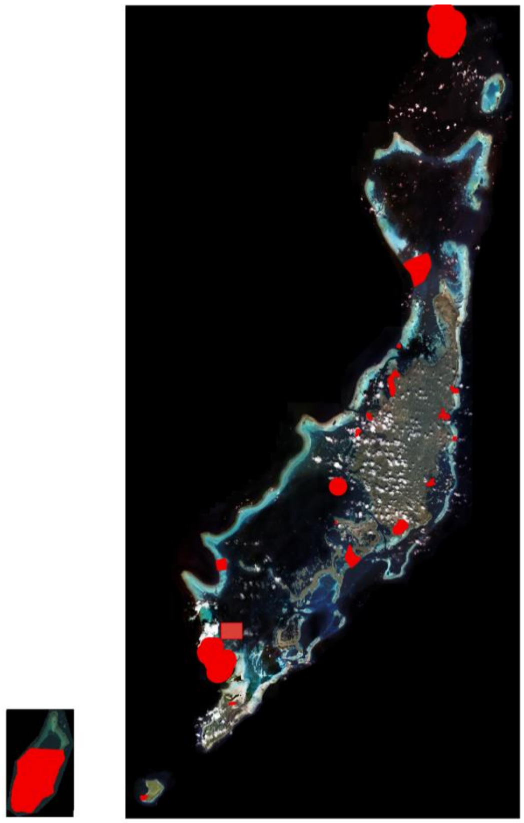
Ecological conditions of coral-reef and seagrass marine protected areas in Palau



Marine Gouezo, Shirley Koshiba, Evelyn I. Otto, Dawnette Olsudong,

Geory Mereb, Randa Jonathan

Palau International Coral Reef Center

PICRC Technical Report No 16-06

March 2016

Abstract

Marine protected areas (MPAs) have been widely used as an effective conservation tool against anthropogenic threats. In 2003, the government of Palau established the Protected Areas Network (PAN) to effectively protect and sustain marine resources. In addition, as part of the Micronesia Challenge, Palau committed to effectively protected 30% of its marine habitat by 2020. Despite these great advances in protective management, since 2006, very few data have been collected on the baseline condition of MPAs. The main objectives of this study are (1) to show the baseline ecological conditions of coral-reef and seagrass MPAs in Palau, (2) to investigate the drivers of ecological conditions and (3) to recommend adapted management actions to improve the existing marine protective management. Our results demonstrated that 14% of coral reef and seagrass ecosystems areas were protected; 11.2% of which were under PAN legislation. The marine habitats the most protected were channel and outer reef (> 25 %) and the least protected were reef flat and lagoon (<10%). Fringing and barrier reef MPAs had relatively good ecological conditions that were mainly driven by the length of protection, the size of the MPAs and the remoteness of the MPAs. Inner reef MPAs displayed good ecological condition as opposite to nearshore seagrass beds MPAs, where more than half had a score lower than 50%. For both inner reef and nearshore MPAs, ecological conditions were driven by pollution caused by poor-land use. To increase the effectiveness of the marine PAN, we recommend that better land use practices that would minimize land erosion and sedimentation nearby MPAs should be implemented as soon as possible with a focus on location with the lowest scores. If new MPAs were to be implemented, they should be in the lagoon and reef flat habitats, as far as possible from the land and river discharges.

Introduction

Marine Protected Areas have been widely used as an effective conservation tool against anthropogenic threats such as overfishing (Halpern et al. 2009; Lester et al. 2009; Edgar et al. 2014). MPAs have been proved to increase fish biomass, abundance, mean size and species biodiversity (Friedlander and DeMartini 2002; Abesamis et al. 2006; Hamilton et al. 2011). In addition, it has been shown that they benefit adjacent non-protected areas (McClanahan and Mangi 2000; Agardy et al. 2003). The Republic of Palau, located in western Micronesia, has made great advances in its marine protective management. In 1994, the Marine Protection Act implemented fishing restrictions on several commercially-important species, and in 2003 the Palauan government started to establish the Protected Areas Network (PAN). This network aims to effectively protect both terrestrial and marine habitats of Palau. In 2006, an international initiative called the Micronesia Challenge (MC), required Micronesian nations (The Federated States of Micronesia, The Republic of Marshall Islands, Guam, The Commonwealth of the Northern Marianas Islands, and The Republic of Palau) to commit to effectively protect at least 20% of their terrestrial habitats and 30% of their marine habitats by 2020 (Micronesia Challenge Steering Committee 2011). This initiative far exceeds the current request for countries to protect 10% of their marine and terrestrial habitats through international conventions and treaties by 2020 (United Nations 1992). The Palauan government is using its PAN to meet the goals of the MC and to effectively expand its protected areas.

While there have been some studies on the effectiveness of some MPAs, there has been no comprehensive assessments on the baseline status of all MPAs in Palau. As an organization that is committed to guide efforts supporting coral reef stewardship through research and its applications for the people of Palau, Palau International Coral Reef Center (PICRC) collected baseline ecological data at coral reef and seagrass MPAs throughout 2014 and 2015. As for today, there are a total of 22 reef and seagrass no-takes zones in Palau under State legislations. 14 of these MPAs are registered PAN sites (national law).

In order to meet the goals of the MC, Palau has to show that its MPAs network is effective at protecting biodiversity and increasing marine resources. The main objectives of this report are to:

- Define the overall percentage of marine protected habitats in Palau
- Show the ecological baseline condition of coral reef and seagrass beds MPAs
- Score MPAs based on ecological state and processes within their group (reef flat, lagoon, fringing/barrier)
- Investigate what are the drivers to these scores
- Provide recommendations to States, PAN and the Palau Government to increase the effectiveness of marine protective management in Palau

Methods

1. Study Sites

Baseline ecological surveys were conducted at 18 MPAs that had been protected for various amounts of years (Figure 1, Appendix 6). Helen Reef Conservation Area and Ngerukeuid Island Preserve were not surveyed due to remoteness and logistics constraints

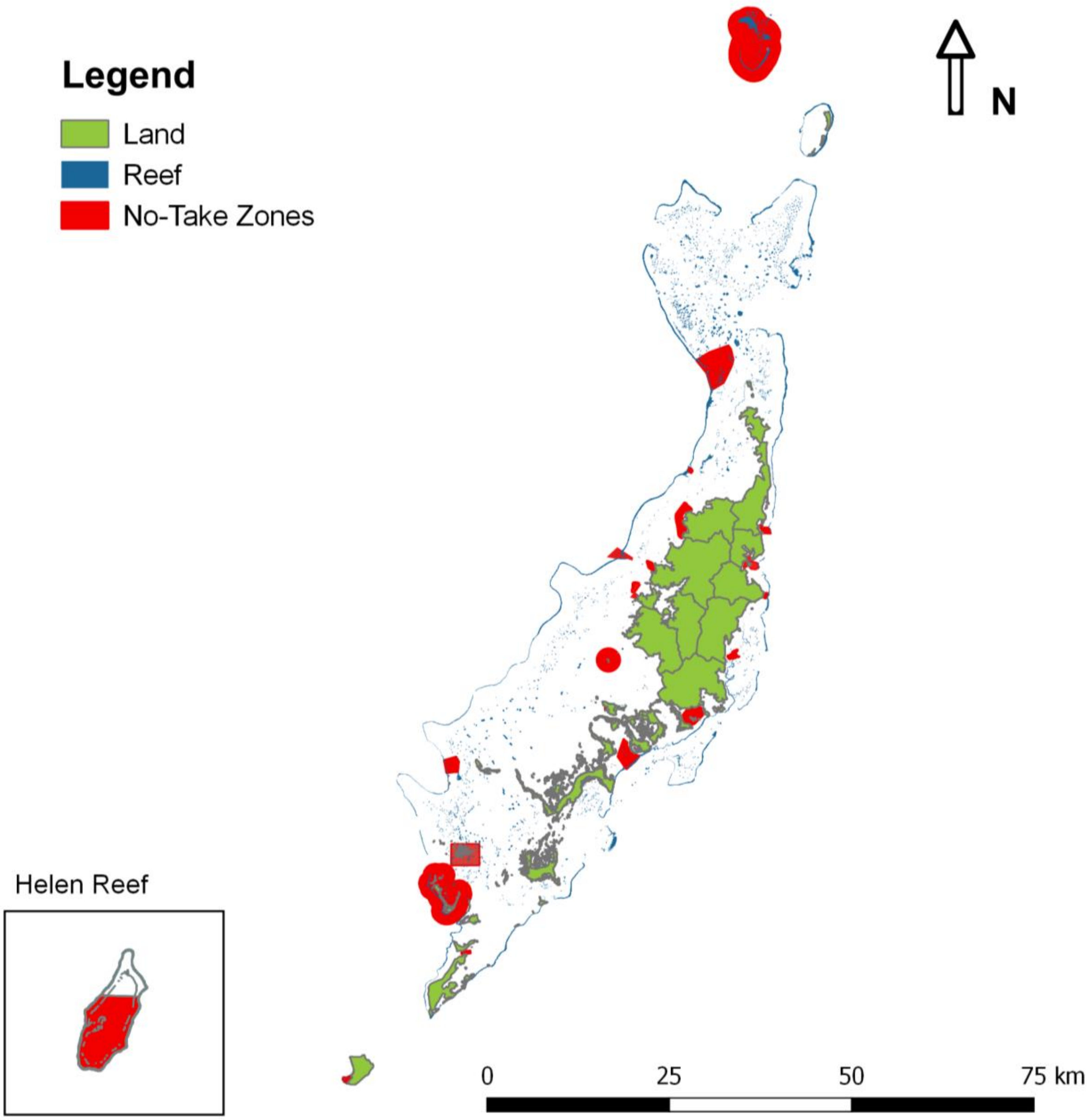


Figure 1: Map of the coral reef and seagrass no take zones (in red) in Palau

The monitoring protocol followed a stratified sampling design. Random stations' locations were allocated within each habitat present in the MPA depending on their size using the NOAA shallow water habitat map of Palau (NOAA 2014) and QGIS (QGIS Development Team 2015). Areas smaller than 900,000 m^2 were allocated three random points; areas from 1 km^2 to 5 km^2 in size were allocated one random point per 300,000 m^2.

MPAs sampling followed a habitat-stratified sampling design. Sampled habitats included fore reef, channel, back reef, lagoon and reef flat. Mangrove habitats were not included in this study. Reef crest habitat was excluded from the sampling design because of shallow and swell conditions.

2. <u>Measurements of ecological variables</u>

At each site, three 30-m transects were laid at a maximum depth of 5-m, following the same direction as the current, and consecutively with a few meters separating each transect. Along each 30-m transect, four surveyors recorded data on fish, invertebrates, benthic cover and coral recruitment. The first surveyor recorded the abundance and size estimates of the most common commercially important and protected fish species within a 5-m wide belt (see fish list in Appendix 1). The second surveyor recorded the abundance of macro-invertebrates within a 2-m wide belt (see invertebrates list in Appendix 2). For the estimation of benthic cover, the third surveyor took a photo every meter along the 30-m transect using an underwater camera (model: Canon G16, mounted on a 1-m x 1-m photo-quadrat PVC frame), for a total of 30 photos per transect. The fourth surveyor recorded the abundance of juvenile corals smaller than 5-cm diameter (to genera) within a 30-cm wide belt of the first 10-m of each transect.

