Herbivorous fish increase significantly at Iuaiu Conservation Area after damages from Tropical Storm Lan in 2017

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Abstract

The Palau International Coral Reef Center (PICRC) is tasked to monitor trends in ecological indicators within the PAN MPAs in each of the participating states. Thus, the first assessment of the Iuaiu Conservation Area of Angaur State was completed in 2014 with a subsequent follow-up assessment conducted in 2018. This report provides the results of these past assessments in addition to the most recent survey conducted in March 2020. The main objective of these survey efforts is to collect data that showcase the status and trends of ecological indicators within the conservation area (CA) in comparison to nearby reference areas (REF) through time. Surveys were conducted on the reef flat habitat of Iuaiu Conservation Area, which consists of a seagrass bed and a coral dominated reef flat. Underwater surveys consisted of recording data on commercially important fish, commercially important edible macro-invertebrates, juvenile coral density, and benthic coverage. Results of the study show that within the seagrass habitat in the CA, fish density had significantly declined since 2014, while seagrass cover and macro-invertebrate densities remained the same through time and between protection levels. In 2017, the Tropical Storm Lan caused extensive damage on the Western reef of Palau, including the Iuaiu CA and REF sites on the reef flat. This led to a significant increase in carbonate and rubble cover on the substrate of both the CA and REF sites, and a significant decrease in coral cover. However, there was a significant increase in fish densities - primarily herbivorous fish – in 2020 within both the CA and REF sites. This points to a positive direction towards reef recovery as herbivorous fish are known to aid in recovery post natural disturbances. Recommendations to the State managers would be to implement temporary restrictions (i.e. size restrictions, seasonal) on fishing of herbivorous fishes, especially on the reef flat, to allow the reef to recover naturally. Furthermore, as the seagrass bed is the only seagrass area of Angaur, close monitoring of the seagrass beds should be conducted to ensure that no major disturbances (anthropogenic or natural) negatively impact the seagrass habitat as it is a vital ecosystem for the marine environment.

Introduction

For many decades throughout Palau's history, natural resource management and conservation have been a major part of Palauan culture and traditions. Because of its deep roots, in recent years, marine resource conservation practices have evolved from the traditional method of 'bul' – where a ban on harvest of a particular resource is implemented by the chiefs for a certain amount of time – to modernized marine protected areas (MPA) (Johannes, 1981). In Palau, the very first permanent closure was implemented in 1956 with the legislated closure of the Ngerukewid Island Wildlife Preserve located in the Rock Islands Southern Lagoon in Koror State. Since then, other states have implemented MPAs, leading to the creation of the Protected Areas Network (PAN) by the National Government. Under the PAN, 14 no-take MPAs and 13 terrestrial protected areas are protected. In order to meet national and regional conservation targets, especially the Micronesia Challenge (MC), the PAN is continually expanding to include additional sites to protect both marine and terrestrial resources.

The Palau International Coral Reef Center (PICRC) began monitoring all the PAN-member MPAs in 2014, providing baseline information for each of the 14 no-take, no-entry MPAs (Gouezo et al, 2016). Thereafter, every two years, research teams conduct reassessments of these same protected areas to monitor long-term trends and status of resources in the MPA, as well as understand MPA effectiveness in protecting marine resources. This study was conducted in Iuaiu Conservation Area located in Angaur State (Fig.1). Due to limited fringing reefs and increasing fishing pressures, the Angaur State Government passed a law in 2005 to establish a conservation area where Iuaiu Conservation Area is currently located, and at the same time, prohibited fishing activities within the area for a two-year period (Koshiba et al. 2014). It has since been protected under the state and is now part of the Protected Areas Network (PAN), however, a management plan has not been developed nor implemented for this conservation area.

Methods

1. Study site

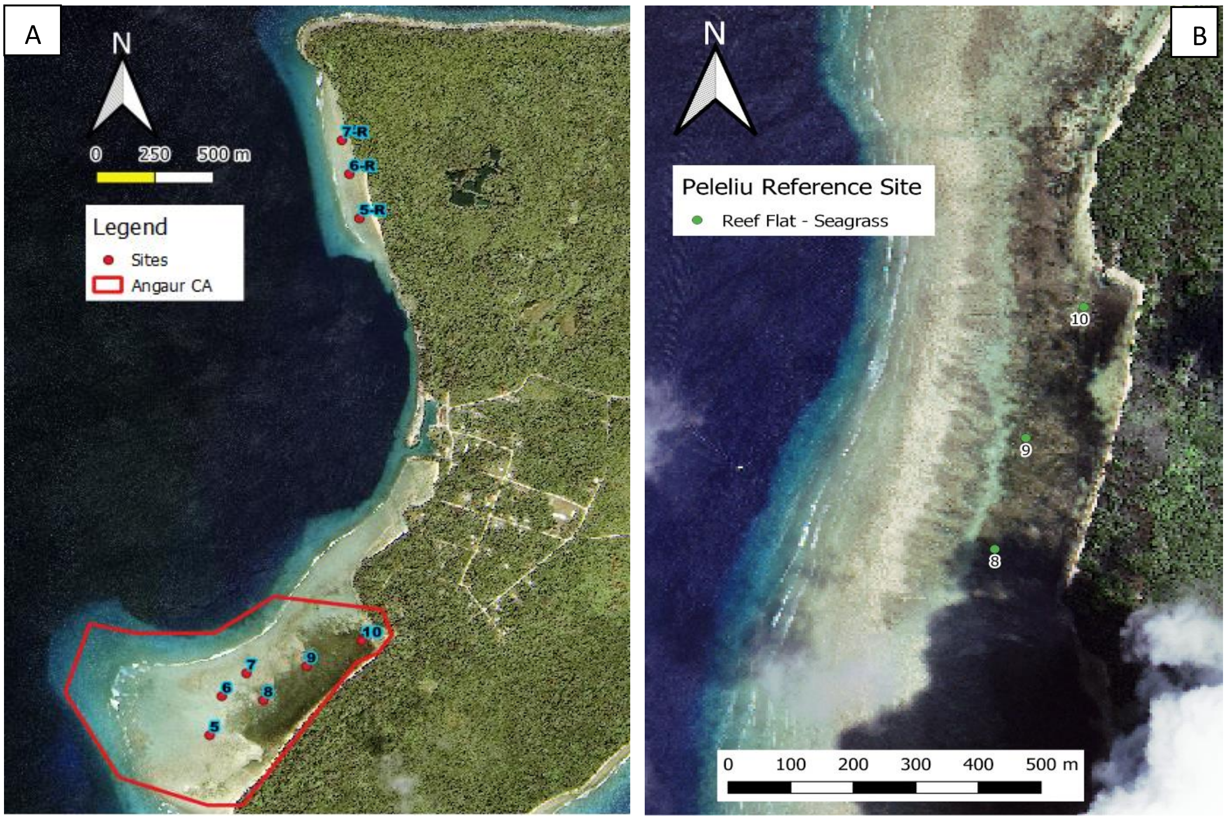

Fig. 1(a): Map of Iuaiu Conservation Zone with monitoring sites inside (red) and outside the protected area. **(b):** Reference site for seagrass bed is in Peleliu due to lack of other seagrass areas in Angaur for comparison.

2. Ecological surveys

A total of 12 sites were surveyed, with six sites located within the CA and six in the reference areas. Iuaiu Conservation Zone encompasses two sub-habitats located on the reef flat – a coral dominated reef flat (referred to as Reef Flat – Coral) and a seagrass dominated reef flat (Reef Flat – Seagrass). As such, on each sub-habitat, three sites were designated as permanent monitoring sites within both the protected and open-access areas, making up a total of six Reef Flat – Coral and six Reef Flat – Seagrass sites monitored every two years (appendix 4).

2.1. Reef Flat – Seagrass

Within the Reef Flat – Seagrass, the chosen REF sites in 2018 were not similar to the CA sites, as the seagrass species found were not the same and the REF seagrass beds had more seagrass cover than the CA, so in 2020, the REF sites were changed to a site where the indicators can be compared due to similar characteristics. Within the seagrass dominated reef flat, the maximum depth was 2 meters. At each of the sites, five 25m long transects were laid consecutively with a few meters separating each transect. Along these five transects, data on various ecological factors were collected. These included seagrass species (at the species level) and percentage cover within 0.5 m^2 quadrats that were placed every 5 meters (0m, 5m, 10m, 15m, and 20m); fish data collected within a 5 m wide belt via Underwater Visual Census (UVC) method where the observer identifies and estimates the size (cm) of all commercially important fish observed; and any edible macro-invertebrates found in a 2 m wide belt. Seagrass reference sites were changed in 2020 due to improved accessibility to the seagrass sites in Peleliu State and similar ecological characteristics compared to the CA sites.

2.2. Reef Flat - Coral

On the coral dominated reef flat, five transects of 50 m lengths were laid consecutively with a few meters separating each transect. Benthic photos were taken every meter along the transect using an underwater camera (model Canon G16) mounted on a 0.5 m x 0.5 m photo quadrat PVC frame. A total of 50 photos were taken on each transect, with a cumulative total of 250 photos taken at each site. Additionally, juvenile corals, measuring less than 5 cm, were recorded in the first 10 meters of each transect in a 0.3 m wide belt. Fish datum were recorded using a stereo-DOV (diver operated video) system, using two GoPro Hero4 cameras mounted onto a metal frame. With the stereo-DOV any commercially important fish within a 5 m wide belt was recorded. Finally, edible macro-invertebrates were recorded in a 2 m wide belt along each transect. In addition to the macro-invertebrates survey, crown-of-thorns starfish were recorded along a 4m wide belt along each transect. Maximum depths at all sites was 5 m.

4. Data processing and analysis

For the seagrass dominated reef flat, seagrass cover and fish and macro-invertebrate abundance and size were entered into excel spreadsheets and imported into R for analysis (R version 3.5.1). Fish size was used to calculate fish biomass. See below for the equation and further explanation.

