Palau's larger MPAs have higher fish biomass than smaller ones

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Abstract

Since 2014, the Palau International Coral Reef Center (PICRC) researchers have monitored the 13 coralreef and seagrass marine protected areas (MPA) within the Palau Protected Areas Network (PAN). Baseline assessments were conducted between 2014 and 2015, with subsequent re-assessments conducted three years later between 2017 and 2018. This study is a collective assessment of all 13 PAN MPAs baseline and follow-up surveys. MPAs were categorized and grouped according to habitat – channel, fore reef, lagoon, coral dominated reef flat (RFC), and seagrass dominated reef flat (RFS). Fish abundance and biomass, macro-invertebrate abundance, and macroalgae cover were the chosen ecological indicators used to investigate the effectiveness of protection on marine resources and overall coral reef resilience. For all three variables, the effect of reef habitat, protection status (protected vs not protected), and change over time (two time points) were explored, whenever possible.Commercially important fish abundance was significantly higher within the fore reef and RFCcompared to the other habitats. However, fish biomass was significantly higher within MPAs compared to their respective reference sites, and among some habitats (fore reef and RFC). Though there was no interaction of overall surveyed commercially important fish biomass among protection status and habitat,although biomass of herbivorous fish wasfound to be significantly lower within the lagoon than any other habitat.Edible macro-invertebrate abundance significantly decreased over time within the channel and the lagoon habitats, but increased in the RFC habitat. Edible sea cucumbers in the RFS did not change over time, but were significantly higher within the MPAs than the reference sites. Over time, clam abundance had decreased within the MPAs in the channel, fore reef, and the lagoon, with the exception of the RFC, where clam abundance had significantly increased.A multiple regression analysis was done to investigate what drove MPA effectiveness (ie. MPA size, habitat, habitat size, length of protection, distance to land, distance to port, coral cover, and macroalgae cover). Results showed that with the increase of herbivorous fish biomass, macroalgae cover also increased. Over time, macroalgae cover had significantly increased within the MPAs by 7.3 times within the channel, 1.7 times within the RFC, and 1.4 times within the lagoon.Distance from the closest port and habitat type had a significant positive effect on clam abundance, indicatingthat an increase in accessibility to sites and sheltered, easily accessible habitats, could possibly increase the threats to clams.

1. Introduction

A Marine Protected Area (MPA) is a management tool used to protect marine biodiversity and in Palau, it is used mainly for protection of fisheries resources. Nationwide, Palau has over 44 protected areas, 35 of which cover marine habitats (Friedlander et al., 2017). The Palau Protected Areas Network (PAN) was established in 2003 by the Palau National Government and serves as a nation-wide system of protected areas. States may designate their protected areas as a PAN site pending approval of the network-wide guidelines for management and development of PAN sites (RPPL No. 7-42). There are currently 34 PAN sites located across 15 of Palau's 16 states. Fifteen of the 34 PAN sites are MPAs (PAN Status Report 2003-2015).

Since 2014, the Palau International Coral Reef Center (PICRC) has been conducting ecological surveys to assess the effectiveness of state marine conservation areas (CA) that are part of the PAN. Biological monitoring is an essential component of adaptive management to measure the effectiveness and progress of MPAs. Baseline assessments of all incorporated habitats were conducted at each of the 13 out of 15 PAN MPAs between 2014 and 2015 (Gouezo et al., 2016). To assess their effectiveness, PICRC has subsequently re-surveyed each of the PAN MPAs between 2017 and 2018. In order to effectively manage protected areas, resource managers and relevant stakeholders need information on the changes and trends in the condition of resources.

The objectives of this study were to evaluate the status and trends of the natural resources (fish and macro-invertebrates) of Palau's PAN MPAs habitats – channel, fore reef, lagoon, coral dominated reef flat (RFC), and seagrass dominated reef flat (RFS). Additional objectives were to (1) assess the effectiveness of the conservation areas (CA) in protecting resources over time, (2) compare resources found within the protected area and nearby, non-protected reference area, and (3) investigate specific attributes of MPAs that drive higher fish biomass and macro-invertebrates. This report sought to answer four questions in regards to commercially important fish abundance and biomass, as well as macro-invertebrate abundance:

1) What are the major differences across habitats?
2) Within each habitat, is there a difference between the status of protection (protected vs not protected)?
3) Within each habitat, with the exception of fish data, was there a change over time?
4) What are the attributes of the MPAs which drive the observed differences in fish biomass and macro-invertebrate abundance?

Additionally, among some of the individual MPA reports, increased macroalgae cover was reported either through time or between protection status. This study looked at macroalgae cover increase among habitats and if this increased cover was a driving for the changes in the above-mentioned indicators.

2. <u>Methods</u>

2.1. <u>*Study sites*</u>

Ecological surveys were conducted in 13 of Palau's 15 PAN MPA sites spanning from the most norther tip (8º12'18.12"N, 134º37'01.25"E) to the most southern end (2º47'52.76"N, 131º 44'38.23"E) of Palau's archipelago chain. Throughout the report, CA and MPA are interchangeable.

With the exception of Hatohobei State's Hotsarihie CA, the baseline surveys were conducted between 2014 and 2015 within all habitats in each PAN MPA. Between 2017 and 2018, subsequent follow-up assessments were conducted within these same MPAs, including Hotsarihie CA. For the purpose of the reassessment, only the two main habitats within each MPA were selected for continuous monitoring. PAN MPA surveys were replicated around the same time of the year to avoid possible seasonal variability (table 1). Reference sites (REF)were chosen for each MPA based on similarities with their respective MPA in terms of habitat and ecological makeup, as well as size to examine the effectiveness of the MPA. MPAs were examined through time while MPA-REF comparison were examined during the follow up in 2017-2018 (fig. 1).

Due to limited accessibility, the last survey conducted at Hatohobei's Hotsarihie CA prior to 2018 was in 2007, and therefore excluded from the time comparison. A report comparing Hotsarihie CA resources through time was previously written – *Survey indicate that Hotsarihie MPA took 10 years to recover from 1998 bleaching event* (Marino et al., 2019). In addition, due to limitations of accessibility, all habitats of Hotsarihie CA were surveyed whereas all other PAN MPAs were limited to 2 main habitats.

Table 1: List of PAN MPAs, the respective survey time periods, and surveyed habitats.
*RFC-coral dominated reef flat, RFS-seagrass dominated reef flat.

	State	MPA	Year Established	Total Size (km2)	Habitat surveyed	Habitat Size (km2)	Baseline Month_Year	Follow-up Month_Year
1	Ngchesar	Ngelukes_CA	2002	1.043	Fore reef	0.068	August_2014	August_2017
					RFS	0.815		
2	Melekeok	Ngermedellim_CA	1999	0.448	RFC	0.35	September_2014	September_2017
					RFS	0.098		
3	Airai	Medal_Ngediull_CA	2005	3.184	Lagoon	1.423	October_2014	October_2017
					RFS	2.995		
4	Ngardmau	Ngermasech_CA	2005	2.922	Lagoon	0.176	November_2014	November_2017
					RFS	2.75		
5	Peleliu	Teluleu_CA	2001	0.54	RFS	0.54	January_2015	January_2018
6	Angaur	Iuaiu_CA	2005	0.855	RFC	0.602	February_2015	February_2018
					RFS	0.254		
7	Ngiwal	Ngemai_CA	1997	2.922	Fore reef	0.075	March_2015	March_2018
					RFS	1.717		
8	Ngarchelong	Ebiil_CA	2000	17.798	Channel	1.619	April_2015	April_2018
					Fore reef	0.8		
9	Hatohobei	Hotsarihie_CA	2000	121.201	Channel	4.247	*N/A*	May_2018
					Fore reef	7.576		
					Lagoon	69.039		
10	Ngatpang	Oruaol_Ibuchel_CA	2006	0.716	Lagoon	0.49	May_2015	May_2018
					RFC	0.227		
11	Ngardmau	Ileakl_beluu_CA	2005	0.359	Fore reef	0.074	June_2015	June_2018
					RFC	0.255		
12	Kayangel	Ngeruangel_CA	1996	56.547	Fore reef	3.589	July_2015	July_2018
					Lagoon	5.808		
13	Koror	Ngerumekaol_CA	1999	3.52	Channel	0.218	August_2015	August_2018
					Fore reef	0.449		