3. <u>Data extraction</u>

To estimate benthic cover, photo-quadrats were analyzed using CPCe software (Kohler and Gill 2006). Five random points were allocated to each photo and the substrate below each point was classified into benthic categories (Appendix 3). The mean percentage benthic cover of each category was calculated for each transect (n = 30 photos per transect, n = 3 transects per site).
The biomass of fish was calculated using the total length-based equation: W= (aT)^b, where W is the weight of the fish in grams, TL the total length of the fish in centimeters (cm), and a and b are constant values from published biomass-length relationships (Kulbicki et al. 2005) and from Fishbase (http://fishbase.org).

4. <u>GIS</u>

The total area of each of the habitat of interest (fore reef, channel, back reef, lagoon and reef flat) was calculated using the NOAA shallow water habitat map of Palau (NOAA 2014) and the plugin Group Stats in QGIS (QGIS Development Team 2015). Areas of protected habitats were calculated by clipping the MPA boundaries layers into the NOAA habitat map using QGIS. Percentage of total habitats and protected areas were calculated.

5. Data analysis

For the main ecological indicators: fish biomass, coral cover, seagrass cover, invertebrates' density and juvenile corals' density, comparison among MPAs was done visually. Bar plots were generated using R statistical software (R Development Core Team 2015).

For ecological scores, MPAs were grouped together depending on their main habitat: (fringing/barrier coral reef, inner coral reef and reef flat). For coral reef MPAs, Principal Component Analysis (PCO) was used to distinguish groups using coral community data and PERMANOVA in Primer (Anderson 2005)(Appendix 4). The ecosystem condition (or score) of each MPA was derived from several metrics that define ecological state and processes and was calculated using similar method as in Houk et al. (2015) (Figure 2).

For each MPA, a score for benthic assemblages and a score of fish and invertebrates assemblages were calculated using several metrics (Figure 2). Each metric was standardized to the mean and standard deviation within the group (fringing/barrier, inner reef, reef flat). All benthic metrics were averaged together; all fish and invertebrates metrics were averaged together to get two final metrics (one for benthic assemblages, one for fish and invertebrates assemblages). To obtain the final score of the MPA, both final metrics were averaged together (Figure 2). Scores were then normalized to maximum and minimum values within the group and multiplied by 100 to get a score between 0 and 100. The stacked bar plots showing the MPAs scores relative to each other were generated in Excel.

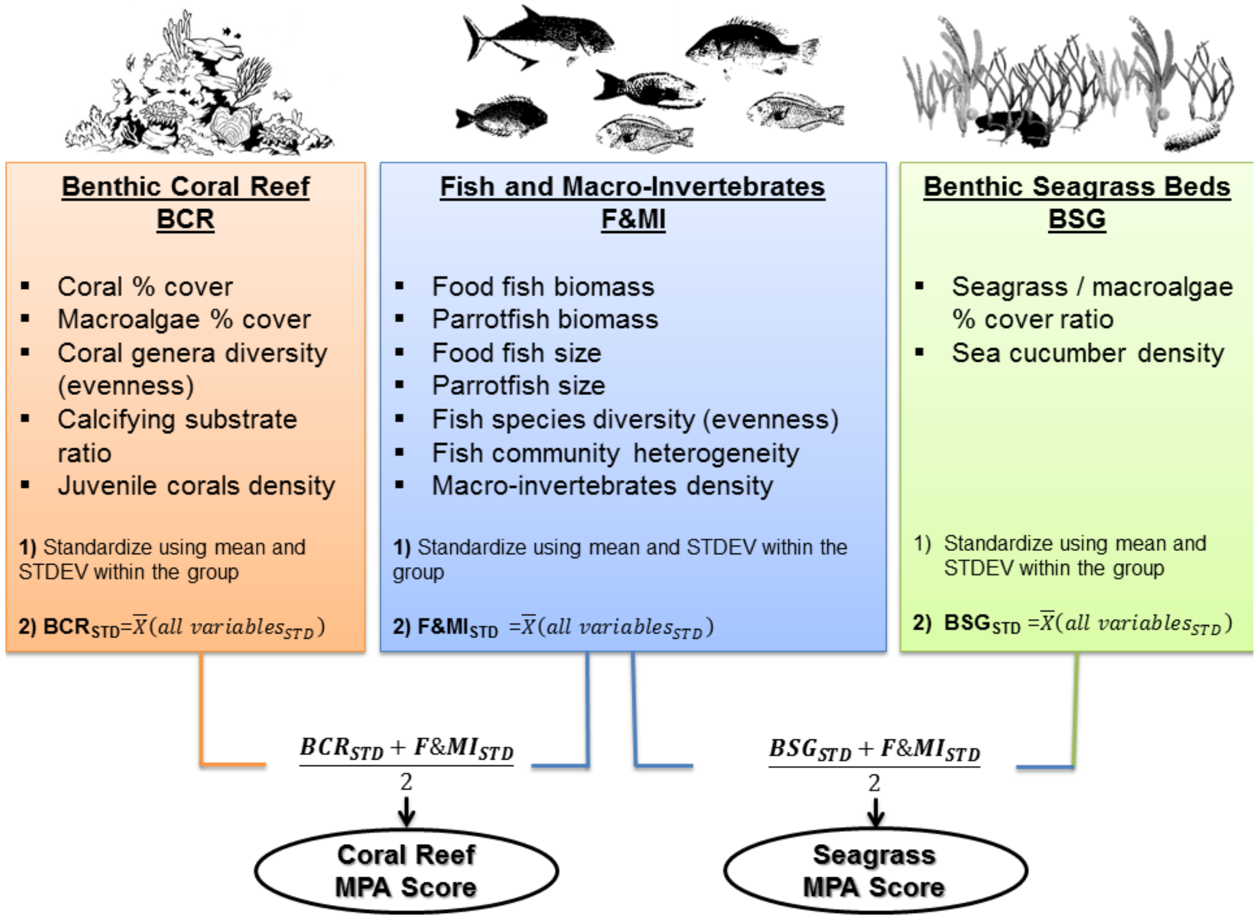


Figure 2: Diagram explaining how to generate MPA scores for coral reef and seagrass beds habitats.

Several predictor variables were tested to better understand the drivers of ecological condition of the MPAs. These drivers were:

- Protection time (years)
- MPA Size (km^2)
- Wave exposure (only for fringing / barrier MPAs)

The wave energy in J/m^3 was calculated at each MPAs on their outer reefs based on Quickscat wind datasets from 1999 to 2009 by Dr. P. Houk with the same methods as in Houk et al. (2015).

- Local access

Local access was defined by calculating the distance from the MPA to the nearest port / boat ramp / jetty using the measuring tool in QGIS.

- Land-based Pollution (only for lagoon and reef flat MPAs located close to watersheds in Babeldaob)

The pollution proxy was defined using (a) the percentage of non-secondary forest in adjacent watershed to the MPAs and (b) the distance between the MPAs and the main river discharge (Houk et al. 2015). The pollution proxy was calculated by multiplying (a) and (b). Vegetation data in Babeldaob was extracted from United States Forest Service land-use data (United States Forest Service, http://www.fs.usda.gov/r5). The vegetation layer was clipped to the watershed area layer (adjacent to the MPA). All non-secondary vegetation was summed using the plugin Group Stats in QGIS (QGIS Development Team 2015) and percentage were calculated. Distances from the MPA to the river discharge was measured using the measuring tool in QGIS.

All drivers were standardized to the mean and standard deviation within their group for scaling purposes before statistical analysis. To explore how the drivers were explaining the ecological condition of the MPAs, generalized linear mixed-effects (glm) modeling was conducted using a nested design with MPAs sites nested within habitats and included as a random term to account for variation among groups (habitats). The range of models were examined using a stepwise model simplification starting with the most complicated model (interaction among all predictor variables) and the elimination of the non-significant terms throughout the process until the best model fit (lowest AIC). The resulting model was then checked for residual normality. Linear models (lm) were also processed within each group to explore any habitat-specific response with a similar approach than for glm. All statistical modeling was performed using “lme4” package and R statistical software (R Development Core Team 2015)

Results

1. Overview of Protection

According to the shallow water habitat map of Palau (NOAA 2014), the total area of outer reef, channel, back reef, lagoon and reef flat is 2,010 km^2 (Table 1). 14 % of this area is under protection (no-take zone under state and national legislatures). 11.2 % of this area is protected under PAN. The proportion of marine habitat that is the most protected is channel habitat with 29 %, followed by outer reef (25.7 %) and back reef (16.8 %). Less than 10 % of the lagoon and reef flat habitats are protected.

Table 1: Coral reef and seagrass beds MPAs in Palau, their total area, the area of surveyed habitats and the percentage of protected habitats

		Area (m^2)						
STATE	**Name**	**Total**	**Outer Reef**	**Channel**	**Back Reef**	**Lagoon**	**Reef Flat**	**PAN Site**
Aimeliik	Ngerchebal Island Wildlife Conservation	8,136,050				8,131,892		**NO**
Airai	Medal Ngediull Conservation Area	3,184,610				1,422,550	1,362,060	YES
Angaur	Iuiau Conservation Area	3,411,535	2,508,662				714,726	YES
Hatohobei	Helen Reef	121,200,516	7,575,783	4,246,700	31,509,569	69,039,136		YES
Kayangel	Ngeruangel Reserve	56,546,700	3,588,560		9,259,480	5,808,380		YES
Koror	Ngemelis Island Complex	40,280,200	1,482,141	330,002	17,804,336	18,228,147		**NO**
Koror	Ngerumekaol Spawning Area	3,519,920	449,405	217,995	2,852,520			YES
Koror	Ngemelachel-Ngederrak Seagrass Beds	5,882,770	559,199	1,062,670		643,220	3,282,560	**NO**
Koror	Ngerkebesang Conservation Zone	117,732				97,823	19,909	**NO**
Koror	Ngerukeuid Island Preserve	11,396,600				10,546,918		YES
Melekeok	Ngermedellim Management Area	447,653					447,653	YES
Ngaraard	Ongiil Conservation Area	1,171,463	216,525	230,744			685,277	**NO**
Ngarchelong	Ebiil Channel Conservation Area	17,798,100	799,775	1,618,880	7,515,290	7,864,155		YES
Ngardmau	Ngermasech Conservation Area	2,925,940				176,122	2,749,818	YES
Ngardmau	Ileyakl Beluu Conservation Area	359,333	74,443		255,397	29,493		YES
Ngaremlengui	Bkulengriil Conservation Area	665,899			31,633		634,266	**NO**
Ngatpang	Oreuaol Ibuchel Conservation Area	716,256				489,523	226,733	YES
Ngchesar	Ngelukes Conservation Area	1,043,340	68,333				815,355	YES
Ngiwal	Ngemai Conservation Area	2,922,140	75,282	383,699			1,716,760	YES
Peleliu	Teluleu Conservation Area	540,143					540,143	YES

Total Protected Area (m^2)	282,266,900	17,398,108	8,090,690	69,228,225	122,477,359	13,195,260
Total PAN Protected Area (m^2)	226,012,786	15,140,243	6,467,274	51,392,256	95,376,277	8,573,248
Total area of outer reef, channel, back reef, lagoon and reef flat in Palau (m^2)	2,009,846,224	67,612,119	27,507,680	412,901,098	1,346,697,292	155,128,034

Percentage of protected habitats	**14 %**	**25.7%**	**29.4%**	**16.8%**	**9.1%**	**8.5%**
Percentage of PAN protected habitats	**11.2%**	**22.4%**	**23.5%**	**12.4%**	**7.1%**	**5.5%**

2. Overview of main ecological indicators within each MPA

2.1. Fish Biomass

Over all the MPAs, regardless of their habitats, the highest biomass of commercially-important fish species (Appendix 1) was found in Ebiil CA with more than 20,000 g per 150 m^2 (Figure 3). The lowest fish biomass was found in Teluleu CA with 316 g per 150 m^2.

