Northern Reef Fisheries Management Project

2012-2020

The Nature Conservancy

The Nature Conservancy Micronesia

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Vision

The people of Micronesia taking local action and inspiring leadership to sustain their natural heritage in a rapidly changing world.

Northern Reef Fisheries Management Project Summary

The Northern Reefs of Palau- Management Zones

The Northern Reefs of Palau (NR) comprise the largest managed area within the Palau Protected Areas Network (PAN). It includes the territorial waters of Kayangel and Ngarchelong States, made up of reefs and deep waters up to 12 miles. The NR has a total combined area of 3,930 km^2, with 172 km^2 of reef area treated as a no take zone —representing 32% of Palau's coral reefs—; 221 km^2 settled as a subsistence fishing zone (6.5% of the total marine area in the NR), and 2,997 km^2 treated as a commercial fishing zone (88% of which are pelagic waters). The NR ecosystem is comprised of mangroves, seagrasses, fringing reefs, patch reefs, lagoons, channels, barrier reefs, sunken reefs, atoll reefs, and deep water that extends beyond 1000 m in depth.

Basic fishers profile based on a 2016 socio-economic survey:

- A total of 87 fishers (classified as the primary persons engaged in fishing at least once/week) were identified in 2014 for Ngarchelong and Kayangel States
- The average age of fishers was 52 years old
- Most active fishers were male
- Fishing for subsistence (for food and sharing with relatives) was the predominant driver of fishing
- Most fishers obtained income from a paid job and/or were receiving social security and pension benefits

What have we done

We worked with fishers from the communities of Kayangel and Ngarchelong States in the northern reefs, to increase their engagement and participation in conservation, with the following goals in mind:

- Collect data that improved the understanding of fisheries in the NR, where data showed that over 50% of fish being caught were immature
- Establish the Northern Reef Fisheries Cooperative, which would provide a platform to engage with fishers, while supporting their livelihoods as fishers
- Work with fishers to explore sustainable livelihood opportunities
- Work towards the improvement of management capacity
- Establish the 1st comprehensive fisheries management legal framework at the state level
- Create the 1st comprehensive regulatory framework and fisheries management plan at the state level, while establishing the following:
  1. Size limit for 14 species
  2. 10-year ban for 2 species of giant clam
  3. 10-year ban for giant trevally
  4. Ban the trade of wild harvested aquarium species
  5. Fishing permit system
  6. Enforcement citation system
  7. Fines for the violation of regulated activities

Status

Management sufficiency

- Increased the targeting of pelagic species by NRFC, from 15% in 2011- 2012, to 41% in 2018-2019
- 70% of the fish sold to the Northern Reef Fisheries Cooperation (NRFC) are pelagic species
- By selling their catch to NRFC, an annual average of $20k is being contributed towards fishers' livelihoods
- 16,000 giant clam seedlings were planted in 16 giant clam farms, with an overall maturity survival rate of >60%. Farmers reported an increase in giant clam seedlings around the vicinity of their farms
- Identified four livelihood opportunities —giant clam and rabbitfish aquaculture, targeting of pelagic species for sale, and sport fishing tourism— with the potential to further their development in order to support fishers' sustainable livelihoods
- Established an additional 112 km² of no take zones
- Secured the size limit of 14 reef fish species
- Two species of giant clam were put on a 10-year moratorium
- Giant Trevally was secured a 10-year moratorium
- A moratorium on wild harvest of aquarium species was established
- A fishing permit system was set in place, covering subsistence, commercial, and recreational fishing
- Established commercial and subsistence fishing zones

Needs improvement

- Fisheries dependent and independent data collection
- Management of Northern Reef Fisheries Cooperative
- Enforcement and compliance management
- Strengthening community development on sustainable livelihood

Ecological Condition

- 7 of the 14 species that were regulated through size limits showed positive changes in size structure within 3 years of monitoring
- An increase in grouper- *Plectropomus areolatus* after a 3-year moratorium was observed. However, after lifting the ban in 2018, *P. areolatus* size frequency in 2019 almost resembled that which was observed pre-moratorium
- Biomass of Lethrinidae, Scaridae, and Lutjanidae remained stable

Needs improvement

- Overall fisheries biomass continued to decline based on fisheries independent data; there needs to be monitoring 5 years after the implementation of the regulations in 2017, to determine if the implementation of harvest control rules had any impact on fish biomass
- Updating regulations on species that need it, based on new scientific information and considering other harvest control rules to address species that are not regulated by size

Durability

Finance

• Increase of funding for PAN, from an annual average of $94K prior to 2015, to an average of $126K

Needs improvement

• Increase funding to cover management needs, which has an annual average of $184K

• Increase financial investment from the local government into management efforts

Governance

- A fisheries legal framework —Fisheries Act of 2015 for both Kayangel and Ngarchelong States— and state-level fisheries regulations have been set in place, to support fisheries management
- Establishment of Conservation and Law Enforcement Departments within the States of Kayangel and Ngarchelong
- Fisheries management integrated with respective state Protected Areas Programs and within management plans; all of the northern reef waters are part of the Palau PAN Network

Needs improvement

- Citation process in place to support enforcement; implementation and prosecution of violation needs to improve
- Development of joint enforcement between Kayangel and Ngarchelong needs to improve
- Development of joint enforcement coordination between state and national enforcement agencies
- Improve the retention rate of the conservation and law enforcement program by improving job security and satisfaction

Community support

- In 2019, only 15% of community members recorded in a survey that they did not support the management of the northern reefs, indicating strong community support
- 90% of the catch sold to NRFC meet size limits, indicating relatively good compliance of size regulation by NRFC fishers.

Management capacity

- Increased number of rangers prior to 2015, from 4 to 5 in Kayangel, and 7 to 8 in Ngarchelong (minimum number of rangers required is 7 for each state)
- Increased skills in surveillance

Needs improvement

- Program management (including budgeting, staff management, project planning, enforcement planning, partnership building, etc.)
- Improve leadership capacity, to better lead the PAN programs that continue to implement adaptive management
- Improve the delivery of awareness programs, to sustain understanding of management and rules governing fisheries
- Establish a formalized partnership, to bring needed technical support in the implementation of management, including data collection, monitoring and evaluation, enforcement coordination, and mentoring for capacity building

Project Objectives

Palau has over 20 years of experience using area-based management, employing tools like Marine Protected Areas (MPAs), to manage fisheries. We recognize that MPAs have limitations when it comes to fisheries management, particularly in establishing size, location, and enforcement measures that ensure their effectiveness. Both Palauan fishermen and conservation practitioners recognize that MPA effectiveness is limited and that fish stocks continue to downturn, as evidenced by the declining fish catch. Even though there is no stock assessment data, or any other fisheries data available to ascertain this perception, there is a general agreement that there is less fish today than there was 10 years ago, even with the establishment of MPAs 20 years ago.

Not everything is gloom and doom when it comes to fisheries. There are MPAs that show promise, particularly where enforcement is effective. Some limited fisheries management strategies in Palau have had limited positive impacts, but increasing fishing pressures negate those impacts in the long term. Nevertheless, there is hope that fish stocks are still at a level where they can rebound if proper management is implemented, as evidenced by the increased numbers of Bumphead parrotfish and Humphead wrasse, which were put under moratorium in 2006. There is a strong recognition by fishermen and conservation practitioners that managing fisheries beyond MPAs is necessary to improve fisheries stocks; which will in turn support local's fishing activities and livelihoods.

This project was developed with the collaboration of scientists, conservation practitioners, fishers and community members from Kayangel and Ngarchelong States, with the following core objectives:

- **Increase fisher engagement**

There is a good body of evidence indicating that when fishers are engaged in management practices —from data collection to developing harvest control rules— they are more likely to comply with rules and thus improving the management of fisheries.

- **Improve the understanding of fish stocks by using data-poor fisheries stock assessment techniques**

In order to manage fisheries, understanding the behavior and performance of stocks is important. However, many fishers are unassed due to high costs of assessment. We used an assessment technique that is low cost and worked with fishermen to understand the spawning potential ratio (SPR) of key reef fish resources.

- **Develop a management framework to recover fisheries**

Determining appropriate harvest control strategies that benefit both fishers and fish resources, is essential to minimize the impact on livelihood while increasing return on investment at the management level. Harvest control strategies need to be developed while working with fisher stakeholders and need to be supported by policy, legal framework, and implemented mechanisms.

- **Improve management capacity**

Building capacity for management, particularly in human resource and finance, is needed to ensure that adaptive management strategies are implemented in response to changing fisheries and socio-economic and political landscapes.

- **Improve fishers' sustainable livelihoods**

With the shift from subsistence to cash-based economy, developing sustainable livelihoods is necessary to ensure that the gains in fishery stocks can be maintained, while contributing to fishery recovery.

- **Establish a northern reef co-management**

The northern reefs combine Ngarchelong and Kayangel States' owned reefs and waters. In order to protect and manage fisheries resources for the benefit of the people, it is necessary for the two state governments, along with traditional leaders, to work with fishers in the management of this large reef system.

- **Integrate the management of fisheries with Palau Protected Areas Network (PAN)**

The Palau Protected Areas Network currently aims to improve the effectiveness in management of Palau's nearshore marine resources. However, the current approach focuses on area-based management, which has benefitted biodiversity and fisheries to a certain extent. There needs to be an integration between management and fisheries to achieve PAN's broader goals.

Overview of the Northern Reefs of Palau

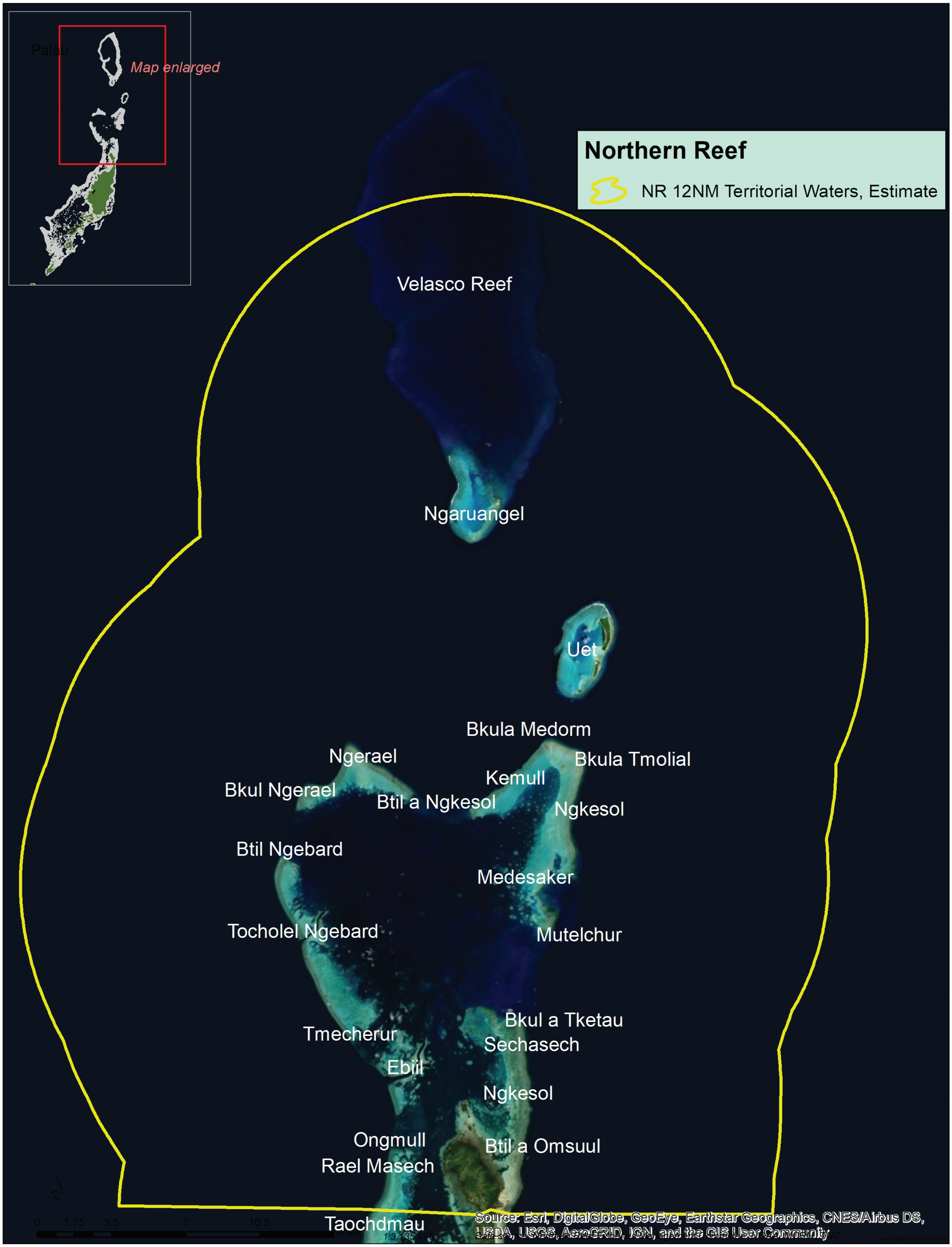
Ecological profile

The northern reefs of Palau (NR) include the marine area north of the Babeldaob Peninsula, and extends to the Velasco Reef —a 20-mile-long submerged reef system at the northern tip of the Palau archipelago, with a relatively untapped fishery. The northern reef ecosystems, comprised of mangroves, seagrasses, fringing reefs, patch reefs, lagoons, channels, barrier reefs, sunken reefs, atoll reefs, and deep water that extends beyond 1000 m in depth, represent a substantial portion of the total marine area of Palau. The northern reef region includes 1,015.6 km2 of shallow marine habitat and 2,916 km2 of pelagic waters, up to 12 nm.

A total of 520 species of reef fishes from 51 families were recorded*[1] in the northern reef area. Fish species diversity was highest along outer reef drop-offs and was lowest in deep channels. The most common food fish observed were *Lutjanus gibbus, Lethrinus olivaceus, Acanthurus nigricauda, Caranx melampygus, Naso lituratus, Ctenochaetus striatus, Bolbometopon muricatum, Sphyraena genie,* and *Cheilinus undulatus**[2].

There have been 248 species of coral observed in the northern reefs, with live coral coverage ranging from 7% to 71%, with a mean of 32%*[3]. Likewise, a total of 13 species of sea cucumbers were observed, including two commercially valued species: *Thelenota ananas* and *Holothuria nobilis**[2].

Ngariuns islets in the NR host the largest colony of the endangered megapod bird populations in Palau. In addition to Ngariuns, Ngaruangel islets are also home to one of the largest seabird colonies, as well as green turtle nesting. Due to the remoteness of its vast reef and lagoon areas, it is a significant fishing ground with a largely stable fish biomass. However, both human and natural threats are creeping into the NR, threatening the sustainability of its marine resources, food security, and livelihood of the communities that are dependent on them.



Palau
Map enlarged
Northern Reef
NR 12NM Territorial Waters, Estimate
Velasco Reef
Ngaruangel
Uet
Bkula Medorm
Ngerael
Bkula Tmolial
Kemull
Bkul Ngerael
Btil a Ngkesol
Ngkesol
Btil Ngebard
Medesaker
Tocholel Ngebard
Mutelchur
Bkul a Tketau
Tmecherur
Sechasech
Ebiil
Ngkesol
Ongmull
Btil a Omsuul
Rael Masech
Taochdmau
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Protected Area Status

The northern reefs of Palau represent the largest managed area within the Palau Protected Areas

Network (PAN) with a total combined area of 3,930 km^2, which include the territorial waters of Kayangel and Ngarchelong States—shallow marine (1015.6 km^2) and deep water (2,916 km^2). The northern reef region is managed through a spatial and non-spatial management approach. There is a total combined area of 172 km^2 of reef area as no-take zone, representing 32% of Palau's coral reefs. These no-take areas include:

(1) Ngaruangel Marine Preserve (42 km^2), established in 1996 : A 2018 assessment by Gouezo et. al, 2020, showed no difference in biomass between areas open for fishing and the no-take zone.

(2) Ebiil Conservation Area (17 km^2), established in 2000 to protect grouper aggregations: A 2018 assessment by Gouezo et al., 2020, showed a significantly higher biomass of fish in the no-take area, compared to areas open for fishing.

(3) Ngerael/Ngkesol No-take zone (112 km^2), established in 2017: The single largest no-take area throughout Palau. Combines the reef areas of Ngarchelong and Kayangel States.

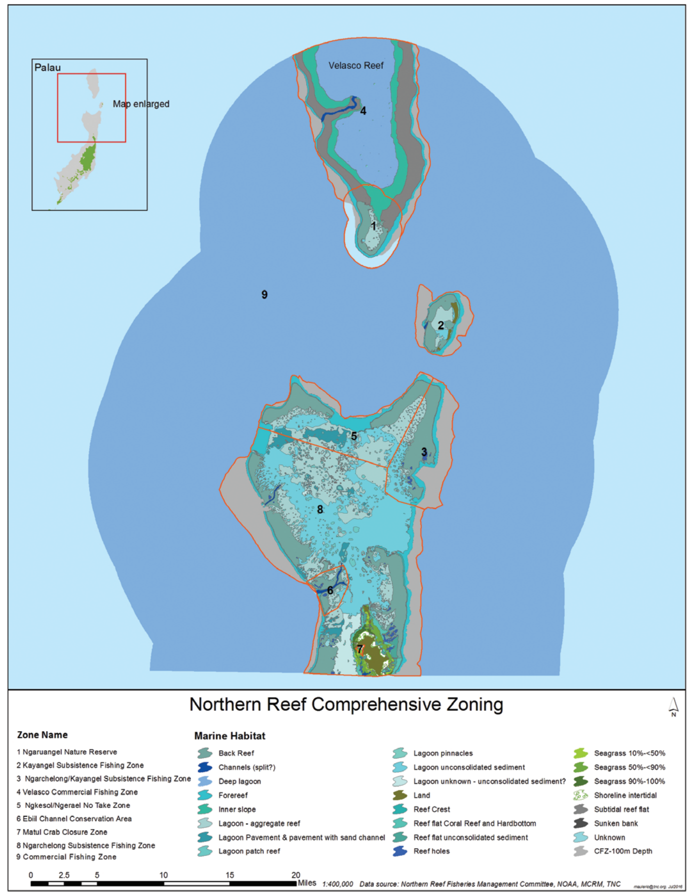
Other management zones include:

(1) 601.5 km^2 (59% of the total shallow marine area of NR) as subsistence fishing zone: In 2019, a total of 240 subsistence permits and 178 guest fishing permits were issued.

(2) 3,158 km^2 (80% of the total territorial waters of Kayangel and Ngarchelong States) as commercial fishing zone. In 2018, one commercial license was issued and in 2019 no commercial licenses were applied for.

Community Profile

The northern reef region includes the communities of Kayangel and Ngarchelong States. In each state, there are traditionally established communities governed by traditional leaders. These communities are now called hamlets in the modern democratic government



system. Both states are run by a democratically elected government, with a Governor as the executive officer of the state, and an elected legislature. Traditional chiefs still exist in both states and hold respect of community members and governments. In Ngarchelong, the first ranking chiefs of the 8 villages are members of the state legislature, while in Kayangel, traditional chiefs do not participate in the elected government. Nonetheless, traditional chiefs still play a role in governing traditional communal affairs and are often sought for advice from elected leaders.

Characteristics of Ngarchelong State

- 90 households*4
- Population (2015)- 316*5
- 53.4% of the population participated in fishing activities; of that, 20.3% of the population depends on fishing for both consumption and income*6
- 33.9% of the population depends on government employment for income*7
- There are at least 3 mom and pop stores that serve the community, which also sell gasoline that serve the

community

- 1 gas station opened in 2018 in Ollei port
- There are 2 local markets where residents can sell their produce, fish catch, and processed food
- The Northern Reef Fisheries Cooperative (NRFC) operates out of Ollei Village and purchases fish from fishers and sells them to Koror-based vendors
- There is a paved road that connects Ngarchelong State to Koror and there are community members who commute to Koror on a daily basis for employment
- Approximately 50 boats are registered in Ngarchelong State*[8]
- Ngarchelong State Government and the Ministry of Education are the main employers within the community.

Characteristics of Kayangel State

- 35 households
- Population (2015)– 54*[9]
- 76% of the population participated in fishing activities, mainly for consumption. 4% of the population depended on fishing for both consumption and income*[10]
- 48% of the population depended on their pension/social security for income*[11]
- Approximately 4 boats are registered in Kayangel State
- There is 1 mom and pop store that serves the community and visitors
- There are 3 facilities that serve as rental accommodations for visitors to Kayangel
- A state operated boat serves Kayangel community every 2 weeks between Kayangel and Koror, the main center of population.
- Kayangel State, Ministry of Education, Palau National Communication Corporation, and Palau Public Utilities Corporation are the main employers within the community

Fishers Profile

In 2016, the Palau International Coral Reef Center (PICRC) conducted a socio-economic survey of the northern reef fishers*[12]. The fin fish fishery was dominated by men, with

an average age of 52 years old. Most of the fishers live outside of the communities of Kayangel and Ngarchelong, and had fished for an average of 28 years. The fishers owned on average, 20ft boats with an 85 horse power, 2 stroke Yamaha engine. The fishers would fish at least once a week, or once a month. Fishers primarily fish for subsistence, with an occasional selling of their catch. Less than 3% of fishers fish primarily for income. Many of the fishers had day jobs, or were receiving social security and retirement benefits. Primary fishing methods used were hook and line and spearfishing. Primary target fish were emperors, snappers, groupers, and parrotfish. In 2019, NRFC catch data shows an increase in trolling, due to an increased demand for pelagic species for markets outside of Koror.

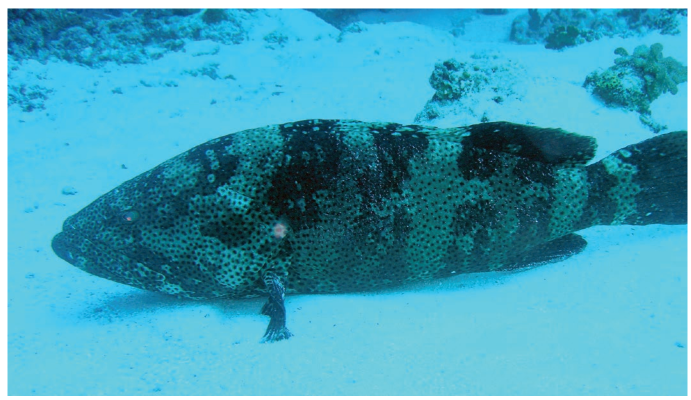
Fisheries of the Northern Reefs

The establishment of four fishing ports at strategic locations (Ngarchelong and Kayangel -north, Melekeok -east, Ngeremlengui -west, and Peleliu -south of main Palau islands) throughout Palau in the mid 1980's, was meant to encourage off-shore fishing. However, fishing for off-shore species did not materialize as planned, but the facilities continued to support strong fishing efforts for reef-associated species, which led to a decline in reef fish. When fishing could not provide enough fish to keep the facilities operating the fishery cooperative became inactive, thus, organized fishing ceased for the most part by the communities in the Northern Reefs. Nonetheless, fisheries facilities continued to support community development activities and some sport fishing, as well as the fledgling

Subsistence fisherman from Ngarchelong. Photo courtesy of The Nature Conservancy.

diving activities.

Despite the cessation of organized commercial fishing by the communities in the northern villages, fishing pressure continued by fishermen from out-of-community residents, residing in Koror, who could afford high fuel cost and access to markets. One example is the Live Reef Food Fish Trade fishery which was based out of Hong Kong. It targeted groupers, wrasse, and coral trout, as well as their major fish spawning aggregation sites. It was the communities of Kayangel and Ngarchelong that raised concerns about the wasteful fishing and the lack of respect for traditional fishing practices and traditional boundaries. This led the communities of Kayangel and Ngarchelong to declare in 1994, a traditional "bul" for the spawning channels; initiating some protection for northern fish stocks. While it appeared effective at first, it turned out to be insufficient in the long run. At about the same time, with the knowledge from fishermen, the Palau Marine Protection Act of 1994 was enacted. The act puts restrictions on fishing gear, species restrictions, seasonal closures, and ban exports of certain species. These measures were not enough to stem the continued decline in reef fish so in 1996, Kayangel established the Ngaruangel Marine Preserve, while in 2000, Ngarchlelong established the Ebiil Conservation Area, to help protect reef fisheries and spawning aggregations. Fisheries resources, however, continued to decline and in 2015, Ngarchelong and Kayangel established their respective Fisheries Act of 2015 that led to the development of fisheries regulations for both states in 2016 and 2017.



*1: Masburger, G. 2009. Rapid Ecological Assessment of Northern Reefs of Palau: assessment of reef fish biodiversity

*2: Kitalong, A. and Kitalong,Jr., C. 2009. Rapid Ecological Assessment of the Northern Reefs of the Republic of Palau: Assessment of key food invertebrates and fish.

*3: Houk, P. 2009. Rapid Ecological Assessment of Palau's Northern Coral Reefs. Quantitative Assessment of Coral-Reef Assemblages

*4: http://picrc.org/picrcpage/wp-content/uploads/2020/01/Marino_NgarchelongSE2019.pdf

*5: https://en.wikipedia.org/wiki/States_of_Palau

*6: Ibid 5

*7: Ibid 5

*8: Based on revenues reported through the Kayangel Financial PAN Report of 2019?

*9: Ibid 5

*10: Ibid 4

*11: Ibid 4

*12: Isechal, A.L., Olsudong, D., Otto, El, Koshiba, S. 2016. Fisheries profile of the northern reefs of Palau: A socioeconomic assessment of fishers and their households. Report to The Nature Conservancy

01 Community Engagement

Conservation success in Palau has long been rooted in engaging with the community, as the resource owners and users. Modern conservation efforts have been ongoing in the northern reefs of Palau since the mid-1990's, with the establishment of Ngaruangel Marine Preserve and Ebiil Conservation Area in the early 2000's.

The northern reefs of Palau are the second largest fishing grounds in the main Palau archipelago, and are owned by the State of Kayangel and Ngarchelong. The communities in these two states have shared these fishing grounds for generations and have long established traditions and understanding of access to these fishing grounds. In the 1990's, these communities worked together to ban commercial fishing in spawning aggregations channels in the northern reefs, to stop live grouper trade. In addition, long lasting traditional community ties between villages in Ngarchelong and Kayangel have resulted in community developments, playing an important role in the establishment of conversations around the co-management of the northern reefs.

We approached this project on engaging with the community at the following levels

Selected Community Elders

We had worked with the communities in the northern reefs for many years and had developed trusted relationships with selected community elders, who have a deep understanding of their communities. We initiated this project by engaging with them to get guidance and assistance in bridging us to the fishing community, as well as identifying key and influential fishermen to talk to and get their buy in and support.

Fishermen

Following introduction to the fishermen by these selected community elders, we held individual meetings with specific fishermen to discuss the proposed project, and solicited their feedback. Following these individual meetings, we held meetings with groups of fishermen in a focus group approach, i.e. small groups that allowed for a more engaged conversation. Fishermen were engaged in the project in several ways: fish landing data collectors, community organizers, preparing food for community meetings, and operating boats for meetings and field visits. Fishers who were asked to provide these types of work were paid for their efforts.

Elected State Leadership and Traditional leaders

Governors and speakers of state legislatures and traditional leaders, for both Kayangel and Ngarchelong, were engaged separately to provide them with a briefing of the proposed project, and to solicit their feedback on what was being proposed. After building awareness and understanding of the project, leadership from both states were engaged to discuss general approach to work with the community to implement the project.

General community outreach

Once a general support and consensus of fishermen was established on the proposed project, and the approaches to addressing the challenges, general community meetings were held to discuss the proposed project and to provide a snapchat of the status of the fishery, based on the data that we collected alongside the fishermen. The meetings allowed for a broader range of stakeholders, especially women, who were not regularly engaged in the meetings with fishermen, to provide their concerns and feedback to the project as well as general approaches for managing the fisheries.

Dialogues with the communities started in 2011; process by which Kayangel and Ngarchelong State Government, fishers, and community members where given the opportunity and the responsibility of making decisions that directly affected their well-being, defined their needs, and ultimately, that managed their own resources. Community engagement in any project improves the legitimacy and transparency of the project, thus increasing the acceptance and commitment of the community to the project-activities and intended outcomes. At the same time, it increases community participation to include all stakeholders - including individuals, groups, and organizations- who are interested, involved, or affected –either positively or negatively - in the making of decisions that are meant to find effective solutions with hopes to address the communities' issues and needs. A common understanding on the status of Kayangel and Ngarchelong's fisheries and fish stock was established within the Northern Reef community after presenting community fisher observations and experiences, as well as expert-understanding on the topic.

Through this process, both fishers and leadership agreed that something needed to be done to address the decline in the health of fisheries resources in the Northern Reef. For several months, The Nature Conservancy (TNC) convened and facilitated the dialogue between community traditional leadership, state leadership, and community fishers, who acted on behalf of their communities, to discuss shared concerns, commitments, and supports. Through these dialogues, it was evident that partnership was needed to ensure that all of the key stakeholder where involved in the planning, designing, and implementing of this project (to be discussed further in the following sections).

Lessons Learned:

- **Remoteness**

One of the initial challenges with community engagement was the distance needed to travel in order to reach the communities in the Northern Reef. The travel and logistics to get to Kayangel were more challenging than those to Ngarchelong. Careful planning, however, and good communication with the communities ensured greater success.

- **Competing priorities**

Many fishermen today have day jobs, and fish in the evenings or on weekends to supplement their income. In addition to their daily jobs, there are also many customary obligations that fishermen have to attend to. For this reason, many of our meetings were scheduled in the evenings, which allowed for greater engagement with the fishermen.

- **State boundary**

There has been ongoing efforts by both Kayangel and Ngachelong states to settle state's marine their boundaries. At the beginning of the project, elected and traditional leadership of both states agreed there is an appropriate process to hold this discussion, and conceded not to address this matter through this project. While there was consensus at the leadership level, there continued to be challenges within the community and amongst the fishermen on the need to address the issue. We made sure, however, not make this matter a discussion or active goal within this project and instead emphasize the need to manage fisheries resources that extends beyond each state's boundaries.

- **Early community-wide engagement**

There was a general recognition within community that fishing was a man's domain and women generally differ to men on this discussion. Efforts were made later in the project to integrate women in fisheries engagement through the Northern Reef Fisheries Cooperative. Efforts in engaging women need to be a strong component of engagement.

- **Building youth leadership**

Building leadership among young community members, and encouraging them to take on leadership roles, can be beneficial in the planning and implementation of present and future projects.

- **Establishing processes**

The establishment of processes within the management entity at the state level will help continue these community engagements.

02 Development of Co-Management

It has long been recognized that there is a need for Kayangel and Ngarchelong States to cooperatively and collaboratively manage the northern-reef marine ecosystems. In 1994, the traditional leaders of Kayangel and Ngarchelong imposed a traditional "bul" on the spawning channels in the northern reefs, for the protection of fish stocks. Challenges experienced from the initial implementation of this "bul", however, led both the Kayangel and Ngarchelong State legislations into providing additional protection to Ngaruangel Marine Preserve, in 1996, and Ebiil aggregation channels and adjacent reefs, in 2000, respectively. In May 2008, traditional and elected leaders alongside community members from Ngarchelong State held a 3-day summit to try to understand current efforts and related work being done in the northern reefs to address declining fisheries. This led to the Mengellakl Declaration, an effort meant to enhance the management of the northern reefs. In July 2013, a joint leadership meeting between Kayangel and Ngarchelong was held, where both parties vowed to work together towards the improvement of the northern reef management.

On July 2013, after nearly two years from the initial community engagement, the leadership of both Kayangel and Ngarchelong States signed a *Cooperative Agreement between the State of Kayangel and Ngarchelong on Sustainable Fisheries Management and PAN Sites Management.* The agreement strengthened and old age tradition of friendship between the people of Kayangel and Ngarchelong that renewed their desire to reverse the decline in fish stocks, while achieving a long term sustainability of fisheries resources in the Northern Reefs. Through this agreement the leadership and community of Kayangel and Ngarchelong committed to[i] :

1. Cooperate and establish sustainable fisheries management and integration with PAN sites management and;
2. Cooperate on establishment of joint monitoring, surveillance and enforcement program; and
3. Cooperate on empowering fishers and communities to become active participants in fisheries management and be the main beneficiaries of sustainable harvest programs; and
4. Cooperate on other related topic of interest.

Throughout the project, the advisory committee worked with implementing partners of the Northern Reef Fisheries Project to discuss priorities, strategies, plans, recommendations, financial and technical needs, work plans, and timelines. Resulting from those discussions, the advisory committee agreed on the co-management of resources within the boundaries of the two states, and called for a new mechanism to co-manage the Northern Reef. TNC, alongside partners with legal expertise, worked with the planning teams of both states -which included diverse members of the community- on the development of a comprehensive legislation and its implementing regulations. In 2015, Kayangel and Ngarchelong states enacted the legislations known as *the Coastal Fisheries Management Act Bill No. 15-16 and Bill No. 15-57*, respectively. Comprehensive legislations for both states were developed through the consolidation and updating of the existing marine-resource legislations and regulations. This ensured an effective legal and administrative framework for both states, where fisheries resource-conservation and management was established. Both legislations redefined general fisheries policies for each state, defined the scope of its applications, defined management responsibilities, established processes for compliance and enforcement, and most importantly, recognized the interest of fishers and other stakeholders, while establishing new mechanisms to help their respective co-management in the Northern Reef. Specifically, the legislations established a 3-year moratorium on 5 species of groupers, enhanced and clarified enforcement authority, and mandated the Governor to establish further regulations to protect and improve fisheries resources in the Northern Reefs. These legislations also provide the basis for the Northern Reefs Fisheries Management Plan (NRFMP).

In addition to providing legal and administrative frameworks, TNC and other partners worked with Kayangel and Ngarchelong's planning teams to formulate the NRFMP – a key instrument in addressing and integrating different components of the management of fisheries, by specifying access, harvest control rules, and area base management of the Northern Reef. The goals of the NRFMP were to[ii] :

1. Rebuild fish populations and improve ecosystem health to support long-term sustainable use of resources; and
2. Ensure that the people of Ngarchelong and Kayangel have access to the resources they need and benefit directly from long-term stewardship.

The NRFMP agreed on fisheries measures, compliance and enforcement, and adaptive management. Measures passed in legislation and regulation included, but was not limited to, permitting measures, non-spatial management measures, and spatial management measures. These will be discussed in more detail in the following sub-sections[iii].

Permitting measures: To track fishing and other activities, promote local access, limit access to non-residents, and generate revenues to recover administrative costs. The following fishing permits/licenses and fees were adopted and are currently being enforced[iv] by the two state governments, with a small variation on fees, permit condition, and length of permit validation.

TABLE 1: PERMITTING MEASURES

PERMITS & LICENSE	DESCRIPTION	NGARCHELONG FEES	KAYANGEL FEES	FINES
Boat Registry	All boats require license under state regulations, with fee determined by horsepower; requires use of flag for different activities.	As per state regulations 1. Under 15 hp - $10.00 2. 16-55 hp - $20.00 3. 56-115 hp - $30.00 4. 116-175 hp - $40.00 5. 176-235 hp - $50.00 6. 236 hp and above - $100.00	As per state regulations 1. 0-55 hp - $20.00 2. 56-85 hp - $50.00 3. 85 and above - $60.00	$150.00
Subsistence Fishing Permit	A person must have a subsistence fishing permit in order to fish within state waters for sustenance and artisanal (local "makit") purposes. Catch limit of 100lbs per day.	$ 10 per person/year Catch Limit – 100lbs	$10 per person/year Catch Limit – 100lbs	$50.00
Guest Fishing Permit	Palauan guest who is non-citizen of Kayangel or Ngarchelong. Fishing for food with limit of up to 25lbs/ day per person.	$5 per day, up to 7 permits/year Catch Limit – 25lbs	$5 per day, up to 7 permits/year Catch Limit – 25lbs	$200.00
Commercial Fishing Permit	A person must have a commercial fishing permit in order to fish within state waters for commercial fishing purposes - Fishing for primary purpose of selling.	Annual fee $50 per person for Palauan $100 per person for Non-Palauan; No catch limit	Annual fee $25 per person for Palauan $50 per person for Non-Palauan; No catch limit	$200.00
Recreational Fishing Permit - Fishing Derby	Boat or vessel must have a Fishing Derby Permit in order to participate in a fishing derby within state waters.	$50 per boat per derby	$50 per boat per derby	$200.00

PERMITS & LICENSE	DESCRIPTION	NGARCHELONG FEES	KAYANGEL FEES	FINES
Recreational Fishing Permit - Catch & Release	A person must have a Catch & Release fishing permit in order to participate in Catch & Release recreational fishing within the state waters. A recreational fishing permit holder that is participating in Catch & Release must not keep any fish caught in no-take zones in Ngarchelong and Kayangel State waters, but may keep fish caught in other zones, and are restricted to rod and reel fishing gears.	$30 per person per day	$30 per person for three days	$200.00
Aquaculture (fish, crab, giant clam) permit	A person must have an aquaculture permit in order to establish an aquaculture farm within the state	Annual fee of $100 if applicant is not generating revenue and $200 if applicant is generating revenue.	Annual fee of $100 if applicant is not generating revenue and $200 if applicant is generating revenue.	$200.00
Commercial Fishing License	Every person or business that fishes within the waters of Kayangel and Ngarchelong State for the purpose of commercial fishing must first be issued a commercial fishing license by the State Governments.	Annual fee $500	Annual fee $500	$200.00
Commercial Photography	A person must first obtain a commercial photography permit issued by Ngarchelong and Kayangel State in order to take any photograph, video, recording, film, or make any other reproduction of any image of anything within the state for any commercial purpose.	$50 per day for 10 days and $500 for one month	$50 per day for 10 days and $500 for one month	$500.00 per day
Research Study		$500.00	none	

Non-spatial management measures: Includes the ban on certain species, minimum size limits, and seasonal/temporal closures to promote the rebuilding of depleted stocks. The measures were adopted by the two states with small variation on size limit and species ban[v].

1. Size limit

Implementation of minimum size limit for 15 species of finfish. The following table is the summary of the size limits adopted by both States:

TABLE 2: NON-SPATIAL MANAGEMENT MEASURES

No.	Species	Palauan name	Ngarchelong		Kayangel	
			Minimum size limit (inches)	Period of Implementation	Minimum size limit (inches)	Period of Implementation
1	*Lutjanus bohar*	Kedesau	16	May 2017	18	April 2016
2	*Lethrinus olivaceus*	Melangmud	16	May 2017	18	April 2016
3	*Naso unicornis*	Chum	16	May 2017	18	April 2016
4	*Lethrinus xanthochilus*	Mechur	13	May 2017	15	April 2016
5	*Cetoscarus oscellatus*	Beadel	11	May 2017	13	April 2016
6	*Chlorurus microrhinos*	Otord	11	May 2017	13	April 2016
7	*Hipposcarus longiceps*	Ngyaoch	10	May 2017	12	April 2016
8	*Lutjanus gibbus*	Keremlal	10	May 2017	12	April 2016
9	*Plectropomus leopardus*	Red Tiau	11	July 2018	13	August 2018
10	*Plectropomus areolatus*	Black Tiau	14	July 2018	16	August 2018
11	*Plectropomus laevis*	Mokas	22	July 2018	24	August 2018
12	*Epinephelus fuscogutattus*	Meteungerel'temekai	14	July 2018	16	August 2018
13	*Epinephelus polyphekadion*	Ksau'temekai	14	July 2018	16	August 2018
14	*Variola louti*	Baselokil	10	May 2017	-	-

2. Species ban & Sex Specific regulation

The moratorium for fishing finfish and invertebrates for a specific time period is listed below. The following tables summarize the species ban and sex specification measures adopted by both states:

TABLE 3: SPECIES BAN & SEX SPECIFIC REGULATION

No.	Species	Palauan name	Ngarchelong	Kayangel
			Period of Implementation	Period of Implementation
1	*Plectropomus leopardus*	Red Tiau	July 2015 – 2018	August 2015 - 2018
2	*Plectropomus areolatus*	Black Tiau	July 2015 – 2018	August 2015 - 2018
3	*Plectropomus laevis*	Mokas	July 2015 – 2018	August 2015 - 2018
4	*Epinephelus fuscogutattus*	Meteungerel'temekai	July 2015 – 2018	August 2015 - 2018
5	*Epinephelus polyphekadion*	Ksau'temekai	July 2015 – 2018	August 2015 - 2018
6	*Variola louti*	Baselokil	July 2015 – 2018	August 2015 - 2018
7	*Caranx ignobilis*	Eropk	May 2017 – 2020	April 2016 – 2019
8	*Tridacna gigas*	Otkang	May 2017 - 2027	April 2016 – 2026
9	*Tridacna derasa*	Kism	May 2017 - 2027	April 2016 – 2026
10	*Panulirus genus*	Cherebrukl	May 2017 – 2020	April 2016 – 2019
11	Aquarium trade species		May 2017 – 2020	April 2016 – 2019
12	*Scylla serrata*	Chemang (Female crab for Kayangel)	May 2017 – 2018	April 2016 – 2019

Spatial management measures: Comprehensive zoning scheme that includes fully protected no-take zones, limited use of areas, and multi-use areas to promote rebuilding of fish stocks and ecosystem protection, as well as to limit the impacts of human activities to certain areas. The following are the three categories of zones established in the Northern Reef

1. Fully protected no-take zones (NTZ):

Zones that prohibit all extractive and destructive activities that provide the most protection to a broad range of habitats and species. If designed properly and effectively managed, no-take zones provide the most benefits toward rebuilding fish populations and protecting ecosystems and a broad range of species.