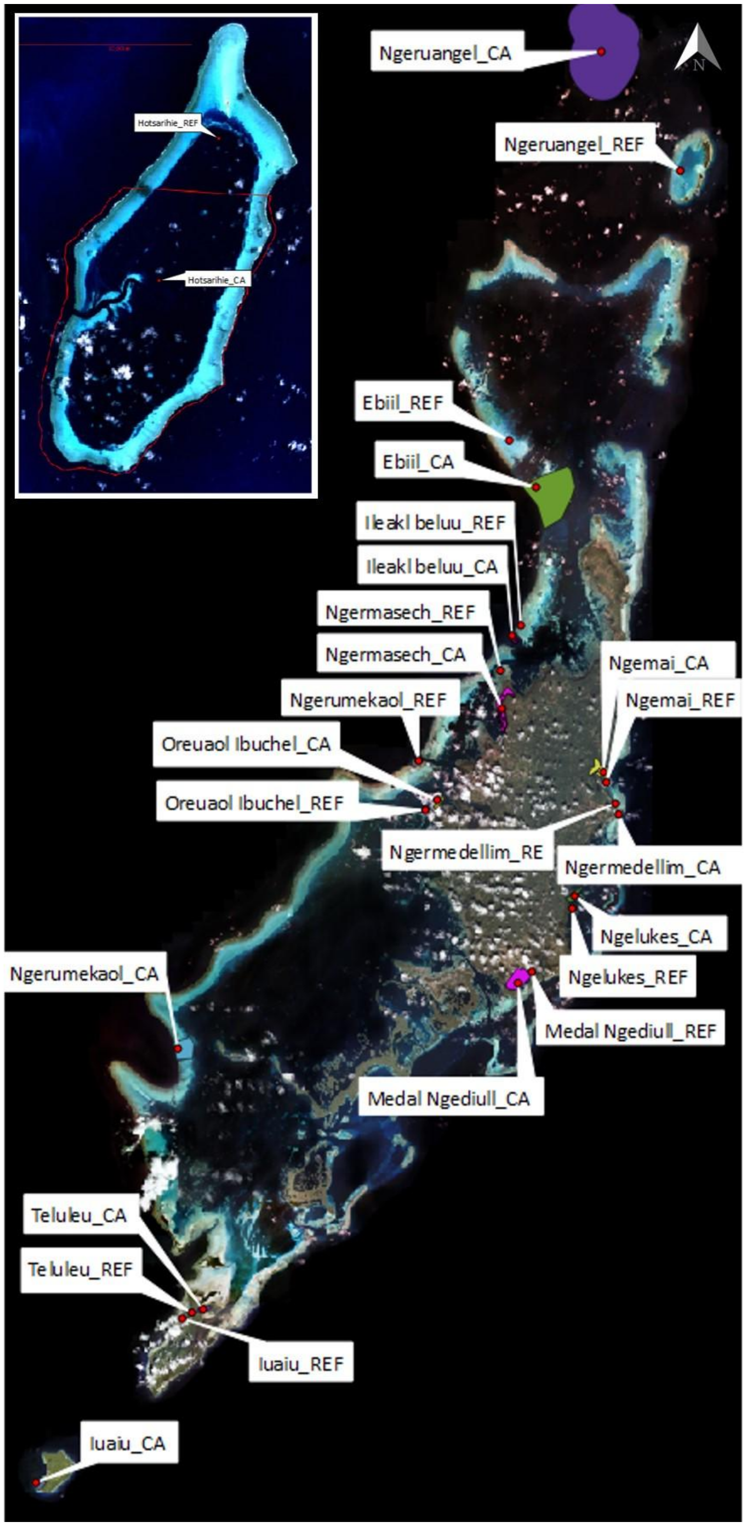

Figure 1: Palau map with 13 PAN MPA's and their respective reference sites, inset of Hatohobei's Hotsarihie CA.

2.2. *Ecological surveys*

All surveys recorded multiple indicators, but for the purpose of this study, commercially important fish abundance and biomass, edible macro-invertebrate abundance, and benthic cover were selected and methods of surveying are further described in depth.For detailed information on complete survey methods, refer to the baseline and follow-up reports for each MPA located on PICRC's website (www.picrc.org).

2.2.1. *Survey depths*

Within the reef flat habitats (with dominating coral and seagrass), surveys were conducted at a maximum depth of 3 m. Within all other habitats, surveys were conducted at a maximum depth of 10 m.

2.2.2. *Baseline survey*

In 2015, baseline assessments were conducted in the MPAs only with no reference sites. Commercially important fish abundance and size (cm) estimates were recorded following a standard Underwater Visual Survey (UVS) approach along a 30 m x 5 m belt transect (appendix 1a). Three transects, each spaced 1-3 m apart, were sampled within each habitat type in the MPA. All edible macro-invertebrates, such as sea cucumbers and clams (appendix 2), were recorded along the same three 30 m transects using a 2 m search width. The benthic community was measured using photographs taken at every meter along each transect using an underwater camera (Canon G16) mounted on a 1 m^2 photo-quadrat frame.

In the case of Medal Ngediull CA, Ngekules CA, and Teluleu CA, these three MPAs have been surveyed since 2011 as part of the PICRC Long term seagrass monitoring and their 2014-2015 data was used for the purpose of the baseline data. Methods remain the same with the exception that the survey was conducted on five-25 m transect tapes (table 2).

2.2.3. Seagrass dominated reef flat (RFS)

On the reef flat, where the seagrass bed was the predominant benthic community, five-25 m transect tapes were laid on the substrate with 1-3 m gap between each tape. For fish surveys, an underwater visual census (UVC) method was used. Visual fish surveys of commercially important fish (appendix 1a) were recorded by size (cm) and abundance within a 5 m wide belt along each transect. Edible macro-invertebrates, such as sea cucumbers and clams (appendix 2), were recorded within a 2 m wide belt along each transect. All data was compared to the seagrass assessment conducted in 2015, as well as the respective 2017-2018 reference site (table 2).

2.2.4. Follow-up survey

During the follow-up survey, within all habitats except for RFS, five-50 m transect tapes were laid with a 1-3 m gap between each tape. Commercially important fish (appendix 1b) size and abundance were surveyed using stereo-DOV (Diver Operated Stereo-Video) within a 5 m wide belt. Edible macro-invertebrates (appendix 2) were recorded within a 2 m wide belt along each transect. The benthic community was measured using photographs taken at every meter along each transect using an underwater camera (Canon G16) mounted on a 0.5 m^2 photo-quadrat frame (table 2).

Table 2: Survey methods and transect lengths according to survey period, indicator, and type of habitat – coral or seagrass dominated reefs.

Habitat	Indicator	Baseline (2014-2015) method	Long terms SG monitoring	Transects	Follow-up (2017-2018) method	Transect
RFS	Fish	UVC, 5m wide belt		3 x 30m	UVC, 5m wide belt	5 x 25m
RFS	Inverts	2m wide belt		3 x 30m	2m wide belt	5 x 25m
(3) RFS	Fish		UVC, 5m wide belt	5 x 25m	UVC, 5m wide belt	5 x 25m
(3) RFS	Inverts		2m wide belt	5 x 25m	2m wide belt	5 x 25m
Coral	Fish	UVC, 5m wide belt		3 x 30m	Stereo-DOV	5 x 50m
Coral	Benthic	Canon-camera (1m^2 quadrat)		3 x 30m	Canon-camera (0.5m^2 quadrat)	5 x 50m
Coral	Inverts	2m wide belt		3 x 30m	2m wide belt	5 x 50m

2.3. *Data extraction and analysis*

Fish videos were processed using the software, *EventMeasure*, where all commercially important fish (appendix 1) were counted and measured (fork length)(Goetze et al., 2019; Whitmarsh et al., 2017). Fish biomass was calculated using the total length-based equation $W=aTL^b$ where *W* is the weight of the fish in grams (g), *TL* is the total length of the fish in centimeters (cm), and *a* and *b* are constant values that were derived from published biomass-length relationships (Kulbicki et al., 2005) and from Fishbase (http://fishbase.org).Macro-invertebrate (appendix 2) data were entered into excel for further analysis. Photographs of the benthic community to determine substrate percent cover were analyzed using CPCe (Coral Point Count with excel extensions, Kohler and Gill 2006, appendix 3). Due to different survey methods, data were standardized to per m^2.

Data for multiple ecological indicators were collected during the surveys but for the purpose of this report, four indicators are presented – commercially important fish biomass and abundance, edible macro-invertebrate abundance, and macroalgae coverage. For details and results of all measured indicators, refer to technical reports of each MPA accessible on PICRC's website (www.picrc.org/picrcpage/technicalreports/).Surveyed habitats from 2017-2018 were grouped and compared for the intent of examining the most effectively protected habitat.Whenever possible, indicators were compared between protection status in 2017-2018 (MPA versus REF) and through time within the MPA (2014-2015 versus 2017-2018). Indicators were tested for significance amonghabitats and between protection status (2017-2018: MPA versus REF), as well as interaction among habitats and through time (MPA: 2014-2015 versus 2017-2018). Whenno significance was found among interactions, the ecological indicators were tested separately among habitat, between protection status, and through time to examine overall changes. Analysis was conducted using a linear mixed effect model (LMER) with sites added as a random effect to account for repeated measures through time at the same location. Pairwise comparison was conducted when results indicated significance. Possible drivers were investigated using a multiple regression model to understand what drove differences in ecological indicators (response variables) across studied MPAs.

Effects of MPA attributes were examined. These attributes are described in the following table:

Table 3: MPA attributes used in multiple regression analysis. Distance to land/port were measured using QGIS

Fish	Macro-invertebrates	Drivers
Total fish biomass (g/m^2)	Total macro-invertebrate abundance (per m^2)	Total MPA size (km^2)
Herbivorous fish abundance (per m^2)	Edible clam abundance (per m^2)	Habitat types
Herbivorous fish biomass (g/m^2)	Edible sea cucumber abundance (per m^2)	Number of years under protection
		Approximate distance from MPA to land (km)
		Approximate distance from MPA to nearest port (km)
		Coral cover (%)
		Macroalgae cover (%)

The continuous predictor variables were first normalized and checked for collinearity prior to regression analysis. Response variables were checked for normality using normal quantile plot and the Shapiro test. When data were non-normal, data were transformed (log, $\sqrt{}$, $\sqrt[3]{}$, $\sqrt[4]{}$) and re-tested. Normal data were analyzed using LMER. Non-normal data were analyzed using either Mann-Whitney U test or Kruskal Wallis test.All analysis was done using *R* statistical software (R Development Core Team 2017) using the following packages: lme4, emmeans, dplyr, ellipse, lme4, lmerTest,ggplot2.

3. Results

3.1. Commercially Important Fish

3.1.1. Fish abundance

Results of the 2017-2018 survey showed a significant difference in abundance of commercially important fish among habitat.The RFC had the highest fish abundance out of all the habitats of 0.14 ($\pm$ 0.03) fish per m^2. The RFC was significantly higher fish abundance than the RFS (p-value <0.05), while thefore reef habitat had a significantly higher fish abundance than to the RFS (p-value <0.001) (fig. 2). There was no significant interaction of fish abundance between protection and habitat (p-value >0.05), nor was there a significance of fish abundance at the protection status (p-value >0.05).

When the RFS was removed from the analysis due to method difference (UVC vs. Stereo-DOV), habitat remained significant while the interaction between protection and habitat, and protection status remained non-significant. With RFS removed, the fore reef and the RFC, both had significantly higher fish abundance than the lagoon (p-value <0.01, <0.001, respectively). The effect of time was examined within the RFS due to method consistency and found to have no significant change from 2014-2015 to 2017-2018 (p-value >0.05).

