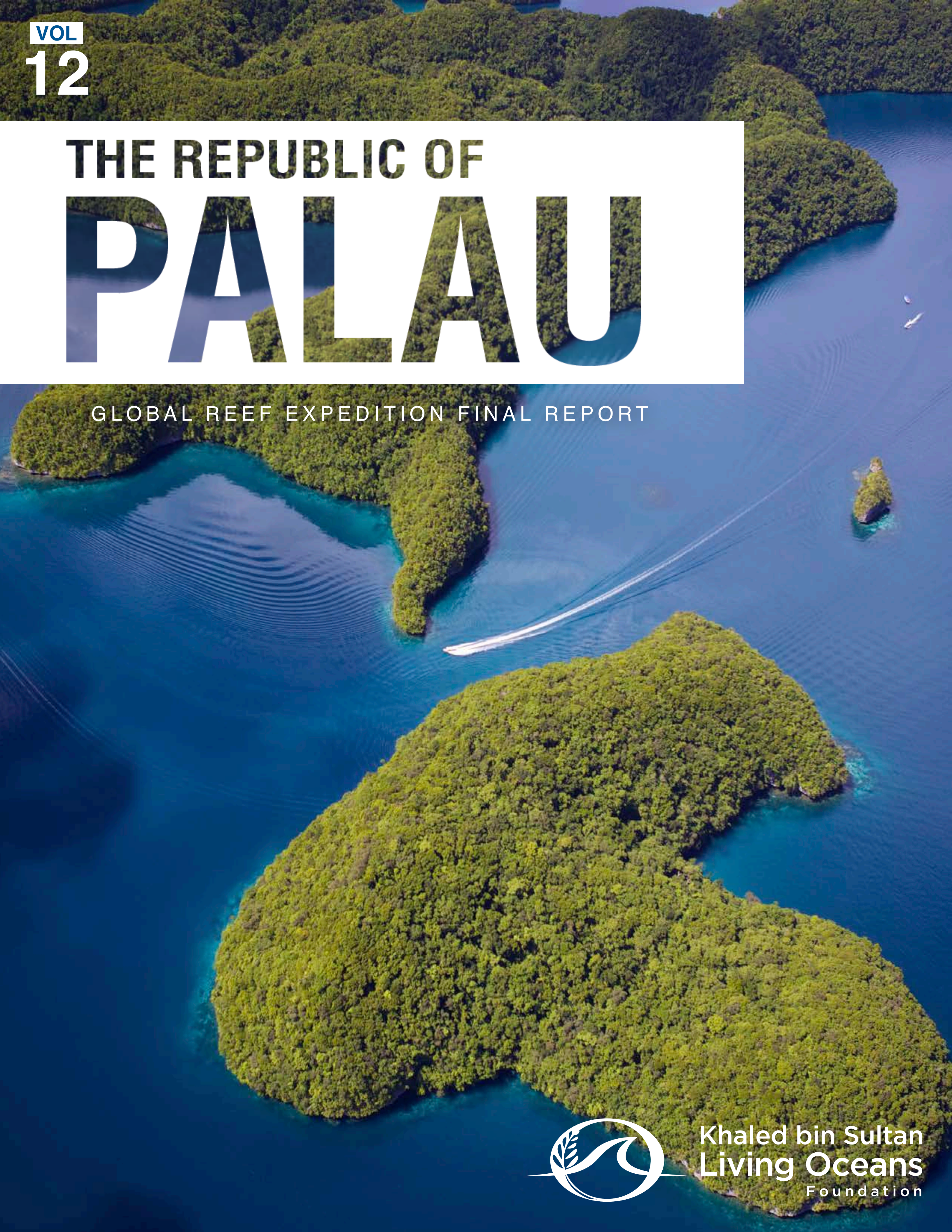

VOL 12

THE REPUBLIC OF PALAU

GLOBAL REEF EXPEDITION FINAL REPORT

Khaled bin Sultan Living Oceans Foundation

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Khaled bin Sultan Living Oceans Foundation

Science Without Borders®

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The Khaled bin Sultan Living Oceans Foundation (KSLOF) is a nonprofit organization dedicated to providing science-based solutions to protect and restore ocean health. KSLOF was incorporated in California as a 501(c)(3), public benefit, Private Operating Foundation in September 2000. Since then, the Living Oceans Foundation has worked to conserve the world's oceans through research, outreach, and education.
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EXECUTIVE SUMMARY

The Khaled Bin Sultan Living Oceans Foundation (KSLOF) embarked on the Global Reef Expedition (GRE) to better understand the status of coral reefs around the world. This ambitious five-year scientific mission was designed to assess the impact of anthropogenic and natural disturbances on coral reef ecosystems and provide communities with the findings so they can inform marine conservation and management plans. Our mission to Palau in January 2015 allowed us to observe some of the most beautiful and pristine coral reefs in the western Pacific Ocean. We found the benthic communities to be in good condition and the reef fish communities to be comparable to other nearby countries surveyed in the south and western Pacific. With additional management of local fishing pressure, particularly near more populated areas, it is possible that the fish communities can be some of the best in the world.

KSLOF brought an elite team of scientists from around the world, including local experts from the Coral Reef Research Foundation (CRRF) and the Palau International Coral Research Center (PICRC), to complete an assessment of the benthic and fish communities in Palau. The team used a standardized methodology to survey reefs around the islands of Babeldaob, Kayangel, Ngeruangel, Koror and the Rock Island Southern Lagoon, Peleliu, and Anguar. This report presents the findings and recommendations by state, as marine conservation in Palau is frequently enforced at the state level. Surveying the reefs of Palau provides critical data that KSLOF will incorporate with our global database to gain a better understanding of the status and resilience of coral reefs globally.

Palau is well known for its advanced coral reef conservation efforts. Palauan's have been practicing conservation for hundreds of years and, to date, have protected nearly 80% of its exclusive economic zone (EEZ). This report provides a strong baseline understanding of the differing status of coral reef communities around Palau, so that this information can be used to make informed marine conservation decisions. The findings from this report highlight areas where Palauans can focus their conservation efforts for the long-term sustainable use of Palau's marine resources.

BENTHIC COMMUNITY ASSESSMENTS

Overall, the benthic communities studied in Palau were some of the best managed and most pristine reefs surveyed on the Global Reef Expedition, particularly compared to other parts of the south and western Pacific. The overall average live cover was the highest observed on the Global Reef Expedition within this region of the world. It is worth noting that our study occurred prior to the global bleaching event in late 2015, when some of the highest coral bleaching was observed at other locations. Coral diversity was high across all states, with a slightly higher diversity being observed outside of the lagoon. Generally, live coral cover was slightly higher outside of the lagoon than inside, which is likely due to the inherent ecological differences of these to reef zones. The high live coral cover observed inside the lagoon was encouraging as it indicates there may be less stress on these reefs, possibly due to the successful establishment of many conservation areas. Two states, Kayangel and Anguar, were hit particularly hard by two typhoons and had overall lower live coral cover, likely due to damage sustained from these disturbances.

FISH COMMUNITY ASSESSMENT

The fish communities of Palau were in relatively good condition, with similar reef fish biomass and density as other nearby countries surveyed in the south and western Pacific. Within Palau, fish biomass and density were higher outside of the lagoonal sites across states when compared to inside, as was the proportion of large fish. Across all states, diversity, biomass, and fish size were generally smaller inside of the lagoon; fish density did not show a clear pattern between sites inside and outside of the lagoon. The differences in fish biomass were driven by differences in fish size rather than abundance. In general, fish populations were less diverse and characterized by smaller fish and lower biomass inside of the lagoons.

Across all states, the fish communities closest to human population centers, such as in Koror, showed the largest disparity in fish diversity and biomass between sites inside and outside of the lagoon. These findings indicate the fish communities are experiencing higher anthropogenic pressures near populated areas, likely due to increased fishing pressure and possible land-based pollution.

RECOMMENDATIONS

Based on the findings from this research mission, it is clear the conservation efforts in Palau are helping maintain a stable coral reef ecosystem, particularly outside of the lagoon. Many of the conservation and protected areas focus restrictions within the lagoon and require special use permits for non-Palauan's and tourism, with some areas requiring fishing permits.

Implementing fisheries management regulations such as fish size and catch limits, as well as additional gear restrictions will help curb the overexploitation of these nearshore lagoonal reefs. It may be prudent to consider increasing protection in areas adjacent to large population centers, such as around Koror to be more restrictive and expand no-take, no-entry area size to allow for recovery of fish populations.

In summary, the following conservation measures could help to ensure the long-term sustainability of Palau's coral reefs and nearshore fisheries:

1. **Implement additional fisheries management regulations**
2. **Improve marine conservation near population centers**
3. **Expand no-take, no-entry areas**

KSLOF commends the people of Palau for the prioritizing conservation of its marine resources. Expansion of current management plans will help ensure the longevity of the coral reefs and fish communities for generations to come.

> This report provides an assessment of **coral reefs** and **reef fish** in **Palau** along with **conservation recommendations** that could help preserve these remarkable coral reefs for the use and enjoyment of **future generations.**

1.0 INTRODUCTION

INTRODUCTION

1.0

The global survival of coral reefs is threatened by both anthropogenic and natural causes, including overfishing, habitat degradation, crown-of-thorns starfish (COTS) outbreaks, storm damage, and climate change. Whereas the Republic of Palau employs some of the most comprehensive marine conservation measures in the western Pacific, it is not excluded from these threats[1].

Studying the reefs of Palau was a priority for the Khaled Bin Sultan Living Oceans Foundation's Global Reef Expedition (KSLOF GRE). Even though Palau's reefs are some of the better studied by the scientific community when compared to other countries visited on the GRE, Palau's commitment to conserving its marine habitats made it an important place to include on the Expedition.

Palau is the westernmost archipelago of the Caroline Islands in the western Pacific Ocean. Palau is closely located northeast of a region referred to as the Coral Triangle, where some of the highest marine biodiversity in the world is found[2]. It is estimated that 415 species of stony corals and about 1,400 species of fish have been recorded in on the reefs of Palau[3–5]. Palau has an exclusive economic zone (EEZ) measuring 629,000 km^2, which borders Indonesia, the Philippines, and the Federated States of Micronesia **(Figure 1)**. The main island group of Palau has one large island, Babeldaob, which is bordered by smaller uplifted reef islands. To the north of the main island are two smaller atolls, Kayangel and Ngeruangel, and immediately to the south is the island, Angaur. The Southwest Islands are the farthest from Babeldaob and are comprised of five small islands and one atoll.

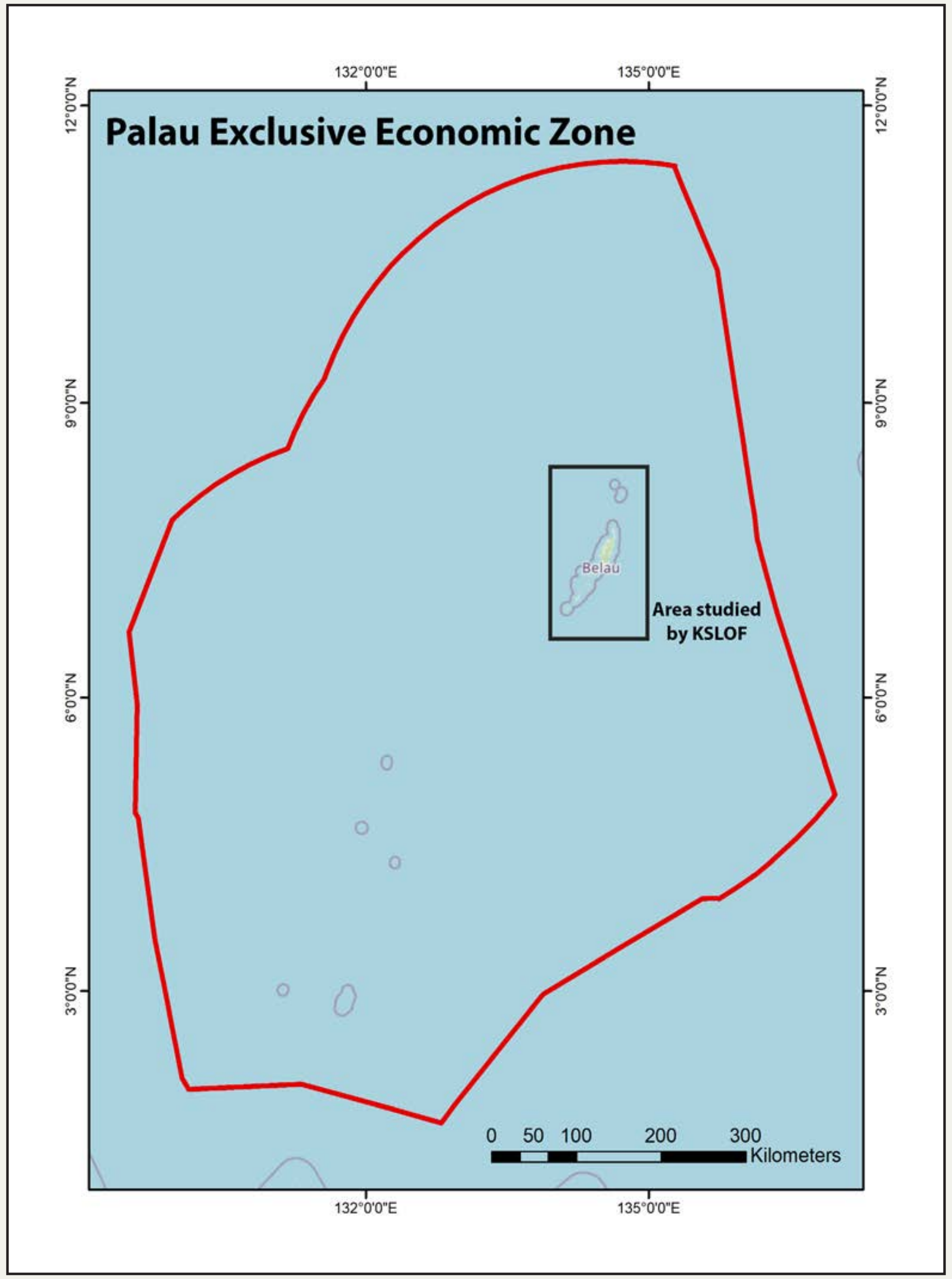
On the Global Reef Expedition, KSLOF scientists and partners surveyed reefs within and outside of the lagoon surrounding Babeldaob, Kayangel, Ngeruangel, Koror and the Rock Island Southern Lagoon, Peleliu, and Anguar. Palau has been divided into numerous governmental-recognized states and for simplicity, the findings in this report have been presented according to each state that the data were collected in. The Global Reef Expedition worked closely with scientists from the Coral Reef Research Foundation (CRRF) and the Palau International Coral Research Center (PICRC) to complete an assessment of the benthic and fish communities of Palau.

Both cultural- and government-driven enforcement of the country's marine management efforts have helped to conserve reef resources in Palau. Traditionally, Palauans have implemented "*bul*," a customary conservation practice in which the communities close areas to fishing and prohibit access for a designated amount of time, though not indefinitely[6,7]. *Bul* is based on traditional knowledge and practices and was enforced when changes of the marine resources were observed[8]. Most of the marine conservation in Palau has been primarily led by individual states, with the first recognized conservation area being established as far back as the 1950s. When gaining its independence from the United States in 1994, the Palauan Government continued to instill the tradition of bul and expand its marine conservation efforts through adoption of the more modern Marine Protected Areas (MPAs), and prioritized management of its marine resources[7,9,10]. In addition to nearshore MPAs, Palau also implemented a large-scale MPA for its offshore waters, protecting 80% of its Exclusive Economic Zone (EEZ) from commercial fishing[11,12].

Palauans rely heavily on the ecosystem services provided by its coral reefs, including storm surge protection, sustenance, and income generation through tourism and fishing exports. It is estimated that 87% of the households in Palau are linked to either commercial or subsistence fishing[13]. Because of Palauan's reliance on their nearshore and coral reef ecosystems, KSLOF partnered with local conservation and research organizations to help collect a country-wide assessment of the coral reefs' benthic and fish communities. This assimilation of data will allow local, state, and national government managers to have a comprehensive database to refer to when expanding and implementing conservation and management plans. These plans include protections, mostly of the nearshore ecosystems, both within and outside of the lagoon.