For the coral dominated reef flat, juvenile coral and macro-invertebrate abundance were entered into excel spreadsheets. Benthic cover data were processed using CPCe (Coral Point Count with excel extension) software (Kohler and Gill, 2006), where five random points were allocated on each photo, and the substrate below each point was classified into the appropriate benthic category (Appendix 1). The mean percentage of the benthic cover of each category was calculated for each transect (n= 50 photos per transect, n= 5 transects per site). The fish videos were processed using the software EventMeasure. Only fish with economical, subsistence, and/or ecological importance were counted and measured. Length rules for size estimates were used according to Goetze et al. (2019). If the measurement precision was too low to be accurate, the fish was counted and the mean fish size within the site was substituted for biomass estimates. The biomass of fish was calculated using the length-based equation:

$$W = aL^b$$

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

Prior to statistical analyses, data were checked for normality using histograms and the Shapiro-Wilk test. Non-normal data were log-transformed and re-tested. For normal data a One-way Anova and post-hoc test, using Tukey Contrasts, was used to investigate any spatial and temporal changes for the various indicators. Non-normal data were testing using a Kruskal-Wallis Test with a corresponding post-hoc test, Nemenyi test, using Tukey distributions.

Results

The results are presented for each sub-habitat – seagrass dominated reef flat (Reef Flat – Seagrass) and coral dominated reef flat (Reef Flat – Coral), where results for each indicator are outlined and compared spatially (protected area vs. reference area) and temporally (across survey events since 2014)

1. Reef Flat – Seagrass

Within the Reef Flat – Seagrass, the chosen REF sites in 2018 were not similar to the CA sites, so in 2020, the REF sites were changed to a site where the indicators can be compared due to similar characteristics. Thus, 2018 REF data are not presented in this report. Baseline data for this habitat is not presented as survey methods were different and comparisons are not possible.

1.1. Seagrass Cover

Seagrass cover in the conservation area remained constant since 2018. In 2018 the mean seagrass cover within the CA sites was 32.8% (±2.6) which increased to 37.9% (±4.5) in 2020. Mean seagrass cover within the REF sites was slightly higher at 39.6% (±3.1) in 2020 (Fig. 2).

There was no significant difference in the seagrass cover through time or between protection statuses (ANOVA, p>0.05).

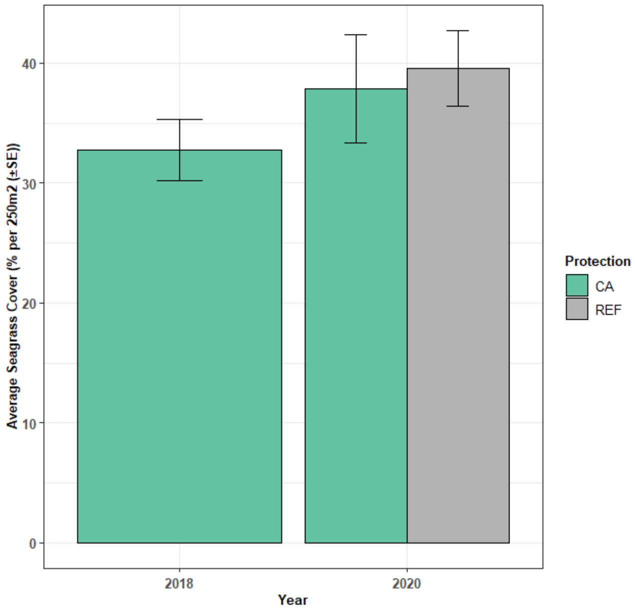

Fig. 2: Average seagrass cover (%) in 2018 and 2020, n=15, error bars signify standard error (±SE).

1.1.1. Seagrass Species Cover

Since 2018, the two most abundant seagrass species in the CA and REF were *Cymodocea rotundata* and *Thalassia hemprichii*. Additional seagrass species – *Enhalus acoroides* and *Halodule ovalis* – were found in the CA only in 2020 (Fig. 3).

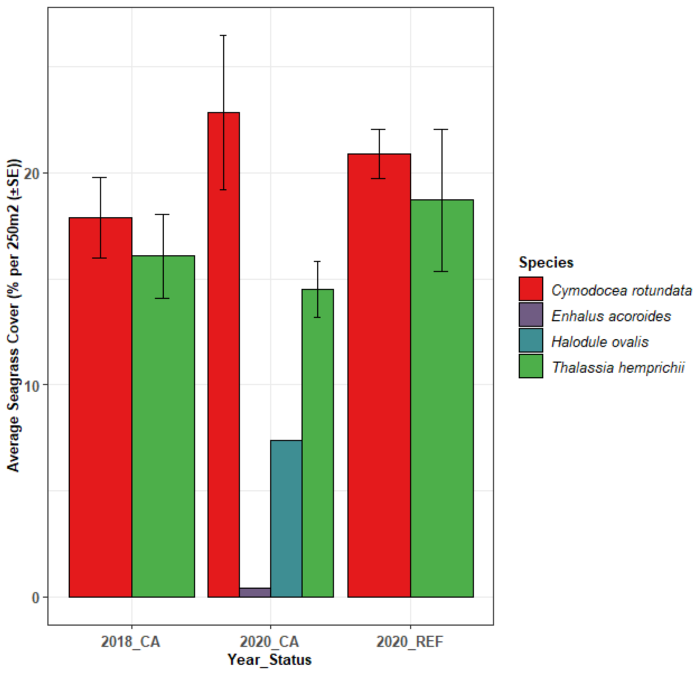

Fig. 3: Average seagrass species cover (%) in the CA and REF sites, n=15, error bars signify standard error (±SE).

1.2. Fish

Fish data since 2014 are presented since the same survey methods were used. Only 2020 data presented comparison between CA and REF.

1.2.1. Density

In 2014, the average fish density recorded in the CA was 9.13 (±3.28) fish per 100m^2 which decreased significantly to 2.08 (±0.66) fish per 100m^2 in 2018 and 1.17 (±0.35) fish per 100m^2 in 2020 (Kruskal-Wallis, $p<0.05$). A higher average fish density of 2.75 (±1.56) fish per 100m^2 was found in the REF sites in 2020, although no statistical difference between fish density in the CA and REF sites were found (Kruskal-Wallis, $p>0.05$) (Fig. 4).

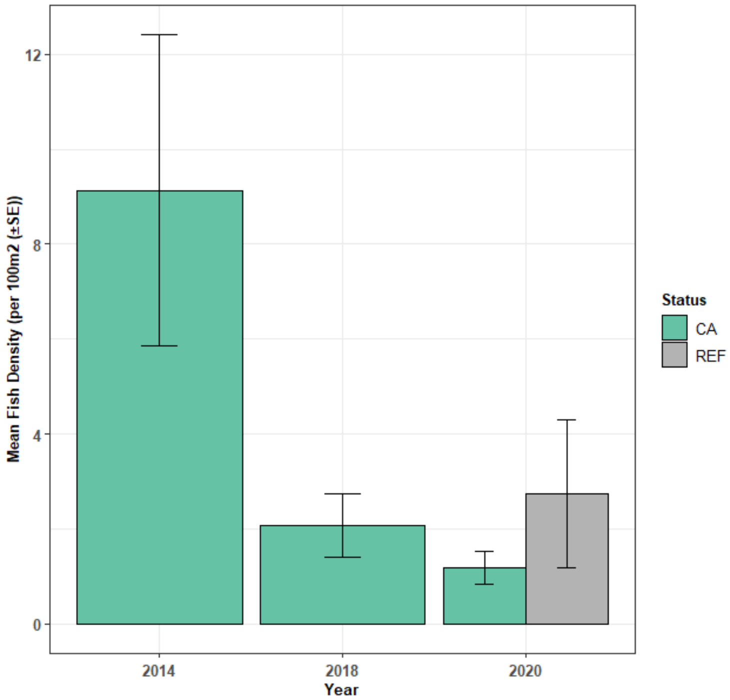

Fig. 4: Mean fish density per 100m^2 (2014, n=9; 2018 and 2020, n=15). Error bars signify standard error (±SE).

1.2.2. Fish biomass

In 2014, overall fish biomass averaged 1,357.16g (±499.53g) per 100m^2 which decreased in 2018 to 521.08g (±191.94g) per 100m^2 and again in 2020 to 204.73g (±148.72g) per 100m^2 (Fig. 5). No significant difference was found between the biomass in 2014 and 2018 (Kruskal-Wallis, $p>0.05$), nor between 2018 and 2020 (Kruskal-Wallis, $p>0.05$). However, the fish biomass in 2020 was significantly less than the baseline (Kruskal-Wallis, $p<0.01$). In 2020, there was no significant difference in fish biomass between the CA and REF (Kruskal-Wallis, $p>0.05$).

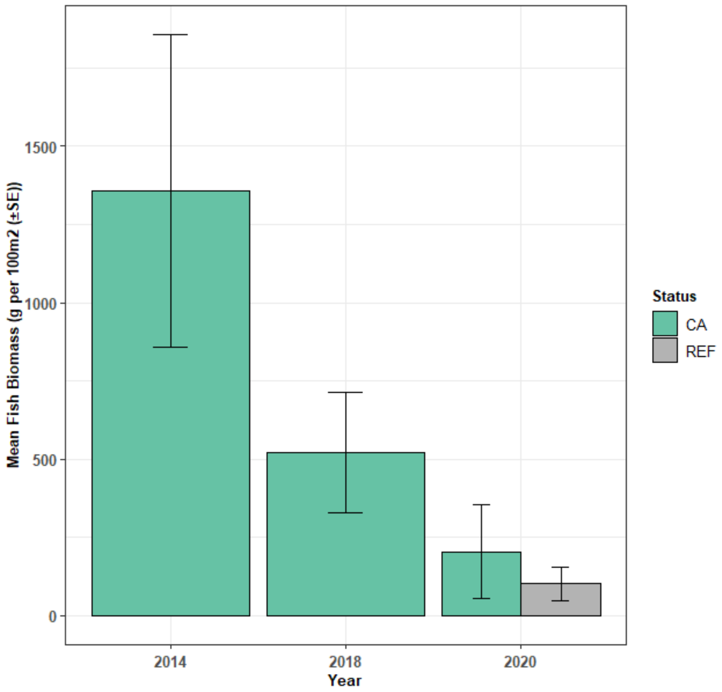

Fig. 5: Mean fish biomass (g) per 100m^2 (2014, n=9; 2018 and 2020, n=15). Error bars signify standard error (±SE).

