Oreuaol Ibuchel Conservation Area is a refuge to *Tridacna crocea* (Oruer) and may be affected by runoff

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Abstract

Coral reefs support important resources especially for island communities. Human activities on land, when not regulated properly, often lead to pollution and bad fishing practices that eventually degrade coral reefs. To combat the degradation of coral reefs, communities throughout Palau have established Marine Protected Areas (MPAs) to manage their marine resource. To support these conservation efforts, Palau National Government initiated the Protection Areas Network (PAN) to bring all the local MPAs into a single network of conservation areas. In 2015, Palau International Coral Reef Center (PICRC) conducted a baseline survey at Oreuaol Ibuchel Conservation Area (CA) in Ngatpang State, which is one of the PAN sites. Following the baseline, PICRC conducted follow-up assessments every 2 years within the same conservation area. In addition, a corresponding non-protected reference (REF) area was surveyed starting in 2018. Resources surveyed were fish, invertebrates, reef substrate, and coral recruits. All surveys were conducted at two of the major habitats in the MPA, reef flat and lagoon reef. The main objective of the follow-up assessments was to determine effectiveness of the MPA in conserving resources over time. Resources inside the MPA were also compared across the two habitats. Our findings showed that protection status had little effect on resource condition. Macroalgae and non-living substrate dominated the reef flat and lagoon reefs. In contrast, coral cover inside the MPA decreased and remained low over time. Fish density was similar over time and between habitats; however, larger fish were found in the lagoon reef. Density of macro-invertebrates, specifically *Tridacna crocea* (Oruer), decreased over time and was not affected by protection status. Similarly, density of coral recruits was not affected by the protection status, and showed a negative trend over time. With abundant macroalgae, low coral recruits and presence of COTS, coral population

in the MPA may not recover quickly. Although not significant, mean density of fish and fish biomass has the potential to increase over time. Therefore, it is recommended to monitor nutrient level and turbidity to help manage terrestrial runoff. Decreased runoff over time has the potential to increase coral recruits and survival of adult corals; therefore, speed up recovery of coral and fish population inside Oreuaol Ibuchel CA.

Introduction

Coral reefs are important for numerous reasons. Coral reefs sustain marine resources, such as fish and clams. These marine resources are important source of food and income, especially for communities on an island. Despite their importance, coral reefs are degrading around the world, mainly due to pollution (Eriksen et al. 2014), overfishing (Fitzpatrick et al. 2007), and climate change (Hoegh-Guldberg et al. 2007). Fish and other edible marine organisms are the main source of protein for human populations on an island (Johannes 1981). Therefore, the conservation of marine resources is important for the survival of local communities in Palau.

Conservation has been part of Palauan society for many generations through traditional practices. When the village chiefs feel that resources are low and in need to be protected, the chiefs ban harvesting in certain areas (e.g. fishing ground), or resources (like reef fish). The ban on harvesting is referred to as a *bul* (Johannes 1981). The temporal closure enables the declining population of a resource to recover.

Inspired by traditional conservation practices, Palau initiated the Protected Areas Network (PAN) in 2003. The PAN brings financial and technical support to state governments in managing their conservation areas. In 2015, Ngatpang State became a member of the PAN with three conservation areas (CA), or marine protected areas (MPAs). These conservation areas, covering a total area of 0.125 km^2, represent three ecosystems for economically and ecologically important species, such as rabbit fish. Chiul (located in a mangrove forests) is where fish eggs hatch, Olterukl (a seagrass bed) is an important habitat for juvenile fish, and Oreuaol Ibuchel (a patch reef) is where adult fish aggregate, feed, and breed (CASRUPT and

PCS, 2016). All three conservation areas are no-entry and no-take zones (CASRUPT and PCS, 2016).

To efficiently manage resources, long-term monitoring of resources is essential. As pointed out by Molloy et al. 2009, older MPAs (>15 years) has positive effect on fish population compared to MPAs that were established within 10 years (Molloy et al. 2009). Therefore, monitoring marine resources (i.e. fish population) in an MPA will bring forth a better understanding of these resources over time. Instead of waiting for 15 years to determine MPA effectiveness, information from such monitoring project can enable managers to adapt and improve the management of their conservation area within a shorter period of time.

In 2015, Palau International Coral Reef Center (PICRC) conducted a baseline assessment of resources in Oreuaol Ibuchel Conservation Area. After the baseline survey, PICRC surveyed the MPA along with its reference site once every two years. This report presents the status of resources in Oreuaol Ibuchel Conservation Area after the second follow-up survey in 2020. The objectives of this report is to 1) determine if the MPA is effective in conserving its resources (i.e. fish density, coral cover, invertebrate density) and; 2) determine the trends of these resources are over time.

Methods

Oreuaol Ibuchel CA (Figure 1) was legislated as a conservation area in 2004, NSPL No. 20-04, so it has been closed to fishing activities for 11 years before the baseline assessment was conducted by PICRC in April of 2015. For methods of the baseline survey, refer to Otto et al. 2015. Follow up surveys were conducted every two years after the baseline assessment. The first follow up survey was done on May 2018 and the second was done in May 2020.

