A six year review of Palau Marine Protected Areas

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Abstract

The Palau International Coral Reef Center (PICRC) has conducted long-term monitoring of Marine Protected Areas (MPAs) throughout Palau since 2014 to evaluate the effectiveness of conservation and fisheries management efforts. Monitoring surveys compare sites within MPAs to reference sites across multiple habitat types and include assessments of benthic communities, commercially important fish and invertebrates, and coral recruits. To improve data accessibility and visualization, PICRC collaborated with the University of Guam to incorporate monitoring data into the Micronesia Reef Monitoring Portal and the Micronesia Protected Area Atlas, two web-based platforms that provide interactive maps, automated data-driven summary graphs, and other relevant information on protected areas throughout Micronesia. This report presents selected examples of MPA monitoring results derived from data and visualizations available through these portals, with a particular focus on fish monitoring data collected between 2017 and 2022. The report highlights the current status of Palau MPA and the capacity of the portals to provide automated status updates that are available to a variety of stakeholder audiences. In addition to their scientific value, the portals serve as effective tools for outreach, education, and communication with stakeholders by presenting complex monitoring information in an accessible and interactive format. The findings demonstrate successes and challenges with Palau MPA and the potential of these platforms to support marine resource management, improve transparency and data sharing, and enhance public engagement in marine conservation efforts throughout Palau and the wider Micronesia region.

Introduction

Since 2014, the Palau International Coral Reef Center (PICRC) has conducted long-term monitoring of Marine Protected Areas (MPAs) throughout Palau to assess the effectiveness of conservation and fisheries management measures. Monitoring surveys are carried out across twelve MPAs (excluding Helen reef conservation area) (Fig. 1) and encompass a range of habitat types, with sites located inside MPAs compared to reference sites outside protected boundaries. The monitoring program evaluates key ecological indicators, including benthic community composition, commercially important fish populations, invertebrate assemblages, and coral recruit abundance (see the most recent report: Otto et al., 2026; PICRC Technical Report 26-02). Effectiveness of MPAs protection has been shown to be variable across MPAs, years and habitats. Variable success with MPA may seem discouraging, however, across Micronesia and the tropical Pacific, variable success is very common (Houk et al., 2022). Improving conservation outcomes hinges upon PICRC researchers providing timely updates following MPA surveys to each State to share the results about all ecological indicators. The present reports provide these updates and also introduces automated platforms for enhanced access to trends shortly after data collection and processing events.

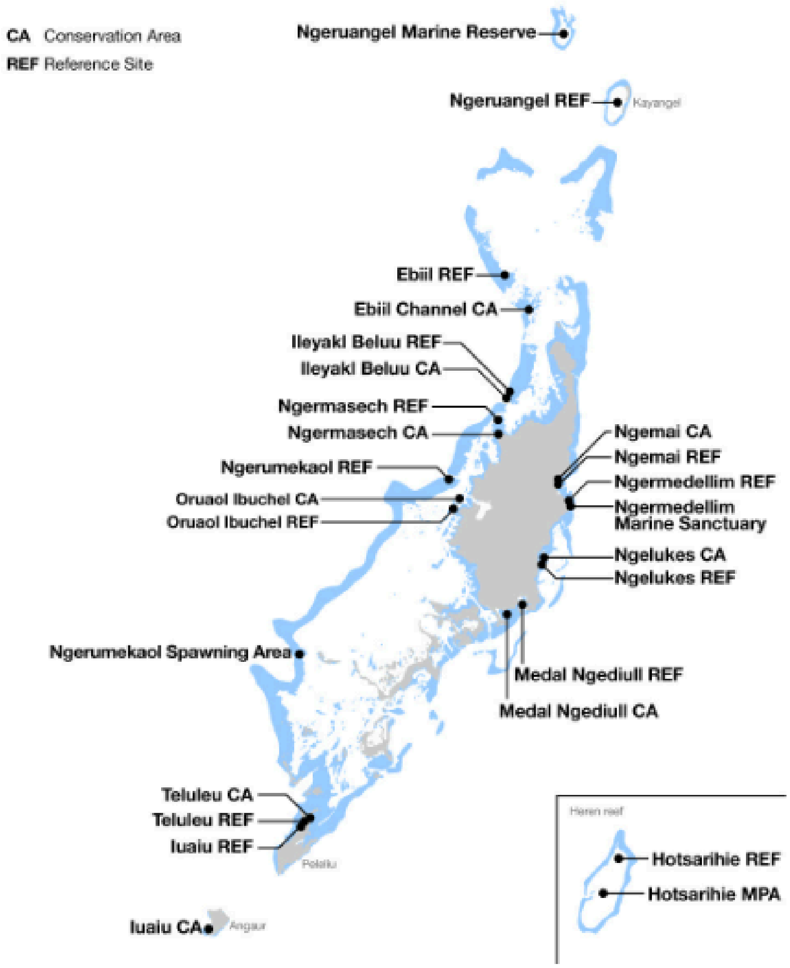

Fig. 1: Map of the PAN MPAs included in the PICRC long term monitoring program.

Long-term ecological monitoring provides critical information for understanding changes in reef ecosystems, evaluating management performance, and supporting adaptive conservation strategies. However, effectively communicating monitoring results to managers, stakeholders, and the public remains a challenge.

To improve data accessibility and visualization, PICRC initiated a collaboration with the Micronesia Coral Reef Monitoring Program currently based within the lab of Peter Houk from the University of Guam. Through this collaboration, reef monitoring data have been incorporated into two online platforms: the Micronesia Reef Monitoring Portal (Fig. 2) and the Micronesia Protected Area Atlas (Fig. 3). These portals provide interactive maps, graphical summaries, MPA boundary information, and other visualization tools designed to support scientific analysis, management decision-making, and public outreach.

