# ABUNDANCE OF FISHED INVERTEBRATES IN MARINE PROTECTED AREAS AND UNPROTECTED AREAS AROUND MO'OREA, FRENCH POLYNESIA

LAUREN WILLIAMS

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

*Abstract.* In response to declining fish stocks, eight marine protected areas were established around the island of Mo'orea, French Polynesia, in 2004. Since then, follow up studies have shown increases in fish population. This study attempted to characterize the state of marine invertebrate fisheries around the island. Timed-effort snorkeling was used to estimate abundance of fished marine invertebrates, and habitat assessments were done by estimating substrate cover along a transect. There was no clear trend between all organisms studied, but there were significant differences found between marine protected and unprotected areas. The only significant difference in substrate cover of the habitats was algal growth, but visual surveys suggest minor differences between habitats are important.

*Key words: marine reserves,* Trochus niloticus, Tridacna maxima, Holothuria *spp., marine resources, reef fisheries*

## INTRODUCTION

The 2005 Millennium Ecosystem Assessment defined coastal systems as "places where people live and where a spate of human activity affects the delivery of ecosystem services derived from marine habitats" (Agardy et al. 2005). With rapid global population growth and increasing numbers of people migrating to coastal areas, these areas have experienced dramatic physical, hydrological and biological transformations. Heavy development, fishing pressures, and pollution have contributed to the decline of marine ecosystems as a whole, and continued growth will only make it increasingly difficult to rehabilitate or protect natural resources (Craik et al. 1990). Over the past century, technological advances have allowed for greater and greater fish catches in the open ocean, while growing coastal populations puts increased pressure on reef fish populations. Only recently has it become clear that global fish stocks have been severely overexploited and will require wholehearted conservation efforts in order to recover (Hutchings and Reynolds 2004). In particular, subsistence fishers will experience the effects of overfishing as the abundance and biodiversity of their stocks decline.

Mo'orea, on the windward end of the Society Islands chain in French Polynesia, supports a population of over 15,000 people and is encircled by a barrier reef that protects a 30 $km^2$ lagoon. In 2004, eight marine protected areas (MPA) were established around the island. These marine protected areas were created in response to the declining density of commercial fish following several cyclones that greatly depleted fisheries stocks in the late 1980s. While many barrier and fringing reef species were able to recover after these natural disasters, the inability of commercial fish to do so in both Mo'orea and Tahiti suggested that these species were overfished and needed a chance to repopulate (Lison de Loma et al. 2008). The marine protected areas are the result of le Plan de Gestion de l'Espace Maritime (PGEM) that "encompasses the entire lagoon and all waters beyond the reef crest out to a depth of 70 m on the outer reef slope" (Lison de Loma et al. 2008). The planners included local community leaders, government officials, researchers, and non-governmental organizations. Five of the eight MPAs they created are on the northern side of the island since most of the tourism activity occurs here, in addition to the significant portion of the population that lives along this coast.

A recent study analyzed the effects of the MPAs on *Acanthaster placi* populations, but with inconclusive results as to whether the MPAs were replenishing predatory fish populations to help control *A. placi* (Park 2008). Additionally, a six year study comparing the before and after effects of MPAs on commercial fish populations showed positive correlations between MPA and fish biodiversity and population size, but invertebrates were not studied closely (Kernaleguen et al. 2009). With the exception of these studies, little research has been done to document how effective the MPAs have been in protecting all aspects of the lagoon marine resources. Conversations with Hinano Murphy and Arsène Stein, Tahitians knowledgeable about local fishing practices, suggest that residents often disregard the MPA boundaries when collecting invertebrates (pers. com.). Fishers with spearguns frequently hunt within MPA boundaries, while at low tide people have been observed walking along the algal ridge for invertebrate collection.