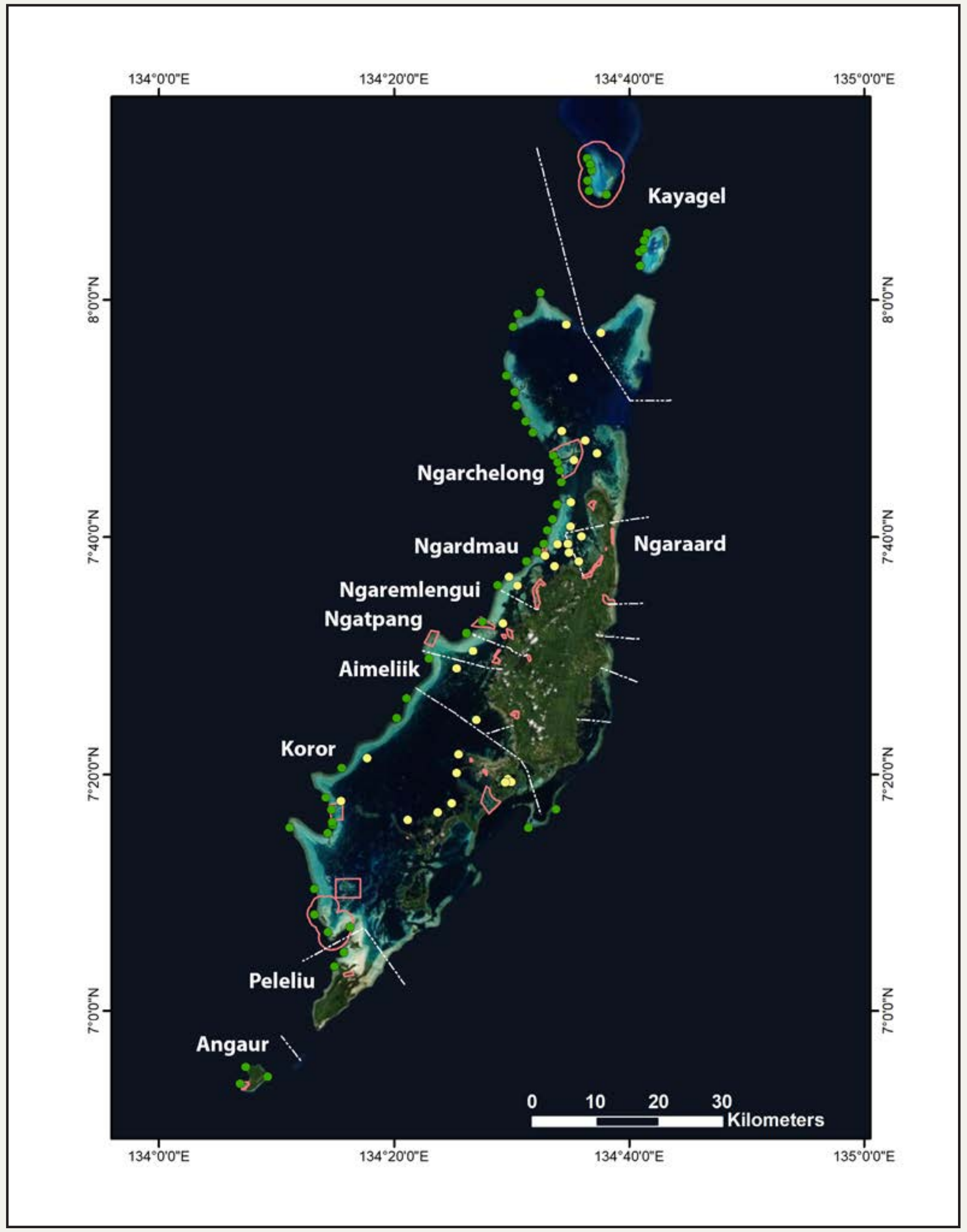
> The **Global Reef Expedition** surveyed **benthic** and **fish** communities on **coral reefs** in **Palau.**

Figure 1 EXCLUSIVE ECONOMIC ZONE (EEZ) OF THE REPUBLIC OF PALAU IS OUTLINED IN RED. THE AREA SURVEYED BY KSLOF FALLS WITHIN THE BLACK BOX.



PALAU EEZ   STUDY AREA

Figure 2 MAP OF GRE PALAU SURVEY SITES, DIFFERENTIATED BY THOSE FALLING INSIDE AND OUTSIDE OF THE LAGOON. STATE BOUNDARIES ARE APPROXIMATIONS RETRIEVED FROM OPENSTREETMAP.ORG.



SITE – OUTSIDE LAGOON SITE – INSIDE LAGOON MPA BORDER

The states surveyed on the GRE Mission to Palau included: Aimeliik, Angaur, Kayangel, Koror, Ngaraard, Ngarchelong, Ngardmau, Ngaremlengui, Ngatpang, and Peleliu (Figure 2). Each of these states has ownership of the marine habitats extending to up to 12 miles offshore and have each established varying levels of conservation. Prior to the 2003 formation of the Protected Areas Network (PAN), each state established and enforced its own conservation measures, most of which included designated areas as either no-take, no-entry, or permitted use only[6]. PAN was established with the goal of increasing the conservation measures to a more unified, national level, across state boundaries[14,15]. By becoming a member of the PAN, individual states allow the national government to enforce regulations where the state may not have specific laws in place. As of 2015, 41% of Palau's nearshore marine areas have been established as PAN sites[16], which include large managed areas that are not necessarily no-take zones. Overall, it was calculated that 14% of the nearshore reef and lagoon area was protected as no-take zones under state and national legislatures in 2016[17].

Ecologically, the benthic and fish communities within and outside of a tropical lagoon can be different[1,11,17,18]. Understanding these differences and the marine communities found within these two environments can be important in developing successful management plans. For example, the most northern part of the lagoon surrounding Babeldoab, referred to as the "Northern Reefs," is a complex system of reefs that have high benthic biodiversity and known fish-aggregating areas that attract fishermen from surrounding states. This area falls between Babeldoab Island and Kayangel State, and is co-managed by Ngarchelong and Kayangel States[19,20]. Because this area is important for fishers, these states are currently working to best manage these reefs and their marine organisms to ensure long-term sustainability. Understanding the differences of the forereef and lagoonal reefs may help managers develop best practices more specifically for the different habitats or reef zones. Because of the more direct and easier access to the lagoonal reefs, compared to outer forereefs, these areas are often preferentially targeted for subsistence fishing and can be the first areas where fish stocks are depleted.

This report provides a strong baseline understanding of the status of coral reefs in Palau and provides the people of Palau with relevant information they can use to prioritize management efforts and make informed conservation decisions.

> This report provides the people of **Palau** with relevant information they can use to **prioritize management efforts** and **make informed conservation decisions.**

2.0 METHODS

2.1 SITE DESCRIPTIONS

The GRE surveyed coral reefs in 10 states of the Republic of Palau. State boundaries were retrieved from openstreetmap.org and may not reflect actual boundaries across the barrier reef and lagoon. A total of 86 dive sites (Figure 2) were surveyed, among which 1,011 benthic habitat surveys and 874 fish surveys. Table 1 shows the total number of surveys conducted at each location. Survey sites were selected in an effort to encompass areas within nearly all of the conservation management areas in the major lagoon surrounding the main island, as well as the two northern atolls in Kayangel, and southern island in Angaur. The M/Y *Golden Shadow* and its support vessels were graciously donated for use on this expedition to allow KSLOF and invited researchers to easily gather data in these different locations.

Table 1 NUMBER OF FISH AND BENTHIC TRANSECT SURVEYS COMPLETED INSIDE AND OUTSIDE OF THE LAGOON IN EACH STATE.

STATE	LAGOON	NUMBER OF DIVE SITES	NUMBER OF STATIONS	NUMBER OF FISH TRANSECTS	NUMBER OF BENTHIC TRANSECTS
AIMELIIK	INSIDE	2	2	23	33
	OUTSIDE	1	1	9	10
	TOTAL	**3**	**3**	**32**	**43**
ANGAUR	INSIDE	NA	NA	NA	NA
	OUTSIDE	3	3	21	20
	TOTAL	**3**	**3**	**21**	**20**
KAYANGEL	INSIDE	NA	NA	NA	NA
	OUTSIDE	3	11	123	92
	TOTAL	**3**	**11**	**123**	**92**
KOROR	INSIDE	6	11	101	62
	OUTSIDE	12	15	136	124
	TOTAL	**18**	**26**	**237**	**186**
NGARAARD	INSIDE	2	2	24	18
	OUTSIDE	NA	NA	NA	NA
	TOTAL	**2**	**2**	**24**	**18**
NGARCHELONG	INSIDE	5	9	102	102
	OUTSIDE	9	15	159	246
	TOTAL	**14**	**23**	**261**	**348**
NGARDMAU	INSIDE	5	7	80	67
	OUTSIDE	4	4	45	118
	TOTAL	**9**	**11**	**125**	**185**
NGAREMLENGUI	INSIDE	1	1	8	33
	OUTSIDE	1	1	5	26
	TOTAL	**2**	**2**	**12**	**59**
NGATPANG	INSIDE	1	1	9	11
	OUTSIDE	1	1	9	31
	TOTAL	**2**	**2**	**18**	**42**
PELELIU	INSIDE	NA	NA	NA	NA
	OUTSIDE	2	2	20	18
	TOTAL	**2**	**2**	**20**	**18**
GRAND TOTAL		**50**	**86**	**874**	**1011**

2.2 CORAL REEF COMMUNITY SURVEYS

The KSLOF Scientists and Fellows on the GRE used a combination of quantitative methods, including belt transects, point intercept transects, and quadrats to assess benthic and fish communities of reefs located in the Palau. This standardized collection methodology provides robust data that can be compared regionally and globally. This report provides a broad discussion of trends and patterns as a prelude to more in-depth analyses.

2.2a BENTHIC COVER ASSESSMENTS

Cover of major functional groups and substrate type (Box 1) were assessed along 10 m transects using recorded observations and/or photographic assessments. The major functional groups included: corals identified to genus, other sessile invertebrates such as giant clams, anemones, and others identified to phylum or class, and six functional groups of algae: crustose coralline algae (CCA), erect calcareous algae, cyanobacteria, fleshy macroalgae, turf algae, and turf mixed with sediment.

At least two KSLOF surveyors used SCUBA-recorded observations to record what was observed on the benthos using a point intercept method. This technique required the surveyor to lay out a 10 m transect line and record the organism and substrate type at every 10 cm mark (total 100 points per transect). A minimum of four transects among the five depth strata were completed at each dive site (Figure 3), and when possible, surveys were completed at 25, 20, 15, 10, and 5 m water depths.

At some locations, we conducted a photographic assessment to supplement the point-intercept surveys. On occasion, we were not able to complete these surveys at every

Box 1 CLASSIFICATION OF SUBSTRATE TYPES RECORDED DURING BENTHIC TRANSECT SCUBA SURVEYS.

BENTHIC HABITAT
SUBSTRATE TYPE
Live Coral
Dead Coral
Fused Rubble
Pavement
Rubble
Sand/Sediment
Recently Dead Coral
LIVE COVER
Algae
Macroalgae
Crustose Coralline Algae (CCA)
Erect Coralline Algae
Turf Sediment
Turf
Cyanobacteria
Other Invertebrates
Coral (to Genus)

Figure 3 A DIVER CONDUCTING A BENTHIC SURVEY. DIVER USES A 10 M TRANSECT LINE AND RECORDS BENTHIC SUBSTRATE TYPE AND COVER EVERY 10 CM. PHOTO BY KEN MARKS.

Figure 4 A DIVER TAKES A PHOTO OF A 1 M X 1 M SQUARE QUADRAT. TRANSECTS OF TEN PHOTOS ARE COMPLETED AT MULTIPLE DEPTHS TO SUPPLEMENT BELT TRANSECTS. PHOTO BY PHILIP RENAUD.

depth due to SCUBA time limitations, so we supplemented this dataset with photographic assessments. In this sampling technique, a scientific diver used a 1 m × 1 m quadrat, flipping it over a total of 10 times per transect to photograph a full 1 × 10 m photo transect **(Figure 4)** at each depth. As before, when possible, the diver completed at least one survey at 20, 15, 10, and 5 m depth at each site.

In order to measure the benthic community, the digital photographs were downloaded and analyzed using *Coral Point Count with Excel Extensions* (CPCe), a software developed by Nova Southeastern University's National Coral Reef Institute (NCRI)[21]. The 1 × 1 m images were imported into the software where 50 random points were overlaid on each photograph. A KSLOF scientist then defined the organism and substrate type directly underneath the point **(Figure 5)**. These data were then exported into a Microsoft Excel (2013) spreadsheet and added to the benthic survey database for further analysis.

The benthic substrate cover percentages were calculated for each reef zone at each island as the average percentage of all transects collected at in that zone, binned first by depth, then by site. The percentage of each substrate type was calculated by dividing the total number of samples observed in each depth on each transect by the total number of points recorded, multiplied by 100. The average percentage of all transects at each location is presented as the measure of each substrate type. To further analyze the coral and algal cover, the sum of the specific algae types or coral genera recorded on each transect was divided by the total number of algae or coral observed per transect. The average of the percentages for each algae type is presented in **(Figure 8)**.

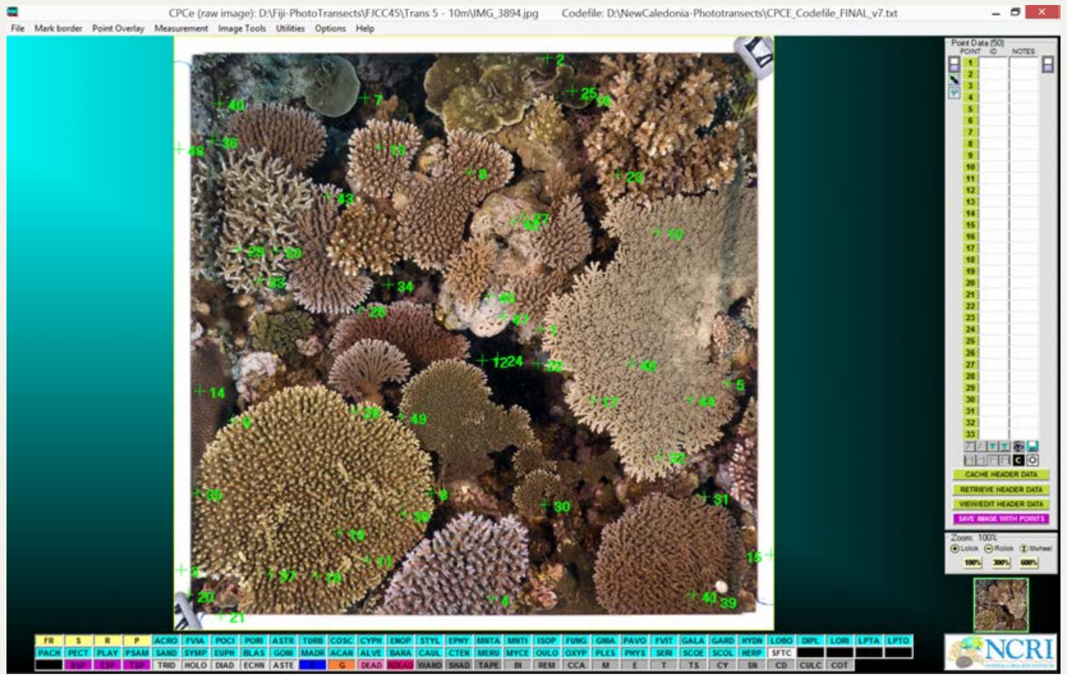
To measure overall coral diversity by genus, we used the Simpson Index of Diversity which is commonly used to characterize species diversity in a community[22]. This index uses the total number of individual coral colonies of a specific genus observed per island and location either inside or outside of the lagoon, and the total number of genera, to provide a number to represent the total diversity of the island community. Using this index, the diversity will fall within a range of 0-1 with 0 being low diversity, and 1 being the most diverse.

2.2 b FISH ASSESSMENTS

Reef fish surveys were conducted by KSLOF Scientists and Fellows at selected locations. The survey transects covered depths between 1 to 22 m, but most of the surveys were between 5 and 20 m depth **(Figure 6)**. Transects were deployed at deep (>11 m) and shallow (<10 m) sections of the reefs, as allowed by the morphology of the dive site. At least two deep and two shallow transects were conducted by divers at each site. The fish assemblages at each dive site were surveyed following a fish visual census technique modified from the survey principles described by English *et al.* (1994)[23]. The diver identified and counted fish along a 30 × 4 m transect over a period of 10 to 15 minutes.

Fish assemblages were characterized in terms of species richness, abundance, and standing stock biomass. Fish were identified to species level whenever possible with the aid of photographic fish guides[24–27] and their body lengths were visually estimated to the nearest centimeter. The abundance of each species of a particular size was estimated by actual counts or by cluster in the case of a school of fish. The biomass of each species was then computed using the formula $\mathbf{W=aL^b}$ where $\mathbf{W}$ is the weight in grams, $\mathbf{L}$ is the length of the fish in centimeters, and $\mathbf{a}$ and $\mathbf{b}$ are the species-specific growth constants derived from the length-weight relationships[28–32]. Abundance and biomass data were then converted and represented as density by individuals/100 m^2 and biomass by kg/100 m^2.

Figure 5 EXAMPLE OF A PHOTOGRAPHED QUADRAT IMPORTED INTO CPCE SOFTWARE, WITH RANDOMLY PLACED POINTS FOR IDENTIFICATION. FIFTY RANDOM POINTS ARE OVERLAID ON EACH PHOTO QUADRATE AND SUBSTRATE TYPE AND LIVE COVER CLASSIFICATION ARE IDENTIFIED FOR EACH POINT.



The counted fish were also attributed to trophic-level categories based on diet by species[31]. The correspondence between trophic levels and feeding habits is not strictly straightforward, or well-defined, because of wide overlaps in the food items consumed by different species[33]. Hence, the trophic levels under which a specific species is classified may be considered elastic and representative of the mean of its diet items.

