Surveys indicate that Hotsarihie MPA took 10 years to recover from 1998 bleaching event

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Abstract

Conservation is embedded in Palauan culture and tradition. Informed with a combination of traditional knowledge and modern science, marine resource conservation practices have evolved into what we now call marine protected areas (MPA). In 2003, the national government of the Republic of Palau established the Protected Areas Network (PAN), a nationwide conservation effort, geared towards effective conservation and management of natural resources, in both marine and terrestrial environments. In line with PAN goals, PICRC researchers conducted surveys in Hotsarihie MPA (also known as Helen Reef), located in Hatohobei State, which is about 450km southwest of the main islands of Palau, in May 2018. Previous surveys had been conducted in Hotsarihie MPA in 2000 and 2007, thus, this 2018 survey effort adds on to past datasets with the aim of comparing ecological indicators through time, as well as inside and outside the MPA, to assess management effectiveness. Surveys were conducted in the fore reef, lagoon, and channel habitats of Hotsarihie, inside and outside the MPA. Underwater surveys consisted of recording data on fish, macro-invertebrates, juvenile coral abundance and size, and benthic coverage at two depths. Across nearly all ecological indicators – benthic cover, macro-invertebrate abundance, and fish abundance and biomass – protection did not have a significant effect on this remote reef. Bare substrata, composed of carbonate and turf algae, has significantly decreased while coral cover and crustose coralline algae has significantly increased since 2000 and remained stable since 2007, demonstrating complete recovery from the 1998 bleaching event and the absence of large-scale disturbances since 2007. Macro-invertebrate abundance was higher overall in shallow areas but, within the MPA, it was higher on the fore reef compared to the reference area. Fish abundance was greater at 3m in 2018 compared to 2007, however, at 10m depth, there was a great decrease in the abundance of fish in 2018 compared with 2000 and 2007. Fish biomass has remained stable since 2007 in all habitats surveyed. Fish biomass on the Hotsarihie fore reef was recorded at 1,762.9 kg per ha, which is higher than the accepted pristine reef fish biomass of 1,000 kg per ha. This fish biomass value is the highest found in Palau and can be used as an example of ‘pristine’ reef fish biomass for Palau.

Introduction

Environmental stewardship and natural resource management has been a part of Palau's history for many decades, as conservation is deeply rooted into the Palauan culture. Through the concept of 'bul'- where traditional chiefs prohibited use of or harvesting of resources for restricted periods of time- Palauans were able to conserve their resources (Johannes 1981). Today, the concept of 'bul' has evolved into modern day conservation practices like the Marine Protected Areas (MPA). The first MPA was established in 1956, called Ngerukewid, located in the Rock Islands Southern Lagoon in Koror State. Ngerumekaol – in Koror State - and Ebiil Channel – in Ngarchelong State - were later designated as MPAs. Since 2003, with the creation of the Protected Areas Network (PAN) by the National Government, 14 no-take MPAs and 13 terrestrial protected areas have been inducted into the PAN system. In order to meet the national and regional conservation targets, especially the Micronesia Challenge, the PAN is continually growing to include more sites to protect both marine and terrestrial resources.

This study was conducted in Hotsarihie MPA (also known as Helen Reef), located in Hatohobei State. In 2001, the Hatohobei State Legislature passed the Helen Reef Management Act, which declared Hotsarihie a state protected area (Andrew et al, 2011). This Act designated the entire Hotsarihie reef system as a full no-take zone until 2006, when the first management plan was drafted. The plan proposed a zoning scheme where 30% of the reef was to be open to subsistence fishing, and 70% would remain a no-take zone (Andrew et al, 2011). In 2000, to assess the extent of the damages of the 1998 bleaching event, a survey team surveyed Hotsarihie MPA (Weng et al, 2000). In 2007, the Palau International Coral Reef Center (PICRC) conducted a second assessment in Hotsarihie, observing the status and trends of ecological factors since the 2000 surveys (Golbuu et al, 2013). In 2015, when PICRC began gathering baseline data for each PAN site in Palau, Hotsarihie MPA was not surveyed due to its remote location (Gouezo et al, 2016). During the reassessments of all PAN MPAs conducted by PICRC in 2017 and 2018, the Hotsarihie MPA survey was conducted in May 2018 and is presented here and compared to previous data recorded data in 2000 and 2007.

Methods

1. *Study site*

Helen Reef Marine Protected Area, hereinafter referred to as Hotsarihie Marine Protected Area (MPA), is located in Hatohobei State, which is about 450km SW from the main islands of Palau (Figure 1). Hotsarihie MPA is a large enclosed atoll, measuring about 163 $km^2$and consists of a small island, an extensive reef and a large channel (Oldiais et al, 2009).

The surveys were conducted on the fore reef, lagoon, and channel habitats of the reef. As Hotsarihie is divided into two zones (no-take MPA and open fishing areas), sites were chosen within the MPA and open fishing areas (reference sites - REF) (Figure 1). To keep data and results consistent through time, the sites surveyed in 2018 were the same sites surveyed in 2000 and 2007.

Figure 1: Map of Hotsarihie MPA with monitoring sites in MPA (inside red polygon) and REF sites.

2. *Ecological surveys*

A total of 11 sites were surveyed, covering fore reef, lagoon, and channel habitats. At each of these sites, researchers surveyed at both 3m and 10m depths. At each station, five 50m transects were laid consecutively with a few meters separating each transect. Juvenile corals ≤ 5 cm, were recorded in the first 10 meters of each transect in a 0.3m wide belt. Edible macro-invertebrates were recorded in a 2m wide belt along each transect. Benthic photos were taken along the transect using an underwater camera (model Canon G16), mounted on a 0.5m x 0.5m photo quadrat PVC frame. A total of 50 photos were taken on each transect, with a cumulative total of 250 photos taken at each station. Finally, fishery-independent fish data was recorded using a diver operated video system, called stereo-DOV, which uses two GoPRO Hero4 cameras in underwater housings, mounted onto a metal frame, which are calibrated to allow for post-processing on a computer using EventMeasure (Stereo) software (http://www.seagis.com.au/event.html; Version 4.42). With the stereo-DOV, fish within a 5m wide belt were recorded.

Fish survey methodology has changed since 2000. In 2000 and 2007, fish observations were done using the underwater visual count (UVC) method, while in 2018, the stereo-DOV method was used, giving more accurate measurements but making comparison through time difficult due to variability associated with observers' bias. In 2000, researchers counted fish within a 3m wide belt along 5x50m transects. In 2007 and 2018, fish were counted within a 5m wide belt along the same transect length. Fish observers differed in 2000 and 2007. Fish abundance and biomass were standardized to $100m^2$ area and compared through time, but are carefully interpreted due to likely observer bias in 2000 and 2007.

3. *Data processing and analysis*

Juvenile corals and macro-invertebrate data were entered into Excel spreadsheets. In order to estimate benthic cover, the photos taken were analyzed using CPCe (Coral Point Count with Excel extension) software (Kohler and Gill 2006). In CPCe, five random points were allocated to each photo, and the substrate below each point was classified into the appropriate benthic category (see the benthic categories list in Appendix 1). In the end, the mean percentage of benthic cover of each category was calculated for each transect (n= 50 photos per transect, n=

5 transects per site and depth). The fish videos were processed using the software EventMeasure. Only fish with economic, subsistence and/or ecological importance were counted and measured (Appendix 2). If the measurement precision given by the software was too low to be accurate, the fish was counted and the mean fish size within the site was attributed for biomass estimates. The biomass of fish was calculated using the total length-based equation:

$$W = aTL^b$$

where W is the weight of the fish in grams, TL is the total length of the fish in centimeters (cm), and a and b are constant values that derive from published biomass-length relationships (Kulbicki et al. 2005) and from Fishbase (http://fishbase.org).

The analyses were done for each habitat separately. Before analyzing and testing, data were checked for normality using histograms and the Shapiro test. However, when the data was non-normal, the data was log-transformed and re-tested. For juvenile corals and macro-invertebrate which were only recorded in 2018, when data was normal, Welch Two-sample t-test was used to compare the MPA with the reference area. When the data was non-normal, the non-parametric Mann-Whitney U test was used instead.

