Monitoring of Teluleu Conservation Area from 2011-2020 shows fish populations are stable over time

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Abstract

The Palau International Coral Reef Center (PICRC) has been conducting ecological monitoring of Marine Protected Areas (MPAs) across Palau, and more recently MPAs that are institutionalized under the Protected Areas Network (PAN). Since 2011, PICRC has been conducting ecological monitoring in the Teluleu Conservation Area (CA) in Peleliu State. Ecological surveys were carried out in randomly selected survey sites in the reef flat area of Teluleu CA and adjacent reference sites. Biological indicators measured over time included seagrass coverage, fish biomass and density, and commercially valuable and density edible macro-invertebrates. Results of the study show that despite slight fluctuations over time, Teluleu CA has continued to benefit fish populations by having a relatively stable mean fish biomass ~5,000 g to 7,000 g per 125 m^2 across eight years. Fish biomass in Teluleu CA continues to be the highest in comparison to other protected seagrass/reef flat habitats across Palau; which also shows its critical importance as a nursery for fish assemblages. In terms of seagrass coverage, there is a decreasing trend in overall seagrass cover in Teluleu CA, which could indicate possible negative impacts of run-off and sedimentation from land development. Teluleu CA is in close proximity to Peleliu's main port of entry and nearby sewage outflow. This implies a critical need to implement a more comprehensive, ridge-to-reef approach that includes measuring water quality parameters and additional information on the substrate characteristics of Teluleu CA. Macro-invertebrate densities in both the CA and reference area have consistently remained very low since 2011 with less than 1 individual per 50 m^2. This low abundance of sea cucumbers and clams could be attributed to a lack of suitable habitat and structure that would be conducive for healthy invertebrate populations. The current small size of the CA, may be a limiting factor for sea cucumber reproduction. Sea cucumbers are slow moving organisms that depend on an adequate number of individuals in a given area for successful reproduction to take place. Therefore, management strategies should integrate the ridge-to-reef approach in addition to re-stocking and monitoring invertebrate densities overtime. This will help in ensuring that Teluleu CA is beneficial for the seagrass ecosystem and related fish and macro-invertebrate populations.

Introduction

Marine Protected Areas (MPAs) have been widely implemented globally as a tool for sustaining marine resources and protection against anthropogenic threats such as overfishing (Lester, 2009). More specifically in Palau, the notion of natural resource conservation is deeply rooted in Palauan cultural traditions. The concept of 'bul' is a Palauan tradition whereby restrictions are placed regarding the use of natural resources for specified periods of time (Johannes, 1981). In Palau, the concept of Bul has in many ways evolved to include modern conservation practices resulting in more institutionalized and legislated MPAs. In 2003, the National Government of Palau enacted the Palau Protected Areas Network (PAN), which is a collection of marine and terrestrial protected areas for the purposes of conserving Palau's rich biodiversity. Over time, the PAN has become a mechanism for achieving goals of regional initiatives such as the Micronesia Challenge (MC), a regional initiative by Micronesian leaders to effectively conserve 30% of nearshore marine resources and 20% of terrestrial resources across Micronesia.

As the monitoring arm of the Palau Protected Areas Network, the Palau International Coral Reef Center (PICRC) provides scientific information and support for the PAN, serving various purposes, including assessing the effectiveness of PAN MPAs overtime. This report provides the biological trends and status of various ecological indicators within Teluleu conservation area, from 2011 to 2020. In this report, MPA and Conservation Area (CA) are used interchangeably.

Teluleu CA is situated in close proximity to Peleliu's main port of entry, and is strictly a no-take and no-entry zone. The area has a depth range from the lowest tide of 0.5 meters to the highest of approximately 2.9 meters.

Methods

Study site

Teluleu Conservation Area is a nearshore marine area located in Peleliu State (7 °3.137' N, 134 °16.189 E) and measures 0.83 km^2 in total area. It comprises mainly of one habitat (reef flat) which includes large seagrass beds that are surrounded by a reef crest. Three randomly selected survey sites were monitored inside and outside the CA (Figure 1). In 2018, survey sites in the reference area were relocated to a nearby seagrass area with similar characteristics to Teluleu CA. It was designated as a protected area, largely due to its seagrass beds which provide refuge or nursery for juvenile fish in their growth cycle and habitats for a variety of macro-invertebrates (Peleliu Management Team and PCS, 2012). The area has been identified as receiving larval supplies from nearby fish spawning areas located outside of the protected area (Peleliu Management Team and PCS, 2012). It has been a legislated protected area since 2001 under Peleliu State legislation and in 2012 it became a part of the Palau Protected Areas Network.