To determine effectiveness of the MPA, PICRC compared ecological indicators inside the MPA and a reference site. Ecological indicators, such as fish density, density of macro-invertebrates, were surveyed in order to determine the condition of marine resources at each survey site. The reference site is a nearby patch reef outside the MPA and is open to the harvest of its resources (Figure 1). Surveys at both MPA and reference sites were conducted in two habitats, lagoon reef (yellow squares) with depth of 10m and reef flat (blue triangles) of 2m depth. Three sites were surveyed at each habitat, so a total of 6 sites were surveyed at each reef (MPA and the reference site).

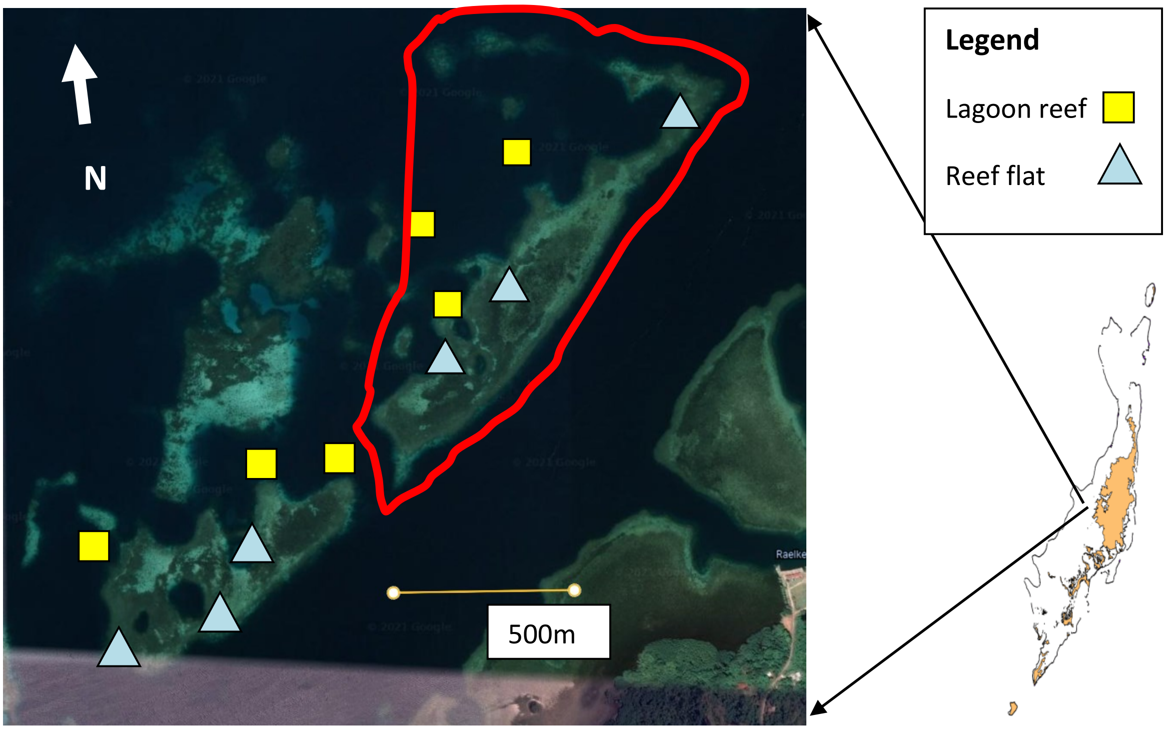

Figure 1. Map of study sites inside Oreuaol Ibuchel Conservation Area (red boundary) and the reference sites (outside the conservation area). Google Earth 2021

To determine density of targeted fish species, fish surveys were conducted within five 5m x 50m belt transects using a diver-operated stereo-video (DOV) system. Videos were later analysed in the lab using the software EventMeasure, where target fish species (Appendix A) were identified and recorded, along with their abundance and size (fork length). Fish biomass was then calculated with published fish-weight relationship (Kulbicki et al. 2005).

$$W = a*L^b$$

Where W = weight in grams, L = size in cm, and the variables a and b are constants.

To determine density of commercially important macro-invertebrate, surveys were conducted using five belt transects. Within each 2m x 50m belt transect, economically important macro-invertebrate species (Appendix B) were identified and their size recorded.

The Ngatpang State Conservation officers had stated a possible outbreak of Crown-of-thorns starfish (COTS). So survey for COTS was included in this survey starting in 2018. To determine density of COTS, five belt transects were in the survey. The number of COTS were recorded within each 4m x 50m belt transects.

To determine coverage of different reef substrate, photographs of the reef were taken every meter along five 50m transects using an underwater camera (Canon, Powershot G16) mounted on a 0.25m^2 quadrat. A total of 50 photos were taken per transect. These underwater photos were analysed using the software Coral Point Count with excel extension (CPCe, Kohler and Gill 2006) to determine percent cover of major reef substrate (Appendix C).

Finally, five 0.3m x 10m belt transects were used to determine density of coral recruits. This survey was conducted on the first 10m of each transect. Each coral recruit that had a diameter less than or equal to 5 cm was identified to the lowest taxonomic level possible and its diameter measured.