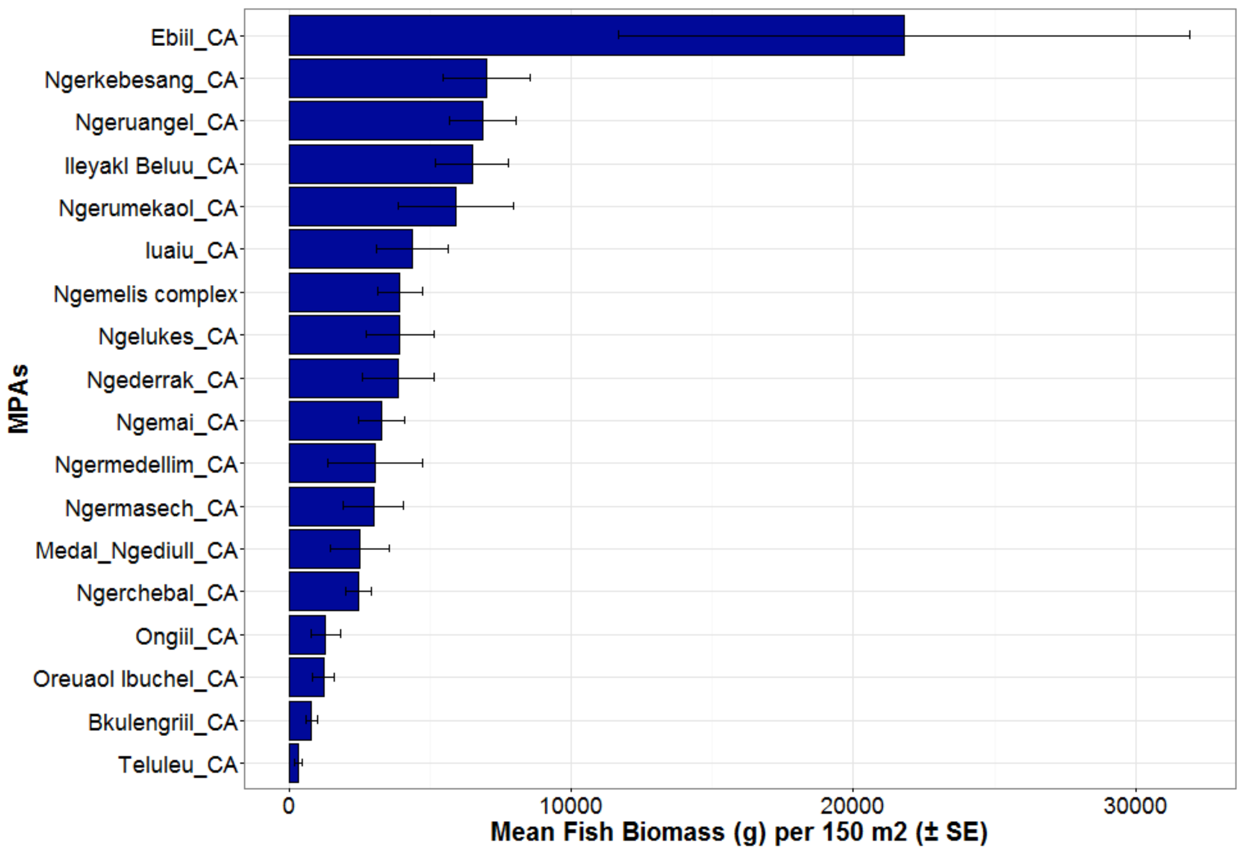


Figure 3: Mean fish biomass within the MPAs (all habitats combined)

Over all the MPAs, the habitat that hosted the highest biomass of commercially-important species was channel and outer reef habitats (Appendix 5). The reef flat habitat had the lowest fish biomass.

The abundance of protected fish species (Appendix 1) was high in Ngerkebsang CA with 2.2 ± 0.9 individuals per 150 m^2, in Ngederrak CA with 2.02 ± 1.1 individuals per 150 m^2, and in Ngermasech CA with 1.8 ± 1.4 individuals per 150 m^2.

2.2. Live coral cover

Overall the MPAs, regardless their reef habitats (outer reef, channel, back reef, lagoon), inner reef MPAs had the highest live coral cover: Ngerchebal, Medal Ngediull, Bkulengriil, Oruaol Ibuchel and Ngelukes with more than 35 % cover (Figure 4). Ongiil and Ngeruangel CA exhibited low coral cover (less than 5%).

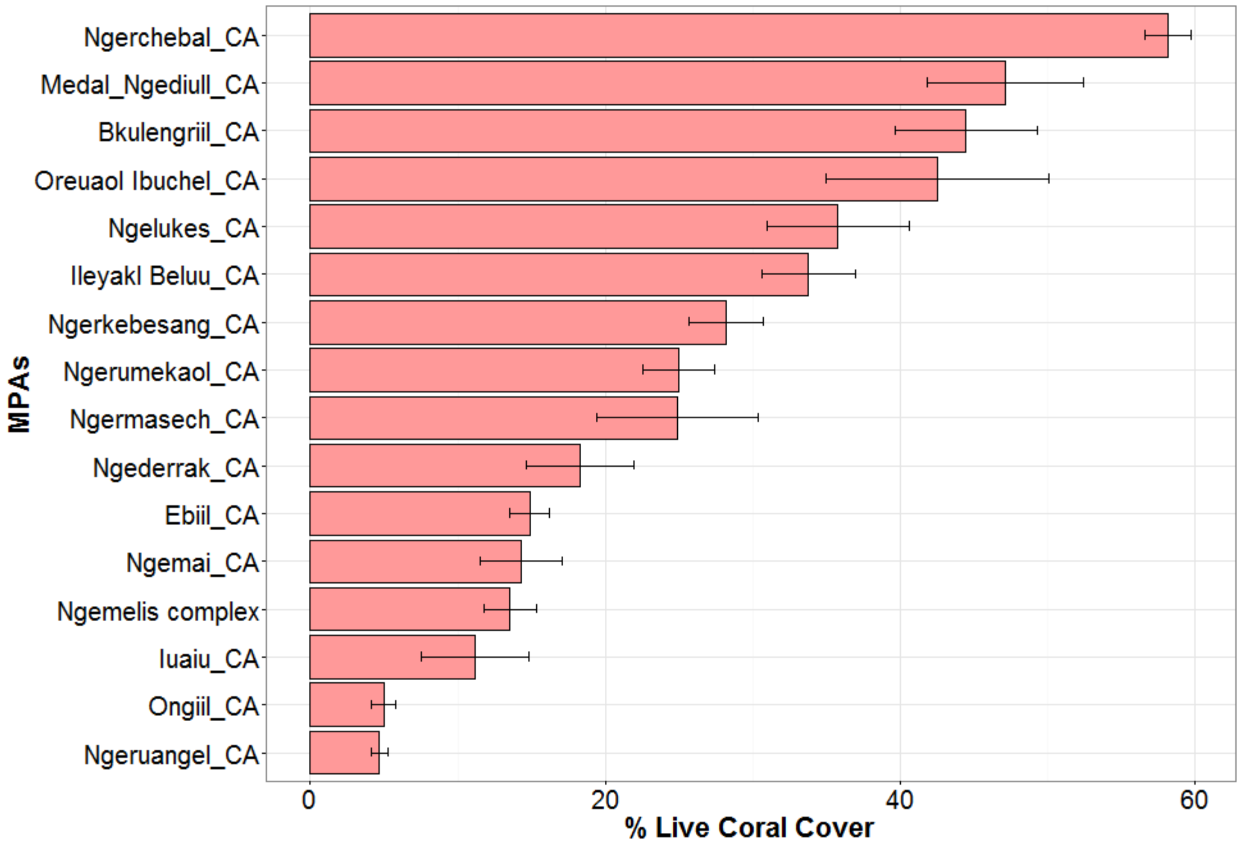


Figure 4: mean percentage cover of coral at MPAs within coral reef habitat (averaged over fore reef, back reef, channel and lagoon)

The cover of live coral differed greatly among habitats within an MPA. Overall, outer reef and channel habitats had higher coral cover than lagoon and back reef habitats.

2.3. Seagrass cover

Seagrass were only found in the reef flat habitat. Seagrass cover was high at Teluleu and Bkulengriil CA with 42.7% ± 5 % and 39.4% ± 4.2% respectively. The MPAs with the lowest seagrass cover were Oruaol Ibuchel and Medal Ngediull CAs with 9.6 ± 4.7 and 2.2 % ± 0.8 (Figure 5). All the other MPAs had a seagrass cover greater than 25 %.