1.2.3. Species Density

In 2014, the most abundant fish was of the Lethrinidae family. Other fish recorded include Siganidae, Acanthuridae, Lutjanidae, and Labridae. In 2018, these same fish families were recorded in addition to Balistidae, Carangidae and Mullidae. In 2020 within the CA, Epinephelidae family and in the REF, Scaridae was recorded in addition to those recorded in 2014 (Fig. 6).

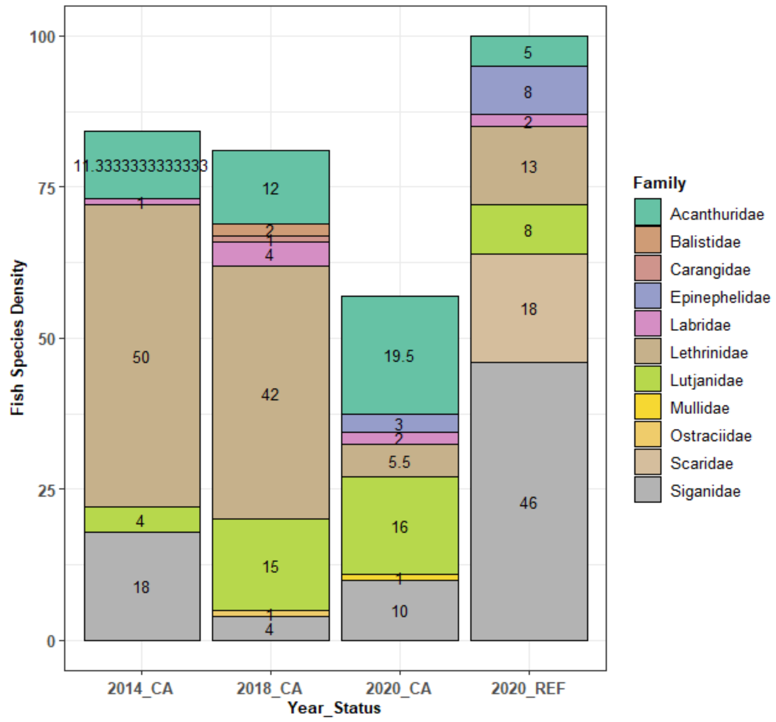

Fig. 6: Fish species density over time and between protection levels; (2014, n=9, 2019, n=15).

1.3. Macro-invertebrates

Since the baseline survey in 2014, macro-invertebrate density has increased from 0.12 (±0.12) macro-invertebrates found in 100m^2 area to 1.76 (±1.22) macro-invertebrates found per 100m^2 in 2018 with a subsequent decrease to 0.69 (±0.37) individuals per 100m^2 in 2020. However, there is no statistically significant difference between macro-invertebrate density, either through time or between protection levels (Kruskal-Wallis, $p>0.05$) (Fig. 7).

The only macro-invertebrate species recorded in Iuaiu CA were giant clams. In 2014, the only recorded species was *Tridacna crocea* (oruer). In 2018, *Hippopus hippopus* (duadeb) was recorded in addition to *T. crocea*. Furthermore, in 2020, within the CA and REF, *Hippopus porcellanus* (duadou), *Tridacna maxima* (melibes), and *T. crocea* were recorded.

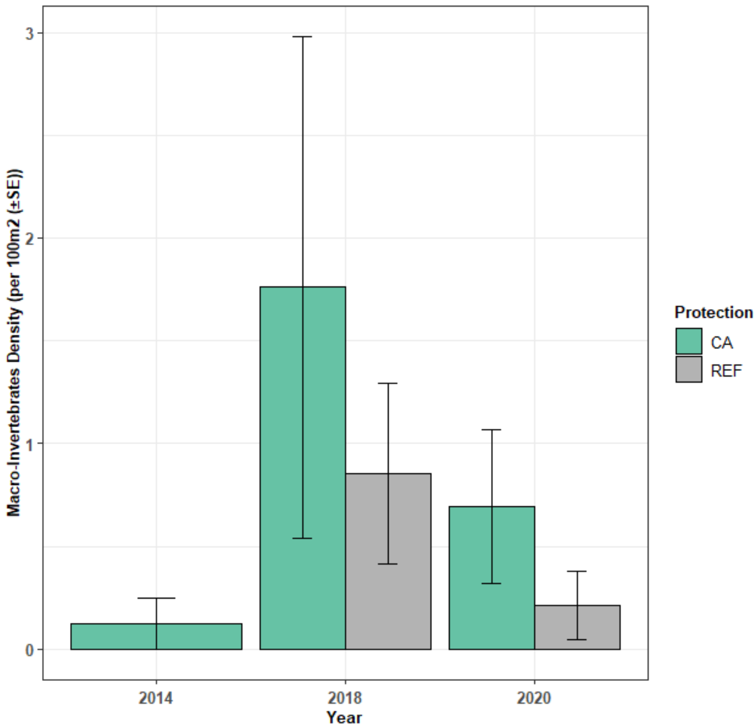

Fig. 7: Edible macro-invertebrate density per 100m^2 through time (2014, n=9; 2018/2020, n=15); Error bars signify standard error (±SE).

2. Reef Flat - Coral

2.1. Benthos

Benthic data is presented in the following subsections – major categories summary, live coral cover, and recruit density. With the exception of recruits' density which is given in mean density per 3m^2, the benthic and coral data are presented as percentage cover.

2.1.1. Major benthic categories

The benthic substrate consisted predominantly of carbonate, turf, sand, rubble and live coral. Within the CA, carbonate cover had significantly increased since 2014 (Kruskal-Wallis, $p<0.01$). Furthermore, carbonate cover had also increased within the REF from 2018 to 2020 (Kruskal-Wallis, $p<0.01$); there was, however, no significant difference in carbonate cover between the CA and REF in 2020 (Kruskal-Wallis, $p>0.05$) (Fig. 8).

In 2018, crustose coralline algae (CCA) cover had significantly increased in the CA from 2014 to 2018(Kruskal-Wallis, $p<0.05$), with no difference in cover noted between the CA and REF (Kruskal-Wallis, $p>0.05$). In 2020, in both CA and REF, no CCA was recorded, indicating a significant decrease in CCA cover since 2018 in both areas (Kruskal-Wallis, $p<0.001$). Rubble cover had significantly increased from 2014 to 2018 in the CA (Kruskal-Wallis, $p<0.05$), but remained constant from 2018 to 2020 in both the CA and REF (Kruskal-Wallis, $p>0.05$). Additionally, sand cover had decreased from 2014 to 2018 (Kruskal-Wallis, $p<0.05$) and has remained constant until 2020 within the CA, with no significant difference found between the REF and CA in 2020 (Kruskal-Wallis, $p>0.05$) (Fig. 8).

Turf cover decreased significantly from 2014 to 2020 (Kruskal-Wallis, $p<0.05$), but remained the same between protection levels in 2018 and 2020 (Kruskal-Wallis, $p>0.05$). In 2020, within the REF sites, the turf cover had decreased significantly compared to 2018 (Kruskal-Wallis, $p<0.01$). Little to no macroalgae was recorded since 2014 (Fig. 8).

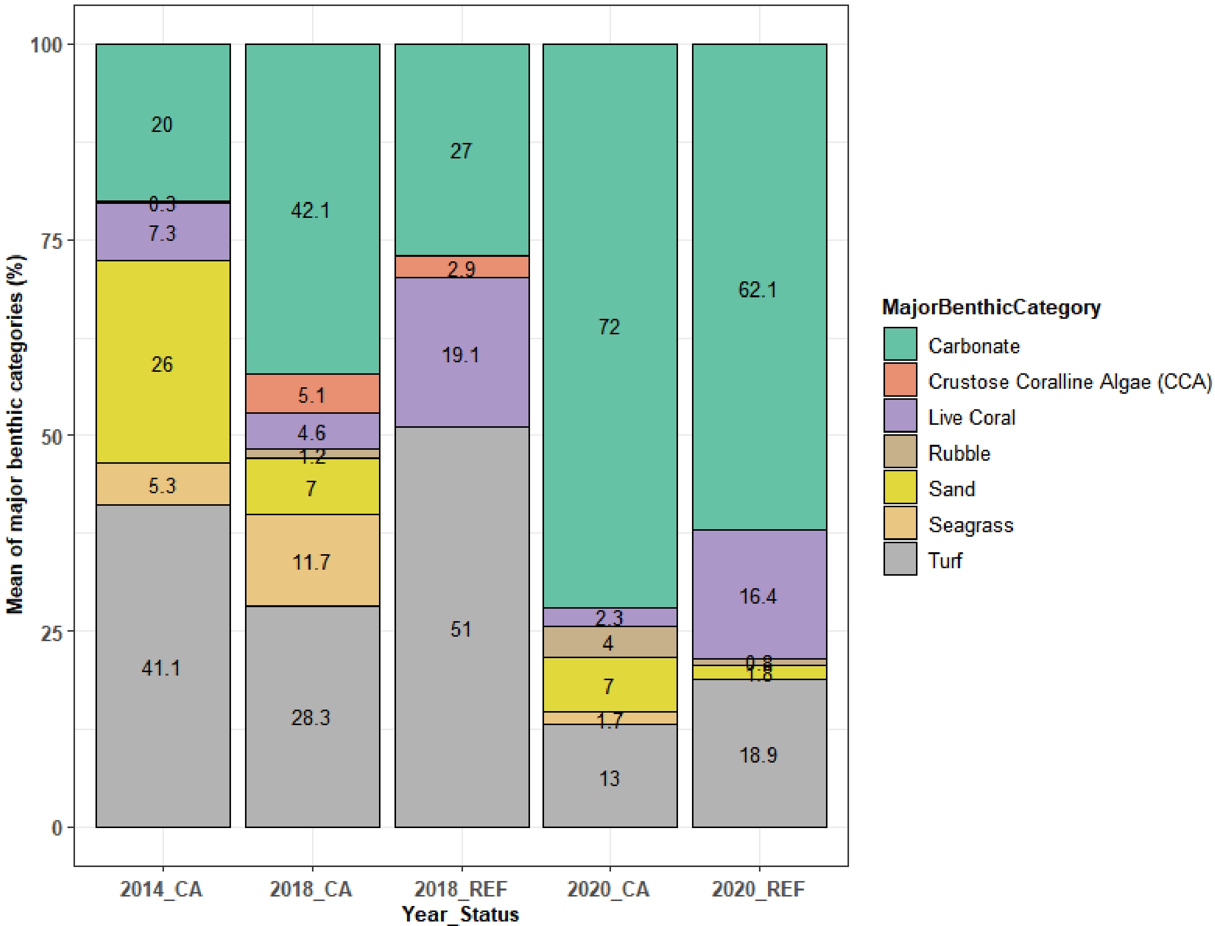

Fig. 8: Major benthic cover (%) through time and protection levels.