Much of Mo'orea's population still relies on local produce and subsistence fishing within the lagoon for basic food staples such as fish, *Tridacna maxima*, marine snails *Trochus niloticus, Turbo setosus* and *Turbo marmarotous*, and occasionally *Holothuria* spp. for use as bêche-de-mer. However, over the past 2 decades, government initiatives and funding have played a major role in transforming local food production and small scale economies into tourism and export agriculture (Walker and Robinson 2009). In addition to this economic change, Mo'orea's population has grown, putting increasing pressure on local reef fisheries. Although the introduction of western cultures into the pacific islands has varied native diets, many islanders still rely on subsistence fishing and collecting marine invertebrates as an important source of protein in their diets. Populations of marine invertebrates are vulnerable to subsistence harvesting as island populations increase, especially because lagoon reef areas and resources are limited (Dalzell and Adams 1996).

This study examined whether marine protected areas have been an effective way for the government to regulate invertebrate collection. Populations of *Trochus niloticus, Tridacna maxima, Holothuria* spp. and *Turbo* spp. were compared between MPAs versus unprotected areas. If MPAs actually reduce fishing and invertebrate collecting, these population numbers should be greater in MPAs than in unprotected areas because they will experience less collecting pressure.

## METHODS

### *Study Sites*

Sampling was conducted in three of the eight marine protected areas: AMP de Tiahura, located at the northwest corner of Mo'orea, east of Motu Tiahura; AMP de Pihaena, located on the northern coast at the entrance of Cook's Bay; AMP de Nuarei, located on the northeast corner at Temae

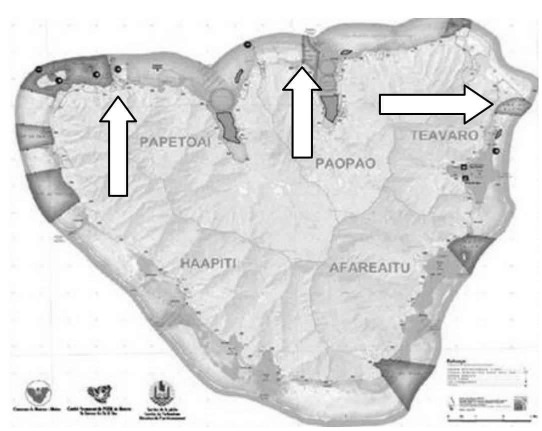


FIG 1. Study sites indicated with arrows

public beach.

The east, west, and southern reefs were not sampled because a variety of other factors such as currents, different ecological conditions, and the size of the human population would have been introduced into the study, possibly influencing my results. All sampling was done between October 14th of 2010 and November 12th of 2010, between the hours of 0830 and 1300.

*Study Organisms*

The mollusc *Trochus niloticus* is a large marine gastropod found throughout most of the Indo-Pacific, inhabiting shallow intertidal and subtidal reef habitats. It was introduced to Tahiti from Vanuatu in 1957 and then to Mo'orea in 1963 as a potential export good and to augment reef fisheries for subsistence and commercial fishing (Gillett 2002). While its population numbers in Mo'orea are not thought to be threatened, they have been overfished elsewhere in the Pacific and they now need stock enhancement or reintroduction to those areas. *T. niloticus* fisheries are commonly regulated by minimum and maximum size limits, short fishing seasons, and through the creation of marine reserves (Bell and Gervis 1999).

*Tridacna maxima*, commonly known as giant clams, are bivalve mollusks found throughout the South Pacific and Indian Ocean. They attach themselves to rocks, can be partially embedded in coral, or on the sea floor, and rely on symbiotic interactions with zooxanthellae, tiny photosynthetic algae that live in their mantle, for most of their energy production (Munro 1993).

*Turbo marmoratus*, commonly known as the green snail, has been introduced several times to the lagoon reefs, but populations are highly exploited for their shells and meat. They tend to occupy similar habitats as *T. niloticus*, and are primarily found in reef crest habitats between 1 and 5 meters in depth (Yamaguchi 1997). *Turbo setosus*, the smaller of the two *Turbo* spp. snails, is native to the barrier reefs and algal ridge habitats in French Polynesia but has experienced such high levels of overfishing that they are now much less numerous than they once were (Hutchings et al, 1994).

*Holothuria* spp., commonly known as sea cucumbers, usually inhabit areas with sandy sediment, where they feed on bacteria and organic matter in the sand. Sea cucumber distribution is dependent on food availability, and they are less common at barrier reefs and back reefs than coastal reef flats, but large commercial species can be found near the barrier reef. Sea cucumbers are collected for use as bêche-de-mer, a dried and dehydrated form that is often shipped to China for sale in Asian markets but its consumption has spread throughout the Pacific (Preston 1993).