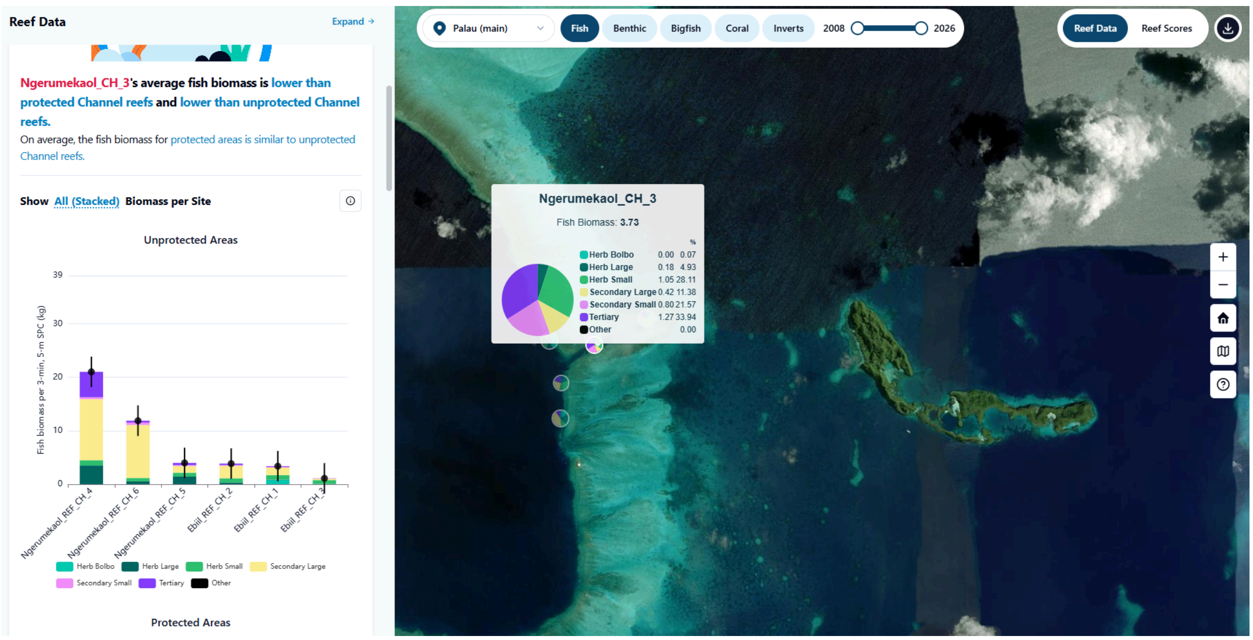

Fig. 2: Micronesia reef monitoring portal showing fish biomass at one of the PAN MPA (Ngerumekaol) surveyed by PICRC.

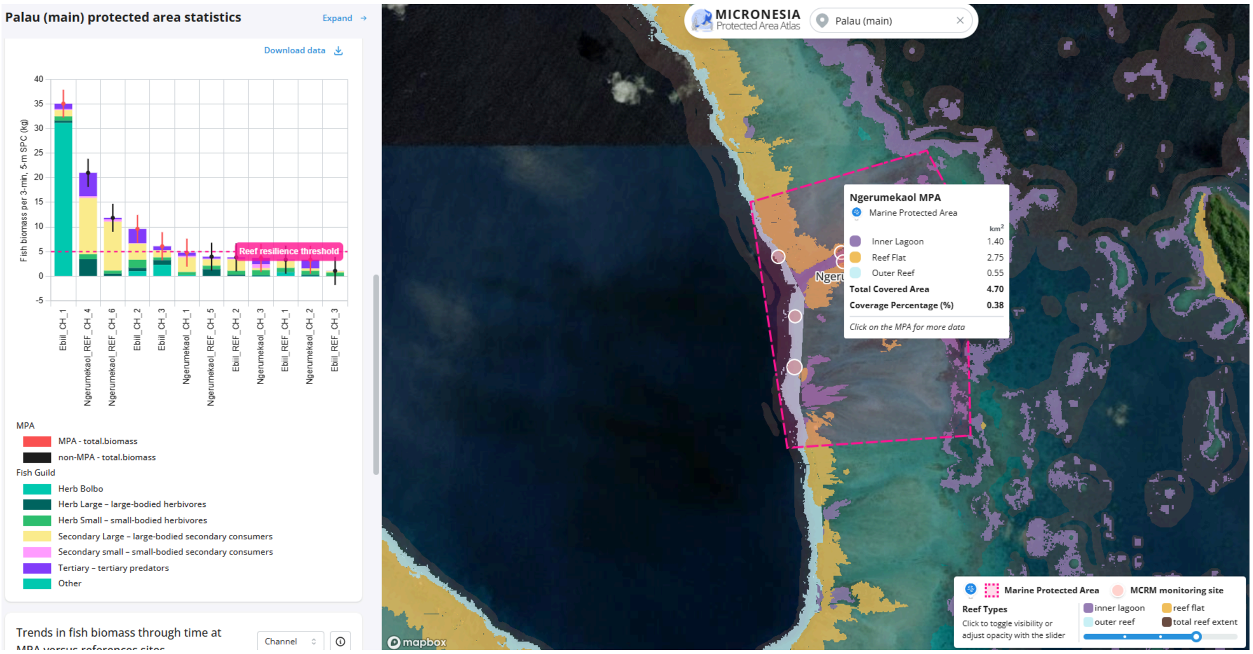

Fig. 3: Micronesia Protected Area Atlas showing fish biomass at one of the PAN MPA (Ngerumekaol) surveyed by PICRC.

As part of this collaboration, PICRC contributed fish monitoring data collected from MPAs and reference sites between 2017 and 2022, the baseline of 2014 was not included due to the fact that reference sites were not implemented yet and methods were slightly different. This project provided the opportunity to visualize and analyze fish biomass data over 6 years of surveys across different MPAs. The objective of this report is to present selected results from MPAs monitoring derived from the visualizations and datasets available through these portals and demonstrate the utility of these platforms for exploring ecological trends, communicating monitoring outcomes, and enhancing the accessibility of MPAs monitoring information for scientists, resource managers, and the broader community.

Materials and Methods

To survey commercially important fish, PICRC used a diver operated stereo-video (stereo-DOV) system along five 50x5m belt transects along 5 transects. Each video was analyzed using SeaGIS EventMeasure software (https://www.seagis.com.au/event.html) and the fish were counted, identified, and measured (fork length). For each measured fish, the biomass was then calculated using the formula W = aFLb where W is the weight of the fish in grams (g), FL is the fork length of the fish in centimeters (cm), and a and b are constant values from previously published biomass-length relationships (Kulbicki et al., 2005) and from Fishbase (http://fishbase.org). In cases where the length of the fish was not available, it was estimated by calculating the average of lengths of the same fish species or genus within the same habitat type.

Fish were classified in different trophic levels (Appendix A) and data were then uploaded into the portals.

Results

A total of 104 species were identified during 5 years of MPAs survey. The most abundant species recorded was *Lutjanus gibbus* (Humpback red snapper) with a total of 7148 individuals in the Reference area and 2795 individuals in the MPAs, followed by mixed assemblages of parrotfish (Labridae). Species recorded with a count >10 individuals were generally the same between MPA and reference area (Fig. 4). The only species recorded (with a count above 10 individuals) only inside the reference area over the years was *Caranx sexfasciatus* (Big eye trevally) with 460 individuals.