2.1.2. Hard coral cover

The coral cover remained stable within the CA from 2014 with a mean cover of 7.3% (±1.05%) to 4.5% (±0.8%) in 2018, but had significantly decreased in 2020 to mean cover of 2.3% (±0.5%)

(One-Way ANOVA, p<0.01). In 2018 and 2020, when comparing average coral cover between protection levels, the REF sites had significantly more coral cover than the CA sites (One-Way ANOVA, p<0.001). Coral cover in 2020 CA was 2.3% (±0.5%), while the REF had a cover of 16.4% (±3.2%). Live coral cover remained the same in the REF sites over time (2018 – 19.06% (±2.6%) and 2020 – 16.4 (±3.2%)) (One-Way ANOVA, p>0.05) (Fig. 9).

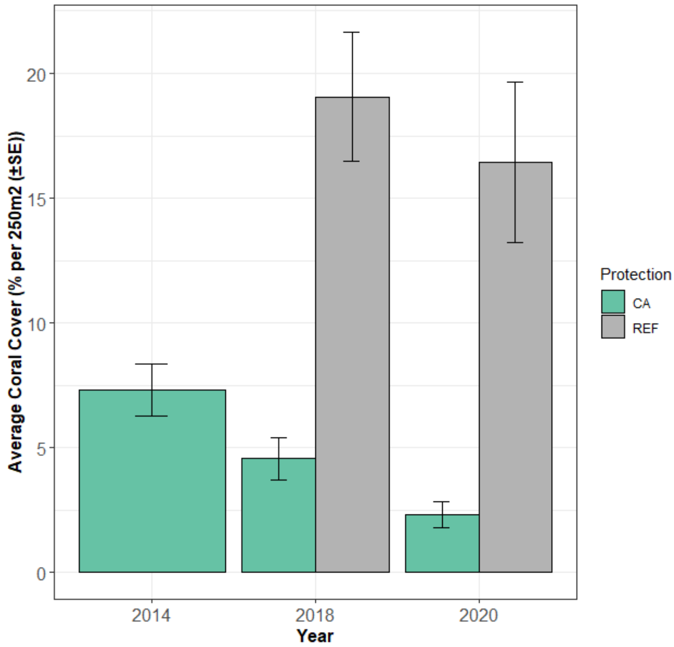

Fig. 9: Mean live coral cover (%) through time and between protection levels (2014, n=9; 2017 & 2019, n=15); Error bars signify standard error (±SE)

2.1.3. Coral Recruits

Coral recruit data are presented in two categories – density and species diversity. Coral recruits data are only available for 2018 and 2020, and comparisons were made through time and between protection levels.

Coral recruit density remained the same through time within the CA and REF sites (Kruskal-Wallis, p>0.05) (Fig. 9). Within the CA in 2018 5.3 (±0.7SE) individual coral recruits were recorded within a 3 m^2 area and in 2020 this decreased to 5.1 (±1.1SE) recruits. Within the REF sites in 2018 6.2 (±0.8) recruits were recorded which decreased to 5.3 (±1.0SE) recruits in 2020.

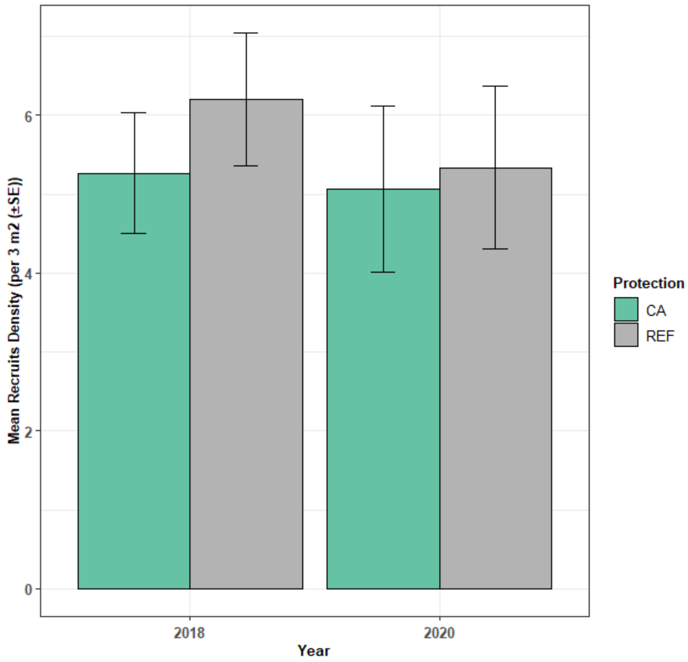

Fig. 10: Mean **c**oral recruit density per 3m^2 in CA and REF (n=15); Error bars signify standard error (±SE)

Since 2018, sixteen genera of coral recruits were recorded. The top three most abundant recruit genera recorded were porites, montipora, and pocillopora. In terms of the abundance of porites, no difference was found over time, either in the CA or REF (Kruskal-Wallis, $p>0.05$); however, porites abundance was significantly less within the REF sites compared to the CA sites in both 2018 and 2020 (Kruskal-Wallis, $p<0.01$) (Fig. 11). In 2018, montipora was more abundant in the REF site compared to the CA (Kruskal-Wallis, $p<0.001$), but in the CA montipora abundance remained the same from 2018 to 2020 and no significant difference was found in montipora abundance between 2020 CA and REF (Kruskal-Wallis, $p>0.05$). Furthermore, in terms of pocillopora abundance, it was significantly more abundant in the REF compared to the CA in 2020 (Kruskal-Wallis, $p<0.01$). Other genera recorded include acropora, favia, psammocora and more (Fig. 11). There was also a higher diversity of coral recruits in the REF (13 genera) compared to the CA (5 genera) in 2020.

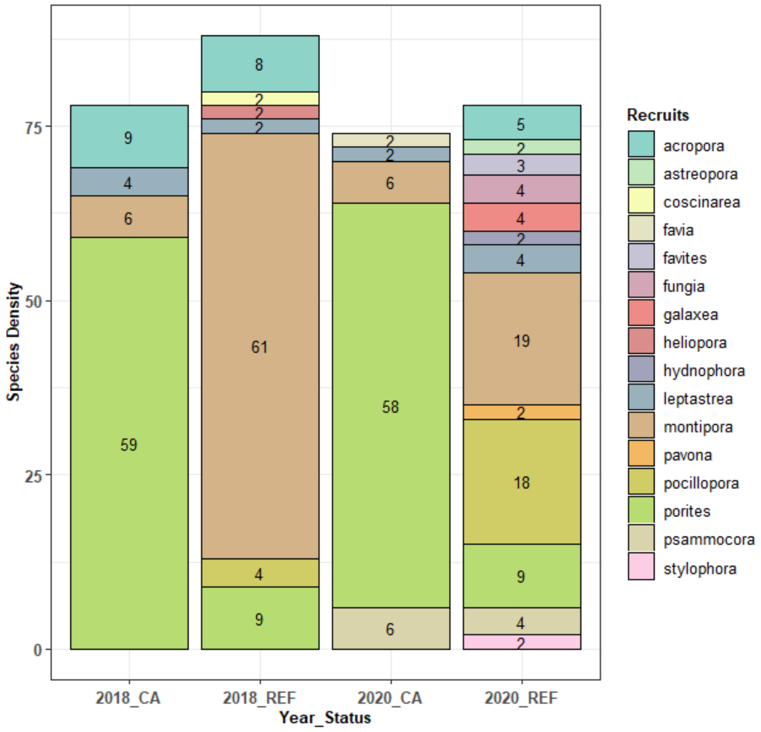

Fig. 11: Recruits species density in CA and REF through time (n=15).

2.2. Fish

Fish data results only show comparisons between 2018 and 2020 in both the CA and its REF site, due to the fact that 2014 fish data were collected using a different method, which does not allow for accurate comparison with present data. In addition to all fish density and biomass, fish data were separated into two categories – commercially-important fish and herbivorous fish – to draw conclusions on density and biomass for both categories.

2.2.1. Fish Density

2.2.1.1. All Fish Density

There was a significant difference in fish density in 2018 between the CA and REF (One-way ANOVA, $p<0.001$) and in 2020 the density of fish within the CA had significantly increased from 4.2 (±1.9) fish to 20.7 (±3.1) fish per 250 m^2 (One-way ANOVA, $p<0.001$) (Fig. 12). There was no difference in density between the CA and REF in 2020 (One-way ANOVA, $p>0.05$).