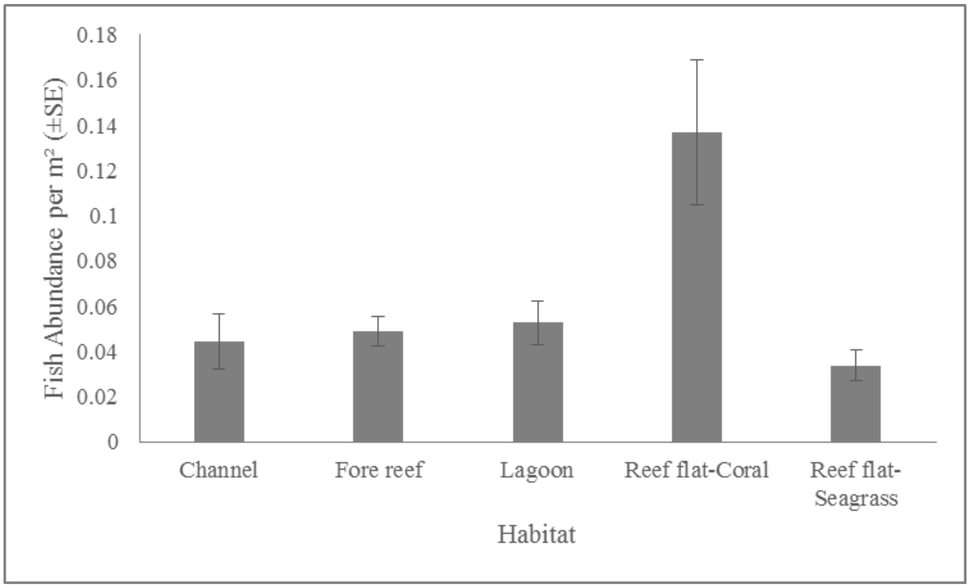

Figure 2: Mean fish abundance (per m^2) at the habitat level in 2017-2018 (error bars indicate standard error (±SE)).

The commercially important fish were grouped according to trophic level and further examined. Results showed a significance in the abundance of herbivorous fish, while no significance was found among omnivores and carnivores' abundance. Herbivorous fish abundance was significantly different among the habitats; however, no significant interactions were found between protectionand habitat, nor between the protection status(p-value <0.001, >0.05, >0.05, respectively). Within the coral habitats, there were significantly more recorded herbivorous fish within the channel, fore reef, and RFC compared to the lagoon habitat (p-value <0.01, <0.001, <0.001, respectively) (fig. 3).

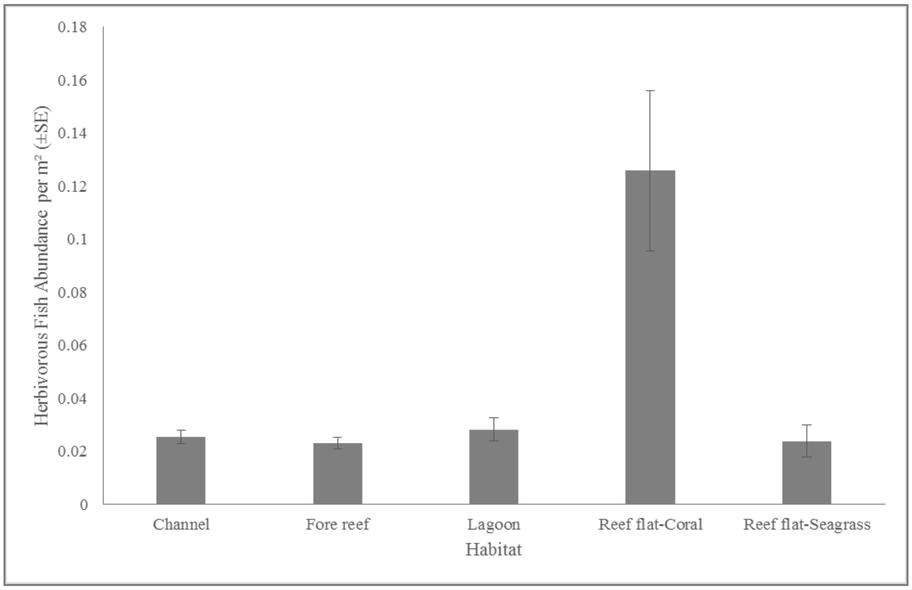

Figure 3: Mean abundance (per m^2) of herbivorous fish within each habitat in 2017-2018 (error bars indicate standard error (±SE)).

3.1.2. *Fish Biomass*

Results indicated no significant interaction between protection status and habitat types (p-value >0.05) during the follow up (in 2017-2018) or at the protection status (p-value >0.05) (fig. 4a), but there was significance differenceof fish biomass amonghabitats (p-value <0.001)(excluding the RFS). Among habitats, the biomass was significantly higher within the channel than the lagoon (p-value <0.01). The fore reef had significantly higher biomass than the lagoon (p-value <0.0001) and the RFC (p-value <0.01) (fig. 4b).At the protection status, the RFS MPA had a significantly higher biomass than the reference sites (p-value <0.05) (fig. 5). Since the fish survey method was consistent through time in the RFS, time comparison was examined. Through time, there was no significant difference of biomass among the RFS MPAs (Mann-Whitney p-value >0.05).

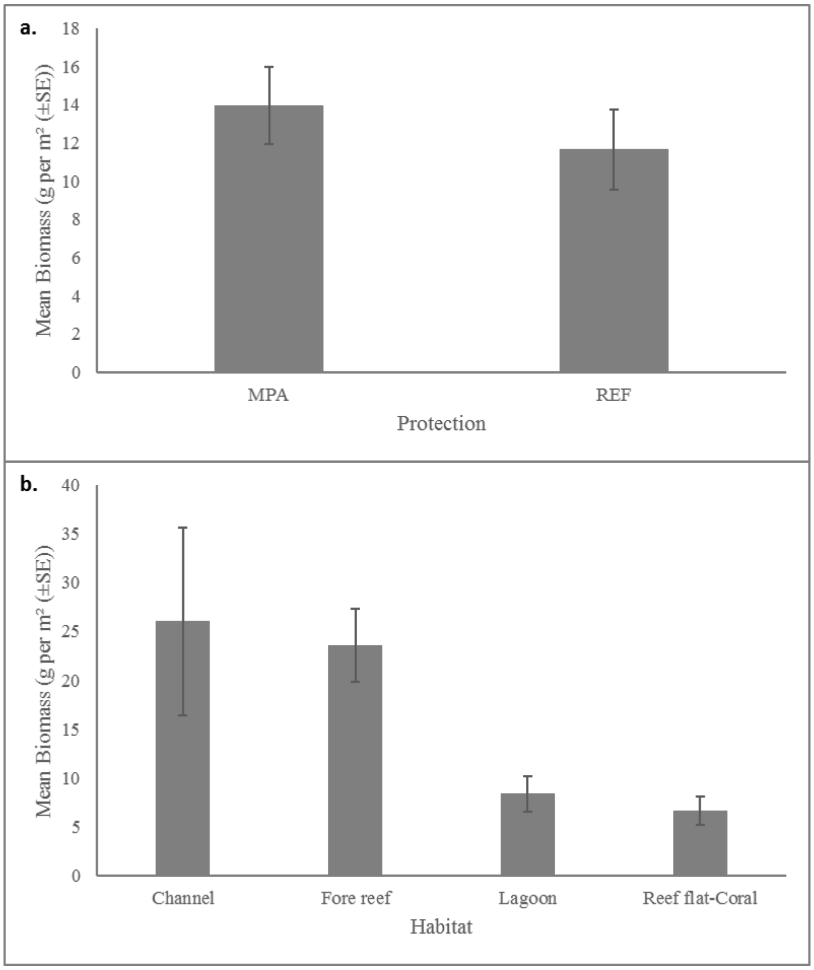

Figure 4: Mean fish biomass (g per m^2) **(a)** at the protection status of all habitats (excluding reef flat with seagrass) and **(b)** at the habitat level (error bars indicate standard error (±SE)).

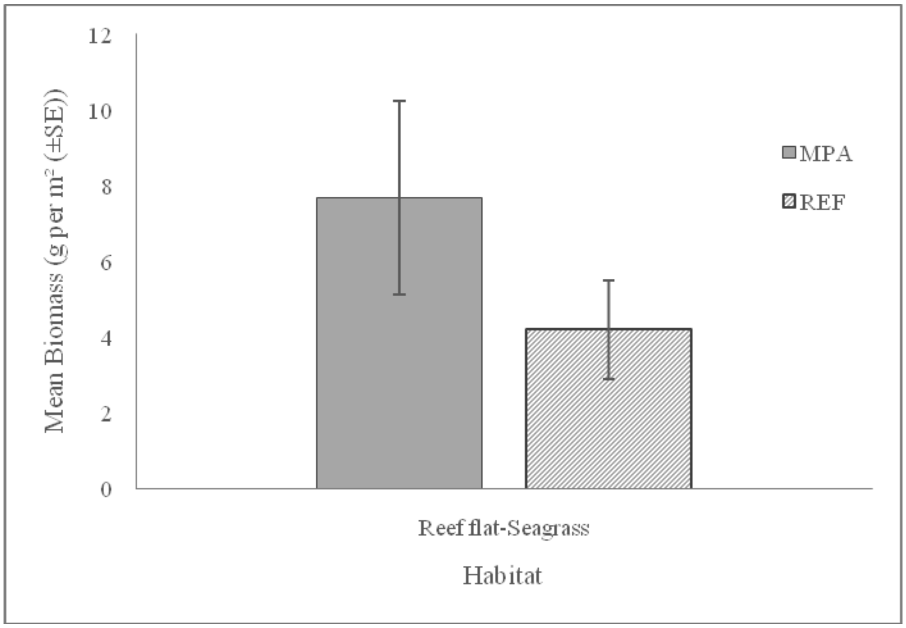

Figure 5: Mean fish biomass (g per m^2) between protection status at the RFS (error bars indicate standard error (±SE)).

Herbivorous fish biomass was significantly different among the habitats (p<0.001). However, there were no significant interactions between protection and habitat, nor between the protection status(p-value >0.05, >0.05, respectively). Within the habitats, the lagoon had the lowest biomass of herbivorous fish compared to the three other coral habitats (channel, p-value <0.001; fore reef, p-value <0.001; RFC, p-value <0.001), while the fore reef had significantly higher herbivorous fish biomass than the RFC (p-value <0.05) (fig. 6).