For fish and benthic data, which were recorded in 2000, 2007 and 2018, linear mixed effect models were used to investigate the interactive effect of time, protection and depth, including sites as a random effect to account for the non-independence of repeated measurements at the same sites through time. Model simplification was conducted using likelihood ratio tests. In cases when the 3-way interaction was significant, the interactive effect of protection and time was investigated for each depth separately. Tukey Contrasts, using the ghlt function, were used to assess the significance terms of the most simplified model.

Data analyses were done using R statistical software (version 3.5.1) (R Development Core Team, 2018) using lme4 (Bates et al, 2014) and multcomp (Hothorn et al, 2007) packages.

Results

The findings from the monitoring surveys are presented for each indicator in each habitat and, in some instances, by depth within habitat. Additionally, comparisons were made, whenever possible, between the 2018 data and previously attained data, 2000 and 2007.

1. *Juvenile Corals Density*

Juvenile coral density were recorded in 2018 only, thus the following graphs present findings by comparing MPA and REF sites by depth in each habitat (Figure 2). Understanding juvenile coral density on the reef can show indications of reef health or decline.

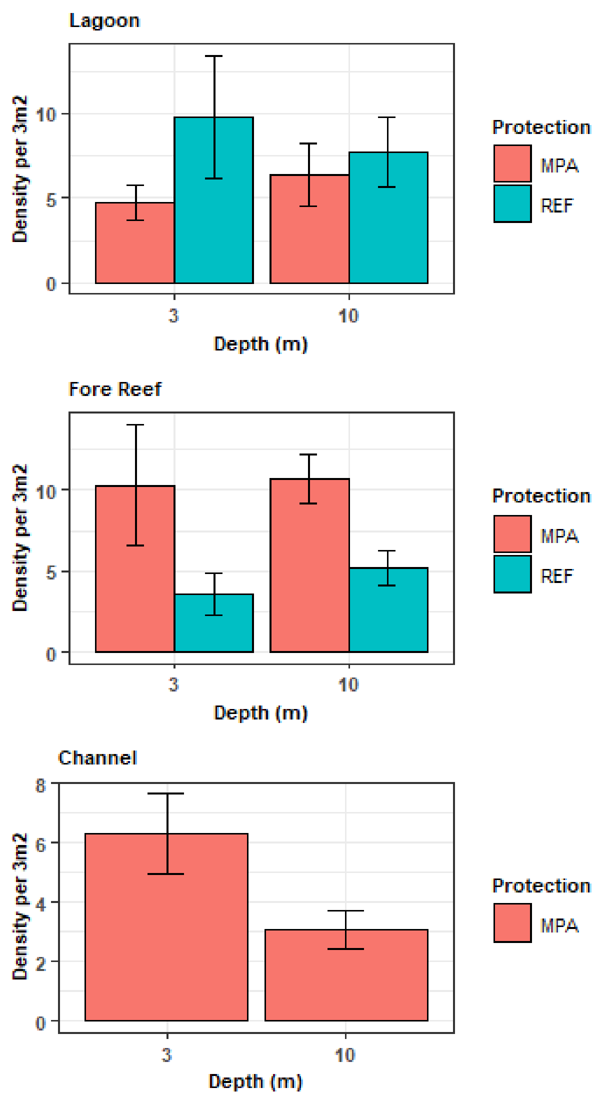


Figure 2: 2018 average cover (± SE) of juvenile corals in MPA and reference sites.

In the lagoon, there was no significant difference in juvenile coral density by protection ($p>0.05$) or by depth ($p>0.05$).

Within the fore reef, there was significantly more juvenile coral found within the MPA than in the REF ($p<0.001$), but no difference was found between depths ($p>0.05$).

Finally, in the channel, the only comparison made was between depths, as the only channel is located within the protected area. A significant difference was found between 3m and 10m depths ($p<0.05$).

2. *Edible macro-invertebrates*

Edible macro-invertebrates were also recorded only in 2018, thus, comparisons are made between depths in MPA and REF sites in each habitat (Figure 3). Macro-invertebrates abundance and size are presented in the following sections. Macro-invertebrates that were recorded included various species of edible sea cucumbers and giant clam species.

a. *Abundance*

In the lagoon habitat, there were a lot more invertebrates found at 3m depth compared to 10m ($p<0.01$). When comparing protection status, no significant difference was found ($p>0.05$) (Figure 3).

In the fore reef habitat, at 3m, the abundance of invertebrates was more than three times higher within the MPA as compared to the REF sites ($p<0.001$). Whereas at 10m, there was no significant difference found in abundance between MPA and REF ($p>0.05$). Within the MPA at both depths, more invertebrates recorded at 3 m than at 10 m ($p<0.001$), whereas abundance of invertebrates were the same between depths in the REF sites ($p>0.05$) (Figure 3).

Since the channel habitat is protected, comparison was made only by depth. The abundance of macro-invertebrates was higher at 3m than at 10m, ($p<0.01$) (Figure 3).

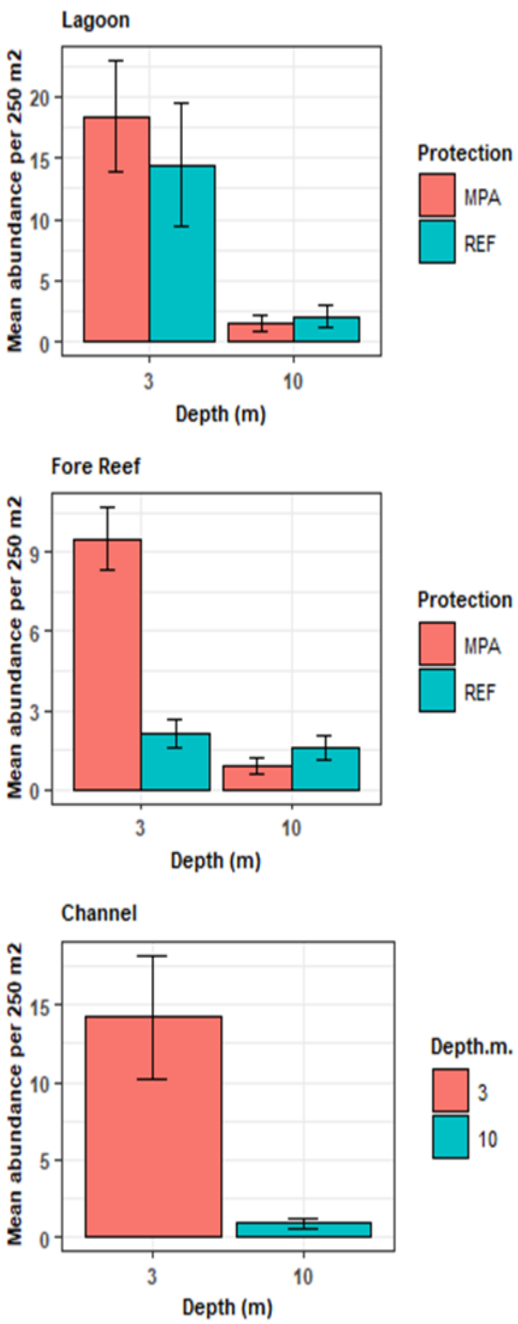


Figure 3: 2018 mean invertebrates abundance (± SE) within MPA and reference sites.