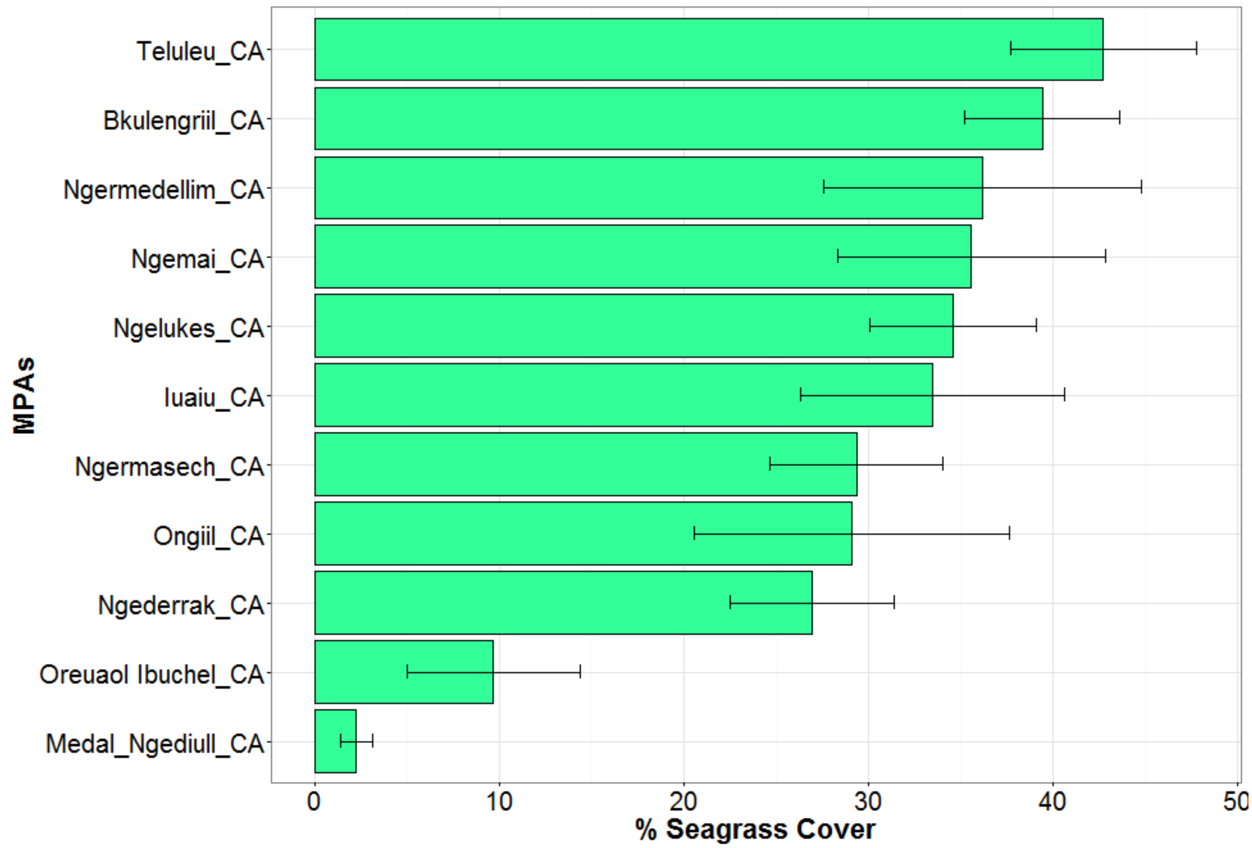


Figure 5: Mean percentage cover of seagrass at MPAs with a reef flat habitat

2.4. Juvenile coral density

Juvenile corals were present in the fore reef, lagoon, back reef and channel habitats. The highest density of juvenile corals was found in Ileakl Beluu CA with 9.7 ± 1.2 individuals per m^2 (Figure 6). The lowest densities were found on the east coast in Ngelukes and Ngemai CAs with less than 1 individuals per m^2. Overall all MPAs, juvenile corals were more abundant in the fore reef, followed by lagoon and channel habitats

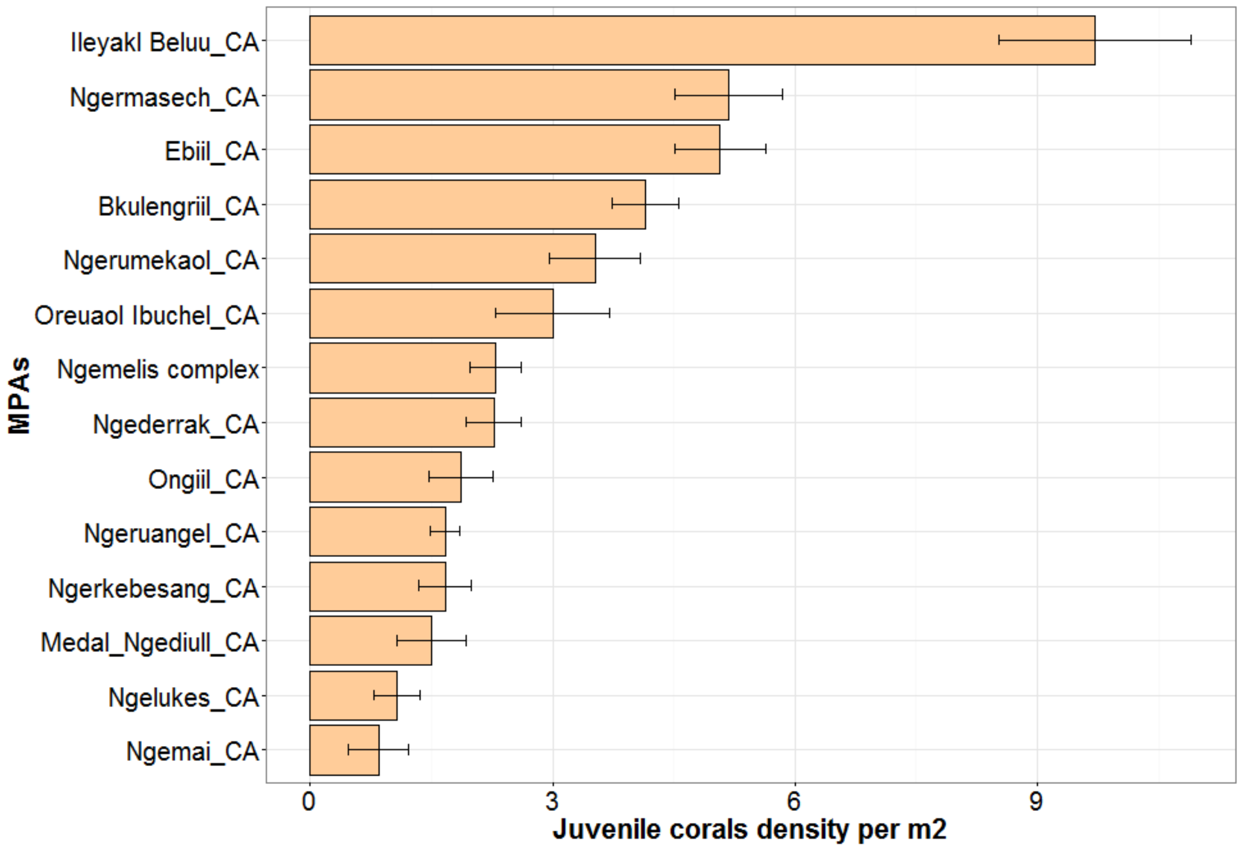


Figure 6: Mean juvenile coral density per m^2 at MPAs

2.5. Macro-invertebrates density

The density of macro-invertebrates was the highest at MPAs that had a reef flat habitat. Ngermasech, Ngerkebesang and Ngemai CAs had the highest abundance of invertebrates (Figure 7). Ngermasech and Ngemai had high edible sea cucumbers densities with 30.4 ± 3.9 and 20.8 ± 14.2 individuals per 60 m^2 (Figure 7). The lowest abundance of macro-invertebrates was found in Iuaiu, Teluleu, Bkulengriil and Ongiil CAs with less than 0.5 individuals per 60 m^2. Overall, there were more invertebrates and especially sea cucumbers in the reef flat habitat than in all other studied habitats. Clams were equally distributed in all habitats but at slightly higher density in the reef flat.

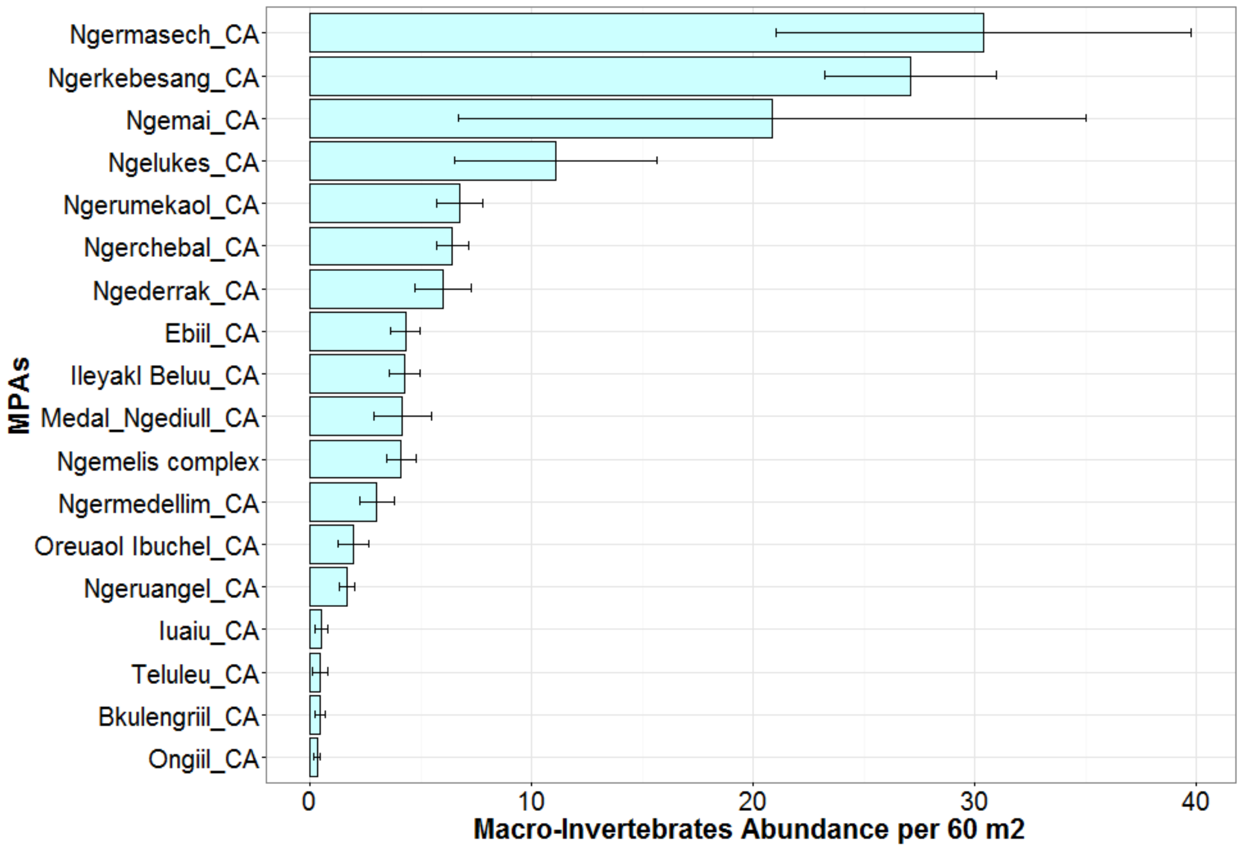


Figure 7: Macro-invertebrates abundance at MPAs

3. <u>Ecological scores</u>

Ecological scores of MPAs were based on all the ecological indicators previously presented. Details on how to calculate them were described in the Methods section. For fringing / barrier and inner reef MPAs, more than two third of the MPAs had a score higher than 60 % (Figure 8). For inshore seagrass bed MPAs, more than half of the MPAs had a score lower than 50 %. MPAs with the highest scores were Ebiil and Ngermasech CAs. The lowest scores were attributed to Ongiil and Ngelukes CAs.

