Assessment of Ngemai Conservation Area indicates a significant decrease in seagrass cover from 2018 to 2020

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Abstract

The Palau International Coral Reef Center (PICRC) conducts ecological monitoring of Palau's Protected Areas Network (PAN) marine protected areas (MPAs) to assess their effectiveness in conserving marine resources. This study is the second follow-up assessment of the Ngemai Conservation Area (CA) in the state of Ngiwal. Ecological surveys were carried out within the reef flat and fore reef habitats of the Ngemai CA, recording the density of commercially important fish and edible macroinvertebrates, as well as seagrass cover (on the reef flat), coral recruits and benthic community structure (on the fore reef). Within the reef flat habitat, there was a significant decrease in average seagrass cover over time, from ~21 % in 2018 to ~13 % in 2020 in the MPA. Reef flat fish biomass, density and diversity also significantly decreased in the MPA over time, with a 40-fold decrease in biomass and a 10-fold decrease in density seen from 2015 to 2020. Macroinvertebrate density remained similar over time and between the MPA and reference site in the reef flat habitat. In the fore reef habitat, both average hard coral cover (~19-24%) and coral recruit density remained stable over time and between protection levels. Even though turf cover decreased significantly within the reef flat MPA area from 2018 to 2020, cover was still two times higher than within the reference site. Fore reef fish biomass was not significantly different over time or between the MPA and reference site, however there was a significant increase in fish density from 2018 to 2020 at the reference site. Biomass of herbivorous fish was also significantly higher within the reference site compared to the MPA in 2020. Macroinvertebrate density remained similar over time and between the MPA and reference site in the fore reef habitat. Water quality measurements from 2020 indicate that turbidity and chlorophyll *a* are highest in the reef flat of the MPA. These results may indicate that the Ngemai CA has not been effective at protecting marine resources in either the reef flat or fore reef habitat. Sedimentation originating from the Ngerbekuu Watershed or movement of sand from high wave exposure may be responsible for the decline in seagrass cover. This has likely affected the fish and macroinvertebrate populations due to a reduction in seagrass habitat. In addition, the density of sea cucumbers and clams may be too low for successful reproduction to occur. The Ngemai CA is a small MPA so protection may be limited to certain fish species with smaller home ranges and more time may be required for positive changes to be observed.

1. Introduction

Marine Protected Areas (MPAs) are considered to be an important marine conservation and management tool around the world (Laffoley et al, 2019). No-take MPAs, which are fully protected, have been shown to be one of the best approaches to restore and preserve marine biodiversity and ecosystems (Sala & Giakoumi, 2018). In Palau, the conservation of marine resources is a deeply rooted tradition, which has continued into the present day in the form of MPAs. Palau currently has 35 MPAs, 14 of which are part of the Palau Protected Areas Network (PAN), which is a nationwide network of MPAs set up in 2003 to conserve Palau's unique biodiversity (Friedlander et al, 2017). In 2014 and 2015, the Palau International Coral Reef Center (PICRC) carried out baseline assessments of all PAN MPAs in Palau (Gouezo et al, 2016). Subsequently, PICRC continues to conduct ecological surveys of the PAN MPAs every two years in order to assess their effectiveness in conserving marine biodiversity.

The Ngemai Conservation Area (CA) is a marine MPA located in Ngiwal State that was first established in 1997 and was closed to fishing for 5 years. In 2002 the MPA was reopened until 2008 when it became a PAN site together with Ngiwal's terrestrial Olsolkesol Conservation Area (Palau Protected Areas Network, 2016). The Ngemai CA is designated as a "no entry or fishing" zone, for the purpose of recovery of depleted fish and invertebrates (Palau PAN Fund, 2016). Ngemai was historically known for its high abundance of collector urchin (*Tripneustes gratilla*), however this edible sea urchin has been depleted. In addition, dugongs have been seen feeding on seagrass beds in the area (Palau PAN Fund, 2016). This study is the second follow-up assessment of the Ngemai CA since the baseline in 2015. The objectives of this study were: 1) to show the current status of natural resources within the reef flat and fore reef habitats, 2) to compare data to the baseline in 2015 and first follow-up assessment in 2018, and 3) to compare data from within the MPA to the non-protected reference sites.

2. Methods

2.1 Study site

The Ngemai CA is a patch reef, approximately 1 km^2 in size, consisting of reef flat (containing seagrass) and fore reef habitats, with a channel to the north and south of the CA (Palau PAN Fund, 2016). In the 2015 baseline assessment, three habitats were surveyed within the MPA; reef flat, fore reef, and channel (Gouezo et al, 2015). In the first follow-up assessment in 2018 (Gouezo et al, 2018), the two main habitats identified in the baseline, reef flat and fore reef, were reassessed, and these two habitats will continue to be surveyed every two years. The current survey was carried out from the 17th to 19th March 2020 and included three sites per habitat inside the MPA and outside at the reference site in

Melekeok (Figure 1). In order for data to be comparable over time, surveys are carried out around the same time of year, with the baseline survey carried out in March 2015 and the first follow-up in April 2018. Sites for the current survey are the same as in 2015 and 2018, apart from FR_8 which was not surveyed in the baseline.

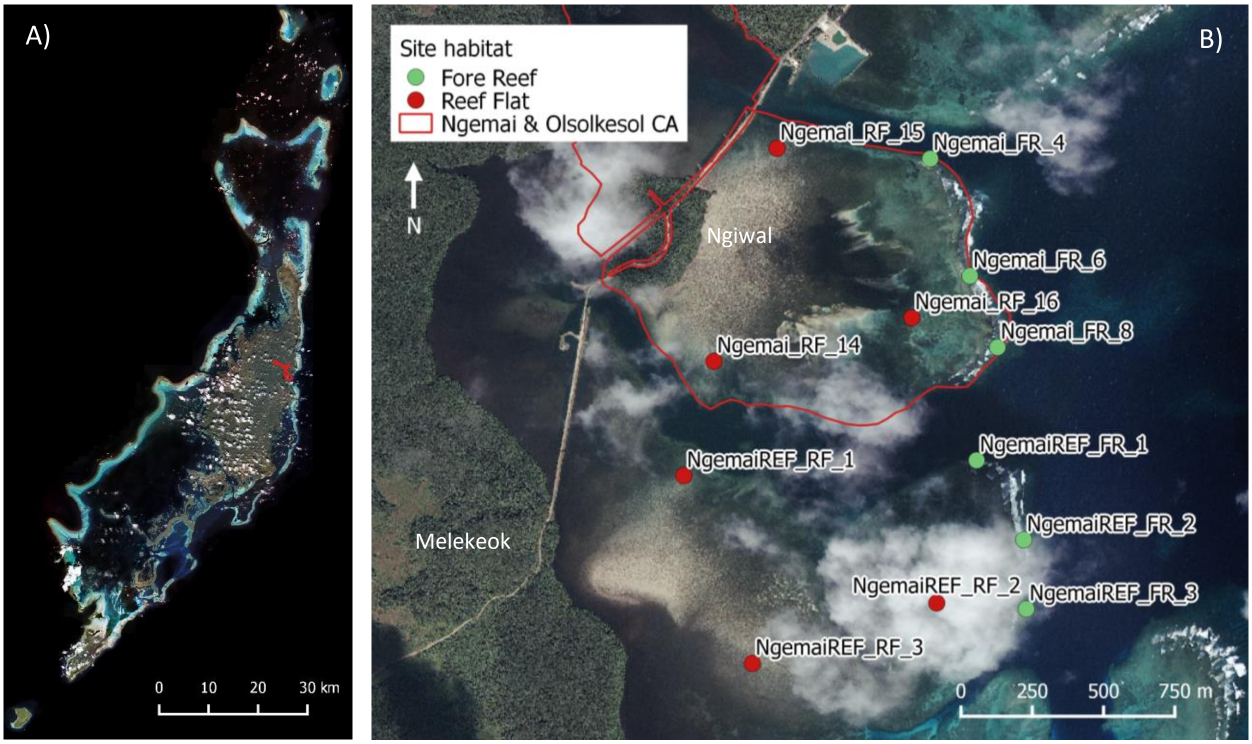

Figure 1. Location of Ngemai and Olsolkesol Conservation Area within Palau (A) and location of fore reef and reef flat monitoring sites inside the protected area in Ngiwal and outside at the reference site in Melekeok (B).

2.2 Data collection

Ecological surveys were carried out at all reef flat and fore reef sites. Reef flat sites were surveyed during an incoming tide, when the depth was approximately 0.5 – 1 m. At each reef flat site, five-25 m transects were laid out consecutively, with a few meters gap between each tape. Along each transect, seagrass percentage cover, to species level, was recorded within a 0.5 m^2 quadrat placed every 5 m (5 quadrats per transect). Size and abundance of 34 commercially important and protected fish species were surveyed within a 5 m belt along each 25 m transect using underwater visual census (UVC) (see Appendix 1 for list of fish species included in UVC). Edible and commercially important macroinvertebrates were recorded within a 2 m belt along each 25 m transect (see Appendix 2 for list of edible macroinvertebrates).

At each fore reef site, at 10 m depth, five-50 m transects were laid out consecutively with a few meters gap between each tape. For benthic cover, photographs were taken every 1 m using an underwater camera (Canon G16) mounted on a 0.5 m^2 photo-quadrat frame (50 photos per transect). Coral recruits (<5 cm in size) were recorded in the first 10 m of each transect within a 0.3 m wide belt. Fish abundance and size were recorded using diver-operated stereo-video (stereo-DOV) within a 5 m belt, while edible and commercially important macroinvertebrates were recorded within a 2 m wide belt, along each 50 m transect. The stereo-DOV system is calibrated annually by PICRC and was calibrated before this survey in February 2020.

During the 2015 baseline, different methods were used to estimate seagrass cover on the reef flat, as well as fish abundance and size on the fore reef (UVC instead of stereo-DOV); therefore, this data is not comparable to data collected in 2018 and 2020 and has been excluded from the results. In the reef flat, seagrass cover is compared between 2018 and 2020 only, whereas fish and macroinvertebrates are compared between 2015, 2018 and 2020. In the fore reef, fish is compared between 2018 and 2020 only, whereas benthic cover, coral recruits and macroinvertebrates are compared between 2015, 2018 and 2020.