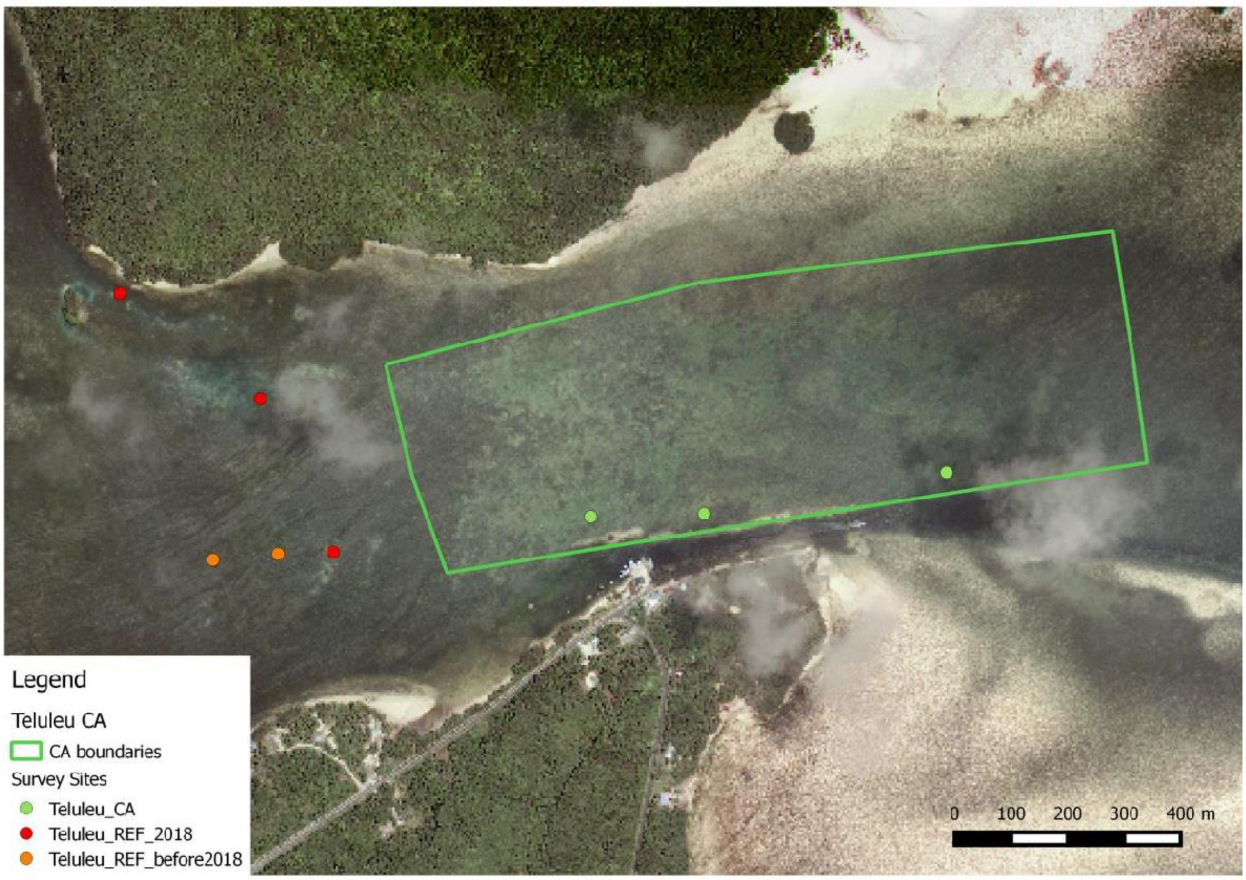


Figure 1. Map of randomly selected survey sites in Teluleu CA and reference area. Green dots indicate Teluleu CA survey sites. Orange dots indicate reference sites surveyed from 2011 to 2017. Red dots indicate relocated survey sites in the reference area due to a change in survey sites in 2018.

Seagrass Surveys

In the seagrass beds, five 25 meter transects were laid consecutively, separated a few meters apart. Seagrass percentage cover, identified to the species level, was visually estimated in a 0.5 meter quadrat placed every 5 meters along each transect.

Fish surveys

Commercially important fish were visually observed within a 5 meter belt along each transect at each site (see Appendix – Table 1 for list of commercially important fish). Fish were counted, identified to the lowest possible taxonomic level and their length estimated in cm. Fish biomass was calculated using the weight-length equation below.

$$W = aTL^b$$

Where W is the weight of fish in grams, TL is the total length of the fish length in cm, and a and b are constant values of biomass-length relationships of fish species retrieved from Kulbicki et al. (2005) and the website Fishbase (www.fishbase.org).

Macro-invertebrate surveys

Commercially important invertebrates were visually identified within a 2 meter belt along each transect at each site (see Appendix – Table 2 and 3 for list of commercially important invertebrates). Invertebrates were counted, identified to the lowest possible taxonomic level and their length in cm recorded.

Data Processing and analysis

All data were entered into excel spreadsheets. Data were checked for normality using histograms and the Shapiro-Wilk test. All data were not normally distributed and were transformed using log(x+1) and re-tested for normality. All data were analyzed using the nonparametric Kruskal-Wallis test and analyzed further for comparisons between MPA and reference sites using Nemenyi's post-hoc test. All statistical analyses was completed using R software (R Development Core Team 2019).

Results

Seagrass beds

Seagrass coverage has continually fluctuated in Teluleu CA and its reference site since 2011 (Figure 2), and mean seagrass cover has consistently been higher in the reference area compared to the MPA. Mean seagrass cover within the MPA fluctuated (~10-30%), while the reference area had a fluctuating mean seagrass coverage of around (~30-50%) across eight years. From 2011 to 2013, there was a decrease in seagrass coverage within the MPA but this was only slightly significant (p=0.041), with a similar corresponding decrease in the reference area. A significant difference was found between the MPA and reference site in 2012 (p=0.027), 2015 (p=0.015) and 2016 (p<0.001). Mean seagrass coverage slightly increased in both the MPA and reference area from 2013 to 2015, with a gradual decreasing trend in the MPA from 2015 to 2020. Even though seagrass cover in the reference area decreased from 48 ± 1.5 % to 26 ± 3.2% from 2016 to 2018, the decrease was not statistically significant (p=0.068). During the 2020 surveys, seagrass coverage in the reference area 33 ± 2.2% was significantly higher (p=0.006) compared to the MPA with a mean of 10 ± 2.4 % (Figure 2).

