed that the differences in *A. planci* populations were not statistically significant. With a larger sample size we may be able to determine that there is a trend towards more *A. planci* within the MPAs as is possible given the data for Pihaena.

The spike in numbers of *A. planci* in the Pihaena study site may also be due to the proximity of the study site to the pass. *A. planci* cannot cross over the barrier reef to the back reef, but must enter via the pass. Since the inside site for Pihaena was closest to the pass, it is possible that this spike in the data can be attributed to proximity of sample site to a pass in the barrier reef.

The choice of sampling during the day for *A. planci* may also have skewed the surveys to under represent the population because only the largest adults feed during the day (Moran 1992). Juveniles and smaller adults hide during the day and detection is hard. It is also possible that *A. planci* stay out of the surveyed areas during the day and move in at night to feed.

Conclusions

This study has shown that there are no statistically significant differences in the metrics chosen to assess the health of the coral reef ecosystem. This potentially means that the MPAs are ineffective in their task of protecting the coral reef ecosystems.

The MPAs are subject to a lot of edge effects since it is a collection of small reserves. This potentially limits the ability for the MPAs to protect the coral reef ecosystem from the fishermen, and tourists.

There also comes to question the enforcement of the MPAs and whether or not the locals abide by the no-take rules. During the course of our project we observed, on multiple occasions, fishermen spear fishing within the boundaries of the MPAs and driving boats outside designated boating lanes.

Perhaps the MPAs are doing such a good job at protecting the coral reef ecosystem and marine life that they are acting as sources for populations of fish and coral, that the areas beyond their borders are also benefiting by having their populations constantly replenished.

However, assessing each of the metrics, it is likely that the coral reef ecosystem of the back reef and sand flats are simply healthy to begin with. If we add additional protection to an ecosystem that is already healthy, it is unlikely that we will see a large change in the health.

Looking at the fish diversity metrics, Shannon's and Simpson's 1-D, we see that overall, a high diversity exists both inside and outside of the MPAs. The percentages of live coral reef coverage are also what is considered a healthy reef ecosystem for all sites, inside and outside of MPAs. Lastly, we see that the density of *A. planci* is not high enough to be considered an outbreak, both inside and outside of the protected areas.

Future Work

Studying the effects of distance to a pass in the barrier reef against populations of *A. planci* would be interesting. A density map of *A. planci* would allow us to see if distance to a pass is a confounding factor in the numbers of *A. planci* found in Pihaena.

Night surveys of *A. planci* would allow us to get a more detailed view of the population distribution by cohorts instead of just a survey of the large adults. It is possible that the younger and smaller *A. planci* stay deeper and closer to the passes, relative to the larger adults which feed freely during the day.

Though not feasible for the scope of this project, a genetic analysis of the population of *A. planci* would be interesting to see if the local population is a result of multiple recruitment events, or a singular recruitment.

Simply running the same project again, but with more samples would be a great way to test the conclusions drawn from this project, and to potentially prove or disprove trends observed from this survey with multiple replications.

Including more of the MPAs would also be interesting to see, along with taking more data about the environment at the time of sampling. Data such as amount of ambient light, water turbidity, current speed, water temperature – then running an ordination against the data set to see if there are any factors that we may not have considered which are affecting the distribution of *A. planci*.

ACKNOWLEDGMENTS

I would like thank first and foremost my classmate Jennifer Hoey for all the hours spent in the field gathering data and dragging the gear all around the back reef from sample area to sample area. The GSIs and Professors for all their guidance and wisdom in how to setup a successful and relevant project. Jacques You Sing for driving us to our sample sites all over the north coast of Moorea. Frank Murphy for providing the station resources and logistics to get us to our sample sites. Jenny Oates, Christian McKeon, and Jenna Moore for the rides out in the skiffs when our kayaks sank. Wes for his superb advice on underwater filming and identifying fish on video. Ben Ginsberg, and Brandon Endo for the selfless use of their underwater video cameras, and subsequent sacrifices to leaky housings. Of course, all the support, advice and hugs from my classmates of the 2008 Moorea class.