Data analysis

Ecological indicators surveyed were fish density, fish biomass, macro-invertebrate density, COTS density, reef substrate, and coral recruits. Each dataset was tested for normality using the Shapiro-Wilk test. When not normal, data were log- or square root-transformed and re-tested for normality. When normal, Two-Way ANOVA was used to test for 1) changes over time within the MPA, 2) the effect of protection status over time, and 3) the effect of habitat type within the MPA. When non-normal after transformation, the non-parametric Kruskal-Wallis rank sum test was used instead. All data analyses were done using R Program (R Core Team 2020).

Note that underwater visual census (UVC) was used for fish survey for baseline assessment (2015) while stereo-video system was used for fish survey during the follow up surveys (2018-2020); therefore, fish data was only compared between 2018 and 2020. All follow-up surveys with similar methods as the baseline (i.e. macro-invertebrates and coral recruits) were standardized then compared to the baseline data.

Results

A. Fish density

In the reef flat, average fish density was not affected by protection status over time (2-way ANOVA, $p < 0.05$, Figure 2). In contrast, average fish density in the lagoon habitat was the same between protection and over time (2-way ANOVA, $p > 0.05$, data not shown). The most observed fish species observed in both habitats was *Scarus* sp. (Melemau).

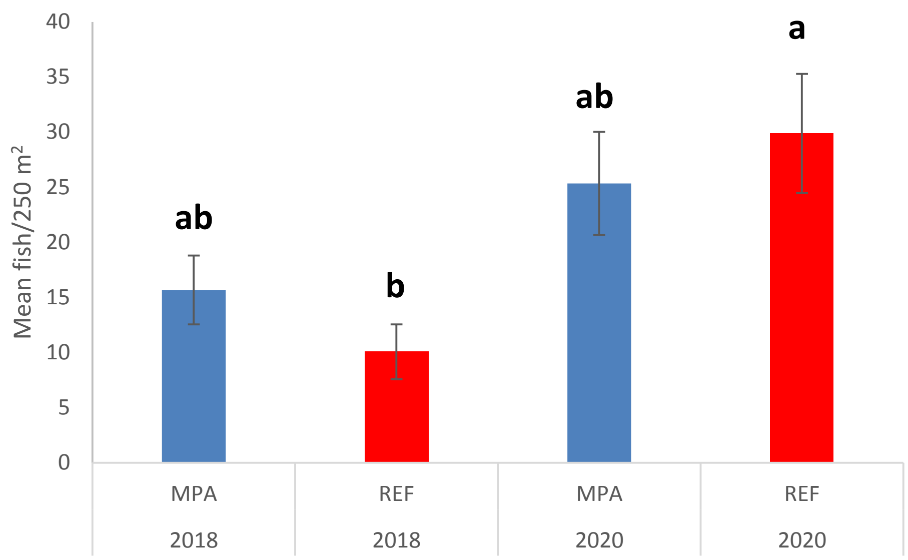

Figure 2. Fish density (mean ± SE) per 250 m^2 within and outside the MPA in 2018-2020). Groups with different alphabets indicate significant difference. n=15

Fish density inside the MPA alone was significantly different between habitat over time (2-way ANOVA, $p < 0.05$, Figure 3). Inside the MPA, fish density on the reef flat in 2020 (25 ±5 fish per 250 m^2) was significantly higher than that in the lagoon in 2018 (8 ±2 fish per 250 m^2). Although not significant, fish density in the MPA seem to be higher on the reef flat compared to that of the lagoon habitat over time.

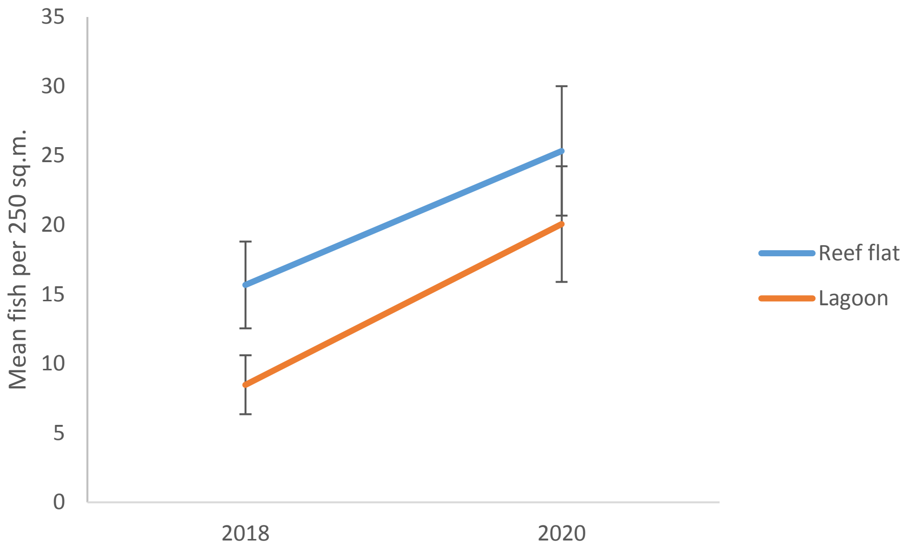

Figure 3. Fish density (mean ± SE) per 250 m^2 of the two habitats surveyed within the MPA in 2018-2020. n=15

B. Fish biomass

Mean fish biomass in the reef flat was similar inside and outside the MPA for both survey periods (Kruskal-Wallis, $p > 0.05$, data not shown). Moreover, mean fish biomass in the lagoon habitat was not affected by protection over time (2-way ANOVA, $p > 0.05$, data not shown). Inside the MPA alone, fish biomass was not affected by habitat type (2-way ANOVA, $p > 0.05$, Figure 4). Although not significant, fish biomass inside the MPA at the lagoon habitat seem to be higher than that of the reef flat over time.