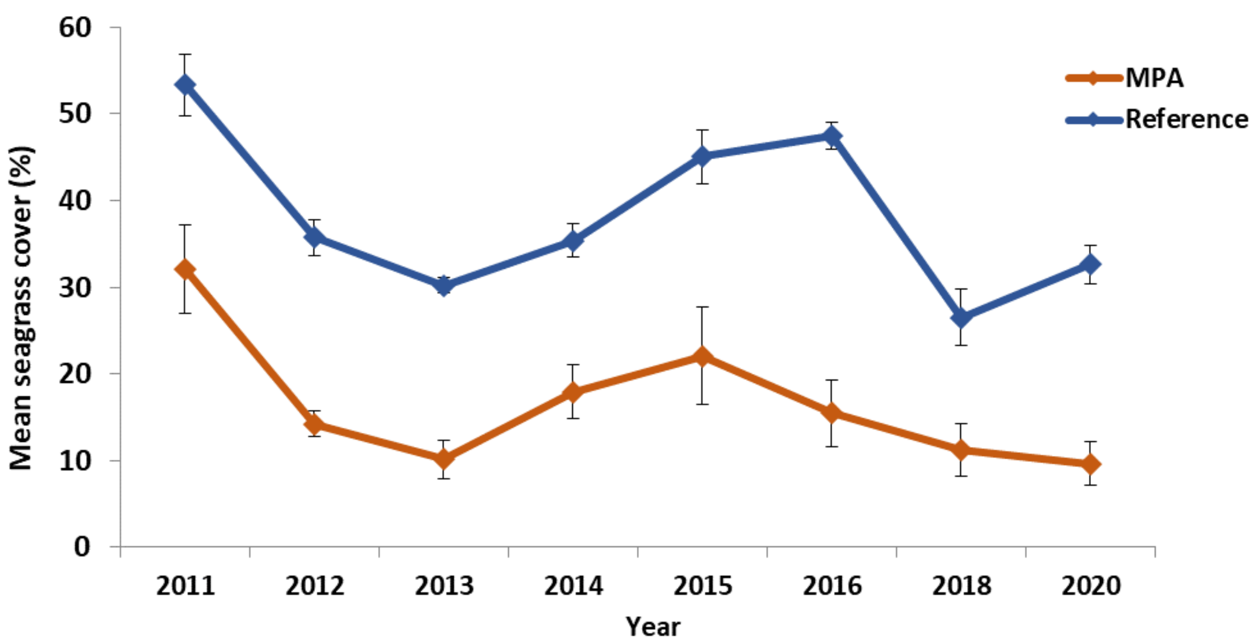


Figure 2. Trends in mean seagrass coverage in Teluleu MPA and its reference site over time. Error bars indicate standard error.

Teluleu conservation area is dominated by three species of seagrass namely *Thalassia hemprichii, Cymodocea rotundata,* and *Enhalus acaroides* (Figure 3). The mean coverage of *T. hemprichii* and *E. acaroides* in the MPA has fluctuated over time, with a gradual decline for both species over a period of 5 years from 2015 to 2020. During the 2020 surveys, mean coverage of *T. hemprichii* in the MPA was 6 ± 2.2 %, followed by *E. acaroides* at 4 ± 0.5 %. The seagrass species *Halophila ovalis* was recorded for the first time in the MPA during the 2020 surveys, although with very low percent cover of only 0.2%. *Cymodocea serrulata* was also recorded for the first time in both the MPA and reference areas during the 2020 surveys, also with low percent cover of less than 0.3% for both MPA and Reference areas. *Halophila pinifola* was only recorded in the MPA during the 2014 surveys and was not observed in any other survey year. Species richness was lower in the reference area; however percentages of *T. hemprichii* were consistently higher overtime in the reference site compared to the MPA.