An examination of the fish community indicated that kemedukl (*Bolbometopon muricatum*), otord (*Chlorururs microrhinos*), mellemau (*Chlorururs sordidus*), ngiaoch (*Hipposcarus longiceps*), um (*Naso unicornis*), maml (*Cheilinus undulatus*), kedesau (*Lutjanus bohar*), keremlal (*Lutjanus gibbus*), and tiau (*Plectropomus areolatus*) were the top 10 species driving the difference between abundance and biomass. While the abundance of fish was lower within the channel and fore reef habitats, the fish species assemblage within were made up of larger species than the RFC.

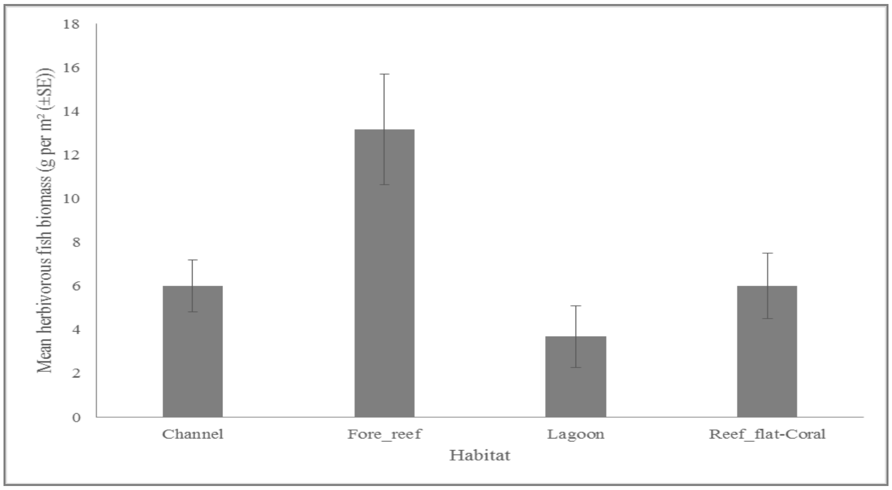

Figure 6: Mean herbivorous fish biomass (g per m^2) at the habitat level (error bars indicate standard error (±SE)).

3.1.3. Drivers of fish biomass within MPAs

A multiple regression model on commercially important fish biomass demonstrated a significant positive effect of the MPA habitat size (R^2=0.67, p-value <0.001), indicating an increase in biomass with the increase in MPA habitat size (fig. 7a). Since herbivory on reefs affects macroalgae cover, the interaction to see if the increase of macroalgae has an impact on herbivorous fish biomass was examined. Results indicated a significant positive effect of increased macroalgae cover on herbivorous fish biomass (R^2=0.25, p-value <0.05), indicating that herbivorous fish biomass increases with the increased abundance of macroalgae (fig. 7b).

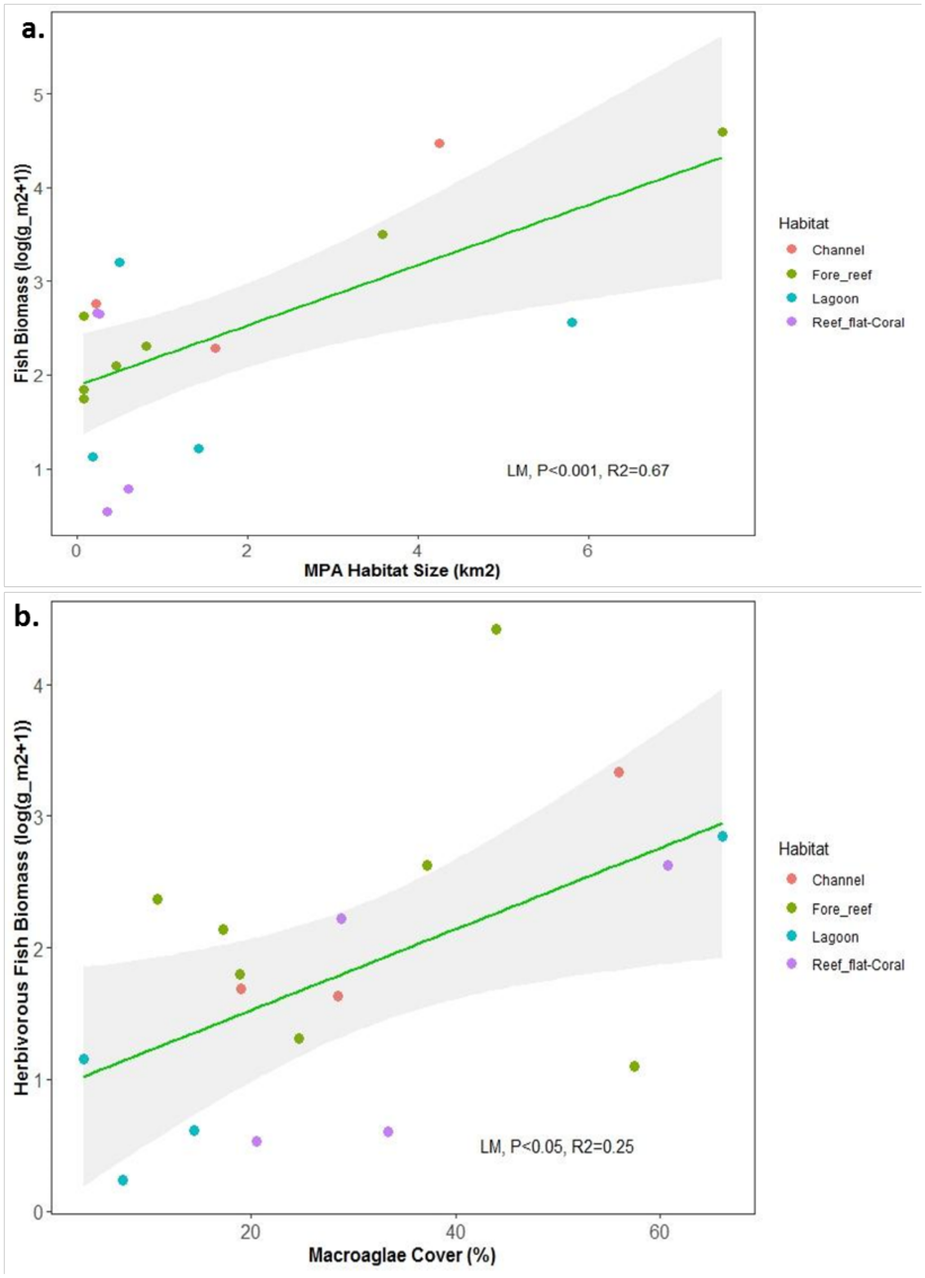

Figure 7: Regression model showing a positive relationship **(a)** between biomass of commercially important fish and MPA habitat size, and **(b)** between herbivorous fish biomass and macroalgae cover (%).

3.2. *Edible Macro-Invertebrates*

Macro-invertebrate abundance within habitats were analyzed in two parts – RFS and all coral habitats (without seagrass). Additionally, due to the patchiness and variation inthe abundanceof macro-invertebrates between the two habitat categories (with coral and with seagrass), they were examined separately, as either clams or sea cucumbers.

LMER indicated a significant interaction between the protection status and coral habitats during the 2017-2018 survey (p-value <0.05). Among the coral habitats, the channel had significantly more macro-invertebrates within the MPA compared to the reference areas (p-value <0.001) (fig. 8) with giant clams (*Tridacna* spp*., Hippopus* spp*.)*being the most abundant of the edible macro-invertebrates within the coral habitats (fig. 9).

Macro-invertebrate abundance was also significantly greater within the MPA than the reference site within the RFS (p-value <0.001)(fig. 8) withsea cucumbers being the most abundant type (*Actinopyga* spp*., Bohadschia* spp*., Holothuria* spp*., Stichopus* spp*., Thelenota* spp*.*) (fig. 9).

Analysis showed significance in abundance of edible clams among habitats and protection status. Clams abundance was significantly higher within the channel MPA (p-value <0.001) and the RFS MPA (p-value <0.05) compared to their respective reference sites, while sea cucumbers were significantly higher within the channel, lagoon, and RFS MPA (p-value <0.001, <0.05, <0.05, respectively) compared to their respective reference sites (fig. 9).

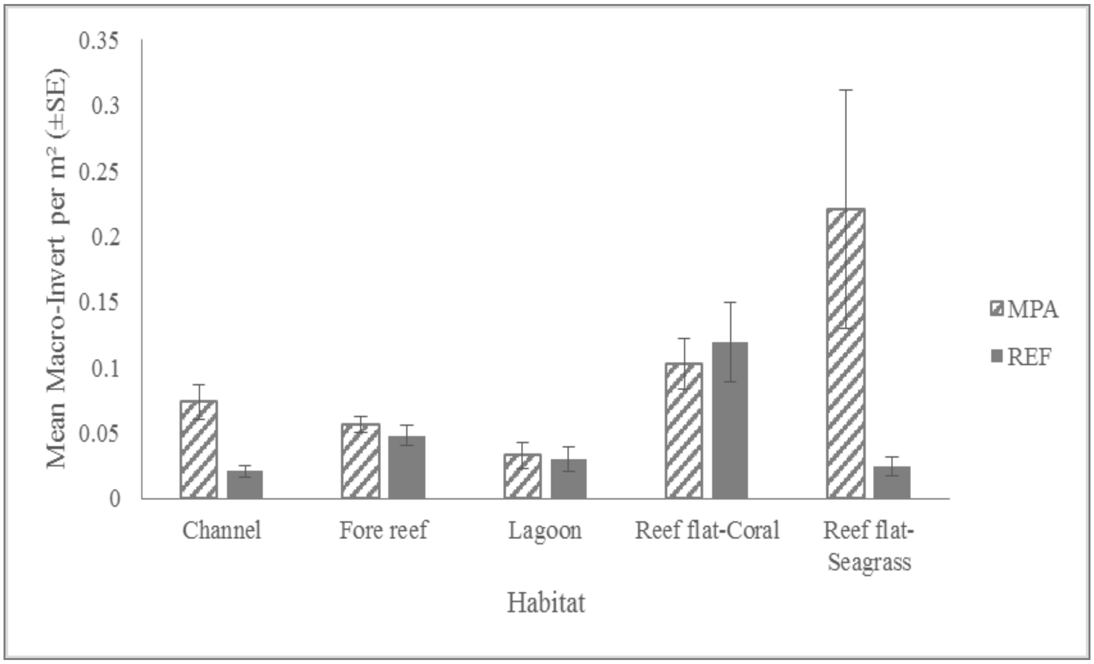

Figure 8: Mean abundance of edible macro-invertebrates among each habitat and protection status between 2017-2018 (error bars indicate standard error (±SE)).