Trophic levels were expressed numerically and broadly represented herbivores (2.0–2.5), corallivores (2.6–3.0), planktivores (3.1–3.5), benthic carnivores (3.6-4.0), and piscivores (4.1–4.5)[34]. By analyzing the fish communities using trophic levels, we strived to understand the community structures and determine how fishing pressures might be affecting the fish communities. Fish in trophic levels 2.0-2.5 and 2.5-3.0 are typically small in size and are not considered important to local fisheries[35].

Fish that are classified in trophic levels 2.0-3.0 are usually important indicator species that contribute to the health of the reef by providing such services as cropping algal growth which otherwise would impede the settlement of juvenile corals[36,37]. These fish include damselfish, tangs, surgeonfish, butterflyfish, and a few small-bodied parrotfish. Fish in trophic level 3.0-3.5 and 3.5-4.0 include larger-bodied herbivores, planktivores, omnivores, or carnivores that feed on small benthic invertebrates. Fish classified in these ranges include wrasses, some species of butterflyfish, damselfish, hogfish, goatfish, snappers, and triggerfish. Fish in trophic level 4.0-4.5 are typically considered top predators and prey on finfish of the lower trophic levels. These predatory fish include large wrasse, grouper, hawkfish, snapper, goatfish, and sharks. The majority of the fish important to local fisheries are found in trophic levels 3.5-4.0 and 4.0-4.5[35].

Figure 6

A SCIENTIFIC SCUBA DIVER RECORDS FISH ALONG A TRANSECT LINE. SCIENTIST RECORDS FISH OBSERVED ALONG A 30 M × 4 M TRANSECT OVER A 10-15 MINUTE PERIOD. PHOTO BY KEN MARKS.

The **Khaled bin Sultan Living Oceans Foundation** used standarized methods to quantitatively **assess benthic** and **fish** communities in **Palau**.

3.0 RESULTS

3.1

BENTHIC COMMUNITY ASSESSMENT

Palau has some of the most diverse reefs in the world with the benthic communities both within and outside of the lagoon being in good condition. There was minimal difference in the benthic cover among most states with the exception of Kayangel and Angaur who experienced damage from recent tropical typhoons.

3.1 a KAYANGEL STATE

Kayangel State is the most northern state visited on the GRE mission to Palau. This state includes two atolls, Kayangel and the Ngeruangel and Velasco Reef complex, which is a partly drowned atoll. On the GRE, KSLOF surveyed the reefs of Kayangel and Ngeruangel. Currently, Ngeruangel is protected as the Ngeruangel Marine Reserve, designated as a non-extractive area that was established in 1996[38]. In the marine reserve, fishing extraction is prohibited to the public with other limited activities including diving, research, and catch-and-release sportfishing, all of which are only allowed with permits, as outlined by the Kayangel Protected Areas Network Management Plan[38]. The waters surrounding Kayangel Atoll are designated for sustainable use and unregulated fishing is allowed for subsistence while all other commercial fishing requires a permit and fee. All of the sites surveyed were on the outside or forereefs of the two atolls, with no sites falling inside the lagoon. This area was damaged by super-Typhoon Haiyan in 2014, particularly the Kayangel Atoll where the eye of the storm passed over. The east coast reefs were most exposed to the typhoon wave energy, and without baseline data prior to these surveys and the majority of survey sites being on the west coast, KSLOF surveys could not attribute differences in benthic community composition between reefs to the typhoon.

Nonetheless, Kayangel had less live cover with 26% (±12 % S.D.) compared to Ngeruangel, where live coral cover accounted for 44% (± 13% S.D.) of the total benthic habitat **(Figure 7)**. Algae accounted for 62% (±11% S.D.) of the total algae found at Kayangel and was dominated by turf and crustose coralline algae (CCA) **(Figure 8)**. Turf algae accounted for 36% (±4% S.D.) of the total algae observed at Kayangel Atoll and CCA accounted for 34% (±16% S.D.). CCA is an important settlement cue for coral larvae and can be especially important following a major disturbance, such as the damage sustained by Typhoon Haiyan. In order to rebuild the reefs, coral larvae use environmental cues such as the presence of CCA seek out settlement sites that are mostly undisturbed and use chemical cues from CCA to find viable places to settle and grow[39]. Ngeruangel's algal community accounted for 43% (±7% S.D.) of the substrate with turf and CCA also being the dominant algae present.

The coral diversity (by genus) of these sites was calculated using the Simpson Diversity Index. The diversity of Kayangel and Ngeruangel atolls were very similar, with both being 0.87. The scale of the Simpson diversity index is from 0 to 1, with one having the highest diversity. *Porites* accounted for 33% (±14% S.D.) of the coral observed around Kayangel and 28% (±12% S.D.) of the coral of Ngeruangel. *Acropora* is a common genus of coral found in Palau. However, at Kayangel it only accounted for 7% (±2% S.D.) and 12% (±9 S.D.) of the coral observed at Ngeruangel. This lower prevalence of *Acropora* is plausibly due to damage wrought by Typhoon Haiyan; *Acropora* is more easily broken than the massive corals, such as *Porites*.

Figure 7

(RIGHT) AVERAGE BENTHIC COVER (%) OF EACH ATOLL SURVEYED IN THE KAYANGEL STATE, PALAU. ALL SITES FELL OUTSIDE THE LAGOON. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND INVERTEBRATES. THESE VALUES WERE CALCULATED FROM THE BENTHIC SURVEYS, AVERAGING ACROSS DEPTH, THEN SITE. NUMBER OF TRANSECTS (N) AT EACH LOCATION: NGERUANGEL, N=59; KAYANGEL, N=33.

- BARE SUBSTRATE
- ALGAE
- CORAL
- INVERTEBRATE

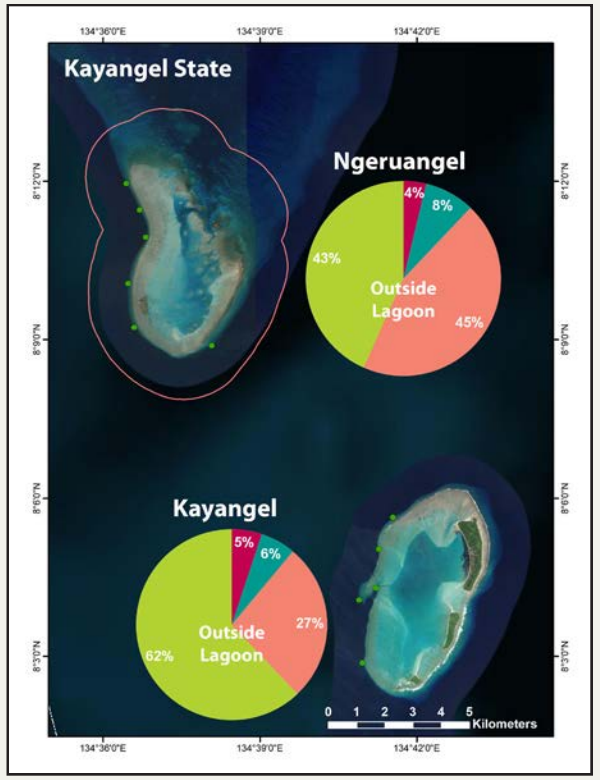
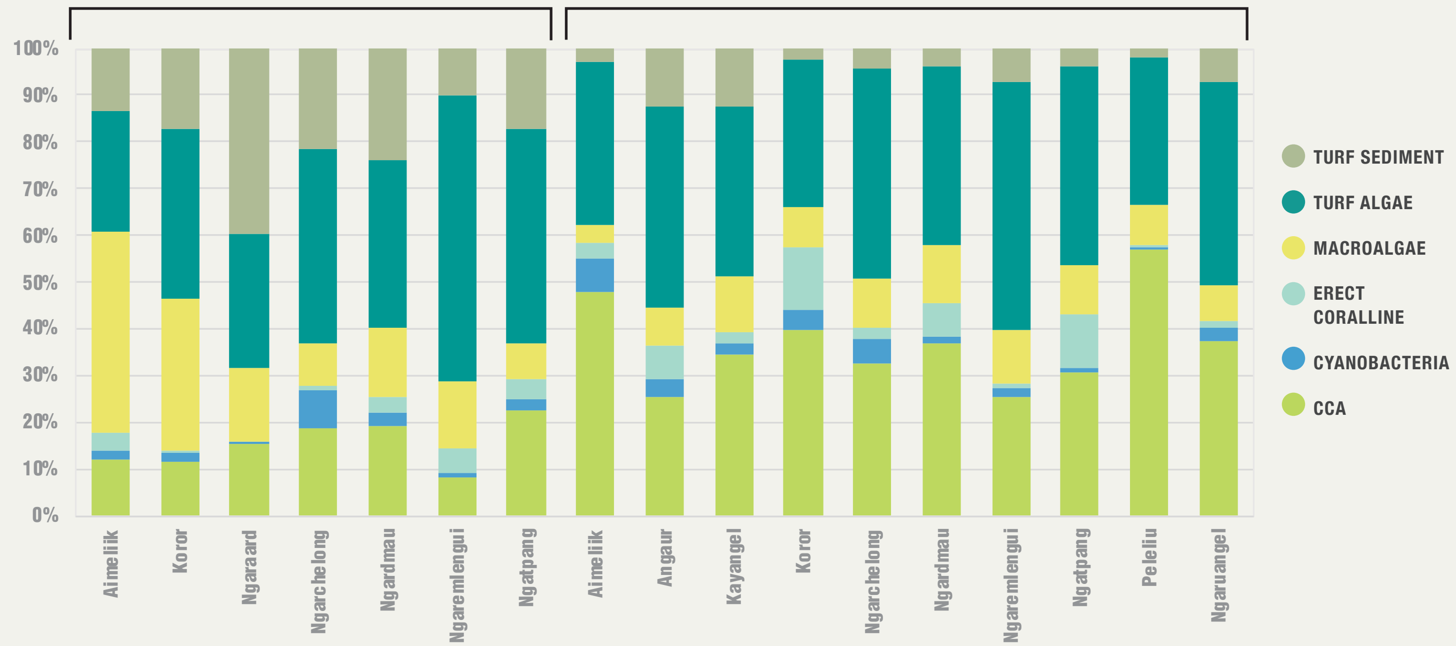


Figure 8

(BELOW) RELATIVE COMPOSITION OF ALGAE (%) AT EACH SITE SURVEYED IN PALAU. THE DATA PRESENTED ARE AVERAGED ACROSS DEPTH FROM DATA COLLECTED ON THE BENTHIC TRANSECTS AT EACH SITE. ALGAE CATEGORIES ARE: CCA= CRUSTOSE CORALLINE ALGAE; CY= CYANOBACTERIA; E= ERECT CALCAREOUS ALGAE; M= MACROALGAE; T= TURF ALGAE; TS= TURF MIXED WITH SEDIMENT.



3.1 b NGARCHELONG STATE/NORTHERN REEFS

Ngarchelong State occupies the northern-most region of the main archipelago and lagoon surrounding the island Babeldaob, generally referred to as the Northern Reefs. Within this area, KSLOF surveyed inside the Ngkesol Barrier Reef Marine Protected Area, Ebiil Channel Conservation Zone and the larger Ngarchelong Marine Managed Area. The Ngkesol Barrier Reef Marine Protected Area is jointly managed with Kayangel State and is included in the Kayangel Protected Areas Network and Northern Reefs, as it is utilized by residents of both states. While the sites visited by KSLOF may be managed partially by Kayangel State, they are being grouped with nearby sites within Ngarchelong State since, geographically they are located within the barrier reef surrounding Babeldaob.

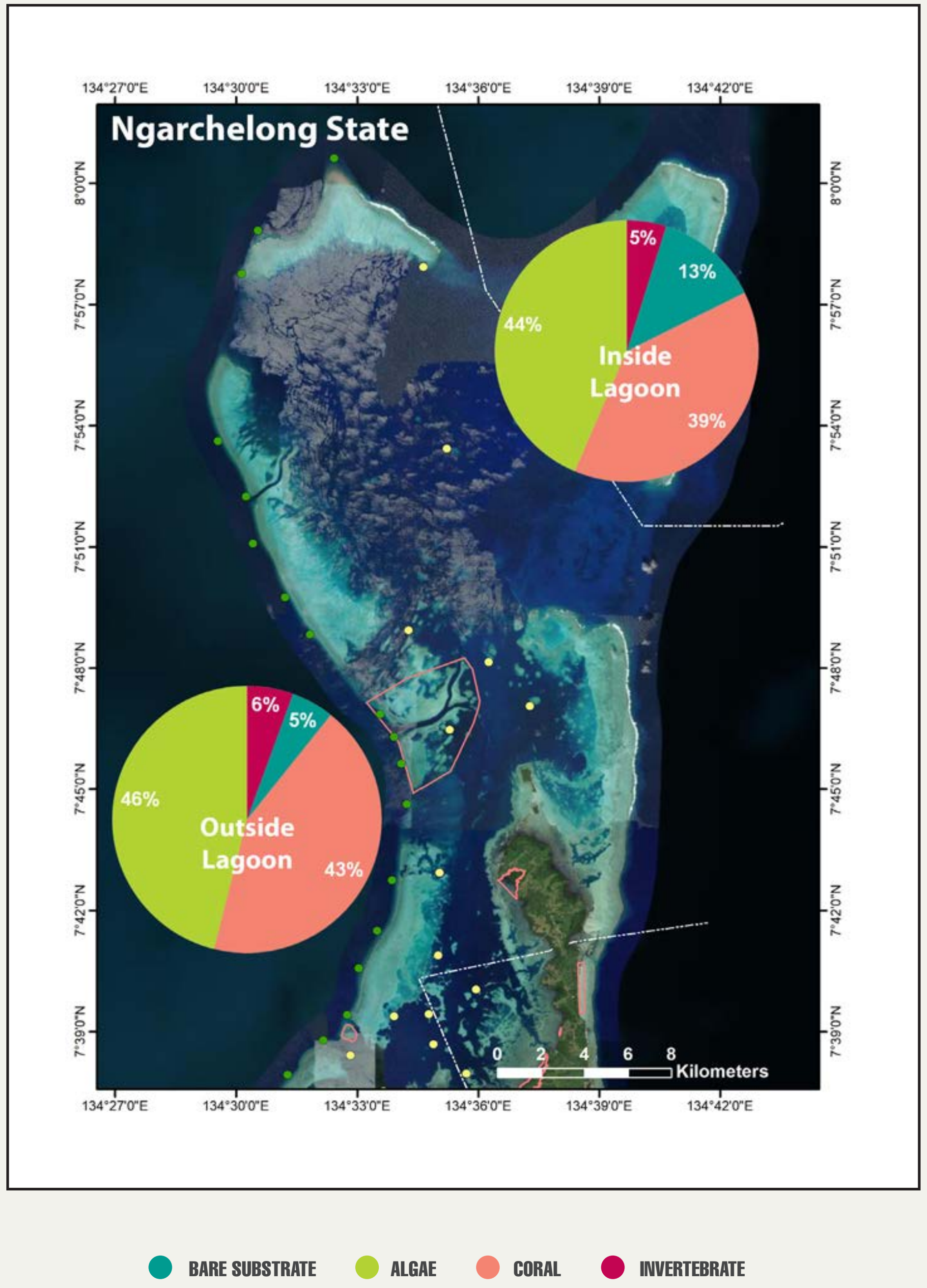
> In the **Northern Reefs,** KSLOF surveyed inside the **Ngkesol Barrier Reef Marine Protected Area, Ebiil Channel Conservation Zone** and the larger **Ngarchelong Marine Managed Area.**

Sites surveyed inside of the lagoon had an average live coral cover of 39% (±20% S.D.) **(Figure 9)**. Site 69, which had the highest live coral cover observed in this state, was found within the Ebiil Conservation Area and had 70% (±6% S.D.) live coral cover. The average live coral cover observed within the Ngkesol Barrier Reef Marine Protected Area was 30% (±1% S.D.). On average, algae covered 44% (±16% S.D.) of the benthic habitat of the sites surveyed within the lagoon, being mostly dominated by turf algae and turf mixed with sediment. Combined, these two algae groups accounted for 78% of the total algae observed in the benthos **(Figure 8)**.

The average live coral cover of sites surveyed on the outside of the lagoon was 44% (±16% S.D.), slightly higher than what was observed inside, 39% (±20% S.D.). Algae accounted for 44% of the benthic habitat with turf and CCA being the dominant growth forms of algae observed **(Figure 9)**. The sites found within the Ebiil Conservation Area and outside of the lagoon, while not the highest observed on the forereef, had an average of 48% (±8% S.D., N-site=2, N-transect=43) live coral. Only one site was surveyed outside of the lagoon that fell within the boundaries of the Ngkesol Barrier Reef Marine Protected Area. This sited had a live coral cover of 34% (±13% S.D., 10 transects).