*Timed-effort*

All sampling was done by snorkeling, and each sample consisted of a one-hour timed effort where the area covered was scrutinized for *Holothuria* spp., *T. niloticus*, *T. maxima*, and *Turbo* spp. During that hour, the shell diameters of all *T. niloticus*, *T. Maxima*, and *Turbo* spp. were recorded. When the organisms were inaccessible due to danger from urchins or fire coral, mean basal diameter was estimated. Snorkeling occurred within 120 meters of the algal ridge starting at

FIG 2. Timed-effort snorkeling at Nuarei.

the back reef and proceeded in a zig-zagging pattern toward the algal ridge.

Five replicates were done at each site in order to ensure a thorough search and to account for days with poor visibility or strong currents, and each replicate was picked haphazardly in the back reef habitat near the algal ridge. Start and end locations were documented to ensure that replicates did not overlap on subsequent sampling days.

Adjacent sites were selected just outside of the protected areas for use as paired comparisons to assess the effectiveness of MPAs. To create a buffer zone between the edge of the MPA and unprotected area, at least 30 meters were left between the edge and where I began sampling within the MPA.

### *Habitat Assessment*

At each site, a habitat assessment was also conducted in order analyze habitat preference for the study organisms and as a way to account for possible differences in population sizes.

Habitat assessments consisted of one transect at each study site, beginning at the algal ridge and extending 100 meters toward the shore. Along this transect, a 1 meter by 1 meter quadrant was placed every 20 meters starting at 0 meters. In each quadrant, the percent rubble, sand, dead coral, live coral, and algae were measured, as well as the density of coral heads in that quadrant. Density was recorded as dense (<1 m between corals), medium (1-1.5 m between corals) or sparse (>1.5 m between corals).

### *Statistical Analysis*

I compared the abundance of each species with histograms, and analyzed the results with Chi-Squared and one-way ANOVA tests. The statistical tests analyzed whether the invertebrate populations differed enough to be statistically significant between the paired sites.

Using the size data, I created age-size distributions of individuals in each sample site to estimate how many mature versus young organisms inhabit the back reef and barrier reef habitats. Kolmogorov-Smirnov tests computed the difference between  if the age-size distribution at each site differed enough to be statistically significant.

Habitat characteristics were analyzed with a two-way ANOVA test to see what differences existed between percent cover of substrate at each site.

## RESULTS

### *Trochus niloticus*

The timed-effort snorkeling samples in each site show drastically different results in each paired protected area versus unprotected area (FIG. 3). One way ANOVA tests confirm the significance of differences at ($X^2$=28.973, DF=1, P<.0001*), and Tiahura ($X^2$=152.66, DF=1, P<.0001*). In AMP de Nuarei, only slightly more *T. niloticus* are present in unprotected areas than in protected areas ($X^2$=1.2266, DF=1, P=.2681),. Significantly more organisms are observed in AMP de Pihaena

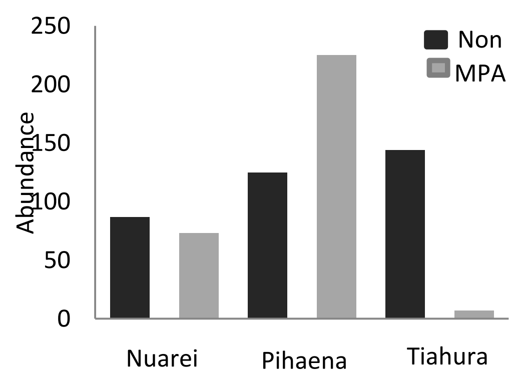


FIG 3. Abundance of *T. niloticus* at each site

than in the unprotected site, while at AMP de Tiahura there is an extremely low abundance in the protected area and many more individuals in the unprotected area. Analysis of the data using chi-squared tests shows statistically significant differences between sites (P<.0001, DF=2).