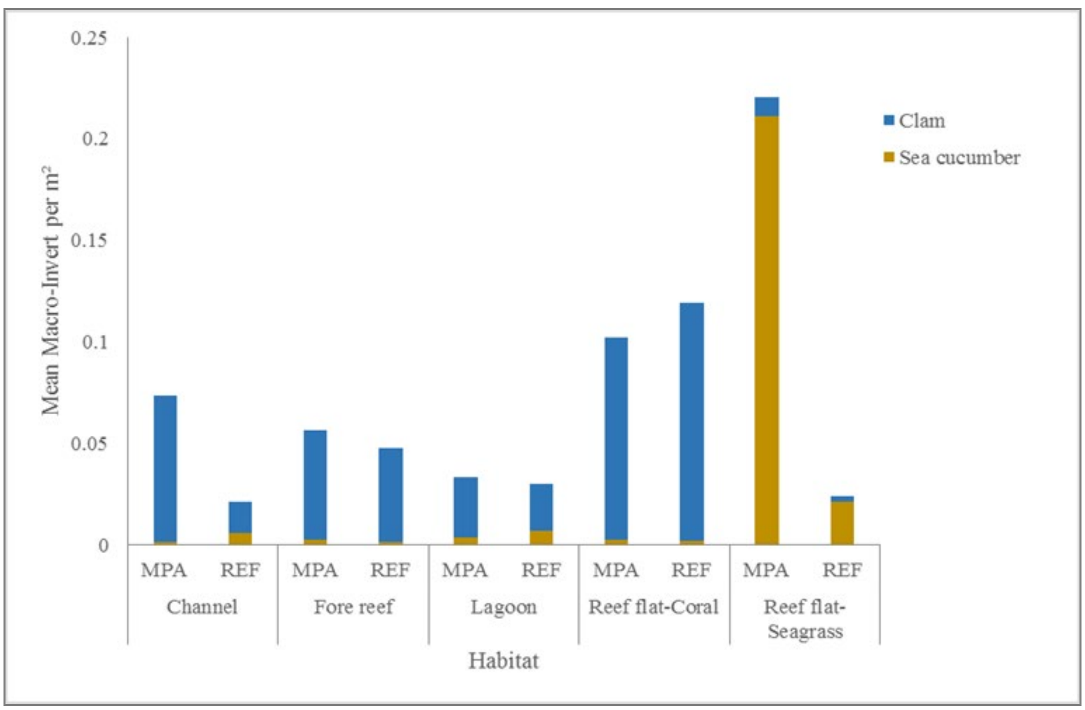

Figure 9: Mean abundance of edible macro-invertebrates observed within each habitat and protection status.

LMER indicated a significant interaction in macro-invertebrate abundance between time and coral habitats within the MPAs (p-value <0.05). There was significant increase of macro-invertebrates in 2017-2018 since the baseline assessment in 2014-2015 (p-value <0.05) in the RFC, while all other habitats showed a decrease over time. While the change in abundance along the fore reefs and the RFS were not significant, both the channel and the lagoon had significantly more macro-invertebrates during the baseline (2014-2015) compared to the reassessment in 2017-2018 (p-value <0.05, p-value <0.01, respectively) (fig. 10a).

Examining the difference in the types of macro-invertebrates, analysis showed significant difference in abundance of edible clams among habitats and through time (p-value <0.05), while there was no significant change in sea cucumber abundance among habitats and through time (p-value >0.05). Clam abundance was significantly higher during the baseline in 2014-2015 within channel, fore reef, and lagoon (p-value <0.01, <0.05, <0.01, respectively), while the abundance in the RFChad significantly increased from 2014-2015 to 2017-2018 (p-value <0.01) (fig. 11).

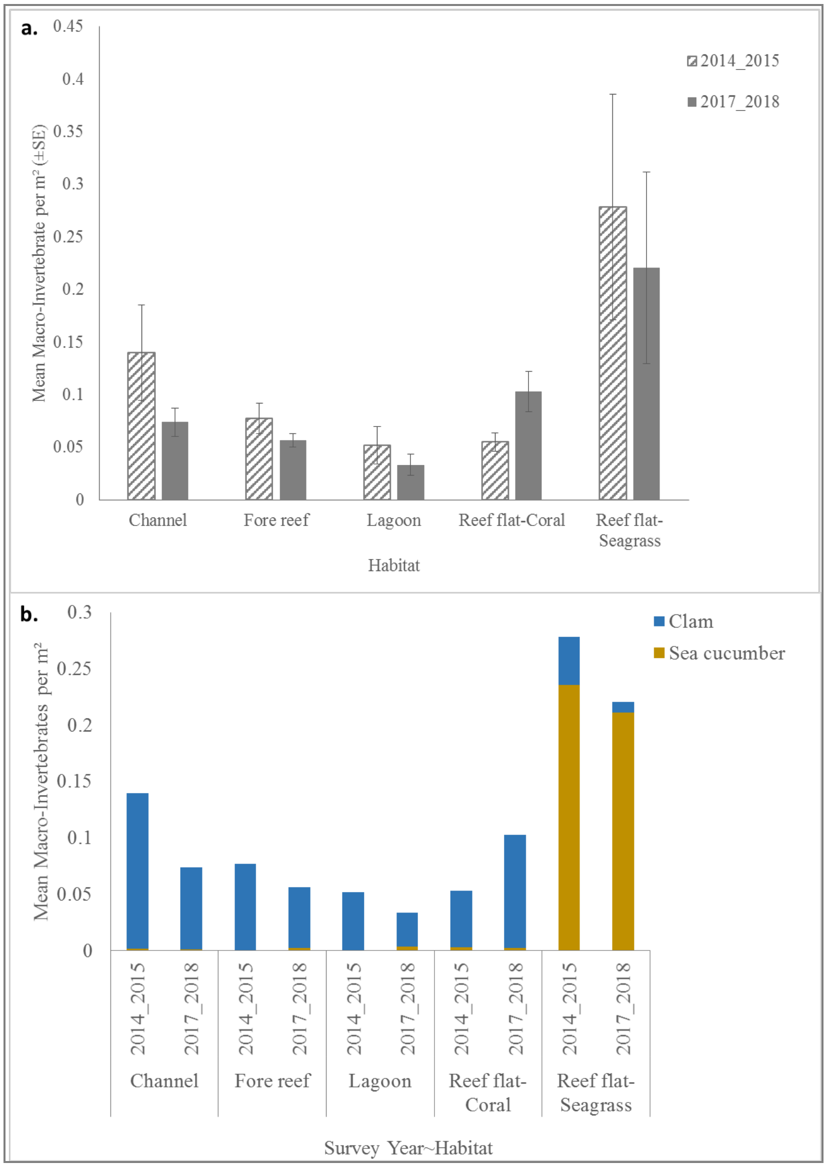

Figure 10:(a) Mean edible macro-invertebrate abundance among coral habitats and survey period, and**(b)** edible macro-invertebrate types surveyed (error bars indicate standard error (±SE)).

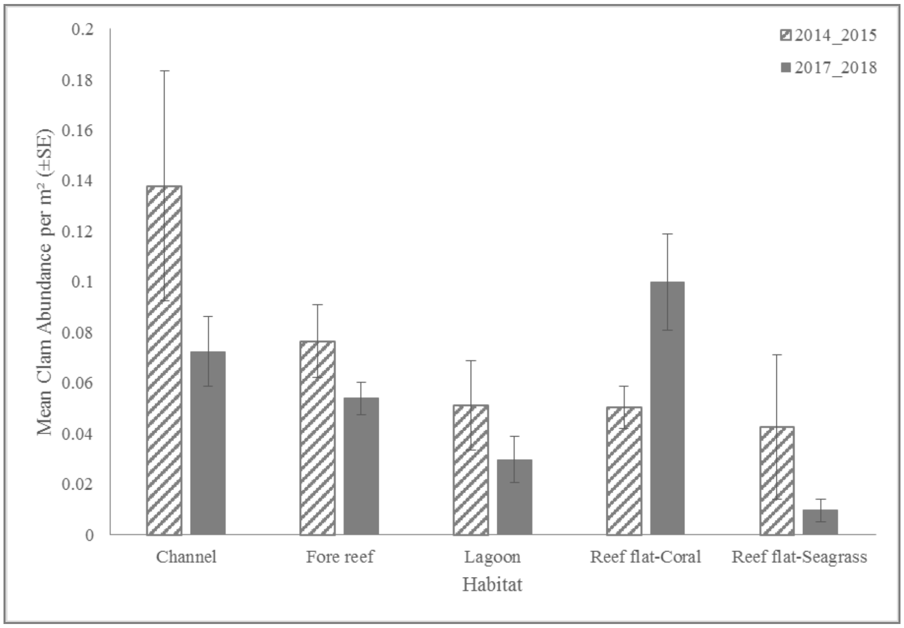

Figure 11: Mean clam abundance observed within each habitat and survey period through time (error bars indicate standard error (±SE)).

3.2.1. Drivers of edible macro-invertebrates within MPAs

A multiple regression model on commercially important edible macro-invertebrates demonstrates significantly higher clam abundance with the types of habitat and distance to port (R^2=0.48, p-value<0.05, p-value <0.05) (fig. 12).