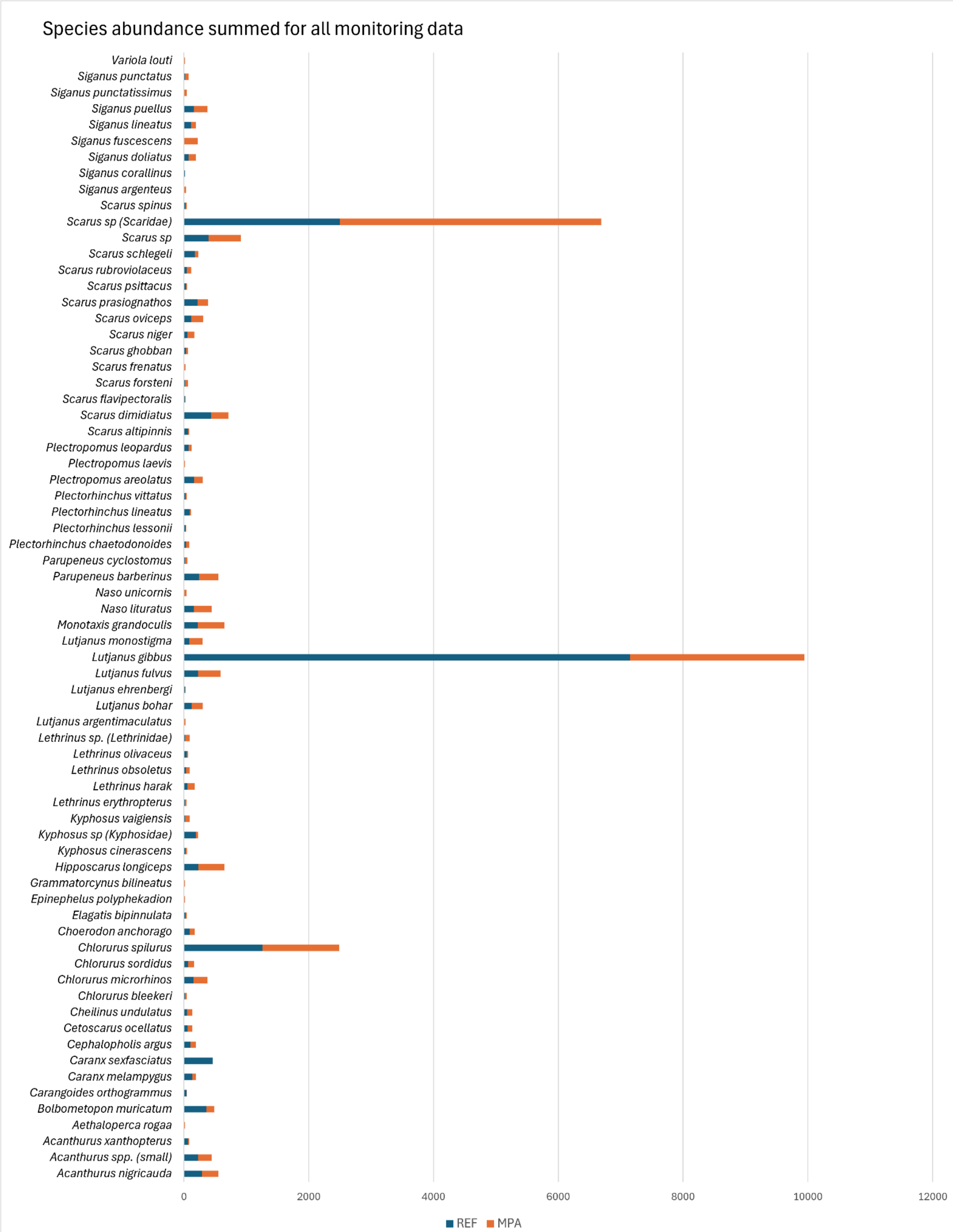

Fig. 4: Fish species abundance with a count above 10 individuals within MPA and Reference areas among five years survey.

Kayangel

The Kayangel survey included two habitat types, the Fore Reef and the Lagoon. The graphs below show the results of fish biomass from 2018 to 2022 for these two habitats (Fig. 5 and 6). For both habitats, the MPA shows a higher biomass over the early years compared to the reference area, but the presence of large *Bolbometopon muricatum* (bumphead parrotfishes) populations were found in the reference area in 2022. For the fore reef habitat there was also an increase of fish biomass over the years while in the lagoon fish biomass slightly decreased over time.

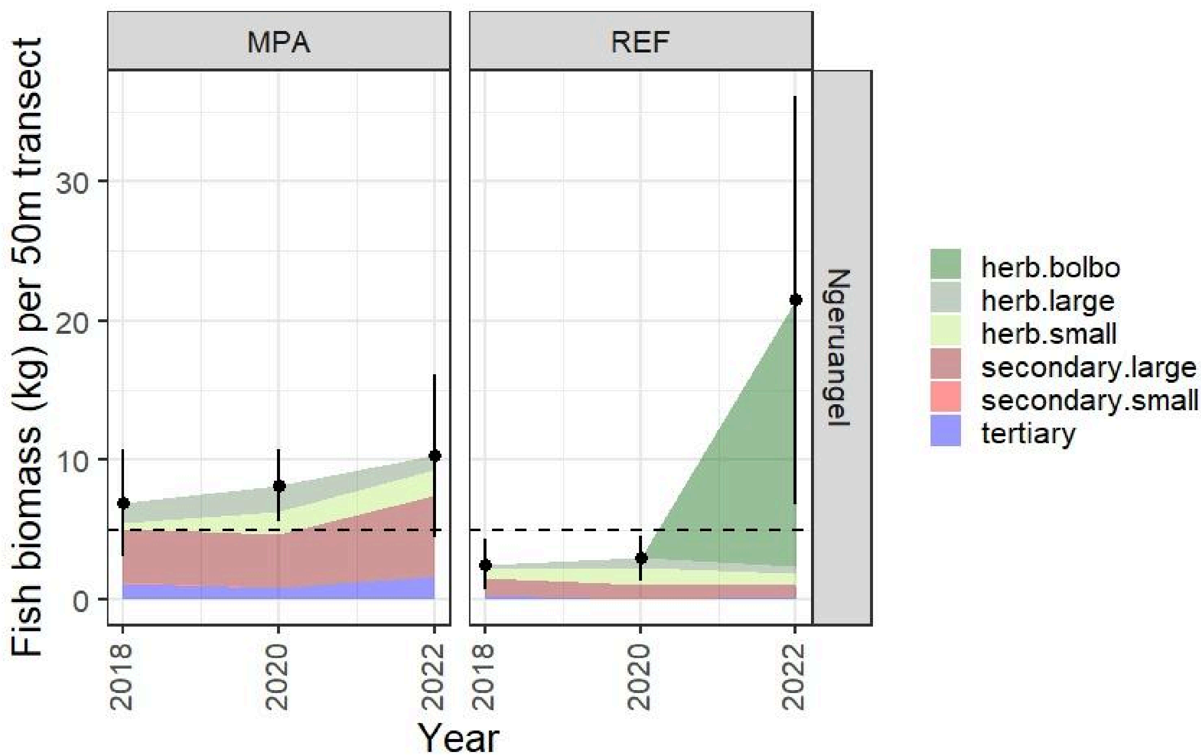

Fig. 5: Mean Fish biomass (kg per 50m transect) over the years at the Fore Reef sites for Ngeruangel MPA. Black dots and lines represent total biomass and standard errors.