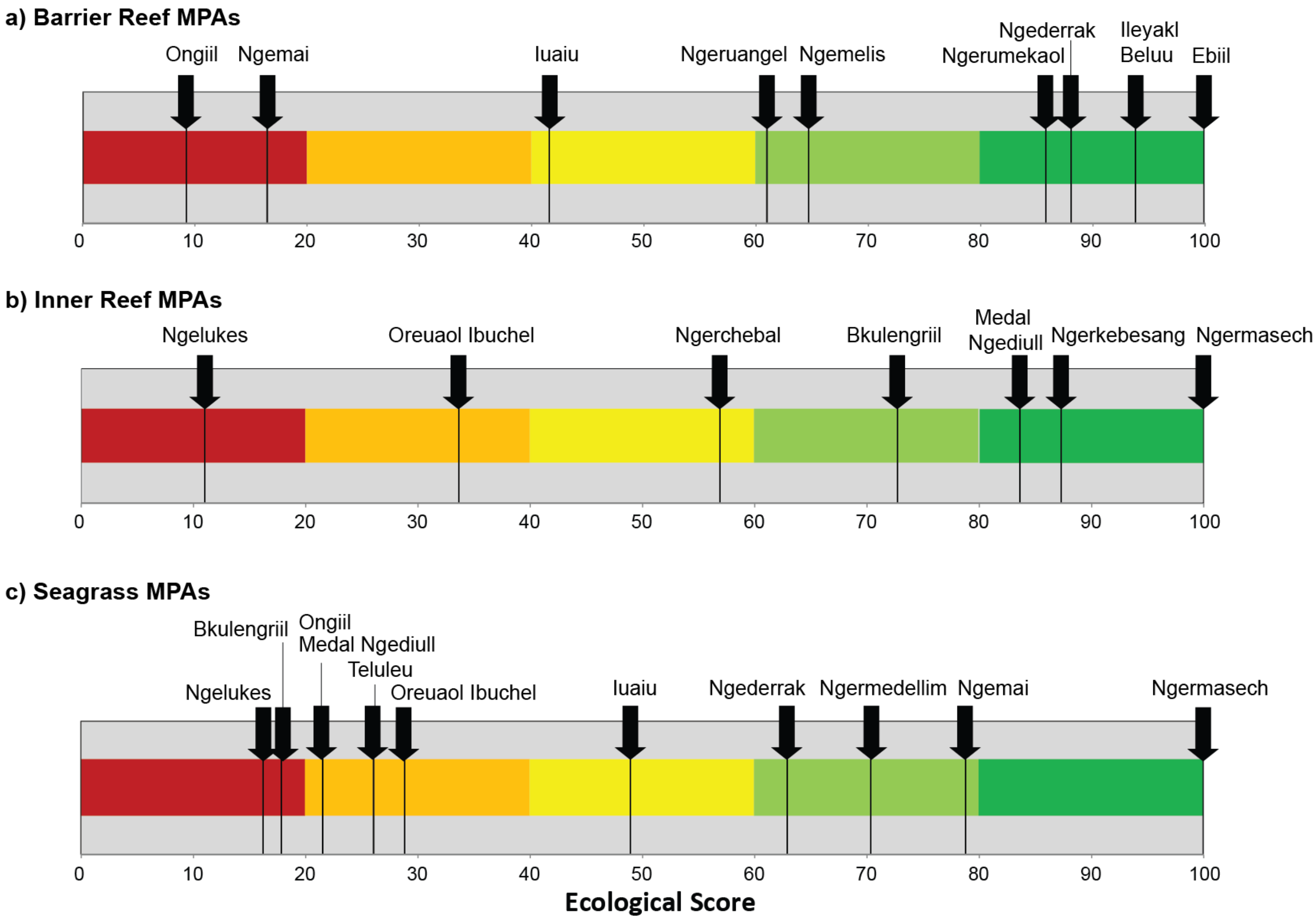


Figure 8: Ecological scores of MPAs according to their main habitat a) fringing and barrier reef, b) lagoonal inner reef, c) reef flat with seagrass beds

4. Potential drivers of ecological conditions of MPAs

General linear regression modeling on the ecological condition of all the MPAs, regardless their group, demonstrated a significant positive effect of the length of protection ($P < 0.05$) (Figure 9).

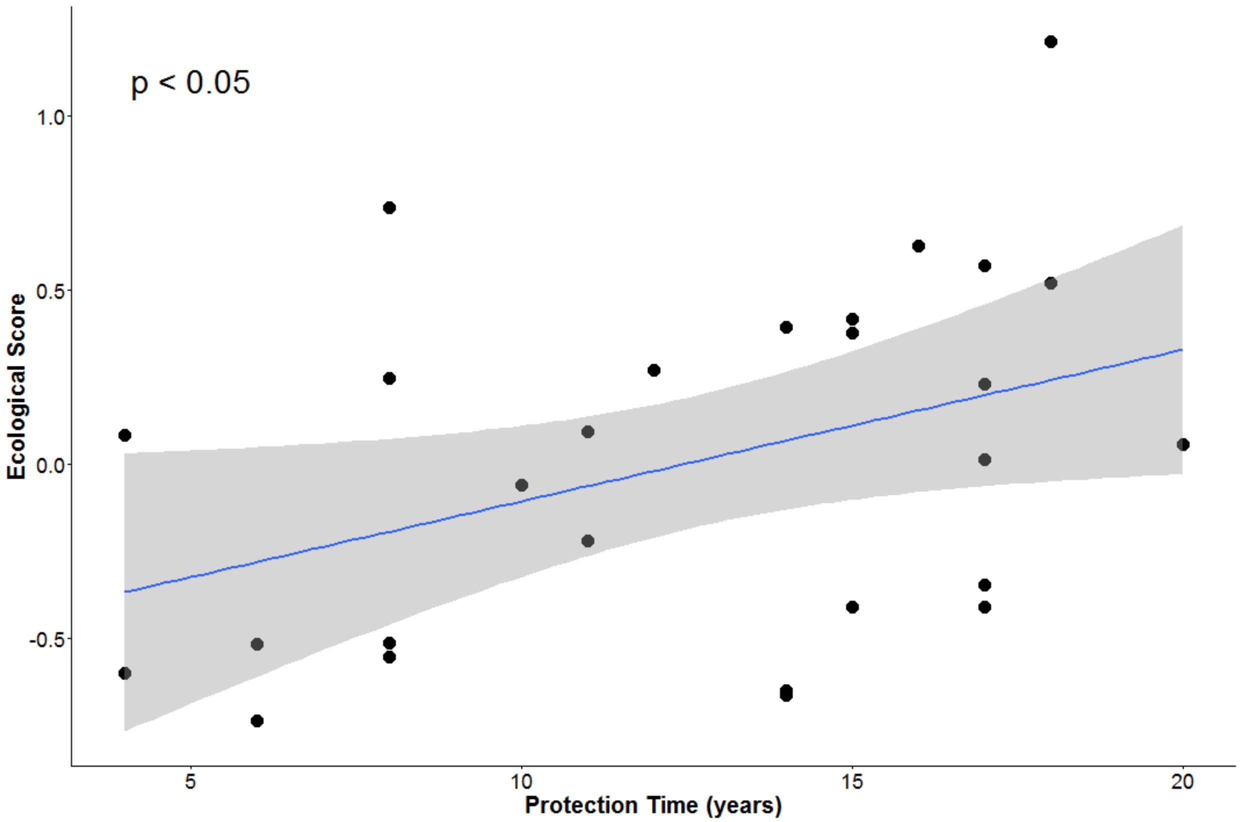


Figure 9: Regression model showing the positive relationship between the ecological conditions of the MPAs and number of years they have been protected for. The grey area represents 95 % confidence interval around the regression line.

Linear regression within the group fringing / barrier MPAs showed an additive positive effect of the length of protection ($P < 0.01$), the size of the MPA ($P = 0.01$), and distance to the closest boat ramp or port (marginally significant, $P = 0.06$) (Figure 10).

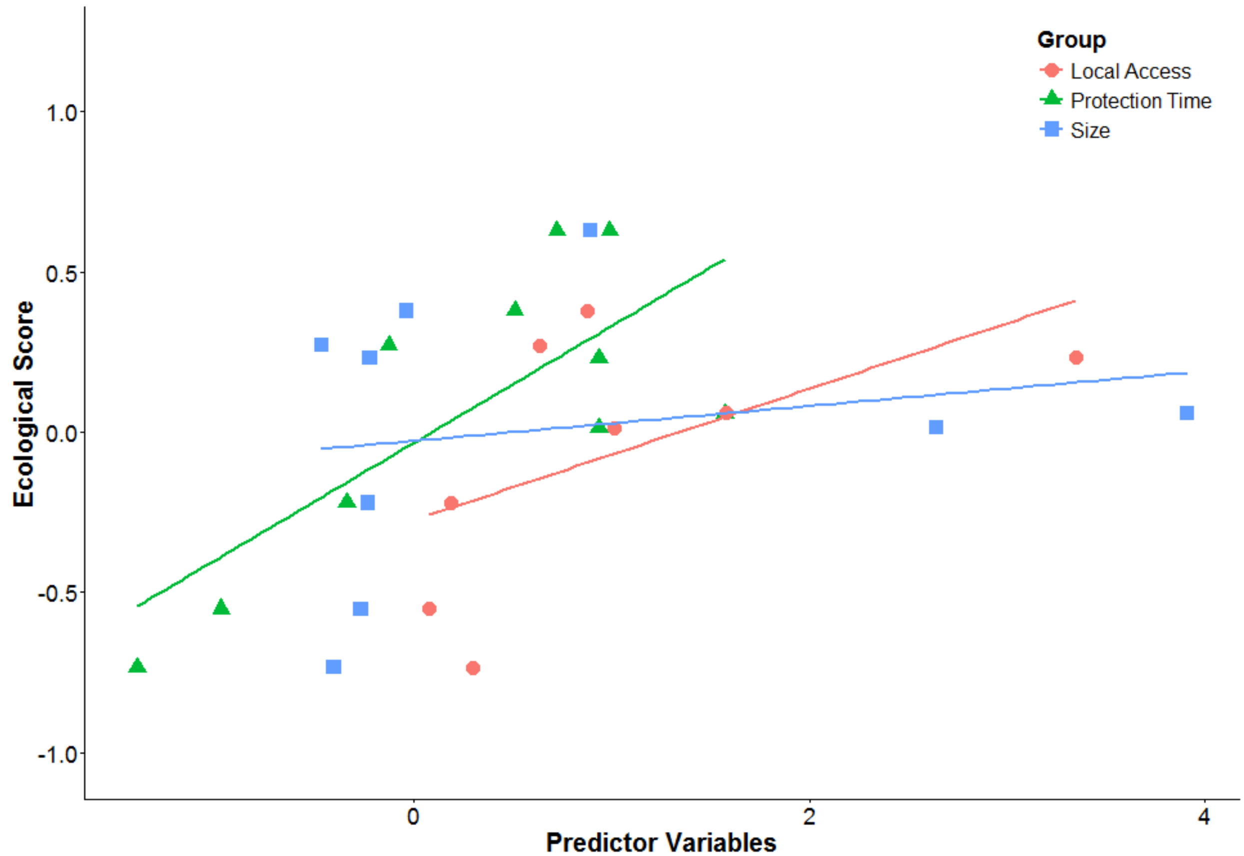


Figure 10: Linear regression plot showing the positive relationship between the ecological condition of fringing / barrier reef MPAs and the length of protection (green triangular symbol), the size of the MPA (blue square symbol) and remoteness (distance from local access, red circular symbol)

To explore the effect of coastal pollution on MPAs, all MPAs located in the lagoon, close to the watersheds of the main island, Babeldaob, were grouped together. This included all lagoon and seagrass MPAs except Ngederrak, Ngerkebesang, Iuaiu and Teluleu CAs. In this study, pollution index was defined using the percentage of non-secondary vegetation in the adjacent watershed to the MPA and the distance to the main river discharge (detailed in the Methods section). General linear regression modeling on the ecological condition of these MPAs demonstrated a significant negative effect of pollution ($P < 0.05$) (Figure 11).