The coral diversity of the sites surveyed inside the lagoon was 0.84 and outside was 0.81. The reef communities surveyed inside the lagoon were partially covered by *Acropora* and *Porites* which combined accounted for 47% of the coral observed. On the forereef, *Acropora* and *Porites* also dominated the coral, combined accounting for 49% of the coral measured. *Monitpora* was the third most prevalent genus of coral recorded on the forereef, accounting for 14% (±8% S.D.), over double what was observed at the sites inside the lagoon.

Figure 9 AVERAGE BENTHIC COVER (%) INSIDE AND OUTSIDE THE LAGOON IN NGARCHELONG STATE, PALAU. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND INVERTEBRATES. THESE VALUES WERE CALCULATED FROM THE BENTHIC SURVEYS, AVERAGING ACROSS DEPTH, THEN SITE.



3.1 c

NGARAARD STATE

Ngaraard State is found directly south of Ngarchelong State. This state has prioritized its conservation efforts toward the terrestrial and nearshore mangrove habitats[40]. KSLOF only surveyed two sites within the jurisdiction of Ngaraard State and were at patch reefs found within the lagoon. The average live coral cover at these sites was 34% (±6% S.D.; Figure 10). Algae accounted for 31% (±11% S.D.) of the benthos and was dominated by turf and turf mixed with sediment (Figure 8). These two algal classifications accounted for 67% of the total algae observed in this area. This state had the highest bare substrate measured in Palau, 30% (±16% S.D.), which is likely because the sites selected were on patch reefs that are typically surrounded by sand. In Ngaraard State, sand accounted for 25% (±14% S.D.) of the benthic substrate surveyed which is the highest percentage recorded for Palau. Sand is an unconsolidated substrate and for this reason, most sessile organisms have a difficult time settling and growing on it. The coral diversity of the sites surveyed in Ngaraard State was 0.79. *Acropora* and *Porites* were the most common genus measured, combined accounted for 56% of the coral counted. Of all the areas surveyed in Palau, this state had the highest percentage of *Pectinia* observed with one patch reef having 8% (±13% S.D.) of the total coral measured being this genus.

Figure 10

AVERAGE BENTHIC COVER (%) INSIDE THE LAGOON IN NGARAARD STATE, PALAU. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND INVERTEBRATES. THESE VALUES WERE CALCULATED FROM THE BENTHIC SURVEYS, AVERAGING ACROSS DEPTH, THEN SITE.

- BARE SUBSTRATE
- ALGAE
- CORAL
- INVERTEBRATE

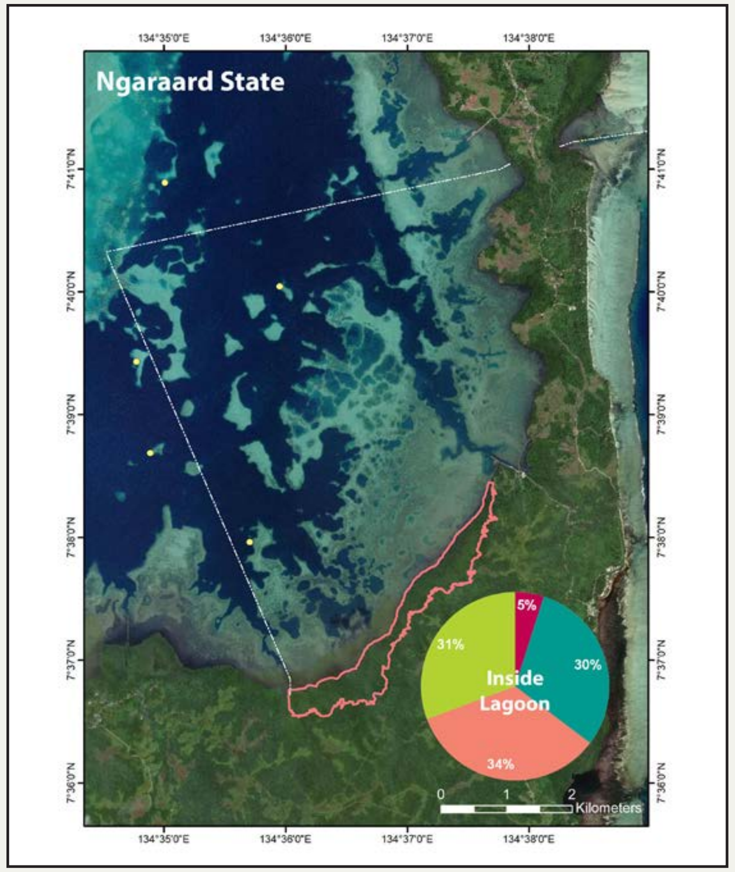
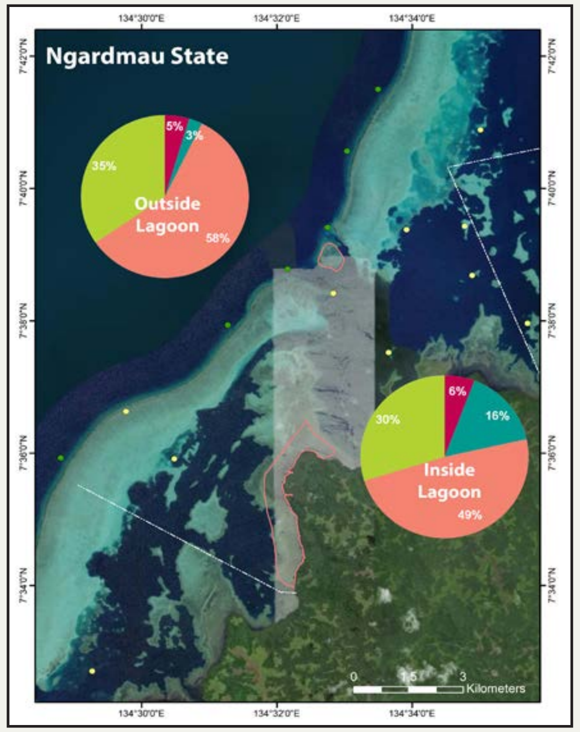


Figure 11

AVERAGE BENTHIC COVER (%) OF INSIDE AND OUTSIDE THE LAGOON IN NGARDMAU STATE, PALAU. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND INVERTEBRATES. THESE VALUES WERE CALCULATED FROM THE BENTHIC SURVEYS, AVERAGING ACROSS DEPTH, THEN SITE.

- BARE SUBSTRATE
- ALGAE
- CORAL
- INVERTEBRATE



3.1 d

NGARDMAU STATE

Ngardmau State is found on the western side of Babeldaob, bordering Ngaraard and Ngeremlengui states. In 2005, Ngardmau established the Ongedechuul System of conservation areas which included the establishment of Ileyaklbeluu Marine Protected Area, which is a designated non-extractive area except for sustainable uses[41]. The Ongedechuul System of Conservation Areas also included the establishment of the Ngermasch Marine Protected Area which encompasses a nearshore mangrove reef flat and seagrass meadow. This area is managed for sustainable uses and restricted extractions. Although KSLOF was not able to survey inside these MPAs, surveys were completed nearby both inside and outside of the lagoon in the waters managed by Ngardmau State.

The sites surveyed inside of the lagoon had a high live coral cover, measuring 49% (±16% S.D.)(Figure 11), and algae covered 29% (±14% S.D.) of the benthic habitat. The algal community was dominated by turf and turf with sediment combined measuring 61% of the algae observed. Fleshy macroalgae accounted for 19% (13% S.D.) and CCA accounted for 16% (±11% S.D.; Figure 8) of the total algae observed. The coral diversity found inside of the lagoon was 0.71 with 39% (±20% S.D.) of the total coral observed being *Acropora*. The next most common genus observed was *Porites* accounting for 20% (±10% S.D.) of the coral recorded in the lagoon.

On the forereef area managed by Ngardmau State, 58% (±3% S.D.) live coral cover was observed (Figure 11). Algae accounted for 34% (±5% S.D.) of the benthos being dominated by CCA and turf algae. Of the total algae observed, turf measured 40% (±20% S.D.) and CCA measured 37% (±19% S.D.; Figure 8). The forereef coral community had a diversity of 0.80 with very similar coral genus dominating the reef. Similar to the inside of the lagoon, *Acroproa* accounted for 40% (±16% S.D.) of the coral observed with *Porites* accounting for 20% (±6% S.D.) of the coral on the forereef.

3.1 e NGAREMLENGUI STATE, NGATPANG STATE, AND AIMELIIK STATE

In Ngaremlengui State, conservation of its natural resources has led to the development of the Ngaremeduu Conservation Area which has been designated as a UNESCO Biosphere Reserve[42]. Ngaremeduu Bay is an important bay and estuary surrounded by mangroves and is fed by three different rivers. The designated conservation area protects multiple habitats, from the terrestrial forests to the many marine habitats found in the bay. The Ngaremeduu Conservation Area spans three states, including Aimeliik and Ngatpang. The reefs of Ngaremlengui, Ngatpang and Aimeliik are used for subsistence and small commercial fishing by the local villagers who live within the conservation area. The Bkul Lengriil Area, Mecheron Outer Reef, and Tewachel Mlengui Areas are three small MPAs in Ngaremlengui State and are all designated as conservation areas that can only be used for permitted tourism, diving, and subsistence fishing[42]. Similarly, Ngatpang State has established three small MPAs, Olterukl, Orauaol Ibuchel, and Chiul (luul) which are all restricted to non-extractive use, including the prohibition of subsistence fishing, although these areas are all less than 0.07 km^2 in size[43]. Aimeliik is the southernmost state of the Ngaremeduu Conservation Area. Besides its inclusion in the Ngaremeduu Conservation Area, the State has established three MPAs, the Imul Mangrove Conservation Area, Marine Reef Sanctuary, and Ngerchebal Island Wildlife Conservation Area. Many of Aimeliik's conservation efforts have been focused on the establishment of the Ngerderar Watershed Reserve, the only terrestrial reserve included as a PAN site. This reserve focuses on protecting the upstream habitats to prevent damage to the marine habitats downstream[44].

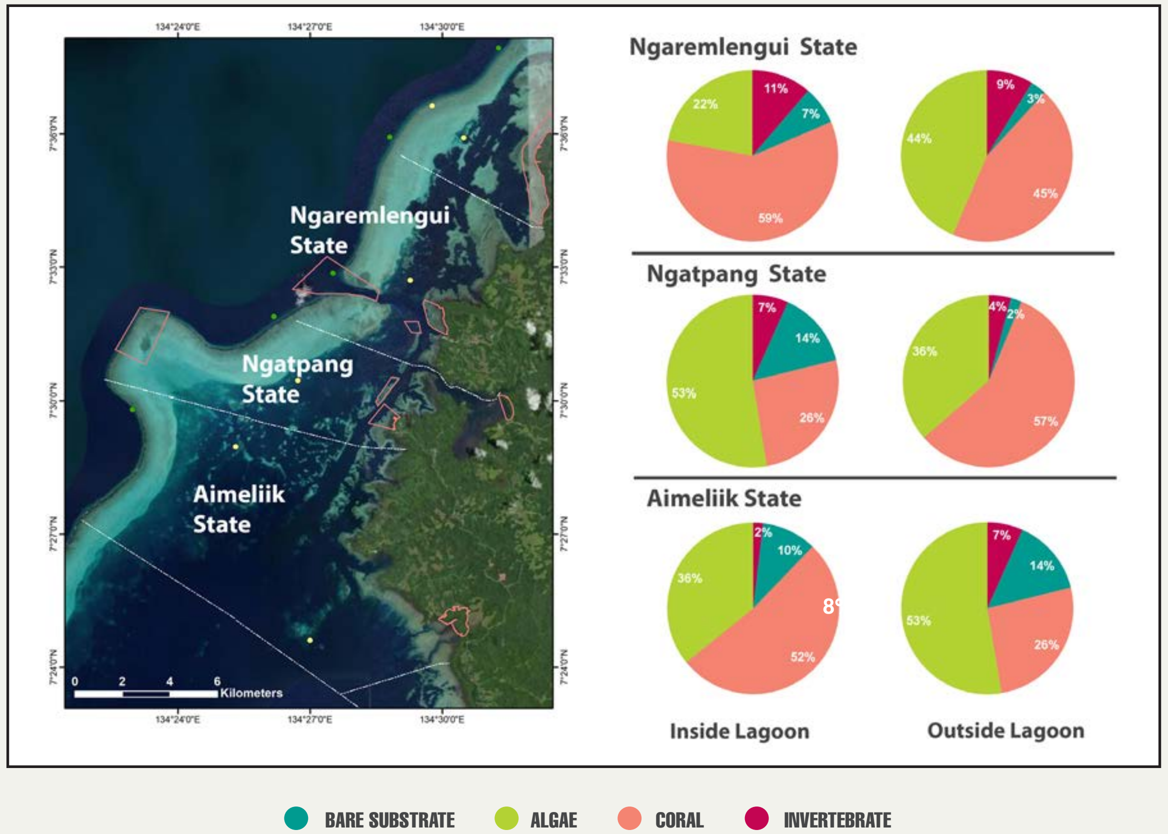
KSLOF surveyed two sites that fell in the jurisdiction of Ngaremlengui and Ngatpang States, each having only one survey site inside the lagoon, and one on the forereef. Two sites were surveyed inside the lagoon in Aimeliik and one on the forereef.

In Ngaremlengui, the lagoon had a live coral cover of 60% (± 13% S.D.; Figure 12). This site also had the highest percentage of sessile invertebrates recorded in Palau, accounting for 11% (±9% S.D.) of the recorded benthic substrate, of which, majority were either octocorals or encrusting sponges. The algal community accounted for 22% (±14% S.D.) of the total benthic habitat with turf algae being the most dominant, measuring 60% (±9% S.D.) of the total algae observed (Figure 8). The coral community had a diversity of 0.81 with the dominant coral genera being Acropora and Porites, combined accounting for 61% of the coral measured.

The site surveyed on the forereef in Ngaremlengui State had a lower live coral cover, accounting for 45% (±11% S.D.) of the total substrate (Figure 12). The algal community covered 44% (±14% S.D.) of the substrate with turf algae measuring 53% (±20% S.D.) and CCA measuring 25% (±19% S.D.) of the total algae observed. The coral diversity of the forereef was 0.79. *Acropora* and *Porites* accounted for 25% (±9% S.D.) and 30% (±9% S.D.) of the coral observed on the forereef. This site also had the highest percentage of *Montipora* recorded on the forereef, measuring 18% (±5% S.D.) of the coral genera observed at this site, and nearly double what was recorded in other sites surveyed along the forereef surrounding Babeldaob.

The lagoon in Ngatpang had a live coral cover of 26% (±18% S.D.) which was the lowest recorded by KSLOF in Palau. Algae covered 53% (±25% S.D.) of the substrate with turf being the most common, totaling 46% (±29% S.D.) of the algae observed (Figure 8). The algal communities were variable by transect with inconsistent dominant algae being measured on each survey. The coral community had a diversity of 0.69. *Acropora* was the most dominant genera, accounting for 44% (±42% S.D.) of the coral observed. *Fungia* were surprisingly common at this site, totaling 5% (±1% S.D.) of the coral recorded. At all other lagoonal

Figure 12 AVERAGE BENTHIC COVER (%) OF INSIDE AND OUTSIDE THE LAGOON IN NGAREMLENGUI, NGATPANG, AND AIMELIIK STATES, PALAU. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND INVERTEBRATES. THESE VALUES WERE CALCULATED FROM THE BENTHIC SURVEYS, AVERAGING ACROSS DEPTH, THEN SITE.



sites in Palau, the number of *Fungia* observed was less than 1.25% of the total coral recorded. The highest percentage of *Acanthastrea* of all the lagoon sites surveyed was also observed at this site, totaling 8% (±13% S.D.) of the coral observed. The average *Acanthastrea* observed at other lagoonal sites in Palau was 0.27%.

The site surveyed on the forereef of Ngatpang State had 57% (±5% S.D.) live coral cover and 36% (±6% S.D.) algal cover. Turf algae was the most common algae, accounting for 43% (±17% S.D.) of the total algae observed. CCA accounted for 31% (±23% S.D.) and erect calcareous algae measured 12% (±15% S.D.) of the total algae recorded. This site had the second most prevalent amount of erect calcareous algae observed with Koror having a slightly higher average percentage, 14% (±16% S.D.). The coral diversity of Ngatpang's forereef was 0.87, higher than what was observed inside the lagoon. *Porites* was the most common coral genus recorded, totaling 24% (±14% S.D.) of the coral recorded, followed by *Acroprora* at 21% (±9% S.D.).