b. Size

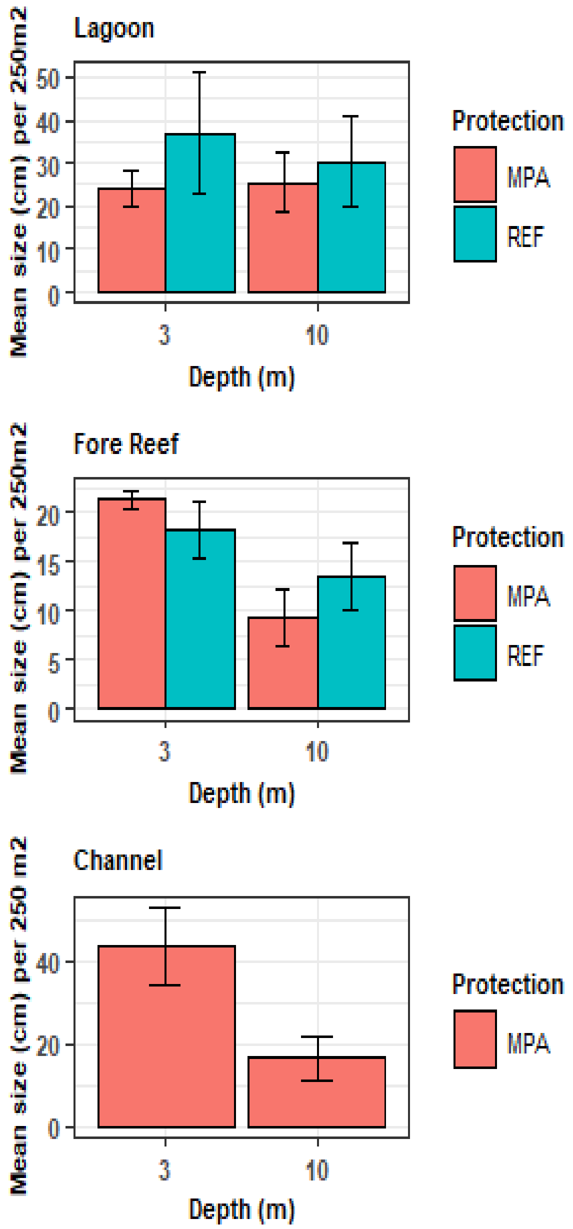


Figure 4: 2018 mean macro-invertebrates size (±SE) in each habitat and depth. *n=10*

There was no significant difference found in invertebrate sizes when comparing both depths and protection in the lagoon habitat, averaging between 25cm to 35cm in size ($p>0.05$).

Within the fore reef habitat, invertebrates' sizes were the same regardless of protection ($p>0.05$). On the other hand, within the MPA sites, the invertebrates were bigger at 3m depth than at 10m ($p<0.001$) while invertebrate sizes were about the same in the REF sites at both depths ($p>0.05$).

Finally, in the channel, invertebrates were found to be bigger in the shallow depth (3m), measuring about 43.6cm (±9.3), compared to the deep (10m), where they averaged about 16.6cm (±5.2) in size ($p<0.01$).

c. Species

The most abundant species of macro-invertebrates was a clam species, *Tridacna maxima* (melibes), mostly found on the fore reef with 176 counted in the MPA and 34 within the REF sites. Additionally, *Tridacna crocea* (oruer), was the second most abundant invertebrate, with 111 found in the lagoon MPA and 95 in the lagoon REF sites. Other recorded species included *Tridacna derasa* (kism) and *Tridacna squamosa* (ribkungal), and the sea cucumber species *Bohadschia spp.* (mostly recorded in the lagoon MPA) and *Holothuria spp*. (Figure 5).

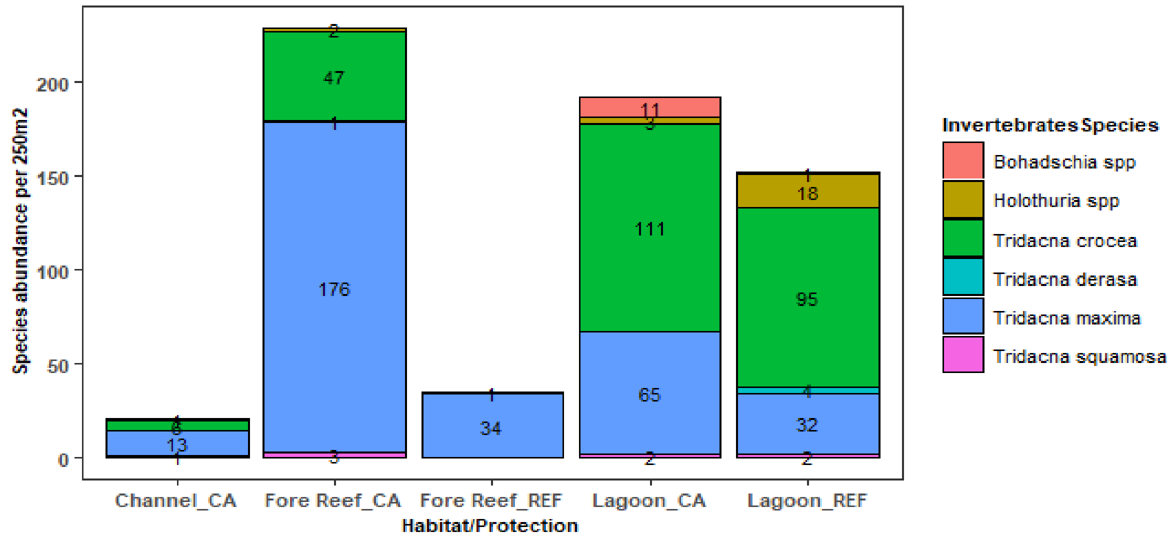


Figure 5: 2018 macro-invertebrate species abundance in each habitat.

3. *Benthic*

This section will concentrate the make-up of the seafloor in Hotsarihie: the benthos. Because the benthic data includes all three survey time points (2000, 2007 and 2018), the following results will be presented by habitat, encompassing both depths. Major benthic categories cover will be presented first, followed by live coral cover trends.

a. Major benthic categories by habitat

Loose substrate, consisting of rubble and sand, was the most abundant benthic category within the lagoon at both 3m and 10m depths, averaging about 68% cover through time (Figure 6). Followed by live coral cover which averaged about 12.2% and bare substrate (carbonate and turf) at 11.4% cover over time. Overall, there was no protection effect on benthic cover through time.

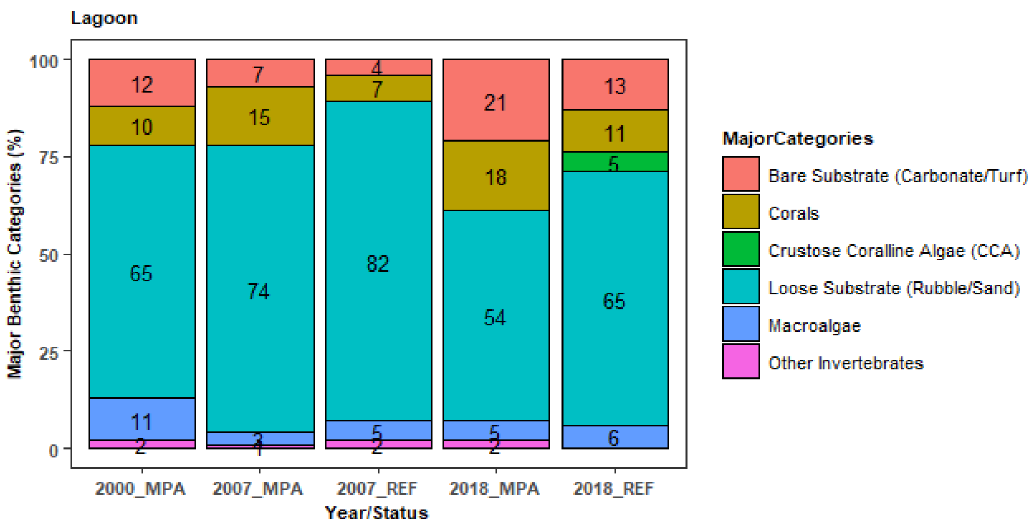


Figure 6: Major benthic categories (%) in lagoon habitat through time in MPA and REF sites.

In 2000, the fore reef had the highest coverage of bare substrate, which consists of carbonate and turf; bare substrate coverage in the MPA was 60% and 54% in the REF sites. Bare substrate decreased significantly in the MPA in 2007 compared to 2000 MPA ($p<0.001$) and decreased even further in 2018 within both MPA and REF sites ($p<0.001$). Finally, the crustose coralline algae (CCA) cover has significantly increased in 2018, in both the MPA and REF sites, since 2000 and 2007 ($p<0.001$) (Figure 7). Significance in coral cover will be presented in the next sub-section.