Ngaruangel Marine Preserve = 42 km^2 - established in 1996

2. Ebiil Conservation Area = 17 km^2 - established in 2000

3. Ngerael/Ngkesol No take zone = 112 km^2 established in 2017

2. Limited-take zones:

Zones that protect some species, but allow other species to be taken (e.g. a mangrove crab closure area only protects that species of crab, while allowing other species to be harvested), can support the rebuilding of some species, while reducing socioeconomic impacts on resource users. The level of ecosystem protection afforded by limited-take zones depends on how many species, and what types of species, can be harvested.

3. Limited-use or Multiple-use zones:

Zones that allow or limit certain activities, like fishing or tourism, can help focus impact on certain areas, while protecting other areas from those activities. These types of activity zones should be managed for long-term sustainable use.

Figure 1: *Northern Reef Comprehensive Zoning Map*

The following table summarizes the spatial management measures that where designed and adopted by both State Governments:

TABLE 4. EXISTING AND PROPOSED SPATIAL MANAGEMENT MEASURES IN A COMPREHENSIVE MARINE ZONING SCHEME

ZONE #	MANAGEMENT ZONE	TYPE OF ZONE	PROJECTED BENEFITS TO ECOSYSTEMS & PEOPLE	MEASURABLE INDICATORS	REVIEW/ ADJUSTMENT PROCESS
1	Ngeruangel Nature Reserve (established 1996)	Permanent no-take zone; no access except for permitted customary use	• Ecosystem benefits to a broad range of reef and lagoon habitats, and species dependent on those habitats • Rebuild fisheries by protecting a full range of species, habitats, and spawning areas	Live coral cover and resilience and fish size and abundance trends over time inside/outside the no-take zone	Review after 3 years to evaluate effectiveness
2	Kayangel Subsistence Fishing Zone (established 2016)	Zoned for subsistence fishing	• Secures local access to fishery resources near villages and removes commercial fishing pressure • Ecosystem benefits to a broad range of reef and lagoon habitats and species dependent on those habitats	Size and abundance of fish in subsistence catch and on reef over time	Review after 3 years to evaluate effectiveness
3	Velasco Commercial Fishing Zone (established 2016)	Zoned for non-resident commercial fishing	• Reduced commercial fishing pressure in other areas as commercial pressure limited to 3 permitted boats in Velasco reef and the overall commercial fishing zone in NR only • Multiple use area with lots of activities permitted but far distance from human populations will limit impacts	Size and abundance of subsistence and commercial catch and on reef over time	Review after 3 years to evaluate effectiveness
4	Ngerael-Ngkesol No-take Zone (established 2017)	No-take zone, except for catch-and-release sport-fishing only (w/ permit)	• Ecosystem benefits to a broad range of reef and lagoon habitats and many species dependent on those habitats • Rebuild fisheries by protecting a wide range of species, habitats, and fish spawning areas • Some mortality expected from catch-and-release • Revenue generated from tourism permit fees	• Live coral cover and resilience and fish size and abundance trends over time inside / outside no-take zone • Size and abundance of "trophy" catch-and-release target species • Revenues generated from tourism activities	Review after 3 years to evaluate effectiveness

fully protected no-take zone | no-take zone with catch-and-release sport fishing | subsistence fishing zone | commercial fishing zone | crab closure zone

ZONE #	MANAGEMENT ZONE	TYPE OF ZONE	PROJECTED BENEFITS TO ECOSYSTEMS & PEOPLE	MEASURABLE INDICATORS	REVIEW/ ADJUSTMENT PROCESS
5	Ebiil Channel Conservation Area (established 2017)	Permanent no-take zone	• Ecosystem benefits to a broad range of reef and lagoon habitats and species dependent on those habitats • Rebuild fisheries by protecting a wide range of species, habitats, and spawning areas	Live coral cover and resilience and fish size and abundance trends over time inside / outside no-take zone	Review after 3 years to evaluate effectiveness and consider expansion of area if necessary
6	Ngerkeklau Tourism No-Take Zone (proposed)	No take zone, except for tourism activity only with permit	• Ecosystem benefits to a broad range of reef and lagoon habitats and many species dependent on those habitats • Rebuild fisheries by protecting a wide range of species, habitats, and fish spawning areas • Some mortality expected from catch-and-release • Revenue generated from tourism permit fees	• Live coral cover and resilience and fish size and abundance trends over time inside / outside no-take zone • Size and abundance of “trophy” catch-and-release target species Revenues generated from tourism activities	Review after 3 years to evaluate effectiveness
7	Matul Crab Closure Zone (established 2017)	No take of mangrove crab	Reduce pressure on mangrove crabs to promote rebuilding of fishery	Size and abundance of mangrove crabs	Review after 3 years to evaluate effectiveness
8	Ngarchelong Subsistence Fishing Zone (established 2017)	Zoned for subsistence fishing only	• Maintain local access to fishery resources near villages • Rebuild or halt decline of fish populations faster by reducing commercial fishing pressure inside the reef complex • Protect full range of habitats and species	Size and abundance of fish in subsistence catch and on reef over time.	Review after 3 years to evaluate effectiveness
9	Commercial Fishing Zone (established 2017)	Zoned for commercial fishing	• Reduced commercial fishing pressure in other areas as commercial pressure is limited to total of 6 permitted boats for both Kayangel and Ngarchelong • Multiple use area with lots of activities permitted but far distance from human populations will limit impacts	Size and abundance of subsistence and commercial catch and on reef over time	Review after 3 years to evaluate effectiveness

Challenges:

Maintaining Champions

The project benefitted initially from having state leadership and PAN Staff who understood and prioritized improving management capacity. As leadership changed and staff turnover occurred, maintaining the same level of needed leadership at the state to address issues and improve on key implementing state level process on accountability, cross state discussion on establishing process for join enforcement stalled.

Co-management advisory committee

The committee members actively participated in the meetings to discuss issues and provided guidance on engagement strategy. The committee operated on a mutual understanding of roles, where the governors from Kayangel and Ngarchelong co-chaired the committee. Their initial involvement in the discussion and the design of the committee allowed for this mutual understanding. The mandate that created the committee did not clearly specify leadership roles and engagement process. When there was leadership change at the state, the same mutual understanding was not there. In addition, challenged faced in coordinating the advisory resulted in the committee not able to meet. Ensuring that clear leadership roles, functions, and process for how the committee operates can help to address this challenge in the future.

Development of mirror legislation

Mirror legislation/regulations were recommended legally to accommodate cross border enforcement between the two states. However, due to different understandings and perspectives between the two communities, variation on regulations for some of the measures, like size limits on different fish species and moratorium on grouper, posed some challenges for cross-border enforcement. This will be discussed in more detail in the next section.

Management structure and capacity

Kayangel and Ngarchelong State, similar to many other state throughout Palau have PAN programs that were established around 2010. The programs were established and funded by the Green Fee. There was no clear management structure within the state that address natural resource management. The respective state Fisheries Act of 2015, established state respective Conservation and Law Enforcement Department. The respective Department within each state absorbed the PAN Programs, which has traditionally focused on enforcement. There still lacks a structure on resource management on ecological monitoring, adaptive management, and policy reforms. The lack of clear structure can be attributed to limited financial rsources and limited human resource capacity.

Human resource capacity

Kayangel and Ngarchelong State face a relatively high staff turnover rate due to lack of job security and better opportunities in Koror. Key recommendations from a human resource assessment conducted has not been implemented, such as developing human resource policy for each state and implementation of a transparent employee evaluation process.

Communication

Lack of clear mandate and process for joint management of the northern reefs between Kayangel and Ngarchelong often lead to lack of communication and coordination. In addition, the lack of mandate and established coordinating process between national enforcement and the state resulted in lack of communication/coordination with national enforcement officers to provided needed support in monitoring, control, and surveillance (MCS) of the northern reefs, where often national officers would conduct their own MCS.

Capacity Building for Management and Enforcement

Any legal and administrative fisheries-resource conservation and management frameworks that have been set in place for both states, will not be effective if the states do not have the capacity to effectively implement them. One of the key requirements needed to ensure effective management was the institutional capacity of both state governments in order to effectively facilitate fisheries stakeholders into playing their role in management. Institutional capacity assessments and enforcement capacity assessments were conducted to better understand the capacity gaps and needs of both states. By understanding where the intervention is needed, and improving their respective performances, conservation and management measures can be effectively implemented.

Institutional Capacity

Even though both state governments are small, with limited number of financial and human resources, there is always potential for growth and improvement. If appropriate steps are taken in order to address capacity gaps and needs, the organization will eventually obtain sustainability. For this component of the project, TNC worked together with state governments, WildAID, and a private consultant to understand where intervention is needed. An assessment of both Kayangel and Ngarchelong was conducted in 2016 by an independent contractor to better understand the existing capacity building gaps and needs of these two organizations. Below is the summary table of key findings and recommendations covering three capacities – Organizational Structure, Systems, and Human Resources – for both states, a grade/rating of the situation, and lists of specific recommendations to address the issues[vi]:

TABLE 5: SUMMARY OF KEY FINDINGS AND RECOMMENDATIONS

The rating/grading can be summarised as follows: 1: Poor; 2: Fair; 3: Average; 4: Good; 5: Excellent.

Capacity Issue	Kayangel State DNRCE	Rating	Ngarchelong State DNRD	Rating
Laws, Policies, Regulations *Type of Capacity: ORGANIZATIONAL AND SYSTEMATIC*	There are no established laws, policies, or procedures that govern Employment for the State. Kayangel State Marine Resource Rules and Regulations has been enacted. Kayangel State Marine Resource Conservation Act 2015 does not specify what the fines/ penalties are to be used for. As such, any possible fines are deposited into the General Fund.	1	There are no established laws, policies, or procedures that govern Employment for the State. Ngarchelong State Marine Resource Rules and Regulations has not been enacted.	1

Recommendations

These specific recommendations should be considered Government-wide Initiatives that should be taken by the State Governments as a whole.

1. (Both States) Need to establish a more permanent and sustainable employment system. This entails developing a bill for an Act to establish a State Government Public Service System that would outline basic employee benefits such as leave and pay differentials (e.g. Hazardous Pay, Overtime Pay, and Night Differentials). At the least and/or in the interim, the Governor should develop an employment policy to include such benefits.
2. (Both States) Need to establish Regulations and/or HR Policies regarding Recruitment, Hiring, Firing, Evaluation, Code of Conduct, and Pay Increments for employees.

(Kayangel) Amend the Law to include portions of the collections to be used specifically by the Department for recurring costs and possibly, for incentive pay (reward system). This can motivate and encourage Officers to be more vigilant and active at their work.

Organizational Structure *Type of Capacity: ORGANIZATIONAL*	There is no actual formal organizational structure for the Department of Natural Resources and Enforcement; however, based on the K-PAN Management Plan, the structure found in Figure 1 is the current structure. Need for more streamlined reporting structure.	3	Like Kayangel, there is no actual formal organizational structure for the Department of Natural Resources and Development (DNRD); however, based on the interview with the Director and the Governor, the structure found in Figure 2 is the current structure. Although the Department's name implies that its mandate cover management and implementation of programs and activities relating to the State's Natural Resource Development, it was found that the Department is lacking on the management and planning of developing the natural resources and/or sites. The Department as it stands, is only focused on enforcement of the Conservation requirements set forth in the Management Plan associated with PAN. At the same time, the Governor established a Tourism Board with a mandate to provide guidance on developing the Tourism Industry in the State, which includes the use of Historical Sites, and/or Conservation sites as attractions. There are weaknesses in both organizations (DNRD) and the Tourism Board that could possibly be addressed by merging the two into one umbrella.	2

Recommendations

1. (Both States) Development of Department Organizational Structure and revision of Position Descriptions that outline clear reporting lines.
2. (Kayangel) Adoption of the recommended Organizational Chart that includes 2 Sections – 1) Enforcement Section; 2) Outreach and Development Section.
3. (Ngarchelong) Development of Department Organizational Structure and revision of Position Descriptions that outline clear reporting lines.
4. (Ngarchelong) Adoption of the recommended Organizational Chart that includes 2 Sections – 1) Enforcement Section; 2) Development Section. This recommendation also includes merging and making the Tourism Board a more permanent part of the Administration. The Board can still exist and be a guiding body for the Development Section, however, there needs to be dedicated personnel coordinating and managing the day-to-day activities related to the mandates of the Tourism Board.

Update on the findings and recommendations since the review

Findings

- Ngarchelong State Marine Resource Rules and Regulations was adopted 30 May 2016
- Kayangel State Resource Rules and Regulation was enacted on 22 April 2016 Recommendations

1. Discussion with the state leadership stalled due to financial constraints at the state level to implement these recommendations.
2. There has been discussion regarding state level employment policy by the states, however, since the issue is a nation-wide issue discussion has been elevated to PAN level and discussions are still ongoing.
3. No action on this recommendation yet

Personnel *(TYPE OF CAPACITY: HUMAN RESOURCES)*	There are currently 2 Vacancies per the descriptions in the Management Plan for the Conservation Coordinator and Officer. Current Roster: 1 Director, 2 Active Rangers, 1 Ranger in Training (off-island), 1 Senior Ranger who also serves as the Conservation Officer. The average age of employees at the Department is estimated at 34. There are 2 Rangers listed in the Employment listing, however, they are not active. The Director and Governor both agree that additional Rangers are needed to cover the size of the patrol area. Position Lists include inactive employees. This has created mis-conception and/or assumption by other employees as well as community that there are 'ghost employees' within the department and as a result, it has created a negative image for the Governor's Office and/or Department. Need to review and revise current Position Descriptions to match needs of Department and consideration of labor force. There is need to establish other supporting positions within the department as well as the creation of a Job Series to provide for a career ladder for employees. Need to improve capacity of current employees, especially planning, management, and establishing SOPs. Need to establish HR Policies and procedures that include standardized recruitment, hiring, evaluation, and pay increments. Need to establish employee benefits (i.e. Leave, pay differentials). Need to create a stronger image of the Rangers by requiring use of uniforms, hats, and badges.	2	There are currently 8 Rangers under the Department, with an estimated average age of 37. The Director stated that this was the highest number of Rangers since the program's inception, however, adequate staffing proves not to be an issue, but rather hiring staff with the adequate and appropriate skills and motivation; and/or training employees to come to the appropriate capacity level. There are no other positions under the department aside from Rangers. There is need to establish other supporting positions within the department, as well as the creation of a Job Series to provide for a career ladder for employees. Need to improve capacity of current employees, especially planning, management, and establishing SOPs. Need to establish HR Policies and procedures that include standardized recruitment, hiring, evaluation, and pay increments. Need to establish employee benefits (i.e. Leave, pay differentials). Need to create a stronger image of the Rangers by requiring use of uniforms, hats, and badges.	2

Recommendations

1. (Both States) Adopt short term interim HR Policy via Executive Order (if applicable) until Law is passed for a Public Employment Policy of the State. This interim policy will include Recruitment, Hiring, Evaluation, Code of Conduct, and Taking Adverse Action protocols. There should be an Orientation on this system for all current employees and for all new employees.
2. (Both States) Revise Recruitment Strategy and fill the Vacancies with the "right person" for the right job with the right set of skills. In addition, the States should consider a recruitment strategy of "Branding" the work environment and the sector.
3. (Both States) Develop regular training and a skill updated schedule for employees to follow.
4. (Both States) Require Rangers to adopt a sharp image by utilizing uniforms every day they report to work. Department should also design and order Badges for the Officers.
5. (Both States) Adopt the Job Series and Career Ladder for the Enforcement Section(s).

6. (Both States) Re-train and place current employees in the right position. Possibly re-position current employees into more suitable positions (e.g. Officer who has background in marine resource management may be more suited to handle Conservation projects involving marine resource management rather than Law Enforcement).
7. (Kayangel State) Terminate and/or recall the 2 Inactive Rangers and if performance is an issue, then develop a Performance Improvement Plan (Ngarchelong State) Recruit for a "Development Coordinator" to oversee the Development Section.

Organizational Processes *Type of Capacity: ORGANIZATIONAL AND SYSTEMATIC*	The Department faces issues when accounting for expended funds, since the State uses one account for expenditures. Lack of Administrative Procedures and Financial/Cash/Accounting Manual in place with appropriate standards in place. Carry-over funds (for PAN Activities) continue to plague the Department's financial report and program reporting. A better understanding of the PAN fund use is required, as well as a better management and planning of annual activities.	1	Like Kayangel State, Ngarchelong State Government office needs to ensure that expenditures are recorded accurately and separately from the Office of the Governor's expenses. Like Kayangel, there is lack of Administrative Procedures and/or financial cash flow plans in place, and there are no established internal control procedures. Carry-over funds (for PAN Activities) continue to plague the Department's financial report and program reporting. A better understanding of the PAN fund use is required, as well as better management and planning of annual activities.	1

Recommendations

1. (Both States) Recommend for the Accounting/Finance section of the Governor's office to create separate Account numbers within the State's Accounting Records, to record expenditures of the Department's activities/expenses. This is very important for authorizing funds for PAN Activities.
2. (Both States) Develop and/or adopt a cash management plan, as well as internal controls to ensure standards are set in place for accountability purposes.

Training *Type of Capacity: HUMAN RESOURCES*	Need for a New Hire Orientation Program. Need for more periodic and regularly scheduled training on various skill sets. Need to establish a Memorandum of Agreement with the Bureau of Marine Law and/or Bureau of Public Safety for a training/ exchange program for State Rangers to continue to build and retain Law Enforcement knowledge and skills.	2	Need for a New Hire Orientation Program. Need for more periodic and regularly scheduled training on various skill sets. Need to establish a Memorandum of Agreement with the Bureau of Marine Law and/or Bureau of Public Safety for a training/ exchange program for State Rangers to continue to build and retain Law Enforcement knowledge and skills.	2

Recommendations

1. (Both States) Establish the New Hire Orientation Program.
2. (Both States) Schedule regular in-house trainings with external organizations, such as the PAN Office or the Bureau of Public Service System (MOF), to have a better understanding of Marine Resource Management Regulations, basic law enforcement skills, report writing, customer service, and other professionalization skills.
3. (Both States) Through the Governor, the Department needs to establish an Agreement with the Bureau of Marine Law to establish a training/ exchange program for State Rangers.

Tools *Type of Capacity: SYSTEMATIC*	There is a radio that is used when Rangers go on patrol. However, there is no clear established SOP for reporting to base camp. This issue was cited in a previous report (*Palau Northern Reef Assessment: Control and Vigilance System Design, 2014*) but does not appear to have been established. Standard Operating Procedures for various transactions: • Personnel Management • Department Management, including reporting requirements and timelines • Conservation Patrols • Safety and Security (general)	2	Rangers on Patrol should utilize the Radio to provide regular reporting to Base Camp. Base Camp needs to be able to record such communication. Need to establish Standard Operating Procedures for various transactions: • Personnel Management • Department Management, including reporting requirements and timelines • Conservation Patrols • Safety and Security (general)	2

Recommendations

1. Adopt and Establish Standard Operating Procedures for various transactions. One priority is to adopt the SOP on *"State Conservation and Law Enforcement"* that is available to the Department.

Others *(TYPE OF CAPACITY: OGANIZATIONAL AND SYSTEMATIC)*	Need of more program and technical support from the PAN Office under MNRET, including regular and/or periodic trainings and workshops. Need to clarify and/or identify the personnel under the Office of the Governor that would be responsible for providing administrative and financial reporting support.	2	Need of more program and technical support from the PAN Office under MNRET, including regular and/or periodic trainings and workshops. Need to clarify and/or identify the personnel under the Office of the Governor that would be responsible for providing administrative and financial reporting support. Office space (desk area) provided by the State Office, however, the Marine Rangers spend most of their time (when not on patrol) in a summerhouse at the Ollei Port. There were plans to locate the Department's HQ at Todai due to its high location where Rangers are able to have a good visual of the entire monitored area.	2

Recommendations

1. (Both States) Send request to PAN Office to provide training on the specific problematic issues (program reporting).
2. (Both States) Governor needs to ensure that his office staff understands its role as support providers to the Department. Possibly develop a schedule for Finance and Administrative Staff to meet with the Department Director on a monthly, or as needed, basis to complete reports and other needs.
3. (Ngarchelong) Recommend identifying and developing an actual HQ/Base for the Department; or at least for the Enforcement Section to have a designated base with appropriate tools (VHF Radio, desktop) and conducive for professional conduct and training. Allowing law enforcement officers to be "housed" in a summerhouse where local fisherman, and others, regularly lounge reduces the effectiveness of the chain of command and strict code of conduct.

Total Average Score for Kayangel	**1.86**	**Total Average Score for Ngarchelong**	**1.71**

Enforcement Capacity

Although a comprehensive fisheries legislation and its implementing regulations may look good in paper, the measures are pointless without adequate enforcement. Assessment was conducted by WildAID in 2014, to understand the level of co-enforcement required, costs and practicalities of enforcement, and cost of enforcement against expected benefits from the measures, taking into consideration the limited resources in the Northern Reef. Palau Northern Reef Assessment was conducted and focused on the following:

- Surveillance and interdiction – examine a cost-effective way to improve enforcement;
- Systematic training – examine key elements required to establish and sustain an effective law enforcement training program;
- Prosecution and sanction – examine traditional and non-traditional strategies to enforce regulation;
- Education and outreach – explore strategies to obtain stakeholder-buy-in; and
- Sustainable finance – examine potential financial resources to pay for enforcement.

The following table summarizes the key findings from the assessment based on interviews, site visits, and participation of patrols[vii]:

TABLE 6: SUMMARY OF KEY FINDINGS

OBSERVED FACTOR	KAYANGEL	NGARCHELONG
Personnel	2014 Budget: $143,000: $60,000 for staff, $50,000 for OPEX and $33,000 CAPEX. 4 Rangers and 1 Director who spends 50% in Koror and 50% in Kayangel. Ranger salaries are low. The Rangers only carry out patrols during the day. Three Rangers have undergone 3-month Police Academy training and1-week Special Enforcement Tactical Training (SETT). There were no regulations that can be enforced. Rangers did possess uniforms, but do not utilize SOPS, manuals, nor reporting formats. In FY2020, due to performance issues, PAN budget got reduced to $96,000. There are 5 rangers staff and program is in process of recruiting coordinator. There are regulations that can be enforced but due to operational challenges no surveillance has been conducted since Nov. 2019	2014 Budget: $80,000 Budget: $50,000 for staff and $30,000 for OPEX. 5 Rangers and 1 Coordinator (position currently vacant). Ranger salaries are low. Three Rangers have undergone 3-month Police Academy training and 1-week Special Enforcement Tactical Training (SETT). 1 Ranger is a certified Boat Captain. There were no regulations that can be enforced. Rangers did not possess uniforms, nor do they utilize SOPS, manuals, or reporting formats. In FY2020, Budget is $136,000 and there are 1 Program Director and 7 Rangers. There are regulations that can be enforced and surveillance is being conducted on scheduled patrol. Rangers are now able to issue citations and in 2019, issued total of 8 citations for infractions of state fisheries regulations. However due to lack of dedicated legal counsel for the state the citations were not able to be processed through the coursts.
Size and complexity of marine area	The Kayangel Marine Managed Area (KMMA) is 1,685 Km² in size (1,966 Km² when using 12 nautical miles from baseline) and possesses one main port. Out-of-state fishers can access Kayangel territorial waters (Velasco Reef) from the south, via the Ngarchelong lagoon, or outside of barrier reefs. The local population has easy access to the primary lagoon and must travel 7NM to access Ngeruangel Marine Reserve/ Velasco Reef. Historically, winds blow from West to East, which causes vessels to approach from the wind protected East side, and from September- April the winds blow from East to West causing vessels to approach via western reefs. The monsoon season limits vessel activity from November to April. The primary fishing season begins in April and ends in August. Due to its remote location, a logistics vessel serves Kayangel every two weeks correlating with paydays. Logistics have posed problems with fuel availability for Rangers in the past.	The Ngarchelong Marine Managed Areas (NMMA) is 1,994 Km² in size and possess three key ports (2 on the West and 1 on the East). There are a number of passageways on the Western side of the Island, which are used by out-of-state fishers to access Ngarchelong and Kayangel territorial waters. The local population has easy access to the primary lagoon and outer reefs. From May – August, vessels approach territorial waters via the wind protected Eastern side, and via the western canals from September- April. The monsoon season limits vessel activity from November to April.

OBSERVED FACTOR	KAYANGEL	NGARCHELONG
Vigilance means	At the end of 2019, PAN Rangers vessels were not operable to support surveillance and no active surveillance is ongoing. State is in the process of trying to acquire twin engines for one of its existing ranger boat as engines have failed.	The Ngarchelong State Rangers possess 3 patrol vessels: a 27 ft. with one 225 HP (4 stroke Mercury) and 23 ft. with one 150HP (4-stroke Mercury) and a twin 250 hrs power Yamaha Dealer in Koror carries out motor maintenance.
Technology used in vigilance	The Kayangel State Rangers possess one radar at the State office building that has never operated. At the time of our visit, the Rangers possessed only one base VHF radio, and the Director stated that an order had been placed for an additional base radio and handhelds. Rangers used per-zonal cellular phones with voice and SMS for communication with team members when necessary and coordinated with Ngarchelong Rangers on occasion. The Rangers did possess binoculars, a satellite phone with no prepaid minutes, and a camera. They did not have GPS, video cameras, safety gear or any other equipment for patrols.	Rangers have one base VHF radio and NHF radios on all ranger boats.. The Rangers have binoculars, camera and GPS,
Distance of populations and multiple uses within the MPA	Kayangel possesses an estimated 14 local vessels that are involved in fishing activities. Rangers report the entrance of 1-2 out-of-state vessels a week. There is a minimum of 10 tourist sites for snorkelling, scuba, research and sports fishing (both catch and release & catch and consume.)	Ngarchelong possesses an estimated 48 local vessels that are involved in fishing activities. There is a minimum of 16 tourist sites for snorkelling, scuba, research and sport fishing (both catch and release & catch and consume.) There is tourism and fisher vessels that passes through territorial waters en route to Kayangel.
MPA proximity to maritime traffic routes	No maritime traffic routes near MPAs.	Kayangel residents pass through Ngarchelong waters.
Availability of means	Vessel availability does not appear to be a problem, as they possess two vessels leaving one operative, while the other is under maintenance. Fuel appears to be the limiting factor.	Vessel availability does not appear to be a problem, as they possess two vessels leaving one operative, while the other is under maintenance. Fuel appears to be the limiting factor.
Systematization and planning of vigilance	Proper planning and execution of surveillance remains a challenge due to properly trained leader. Standard operating procedures for enforcement exist but are not regularly followed.	The Ngarchelong Rangers currently carry out limited strategic annual and monthly planning. Standard operating procedures for enforcement exists and are being followed and improvements in execution will increase effectiveness of enforcement. Formal reporting formats exist.
Availability of intelligence information	Limited coordination and intelligence gathering continues to be a challenges.	Limited coordination and intelligence gathering continues to to be.
Days operating per month/ year	Given their limited budget, the Kayangel Rangers currently patrol 3 days/week. The Director states that they possess an annual fuel budget of 3,100 gallons, which limits the number and duration of patrols.	The Ngarchelong Rangers face similar budget constraints. The Rangers stated they averaged 18 gallons of fuel for 8-hour patrols.

The following are some of the priorities and general recommendations from the assessment report that was achieved:

Rangers capacity building on enforcement

As a result of the following capacity building for enforcement eight state rangers completed the courses and were certified

- **Refresh and build on initial course objectives.** This includes supporting the local Ranger training officer, measuring the effectiveness of their implementation efforts, and help them address any implementation issues.
- **Develop basic chart plotting, navigation, and piloting skills.** As the Rangers conduct more night patrols, closed area enforcement, coastal track-line patrols, and closed border patrols these skills will become more critical to prove closed area cases, plan patrol movements, and safely conduct operations.
- **Develop basic water survival skills.** This includes basic water survival techniques and potentially basic first aid. This is a confidence builder for Rangers, especially when they begin conducting night operations and more aggressive patrolling.
- **Support Director-level operations and management actions.** Provide additional implementation mentoring and technical support as the Directors implement the changes fostered during the program, including applying lessons learned as they manage the training plan, operational patrol planning and data collection process, and conduct enforcement actions associated with implementing new regulations and rules.
- **Provide Use of Force decision-making.** This should focus on use of force scenarios associated with the fisheries enforcement mission. Rangers are receiving firearms as part of their equipment, including arming deputized/state certified officers. Use of Force training related to the maritime enforcement mission will assist Rangers as they establish themselves as a professional law enforcement organization.
- **Develop defensive tactics and control skills.** These skills are associated with Use of Force application and non-cooperative enforcement. Training in this area is particularly useful to build Ranger confidence, especially when dealing with larger vessels with marginally compliant crews and if they need to respond to an aggressive and / or non-compliant violator.
- **State legislations and regulation.** These help build Ranger's understanding of the existing laws they were mandated to enforce.

Development of SOPs, job aide, and checklists:

- Brevity Code SOP and Checklist
- Digital Cameral Job Aide
- Evidence Collection SOP and Job Aide
- GAR SOP and Job Aide
- Getting Underway SOP and Job Aide
- GPS Job Aide
- Log Note Keeping SOP and Job Aide
- LR Camera Job Aide
- Patrol Plan SOP and Job Aide

Systematic patrol planning with Marine Law Enforcement Director

Joint enforcement pilot was established with Fish and Wildlife for a period of 1 year. Surveillance coordination was difficult due to lack of established coordinating mechanism and process. PAN Office and Fish and Wildlife are working on establishing coordination mechanism and process to support joint enforcement coordination.

Installation of high-powered surveillance equipment in Ngarchelong and Kayangel

Due to lack of technical capacity needed to operate the equipment and lack of maintenance capacity in Palau, the use of this equipment has been discontinued due to cost consideration.

Establishment of citation process from state to national judicial system.

TNC worked with the Ministry of Justice (MOJ), PAN Office and WildAID to develop the enforcement component of this project. With limited financial and human resources within both States, co-enforcement was a new approach with hopes of consolidating efforts and limited resources, strengthening capacity and improving overall enforcement capacity performance of both states. The *Memorandum of Agreement for Cooperation in joint surveillance and enforcement operations and sustainable fisheries management over the Kayangel Protected Area Network (KPAN) and Ngarchelong Marine Managed Area (NMMA)* was then established in 2017. Co-enforcement between the two states still had its own gaps and therefore, additional support was sought from MOJ to support enforcement in the Northern Reef. Subsequently, *Memorandum of understanding between the Northern Reef and Ministry of Justice* was established in 2017 to provide additional support to help improve enforcement performance in the Northern Reef. In addition to the above mentioned work, TNC is working with PAN Office to develop a capacity building training standard to help consistently build capacity of state rangers.

Challenges:

The following are the challenges associated with capacity and enforcement for both states; as identified in the assessments[viii] :

- **Lack of Law, Policy and/or Regulation regarding Employment (including benefits, and programs)**

this continues to be an issue for both Kayangel and Ngarchelong.

- **Retention Issues (location, size, resources)**

Human capacity for both states continue to be impacted by high staff turnover. Better financial and benefit opportunities offered by other enforcement agencies, including the national marine law, continued to recruit state rangers which made it harder for the state to retain their trained staff. To address the issue, it was recommended to increase the salary and benefits of staff, which helped not only to retain, but to recruit more staff.

- **Lack of Standardized Job Evaluation Scheme**

Like in most states, there is no human resource policy in Kayangel and Ngarchelong. Therefore, a standard evaluation scheme was never employed. The assessment highlighted this issue and recommendations were made to both states; which have yet to be implemented.

- **Lack of Periodic and Consistent Training and Support**

Due to limited resources, capacity training was limited to what was offered by the national government and/or non-government partners. Most of the time, however, the training was not really geared to the specific state capacity needs. Under this project, there is currently an effort, lead by PAN Office, to develop a standard training for rangers and conservation officers, to ensure that appropriate trainings are being conducted and are consistent for all states.

- **Access to resources (financial and human)**

Although there was some level of consistent financial resources, accessing the funding has always been an issue due to the process that was in place. Resources should not be the determining factor of the capacity of such organization, but rather good management and leadership.

- **Lack of good management & leadership**

On the surface, human resource management seems to always depend on the compensation of employees. However, as we delve deeper, it becomes apparent that employees need and/or want more than a pay raise. In fact, higher salaries do not necessarily translate into a better performance, but rather, a good manager with leadership qualities. In the case of Ngarchelong and Kayangel, adequate leadership was lacking.

- **Lack of good leader/manager**

At the end of the day, most of the resource conservation and management issues and challenges were attributed to bad management and leadership. With adequate leadership in place, management performance will improve, and therefore, the overall performance of resource conservation and management will improve as well.

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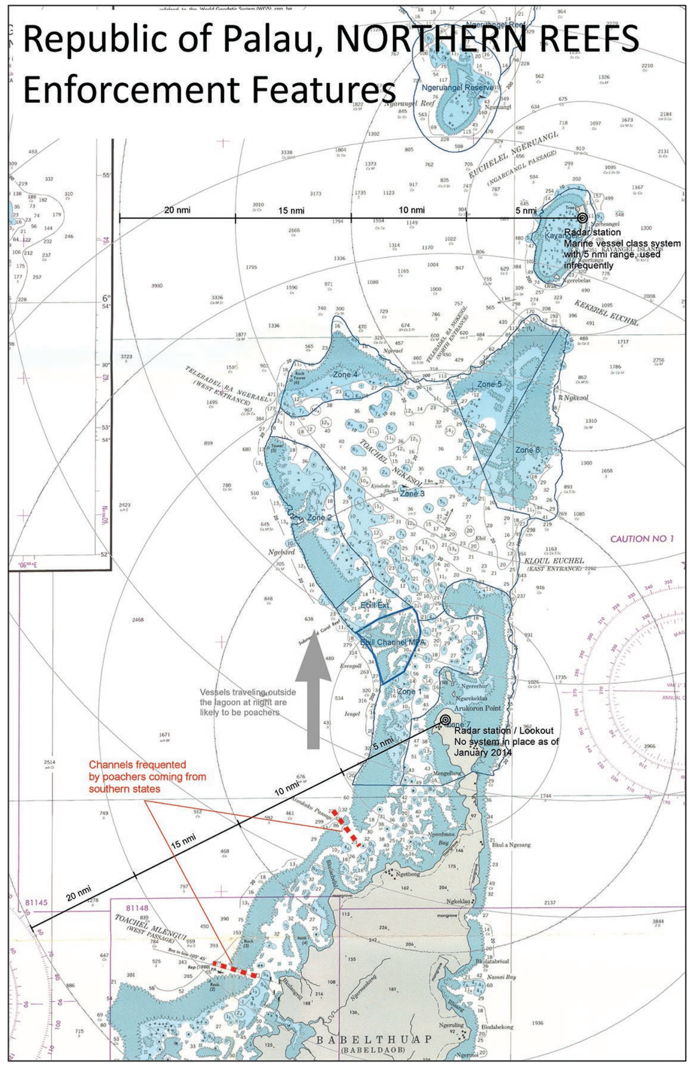
i) Cooperative Agreement Between the State of Kayangel and Ngarchelong on Sustainable Fisheries Management and PAN Sites Management 2013
ii) Ibid (i)
iii) Ibid (i)
iv) Ibid (i)
v) Ibid (i)
vi) Northern Reef Capacity & Institutional Assessment 2016
vii) Palau Northern Reef Assessment – Control and Vigilance System Design 2014
viii) Ibid(ix)

Enforcement

Upon the start of the project, law enforcement was identified by many stakeholders as a main priority in order to recover fisheries stocks in the northern reefs. Recognizing the lack in capacity building within enforcement agencies, we enlisted the support of WildAid to conduct an analysis that would enable the designing of a practical, affordable, and feasible enforcement system in the Northern Reef, that could be implemented over a period of four years. The analysis looked over legal frameworks, competencies, and jurisdictions of all marine enforcement agencies in Kayangel and Ngarchleong. The enforcement plan produced by Wild Aid recommends the following:

Surveillance & Interdiction: Improving surveillance and interdiction in the Northern Reef area by exploring advances in technology that could help reduce costs, while increasing coverage. Recognizing that technology has limitations, however, is also important as there would be a need to develop a strong and clear legal framework, along with investment in vessels and trained in-water personnel.



Map of Palau's Northern Reef showing key enforcement features, such as reef channel and the location of high powered camera systems, to support surveillance and monitoring

Staffing

A minimum of 7 Rangers is needed to operate the enforcement system at each state, assuming there are two shifts per day. A minimum of 3 Rangers must be on duty at any given moment. Each patrol vessel should be staffed with at least 2 Rangers: A Boat Captain and one Ranger, whom will be responsible of performing interdiction and boarding activities. The patrol vessel should be in contact with the control center officer every hour to report location and situation. Neither Kayangel nor Ngarchelong have been able to meet this minimum standard; Ngarchelong faces high turnover rates, and Kayangel has not been able to hire a minimum of 7 rangers (Table 1). The Marine Enforcement Director, also known as the State PAN Director, should spend a minimum of 75% of the time on site, overseeing strategic planning, coordination, and overall management activities. Due to limited capacity, however, this recommendation has not been achieved to date, presenting a continuous challenge in the management of the program within each state. In 2018, WildAid conducted a PAN Wide Enforcement assessment, where it was found that the majority of the states do not count with supervisors with strong leadership skills, or adequate knowledge in the various tasks necessary to achieve PAN goals.

Kayangel Rangers with their duputization certificate @ TNC

Position	Ngarchelong					
	2015	2016	2017	2018	2019	2020
Director	Occupied	Occupied	Occupied	Occupied	Occupied	Occupied
Conservation Coordinator	N/A	N/A	N/A	Occupied	Vacant	Vacant
Rangers	7	6 (5 staff are new + 1 from previous year)	7 (3 new staff + 4 from previous year)	8 (1 new staff + 7 from previous year)	8 (same staff from previous year)	9 (4 new staff + 5 from previous year)

Position	Kayangel					
	2015	2016	2017	2018	2019	2020
Director	Occupied	Vacant	Occupied	Occupied	Vacant	Vacant
Conservation Coordinator	Occupied	Vacant	Occupied	Occupied	Occupied	Occupied
Rangers	4	5 (1 new staff + 4 from previous year)	6 (3 new staff + 3 from previous year)	6 (1 new staff + 5 from previous year)	6 (same from previous year)	5 (same from previous year)

Table 1.
Status of staffing patterns for Kayangel and Ngarchelong PAN programs. Director and Conservation Coordinator positions involve leadership and administrative roles. Ranger positions include enforcement and monitoring. Source of data: PAN Office.

Technology support

A network of Very High Frequency (VHF) radio systems were installed on a land station in both Kayangel and Ngarchelong, as well as in the ranger's patrol boat. Due to the limited coverage offered by the VHF radio system, blind spots were still identified within the northern reefs: In particular, areas within Ngebard and Btil Ngerael reef in Ngarchelong, and Ngeruangel Marine Protected Areas in Kayangel. Efforts were made to improve the VHF radio system, but due to limited availability of hardware and technical capacity on island, it has not improved considerably. The VHF radio system was intended to be utilized by fishermen, to increase their safety while accessing fishing grounds outside of the reef system. However, due to its limited coverage, the system has not been able to address this safety concern shared amongst the fishermen who want to access anchored fish aggregating devices (aFAD), found outside the reefs. Despite its limited coverage area, the VHF radio has improved communications between in water surveillance patrols and the ranger station.

High powered surveillance video camera systems were installed in both Kayangel and Ngarchelong States, to explore the feasibility of using technology to support surveillance. Due to limited capacity in the use of these systems, and the lack of technical capacity to maintain the video surveillance systems, it was determined after 1 year of operation that it was not practical to continue using these surveillance systems and were, therefore, discontinued. While the surveillance systems did not function as intended, poaching, as observed by fishermen from Kayangel and Ngarchelong, decreased due to the community's awareness of increased surveillance in the area.

While technology can have a tremendous contribution towards achieving effective surveillance, in-water presence is critical to implementing interdiction and increasing compliance. In-water presence, however, require durable and safe vessels, trained staff, and effective surveillance planning. At the beginning of the project, both Ngarchelong and Kayangel PAN programs did not have vessels that were durable enough to support extended surveillance presence in water, as their vessels were open boats unable to protect rangers from the elements. Through the PAN Office, efforts were made to assist both Ngarchelong and Kayangel States, to obtain vessels that were safe enough to support enforcement. Cabin vessels (1 for Kayangel and 1 for Ngarchelong) were obtained and equipped with twin engines, a radar system, and a VHF radio to help support surveillance. Even though the vessels have been a great added asset to the PAN Program of both states, an increased in-water presence has not substantially strengthened the controlling and monitoring of activities in the northern reefs. Challenges, such as a lack of trained staff, ineffective surveillance planning, and limited budget to support fuel costs, continue to hamper increased surveillance in the northern reefs. To date, both Kayangel and Ngarchelong have not been able to implement a sustained 24 hr surveillance in the northern reefs

VHF radios for Kayangel and Ngarchelong state Ranger's boat.


Ribbon cutting ceremony for newly installed high powered video camera at Todai, Ollei.