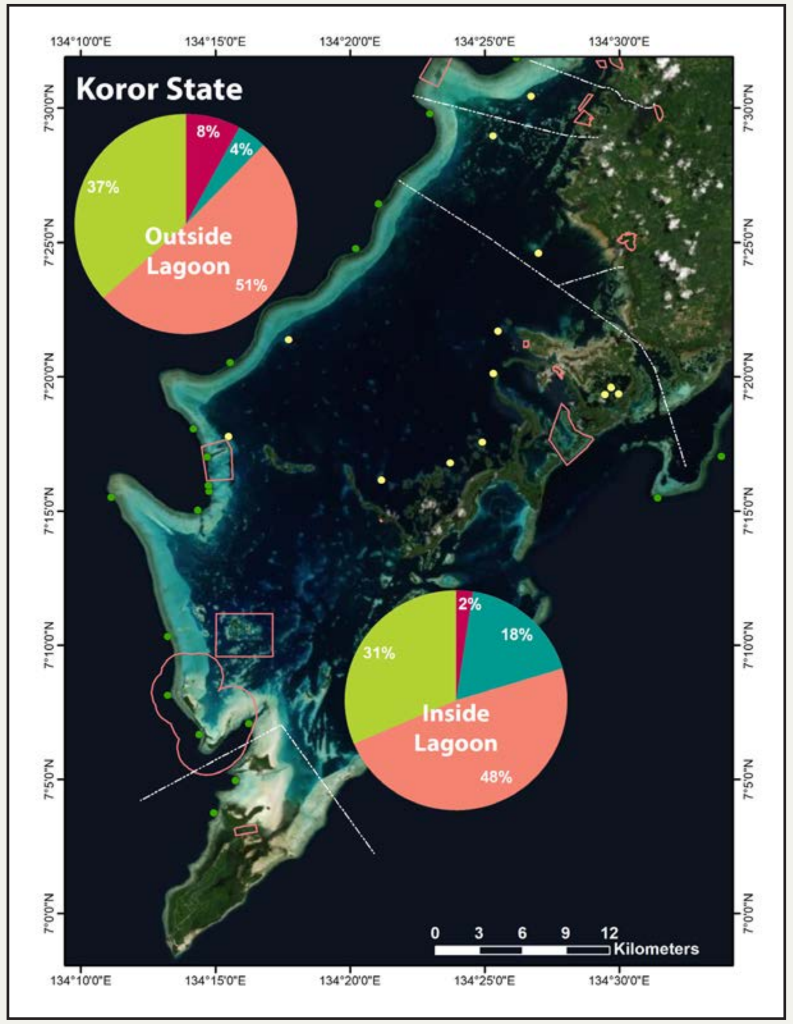
Aimeliik State had an average live coral cover of 52% (±9% S.D.) found inside the lagoon (Figure 12). The algal communities covered 36% (±18% S.D.) of the benthic habitat and was dominated by fleshy macroalgae (Figure 8). This state had the highest percentage of macroalgae found in Palau, averaging 43% (±50% S.D.) of the algae observed in this area. One of the sites surveyed inside the lagoon at Aimeliik had a much higher percentage of macroalgae observed, where 78% (±27% S.D., n-transect=10) of the total algae recorded was macroalgae. The coral diversity of the lagoon in Aimeliik was 0.73. The highest percentage of *Porites* in all of Palau was recorded in this area, including what was observed on the forereef, totaling 61% (±46% S.D.) of the coral recorded at these sites. At the same site with the high macroalgal presence, 93% (±8% S.D., n-transect=10) of the coral genera recorded was *Porites*.

The forereef of Aimeliik had a slightly lower live coral presence, accounting for 50% (±15% S.D.) of the benthic cover. Algae covered 40% (±22% S.D.) of the benthic habitat, with CCA being the most dominant algae observed accounting for 48% (±8% S.D.) of the total algae recorded. Turf algae was the second most common algal group recorded, totaling 35% (±8% S.D.) of the algae recorded. The coral diversity on the forereef of Aimeliik was 0.84. *Porites* was the most common genus recorded, totaling 34% (±10% S.D.) of the coral recorded, followed by *Acropora* at 22% (±13% S.D.). This site had the highest percentage of *Seriotopora* recorded on the forereef of Palau, totaling 6% (±7% S.D.) of the coral found in that area.

Figure 13

AVERAGE BENTHIC COVER (%) OF INSIDE AND OUTSIDE THE LAGOON IN KOROR STATE, PALAU. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND INVERTEBRATES. THESE VALUES WERE CALCULATED FROM THE BENTHIC SURVEYS, AVERAGING ACROSS DEPTH, THEN SITE.

- BARE SUBSTRATE
- ALGAE
- CORAL
- INVERTEBRATE



3.1 f KOROR STATE

The state of Koror is the most developed state, with 65% of the human population in Palau living here. The state manages the marine resources of the most southern portion of the lagoon surrounding Babeldaob. The majority of the marine habitats and islands managed by Koror State have been designated as the Rock Islands Southern Lagoon, a conservation zone with specially managed areas[45]. This is an important cultural, economic, and biological area of Palau that was designated as a UNESCO World Heritage Site in 2012[45]. Within the Koror State, eight state regulated protected areas have been also been designated. These include Ngerukewid Islands Wildlife Preserve; Ngerumekaol Spawning Area; Ngemelis Island Complex; Ngkisaol (Inlet) Sardines Sanctuary; Soft Coral Arch, Cemetery Reef, and any marine lakes; Ngederrak Conservation Area; the Ngerkebesang Conservation Zone; and the Long Island Park and Conservation Area. Each of these areas has varying degree of conservation from no take and no entry, to subsistence use only.

Inside of the Rock Island Southern Lagoon, live coral cover accounted for 48% (±9% S.D) of the benthic substrate recorded (Figure 13). Algae covered 31% (±15% S.D.) of the total benthic habitat with turf and macroalgae being the two most dominant algae types (Figure 8). Turf accounted for 36% (±21% S.D.) of the total algae observed and macroalgae totaled 33% (±29% S.D.). The coral community was dominated by *Porites* with over 50% of the total coral recorded being of this genus. *Acropora* only accounted for 5% (±10% S.D.) of the coral observed which was the least amount seen on the GRE mission to Palau. The coral diversity found inside the lagoon was 0.63. This was the lowest diversity seen in all of Palau and might be attributed to sedimentation as the majority of Rock Islands are well inside of the barrier reef, and the waters near these islands are usually turbid and receive less flushing from the open ocean which in turn limits coral growth and diversity.

The sites surveyed outside of the lagoon had a live coral cover of 51% (±17% S.D.), only slightly higher than what was observed inside the lagoon (Figure 13). Sessile invertebrates accounted for 8% (±8% S.D.) of the substrate with one site (Site 21, see Appendix 1) found inside the Ngemelis Island Complex having 19% (±3% S.D.) of the total substrate recorded being invertebrates. This site was dominated by sponges and soft corals, more than was observed at any other forereef or lagoon site. Algae accounted for 37% (±13% S.D.) of the total benthic habitat. CCA and turf algae combined accounted for over 70% of the total algae observed. Erect calcareous algae measured 14% (±15% S.D.) of the algae recorded. The coral diversity on the forereef was 0.82, much higher than what was observed inside the lagoon. *Acropora* was more prevalent on the forereef, measuring 20% (±12% S.D.) of the coral recorded, and *Porites* was the most common coral genera totaling 32% (±13% S.D.) of the coral observed.

> The majority of **marine habitats** and **islands** managed by **Koror State** are in the **Rock Islands Southern Lagoon** conservation zone.

3.1 g PELELIU STATE

The island of Peleliu is the southernmost island found within the lagoon surrounding Babeldaob. The state of Peleliu has one designated marine management area, the Teluleu Conservation Area which is an important juvenile fish nursery[46]. The conservation area is no-take and can only be accessed for permitted purposes. KSLOF did not survey inside the conservation area and instead surveyed two sites on the forereef. The benthic habitat on the forereef was dominated by coral, totaling 66% (±4% S.D.) of the total substrate (Figure 14). The coral diversity for the state was 0.72 with *Porites* being the most common coral recorded, measuring 46% (±1% S.D.) of the total coral observed. *Acropora* was the second most common coral observed, measuring 19% (±10% S.D.) of the coral recorded. This was the lowest coral diversity observed on the forereef in Palau and may be attributed to the southernmost exposure, however, this should be explored further. This state had an average of 23% (±5% S.D.) algae covering the substrate. CCA accounted for 57% (±10% S.D.) of the total algae recorded (Figure 8). Turf was the second most common algal group recorded, measuring 32% (±9% S.D.) of the remaining algae.

Figure 14

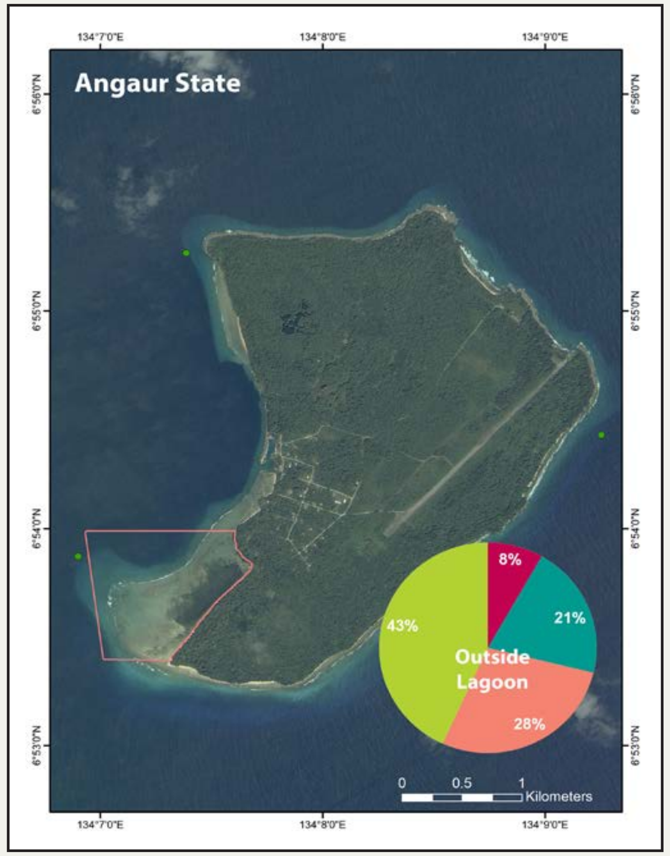
AVERAGE BENTHIC COVER (%) OF OUTSIDE THE LAGOON IN PELELIU STATE, PALAU. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND INVERTEBRATES. THESE VALUES WERE CALCULATED FROM THE BENTHIC SURVEYS, AVERAGING ACROSS DEPTH, THEN SITE.

- BARE SUBSTRATE
- ALGAE
- CORAL
- INVERTEBRATE

Figure 15

AVERAGE BENTHIC COVER (%) OF OUTSIDE THE LAGOON IN ANGAUR STATE, PALAU. THE SUBSTRATE TYPES ARE BARE SUBSTRATE, ALGAE, LIVE CORAL, AND INVERTEBRATES. THESE VALUES WERE CALCULATED FROM THE BENTHIC SURVEYS, AVERAGING ACROSS DEPTH, THEN SITE.

- BARE SUBSTRATE
- ALGAE
- CORAL
- INVERTEBRATE



3.1 h ANGAUR STATE

Angaur is the most southern state surveyed by KSLOF. The Angaur State Government designated the Iuaiu Conservation Area in 2005, prohibiting fishing activities within the area for a two year period following its establishment[47]. Since then, no formal management plan has been in developed or implemented. The site was designated because of increased fishing pressure and limited access to fringing reefs. KSLOF surveyed one site inside of the conservation area and two on the outside. In 2013, Typhoon Bopha passed closely by Angaur, damaging some of the reefs[48]. The sites surveyed in Angaur had the overall highest average percentage of bare substrate observed in Palau, totaling 21% (±4% S.D.) of the benthic substrate (Figure 15). The live coral cover totaled 28% (±24% S.D.) and algae was the most prevalent, covering 43% (±33% S.D.) of the substrate. One site had 79% (±9% S.D.) algae and only 2% (±1% S.D.) live coral on the benthos. Turf algae was the most dominant algae, measuring 43% (±22% S.D.) of the total algae recorded (Figure 8). The coral diversity was 0.73, only slightly more diverse than neighboring Peleliu. This state had the highest percentage of *Pocillopora* observed, totaling 32% (±37% S.D.) however, this data may be skewed due to the very low coral cover measured at one site. *Porites* was the second most observed coral, totaling 28% (±25% S.D.).

3.2 FISH COMMUNITY ASSESSMENT

The Khaled bin Sultan Living Oceans Foundation conducted 874 fish survey transects across 10 states in Palau. Overall, the average species richness was 44.4 species/120 m², the average density of fish was 200.2 individuals/100 m², and the average biomass was 17.28 kg/100 m² across all sites surveyd (Table 2).

3.2a SPECIES RICHNESS OF THE FISH ASSEMBLAGE

In total, 633 fish species from 50 different families were surveyed in Palau (Table 2). In general, species richness was higher at sites outside of the lagoon; however, one exception was Ngaremlengui, where species richness was higher inside than outside the lagoon (Figure 16). In fact, inside the lagoon, Ngaremlengui had the highest diversity in the 2.0-2.49 (9.6 species/120 m² +/- 4.5 S.D.), 2.5-2.99 (7.9 species/120 m² +/- 2.7 S.D.), 3.0-3.49 (14.9 species/120 m² +/- 5.4 S.D.), and 4.0-4.5 trophic categories (3.6 species/120 m² +/- 2.9 S.D.). This site falls within the boundaries of the Ngaremeduu Conservation Area and a UNESCO World Heritage Site. The sites that fell in the Rock Island Conservation in Koror had the lowest diversity in the 2.0-2.49 (4.3 species/120 m² +/- 3.0 S.D.), 2.5-2.99 (2.7 species/120 m² +/- 2.5 S.D.), and 3.0-3.49 trophic categories (6.7 species/120 m² +/- 3.2 S.D.).

Outside of the lagoon, Aimeliik had the highest diversity in the middle trophic categories, with 9.0 species/120 m² (+/- 3.7 S.D.) in the 2.5-2.99 category, and 17.4 species/120 m² (+/- 6.1 S.D.) in the 3.0-3.49 category. Interestingly, Peleliu had the highest diversity in the 4.0-4.5 trophic category (6.2 species/120 m² +/- 3.0 S.D.; Figure 16). While Ngaremlengui had the highest overall diversity inside of the lagoon, it had the lowest overall value outside of the lagoon, due to particularly low diversity in the 2.0-2.49 trophic category compared to other locations (4.2 species/120 m² +/- 3.3 S.D.).

Figure 16 MEAN FISH SPECIES RICHNESS (NUMBER OF SPECIES/120 M²) BY TROPHIC CATEGORY AT SITES INSIDE AND OUTSIDE OF THE LAGOON IN 10 STATES IN PALAU. TROPHIC CATEGORIES ARE BASED ON DIET BY SPECIES. SMALLER TROPHIC CATEGORIES TYPICALLY INCLUDE SMALLER HERBIVOROUS FISH SUCH AS BUTTERFLY FISH AND WRASSES WHILE LARGER CATEGORIES INCLUDE PREDATORY CARNIVORES SUCH AS SHARKS AND GROUPERS.

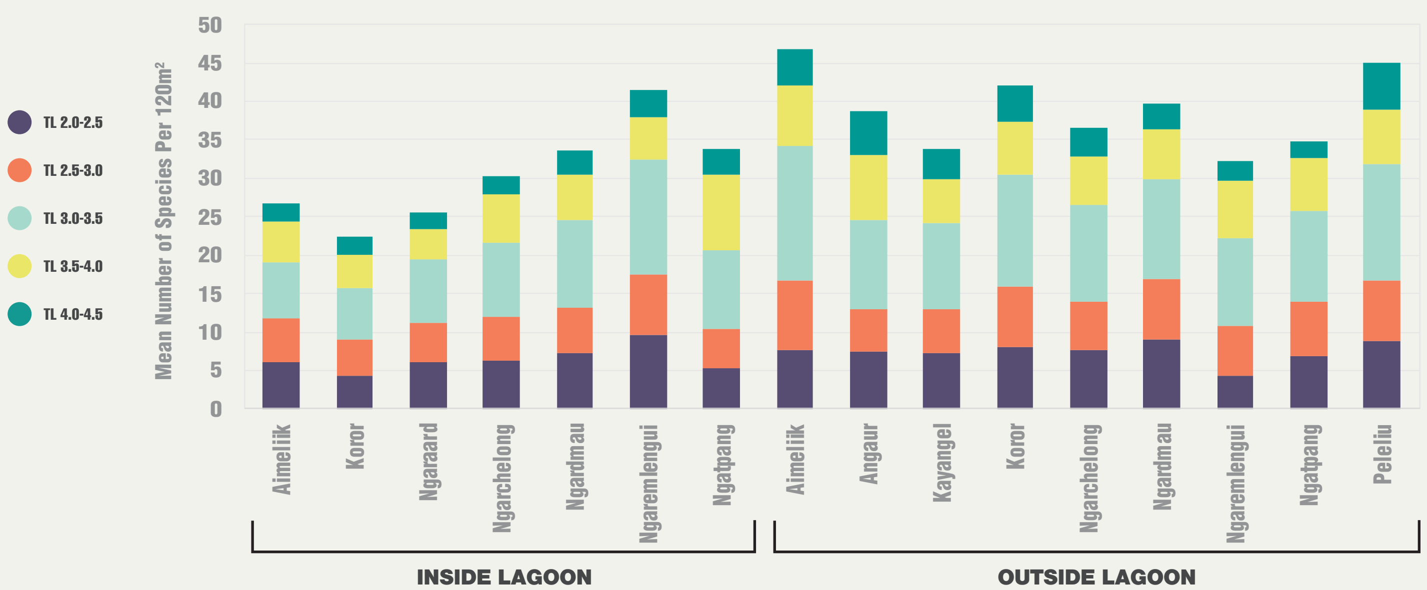


Table 2 SAMPLING INTENSITY, DIVERSITY, AND MEAN SPECIES RICHNESS (NUMBER OF SPECIES/120 M²), MEAN DENSITY (INDIVIDUALS/100 M²), AND MEAN BIOMASS (KG/100 M²) AT SITES INSIDE AND OUTSIDE THE LAGOON IN 10 STATES IN PALAU.

