# ASSESSING THE EFFECTIVENESS OF MARINE PROTECTED AREAS ON LARGE GASTROPOD STOCKS

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Abstract. Marine protected areas (MPAs) have been promoted as an effective tool to manage marine resources and increase species abundance; however, there is considerable scientific doubt about their ability to do so. In 2004, eight MPAs were created around the island of Moorea, French Polynesia, in response to a decline in fish and invertebrate stocks. This study attempted to assess the effectiveness of the MPAs on Moorea by examining the size and abundance of two commonly harvested gastropods, Tectus niloticus and Turbo marmoratus, inside and outside of MPAs. This study examined six MPAs and six paired non-MPA sites by performing transects along the algal ridge and slope, recording the size and abundance of T. niloticus and T. marmoratus. This study found that there was no significant difference in the abundance of live *T. niloticus* and *T.* marmoratus between MPAs and paired non-MPA sites. Furthermore this study found that significantly more dead T. niloticus exist in MPAs than paired non-MPA sites while dead T. marmoratus abundance did not differ significantly between MPAs and paired non-MPA sites. Lastly it was found that the average size of both live and dead *T. niloticus* and T. marmoratus did not differ between MPAs and paired non-MPA sites. The results of this study suggest that either: (a) the harvesting pressure on T. niloticus and T. marmoratus is low relative to total population size; or (b) that harvesting is happening in both MPAs and non-MPAs indiscriminately due to a lack of enforcement.

*Key words: gastropods; conservation; marine protected areas; Moorea, French Polynesia;* Turbo marmoratus; Trochus niloticus; Tectus niloticus

#### **INTRODUCTION**

Fisheries are important to the economy and wellbeing of global communities (FAO 2014). Today fisheries provide about 16% of the total human protein consumption, with higher percentages occurring in developing nations (FAO 2014). However, due to the constant increase in human population and development of modern fishing technologies, the oceans have been and are overfished (FAO 2014). With predicted increasing human population growth, protecting and restoring marine ecosystems will become increasingly necessary (FAO 2014).

Globally in the last ten years, marine protected areas (MPAs) have become a popular form of marine resource management (Kelleher et al. 1995). The protection of aquatic areas, and in particular MPAs, is a comparatively recent concept compared with the protection of terrestrial areas. While the oceans comprise over 70% of the earth's surface, MPAs currently cover less than 1% of the earth's surface, whereas terrestrial protected areas cover nearly 9% of the earth's surface (Day et al. 2002). It is now generally recognized that MPAs are an important tool in marine conservation as they can provide unique protection for critical areas and spatial escape for overexploited species (Kelleher et al 1995, Branch and Odendaal 2003, Terlizzi et al. 2004). MPAs also benefit fisheries through leakage of 'surplus' adults (spillover) and larvae (larval replenishment) across reserve boundaries (Boersma et al. 1999) which helps maintain biodiversity and large population size both within and outside of MPAs.

One group of organisms that are indiscriminately harvested and over-exploited around the world are the marine gastropods (FAO 1999). Marine gastropods are subject to small-scale harvest for subsistence as well as commercial harvesting (FAO 1999). Globally, marine gastropods are utilized as a common source of protein, particularly for people in the developing countries of the Indo-Pacific region (Poulsen 1995). They are also harvested for shell craft production, buttons, jewelry, mother of pearl and the ornamental shell trade which includes some 5000 mollusk species (Nash 1993, Poulsen 1995). To continue such widespread use, it is important that this resource be harvested in a sustainable manner to ensure its presence for future generations (FAO 1999). However marine protected areas have been an effective resource management technique for commonly harvested gastropods in certain places around the world (Branch and Odendaal 2003).