Water quality measurements which included temperature, salinity, conductivity, chlorophyll *a*, turbidity, pH and dissolved oxygen were taken using a multi-parameter sensor (AAQ-RINKO Series AAQ-PRO2 Communication Software Version 1.06, JFE Advantech Co, Japan) at one representative site within each habitat in both the MPA and reference areas (four sites in total). At each site, the sensor was lowered through the water column from the surface to the sea bed and back up while taking continuous measurements. Averages were calculated for the top 0.5 – 1 m for each parameter after data for the top and bottom 0.5 m was removed to avoid erroneous readings caused by disturbances on the surface and seabed. The number of readings at each site ranged from 7 to 24 depending on the speed the probe was lowered. Chlorophyll *a* values were recalculated using the formula:

$$\text{Chlorophyll } a = 1.525\, x + 0.1559$$

based on known chlorophyll *a* concentrations of sampled seawater throughout Palau (Kurihara, unpublished data) and measured by a TURNER fluorometer (Trilogy, TURNER DESIGN, USA). The AAQ-RINKO sensor is calibrated before every survey.

2.3 Data processing and analysis

Data collected for seagrass cover, macroinvertebrates, coral recruits, and reef flat fish were entered into excel spreadsheets. For seagrass cover, the percentage of each species was summed to get the total seagrass cover in each quadrat and the average seagrass cover was calculated for each transect (5 transects per site). For macroinvertebrates and coral recruits, the total number of individuals counted per transect were summed and then divided by the transect length multiplied by the width to get the density.

Fish videos from the fore reef habitat were analyzed using the SeaGIS EventMeasure software (Version 4.42). The Length/3D rules in EventMeasure were set up as in Goetze et al (2019), where the maximum range = 8000 mm, maximum RMS = 20 mm, maximum precision to length ratio = 10%, minimum x coordinate = -2500 mm and maximum x coordinate = 2500 mm. Fork length measurements were made for all commercially important fish (see Appendix 3 for list of commercially important fish species included in stereo-DOV). In addition, key herbivorous fish from six families (Acanthuridae, Ephippidae, Kyphosidae, Pomacanthidae, Labridae-Scarinae and Siganidae) chosen based on Green & Bellwood (2009), were measured to investigate the status of herbivorous fish. Where the precision to length ratio exceeded 10%, the fish was counted and an estimated length was calculated based on the mean fish length of that species within the MPA or the reference site (Goetze et al, 2019). The weight of fish within the reef flat and fore reef habitats were calculated using the length-based equation:

$$W = aFL^b$$

where W is the weight of the fish in grams, FL is the fork length of the fish in centimeters, and a and b are constant values from published biomass-length relationships (Kulbicki et al, 2005; Kamikawa et al, 2015) and Fish Base (Froese & Pauly, 2019). Average fish biomass and density per transect was then calculated by dividing the total weight and total number by the transect length multiplied by the transect width. In addition, species richness (the number of species observed) and Shannon's diversity index (a measure of diversity that combines species richness and their abundances) was calculated for each transect and averaged for each year and protection level combination.

Benthic photos were analyzed using CPCe software (Kohler & Gill, 2006), where five random points were allocated to each photo and the substrate below each point was classified into benthic categories (see

Appendix 4 for list of benthic categories). This data was then used to calculate the mean percentage cover of each benthic category per transect (5 transects per site).

All statistical analyses were completed using R software. Prior to analysis, data were checked for normality using histograms and the Shapiro-Wilk test. Non-normal data were log-, square root-, or cube root-transformed and re-tested for normality. Normal data were analyzed using linear mixed effects models using the 'lme4' package to compare marine resources within the MPA to the reference area and to assess changes over time. Site was added as a random effect to account for repeated measures over time at the same location. Pairwise comparison was conducted when results indicated significance using the 'emmeans' package. Following analysis, residuals were plotted and tested for normality using the Shapiro-Wilk test. Non-normal data were analyzed using the Kruskal-Wallis test. Where a significant difference was found the data were analyzed further using Dunn's post-hoc test. Herbivorous fish data were analyzed using an ANOVA, since data on herbivores were not collected in 2015 or 2018. All values are reported as means and one standard error, apart from water quality measurements which are reported as means and one standard deviation.

3. Results

3.1 Reef flat

Mean seagrass cover in the MPA decreased significantly from 2018 (21.3 ± 2.2 %) to 2020 (12.9 ± 2.8 %) ($p<0.001$) (Figure 2a). The same trend was seen at the reference site with a significant decrease from 2018 (34.1 ± 2.7 %) to 2020 (22.9 ± 2.9 %) ($p<0.001$). Although seagrass cover was lower in the MPA compared to the reference site in both 2018 and 2020, these differences were not significant. Six seagrass species were observed in the MPA in 2020, with *Thalassia hemprichii*, *Cymodocea rotundata*, *Syringodium isoetifolium,* and *Enhalus acoroides* being the most dominant species and *Cymodocea serrulata* and *Halophila ovalis* observed at lower percentages (Figure 2b). *Cymodocea serrulata* was not observed in the reference site in 2020 and *Cymodocea serrulata* and *Halophila ovalis* were not observed in the MPA in 2018.

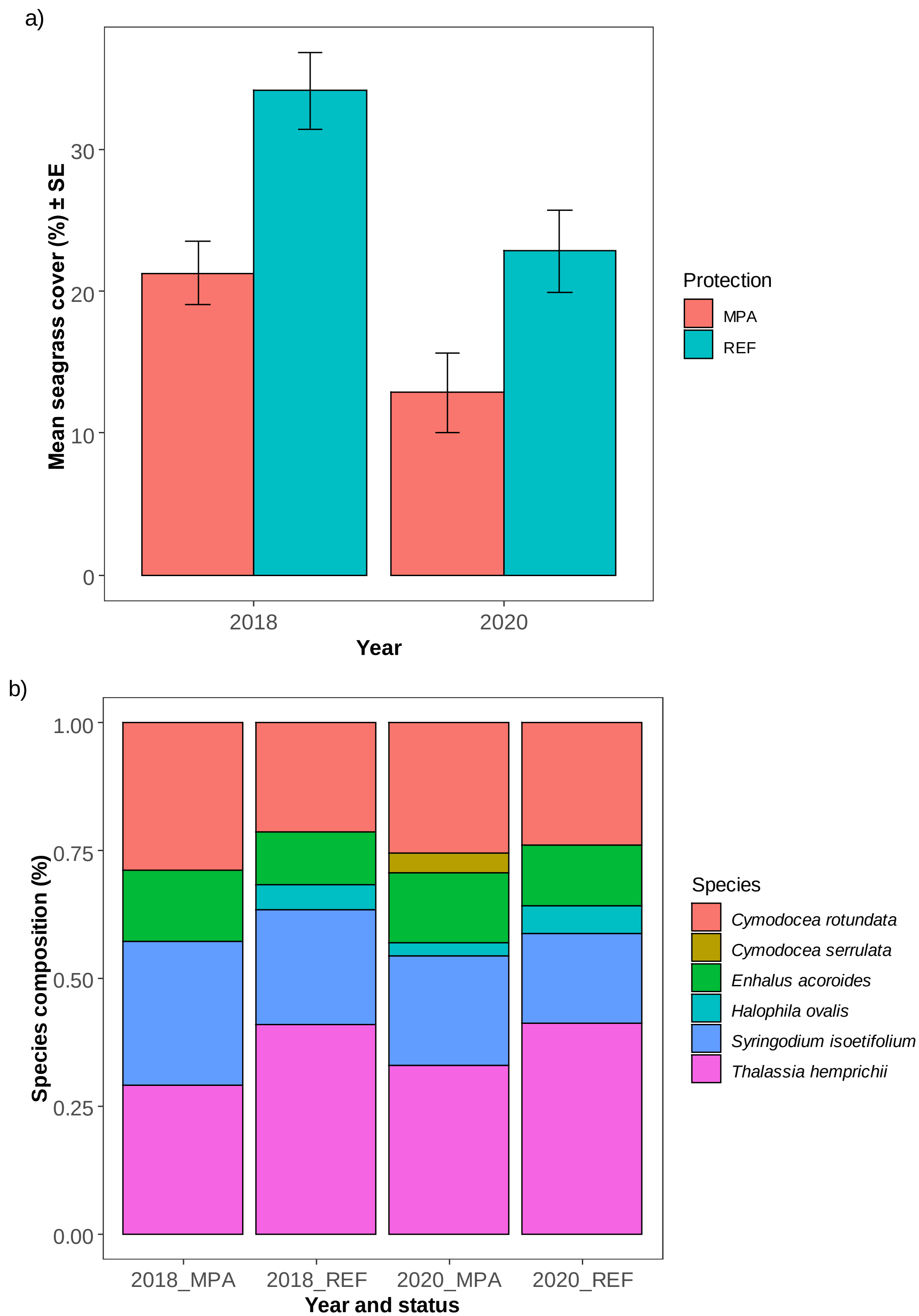

Figure 2. Mean seagrass cover within the reef flat habitat in the MPA and reference site (REF) over time (a). Error bars indicate standard error (± SE). Seagrass species composition within the reef flat habitat in the MPA and reference site over time (b). Baseline data from 2015 is not shown since a different method was used and data is not comparable.

Mean biomass of 34 commercially important fish within the reef flat MPA habitat was significantly higher in 2015 (2.53 ± 1.59 g/m^2) compared to both 2018 (0.03 ± 0.02 g/m^2) ($p<0.01$) and 2020 (0.06 ± 0.04 g/m^2) ($p<0.01$) (Figure 3a). There was no significant difference between mean fish biomass in the MPA and the reference site (0.07 ± 0.06 g/m^2) in 2020. Mean fish density within the reef flat MPA habitat was also significantly higher in 2015 (0.03 ± 0.01 ind/m^2) compared to both 2018 (0.01 ± 0.01 ind/m^2) ($p<0.01$) and 2020 (0.003 ± 0.003 ind/m^2) ($p<0.01$) (Figure 3b). There was no significant difference between mean fish density in the MPA and the reference site (0.003 ± 0.002 ind/m^2) in 2020.