Enforcement vessel for Ngarchelong @TNC

Coordination between Kayangel and Ngarchelong States and the Division of Fish and Wildlife

It was intended at the beginning of the project to encourage joint enforcements between rangers from Kayangel and Ngarchelong States in the northern reef area. The establishment of the co-management agreement between the two states was initiated to explore the feasibility of collectively managing the northern reef area, including enforcement. One of the main challenges encountered in establishing this joint enforcement, however, was the lack of legal framework that would support cross-state boundary enforcement. At the same time, one issue that hampered the exploration of a legal framework, was the allocation of potential revenue that could be generated through imposed fines. No viable mechanism could be settled at the time to address these challenges and therefore, this led to the establishment of a coordination between the states and the national government, to improve enforcement. The option of deputizing state rangers from Kayangel and Ngarchelong by the Director of Palau Public Safety, to be able to enforce national law, was also explored. The intention behind this measure was to allow rangers to carry fire arms to increase their personal safety while conducting surveillance in the northern reef area, which is quite remote from Koror, where Palau's public safety capacity is centered. There were challenges in getting the rangers access to fire arms, including (1) authorization to bear fire arms – as only law enforcement officers are allowed to bear fire arms, and (2) proper facilities for handling firearms, while establishing processes in state governments to ensure public safety. In addition, there were differing legal opinions as to whether the Memorandum of Understanding (MOU) that was established for deputizing the state rangers had legal standing. Eventually, the MOU was rescinded.

To address the continued need to establish a coordination in enforcement between national government agencies and the states, the Palau Protected Areas Network Office and Palau PAN Fund funded a joint enforcement project between the Division of Fish and Wildlife and Kayangel and Ngarchelong states, with the following goals in mind: (1) increase enforcement presence in the northern reefs, (2) provide additional training capacity to state rangers, and (3) explore options to establish mechanisms for a joint/coordinated enforcement. A MOU between the Ministry of Justice, the Ministry of Natural Resource Environment and Tourism (MNRET), Kayangel State, and Ngarchelong State was executed in April 2017 to support the project. After a year of implementation, it was clear that without proper mechanisms, processes, and an effective implementation, a joint enforcement would continue to be difficult, especially with lacking mandates from both the national and state governments. At the same time, we learned that operating on a voluntary basis is neither effective, nor sustainable, when it comes to meeting the coordination of law enforcement objectives. As a result, joint enforcement activities were discontinued. The project is currently ongoing and is mainly focused on guiding the development of a curriculum that will help train PAN state rangers, while coordinating the implementation of mechanisms and processes that ensure an effective cooperation between national and state governments, to establish effective coastal enforcement in Palau.


KAYANGEL

NGARCHELONG

MEMORANDUM OF AGREEMENT

FOR

Cooperationin joint surveillance and enforcement operations and sustainable fisheriesmanagement over the Kayangel Protected Areas Network and the Ngarchelong Marine Managed Area, (hereinafter collectively referred to as the "Northern Reef").

This Memorandum of Agreement (MOA) is entered into by and between:

- Kayangel State, represented by Governor Midas Ngiracheluolou; and
- Ngarchelong State, represented by Governor Browny Salvador
- Together, both states are hereinafter referred to as the "Parties".

Statement of Purpose and Findings

Each of the parties has an interest in ensuring public compliance of state and national laws, and corresponding rules and regulations over the Northern Reef. The parties have found that illegal entry, poaching, overharvesting, taking or the reckless handling of marine resources due to human activities in the Northern Reefs persists and over time cause:

- Negative impacts over fragile coral reef ecosystems and animals within them;
- Negative disturbance on critical fish spawning and aggregation sites;
- Negative disturbance on critical turtle nesting and foraging grounds, and other threatened marine species;
- Severe decline of fish stock;
- Negative impact on local livelihoods; and
- Loss of revenue to state governments.

Copy of the MOU that establishes a joint enforcement in the northern reefs

Systematic Training:

In order to support enforcement in the northern reef area, a training program was designed and implemented (see Table 2). A total of 20 individuals, belonging to the enforcement teams in Kayangel and Ngarchelong, underwent the training program over the course of 4 years. Due to high turnover rates within the Kayangel and Ngarcheong PAN Program, however, only less than 50% of the individuals that went through this training are still with the PAN program in both states. As of today, Kayangel State counts with 5 trained rangers, while the Director position is still vacant. Ngarchelong, on the other hand, counts with 9 rangers, two of which count with the recommended training course, and a Director who has undergone these trainings as well.

Table 2.
Recommended training course for improving enforcement.

COURSE TOPIC	COURSE DESCRIPTION	
Basic IMO Training	First Aid Fire fighting	Survival at Sea
Surveillance, Detection, Interdiction and Boarding	Operations planning and preparation Use of visual and electronic sensors in marine patrolling Boarding procedures: Performing Inspections, documentation to request, what to look for, and documenting your inspection. Training must be coordinated with state attorneys.	Interviewing the suspect´s boat crew Crime Scene Key practices. Evidence collection and handling. Operations/Felony Reports. *Information and items that are typically in a "good" report.*
Operations Planning and Control Center Management	Control Center functions including risk assessment (GAR model), asset use, reporting, communications procedures, surveillance proce-dures, and documentation. Telecommunications lines and coordination procedures with the Coast Guard Situation escalation procedures and real time reporting	Terrestrial Charts interpretation and navigation Nautical Charts interpretation and navigation Search and rescue First aid provided in the field Personal safety issues for patrolling and boarding
Yamaha Basic and Advanced O/B Service Training Course	All wardens must participate in an OEM basic outboard motor main- tenance certification course	Two of the wardens will be trained in second level maintenance: computerized diagnostic, critical spares replacement and motor tuning. Overhauls are carried out in Koror
Standard Operating Protocols (SOPs)	Control Center Boarding Teams Patrolling Maintenance	

Prosecution & Sanction: Developing state processes to improve regulation, support, and prosecution.

At the beginning of the project in 2014, a legal analysis was conducted to determine the status of enabling legislation related to natural resource management. The assessment showed that no regulation existed on the use and management of marine resources at the state level. In order to address this deficiency, legislation was established to protect areas and/or species of interest. This approach, however, has resulted in a legislation that is sometimes ambiguous, with an unclear definition of language within state law, leading to conflicting laws that cannot be enforced. The assessment recommended key state laws to be amended (A total of 9 laws for both states were deemed unenforceable) to make them enforceable. As a result, Kayangel and Ngarchelong states went through their respective state legislative processes to amend their respective state laws. In addition, Kayangel and

Ngarchelong passed their respective marine resource acts in 2015, mandating the establishment of regulations meant to improve the management and use of their territorial waters and marine resources.

Kayangel and Ngarchelong established their respective state marine regulations in 2016, which dictate as follows:

Inspection. Authorized persons have the authority to temporarily stop a boat and examine all boats, equipment, persons, and catch without a warrant. Inspection of catch includes the inspection of a cooler, hatch, or any other place or container on a boat that may be used to store or conceal marine resources. Authorized persons must carry out this routinary inspection at a reasonable time and in a reasonable manner.

Citation.

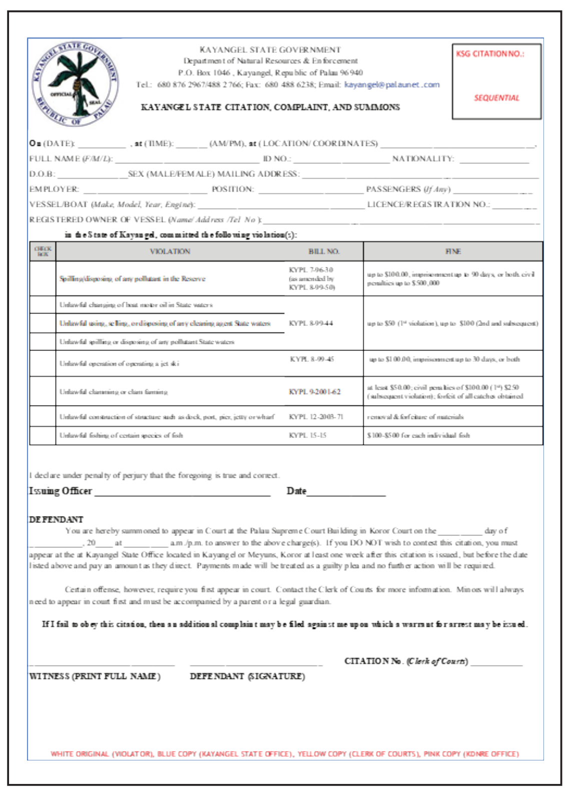
Authorized persons must issue citations for violations of State's marine laws. The Governor has the authority to determine how to proceed with a citation, and whether a violation, civil, criminal action, or a combination of the preceding, is appropriate in accordance with these Regulations. Both Kayangel and Ngarchelong established an administrative procedure to settle citation within the State Government within 30 days of issuance of citation before being addressed in the court system. In 2018, Ngarchelong rangers conducted 300 hrs of surveillance, resulting in 1 citation and 7 warnings; in 2019, they conducted 356 hrs of surveillance, resulting in 10 citations and 29 warnings (source: Ngarchelong PAN Office).

While the process that enables rangers to issue citations for violations has been improved, the process for addressing such violations has not ameliorated. The continued lack of prosecution for violators is due to a shortage of dedicated attorneys at the state level, willing to address prosecution related to marine resource violation. Due to limited financial resources, both Kayangel and Ngarchelong states have not been able to retain an attorney that focuses on prosecuting violations relating to marine resources. To date, there has been no successful prosecution of citation that has been issued.

Ngarchelong Rangers being deputized.@TNC

Seizure and Forfeiture.

Authorized persons shall have the authority to seize tools, equipment, or any apparatus used to violate any provisions of any state marine law; and to seize any marine resource harvested, taken, or possessed in violation of any provisions relating to any state marine law.



KAYANGEL STATE GOVERNMENT
Department of Natural Resources & Enforcement
P.O. Box 1046, Kayangel, Republic of Palau 96940
Tel.: 680 876 2967/488 2766; Fax: 680 488 6238; Email: kayangel@palaunet.com

KSG CITATION NO.:
SEQUENTIAL

KAYANGEL STATE CITATION, COMPLAINT, AND SUMMONS

On (DATE): __________ , **at** (TIME): ______ (AM/PM), **at** (LOCATION/ COORDINATES) ____________________,
FULL NAME (*F/M/L*): ____________________ ID NO.: ______________ NATIONALITY: __________
D.O.B: ____________ SEX (MALE/FEMALE) MAILING ADDRESS: ____________________
EMPLOYER: ______________ POSITION: ______________ PASSENGERS (*If Any*) __________
VESSEL/BOAT (*Make, Model, Year, Engine*): ____________________ LICENCE/REGISTRATION NO.: ________
REGISTERED OWNER OF VESSEL (*Name/ Address /Tel No*): ____________________

in the State of Kayangel, committed the following violation(s):

CHECK BOX	VIOLATION	BILL NO.	FINE
	Spilling/disposing of any pollutant in the Reserve	KYPL 7-96-30 (as amended by KYPL 8-99-50)	up to $100.00, imprisonment up to 90 days, or both. civil penalties up to $500,000
	Unlawful changing of boat motor oil in State waters		
	Unlawful using, selling, or disposing of any cleaning agent State waters	KYPL 8-99-44	up to $50 (1st violation), up to $100 (2nd and subsequent)
	Unlawful spilling or disposing of any pollutant State waters		
	Unlawful operation of operating a jet ski	KYPL 8-99-45	up to $100.00, imprisonment up to 30 days, or both
	Unlawful clamming or clam farming	KYPL 9-2001-62	at least $50.00; civil penalties of $100.00 (1st) $250 (subsequent violation); forfeit of all catches obtained
	Unlawful construction of structure such as dock, port, pier, jetty or wharf	KYPL 12-2003-71	removal & forfeiture of materials
	Unlawful fishing of certain species of fish	KYPL 15-15	$100-$500 for each individual fish

I declare under penalty of perjury that the foregoing is true and correct.

Issuing Officer ____________________ **Date** __________

DEFENDANT

You are hereby summoned to appear in Court at the Palau Supreme Court Building in Koror Court on the ________ day of __________, 20____ at ________ a.m./p.m. to answer to the above charge(s). If you DO NOT wish to contest this citation, you must appear at the at Kayangel State Office located in Kayangel or Meyuns, Koror at least one week after this citation is issued, but before the date listed above and pay an amount as they direct. Payments made will be treated as a guilty plea and no further action will be required.

Certain offense, however, require you first appear in court. Contact the Clerk of Courts for more information. Minors will always need to appear in court first and must be accompanied by a parent or a legal guardian.

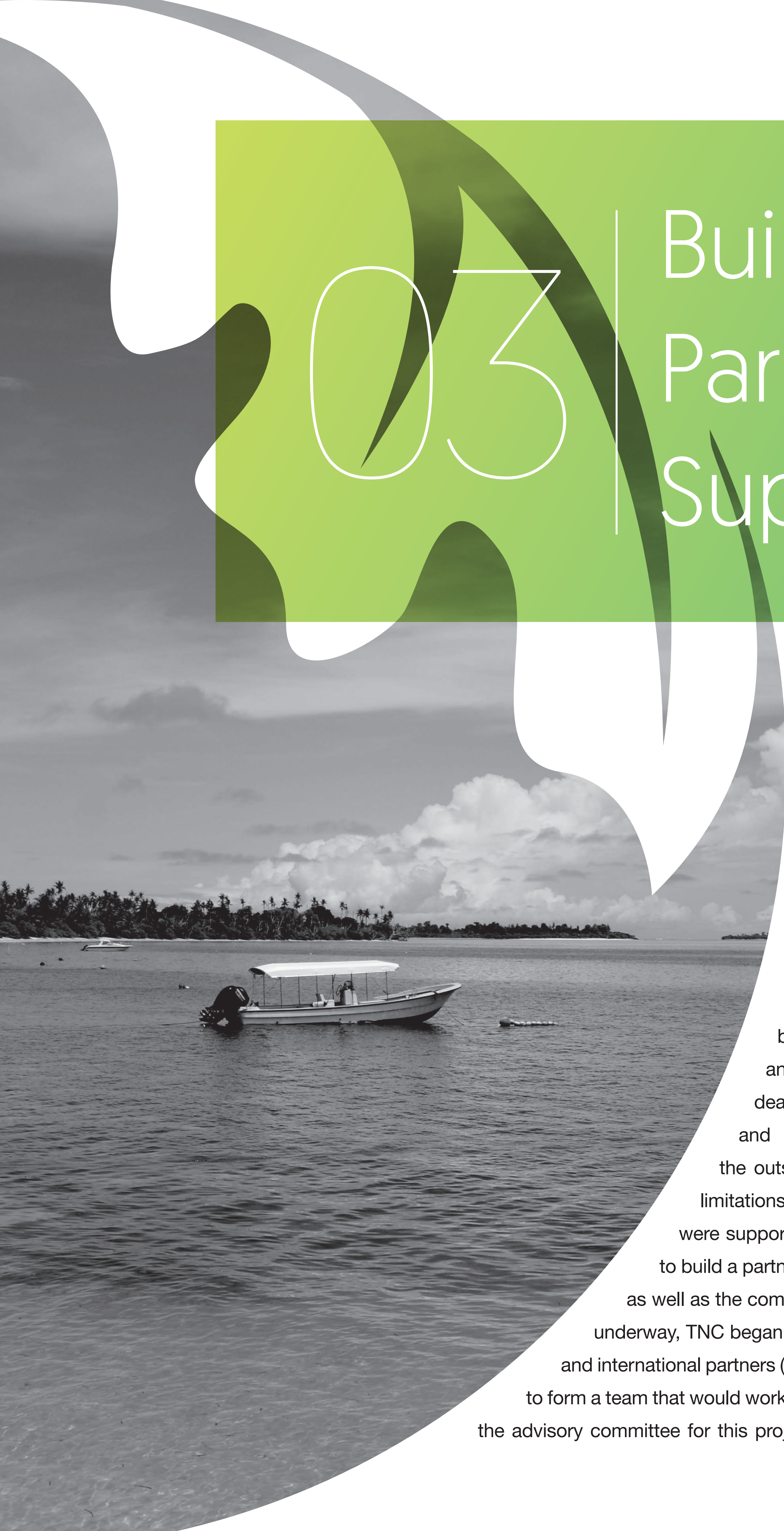
If I fail to obey this citation, then an additional complaint may be filed against me upon which a warrant for arrest may be issued.

______________________ ______________________ **CITATION No.** (***Clerk of Courts***) __________
WITNESS (PRINT FULL NAME) **DEFENDANT (SIGNATURE)**

WHITE ORIGINAL (VIOLATOR), BLUE COPY (KAYANGEL STATE OFFICE), YELLOW COPY (CLERK OF COURTS), PINK COPY (KDNRE OFFICE)

Copy of citation for Kayangel

03 | Building Partnership Support



Partnership is an important tool that can address capacity and resource limitations to support community-based fisheries management, or any other community-based efforts dealing with community development and natural resource-management. At the outset of the project, we recognized the limitations that existed in the communities we were supporting, and we made a conscious effort to build a partnership that would support this project, as well as the community. With community engagement underway, TNC began soliciting support from local, regional, and international partners (individuals, groups, and organizations) to form a team that would work with the communities and would form the advisory committee for this project. Partnership was one of the key elements of success for this project. *A Memorandum of Understanding between the Ministry of Natural Resources, Environment and Tourism (MNRET), Palau International Coral Reef Center (PICRC), and Palau Conservation Society (PCS)* was executed in 2014 with objectives to cooperate within the following scope :

- Development of alternative livelihood
- Community engagement and awareness
- Capacity Building (management and enforcement)
- Fisheries policy
- Fisheries monitoring (data collection protocol, data collection, data storage and management, and stock baseline assessment)

As the project progressed, additional partnerships with other entities, such as the Ministry of Justice (MOJ), Koror State Government (KSG), and Protected Area Network (PAN) Office were established.

In addition to the partnership established between the implementing partners, partnerships with the community's leadership, fishers, and other interested local groups were needed to ensure that all of the stakeholders were part of the designing, planning, and implementing of this project. Partnerships helped build trust by assuring the resource-owners and users that fisheries issues were being addressed with consideration to their needs and concerns. There was also a need to demonstrate that fishers and users are key to all of the functions and responsibilities involved in fisheries management and conservation. The Northern Reef Fisheries Co-Management Advisory Committee (NRFCA) was established to help steer and facilitate the efforts under this project, ensuring that all stakeholders were involved. Members of the advisory committee included the following:

1. Billy Graham, Kayangel fishers representative
2. Masao Salvador, Ngarchelong fishers representative
3. Jeffrey Titiml, Kayangel Governor
4. Browny Salvador, Ngarchelong Governor
5. F. Umiich Sengebau, Minister of Natural Resources, Environment and Tourism
6. Yimnang Golbuu, Chief Executive Officer of the Palau International Coral Reef Center
7. Chuck Cook, TNC Representative

Project partners had regular quarterly meetings, to provide progress updates and discuss issues and concerns that partners were having with their deliverables.

Lessons Learned:

Communication

One of the main challenges the partners had was communication. However, once the quarterly meetings were agreed upon, communication issues where addressed and the project progressed with everyone's full support.

Turnover of staff

Turnover of staff was also one of the key challenges that the project faced. Even though there was very little we could do about this issue, strong guidance from project managers -and the team as a whole- was key to ensuring that incoming staff were up to par on the project. This made their transition into the project more at ease.

Partnership Coordination

TNC assumed the role of coordinating the partnership between the resource-agencies, as well as the Co-management Committee. Because TNC has other project commitments, it became a challenge for TNC to maintain coordination of these partnerships.

Ensuring processes and contacts beyond the project

Ensuring that there are processes in place, and an identified person at the state level able to lead the coordinating partnership beyond the project period, is important to guarantee the success of the natural resource management program in the states of Kayangel and Ngarchelong.

Agency support

Agency support to the state can be identified in their annual work plan to ensure a consistent commitment, and not just based on project-level support; this can be developed under the PAN framework.

04 Building Fishers Engagement Platform

It has been shown in other community-based fisheries management projects that when fishers are engaged in management, projects are more successful. In the past, fishermen had the responsibility of taking care of their fishing activities to minimize impacts on the community's resources. Palau's journey into a democratic government essentially shifted the community's perspective from being owners and managers of their resources, to primarily users. This means that management responsibilities were shifted to State governments, which subsequently eroded traditional conservation principles and values that were key to traditional conservation and management practices over generations. In Ngarchelong and Kayangel State governments, there was no existing platform by which fishermen could actively engage in the management of their fisheries and the development of livelihood opportunities. There had been fishing cooperatives in the past, but these cooperatives had simply focused on creating an opportunity for fishers to make an income. Cooperatives had essentially outlived their purpose when fishermen found more regular employment, offered by the Palau national, and their respective, state governments. In addition, a community organization exists between villages in Kayangel and Ngarchelong that operates as a cooperative by utilizing the traditional concept of helping one another. We discussed how these traditional concepts of working together as a community, and the experiences in participating in fishing cooperatives, can help inform the development of a platform that would enable the engagement fishers in management and livelihood development. We had conversations and meetings with fishermen for about six months before the fishermen decided to establish a fishing cooperative with the following purposes :

"The purposes for which this corporation is organized include, but are not limited to the following: To promote sustainable fisheries management to ensure economic and social benefits; To work with a community-centered approach that will guide decision-making and inform cooperative policies; To rely on sound, objective and professional analysis and meaningful engagement with members tin order to inform positions taken and decisions made by the cooperative; To perpetuate the Palauan conservation ethic by mentoring the Palauan youth and showcasing the wisdom of Palauan elders; To empower members to shape the community through participatory

engagement and create opportunities for greater community involvement; To create high quality environments and sustainable and prosperous lives; To base all of the foregoing purposes and any other activities on an open, transparent dialogue and process and; To engage in any and all other activities reasonably related to the purposes stated in this articles of incorporation;"

With the support from TNC, a selected group of fishermen began engaging with their communities, state governments, MNRET, PAN Office, and PCS to establish the Northern Reef Fisheries Cooperative (NRFC). The NRFC strategic plan and its respective SOPs where developed to help organize the cooperative. NRFC was key in helping to reach out to fishers and community members in getting them involved in fisheries data collection, providing input into the planning and development of fisheries regulations, and providing awareness that contributed to fishers compliance with fisheries regulations. To date, the cooperative has one full time staff, 9 board members, and over 80 members with established office and market space in Ollei, Ngarchelong. NRFC has been representing fishers' interests by ensuring that all concerns and needs are being addressed in the fisheries legislation, and by implementing regulations through the coordination of fishers, management agencies, and partners.

Lessons Learned:

Fishers buy-in and support

One of the biggest challenges we had was getting the fishers buy-in on the resource-conservation and management mechanisms formulated in the regulation. Careful discussions with fishers overtime, where issues were discussed and conditions were negotiated, helped win fishers support; which led to the adoption of the regulations. In addition, while there was an initial attempt to engage and get fishers involved in the cooperative, it became clear that few of them were willing to dedicate their time into supporting the management of the organization. There is a need to focus on those with a high level of commitment, to ensure that the organization can be sustainable, while continuing to engage and bring new members on board.

Financial sustainability of the organization

One of the biggest issues we continue to have is the sustainability of NRFC. After five years since its establishment, it continues to struggle financially. To address sustainability, the organization is developing a for profit component to help sustain the cooperative financially. A business plan is being developed with the support of the Palau Small Business Development Center (SBDC). There is a need to develop partnerships with various partners to help support the organizational capacity needed to operate as a small NGO. Rather than building an organizational supporting structure within NRFC, consider sharing both, costs and operational support, with similar organizations that operate within a given geographic area.

Organizational and business management

Due to the remoteness of the location of the NRFC office, and the financial resources available, it was difficult to find an individual with the right skillset needed to run a newly established NGO, as well as managing a board of directors, with limited experience in guiding an organizational development. Developing a partnership with a more mature organization with adequate leadership could help provide the needed mentoring/coaching to both, the management and the board of directors. NRFC is currently exploring this option with other community-based organizations operating within the northern reefs.

Engagement approach

NRFC management and members need to agree on an engagement approach that is membership-inclusive. There needs to be a clear process for reaching out to members, as well as clear guidelines for ways in which members could support the NRFC management. Currently, there is an expectation that members can benefit from NRFC's operating programs, without them giving clear and consistent support back to the NRFC.

05 Science and Research

Length based SPR assessment of eleven Indo-Pacific coral reef fish populations in Palau.

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Abstract

The theoretical basis of a new approach to data poor fisheries assessment, length-based assessment of spawning potential ratio, has been recently published. This paper describes its first application over two years to assess 12 of the 15 most numerous species of Indo-Pacific coral reef fish in Palau. This study demonstrates the techniques applicability to small-scale data-poor fisheries and illustrates the type of data required, and the assessment's outputs. A methodology is developed for extending the principles of Beverton–Holt Life History Invariants to use the literature on related species within the Indo-Pacific reef fish assemblage to 'borrow' the information needed to parameterize assessments for Palau's poorly studied stocks. While the assessments will continue to be improved through the collection of more size and maturity data, and through further synthesis of the literature, a consistent and coherent picture emerges of a heavily fished assemblage with most assessed species having SPR < 20% and many <10%. Beyond the technical aspects of this study, the relative simplicity of the data being collected and the underlying concept of spawning potential facilitated the involvement of fishers in collecting their own data and community ownership of the results.

1. Introduction

A persistent challenge for sustainable fisheries is the scale, com- plexity and cost of fishery assessment and management (*Walters and Pearse, 1996; Mullon et al., 2005*). Conventional assessment methods on which fisheries management is predicated require large amounts of data, including good biological information for the exploited stock and historical time series of catch and effort data, so that the annual costs per assessed stock can be in the order of $US50,000 to millions of dollars (*Pauly, 2013*). Only a small fraction of exploited fish stocks can be assessed using conventional stock assessment methods (*Costello et al., 2012*). By some estimates, 90% of the world's fisheries, which directly support 14–40 million fishers and indirectly support approximately 200 million people, are un-assessable with current methods (*Andrew et al., 2007*). In this context the development and demonstration of new methodolo- gies for assessing stocks with limited biological information and fisheries data is of high priority.

Palau is a small independent island nation in Micronesia about 800 km east of the Philippines (Fig. 1). Palau has a population of approximately 12,000 resident nationals and approximately 8000 resident guest workers mainly from the Philippines. With the main island group extending approximately 200 km from north to south, and having a relatively small linearly shaped area of lagoon and fringing reef the scale of Palau's fisheries resource is small. Preston (1990) estimated total seafood production during the

1980s at 1700 t per annum, and observed that the 10 most important reef fish, *Naso unicornis, Bolbometopon muricatum, Hipposcarus longiceps, Scarus rubroviolaceus, Siganus canaliculatus, Siganus lineatus, Lutjanus gibbus, Lethrinus obsoletus, Lethrinus xanthochilus* and *Epinephelus spp.*, comprised 52% of the Palau Federation of Fishing Association's landings (*Perron et al., 1983*). Despite their small-scale, fishing plays a central role in the Palauan culture, economy and character. Traditionally Palauans depended on the sea for the majority of their protein, and subsistence fishing remains a major activity, but with the growth of paid employment and tourism, a local cash market for fresh fish developed and fishing became an important source of economic activity. A Forum Fisheries Agency study estimated that in 1992 fishing contributed 26% of Palau's GDP (*Forum Fisheries Agency, 1995*). Since that time Palau has developed as prime destination for diving tourism, and over 100,000 tourists now visit annually, expecting to both see and eat fish, increasing the pressure placed upon Palau's fisheries resources.

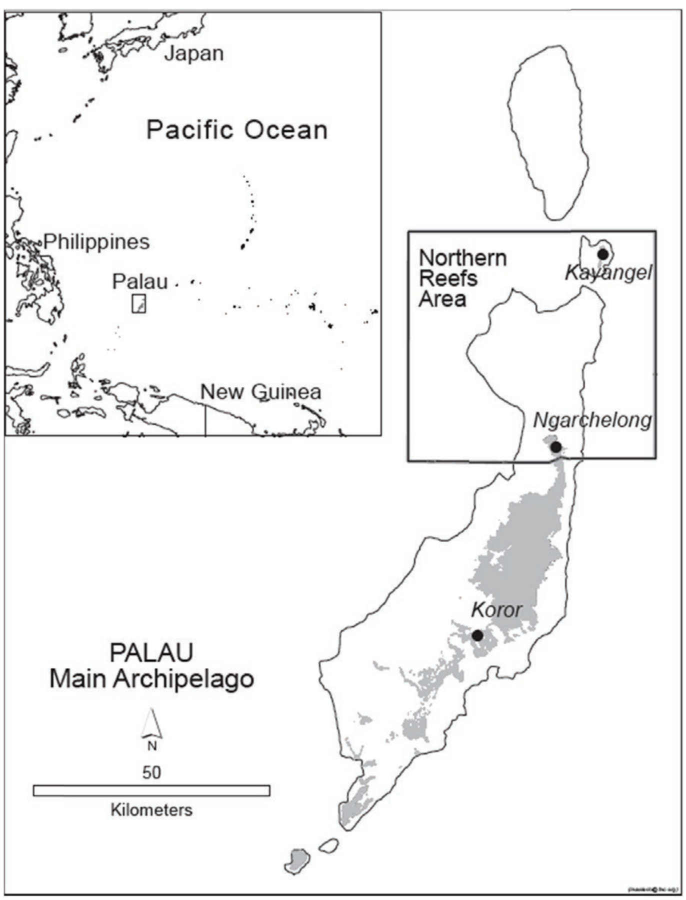

Fig. 1.
Map of Palau showing its size and position in the western Pacific Ocean, andthe location of the Northern Reef Area, the location of this study.

Currently there are only a limited number of fishermen who fish exclusively for a living, although it is difficult to ascertain exactly how many. There are a limited numbers of reef fish buyers, mainly hotels and restaurants who buy directly from some fishers, and only one public fish market for reef fish, The Happy Fish Market situated in the main town of Koror, into which some fishers land their catch for direct sale to the public and restaurants. In 2014, *Gleason et al. (2014)* estimated that it takes about 6 fishermen operating out of 6–8 m outboard powered boat to catch 100–150 kg of fish per night for the market, and that each fishermen received about $125 for their share of catch. The boats of the fishermen fishing for a living typically go out 3–4 times per week, particularly on a good (dark) moon and on average fishermen fish about 150 nights per year. On a daily basis, approximately 400–500 kg of fish moves through The Happy Fish Market, with a slight increase on weekends due to the increased participation of part-time fishermen.

The Palauans have been expressing concern about a perceived dwindling in the abundance of many species of food fish since at least the mid-1970s (*Johannes, 1991*). A recent consultation found that there is a general perception that catch rates today are generally less than half what they were just 7 years ago, that reef fish in general are much smaller, and that local reefs are now being exhausted by the current level of local and tourism-driven demand for fresh fish (*Gleason et al., 2014*). In this context, few estimates of catch or effort are available, and apart from *Kitalong and Dalzell's (1994)* length based assessment of 10 species using Elefan, no quantitative assessments have been made. Only a few legislated management controls are in place; a 300 mm minimum size limit and spawning season closure for plectropomids, a 50 mm minimum mesh size on nets, and a fishing ban on B. muricatum and Cheilinus undulatus.

This study was motivated by the two northernmost states of Palau, Ngarchelong and Kayangel who together fish an area known as the Northern Reefs. The state of Ngarchelong at the northern end of the main Palauan island of Babeldaob, has approximately 101 households and about 320 residents of which about 38 fish regularly. Kayangel is a low lying coral atoll island to the north of Babeldaob with about 28 permanent households with 70 residents, of which 15 people fish regularly. The main fishing techniques used are spearfishing, in daylight hours and at night with flashlights, and hand-line fishing using a wide range of hook sizes, which by all accounts are becoming smaller as average fish size declines. With declining fish abundance closer to the main town of Koror it is believed that about 30–50% of the reef fish being landed into the Happy Fish Market is now being taken from the Northern Reefs by fisherman resident in the main town of Koror (*Gleason et al., 2014*). These two communities have been expressing their concerns to The Nature Conservancy (TNC) for the last seven years, about the trends they have been observing in their fish stocks despite Palau having kept 40% of their reef area closed to fishing for the last 20 years.

A new approach to the length-based assessment of spawning potential ratio (LB-SPR) has recently been described, and its sensitivity to bias and variability in the input data tested with simulation studies (*Hordyk et al., 2014a,b*). The new technique uses the life history ratios (LHR) M/k and L_m/L_∞ and the shape of a population's size structure, along with estimates of size of maturity, to estimate the ratio of fishing and natural mortality (F/M) and spawning potential ratio (SPR). The spawning potential ratio (SPR) of a stock is defined as the proportion of the unfished reproductive potential under any given level of fishing pressure (*Mace and Sissenwine, 1993; Walters and Martell, 2004*). Its utility for data-limited assessment has been recommended because of its relative simplicity (*Brooks et al., 2010; Walters and Martell, 2004*). Generic SPR-based reference points have been developed theoretically and through the meta-analysis of quantitatively assessed fisheries and have been recognized in international fisheries law; SPR40% is generally considered a conservative proxy for MSY, and SPR 20% is proxy for when recruitment rates are likely to be impaired for finfish (*Mace and Sissenwine, 1993; Restrepo and Powers, 1999; Walters and Martell, 2004*). Extending the theory of Beverton–Holt Life History Invariants (*Beverton and Holt, 1959; Charnov, 1993*) it is proposed that LB-SPR can be applied to relatively unstudied stocks, by 'borrowing' information about poorly studied species from the literature for taxonomically related species (*Prince et al., 2014*). This paper describes the first application of LB-SPR technique to data collected for the purpose by fishermen in Palau. In August 2012 local fishermen were trained to begin collecting data on their catches and by August 2014 they had measured 6852 fish from 106 species. This paper describes the initial assessments of 12 of the 15 most numerous species in their catches, illustrating the potential utility of this new approach to other data-limited and small-scale fisheries.

2. Methods

2.1 Overview of LB-SPR assessment

The LB-SPR assessment technique utilizes the fact that size structure and spawning potential ratio (SPR) in an exploited population are a function of the ratio of fishing mortality to natural mortality (F/M), and the two life history ratios M/k and L_m/L_∞; where M is the rate of natural mortality, k is the von Bertalanffy growth co-efficient, L_m is the size of maturity (SoM) and L_∞ is asymptotic size (Hordyk et al., 2014a). The inputs to the LB-SPR model are: (i) the M/k ratio, (ii) the mean asymptotic length (L_∞), (iii) the variability of length-at-age ($CV_{L\infty}$), which is difficult to estimate directly without reliable length and age data, and normally assumed to be around 10%; and (iv) a description of the size of maturity (SoM) schedule specified in terms of $L_{50\%}$ and $L_{95\%}$, the size at which 50% and 95% of a population matures. In practice the L_∞ of a stock is unlikely to be known in a data poor fishery, so the life history ratio L_m/L_∞ is combined with the estimate of $L_{50\%}$, which is more easily estimated, to estimate L_∞. Given the assumed values for the M/k and L_∞ parameters and length composition data from an exploited stock, the LB-SPR model uses maximum likelihood methods to simultaneously estimate the selectivity ogive, which is assumed to be a logistic curve defined by the selectivity-at-length parameters S_{L50} and S_{L95} , and the relative fishing mortality (F/M), which are then used to calculate the SPR (*Hordyk et al., 2014a,b*).

Estimates of SPR are primarily determined by the size of the fish in a sample, relative to SoM and L_∞. At its simplest, if a reasonable proportion of fish in a sample attain sizes approaching L_∞ a high estimate of SPR will be derived, where as if there are few fish much larger than the SoM, a very low estimate of SPR is derived. Our sensitivity testing (Hordyk et al., 2014b) with the LB-SPR technique shows that at high levels of relative fishing pressure the technique has relatively little discriminatory power in estimating *F/M* and selectivity, but still robustly estimates SPR. This is because the relationship between *F/M* and SPR is asymptotic, and determined by the selectivity parameters, so that at high fishing pressure, many combinations of *F/M* and selectivity produce similar values of SPR. Whereas the estimate of SPR is strongly informed by the size of the biggest fish in the sample.

Like many length-based methods, the LB-SPR model is an equilibrium based method, and relies to differing degrees on a number of assumptions, which have to be made relatively arbitrarily in a data-poor fishery. These underlying assumptions include: (i) asymptotic selectivity, (ii) growth is adequately described by the von Bertalanffy equation, (iii) a single growth curve can be used to describe both sexes which have equal catchability, or that female parameters and length composition data can be used, (iv) length- at-age is normally distributed, (v) rates of natural mortality are constant across adult age classes, and (vi) growth rates remain constant across the cohorts within a stock. Simulation testing of the LB-SPR model has shown that the method is most sensitive to the under-estimation of L_∞, and large rapid changes in recruitment rates (*Hordyk et al., 2014b*). The LB-SPR assessment technique has not been developed to replace more precise, data-intensive assessment techniques. Rather it should be considered as a technique for applying a 'weight of evidence' approach to developing initial estimates of stock status, and a means of implementing longer-term data collection processes that can lead toward the application of more precise assessment methods.

2.2. Synthesis of life history ratios & parameter estimation

It is assumed that in the case of data-poor fisheries the biological knowledge needed to apply the LB-SPR technique will not be available from studies of the population being assessed, but that the two life history ratios (LHR) required might be estimated through synthesis of the scientific literature for species, and closely related species. The theory behind Beverton–Holt Life History Invariants (BH-LHI) is that the LHR are the formulaic expression of each species' life history strategy, and determine when, and in what proportion, energy budgets are switched from somatic growth into reproductive output (*Charnov, 1993*). Consequently, while the individual life history parameters of a species are thought to be dynamic and changeable, with regard to environmental variability across a species' range, and changing population densities over generations. The LHR are expected to be more stable across species' ranges and equilibrium states, as well as across taxonomically related groups, and species with shared life history strategies than the

individual parameters contributing to the LHR (*Beverton and Holt, 1959; Prince et al., 2014*). Following from this foundation, the overarching criteria which we apply most rigorously, is that the LHR cannot be robustly estimated by combining estimates of the individual parameters derived from different regions, or time periods that could encompass shifts in productivity regimes and population densities. The LHR should only be estimated from related studies that have been conducted in close temporal and spatial proximity to each other, so that they can be reasonably expected to reflect the parameters of a single stock around a specific equilibrium state.

Many of the families and species of interest here are long lived and grow slowly as adults causing the size distributions of differing age cohorts to overlap substantially with the consequence that length based techniques may not accurately estimate growth and mortality. Studies of growth and mortality based on ageing have been preferred over purely length-based studies, although when little other information is available length based studies maybe referred to as well. If conducted at a place and time when exploitation pressure was likely to have been relatively low, length-based estimates of L_∞ have been considered potentially informative. Many published age and growth studies are also surprisingly problematic in the way they estimate growth parameters (*see Cailliet et al., 2006; Pardo et al., 2013*). Synthesizing the literature to relibly estimate the LHR parameters requires a degree of professional judgment, and in some cases the digitizing of published data so that growth curves can be re-estimated. This is discussed and described in more detail in the appendix. In applying our judgments the aim is to use whatever information is available to derive the best possible estimates of the LHR, rather than to rigidly apply rules that end up excluding what little information may exist.

2.3. Assumptions relating to stock structure

Through this study it is assumed that the Northern Reef study area contains units of stock (*sensu Gulland, 1969*) for all the species assessed. This is a convenient assumption to make because it is the area from which we could collect sufficient data to analyze within the time period of our study. While the data we collected can be attributed to the individual reefs named by Palauans sub-dividing the data reduces sample sizes. Our sensitivity testing (*Hordyk et al., 2014b*) along with the results presented here, suggest the sample sizes used are barely sufficient for our purpose. The extent to which our pragmatic assumption about stock structure reflects biological reality is open to conjecture as discussion about the scale of tropical reef fish stocks continues (*Swearer et al., 2002*). Originally thought to have scales of 100–1000 km, *Cowen et al. (2000, 2006)* who modeled meso-scale oceanography and assumed larvae are passive particles concluded the scale of self-recruiting populations should be considered to be 10–100 km. While experimental studies in the field are now concluding self-recruiting populations of Indo-Pacific reef fish species can occur at scales of 1–10 km (*Jones et al., 1999, 2005; Almanny et al., 2007; Planes et al., 2009*).

2.4. Assumptions relating to sexual ontogeny

Tropical teleost species exhibit a diverse range of sexual ontogenies; serranids, lethrinids and scarines are typically protogynous hermaphrodites, changing sex from female to male (*Sadovy, 1996; Sadovy de Mitcheson and Liu, 2008; Taylor and Choat, 2014*). While the growth of lutjanids, which tend to be gonochoristic and remain the same sex throughout life, is often described with separate gender specific growth curves. With regard to gender specific growth curves of gonochoristic species, it was not feasible in this study to sex every fish measured and so simplifying assumptions have occasionally been necessary in our synthesis of the literature. Where authors have estimated gender combined growth curves and SoM we have used these estimates. Where only gender specific estimates have been published; males and females tend to comprise an upper and lower part of a shared growth curve or SoM rather than distinctly different curves and SoMs (*e.g. Nanami et al., 2010*). In these cases we have used the data presented to derive our own estimates of gender combined growth curves and SoMs. With regard to the growth of the protogynous hermaphrodites we assume, as have most other workers, that male growth represents a continuation of the female growth curve. With regard to the estimation of SPR for protogynous hermaphrodites we assume that the reproductive potential of males is a continuation of the population's reproductive output, albeit in a different form, and that reproductive output remains proportional to adult body weight. In this case we define SoM as the size at which 50% of females reach maturity, and we regard females transitioning into males as part of the adult population. We are still in a relatively early phase of our development of this approach and these working assumptions remain to be tested more fully with simulation modeling. It seems likely that in the case of the protogynous hermaphrodites SPR reference points will need to be adjusted upwards to ensure sufficient survival of larger males, but the analyses needed for that purpose have yet to be conducted.