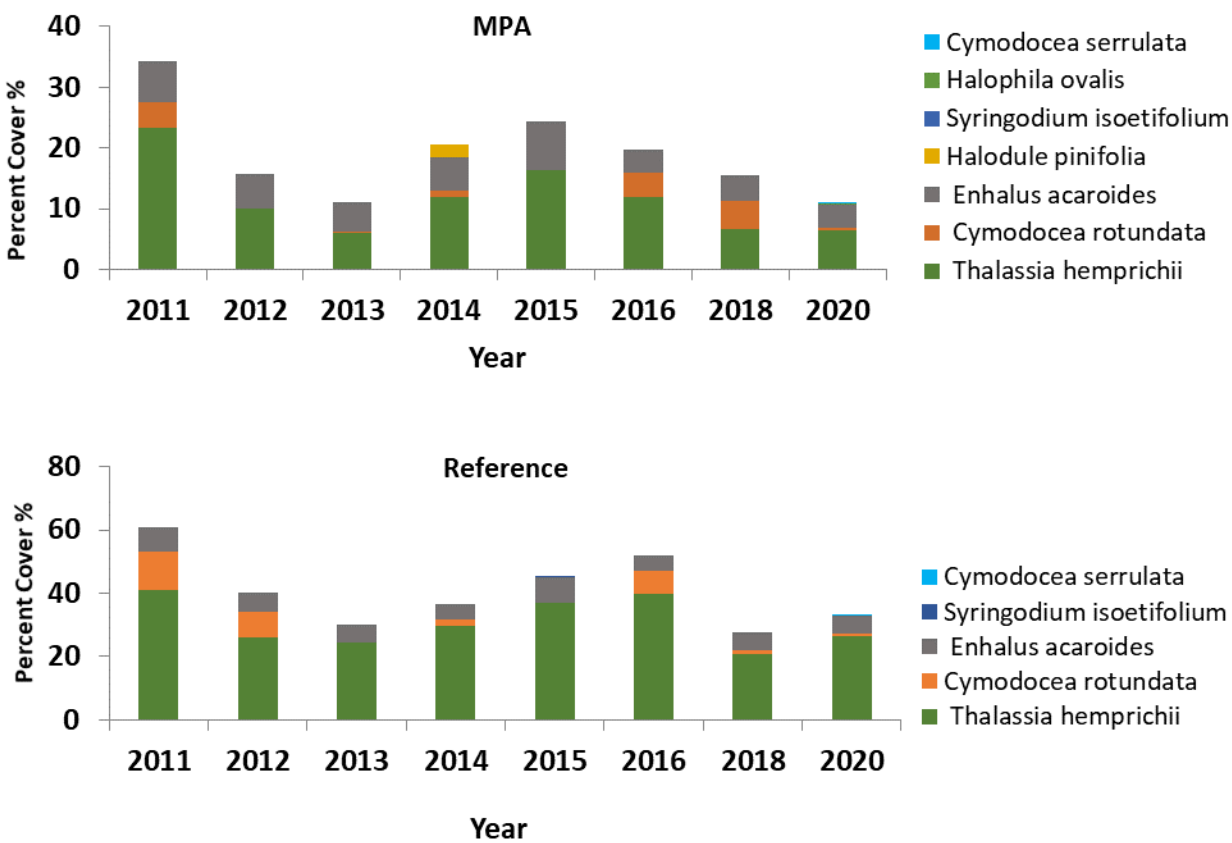


Figure 3. Stacked bar plots showing seagrass species composition within Teluleu MPA and its reference site over time.

Fish biomass and abundance

Fish biomass and density for Teluleu CA and the reference site were analyzed based on PICRC's fish list of commercially valuable species (see Appendix 1). Fish biomass in Teluleu CA has continually fluctuated over time (Figure 4) with an average biomass of around ~6,000 g to 7,000 g per 125 m^2 (Figure 4). A significant difference was found between the MPA and reference site in 2014 ($p<0.05$), as well as 2016 ($p<0.01$). From 2011 to 2013, fish biomass fluctuated in the MPA, but was not statistically significant ($p>0.05$). In the MPA, a decreasing trend in fish biomass was observed between 2013 and 2015 however this was not statistically significant. Even though there was a large increase in mean fish biomass observed in the MPA in 2016, it was not statistically significant due to the large variability. A gradual decrease in fish biomass was seen from 2016 to 2020 in the MPA however this declining trend was not statistically significant. Fish biomass has remained consistently lower in the reference site compared to the MPA, with an average biomass of 665 g per 125 m^2. There were no significant differences or trends of fish biomass observed in the reference site from 2011 to 2020.

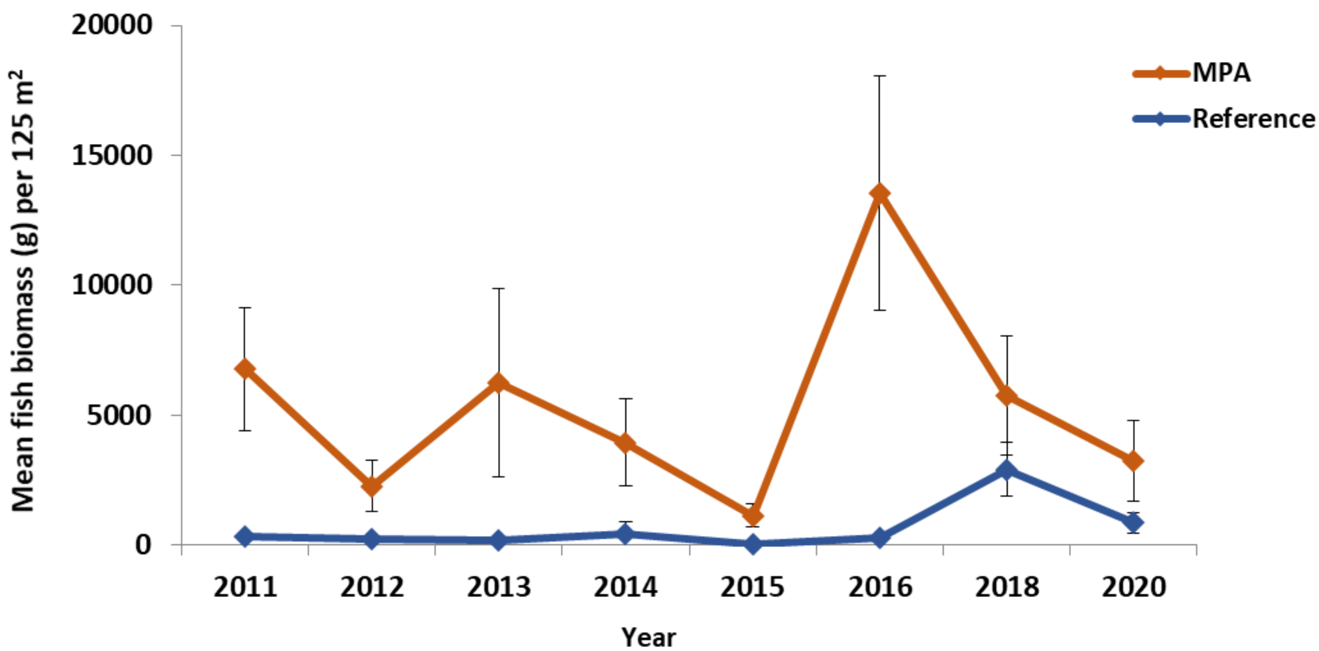


Figure 4. Trends in fish biomass within Teluleu MPA and its reference site from 2011 to 2020. Error bars indicate standard error.

Despite slight fluctuations over time, fish density has remained relatively stable within Teluleu CA, averaging ~14 individuals per 125 m^2 (Figure 5) over the course of eight years. The highest recorded fish density in the MPA was observed in 2016, with approximately 27 ± 5.0 individuals per 125 m^2, and was mostly attributed to an increase in schools of *Siganus lineatus* (kelsebuul) and *Scarus* spp. (mellemau) (Figure 6). A significant difference was found between the MPA and reference site in 2015 ($p=0.008$), whereas no significant difference between MPA and reference area was found for 2014 ($p=0.225$) or 2013 ($p=0.676$). In the reference area, fish density averaged ~ 8 individuals per 125 m^2 across eight years, with a significant decrease in fish density observed from 2011 to 2015 ($p<0.05$).