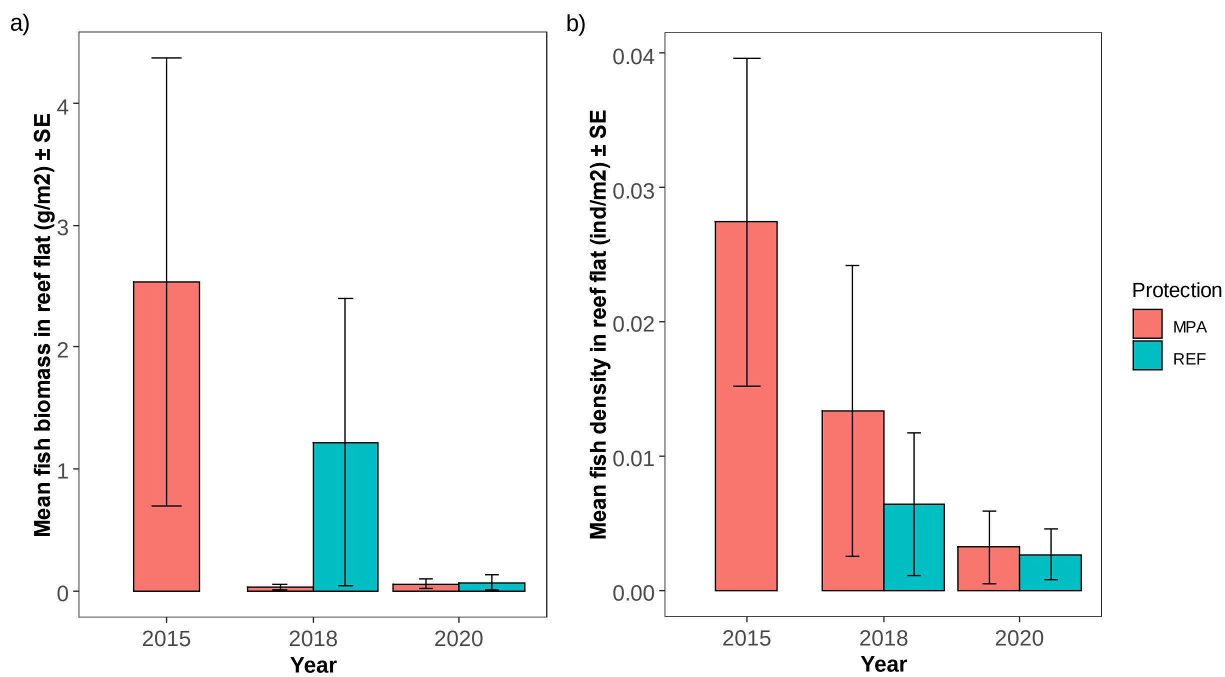

Figure 3. Mean fish biomass (a) and density (b) of 34 important reef fish within the reef flat habitat in the MPA and reference site (REF) over time. Error bars indicate standard error (± SE).

In the 2015 baseline assessment, out of the 34 commercially important fish species, five species were recorded in the MPA, with *Siganus argenteus* (beduut) making up more than half of the total abundance (Figure 4). In 2018, 100% of the fish recorded in the MPA were *Scarus* spp. (mellemau), whereas in 2020, two species were recorded in the MPA; *Leptoscarus vaigiensis* (kesuu) and *Siganus fuscescens* (meyas). Comparatively, in the reference site in 2020 the species that contributed the highest percentage to total abundance was *Lutjanus gibbus* (keremlal).

The highest mean species richness (1 ± 0.29) was observed in the MPA in 2015. This was significantly higher compared to the mean richness in the MPA in 2018 (0.13 ± 0.09) ($p<0.01$) and 2020 (0.2 ± 0.14) ($p<0.01$). Shannon's diversity index was also the highest in the MPA in 2015 (0.18 ± 0.09), which was significantly higher compared to the mean diversity index in the MPA in 2018 (0) ($p<0.01$) and 2020 (0.04 ± 0.04) ($p<0.05$).

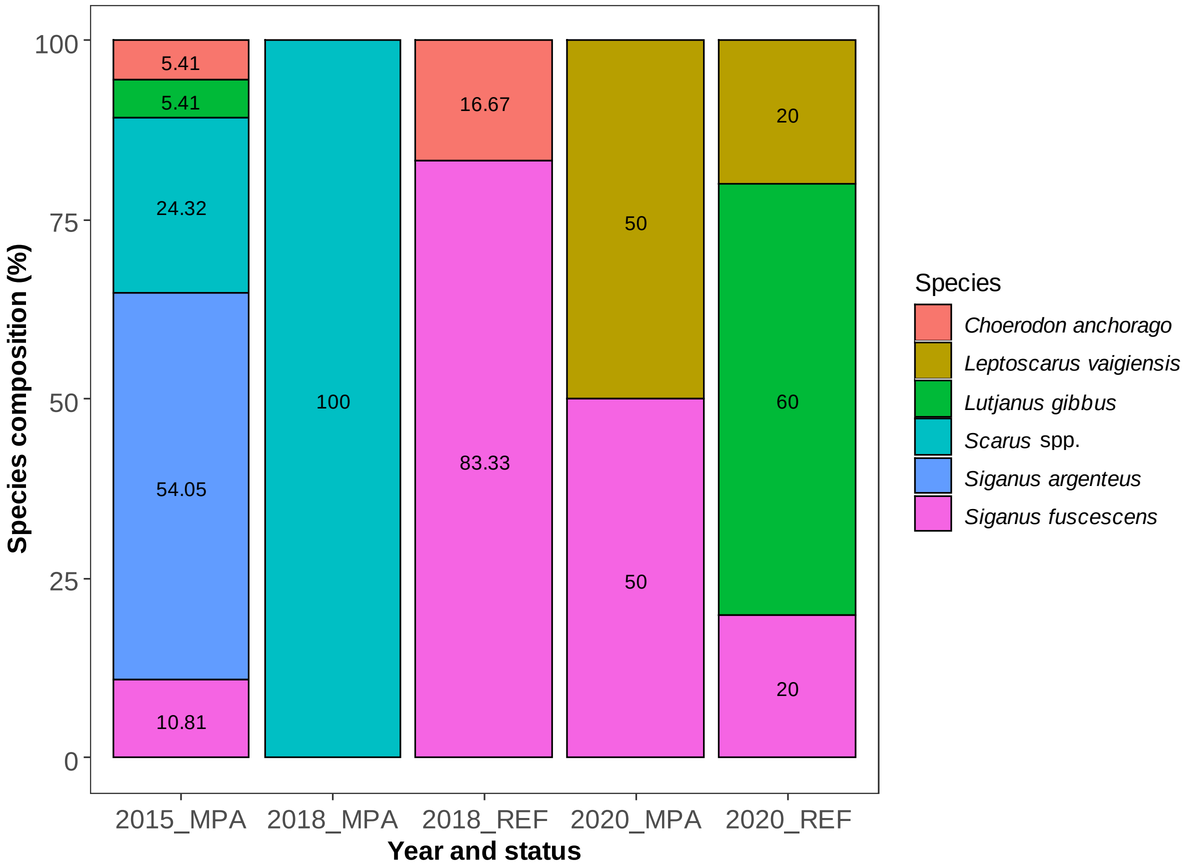

Figure 4. Species composition of total fish abundance observed within the reef flat habitat in the MPA and reference site over time.

Mean density of edible macroinvertebrates in the reef flat MPA habitat was much higher in 2015 (1.03 ± 0.68 ind/m^2) compared to 2018 (0.02 ± 0.01 ind/m^2) and 2020 (0.004 ± 0.003 ind/m^2), however no significant difference was found over time (Figure 5). There was also no significant difference between the MPA and reference site (0.163 ± 0.08 ind/m^2) in 2020. Sea cucumbers were the only macroinvertebrates found in the reference site, whereas in the MPA, one species of giant clam, *Hippopus hippopus* (duadeb), was recorded in all three years. In the 2015 baseline, the most abundant edible macroinvertebrate found in the MPA were the sea cucumbers *Stichopus vastus* (ngimes) and *Holothuria impatiens* (sekesaker), whereas in 2018 the most abundant species was the sea cucumber *Actinopyga* spp. (cheremrum). In 2020, the most abundant macroinvertebrate was the giant clam *Hippopus hippopus* (duadeb). In the reference site in both 2018 and 2020, the most abundant macroinvertebrate was the sea cucumber *Stichopus vastus* (ngimes).

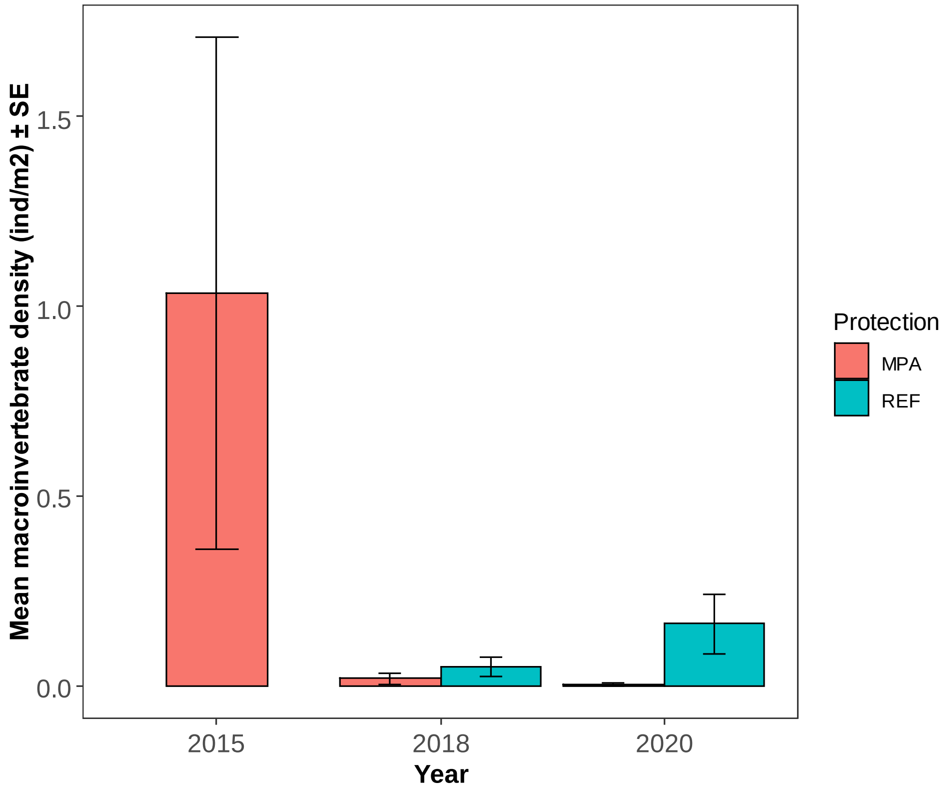

Figure 5. Mean density of edible macroinvertebrates within the reef flat habitat in the MPA and reference site (REF) over time. Error bars indicate standard error (± SE).