2.5. Bounding estimates of F/M and selectivity

As discussed above, the relationship between *F/M* and SPR is asymptotic, and determined by the selectivity parameters, so that at high fishing pressure, many combinations of *F/M* and selectivity produce similar values of SPR. Thus our estimates of selectivity and *F/M* are not considered as definitive as our estimates of SPR. In some cases implausibly high sizes of selectivity (e.g., S_{L50} = L_∞) and high *F/M* fit the data just as well as more realistic values. The implausibly high estimates of the sizes of selectivity may reflect the fact that the size compositions are so heavily truncated that fully mature size classes are rare, and so also uninformative for estimating the size of full selectivity. We addressed this issue by bounding the selectivity parameters. We initially ran the LB-SPR model on all 12 datasets with no constraints on the selectivity parameters. We then ran the model a second time, with the estimate for S_{L50} bound between the minimum observed length and the modal length class (*i.e., the length class with the highest number of observations*). Overall, implementing this constraint resulted in very little difference in the estimated SPR and the resulting selectivity curves appear more 'reasonable'. Similarly at high fishing mortality, estimates of SPR are relativity unaffected by differences in F/M (*Hordyk et al., 2014a,b*) and we capped all estimates of F/M to an upper limit of 5. These constrained estimates are reported in this study.

2.6. Quantifying uncertainty

Length data that is representative of the exploited stock is crucial for the LB-SPR model. The LB-SPR model assumes that sampled length data adequately describes the size structure of the exploited stock. Poor quality or 'noisy' length data can add considerable uncertainty to the estimates of SPR. To describe the uncertainty in our estimates of SPR that is due to variability in the length data, we used a bootstrapping routine, where one thousand iterations were run for each species. The biological parameters were fixed at the "best estimates" (Table 1) and the length data were resampled with replacement. For example, Fig. 2a shows the length composition for *L. gibbus*, which has the largest sample size (*n* = 1, *n* = 1225) and most coherently shaped size composition. The variability in the estimates of SPR resulting from the uncertainty in the length data and estimated by boot-strapping is shown in Fig. 2b. For comparison, Fig. 3a shows the length composition data for *L. xanthochilus* which has the smallest sample size in our study (*nn* = 144) and relatively noisy length frequency data. The corresponding more variable estimates of SPR from the bootstrapping routine reflect the lower quality length data (Fig. 3b). While showing a single fit to the length composition data using what we consider to be the best parameters for each of the 12 species (Fig. 4a–l), for brevity we display the bootstrapped SPR estimates for the 12 species as boxplots in Fig. 5a. The complete set of the histograms of bootstrapped SPR estimates for all 12 species are presented in the appendix (Figs. A2b–A13b).

A second way in which variability in LB-SPR estimates can arise is from uncertainty in the input parameters (Hordyk et al., 2014b). It is difficult to obtain empirical estimates of $CV_{L\infty}$, and because the LB-SPR model is least sensitive to error in this parameter (*Hordyk et al., 2014b*) $CV_{L\infty}$ was fixed at 0.1, and assumed to be without error. Our sensitivity analyses shows that our estimation routine is most sensitive to the mis-estimation of L_∞, as individuals in a sample around this size are indicative of high SPR. The technique is moderately sensitive to misspecification of M/k, but in a direct sense relatively insensitive to uncertainty in the estimate of L_m. Superficially the SoM parameters are assumed to be estimated without error, but in reality the error associated with our estimation SoM, is compounded into the uncertainty we associate with L_∞ through our use of the L_m/L_∞ ratio to estimate L_∞.

To account for the uncertainty in the biological parameters, we used a sampling-importance-resampling (SIR) algorithm, where we specified prior distributions for the M/k, and L_∞ parameters and updated the posterior distribution based on the conditional likelihood of each set of parameters. The upper and lower bounds for the M/k, and L_∞ parameters were chosen by examining the range of parameter estimates from studies of the same and closely related species in other parts of the world, and our own estimates of SoM. For each dataset, values for the L_∞ and M/k parameters were drawn from a uniform distribution, with the lower and upper bounds given in Table 1, and the corresponding likelihood (importance ratio) was calculated for each parameter set with the LB-SPR model. One thousand parameter vectors were then resampled with probability proportional to the importance ratio.

Our starting assumption was that the upper and lower bounds we select for the M/k, and L_∞ parameters should be broad enough to capture the plausible range but that the selection process is not critical, as the bounds only define the range over which the SIR algorithm calculates the likelihood profiles. We revisit this assumption in our discussion. Generally with the small data sets we are using, there is little information in the length data to inform the values of the life history parameters, and in most cases the posterior distribution for the L_∞ and M/k parameters are not appreciably updated from the uniform priors we assume (*e.g. Figs. 2c and d and 3c and d*). Some combinations of the L_∞ and M/k parameters fit the data very poorly, and the SIR algorithm allows us to examine the uncertainty in the estimates of F/M (e.g. Figs. 2g and 3g) and SPR (e.g. Figs. 2h and 3h) and, to a lesser extent, the selectivity parameters (e.g. Figs.2e and f and 3e and f) that arises from our uncertainty about these input parameters. Note our capping of F/M can be seen in Figs. 2g and 3g where a large proportion of the estimates of F/M from the SIR algorithm are stacked up at F/M = 5. For brevity, we only present boxplots of the estimates of SPR from the SIR algorithm for the 12 species in this analysis (Fig. 5b). The complete set of histograms of the posterior distributions for the M/k, and L_∞ parameters, and the selectivity parameters, F/M, and SPR for all 12 species are presented in the appendix (Figs. A2–13).

2.7. Data collection

2.7.1. Scoping trip & training program

An initial scoping study was conducted in November 2011, which concluded that the LB-SPR technique could be applicable to Palau, and that the Northern Reef communities were suitable community partners. In August 2012 a two day workshop was used to give 12 Palauan collaborators a basic training in the technique including the collection size of maturity and size frequency data, a data sheet with standardized Palauan/scientific nomenclature was developed, and fish measuring boards were made. Not all the collaborators were expected to continue collecting data, some were selected in the expectation that they would support the project in other ways; such as policy development, community leadership and technical support. Approximately half the trainees went on to collect data and train fellow fishermen to measure fish.

2.7.2. Length measurements

For simplicity the data measurers were taught:

- To measure length along the middle of the side of all species of fish i.e. fork length, or standard length depending on morphology.
- To measure the length of all the fish in the catch of a boat on any day to ensure that lengths were sampled non-selectively.

2.7.3. Size of maturity studies

The diverse range of sexual ontogenies observed in tropical species makes the classification of sexual development and gender challenging, even for professionally trained

Table 1

The assumed parameter estimates, with bounds, and the sample sizes, used to assess 12 Indo-pacific reef species of reef fish in Palau, M/k—the ratio of natural mortality (M) and von Betalanffy growth coefficient (k), L_∞—asymptotic size, $L_{50\%}$—size of 50% maturity, $L_{95\%}$—size of 95% maturity, Lm/L_∞—the ratio of size of maturity and asymptotic size, *n* – Length Comp. – length frequency composition sample size, *n* – SOM – sample size for size of maturity estimate.

Species	M/k best	M/k upper	M/k upper	L_∞ best	L_∞ upper	L_∞ lower	L_{50}	L_{95}	Lm/L_∞ best	n-Length comp.	n-SOM
Lutjanus gibbus	0.41	0.60	0.30	343	400	340	257	320	0.75	1227	449
Lutjanus bohar	0.41	0.60	0.30	487	570	470	365	460	0.75	145	38
Lethrinus rubrioperculatus	0.62	0.89	0.35	306	370	300	214	270	0.70	533	300
Lethrinus olivaceus	0.62	0.89	0.35	584	670	550	409	500	0.70	366	155
Lethrinus xanthochilus	0.62	0.89	0.44	463	640	390	324	380	0.70	144	103
Lethrinus obsoletus	0.62	0.89	0.44	343	365	330	240	300	0.70	211	83
Plectropomus areolatus	0.91	1.30	0.46	649	815	540	383	460	0.59	322	136
Plectropomus leopardus	0.91	1.00	0.46	627	811	537	370	440	0.59	185	53
Variola louti	0.86	1.50	0.58	483	527	419	285	350	0.59	578	113
Hipposcarus rubroviolaceus	0.36	0.79	0.25	433	459	410	312	400	0.72	159	116
Chlorurus microrhinos	0.70	1.26	0.53	470	500	395	315	380	0.67	150	111
Hipposcarus longiceps	1.07	1.26	0.81	423	440	360	300	330	0.71	403	181

fisheries biologists, let alone the artisanal fishers used to collect the data for this study. Basic protocols were developed and taught to the fishers for classifying the gonad of a fish as either immature, or otherwise maturing and mature. The primary distinguishing features for mature, maturing or transitional gonads being:

- Whether the length of the gonads is longer than one third the length of the body cavity,
- The gonads have a distinct, three dimensional shape; lobed, and triangular in cross section, for testis, or sausage, tube, or sack-like for ovaries,
- In the case of mature ovaries an obvious network of blood vessels.

Many Palauans sell a portion of their daily catch, normally the larger more valuable fish in the catch, and are reluctant to cut open and inspect the gonads of the fish they intend to sell. Consequently the collection of gonad data was left up to the discretion of the measurers who were taught that fish could be selected from a catch they were measuring for maturity classification. This impeded the collection of SoM data but was considered necessary to ensure sufficient size data that was representative of the catch would be collected. A second factor that impeded the collection of SoM data was that the size structure of the assemblage being studied is heavily truncated so that it is difficult to find individuals from the size classes expected to be 100% mature. In an attempt to overcome these challenges, the

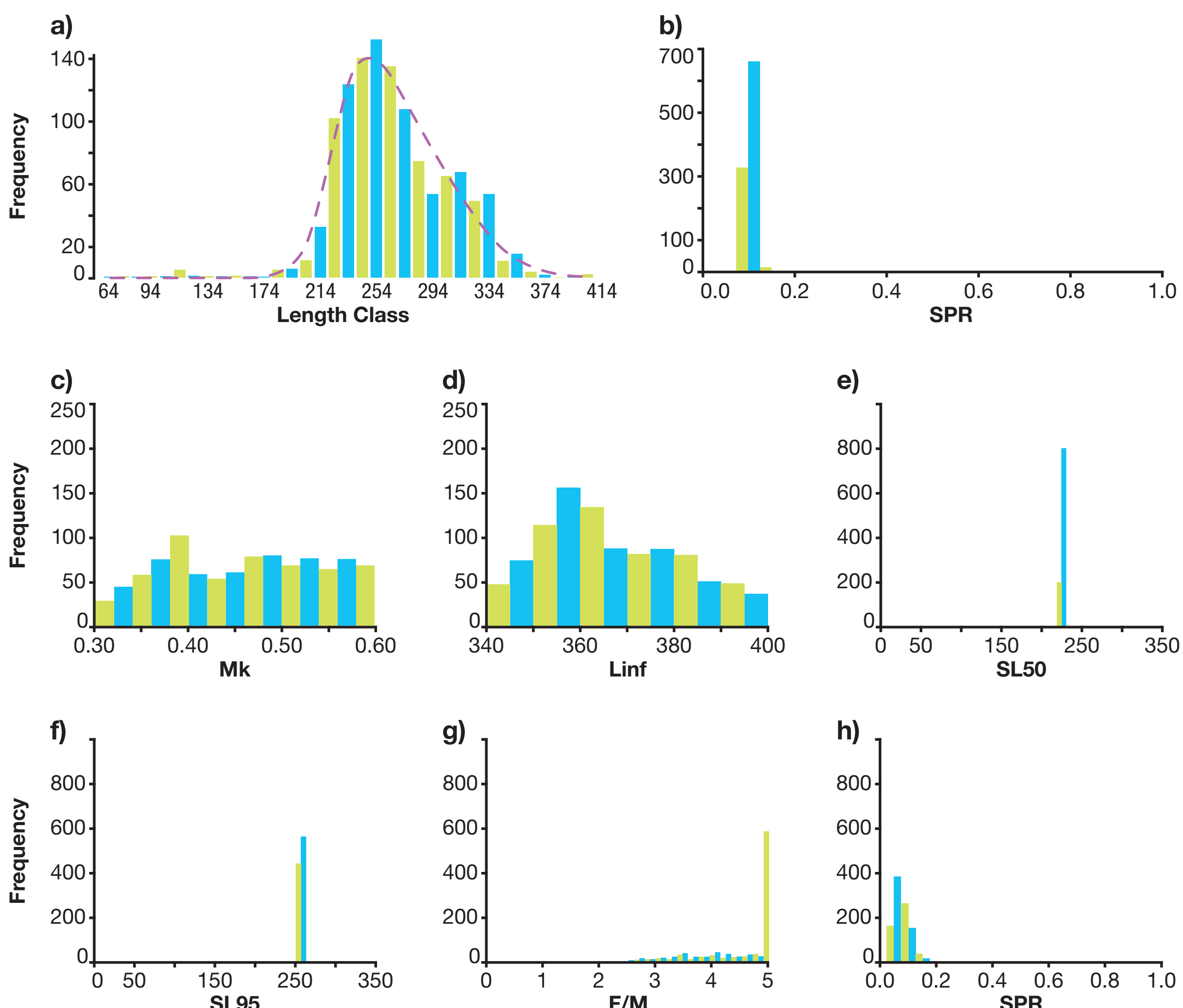

Fig. 2.
An examples of output from the length-based SPR assessment software for *Lutjanus gibbus*; (a) length-frequency histogram with fitted size composition curve (dashed line), (b) frequency distribution of SPR estimates from one thousand bootstrapped iterations of the length-frequency data, and SIR estimated posterior distributions across the assumed plausible range of (c) for *M/k*, (d) L_∞, (e) S_{L50} , (f) S_{L95} , (g) *F/M* estimated similarly, and (h) SPR.

proprietor of the fish market in Koror agreed to our training one of his staff to collect gonad information from fish processed for customers. These fish were generally the largest premium fish and not representative of the normal size structure of the catch, so this data was used only in the SoM studies. Many of the fish measured at the market will not have come from the Northern Reef Area, which is the focus of this study, the implicit assumption here is that the SoM of the fish measured in the market are still to some extent representative of the SoM of the fish in the Northern Reef Area. Considering the other assumptions being made to make these data-poor assessments possible this is not thought to be a critical assumption.

2.7.4. Estimating size of maturity

The size at which 50% ($L_{50\%}$) and 95% ($L_{95\%}$) maturity occurs was estimated by fitting a standard logistic curve, which was constrained to pass through selected data points by manually minimizing a sum of squares routine written in Excel. Because of the relatively low sample sizes, the complexity of categorizing the developmental stages of tropical fish, the truncated nature of size structures, and the relatively low level of training provided to the collaborating fishers, the SoM data for most species is sparse and very noisy. These are not the type of data that would normally be published as a part of a biological study. The aim being to use informed interpretation to make the most of the limited data available, in this context we have evaluated these data using a weight of evidence approach which is described in the appendix to this study.

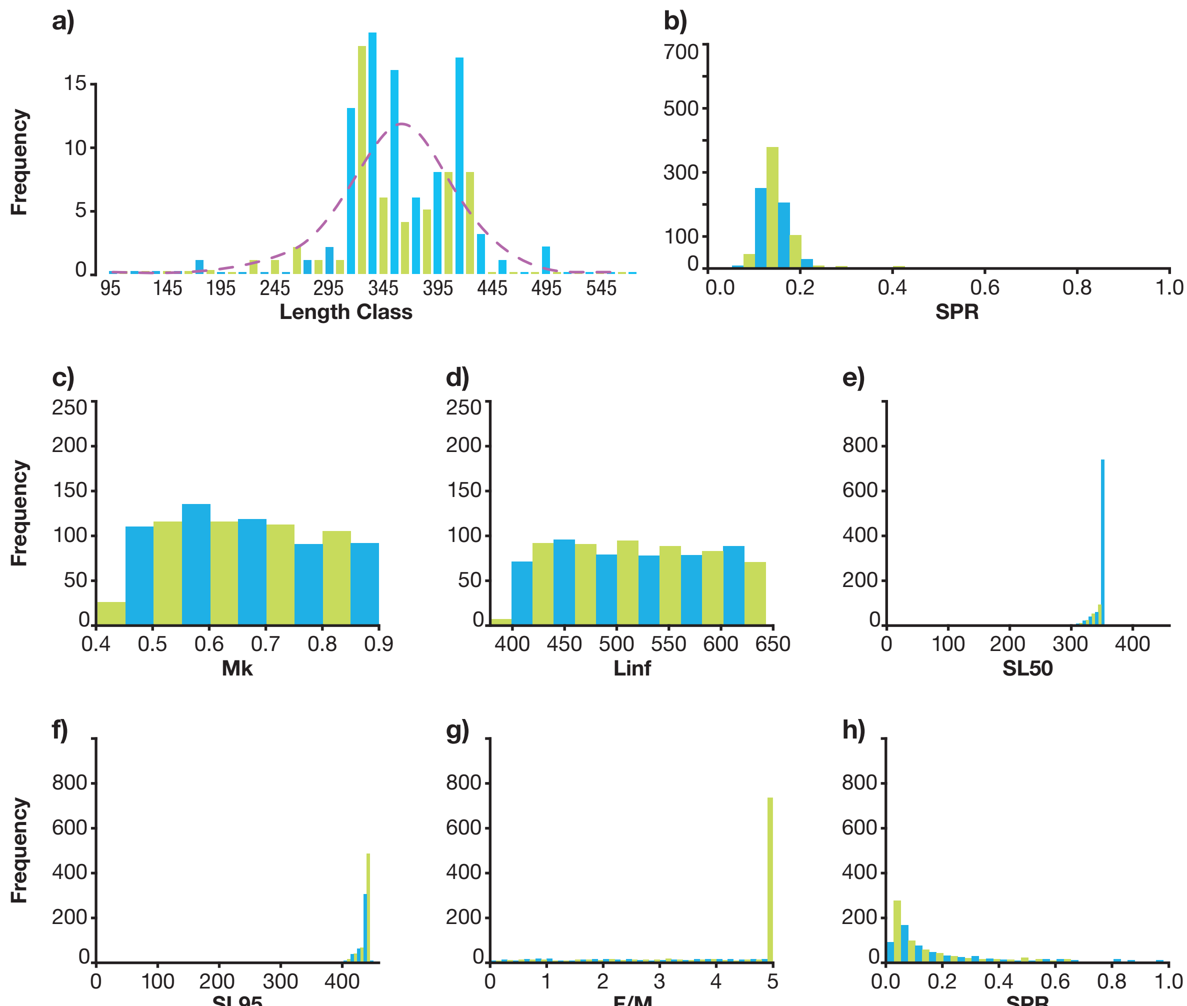

Fig. 3.
An examples of output from the length-based SPR assessment software for Lethrinus xanthochilus; (a) length-frequency histogram with fitted size composition curve (dashed line), (b) frequency distribution of SPR estimates from one thousand bootstrapped iterations of the length-frequency data, and SIR estimated posterior distributions across the assumed plausible range of (c) for M/k, (d) L_∞, (e) S_{L50} , (f) S_{L95} , (g) F/M estimated similarly, and (h) SPR.

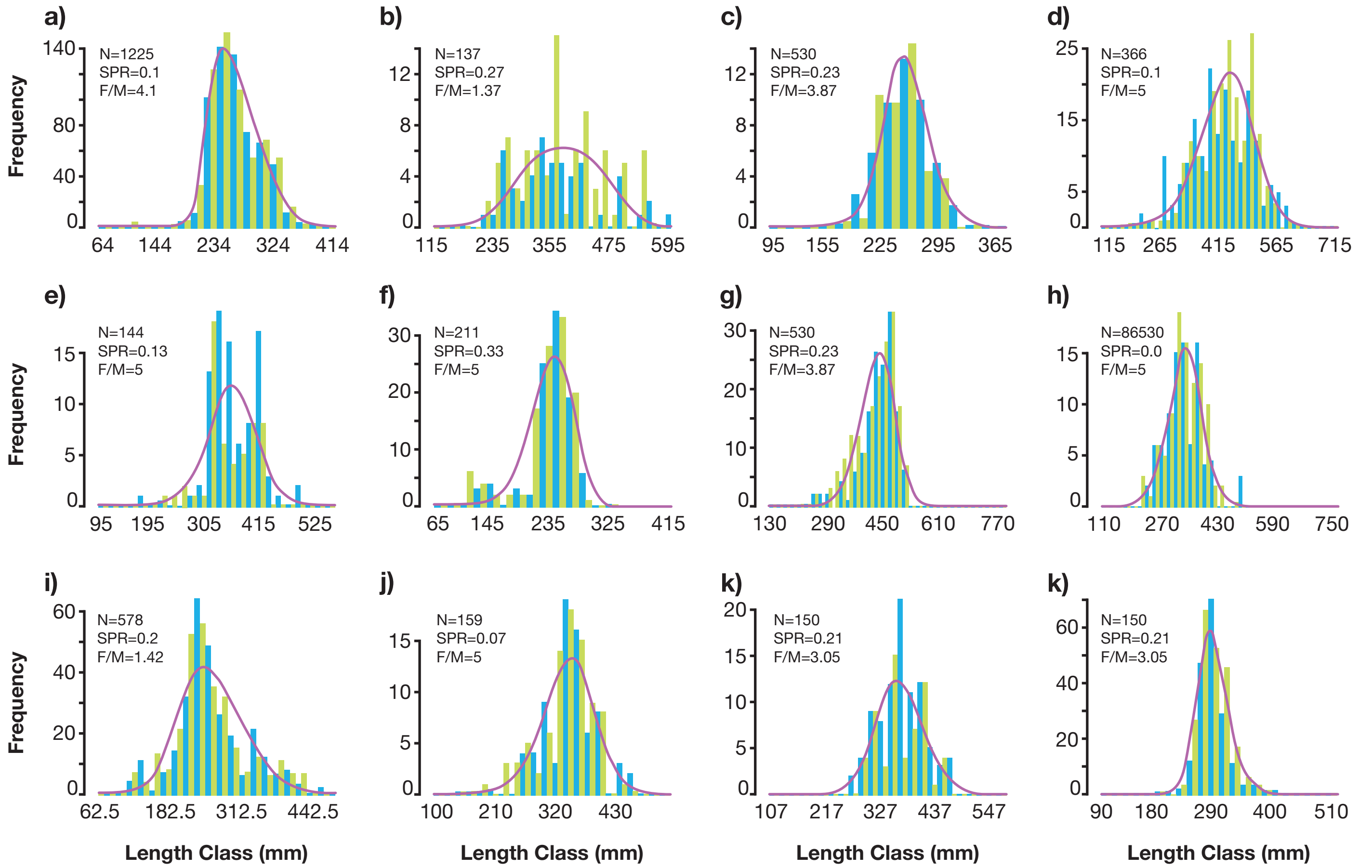

Fig. 4.

Length composition histograms for 12 Indo-pacific species of reef fish in Palau with curves fitted by the Length Based SPR assessment software; (A)—*Lutjanus gibbus*, (B)—*Lutjanus bohar*, (C)—*Lethrinus rubrioperculatus*, (D)—*Lethrinus olivaceus*, (E)—*Lethrinus xanthochilus*, (F)—*Lethrinus obsoletus*, (G)—*Plectropomus areolatus*, (H)—*Plectropomus leopardus*, (I)—*Variola louti*, (J)—*Scarus rubroviolaceus*, (K)—*Chlorurus microrhinos*, (L)—*Hipposcarus longiceps*.

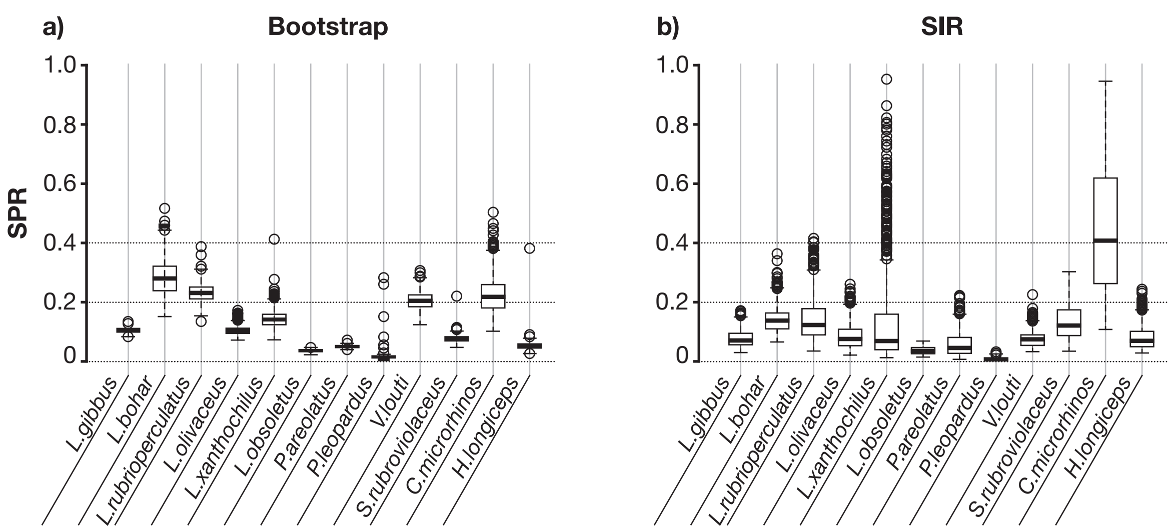

Fig. 5.

Two sets of box plots depicting the uncertainty expected around the SPR estimates from the 12 assessments; (a) distribution of SPR estimates from bootstrapping the length frequency data, and (b) distribution of SPR estimates based on SIR resampling of the plausible range of parameter estimates (Table 1). In these plots the 25th, 50th (median) and 75th percentiles are shown by the bottom, middle and top lines of the box, respectively. The broken line 'whiskers' extend to 1.5 times the interquartile range from the box, and all observations outside this range are presented as open circles. Horizontal dotted lines indicate SPR20% and SPR40%.

3. Results

Here we begin by describing the results of our synthesis of the LHR literature for *Lutjanids, Lethrinids, Plecropomids* and *Scarines*. From these syntheses we derive estimates of LHR for these broader groups which we then use in the subsequent sections which deal with the 12 species assessments which are the primary focus of this study.

3.1. Literature synthesis

3.1.1. *Lutjanids*

Eighteen publications were collected covering 16 lutjanid species, from which 21 estimates of L_m/L_∞ and 28 estimates of M/k were derived (*Davis and West, 1992, 1993; Grandcourt et al., 2006a; Heupel et al., 2010a; Kritzer, 2004; Loubens, 1980a,b; Luckhurst et al., 2000; Marriott et al., 2007; McPherson et al., 1992; Nanami et al., 2010; Newman et al., 1996; Newman et al., 2000a; Newman et al., 2000b; Pember et al., 2005; Shimose and Nanami, 2014; Shimose and Tachihara, 2005*). Ten of the growth curves used were corrected so that the estimate of t0 conformed to the approximate size of settling post-larvae (*Leis and Rennis, 1983*). Two studies produced LHR estimates that appeared anomalous and would have contributed disproportionately to the estimated variance of the estimates (*Loubens, 1980a,b; Davis and West, 1992*). Loubens produced estimates of growth, maturity and longevity for a wide range of the Indo-Pacific assemblage in Noumea, and for most of the species they studied, the LHR we derive conform closely to comparable studies and species, however the maximum age of two small bodied species of lutjanid (*Lutjanus vitta* & *Lutjanus kasmira*) are anomalously low (8 years) resulting in outlying estimates of M/k (1.00 & 1.58, respectively). These estimates were excluded from our analysis. Their results for a third small bodied species of lutjanid (*Lutjanus fulviflamma*) produced relatively low estimates of longevity (13 years), and relatively high estimates of M/k (0.70), but we included this value in our analysis. *Davis and West (1992, 1993)* studied *Lutjanus vittus* on the northwest shelf of Australia and decided against reading otoliths, because in older fish they required sectioning, instead they decided to read urohyal bones which required little preparation, despite the fact that 'checks in older fish were represented by a cluster of bands'. Their study produced anomalous estimates of female and male L_m/L_∞ (0.48, 0.38, respectively) and M/k (2.51, 3.8, respectively), which we also excluded from our analysis.

The mean LHR values (Table A2) derived by pooling the selected lutjanid studies (L_m/L_∞ = 0.75 s.d. = 0.17, n = 21, range 0.62–0.85; M/k = 0.41 s.d. = 0.14, n = 28, range 0.22–0.70) are the same as those derived using a single 'best' estimate (mean or single estimate) for each species (L_m/L_∞ = 0.75, s.d = 0.06, n = 14; M/k = 0.41, s.d. = 0.09, n = 15). The similarity of these estimates across the range of lutjanid studies collected is quite remarkable, and suggests these average values provide a good proxy for lutjanid species for which the LHR are either unstudied or poorly estimated.

3.1.2. *Lethrinids*

A total of 19 publications on age, growth and longevity of 14 lethrinid species have been collected (*Brown and Sumpton, 1998; Currey et al., 2009, 2010, 2013; Ebisawa, 2006; Ebisawa and Ozawa, 2009; Grandcourt, 2002; Grandcourt et al., 2006b, 2010, 2011; Loubens, 1978, 1980a,b; Marriott et al., 2010, 2011; Taylor, 2010; Taylor and McIlwain, 2010; Toor, 1964a,b; Trianni, 2011*) from which 29 estimates of L_m/L_∞ and 41 estimates of M/k were derived (Table A3). Nineteen of the growth curves used were corrected so that estimates of t_0 conformed to the approximate size of settling post-larvae (*Leis and Rennis, 1983*). As for the lutjanids the average values derived by pooling all lethrinid studies (L_m/L_∞ = 0.70, s.d. = 0.11, n = 29, range = 0.47–0.86; M/k = 0.62, s.d. = 0.23, n = 41, range = 0.24–1.25) are similar to the averages derived using a single 'best' value for each species (L_m/L_∞ = 0.72, s.d. = 0.22, n = 13, range = 0.63–0.86; M/k = 0.60, s.d. = 0.15, n = 14, range = 0.36–0.89) and suggests these average values provide a good proxy for lethrinid species for which the LHR are either unstudied or poorly estimated.

3.1.3. Plectropomids & variola

A total of 11 publications on 4 plectropomids were used (*Currey et al., 2010, Ebisawa, 2013; Ferreira and Russ,* *1992; Grandcourt, 2005; Heupel et al., 2010b; Loubens, 1978, 1980a,b; Russ et al., 1998; Rhodes et al., 2013; Williams et al., 2008*) to develop 8 estimates of L_m/L_∞ and 14 estimates of *M/k* (Table A4). Five published studies on 2 *Variola* species (*V. albimarginatus* and *V. louti*) were also collected and used to derive 2 estimates of L_m/L_∞ and 3 estimates of *M/k* for this genus (*Currey et al., 2010; Grandcourt, 2005; Loubens, 1978, 1980a,b*). Nine of the growth curves used were corrected so that the estimate of t_0 conformed to the approximate size of settling post-larvae (*Leis and Rennis, 1983*). The average values derived by pooling all plectropomid studies (L_m/L_∞ = 0.59, s.d. = 0.13, *n* = 8, range = 0.43–0.80; *M/k* = 0.91, s.d. = 0.21, *n* = 14, range = 0.59–1.3) was relatively similar to the average values derived using a single 'best' estimate for each plectropomid species (L_m/L_∞ = 0.58, s.d. = 0.06, *n* = 4, range = 0.51–0.64; *M/k* = 0.91, s.d. = 0.02, *n* = 4, range = 0.89–0.92), and not dissimilar to the mean LHRs derived by pooling all the *Variola* studies (L_m/L_∞ = 0.64, *n* = 2, range = 0.54–0.74; *M/k* = 0.86, *n* = 3, range = 0.58–1.13).

3.1.4. *Scarines*

Parrotfishes (Labridae: tribe Scarinae) are among the most diverse and abundant groups found on coral reefs and have highly plastic growth and complex sexual ontogenies, as a group, they encompass a variety of body sizes and can range considerably in maximum life span among species (*Taylor and Choat, 2014*). A total of 7 publications describing age, growth and maturity in 17 scarine species of the genera of *Cetoscarus, Chlorurus, Hipposcarus* and *Scarus* have been collected to date (*Choat and Robertson, 2002; El-Sayed Ali et al., 2011; Gust et al., 2002; Grandcourt, 2002; McIlwain and Taylor, 2009; Sabetian, 2010; Taylor and Choat, 2014*) and were used to develop 21 estimates of L_m/L_∞ and 53 estimates of *M/k* (Table A5). Only three of the growth curves used required re-estimating so that t0 approximated the size of settling post-larvae (*Leis and Rennis, 1983*). We did however, exclude from our analysis an estimate of *M/k* = 2.39 for *Scarus rivulatus* which was derived from *Choat and Robertson (2002)*. We excluded this estimate because it was so far outside the range of other estimates (0.25–1.27) and contributed disproportionately (>33%) to the estimate of variance if included.

The mean value for L_m/L_∞ derived by pooling all the studies of the remaining 16 species (L_m/L_∞ = 0.71, s.d. = 0.09, *n* = 21, range = 0.50–0.87) was similar to the average estimated using a single 'best' estimate for each species (L_m/L_∞ = 0.73, s.d. = 0.08, *n* = 13, range = 0.57–0.87), and similar to the estimate of 0.68 derived by Choat and Robertson (2002) for the genera *Chlorurus* & *Scarus* combined. Note that 6 of 21 estimates used here were derived from *Choat and Robertson (2002)*.

The estimates of *M/k* derived by pooling all scarine studies (*M/k* = 0.62, s.d. = 0.34, *n* = 53, range = 0.12–1.31) is a little different to the ratio estimated using a single estimate for each species (*M/k* = 0.73, s.d. = 0.27, *n* = 13, range = 0.25–1.07). This difference is largely attributable to the 10 studies of *Scarus frenatus* derived from *Choat and Robertson (2002)* and *Gust et al. (2002)*, which produce a range of comparatively low values (0.12–0.34). These studies lower the average estimated by pooling individual studies, but the effect of these studies are down-weighted, when a single 'best' value is used for each species. The multiple studies of *S. frenatus* are consistent in suggesting the species has a lower *M/k* than the other scarines in our synthesis, and along with the high values of *M/k* estimated for some other species (*H. longiceps, Scarus schlegeli*) seem indicative of the variability of this group of species. On this basis we conclude that estimating this LHR using a single 'best' estimate for each species, rather than by pooling all studies, provides the better estimate of an average *M/k* for this group of species. Considering the genera in isolation to each other, and estimating averages across species rather than by pooling individual studies suggests some degree of difference between the scarine genera, although these differences may also reflect low sample sizes and variable quality of results between studies (Table A5).

3.2. *Lutjanus gibbus*

3.2.1. Data used

Up until August 2014 a total of 1225 *L. gibbus* had been measured for length and 449 had also been categorized by sex and maturity from which $L_{50\%}$ = 257 mm and $L_{95\%}$ = 320 mm was estimated (Table 1; Fig. A1a).

3.2.2. Literature synthesis & parameter estimation

Kitalong and Dalzell (1994) collected length data for *L. gibbus* in Palau and analysed modal progression with Elefan to produce estimates of growth (L_∞ = 398 mm; k = 0.4), and natural mortality (M = 0.91) using the Pauly (1980) technique. The results of that study imply that M/k = 2.28 which is inconsistent with the average value (0.41) we derive from our synthesis of lutjanid studies. The results of an age and growth study of *L. gibbus* on the Great Barrier Reef (GBR) of Australia (Heupel et al., 2010a) allow an estimate of M/k = 0.69 to be derived, which while more consistent is still relatively high. Estimates of L_m/L_∞ = 0.76 and M/k = 0.51 can be derived from combining the gender based estimates of Nanami et al. (2010) from Okinawa. Given the low sample size and variability of these LHR for *L. gibbus*, but also their relative similarity to the generic estimates, we preferred to use the average LHR values (L_m/L_∞ = 0.75; M/k = 0.41) derived from all the lutjanid studies in our synthesis (Table A2).

When t0 is constrained to the approximate size of lutjanid post-larvae the corrected estimates of L_∞ derived from the literature for *L. gibbus* range from 340 to 398 mm. Combining our estimate of Lm = 257 mm with the lutjanid estimate of L_m/L_∞ = 0.75 we estimate L_∞ = 343 mm in Palau. We assumed lower and upper bounds for the estimate of L_∞ (340–400 mm) based on the lowest and highest values reported in the literature for *L. gibbus* (Table 1). We assumed lower bound and upper bounds of 0.3 and 0.6 for M/k based on the range observed for 27 of the 28 species, choosing not to use the lowest value in our synthesis (0.22) which was derived for *Lutjanus synagris*, but to encompass the value derived for *L. gibbus* (0.57) which was the highest (Table 1A).

3.2.3. Assessment results

With these assumed parameters and our size composition data (Figs. 2a and 4a) we estimated $S_{L50\%}$ 224 mm, $S_{L95\%}$ 252 mm, SPR = 10% and F/M = 4.1 (Table 2). Bootstrapping the length composition data with our best parameter estimates (Figs. 2b and 5a) suggests a reasonably good fit to this relatively large sample (n = 1227) and that all plausible estimates of SPR lie in the range 8–16%. Application of the SIR routine across our assumed range of plausible parameter values suggests the data is relatively uninformative with regard to M/k for which the uniform priors were barely updated (Fig. 2c), somewhat informative with regard to L_∞ (Fig. 2d) for which the uniform priors were updated to indicate a peak probability in the range (350–365 mm), and also with regard to the selectivity parameters (Fig. 2e and f). A broad range (2.5–5+) of F/M estimates were compatible with a plausible range of parameters (Fig. 2g) with most values clumping against our upper bound of F/M = 5. The application of the SIR routine suggest that using our best parameter estimates with our assumed plausible range of parameter estimates we can be confident that the SPR of L. gibbus in the Northern Reefs of Palau is <20% SPR (Figs. 2h and 5b).

Species	SPR (%)	F/M	$S_{L50\%}$ (mm)	$S_{L95\%}$ (mm)
Lutjanus gibbus	0.10	4.1	224	252
Lutjanus bohar	0.27	1.4	265	347
Lethrinus rubrioperculatus	0.23	3.9	239	279
Lethrinus olivaceus	0.10	5+	465	608
Lethrinus xanthochilus	0.13	5+	351	440
Lethrinus obsoletus	0.03	5+	260	325
Plectropomus areolatus	0.05	5+	480	571
Plectropomus leopardus	0.01	5+	334	419
Variola louti	0.20	1.4	203	266
Scarus rubroviolaceus	0.07	5+	355	454
Chlorurus microrhinos	0.21	3.1	333	406
Hipposcarus longiceps	0.05	5+	276	313

Table 2
Point estimates of spawning potential (SPR), fishing pressure (F/M) and selectivity ($S_{L95\%}$, $S_{L50\%}$) derived with 'best' estimate parameters from the length-based assessment of 12 Indo-pacific reef species of reef fish in Palau.

3.3. Lutjanus bohar

3.3.1. Data used

A total of 145 *L. bohar* have been measured for length and 38 had been categorized by sex and maturity from which $L_{50\%}$ = 365 mm and $L_{95\%}$ = 460 mm was estimated (Table 1; Fig. A1b).

3.3.2. Literature synthesis & parameter estimation

Studies of *L. bohar* by Loubens (1980a,b) in New Caledonia and *Marriott et al. (2007)* on the GBR have been used to derive two estimates of M/k = 0.40 (Table A2). The growth curve from *Loubens (1980a,b)* required correcting so that t0 approximates the size of settling lutjanid post-larvae. A single estimate of L_m/L_∞ = 0.76 was derived from *Marriott et al. (2007)* on the GBR. Both these estimates of the *L. bohar* LHR are extremely similar to the average values we derive from all studies of the lutjanid genus in our synthesis (M/k = 0.41; L_m/L_∞ = 0.75). For consistency and the larger sample size we have preferred the average values for the genus. Combining our estimate of L_m = 365 mm with L_m/L_∞ = 0.75 we estimate L_∞ = 487 mm which lies between our corrected estimate from New Caledonia (460 mm) and the GBR estimate (567 mm). We selected lower (470 mm) and upper bounds (570 mm) for our estimate of L_∞ loosely on these other estimates, adding 10 mm to the lower New Caledonian estimate so that our lower bound is slightly larger than our estimate of $L_{95\%}$ = 460 mm. For M/k we assumed lower and upper bounds (0.3 and 0.6), based on the range observed across 27 of the 28 lutjanid species in our synthesis (Table A2). Again excluding the lowest value (0.22) derived for *L. synagris* but encompassing the highest value derived for *L. gibbus* (0.57).

3.3.3. Assessment results

With these parameters and our size composition data (Fig. 4b and Fig. A3a) we estimated $S_{L50\%}$ 265 mm, $S_{L95\%}$ 347 mm, SPR = 27% and F/M = 1.4 (Table 2). Bootstrapping the length composition data with our best parameter estimates (Fig. 5a and Fig. A3b) indicates a poor fit to this small (n = 145) noisy sample and a relatively wide range of possible SPR estimates 15–50% SPR. Application of the SIR routine across our assumed range of plausible parameter values suggests the data were relatively uninformative with regard to M/k (Fig. A3c) for which the uniform priors were left relatively unchanged in the posterior, for L_∞ (Fig. A3d) which the probability profile increases monotonically through our bounded range, and with regard to F/M (Fig. A3g) for which a wide range of estimates (1.0–4.5) were plausible. The data were only informative for the selectivity parameters (Fig. A3e and f) where the estimate of $S_{L95\%}$ is smaller than L_m (347 mm, cf. 365 mm). The application of the SIR routine across our assumed range of parameter values suggests that SPR could lie in the range 5–30% SPR although 75% of the estimates were <20% (Fig. 5b and Fig. A3h).