Coral reef-associated gastropod fauna exhibit low population densities and a range of life histories (Kohn and Nybakken 1975; Endean and Cameron 1990 in Poulsen, Ann L. 1995). Furthermore many gastropod (and fish) species are slow growing and can take many years to reach sexual maturity, which makes them very susceptible to overfishing (Bouchet and Bour 1980, in Smith 1987, Smith 1987, Cledon, et al. 2008). Comparison of body size inside and outside of MPAs can be used to reveal the extent that fisheries are truncating size/age structure. Such comparisons can help reveal if MPAs are indeed serving as effective nurseries and providing a safe refuge for reproduction and the full expression of the life history. Unfortunately, MPAs are rarely monitored, leaving it unclear whether they are as an effective tool as they could be. Because of this it is crucial to monitor the stocks of harvested species most commonly poached by humans inside and outside of MPAs to assess the effectiveness of the MPAs. A good example of this issue comes from the MPAs surrounding the island of Moorea in French Polynesia.

In the early 1980s Moorea was struck by series of severe cyclones, which disturbed reef habitats, greatly reducing fish density and species richness (Harmelin-Vivien 1994, Lison de Loma et al. 2008). Since the cyclones of the 1980s many unfished species have increased in abundance in the barrier and fringing reef habitats of Moorea, whereas many commercially fished species have not. This result suggests that they had been overharvested prior to the cyclones of the 1980s (Lison de Loma et al. 2008). In Moorea, concerns about this overfishing led to the implementation of a comprehensive marine management plan, The Plan de Gestion de l'Espace Maritime (PGEM, JOPF 22/10/04). Established in 2004, the PGEM created eight MPAs or no take zones along the coast of Moorea, with five of the eight located on the northern side of the island (Fig. 1). In this region many gastropods are commonly harvested for food, shells, and nacre (mother of pearl). Green snails (Turbo marmoratus), other turbo species and topshell snails (Tectus niloticus) are most commonly harvested for food in Moorea and throughout the indoPacific (FAO 1999, "H. Murphy, personal communication").





In 2010 a study on the size and abundance of commonly harvested marine invertebrates Tectus niloticus and including Turbo marmoratus was conducted inside and outside of Moorea's MPAs to evaluate the effectiveness of them. The results of this study provided only weak evidence that there were differences in abundance or average size of harvested gastropods between MPAs and non-MPAs (Williams, 2010), suggesting the MPAs may not be serving their desired function.

The overall goal of this study is to reassess the effectiveness of the MPAs on Moorea and reexamine the three MPA sites studied in the 2010 Williams study. This study will include a total of 6 MPAs, including the original three. The larger sample size will allow a more rigorous examination of differences in abundance and body size between MPAs and non-MPAS. Assuming the MPAs on Moorea offer refuge to certain collected species from harvesting, I hypothesize that the abundance and average size of commonly harvested gastropods will be higher inside then outside of the MPAs.

#### METHODS

#### Study site

The island of Moorea is a high island in the Society Islands, French Polynesia, situated 17.32' south and 149.50' west, just 17 km northwest of Tahiti. Moorea formed as a volcano 1.5 to 2 million years ago, the result of a geological hot spot, which formed the whole archipelago (Faure 1989). Since its formation much of the island has eroded leaving a barrier reef encircling the island with 11 passes cut in it. (Faure 1989) Like most high island reef complexes, Moorea exhibits a fore reef slope, reef crest, back reef, lagoon and a fringing reef.

A total of nine sites were selected to survey on Moorea (five MPAs and four paired control sites, two MPAs shared a paired site). The five MPAs chosen were Tiahura Motu, Pihaena, Nuarei, Motu Ahi and Tetaiu. MPA Tiahura Motu and MPA Tetaiu were geomorphologically similar and thus shared a paired site. Two different areas were surveyed at Motu Ahi, Ahi and Ahi 2. Each of the MPA sites was uniquely paired with its own Control site based on proximity and geomorphology (Fig. 2).

Paired sites were visually assessed comparing depth, percent cover of different types algae, live and dead coral, sea floor composition, rubble and sediment type, physical characteristics such as spurs and grooves on the reef slope or inlets and pockets along the back reef, current and wave action was also assessed. Only paired sites with similar geomorphologies were surveyed. This was done to help remove confounding factors, which may interfere with gastropod abundance.



FIG. 2. Study sites. Green stars indicate sites inside of MPAs and Red stars indicate paired sites outside of MPAs.