3.2 Fore reef

Benthic cover in the fore reef habitat in all three years consisted mainly of turf and hard coral in the MPA, and carbonate, turf and hard coral in the reference site (Figure 6). There was a significant decrease in mean turf cover in the MPA from 44.73 ± 3.42 % in 2018 to 36.02 ± 4.68 % in 2020 ($p<0.001$) and in the reference site from 30.85 ± 3.87 % in 2018 to 16.23 ± 2.35 % in 2020 ($p<0.001$). However, there was no difference between the MPA and reference site in 2020 despite there being more than double the turf cover in the MPA. Mean carbonate cover was similar over time in the MPA site but increased from 2018 to 2020 in the reference site, although this was not significant. There was a significant difference in carbonate cover between the MPA (1.46 ± 0.37 %) and reference site (28.93 ± 2.67 %) in 2018 ($p<0.001$) and between MPA (2.60 ± 0.86 %) and reference site (46.25 ± 2.27 %) in 2020 ($p<0.001$).

Other benthic categories recorded include crustose coralline algae (CCA), macroalgae, other macroinvertebrates, soft coral and rubble, sand and mud (Figure 6). Mean CCA cover was significantly higher in 2018 compared to 2020 within the reference site ($p<0.001$) but there was no difference over time in the MPA. There was also significantly higher CCA cover in the MPA compared to the reference site in 2020 (p<0.001). Mean macroalgae cover was similar over time and between the MPA and reference site. Mean cover of other macroinvertebrates increased significantly within the MPA from 2015 to 2020 (p<0.05). There was no significant difference in other macroinvertebrate cover between the MPA and reference site in 2020, however there was a significant difference in 2018 (p<0.01). Mean soft coral cover was significantly higher within the MPA compared to the reference site in 2020 (p<0.01), however there was no difference over time within the MPA or reference site. Mean cover of rubble, sand, and mud was similar over time and between the MPA and reference site.

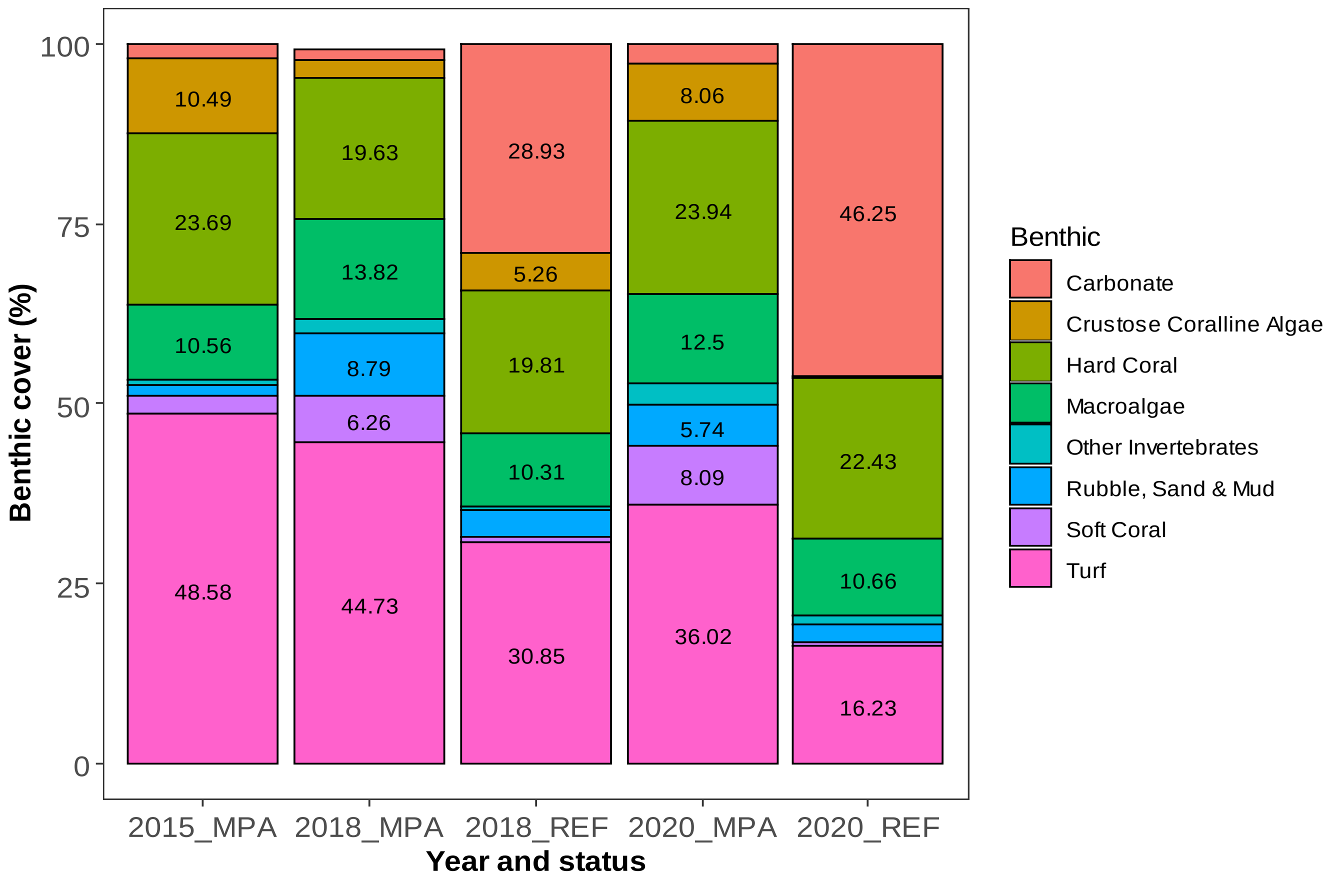

Figure 6. Mean percentage cover of major benthic categories within the fore reef habitat in the MPA and reference site over time.

Mean hard coral cover was similar within the MPA and reference site over time and between the MPA and reference site in 2018 and 2020, ranging from 19.63 ± 3.48 % to 23.94 ± 3.53 % (Figure 7a). Mean density of coral recruits within the fore reef habitat was also similar over time and between the MPA and reference site, with an average of ~1-2 recruits per m^2 (Figure 7b).

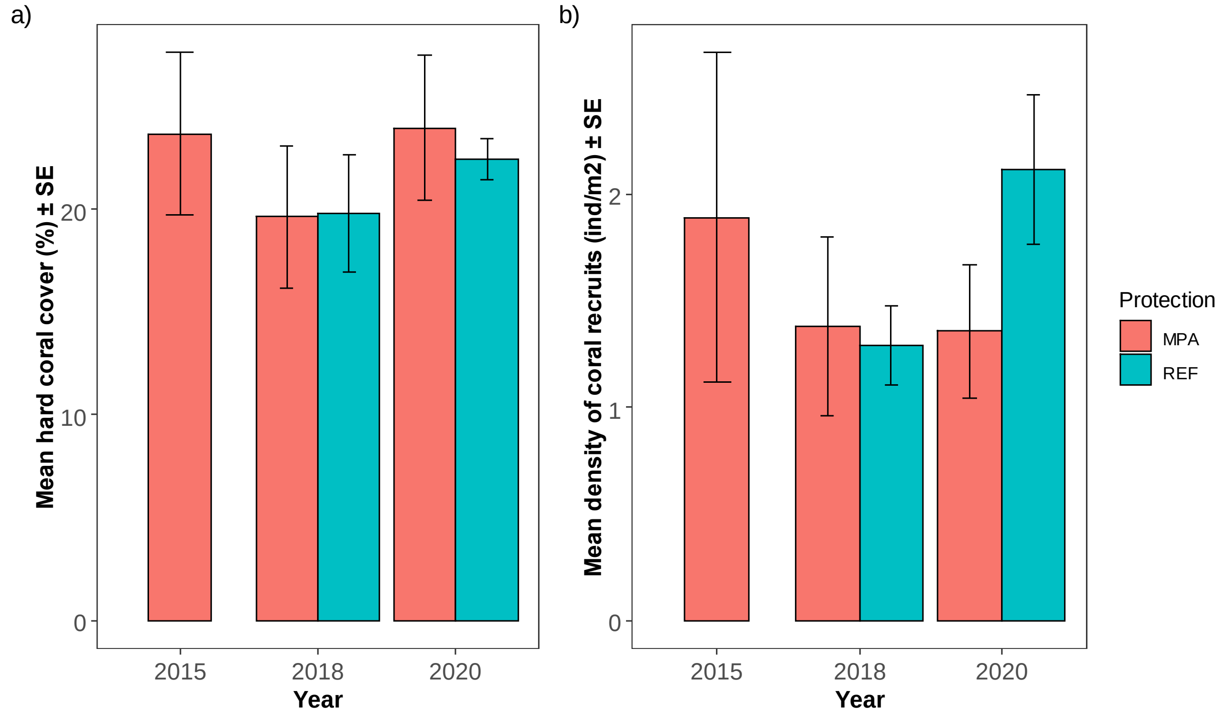

Figure 7. Mean hard coral cover (a) and density of coral recruits (b) within the fore reef habitat in the MPA and reference site (REF) over time. Error bars indicate standard error (± SE).

Mean biomass of commercially important fish within the fore reef habitat was not significantly different over time or between the MPA and reference site, although a slight increase was seen from 2018 (6.34 ± 2.19 g/m^2) to 2020 (11.39 ± 3.91 g/m^2) in the MPA and from 2018 (7.74 ± 1.23 g/m^2) to 2020 (9.63 ± 1.48 g/m^2) in the reference site (Figure 8a). Mean density of fish within the fore reef habitat significantly increased within the reference site from 2018 (0.040 ± 0.008 ind/m^2) to 2020 (0.095 ± 0.012 ind/m^2) ($p<0.01$) (Figure 8b). There was no significant difference in mean density within the MPA over time or between protection levels in 2018 or 2020, with a mean density of 0.046 ± 0.01 ind/m^2 seen in the MPA in 2020. Mean biomass of herbivorous fish from six key families was significantly higher in the reference site (9.25 ± 0.90 g/m^2) compared to the MPA (4.28 ± 1.01 g/m^2) (Figure 8c).