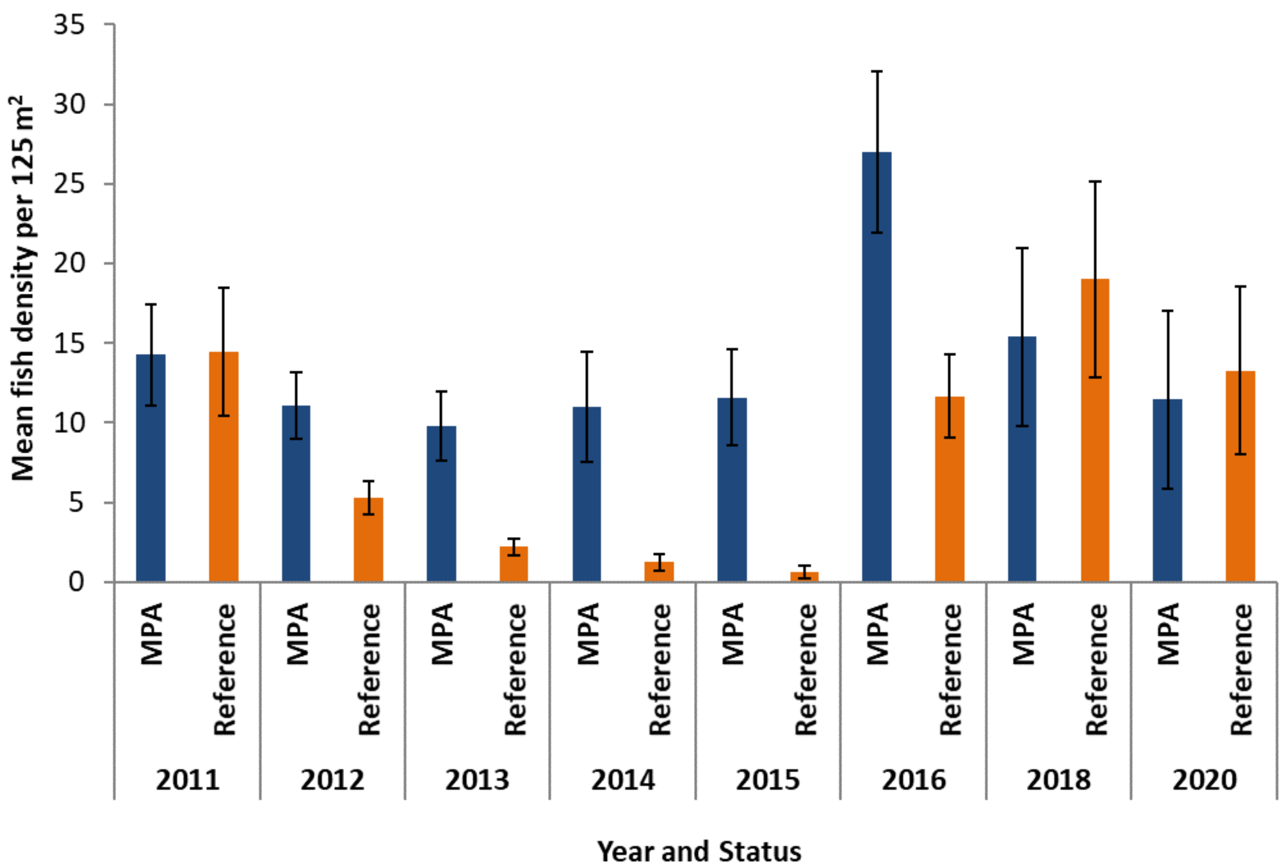
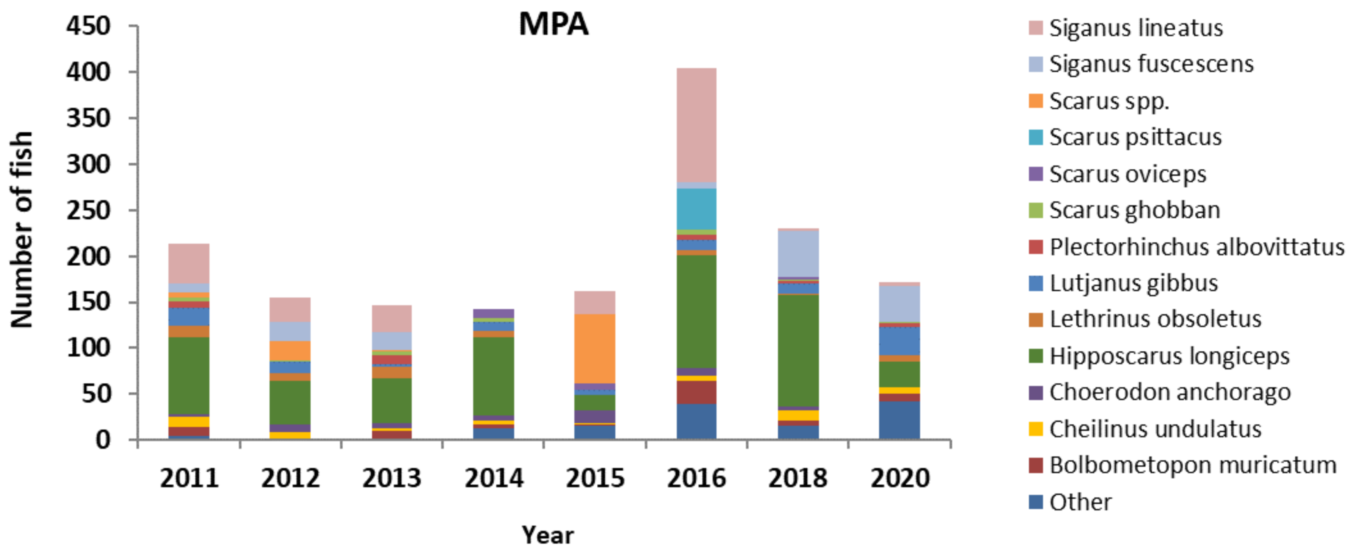


Figure 5. Trends in fish density within Teluleu MPA and its reference site from 2011 to 2020. Error bars indicate standard error.