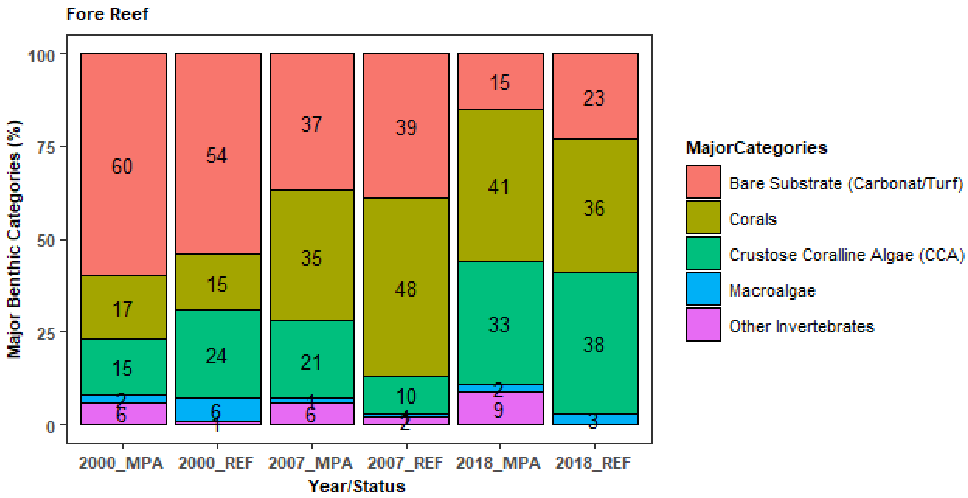


Figure 7: Major benthic categories (%) in fore reef habitat through time in MPA and REF sites.

In 2000, bare substrate (carbonate/turf) covered the sea floor of the channel in Hotsarihie, which was significantly higher than in 2007 and 2018 ($p<0.001$). In 2007, coral cover amounted to about 32% of the substrate, and 26% in 2018. The coral cover in 2007 and 2018 was not found to be significantly different ($p>0.05$) but was significantly more than the coral cover in 2000 ($p<0.001$). The cover of CCA was also significantly greater in 2018 compared to both 2007 and 2000 ($p<0.001$) (Figure 8).

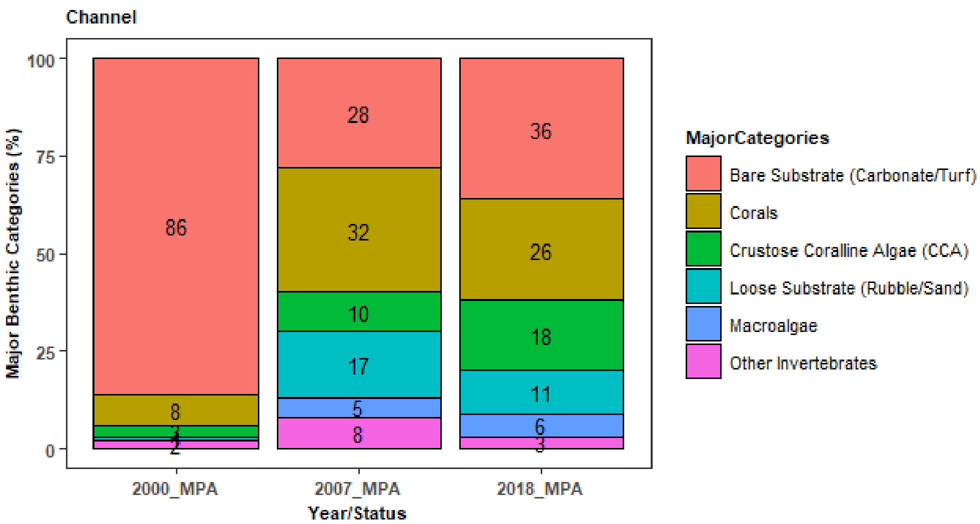
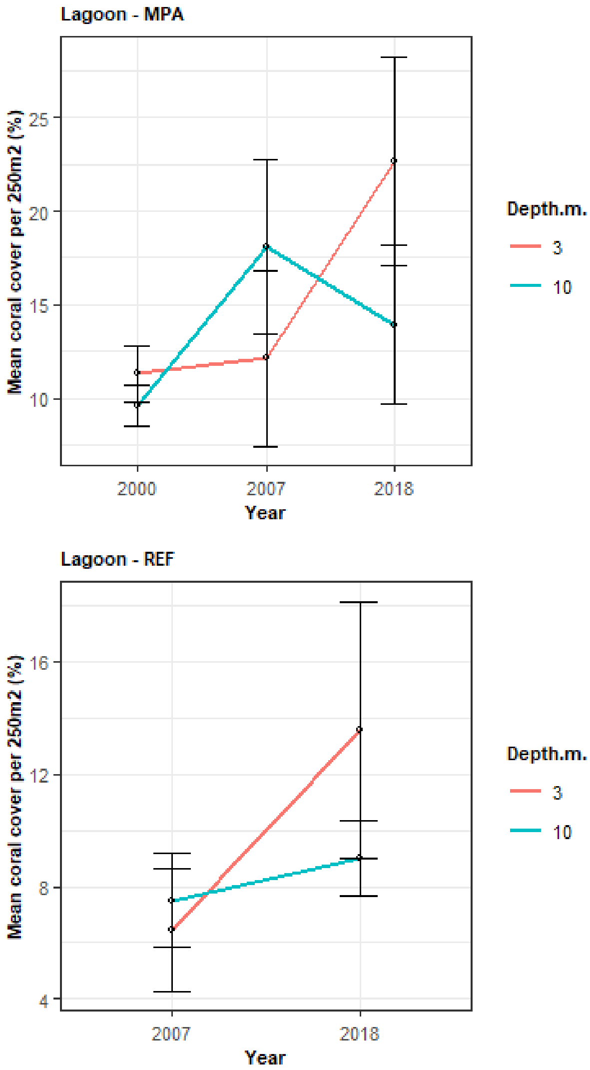


Figure 8: Major benthic categories (%) in channel habitat through time in MPA and REF sites.

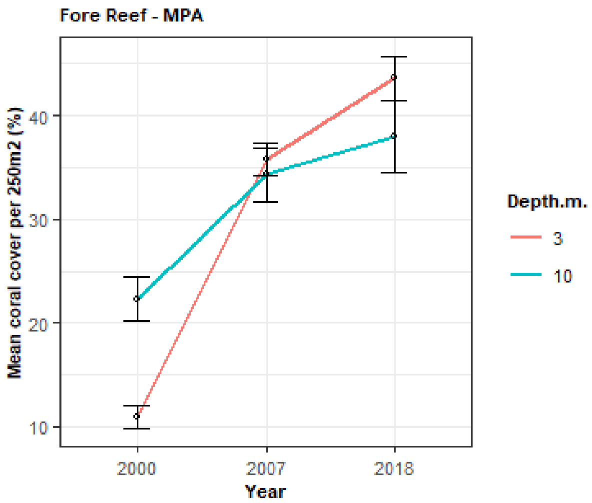
b. Live coral cover by habitat

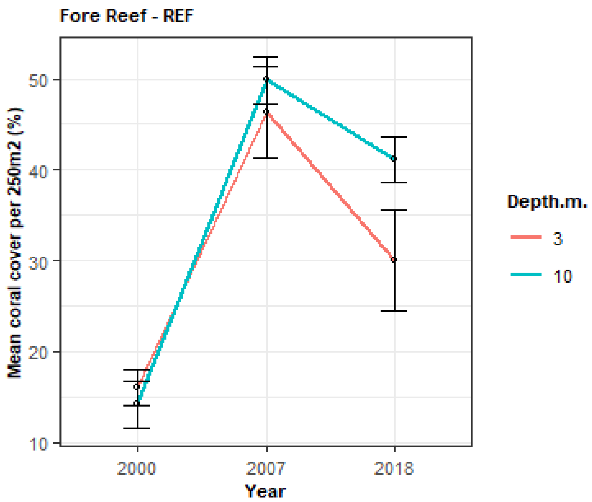


No significant difference in live coral cover was found between MPA and REF sites through time in the lagoon and fore reef habitats. The only differences in live coral cover were found over time. The following results are presented by habitat and protection through time and depth.