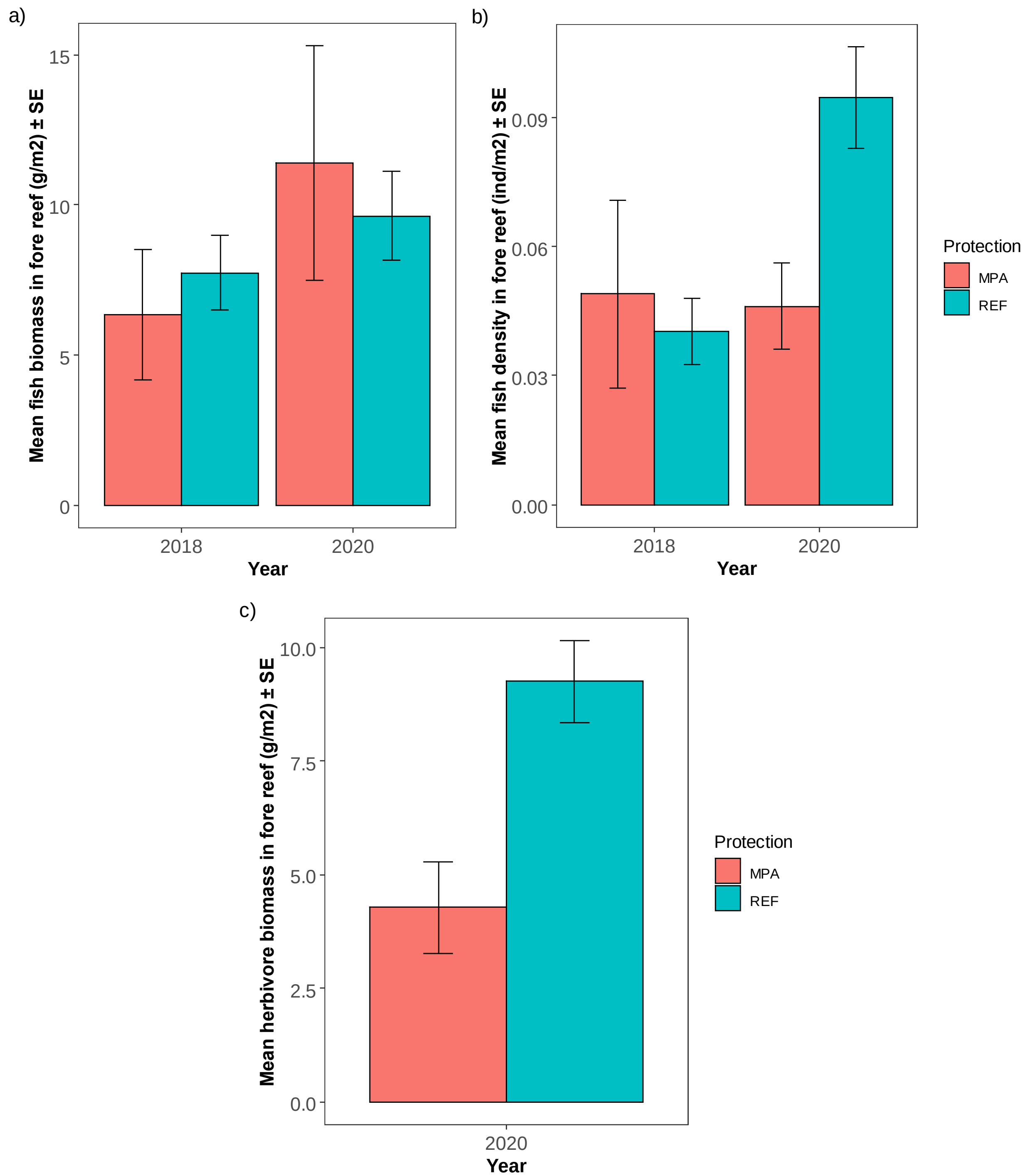

Figure 8. Mean fish biomass (a) and density (b) of commercially important reef fish and mean herbivore biomass (c) within the fore reef habitat in the MPA and reference site (REF) over time. Baseline data from 2015 is not shown since a different method was used and data is not comparable. Herbivore biomass is only shown for 2020 since data for key herbivore families was not collected in 2015 or 2018. Error bars indicate standard error (± SE).

In 2018 the most abundant species recorded in the fore reef habitat in the MPA was *Lutjanus gibbus* (keremlal), making up 45.11 % of the fish observed (Figure 9). In the reference site the most abundant species observed was *Scarus* spp. (mellemau) (27.15 %). In 2020 the most abundant species recorded was Labridae: Scarinae spp. (mellemau), making up 43.35 % of fish observed in the MPA and 68.17 % in the reference site.

The highest mean species richness (5.27 ± 0.59) was observed at the reference site in 2020, whereas the MPA site in both 2018 and 2020 had the lowest richness (3.47 ± 0.50 and 3.47 ± 0.45 respectively). There were no significant differences in species richness over time or between protection levels. Shannon's diversity index was the highest at the reference site in 2018 (1.28 ± 0.44) and the lowest in the MPA in 2020 (0.82 ± 0.43), however there were no significant differences in diversity over time or between protection levels.

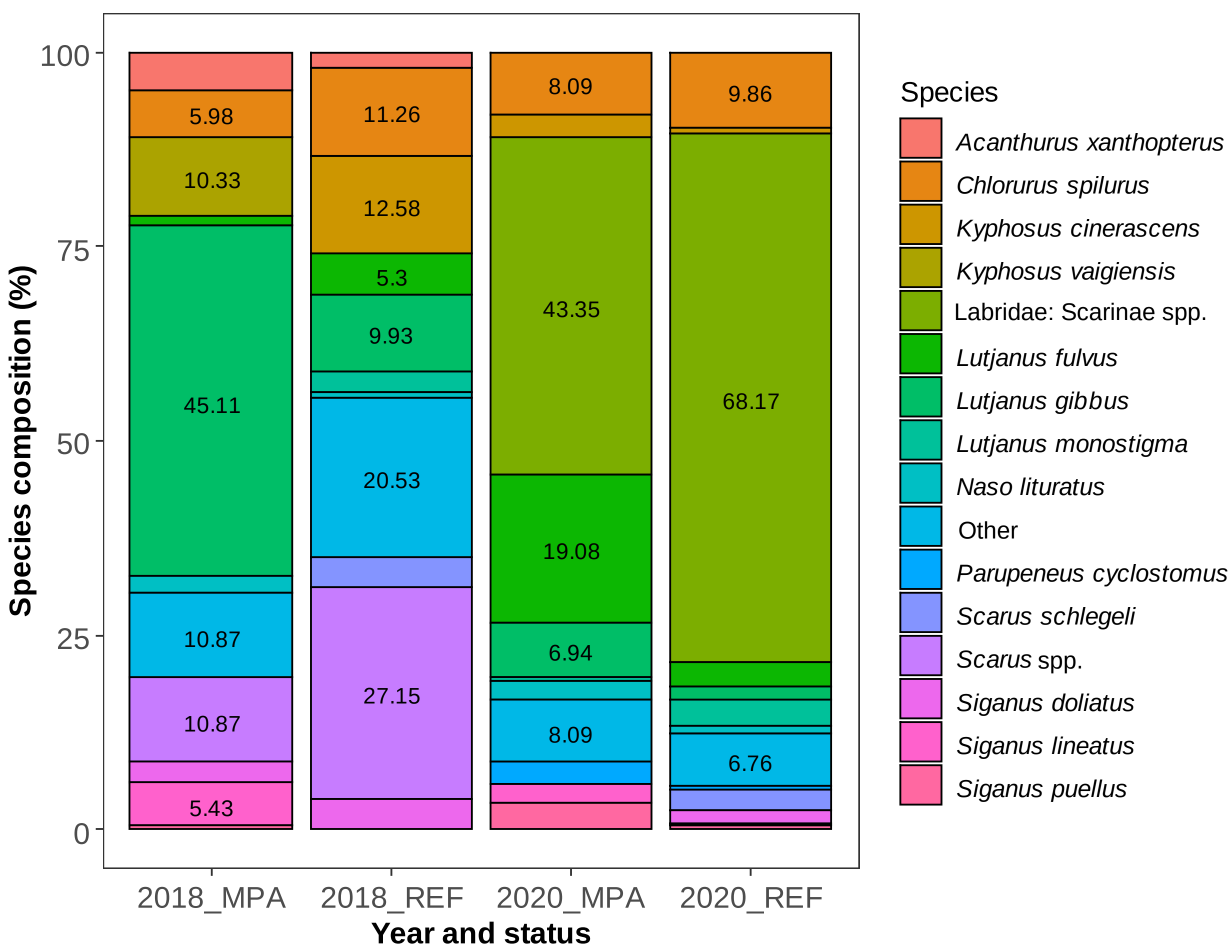

Figure 9. Species composition of total fish abundance observed within the fore reef habitat in the MPA and reference site over time.

There was an increase in mean density of edible macroinvertebrates in the fore reef habitat from none being recorded in 2015 to 0.004 ± 0.002 ind/m^2 in 2018 and 0.002 ± 0.001 ind/m^2 in 2020, however this difference was not significant (Figure 10). There was also no significant difference between mean macroinvertebrate density in the reference site over time, or between the MPA and reference site, although there was a higher density of macroinvertebrates in the reference site in 2020.

In 2018, the most abundant macroinvertebrate found in the MPA was the sea cucumber *Bohadschia argus* (esobel), whereas in the reference site it was the sea cucumber *Holothuria impatiens* (sekesaker). In 2020, there were only two macroinvertebrates found in the MPA across all sites, including one *Holothuria whitmaei* (bakelungal-chedelkelek) and one *Trochus niloticus* (semum). In the reference site in 2020, the most abundant macroinvertebrate was *Trochus niloticus* (semum). Clams, including *Tridacna crocea* (oruer) and *Tridacna squamosa* (ribkungel), were found in 2018 but no clams were recorded in 2020 in either the MPA or reference site.

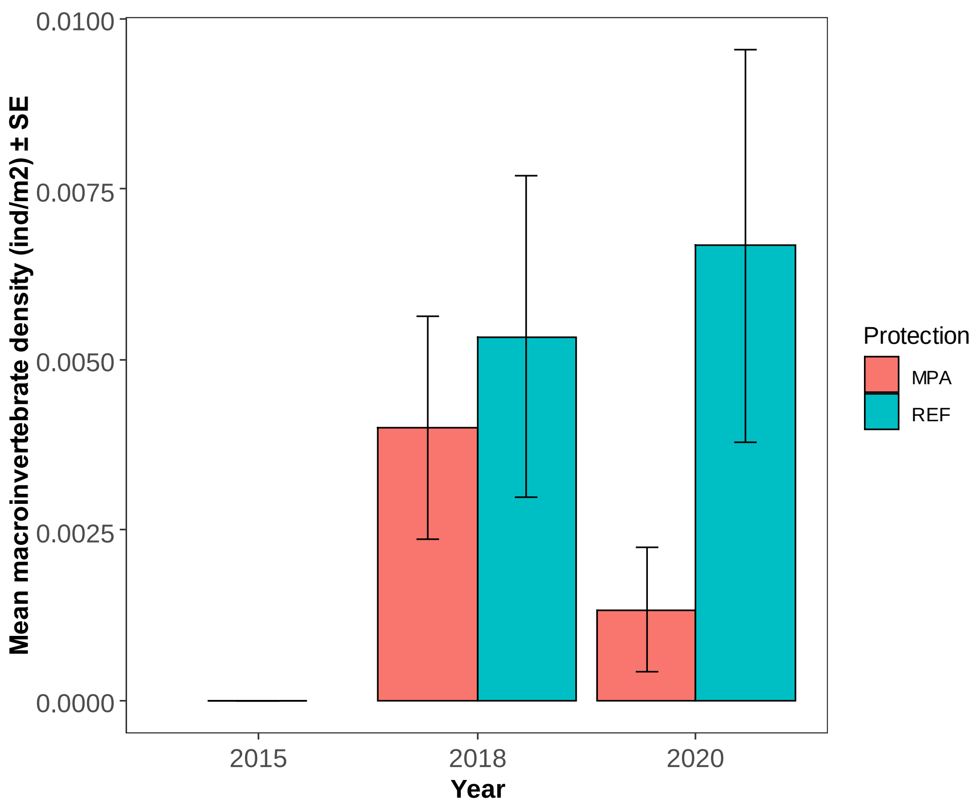

Figure 10. Mean density of edible macroinvertebrates within the fore reef habitat in the MPA and reference site (REF) over time. Error bars indicate standard error (± SE).