3.4. Lethrinus rubrioperculatus

3.4.1. Data used

A total of 530 *L. rubrioperculatus* have been measured for length and 300 categorized by sex and maturity from which $L_{50\%}$ = 214 mm and $L_{95\%}$ = 270 mm have been estimated (Table 1; Fig. A1c)

3.4.2. Literature synthesis and parameter estimation

Studies of *L. rubrioperculatus* conducted by *Loubens (1978, 1980a, 1980b)* in New Caledonia, Ebisawa and Ozawa (2009) in Okinawa and Trianni (2011) in the Northern Mariana Islands allow the necessary LHRs to be estimated. In each case the estimated growth curves had to be corrected so that t_0 approximates the expected size of settling lethrinid post-larvae. An average L_m/L_∞ = 0.66 (n = 3; range = 0.62–0.70) and average M/k = 0.63 (n = 3; range = 0.56–0.69). Being similar to the average values estimated across the larger number of lethrinid studies (Table A3) we prefer the estimates from the larger sample (L_m/L_∞ = 0.70; M/k = 0.62) and the range of values estimated across the 14 species (0.35–0.89) has been assumed to provide lower and upper bounds for M/k (Table 1). Once corrected the estimates of L_∞ contained in the literature for *L. rubrioperculatus*, range from 303–370 mm. Combining our estimates of L_m = 214 mm and L_m/L_∞ = 0.70 we estimate L_∞ = 306 mm in Palau. We assumed lower and upper bounds for our estimate of L_∞ (300–370 mm) based loosely on lowest and highest values reported in the literature (Table 1).

3.4.3. Assessment results

With these parameters and data (Fig. 4c and Fig. A4a) we estimated $S_{L50\%}$ 239 mm, $S_{L95\%}$ 279 mm, SPR = 23% and F/M = 3.9 (Table 2). Bootstrapping the length composition data with our best parameter estimates (Fig. 5a and Fig. A4b) indicates a reasonable fit to this moderately sized (n = 533) length sample and although our SPR estimates ranged from 10 to 40% SPR some 75% of the estimates lie within 20–24% SPR. Application of the SIR routine across our assumed range of plausible parameter values suggests the data is relatively uninformative with regard to *M/k* and L_∞ (Fig. A4c and d), and with regard to *F/M* (Fig. A4g) for which a wide range of estimates (2.0–5.0) were possible, although most were clustered against our upper bound (F/M = 5). The data were only informative for the selectivity parameters (Fig. A4e and f), which may coincide with the maturity ogive ($L_{50\%}$ = 214 mm; $L_{95\%}$ = 270 mm). The application of the SIR routine across our assumed range of parameter values suggests that SPR could possibly lie in the range 2.5–40% SPR although the 75th percentile of the estimates was 8–15% SPR (Fig. 5b and Fig. A4h).

3.5. Lethrinus olivaceus

3.5.1. Data used

A total of 366 *L. olivaceus* have been measured for length and 155 categorized by sex and maturity from which $L_{50\%}$ = 409 mm and $L_{95\%}$ = 500 mm was estimated (Table 1; Fig. A1d).

3.5.2. Literature synthesis & parameter estimation

Only a single age and growth study of *L. olivaceous*, on the GBR of Australia by *Currey et al. (2013)*, has so far been found. That study estimated L_∞ = 660 mm and allows an estimate of *M/k* = 0.36 to be derived. This estimate of *M/k* is considerably lower than the average (0.62) derived using all studies of the genus (Table A3). *Currey et al. (2013)* worked with a sample of just 53 individuals, most of which were <5 y.o, although individuals up to 15 years of age were observed, thus along with the authors of that study, we are not entirely confident in that estimate. No studies have been found to date from which L_m/L_∞ can be estimated. On this basis the average lethrinid LHR (L_m/L_∞ = 0.70; *M/k* = 0.62) have been assumed for this species (Table 1), and the range of the 14 lethrinid species (0.35–0.89) has been assumed to provide lower and upper bounds for *M/k* (Table A3). Combining our estimate of L_m = 410 mm with the lethrinid estimate of L_m/L_∞ = 0.70 allows us to estimate L_∞ = 584 mm in Palau. To bound our estimate of L_∞ we have used a value 10% larger than our estimate of L_{95} in Palau (500 mm) as the lower bound and *Currey et al.'s (2013)* relatively unconstrained estimate of L_∞ (670 mm; Table 1) as the upper bound.

3.5.3. Assessment results

With these parameters and data (Fig. 4d and Fig. A5a) we estimated $S_{L50\%}$ 465 mm, $S_{L95\%}$ 608 mm, SPR = 10% and the *F/M* = 5+ was constrained (Table 2). Bootstrapping the length composition data with our best parameter estimates (Fig. 5a and Fig. A5b) indicates a reasonable fit to this moderately sized (*n* = 366) length sample and a possible range of 8–18% SPR, with 75% of the estimates falling within the range 10–14% SPR. Application of the SIR routine across our range of plausible parameter values suggests the data is relatively uninformative with regard to *M/k* and L_∞ the selectivity parameters (Fig. A5c–f). All the possible estimates *F/M* (Fig. A5g) were high >4.0 and most were constrained by our upper bound (*F/M* = 5). The application of the SIR routine across our assumed range of parameter values (Fig. 5b and Fig. A5h) suggests all possible SPR are <25% and 75% were <10%.

3.6. Lethrinus xanthochilus

3.6.1. Data used

A total of 144 *L. xanthochilus* have been measured for length and 103 categorized by sex and maturity from which $L_{50\%}$ = 324 mm and $L_{95\%}$ = 380 mm were estimated (Table 1; Fig. A1e).

3.6.2. Literature synthesis & parameter estimation

No age and growth studies of *L. xanthochilus* have been found to date. The only studies found to date come from length based studies conducted by Wright *et al. (unpubl.) and Dalzell et al. (1992)* which are cited in a species synopsis by *Williams and Russ (1994)*. Those studies are cited as estimating L_∞ as ranging from 540–640 mm. The information cited from *Dalzell et al. (1992)* make it possible to derive estimates of *M/k* ranging from 2.65 to 2.79 which are inconsistent with lethrinid estimates derived from age and growth studies (Table A3) and so have been discounted here. Instead, as with *L. olivaceous*, we preferred the lethrinid average LHR (L_m/L_∞ = 0.70; *M/k* = 0.62) and the range of values estimated across the 14 species (0.35–0.89) to provide lower and upper bounds for M/k (Table 1). Combining our estimate of L_m = 324 mm with L_m/L_∞ = 0.70 we estimate L_∞ = 463 mm for Palau. Our assumed lower bound for L_∞ (390 mm) is 10 mm larger than our estimate of L95 and the assumed upper bound (640 mm) is the largest of the length-based estimates (Table 1).

3.6.3. Assessment results

With these parameters and data (Figs. 3a and 4e) we estimated $S_{L50\%}$ 351 mm, $S_{L95\%}$ 440 mm, SPR = 13% and F/M = 5+ (Table 2).

Bootstrapping the length composition data with our best parameter estimates (Figs. 3b and 5a) suggests a poor fit to this small (n = 144) noisy sample and a possible range of 4–41% SPR but with 75% of estimates falling within the range 10–16% SPR. Application of the SIR routine across our plausible range of parameters suggests the data is relatively uninformative with regard to M/k and L_∞ (Fig. 3c and d), and with regard to F/M (Fig. 3g) for which almost any estimate is possible (0–5.0) although most estimates were constrained against our upper bound (F/M = 5). Our estimates of the selectivity parameters (Fig. 3e and f) were also constrained by our estimate of L_∞, which was the upper bound. The application of the SIR routine across our assumed range of parameter values suggests that SPR could possibly have almost any value (0–1.0) although 75% of the estimates were <16% SPR (Figs. 5b and 3h).

3.7. Lethrinus obsoletus

3.7.1. Data used

A total of 211 *L. obsoletus* have been measured for length and 83 categorized by sex and maturity from which $L_{50\%}$ = 240 mm and $L_{95\%}$ = 300 mm was estimated (Table 1; Fig. A1f).

3.7.2. Literature synthesis & parameter estimation

Studies of age and growth of *L. obsoletus* conducted by *Taylor (2010)* in Guam, and by *Ebisawa and Ozawa (2009)* in Okinawa, allow the necessary LHRs to be estimated, although in both cases the estimated growth curves need to be corrected so that t_0 approximates the size of settling post-larvae. The corrected estimates of L_∞ were 280 mm and 313 mm, respectively. From these studies estimates were derived for L_m/L_∞ = 0.76 (n = 2; range = 0.75–0.77) and M/k = 0.44 (n = 2; range = 0.40–0.47). The estimate for L_m/L_∞ is similar to the average lethrinid value (0.70) although the estimate of M/k is somewhat lower than the lethrinid average (0.62). Considering the small number of studies involved, the average lethrinid LHR have been preferred for this species, and the estimated range (0.35–0.89) for the 14 lethrinid species (Table A3) has been used for the lower and upper bounds for M/k (Table 1). Combining our estimate in the literature (313 mm). Note these criteria forselecting the bounds for L_∞ are more restrictive, than those appliedfor the other species.

3.7.3. Assessment results

We estimated $S_{L50\%}$= 260 mm, $S_{L95\%}$= 325 mm, SPR = 3% andF/M = 5+ (Table 2) and although the model appears unable to fitto this small (n = 211) sample neatly (Fig. 4f and Fig. A7a), boot-strapping the length composition data with our best parameterestimates (Fig. 5a and Fig. A7b) suggests all possible estimates of SPR are <5%. Application of the SIR routine across our assumedrange of plausible parameter values suggests the data is relativelyuninformative with regard to M/k and L_∞ (Fig. A7c and d), and weconstrained our estimate of S_{L95} with our assumed L_∞. Likewise allthe estimates of F/M (Fig. A7g) are constrained against our upperbound (F/M = 5). Despite the limitations of the data, application ofthe SIR routine across our assumed range of parameter values suggests all possible estimates of SPR are <10% SPR (Fig. 5b and Fig. A7h). Note the apparently very high confidence of this SPR estimate (Fig. 5b) coinciding with our assumption of tighter boundsfor L_∞.

3.8. Plectropomus areolatus

3.8.1. Data used

A total of 322 *P. areolatus* have been measured for length and 136 categorized by sex and maturity from which $L_{50\%}$ = 383 mm and $L_{95\%}$ = 460 mm was estimated (Table 21; Fig. A1g).

3.8.2. Literature synthesis & parameter estimation

Three studies of *P. areolatus* were used to estimate LHR; *Williams et al. (2008)* from the eastern Torres Strait, Australia, *Currey et al. (2010)* from the GBR, Australia and *Rhodes et al. (2013)* from Pohnpei in Micronesia. With the exception of the Currey et al. study all the growth curves derived by these studies needed correction so that t_0 reflects the size of settling plectropomid post-larvae. The re-estimated L_∞'s range from 454 mm in Pohnpei to 660 mm in Eastern Torres Strait. Having made these corrections an average L_m/L_∞ = 0.64 (n = 2, range = 0.48–0.80) and an average M/k = 0.94 (n = 3, range = 0.67–1.30) were derived. On the basis of the apparent similarity of the LHRs found in the plectropomid literature (Table A4), because of the larger sample size we preferred to use the average values for the genera (L_m/L_∞ = 0.59; M/k = 0.91). With fewer estimates available for P. areolatus than for Plectropomus leopardus (Table A4) we chose to use the lower bound of M/k estimated for *P. leopardus* (0.46) as the lower bound for *P. areolatus* and the highest estimate for *P. areolatus* (1.3) as the upper bound (Table 1). Using our best estimate for the genera of L_m/L_∞ (0.59) and our estimate of L_{50} = 383 mm we estimate L_∞ = 649 mm in Palau. Because our estimate of L_{95} = 460 mm is greater than the lowest estimates of L_∞ in the literature and our estimate of L_∞ is close to the largest, we chose to extend our possible bound of L_∞ estimates by using the range of L_m/L_∞ estimates we derived from the literature for this species (0.48–0.80; Table A4) to derive lower and upper bounds of 540 mm and 815 mm (Table 1).

3.8.3. Assessment results

With these parameters and size composition data (Fig. 4g and Fig. A8a) we estimated $S_{L50\%}$= 480 mm,$S_{L95\%}$= 571 mm, SPR = 5%and F/M = 5+ (Table 2). Bootstrapping the length composition datawith our best parameter estimates (Fig. 5a and Fig. A8b) suggests areasonable fit to this moderately sized sample (n = 322) all SPR estimates being in the range 2–8%. Application of the SIR routine acrossour assumed range of plausible parameter values suggests the datais relatively uninformative with regard to M/k and L_∞(Fig. A8c andd), and all our estimates of F/M (Fig. A8g) were constrained against our upper bound (F/M = 5). Our estimates of selectivity parametersare apparently informative and hint at a link between maturationand selectivity ($S_{L50\%}$= 480 mm, cf. L_{95}= 460 mm). The applicationof the SIR routine across our assumed range of parameter valuessuggests that almost all possible estimates of SPR are <20% SPR and 75% of the estimates were <10% (Fig. 5b and Fig. A8h).

3.9. Plectropomus leopardus

3.9.1. Data used

A total of 186 *P. leopardus* have been measured for length and 53 categorized by sex and maturity from which $L_{50\%}$ = 370 mm and $L_{95\%}$ = 440 mm was estimated (Table 1; Fig. A1h)

3.9.2. Literature synthesis & parameter estimation

Four studies of *P. leopardus* were used to estimate the relevant LHRs of this species; *Loubens (1978, 1980a,b)* in New Caledonia, Williams et al. (2008) in the eastern Torres Strait, Australia, *Currey et al. (2010)* on GBR, Australia, and *Ebisawa (2013)* in Okinawa, Japan. With the exception of Currey et al. all the growth curves needed correction so t0 reflects the size of post-larvae. The re-estimated L_∞'s range from 420 mm in New Caledonia to 620 mm in Okinawa. Having made these corrections an average L_m/L_∞ = 0.63 (n = 3, range = 0.47–0.71) and an average M/k = 0.89 (n = 5, range = 0.60–1.00) were derived for *P. leopardus* (Table A4). The ranges of both M (0.25–0.35) and k (0.24–0.41) estimated for *P. leopardus* are lower than for *P. areolatus* (M = 0.30–0.43; k = 0.30–0.64) with the result that the average estimates of M/k for these two species are extremely similar (Table A4). On the basis of the apparent similarity of the LHRs found in the plectropomid literature we preferred to use the average values estimated across all species in the genera (L_m/L_∞ = 0.59; M/k = 0.91) because of the larger sample size.

Russ et al. (1998) used an aging study over time to track the abundance of a single strong cohort of *P. leopardus* in an area of the GBR closed to fishing over time, and estimated M for 7–9 y.o. fish as 0.115–0.189. They argued that other studies had over-estimated M. With regard to the studies we have used here; *Currey et al. (2010)* used samples from areas closed to fishing to estimate M = 0.25, the same value estimated by *Ebisawa (2013)* from areas fished with a relatively high size limit, however the other two estimates (0.25 and 0.35) were derived from areas open to fishing. If the mid-point of the Russ et al. estimates (M = 0.15) is substituted into the studies we used, instead of the mortality rates derived by, or from, each study, a lower M/k = 0.46 (n = 5, range = 0.35–0.60) is derived. Notwithstanding the argument we advance in the methods section of the appendix that with stocks around equilibrium this LHR should be approximated by Z/k, here for interest, we used the estimate of M/k (0.46) derived with the Russ et al. M as the lower bound for M/k, and used the highest estimate (M/k) derived from the studies in the literature (1.00) as upper bound (Table 1).

Using our Palauan estimate of L_{50} = 370 mm and the estimate of Lm/L_∞ = 0.59 we estimate L_∞ = 627 mm in Palau, and in this case, because our estimate of L95 = 440 mm is larger than the smallest estimates of L_∞ found in the literature and our estimate of L_∞ outside the range of estimates in the literature, we used our range of Lm/L_∞ estimates for this species (0.47–0.71) to derive lower and upper bounds of 521 mm and 787 mm for L_∞.

3.9.3. Assessment results

With these assumed parameters and data (Fig. 4h and Fig. A9a) we estimated $S_{L50\%}$ 334 mm, $S_{L95\%}$ 419 mm, SPR = 1% and F/M = 5+ (Table 2). Bootstrapping the length composition data with our best parameter estimates (Fig. 5a and Fig. A9b) suggests a reasonable fit to this relatively small sample (n = 185) with most estimates of SPR being <2%. A thin tail of outlying estimates extending up to 30% SPR relates to the measurement of a few larger (>400 mm) individuals which are poorly explained by the model but if given sufficient weight suggest higher SPR levels (Fig. 4h). Application of the SIR routine across our assumed range of plausible parameter values suggests the data is relatively uninformative with regard to M/k and L_∞ (Fig. A9c and d), and all the estimates of F/M (Fig. A9g) were constrained by our upper bound (F/M = 5). Our estimates of the selectivity parameters are apparently informed by the data and are again perhaps coincidental with our estimated maturity ogive ($S_{L95\%}$ 419 mm, cf. $L_{95\%}$ = 440 mm). The application of the SIR routine across our assumed range of parameter values suggests that all possible estimates of SPR are <5% SPR (Fig. 5b and A9h).

3.10. Variola louti

3.10.1. Data used

A total of 578 *V. louti* have been measured for length and 113 and categorized by sex and maturity (Table 1; Fig. A1i).

3.10.2. Literature synthesis & parameter estimation

Studies of *V. louti* by *Currey et al. (2010)* on the *GBR, Grandcourt (2005)* and *Loubens (1978, 1980a,b)* in New Caledonia estimate L_∞ ranging from 390–510 mm and allow mean LHR values Lm/L_∞ = 0.64 (n = 2, range = 0.54–0.74) and M/k = 0.86 (n = 2, range = 0.58–1.13) to be estimated (Table A4), which are similar to the average plectropomid values (Lm/L_∞ = 0.59; M/k = 0.91). Given the close relationship between *Variola* and *Plectropomus* and the larger number of plectropomid studies available to us, we chose to use the plectropomid LHR as the best estimates for *V. louti* as well, and the range of M/k values estimated for Variola as the upper and lower bounds (Table 1). Our SoM data for this species were noisy and uninformative, although not inconsistent with the only estimate of L_{50} = 290 mm we found in the literature (*Loubens, 1980a*) and an estimate of L_{50} = 260 mm we derived from *Maplestone et al. (2009)*. On this basis we tightly constrained a logistic curve, to pass through our scatter of data, and assume L_{50} = 285 mm and L_{95} = 350 mm which when combined with our best estimate of Lm/L_∞ (0.59) enables us to estimate L_∞ = 483 mm (Table 1). Again our estimate of L_{95} is larger than some estimates of L_∞ found in the literature, so we used our range of Lm/L_∞ estimates for *Variola* (0.54–0.74) to derive lower and upper bounds for L_∞ of 385 mm and 527 mm.

3.10.3. Assessment results

With these parameters and data (Fig. 4i and Fig. A10a) we estimated $S_{L50\%}$ 203 mm, $S_{L95\%}$ 266 mm, SPR = 20% and F/M = 1.4 (Table 2). Bootstrapping the length composition data with our best parameter estimates (Fig. 5a and Fig.

A10b) suggests a relatively poor fit to this moderately sized (n = 578) sample, with the model unable to fit the tails of smaller and larger individuals, resulting in a possible range of 10–30% SPR. Application of the SIR routine across our assumed range of plausible parameter values suggests the data is relatively uninformative with regard to M/k and L_∞, with the probability profile of the latter increasing monotonically through our assumed range for this parameter (Fig. A10c and d). The data were apparently informative for the estimation of the selectivity parameters (Fig. A10e and f), and in this case were considerably smaller than the maturity ogive we assumed ($S_{L95\%}$ = 266 mm, cf. L_{50} = 285) however the context for this is that our SoM estimate is very poorly informed by our data. The SIR routine suggests a wide range (1.5–5.0) of F/M estimates (Fig. A10 g) are compatible with our range of assumed parameter estimates, but that 75% our SPR estimates are <10% and all but a few outlier estimates are <20% (Fig. 5b and Fig. A10h).

3.11. Scarus rubroviolaceus

3.11.1. Data used

A total of 159 S. rubroviolaceus have been measured for length and 116 categorized by sex and maturity from which $L_{50\%}$ = 312 mm and $L_{95\%}$ = 400 mm was estimated (Table 1; Fig. A1j).

3.11.2. Literature synthesis & parameter estimation

Studies of age and growth in *S. rubroviolaceus* in the *Seychellesby Grandcourt (2002), Sabetian (2010) in Taiwan and Seychelles, and Taylor and Choat (2014)* from Micronesia have been used toestimate the relevant LHRs. All these studies constrained t_0 toapproximate the expected size of settling post-larvae so no correction was required. These studies estimate L_∞ as ranging from 308 to 459 mm, k from 0.43 to 1.05, and M or Z from 0.18 to 0.63. From these studies L_m/L_∞ = 0.75 (n = 2; range = 0.72–0.78) was estimated,similar to the value we derived (Table A5) pooling all scarine studies (0.71), using a single 'best' value for each species (0.73), and also by *Choat & Robertson's (2002)* for Chlorurus and Scarus genera (0.68). Given the small sample size for *S. rubroviolaceus* we prefer the estimate derived using the 'best' estimates for each of the 10 Scarus species (0.72) as being the most recent and comprehensive. Basedon this estimate of L_m/L_∞ and our estimate of L_{50}= 312 mm in Palau we estimate L_∞= 433 mm (Table 1). Given the lowest estimate of L_∞ in the literature (308 mm) is below our estimate of L_{50} in Palau (312 mm), we assumed the lower bound on L_∞ to be 10 mm greaterthan our estimated L_{95} (410 mm) and used the highest estimate of L_∞ in the literature (459 mm) as our upper bound. From the collected studies of *S. rubroviolaceus* we estimate M/k = 0.51 (n = 4; range = 0.27–0.95). The highest derived value of M/k is based on an estimate of Z (0.95) from a study by *Taylorand Choat (2014)* from the heavily exploited waters off Guam andis notably higher than the estimates of the other three studies. If this estimate is excluded, M/k for this species is re-estimated as 0.36 (n = 3; range = 0.27–0.42) which is considerably lower than theaverage derived for the 10 Scarus species (0.53) in our synthesis (Table A5). Variability in the M/k ratio does seem to be an actualcharacteristic of the scarines, and not entirely attributable to noisein the data. In this situation, despite the low sample size we preferthe estimate of M/k = 0.36 as our best estimate for this species. We use the estimate for *S. frenatus* (0.25), the lowest estimated for the Scarus species, as our lower bound and the average estimate for allScarus species (0.79) as our upper bound (Table 1).

3.11.3. Assessment results

With these parameters and our data we estimated $S_{L50\%}$ = 355 mm, $S_{L95\%}$= 454 mm, SPR = 7% and F/M = 5+ (Table 2). The modelfit to this noisy small sample (n = 159) was relative poor (Fig. 4jand Fig. A11a), however, bootstrapping the length composition data with our best parameter estimates (Fig. 5a and Fig. A11b) suggests all but a few outlier estimates of SPR are <10%. Application of the SIR routine across our assumed range of plausible parameter values suggests the data is relatively uninformative with regard to M/k and L_∞ (Fig. A11c and d). Our estimates of the selectivity parameterswere also not well informed by our data and instead constrainedby our estimates of L_∞(Fig. A11e and f). Likewise our estimatesof F/M (Fig. A11 g) were constrained by our upper bound (F/M = 5). Nevertheless, taking into account the range of parameter estimates we considered plausible almost all possible estimates of SPR were<30% and 75% were <18% (Fig. 5b and Fig. A11h).

3.12. Chlorurus microrhinos

3.12.1. Data used

A total of 150 *C. microrhinos* have been measured for length and 111 categorized by sex and maturity from which $L_{50\%}$ = 315 mm and $L_{95\%}$ = 330 mm was estimated (Table 1; Fig. A1k).

3.12.2. Literature synthesis & parameter estimation

The LHR of *C. microrhinos* can be estimated from studies by *Choat and Robertson (2002)* from the GBR, by *Sabetian (2010)* from the GBR, Seychelles and Cocos Keeling Islands, and by *Taylor and Choat (2014)* from Guam. All these studies constrained t_0 to the approximate of post-larvae and required no correction. These studies estimate L_∞ as ranging between 395 and 499 mm, *k* from 0.30 to 0.65, and *M* from 0.32 to 0.52. From these studies we derived estimates of L_m/L_∞ = 0.74 (*n* = 4; range = 0.67–0.77), similar to the value we estimate (0.73) using the single 'best' estimates of each of the 15 scarine species in our synthesis, but slightly higher than the average (0.66) of the three *Chlorurus* species for which we have data, and the average (0.67) of all eight *Chlorurus* studies (Table A4). It is also slightly higher than the value (0.68) derived by *Choat and Robertson (2002)* for all *Chlorurus* and *Scarus* species. Given our relatively small sample size for *C. microrhinos* (*n* = 4), in this case we prefer the estimate derived by pooling all eight studies of *Chlorurus* (0.67). Based on this L_m/L_∞ and our estimate of L_{50} = 315 mm in Palau we estimate L_∞ = 470 mm (Table 1). We have used the range of L_∞ estimates in the literature for this species (395–500 mm) to define the upper and lower bounds (Table 1).

From the collected studies of *C. microrhinos* we initially estimated *M/k* = 0.91 (*n* = 6; range = 0.53–1.26). This estimate of *M/k* is higher than the average of 16 *Chlorurus* studies (0.57), than the three *Chlorurus* species (0.62) and the average of 'best' estimates (0.70) for all 16 scarine species in our synthesis (Table A4). Again the highest value of *M/k* we derived for this species (1.26) uses an estimate of *Z* taken from the study by *Taylor and Choat (2014)* in Guam, although in this case, their estimate of total mortality (0.43) falls within the range of the other C. microrhinos estimates (0.32–0.52). However, if for the sake of consistency, we also remove that value from our analysis we re-estimate *M/k* for this species as 0.84 (*n* = 5; range = 0.53–1.06) which while closer is still above the average *M/k* estimated across all 16 scarine species in our sample (0.70). On this basis, and considering our relatively small sample size for *C. microrhinos* (*n* = 6) we prefer the estimate of *M/k* = 0.70 derived from all 16 scarine species. We use the range of estimates for *C. microrhinos* (0.53–1.26) to define our lower and upper bounds for this LHR (Table 1).

3.12.3. Assessment results

With these parameters and data we estimated $S_{L50\%}$ = 333 mm, $S_{L95\%}$ 406 mm, SPR = 21% and *F/M* = 3.1 (Table 2). The model fit to this small (*n* = 150) noisy sample was relative poor (Fig. 4k and Fig. A12a) and bootstrapping with the best parameter estimates (Fig. 5a and Fig. A12b) suggested estimates of 10–50% SPR are compatible with the data, with 75% of the SPR estimates falling in the range 18–26% SPR. Application of the SIR routine across our assumed range of plausible parameter values suggests the data is relatively uninformative with regard to *M/k*, L_∞ and the selectivity parameters (Fig. A12c–f). Taking into account the range of parameter estimates we considered plausible the SIR routine suggests that almost any value of *F/M* (0–5) and SPR (0.1–1.0) is possible (Fig. 5b and Fig. A12g and h).

3.13. Hipposcarus longiceps

3.13.1. Data used

A total of 403 *H. longiceps* had been measured for length and categorized by sex and maturity from which $L_{50\%}$ = 300 mm and $L_{95\%}$ = 330 mm was estimated (Table 1; Fig. A1l).

3.13.2. Literature synthesis & parameter estimation

Kitalong and Dalzell (1994) used length based techniques to study *H. longiceps* in Palau and estimated L_∞ = 439 mm, *k* = 0.5 and *M* = 1.02, suggesting *M/k* = 2.04, but we do not consider these estimates as reliable as the estimates based on aging studies. Three age and growth studies of *H. longiceps* have been used to estimate the LHR for this species; *Choat and Robertson (2002)* on the GBR, *Sabetian (2010)* from the Solomon Islands and *Taylor and Choat (2014)* from Pohnpei, Micronesia. These studies estimate L_∞ as ranging between 286 and 366 mm, k from 0.28 to 1.19, and M from 0.32 to 1.22. The only estimate of L_m/L_∞ = 0.87 we could derive is based on *Taylor and Choat (2014)*. Given the single sample involved and that the result is at the outer edge of the range observed for the other scarine studies (Table A5) we prefer to use the estimate derived by pooling all 21 scarine studies (0.71) and with our estimate of L_{50} = 300 mm derive L_∞ = 423 mm. Relatively arbitrarily, we have selected 360 mm as the lower bound for this estimate, being approximately 10% greater than our approximation of L_{95} (330 mm), and the estimate of L_∞ = 440 mm derived by *Kitalong and Dalzell (1994)* using length based methods in Palau as our upper bound (Table 1).

An average estimate of M/k = 1.07 (n = 3; range = 0.93–1.26) is derived from the three age and growth studies collected, which is considerably higher than the single estimate (0.67) we derive for the other species in this genus for which we have data (*Hipposcarus harid*) and also the average (0.70) of all 16 scarine species (Table A5). Given the relative consistency of the three *H. longiceps* estimates, the variability which seemingly characterizes scarine species, our own observation in Palau suggesting it is one of the species in this assemblage persisting longest under heavy fishing pressure, and despite the small number of studies, we think it likely this species does have a comparatively high M/k ratio. Consequently, in this case we chose to use the estimate we derived for *H. longiceps* (1.07) as our best estimate, the average derived across all 16 scarine species (0.81) as our lower bound, and the highest estimate for *H. longiceps* derived by age and growth studies (1.26) as our upper bound (Table 1).

3.13.3. Assessment results

With these parameters and data we estimated $S_{L50\%}$ = 276 mm, $S_{L95\%}$ 313 mm, SPR = 5% and F/M = 5+ (Table 2). The model fit to this moderately sized sample (n = 403) was reasonable (Fig. 4l and Fig. A13a). Bootstrapping the length composition data with our best parameter estimates (Fig. 5a and Fig. A13b) suggests all possible estimates are <10% SPR. Application of the SIR routine across our assumed range of plausible parameter values suggests the data is relatively uninformative with regard to M/k and L_∞ (Fig. A13c and d), although estimates of the selectivity parameters are apparently informed by our data (Fig. A13e and f) and again approximately coincide with the maturity ogive. Our estimates of F/M (Fig. A13g) are relatively uninformed by the data, with all possible estimates being >2 and most values being constrained by our upper bound (F/M = 5). Taking into account the range of parameter estimates we considered plausible 75% of our SPR estimates are <10% and all but a few outlier estimates are <20% (Fig. 5b and Fig. A13h).

4. Discussion

This paper documents the first application of the LB-SPR approach advanced by *Hordyk et al. (2014b)* to developing an assessment of SPR in a small-scale and data-poor fishery. The LB-SPR assessment technique has not been developed to replace more precise, data-intensive assessment techniques, rather to provide a widely applicable and cost-effective starting point with which to begin longer term processes of data collection, assessment and management when there is little, if any, pre-existing data, and few other options. This first study of 12 species allows us to start evaluating the techniques' potential for real world implementation. In two years with the support of artisanal fishers to collect the data we have developed assessments for 12 of the 15 most abundant of the 106 species in the catch of the Northern Reefs of Palau (Table A1). Of the remaining three of the 15 most abundant species that we have been unable to assess, we have so far been unable to reliably estimate the LHR of one (*S. lineatus*), and have collected insufficient SoM data for the other two (*N. unicornis, Cetoscarus ocellatus*), to begin formulating assessments.

4.1. Estimation of life history ratios

An expected limitation to the application of the LB-SPR technique, which we were interested in testing with this study, was the extent to which the required LHR might, or might not, be estimable using published studies of the species in question, and of taxonomically related species. This study demonstrates that the BH-LHI principles can be used to borrow information from related species within the Indo-Pacific coral reef fish assemblage, and inform the LB-SPR assessment of less studied species. This study also begins developing a methodology for estimating from the literature the LHR required to parameterize LHR assessment. We found sufficient quality information for lutjanids, lethrinids, serranids and the scarines, to derive what we regard as robust starting estimates to formulate assessments for those genera. Having made allowances for the variable quality of the growth curves described in the literature (*Cailliet et al., 2006; Pardo et al., 2013*), we were agreeably surprised at the intra-genera consistency of LHR estimates for the lethrinids, lutjanids and plectropomids. On this basis we had little hesitation in applying the average values for each of those groups to poorly or unstudied species of those groups. In contrast the scarines are acknowledged as being a highly variable group of species and genera (*Taylor and Choat, 2014*), and this seems evident in the more variable LHR estimates that we derived for this species complex. At this stage it is difficult to determine to what extent this variation also reflects the variable quality of the results being synthesized.

From what we have seen of the Indo-Pacific teleost literature so far, we expect there to be sufficient information based on aging studies to derive robust LHR estimates for the acanthurids, another important groups for the Indo Pacific coral reef fish fisheries of the Indo-Pacific, but that it is unlikely similar quality LHR estimates will be possible for the siganids, a sixth important species group for these fisheries. All the siganid studies we have collected to date are length-based.

4.2. Estimation of size of maturity

In developing LB-SPR we had anticipated that estimating asymptotic size from exploited data-poor stocks would be problematic, and for this reason developed the approach of using estimates of L_m/L_∞ derived from the literature, together with in situ estimation of L_m to estimate asymptotic size. We had not anticipated the difficulty we would encounter completing SoM studies with depleted stocks. In practice we found fully mature size classes difficult to sample because they have become rare in Palau. This made the estimation of SoM challenging. The reluctance of fishers wishing to selling their catch to have their catch cut open for gonad inspection increased the difficulty of deriving good SoM estimates, a challenge we are also encountering in the Solomon Islands where we are also trialing the LB-SPR approach. In Palau we now seem to have overcome this problem by collaborating with the proprietor of the fish market to opportunistically collect data on selected larger fish. In the Solomon Islands we are resorting to buying the fish we require for our SoM studies, a more expensive option. The complexity of the sexual ontogeny of tropical species further compounds the challenge of this aspect of the study, forcing us to adopt a weight of evidence approach to evaluating the SoM data gathered by the Palauan fishers, and accepting our resulting estimates of L_∞ have broad ranges of uncertainty around them. Undoubtedly accepting the added expense of having trained scientists collect these data would improve the quality of these data and the resulting SoM analyses. Nevertheless we hope that by continuing to collect these data we will over time enlarge the sample sizes at the tails of our size distributions, and improve our current estimates, as well as extend the number of species.

4.3. Evaluating the uncertainty of LB-SPR estimates

At this stage of our technique's development we have yet to develop an explicit means of quantifying uncertainty around the SoM estimates, and are conveniently compounding it into our uncertainty with regard to L_∞, which we know from sensitivity testing is the most important determinant of LB-SPR assessments (*Hordyk et al., 2014b*). Also lacking is a single comprehensive metric for evaluating the total uncertainty that comes from combining noisy length composition data with uncertain parameter estimates. Some multiplicative combination of the bootstrapping and sampling–importance–resampling we describe here, would provide the best holistic description of our uncertainty around these estimates. What is presented here is not an ideal solution to this issue, but our development of the LB-SPR methodology and software remains a work in progress. Although a strength of our current approach is that the different sources of uncertainty remain to some extent explicit and separable, enhancing our opportunity for learning from what we are doing, and informing our next steps in development.

The LB-SPR methodology is known to be extremely sensitive to the estimate of L_∞ (*Hordyk et al., 2014b*). The SIR estimates suggest 11 of the 12 assessments have <20% SPR and are systematically lower than the bootstrapped values which suggest 4 or 5 stocks have ~20% SPR (Fig. 5a and b). The SIR algorithm considers a wider range of L_∞ than the single 'best' estimate of the bootstrap routine, many of which are higher than the single 'best' bootstrap estimate, and equally compatible with the relatively uninformative size composition data. This mass of equally possible lower SPR estimates drags the distribution of estimates lower.

Ranking the variance estimated for each species by each technique 1–12, highest to lowest (Table 3) we see that with bootstrapping the five species with the lowest ranking and highest variance are; *L. bohar* (*n* = 145), *C. microrhinos* (*n* = 150), *L. rubrioperculatus* (*n* = 533), *V. louti* (*n* = 578), *L. xanthochilus* (*n* = 144). Ranking the variance of each species' SIR estimates the lowest ranking highest variance estimates were for *C. microrhinos* (*n* = 150), *L. xanthochilus* (*n* = 144), *L. rubrioperculatus* (*n* = 533), *S. rubroviolaceus* (*n* = 158), *L. bohar* (*n* = 145). These two lists of most uncertain assessments are comprised of the four species with the smallest sample sizes, together with the second and third most numerously sampled species, *L. rubrioperculatus* and *V. louti*.

Generally the estimates of variance seem to decline and stabilize with n > 350, suggesting estimates can clearly be substantiallyimproved by collecting more size data. In the case of *L. rubrioperculatus* and *V. louti* the 'noise' in their size composition histogramspersists despite larger sample sizes than most other species. Noting that they are the smallest bodied members of this assemblage,it is tempting to attribute this to a greater degree of spatial variability, similar to that now being documented across reef profiles for other small-bodied Indo-Pacific coral reef species (*Gust et al.,2002; Gust, 2004*). Some degree of finer data collection could beconsidered, along with tolerating the greater degree of uncertaintyfor these species.

The LB-SPR methodology is particularly sensitive to the under-estimation of L_∞ (*Hordyk et al., 2014b*) because when the largestsized individuals in a sample begin to approach L_∞ estimates of SPR increase rapidly. The lower bounds we selected for the L_∞ apparently played a role in determining the upper limit of possible SIR estimates of SPR and confidence intervals. The order of the speciesin Table 3 has been determined by the ratio of the lower boundon L_∞, and the $L_{95\%}$ assumed for each species in our analysis. Avalue approaching 1.0 indicates the range assumed for L_∞ includesthe lowest possible values (i.e. $L_\infty = L_{95\%}$). Besides the influence oflow sample size there also appears to be a co-occurrence with thespecies having the lowest L_∞ bounds (the top half of the table) also tending to have lower rankings and higher levels of variance.With regard to L_∞ of a heavily fished species in a data-poor

Species	SPR (%)	*F/M*	$S_{L50\%}$ (mm)	$S_{L95\%}$ (mm)
Lutjanus gibbus	6.3	4.9	222	251
Lethrinus rubrioperculatus	26.5	2.9	239	288
Lethrinus olivaceus	15.3	8.6	505	666
Lethrinus xanthochilus	21.5	3.9	362	455
Lethrinus obsoletus	13.1	>10	297	368
Plectropomus areolatus	2	>10	513	615
Plectropomus leopardus	<1	>10	345	434
Variola louti	1.3	5.3	211	279
Scarus rubroviolaceus	4.1	>10	388	475
Scarus microrhinos	95.9	0.15	397	512
Hipposcarus longiceps	14.7	4.2	272	309

Table 3
Listing of the 12 assessed species with their sample size (*n*) and ranking from highest (1) to lowest (12) of the variance around their SPR assessment based on Bootstrapping the size data (BS Var) and SIR analysis of parameter uncertainty (SIR Var) (Fig. 5a and b). In this table the species are ordered from low to high, by each species ratio of assumed lower bound on L_∞, and the $L_{95\%}$. As this value approaches 1.0, the bounds placed upon L_∞ converge with SoM, a logical minimum possible value. Note the assessments with lower ratios, at the top of this table, have a tendency to coincide with higher variance ranking (lower numbers).

fisherythere will always remain a sense of, 'not being able to know whatyou don't already know'. An argument can be made that we have systematically under-estimated our actual uncertainty about thisparameter. Developing robust consistent protocols for setting thebounds for L_∞ will be essential for ensuring the comparability of SIR estimated confidence intervals.

4.4. The benefit of LB-SPR

While there is a lot of scope for further development the current weaknesses in our quantification of uncertainty around our estimates should not obscure the potential we think this new technique has for the field of data-poor assessments. Within two years of commencing our study we have completed conclusive SPR assessments for 11 of the most important species in the Northern Reefs of Palau showing that these stocks are all currently around or below the SPR reference point at which recruitment impairment is likely. The relative simplicity of the data being collected, and the underlying concept of spawning potential, is a great advantage in the application of the technique, because they facilitate the involvement of fishers in collecting their own data, reducing costs and fostering community ownership of the results. While basing our data collection program on the participation of local fishers may have added some noise to the data we collected, our judgment is that in the context of data poor fisheries, accurate determinations of scientific uncertainty are less important than a fishing community's qualitative understanding and acceptance of the results. These results have been rapidly accepted by the Palauans, providing for them a convincing explanation of the changes they have been observing over the last two decades and confirming what they suspected, but were not acknowledging. We believe it is the involvement of the fishers in our study, as much as the results of our assessments, that has generated community support for implementing minimum size limits based on our estimates of size at SPR20%, and resulted in national and state laws being changed to support this occurring.

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Improving understanding of fish stocks - Fishery- independent monitoring

Introduction

The coral reef fisheries of the northern reefs are vital to Palauan food security and provide economic opportunity via sportfishing ecotourism, diving ecotourism, and small-scale commercial fisheries (*Golbuu et al. 2005; Wabnitz et al. 2018*). However, both traditional ecological knowledge, and previous fisheries research, suggest that the abundance and size of many principle fisheries species in the region have declined (*Prince et al. 2015*). In response to these declines, the states of Ngarchelong and Kayangel, located in the northern reef region of Palau, passed fisheries regulations for 14 species, between 2015 and 2018. These regulations included temporary moratoriums on harvest and/or length-based size limits (Table 1). In order to improve the understanding of the fish stocks in this region of Palau, and monitor the status of important fisheries species in response to these management actions, researchers from the Palau International Coral Reef Center (PICRC) and The Nature Conservancy (TNC) conducted annual fisheries independent underwater surveys across the costal reefs of Ngarchelong and Kayangel, from 2015 to 2017. These surveys provide time series data on the size-frequency distributions of the region's import fisheries species. Known as Spawning Potential Ratio (SPR), this length-based stock assessment methodology allows to evaluate the stock status with limited data. The following is a description of the surveys completed to assess the status of the northern reef fish stocks between 2015 and 2017, as well as the estimates of biomass for the families of the 14 regulated species overtime, SPR for *Lutjanus gibbus*, and recommendations to improve the efficacy of these surveys.