No significance was found in coral cover between the two depths, 3m and 10m ($p>0.05$). However, through time coral cover was significantly higher in 2018 compared to 2000 at 3m ($p<0.001$), though it was not different from the 2007 coral cover ($p>0.05$). Coral cover in 2007 was higher in the MPA than in 2000 at 10m ($p<0.01$). There was no difference in coral cover through time in the reference sites at either depth (Figure 9).

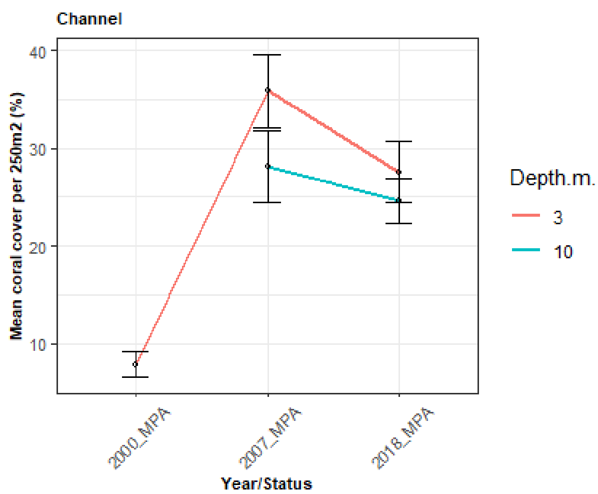
Figure 9: Mean coral cover in the lagoon habitat through time in MPA and REF sites.





Within the MPA fore reef, coral cover increased in 2007 and 2018, showing a great increase since 2000 (p<0.001). However, in the reference sites, at both depths, coral cover slightly decreased in 2018 compared to 2007 from ~ 40 % to ~ 30 % coverage (p<0.05)(Figure 10).

Figure 10: Mean coral cover in the fore reef habitat through time in MPA and REF sites.



Coral cover in the channel habitat had increased significantly since 2000, an estimated 15% increase (p<0.001) and has remained stable since 2007, showing no difference in cover from 2007 to 2018 (p>0.05). There was no significant difference in coral cover at 3m and 10m depth in 2007 and 2018 (p>0.05).

Figure 11: Mean coral cover in the channel habitat through time.

4. *Fish Data*

The following sections present the results for overall fish abundance, species abundance, and overall fish biomass. The data are presented by habitat. In 2000, fish data were collected only at 10m depth, but in subsequent years, data were collected at 3m and 10m depths.

a. *Abundance by habitat*

Overall, fish abundance remained the same through time, with some differences between depths for all habitats except for the fore reef. On the fore reef, fish abundance was found to be different between MPA and REF sites. Thus, the following results are presented by habitat and depth over time, except for the fore reef habitat, which also include protection status.

Since 2000, there has not been a significant change in fish abundance over time within the lagoon habitat ($p>0.05$), but trends were different between depths. In 2007, there were more fish recorded at 10m than at 3m ($p<0.05$) (Figure 12).

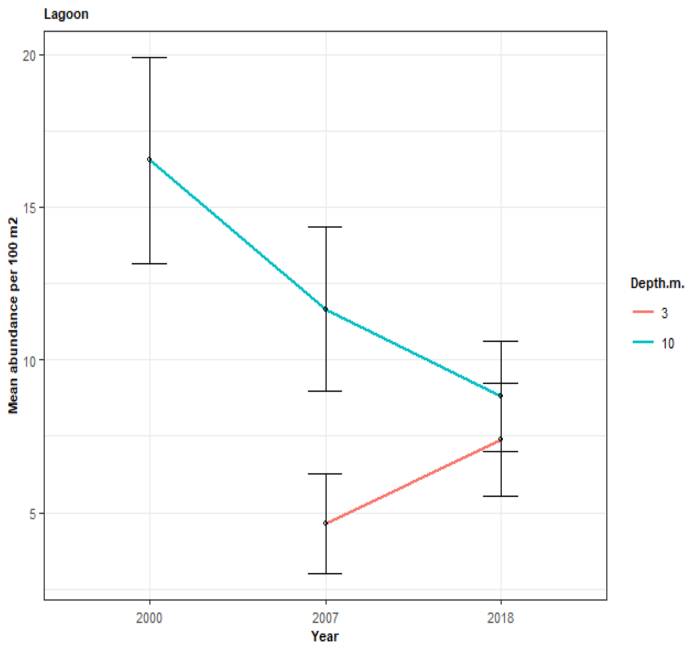


Figure 12: Mean fish abundance per 100m^2 (± SE) in lagoon habitat at 3m and 10m through time.

In contrast to other habitats, protection had an effect on fish abundance on the fore reef. In the MPA, at 3m depth, there was an increase in fish abundance in 2018 compared to 2007 ($p<0.05$); in contrast, there was a significant decrease in fish abundance in 2018 compared to 2007 and 2000 at 10m depth ($p<0.001$). Within the reference sites, no difference in abundance was found at either depth through time ($p>0.05$) (Figure 13). In one of the fore reef reference sites at 3m, a large school of about 820 *Lutjanus gibbus* (keremlal) was recorded, resulting in a large error bar as seen in the REF graph in Figure 13.

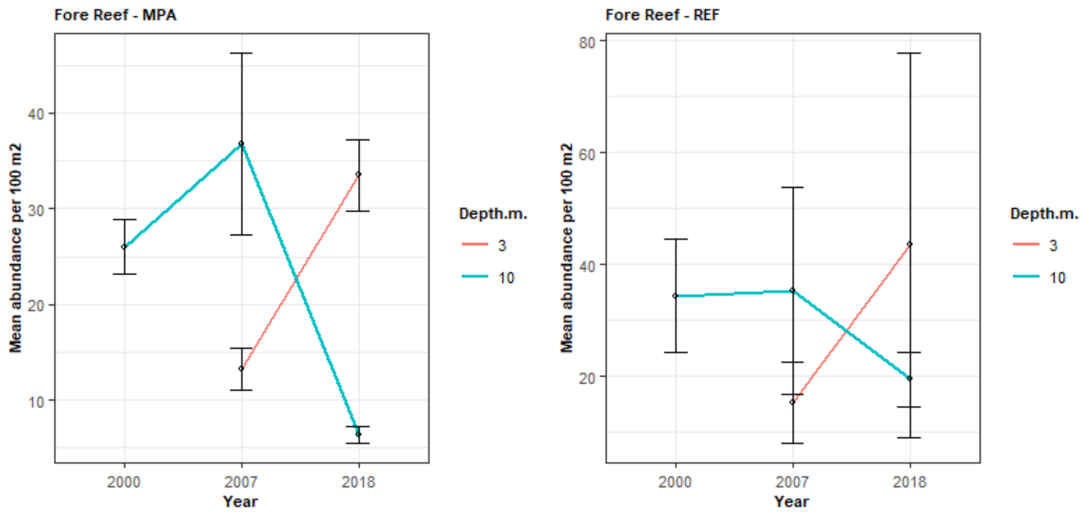


Figure 13: Mean fish abundance per 100m^2 (± SE) in fore reef habitat, MPA and REF sites, through time.

There was no significant difference found in fish abundance in the channel habitat through time (p>0.05). In 2018, at 3m depth, fish abundance was more than at 10m, but it's only a slight difference (p=0.07) (Figure 14).