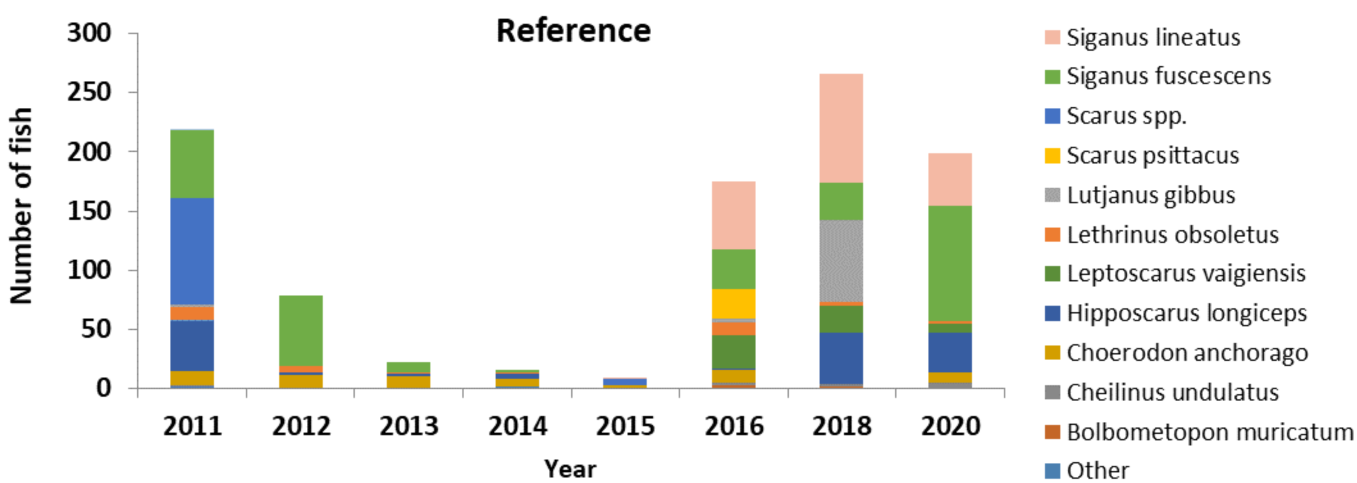


Figure 6. Stacked bar plot showing fish species composition within Teluleu MPA and its reference site from 2011 to 2020.

Fish species richness has consistently remained higher in Teluleu CA compared to the reference site over time. Since 2011, the number of fish in the CA has remained around 120 to 200 fish of various species, while in the reference area there was overall low diversity, especially between 2012 and 2015. The most commonly observed fish species recorded in the

CA included *Siganus lineatus* (kelsebuul), *Hipposcarus longiceps* (ngiaoch), *Siganus fuscescens* (meyas), *Scarus* spp. (mellemau) and *Lutjanus gibbus* (keremlal). In the reference site, a slightly similar but much lower number of fish species was observed, including *Hipposcarus longiceps* (ngiaoch), *Siganus fuscescens* (meyas), *Siganus lineatus* (kelsebuul) and *Scarus spp.* (mellemau). The protected fish species *Bolbometopon muricatum* (kemedukl) and *Cheilinus undulatus* (maml) were both observed and recorded in all years within Teluleu CA. Whereas in the reference site, both fully protected species (maml and kemedukl) were only observed for 3 years between 2011 to 2020.

Macro-invertebrates

Macro-invertebrate density in Teluleu CA and its reference site has remained relatively low over time. Since the initial 2011 surveys, the densities of edible and commercially valuable invertebrates such as sea cucumbers and clams have remained at less than 0.5 individuals per 50 m^2 in the MPA (Figure 7). In the reference area, invertebrate densities increased slightly in 2012 with approximately 1.5 ± 0.4 individuals per 50 m^2 which gradually decreased in the following years. There were no statistical differences between years and protection status for macro-invertebrate densities throughout all eight years of monitoring. The most commonly observed macro-invertebrate species in both the MPA and reference area were *Stichopus vastus* (ngimes), *Bohadschia spp.* (mermarech), and *Hippopus hippopus* (kism).