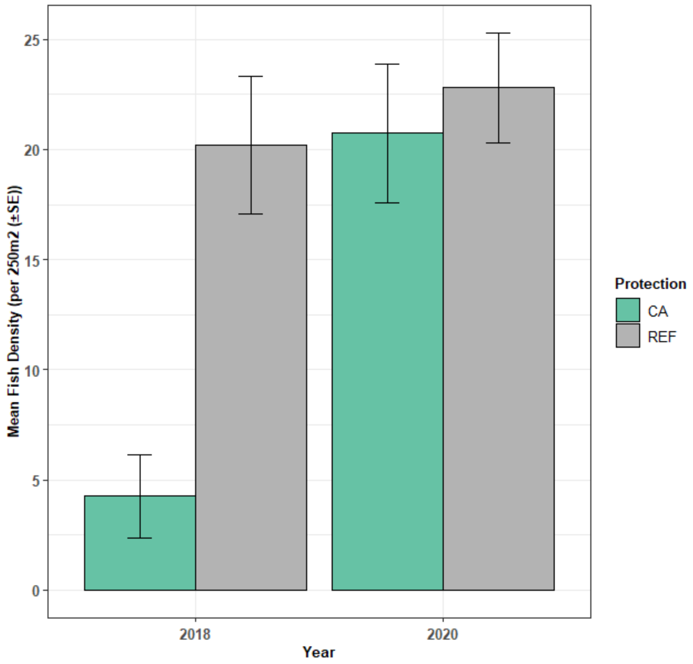

Fig. 12: Fish density (n=15); Error bars signify standard error (±SE)

2.2.1.2. Commercially-Important Fish density

The density of commercially important fish species in 2020 (16.67 (±3.34) fish per 250m^2) was significantly higher in the CA compared to 2018, where 3.93 (±2.96) fish was recorded per 250m^2 (Kruskal-Wallis, $p<0.001$) (Fig. 13). There was no difference in density of commercially-important fish in the REF compared to the CA in either 2018 or 2020 (Kruskal-Wallis, $p>0.05$). A list of recorded commercially-important fish is found in Appendix 2.2.

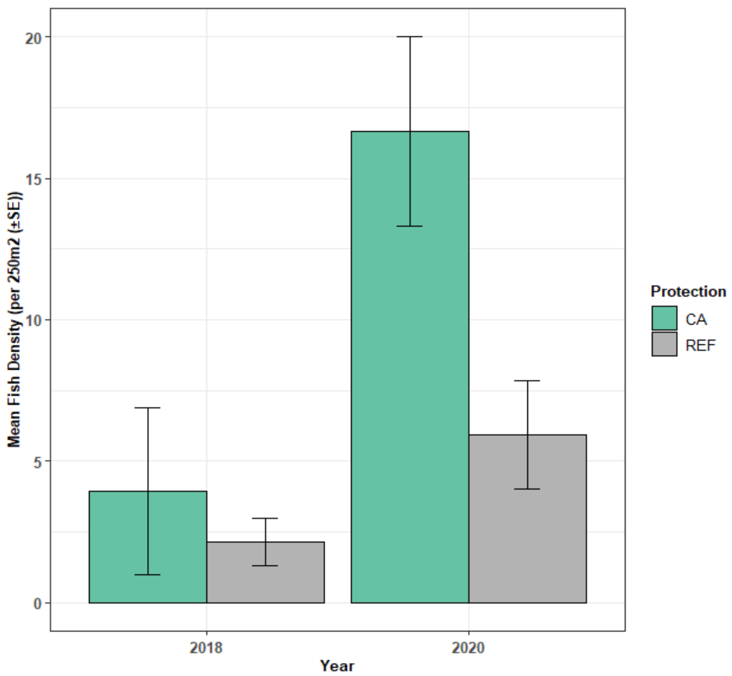

Fig. 13: Density of commercially-important fish (n=15); Error bars signify standard error (±SE)

2.2.1.3. Herbivorous Fish density

The density of herbivorous fish had significantly increased since 2018 within the CA (Kruskal-Wallis, $p<0.001$), but had remained the same in the REF sites through time (Kruskal-Wallis, $p>0.05$) (Fig. 14). The density in the CA in 2018 was 5.40 (±2.81) fish per 250m^2 with an increase to 34.73 (±5.78) fish per 250m^2 in 2020. In the REF site in 2018, there were 28.60 (±6.37) fish per 250 m2, and 28.67 (±3.14) fish per 250m2 were recorded in 2020 in the REF site. A list of recorded herbivorous fish are specified in Appendix 2.3.

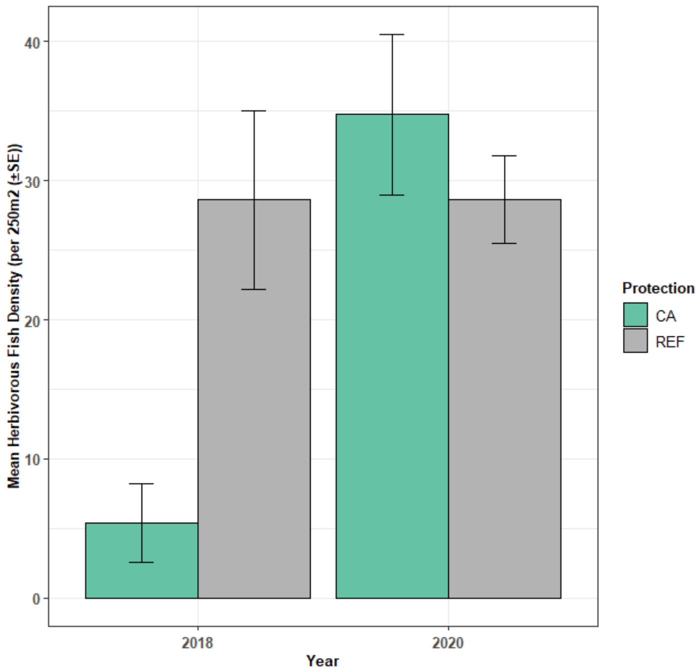

Fig. 14: Density of herbivorous fish (n=15); Error bars signify standard error (±SE)

2.2.2. Biomass

Within the REF sites in 2018 and 2020, a small school of *Bolbometopon muricatum* (kemedukl) were recorded. These biomass values were excluded from the data analysis due to either the inflation of biomass values or inaccurate length measurements from EventMeasure as a result of length-precision ratio being more than 10%. *B. muricatum* was factored into abundance, but not biomass.

2.2.2.1. All Fish Biomass

In 2018, fish biomass was significantly lower within the CA compared to the REF (One-way ANOVA, $p<0.05$), but there was no difference through time or between the CA and REF in 2020 (One-way ANOVA, $p>0.05$) (Fig. 15).

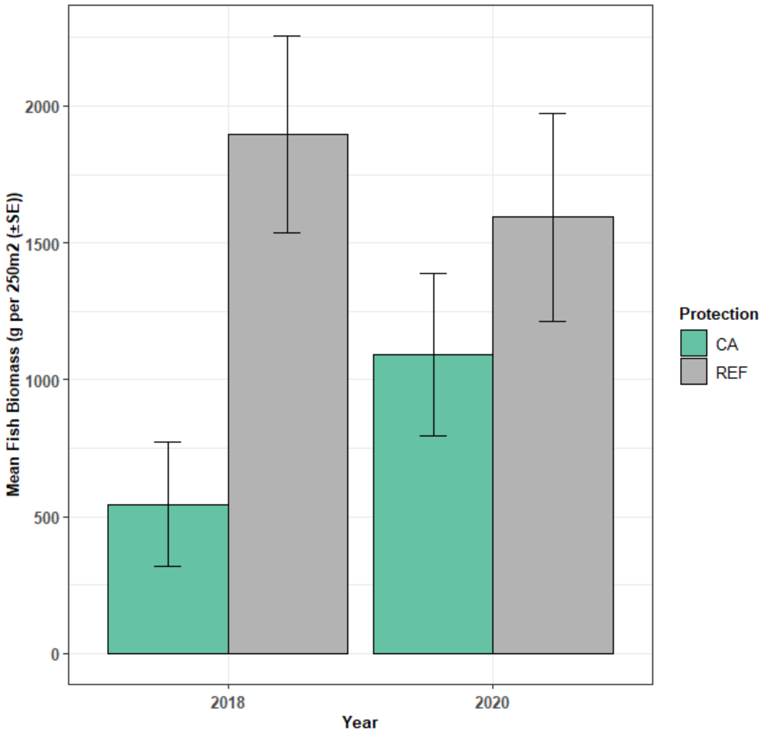

Fig. 15: All fish biomass (n=15); Error bars signify standard error (±SE)

2.2.2.2. Commercially-Important Fish Biomass

There was no difference in commercially-important fish biomass through time or between protection levels (Kruskal-Wallis, $p>0.05$) (Fig. 16). In 2018, the fish biomass in the CA was 355.42g (±171g) and in the REF was 273.25g (±177.01 g) per 250m^2. In 2020, within the CA, the fish biomass was 852.42g (±298.92g) and in the REF, the biomass was 339.46 g (±160 g) per 250m^2.