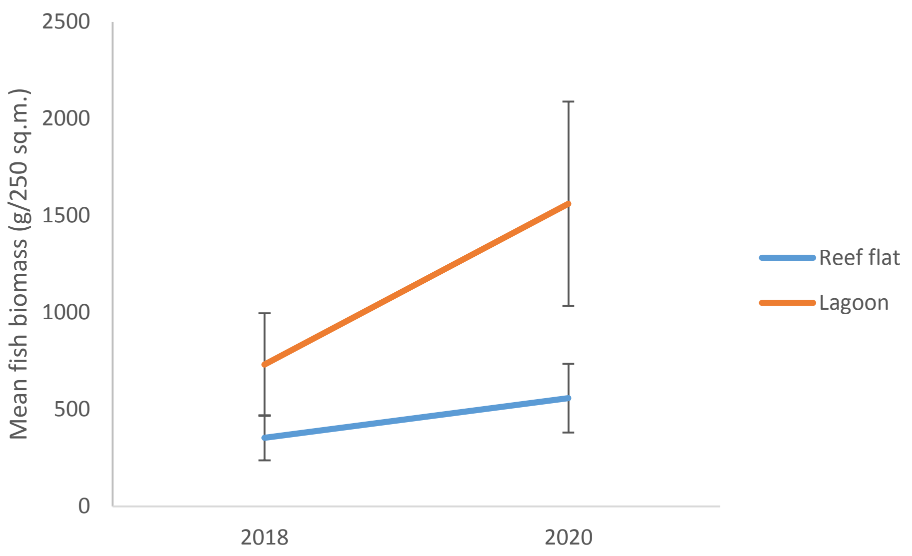

Figure 4. Fish biomass in grams (mean ± SE) per 250 m^2 of the two habitats surveyed within the MPA in 2018-2020. n=15

C. Macro-invertebrates

From 2015 to 2020, 99% of all the 1,966 macro-invertebrates recorded were *Tridacna crocea* (Oruer). Moreover, 89% of all *T. crocea* recorded were in the reef flat habitat. Our data in the reef flat showed that macro-invertebrates was the same inside and outside the MPA (Kruskal-Wallis, $p > 0.05$, data not shown). The most abundant macro-invertebrate in the reef flat was *Tridacna crocea* (Oruer) followed by *Tridacna maxima* (melibes).

Density of macro-invertebrates in the lagoon habitat was also similar inside and outside the MPA (Kruskal-Wallis, $p > 0.05$, data not shown). The most abundant macro-invertebrates in the lagoon habitat was *T. crocea* (Oruer) followed by *Thelenota ananas* (temetaml). Figure 5 shows mean density of macro-invertebrates inside the MPA for both habitats in 2015-2020. Although not significant, there seem to be a negative trend of macro-invertebrates inside the MPA for both habitats over time.

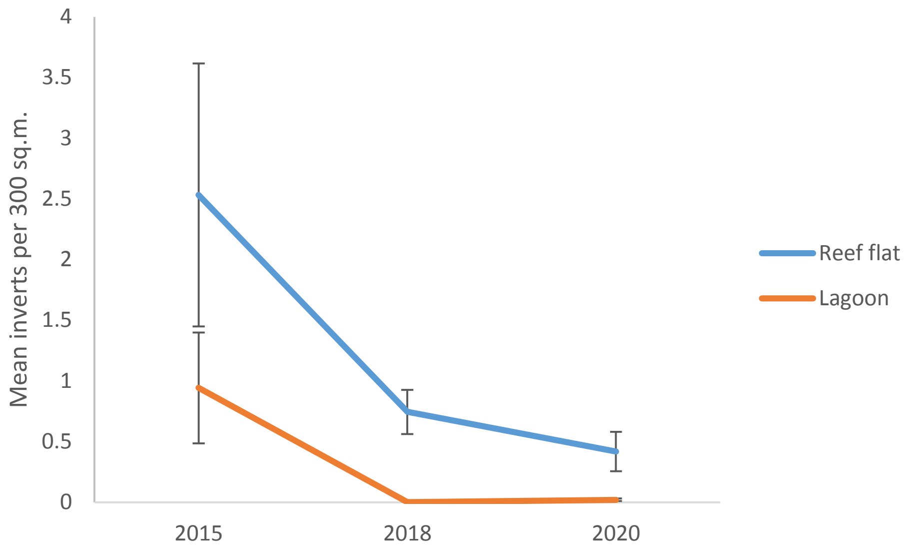

Figure 5. Density of macro-invertebrates (mean ± SE) per 300 m^2 of the two habitats surveyed within the MPA in 2015-2020. 2015 (n=9), 2018-2020 (n=15)

D. Crown-of-thorns starfish

Mean density of Crown-of-thorns starfish (COTS) in the reef flat was similar in the MPA and the reference site (Kruskal-Wallis, $p > 0.05$, data not shown). Similarly, COTS in the lagoon was similar inside and outside the MPA (Kruskal-Wallis, $p > 0.05$, data not shown). Figure 6 shows total count of COTS surveyed.