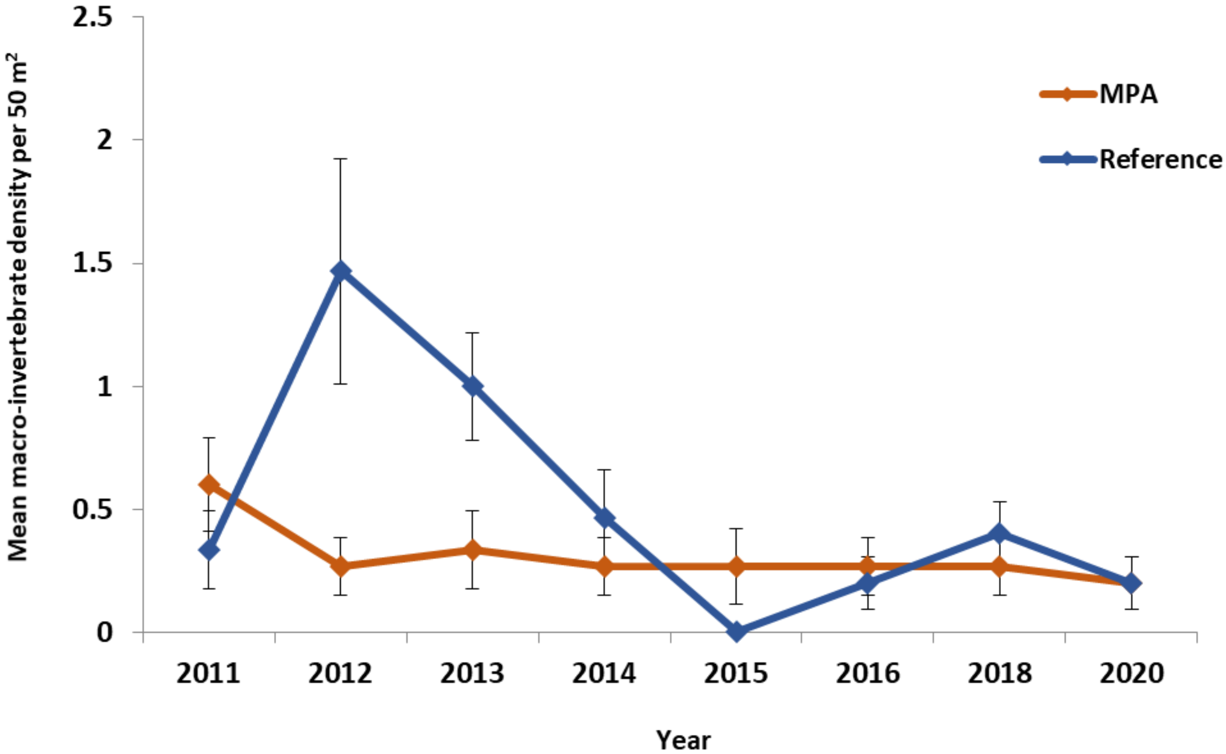


Figure 7. Trends in densities of edible and commercially valuable macro-invertebrates in Teluleu CA and its reference site from 2011 to 2020. Error bars indicate standard error.

Discussion

The results of PICRC's monitoring data from 2011 to 2020 indicate that Teluleu CA has been beneficial in large part for fish communities. On the contrary, the MPA is seemingly less productive in benefitting macro-invertebrate densities and seagrass coverage has continually fluctuated over time.

The mean seagrass coverage in Teluleu CA has fluctuated in the past eight years, and has generally decreased in the MPA compared to the reference site. The most abundant seagrass species *Thalassia hemprichii* has gradually decreased inside the MPA, compared to the reference site, while *Enhalus accoroides* has remained quite stable over time in both the MPA and reference area. Two new species of seagrasses (*Halophila ovalis* and *Cymodocea serrulata*) were recorded for the first time in the MPA and reference area during the 2020 surveys, although in very low percentages (overall less than 0.3% coverage); while *Halodule pinifolia* was only recorded in the MPA in 2014.

One possible explanation for newly recorded seagrass species in Teluleu CA and reference area may be due to Peleliu's nearly continuous and vast seagrass beds. Peleliu is host to Micronesia's largest seagrass meadows that are maintained and supported by wave action and tidal currents (PCS and Peleliu Management team, 2014; Maragos et al., 1994). Moreover, waves and currents particularly have an influence on the spatial distribution as well as the transport, establishment and survival rates of seagrass propagules (Pereda-Briones et al., 2018) which may help to explain the sporadic occurrences of new seagrass species across eight years. Although present in relatively small percentages, this could be a positive finding for Teluleu MPA in the longer term; since hosting higher species diversity is also a key factor that may lead to increased ecosystem stability and biodiversity (McCann, 2000).

The presence of herbivorous fish species such as Siganids could possibly contribute to slight fluctuations in seagrass coverage in the MPA and reference sites. For instance, seagrass beds with higher seagrass biomass often support a higher proportion of herbivorous fish (Aller et al., 2014) which may have an impact on seagrass growth or seagrass biomass fluctuation due to herbivory (Verges et al., 2008). The gradual decline in seagrass coverage in Teluleu MPA could be attributed to various factors including seasonality, however it is uncertain with the absence

of water quality data and additional data on substratum characterization. Slight differences in seagrass coverage could also be due to a change in surveyors of seagrass overtimes.
Teluleu CA has the highest percentage of seagrass cover in comparison to all seagrass MPAs across Palau (Gouezo et al., 2016); however the CA is highly susceptible to local disturbances originating from outside of MPA boundaries which include increased nutrients, pollutants and sediment runoff from land based activities (Quiros et al., 2017). The MPA is within close proximity to Peleliu's main port of entry as well as coastal homes and nearby sewage outflow (Gouezo et al. 2018). A more comprehensive, ridge-to-reef approach accounting for impacts of land based activities that includes measuring water quality factors such as turbidity, nutrient concentrations, and substrate conditions are needed for a more thorough assessment. Seagrass biomass has been shown to have a positive influence on seagrass-associated fish assemblages; however this positive influence decreases with increasing levels of human development and/or land use changes (Aller et al., 2014; Quiros et al., 2017).