Preliminary transects along the Pihaena MPA fore reef slope, reef crest, back reef, lagoon and fringing reef, were done to determine where *T. niloticus* and *T. marmoratus* abundance is greatest so study effort could be focused to certain reef environments.

Preliminary transects were preformed using 50 meter by 4 meter transects, the abundance of *T. niloticus* and *T. marmoratus* were recorded for each reef environment (Fig. 7). The reef crest/algal ridge and fore reef slope supported a significantly different gastropod population than other reef environments, shown in (Fig. 7). Because of this all latter surveys were performed on the back reef side of the algal ridge or reef slope.

Four of the five MPAs studied were located on the northern side of the island with Motu Ahi being the exception located on the southeastern side. All sites exhibited normal reef characteristics except for MPA Nuarei and its paired site which lacked a channel. At all sites the algal ridge was the primary focal point of surveys and was approximately 1 km from shore at all sites. The environment of the algal ridge at paired sites varied slightly with location but in general shared the similar characteristics of heavy surf, shallower water, less live coral and high amounts of different algae and high amounts of sediment and ruble along the back side. The reef slope of paired sites was characterized by having gradually deepening water along a dead coral pavement with little to no sediment or live coral, but exhibited a thin layer of red algae. The slope often times exhibited spurs and grooves. Surveys were performed along the shore side of the algal ridge or along the top, if the environment permitted. Surveys along the slope were done just behind where waves start to feel bottom and focused on regions which exhibited a thin layer of red algae.

# Study Organisms

*Tectus niloticus,* the commercial topshell snail is a large (up to 15 cm) indo pacific gastropod. It was introduced to Tahiti from Vanuatu in 1957 and then to Moorea in 1963 as a potential export good and to augment reef fisheries for subsistence and commercial fishing (Gillett 2002). Due to the many uses of this marine animal it has been over harvested in many regions of the South Pacific (FAO, 1999). However the population in Moorea does not appear to be threated.

*Turbo marmoratus,* the green snail, is the largest herbivorous gastropod, which inhabits the shallow reefs of the Indian Ocean and Indo Pacific. In 1967, 42 *T. marmoratus* were introduced to Tahit from Vanuatu as a potential export good and to augment reef fisheries for subsistence and commercial fishing (Andrefout et al. 2014). It was later

introduced to Moorea in 1980 (Andrefout et al. 2014). Because of their highly valuable nacreous shell and prized meat they have been exploited extensively and are now rare or extinct in many areas where they were once abundant. In French Polynesia T. marmoratus has been protected since 1977 because poaching posed an apparent threat to their dispersal and establishment. However in 1993, 1995 and 2000 the complete ban was revoked, and fishing was authorized for short periods. Legal fishing in Tautira Tahiti yielded more than 53,000 shells in 1993, sold for 800,000US\$. In contrast, the fishery in 2000 vielded only 3,000 shells sold for 21,000US\$. Whether the smaller harvest in latter years is the consequences of overfishing in 1993 is unknown, but likely (Andrefout, et al. 2014). Today in Moorea, despite T. marmoratus still being protected, their abundance is scarce. A 2010 study which looked at the abundance of commonly fished invertebrates reported that T. marmoratus occurs very infrequently and in such small numbers that they were not included in the results (Williams, 2010). It is imperative to assess their current stocks and distribution around the island within and outside of MPAs.

#### Surveys

To assess the abundance and average size of both *Tectus niloticus* and *Turbo marmoratus* inside and outside of marine protected areas surveys were preformed by snorkeling along a variety of geomorphologicaly different reef units on Moorea: forereefs, reef crests, back reefs, lagoons and fringing reefs. In each location the abundance and size of *T. niloticus* and *T. marmoratus* were recorded. The shore side of the algal ridge was the most commonly surveyed reef type. Due to dangerous hydrodynamic conditions (current and waves) the reef slope was not surveyed as frequently.