Age-size distributions of *T. niloticus* populations at each site show that most individuals fall into the 11 to 14 cm range, with a few smaller individuals. Kolmogorov-Smirnov tests indicate no significant difference between the age-size curves for the protected and unprotected areas at Nuarei (D=.1021, P=.797) and Pihaena (D=.1431, P=.067). Too few organisms were present in the Tiahura protected area to compare to the unprotected area.

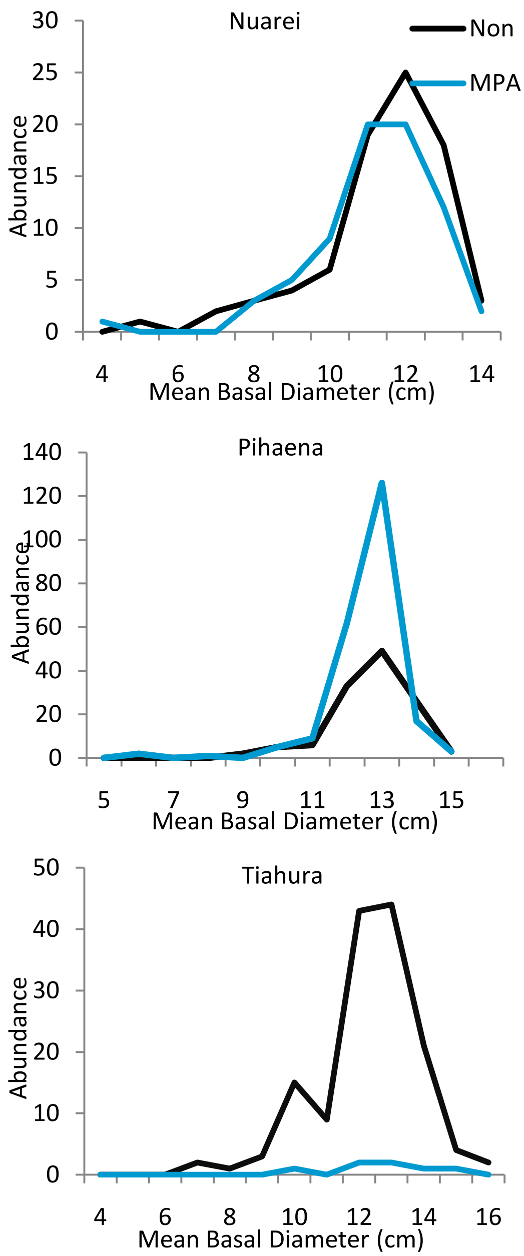


FIG 4. Age-size distribution of *T. niloticus* between protected and unprotected area

*Tridacna maxima*

Across all three paired sites, higher abundances of *T. maxima* are found in the unprotected areas than in the protected areas. As shown in Figure 5, the abundances in paired sites Nuarei and Tiahura are similar, while only organisms sampled at Pihaena show a noticeable difference. One way ANOVA tests confirm the significant difference in population at Pihaena ($X^2$=31.3093, DF=1, P<.0001*), and lack of significance at Tiahura ($X^2$=.6184, DF=1, P=.4316) and Nuarei ($X^2$=2.5736, DF=1, P=.1087). A statistically significant difference between all the sites is illustrated using chi-squared tests for analysis (DF=2, P=.0002*).

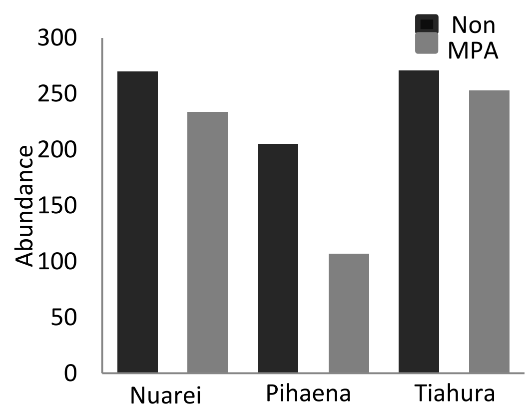


FIG 5. Abundance of *T. maxima* at all sites

The diagrams illustrating the age size distribution within each site show that *T. maxima* in protected areas and unprotected areas follow a similar bell curve shape, so the populations at each paired sites are similar in age (Fig. 6). Kolmogorov-Smirnov tests at each site confirm that there are no significant differences between age-size distribution in protected areas and unprotected areas. At Nuarei, D=.0484 and P=.924; at Pihaena, D=.1274 and P=.189; at Tiahura, D=.0494 and P=.897.