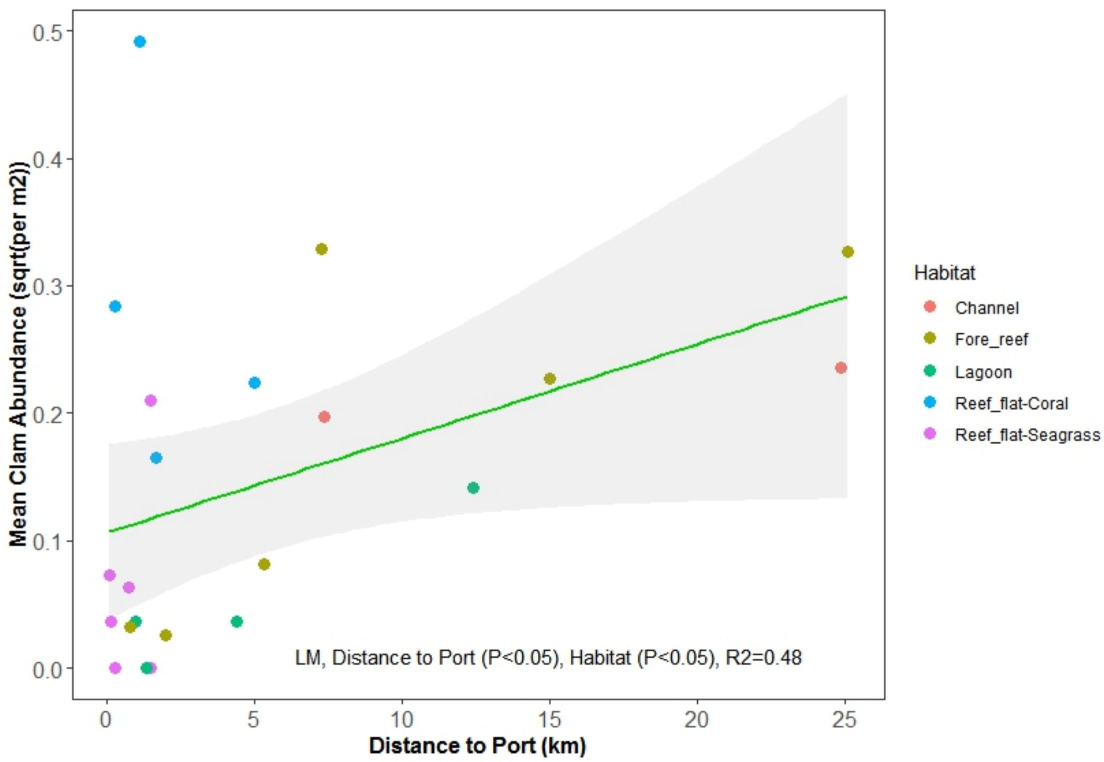

Figure 12: Regression model showing a positive relationship between edible clam abundance and distance to port (km) and habitat.

3.3. Macroalgae cover (%)

LMER showed a significant interaction in terms of macroalgae cover (%) between protection and habitat (p-value <0.000). Among habitats, the channel, fore reef, and RFC had significantly higher macroalgae cover within the MPA compared to their respective reference sites (p-value <0.05, <0.000, <0.01, respectively). The lagoon was the only habitat where the reference site had significantly higher macroalgae cover than the lagoon MPA (p-value <0.01) (fig. 13).

Additionally, there was a significant interaction in terms of macroalgae cover (%) between time and habitat (p-value <0.001). Macroalgae cover had significantly increased in the channel, lagoon, and RFC habitats over time from 2014-2015 to 2017-2018 (p-value <0.001, <0.01, <0.001, respectively) (fig. 14). From 2014-2015 to 2017-2018 within the MPAs, there was a 7.3-

foldincrease of macroalgae cover within the channel, 1.7-fold increase within the RFC, 1.4-fold increase within the lagoon, and 1.1% increase within the fore reef (fig. 14).

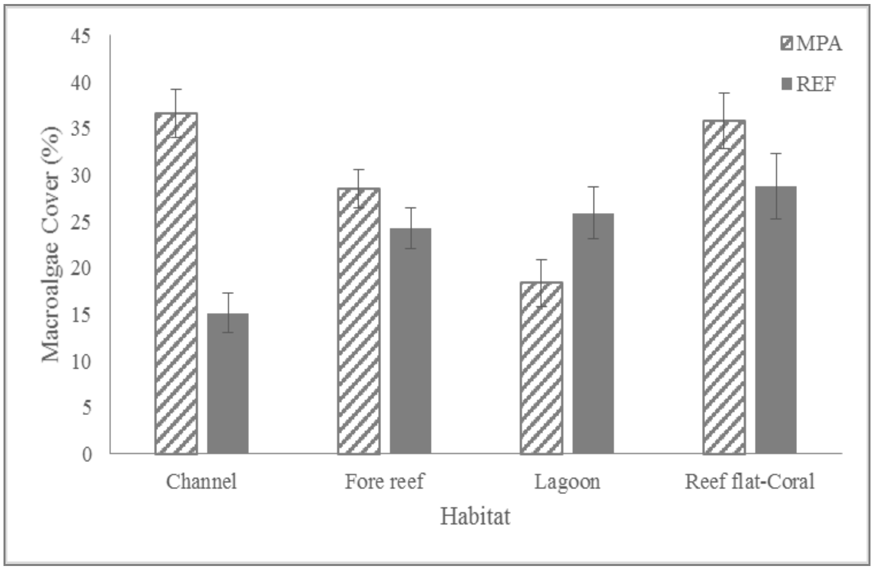

Figure 13: Macroalgae cover (%) within each habitat and protection status (error bars indicate standard error (±SE)).

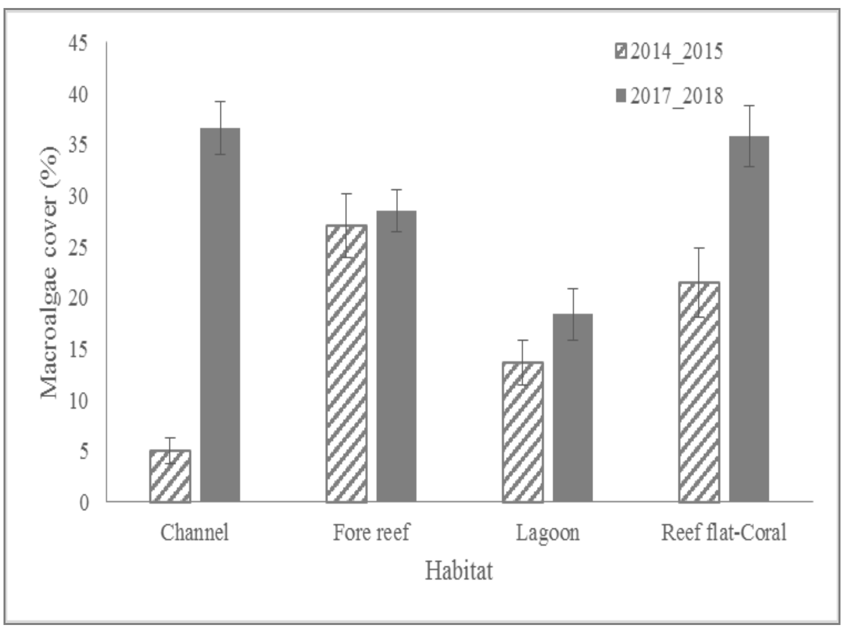

Figure 14: Macroalgae cover (%) within each habitat and survey period through time (error bars indicate standard error (±SE)).

3.3.1. Drivers of macroalgaeincrease within MPAs

A multiple regression model was used to examine possible drivers of macroalgae cover (%)which demonstrates a significant positive relationshipofmean herbivorous fish biomass and distance to port (R^2=0.41, p-value<0.05, p-value <0.1).Independently, macroalgae cover (%) had a significant effect on herbivorous fish biomass (R^2=0.27, p-value<0.05) where herbivorous fish biomass increases with the increase of macroalgae cover (fig. 15).Distance to port (km) had no significant relationship (R^2=0.1, p-value>0.05), nor did any other of the drivers examined.

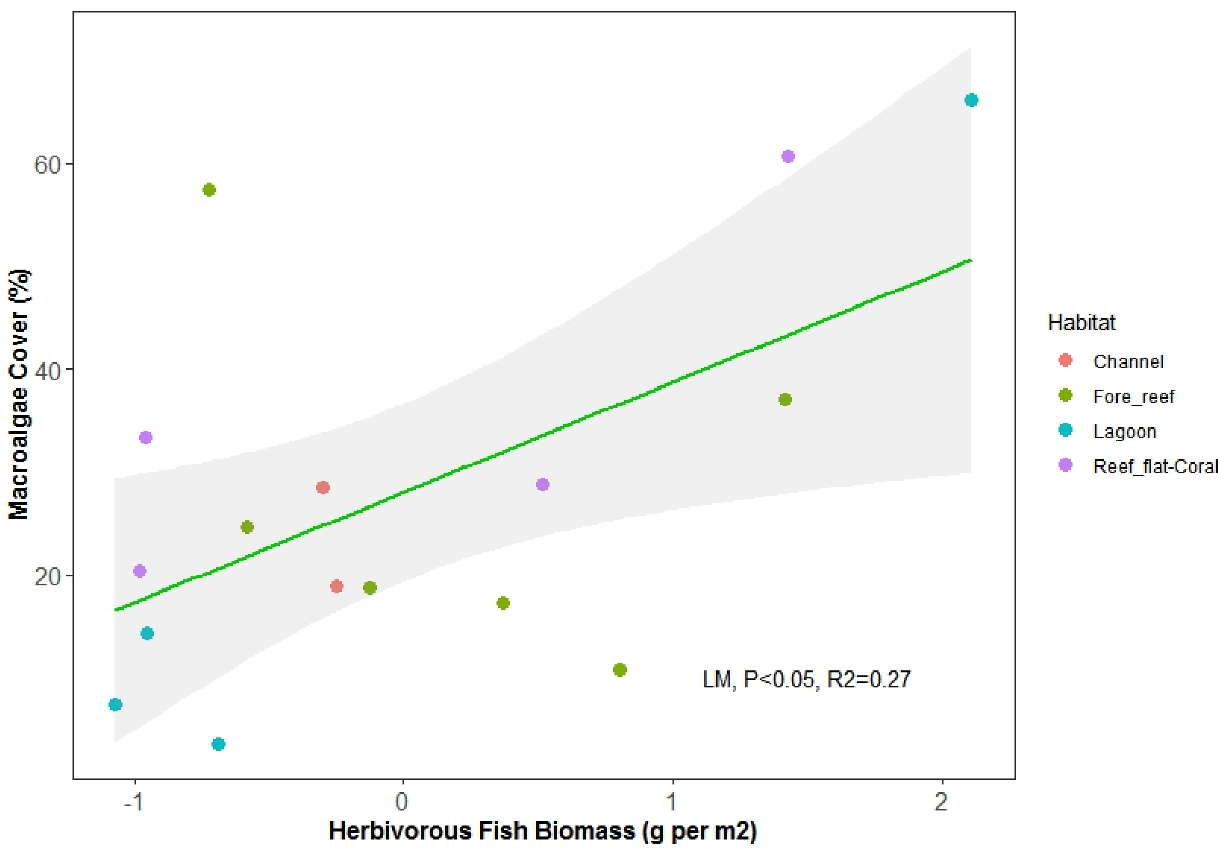

Figure 15: Regression model showing a positive relationship between macroalgae cover (%) and herbivorous fish biomass (g per m^2, normalized for analysis).