At each survey site GPS coordinate were recorded (Table. B1). Surveys were performed using 50 meter by 4 meter transects, set up by transect tapes. Transects were preformed a minimum of 150 meters inside or outside of MPAs and were aligned parallel to the reef crest, outer slope or shore. Then each transect was thoroughly searched using a sweeping pattern from one end to the other recording and measuring each snail as it was encountered. Time spent along transects varied depending on environmental conditions.

Counts and measures were performed by bringing snails to the edge of the transect were they were photographed next to the transect tape to measure size. Then each snail was placed outside of the transect to prevent possible recounting. Photographs were later analyzed using ImageJ (Abramoff, 2004) to record size of each individual and count for species abundance. To measure *T. niloticus* the greatest diameter of the shell was recorded. To measure *T. marmoratus* the greatest diameter of the operculum was taken and the base of the shell was measured from the suture to the basal lip.

# Data Analysis

A Wilcoxon signed-rank test (Ambrose, 2007) was used to test whether the abundance of live *T. niloticus* and *T. marmoratus* was significantly different between MPAs and paired sites. The same test was also used to determine if the abundance of dead *T. niloticus* and *T. marmoratus* was significantly different between MPAs and paired sites. Paired t-tests (Ambrose, 2007) were used to determine if there was a significant difference in the size of *T. niloticus* and *T. marmoratus* between MPAs and non MPAs. Paired t-tests were also used to determine if there was a significant difference in the size of *determine* if there was a significant difference and *T. niloticus* and *T. marmoratus* between MPAs and non MPAs.

# RESULTS

The average abundance of live *T*. marmoratus inside of MPAs and in paired non-MPA sites was 6.3 and 3.16 snails per survey (Fig.3) The average abundance of live T. niloticus inside of MPAs and in paired non-MPA sites was 33.8 and 28.8 per survey, respectively (Fig. 3). The abundance of live snails did not differ significantly between MPAs and paired sites for either *T. marmoratus* (Wilcoxon rank-sum, W = 20.5, df = 5, p>0.05, Fig. 3) or *T. niloticus* (Wilcoxon rank-sum, W = 20, df = 5, p>0.05, Fig. 3). Power analysis showed that a sample size of n=37.4 for T. marmoratus and n=329 for T. nilocticus would be required to determine significant differences between MPA and non-MPA sites at a statistical power of .80. The abundance of live T. niloticus and T. marmoratus found at each MPA and paired non-MPA varied across sampling sites (Fig. A1).



FIG. 3. Average abundance of live *T. niloticus* and *T. marmoratus* in MPAs and paired no-MPA sites.

The average abundance of dead *T*. marmoratus inside of MPAs and in paired non-MPA sites was 1.8 and 2 snails per survey, respectively (Fig. 4). The average abundance of dead T. niloticus inside of MPAs and in paired non-MPA sites was 6.67 and 1.66 snails per survey, respectively (Fig. 4). There was no significant difference in abundance of dead T. marmoratus between MPAs and their paired sites (Wilcoxon rank-sum, W = 16, df = 5, p>0.05, Fig. 4). However, there were significantly more dead T. niloticus in MPAs than in their paired sites (Wilcoxon rank-sum, W = 29, df = 5, p<0.05, Fig. 4). Power analysis reported n=5.2, showing that enough paired sites were sampled to adequately reject the null hypothesis for *T. niloticus*. The abundance of dead T. niloticus and T. marmoratus found at each MPA and paired non-MPA site is shown in (Fig. A2).



FIG. 4. Average abundance of dead *T. niloticus* and *T. marmoratus* between MPAs and paired no-MPA sites.

The average size of live *T. marmoratus* inside of MPAs and in paired non-MPA sites was 17.24 cm and 17.29 cm, respectively (Fig. 5). The average size of live *T. niloticus* inside of MPAs and in paired non-MPA sites was 11.02

cm and 11.2 cm, respectively (Fig. 5). The size of live snails did not differ between MPAs and paired sites for either T. *marmoratus* (Paired T-test, T = -0.311, df = 3, p>0.05, Fig. 5) or T. *niloticus* (Paired T-test, T = -0.147, df = 4, p>0.05, Fig. 5). Power analysis reported that n=24.7 samples for T. *marmoratus* and n=60.7 samples for T. *nilocticus* would be required to determine to determine significant differences between MPA and non-MPA sites at a statistical power of .80. The average size of T. *niloticus* and T. *marmoratus* found at each MPA and paired non-MPA site is shown in (Fig. A3).