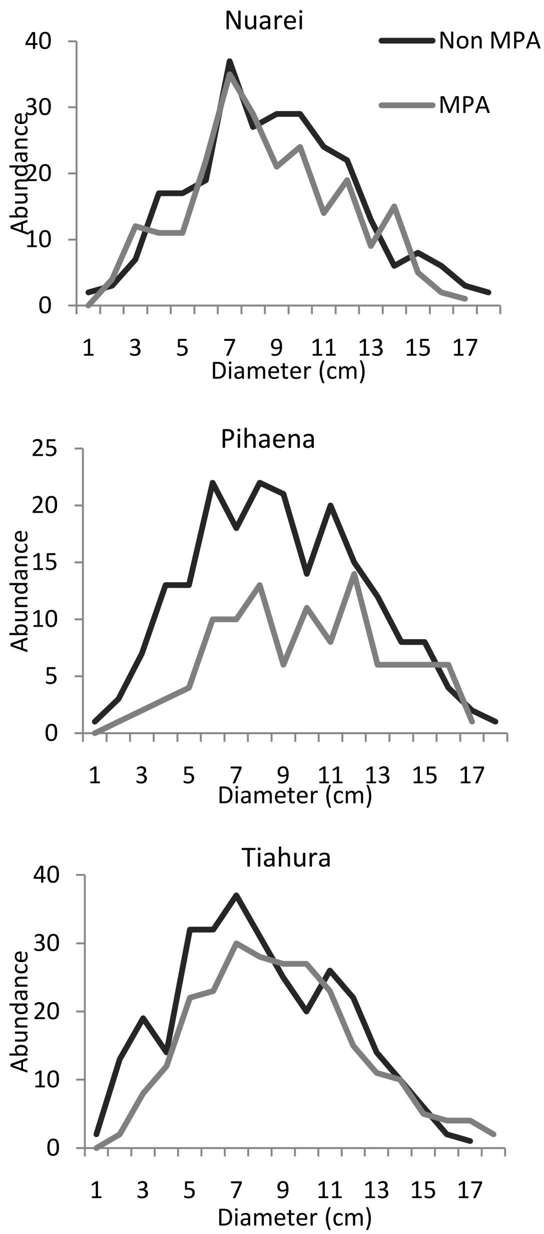


FIG 6. Age-size distribution of *T. maxima*

*Other Study Organisms*

At all paired sites, abundance of *Holothuria* spp. is greater within protected areas than in unprotected areas (Fig. 7), and chi-squared statistical analysis shows that the differences between protected and unprotected areas at all sites are significant (DF= 2, P<.0001). This was supported by one-way ANOVA tests at each paired protected versus unprotected site where there were significant differences at Nuarei ($X^2$=16.225, DF=1, P<.0001*), Pihaena ($X^2$=292.694, DF=1, P<.0001*), and Tiahura ($X^2$=28.941, DF=1, P<.0001*).

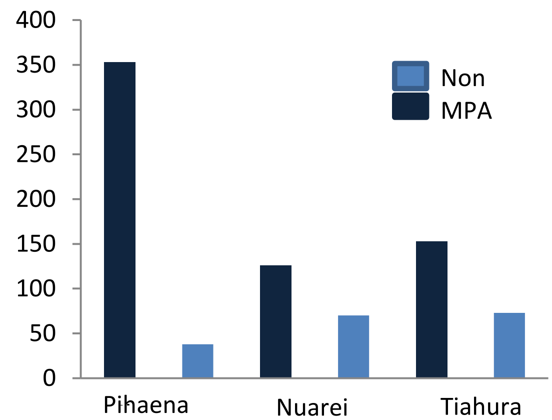


FIG 7. Abundance of *Holothuria* spp. at all sites

*Turbo marmoratus*, the other primary focus of this study, occurs very infrequently and in such small numbers that they were not included in the results, and no *Turbo setosus* were found over the course of the study.