Species	Ngarchelong			Kayangel		
	Minimum size (cm)	Implementation date	Moratorium	Minimum size (cm)	Implementation date	Moratorium
Lutjanus bohar	40	May 2017	-	40	May 2017	-
Lethrinus olivaceus	40	May 2017	-	40	May 2017	-
Cetoscarus ocellatus	28	May 2017	-	28	May 2017	-
Chlorurus microrhinos	28	May 2017	-	28	May 2017	-
Hipposcarus longiceps	25	May 2017	-	25	May 2017	-
Lutjanus gibbus	25	May 2017	-	25	May 2017	-
Naso unicornis	-	-	-	-	-	-
Lethrinus xanthochilus	-	-	-	-	-	-
Plectropomus leopardus	28	After 3-year ban	July 2015 –July 2018	28	After 3-year ban	July 2015 –July 2018
Plectropomus areolatus	36	After 3-year ban	July 2015 –July 2018	36	After 3-year ban	July 2015 –July 2018
Plectropomus laevis	56	After 3-year ban	July 2015 –July 2018	56	After 3-year ban	July 2015 –July 2018
Epinephelus fuscoguttatus	36	After 3-year ban	July 2015 –July 2018	36	After 3-year ban	July 2015 –July 2018
Epinephelus polyphekadion	36	After 3-year ban	July 2015 –July 2018	36	After 3-year ban	July 2015 –July 2018
Variola louti	25	May 2017	-	25	May 2017	-

Table 1:
Fisheries regulations for 14 managed species in the states of Ngarchelong and Kayangel in the northern reef region of Palau.

Methods

Fisheries independent surveys

Fisheries independent underwater surveys were conducted annually between 2015 and 2017, on the reefs of Ngarchelong and Kayangel States. At each survey location, a 15-minute timed swim was done along the reef by a team of divers in two different depth categories: “deep” (i.e., 15-20 m) and “shallow” (i.e., 5-10 m). Each depth was counted as a separate sample site. During each survey, a diver recorded all of the fish present along the transect, by using a diver operated stereo video system, while a second diver towed a floating GPS, which tracked the route taken and recorded the transect length of each survey. The videos were then analyzed using EventMeasure software, where all fishery-targeted species that came within a 5 m belt of the transect were identified and their fork length was measured. If a length measurement could not be made accurately with Event Measure software, then a 3D point was added and an estimated length was calculated from the mean length of that species in the given transect. From the fork length estimates, the weight of each fish and biomass per-meter squared were then calculated from the length-weight relationships for each species. In 2015, a total of 190 sites were surveyed, in 2016, 64 sites were resurveyed and in 2017, 66 sites were resurveyed. However, for the purpose of this analysis, the data was filtered to exclude all locations that were not successively sampled during each of the three consecutive sampling years (Figure 1).

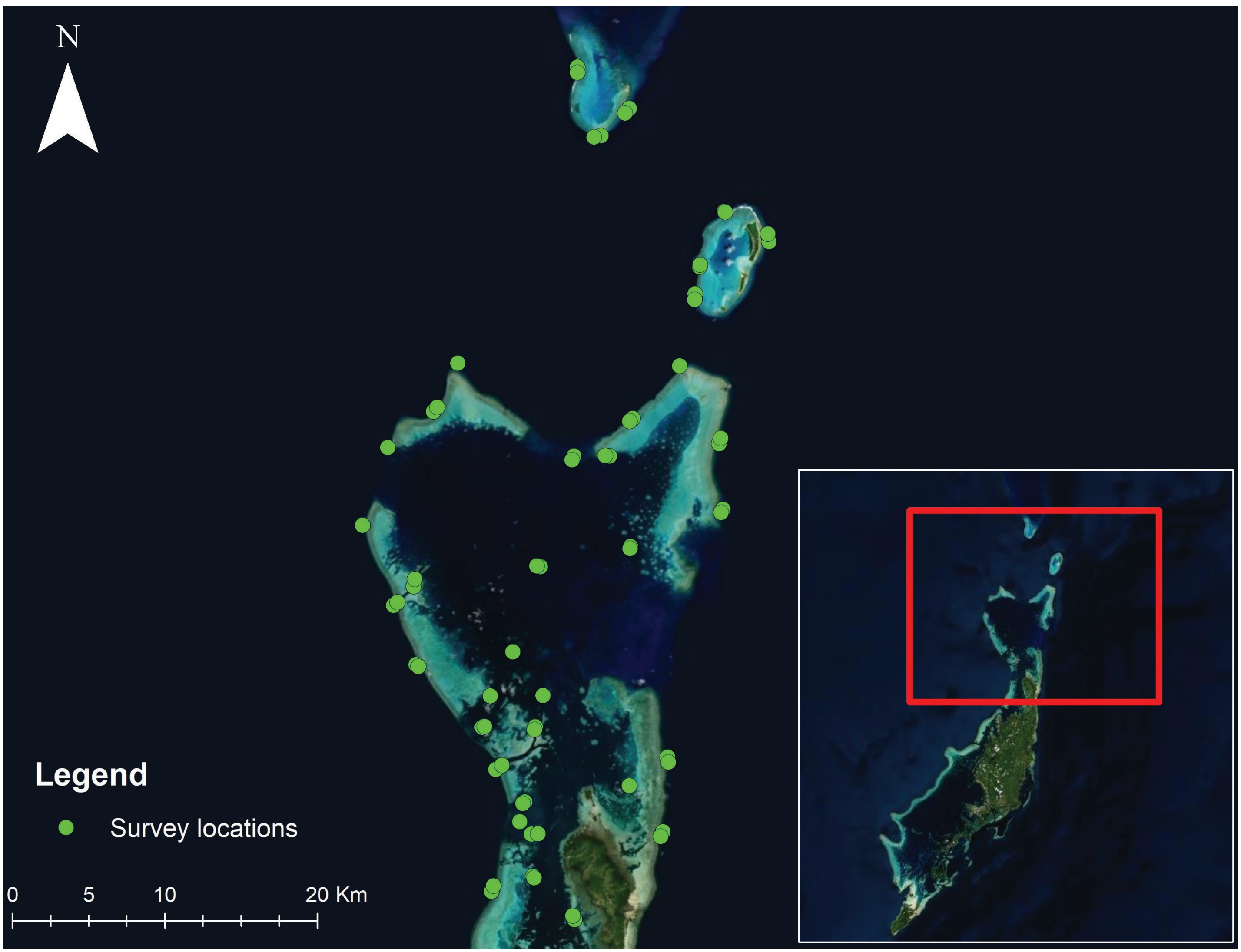


Figure 1:
The 64 survey sites in the northern reefs of Palau that were surveyed consecutively between 2015 and 2017, and were also included in the analysis of fisheries independent underwater survey data.

Statistical analysis

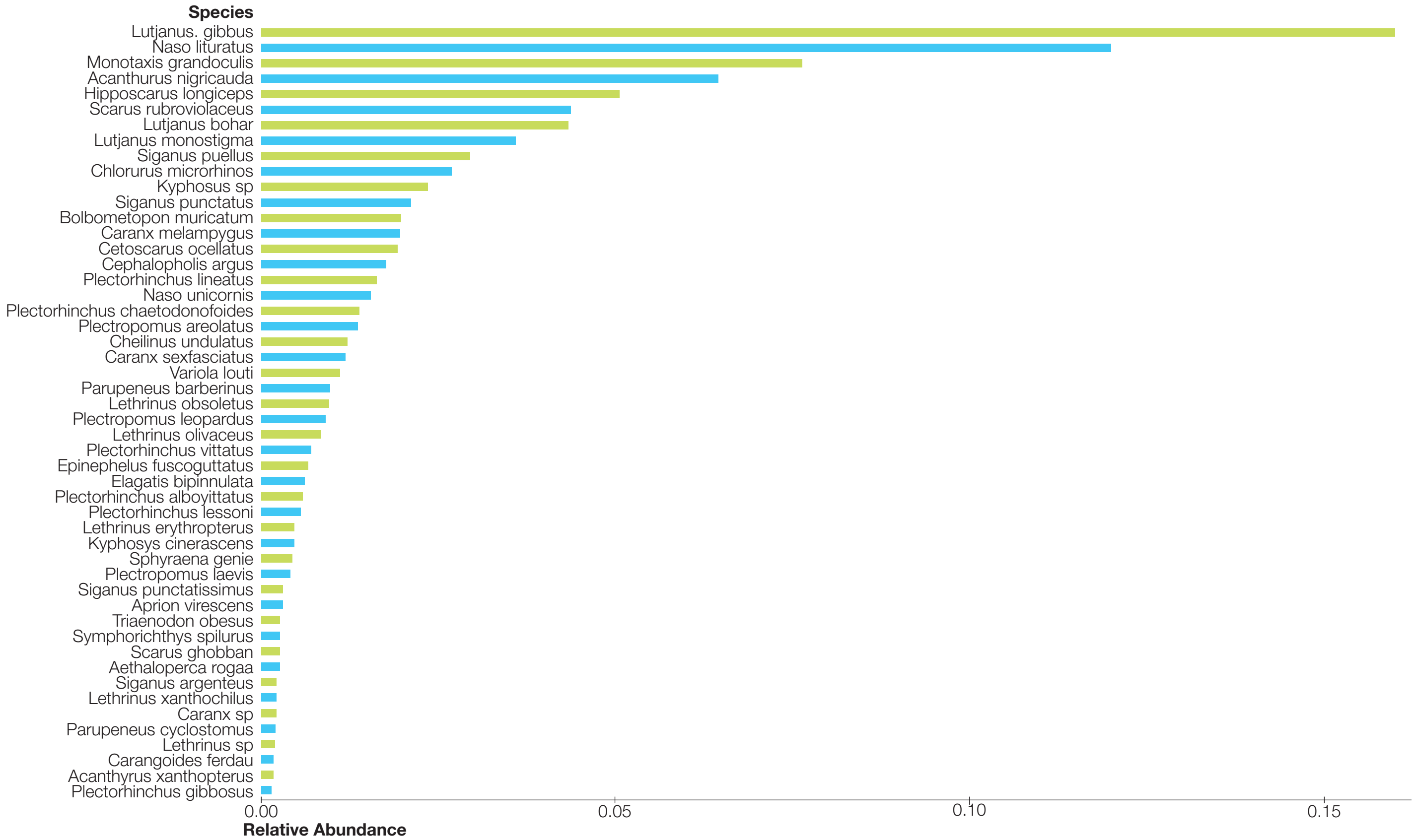
The change in biomass across the three sampling years for each state in the northern reef region (i.e., Ngarchelong and Kayangel) was evaluated by taking the total biomass (grams per-square meter) at each survey location, and calculating the mean of the total annual biomass of the survey locations at each state. The differences in biomass between sampling years were then tested with Kruskal–Wallis one-way analysis of variance using the kruskal.test() function in R, and pairwise comparisons between years were performed with a Wilcoxon rank sum test using the pairwise.wilcox.test() function in R. The species composition of the survey locations was then evaluated by calculating both, the relative abundance (i.e., the total number of a given fishery-targeted species observed during diver operated stereo video surveys, divided by the total number of fish observed from all fishery-targeted species) and biomass (i.e., the total biomass of a given fishery-targeted species, divided by the total biomass of fish observed from all fishery-targeted species) of each species across sampling years. From this data, the top 50 most abundant species were identified, and a literature review was conducted to find the life history parameters of these species; prerequisites to conduct a length-based stock assessment. Because reliable life history data was not available for all 14 regulated species, SPR was not estimated for all species. In addition to the length-based stock assessment, the mean annual biomass was as also calculated for all 14 species at the Family level, and the difference in biomass between sampling years was tested with Kruskal–Wallis one-way analysis of variance, following the procedure described above.

To evaluate the status of the fish stocks in the northern reef region, we filtered the data to exclude all of the length measurements that were estimated from the mean length of that species in a given transect, and estimated the Spawning Potential Ratio (SPR) for each fisheries species that had both the minimum life history data, and sample sizes of at least 50 observations per-sampling year. The SPR of a fish stock is defined as the proportion of unfished reproductive potential remaining in a population at any given level of fishing pressure (*Goodyear 1993; Hordyk et al. 2015*) and is a theoretical ratio of the number of eggs an average recruit could produce over its lifetime in a fished stock, versus the number of eggs an average recruit could produce over its lifetime in an un-fished stock. The SPR model uses a combination of length composition data and life history parameters, including growth rate (K), natural mortality (M), average maximum length (L_∞), length at 50 percent maturity (L_{50}), and length at 95 maturity (L_{95}), to obtain an estimate of a population's current egg production relative to its maximum possible production as a virgin stock. To this end, an estimate of SPR was generated for all species that had a minimum of 50 observations per-sampling year with the growth-structured methods outlined in *Hordyk et al. (2015)*. To account for the limited sample sizes and uncertainty in our length frequency distributions, we aggregated samples from across both states in the northern reef region for each year and followed the procedure of *Prince et al. (2015)*, by generating SPR estimates from both raw data and a bootstrapped dataset, where the length frequency data for each species was resampled with replacement for 1000 iterations (*Prince et al. 2015*). The SPR results for both the raw and resampled datasets were then produced with the LBSPR fit function in the R package LBSPR (*Hordyk et al. 2015; Hordyk 2019*), using the "best life history estimates" for L_{50}, L_{95}, L_∞ and the M/K ratio that are described in *Prince et al. (2015)*.

Results

Over the three sampling years, 7,867 length observations were made from 89 fisheries species in the northern reefs of Palau. Of these observations 4,710 (60%) were mesured with EventMeasure software and 3,157 (40%) were estimated based on the mean length of the species in each transect. The top five most abundant fisheries species by relative abundance were *Lutjanus gibbus* (16%), *Naso lituratus* (12%), *Monotaxis grandoculis* (8%), *Acanthurus nigricauda* (6%), and *Hipposcarus longiceps* (5%), collectively these five species accounted for 47 % of the fisheries species observed in the surveys of the northern reefs (Figure 1). The top five most abundant fisheries species by relative biomass were *Naso unicornis* (13%), *Lutjanus gibbus* (12%), Bolbometopon muricatum

(10%), *Lutjanus bohar* (8%), and *Symphorichthys spilurus* (6%), collectively these five species accounted for 49 % of the biomass observed in the surveys of the northern reefs (Figure 2)



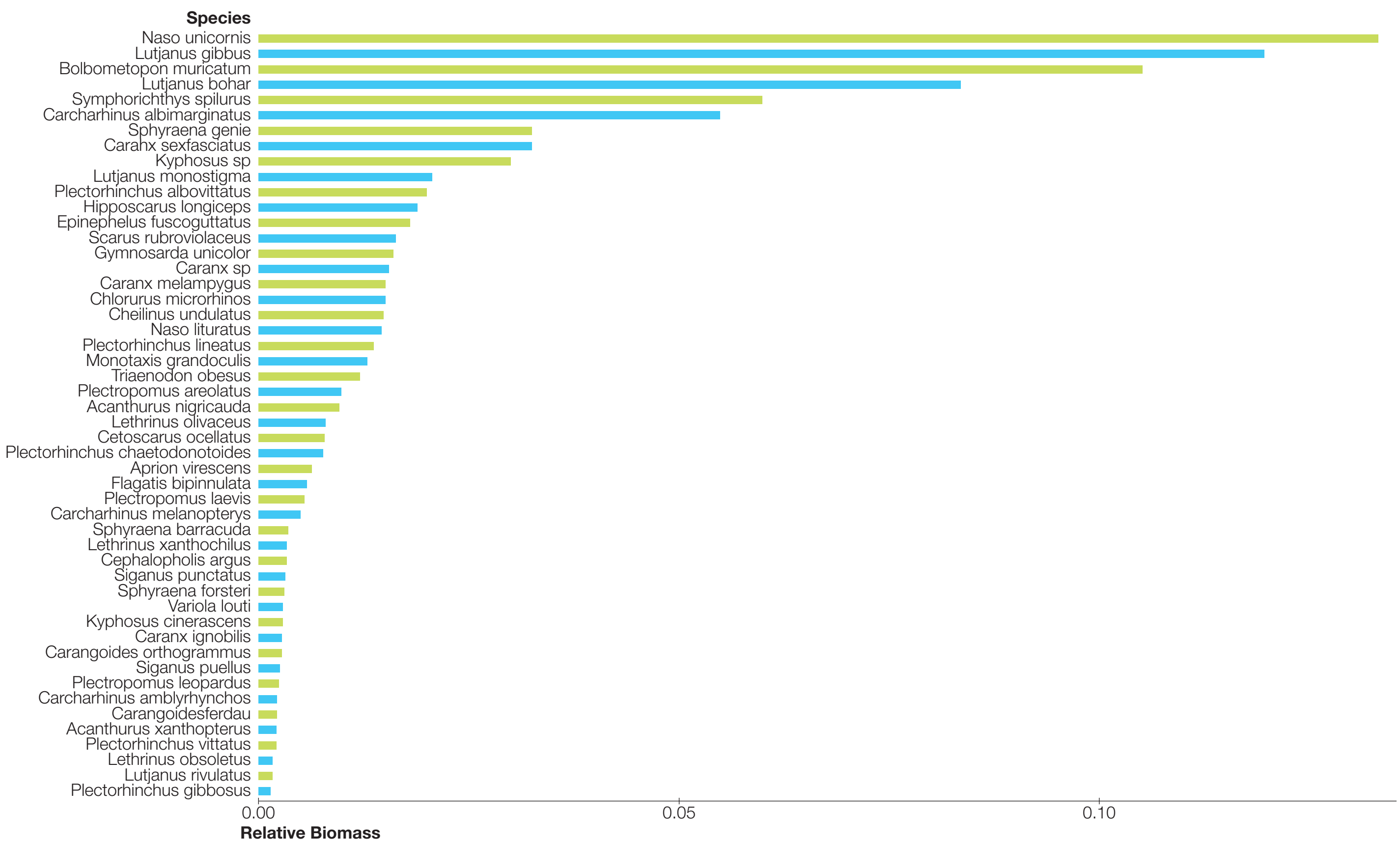


Figure 2:

The relative abundance and relative biomass of the top 50 fishery species observed in diver operated stereo video surveys in the northern reefs from 2015 to 2017.

Using the 4,710 observations that were mesured with EventMeasure software, the mean total biomass of fisheries species observed in the state of Ngarchelong, was 24 ± 72, 5 ± 6, and 14 ± 21 grams per-meter squared from 2015 to 2017, respectively (Figure 3). The results of the Kruskal–Wallis one-way analysis of variance indicates that these differences were significant (P<.005) and a Wilcoxon rank sum test indicates that the observed differences in biomass between 2015 and 2016 (P<.05) and 2016 to 2017 (P<.005) were significant, but no significant differences existed between 2015 to 2017. These fluctuations in mean total biomass of fisheries species suggest that biomass in Ngarchelong declined significantly in 2016, but in 2017, returned to a level that was equivalent to the biomass previously observed in 2015. The mean total biomass of fishery species in Kayangel fluctated and was estimated at 28 ± 39, 10 ± 12, and 20 ± 24 grams per-meter squared between 2015 to 2017, however, when tested with Kruskal–Wallis one-way analysis of variance these differences in mean biomass across sampling years were not significant (Figure 3).

The changes in the mean biomass for the five Families of the 14 regulated species indicate that the biomass of the Family Acanthuridae, which in this case represents *Naso unicornus*, declined across the sampling years 2015 (1.24 ± .37), 2016 (.83 ± .30) and 2017 (.89 ± .55). These differences in *Naso unicornus* biomass were significant (P<.005), with a Wilcoxon rank sum test indicating that biomass, declined significantly between 2015 to 2016 (P<.005), but remained stable in the following years (Figure 4). The biomass of the Family Serranidae, increased across the sampling years 2015 (.76 ± 1.34), 2016 (.96 ± 1.34), and 2017 (1.12 ± 1.17), and these differences were significant between 2015 to 2017 (P<.005). The biomass of the Family Scaridae, remained relatively stable across the sampling years 2015 (.41 ± .19), 2016 (.46 ± .28) and 2017 (.45 ± .33) and these minor differences were not significant. The biomass of the Family Lethrinidae, fluctuated between .62 and.20, but these differences were not significant. Finally, the biomass of the Family Lutjanidae fluctuated between .37 and .52 between years, but these differences were not significant (Figure 4).

After filtering the data to exclude sample sites that were not surveyed in each of the three sampling years, and

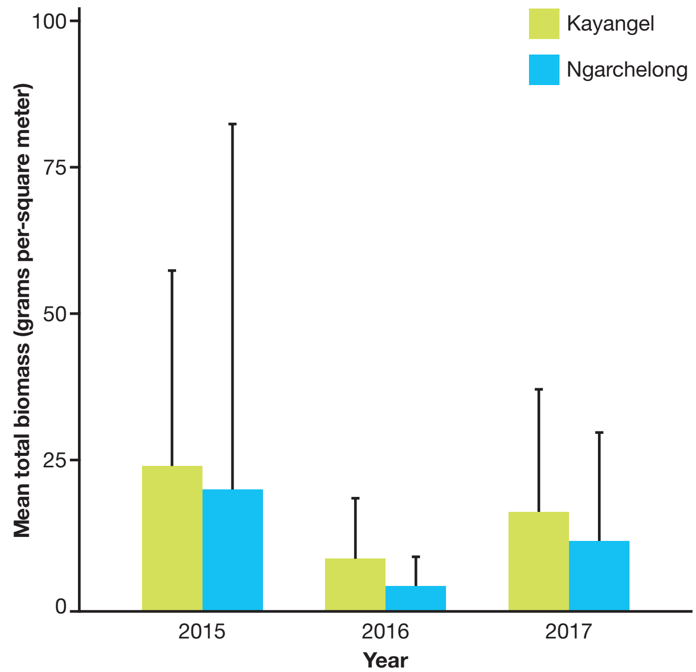


Figure 3:
The mean total biomass of fishery species at each site observed during diver operated stereo video surveys in the states of Ngarchelong (green bars) and Kayangel (red bars) during 2015 to 2017 (error bars represent standard deviations from the mean).

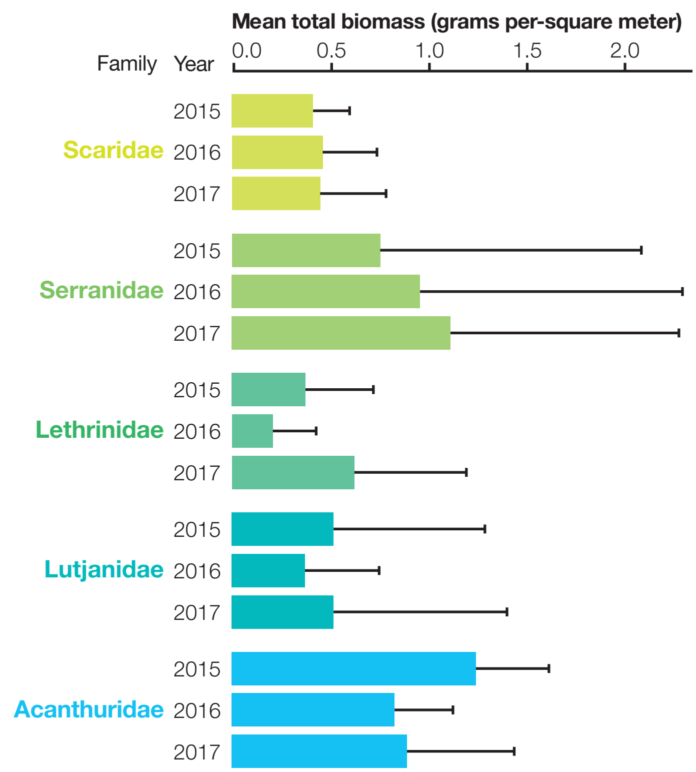


Figure 4:
The mean biomass of regulated species from five Families observed during diver operated stereo video surveys in the states of the northern reefs, from 2015 to 2017 (error bars represent standard deviations from the mean).

excluding length measurements that were estimated from mean length, as opposed to fish measured with EventMeasure software, sample sizes were too small to evaluate SPR for 13 out of the 14 regulated species (Table 2). *Lutjanus gibbus* was the only species with more than 50 observations in each sampling year (Figure 5) and using the life history parameters (L_{50} = 25.7cm FL, L_{95} = 32 cm FL, L_{∞}= 34.3 cm FL and an M/K ratio of 0.41) provided by *Prince et al. (2015)*, its SPR remained between 12 and 15% throughout the study period (Figure 6, Table 3).

Table 2:
The sample sizes of fisheries species in the northern reef region of Palau with measured sizes in EventMeasure software from 2015-2017.

Year	Species	n
2015	*Lutjanus gibbus*	503
2016	*Lutjanus gibbus*	76
2017	*Lutjanus gibbus*	235
2015	*Lutjanus bohar*	104
2016	*Lutjanus bohar*	24
2017	*Lutjanus bohar*	53
2015	*Variola louti*	16
2016	*Variola louti*	1
2017	*Variola louti*	18
2015	*Plectropomus leopardus*	35
2016	*Plectropomus leopardus*	6
2017	*Plectropomus leopardus*	14
2015	*Plectropomus laevis*	8
2016	*Plectropomus laevis*	4
2017	*Plectropomus laevis*	16
2015	*Plectropomus areolatus*	4
2016	*Plectropomus areolatus*	15
2017	*Plectropomus areolatus*	55
2015	*Naso unicornis*	45
2016	*Naso unicornis*	11
2017	*Naso unicornis*	18
2015	*Lethrinus xanthochilus*	4
2015	*Lethrinus olivaceus*	7
2016	*Lethrinus olivaceus*	1
2017	*Lethrinus olivaceus*	13
2015	*Lethrinus obsoletus*	28
2016	*Lethrinus obsoletus*	3
2017	*Lethrinus obsoletus*	11
2015	*Hipposcarus longiceps*	117
2016	*Hipposcarus longiceps*	18
2017	*Hipposcarus longiceps*	47
2017	*Epinephelus polyphekadion*	1
2015	*Epinephelus fuscoguttatus*	3
2016	*Epinephelus fuscoguttatus*	8
2017	*Epinephelus fuscoguttatus*	23
2015	*Chlorurus microrhinos*	42
2016	*Chlorurus microrhinos*	52
2017	*Chlorurus microrhinos*	69
2015	*Cetoscarus ocellatus*	26
2016	*Cetoscarus ocellatus*	25
2017	*Cetoscarus ocellatus*	29

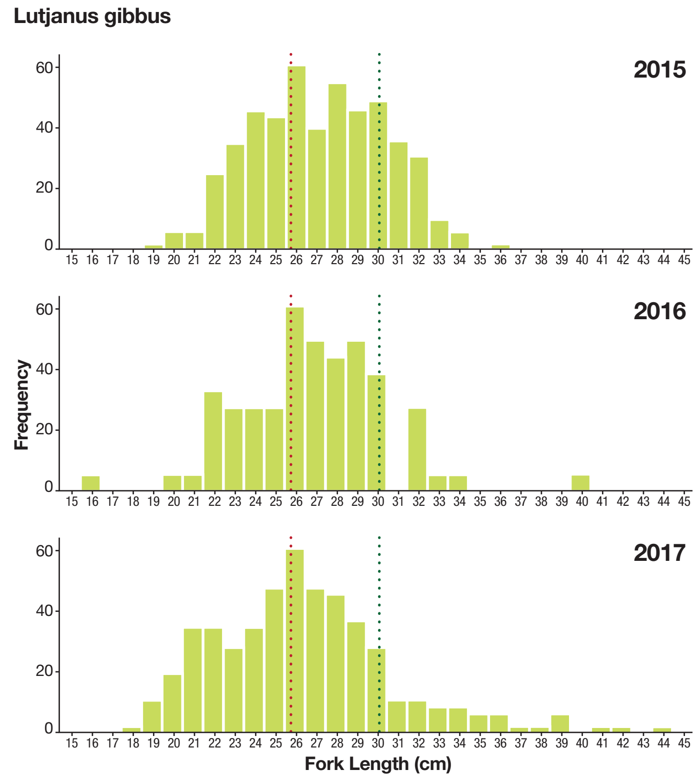


Figure 5:
The size-frequency distributions of *Lutjanus gibbuss* in fork length (raw data that was not resampled) observed in diver operated stereo video surveys of Palau's northern reefs, from 2015 to 2017, and used to estimate the Spawning Potential Ratio of the species across the study period. The length at maturity, which corresponds to the length of minimum harvest size in Ngarchelong (red dashed line, 25.7 cm) and length of minimum harvest size in Kayangel (green dashed line, 30cm), overlaid on the size frequencies.

Year	Species	N	SPR	SPRboot
2015	*Lutjanus gibbus*	503	13	12
2016	*Lutjanus gibbus*	76	12	12
2017	*Lutjanus gibbus*	235	15	15

Table 3:
The sample sizes and Spawning Potential Ratios (SPRs) for *Lutjanus gibbuss* in the northern reef region of Palau from 2015-2017. The column SPR provides yearly estimates derived from raw length frequency data, and the column SPRboot provides yearly estimates derived from the length frequency distributions that were randomly resampled with replacement 1,000 times.

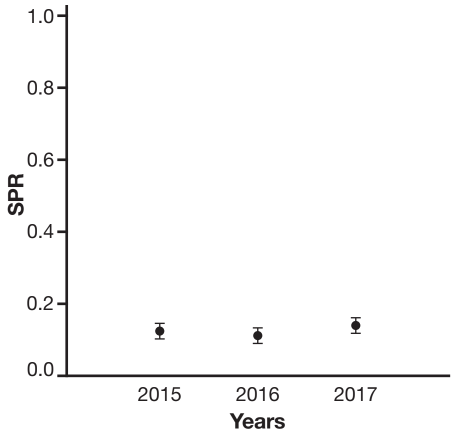


Figure 6:
The bootstrapped estimates of Spawning Potential Ratios (SPRs) for *Lutjanus gibbuss* in the northern reef region of Palau from 2015-2017 (error bars represent the variance of the SPR estimates, see Table 3 for SPR estimates from raw data).

Discussion

The results of the analysis presented above are based on limited sample sizes and, as a result, there is uncertainty associated with these estimates and the status of these fisheries species. Nevertheless, this data provides some important insights into the condition of the northern reef fishery, that can guide future research and discussions on potential management initiatives. The changes in the mean biomass for the five Families of the 14 regulated species indicate that the biomass of *Naso unicornus* declined, *Serranidae* increased, and the biomass of *Lethrinidae*, *Scaridae* and *Lutjanidae* remained relatively stable. The decline in biomass of *Naso unicornis* may be a reflection of the limited regulations that were established for this species, as its harvest remains unregulated in Ngarchelong, and in Kayangel a minimum size limit of 40 cm FL was enacted in 2016. *Naso unicornis* are a long-lived species that is notoriously vulnerable to overexploitation via night time spearfishing (*Taylor 2014; Andrews et al. 2016*), and these results suggest that the current regulations for this species are insufficient to maintain its biomass. In contrast, the increasing biomass of the Family *Serranidae* may be a response to the more conservative fisheries conservation regulations enacted for this Family over the course of the study period, as *Plectropomus leopardus, Plectropomus areolatus, Plectropomus laevis, Epinephelus fuscoguttatus,* and *Epinephelus polyphekadion* were protected with a 3-year moratorium on harvesting, starting in 2015. The observed increase in biomass of these species suggests that a reduction in fishing mortality may have allowed these species to live longer and grow to larger sizes, which is reflected in the increase in biomass of this Family. Even though these results are positive, there were insufficient sample sizes to estimate the SPR of these individual species, and therefore, robust conclusions cannot be made on their status from this Family level analysis.

Lutjanus gibbus was the most abundant species numerically speaking, representing 12 % of the biomass on the northern reefs, and was the only species with an adequate sample size to estimate SPR. To remain consistent with previous research conducted in the region, we used the same life history estimates described by *Prince et al. (2015)* to model the SPR of this species, and this data suggests that in comparison to the 2013 estimates provided by *Prince et al. (2015)*, the SPR of *Lutjanus gibbus* increased from 10 % in 2013 to a high of 15% across the three years of the study period. To put this result into context, an SPR between 20 to 40 % is considered to be the minimum egg production required to maintain fish stocks, while SPRs less than 20% are symptomatic of overexploitation (*Goodyear 1993; Clark 2002; Ault et al. 2008; Nadon et al. 2015; Kindsvater et al. 2016*). In response to the low SPR and overexploited status of this species, the minimum harvest size for *Lutjanus gibbus* was set at 25 cm in Ngarchelong during 2017 and 30 cm fork length in Kayangel, in 2016. The fisheries dependent data presented in the next chapter of this report indicates that the sizes of *Lutjanus gibbus* sold at the fisheries co-operative of the northern reefs shifted to meet these minimum size requirements (cite Christina's chapter on fishery co-operative data), and the boot strapped estimates of SPR suggest that an increase in SPR from 12 to 15% occurred in 2017. Provided the observed increase in SPR for *Lutjanus gibbus* is accurate, this study suggests that the status of *Lutjanus gibbus* may be improving in response to the length-based size limitations enacted to conserve this species. However, it should be noted that the fisheries independent data obtained from diver surveys presented here, is different from fisheries dependent data that was collected directly from fishermen by *Prince et al. (2015)* and the differences between the two methodologies, as well as low sample sizes, may drive the moderate changes in SPR that were found between these two studies.

This analysis was limited by the small sample sizes of fisheries species that were obtained from the current sampling design, which prohibited the assessment of SPR for many species, and highlights the need for continued research and improved fisheries independent monitoring. Length-based stock assessments, like SPR, require length-frequency distributions that are representative of the complete size range of fish present in the stock and, at a minimum, sample sizes need to be in the hundreds for robust results to be obtained from this methodology (*Hordyk et al. 2015*). These assessments and future monitoring efforts can be improved by maintaining a higher rate of sampling. As noted above, 190 sites were sampled in 2015, but the number of sites sampled declined to 64, in 2016, and 66 sites, in 2017. This reduction in sampling effort reduced the amount of available data for a length-based assessment of the 14 regulated species across the three years of the study. To determine the appropriate number of sampling sites for future surveys, the average number of each species of interest that is encountered per-site could be determined, and the total number of sites required to obtain a robust sample size could then be estimated. Additionally, a review of the methodology utilized to measure the size of fish during the post-survey video analysis with EventMeasure software, may increase the sample sizes obtained from these surveys. As noted above, the sizes of 40 % of the fish observed in diver operated surveys could not be accurately measured with EventMeasure software, and this rendered much of the data unusable for length-based stock assessment. Provided post-survey video processing can be enhanced, the amount of usable data obtained from these surveys would increase substantially and permit length-based stock assessment for additional species.

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Northern Reef Fisheries Management Project Fishery-Dependent Monitoring

1. Introduction

Fishery-dependent monitoring of reef fish stocks in the Northern Reefs (NR) of Palau began in August 2012 by TNC, with the assistance of Dr Jeremy Prince, with the aim of providing baseline information to improve the management of fish stocks in the NR (*Prince et al., 2015*). In 2015, the Northern Reef Fisheries Cooperative (NRFC) was established with the aim of recovering fish stocks and promoting sustainable fisheries to benefit local communities and protect marine resources and biodiversity.

Ngarchelong and Kayangel states also enacted legislation in the NR in 2015, placing a three-year moratorium on certain grouper species and in 2016 and 2017 minimum size limits were implemented for additional reef fish species (The Nature Conservancy, 2016). To monitor the response of fish stocks to these new management regulations, TNC carried out further fishery-dependent monitoring in Ngarchelong and Kayangel, with assistance from the Palau International Coral Reef Center (PICRC).

2. Methods

From August 2012 to November 2013, fish length data, mostly from reef fish landings, were manually collected by Palauan fishers after they were trained in data collection methods. Following the creation of the NRFC in 2015, there were three distinct monitoring periods; June 2015 to March 2016 (2015-2016) (*Lindfield, 2016*), March 2017 to April 2018 (2017-2018) and August 2018 to December 2019 (2018-2019). During this time, fishermen selling their fish to the NRFC were asked to answer a short interview and a 3D camera was used to film or take photos of their fish landings at the main ports in Ngarchelong and Kayangel. Since the data from 2015 onwards was only collected from fishermen selling their catch to the NRFC, the results of this report are only informative of the NRFC fishery and are not representative of the whole NR fishery.

3. Results

3.1 Survey effort

A total of 439 fisher interviews were completed during the whole project, including 53 in 2015-2016, 130 in 2017-2018 and 256 in 2018-2019. A total of 340 landings that were recorded with the 3D camera were usable for analysis, including 46 in 2015-2016, 74 in 2017-2018 and 220 in 2018-2019. In 2012-2013 a total of 3,268 fish were measured, in 2015-2016 a total of 1,896 fish were measured, in 2017-2018 a total of 951 fish were measured, and in 2018-2019 a total of 2,659 fish were measured.

3.2 Interview data

3.2.1 Fishing method

Fishing methods associated to NRFC landings have fluctuated over time, with an overall decrease in spear fishing seen (Figure 2). In 2015-2016, handline was the most popular fishing method (37.7%), followed closely by spear fishing (34%). In 2017-2018, trolling was the most popular fishing method used, with more than half of all fishing trips using this method (57.7%), whereas spear and handline fishing use decreased from the last monitoring period (16.9% and 13.8% respectively). In 2018-2019, there was a decrease in trolling, however this method still remained the most popular (44.1%), with handline fishing being the second most popular fishing method (36.3%).

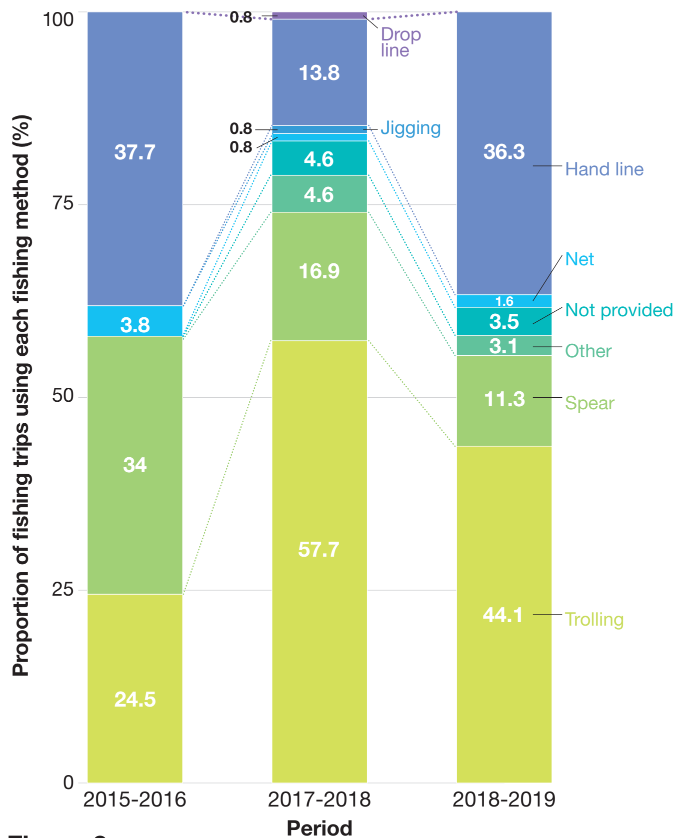


Figure 2.
Percentage of fishing trips that used different fishing methods in each survey period.

3.2.2 Habitat fished

Over time there has been an increase in channel and offshore fishing and a decrease in lagoon patch reef fishing (Figure 3). In 2015-2016, the habitat that was fished the most was lagoon patch reef (30.2%). In 2017-2018, habitat type was not provided for more than a quarter of interviews, however with the information provided the habitat fished the most was offshore (20%). In 2018-2019, the habitats fished the most were channel (26.2%) and offshore (25%).