4. Discussion

4.1. *Commercially important fish*

Within the seagrass dominated reef flat (RFS), no significant difference was found in fish abundance at the protection status nor through time, but fishbiomass was significantly higher within the MPA. The RFC had a higher mean abundance of fish per m^2 than the channel and fore reef while the mean biomass (g/m^2) was higher within the channels and fore reef than compared to the RFC.

As macroalgae cover is a focus in this report, fish were categorized according to their trophic level to examine the difference in fish communities within the habitats. While there was no significant difference in omnivore and carnivore abundance within the habitats, herbivorous fish were significantly more abundant within some habitats (channel, fore reef, RFC) than others (lagoon, RFS).

4.1.2. *Fish biomass drivers*

Overall, habitat size was the only driver that had a positive correlation with fish biomass indicating as the size of the MPA increases per m^2, so does fish biomass.The increased boundaries that allow for “spill-over” are pushed, allowing larger fish a greater area to roamwithin the protected area (Krueck et al., 2018).While habitat size impacted fish biomass as a whole, it had no effect on herbivorous fish biomass.There was a positive correlation between herbivorous fish biomass and macroalgae cover. This could indicate that the increased abundance of food source for herbivorous fish resulted in higher biomass, but did not necessarily increase abundance.Studies have shown that community diversity of herbivorous fish has the ability to impact whether or not macroalgal growth is controlled (Burkepile & Hay, 2010).Therefore, it is possible that the current population of herbivorous fish are not abundant enough or the community of herbivorous fish are not diverse enough to maintain and control the coverage of macroalgae within the habitats. Additionally, our surveys limit the recorded fish to those of commercial importance, therefore, our data could be missing key herbivorous species that might not necessarily be of commercial importance.

4.2. *Edible macro-invertebrates*

This report shows that the protection of MPAs are effective in protecting macro-invertebrates, either for clams, sea cucumbers, or both, specifically within the channel and RFS habitats. Over time, there was a significant decrease in macro-invertebrates within the channel and lagoon habitats, while the abundance in theRFChad significantly increased.

Clam abundance was significantly higher within the channel and the RFS MPAs than their respective reference sites, while sea cucumber abundance was significantly higher within the RFS MPAs than its respective reference sites (fig. 9). The significantly higher abundance of sea cucumbers within the RFS MPAs indicate a positive impact as a result of protection.Since most states' MPA management plans that prioritize the seagrass beds seek to protect their valuable macro-invertebrate population, such as Ngermasech CA and Ngelukes CA(Ngardmau Conservation Board, Ngchesar State Conservation), this increased abundance of macro-invertebrates is a positive sign.Over time, clam abundance had significantly decreasedsince the baseline in three out of five habitats – channel, fore reef, lagoon. One should be concerned that there is a possible 'Allee effect' occurring, where density of key species are too low to naturally recover (Courchamp et al., 1999). Unfortunately, two time points does not provide enough data to show a constant decreasing trend, and therefore macro-invertebrates abundance must be continuously monitored through time.

4.2.1. Macro-invertebrate drivers

Whilemacroalgae cover hadno effect on macro-invertebrate abundance, the survey did not allow for an examination of sedimentation as a possible driver of macroalgae cover and subsequent negative impacts on macro-invertebrate abundance. Assedimentation covers substrate and creates phase shifts from coral to algae dominated habitats (Golbuu et al., 2003),the increased algal cover and sediments could smother already residing clams, while the reduction of ideal substrates for coral and clam larval settlement would prevent any possible recovery of the threatened community.

4.3. *Macroalgae cover and drivers*

Macroalgae cover (%) was significantly higher within three out of the four MPA habitats (channel – 36.6%, fore reef – 28.5%, RFC – 35.9%) than their respective reference sites, while the lagoon had significantly lower macroalgae cover within the MPA than its respective reference site (18.4%). Since their respective baseline assessments, macroalgae cover had significantly increased within the channel, RFC, and lagoon with a 7.3, 1.7, and 1.4-fold increase, respectively.

The only significant effect was herbivorous fish biomass, whereas herbivorous fish biomass increases, so does the percent cover of macroalgae (refer to Discussion 1a.). Water quality data, such as turbidity, Chl-*a*, dissolved oxygen, temperature, salinity, pH, total alkalinity to name a few,was unavailable at the time of this study to further explore as a likely driver of macroalgae cover increase. Since we see the positive relationship with increased distance, water quality and clarity have the tendency to improve with the increased distance from urbanized areas and watersheds(Howell et al., 2012).

5. Conclusion

This report shows that the PAN MPAs are effective in some areas and raisessome concern in others. Within the habitats, the seagrass dominated reef flat MPAssupporteffectiveness in protecting commercially important fish and macro-invertebrates, specifically targeted edible sea cucumbers. While there was no significant change through time within the RFS, this indicates that the MPAsare protecting stable populations of fish and macro-invertebrates though trophic levels of fish are unaffected by the protection status. Walters (2000) suggests that surveys examining protected versus non-protected areas are not enough to determine MPA effectiveness due to dispersal differences within the MPA. Survey site selection was done randomly, and in most cases, are spread apart within each habitat while some sites are positioned closely and might need to be spaced out for further surveys(Walters, 2000).

An increase of macroalgal coverage is a negative indicator of multiple factors such as proximity to urbanized areas, increase in nutrients within the water, or an unbalance of herbivorous fish communities, to name a few(Aronson & Precht, 2000; De'ath & Fabricius, 2010; McCook, 1999). While elevated macroalgae coverage could be a factor of natural conditions and not necessarily an indicator of habitat degradation, increased macroalgae could also be an indicator of nutrient influx due to urbanization (Savage et al., 2010). Additionally, there are instances where isolated reefs had elevated levels of macroalgal coverage; for example, the Northwestern Hawaiian Islands were reported to have 29% macroalgae coverage within some lagoon and back reef habitats (Friedlander et al., 2005). While macroalgae assemblage are known to have seasonal fluctuation, the surveys conducted at each of these sites are done so consistently within the same month with the intent of removing any seasonal variation. The significant increase in macroalgae cover within the channel and the coral dominated reef flat MPAs in just three years could be attributed to a possible change in the herbivory community of the habitats or a possible a change in water quality such as nutrient, turbidity, or temperature, to name a few. The macroalgae changes over time need to be closely monitored as they could be a result of increased partial pressure of carbon dioxide (pCO_2) and temperature that being brought on by the progression of climate change (Olabarria et al., 2013; Tait & Schiel, 2013; Zanini Branco & Necchi Júnior, 1997). PICRC currently focuses on commercially important fish species, therefore key herbivorous fish species that are not necessarily of commercial importance could be missed and not well represented. It should be considered for further assessments to include this underrepresented community. In addition, water quality analysis is needed to further investigate and explain these changes. Water quality (turbidity, Chl-*a*, dissolved oxygen, temperature, salinity, pH) was measured at some of the MPAs in 2018 and has been an addition to MPA survey methods since then.

Continuous surveying and monitoring over the coming years would help to indicate trends within the MPAs. Additionally, water quality monitoring within the MPAs will possibly provide an explanation to the increasing macroalgae cover within the reference sites. Although it is worth mentioning that while this report examines some influencing variables, not all variables that could affect the surveyed ecological indicators were examined – such as seagrass cover, distance to watersheds, wave exposure, larval supply, etc. A high level of public awareness and understanding within each state, as well as increased support of the state’s conservation efforts,is key in ensuring the effectiveness of the conservation zones. However, community support alone is not enough; it is strongly recommended to increase surveillance and enforcement of the MPAs from possible poachers outside of the community. Finally, it is recommended to improve watershed management to minimize sediment run-off into the ocean.

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Appendix

Appendix 1a: Commercially important fish species (UVC)

Commercial species

Scientific name	***Common name***
Siganus lineatus (Kelsebuul)	Lined rabbitfish
Siganus argenteus(Beduut)	Forketail rabbitfish
Naso unicornis (Chum)	Bluespine unicornfish
Naso lituratus (Cherngel)	Orangspine unicornfish
Lethrinus olivaceus (Melangmud)	Longface enperor
Lethrinus obsoletus (udech)	Orangestripe emperor
Lethrinus xanthochilis (Mechur)	Yellowlip emperor
Lutjanus bohar (Kedesau)	Red snapper
Lutjanus gibbus (Keremlal)	Humpback snapper
Caranx ignobilis (Erobk)	Bluefin trevally
Caranx melampygus (Oruidel)	Giant trevally
Cetoscarus/Scarus/Chlorurus Spp. (Melemau)	All species of parrotfish
Hipposcarus longiceps (Ngeaoch)	Pacific longnose parrotfish
Valamugil seheli (Kelat)	Bluespot mullet
Liza vaigiensis (Uluu)	Squaretail mullet

Protected species

Siganus fuscescens (Meyas)	Dusky rabbitfish
Bolbometopon muricatum (Kamedukl)	Bumpead parrotfish
Cheilinus undulatus (Maml)	Humphead parrotfish
Plectropomus areolatus (Tiau)	Squaretail grouper
Plectropomus leopardus (Tiau)	Leopard grouper
Plectropomus laevis (Tiau, Katuu'tiau, Mokas)	Saddleback grouper
Epinephelus fuscoguttatus (Meteungerel'temekai)	Brown-marbled grouper
Epinephelus polyphekadion (Kesau'temekai)	Marbled grouper