*Habitat Assessment*

Habitat assessments quantified the amount of cover of different substrates, and two – way ANOVA tests between each of the habitat characteristics portrayed their significance (Fig. 8). The only characteristic that differed significantly between both MPAs and sites was algae, which had higher levels in all of the unprotected areas than in the protected areas (DF= 35, P= .0207*). Although rubble cover was not statistically significant, the three sites with the highest percentage of coral cover each have over 40% rubble substrate.

## Discussion

*Trochus niloticus*

Analysis of the abundance of *Trochus niloticus* at all three paired sites shows that there is not a consistent relationship between

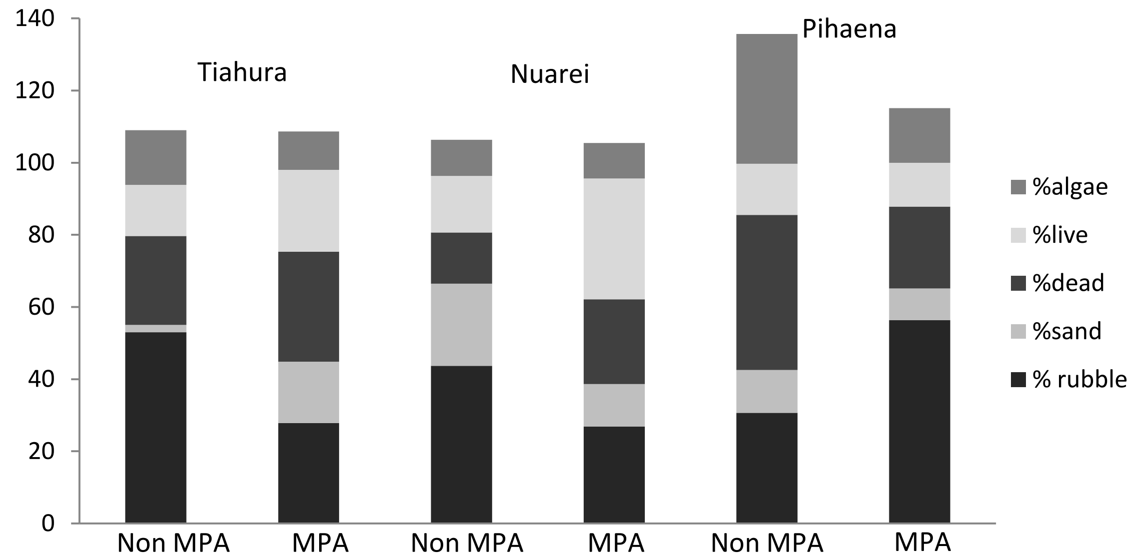


FIG 8. Habitat assessment shows slight differences between habitat characteristics at each site. Two-way ANOVA tests gave the following results: algae (F= 3.16, DF=35, P=.0206*), live coral (F=1.3455, DF=35, P=.2725), dead coral (F=1.2187, DF=35, P=.3246), sand (F=1.8134., DF=35, P=.1403), rubble (F=.8671, DF=35, P=.5146)

observed population size and whether the snails were found inside or outside the MPA, suggesting that the ban on fishing in protected areas has not affected population sizes of this species. While the graphs and statistical analysis do not show an obvious trend between protected and unprotected areas, it is evident that there is a significant difference between the sites and population sizes, suggesting that a variety of factors may be playing a part in determining population size.

Midden piles of broken shells found in both protected and unprotected areas confirm that fishing occurs periodically and indiscriminately, but the presence of midden does not necessarily reflect the scale at which collecting occurs, and fishing pressure could also depend on the accessibility of each site. For example, AMP de Nuarei can be accessed by wading to the algal ridge and AMP de Tiahura is close to a boat launch point while AMP de Pihaena is only easily accessible by fishers with boats moored at their private docks.

Habitat assessment of substrate cover indicates significant differences between algal cover, which could be influencing the population size of *T. niloticus* at the three sites where population numbers are highest: unprotected and protected areas at Pihaena, as well as the unprotected area at Tiahura. While the statistical analysis didn't detect any other significant differences between substrates, during sampling I noticed greater quantities of sand and rubble at AMP de Pihaena, where drastically more *T. niloticus* were located.