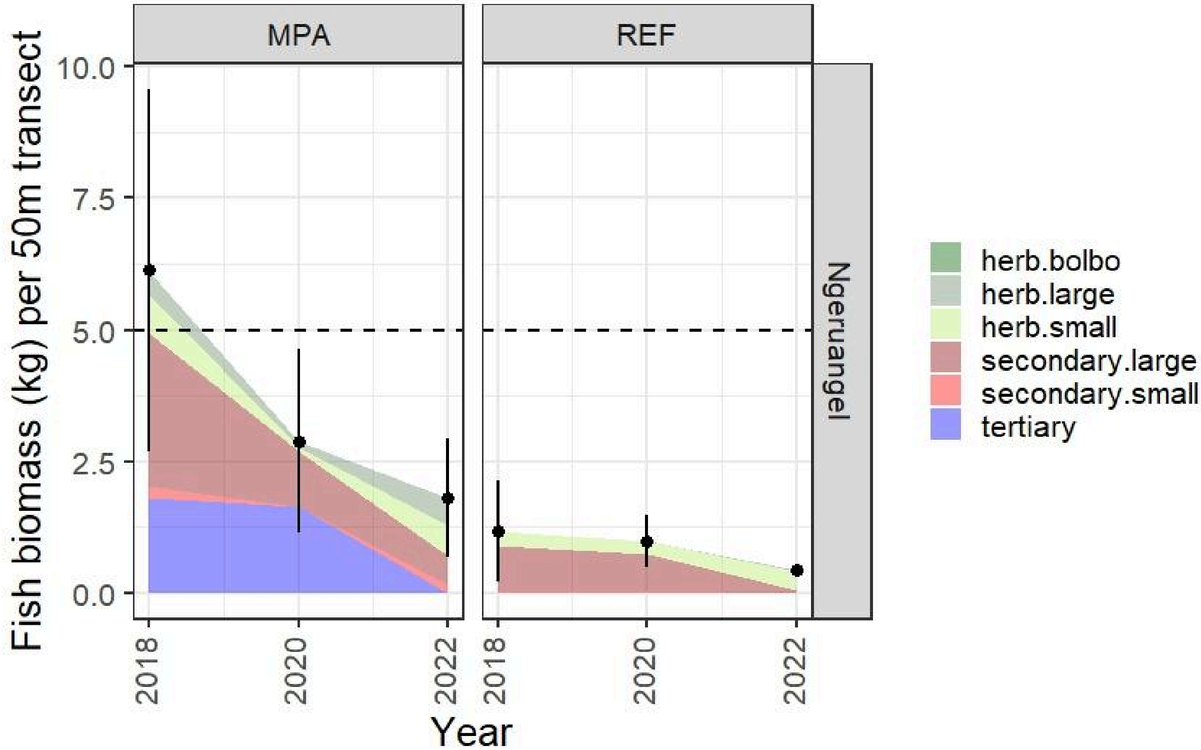

Fig. 6: Fish biomass (kg per 50m transect) over the years at the Lagoon sites for Ngeruangel MPA. Black dots and lines represent average biomass and standard errors.

Palau main island

Palau's main island included ten MPAs with five different habitat types. The graphs below show the trends of fish biomass over the years at different MPAs and habitats.

At the Lagoon habitat, Ngelukes MPA in Ngchesar State was the only one showing higher biomass of fish inside the MPA compared to the reference area over the years. For Medal Ngediull (Airai State), Ngermasech (Ngardmau State) and Oruaol Ibuchel (Ngatpang State), the reference area showed higher biomass than the MPAs, especially for the last survey of 2021/2022 (Fig. 7). These trends highlight the importance of science-to-management feedback loops with each state and community.

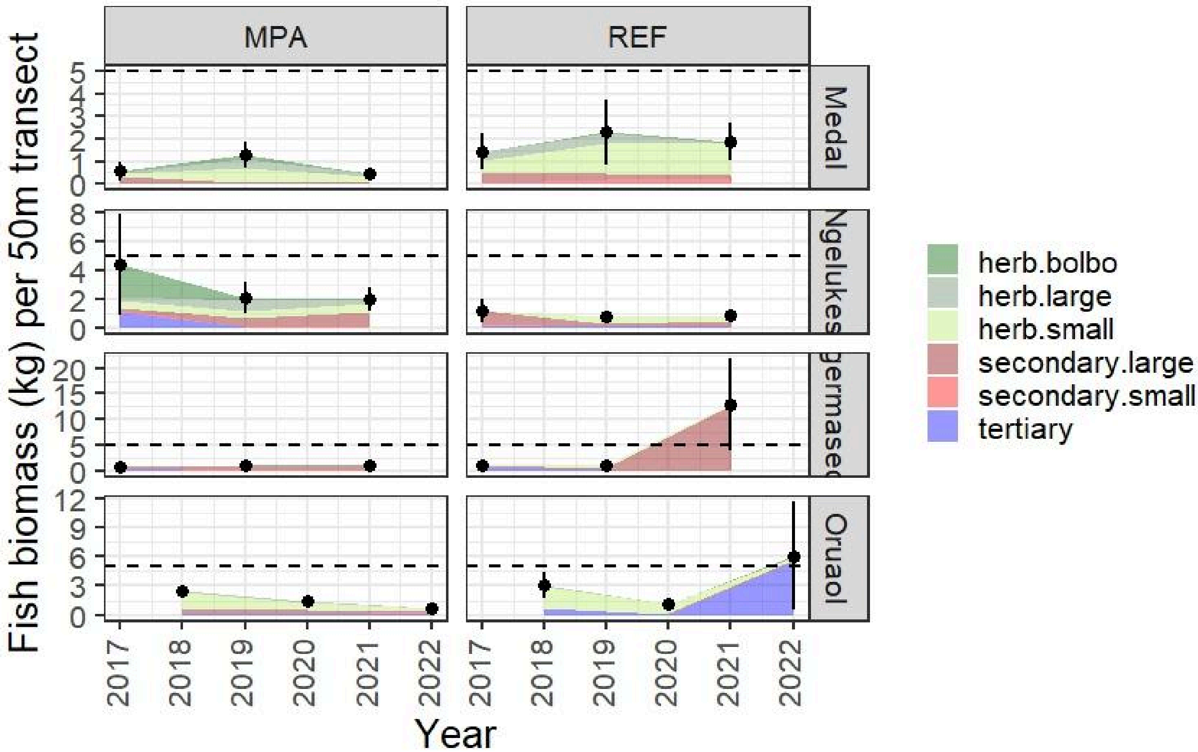

Fig. 7: Fish biomass (kg per 50m transect) over the years at the Lagoon habitat for Medal Ngediul, Ngelukes, Ngermasesh and Oruaol Ibul MPAs. Black dots and lines represent average biomass and standard errors.