Additional species

Kyphosus spp (vaigiensis). (Komud, Teboteb)	Rudderfish (lowfin)
Plectorhinchus albovittatus (Melim ralm,Kosond/Bikl)	Giant sweetlips
Plectorhinchus crysotaenia (Merar)	Yellowstripe sweetlips
Lutjanus argentimaculatus (Kedesau'l iengel)	River snapper

Choerodon anchorago (Budech)	Yellow cheek tuskfish
Siganus puellus (Reked)	Masked rabbitfish
Siganus punctatus (Bebael)	Goldspotted rabbitfish
Cetoscarus bicolor (Beyadel/ngesngis)	Bicolor parrotfish
Hipposcarus harid (Bekism)	Indian Ocean Longnose parrotfish
Lethrinus rubrioperculatus (Rekruk)	Red gill emperor
Scarus micorhinos (Otord)	Pacific steephead parrotfish
Scarus prasiognathus (Udouungelel)	Greenthroat parrotfish

Appendix 1b: Commercially important fish species (Stereo-DOV)

Scientific name	**Common name**	**Palauan name**
Acanthurus nigricauda	Epaulette surgeonfish	Chesengel
Acanthurus xanthopterus	Yellowfin surgeonfish	Mesekuuk
Acanthurus spp.	Surgeonfish species	
Naso lituratus	Orangespine unicornfish	Cherangel
Naso unicornis	Bluespine unicornfish	Chum
Naso spp.	Unicornfish species	
Carangoides ferdau	Blue trevally	Yab
Carangoides fulvoguttatus	Yellowspotted trevally	Uii
Carangoides orthogrammus	Island trevally	Otewot
Carangoides plagiotaenia	Barcheek trevally	
Carangoides spp.	Trevally/jack species	
Caranx ignobilis	Giant trevally	Erobk
Caranx lugubris	Black jack	Omektutau
Caranx melampygus	Bluefin trevally	Oruidel
Caranx sexfasciatus	Bigeye trevally	Esuch
Caranx spp.	Trevally/jack species	
Elagatis bipinnulata	Rainbow runner	Desui
Trachinotus blochii	Snubnose pompano	Luichlbuil
Chanos chanos	Milkfish	Aol, Mesekelat
Aethaloperca rogaa	Redmouth grouper	Chubei
Anyperodon leucogrammicus	Slender grouper	Choloteachi
Cephalopholis argus	Peacock hind	Mengardechelucheb
Cephalopholis cyanostigma	Bluespotted hind	Temekai
Cephalopholis miniata	Coral hind	Temekai
Cephalopholis sonnerati	Tomato hind	Temekai
Cephalopholis spp.	Hind species	
Cromileptes altivelis	Humpback grouper	Meleches
Epinephelus coeruleopunctatus	Whitespotted grouper	

Epinephelus corallicola	Coral grouper	Imirechorch
Epinephelus fuscoguttatus	Brown-marbled grouper	Meteungerel'temekai
Epinephelus melanostigma	One-blotch grouper	
Epinephelus polyphekadion	Marbled grouper	Ksau'temekai
Epinephelus spp.	Grouper species	
Gracila albomarginata	Masked grouper	
Plectropomus areolatus	Squaretail grouper	Tiau (black)
Plectropomus laevis	Saddleback grouper	Katuu'tiau, Mokas
Plectropomus leopardus	Leopard grouper	Tiau (red)
Plectropomus oligacanthus	Highfin coral grouper	
Plectropomus spp.	Coral grouper species	
Variola albimarginata	White-edged lyretail	Baslokil
Variola louti	Yellow-edged lyretail	Baslokil
Diagramma pictum	Painted sweetlips	
Plectorhinchus albovittatus	Giant sweetlips	Melimralm, Kosond, Bikl
Plectorhinchus chaetodonoides	Harlequin sweetlips	Bechol
Plectorhinchus chrysotaenia	Yellowstripe sweetlips	Merar
Plectorhinchus gibbosus	Harry hotlips	
Plectorhinchus lessonii	Lesson's thicklip	
Plectorhinchus lineatus	Diagonal-banded sweetlips	Yaus
Plectorhinchus picus	Painted sweetlip	
Plectorhinchus spp.	Sweetlips species	
Plectorhinchus vittatus	Indian Ocean oriental sweetlips	Yaus
Kyphosus cinerascens	Blue sea chub	Komud, Beab
Kyphosus vaigiensis	Brassy chub	Komud, Beab
Kyphosus spp.	Sea chub species	
Cheilinus undulatus	Humphead wrasse	Ngimer, Maml
Choerodon anchorago	Yellow cheek tuskfish	Budech
Gymnocranius spp.	Bream species	
Lethrinus atkinsoni	Pacific yellowtail emperor	
Lethrinus erythracanthus	Orange-spotted emperor	Menges
Lethrinus erythropterus	Longfin emperor	Kroll
Lethrinus harak	Thumbprint emperor	Itotech
Lethrinus obsoletus	Orangestripe emperor	Udech
Lethrinus olivaceus	Longface emperor	Melangmud
Lethrinus ornatus	Ornate emperor	
Lethrinus rubrioperculatus	Red gill emperor	Rekruk
Lethrinus spp.	Emperor species	
Lethrinus xanthochilus	Yellowlip emperor	Mechur
Monotaxis grandoculis	Humpnose bigeye bream	Besechamel
Aprion virescens	Green jobfish	Udel

Lutjanus argentimaculatus	Mangrove red snapper	Kedesau'liengel
Lutjanus bohar	Red snapper	Kedesau
Lutjanus ehrenbergii	Blackspot snapper	Dodes
Lutjanus fulvus	Blacktail snapper	Reall
Lutjanus gibbus	Humpback snapper	Keremlal
Lutjanus monostigma	One-spot snapper	Kesebii
Lutjanus rivulatus	Blubberlip snapper	Korriu
Lutjanus spp.	Snapper species	
Symphorichthys spilurus	Sailfin snapper	Chedui
Valamugil seheli	Bluespot mullet	Kelat
Liza vaigiensis	Squaretail mullet	Uluu
Parupeneus barberinus	Dash-and-dot goatfish	Bang
Parupeneus cyclostomus	Gold-saddle goatfish	Bang
Parupeneus spp.	Goatfish species	
Bolbometopon muricatum	Bumphead parrotfish	Berdebed, Kemedukl
Cetoscarus ocellatus	Spotted parrotfish	Beyadel, Ngesngis
Cetoscarus spp.	Parrotfish species	Mellemau
Chlorurus spp.	Parrotfish species	Mellemau
Scarus spp.	Parrotfish species	Mellemau
Chlorurus bleekeri	Bleeker's parrotfish	Besachel otengel
Chlorurus frontalis	Pacific slopehead parrotfish	
Chlorurus japanensis	Palecheek parrotfish	
Chlorurus microrhinos	Pacific steephead parrotfish	Otord
Chlorurus spilurus (previously sordidus)	Pacific bullethead parrotfish	
Hipposcarus longiceps	Pacific longnose parrotfish	Ngiaoch
Hipposcarus harid	Candelamoa parrotfish	Berkism
Scarus altipinnis	Filament-finned parrotfish	Udoud ungelel
Scarus chameleon	Chameleon parrotfish	
Scarus dimidiatus	Yellowbarred parrotfish	Butiliang
Scarus flavipectoralis	Yellowfin parrotfish	
Scarus forsteni	Forsten's parrotfish	Mul
Scarus frenatus	Bridled parrotfish	
Scarus ghobban	Bluebarred parrotfish	Mertebetabek
Scarus globiceps	Globehead parrotfish	Ngemoel
Scarus niger	Dusky parrotfish	Kiuiid
Scarus oviceps	Dark capped parrotfish	
Scarus prasiognathos	Greenthroat parrotfish	Melechotech a chau
Scarus psittacus	Common parrotfish	
Scarus quoyi	Quoy's parrotfish	
Scarus rivulatus	Rivulated parrotfish	Besachel-otengel
Scarus rubroviolaceus	Redlip parrotfish	Mesekelat mellemau

Scarus schlegeli	Yellowband parrotfish	
Scarus spinus	Greensnout parrotfish	
Scarus tricolor	Tricolour parrotfish	
Scarus xanthopleura	Red parrotfish	Butiliang
Grammatorcynus bilineatus	Double-lined mackerel	Beterturech
Gymnosarda unicolor	Dogtooth tuna	Kerengab
Scomberomorus commerson	Narrow barred Spanish mackerel	Ngelngal
Siganus argenteus	Forketail rabbitfish	Beduut
Siganus corallinus	Blue-spotted spinefoot	Reked
Siganus doliatus	Barred spinefoot	Reked
Siganus fuscescens	Dusky rabbitfish	Meyas
Siganus lineatus	Lined rabbitfish	Kelsebuul
Siganus puellus	Masked rabbitfish	Reked
Siganus punctatissimus	Peppered spinefoot	Bebael
Siganus punctatus	Goldspotted rabbitfish	Bebael
Siganus spp.	Rabbitfish species	
Sphyraena barracuda	Great barracuda	Ai
Sphyraena forsteri	Bigeye barracuda	Lolou
Sphyraena qenie	Blackmargin barracuda	Meyai

Appendix 2: Edible and commercially importantmacro-invertebrate

Clams

Scientific name	**Palauan name**
Tridacna crocea	Oruer
Tridacna derasa	Kism
Tridacna gigas	Otkang
Tridacna maxima	Melibes
Tridacna squamosa	Ribkungel
Hippopus hippopus	Duadeb
Hippopus porcellanus	Duadou

Sea cucumbers

Scientific name	**Palauan name**
Actinopyga echinites	Cheremrum
Actinopyga mauritiana	Bedelchelid
Bohadschia argus	Mermarch
Bohadschia marmorata	Mermarch
Holothuria impatiens	Sekesaker
Holothuria nobilis	Bakelungal
Holothuria scabra	Molech
Stichopus horrens	Irimd
Stichopus noctivagus	Irimd

Stichopus spp.	Ngimes
Thelenota ananas	Temetamel

Appendix 3: Benthic categories used to analyze benthic photos

CORAL (C)	Montiporasubmassive (MONTISB)	Boodlea (BOOD)
Acanthastrea (ACAN)	Mycedium (MYCED)	Bryopsis (BRYP)
Acropora branching (ACB)	Oulophyllia (OULO)	Caulerpa (CLP)
Acropora digitate (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)	