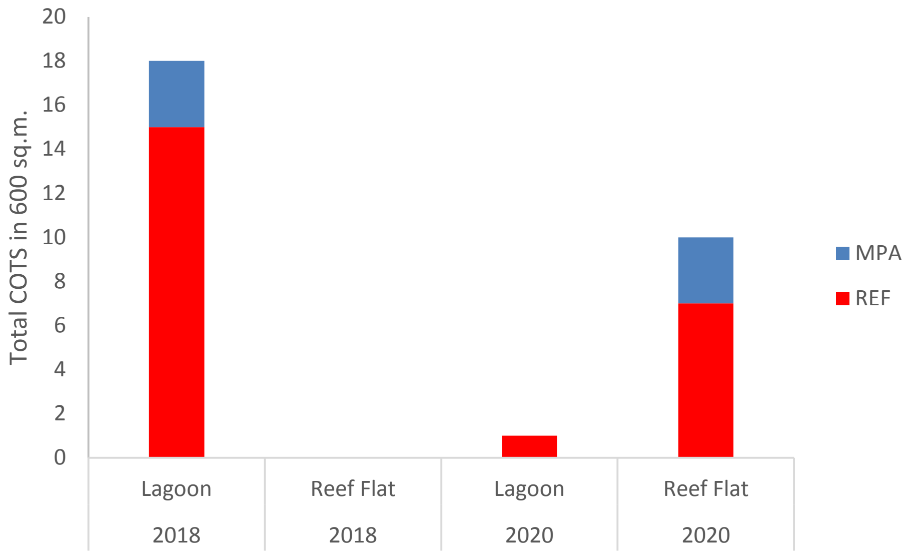

Figure 6. Total count of macro-invertebrates (mean ± SE) in 600 m^2 inside and outside the MPA in 2015-2020. The x-axis is time and habitat type. n=15

E. Reef substrate

Protection status showed little effect on the major substrate categories. Out of the three dominant substrate categories, non-living substrate on the reef flat was similar inside and outside the MPA from 2015-2018 (2-Way ANOVA, $p > 0.05$, Figure 7). Only in 2020 was non-living substrate on the reef flat significantly lower in the MPA compared to the reference site (2-Way ANOVA, $p < 0.05$, Figure 7).

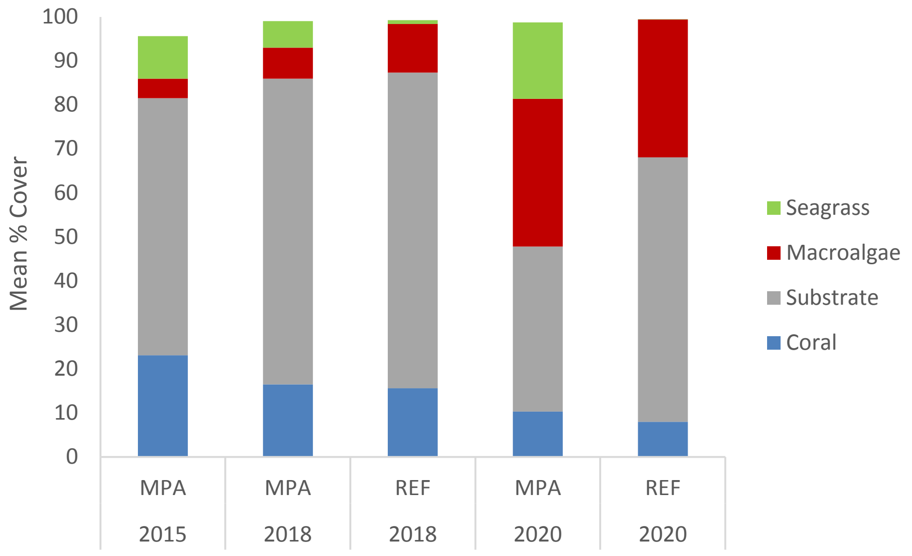

Figure 7. Mean percent cover of major category of substrate on the reef flat, for each protection status over time (which are on the x-axis). 2015 (n=9); 2018 and 2020 (n = 15)

Macroalgae (red bars) on the reef flat was not affected from protection status over time (Kruskal-Wallis, $p > 0.05$, Figure 7). Macroalgae on the reef flat inside the MPA increased from 5% in 2015 and 2018 to 34% in 2020 (Kruskal-Wallis, $p > 0.05$, Figure 7).

Mean coral cover (blue bars) on the reef flat inside the MPA was similar over time (Kruskal-Wallis, $p > 0.05$, Figure 7). Similarly, coral cover on the reef flat was the same inside and outside the MPA (Kruskal-Wallis, $p > 0.05$). Finally, seagrass (green bars) was present mainly in the MPA site.

In the lagoon habitat, protection status had no effect on the non-living substrate (gray bars, Kruskal-Wallis, $p > 0.05$, Figure 7). In the same habitat, for the MPA alone, mean percent cover of non-living substrate was stable in 2015 to 2018 at 49-31% then increased to 67% in 2020 (Kruskal-Wallis, $p < 0.05$, Figure 8).