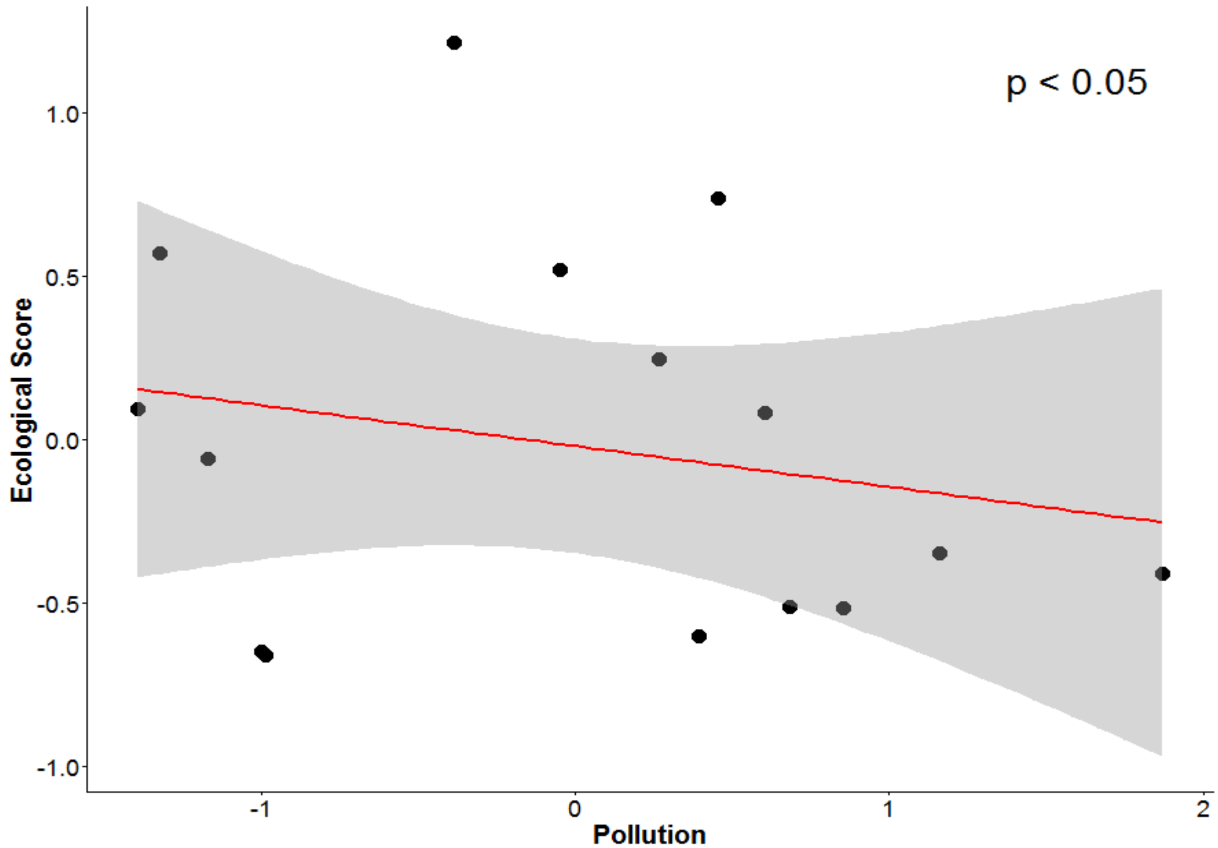


Figure 11: Regression model showing the negative relationship between the ecological conditions of the MPAs close to watersheds in Babaledaob and land-based pollution. The grey area represents 95 % confidence interval around the regression line.

Discussion

MPAs are used worldwide to tackle anthropogenic impacts and help sustain marine resources. In Palau, 14% of coral reef and seagrass ecosystems are protected; 11.2% of which are under PAN legislation. The marine habitats the most protected are channel and outer reef (> 25 %). The marine habitats the least protected are reef flat and lagoon (<10%). Overall, more than half of MPAs were in a relatively good condition with a score greater than 50%. This study demonstrated that the length of protection was the principal determinant to a better ecological condition of MPAs. Additional drivers played significant roles but were specific to MPAs groups (fringing / barrier reef and nearshore) and will be discussed further on.

This study was conducted over two years, in 2014 and 2015, and consisted of one time baseline measurement of several ecological indicators within different habitats of 18 conservation areas. Overall, fish biomass and abundance varied among habitats within MPAs (Appendix 5) which demonstrated that habitat-stratified sampling was required to better capture the condition of fish populations within a conservation area. Live coral cover was much higher in lagoonal MPAs than outer reef MPAs. For outer reef MPAs, MPAs located on the eastern reefs displayed a low coral cover (< 5 %) attributed to the impacts of sequential typhoons in 2012 and 2013 (Gouezo et al. 2015a). The juvenile coral density was greater on the western reefs than on the eastern reefs which may also be a result of the loss of mature colonies related to typhoon disturbances. Lastly, the abundance of macro-invertebrates was much higher in reef flat habitats of nearshore MPAs. This might simply be the result of geographical distribution but this finding highlights the need of appropriate protection management at these sites.

Fringing / barrier reef Conservation Areas

Six out of nine outer reef MPAs demonstrated a score higher than 60%, whose the highest score was for Ebiil CA. The low scores were attributed to Ongiil, Ngemai and Iuaiu CAs. Due to their location on the east coast, these MPAs were potentially impacted by typhoon Bopha and Haiyan in 2012 and 2013 respectively. Because of the absence of data at these sites pre-disturbance (expect for Ngemai CA), we cannot certify that the occurrence of typhoons was the only explanation for low ecological conditions. For Ngemai CA, coral cover remained around 25 % since 2011, despite typhoon disturbance; however, juvenile coral density greatly decreased post-disturbance (Koshiba et al. 2013b; Gouezo et al. 2015b). It seemed that typhoon disturbance had an impact on these MPAs but to a certain degree and other factors are interacting.

Our results of regression modeling analysis showed that there was an additive effect of three main drivers: the length of protection, the size of MPAs and the distance of MPAs to the nearest local access (port, boat ramp, jetty). These findings are very similar to Friedlander et al. (2015) where fish trophic biomass was highly driven by MPA age, offshore location and MPA size in Palau.

Inner reef and nearshore Conservation Areas

Out of seven inner reef MPAs, only two displayed a score lower than 50 %: Ngelukes and Oruaol Ibuchel CAs; the highest score was attributed to Ngermasech CA. Regarding nearshore seagrass MPAs, more than half had a score lower than 50%. Together, these findings showed that the benefits of protection were not maximized and other anthropogenic pressure than fishing must interfere. The level of land-based pollution at each MPA was developed using vegetation data and area of cleared land in adjacent watershed to the MPA as well as the distance to the main river discharge (detailed in Methods section). Results of regression modeling analysis demonstrated that pollution level explained significantly the ecological condition of neashore MPAs. This finding was also showed in other island nations in Micronesia, especially in Yap and Ponhpei, where urbanized adjacent watersheds explained the ecological condition of sites nearby (Houk et al. 2015). Water quality and sedimentation stresses on nearshore coral reefs (Golbuu et al. 2003, 2011a, 2011b; Koshiba et al. 2013a) and seagrass beds (Sampson et al. 2014; Rehm et al. 2015) are well documented in Palau but rarely integrated into management actions to minimize the impacts. In addition to these studies, our results highlighted the impact of poor-land use on the overall ecological condition of several MPAs, on their ecosystems as a whole (including all ecological variables), whether it is a seagrass bed or a coral reef.

Recommendations

This study assumed that there was a good level of enforcement at each of the MPA and that fishing inside a MPA was inexistent. Overall our results showed that MPA age was a significant driver to a better ecological condition which proved that the level of enforcement is respectable. Therefore, enforcement should be maintained and even strengthened to ensure the effectiveness of the following recommendations.

For fringing and barrier MPAs, in order to meet the MC goal (30% of effective marine protection), the percentage of protection covering outer reef and channel is very close to 30%, so we do not recommend implementing new MPAs in these habitats. In addition, according to our findings and Friedlander et al. (2015), benefits of protection were maximized as the MPA gets older. If new MPAs were to be implemented in these habitats, the size (as big as possible) and the remoteness (as far as possible from land) should be prioritized factors.

For nearshore MPAs, inner reefs MPAs had good ecological condition but only 9% of the lagoon habitat is under protection. Nearshore seagrass MPAs had low ecological conditions but only 8.5% of reef flat habitat is under protection. Our findings showed that land-based pollution was a significant driver to the ecological conditions of nearshore MPAs. Therefore, we suggest that better land use practices that would minimize erosion and sedimentation should be implemented as soon as possible with a focus on MPAs with the lowest scores: Ngelukes, Bkulengriil, Ongiil, Medal Ngediull, and Oruaol Ibuchel. The implementation of new nearshore

MPAs to meet the 30% MC goal will not be beneficial to Palau's conservation goals unless land use nearby the MPA is adequately managed.

Acknowledgement

PICRC would like to thank all States rangers and States' Government for allowing us within their MPA and assisting us in the field. This publication was made possible with support from NOAA's Coral Reef Conservation Program, Micronesia Challenge Trust., PEW charitable trusts, and the GEF Small Grant Programme. Thank you to Dr. Peter Houk, from the University of Guam, for providing extensive help with the scoring system and constructive reviewing during the analysis process.

References

Anderson MJ (2005) Permutational multivariate analysis of variance. Dep. Stat. Univ. Auckl. Auckl.