3.3 Water quality

Mean values for temperature, salinity, conductivity, pH and dissolved oxygen were similar between the MPA and reference site and between 2018 and 2020 (Table 1). Mean chlorophyll *a* ranged from 0.507 ± 0.295 µg/l (Fore reef REF) to 0.992 ± 0.667 µg/l (Reef flat MPA) in 2020, with the highest concentration in 2018 observed at the Reef flat REF site, with a value of 1.362 ± 0.362 µg/l. Mean turbidity ranged from 0.303 ± 0.048 FTU (Fore reef MPA) to 1.099 ± 0.844 FTU (Reef flat MPA) in 2020, with the highest concentration in 2018 observed at the Reef flat REF site, with a value of 1.981 ± 0.357 FTU.

Table 3. Mean surface water quality parameters (± SD) taken at 0.5 – 1 m depth inside the MPA and at the reference site in 2018 and 2020. The highest chlorophyll *a* and turbidity values from 2018 and 2020 are shown in red.

Year	Protection	Site	Habitat	Temperature (°C)	Salinity (PSU)	Conductivity (mS/cm)	Chlorophyll *a* (µg/l)	Turbidity (FTU)	pH	Dissolved Oxygen (mg/l)
2018	MPA	8	Fore reef	31.050 ± 0.010	33.744 ± 0.005	57.584 ± 0.008	0.747 ± 0.351	0.225 ± 0.202	8.276 ± 0.000	6.415 ± 0.004
2018	MPA	16	Reef flat	31.727 ± 0.007	33.778 ± 0.002	58.342 ± 0.008	0.666 ± 0.350	0.614 ± 0.195	8.312 ± 0.004	7.357 ± 0.026
2018	REF	3	Fore reef	31.976 ± 0.050	33.752 ± 0.035	58.562 ± 0.072	0.442 ± 0.326	0.383 ± 0.284	8.475 ± 0.001	9.850 ± 0.047
2018	REF	2	Reef flat	31.749 ± 0.009	33.736 ± 0.001	58.299 ± 0.008	1.362 ± 0.362	1.981 ± 0.357	8.419 ± 0.001	8.946 ± 0.032
2020	MPA	8	Fore reef	29.912 ± 0.008	34.139 ± 0.003	56.990 ± 0.006	0.554 ± 0.176	0.303 ± 0.048	8.077 ± 0.001	7.246 ± 0.010
2020	MPA	16	Reef flat	30.014 ± 0.001	34.164 ± 0.001	57.133 ± 0.002	0.992 ± 0.667	1.099 ± 0.844	8.095 ± 0.000	7.074 ± 0.008
2020	REF	3	Fore reef	30.093 ± 0.145	34.120 ± 0.027	57.152 ± 0.131	0.507 ± 0.295	0.437 ± 0.188	8.158 ± 0.008	8.726 ± 0.252
2020	REF	2	Reef flat	30.215 ± 0.006	34.118 ± 0.001	57.275 ± 0.006	0.520 ± 0.257	0.616 ± 0.218	8.167 ± 0.001	8.421 ± 0.024

4. Discussion

4.1 Reef Flat

Ecological monitoring in the reef flat habitat of the Ngemai CA in 2020 indicates that marine resources and ecosystem conditions are similar in the MPA compared to the nearby non-protected reference site. Overtime, however, there have been significant decreases in seagrass cover, fish biomass and fish abundance in the MPA.

Mean seagrass cover decreased by almost half from 2018 to 2020. The baseline study reported a mean seagrass cover of 39 ± 13.1 % in the reef flat of the MPA (Gouezo et al, 2015). Although the method used in the baseline was different to the method used in the 2018 and 2020 surveys, this indicates that the seagrass cover has steadily decreased over time. The largest decline in seagrass cover in the MPA was seen at site Ngemai_RF_14 (see Figure 1 for location), which decreased from a mean of 15.4 ± 3.3 % in 2018 to 0.9 ± 0.4 % in 2020, with the site mostly consisting of sand in 2020. The mean seagrass cover at the same site in the 2015 baseline was 64.7 ± 3.5 %, indicating substantial seagrass loss at this site. The reference site also had a significant decrease in seagrass cover.

Seagrass beds are highly dynamic ecosystems and can be affected by a wide range of human and natural impacts. Direct human impacts such as mechanical damage from dredging, fishing and anchoring, eutrophication, siltation and coastal construction, and indirect human impacts from the effects of climate change such as erosion from sea level rise and increased storms can lead to seagrass loss. In addition, natural effects such as cyclones, diseases, sand waves and grazing by dugongs can cause changes in seagrass cover (Duarte, 2002). Seagrass beds are highly susceptible to siltation and sedimentation which can block sunlight and smother the seagrass (Duarte, 2002).

Historic satellite images show evidence of changing areas and amounts of sandy bottom on the reef flat from 1947 to 2005 (Colin, 2009) and on Google Earth from 2005 to 2019 (Figure 11). The reason for these changes is unclear, but may have been caused by several factors. High wave exposure can cause the movement of sand waves, or large amounts of sediment to be transported, which can lead to the burial of seagrass beds (Koch et al, 2006). Wave exposure is high on the east coast of Palau and the satellite images appear to show sediment movement from east to west over the reef flat, suggesting the change in sandy area is hydrodynamically induced.

Figure 11. Historic satellite images from Google Earth, showing changes in sand coverage in the Ngemai CA from 2005 to 2019.

The Ngemai CA is surrounded by two channels that carry sediment out of the Ngerbekuu Watershed during outgoing tides (Colin, 2009). A study by Golbuu et al (2011) showed that small estuaries in Palau are generally less effective than larger estuaries in trapping sediments before they reach the marine environment. The Ngerbekuu Watershed is the smallest of the five major watersheds in Palau, with an area of 1,056,890 m^2 (Palau PAN Fund, 2016), however the rate of sedimentation has not been previously measured in this watershed. The total number of earthmoving permits issued by the

Environmental Quality Protection Board (EQPB) in Ngiwal and Melekeok have increased in recent years, from a total of 6 permits issued in 2012 increasing to a maximum of 21 permits issued in 2018 (Figure 12). Increased land development within the watershed may have led to higher amounts of sediment being transported into Ngemai Bay. Since the MPA is located closer to the river discharge, larger amounts of sediment likely accumulate in this area compared to the reference site which is located further away. This may explain why there is higher seagrass cover in the reference site compared to the MPA.

Water quality measurements are an important part of environmental monitoring and can provide information on the overall health of the ecosystem. Measurements taken in 2020 indicated the highest mean turbidity and chlorophyll *a* concentrations were in the reef flat of the MPA, indicating higher sedimentation; however in 2018, the reef flat in the reference site had the highest turbidity and chlorophyll *a* concentrations. Since water quality measurements were only taken at one site per habitat within the reference and MPA, it may not be possible to draw specific conclusions from this data.

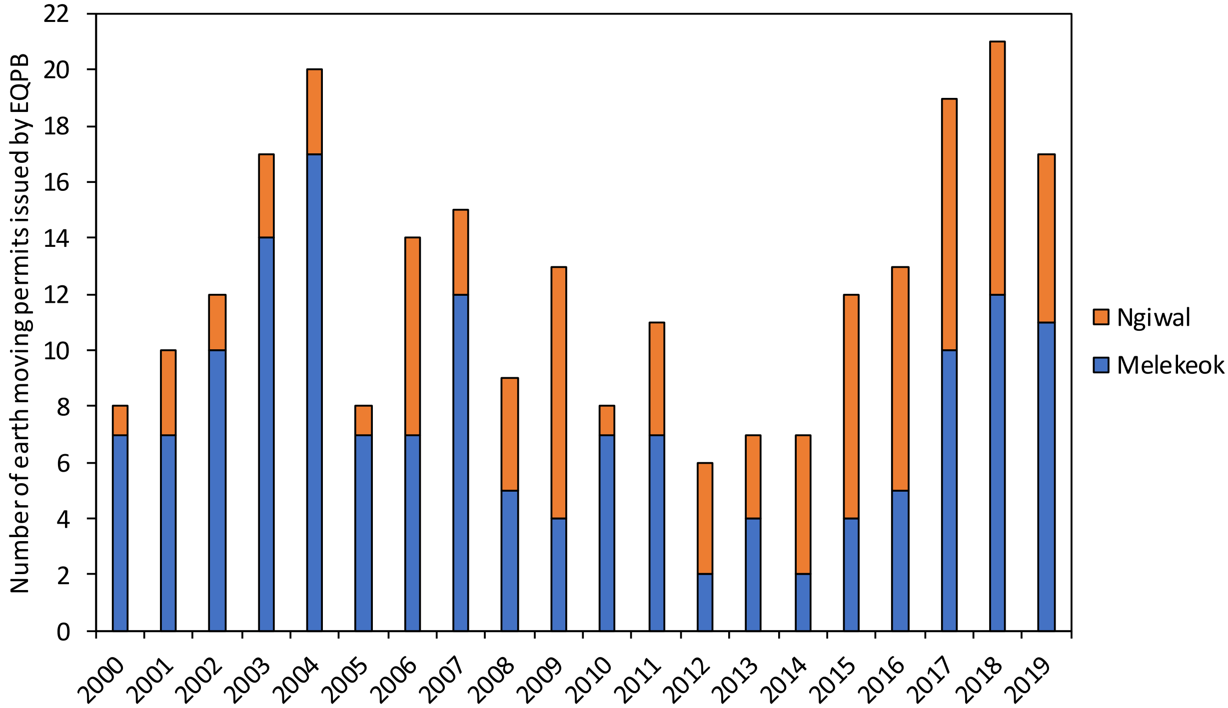

Figure 12. Number of earthmoving permits issued by EQPB in Ngiwal and Melekeok from 2000 to 2019 (data provided by EQPB, 2020).