LITERATURE CITED

Adjeroud, . "Detecting the Effects of Natural Disturbances on Coral Assemblages in French Polynesia: A Decade Survey at Multiple Scales." Aquatic living resources 18.2 (2005): 111-23.

Babcock, R.C., and C.N. Mundy. "Reproductive Biology, Spawning and Field Fertilization Rates of *Acanthaster planci*." Australian journal of marine and freshwater research 43.3 (1992): 525-34.

Barnes, J.H. "The Crown of Thorns Starfish as a Destroyer of Coral." AUSTRALIA NATUR HIST 15.(8) (1966): 257-61.

Berumen, . "Recovery without Resilience: Persistent Disturbance and Long-Term Shifts in the Structure of Fish and Coral Communities at Tiahura Reef, Moorea." Coral reefs 25.4 (2006): 647-53.

BRODIE, , and Brodie. "Are Increased Nutrient Inputs Responsible for More Outbreaks of Crown-of-Thorns Starfish? an Appraisal of the Evidence." Marine pollution bulletin 51.1-4 (2005): 266-78.

Brooks, A. "Fish Families found on Moorea" UC Santa Barbara (2001)

Chesher RH (1969) Destruction of Pacific corals by the sea star Acanthaster planci. Science 18:280–283

de Loma, . "A Framework for Assessing Impacts of Marine Protected Areas in Moorea (French Polynesia)." Pacific Science 62.3 (2008): 431-41.

Dulvy, N., Freckleton, R., and Polunin, N. (2004). Coral reef cascades and the indirect effects of predator removal by exploitation. Ecol. Lett. 7, 410–416.

ISRS (2004). Marine protected areas (MPAs) in management of coral reefs. Briefing Paper 1, International Society for Reef Studies.

McPhaden, MJ. "El Nino - the Child Prodigy of 1997-98." Nature 398.6728 (1999): 559.

Moore RJ (1978) Is Acanthaster planci an r-strategist? Nature (London) 271:56-57

Moran, P.J. and G. De'ath. "Estimates of the abundance of the crown-of-thorns starfish *Acanthaster planci* in outbreaking and non-outbreaking populations on reefs within the Great Barrier Reef." Marine biology 113.3 (1992): 509-15.

Ormond, R., Bradbury, R., Bainbridge, S., Fabricius, K., Keesing, J., DeVantier, L., Medlay, P., and Steven, A. (1990). Test of a model of regulation of crown-of-thorns starfish by fish predators. In Acanthaster and the Coral Reef: A Theoretical Perspective, R.H.

Porter, J.W. 1972. Predation by Acanthaster and Its Effect on Coral Species Diversity. The American Naturalist 106: 487-492.

Ports DC (1981) Crown-of-thorns starfish-man-induced pest or natural phenomenon? In: Kitching RL, Jones RE (ed) The ecology of pests. Some Australian case histories. CSIRO Melbourne, pp 55-86

Pratchett. "Feeding Preferences of Acanthaster Planci (Echinodermata : Asteroidea) Under Controlled Conditions of Food Availability." Pacific Science 61.1 (2007): 113-20.

Salvat, B. "Monitoring of French Polynesia Coral Reefs and their Recent Development." Revue d'écologie 63.1-2 (2008): 145-77.

Sweatman, . "A field-study of fish predation on juvenile crown-of-thorns starfish." Coral reefs 14.1 (1995): 47-53.

Sweatman, . "No-Take Reserves Protect Coral Reefs from Predatory Starfish." Current biology 18.14 (2008): R598-9.

Zann L, Brodie J, Vuki V (1990) History and population dynamics of the Crown-of-Thorns starfish Acanthaster planci (L.) in the Suva area, Fiji. Coral Reefs 9:135–144