In terms of fish assemblages, Teluleu CA continues to support and benefit fish populations, particularly as a nursery habitat for various juvenile fish species. Fish biomass in the MPA has remained relatively stable overtime, averaging ~6,000 g to 7,000 g per 125 m^2, with fish abundance averaging ~14 fish per 125 m^2 indicating that protection has been effective for fish populations. In the reference area, fish biomass has remained low throughout eight years averaging ~665 g per 125 m^2 with an abundance of ~8 fish per 125 m^2 which may indicate high fishing pressure within the reference area. It is also noted that these figures in fish biomass and density were analyzed based on PICRC's basic fish list of 35 commercially targeted species for consistency purposes regarding data analysis. During the 2018 and 2020 surveys, overall fish biomass in the MPA slightly decreased and was mainly due to a decrease in *Siganus lineatus* (kelsebuul) for both years. However, Siganids continued to be present in the nearby reference area, which could indicate the possibility of MPA spillover effect. Additionally, there was a decrease in *Hipposcarus longiceps* (ngiaoch), which contributed to the slight decrease in fish biomass in 2020.

Despite slight fluctuations in fish biomass and density overtime, Teluleu CA continues to support and maintain the highest fish biomass within a protected seagrass bed when compared to other protected seagrass meadows/reef flats in Palau (Gouezo et al., 2018; Rehm et al., 2015; Sampson et al., 2014). For example, within Ngermasech CA, an MPA considered to have a high ecological score, average fish biomass in the reef flat habitat was ~600 g per 125 m^2 (Karanassos et al., 2019; Gouezo et al., 2016) a figure relatively lower than average fish biomass in Teluleu CA.

Since 2011, densities of macro-invertebrates in Teluleu CA and reference area have remained very low and are comprised of mostly sea cucumbers and three species of clams (*Hippopus hippopu*s, *Tridacna derasa* and *Tridacna crocea*), although clam densities were much lower than sea cucumber densities. Invertebrate densities have remained on average less than 1 individual per 50 m^2 consistently across eight years, which is indicative of the low efficiency of Teluleu CA in protecting and increasing macro-invertebrate abundance. This low turnout of invertebrate abundance may be attributed to a lack of suitable area for spawning of certain species of sea cucumbers. Sea cucumbers are slow moving organisms that reproduce through broadcast spawning (Golbuu et al, 2012). Their successful reproduction depends on a variety of factors, including having an adequate number of individuals in a given area (Golbuu et al., 2012). The current size of Teluleu CA may be too small and not conducive for successful reproduction of sea cucumbers. Given that sea cucumber densities are shown to be very low in both the MPA and reference area, it may be critical to increase the size of the MPA, while seeking other options such as re-stocking the MPA for higher chances of sea cucumber reproduction.

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Appendix

Table 1. List of commercially important fish, including the protected fish for seasonal harvests and fish closed for harvest.

No.	Species	Palauan name
1	*Caranx ignobilis*	Erobk
2	*Caranx melampygus*	Oruidel
3	*Cetoscarus ocellatus*	Beyadel/Ngesngis
4	*Cetoscarus/Scarus spp.*	Melemau
5	*Choerodon anchorago*	Budech
6	*Hipposcarus harid*	Bekism
7	*Hipposcarus longiceps*	Ngiaoch
8	*Kyphosus spp. (vaigiensis)*	Komud, Teboteb
9	*Lethrinus obsoletus*	Udech
10	*Lethrinus olivaceus*	Melangmud
11	*Lethrinus rubrioperculatus*	Rekruk
12	*Lethrinus xanthochilis*	Mechur
13	*Liza vaigiensis*	Uluu
14	*Lutjanus argentimaculatus*	Kedesau'l iengel
15	*Lutjanus bohar*	Kedesau
16	*Lutjanus gibbus*	Keremlal
17	*Naso lituratus*	Cherangel
18	*Naso unicornis*	Chum
19	*Plectorhinchus albovittatus*	Melim ralm, Kosond, Bikl
20	*Plectorhinchus crysotaenia*	Merar
21	*Scarus microrhinos*	Otord
22	*Siganus argenteus*	Beduut
23	*Siganus lineatus*	Kelsebuul
24	*Siganus puellus*	Reked
25	*Siganus punctatus*	Bebael
26	*Valamugil seheli*	Kelat

27	*Bolbometopon muricatum*	Kemedukl
28	*Cheilinus undulatus*	Maml
29	*Epinephelus fuscoguttatus*	Meteungerel'temekai
30	*Epinephelus polyphekadion*	Ksau'temekai
31	*Plectropomus areolatus*	Tiau
32	*Plectropomus laevis*	Tiau, Katuu'tiau, Mokas
33	*Plectropomus leopardus*	Tiau
34	*Siganus fuscescens*	Meyas

Table 2. List of commercially important bivalves (invertebrates).

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

Table 3. List of commercially important sea cucumber, sea urchin, and trochus.

Species	**Palauan name**
Actinopyga echinites	Eremrum
Actinopyga lecanora	Ngelau
Actinopyga mauritiana	Badelchelid
Actinopyga miliaris	Eremrum, cheremrum edelekelk
Actinopyga palauensis	Eremrum
Actinopyga sp.	Eremrum
Bohadschia argus	Mermarech, esobel
Bohadschia similis	Mermarech
Bohadschia vitiensis	Mermarech
Holothuria impatiens	Sekesaker
Holothuria atra	Cheuas
Holothuria coluber	Cheuas
Holothuria edulis	Cheuas
Holothuria fuscogilva	Bakelungal-cherou
Holothuria fuscopunctata	Delal a molech
Holothuria lessoni	Delal a molech
Holothuria leucospilota	Cheuas
Holothuria nobilis	Bakelungal-chedelkelek
Holothuria scabra	Molech

Holothuris falvomaculata	Cheuas
Pearsonothuria graeffei	Meremarech
Stichopus chloronotus	Cheuas
Stichopus hermanni	Delal a ngimes, ngimes ra tmolech
Stichopus horrens	Irimd
Stichopus vastus	Ngimes
Thelenota ananas	Temetamel
Thelenota anax	Belaol
Tripneustes gratilla	Ibuchel
Trochus maculatus	Semum