Fish biomass, density and diversity in the reef flat of the MPA decreased significantly from 2015 to 2020, with a 40-fold decrease in biomass and a 10-fold decrease in density. This decline over time may be linked to the decrease in seagrass cover since seagrass is an important habitat for juvenile fish (McDevitt-Irwin et al, 2016). Indeed, higher numbers of juvenile fish were recorded in the reef flat compared to the fore reef habitat. In 2015, the highest biomass and density of fish were recorded at site Ngemai_RF_14, whereas in 2018 and 2020 no fish were recorded at this site. This further indicates that the loss of seagrass, particularly at Ngemai_RF_14, has likely played a significant role in the reduction in fish seen. Fish biomass within the reef flat habitat in 2020 was much lower compared to the average biomass recorded across all reef flat seagrass PAN MPA sites in the first follow-up assessment (2017/2018) (~8 g/m^2) (Otto et al, 2020). Another inshore MPA located on the east coast of Palau, Ngelukes CA, had a mean fish biomass of ~1.24 g/m^2 and a mean density of ~0.034 ind/m^2 in its second follow-up assessment in 2019 (Muller-Karanassos et al, 2019).

The stable density of edible macroinvertebrates over time and between the MPA and reference site may indicate that the MPA is not benefitting populations in the reef flat habitat. Some sea cucumber species require dense numbers of adults for successful reproduction; for example, sandfish require >100 individuals per hectare (0.01 ind/m^2) (Friedman et al, 2008). A certain density of mature clams are also required for successful recruitment (Teitelbaum & Friedman, 2008). Sea cucumber harvesting has historically taken place in Ngiwal state (Pakoa et al, 2014) and the densities of sea cucumbers and clams may currently be too low for populations to recover to previous levels.

4.2 Fore Reef

Ecological monitoring in the fore reef habitat of the Ngemai CA in 2020 indicates that marine resources and ecosystem conditions have remained stable over time and are similar in the MPA compared to the nearby non-protected reference site. Hard coral cover has remained stable over time and is similar in the MPA compared to the reference site, with a mean cover of ~19-24 %. Turf cover significantly decreased from 2018 to 2020 in the MPA, however it was still two times higher (36.02 ± 4.68 %) compared to the reference site in 2020, although this was not significant. Elevated turf algae have been shown to negatively affect coral cover and can inhibit coral settlement and recruitment (Jorissen et al, 2016), which may explain why the density of coral recruits was not higher in the MPA. However, there was also significantly higher CCA in the MPA compared to the reference site in 2020, which is a good sign, since CCA can aid coral recruitment and settlement (Heyward & Negri, 1999). Herbivorous fish, such as rabbitfish, angelfish and surgeonfish, have an important role in grazing turf algae (Green & Bellwood, 2009). Herbivorous fish biomass (from six key families) was found to be significantly lower in the MPA compared to the reference site and was much lower than the average herbivore biomass recorded in all fore reef PAN MPA sites (including MPA and reference sites) (~8 g/m^2) (Otto et al, 2020). This may indicate that there are still an insufficient number of grazing fish in the MPA to maintain the turf algae. There was no difference in macroalgae over time or between protection levels, with a mean cover of ~10-14 %.

Commercially important fish biomass and density were similar within the MPA and reference site in 2018 and 2020. There were no changes over time apart from a significant increase in fish density from 2018 to 2020 in the reference site. Fish biomass within the MPA fore reef are similar to the average biomass recorded across all MPAs (excluding reef flat seagrass sites) in the first follow-up assessment (2017/2018) (~14 g/m^2) (Otto et al, 2020). In addition, biomass and density are similar to the Ngelukes CA reef slope habitat surveyed in 2019, which had a mean biomass of ~11 g/m^2 and density of ~0.05 ind/m^2 (Muller-Karanassos et al, 2019). Friedlander et al (2017) found significantly higher resource fish biomass in five out of seven surveyed MPAs compared to reference sites, indicating that the fish biomass in Ngemai CA has not yet been effective at restoring fish populations in the fore reef habitat.

Harborne et al. (2018) calculated a potential standing stock of 107 g m^{-2} for all reef fish in Palau. Similarly, MacNeil et al. (2015) estimated resident reef fish biomass in the absence of fishing should equal ~100 g m^{-2}, with biomass <25 g m^{-2} potentially leading to negative ecosystem effects due to overfishing. It is noted that these fish biomass values include all non-cryptic reef fish whereas the current study was limited to a subset of commercially important reef fish in Palau (see Appendix 3). The time it takes for fish stocks to recover within an MPA can vary considerably. It has been predicted to take 35 years of protection on average for fished sites to recover and 59 years of protection for heavily fished sites to recover (MacNeil at al, 2015). Other studies have shown that direct effects on target species typically occur within 5 years of MPA establishment, however these effects can vary depending on the life histories of individual species (Babcock et al, 2010; Russ & Alcala, 2004; Barrett et al, 2007). The Ngemai CA has been protected for 12 consecutive years (2008-2020), which may not be long enough for recovery, however, other factors such as size, can also influence the effectiveness of an MPA. Large no-take MPAs have been found to have higher abundance of target taxa compared to small no-take MPAs (Friedlander et al, 2017; Malcolm et al, 2016) and MPAs <2 km in diameter have been shown to achieve only partial protection of fish species, with a bias towards smaller species of lower fishery value with smaller home ranges (Krueck et al, 2018). Since the Ngemai CA is a small MPA (~1 km^2), protection in both habitats may be ineffective for larger commercially important species that have larger home ranges (the area in which a fish spends most of its time) (Green et al, 2014). Alternatively, illegal fishing may be taking place inside the MPA, which is not allowing the populations to recover.

Although there was an increase in edible macroinvertebrate density in the fore reef habitat from 2015 to 2018, there was a decrease from 2018 to 2020 and these differences were not significant. A previous study of the Ngemai CA fore reef by PICRC, found similar invertebrate densities, with a mean density of <0.01 ind/m^2 in 2011 and 2012, and slightly higher densities in the reference site (0.013 ind/m^2 in 2011 and 0.022 ind/m^2 in 2012) (Koshiba et al, 2013). As with the reef flat habitat, the stable density of edible macroinvertebrates over time and between the MPA and reference site may indicate that the MPA is not benefitting populations in the fore reef habitat.

5. Conclusion

Overall, this study indicates that in the reef flat and fore reef habitats, conditions are similar in the MPA compared to the reference site. However, there is a lower biomass of herbivorous fish in the MPA fore reef and in the reef flat there have been negative changes in seagrass cover and commercially important fish over time. Recovery can be slow and therefore the next follow-up assessment in 2022 should be able to provide further information on the status of the marine resources. In the meantime, it is recommended that Ngiwal State introduce better management practices within the watershed to reduce the amount of sediment that is discharged into Ngemai Bay, to consider increasing the size of the Ngemai CA in order to maximize the benefits of the MPA and to consider aggregating or restocking sea cucumbers and giant clams to assist population recovery within the MPA. In addition, PICRC plans to increase the water quality monitoring effort for the next round of MPA surveys by collecting water measurements and samples at all sites in the MPA and reference site in order increase confidence in this data.

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Appendices

Appendix 1. List of 34 commercially important fish species used in the reef flat habitat

Common name	**Palauan name**	**Species**
	Commercial species	
Lined rabbitfish	Kelsebuul	*Siganus lineatus*
Forktail rabbitfish	Beduut	*Siganus argenteus*
Bluespine unicornfish	Chum	*Naso unicornis*
Orangespine unicornfish	Cherangel	*Naso lituratus*
Longface emperor	Melangmud	*Lethrinus olivaceus*
Orangestripe emperor	Udech	*Lethrinus obsoletus*
Yellowlip emperor	Mechur	*Lethrinus xanthochilus*
Red snapper	Kedesau	*Lutjanus bohar*
Humpback snapper	Keremlal	*Lutjanus gibbus*
Bluefin trevally	Erobk	*Caranx ignobilis*
Giant trevally	Oruidel	*Caranx melampygus*
All species of parrotfish	Mellemau	*Cetoscarus/Scarus/Chlorurus/ Leptoscarus* spp.
Pacific longnose parrotfish	Ngiaoch	*Hipposcarus longiceps*
Bluespot mullet	Kelat	*Moolgarda seheli*
Squaretail mullet	Uluu	*Ellochelon vaigiensis*
	Protected species	
Dusky rabbitfish	Meyas	*Siganus fuscescens*
Bumphead parrotfish	Berdebed, Kemedukl	*Bolbometopon muricatum*
Humphead wrasse	Ngimer, Maml	*Cheilinus undulatus*
Squaretail grouper	Tiau	*Plectropomus areolatus*
Leopard grouper	Bekerkard el tiau	*Plectropomus leopardus*
Saddleback grouper	Katuu'tiau, Mokas	*Plectropomus laevis*
Brown-marbled grouper	Meteungerel'temekai	*Epinephelus fuscoguttatus*
Marbled grouper	Ksau'temekai	*Epinephelus polyphekadion*
	Additional species	
Brassy chub	Komud, Beab	*Kyphosus vaigiensis*
Giant sweetlips	Melimralm, Kosond, Bikl	*Plectorhinchus albovittatus*
Yellowstripe sweetlips	Merar	*Plectorhinchus crysotaenia*
River snapper	Kedesau'liengel	*Lutjanus argentimaculatus*
Yellow cheek tuskfish	Budech	*Choerodon anchorago*
Masked rabbitfish	Reked	*Siganus puellus*
Goldspotted rabbitfish	Bebael	*Siganus punctatus*
Bicolor parrotfish	Beyadel, Ngesngis	*Cetoscarus ocellatus*
Red gill emperor	Rekruk	*Lethrinus rubrioperculatus*
Pacific steephead parrotfish	Otord	*Chlorurus micorhinos*
Greenthroat parrotfish	Melechotech a chau	*Scarus prasiognathus*