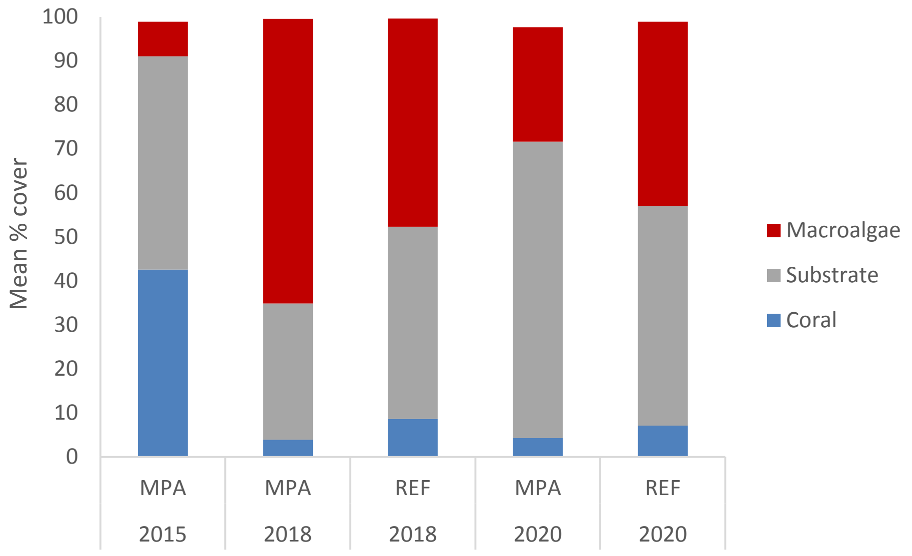

Figure 8. Percent cover of substrate (mean ± SE %) in the lagoon habitat. Corals (blue bars), macroalgae (red bars), and non-living substrates (gray bars). 2015 (n = 9), 2018-2020 (n=15)

Macroalgae (red bars) in the lagoon habitat was not affected by protection status (Kruskal-Wallis, p > 0.05, Figure 8). Macroalgae on the lagoon habitat in the MPA increased from 8% in 2015 to 65% in 2018, and then decreased in 2020 (26%, Kruskal-Wallis, p > 0.05, Figure 8).

Finally, coral cover in the lagoon decreased from 43% in 2015 to 4% in 2018 (Kruskal-Wallis, p < 0.05, Figure 8). Then in 2020 mean percent cover of 7% was similar to that in 2018 (Kruskal-Wallis, p > 0.05, Figure 8).

F. Coral recruits

On the reef flat, protection status had no effect on the mean density of coral recruits (Kruskal-Wallis, p > 0.05, Figure 9). Similarly, coral recruits in the lagoon were the same inside and outside the MPA (Kruskal-Wallis, p > 0.05, data not shown).

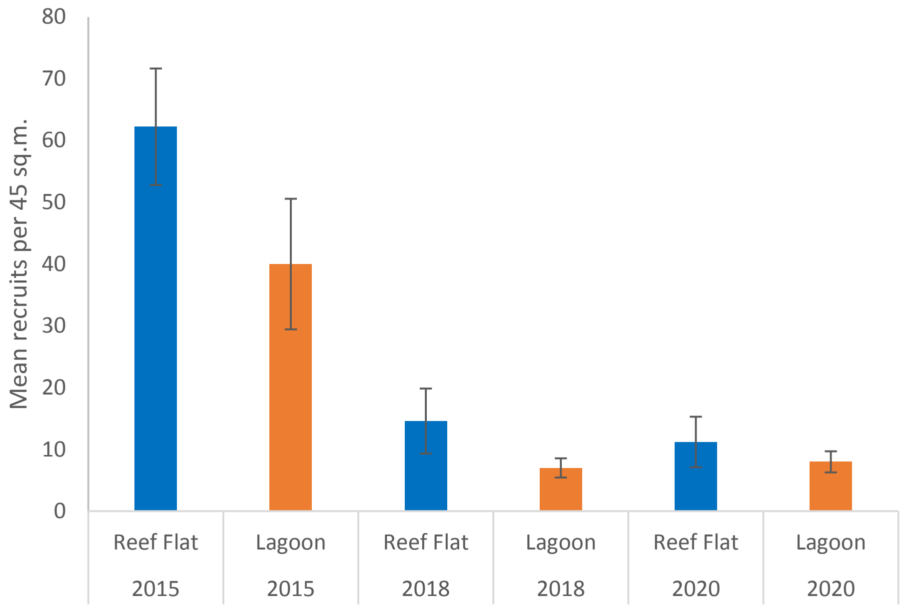

Figure 9. Density of coral recruits (mean ± SE %) per 45 m^2 on the reef flat and lagoon habitats within the MPA in 2015 to 2020. 2015 (n=9), 2020 (n=15)

Inside the MPA alone, coral recruits in both habitats seem to show a negative trend over time; however, our statistical test show that the difference is not significant (Kruskal-Wallis, $p > 0.05$, Figure 10).