STATE	LAGOON	NUMBER OF SITES	NUMBER OF STATIONS	NUMBER OF TRANSECTS	NUMBER OF FAMILIES	NUMBER OF SPECIES	SPECIES RICHNESS	DENSITY	BIOMASS
Aimeliik	Inside	2	2	23	28	202	33.0	163.3	3.3
	Outside	1	1	9	32	225	64.8	247.5	15.8
	Total	3	3	32	35	320	41.9	187.0	6.8
Angaur	Inside	NA	NA	NA	NA	NA	NA	NA	NA
	Outside	3	3	21	35	278	48.4	244.5	10.9
	Total	3	3	21	35	278	48.4	244.5	10.9
Kayangel	Inside	NA	NA	NA	NA	NA	NA	NA	NA
	Outside	3	11	123	40	376	45.0	126.6	11.7
	Total	3	11	123	40	376	45.0	126.6	11.7
Koror	Inside	6	11	101	32	284	25.7	184.7	2.9
	Outside	12	15	136	45	431	54.2	204.5	15.9
	Total	18	26	237	46	507	42.1	196.0	10.4
Ngaraard	Inside	2	2	24	32	222	33.7	126.5	4.3
	Outside	NA	NA	NA	NA	NA	NA	NA	NA
	Total	2	2	24	32	222	33.7	126.5	4.3
Ngarchelong	Inside	5	9	102	41	414	39.8	147.2	4.5
	Outside	9	15	159	48	406	48.8	147.8	11.4
	Total	14	23	261	49	503	45.3	147.6	8.7
Ngardmau	Inside	5	7	80	39	389	41.6	182.1	6.2
	Outside	4	4	45	39	304	52.8	150.1	11.1
	Total	9	11	125	42	444	45.7	170.6	8.0
Ngaremlengui	Inside	1	1	8	27	168	47.1	331.9	4.6
	Outside	1	1	5	21	137	54.2	98.2	7.9
	Total	2	2	12	30	237	49.9	242.0	5.9
Ngatpang	Inside	1	1	9	24	156	39.4	157.3	3.5
	Outside	1	1	9	25	178	51.2	108.5	8.2
	Total	2	2	18	30	262	45.3	132.9	5.9
Peleliu	Inside	NA	NA	NA	NA	NA	NA	NA	NA
	Outside	2	2	20	38	254	56.4	213.1	15.8
	Total	2	2	20	38	254	56.4	213.1	15.8
TOTAL		**50**	**86**	**874**	**50**	**633**			
MEAN							**44.4**	**200.2**	**17.28**

3.3 b FISH DENSITY

Fish density showed no clear pattern between reef zones. Mean values varied widely in both groups, and values were not consistently higher or lower inside or outside of the lagoon.

Inside the lagoon, Ngaremlengui had the highest fish density, and the highest density in all but the top two trophic categories, with mean values of 62.0 individuals/100 m^2 (+/- 47.2 S.D.), 67.1 individuals/100 m^2 (+/- 52.6 S.D.), 185.0 individuals/100 m^2 (+/- 138.9 S.D.) in the 2.0-2.49, 2.5-2.99, and 3.0-3.49 trophic categories, respectively (Figure 17). Ngatpang had the highest densities in the two highest trophic categories inside the lagoon, with a mean of 61.9 individuals/100 m^2 (+/- 108.5 S.D.) in the 3.5-3.99 category and 7.5 individuals/100 m^2 (+/- 5.9 S.D.) in the 4.0-4.5 category; interestingly, this location also had the lowest density of fish in the 2.0-2.49 category (14.3 individuals/100 m^2 +/- 13.1 S.D.). The sites inside the lagoon of Ngatpang also fall within the Ngaremeduu Conservation Area and borders Ngaremlengui where some of the highest diversity was observed. Ngaraard had the lowest fish density inside the lagoon, with minimum values in the 2.5-2.99, 3.5-3.99, and 4.0-4.5 trophic categories (15.4 individuals/100 m^2 +/- 20.7 S.D., 9.3 individuals/100 m^2 +/- 10.0 S.D., 2.5 individuals/100 m^2 +/- 2.7 S.D., respectively).

Outside of the lagoon, Aimeliik had the highest fish density, with the highest values in the 2.5-2.99 trophic category (31.8 individuals/100 m^2 +/- 34.5 S.D.) and 3.0-3.49 category (151.4 individuals/100 m^2 +/- 82.0 S.D.; Figure 17). Angaur had particularly high density in the 3.5-3.99 trophic category (49.4 individuals/100 m^2 +/- 51.6 S.D.), while Peleliu had the highest density in the 4.0-4.5 category, by far (31.0 individuals/100 m^2 +/- 61.7 S.D.). Despite having the highest fish density inside the lagoon, Ngaremlengui had the lowest overall density outside of the lagoon, and the lowest mean values in the 2.0-2.49 (15.8 individuals/100 m^2 +/- 10.8 S.D.) and 3.0-3.49 trophic categories (43.8 individuals/100 m^2 +/- 29.4 S.D.). Similarly, Ngatpang, which had the highest values in the two highest trophic categories inside of the lagoon, had the lowest values for these categories outside the lagoon (9.3 individuals/100 m^2 +/- 4.9 S.D. in the 3.5-3.99 category and 4.3 individuals/100 m^2 +/- 3.7 S.D. in the 4.0-4.5 category).

3.3 c FISH BIOMASS

Fish biomass was higher outside of the lagoon than inside at all locations. Of the sites inside of the lagoon, biomass was highest at Ngardmau, which had the highest biomass in the 2.0-2.49 (2.1 kg/100 m^2 +/- 2.3 S.D.), 3.0-3.49 (1.3 kg/100 m^2 +/- 1.4 S.D.), and 4.0-4.5 trophic categories (1.6 kg/100 m^2 +/- 2.3 S.D.; Figure 18). The sites surveyed in the lagoon here did not fall within the conservation areas of this state, so observing the higher biomass in the higher trophic levels is encouraging and should be monitored further. Koror had the lowest overall biomass inside the lagoon, due to the particularly low biomass found in the 2.0-2.49 trophic category (0.6 kg/100 m^2 +/- 0.7 S.D.) in this location. Ngatpang stood out among the locations inside the lagoon for having particularly low biomass in the 2.5-2.99 trophic category (0.2 kg/100 m^2 +/- 0.2 S.D.) and high biomass in the 3.5-3.99 category (1.2 kg/100 m^2 +/- 0.8 S.D.) compared to other locations.

Despite having the lowest overall biomass inside the lagoon, Koror had the highest biomass of all of the locations outside of the lagoon. Biomass in the 2.5-2.99 trophic category was much higher within this state (2.4 kg/100 m^2 +/- 6.4 S.D.) than at any other location. Koror also had the highest biomass in the 4.0-4.5 trophic category (5.4 kg/100 m^2 +/- 9.7 S.D.; Figure 18). Aimeliik and Peleliu had similar overall biomass to Koror outside of the lagoon, with the highest value for trophic level 3.0-3.49 at Aimeliik (4.2 kg/100 m^2 +/- 2.3 S.D.). These states are all adjacent to each other and makeup the southwestern region of the barrier reef surrounding Babeldaob. Ngaremlengui had the lowest overall biomass of sites outside the lagoon, and the lowest values in the 2.0-2.49 (1.7 kg/100 m^2 +/- 1.9 S.D.), 3.0-3.49 (1.2 kg/100 m^2 +/- 1.6 S.D.), and 3.5-3.99 trophic categories (0.7 kg/100 m^2 +/- 0.6 S.D.). Ngatpang had notably low biomass in the 4.0-4.5 trophic category (1.2 kg/100 m^2 +/- 1.9 S.D.).

Figure 17 MEAN DENSITY OF FISH (INDIVIDUALS/100 M²) BY TROPHIC LEVEL AT SITES INSIDE AND OUTSIDE OF THE LAGOON IN 10 STATES IN PALAU.

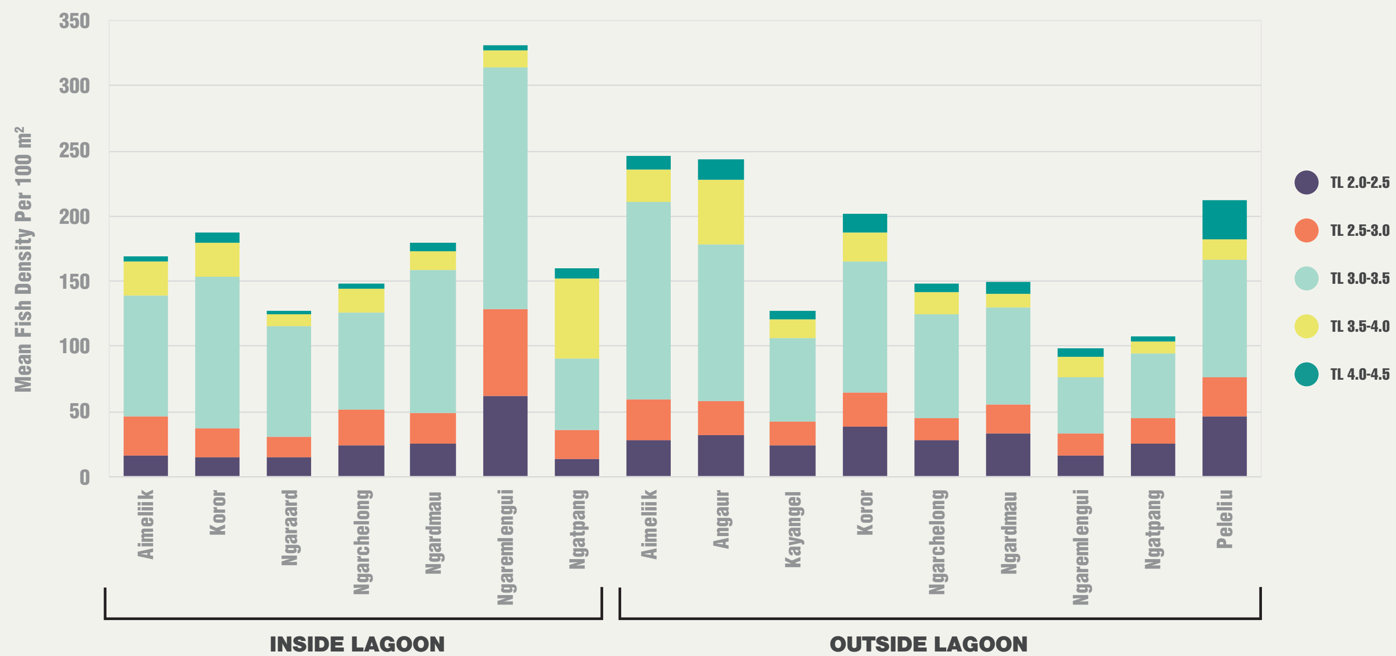
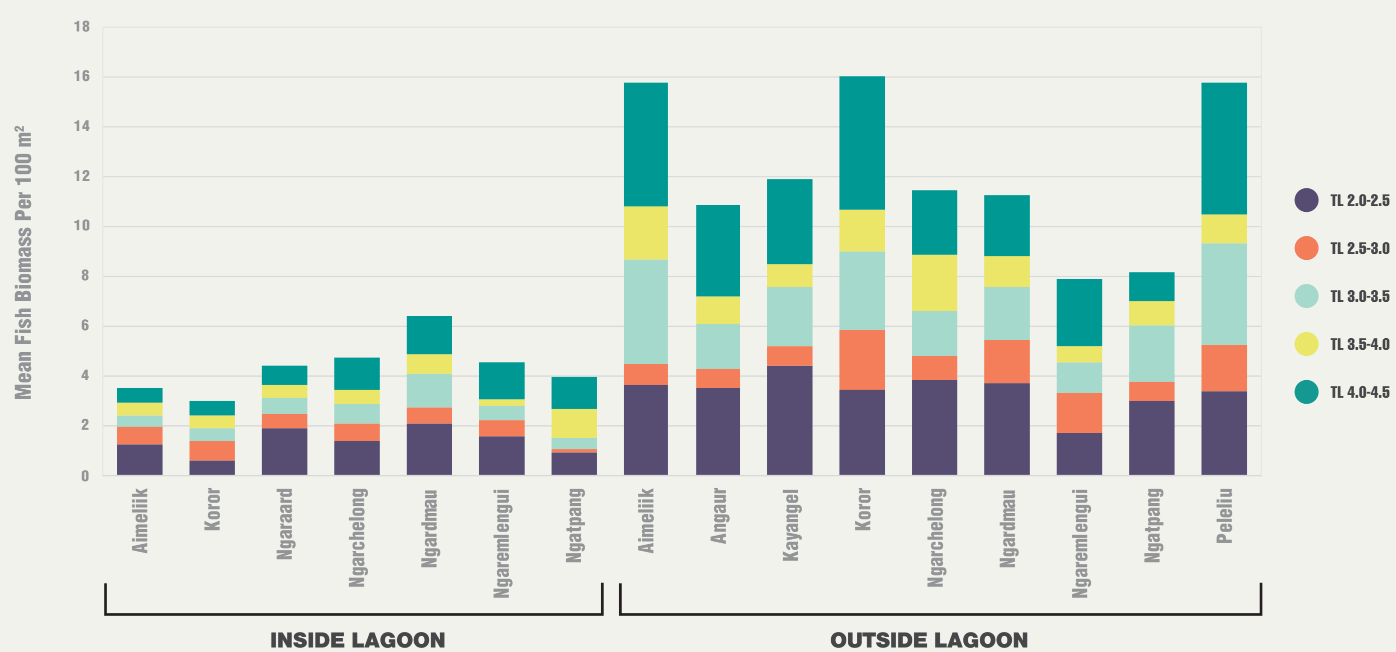


Figure 18 MEAN BIOMASS OF FISH (KG/100 M²) BY TROPHIC LEVEL AT SITES INSIDE AND OUTSIDE OF THE LAGOON IN 10 STATES IN PALAU.

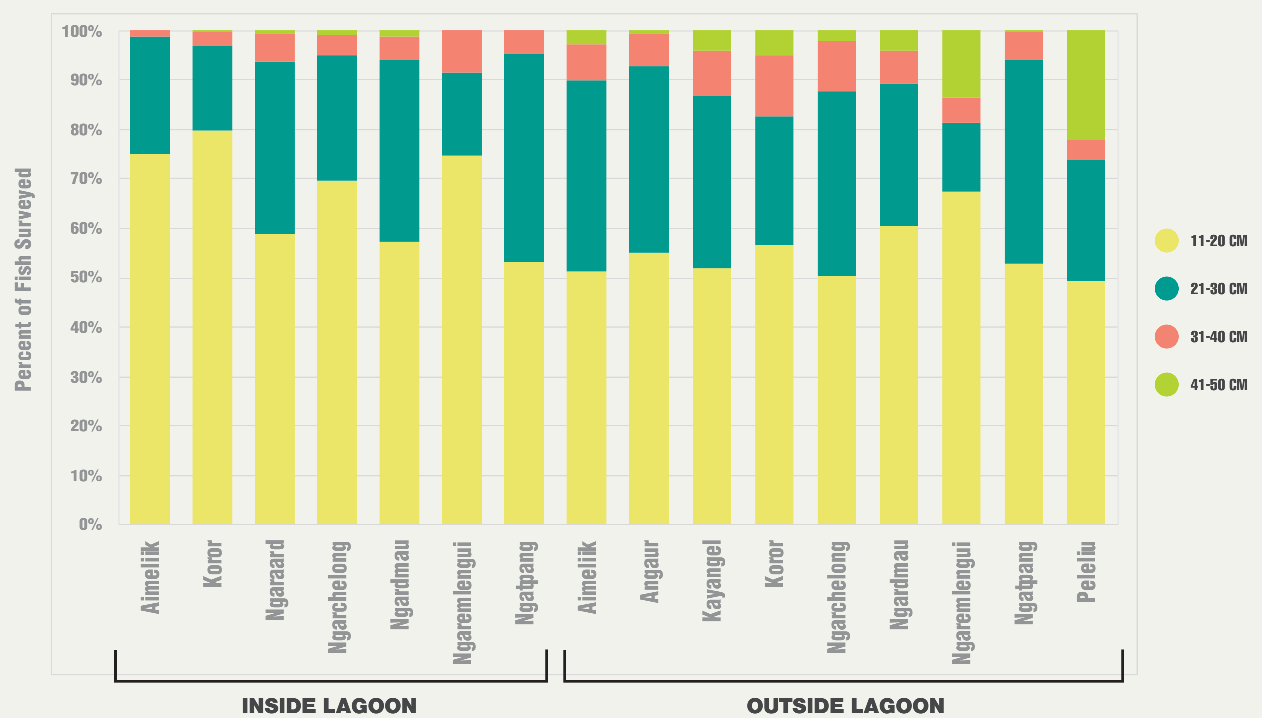


3.3 d SIZE DISTRIBUTION OF FISH

Fish that measured 11-20 cm dominated all sites inside and outside of the lagoon, making up at least 50% of the fish surveyed at each location except for Peleliu outside the lagoon, where 49.4% of fish surveyed fell into this category (Figure 19). At all but the same site, the smallest two size categories made up over 75% of the fish surveyed. However, in general, sites outside of the lagoon had higher proportions of larger fish (41-50 cm) than those inside the lagoon. In fact, at three sites inside the lagoon (Aimeliik, Ngaremlengui, and Ngatpang), no fish in the 41-50 cm size category were recorded.