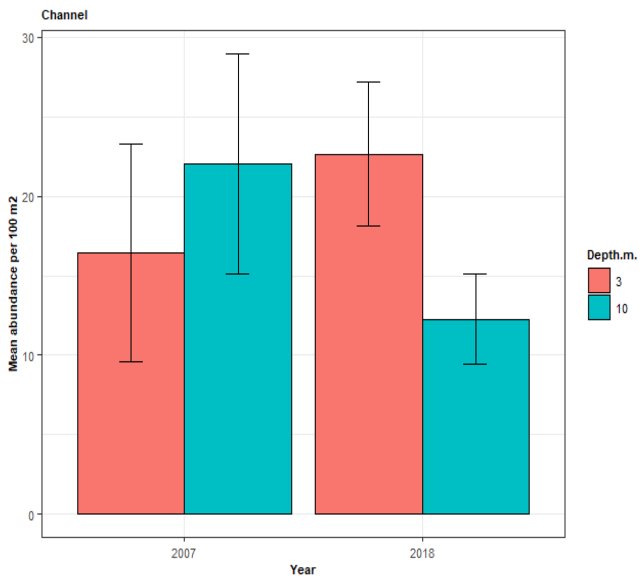


Figure 14: Mean fish abundance per 100m^2 (± SE) in channel habitat at 3m and 10m through time.

b. Species abundance by habitat

The majority of the observed fish families throughout each habitat were: Scaridae (parrotfish), Lutjanidae (snappers), and Acanthuridae (surgeonfish). Other observed famlies include Carangidae (trevallies), Lethrinidae (emperorfish), and some Ephinephelidae (groupers) and Siganidae (rabbitfish) (Figure 15). The only Labridae species that was counted was *Cheilinus undulatus* (maml) in the fore reef and lagoon habitats.

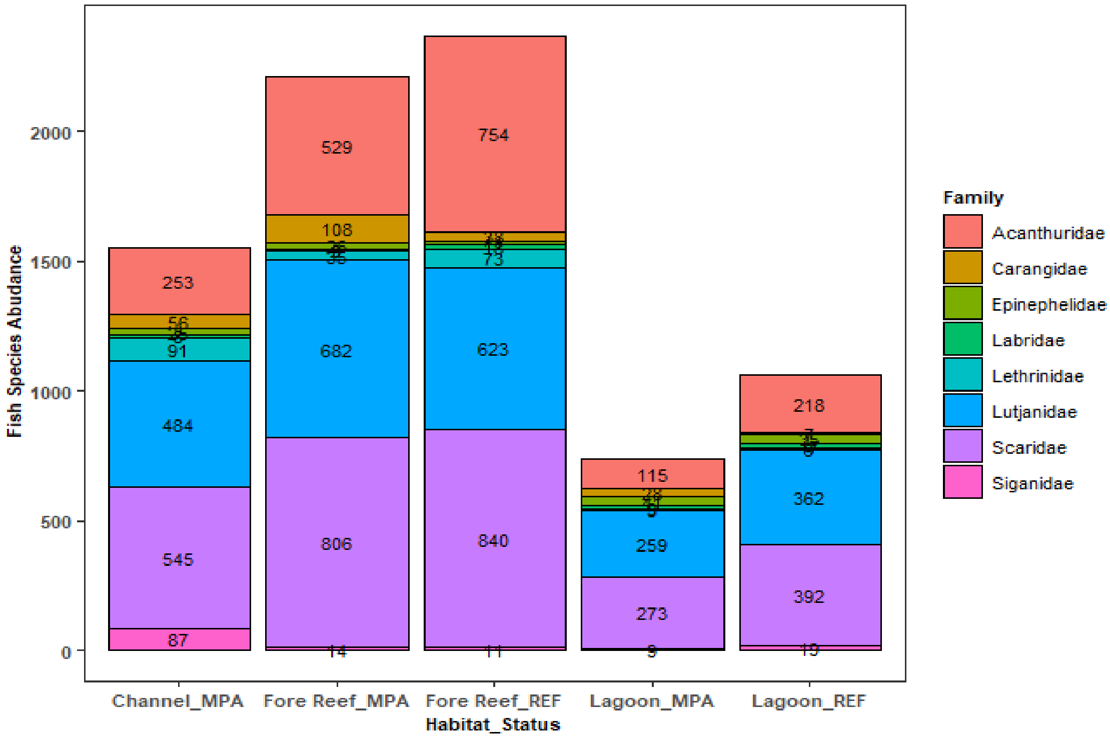


Figure 15: Fish species abundance in each habitat within the MPA and REF sites.

c. *Biomass by habitat*

Overall, there was no effect from protection in any habitat in terms of biomass. Thus, in the following section, comparisons for biomass are only made through time and depth within each habitat.

There was no significant difference in fish biomass through time in the lagoon habitat at 3m and 10m (p>0.05). However, in 2007 and 2018, there is a significant difference between the fish biomass between depths (p<0.001), where there were bigger fish at 10m than at 3m (Figure 16). In the lagoon, 55 individual *Lutjanus vulvus* (reall) were recorded in the MPA in 2018, amounting to about 4,600 kg. This explains the large error bar in the 2018 biomass point at 10m (Figure 16). Fish biomass in 2018 at 3m was 101.8 (±31.4) kg per ha, while it was 1,680.5 (±1248.5) kg per ha at 10m depth.

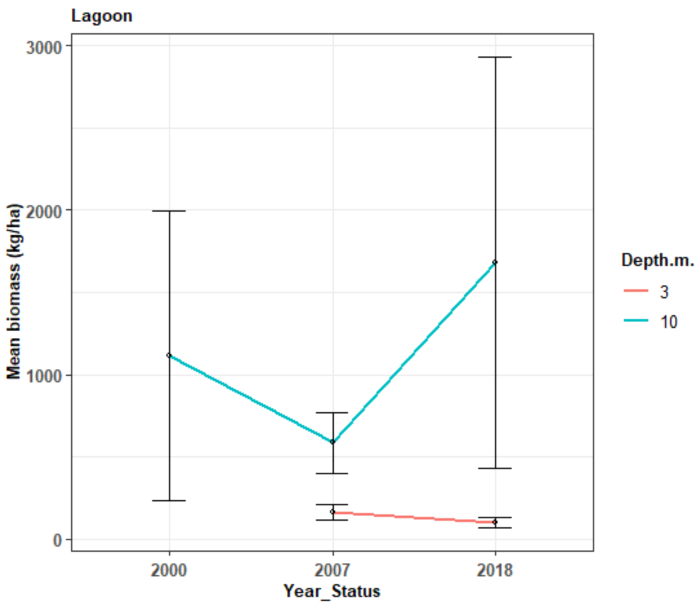


Figure 16: Mean biomass (± SE) kg per ha within lagoon habitat at 3m and 10m depth through time.

In 2007, fish biomass was greater at 10m depth compared to 3m (p<0.001) (Figure 17). However, no difference in biomass was found in 2018, by depth. Additionally, in 2018, in the MPA, at various stations within the habitat, *Bolbometopon muricatum* (kemedukl), were recorded, averaging about 2,646.7 kg. Furthermore, in 2018, fish biomass in the fore reef had significantly declined since 2007 (p<0.001), however, this may be due to the change in fish survey methods. Fish biomass in 2018 at 3m was recorded at 1,934.5 (±547.7) kg per ha, and at 10m was 1,469.6 (±275.4) kg per ha.

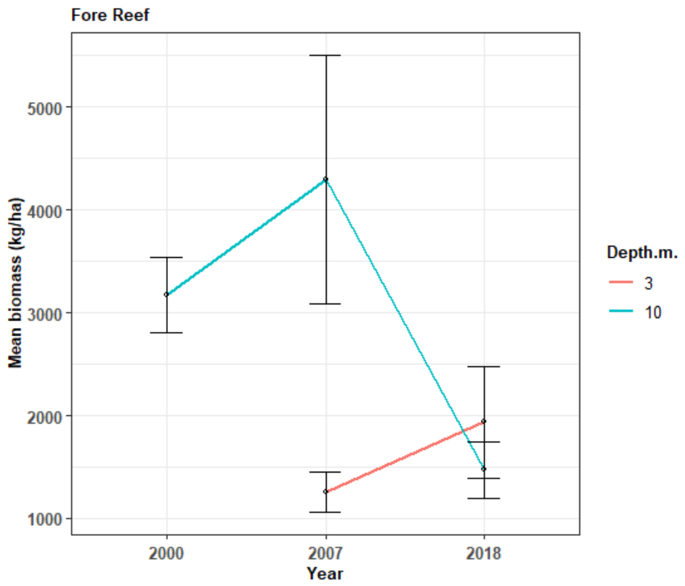


Figure 17: Mean biomass (± SE) kg per ha within fore reef habitat at 3m and 10m through time.