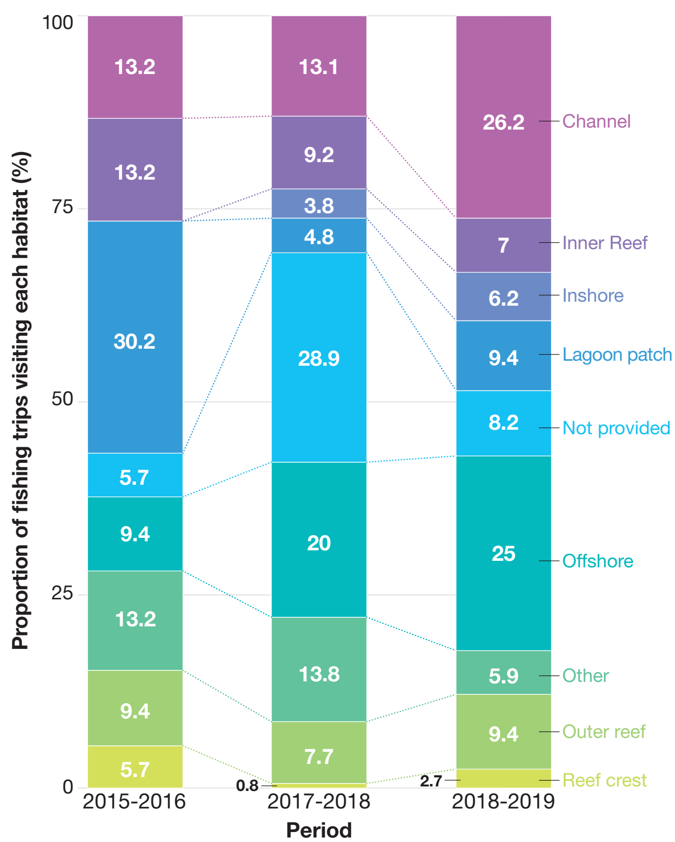
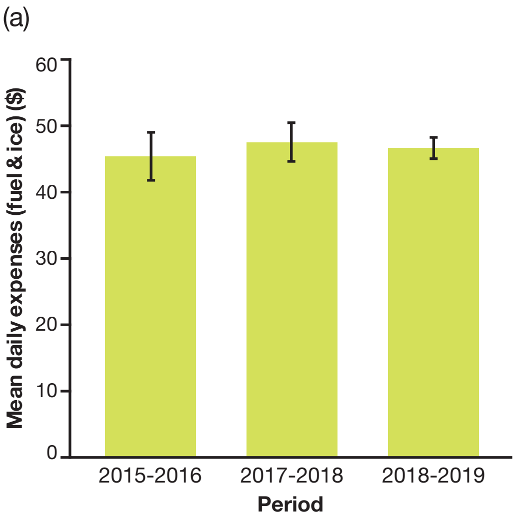


Figure 3.
Percentage of fishing trips that fished in different habitats in each survey period.

3.2.3 Daily expenses and cost per pound of fish

Mean daily expenses, including fuel and ice, which were recorded during fisher interviews, were similar between all three survey periods at around $ 45-46 (Figure 4a). Mean daily expenses by fishing method were highest for trolling in all three time periods, followed by handline and spear fishing. None of the three fishing methods were significantly different across periods (Figure 4b). Not enough data was available to assess other fishing methods.



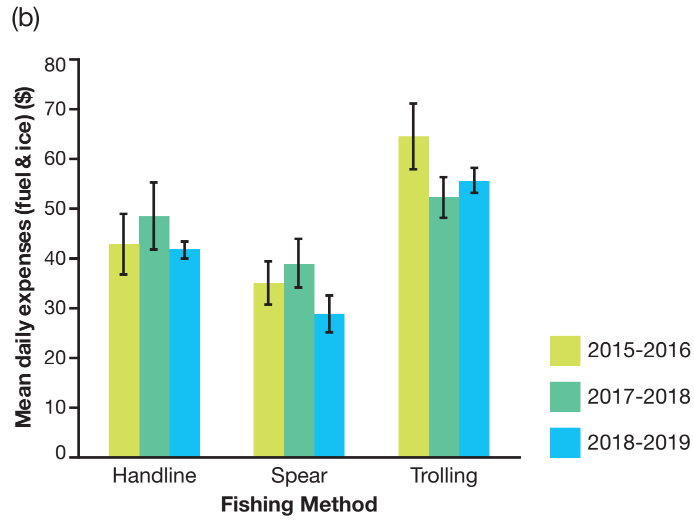


Figure 4.
Mean daily expenses (fuel and ice) in each survey period (a) and by fishing method with sufficient data (b).

Mean fishing cost per pound of fish caught, was significantly higher in 2018-2019 (1.02 ± 0.07 $ per lb) compared to 2017-2018 (0.53 ± 0.05 $ per lb) for all fishing methods combined ($p<0.001$). Mean fishing cost per pound of fish caught by trolling also doubled from 0.55 ± 0.06 $ per lb in 2017-2018 to 1.18 ± 0.16 $ per lb in 2018-2019 ($p<0.001$) (Figure 5). Not enough data was available to assess other fishing methods.

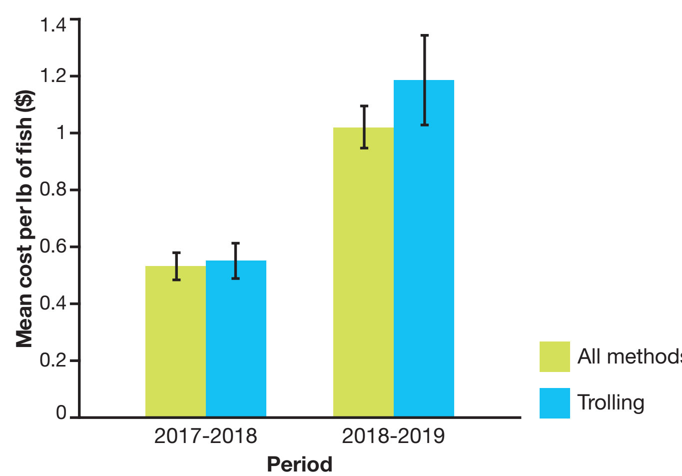


Figure 5.
Mean fishing cost per pound of fish caught in each survey period for all fishing methods and for trolling. Total catch data was not collected in 2015-2016.

3.2.4 Catch per unit effort (CPUE) and total catch

Mean CPUE for all fishing methods combined was similar in 2017-2018 and 2018-2019, at around 7-8 lbs per hour. There was also no significant difference in mean CPUE from trolling between 2017-2018 and 2018-2019 (Figure 6a). However, mean total catch for all fishing methods combined was significantly higher in 2017-2018 compared to 2018-2019 ($p<0.001$). Mean total catch by trolling was also significantly higher in 2017-2018 (95.5 ± 8.9 lbs) compared to 2018-2019 (71.2 ± 5.3 lbs) ($p<0.05$) (Figure 6b).

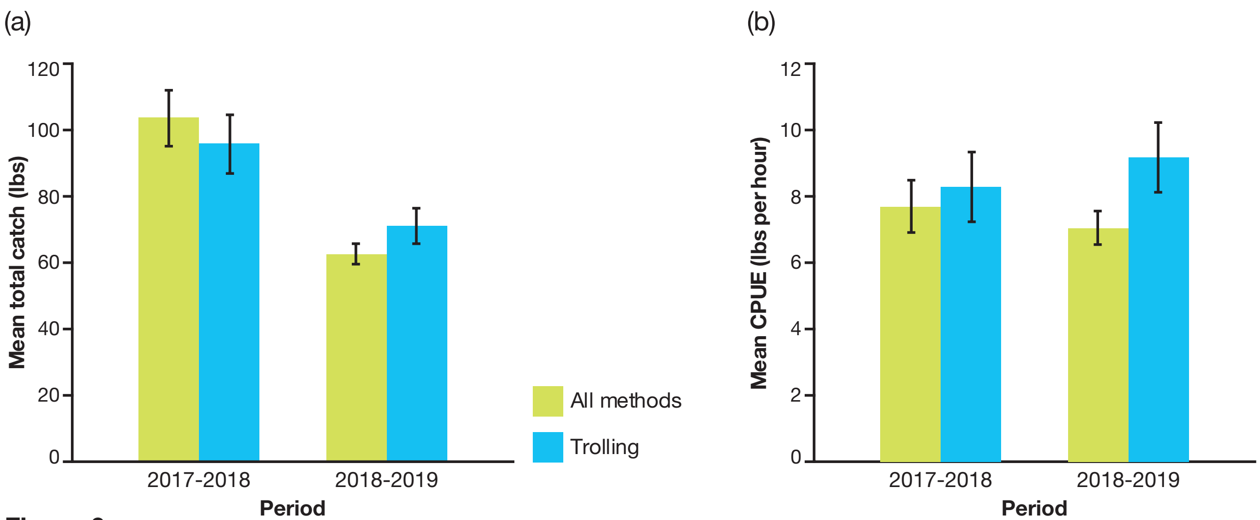


Figure 6.
Mean catch per unit effort (CPUE) (a) and mean total catch (b) in each survey period for all fishing methods and for trolling. Total catch data was not collected in 2015-2016.

3.3 Species data

3.3.1 Species contribution to landings

In 2012-2013, Lethrinus olivaceus contributed the highest percentage by weight to landings (13.5 % - 338 kg), followed by *Lutjanus gibbus* (12.3 % - 307 kg) and *Chlorurus microrhinos* (10.3 % - 257 kg) (Figure 7). In 2015-2016, *Chlorurus microrhinos* made up almost a quarter of the landings by weight (23.8% - 391 kg). In 2017-2018, *Sphyraena barracuda* had the highest contribution (17.7 % - 543 kg), followed by *Thunnus albacares* (14.6 % - 447 kg) and *Chlorurus microrhinos* (11.4 % - 350 kg). In 2018-2019, *Plectropomus areolatus* had the highest contribution (22.5 % - 1311 kg), followed by *Sphyraena barracuda* (14.4 % - 841 kg). From 2012-2013 to 2018-2019, the biggest differences in species contribution to landings were a 14.8 % increase in *Plectropomus areolatus,* 13.8 % increase in *Sphyraena barracuda* and a 10.4 % decrease in *Lutjanus gibbus* (Figure 8). See full report in the Appendix for total weight of important species per survey period.

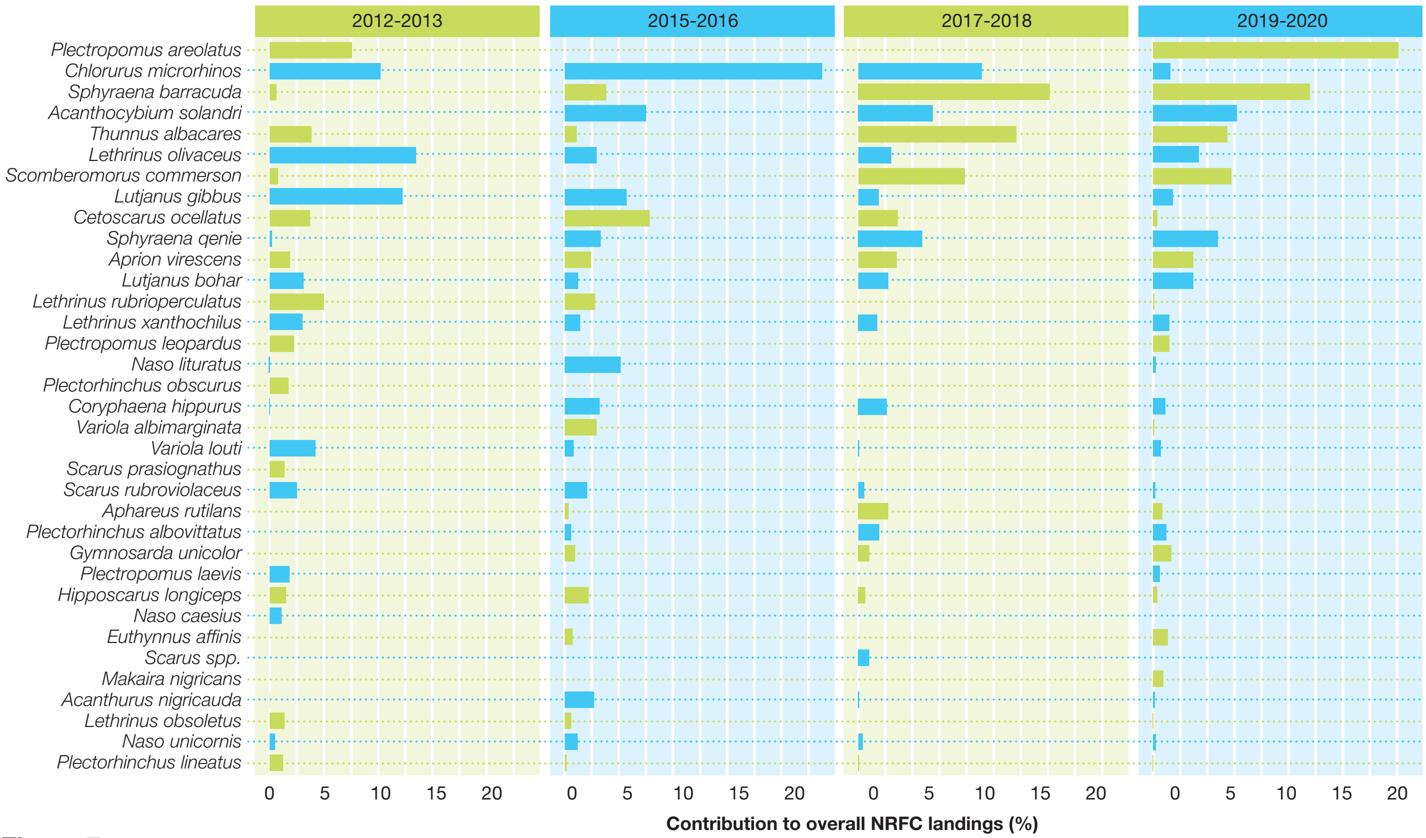


Figure 7.
Species contribution to landings (%) over time by weight. Reef fish-dominated landings in 2012-2013, and NRFC landings thereafter. Only species contributing >1% to landings are shown.

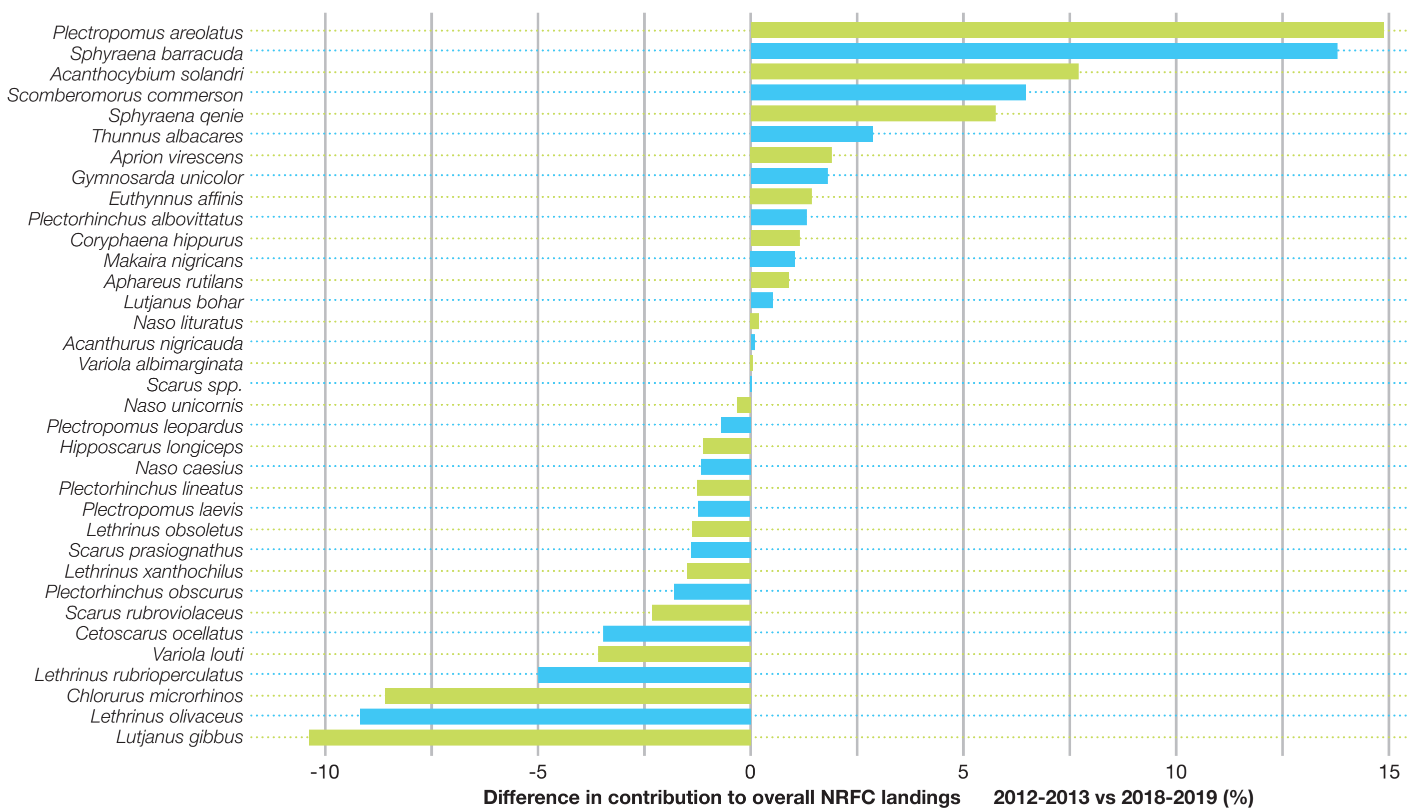


Figure 8.
Difference in species contribution between reef fish-dominated landings in 2012-2013, and NRFC landings from 2018-2019 (% of total weight).

3.3.2 Species size structure

There was only sufficient data available to conduct overtime size-structure comparisons for nine species (*Plectropomus areolatus, Lutjanus gibbus, Lethrinus olivaceus, Lethrinus xanthochilus, Plectropomus leopardus, Variola louti, Lutjanus bohar, Chlorurus microrhinos* and *Cetoscarus ocellatus*). Of those, seven species had minimum size regulations established in 2016 and/or 2017 (*Lutjanus gibbus, Lethrinus olivaceus, Lethrinus xanthochilus, Variola louti, Lutjanus bohar, Chlorurus microrhinos* and *Cetoscarus ocellatus*). In addition, a full harvest ban was in place between 2015 and 2018 for three of those species (*Plectropomus areolatus, Plectropomus leopardus* and *Variola louti*). See full report in the Appendix containing length-frequency distributions for all nine species.

Plectropomus areolatus

From 2012-2013 to 2018-2019 there was a clear shift from smaller to larger fish being caught; however, in 2018-2019 there were still some fish (1.62% of total landings) being caught that were below the minimum size limit (Table 1). When fish below the minimum size limit were excluded, the distribution was found to be significantly different between the two time periods, as larger fish were found in landings from 2018-2019 ($p<0.001$). We also examined the changes between the peak month of landings right after the 3-year moratorium was lifted and a year later (November 2018 and November 2019). Analysis revealed a significant shift to smaller fish from 2018 to 2019 ($p<0.001$), with only 14.6 % of fish larger than 500 mm caught in November 2019, one year after the three-year ban was lifted, compared to 32.3 % in November 2018. The size structure observed in the peak November month of 2019 highly resembled that of 2012-2013.

Lutjanus gibbus

From 2012-2013 to 2018-2019, there was a clear shift from smaller to larger fish being caught, however in 2018-2019 there were still some fish (9.66 % of total landings) being caught below the minimum size limit (Table 1). When fish below the minimum size limit were excluded, the distribution was found to be significantly different between the two time periods ($p<0.001$).

Lethrinus olivaceus

From 2012-2013 to 2018-2019 the length-frequency distribution shifted to fewer small fish being caught, however in 2018-2019 there were still fish (7.69 % of total landings) caught that were below the minimum size limit (Table 1). When fish below the minimum size limit were excluded, the distribution was found to be significantly different between the two time periods ($p<0.01$).

Lethrinus xanthochilus

From 2012-2013 to 2018-2019, fewer small fish were caught, however there were still fish (4.71 % of total landings) caught below the minimum size limit in 2018-2019 (Table 1). When fish below the minimum size limit were excluded, the distribution was found to be significantly different between the two time periods ($p<0.01$).

Variola louti

From 2012-2013 to 2018-2019 there was a large shift in the length-frequency distribution from the majority of fish being caught below the minimum size limit (60.6 %), to almost all fish being caught above the minimum size limit in 2018-2019, apart from 1.79 % of total landings (Table 1). When fish below the minimum size limit were excluded, the distribution was found to be significantly different between the two time periods ($p<0.001$). There was insufficient data for a comparison after the 3-year ban in Kayangel, between November 2018 and November 2019.

Lutjanus bohar

From 2012-2013 to 2018-2019 there was a clear shift from smaller to larger fish being caught, however there were still fish (9.09 % of total landings) caught below the minimum size limit in 2018-2019 (Table 1). When fish below the minimum size limit were excluded, the distribution was found to be significantly different between the two time periods ($p<0.001$). The sample sizes for L. bohar were low and the results should therefore be treated with caution.

Cetoscarus ocellatus

The length-frequency distribution was similar between 2012-2013 and 2017-2018, with a slight shift towards larger fish. However, when fish below the minimum size limit were excluded, there was a significant difference between the two distributions ($p<0.01$).

Plectropomus leopardus

From 2012-2013 to 2018-2019 the length-frequency distribution remained similar and in 2018-2019 there was still a small percentage of fish below the minimum size limit (0.77 % of total landings) (Table 1). When fish below the minimum size limit were excluded, the distribution was not significantly different between the two time periods. There was insufficient data for a comparison after the 3-year ban, between November 2018 and November 2019.

Chlorurus microrhinos

The length-frequency distribution was similar between 2012-2013 and 2017-2018. When fish below the minimum size limit were excluded, there was no significant difference between the two distributions.

4. Discussion

Many of the findings in this report cannot be extrapolated with confidence to the overall NR fishery due to the limited number of fishermen selling their catch to the NRFC and subsistence fishing activity not being captured in the data. Based on the list of fishing permits from Ngarchelong issued in 2017 and 2018, an estimated 22.3% of key fishermen sold their catch to the NRFC during the 2015-2016 period, increasing to 28.6% in 2017-2018 and 29.5% in 2018-2019. In addition, a recent study from 2018 found that only 11% of fish caught in Ngarchelong are sold (James, 2019), whereas a study by the Ebiil Society in 2011 and 2012, estimated that around 42% of the fish caught in Ollei Port, Ngarchelong were used for commercial or sales purposes (Singeo et al., 2012). Using the total catch data for November 2011 to November 2012 collected by the Ebiil Society as an estimate of the overall annual landings, an estimated 19% of fish landed in Ollei were sold to the NRFC from November 2018 to November 2019. This is a very rough estimate since total catch data was missing for numerous fishing trips from both 2011-2012 and 2018-2019 but still gives an indication of how the data is limited to a small percentage of fish sold to the NRFC.

Findings related to fishing methods, habitat types and CPUE are especially affected by specific fisher behavior. Fishermen selling to the NRFC may use certain fishing methods over others and target certain habitats and species which also affects CPUE, therefore the data could potentially be very biased. The increase in trolling and fishing in channel and offshore habitats and decrease in spear fishing observed from 2015-2016 to 2018-2019 is likely due to changes in fishermen selling their catch to the NRFC over time. The proportion of fishing trips using trolling was much lower in 2011-2012 (13%) (data from the Ebiil Society study - Singeo et al, 2012) compared to 2018-2019 (44%). The change in methods may also explain the lower CPUE (7-8 lbs per hour) seen in 2017-2018 and 2018-2019 compared to an average of 13.8 lbs per hour in 2011-2012 (Singeo et al., 2012), since trolling is a less efficient fishing method compared to other methods (e.g. Western Pacific Regional Fishery Management Council, 2019). The significantly higher mean cost per pound of fish in 2018-2019 (1.02 ± 0.07 $ per lb) compared to 2017-2018 (0.53 ± 0.05 $ per lb) is consistent with a significantly lower mean total catch in 2018-2019 (62.6 ± 3.0 lb) compared to 2017-2018 (103.3 ± 8.4 lb) for all fishing methods combined. The same pattern was seen for trolling. This may indicate that in 2018-2019 more money was spent on a daily basis to catch less fish compared to 2017-2018, however total catch data was missing for fishing trips from both 2017-2018 and 2018-2019 so these results and results for CPUE may not be reliable.

Similar biases can be expected regarding catch composition, and this is closely linked to fishing methods used by fishers. It is noted that the data only represents what fishers were able to allowed NRFC to collect and does not represent all fishing activities that may have occurred in the NR. The shift in species contribution to a higher percentage of pelagic species such as *Sphyraena barracuda, Acanthocybium solandri, Scomberomorus commerson, Sphyraena qenie and Thunnus albacares and fewer reef species such as Lutjanus gibbus, Lethrinus olivaceus* and *Chlorurus microrhinos* being caught in 2018-2019 compared to 2012-2013 corresponds to the increase in offshore and channel fishing and the increase in trolling. A probable driver of the observed changes is the fact that landings recorded in 2012-2013 included a wider representation of NR fishers, including many spearfishes that exclusively target reef fishes, and whose landings were absent in later monitoring periods. While links to changes in regulations are not clear, NRFC efforts to encourage a shift from reef fishing to pelagic fishing may also be a contributor to this change. Additionally, the Ministry of Education is the largest fish vendor for the NRFC and they preferentially purchase larger fish for the public-school feeding program, which may influence whether fishers target reef or pelagic fish. From 2012-2013 to 2018-2019, the biggest difference in species contribution was a substantial increase in *Plectropomus areolatus* landings. This increase is probably associated with the 3-year ban being lifted in 2018 that lead to a noticeable increase in fishing of this species. Interestingly, stock gains made by this species over the 3-year ban were apparently lost over the course of the next year following reopening, as reflected by a significant shift in the size structure. From November 2018 to November 2019 an increase in smaller fish and decrease in larger fish was seen, with a similar size structure to 2012-2013 seen in November 2019. Low numbers of fish in larger size classes can indicate high mortality of adult fish (*Neumann and Allen, cited in Schultz et al., 2016*) and the increased reliance of NRFC landings on a vulnerable grouper species whose stocks are in very poor condition in Palau is of concern (*Rhodes, 2018; Sadovy, 2007*).

Findings related to species-specific size structures are perhaps more robust than interview data, especially because limited effects of changing fishing methods were found, making these findings potentially more representative of the NR stock status. After minimum size limit regulations were introduced in 2016 and 2017 there was a general shift to more large fish and fewer small fish being caught for seven of the nine species from 2012-2013 to 2018-2019 or 2017-2018 (Table 1). This indicates that the regulations implemented have worked to encourage a reduction in fishing of smaller fish, and that a shift in population structure towards larger fishes is occurring. However, in 2018-2019, there were still fish being caught by fishermen and bought by the NRFC that were below the minimum size limit, for seven of the nine species (Table 1). Some of this can be explained by the accuracy of length measurements, by the fishermen, NRFC and Event Measure program, however some fish were well below the minimum size limit. In addition, anecdotal evidence suggests poorer compliance by fishers who don't sell their catch. This indicates that better enforcement needs to be implemented for fish below the size limits to not be caught. It is noted that a minimum sample size of 50 was used for length-frequency histograms due to a lack of data, however, larger sample sizes are needed for a more accurate assessment of size structure, especially for larger-bodied fish (*Vokoun et al., 2001*). Some species, including *Lethrinus xanthochilus*, *Plectropomus leopardus*, *Variola louti*, *Lutjanus bohar*, *Chlorurus microrhinos* and *Cetoscarus ocellatus*, had a sample size <100 for one or both time periods; the results for these species should therefore be interpreted with caution.

Species	Change in size structure over time	Period	Percentage of fish below minimum size limit (%)
Lutjanus gibbus	Yes	2012-2013 to 2018-2019	9.66
Lutjanus bohar	Yes	2012-2013 to 2018-2019	9.09
Lethrinus olivaceus	Yes	2012-2013 to 2018-2019	7.69
Lethrinus xanthochilus	Yes	2012-2013 to 2018-2019	4.71
Variola louti	Yes	2012-2013 to 2018-2019	1.79
Plectropomus areolatus	Yes	2012-2013 to 2018-2019	1.62
Plectropomus leopardus	No	2012-2013 to 2018-2019	0.77
Chlorurus microrhinos	No	2012-2013 to 2017-2018	0.00
Cetoscarus ocellatus	Yes	2012-2013 to 2017-2018	0.00

Table 1.
Summary of change in size structure over time for nine species with sufficient data (excluding fish below the minimum size limit) and number of fish recorded below the minimum size limit in 2018-2019 or 2017-2018.

6. Recommendations

Due to limited length data, it was only possible to analyze the overtime changes of size structure for nine species. Other species that were under the 3-year moratorium (*Plectropomus laevis*, *Epinephelus fuscoguttatus* and *Epinephelus polyphekadion*) and have minimum size limits (*Hipposcarus longiceps* and *Naso unicornis*) were not able to be assessed. In order to be able to accurately assess the size structure of all species of interest and be able to do further analysis such as estimating spawning potential ratio, more length data is needed from each time period for each species.

A lot of data from both fisher interviews and fish landing videos that could have been used was lost due to poor data collection. Interview forms from 2015-2016 didn't include a field for catch weight but only the number of fish caught, meaning CPUE, cost per pound of fish and total catch could not be calculated for this time period. In addition, a large amount of important information was missing from many interview forms such as fishing method, habitat, expenses, number of people fishing, time spent fishing and catch weight. Many fish landing videos were not usable due to overlapping of fish, part of the fish being cut off from the video, poor image quality such as videos taken at night with poor lighting or fish not being videoed close enough or at an angle that didn't allow for the lowest taxonomic identification. In addition, sometimes fish written on the form were different or did not match up to the species in the videos.

In order to assess the status of fish stocks in the NR, good quality fish landing data representative of the whole NR fishery and not only from fishermen selling their catch to the NRFC should be collected. This would allow a comparison of current data to data collected in 2012-2013, before the NRFC was created. The response of fish species to fishing regulations and comparison of vulnerable grouper species before and after the harvest ban across the whole NR fishery could be assessed. To improve data collection, it is suggested that standardized survey methods are used by trained personnel. This would include using a standardized interview form containing all information required for the desired analysis filled out correctly and in full and good quality fish landing videos allowing for identification and length measurements of all fish landed.

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Appendix

Full Northern Reef Fishery-Dependent Report

Summary Report:

Socio-economic Profile and Economic Valuation of Fisheries and Related Ecosystem Services of the Northern Reefs of Palau

Key Findings

1. Socio-demographic Profile of Northern reef Households and Fishers

According to the socio-economic survey conducted by Isechal et al, 2016, the mean age of fishers in the Northern communities is around 52 years old, ranging from 30-80 years of age. Most fishers are male (95% of all surveyed), and have fished for an average of 28 years. More than half (66%) of all fishers in the Northern communities fish for food, while 33% fish for both personal consumption and income. More than half of all fishers also reported using their own boat for fishing trips, which occur weekly and monthly, primarily. Most fishers in the Northern communities reportedly prefer to catch Emperors, Snappers and groupers amongst others fish species. The most frequently bought fish by households in the Northern communities are surgeonfish, parrotfish and rabbitfish.

1.1 Perceptions of fishers regarding management schemes

Most fishers in the Northern reefs reported having adequate awareness of laws and regulations regarding fisheries. Almost half of all fishers are aware of the regulations within Marine Protected Areas, while 24% are aware of grouper species regulations. The majority of Northern reef fishers (74%) positively support the implementation of fishing licenses, with 89% supporting recreational fishing licenses for tourists, 83% supporting commercial fishing licensing, and 83% supporting licensing for private individuals.

Photo of Northern Reef Kayangel Community members. Photo Courtesy of the Palau International Coral Reef Center.

The valuation of ecosystem services for Palau's northern reefs was computed by using non-market valuation methods, utilizing subsistence and commercial fishing data collected via the Isechal et al 2016 socio-economic study. Complete economic valuation results, and detailed explanations of the supply and demand of non-marketed ecosystem services, are further elaborated in Brander et al, 2016. Results indicate that the Northern reefs of Palau have an estimated annual Gross Revenue from fishing-related activities of approximately US$364,168; a figure that combines the Gross Revenue of all fishing locations. The fishing location, or habitat, with the highest annual Gross Revenue is the Outer reef (US$ 84,977), followed by the Inner reef (US$77,225), and the Lagoon (US$ 60,776). These habitats (Outer reef, Inner reef and Lagoon) remain the most important economical locations for commercial fishing, even when taking into account incurred costs. For the Northern fisheries as a whole, it is estimated that costs only account for 14% of total revenues. These estimated fishing costs, however, are only limited to fishing equipment (boat) and fuel, and do not include any associated labor costs of fishers in the Northern reefs.

Fish Aggregating Device (FAD). Photo courtesy of Bureau of Marine Resources.

2.1 Subsistence Fishing:

Subsistence fishing is highly predominant in Ngarchelong and Kayangel, and strictly refers to the fishing or harvesting of seafood that is consumed and/or exchanged without monetary transactions. Data from the Isechal et al, 2016 household surveys were extracted and used to compute the value of subsistence fishing, including subsistence surplus which are detailed in Brander et al, 2016. Subsistence surplus was calculated using the formula below and based on information related to weight, consumption, and price of fish, in addition to associated costs of fishing and equivalent protein in the Northern reefs. The spatial distribution of consumer surplus was also computed based on the proportion of fishing efforts per fisher, in relation to fishing habitats (locations).

$$\textit{Subsistence Surplus} = \left(\textit{Harvest}_{lbs} * \textit{Price of Fish}_{\frac{\$}{lbs}}\right) - \textit{Harvest Costs}_{\$}$$

In the Northern reefs, the most important locations/habitats based on economic value are the outer reef, inner reef, and lagoon. The total estimated annual value of subsistence surplus for the Northern reefs is of approximately US $150,000, which roughly equates to US$2,200 per household. The highest subsistence surplus was found for the outer-reef habitats, which had an estimated annual value of (US$ 38,851), followed by the inner reef (US $31,296), and lagoon habitat (US$28,420). The remaining fishing locations (Fore reef, Reef Crest, Channel, Inshore), each had an estimated annual subsistence surplus of less than US$ 19,000.

Subsistence fisherman from Ngarchelong. Photo courtesy of The Nature Conservancy.

2.2 Commercial Fishing:

Commercial fishing is simply the harvesting, or fishing, of seafood that is sold or bought through monetary transactions. Valuation of commercial fishing involves the sum of producer surplus of sellers (individuals and businesses), as well as the consumer surplus—the buyers in a market. As opposed to subsistence surplus, producer surplus is calculated by subtracting the costs of fishing, from the total revenue of fishing activities.

The annual producer surplus for the Northern reefs is estimated at approximately US$ 314,000, equating to ~US$ 14,000 per household engaging in commercial fishing. The fishing locations with the highest producer surplus are as follows: Outer reef (US$ 72,401), Inner reef (US$ 67,989), Inshore (US$53,704).

Commercial catch from the Northern reefs. Photo courtesy of The Nature Conservancy.

$$Producer\ Surplus = \left(Harvest_{lbs} * \ Price\ of\ Fish_{\frac{\$}{lbs}} \right) - Harvest\ Costs_{\$}$$

3. Characteristics of the Northern Reef Lower fisheries value chain

In 2019, the fisher-end of Palau's fisheries lower value chain was characterized, and thoroughly detailed, in James et al 2019. The study focused on 4 states in Palau (Koror, Airai, Ngarchelong, and Kayangel), all of which have high fishing-related activities. This summary report only presents the key findings of the value chain analysis for the states of Ngarchelong and Kayangel. Of the two communities in the Northern reef area, 83% of the reef fish are landed by Ngarchelong fishers, making it a dominant fishing area. In addition, more than half (60%) of fish landed in Ngarchelong is used for household consumption purposes, with 26% given away. In Ngarchelong, there is a small and short value chain, which only accounts for 11% of total fish landed, where only 14% is bought locally within Ngarchelong State. Kayangel on the other hand, has no regular selling of fish; with an estimated 400 pounds of fish harvested per week, half is eaten and the remaining half is given away. Of the total given away, 15% is given to the community, while 85% is given to family members. In terms of pelagic fish harvesting, there was reportedly only 5 pelagic fishers in Ngarchelong, and 1 pelagic fisher for the community of Kayangel.

Fish being sold to the NRFC fish market.

4. Conclusions

The results of these socio-economic surveys have been important in guiding engagement efforts with the communities in Ngarchelong, while improving the management of the northern reefs. The strong support from community members to improve management led to the development of marine-resource regulations that implemented a fishing permit system, as well as other fisheries harvest-control rules in the northern reefs. Ngarchelong households still rely on fishing for subsistence, but the economic valuation shows that there is a livelihood potential to be made from fishing, particularly targeting non reef fish species outside of the reef. The lower fisheries value chain analysis also shows that there is very little link to the market. Improving these links around pelagic fisheries offers an opportunity to support the livelihood of fishers in Ngarchelong, and potentially Kayangel.

06 Developing Sustainable Livelihoods

In 2007, while 12% of fishers in Ngarchelong indicated fishing as their primary source of income, 24% reported it being a supplementary source[*1]. In 2014, we identified 87 fishermen, 24 from Kayangel and 63 from Ngarchelong, as the primary fishers in their households; fishing for trade, subsistence, or a combination of both. In 2016 according to a survey by Lukes et al., fishing was yet to become a primary source of income for these communities, with less than 3% of interviewees fishing for profit, and 8% fishing as a means to subsist and/or to trade. Even though 33% of the survey respondents failed to indicate the purpose of their fishing trips, it is safe to assume that similar trends like the ones found in 2007, continue to drive fishing activities today.

There was an overwhelming support from the fishers that we engaged with; and a subsequent survey, in 2016, showed that over 80% of the community agreed to adopt actions that would improve the management of the northern reefs[*2]. Fishers, however, had two major concerns regarding the implementation of management actions, and their impact on fishing activities: (1) enforcement – fishers felt that, unless enforcement was improved, fishers from outer communities would not comply with the established rules and regulations, whilst fishers belonging to the local villages would have to look for other sources of income, and (2) livelihoods – fishers were concerned with the imposition of harvest-control rules and their impact on their livelihoods, giving them no choice but to find alternate activities to support them.

Deep water snapper fishery

Due to their high species value, deep water snappers (*Etelis, Pristipomoides*) were identified as a potential fishery alternative; one that could sustain the livelihood of fishermen. In 2014, efforts were made to engage and train fishermen from Kayangel and Ngarchelong in deep water fishing methods. Staff from Palau Bureau of Marine Resources (BMR) provided the training, which included the use of both, the electric reel, and the traditional drop-stone technique. After several trials, however, in locations identified by fishers from the northern reefs— who have deep water fishing knowledge— fishing efforts did not prove successful. After consulting with experts from SPC, it was determined that Palau's habitat is limited to sustain a deep water snapper fishery, including the species of interest*[3]. With this knowledge in hand, efforts were discontinued to further explore this fishery potential. Exploiting these species for commercial purposes would result unsustainable, and would not meet the needs of fishers in the northern reefs.

Deep water red snapper. @TNC

Sport Fishing

In November 2017, Michel Blanc from SPC conducted a sport fishing assessment in Kayangel. The assessment showed that there is a potential to develop sport fishing and eco- tourism in this state. The assessment also identified key constrains that need to be addressed:

- Very limited workforce (approximately 25 households) in Kayangel;
- Large reef area that is challenging and costly to control;
- Constant influx of marine debris from neighbouring Asian countries;
- Absence of an 'iconic' sport fish species that would appeal to expert anglers;
- Illegal commercial fishing (local and foreign) that may threaten Kayangel's marine resources;
- Sport fishing as currently practised in Palau (including in Kayangel) does not follow the best practices and ethical standards promoted by SPC;
- Absence of petrol retailing in Kayangel;
- Absence of financial incentives for tourism operators e.g. petrol subsidy or discounts on specialised gear;
- Absence of top-of-the-range sport fishing gear and tackle in Palau;
- Cost of travelling to Palau for anglers from key sport fishing markets (US, Australia, Europe);
- Time, efforts and finances required to put Kayangel on the global sport-fishing map.

If this development were to occur and be sustainable, it would be important to maximize existing resources, such as Palau's spectacular and renowned marine ecosystems and biodiversity, and develop and market products that will stand out from the existing, predominantly Koror-based ecotourism fishing industry. It has been suggested that a gradual development approach is likely to have the best chance of success. Firstly, KPAN and the State rangers would need to be trained and empowered, to take up a leading role in the management of eco- and sport-fishing tourism in Kayangel. Secondly, there needs to be a strong advertising campaign. Sport fishing and ecotourism activities would be conducted in Kayangel through a partnership between KPAN and existing tourism operators from Ollei and Koror. Working with local entrepreneurs is critical to ensure that the benefits of sport fishing fall within the local community.

Currently, Koror-based sport fishing companies carry out most of the sport fishing in the northern reefs. Catch and release fishing in the waters of Kayangel and Ngarchelong roughly generate $5-6K*[4] per annum, a sum that includes permit fees for each state. There is only one local company based in Ollei, Ngarchelong that offers sport fishing, but has limited connections to anglers and only offers sport fishing when opportunities arise. Developing a sport fishing sector in Kayangel will require addressing the following:

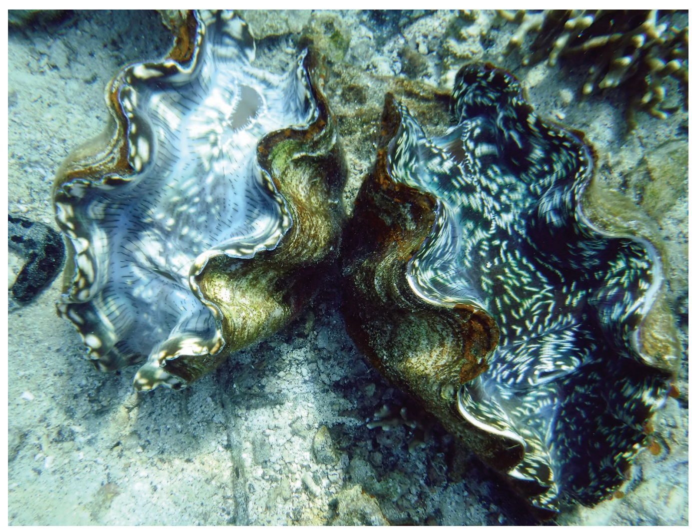
- Develop and market a multi-experience fishing package, with different fishing methods and fishing locations, coupled with other locally managed, eco-friendly tourism products (snorkelling, kayaking, islet trekking, etc.)
- Establish a partnership with accommodation providers in Kayangel. Palau Visitors Authority (PVA) could potentially coordinate, while providing advice and support to increase customer base
- Link Kayangel's sport fishing development to a sustainable national FAD program, with at least one FAD being accessible from Kayangel at any given time
- Establish a partnership between KPAN and selected existing tourism operators from Ollei and Koror, to quick start quality sport fishing operations in Kayangel

Catch and release in the northern reefs. @TNC

- Hire properly trained sport fishing guides (KPAN, rangers, tourism operators)
- Develop an advertising campaign with local guides and skippers, while using social media networks to publicize ongoing sport fishing events in Kayangel

Giant Clam

Palau has had a long history of hatchery production and farming of giant clams, mainly the following species: *Hippopus hippopus*, and *Tridacna crocea, Tridacna squamosa, Tridacna derasa,* and *Tridacna maxima.* Juvenile *Tridacna sp.* are highly priced in the aquarium trade and a farmer can receive $5-8/piece for a clam of 6-14 cm in size, and $10 -15/piece for a size of 15 cm and up. Smaller sizes, up to 14 cm, are usually preferred for the aquarium trade. In 2014, there were 60 members of the Palau Giant Clam Farmers Association, 30 of whom were still actively maintaining their farms. Some farmers, however, had abandoned their farm due to the lack of giant clam seedlings; attributed to the renovation of Palau Mariculture Center's facilities, which went under construction in 2018, halting the production of giant clam seedlings. The new facilities opened in early fall of 2019, with an annual target production of 1M seedlings. In addition to limited giant clam seedlings, many farms were poached, and some farmers decided not to restock their farms. Likewise, in Ngarchelong, there were fishers who farmed giant clams, but had abandoned them due to poaching.