Large fish made up the smallest percentage of fish surveyed at all sites except outside of the lagoon at Ngaremlengui and Peleliu, where fish in the 41-50 cm size category outnumbered those in the 31-40 cm size category, representing 13.6% and 22.1% of the fish surveyed at each site, respectively. Peleliu outside the lagoon had the highest percentage of fish in the upper two size categories overall (26.3%), whereas Aimeliik inside of the lagoon had the highest percentage of fish in the smaller two size categories (99.2%).

Figure 19 THE RELATIVE SIZE DISTRIBUTION (%) OF SELECTED IMPORTANT FISH FAMILIES AT SITES INSIDE AND OUTSIDE OF THE LAGOON IN 10 STATES IN PALAU. FAMILIES INCLUDED WERE: ACANTHURIDAE, CARANGIDAE, HAEMULIDAE, LETHRINIDAE, LUTJANIDAE, NEMIPTERIDAE, SCARIDAE, SERRANIDAE, AND SIGANIDAE. FISH WITH TOTAL LENGTHS BELOW 10 CM AND GREATER THAN 50CM WERE EXCLUDED.



The data collected on this mission can help marine managers **monitor changes** over time and **adapt management plans** to **conserve** these habitats.

4.0 DISCUSSION

DISCUSSION

4.0

Overall, KSLOF found the reefs of Palau to be in some of the best condition of those visited on the Global Reef Expedition, particularly so for those in the south and western Pacific. The average live coral cover for the country was the highest seen on the Global Reef Expedition **(Figure 20)**. While not the highest observed on the Global Reef Expedition, the fish biomass and density were comparable to nearby countries **(Figures 21-22)**.

In nearly every state surveyed, the reefs outside of the lagoon had only slightly higher coral cover and coral diversity than what was observed inside of the lagoon. Additionally, fish biomass and diversity were generally higher outside of the lagoon compared to what was observed inside, as was the proportion of large fish. Peleliu stood out as having the highest live coral cover, highest proportion of large fish, as well as high values for all metrics in the 4.0-4.5 trophic fish category, indicating a healthy population of large top predatory fish in this state. It is worth noting that these high values found in Peleliu fell outside the boundaries of the MPA. Generally, the differences between sites inside and outside of the lagoon, particularly for the fish communities, are consistent with the findings of Gouezo et al. (2016)[17]. They found that outer reef MPAs of Palau had healthier reef and fish communities than inner reef MPAs, with the highest biomass of commercially-important fish species in outer reef habitats. The authors attributed this difference to the length of time these areas had been protected, the size of the MPAs, and the remoteness of the MPAs to shore. Although not all sites surveyed by KSLOF fall within MPAs, 93% of sites surveyed fell within some sort of management area.

The benthic communities, while having slightly lower average live coral cover inside of the lagoon, was not notably different than what was observed outside. There was, however, a difference in the coral diversity with most lagoonal sites having lower coral diversity. This may be due to the ecological differences of these reef habitats, as corals on forereefs may experience less

Figure 20 GLOBAL COMPARISON OF PERCENT LIVE CORAL COVER AMONG COUNTRIES VISITED ON THE GRE.

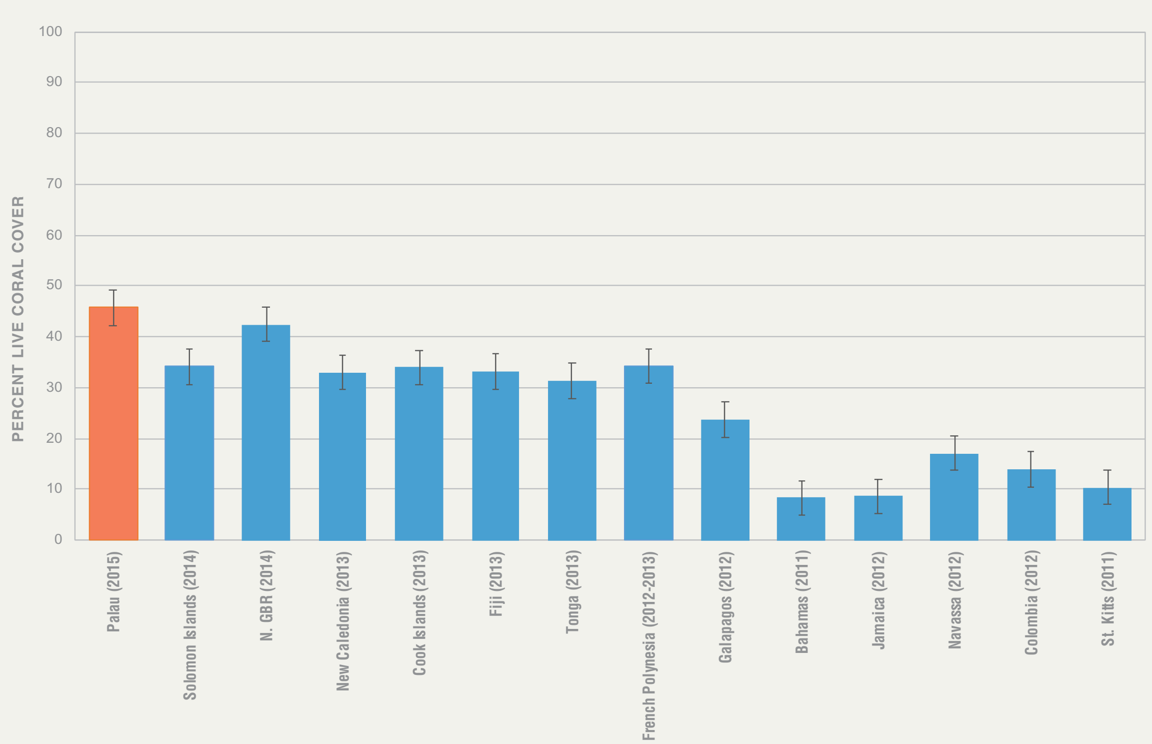


Figure 21 GLOBAL COMPARISON OF FISH BIOMASS AMONG COUNTRIES VISITED ON THE GRE.

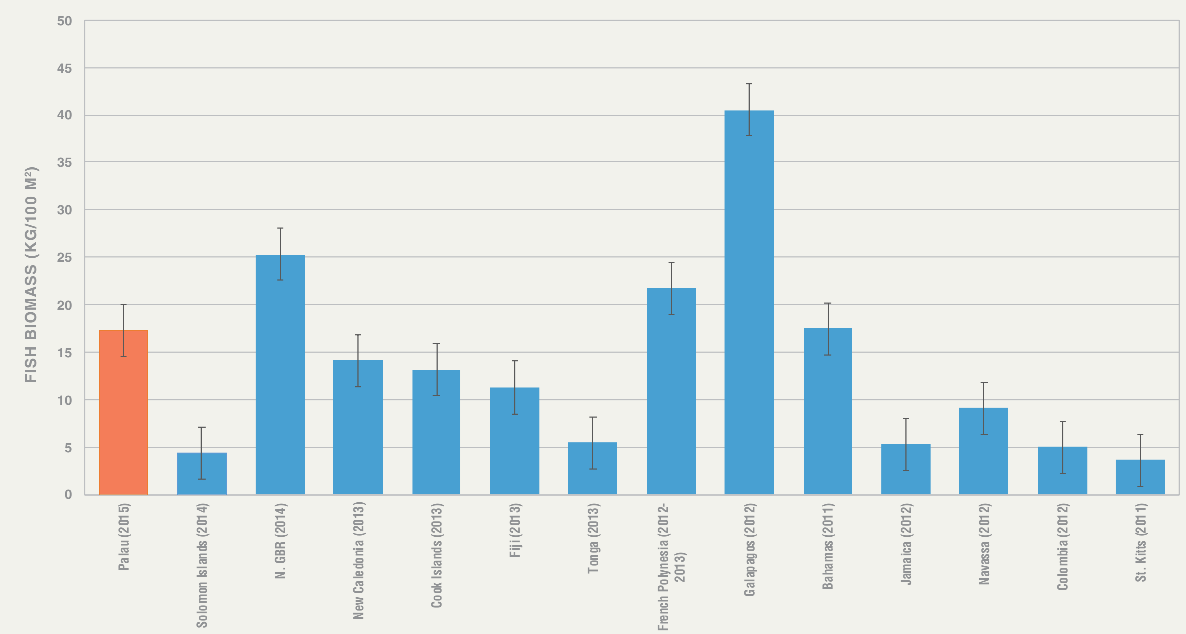


Figure 22 GLOBAL COMPARISON OF FISH DENSITY (NUMBER. OF FISH/100 M²) AMONG COUNTRIES VISITED ON THE GRE.

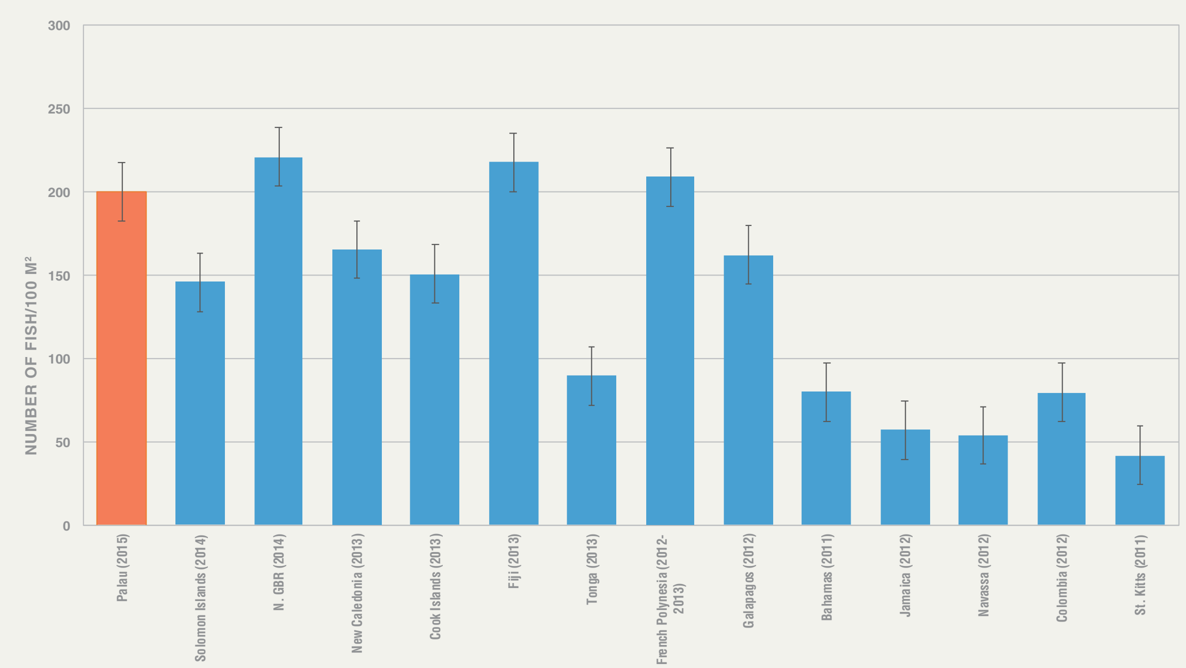


Figure 23

COMPARISON OF HUMAN POPULATION AGAINST PERCENT LIVE CORAL COVER FOR EACH LOCATION INSIDE AND OUTSIDE OF THE LAGOON.

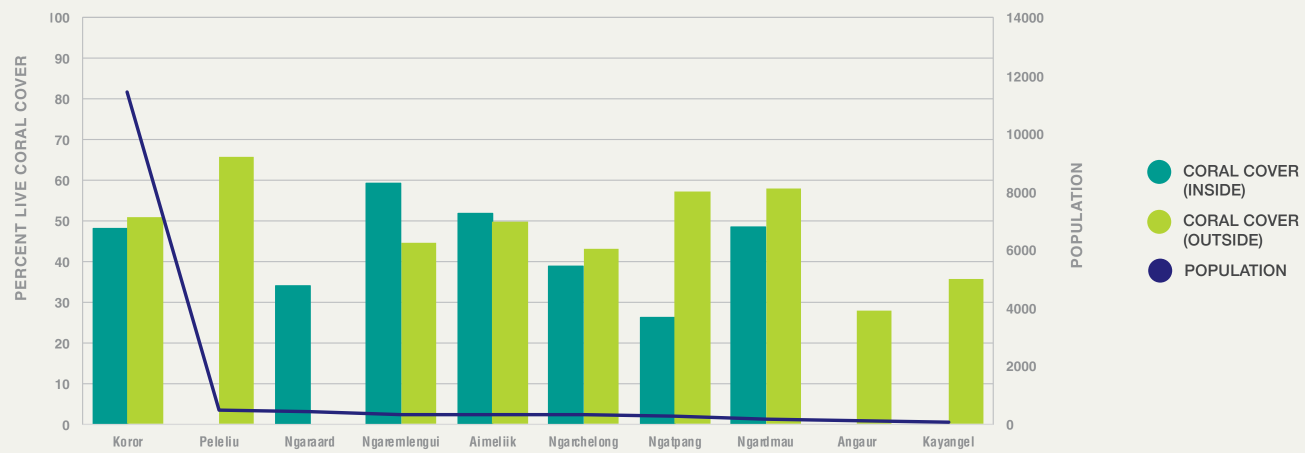


Figure 24

COMPARISON OF HUMAN POPULATION AGAINST FISH BIOMASS FOR EACH LOCATION INSIDE AND OUTSIDE OF THE LAGOON.

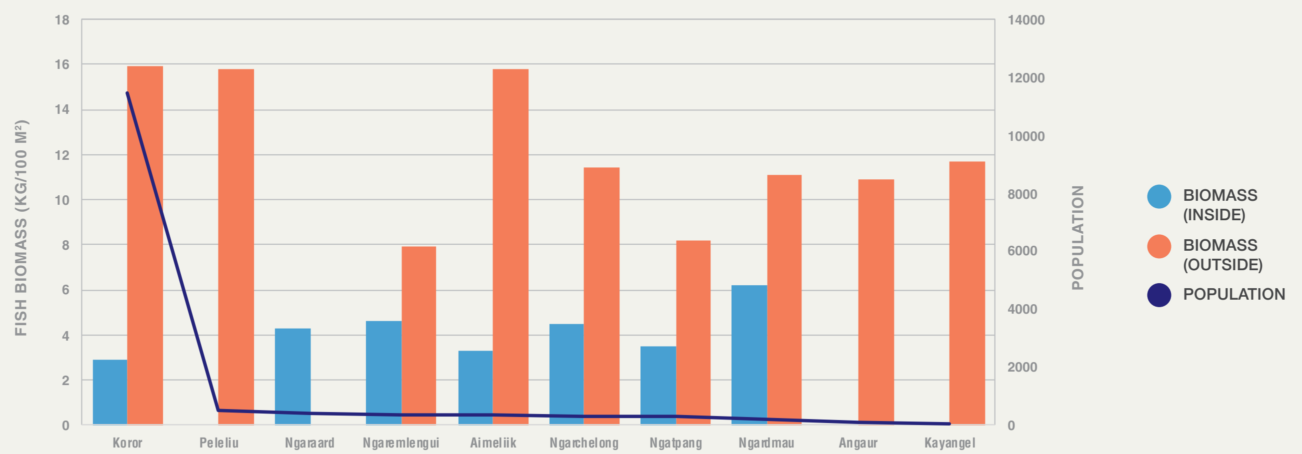
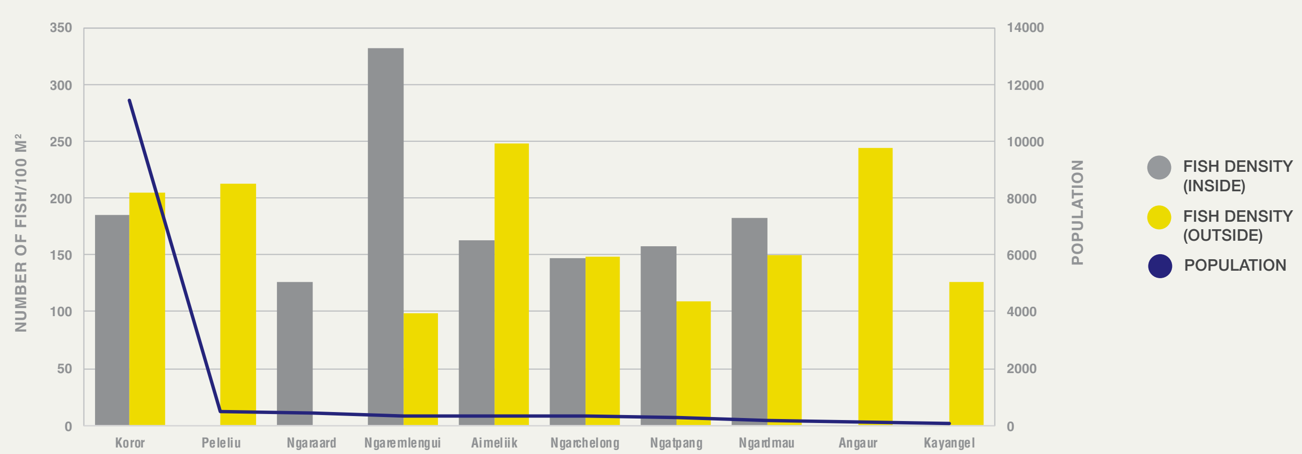


Figure 25

COMPARISON OF HUMAN POPULATION AGAINST FISH DENSITY FOR EACH LOCATION INSIDE AND OUTSIDE OF THE LAGOON.



abiotic stress such as light availability, sedimentation, temperature fluctuations and freshwater influence, allowing for a more diverse coral community[49]. Overall, the benthic communities showed high coral cover both inside and outside of the lagoon **(Figure 23)**. While the benthic communities are not always included in the management plans, which are instead focused on managing fisheries, the overall high coral cover found within the managed areas may be indirectly benefitting from other conservation efforts. This includes the land-based management efforts to reduce sedimentation, such as what is being done in Aimeliik and Ngardmau States.