Friedlander AM, Golbuu Y, Caselle J, Ballesteros E, Letessier T, Meeuwig JJ, Gouezo M, Olsudong D (2015) Marine Biodiversity and protected areas in palau: Scientific report to the government of the Republic of Palau.

Golbuu Y, Victor S, Wolanski E, Richmond RH (2003) Trapping of fine sediment in a semi-enclosed bay, Palau, Micronesia. Estuar. Coast. Shelf Sci. 57:941–949

Golbuu Y, van Woesik R, Richmond RH, Harrison P, Fabricius KE (2011a) River discharge reduces reef coral diversity in Palau. Mar. Pollut. Bull. 62:824–831

Golbuu Y, Wolanski E, Harrison P, Richmond RH, Victor S, Fabricius KE (2011b) Effects of Land-Use Change on Characteristics and Dynamics of Watershed Discharges in Babeldaob, Palau, Micronesia. J. Mar. Biol. 2011:1–17

Gouezo M, Golbuu Y, van Woesik R, Rehm L, Koshiba S, Doropoulos C (2015a) Impact of two sequential super typhoons on coral reef communities in Palau. Mar. Ecol. Prog. Ser. 540:73–85

Gouezo M, Otto EI, Koshiba S, Mereb G, Olsudong D, Jonathan R (2015b) Baseline Assessment of Ngemai Conservation Area.

Houk P, Camacho R, Johnson S, McLean M, Maxin S, Anson J, Joseph E, Nedlic O, Luckymis M, Adams K, Hess D, Kabua E, Yalon A, Buthung E, Graham C, Leberer T, Taylor B, van Woesik R (2015) The Micronesia Challenge: Assessing the Relative Contribution of Stressors on Coral Reefs to Facilitate Science-to-Management Feedback. PLOS ONE 10:e0130823

Koshiba S, Besebes M, Soaladaob K, Isechal AL, Victor S, Golbuu Y (2013a) Palau's taro fields and mangroves protect the coral reefs by trapping eroded fine sediment. Wetl. Ecol. Manag. 21:157–164

Koshiba S, Idechong J, Isechal A, Nakaya S, Merep A, Mereb G, Oldiais N, Olsudong D, Nestor V (2013b) A Biological Survey of Ngemai Marine Protected Area. 1–15

NOAA (2014) NOAA Shallow-Water Benthic Habitats: Republic of Palau. Pacific Islands Ocean Observing System (PacIOOS).

QGIS Development Team (2015) QGIS Geographic Information System. Open Source Geospatial Foundation Project,

R Development Core Team (2015) R: A language and environment for statistical computing. Vienna, Austria

Rehm L, Olsudong D, Mereb G, Gouezo M (2015) Gaining insight on MPA health through long-term seagrass monitoring in Palau (update 2014).

Sampson K, Merep A, Olsudong D, Mereb G, Andrew J (2014) Gaining insight on MPA health through long-term seagrass monitoring in Palau.

Appendix 1:

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	Beyadel/Ngesngis	*Cetoscarus bicolor*
4	Parrotfish species	Melemau	*Cetoscarus/Chlorurus/Scarus spp*
5	Yellow cheek tuskfish	Budech	*Choerodon anchorago*
6	Indian ocean longnose parrotfish	Bekism	*Hiposcarus harid*
7	Pacific longnose parrotfish	Ngeaoch	*Hipposcarus longiceps*
8	Rudderfish	Komud, Teboteb	*Kyphosusspp (vaigiensis)*
9	Orangestripe emperor	Udech	*Lethrinus obsoletus*
10	Longface emperor	Melangmud	*Lethrinus olivaceus*
11	Red gill emperor	Rekruk	*Lethrinus rubrioperculatus*
12	Yellowlip 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	Orangespine unicornfish	Cherangel	*Naso lituartus*
18	Bluespine unicornfish	Chum	*Naso unicornis*
19	Giant sweetlips	Melimralm,Kosond/Bikl	*Plectorhinchus albovittatus*
20	Yellowstripe sweetlips	Merar	*Plectorhinchus crysotaenia*
21	Pacific steephead parrotfish	Otord	*Scarus micorhinos*
22	Greenthroat parrotfish	Udouungelel	*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	Humpheadwrasse	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 2: Macro-invertebrates list

Common names	Palauan name	Scientific name
Black teatfish	Bakelungal-chedelkelek	*Holothuria nobilis*
White teatfish,	Bakelungal-cherou	*Holothuria fuscogilva*
Golden sandfish	Delalamolech	*Holothuria lessoni*
Hairy blackfish	Eremrum, cheremrum edelekelk	*Actinopyga miliaris*
Hairy greyfish	Eremrum, cheremrum	*Actinopyga sp.*
Deepwater red fish	Eremrum, cheremrum	*Actinopyga echinites*
Deepwater blackfish	Eremrum, cheremrum	*Actinopyga palauensis*
Stonefish	Ngelau	*Actinopyga lecanora*
Dragonfish	Irimd	*Stichopus horrens*
Brown sandfish	Meremarech	*Bohadschia vitiensis*
Chalk fish	Meremarech	*Bohadschia similis*
Leopardfish /tigerfish	Meremarech, esobel	*Bohadschia argus*
Sandfish	Molech	*Holothuria scabra*
Curryfish	Delal a ngimes/ngimes ra tmolech	*Stichopus hermanni*
Brown curryfish	Ngimes	*Stichopus vastus*
Greenfish	Cheuas	*Stichopus chloronotus*
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*
Lolly fish	Cheuas	*Holothuria atra*
Pinkfish	Cheuas	*Holothuria edulis*
White snakefish	Cheuas	*Holothuria leucospilota*
Snakefish	Cheuas	*Holothuria coluber*
Red snakefish	Cheuas	*Holothuris falvomaculata*
Surf red fish	Badelchelid	*Actinopyga mauritiana*
Crocus giant clam /	Oruer	*Tridacna crocea*
Elongate giant clam	Melibes	*Tridacna maxima*
Smooth giant clam	Kism	*Tridacna derasa*
Fluted giant clam	Ribkungel	*Tridacna squamosa*
Bear paw giant clam	Duadeb	*Hippopus hippopus*
True giant clam	Otkang	*Tridacna gigas*
Sea urchin	Ibuchel	*Tripneustes gratilla*
Trochus	Semum	*Trochus niloticus*

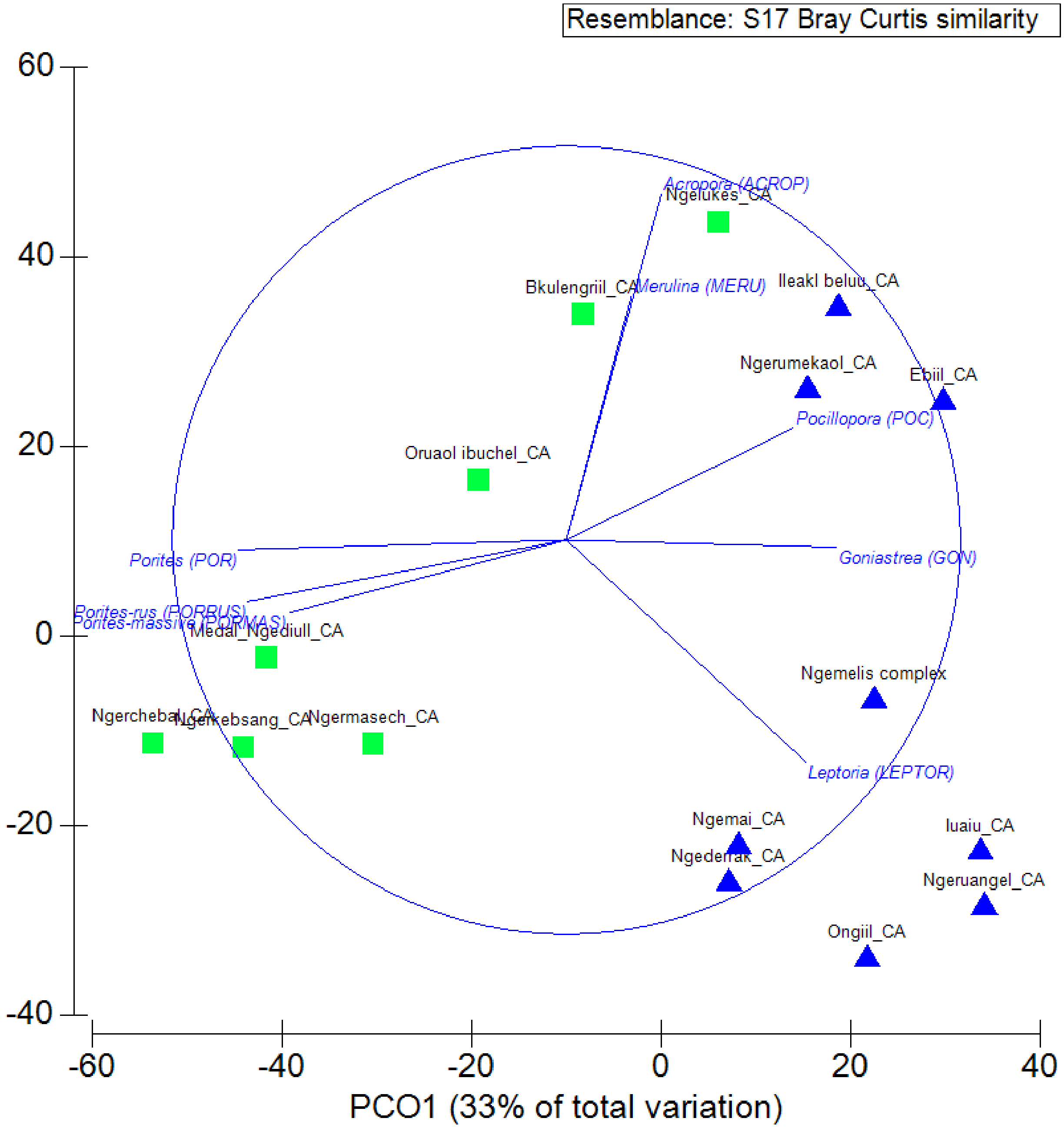
Appendix 3: Benthic categories

CPCe Code	Benthic Categories
"C"	"Coral"
"SC"	"Soft Coral"
"OI"	"Other Invertebrates"
"MA"	"Macroalgae"
"SG"	"Seagrass"
"BCA"	"Branching Coralline Algae"
"CCA"	"Crustose Coralline Algae"
"CAR"	"Carbonate"
"S"	"Sand"
"R"	"Rubble"
"FCA"	"Fleshy Coralline algae"
"CHRYS"	"Chrysophyte"
"T"	"Turf Algae"
"TWS"	"Tape
"G"	"Gorgonians"
"SP"	"Sponges"
"ANEM"	"Anenome"
"DISCO"	"Discosoma"
"DYS"	"Dysidea Sponge"
"OLV"	"Olive Sponge"
"CUPS"	"Cup Sponge"
"TERPS"	"Terpios Sponge"
"Z"	"Zoanthids"
"NoIDINV"	"Not Identified Invertebrate"
"AMP"	"Amphiroa"
"ASC"	"Ascidian"
"TURB"	"Turbinaria"
"DICT"	"Dictyota"
"LIAG"	"Liagora"
"LOBO"	"Lobophora"
"SCHIZ"	"Schizothrix"
"HALI"	"Halimeda"
"SARG"	"Sargassum"
"BG"	"Bluegreen"
"Bood"	"Boodlea"
"GLXU"	"Galaxura"
"CHLDES"	"Chlorodesmis"
"JAN"	"Jania"
"CLP"	"Caulerpa"
"MICDTY"	"Microdictyton"
"BRYP"	"Bryopsis"
"NEOM"	"Neomeris"
"TYDM"	"Tydemania"
"ASP"	"Asparagopsis"
"MAST"	"Mastophora"
"DYCTY"	"Dictosphyrea"