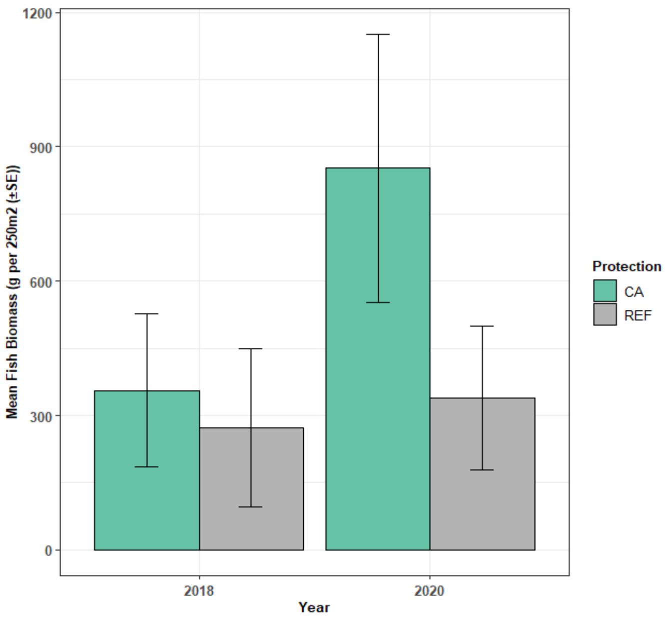

Fig. 16: Biomass of commercially-important fish (n=15); Error bars signify standard error (±SE)

2.2.2.3. Herbivorous Fish Biomass

Significantly higher biomass was recorded in the REF compared to the CA in 2018. In 2020, no difference in biomass were found between protection levels. Fish biomass increased significantly within the CA from 2018 to 2020 (Kruskal-Wallis, $p<0.01$); however, there was no difference in biomass in 2020 between protection levels (Kruskal-Wallis, $p>0.05$) (Fig. 17). The average biomass of herbivorous fish recorded in 2018 within the CA was 434.56 g (±211.60 g) and in the REF, the biomass was 1,639.65 g (±349.61 g) per 250 m^2. In 2020, the herbivorous fish biomass in the CA was 1,805.15 g (±325.74 g) and in the REF, the average biomass was 1,564.14 g (±371.33 g) per 250 m^2.

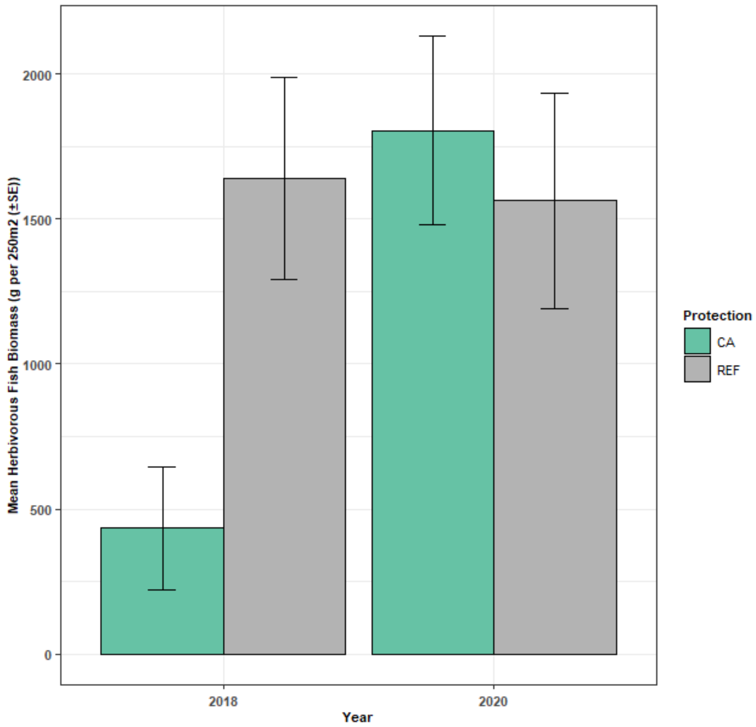

Fig. 17: Biomass of herbivorous fish (n=15); Error bars signify standard error (±SE)

2.2.3. Species Diversity

The most recorded fish in the CA and REF in 2018 and 2020 was of the Acanthuridae family with 71 in 2018 and 290 in 2020 within the CA. In the REF sites there were 428 Acanthuridae individuals recorded in 2018 and 392 in 2020 (Fig. 18). There was significantly more Acanthuridae individuals within the REF compared to the CA in 2018 (Kruskal-Wallis, $p<0.05$); however, there was no difference in Acanthuridae abundance in 2018 to 2020, in both the CA and (Kruskal-Wallis, $p>0.05$). There was a significant increase in the abundance of Scaridae species in 2020 within the CA compared to the CA in 2018, and there was significantly more Scaridae individuals within the CA compared to the REF in 2020 (Kruskal-Wallis, $p<0.001$).

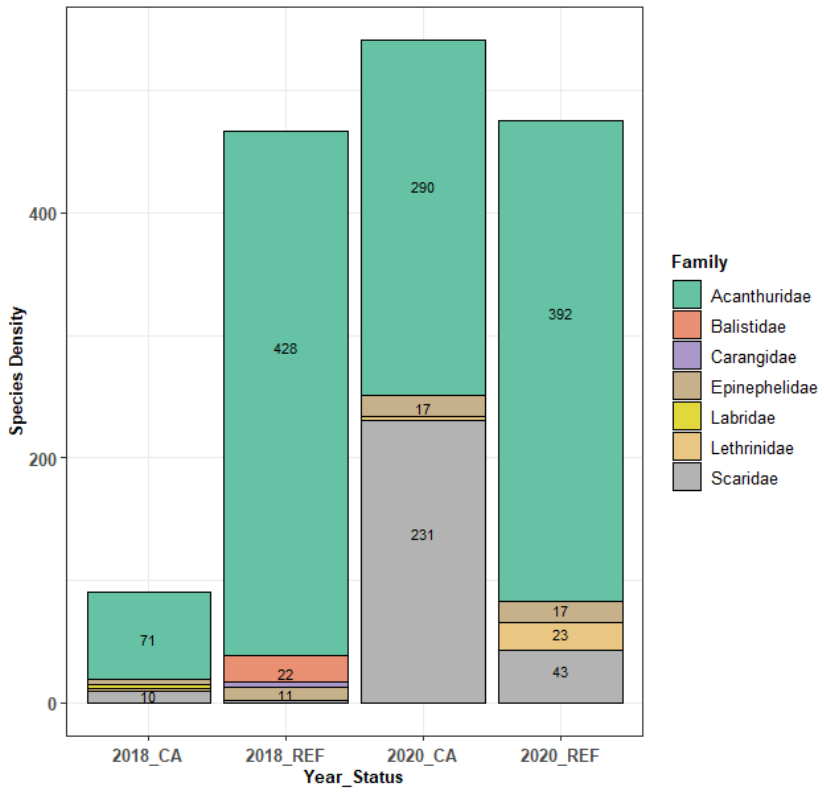

Fig. 18: Total fish species density by family observed through time (n=15)

3.1. Macro-Invertebrates

In 2014, the macro-invertebrate density within the CA was 1.48 (±0.99) individuals per 100m^2 which decreased to 1.09 (±0.27) individuals per 100m2 in 2018 showing no significant difference in density (Kruskal-Wallis, p>0.05) (Fig. 19). In 2018, there was a slightly significant difference in density between the CA (1.09 (±0.27) individuals per 100m2) and REF (0.27 (±0.16) individuals per 100m2) (Kruskal-Wallis, p=0.06); but no significant difference in density in 2020 either in the CA or REF, where less than 0.5 individuals were found per 100m^2 (Kruskal-Wallis, p>0.05) (Fig. 19).

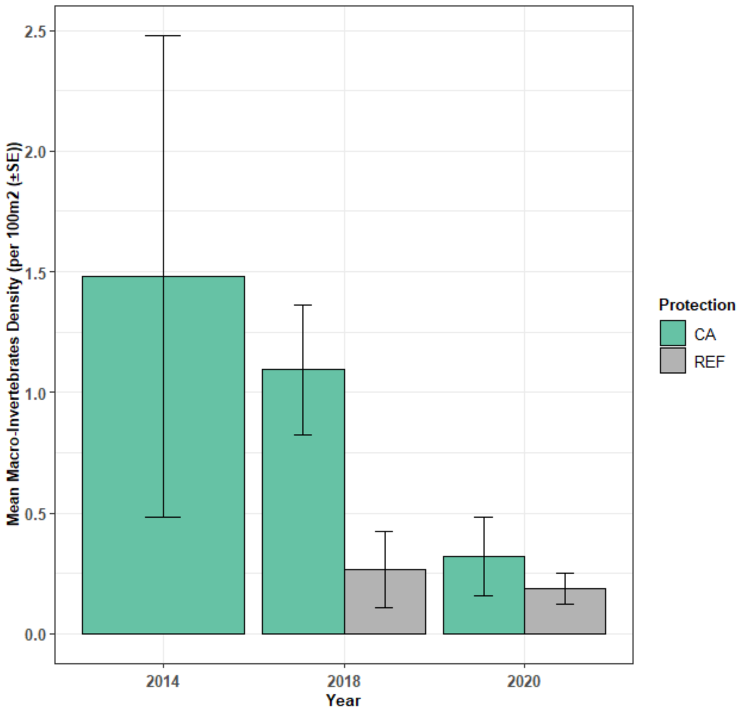

Fig. 19: Macro-invertebrate density in CA and REF through time; (2014, n=9; 2018 & 2020, n=15); Error bars signify standard error (±SE)

The only macro-invertebrate species recorded since 2014 were the giant clam species *Hippopus hippopus* (duadeb), *Tridacna crocea* (oruer), *Tridacna maxima* (melibes), and *Tridacna squamosa* (ribkungal), and the trochus species *Trochus niloticus* (semum) (Fig. 20). There was significantly lower *T. crocea* abundance in the REF compared to the CA in 2018 (Kruskal-Wallis, $p<0.05$).