The Fore reef habitat included four MPAs. There were no significant differences between MPAs and Reference sites in fish biomass for Ebiil (Ngarchelong State), Ngemai (Ngiwal State) and Ngerumekaol (Koror State) for the last survey of 2022. However, Ileaklbeluu Reference sites showed almost double fish biomass in 2022 compared to the MPA, this difference was mostly driven by tertiary consumers (8.5kg per transect) such as large-bodied groupers, trevallies and snappers (Fig. 8).

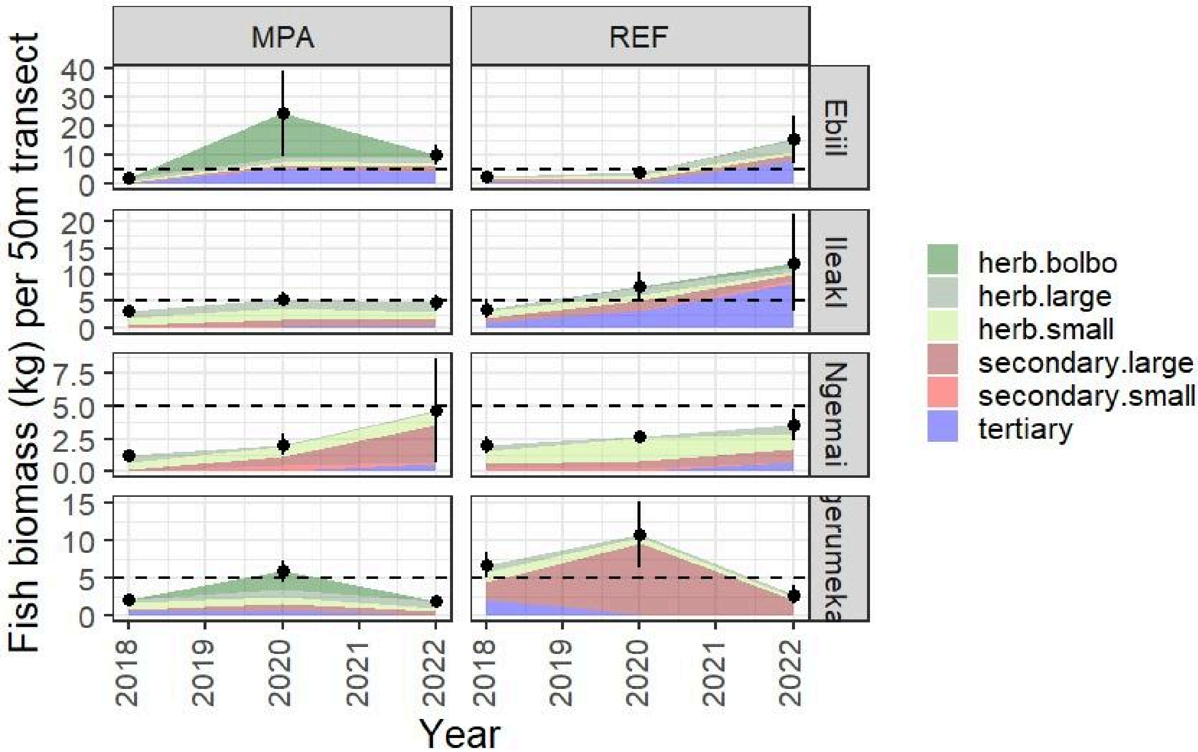

Fig. 8: Fish biomass (kg per 50m transect) over the years at the Fore reef habitat for Ebiil, Ileaklbeluu, Ngemai and Ngerumekaol MPAs. Black dots and lines represent average biomass and standard errors.

The Reef flat habitat included three MPAs. All of these MPAs, Ileaklbeluu, Ngermedellim (Melekeok State) and Oruaol Ibuchel showed higher fish biomass inside the MPA compared to Reference sites during the last survey of 2021/2022. For Ileaklbeluu, the majority of the biomass was made by small and large herbivores such as surgeon fish and parrotfish. For Ngermedellim, most fish biomass included small and large secondary consumers such as snappers and sweetlips and for Oruaol Ibuchel the majority of biomass included small herbivores and small secondary consumers (Fig. 9).