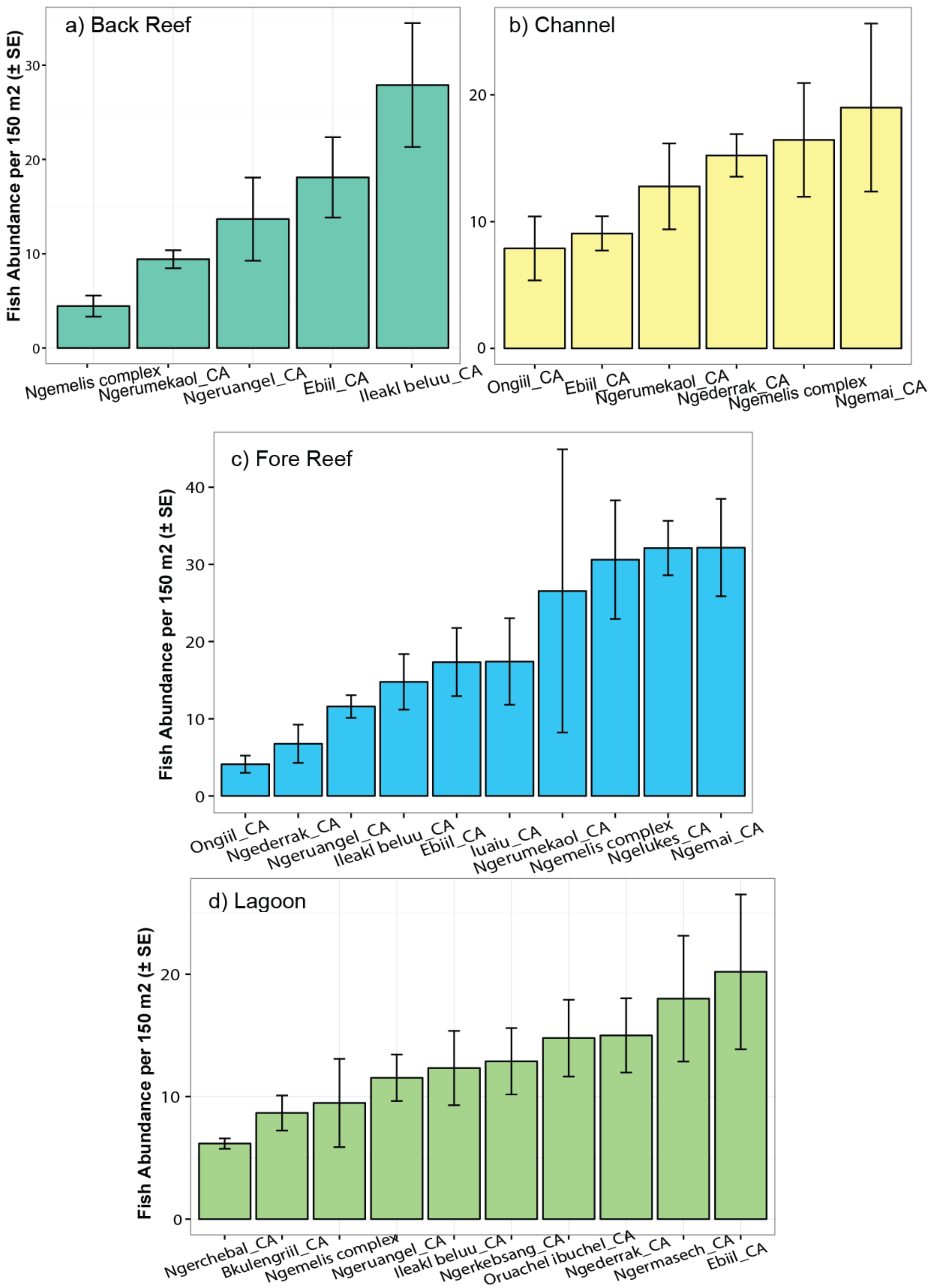
"PAD"	"Padina"
"NOIDMAC"	"Not ID Macroalgae"
"CR"	"C.rotundata"
"CS"	"C.serrulata"
"EA"	"E. acroides"
"HP"	"H. pinifolia"
"HU"	"H. univervis"
"HM"	"H. minor"
"HO"	"H. ovalis"
"SI"	"S. isoetifolium"
"TH"	"T.hemprichii"
"TC"	"T. ciliatum"
"SG"	"Seagrass"
"ACAN"	"Acanthastrea"
"ACROP"	"Acropora"
"ANAC"	"Anacropora"
"ALVEO"	"Alveopora"
"ASTRP"	"Astreopora"
"CAUL"	"Caulastrea"
"CRUNK"	"Coral Unknown"
"COSC"	"Coscinaraea"
"CYPH"	"Cyphastrea"
"CTEN"	"Ctenactis"
"DIPLO"	"Diploastrea"
"ECHPHY"	"Echinophyllia"
"ECHPO"	"Echinopora"
"EUPH"	"Euphyllia"
"FAV"	"Favia"
"FAVT"	"Favites"
"FAVD"	"Faviid"
"FUNG"	"Fungia"
"GAL"	"Galaxea"
"GARD"	"Gardininoseris"
"GON"	"Goniastrea"
"GONIO"	"Goniopora"
"HELIO"	"Heliopora"
"HERP"	"Herpolitha"
"HYD"	"Hydnophora"
"ISOP"	"Isopora"
"LEPT"	"Leptastrea"
"LEPTOR"	"Leptoria"
"LEPTOS"	"Leptoseris"
"LOBOPH"	"Lobophyllia"
"MILL"	"Millepora"
"MONT"	"Montastrea"
"MONTI"	"Montipora"
"MERU"	"Merulina"
"MYCED"	"Mycedium"
"OULO"	"Oulophyllia"

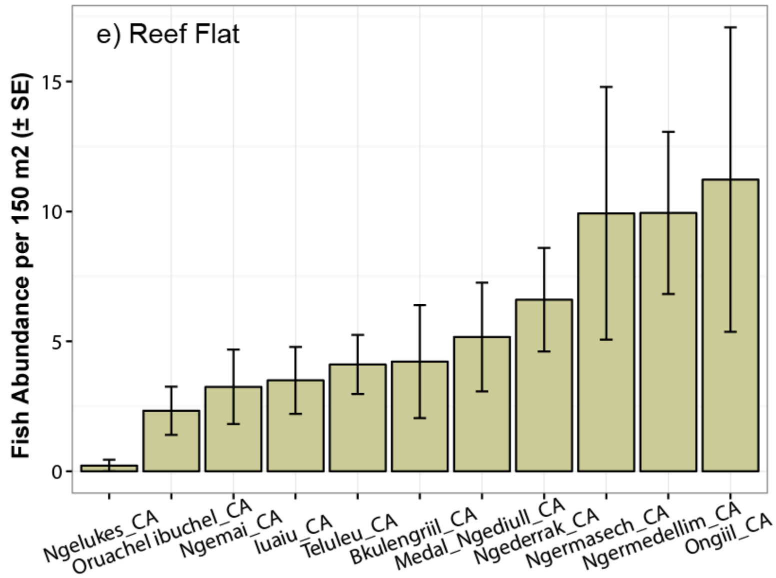
"OXYP"	"Oxypora"
"PACHY"	"Pachyseris"
"PAV"	"Pavona"
"PLAT"	"Platygyra"
"PLERO"	"Plerogyra"
"PLSIA"	"Plesiastrea"
"PECT"	"Pectinia"
"PHYSO"	"Physogyra"
"POC"	"Pocillopora"
"POR"	"Porites"
"PORRUS"	"Porites-rus"
"PORMAS"	"Porites-massive"
"PSAM"	"Psammocora"
"SANDO"	"Sandalolitha"
"SCAP"	"Scapophyllia"
"SERIA"	"Seriatopora"
"STYLC"	"Stylocoeniella"
"STYLO"	"Stylophora"
"SYMP"	"Symphyllia"
"TURBIN"	"Turbinaria"
"CCA"	"Crustose Coralline"
"CAR"	"Carbonate"
"SC"	"Soft Coral"
"Sand"	"Sand"
"Rubble"	"Rubble"
"Tape"	"Tape"
"Wand"	"Wand"
"Shadow"	"Shadow"
"FCA"	"Fleshy-Coralline"
"CHRYOBRN"	"Brown Chysophyte"
"TURF"	"Turf"
"BCA"	"Branching Coralline general"
"BC"	"Bleached Coral"

Appendix 4: Principal Component Analysis of coral reef communities within coral reef MPAs



Appendix 5: Fish Abundance





Appendix 6: Coral reefs and seagrass CAs surveyed in 2014-2015

STATE	Name	No-Take Zone since (State legislature)	PAN Site
Aimeliik	Ngerchebal Island Wildlife Conservation	2006	NO
Airai	Medal Ngedeiull Conservation Area	2008	YES
Angaur	Iuaiu Conservation Area	2005	YES
Hatohobei	Helen Reef	2004	YES
Kayangel	Ngeruangel Reserve	1996	YES
Koror	Ngemelis Island No Fishing Area	1999	NO
Koror	Ngerumekaol Spawning Area	1999	YES
Koror	Ngemelachel-Ngederrak Seagrass Beds	2001	NO
Koror	Ngerkebesang Conservation Zone	2002	NO
Koror	Ngerukeuid Island Preserve	1956	YES
Melekeok	Ngermedellim Management Area	1999	YES
Ngaraard	Ongiil Conservation Area	2010	NO
Ngarchelong	Ebiil Channel Conservation Area	2000	YES
Ngardmau	Ngermasech Conservation Area	1998	YES
Ngardmau	Ileyakl Beluu Conservation Area	2004	YES
Ngaremlengui	Bkulengriil Conservation Area	2012	NO
Ngatpang	Oreuaol Ibuchel Conservation Area	1999	YES
Ngchesar	Ngelukes Conservation Area	2002	YES
Ngiwal	Ngemai Conservation Area	2008	YES
Peleliu	Teluleu Conservation Area	2001	YES