Age-size distribution shows that the marine protected areas are not acting as a source to repopulate surrounding areas because most of the individuals at each paired site were close in size to one another and had a large mean basal diameter. A previous study on *T. niloticus* growth and abundance in New Caledonia found that they take 10 years to reach 12 cm in diameter (Bouchet and Bour 1980, in Smith 1987) and 15 years to reach a 14 cm diameter in Guam (Smith 1987). Therefore, most individuals observed on Mo'orea hatched prior to the implementation of protected areas in 2004 and do not reflect population growth due to protection. It is likely that so few juveniles were observed because they are small enough to hide from predators during the daytime, and only come out of their crevices and from under corals to feed at night, so were hidden from view when sampling occurred.

### *Tridacna maxima*

Tridacna maxima for all paired sites had larger populations in unprotected than protected areas, differing from expected results. Additionally, this is surprising because midden piles of clam shells are present in the unprotected areas, where populations are larger. If the presence of fishing in these areas was affecting population sizes, the presence of midden piles would likely be correlated with lower population sizes. From this, it appears that collecting *T. maxima* is not a significant problem and is not negatively affecting population sizes, so abundance must be influenced by other factors as well.

The only population with significantly different abundance occurred within the Pihaena protected area, likely influenced by the habitat characteristics rather than overfishing. For example, it was noticed when observing the large population of *T. niloticus* at Pihaena that the protected area is dominated by sand and rubble, and has the lowest proportion of live and dead coral that make up the preferred habitat for *T. maxima.*

The lack of a statistically significant difference between the age-size distributions means that the populations in both the protected and unprotected areas are the same for each site. However, it is possible that the population in the protected areas is acting as a "source" population and is helping to restore the population in the unprotected area.

### *Holothuria* spp.

The abundance data for *Holothuria* spp. suggests that the creation of marine reserves has had a positive effect on their population sizes. However, people collect *Holothuria* spp. for bêche-de-mer less frequently than they collect *T. niloticus* or *T. maxima*, insinuating that collecting pressure has not been dramatically affected by protected areas.

The results of this study do not provide strong evidence that the protected areas around Mo'orea are having a positive impact on the fished marine invertebrates, but it is important to understand that the marine protected areas on Mo'orea were originally established to protect commercial reef fish populations, and did not necessarily take into account the ideal habitat for invertebrates. These results cannot be compared to previously published research because on Mo'orea there have not been recent studies on the abundance of fished marine invertebrates. However, other studies that show indicate a positive effect on fish populations found that invertebrate populations do not always increase with the creation of marine reserves (Halpern 2003).

Therefore, follow up studies could build on this preliminary research to determine if the creation of marine reserves is actually leading to an increase in abundance. It would also be beneficial for the Service de la Pêche or other management organizations to enforce reserve boundaries to eliminate the fishing and collecting that frequently occurs in the protected areas around Mo'orea.

## CONCLUSION

Marine reserves have a great deal of potential as a management strategy to restore or strengthen fish and invertebrate populations. With few exceptions, they are able to increase biomass, diversity, and organism density regardless of the size of the reserve (Halpern 2003).

This study suggests that collecting may occur at a low level relative to total population size and that it is not the determining factor of abundance. While fishing and collecting definitely occurs in both protected and unprotected areas, it is likely that other factors such as habitat characteristics and environment primarily determine the population sizes of these marine invertebrates.

The creation of Marine Protected Areas around Mo'orea has been a positive step towards creating a sustainable reef fishery, and protected areas need continued monitoring and attention in order to ensure their success in future years.


## Acknowledgments

I would like to thank all the professors, particularly George Roderick for his help with my statistics and figuring out my results. Thank you to Erin Meyer for your insight in developing my project, both with initial ideas and experimental design. Thank you Hinano Murphy for giving me background information about the cultural and traditional importance of the species I wanted to study. Thank you to Arsène Stein from la Service de la Peche for your knowledge about local fisheries, the establishment of Marine Protected Areas and the history of *Trochus niloticus* on Mo'orea. Thank you to the staff at the Richard B. Gump Station for all your hard work. I would like to thank Team ELAC for contributing to the incredible experience on Mo'orea, and Carrie Boyle, Charlotte Leger and Chris Feng for being my field buddies and braving the elements with me on long kayak rides and through treacherous currents. Finally, I could not have had the opportunity to develop my research project without Mark and Karen Williams, who supported me and made this field work possible.