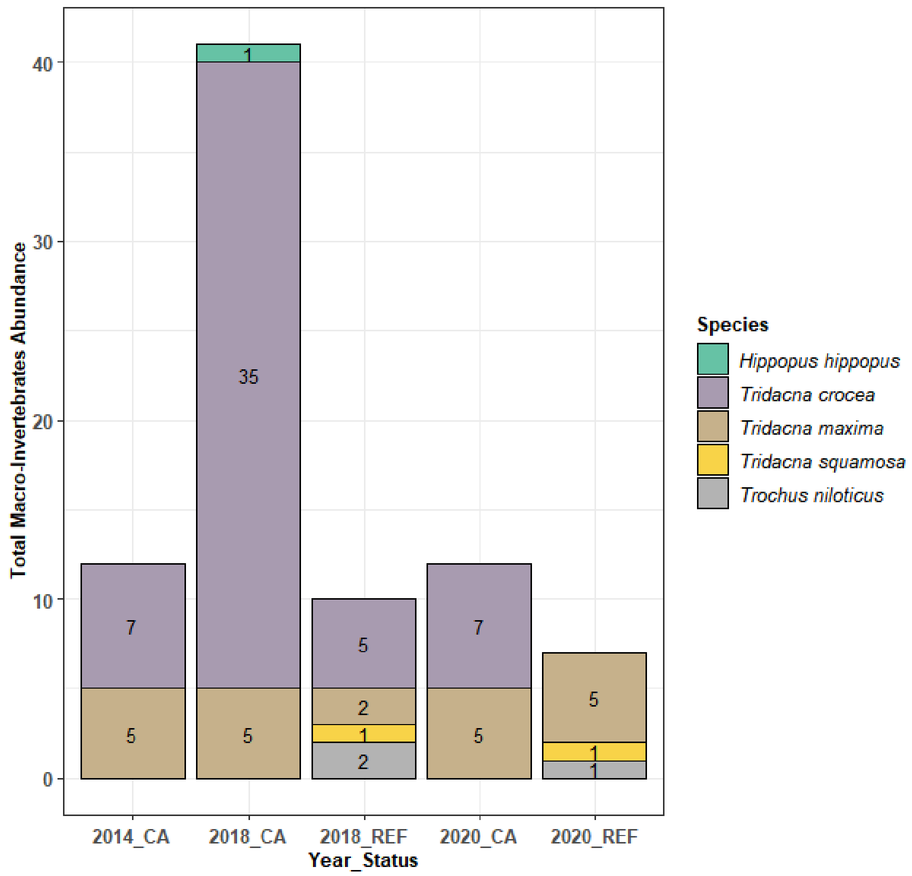

Fig. 20: Total macro-invertebrate species abundance in CA and REF through time; (2014, n=9; 2018 & 2020, n=15)

3. Discussion

Table 1. Summary table of assessment results.

(↑ - increase in trends, = - no change, ↓- decrease; * indicated significance in results; grey areas indicate no comparisons were made in that year for the indicator)

Habitat	Ecological Indicator			CA Trends (↑, =,↓) 2014-2018	CA Trends (↑, =,↓) 2018-2020	CA Trends (↑, =,↓) 2014-2020	Protection (CA <,=,> REF) 2018	Protection (CA <,=,> REF) 2020	Details (*) indicates significant difference
Reef Flat - Seagrass	Seagrass Cover				=			<	32.8% (2018) < 37.9% (2020)
	Fish Density	Density		↓*	=	↓*		<	2.08 > 1.17 (CA)
		Biomass		=	=	↓*		>	521.08g > 204.7g (CA)
	Macro-Invertebrates	Density		=	=	=		>	
Reef Flat - Coral	Fish Density	All Fish			↑*		<*	<	
		Commercially-important			↑*		>	>	CA: 16.67 (2020) > 3.93 (2018)
		Herbivorous fish			↑*		<	=	CA: 34.73 (2020) > 5.4 (2018)
	Fish Biomass	All Fish			=		<*	=	
		Commercially-important			=		>	>	
		Herbivorous fish			↑*		<*	=	CA: 1,805g (2020) > 434.56g (2018)
	Macro-Invertebrates	Density		=	=	=	>*	>	
	Benthos	Macroalgae		-	-	-	-	-	Little to none recorded
		Substrate	Carbonate	↑*	↑*	↑*	>	>	
			Rubble	↑*	↓*	↑*	>	>	
			Sand	↓*	=	↓*	>	>	
			Turf	=	=	=	<	<	
		Crustose coralline algae		↑*	=	=	>	=	
		Seagrass		↑*	=	=	>	>	
		Hard Live Coral		=	=	↓*	<*	<*	2018_CA – 4.5% 2018_REF – 19.06% 2020_CA – 2.3% 2020_REF – 16.4%
	Coral recruits				=		<	=	2020: 5.1 (CA) vs. 5.3 (REF)

3.1. Reef flat – Seagrass

Seagrass habitats are important for marine animals as it provides (1) a permanent habitat for some fish and invertebrate species; (2) temporary nursery for fish and other marine species to live during larval and juvenile phases; (3) a feeding area for turtles and other herbivorous marine animals; and (4) a refuge area from predators (Jackson et al., 2001; Duarte, 2002; Dorenbosch et al., 2005). The Iuaiu CA is the only seagrass habitat on the island of Angaur, thus, its conservation and protection are crucial. According to Machrizal et al. (2019) seagrass cover of 38% is considered to be in fair condition. However, seagrass beds are susceptible to negative impacts due to coastal disturbances like sedimentation, development, and more (McCloskey & Unsworth, 2015). A cover of 50% and more is considered to be a good/healthy cover, however, in the CA, the average seagrass cover was estimated at ~39%, which is well below what is considered to be a healthy seagrass cover (McCloskey & Unsworth, 2015). Thus, the seagrass beds must continue to be monitored to identify any possible disturbances and problems that can be helped before it is irreversible. Furthermore, due to low seagrass cover in the CA over time, the fish density and biomass, and macro-invertebrates density could have declined as well.

Fig. 21: Google Earth Historical Satellite Images of Angaur's Iuaiu CA seagrass bed

The Google Earth historical satellite imagery of the Iuaiu CA seagrass bed shows a visual baseline of the seagrass cover (dark green areas in the images) from 2004 to 2016 (Fig. 21). No updated satellite image was found for 2018 to 2020. With the seagrass beds' close proximity to land, it is crucial to ensure that land runoffs and other land moving activities do not impact the seagrass bed. Because seagrass condition is dependent on various environmental factors like sea surface temperature (SST) and water quality (turbidity, nutrient and chlorophyll a levels), these factors should be incorporated into future assessments. Knowing this information will help researchers make better inferences on the factors that influence seagrass growth and productivity in line with fish and macro-invertebrate densities and biomass.

Since 2014, the fish in the seagrass beds had declined significantly. This may be attributed to the fact that as fish grow bigger, they leave the seagrass bed and venture into the coral dominated reef flat. In the seagrass bed, the fish biomass was 204.7 g whereas in the coral dominated reef flat, the biomass was 1,805 g. This decrease in fish densities in the seagrass may be due to the mobile patterns of the fish as it outgrows the seagrass bed.

3.2. Reef flat – Coral

On the coral dominated reef flat, a significant decrease in live coral cover was seen within the CA compared to baseline surveys conducted in 2014. In 2017, the Western Reefs of Angaur were impacted by the Tropical Storm Lan – a storm that generated swells of about 5m coming from the Southwest that left the western reefs with an absolute coral loss of 10-15% (Gouezo & Olsudong, 2018). Because of Tropical Storm Lan's great wave disturbance, the shallow areas (~3m) of Angaur's western reefs had a significant coral cover loss of nearly 25% (Gouezo & Olsudong, 2018). This meant a loss of corals like Acropora, Montipora, Galaxea, Pocillopora, and Echinopora (Gouezo & Olsudong, 2018). Thus, with the Iuaiu CA and REF sites located on the western side of Angaur, they were affected by the Tropical Storm, resulting in the low coral cover, high carbonate and rubble cover and low recruitment of corals. The CA was more impacted as it was shallower than the REF and sustained more damage (Gouezo & Olsudong, 2018), as evidenced by the significantly higher coral cover the REF in 2020. Two years after the tropical storm, the reef was dominated by significantly higher coverage of carbonate and rubble in the CA compared to the REF areas. Additionally, the reef has not shown recovery post the tropical storm due to low abundance of recruits within both CA and REF sites. Coral recruitment is essential in reef building and recovery from major disturbances (Kuffner et al, 2006).

Despite the low coral cover in the CA through time, fish density has significantly increased since the storm in 2017. This density of fish was primarily made up of herbivorous fish species of the families Acanthuridae and Scaridae. These fish species are crucial in the recovery of damaged reefs from natural disturbances, such as Tropical Storm Lan, as they feed on algal turf and macroalgae and help prevent a phase shift from a coral dominated reef to one of an algae-dominated reef (Khalil et al., 2013; Hughes et al., 2007). Should there be a lack of herbivory on these reefs, they would most likely be overrun by macroalgae and turf and shift into an algae-dominated reef where corals cannot survive (Hoey and Bellwood, 2011). With this increase in the herbivorous fish density on the Angaur reefs, it is a good sign for reef recovery. Additionally, as herbivorous fish feed on turf algae, they leave small pockets of substrate where coral larvae can settle and grow (Bellwood et al, 2006), contributing to reef recovery in the long run.

Conclusion

As such, it is important for the managers of the Angaur CA to ensure that the CA is protected from fishing activities, especially the harvest of herbivorous fishes. Though these fish are highly desirable food fishes, some levels of restrictions (i.e. temporary size restrictions) can be placed on their harvest to prevent overfishing these herbivorous fishes to ensure that they are able to aid the reef in its recovery from Tropical Storm Lan. Understandably, Palauans enjoy eating small surgeonfish (like masech and chesengel), these fishes have the ecological importance in maintaining low levels of algae on the reef. Should size restrictions be applied, for example, only taking those that are 10 inches or more (these fish only grow to a maximum of 14-18 inches), we can ensure that these fish can remain long enough on the reef to reproduce and contribute to maintaining the algal growth at a minimum to allow for the reef to recover from the storm impacts.

Finally, Angaur State has only one seagrass bed, which is a crucial environment for its juvenile fishes. Studies show how important seagrass beds are in the marine ecosystem in providing ecological functions like shelter from predators, nursery for juvenile marine species, and more. Perhaps one of its greatest services is populating adjacent reefs with the fish and other marine animals as they grow larger. Thus, it is vital that the seagrass bed be protected to the state’s full potential to ensure a safety net for the States’ marine ecosystem.