Through time and between depths, there was no significant difference in biomass within the channel habitat ($p>0.05$) (Figure 18). In 2018, the fish biomass at 3m was 431 (±152) kg per ha, and was 332.9 (±85.1) kg per ha at 10m.

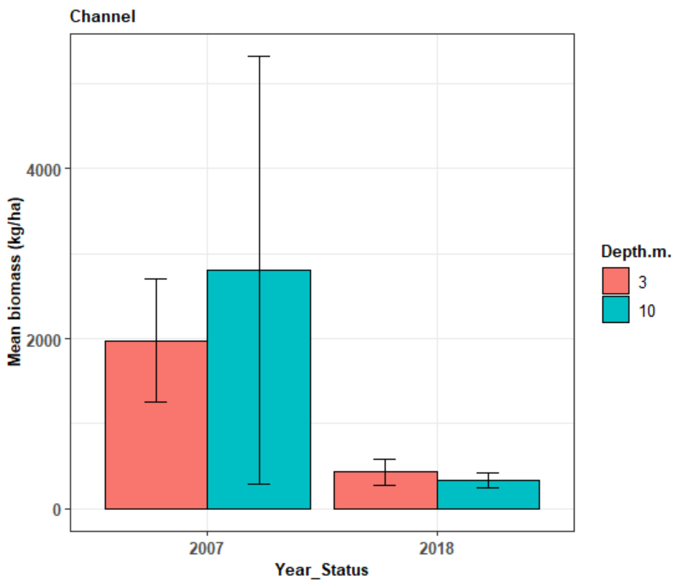


Figure 18: Mean biomass at 3m and 10m depths (± SE) (kg per hectare) within channel habitat through time.

Discussion

The main objectives of this study were to (1) assess the state of the coral reef ecosystem, (2) assess the effectiveness of the Hotsarihie MPA in conserving natural resources, and (3) use the results of the study to inform management about the MPA status. The main findings of the study are that protection had no significant effect on coral cover, size and abundance of macro-invertebrates, or fish abundance and biomass, within each habitat through time. Results are summarized in the following table.

Table 1. Summary of results for each ecological indicator.

Habitat	Resource	Time (2000 → 2018: ↑, =, ↓)	Protection (MPA (+))	Explanation
Lagoon	Juvenile Corals	NA	No effect	
	Inverts	NA	No effect	
	Benthos	=	No effect	
	Coral	↑	No effect	Overall coral abundance increased since 2000.
	Fish Abundance	=	No effect	
	Fish Biomass	=	No effect	
Fore Reef	Juvenile Corals	NA	(+)	Good recovery post bleaching event in 1998.
	Inverts	NA	(+) 3m	Many clams
	Benthos	Bare substrate ↓ CCA ↑	No effect	Decrease may be due to more coral cover as well as CCA, which promote coral growth.
	Coral	↑	No effect	
	Fish Abundance	↑3m, ↓10m	Mixed with depths between 2007 and 2018	Might be due to schools of fish.
	Fish Biomass	=	No effect	
Channel	Juvenile Corals	NA	NA	
	Inverts	NA	NA	
	Benthos	Bare substrate ↓	No effect	Could have been replaced with coral growth.
	Coral	↑	No effect	
	Fish Abundance	=	No effect	
	Fish Biomass	=	No effect	

The results from the surveys also indicate that the reefs of Hotsarihie are quite resilient, displaying (1) an increase and stabilization of coral cover since 2000 and (2) a high abundance of herbivorous fish and low macroalgae cover.

In 2000, the coral cover was low, averaging about 21% across all habitats, whereas bare substrate (carbonate and turf) made up the majority (~70%) of the benthic cover in the channel and fore reef, and loose substrate (sand and rubble) (~65%) was found in the lagoon. Since then, coral cover has significantly increased in all habitats, averaging about 44% across all habitats; and there has been a significant decrease in bare substrate (~30%). This increase in coral cover shows good recovery after the mass bleaching event in 1998. The decrease in bare substrate is likely the result of corals settling and colonizing on the previously bare substrate. Coral cover remained low within the lagoon (~29%), mostly due to the fact that the lagoon is majorly made up of loose substrate – sand and rubble (~60%).

In terms of juvenile coral recruitment, no concrete conclusions can be drawn with respect to juvenile coral densities through time since data on coral recruits were not collected in 2000 and 2007. On average, about 3-10 juvenile corals were found per $3m^2$ on the reefs of Hotsarihie. Because of the low coverage of available substrate due to high coral cover in the fore reef and channel habitats, as well as the high coverage of loose substrate in the lagoon habitat, juvenile coral densities were found to be just average, however, this average density of juvenile coral displays good recruitment in Hotsarihie.

The reefs of Hotsarihie are likely resilient due to the stable coral cover following recovery from the 1998 bleaching event, and thought to be caused by the low macroalgae cover and high abundance of herbivorous fish. Macroalgae cover has been very low (<11%) since 2000. Macroalgae are known to grow quickly, competing with corals at different life stages, smothering their growth potential, and leading to a decline in coral cover and subsequent growth (Mumby et al, 2006; Green and Bellwood, 2009).

A high abundance of herbivorous fishes is a good indicator of a healthy coral reef ecosystem. Herbivorous fishes, such as parrotfish, surgeonfish, and rabbitfish are known to graze macroalgae and turf algae, clearing space for coral larvae to settle and grow (Hughes et al, 2007; Green and Bellwood, 2009). In all surveyed habitats in Hotsarihie, Scaridae (parrotfish) and Acanthuridae (surgeonfish) were found to be the most abundant herbivores. From 2000 to 2018, a total of 1,869 Acanthuridae individuals and 2,856 Scaridae individuals were counted. This high abundance of parrotfish and surgeonfish over the years, together with low algae coverage, demonstrates that these fish must have helped in clearing up space for corals to settle and grow.

In terms of fish biomass, the graphs show a decreasing trend in the biomass, however, the decrease is not significant through the years. This may be due to the change in methods used to estimate fish biomass. In 2000 and 2007, fish surveys relied on underwater visual count (UVC) to estimate fish size. In 2018, fish were recorded using diver-operated stereo-video system (DOV) with GoPro cameras. This recent method allowed for more accurate counts and size estimations because videos were processed and analyzed back in the lab and not *in situ*. Moreover, because of the change in methods for fish observation, there seems to be a decreasing trend in fish biomass through time. However, there was no significance found among depth, time and protection.

MacNeil et al. (2015) estimated that a pristine reef fish biomass (on the fore reefs) was about 1,000 kg per ha in marine reserves that have been protected for at least 40 years. In comparison, as of the 2018 survey, the Hotsarihie MPA average biomass values on the fore reef is 1,762.9 kg per ha. This value (1,762.9 kg/ha) surpasses the accepted pristine reef fish biomass, based on MacNeil et al (2015) published findings. Hotsarihie MPA baseline fish biomass was 3,049.6 kg per ha in 2000 at 10m only, whereas in 2007, it was recorded at an average of 2,642.4 kg per ha.

These values show that Hotsarihie has always had high biomass estimates. This high fish biomass is not seen anywhere else in Palau. Due to its remoteness, Hotsarihie is highly protected against human fishing impacts. However, it is important to continually monitor and enforce regulations to allow the reef to continue being productive.