Appendix 2. List of commercially important and edible macroinvertebrates

Common name	Palauan name	Species
Black teatfish	Bakelungal-chedelkelek	*Holothuria whitmaei*
White teatfish	Bakelungal-cherou	*Holothuria fuscogilva*
Golden sandfish	Delalamolech	*Holothuria lessoni*
Hairy blackfish	Eremrum, cheremrumedelekelk	*Actinopyga miliaris*
Hariy greyfish	Eremrum, cheremrum	*Actinopyga* spp.
Deepwater redfish	Eremrum, cheremrum	*Actinopyga echinites*
Deepwater blackfish	Eremrum, cheremrum	*Actinopyga palauensis*
Stonefish	Ngelau	*Actinopyga lecanora*
Dragonfish	Irimd	*Stichopus horrens*
Brown sandfish	Meremarech	*Bohadschia vitiensis*
Chalk fish	Meremarech	*Bohadschia similis*
Leopard fish	Meremarech, esobel	*Bohadschia argus*
Sandfish	Molech	*Holothuria scabra*
Curryfish	Delal a ngimes/ngimesratmolech	*Stichopus hermanni*
Brown curryfish	Ngimes	*Stichopus vastus*
Slender sea cucmber	Sekesaker	*Holothuria impatiens*
Prickly redfish	Temetamel	*Thelenota ananas*
Amberfish	Belaol	*Thelenota anax*
Elephant trunkfish	Delal a molech	*Holothuria fuscopunctata*
Flowerfish	Meremarech	*Pearsonothuria graeffei*
Surf red fish	Badelchelid	*Actinopyga mauritiana*
Crocus giant clam	Oruer	*Tridacna crocea*
Elongate giant clam	Melibes	*Tridacna maxima*
Smooth giant clam	Kism	*Tridacna derasa*
Fluted giant clam	Ribkungel	*Tridacna squamosa*
Bear paw giant clam	Duadeb	*Hippopus hippopus*
True giant clam	Otkang	*Tridacna gigas*
Sea urchin	Ibuchel	*Tripneustes gratilla*
Trochus	Semum	*Trochus niloticus*

Appendix 3. List of commercially important fish species used in the fore reef habitat

Common name	Palauan name	Species
Epaulette surgeonfish	Chesengel	*Acanthurus nigricauda*
Surgeonfish species		*Acanthurus* spp.
Yellowfin surgeonfish	Mesekuuk	*Acanthurus xanthopterus*
Redmouth grouper	Chubei	*Aethaloperca rogaa*
Slender grouper	Choloteachi	*Anyperodon leucogrammicus*
Green jobfish	Udel	*Aprion virescens*
Bumphead parrotfish	Berdebed, Kemedukl	*Bolbometopon muricatum*
Blue trevally	Yab	*Carangoides ferdau*
Yellowspotted trevally	Uii	*Carangoides fulvoguttatus*

Island trevally	Otewot	*Carangoides orthogrammus*
Barcheek trevally		*Carangoides plagiotaenia*
Trevally/jack species		*Carangoides* spp.
Giant trevally	Erobk	*Caranx ignobilis*
Black jack	Omektutau	*Caranx lugubris*
Bluefin trevally	Oruidel	*Caranx melampygus*
Bigeye trevally	Esuch	*Caranx sexfasciatus*
Trevally/jack species		*Caranx* spp.
Peacock hind	Mengardechelucheb	*Cephalopholis argus*
Bluespotted hind	Temekai	*Cephalopholis cyanostigma*
Coral hind	Temekai	*Cephalopholis miniata*
Tomato hind	Temekai	*Cephalopholis sonnerati*
Hind species		*Cephalopholis* spp.
Spotted parrotfish	Beyadel, Ngesngis	*Cetoscarus ocellatus*
Parrotfish species	Mellemau	*Cetoscarus* spp.
Milkfish	Aol, Mesekelat	*Chanos chanos*
Humphead wrasse	Ngimer, Maml	*Cheilinus undulatus*
Bleeker's parrotfish		*Chlorurus bleekeri*
Pacific slopehead parrotfish		*Chlorurus frontalis*
Palecheek parrotfish		*Chlorurus japanensis*
Pacific steephead parrotfish	Otord	*Chlorurus microrhinos*
Pacific bullethead parrotfish		*Chlorurus spilurus*
Parrotfish species	Mellemau	*Chlorurus* spp.
Yellow cheek tuskfish	Budech	*Choerodon anchorago*
Humpback grouper	Meleches	*Cromileptes altivelis*
Painted sweetlips		*Diagramma pictum*
Rainbow runner	Desui	*Elagatis bipinnulata*
Whitespotted grouper		*Epinephelus coeruleopunctatus*
Coral grouper	Imirechorch	*Epinephelus corallicola*
Brown-marbled grouper	Meteungerel'temekai	*Epinephelus fuscoguttatus*
One-blotch grouper		*Epinephelus melanostigma*
Marbled grouper	Ksau'temekai	*Epinephelus polyphekadion*
Grouper species		*Epinephelus* spp.
Masked grouper		*Gracila albomarginata*
Double-lined mackerel	Beterturech	*Grammatorcynus bilineatus*
Bream species		*Gymnocranius* spp.
Dogtooth tuna	Kerengab	*Gymnosarda unicolor*
Pacific longnose parrotfish	Ngiaoch	*Hipposcarus longiceps*
Blue sea chub	Komud, Beab	*Kyphosus cinerascens*
Sea chub species		*Kyphosus* spp.
Brassy chub	Komud, Beab	*Kyphosus vaigiensis*

Pacific yellowtail emperor		*Lethrinus atkinsoni*
Orange-spotted emperor	Menges	*Lethrinus erythracanthus*
Longfin emperor	Kroll	*Lethrinus erythropterus*
Thumbprint emperor	Itotech	*Lethrinus harak*
Orangestripe emperor	Udech	*Lethrinus obsoletus*
Longface emperor	Melangmud	*Lethrinus olivaceus*
Ornate emperor		*Lethrinus ornatus*
Red gill emperor	Rekruk	*Lethrinus rubrioperculatus*
Emperor species		*Lethrinus* spp.
Yellowlip emperor	Mechur	*Lethrinus xanthochilus*
Squaretail mullet	Uluu	*Liza vaigiensis*
Mangrove red snapper	Kedesau'liengel	*Lutjanus argentimaculatus*
Red snapper	Kedesau	*Lutjanus bohar*
Blackspot snapper	Dodes	*Lutjanus ehrenbergii*
Blacktail snapper	Reall	*Lutjanus fulvus*
Humpback snapper	Keremlal	*Lutjanus gibbus*
One-spot snapper	Kesebii	*Lutjanus monostigma*
Blubberlip snapper	Korriu	*Lutjanus rivulatus*
Snapper species		*Lutjanus* spp.
Humpnose bigeye bream	Besechamel	*Monotaxis grandoculis*
Orangespine unicornfish	Cherangel	*Naso lituratus*
Unicornfish species		*Naso* spp.
Bluespine unicornfish	Chum	*Naso unicornis*
Dash-and-dot goatfish	Bang	*Parupeneus barberinus*
Gold-saddle goatfish	Bang	*Parupeneus cyclostomus*
Goatfish species		*Parupeneus spp.*
Giant sweetlips	Melimralm, Kosond, Bikl	*Plectorhinchus albovittatus*
Harlequin sweetlips	Bechol	*Plectorhinchus chaetodonoides*
Yellowstripe sweetlips	Merar	*Plectorhinchus chrysotaenia*
Harry hotlips		*Plectorhinchus gibbosus*
Lesson's thicklip		*Plectorhinchus lessonii*
Diagonal-banded sweetlips	Yaus	*Plectorhinchus lineatus*
Painted sweetlip		*Plectorhinchus picus*
Sweetlips species		*Plectorhinchus* spp.
Indian Ocean oriental sweetlips	Yaus	*Plectorhinchus vittatus*
Squaretail grouper	Tiau (black)	*Plectropomus areolatus*
Saddleback grouper	Katuu'tiau, Mokas	*Plectropomus laevis*
Leopard grouper	Bekerkard el tiau	*Plectropomus leopardus*
Highfin coral grouper		*Plectropomus oligacanthus*
Coral grouper species		*Plectropomus* spp.
Filament-finned parrotfish	Udoud ungelel	*Scarus altipinnis*

Chameleon parrotfish		*Scarus chameleon*
Yellowbarred parrotfish	Butiliang	*Scarus dimidiatus*
Yellowfin parrotfish		*Scarus flavipectoralis*
Forsten's parrotfish	Mul	*Scarus forsteni*
Bridled parrotfish		*Scarus frenatus*
Bluebarred parrotfish	Mertebetabek	*Scarus ghobban*
Globehead parrotfish	Ngemoel	*Scarus globiceps*
Dusky parrotfish	Kiuiid	*Scarus niger*
Dark capped parrotfish		*Scarus oviceps*
Greenthroat parrotfish	Melechotech a chau	*Scarus prasiognathos*
Common parrotfish		*Scarus psittacus*
Quoy's parrotfish		*Scarus quoyi*
Rivulated parrotfish	Besachel-otengel	*Scarus rivulatus*
Redlip parrotfish	Mesekelat mellemau	*Scarus rubroviolaceus*
Yellowband parrotfish		*Scarus schlegeli*
Greensnout parrotfish		*Scarus spinus*
Parrotfish species	Mellemau	*Scarus* spp.
Tricolour parrotfish		*Scarus tricolor*
Red parrotfish	Butiliang	*Scarus xanthopleura*
Narrow barred Spanish mackerel	Ngelngal	*Scomberomorus commerson*
Forketail rabbitfish	Beduut	*Siganus argenteus*
Blue-spotted spinefoot	Reked	*Siganus corallinus*
Barred spinefoot	Reked	*Siganus doliatus*
Dusky rabbitfish	Meyas	*Siganus fuscescens*
Lined rabbitfish	Kelsebuul	*Siganus lineatus*
Masked rabbitfish	Reked	*Siganus puellus*
Peppered spinefoot	Bebael	*Siganus punctatissimus*
Goldspotted rabbitfish	Bebael	*Siganus punctatus*
Rabbitfish species		*Siganus* spp.
Great barracuda	Ai	*Sphyraena barracuda*
Bigeye barracuda	Lolou	*Sphyraena forsteri*
Blackmargin barracuda	Meyai	*Sphyraena qenie*
Sailfin snapper	Chedui	*Symphorichthys spilurus*
Snubnose pompano	Luichlbuil	*Trachinotus blochii*
Bluespot mullet	Kelat	*Valamugil seheli*
White-edged lyretail	Baslokil	*Variola albimarginata*
Yellow-edged lyretail	Baslokil	*Variola louti*

Appendix 4. List of benthic categories

CORAL (C)	Montipora submassive (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)
Acropora submassive (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)	