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References

1. Bellwood, D. R., Hughes, T. P., & Hoey, A. S. (2006). Sleeping functional group drives coral-reef recovery. *Current Biology*, *16*(24), 2434-2439.

2. Dorenbosch M, Grol MGG, Christianen, MJA, Nagelkerken, I, and van der Velde G. (2005). Indo-Pacific seagrass beds and mangroves contribute to fish density and diversity on adjacent coral reefs. *Marine Ecology Progress Series*, 302, 63-76.

3. Duarte C. (2002). The future of seagrass meadows. *Environmental Conservation*, 29(2), 192-206.

4. Goetze, JS, Bond, T, McLean, DL, Saunders, BJ, Langlois, TJ, Lindfield, S, Fullwood, LAF, Dressen, D, Shedrawi, G, and Harvey, ES. (2019). A field and video analysis guide for diver operated stereo-video. *Methods in Ecology and Evolution*, 10 (7). doi.org/10.1111/2041-210X.13189

5. Gouezo M, Koshiba S, Otto E, Olsudong D, Mereb G, Jonathan R. March 2016. *Ecological conditions of coral-reef and seagrass marine protected areas in Palau.* PICRC Technical Report 16-06. Palau International Coral Reef Center, Koror, Palau.

6. Gouezo M and Olsudong D. May 2018. *Impacts of Tropical Storm Lan (October 2017) on the western outer reefs of Palau.* PICRC Technical Report 18-08. Palau International Coral Reef Center, Koror, Palau.

7. Hoey, A. S., & Bellwood, D. R. (2011). Suppression of herbivory by macroalgal density: a critical feedback on coral reefs?. *Ecology letters*, *14*(3), 267-273.

8. Hughes, T. P., Rodrigues, M. J., Bellwood, D. R., Ceccarelli, D., Hoegh-Guldberg, O., McCook, L., & Willis, B. (2007). Phase shifts, herbivory, and the resilience of coral reefs to climate change. *Current biology*, *17*(4), 360-365.

9. Jackson, Emma & Rowden, Ashley & Attrill, Martin & S.J, Bossey & B, Jones. (2001). The importance of seagrass beds as a habitat for fishery species. *Oceanography and marine biology*. 39. 269-304.

10. Johannes RE. 1981. *Words of the Lagoon: Fishing and Marine Lore in the Palau District of Micronesia*. University of California Press, CA.

11. Khalil, M. T., Cochran, J. E. M., & Berumen, M. L. (2013). *The abundance of herbivorous fish on an inshore Red Sea reef following a mass coral bleaching event. Environmental Biology of Fishes, 96(9), 1065–1072.* doi:10.1007/s10641-012-0103-5

12. Kohler, K, and Gill, S. (2006). Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. *Computers & Geosciences*, 32. 1259-1269. 10.1016/j.cageo.2005.11.009.

13. Koshiba S, Jonathan R, Olsudong D, Oruetamor J, Mereb G, Polloi K. 2014. *Baseline Assessment of Angaur Conservation Area*. PICRC Technical Report 14 -11. Palau

International Coral Reef Center. Koror, Palau.

14. Kuffner, I. B., Walters, L. J., Becerro, M. A., Paul, V. J., Ritson-Williams, R., & Beach, K. S. (2006). Inhibition of coral recruitment by macroalgae and cyanobacteria. *Marine Ecology Progress Series*, *323*, 107-117.

15. Kulbicki, M, Guillemot, N, and Amand, M. (2005). A general approach to length-weight relationships for New Caledonian lagoon fishes. *Cybium: international journal of ichthyology*. 29. 235-252.

16. Machrizal, R et al 2019 *IOP Conf. Ser.: Earth Environ*. Sci. 348 012004

17. McCloskey RM, Unsworth RKF. 2015. Decreasing seagrass density negatively influences associated fauna. *PeerJ* 3:e1053 https://doi.org/10.7717/peerj.1053

Appendix 1. Table of benthic categories.

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

Appendix 2. All fish species recorded in Reef Flat – Seagrass and Reef Flat – Coral

2.1 Reef Flat – Seagrass Fish Species		
Scientific Name	**Common Name**	**Palauan Name**
Acanthurus nigricauda	Epaulette Surgeonfish	Esengel
Acanthurus triostegus	Convict Tang	Elas
Choerodon anchorago	Orange-dotted Tuskfish	Budech
Epinephelus corallicola	Duskyfin Grouper	Temekai
Leptoscarus vaigiensis	Marbled Parrotfish	Kesuu
Lethrinus harak	Thumbprint Emperor	Itotech
Lethrinus obsoletus	Orangestripe Emperor	Chudech
Lutjanus fulvus	Blacktail Snapper	Reall
Lutjanus gibbus	Humpback Snapper	Keremlal
Naso brachycentron	Humpback Unicornfish	Sechou
Naso lituratus	Orange-spine Unicornfish	Erangel
Parupeneus barberinus	Dash-and-dot Goatfish	Bang
Siganus argenteus	Streamlined Spinefoot Rabbitfish	Beduut
Siganus spinus	Spiny Rabbitfish	Meias

2.2 Reef Flat – Coral: Commercially-Important Fish Species		
Scientific Name	**Common Name**	**Palauan Name**
Acanthurus nigricauda	Epaulette Surgeonfish	Esengel
Acanthurus spp.	Surgeonfish	
Bolbometopon muricatum	Bumphead Parrotfish	Kemedukl
Caranx melampygus	Bluefin Trevally	Orwidel
Cephalopholis argus	Peacock Hind	Mengardechelucheb
Cephalopholis miniata	Coral Hind	Temekai
Cetoscarus ocellatus	Spotted Parrotfish	Ngesngis/Beyadel
Chlorurus spilurus	Pacific Bullethead Parrotfish	Mellemau

Epinephelus spp.	Grouper	
Lethrinus harak	Thumbprint Emperor	Itotech
Lethrinus obsoletus	Orangestripe Emperor	Chudech
Lutjanus gibbus	Humpback Snapper	Keremlal
Naso lituratus	Orange-spine Unicornfish	Erangel
Scarus ghobban	Bluebarred Parrotfish	Mertebetabek
Scarus spp.	Parrotfish	Mellemau

2.3 Reef Flat – Coral: Herbivorous Fish Species		
Scientific Name	**Common Name**	**Palauan Name**
Acanthurus auranticavus	Orange-socket Surgeonfish	
Acanthurus blochii	Ringtail Surgeonfish	
Acanthurus fowleri	Fowleri Tang	
Acanthurus lineatus	Striped Surgeonfish	Belai
Acanthurus maculiceps	White-freckled Surgeonfish	
Acanthurus nigricans	Whitecheek Surgeonfish	
Acanthurus nigricauda	Epaulette Surgeonfish	Esengel
Acanthurus spp.	Surgeonfish	
Acanthurus triostegus	Convict Tang	Elas
Cetoscarus ocellatus	Spotted Parrotfish	Ngesngis/Beyadel
Chlorurus spilurus	Pacific Bullethead Parrotfish	Mellemau
Ctenochaetus striatus	Striated Surgeonfish	Masech
Naso lituratus	Orange-spined Unicornfish	Erangel
Scarus ghobban	Bluebarred Parrotfish	Mertebetabek
Scarus spp.	Parrotfish	Mellemau
Zebrasoma scopas	Brown Tang	

Appendix **3. All macro-invertebrate species recorded in (1) Reef Flat – Seagrass and (2) Reef Flat – Coral**

(1) Reef Flat - Seagrass: Macro-Invertebrate Species		
Scientific Name	**Common Name**	**Palauan Name**
Bohadschia argus	Leopard Sandfish	Meremarch
Bohadschia marmorata		Meremarch
Hippopus hippopus	Bear Paw Giant Clam	Duadeb
Hippopus porcellanus	China Giant Clam	Duadou
Tridacna crocea	Boring Giant Clam	Oruer
Tridacna maxima	Maxima Giant Clam	Melibes

(2) Reef Flat - Coral: Macro Invertebrates		
Scientific Name	**Common Name**	**Palauan Name**
Hippopus hippopus	Bear paw giant clam	Duadeb
Tridacna squamosa	Binomial giant clam	Ribkungal

Tridacna crocea	Boring giant clam	Oruer
Tridacna maxima	Maxima giant clam	Melibes
Trochus niloticus	Trochus	Semum

Appendix 4. Permanent GPS Coordinates of Survey Sites in Angaur Iuaiu Conservation Zone

Location	Name of MPA	Habitat	Protection	Site	GPS Name	Lat (UTM)	Long (UTM)
Angaur	Iuaiu_CA	Reef Flat - Coral	MPA	5	ARF5-CA	761999	402888
Angaur	Iuaiu_CA	Reef Flat - Coral	MPA	6	ARF6-CA	762178	402940
Angaur	Iuaiu_CA	Reef Flat - Coral	MPA	7	ARF7_CA	762283	403045
Angaur	Iuaiu_CA	Reef Flat - Seagrass	MPA	8	ASG8-CA	762159	403117
Angaur	Iuaiu_CA	Reef Flat - Seagrass	MPA	9	ASG9-CA	762315	403301
Angaur	Iuaiu_CA	Reef Flat - Seagrass	MPA	10	ASG10-CA	762432	403537
Angaur	Iuaiu_REF	Reef Flat - Coral	REF	5	ARF5-REF	764368	403530
Angaur	Iuaiu_REF	Reef Flat - Coral	REF	6	ARF6-REF	764571	403488
Angaur	Iuaiu_REF	Reef Flat - Coral	REF	7	ARF8-REF	764726	403456
Peleliu	Iuaiu_REF	Reef Flat - Seagrass	REF	8	ASG8-REF-N	773983	413930
Peleliu	Iuaiu_REF	Reef Flat - Seagrass	REF	9	ASG9-REF-N	774190	413980
Peleliu	Iuaiu_REF	Reef Flat - Seagrass	REF	10	ASG10-REF-N	774434	414073