Conclusions

All in all, Hotsarihie MPA and the surrounding reef is a healthy, thriving reef. Corals have recovered considerably since the mass coral bleaching event in 1998, and continued growth can be seen in all habitats. The coral reefs of Hotsarihie are showing resilience post disturbance and the coral cover seems to be stable. Additionally, the high presence of herbivorous fishes, low macroalgae, and turf cover further increases the reef's resiliency. Likewise, fish biomass in Hotsarihie MPA are quite high and its biomass values can be used to compare to other MPAs in Palau as a 'pristine' biomass value for the nation, due to its remoteness and low, chronic human-stressors, such as overfishing. A strong emphasis should be placed on the continued monitoring and protection of Hotsarihie. It is a prime example of a resilient reef ecosystem in Palau and it adds to the nation's biodiversity and pristine marine environment.

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Appendix 1. Table of benthic categories.

CORAL (C)	Montiporasubmassive (MONTISB)	Boodlea (BOOD)
Acanthastrea (ACAN)	Mycedium (MYCED)	Bryopsis (BRYP)
Acropora branching (ACB)	Oulophyllia (OULO)	Caulerpa (CLP)
Acroporadigitate (ACD)	Oxypora (OXYP)	Chlorodesmis (CHLDES)
Acropora encrusting (ACE)	Pachyseris (PACHY)	Dictosphyrea (DYCTY)
Acroporasubmassive (ACS)	Paraclavarina (PARAC)	Dictyota (DICT)
Acropora tabular (ACT)	Pavona (PAV)	Galaxura (GLXU)
Alveopora (ALVEO)	Pectinia (PECT)	Halimeda (HALI)
Anacropora (ANAC)	Physogyra (PHYSO)	Liagora (LIAG)
Astreopora (ASTRP)	Platygyra (PLAT)	Lobophora (LOBO)
Caulastrea (CAUL)	Plerogyra (PLERO)	Mastophora (MAST)
Coral Unknown (CRUNK)	Plesiastrea (PLSIA)	Microdictyton (MICDTY)
Coscinaraea (COSC)	Pocillopora-branching (POCB)	Neomeris (NEOM)
Ctenactis (CTEN)	Pocillopora-submassive (POCSB)	Not ID Macroalgae (NOIDMAC)
Cyphastrea (CYPH)	Porites (POR)	Padina (PAD)
Diploastrea (DIPLO)	Porites-branching (PORB)	Sargassum (SARG)
Echinophyllia (ECHPHY)	Porites-encrusting (PORE)	Schizothrix (SCHIZ)
Echinopora (ECHPO)	Porites-massive (PORMAS)	Turbinaria (TURB)
Euphyllia (EUPH)	Porites-rus (PORRUS)	Tydemania (TYDM)
Favia (FAV)	Psammocora (PSAM)	SEAGRASS (SG)
Faviid (FAVD)	Sandalolitha (SANDO)	C.rotundata (CR)
Favites (FAVT)	Scapophyllia (SCAP)	C.serrulata (CS)
Fungia (FUNG)	Seriatopora (SERIA)	E. acroides (EA)
Galaxea (GAL)	Stylocoeniella (STYLC)	H. minor (HM)
Gardininoseris (GARD)	Stylophora (STYLO)	H. ovalis (HO)
Goniastrea (GON)	Symphyllia (SYMP)	H. pinifolia (HP)
Goniopora (GONIO)	Tubastrea (TUB)	H. univervis (HU)
Halomitra (HALO)	Turbinaria (TURBIN)	S. isoetifolium (SI)
Heliofungia (HELIOF)	SOFT CORAL (SC)	Seagrass (SG)
Heliopora (HELIO)	Soft Coral (SC)	T. ciliatum (TC)
Herpolitha (HERP)	OTHER INVERTEBRATES (OI)	T.hemprichii (TH)
Hydnophora (HYD)	Anenome (ANEM)	CORALLINE ALGAE (CA)
Isopora (ISOP)	Ascidian (ASC)	Amphiroa (AMP)
Leptastrea (LEPT)	Clams (CL)	Crustose Coralline (CCA)
Leptoria (LEPTOR)	Corrallimorph (COLM)	Fleshy-Coralline (FCA)
Leptoseris (LEPTOS)	Discosoma (DISCO)	Jania (JAN)
Lobophyllia (LOBOPH)	Dysidea Sponge (DYS)	SUBSTRATE (SUBS)
Merulina (MERU)	Gorgonians (G)	Carbonate (CAR)
Millepora (MILL)	Not Identified Invertebrate (NOIDINV)	Mud (MUD)
Montastrea (MONTA)	Sponges (SP)	Rubble (RUBBLE)
Montipora branching (MONTIBR)	Zoanthids (Z)	Sand (SAND)
Montipora encrusting (MONTIEN)	MACROALGAE (MA)	Turf (TURF)

Montipora foliose (MONTIF)	Asparagopsis (ASP)	
Montipora other (MONTIO)	Bluegreen (BG)	

Appendix 2. Table of recorded fish.

Recorded fish in Hotsarihie MPA		
Acanthurus auranticavus	*Chlorurus sordidus*	*Naso unicornis*
Acanthurus lineatus	*Ctenochaetus striatus*	*Naso vlamingii*
Acanthurus maculiceps	*Epinephelus fuscoguttatus*	*Ostracion cubicus*
Acanthurus nigricans	*Epinephelus polyphekadion*	*Ostracion spp.*
Acanthurus nigricauda	*Epinephelus spp.*	*Parupeneus barberinus*
Acanthurus nigricaudus	*Eretmochelys imbricata*	*Pastinachus sephen*
Acanthurus olivaceus	*Gomphosus varius*	*Plectorhinchus flavomaculatus*
Acanthurus spp.	*Gracila albomarginata*	*Plectorhinchus lineatus*
Acanthurus xanthopterus	*Gymnosarda unicolor*	*Plectorhinchus unicolor*
Aethaloperca rogaa	*Hipposcarus longiceps*	*Plectorhinchus vittatus*
Aphareus furca	*Kyphosus vaigiensis*	*Plectropomus areolatus*
Aprion virescens	*Lethrinus erythropterus*	*Plectropomus laevis*
Balistoides conspicillum	*Lethrinus obsoletus*	*Plectropomus leopardus*
Balistoides spp.	*Lethrinus olivaceus*	*Plectropomus maculatus*
Balistoides viridescens	*Lethrinus spp.*	*Plectropomus spp.*
Bolbometopon muricatum	*Lethrinus xanthochilus*	*Priacanthus spp.*
Carangoides spp.	*Lutjanus bohar*	*Sargocentron spiniferum*
Caranx ignobilis	*Lutjanus ehrenbergii*	*Scarus altipinnis*
Caranx lugubris	*Lutjanus fulviflamma*	*Scarus dimidiatus*
Caranx melampygus	*Lutjanus fulvus*	*Scarus forsteni*
Caranx sexfasciatus	*Lutjanus gibbus*	*Scarus niger*
Caranx spp.	*Lutjanus monostigma*	*Scarus oviceps*
Carcharhinus amblyrhynchos	*Lutjanus quinquelineatus*	*Scarus prasiognathos*
Carcharhinus spp.	*Lutjanus spp.*	*Scarus rubroviolaceus*
Cephalopholis argus	*Lutjanus vitta*	*Scarus schlegeli*
Cephalopholis miniata	*Macolor macularis*	*Scarus spinus*
Cephalopolis spp.	*Macolor niger*	*Scarus spp.*
Cetoscarus bicolor	*Macolor spp.*	*Scarus tricolor*
Cetoscarus ocellatus	*Monotaxis grandoculis*	*Scarus xanthopleura*
Cheilinus fasciatus	*Monotaxis spp.*	*Scarus xanthpleura*
Cheilinus undulatus	*Myripristis spp.*	*Siganus argenteus*
Chelonia mydas	*Myrispristis berndti*	*Siganus puellus*
Chlorurus bleekeri	*Naso annulatus*	*Siganus punctatus*
Chlorurus bowersi	*Naso brachycentron*	*Sphyraena barracuda*
Chlorurus japanensis	*Naso lituratus*	*Sphyraena jello*
Chlorurus microrhinos	*Naso spp.*	*Variola louti*