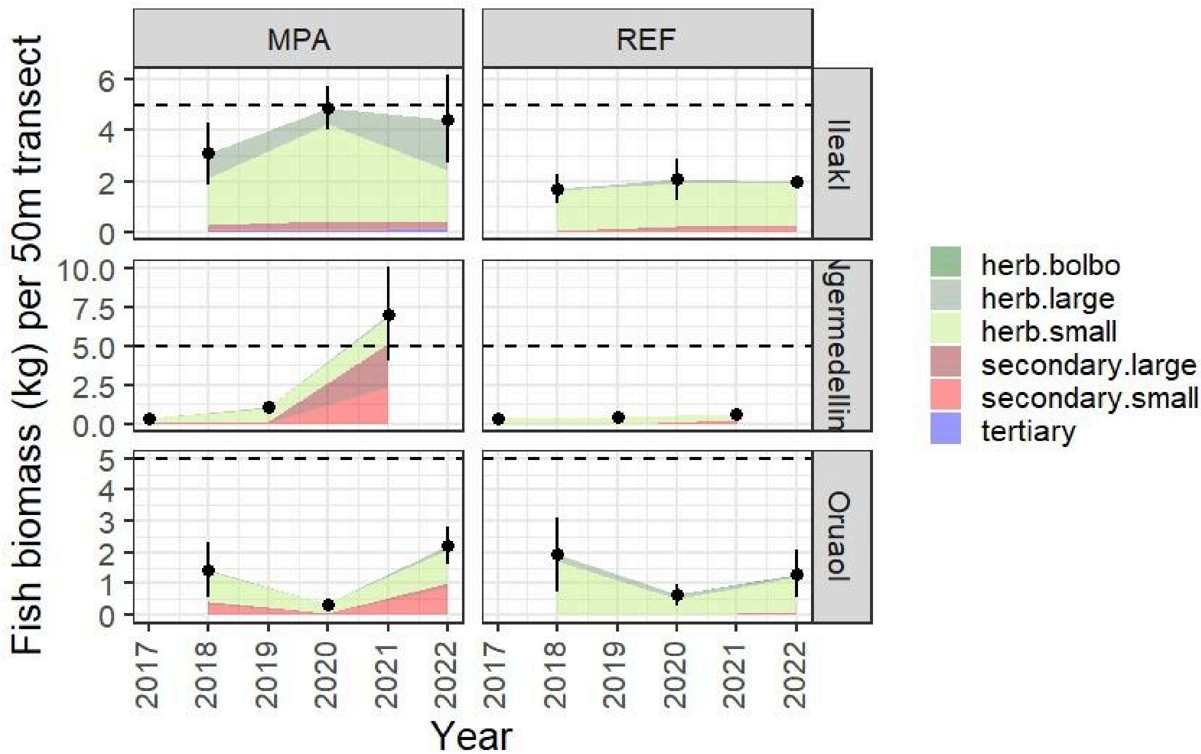

Fig. 9: Fish biomass (kg per 50m transect) over the years at the Reef flat habitat for Ileaklbeluu, Ngermedellim and Oruaol Ibul MPAs. Black dots and lines represent average biomass and standard errors.

The Channel habitat included two MPAs, Ebiil and Ngerumekaol. In Ebiil, the last survey showed a significantly higher biomass in the MPA compared to the reference sites but by looking at the fish trophic levels, this was probably due to a large school of bumphead parrotfish (Fig. 10) accounting for 28kg per transect. By looking at the rest of the fish, no significant differences emerged in biomass between MPA and reference sites at all surveyed years. For Ngerumekaol MPA, fish biomass was always higher at the Reference sites compared to MPA (Fig. 10).

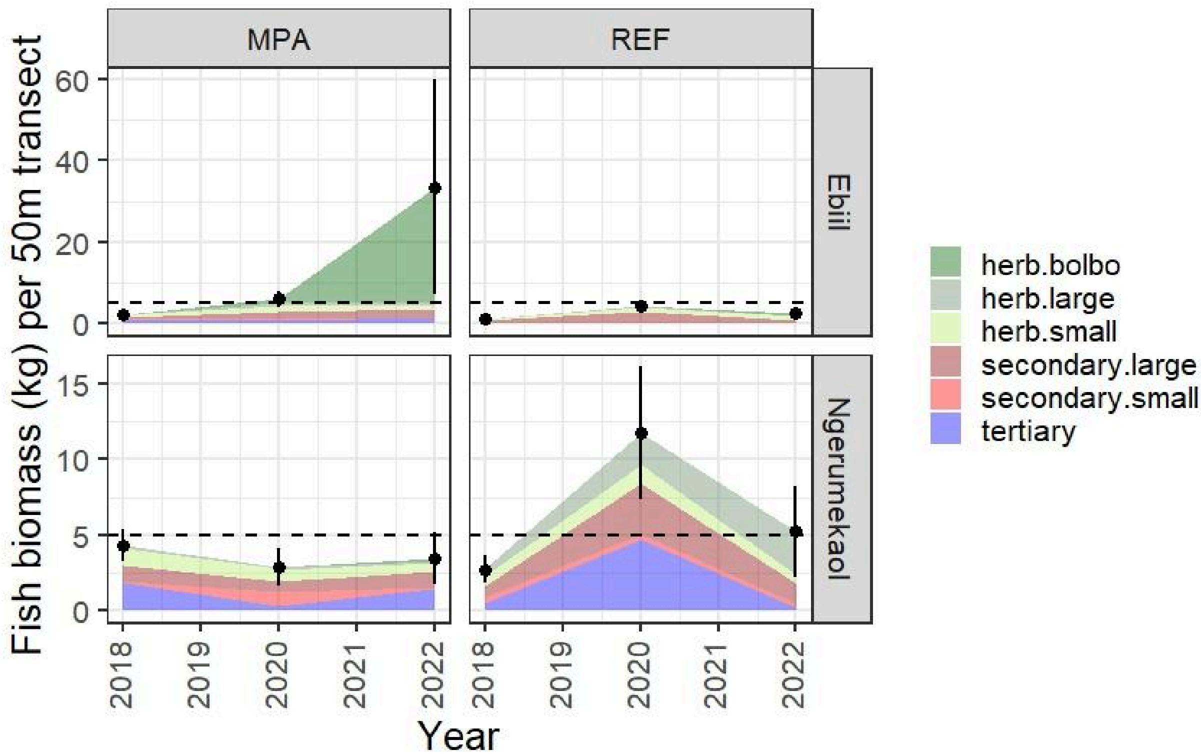

Fig. 10: Fish biomass (kg per 50m transect) over the years at the Channel habitat for Ebiil and Ngerumekaol MPAs. Black dots and lines represent average biomass and standard errors.

For Ngerukeuid (Koror State), fish biomass was higher inside the MPA compared to the Reference sites for both 2020 and 2022 surveys (Fig. 11).