FIG. 5. Average size of live *T. niloticus* and *T. marmoratus* between MPAs and paired no-MPA sites.

The average size of dead T. marmoratus inside of MPAs and in paired non-MPA sites was 19.3 cm and 20.2 cm, respectively (Fig. 6). The average size of dead *T. niloticus* inside of MPAs and in paired non-MPA sites was 11.4 cm and 10.19 cm, respectively (Fig. 6). The average size of T. niloticus did not differ between MPAs and paired sites (Paired T-test, T = 0.834, df = 3, p>0.05, Fig. 6). Power analysis for T. niloticus reported that n=4.7 sites would have been required to detect significant differences between MPAs and non-MPA sites at a statistical power of .80. A paiered T-test for T. marmoratus could not be preformed because there was too little data. The average size of dead *T. niloticus* and *T.* marmoratus found at each MPA and paired non-MPA site is shown in (Fig. A4).



FIG. 6. Average size of dead *T. niloticus* and *T. marmoratus* between MPAs and paired no-MPA sites.

Preliminary transects along the different reef environments at the Pihaena MPA showed that significantly more snails exist along the reef crest and slope (Fig. 7).



FIG. 7. Preliminary abundance survey on both live and dead *T. niloticus* and *T. marmoratus* at different reef environments within the PIhaena MPA.

#### DISCUSSION

#### Abundance of T. niloticus and T. marmoratus

Live snail abundance was found to be the same in MPAs and non-MPAs. This may be because the harvesting pressure on *T. niloticus* and *T. marmoratus* is low relative to total population size. It may also suggest either that fishing of *T. niloticus* and *T. marmoratus* is not occurring in these sites or that it is indiscriminately happening in both MPAs and non-MPAs. Although *T. niloticus* was not in season during the time of this survey (and therefore was not leagal to be collected), visible shell dumps and opportunistic encounters with local cooking *T. niloticus* suggest that the latter explanation is more likely – namely that snails are being removed from both MPA and non-MPA sites and that harvesting is occurring indiscriminately.

T. marmoratus occurred in much lower numbers than *T. niloticus* which may be due to poaching. However, this study was limited in its ability to survey the outer slope, which is where most T. marmoratus were found. In the Pihaena survey, 20 live T. marmoratus were found inside the MPA while only one live snail was found in the paired non-MPA site. However when this data is combined with the other T. marmoratus data on abundance from the other survey sites and analyzed, no significant difference in abundance is observed. This may be because snail abundance was very variable across sites. T. marmoratus exhibited the greatest abundance on the reef slope, which was surveyed only at the PIhaena sites, while all other surveys were done on the back side of the algal ridge. If more surveys had been conducted which focused on *T. marmoratus* abundance along the reef slope inside and outside of MPAs a statistical difference may be found.

#### Abundance of dead T. niloticus and T. marmoratus

The abundance of dead T. marmoratus was found to be the same in MPAs and non-MPAs. whereas dead T. niloticus abundance was significantly greater in MPAs. These results may be because of fishing regulations under which *T. niloticus* is legal to colect and there is no risk of a fine for carrying *T. niloticus* shells whereas possessing a dead or alive T. marmoratus is illegal and subject to fine. After interviews with locals it was found that when fishing *T. marmoratus* they remove the meat in the water and shells are discarded to avoid encounters with local law enforcement. The shells are only collected sometimes and at the end of the fishing trip just before leaving the fishing area. This is done to reduce chances of being caught by the police because possessing the shells is a clear sign of poaching whereas the harvested snail meat is harder to identify especially when combined with other legally fished species. This would suggest that fisherman are dumping T. marmoratus shells in both MPAs and non-MPAs whereas they are removing T. niloticus shells from non-MPA areas.