Two exceptions of the overall high coral cover in Palau were in Kayangel and Angaur. These states were both impacted by recent typhoons with Kayangel Atoll being directly in the storm path of super Typhoon Haiyan. Kayangel had the lowest overall live coral cover observed in Palau and may be partially attributed to this typhoon. A study by Gouezo et al. (2015) looked at the impacts of Typhoons Bopha and Haiyan and found that the reefs of Palau, particularly those closest to the storm path, showed significant decreases in overall live coral cover. This was particularly noted on the southeastern-facing reef slopes following Typhoon Bopha and northeastern-facing slopes following Typhoon Haiyan[48]. KSLOF did not survey on the eastern side of Angaur State, so it is hard to know if the overall live coral cover is directly attributed to storm damage or due to other factors. Continued monitoring of these states will be important to assess the natural recovery of the reefs.

Across all states, diversity, biomass, and fish size were generally smaller at locations inside the lagoon, with almost all surveys falling within MPAs, and fish density did not show a clear pattern between sites inside and outside of the lagoon. The differences in fish biomass between locations inside and outside of the lagoon are driven by differences in fish size, rather than abundance. This pattern could be impacted by several factors, including natural ecological difference between inshore and outer reef habitats; preferential fishing of larger fish in the lagoons; and/or more recent management at sites inside the lagoons.

In general, fish populations were less diverse, and characterized by smaller fish and lower biomass at sites inside the lagoons in Palau. The disparity between sites inside and outside the lagoon was most evident when comparing biomass between locations. Despite biomass and diversity inside the lagoons being distributed across all trophic categories, there was an obvious lack of large fish (41-50 cm) in most states, indicating that though predators are present at these sites, they are generally not large. This also indicates that while there are many conservation efforts in place, particularly within the lagoons, they may not be strict enough and could further benefit from additional regulations such as fish size limits.

Koror, the most populous state in the country, showed a large disparity in fish diversity and biomass between sites inside and outside of the lagoon **(Figure 24)**. In fact, sites falling inside the lagoon had the lowest overall mean values for both metrics, while outside of the lagoon had the highest overall mean biomass. The low values inside of the lagoon in Koror are likely driven by several factors. While all sites inside of the lagoon in this state fall under at least one management regime, for most sites this means only that use permits are required for non-Palauan visitors, tourism is restricted, and that fishing requires a permit. Therefore, due to their proximity to the country's population center, it is likely that these reefs are exposed to the highest fishing and use (i.e. tourism) pressure. Similarly, these reefs are likely exposed to higher levels of land-based pollution than those located away from urbanized areas. Indeed, Gouezo et al. (2016) found that pollution significantly affected the ecological condition of nearshore MPAs in Palau. The presence of some "no fishing" reserves outside of the reef in Koror may have contributed to the high biomass found at these sites.

Sites in the state of Ngaremlengui showed unique patterns when compared to those in other states, with much higher overall mean values for fish diversity and density inside the lagoon than outside the lagoon **(Figure 25)**. However, biomass in this state showed the same pattern as for other states, and fish inside the lagoon were found to be very small on average. This indicates a fish population with high abundance and diversity of small fish species inside of the lagoon in this state, and a less diverse population characterized by fewer, larger fish outside of the lagoon. It must be noted, however, that only one station was surveyed inside and outside of the lagoon in this state, so it is not possible to conclude whether these patterns are representative of all reefs in this location.

5.0 CONSERVATION RECOMMENDATIONS

CONSERVATION RECOMMENDATIONS

5.0

Overall, the reefs of Palau are in good condition when compared to nearby island nations surveyed on the GRE. The conservation efforts by the people of Palau appear to be having a positive effect **(Figure 26)**. When looking at both fish and benthic communities, the forereefs presented better metrics when compared to lagoon sites, indicating a more stable ecosystem. While many of the differences between sites inside and outside of the lagoon may be based on inherent ecological differences between the two reef zones, the patterns in Koror suggest that human population density is having a negative impact on reefs inside the lagoon in Palau, likely due to increased fishing pressure and/or land-based pollution **(Figures 23-25)**.

In Palau, majority of the conservation efforts are focused inside of the lagoon surrounding Babeldaob which is where most of the tourism and fishing activities occur. As many of the MPAs are small in size, it may also be useful to establish fish size and catch regulations to help reduce fishing pressure of these nearshore lagoonal reefs. It may be prudent to consider increasing protection in areas adjacent to large population centers, such as around Koror to be more restrictive and expand no-take, no-entry area size to allow for recovery of fish populations.

Natural disturbances, such as coral bleaching events, storms, and ocean acidification are expected to worsen in the coming years. Protocols for mitigating these disturbances are currently missing from many of the management plans put forth by state governments. While prioritizing management of fisheries is important, mitigating the benthic communities should also be addressed. Groups from the Palau International Coral Reef Center have been monitoring sites impacted by typhoons Bopha and Haiyan and are working to understand recovery of the reefs following these two disturbances. Their findings, when released, should be referenced when expanding and updating current management plans, particularly for areas directly impacted by these storms.

KSLOF commends the people of Palau for the prioritizing conservation of its marine resources. Expansion of current management plans to encapsulate the threats facing benthic habitats along with potential mitigation strategies and additional fisheries management regulations such as size and catch limits will help ensure the longevity of the coral reefs and fish communities for generations to come.

Figure 26 PALAU'S CONSERVATION EFFORTS, SUCH AS ESTABLISHING MPAS LIKE THE ROCK ISLAND SOUTHERN LAGOON MANAGEMENT AREA, APPEAR TO BE HAVING A POSITIVE EFFECT ON CORAL REEFS.

> Additional **fisheries management** regulations will help **conserve Palau's coral reefs** and **fish communities** for generations to come.

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The Khaled bin Sultan Living Oceans Foundation is grateful for the assistance provided by our partners in the Republic of Palau. We would like to express our thanks to Minister F. Umiich Sengebau of the Ministry of Natural Resources, Environment, and Tourism for granting us permission to sample and study the reefs of your country. KSLOF would like to especially thank Dr. Steve Lindfield for his assistance on the research mission, as well as his expertise and contributions to this report.

The research mission to Palau would not have been possible without the leadership, vision, and generosity of His Royal Highness Prince Khaled bin Sultan. We are deeply appreciative of his financial support and for the generous use of his research vessel, the M/Y *Golden Shadow*. His vision of *Science Without Borders®* was materialized in the research mission to Palau through the involvement and partnerships by scientists from the following countries: Republic of Palau, USA, Australia, Germany, UK, Portugal, the Philippines, and Taiwan.

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The Foundation would also like to thank the International League of Conservation Photographers (ILCP) and underwater photographer Keith Ellenbogen, who joined us on the Global Reef Expedition mission to Palau and took most of the beautiful images that appear in this report.

The research mission to Palau benefited from the hard work of the Captain, officers, and crew of the M/Y *Golden Shadow*. They were responsible for getting us safely to our research sites and conducting all logistical operations of the dive and research vessels. They ensured that each researcher had access to the study sites and proper working tools and equipment needed to complete the work and had highly capable engineers and electricians that repaired and fabricated gear when we ran into complications. Behind the scenes, the crew worked at all hours to support the scientists on the Global Reef Expedition, and for that, we are immensely grateful.

As deliverables from this research project are completed, we look forward to continuing these partnerships to ensure the information and data from this project are applied toward the conservation needs and goals of the people of Palau.

Thank you to Prince Khaled bin Sultan, our partners in Palau, esteemed scientists, and crew of the M/Y *Golden Shadow* for making this research mission a success.

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APPENDIX 1 | DIVE SITES AND SITE DESCRIPTIONS

State	Site	Latitude	Longitude	Reef Type	Reef Location
Koror	PA01	7.3271	134.4949	fringing reef	lagoonal
Koror	PA02	7.3355	134.4221	fringing reef	lagoonal
Koror	PA03	7.3617	134.4249	patch reef	lagoonal
Koror	PA04	7.2693	134.3528	fringing reef	lagoonal
Koror	PA05	7.2799	134.3954	patch reef	lagoonal
Koror	PA06	7.2927	134.4153	fringing reef	lagoonal
Koror	PA07	7.2581	134.5238	barrier reef	fore reef
Koror	PA08	7.28401	134.56319	barrier reef	fore reef
Koror	PA09	7.3564	134.2954	patch reef	lagoonal
Koror	PA10	7.301	134.2364	fringing reef	fore reef
Koror	PA11	7.2962	134.258	patch reef	back reef
Koror	PA12	7.2623	134.246	fringing reef	fore reef
Koror	PA13	7.3423	134.2592	barrier reef	fore reef
Koror	PA14	7.2505	134.2391	barrier reef	fore reef
Koror	PA15	7.2586	134.1856	fringing reef	fore reef
Koror	PA16	7.2836	134.2448	fringing reef	fore reef
Koror	PA17	7.2659	134.2456	fringing reef	fore reef
Peleliu	PA18	7.0626	134.2489	fringing reef	fore reef
Peleliu	PA19	7.0827	134.2625	fringing reef	fore reef
Koror	PA20	7.1112	134.2398	fringing reef	fore reef
Koror	PA21	7.1356	134.2204	barrier reef	fore reef
Koror	PA22	7.1722	134.2204	barrier reef	fore reef
Koror	PA23	7.1181431	134.2707481	patch reef	fore reef
Angaur	PA24	6.9211315	134.1231126	fringing reef	fore reef
Angaur	PA25	6.8978678	134.1149993	fringing reef	fore reef
Angaur	PA26	6.9071414	134.1542173	fringing reef	fore reef
Koror	PA27	7.4129204	134.3369557	barrier reef	fore reef
Koror	PA28	7.4406622	134.3508554	barrier reef	fore reef
Ngaremlengui	PA29	7.547774	134.4586631	barrier reef	fore reef
Ngardmau	PA30	7.5988	134.4801	barrier reef	fore reef
Ngaremlengui	PA31	7.5450874	134.4878776	patch reef	lagoonal
Aimeliik	PA32	7.4967	134.3828	barrier reef	fore reef
Ngardmau	PA33	7.6323	134.5213	patch reef	fore reef
Aimeliik	PA34	7.4101	134.45	patch reef	lagoonal
Ngatpang	PA35	7.5315	134.4363	barrier reef	fore reef
Ngardmau	PA36	7.6569	134.54585	barrier reef	fore reef
Ngarchelong	PA37	7.6917	134.5583	barrier reef	fore reef
Ngardmau	PA38	7.6464	134.536	barrier reef	fore reef
Ngarchelong	PA39	8.0103	134.5405	barrier reef	fore reef
Ngarchelong	PA40	7.8514	134.507	barrier reef	fore reef
Ngarchelong	PA41	7.781	134.5594	barrier reef	fore reef
Ngarchelong	PA42	7.7125	134.5644	barrier reef	fore reef
Ngardmau	PA43	7.6563	134.5653	back reef	back reef

State	Site	Latitude	Longitude	Reef Type	Reef Location
Ngarchelong	PA44	7.6761	134.5506	barrier reef	fore reef
Ngarchelong	PA45	7.7717	134.5653	barrier reef	fore reef
Ngarchelong	PA46	7.7439	134.5705	barrier reef	fore reef
Ngardmau	PA47	7.6403	134.5473	channel reef	back reef
Ngarchelong	PA48	7.7156	134.5841	patch reef	back reef
Ngardmau	PA49	7.6448	134.5815	patch reef	lagoonal
Ngaraard	PA50	7.6674	134.5992	patch reef	lagoonal
Ngardmau	PA51	7.5986	134.5081	patch reef	back reef
Ngardmau	PA52	7.6254	134.5609	patch reef	lagoonal
Ngarchelong	PA53	7.6815	134.5835	patch reef	back reef
Kayangel	PA54	8.1677	134.6079	patch reef	fore reef
Kayangel	PA55	8.1823	134.6136	fringing reef	fore reef
Kayangel	PA56	8.1993	134.6074	fringing reef	fore reef
Kayangel	PA57	8.094	134.6924	fringing reef	fore reef
Kayangel	PA58	8.0679	134.6816	fringing reef	fore reef
Kayangel	PA59	8.0716	134.687	fringing reef	fore reef
Ngarchelong	PA60	7.8708	134.5042	barrier reef	fore reef
Ngarchelong	PA61	7.8905	134.5871	patch reef	lagoonal
Ngarchelong	PA62	7.9654	134.5774	back reef	back reef
Ngarchelong	PA63	7.9626	134.5023	channel reef	fore reef
Ngarchelong	PA64	7.9805	134.5091	fringing reef	fore reef
Ngarchelong	PA65	7.9539	134.6266	back reef	back reef
Kayangel	PA66	8.1538	134.6099	fringing reef	fore reef
Kayangel	PA67	8.1481	134.6346	fringing reef	fore reef
Kayangel	PA68	8.1909	134.6116	fringing reef	fore reef
Ngarchelong	PA69	7.7746	134.5882	patch reef	lagoonal
Ngarchelong	PA70	7.8139	134.5305	fringing reef	fore reef
Ngarchelong	PA71	7.8025	134.6044	patch reef	lagoonal
Ngardmau	PA72	7.6572	134.5796	patch reef	lagoonal
Ngardmau	PA73	7.61051	134.4962	barrier reef	back reef
Ngaraard	PA74	7.6327	134.5951	patch reef	lagoonal
Ngarchelong	PA76	7.8292871	134.5201898	fringing reef	fore reef
Ngarchelong	PA77	7.7605478	134.5682935	fringing reef	fore reef
Ngarchelong	PA78	7.8936456	134.4924933	fringing reef	fore reef
Kayangel	PA79	8.048	134.6827	fringing reef	fore reef
Kayangel	PA80	8.084	134.6879	fringing reef	fore reef
Ngarchelong	PA81	7.8157	134.5712	patch reef	lagoonal
Ngarchelong	PA82	7.7844	134.6214	patch reef	lagoonal
Aimeliik	PA83	7.4828	134.4219	patch reef	lagoonal
Ngatpang	PA84	7.5074	134.4454	patch reef	lagoonal
Koror	PA85	7.3267	134.495	fringing reef	lagoonal
Koror	PA86	7.3228	134.4995	fringing reef	lagoonal
Koror	PA87	7.3223	134.4911	fringing reef	lagoonal

APPENDIX 2 | PARTICIPANT LIST

Participant	Institution	Function
Andrew Bruckner	Living Oceans Foundation	Chief Scientist
Badi Samaniego	University of Philippines	LOF Fellow, Fish Surveyor
Ken Marks	Atlantic and Gulf Reef Assessment (AGRRA)	Phototransects
Grace Frank	James Cook University	Coral Surveyor
Joao Monteiro	University of the Azores	Symbiodinium
Anderson Mayfield	National Museum of Marine Biology and Aquarium	LOF Fellow, Coral Physiology
Stefan Andrews	Contract	Fish Surveyor
Shanee Stopnitzky	USC Santa Barbra	LOF Fellow, Benthic Surveyor
Kristin Stolberg	University of Queensland	Benthic Surveyor
Phil Renaud	Living Oceans Foundation	Excecutive Director
Keith Ellenbogen	Photographer, Contract	Photography
Graham Kolodziej	University of Miami, NOAA	Ocean Acidificaiton
Samantha Clements	University of California, San Diego, Scripps Institute of Oceanography	Benthic Surveyor
Georgia Coward	OceansWatch	Fish Surveyor
Steven Lindfield	Palau International Coral Reef Center	Fisheries Researcher
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