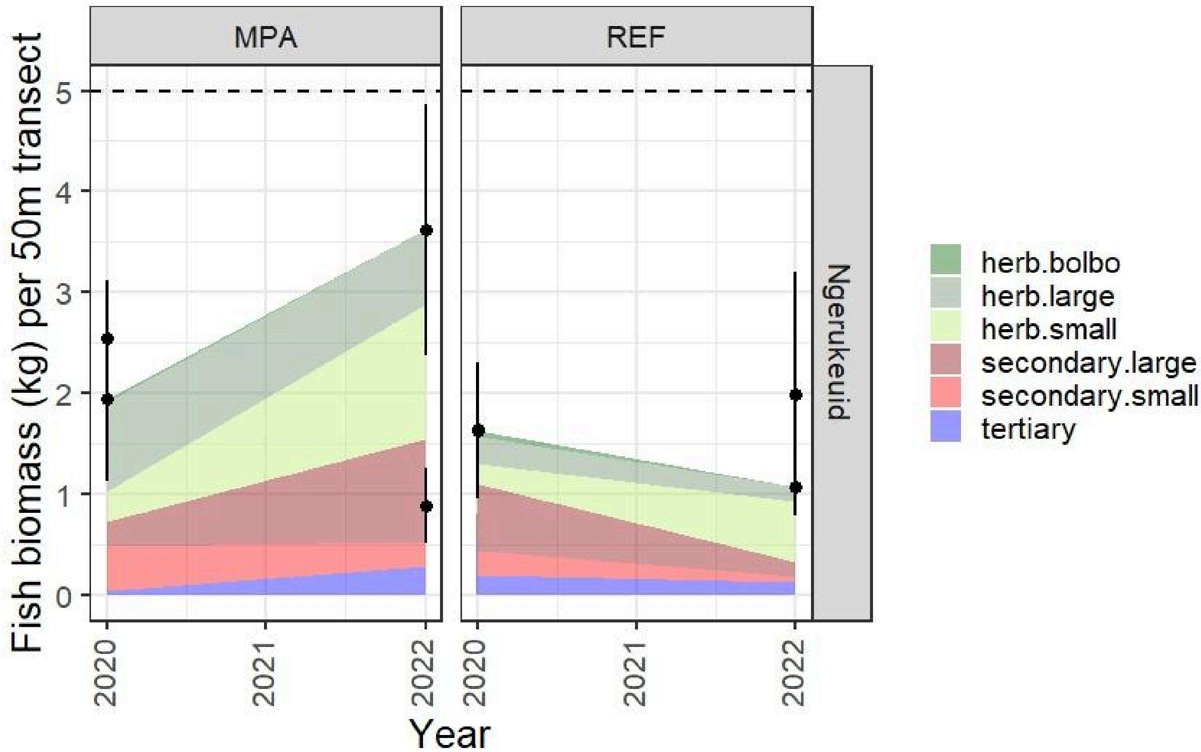

Fig. 11: Fish biomass (kg per 50m transect) over the years at the Back reef habitat for Ngerukeuid MPA. Black dots and lines represent average biomass and standard errors.

Angaur

For the Iuaiu MPA in Angaur, fish biomass increased overtime between 2018 and 2020. Biomass was higher at the Reference sites compared to the MPA but this was due to schools of bumphead parrotfish. If the inconsistent occurrences of this species are not considered, fish abundance for all other taxa combined was actually higher inside the MPA for both years (Fig. 12).

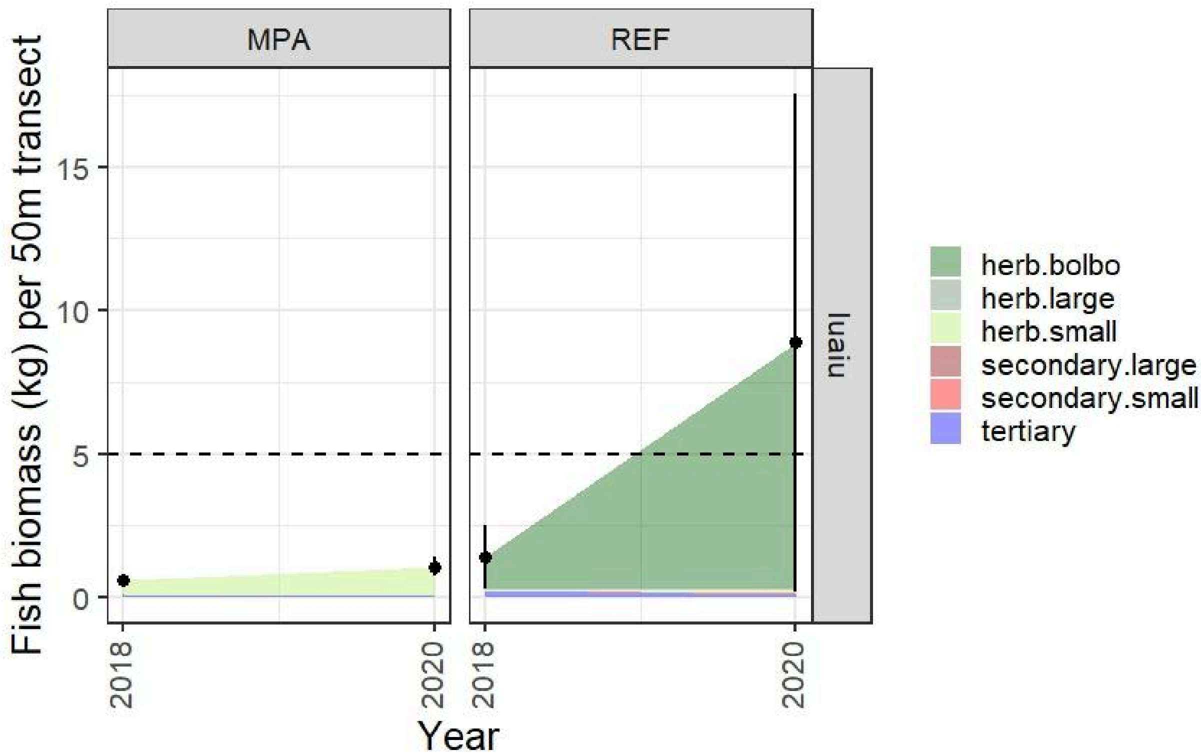

Fig. 12: Fish biomass (kg per 50m transect) over the years at the Reef flat habitat for Iuaiu MPA. Black dots and lines represent average biomass and standard errors.

Discussion

Surveys of the MPAs showed how some MPAs are more effective in protecting fish than others and how these differences vary a lot depending on the habitat type. In a previous study from Friedlander et al., 2017 seven MPAs in Palau were surveyed in 2014 comparing sites in the MPAs with reference sites (different from PICRC ones), results from this study showed how all MPAs presented a higher biomass of fish compared to their unprotected reference sites. This difference was significant especially for Ngermasech, Ileaklbeluu, Ngerumekaol and Ebiil. However, now, the results from this report, these same MPAs shows either a lower biomass than their reference sites such as Ngermasech, Ngerumekaol and Ileaklbeluu fore reef or a similar biomass as their reference sites such as in Ebiil when removing big schools of bumphead parrotfish. Although this previous study was conducted in different sites and with a different method, it is recommended to pay attention to this decrease over time in the effect of protection of some of the MPAs. Overall, ~41% of the habitat surveyed by PICRC presented higher fish biomass at the Reference sites compared to MPA sites, while other MPAs in Micronesia have been found to successfully increase fish biomass over the years (Houk et al. 2022). When we consider the effectiveness of an MPA, we should also consider benthic communities, corals and invertebrates that are not represented in this report. Palau income is highly influenced by tourism. A past economic study in Palau demonstrated that divers would be willing to pay more for experiencing diving in MPAs because of the presence of larger fishes (Koike et al., 2014). This can provide an additional reason to implement enforcement and monitoring of the protected areas.

The Micronesia Reef Monitoring Portal and the Micronesia Protected Area Atlas represent valuable tools for increasing the accessibility and utility of long-term reef monitoring data. By integrating ecological datasets with interactive visualizations, maps, and downloadable outputs, these platforms provide an effective means of exploring trends in reef condition and fisheries resources across space and time.