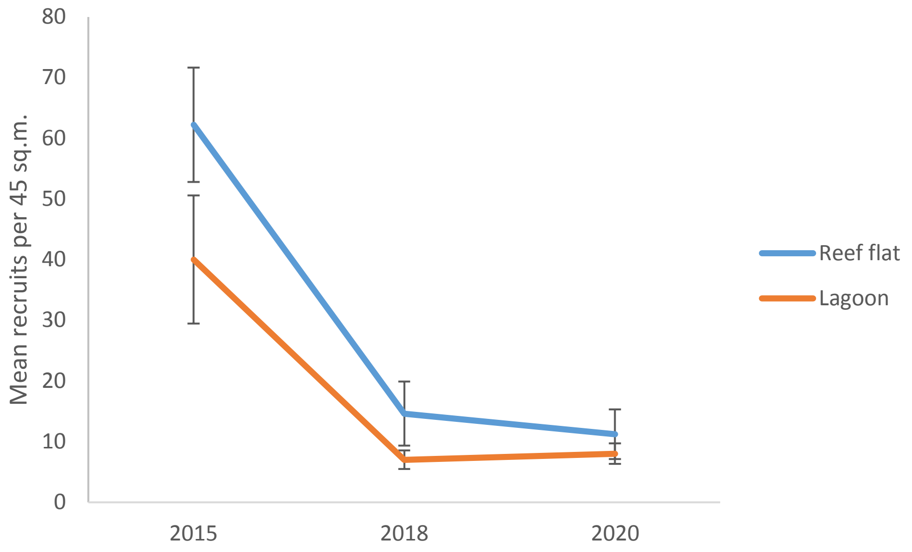

Figure 10. Density of coral recruits (mean ± SE) per 45 m^2 on the reef flat and lagoon habitats within the MPA in 2015-2020. 2015 (n=9), 2020 (n=15)

Discussion

Through this study we could determine the status of marine resources in Oreuaol Ibuchel CA. Presence of hard corals recently decreased, and data show that recovery most likely will be slow. Fish survey show little to no effect from protection. However, from our data fish population has the potential to increase in size and number inside the MPA. Macro-invertebrates, predominately on the reef flat, show little to no effect from protection over time.

Hard corals are essential in a coral reef ecosystem. Yet, coral is the least substrate observed inside Oreuaol Ibuchel CA. The MPA is located about 3km south of Ngarmeduu Bay, which has three rivers draining into the adjacent estuary; therefore, the estuary is a significant source of sediment. Sediments are known to smother corals and cause coral bleaching, and Golbuu et al. 2011 showed that excessive terrestrial runoff had negative impact on coral cover of reefs adjacent to Ngarmeduu Bay. Reefs less than 3km from Ngarmeduu Bay had low coral cover of 6% and reefs further than 3km of the bay had coral cover higher than 20% (Golbuu et al. 2011). Oreuaol Ibuchel CA is less than 3km from the mouth of Ngarmeduu bay. Therefore, excessive sedimentation from rivers draining into Ngarmeduu Bay may be the reason why coral cover in the MPA decreased over time.

In addition to sedimentation, presence of crown-of-thorns starfish (COTS), which prey on hard corals, may contribute to low coral cover in the MPA. COTS in the MPA was present only in the lagoon in 2018. Two years later COTS was present only in the reef flat. Although in low density, COTS were surveyed only during the day for this monitoring project. Pechnik 1996 stated that COTS are nocturnal creatures and if one individual is spotted during the day, most likely 15 would appear in the area at night. Therefore, COTS density for this study may be a conservative estimate.

The dominant substrates in the MPA are non-living substrate and macroalgae. From our data non-living substrate (e.g. carbonate, rubble), which is essentially dead corals, increased in the lagoon habitat while macroalgae (e.g. *Padina* and *Sargassum*) increased on the reef flat. The increase of macroalgae is possibly from eutrophication from Ngarmeduu Bay.

The new dumpsite for solid waste is located upland from Ngarmeduu Bay, and its construction recently took place. Land clearing for this project may have led to eutrophication in Ngarmeduu Bay and onto the adjacent reefs, including Oreuaol Ibuchel CA. Eutrophication is the enrichment of nutrients in coastal waters from terrestrial runoffs. Eutrophication can trigger blooms of algae, including macroalgae, which can smother coral reefs and cause a phase shift. Coral reefs then will be dominated by macroalgae instead of hard corals. Reefs dominated by macroalgae are known to have less number of marine organisms, including fish and clams. In addition to eutrophication, algal bloom is known to cause COTS outbreak.

Terrestrial development most likely will increase in the future. If mitigation for coastal developments are not met, water quality in the MPA will decline in the future. As a result, sedimentation and eutrophication will continue to decrease coral cover in the MPA. In addition, coral recruits show negative trends in the reef flat and the lagoon habitats. Therefore, corals in Oreuaol Ibuchel will recover; however, with the data we have today, it will be a slow process.

As mentioned above, ecological indicators showed little to no effect of the MPA in conserving marine resource. For instance, coral cover decreased and remained low over time. A possible cause may be from poor water condition. Coastal development and near rivers are inevitable, but it is crucial to limit terrestrial runoffs into watersheds and coastal waters. Therefore, it is highly recommended to monitor water quality (turbidity and nutrient level) of Ngarmeduu Bay watershed. Recommendations from this study are listed below.