Hippopus hippopus on a clam farm. @BMR

Fishers, however, got interested in farming giant clams again, after a slight improvement in enforcement measures. In 2015, the Ngarchelong PAN Program increased its staff, trained rangers, and brought general awareness to the efforts being made to improve enforcement in the northern reefs. In early 2017, through the Northern Reef Fisheries Cooperative (NRFC), along with Ebiil Society Inc, and the support of Palau Bureau of Marine Resources, 20 giant clam farms were established in the northern reefs —5 in Kayangel and 15 in Ngarchelong. Eight farms are being operated by women and 12 are operated by men. As of March 2019, a total of 1,300 *Tridacna derasa* and 16,000 *Hippopus hippopus* seedlings had been planted in giant clam farms in the northern reefs. *T. derasa* had a 0% survival rate, while *Hippopus hippopus* had a 62% survival rate*[5]. The high mortality rate for *T. deresa* is due to the current location of the farms; a more suitable location for this species needs to be identified. None of the clams from the northern reef farms have been sold to the aquarium trade, due to a lack of connection with the giant clam traders in Palau. Anecdotal stories from farmers indicate that few clams have been sold to local buyers for consumption, but there is no available data to determine how much has been sold, nor the income generated. By establishing links between the clam farmers in the northern reefs and the giant clam exporters for aquarium trade, while having a better control of giant clam sales, NRFC will improve its ability to establish a sustainable giant clam farming that is able to sustain the livelihood of the communities in the northern reef.

Giant clam pen at Ollei. @BMR

Pelagic Fishery

Pelagic fish species have not been traditionally targeted by many Palauan fishers. In recent years, however, an increased understanding of pelagic fisheries, along with the declining of reef fish populations, and the potential tourist demand of pelagic fish within the restaurant market, have created an opportunity to target these species. With the support of the Secretariat of Pacific Community (SPC) and Palau Bureau of Marine Resources (BMR), fishermen have been undergoing trainings on how to capture flying fish (kok), as well as the fish around anchored Fish Aggregating Devices (aFADs).

In 2014, a total of 10 fishers participated in the flying fish training. The workshop included sessions on constructing necessary equipment, as well as night fishing trips. Two two-hour-long fishing trips yielded an average of 80 fish*[6]. The SPC provided the NRFC with equipment, such as scoop nets and head lamps, so fishers could use while on the training. At the same time, several fishing trips were undertaken following the training. The market for flying fish was then explored and flying fish were introduced in the Taro Festival in Ngarchelong in 2018, and at the Night Market in Koror. There was limited market potential, however, and subsequent fishing trips focused on flying fish for bait. There has not been consistent tracking of the fishers that target flying fish, their catch, nor their sales. No efforts are being undertaken to continue to explore the market potential for flying fish.

In 2017, William Sokimi from SPC, assisted by Erbai Yukiwo and Roman Mongami from BMR, trained a total of 14 fishers from NRFC in a FADs fishing techniques; including vertical long lining, fish safety handling, and sea safety. A four day practical training brought in about 400 lbs of tuna. Following the training, NRFC was provided with fishing materials, for fishermen to construct vertical long lines, fish bags, sea safety grab bags, and wooden reels. Less than five fishing trips, however, went to the FADs after training. With a FADs located at least 7 miles from the reef, fishers boat size, which count with single motor engines, pose safety risks for fishers as they travel.

Even though fishing for pelagic fish on a FADs has been limited, some fishers have increased their activity, and have targeted more pelagic species. This effort is driven by market demands from NRFC, as well as the improvement in pricing for pelagic species. Prior to the establishment

Northern Reef fishers's training on vertical long lining. @TNC

of the NRFC, targeting pelagic species was fairly low. In 2012, Ebiil Society Inc. tracked 62 fishers in Ngarchelong and found that only 15% of fishing activities involved trolling—a fishing method that commonly targets pelagic species. In addition, pelagic species only made up about 11% of the total catch (roughly 34,000 lbs, covering both subsistence and sale) for that year*[7]. In 2016, a socio-economic survey conducted by Palau International Coral Reef Center (PICRC), indicated that only 14.5% of respondents preferred trolling. A value chain analysis conducted by SPC in 2019, found that throughout Palau, only about 15% of fishing activities focused on pelagic species*[8]. In 2019, NRFC catch data at Ollei port tracked 38 fishers who showed that roughly 41% of all fish sold to NRFC, was obtained via trolling. In 2019, NRFC purchased about 10,000 lbs of fish from fishers (equivalent to 29% of total catch measured in 2012) from which about 25% were pelagic species. Prior to NRFC, purchase price per/lb of fish from fishers was averaging $1.60/lb for reef fish*[9] and pelagic species were not included as a commonly sold fish; compared to today's NRFC's purchase price of $1.75 for barracuda and $2.00 for tuna, spanish mackerel, and wahoo, per/lb. Every year, since 2018, NRFC has been purchasing about $20K worth of catch from fishers in the northern reefs; an amount that contributes towards their livelihood.

NORTHERN REEF FISHERIES COOPERATIVE FISH LIST and PRICE as of MAY 1, 2019

TYPE OF FISH:	SIZE	Fisher Price	Coop Price
NGIKEL BALECH:			
NGESNGIS / BEADEL / OTORD (Parrot Fish)	13" & up	$ 1.75	$ 2.35
NGYAOCH / MELLEMAU / ELEBDECHUKL	12" & up	$ 1.75	$ 2.35
BIKL (Sweetlips)		$ 1.75	$ 2.35
ERRANGEL / ESENGEL / MASECH/ (Reef Fish)	7" & up	$ 1.50	$ 2.05
Kelsebuul (Rabbit Fish from Farm)		$ 2.50	$ 3.40
NGIKEL EL KEREEL:			
KEREMLAL (Red Snapper)	12" & up	$ 1.65	$ 2.25
BASLOKIL (Grouper Red Snapper)	13" & up	$ 1.65	$ 2.25
KEDESAU (red snapper)	18" & up	$ 1.65	$ 2.25
MECHUR/MELANGMUD (whitesnapper)	13" & up	$ 1.65	$ 2.25
TEMEKAI (Grouper)		$ 1.65	$ 2.25
OMEKTUTAU (Deep Water fish)		$ 1.90	$ 2.60
METENGUI (Rusty jobfish)(OPEN AUGUST 2019)		$ 4.50	$ 6.05
NGIKEL EL CHETAKL:			
NGELNGAL / KESKAS (Wahoo)	30" & up	$ 2.00	$ 2.70
TEKUU (YELLOWFIN) / KERNGAB (Dogtooth Tuna)		$ 2.00	$ 2.70
KATSUO (SODA TUNA)		$ 1.75	$ 2.35
TEKRAR / MELUIS (Swordfish/Marlin)		$ 2.00	$ 2.70
AI / MEAI (Baraccuda)	30" & up	$ 1.75	$ 2.35
DESUI / CHUDEL (Rainbow runner)		$ 1.65	$ 2.25
OPEN SEASON (NOVEMBER 1, 2019)			
BLACK TIAU (Grouper)	16" & up	$ 2.50	$ 3.40
RED TIAU (Grouper)	13" & up	$ 2.50	$ 3.40
MOKAS (Grouper)	24" & up	$ 2.50	$ 3.40

Targeting pelagic species is probably the most feasible way to sustain the livelihood of fishers from the northern reefs. However, there are some hurdles that fishers need to overcome. During the project, two Anchored Fishing Aggregating Devices (aFADs) where deployed in the Northern Reef, with the objective to increase fishers' access to pelagic resources, which supposedly aggregate around the aFADs. However, due to increased weather conditions, aFADs where lost within 6 months of deployment. The development of a Nationwide aFAD program under the Ministry of Natural Resources, Environment & Tourism (MNRET), however, will help establish an aFAD network around Palau, which will further increase the productivity of the fishery. The mean age of fishers in the northern reef communities is just over 52 years of age, indicating that the fishing population is aging, and with only less than 3% of fishers relying on fishing as primary source of income— the majority have full time jobs and/or have retired. Even with these constraints, we see an increased interest in targeting pelagic species, an activity that results from establishing incentives, such as improved price points and market access. Improving NRFC's fish storage capacity, expanding market options, performing regular aFAD maintenance, expanding the aFAD network, and establishing a consistent market to purchase fish from fishers, could help incentivize fishermen to expand their fishing activities and target pelagic species.

Rabbitfish Farming

Palau Bureau of Marine Resources (BMR) began a successful production and farming of rabbitfish (*Siganus lineatus* and *Siganus fuscescens*) in 2015-2016. Startup costs to establis a fish cage in Koror and around Babeldaob are estimated at $2000 -$2,500, which covers materials, labor, and permits. These costs are currently being subsidized by BMR, though various project-based grants. The cost of 2000 rabbitfish fry, needed to stock the cage, is $100. A farmer would typically need about 25 bags of feed that will last for 7 months, for a total cost of $550. Production in 2016 was estimated at 500lbs/farm with a value of USD 1,500. Starting as fingerlings, it takes about 7 months for the fish to reach a marketable size. Rabbitfish are sold live, or fresh, usually at a size of 200–500 g for a price of USD 3–5 per lb.

Price of materials for floating cage. Courtesy of PNAC Brochure

Material	Quantity	Unit	Unit price($)	Total price($)
Net	1	each	800	800
Styrofoam Float	8	each	40	320
Sinker	4	each	0	0
Rope	400	ft	0.19	76
Lumber 2 x 4 x 18	11	each	14.79	162.69
Lumber 2 x 3 x 18	7	each	12.79	89.53
Lumber 1 x 6x 18	13	each	11.99	155.97
Screws	32	each	0.56	17.92
Nail	3 inch	lb	1.39	4.17
Nail	2 inch	lb	1.39	4.17

In partnership with BMR, we began exploring the potential to farm rabbitfish in Kayangel, in 2018. A total of 3 floating net cages were deployed in Kayangel lagoon, stocked with 2000 fingerlings of *Siganus lineatus*. Three fishers were given the cages to manage, BMR provided the feed, and aquaculture technicians from the Palau Aquaculture Center provided training on farm management and rabbitfish feeding. We quickly recognized the following challenges in aquaculture farming in Kayangel:

- Given the distance away from Koror, the cost of farm construction would be greatly inflated, with an estimate of $5K/farm, which covers materials, transportation, and labor. At the same time, the cost to transport rabbitfish fry would be of around $1,000/trip, and the cost involved with the transport of the feed —one that will ultimately affect the price of farmed fish— is of $10/month for at least 7 mos. = $70.
- Finding a suitable depth, one that enabled the fishermen to access the feeding cage by boat, and location to deploy the cages within the Kayangel lagoon, involved an added cost to farming (estimated at $5/day x at least 230days =$1,150).
- Given the distance, and sometimes bad weather, the required twice/day feeding was not always followed, affecting the growth rate of the rabbitfish. After 7 months, the farmed rabbitfish were still too small to be harvested.
- The lack of consistent data collection regarding feeding rate, growth rate, and environmental data showed that fishers are not regularly maintaining the farms.

Due to the aforementioned factors, it was determined that the financial feasibility of farming rabbitfish in Kayangel was very low and it was decided, in 2019, that we would no longer continue to explore and promote small scale rabbitfish farming in Kayangel. It was decided, however, that we would continue to explore rabbitfish farming in Ngarchelong where to date, one fisherman has been identified. The farm is in process of being developed, pending designation of site for farming, approval of water quality permit from EQPB, the actual construction of the floating cage, and the release of rabbitfish fry.

BMR staff releasing rabbitfish fries in Kayangel. @BMR

Based on observations and limited data, it is likely that individually-owned and operated small scale farms in the range of 1-5 floating cages, may not be economically feasible to operate, unless subsidized. Current sales of farmed rabbitfish per cage range from as low as $996 -$2,365*[10]. Each cage is stocked with one inch, 2000 rabbitfish fry. The variations in survival rate and overall health of the farmed fish result from farm management (cleaning and repairing the net) and feeding. Farms that follow these measures show high rate of survival and healthy rabbitfish. Approaches to reduce the cost of maintaining farms, such as cooperative farming, could be considered to improve the financial feasibility of the farming. Farm management practices from fish farmers need to progress substantially, to optimize the survival and growth rate of rabbitfish, which could contribute to the improvement of financial feasibility.

Farmed rabbitfish for sale. @PNAC

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*3: SPC Factsheet-Deepwater Snapper.

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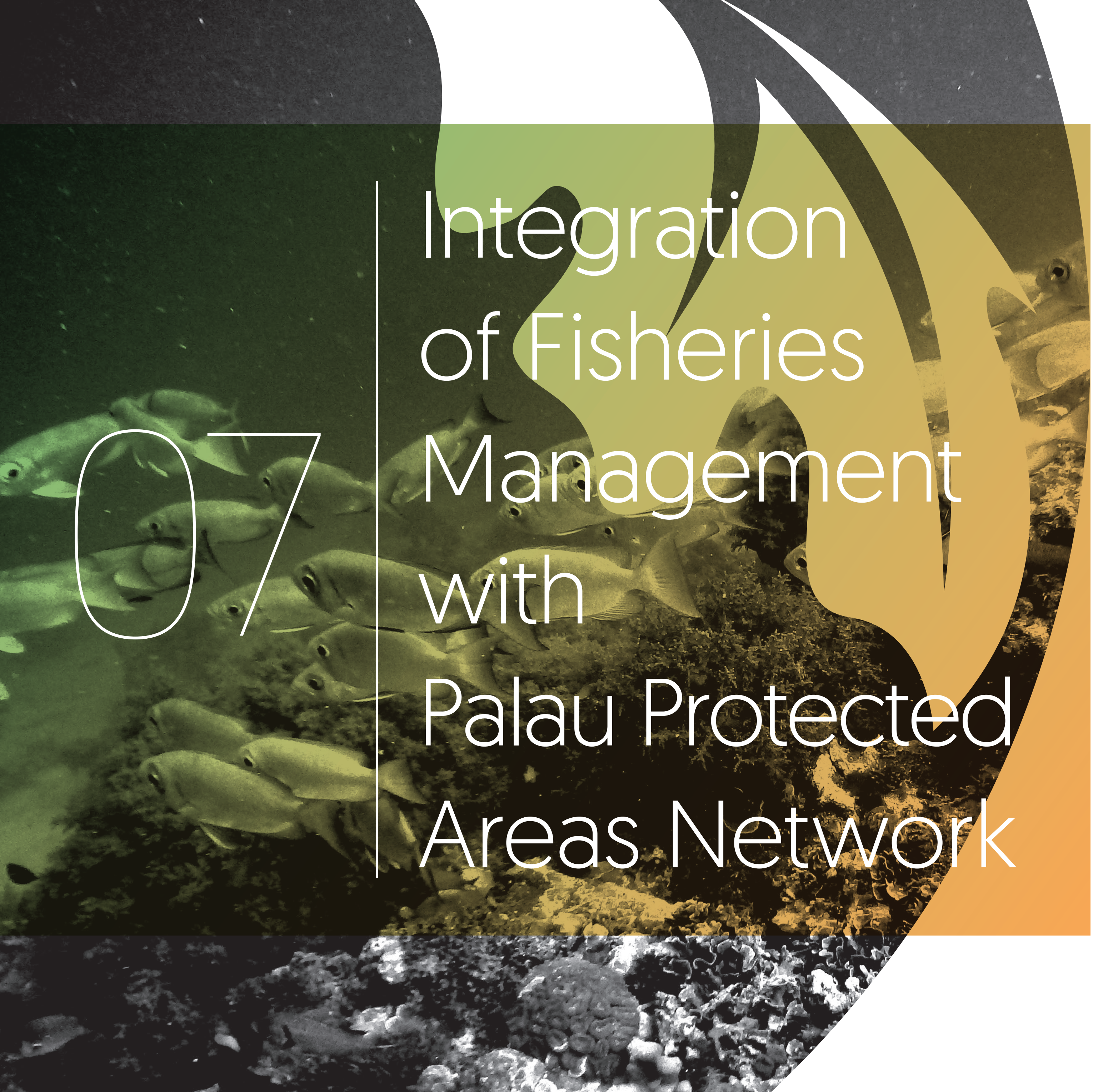
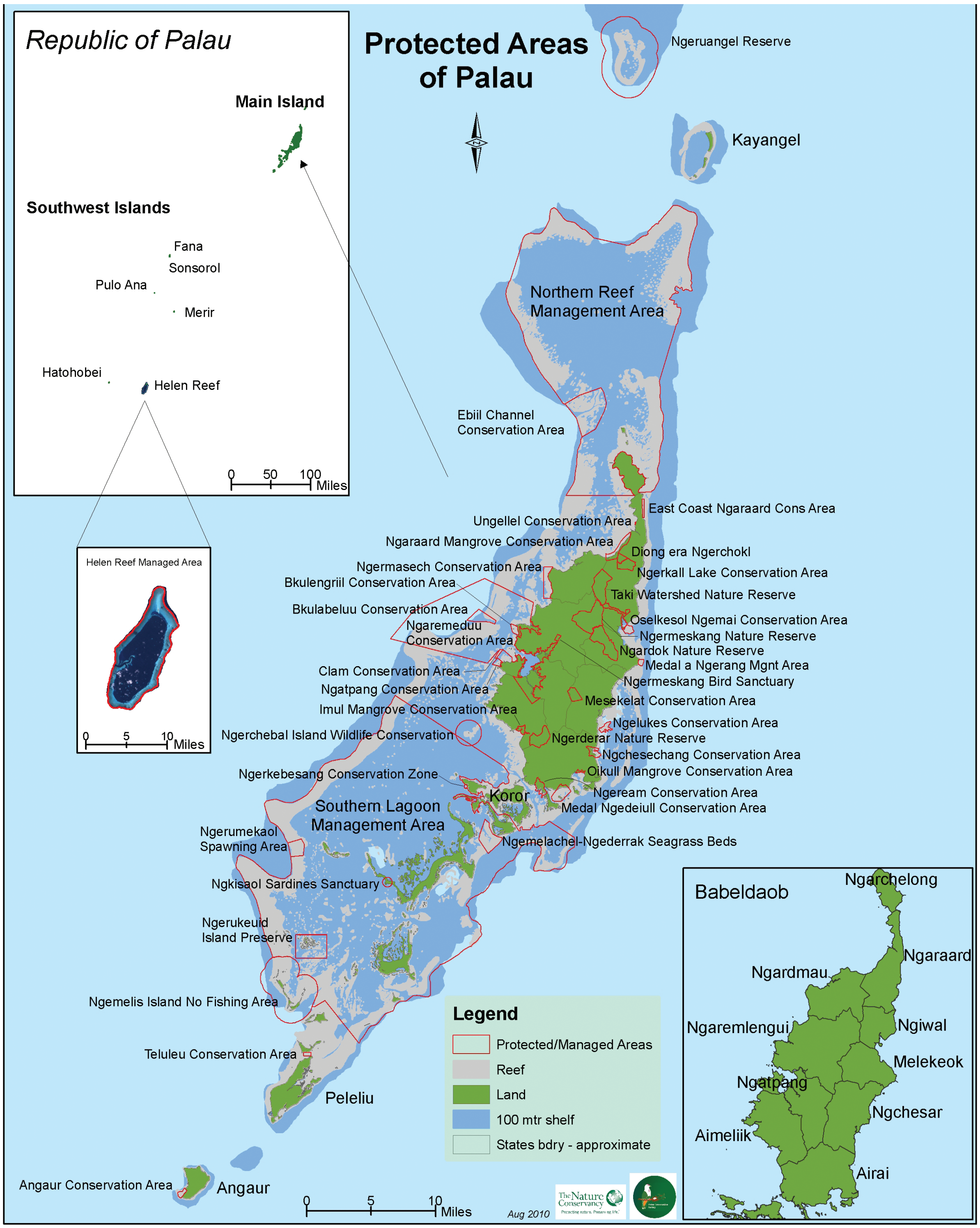
*10: BMR Rabbitfish Harvest Data as of May 2020.



07 Integration of Fisheries Management with Palau Protected Areas Network

Marine Protected Areas (MPAs) can be effective tools in reducing local threats and establishing better fisheries management. Communities across Palau and the national government have supported the establishment of MPA's since the early 1990's. To date, there are about 34 MPAs across Palau's coastal waters, which are mostly located within the lagoon in seagrass beds, patch reefs, fringing reefs, and reef channels. MPA sites range in size from as small as 0.8 km^2, to as large as 112 km^2.

Even though it has been shown that, throughout Palau, the biomass of important fish resources has increased in areas closed to fishing, size and years of protection were the key determinants behind this achievement*[1]. While there has been success in protecting, the study also shows that areas open for fishing have much fewer fish; consistent with what many fishermen have been concerned: a declining fishery. This demonstrates the need to administer fishing activities in concert with the management of protected areas, so important fish resources can be recovered and biodiversity can be protected. The export of fish resources has been managed at the national level through species bans and seasonal closures. These measures, however, have not been enough to stem the declining of important



fish resources, and there is a need for more state-level management; which has demonstrated success in recovery within the no take areas.

The northern reefs of Palau, as the second largest coastal fishing ground in Palau with relatively low number of fishing and recreational activities, offer an opportunity to integrate the management of fisheries with protected areas. The size of an MPA is the best predictor of spillover effects. It is widely accepted that the northern reefs still have the highest biomass of fish throughout Palau, and a 2017 survey by Palau International Coral Reef Center (PICRC) arrayed this area to have the highest fish biomass*[2]. In addition, the survey showed that fish biomass increased as the distance to the closest MPA decreased, and as MPA size increased, higher biomass was seen at nearby sites.

The Northern Reefs of Palau (NR) comprise the largest managed area within the Palau Protected Areas Network (PAN). It includes the territorial waters of Kayangel and

Ngarchelong States, made up of reefs and deep waters up to 12 miles. The NR has a total combined area of 3,930 km^2, with 172km^2 of reef area treated as a no take zone — Ngeruangel Marine Preserve (42km^2 -established in 1996), Ebiil Conservation Area (17km^2 – established in 2000), and Ngerael/Ngkesoll no take zone (11km^2 -established in 2017)— representing 32% of Palau's coral reefs. Ngerael/Ngkesoll is the only no take zone transboundary in Palau that covers reef areas in Ngarchelong and Kayangel State-owned waters. This is an attempt to demonstrate the need to establish a large MPA that may ought to combine multiple state waters to achieve fisheries objectives, while minimizing impacts to the fishing community.

Other management zones in the northern reefs include 221 km2 of subsistence fishing zone (6.5% of the total marine area of NR) and 2,997 km2 of commercial fishing zone (88% of mostly pelagic waters). The NR ecosystem is comprised of mangroves, seagrasses, fringing reefs, patch reefs, lagoons, channels, barrier reefs, sunken reefs, atoll reefs, and deep water that extends beyond 1000 m in depth.

In addition to establishing a management zone, other measures, like the strengthening of law enforcement, needed to be included in the management approach. Prior to 2015, many fishers in the northern reef communities complained of poaching within their not take zones, from fishers that did not belong to the northern reef community. There were, however, no existing laws, regulations or enforcement processes to stop outsiders from fishing in the northern-reef area.

Non spatial management measures have been integrated within the protected areas network in Ngarchelong and Kayangel. The measures are identical for both states and are supported by the Fisheries Act of 2015 and the fisheries regulations enacted in 2016 and 2017 for Kayangel and Ngarchelong, respectively. These measures include: 1) managing fishing activities through a fishing permit system, 2) establishing size limits and a total catch quota for individual fishers to allow the recovering of important food fish resources, where at least a 20% spawning potential ratio is maintained, 3) protecting important and iconic species, such as giant trevally and 2 species of giant clam, by establishing a 10-year ban, and 4) prohibiting wild harvesting of aquarium species. To address the impact of commercial fishing on reef fish species, both Kayangel and Ngarchelong States are only allowing commercial fishing outside the reef, targeting pelagic species, and only a total of 6 commercial fishing licenses are allowed in the pelagic waters of the northern reefs. In addition, both Kayangel and Ngarchelong States created an aquaculture permit process to promote the development of sustainable livelihoods within their protected areas network system. The management scheme that has been developed for the northern reefs integrates the administration of protected areas, fisheries, and the development of sustainable livelihoods.

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Objective: Increase Fisher-Engagement

Fishers in Kayangel and Ngarchelong States have a long history of engaging with one another through traditionally established community relations, such as the Ngarangeseu community group between Ollei Village in Ngarchelong and Kayangel. Even though there were already existing relationships amongst fishers, it was very important for us, who were leading the project implementation, to spend time with fishermen and the communities. This helped

08 | Summary of Key Lessons Learned

build trust and allowed us to gain further insight into their fishing practices, knowledge of the reefs and fisheries, and views on management; information that was important in helping us make necessary adaptive project decisions. We relied on the help of identified community and fisher leaders to bring fishermen into conversation, discussing themes like community engagement, data collection, and management approaches. Having selected fishers, that were also respected within the community, lead the data collection was important in several ways: (1) they were able to reach and capture the catch data of fishers that we would not have been able to obtain otherwise (2) they increased the amount of fisheries dependent data, which was needed to conduct the analysis, (3) they reduced fishers' bias against the results, as these simply reflect the data that they were providing, and (4) they were key in spreading information within the community.

The contribution of fishers towards the development of fisheries regulations was important as they recommended additional areas as no take zones, pointed out species that needed enhanced management —based on their observed decline—, decided appropriate areas for fishing zones, and ensured the inclusion of community members who were not living within the community to be eligible to apply for the permit system. The management approach recommended by these local fishermen did not receive much push back from the state legislators, who needed to approve the regulations. The only harvest control rules that received push back were scientifically recommended size limits, which had to be reduced to a certain size before the state legislators approved the regulations. After several months of deliberation, this was the only compromise that had to be made in order to get the proposed regulations approved.

Fisher-engagement at the beginning of the project increased due to the consistent effort made to connect with the fishermen community. For instance, the development of the Northern Reef Fisheries Cooperative (NRFC) increased engagement. However, as the project team began to step back, transitioning responsibilities to NRFC, fishers' active engagement began to decrease. NRFC was meant to increase the number of fishers involved in management and to develop their livelihoods. Even though efforts were centered on the latter, there is a general feeling that opportunities may have reached only a few. At the same time, NRFC has not yet developed a clear process to work with the State Government, whom is tasked to implement fisheries regulations based on the feedback mechanisms offered by fishers who are contributing towards fisheries management. There were discussions on the possibility of having fishers support enforcement, but no process was established to ensure this happened. Data collection on fishers' catch has been limited to those who sell their catch, as NRFC has struggled to reach those who fish primarily for subsistence. The lack of continued information sharing to fishers and the public, updating on the status of the fishery, may have contributed to fishers' apathy. Regular engagement and information sharing with fishers and community is critical to maintain fisher-engagement.

Objective:
Establish co-management of northern reefs

Managing the fisheries, rather than the state-owned reefs and waters, was a key objective of this project and therefore, establishing a standardized management across the fishery sector was necessary to ensure the effectiveness of administrative actions. A co-management committee was established between the governors of Kayangel and Ngachelong, fisher representatives, and representatives from key partners who were supporting the project. Their input was critical in developing and guiding activities, as well as key project decisions at the beginning of the project. This committee, however, did not have much decision-making power towards the implementation of management activities that could continue to strengthen the co-management arrangement between the two states. In order to improve the role and function of the co-management committee that supports both, the project level guidance and the implementation of management activities, it is necessary to secure broader buy-in and participation of traditional leaders and state elected legislators. It is recommended that, in addition to including governor and fisher representatives in the committee, representatives of traditional leaders and state legislators be considered as part of the committee, as well as female fishers and representatives from the tourism industry operating within the area where management efforts are being implemented. This inclusion ensures broader stakeholder participation in the decision making process, which helps facilitate the coordination of implementation, as well as gaining support for any policy needs that may arise. In addition to expanding stakeholder participation in the committee, it is recommended that the roles and functions of the various committee members be clearly defined to include leadership and coordination positions to help facilitate regular meetings and decisions that can help support the coordinated implementation of management across the co-managed area.

Objective:
Improve the understanding of fish stocks by using data poor fisheries stock assessment techniques

Fishery stock indicator

Spawning Potential Ratio (SPR) as a benchmark to discuss the status of the fishery was easily comprehended by fishers. When the data showed that more than 50% of the fish being captured had not had a chance to reproduce, fishers easily understood the relationship between low reproduction and fewer fish; which is what they had been observing on the reef. While this indicator was easily understood by fishers, a large volume of data was required to conduct a robust analysis. In addition, other scientists raised concerns regarding the applicability of this approach to all reef fish species. The disagreement between scientists led to confusion when it came to establishing size limits, and Ngarchelong State adopted size limits that were about 2 inches lower than the scientifically recommended ones. While the stock indicator that was used may not have been the most robust, it did allow for engaging conversations with fishers, which led them into taking actions that would help develop legislation, some harvest control rules, and regulations. Managing expectations and clarifying confusion within the fishing community, which may arise due to a lack of scientific consensus amongst scientists, is necessary to avoid adverse impact from what science is meant to do: support and guide management decisions.

Data collection

In order to assess the status of fish stocks, building rapport with fishermen was key to enable the collection of their catch data very early on in the project. While fishers were willing to provide their catch data if someone was there to collect it, they were reluctant to collect the data themselves due to the time constraint involved. The fewer the data parameters involved in data collection, the easier it was to engage the fishermen and collect their data. While there is a need to collect a great deal of data in order to understand fishing behavior and the status of fish stocks, there is also a need to ensure simpler and quicker data collection processes that enable fishers to continually provide their catch for data collection. In addition, there is a need to determine minimum data benchmarks from the total fisher population to ensure the minimum amount of data needed for analysis; this will provide reliable management recommendations. It is important to note, however, that the recommendations that may be adopted will not always be dependent on the robustness of the data. In order to effectively contribute to adaptive management decisions, there is a need to consider the cost benefit of data rigor versus practicality while obtaining it.

Fisheries independent data collection remains costly, as it requires technical capacity and time consuming efforts. At this time, Palau counts with technical capacity when it comes to collecting data, but data analysis and interpretation capacity remains a gap. This is an important capacity need, as it is necessary to ensure timely feedback to inform and build awareness, as well as to contribute towards resource management decisions. Fisheries independent data collection may not need to be addressed on an annual basis, but needs to be planned according to the initial baseline assessment and its recommended optimal data collecting time frame. This will help reduce the costs involved in data collection. Likewise, in order to address the gap in data analysis, building partnerships with institutions and/or partners that hold the capacity to conduct remote analysis, is a potential solution while local capacity is being built.

Objective:
Develop a management framework to recover fisheries

The approach taken to develop the management of fisheries includes spatial and non-spatial measures, including:

(1) A No Take Zone (NTZ)

Based on the available scientific data specific to Palau's MPAs and the data on the life history of fish, the size of a no-take zone is important to ensure its contribution towards the management of fisheries. We recognize that it is difficult for one state to close a large tract of its fishing grounds and so, working with two states in the establishment of a large, contiguous area, was an important approach in establishing a no-take zone. The area was chosen based on available information regarding the ecological condition of the reef, as well as fishers' concerns, such as avoiding frequented fishing grounds. The area was mostly targeted, however, by out of community fishers, so impact on the local fishing community was minimal. The no-take zone is large enough to protect the life history of iconic species, such as bumphead parrotfish, humphead wrasse, and giant trevally. This approach can be applied throughout Palau by working with fishers and state governments to protect large areas of reefs, contributing towards fishers' livelihoods, with a minimal impact to their fishing communities. Palau International Coral Reef Center (PICRC) has been monitoring Palau's reefs for almost 20 years; this existing data can be utilized to guide this process. In order to ensure that a selected MPA has meaningful contributions towards the management of fisheries resources, it is key to obtain proper ecological information about the reefs, gain fishers' input, and establish an area large enough to be productive.

(2) Subsistence and commercial zones

There was a perception that commercial activities from fishers outside of the community were causing the decline of fisheries stocks in the northern reefs. In an effort to address this user conflict, fishers recommended the allocation of areas, reserving reef fisheries for subsistence only, while allowing commercial fishing to target pelagic species and deep water species exclusively. There has been limited opportunities for commercial fishing in the northern reefs due to restrained fisher-capacity, including unsuitable small boats (average boat size is 23 ft with single 85 horsepower engine) and narrow knowledge of the fishing grounds found outside the reefs.

The development of an anchored Fishing Aggregating Device (aFADs) Network could help improve the fishing efficiency outside the reef, which could incentivize commercial fishing, which targets pelagic species.

(3) Species ban

Species, such as lobsters and mangrove crabs, are being managed at the national level through size limit and gravid females. Enforcement, however, has been weak leading to their continued decline. For this reason, fishers wanted to put a moratorium to recover these species, but the moratorium period that they were willing to implement was for only one year, which is not enough time to have an impact on the population of these species. Strengthening the enforcement of the existing national regulations, which could also be implemented at the state level, may be more effective than putting into effect short term moratoriums that do not allow for enough recovery to the species of concern.

A 3-year ban on 3 species of grouper, however, was implemented. For 7 months of the year, these species had already been regulated at the national level and so, fishers were only giving up an additional 5 months, for a total of 15 months, in a 3-year period. Three years was the initial recommended moratorium time, as the bio-economic modelling predicted that the weight would double in that period. Only one of the three species, *Plectropomus areolatus*, showed an increase in biomass. After lifting the ban, however, and fishers started fishing for them again, their biomass decreased to almost the level they were found before the 3-year ban was implemented. As these species are targeted while aggregating, they are more vulnerable to overfishing. Therefore, establishing proper management measures, such as banning fishing at aggregation sites, following the recovery period of a species, can help maintain populations while continuing to help the recovery of the species population. If the banning of fishing at aggregation sites is difficult, it is worth considering establishing a limit quota per fisherman. This approach can be managed by licensing the fishers that target species of high market value, where the number of fishers and quote limits can be tracked and enforced. Alternatively, species that are known to be targeted at specific locations on the reef, could be managed through a Territorial Use Rights for Fishing (TURF) management approach.

(4) Size limits

A 20% minimum Spawning Potential Ratio (SPR) was used as a benchmark to set the size limit of some of the key consumption fish, where enough data could be collected to determine their stock status and derive their SPR. This harvest control strategy is showing signs of success with 7 of the 13 species, with size limits showing positive improvement in length frequency distribution. While this harvest control measure is effective, given the many species of reef fish that are targeted, setting size limits for each species can be difficult to implement and enforce, which can lead to an increased lack of compliance. At the same time, setting size limits regulations by state can be challenging and may lead to different size limits for each species, which can potentially cause confusion amongst fishers and those tasked with management and enforcement. Setting standardized size limits at the national level, which would be applied throughout Palau, is probably the best management approach in utilizing size limits to manage fisheries.

(5) Fishing Permits

In an effort to track and control the number of fishers fishing in the northern reefs, a fishing permit system was established, covering activities like subsistence fishing, sport fishing, and commercial fishing. The subsistence fishing permit was based on citizenship of Ngarchelong and Kayangel States; by definition, anyone from Palau who can trace relation to any clan in any of the two states is eligible to apply for a permit and by this definition, almost any Palauan person becomes eligible. Prior to the fishing permit system, there was a general understanding that only people from Kayangel and Ngarchelong were allowed to fish. With the fishing permit system, it allowed for more people to fish but they had to apply for the permit. In addition, a subsistence fishing permit only allowed for 100 lbs/person/day and allowed the selling of the catch without a fishing commercial license. Enforcement of the fishing permit system and the underlying conditions associated with fishing permits, however, remains weak. Enforcement can be improved so that data collection for the number of people fishing and their catch rates, increases the understanding of the fisheries; which can guide management decisions. Re-evaluating the fishing permit system is recommended to address loopholes, such as the increased number of fishers holding a subsistence fishing permit that still sell their catch. At the same time, within further discussions on permit fees, different rates for residents and non-residents should be considered.

The implementation of the fishing permit system by state may not be the most practical approach to control the entry and tracking of the number of fishers throughout Palau. It would be complicated, as fishing grounds overlap between the states, particularly in the shallow waters of Babeldaob Island. Even though implementation at the national level would be the most practical approach, there are several challenges to overcome, including state owned resources, access control, and issues with the allocation of revenue that derives from fishing permits. These issues may be addressed through the establishment of agreements, and require proper consultations with fishers, traditional leaders, and state elected leaders across Palau to develop consensus and agreements towards a nationwide approach. An alternative approach is to consider co-management units, similar to the one established in the northern reef, where 4 co-managed fisheries units can be secured – northern reefs (Kayangel and Ngarchelong), east Babeldaob (Ngaraard, Ngiwal, Melekeok, Ngchesar, and Airai), west Babeldaob (Ngaraard, Ngardmau, Ngeremlengui, Ngatpang, Aimeliik) and southern lagoon (Koror and Peleliu).

Objective:
Improve capacity for management

At the beginning of the project, there was a strong desire from both state government leaderships, fishers, and the states' PAN program to improve the enforcement capacity. This influenced the focus of capacity building by allocating efforts where there was a desire to invest, like the establishment of key processes, mechanisms, technical skills, and procurement of key equipment; all of which were needed within the enforcement chain to support implementation. Even though there is now a strong technical capacity, as well as much needed enabling processes and mechanisms, enforcement continues to remain a key challenge.

Some of the key challenges in capacity that we recognized midway through the project, involves leadership capacity, high staff turnover, planning and execution of activities, and the building of partnerships to support key management implementation needs. There is a lack of key processes within the state government that may inhibit professional development growth. This, however, is not unique to Kayangel and Ngarchelong, but applies to many other states. The lack of human resource policy, which does not support job security, employee evaluation, or reward system; and the lack of revenue reinvestment from the natural-resource-use-fee to support management implementation, often leads to thinking that there is a lack of financial resources, which impedes the implementation of benefits that support the development of human capacity and worker-retention.

In addition to a lacking policy that supports capacity building, the remoteness, and therefore, small populations of Kayangel and Ngarchelong States leaves with very few people that can be recruited to fill key capacity needs within both States. The lack of human resource capital to fill key capacity needs can be addressed through a co-management unit approach, rather than a state by state approach. For example, within a co-management unit approach, only one leadership level position may be needed, as opposed to two, in the case of Kayangel and Ngarchelong. At the same time, financial and human resource-sharing can be mainstreamed into management processes that can also reduce costs and improve management coordination. This is an area of natural resource management structure that will require further consultation, discussion, and planning to explore possible arrangements that are politically and socially acceptable within the communities.

Objective:
Integrate the management of fisheries with Palau Protected Areas Network

A protected area network is perceived as an area based on a management approach. While this approach can help protect biodiversity, contributions towards the management of fisheries is limited, unless large areas are protected. As the science has shown, larger protected areas have higher biomass and therefore, there is some contribution towards the fisheries found outside the borders of the no-take areas. With small reef areas found in many states in Palau, particularly around Babeldaob, establishing a large contiguous area within a state boundary may not have the political and social support needed to be successful. As shown in Kayangel and Ngarchelong, a transboundary approach can be explored to establish large areas that have both, biodiversity and fisheries benefits. In addition, Kayangel and Ngarchelong included their whole states' territorial waters in the PAN, which enabled the managing of fisheries and tourism activities that supported broader marine resource-management for key biodiversity and fisheries threats. These management approaches taken by Kayangel and Ngarchelong States are applicable throughout the Palau Protected Areas Network. These efforts, however, need to be driven between each state and the communities, with the PAN office facilitating the conversation so PAN's broader goals can be reached.

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Key stakeholder groups

Kayangel and Ngarchelong State Government
Kayangel and Ngarchelong State Traditional Leaders
Kayangel and Ngarchelong communities and community groups
Kayangel and Ngarchelong fishers
Fishers with fishing ties to the northern reefs
Palau Bureau of Marine Resources

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Palau Implementing Partners

Kayangel Protected Areas Network Program
Ngarchelong Protected Areas Network Program
Ministry of Natural Resource Environment and Tourism
Palau PAN Office
Palau Bureau of Marine Resource
Ministry of Justice
Maritime Surveillance and Fish and WildLife
Koror State Rangers
Palau PAN Fund
Palau Conservation Society
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