One of the greatest strengths of these portals is their ability to display monitoring results collected over multiple years in an intuitive and user-friendly format. Rather than relying solely on static reports, users can visualize changes in fish biomass, abundance, and other ecological indicators through interactive graphs that facilitate the identification of long-term trends. Once new surveys are completed, this capability allows scientists, managers, and stakeholders to quickly assess whether ecological conditions within MPAs are improving, remaining stable, or declining relative to reference sites.

The portals also enhance transparency and collaboration by providing access to underlying datasets. The ability to download data allows researchers, students, and resource managers to conduct independent analyses, integrate information into other studies, and develop new research questions. By making monitoring information more accessible, the portals help maximize the value of long-term investments in data collection and promote broader scientific engagement.

Beyond their scientific applications, these platforms have significant outreach potential. Interactive maps and visualizations make complex monitoring results easier to understand for non-technical audiences, including community members, policymakers, educators, and visitors. The ability to explore MPA boundaries, monitoring locations, and ecological trends through a web-based interface can increase public awareness of marine conservation efforts and demonstrate the outcomes of management actions. Such tools can strengthen communication between scientists and communities while fostering support for marine protected areas and sustainable resource management.

From a management perspective, the portals provide an efficient mechanism for tracking MPA performance and informing decision-making. Managers can use the available information to evaluate conservation objectives, identify areas requiring additional attention, and communicate monitoring outcomes to stakeholders and funding agencies. The visualization of long-term trends can also support adaptive management by helping managers assess whether current strategies are achieving desired ecological outcomes.

The examples presented in this report demonstrate the considerable potential of these portals as platforms for data visualization, information sharing, outreach, and management support. Continued incorporation of monitoring datasets and regular updates will further enhance their value as regional resources for coral reef conservation and management. As long-term monitoring programs continue to generate data, these portals can play an increasingly important role in transforming scientific information into accessible knowledge that supports effective management and public engagement throughout Micronesia.

Acknowledgements

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Houk, Peter, et al. "Climate change disturbances contextualize the outcomes of coral-reef fisheries management across Micronesia." *PLOS Climate* 1.7 (2022): e0000040.

Koike et al., “Final Report on Diver’s Perception Survey for Palau’s Kemedukl and Maml: Stock Assessment for Humphead Wrasse and Bumphead Parrotfish” PICRC Technical Report 14-02 (2014).

Otto et al., “Ebiil Conservation Area continues to protect and maintain a balanced and healthy reef ecosystem” PICRC Report (2026).

Appendix A: PICRC target species list and trophic levels

Species	**Trophic level**
Acanthurus nigricauda	herb.small
Acanthurus spp. (small)	herb.small
Acanthurus xanthopterus	herb.large
Aethaloperca rogaa	secondary.large
Aprion virescens	tertiary
Bolbometopon muricatum	herb.bolbo
Carangoides ferdau	tertiary
Carangoides orthogrammus	tertiary
Caranx ignobilis	tertiary
Caranx lugubris	tertiary
Caranx melampygus	tertiary
Caranx sexfasciatus	tertiary
Cephalopholis argus	tertiary
Cephalopholis miniata	tertiary
Cetoscarus ocellatus	herb.large
Cheilinus undulatus	secondary.large
Chlorurus bleekeri	herb.small
Chlorurus bowersi	herb.small
Chlorurus frontalis	herb.large
Chlorurus japanensis	herb.small
Chlorurus microrhinos	herb.large
Chlorurus sordidus	herb.small
Chlorurus spilurus	herb.small
Choerodon anchorago	secondary.small
Cromileptes altivelis	tertiary
Elagatis bipinnulata	tertiary

Epinephelus fuscoguttatus	tertiary
Epinephelus melanostigma	tertiary
Epinephelus polyphekadion	tertiary
Gracila albomarginata	tertiary
Grammatorcynus bilineatus	tertiary
Hipposcarus longiceps	herb.large
Kyphosus cinerascens	herb.large
Kyphosus sp (Kyphosidae)	herb.large
Kyphosus vaigiensis	herb.large
Lethrinus erythracanthus	secondary.large
Lethrinus erythropterus	secondary.small
Lethrinus harak	secondary.small
Lethrinus obsoletus	secondary.small
Lethrinus olivaceus	secondary.large
Lethrinus rubrioperculatus	secondary.large
Lethrinus sp. (Lethrinidae)	secondary.large
Lethrinus xanthochilus	secondary.large
Lutjanus argentimaculatus	secondary.large
Lutjanus biguttatus	tertiary
Lutjanus bohar	tertiary
Lutjanus ehrenbergi	secondary.small
Lutjanus fulvus	secondary.small
Lutjanus gibbus	secondary.large
Lutjanus monostigma	secondary.large
Lutjanus rivulatus	tertiary
Monotaxis grandoculis	secondary.large
Naso lituratus	herb.small
Naso unicornis	herb.large
Parupeneus barberinus	secondary.small
Parupeneus cyclostomus	secondary.small
Parupeneus sp.	secondary.small
Plectorhinchus albovittatus	secondary.large
Plectorhinchus chaetodonoides	secondary.large
Plectorhinchus chrysotaenia	secondary.large
Plectorhinchus gibbosus	secondary.large
Plectorhinchus lessonii	secondary.large
Plectorhinchus lineatus	secondary.large

Plectorhinchus picus	secondary.large
Plectorhinchus vittatus	secondary.large
Plectropomus areolatus	tertiary
Plectropomus laevis	tertiary
Plectropomus leopardus	tertiary
Plectropomus oligacanthus	tertiary
Scarus altipinnis	herb.large
Scarus chameleon	herb.small
Scarus dimidiatus	herb.small
Scarus festivus	herb.large
Scarus flavipectoralis	herb.small
Scarus forsteni	herb.large
Scarus frenatus	herb.small
Scarus ghobban	herb.large
Scarus globiceps	herb.small
Scarus niger	herb.small
Scarus oviceps	herb.small
Scarus prasiognathos	herb.large
Scarus psittacus	herb.small
Scarus quoyi	herb.small
Scarus rivulatus	herb.small
Scarus rubroviolaceus	herb.large
Scarus schlegeli	herb.small
Scarus sp	herb.small
Scarus sp (Scaridae)	herb.small
Scarus spinus	herb.small
Scarus tricolor	herb.small
Scomberomorus commerson	tertiary
Siganus argenteus	herb.small
Siganus corallinus	herb.small
Siganus doliatus	herb.small
Siganus fuscescens	herb.small
Siganus lineatus	herb.small
Siganus puellus	herb.small
Siganus punctatissimus	herb.small
Siganus punctatus	herb.small
Sphyraena barracuda	tertiary
Sphyraena qenie	tertiary

Symphorichthys spilurus	secondary.large
Variola albimarginata	tertiary
Variola louti	tertiary