The abundance of dead *T. niloticus* was also much greater then the abundance of dead *T. marmoratus* inside of the transect areas. This is most likely because of wave action and the fact that most dead *T. marmoratus* are washed away from the algal ridge and into the back

reef. This was clearly seen at many sites especially Ahi 2. The greater abundance of *T. niloticus* can most likely be attributed to two reasons. First, they already occur in greater numbers then *T. marmoratus*. Second, many of the dead *T. niloticus* found in the transects along the algal ridge had hermit crabs inside of them most commonly of the genus *Dardanus*. Whereas *T. marmratus* shells are too large and heavy for hermit crabs and are not actively kept in the algal ridge.

# Average size of T. niloticus and T. marmoratus

The average size of both live and dead *T*. niloticus and T. marmoratus did not differ significantly between MPAs and their paired sites. This maybe because the populations of both T. niloticus and T. marmoratus inside and outside of MPAs are large enough that the effects of fishing are not visible. It could also be that T. niloticus and T. marmoratus are harvested with no regard to size both inside and outside of MPAs. Furthermore both T. niloticus and T. marmoratus exhibited a range of sizes both inside and outside of MPAs with many individuals being sexually mature. Most T. niloticus were 11 cm on average. A previous study On T. niloticus growth and abundance in New Caledonia found that T. niloticus take 10 years to reach 12 cm in diameter (Bouchet and Bour 1980, in Smith 1987) this finding shows that fishing pressure on *T. niloticus* may not have a great effect, and that many of the individuals documented are long lived.

# Conclusion

The results of this study offer insights on the effectiveness of the MPAs on Moorea. The MPAs on Moorea may have no effect on harvesting pressure or offer very limited protection to both T. niloticus and T. *marmoratus.* The fact that there was no significant difference between the abundance or average size of live T. niloticus and T. marmoratus between MPAs and paired non-MPa sites suggests that either: (a) the harvesting pressure on T. niloticus and T. marmoratus is low relative to total population size; or (b) that harvesting is happening in both MPAs and non-MPAs indiscriminately due to a lack of enforcement. This second option seems likely after many encounters and discussions with locals.

Even though this study did not offer strong evidence that MPAs produce a

significant difference in the average size and abundance of both *T. niloticus* and *T. marmoratus* it is important to note that MPAs have been a very effective resource management technique in other places around the world (Branch and Odendaal 2003, Terlizzi et al. 2004). The creation of marine protected areas around Moorea was a positive step towards a sustainable reef fishery for future generation but increased monitoring of marine resources inside and outside of MPAs, and increased enforcement of regulation, will be crucial in ensuring their success.

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Graphs showing the live and dead abundance and average size of *Tectus niloticus* and *Turbo marmoratus* found at all MPA sites and paired non-MPA sites on the island of Moorea French Polynesia.



FIG. A1. Abundance of live *T. niloticus* and *T. marmoratus* found at each MPA and paired non-MPA site.



FIG. A3. Average size of *T. niloticus* and *T. marmoratus* found at each MPA and paired non-MPA sites.



FIG. A2. Abundance of dead *T. niloticus* and *T. marmoratus* found at each MPA and paired non-MPA sites.



FIG. A4. Average size of dead *T. niloticus* and *T. marmoratus* found at each MPA and paired non-MPA site.

# APPENDIX B

GPS coordinates of survey locations in MPAs and paired non-MPA sites on the island of Moorea French Polynesia.

TABLE B1. GPS coordinates of survey locations in MPAs and paired non-MPA sites.

Location	Latitude	Longitude
In Temae	-17.501022	-149.75667
Out Temae	-17.50578	-149.76557
In Tetaiuo	-17.507734	-149.924915
Out Tetaiuo	-17.504218	-149.24819
In Motu	-17.4866	-149.916225
Out Motu	-17.504218	-149.24819
In Ahi	-17.553389	-149.775263
Out Ahi	-17.559825	-149.779889
In Pihaena	-17.481279	-149.82558
Out Pihaena	-17.578102	-149.823086
In Ahi 2	-17.553389	-149.775263
Out Ahi 2	-17.559825	-149.779889