- Continue monitoring resources in the MPA
- Monitor water quality (nutrient and turbidity) in Ngarmeduu bay watershed
- Monitor terrestrial projects and make sure they follow EQPB regulations in controlling runoff from project sites

Acknowledgement

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Appendices

Appendix A: Commercially important fish species

Commercially important fish species in Palau			
	Common name	**Palauan name**	**Scientific name**
1	Bluefin trevally	Erobk	*Caranx ignobilis*
2	Giant trevally	Oruidel	*Caranx melampygus*
3	Bicolor parrotfish	Beadle/Ngesngis	*Cetoscarus bicolor*
4	Parrotfish species	Melemau	*Cetoscarus/Chlorurus/Scarus* spp.
5	Yellow cheek tuskfish	Budech	*Choerodon anchorago*
6	Indian ocean long nose parrotfish	Berkism	*Hiposcarus hariid*
7	Pacific long nose parrotfish	Ngeaoch	*Hipposcarus longiceps*
8	Rudderfish	Komud, Teboteb	*Kyphosus spp. (vaigiensis)*
9	Orange stripe emperor	Udech	*Lethrinus obsoletus*
10	Long face emperor	Melangmud	*Lethrinus olivaceus*
11	Red gill emperor	Rekruk	*Lethrinus rubrioperculatus*
12	Yellow lip emperor	Mechur	*Lethrinus xanthochilis*
13	Squaretail mullet	Uluu	*Liza vaigiensis*
14	River snapper	Kedesau'liengel	*Lutjanus argentimaculatus*
15	Red snapper	Kedesau	*Lutjanus bohar*
16	Humpback snapper	Keremlal	*Lutjanus gibbus*
17	Orange spine unicornfish	Cherangel	*Naso lituratus*
18	Blue spine unicornfish	Chum	*Naso unicornis*
19	Giant sweetlips	Melimralm,Kosond/Bikl	*Plectorhinchu salbovittatus*
20	Yellowstripe sweetlips	Merar	*Plectorhinchus crysotaenia*
21	Pacific steephead parrotfish	Otord	*Scarus micorhinos*
22	Greenthroat parrotfish	Udoudungelel	*Scarus prasiognathus*
23	Forketail rabbitfish	Beduut	*Siganus argenteus*
24	Lined rabbitfish	Kelsebuul	*Siganus lineatus*
25	Masked rabbitfish	Reked	*Siganus puellus*
26	Goldspotted rabbitfish	Bebael	*Siganus punctatus*
27	Bluespot mullet	Kelat	*Valamugil seheli*

Protected Fish Species (yearly and seasonal fishing closure)			
28	Bumphead parrotfish	Kemedukl	*Bolbometopon muricatum*
29	Humphead wrasse	Ngimer, Maml	*Cheilinus undulatus*
30	Brown-marbled grouper	Meteungerel'temekai	*Epinephelus fuscoguttatus*
31	Marbled grouper	Ksau'temekai	*Epinephelus polyphekadion*
32	Squaretail grouper	Tiau	*Plectropomus areolatus*
33	Saddleback grouper	Katuu'tiau, Mokas	*Plectropomus laevis*
34	Leopard grouper	Tiau (red)	*Plectropomus leopardus*
35	Dusky rabbitfish	Meyas	*Siganus fuscescens*

Appendix B: Commercially important invertebrate species

Common name	**Palauan name**	**Scientific name**
Black teatfish	Bakelungal-chedelkelek	*Holothuria nobilis*
White teatfish	Bakelungal-cherou	*Holothuria fuscogilva*
Golden sandfish	Delalamolech	*Holothuria lessoni*
Hairy blackfish	Eremrum, cheremrumedelekelek	*Actinopyga miliaris*
Hairy greyfish	Eremrum	*Actinopyga spp.*
Deepwater red fish	Eremrum	*Actinopyga echinites*
Deepwater blackfish	Eremrum	*Actinopyga palauensis*
Stonefish	Ngelau	*Actinopyga lecanora*
Dragonfish	Irimd	*Stichopus horrens*
Brown sandfish	Meremarech	*Bohadschia vitiensis*
Chalk fish	Meremarech	*Bohadschia similis*
Leopardfish/ tigerfish	Meremarech, esobel	*Bohadschia argus*
Sandfish	Molech	*Holothuria scabra*
Curryfish	Delal a ngimes/ ngimesratmolech	*Stichopus hermanni*
Brown curryfish	Ngimes	*Stichopus vastus*
Slender sea cucumber	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 amauritiana*
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*
True giant clam	Otkang	*Tridacna gigas*
Sea urchin	Ibuchel	*Tripneustes gratilla*
Trochus	Semum	*Trochus niloticus*
China giant clam	Duadou	*Hippopus porcellanus*

Appendix C: Major categories of reef substrate

Major Categories	Sub-categories
Coral	Coral genera
Soft Coral	Soft coral genera
Other Invertebrates	Clams, Gorgonians, etc.
Macroalgae	Macroalgae genera
Seagrass	Seagrass species
Coralline Algae	Coralline algae genera
Substrate	Carbonate, Rubble, Sand, Turf