## Literature Cited


Adams, T. 1998. The interface between traditional and modern methods of fishery management in the Pacific Islands. Ocean & Coastal Management, 40:127-142.

Agardy, T., Alder, J., Dayton, P., et al. 2005. Coastal systems. *in* Hassan R., Scholes R., and Ash, N (editors), *Ecosystems and Human Well-Being: Current Status and Trends*, Island Press, Washington DC: 795–825.

Bell, J. D., and M. Gervis. 1999. New species for coastal aquaculture in the tropical Pacific: constraints, prospects, and considerations. Aquaculture International 7:207–223.

Craik, W., Kenchington, R., and Kelleher, G. 1990. Coral-Reef Management. *in* Dubinsky, Z., editor. *Ecosystems of the World 25: Coral Reefs.* Elsevier, New York, pp. 453–467.

Dalzell, P., and Adams, T.J. Sustainability and management of reef fisheries in the Pacific Islands. 8th International Coral Reef Symposium. Panama City, Panama 24-29 June 1996.

Dolorosa, G. *et al*. 2010. Population structure and abundance of Trochus niloticus in Tubbatah Reefs Natural Park, Palawan, Philippines with notes on poaching effects. SPC Trochus Information Bulletin #15: 17-23.

Gillett, R. 2002. Pacific Islands Trochus introductions 1927-1998. SPC Trochus information Bulletin #9. 9-13.

Halpern, B.S. 2003. The impact of marine reserves: do reserves work and does reserve size matter?. Ecological Applications 13 (1): 117-137.

Heslinga, G.A., Orak, O. & Ngiramengior, M. 1984. Coral reef sanctuaries for Trochus shells. Marine Fisheries Review 46 (4): 73-80.

Hutchings, J.A and Reynolds, J.D. 2004. Marine Fish Population Collapses: Consequences for Recovery and Extinction Risk. BioScience 54 (4): 297- 309.

Hutchings, P., Pyri, C., Gabrie, C. 1994. The current status if coral reef management in French Polynesia. Marine Pollution Bulletin 29 (3): 26-33.

Lison de Loma, T., Osenberg, C.W. et al. 2008. A Framework for Assessing Impacts of Marine Protected Areas in Mo'orea (French Polynesia). Pacific Science: 427-437.

McCutchan, M. 1998. Suggestions for management of *Trochus niloticus* stocks based on size-selection by people who collect the marine snail for its meat. Biology and Geomorphology of Tropical Islands: 120-129.

Munro, J. 1993. Chapter 13: Giant Clams. *in* Wright, A, and Hill, L, editors. Nearshore marine resources of the South Pacific. IPS and FFA, Suva, Honaria: 432-450.

Park, A. 2008. Effects of Marine Protected Areas on the population of *Acanthaster planci* in Mo'orea, French Polynesia. Biology and Geomorphology of Tropical Islands: 160-167.

Preston, G.L. 1993. Chapter 11: Beche-de-mer. *in* Wright, A, and Hill, L, editors. Nearshore marine resources of the South Pacific. IPS and FFA, Suva, Honaria: 371-410.

Smith, B. 1987. Growth rate, distribution and abundance of the introduced topshell *Trochus niloticus* Linnaeus on Guan, Mariana Islands. Bulletin of Marine Science, 4 (2): 466-474.

Walker, B.L and Robinson, M.A. 2009. Economic development, marine protected areas and gendered access to fishing resources in a Polynesian lagoon. Gender, Place & Culture, 16: 4, 467 — 484.

Yamaguchi, M. 1997. A synopsis of the biology of the green snail (*Turbo marmoratus*). *in* Workshop on Trochus resource assessment, management, and development. Integrated Coastal Fisheries Management Project. Technical Document 13: 136-142.