Creel survey and demographic assessments of coastal finfish fisheries of southern Palau

September 2014

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by

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Secretariat of the Pacific Community

Original text: English

Secretariat of the Pacific Community cataloguing-in-publication data

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Moore, Bradley

Creel survey and demographic assessments of coastal finfish fisheries of southern Palau: September 2014 / by Brad Moore, Percy Rechelluul and Steven Victor

1. Fishes — Palau.
2. Fisheries — Palau.
3. Fishery resources — Palau.

I. Moore, Bradley II. Rechelluul, Percy III. Victor, Steven
IV. Title V. Secretariat of the Pacific Community

338. 372709966 AACR2

ISBN: 978-982-00-0909-7

Printed on 100% recycled paper at the Secretariat of the Pacific Community headquarters, Noumea, New Caledonia.
Original cover picture by Colette Wabnitz, SPC.

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Acknowledgements

The Bureau of Marine Resources of Palau (BMR), The Nature Conservancy (TNC) and the Secretariat of the Pacific Community (SPC) acknowledge with gratitude the support of the European Union in funding the training and survey work in Palau and the processing of collected otolith material under the Scientific Support for the management of Coastal and Oceanic Fisheries in the Pacific Islands region (SciCOFish) project.

This assessment was made possible by the assistance and contribution of many people and agencies. We gratefully acknowledge the collaboration of the BMR staff and state rangers who participated in the training and assisted with sampling in Palau, in particular (in alphabetical order) Weider Debengek, Lora B. Demei, Robert B. Johnson, Billy G. Kemesong, Valentino Klouchad, Roger Rumong, Scherryl Solang, Janice Temengil and Alfred Tuelbang. We thank the Director of BMR, Mr Leon Remegesa for his support, Mr Charley Matsutaro for assistance with export certificates and the Palau International Coral Reef Centre (PICRC) for the use of their laboratory facilities. Kyne Krusic-Golub and Simon Robertson from Fish Ageing Services (http://www.fishageingservices.com/) assisted with the development of ageing protocols, otolith processing onto slides, and estimation of fish ages. Jeremy Prince (Biospherics Pty Ltd) and Ian Bertram (SPC Coastal Fisheries Programme) provided useful discussions and constructive comments on a draft version of the report, respectively.

We thank the SPC Publications Section, and in particular Frances Pene, for editing a final draft, and the SPC Fisheries Information Unit, in particular Céline Barré, for the final layout.

Summary

In 2013 The Nature Conservancy and Palau's Bureau of Marine Resources (BMR) requested assistance from the Secretariat of the Pacific Community's Coastal Fisheries Programme in training fisheries officers and state rangers to carry out creel surveys and finfish biological sampling, and in establishing baseline data on the status of the coastal finfish resources of southern Palau from these methods. The training took place in September 2014 and involved four BMR staff and five state rangers. In this report we present the results of data collected during the training. We also provide recommendations for management, monitoring and future research on the coastal finfish resources of Palau, based on the results and observations of the survey team during the training.

At BMR's request, creel surveys focused on fishers landing at the Happy Fish Market (HFM) in Koror. Twenty-three landings were met during the training period. Handlining (encountered in 14 landings) and night-time spearfishing (encountered in nine landings) were the most common fishing methods encountered, although three instances each of daytime spearfishing and gillnetting were also assessed. A total of 2,042 individual fish were recorded, weighing an estimated 1.26 t. Ninety-three species from 14 families were observed in the catch. Night-time spearfishing was responsible for 48% of the total catch by abundance and 38% of the total catch by weight, while handlining was responsible for 28% of the total catch by abundance and 26% of the total catch by weight. The most common families in the catch were the parrotfish (Scaridae: 17% of the total catch by abundance and weight), surgeonfish (Acanthuridae: 17% of the total catch by abundance and 16% of the total catch by weight), emperors (Lethrinidae: 13% of the total catch by abundance and weight) and snappers (Lutjanidae: 15% of the total catch by abundance and 11% by weight). The species most commonly observed were the parrotfish *Hipposcarus longiceps*; the surgeonfish *Naso lituratus*, *N. unicornis* and *Acanthurus nigricauda*; the rabbitfish *Siganus lineatus*; and the snapper *Lutjanus gibbus*.

Catch per unit effort (CPUE) was estimated for each fishing method encountered, in terms of both abundance ($CPUE_N$ = no. individuals fisher^{-1} hour fishing^{-1}) and weight ($CPUE_W$ = kg fisher^{-1} hour fishing^{-1}). $CPUE_N$ was highest for night-time spearing (14.8 individuals fisher^{-1} hour^{-1}), while $CPUE_W$ was highest for daytime spearing (7.8 kg fisher^{-1} hour^{-1}). $CPUE_N$ for night-time spearing was higher than that estimated elsewhere in Micronesia for this method.

Perceptions were collected from 15 lead fishers during the training and initial survey. The majority of fishers interviewed stated that they had seen changes in the fishery in the last few years, with 73% of all respondents stating that the quantity of fish caught had decreased over the last five years and 80% of all respondents stating that the size of fish had decreased over the same period.

Length data obtained for six key finfish species were compared against those collected in 1990–1991 to assess temporal trends. Slightly fewer small individuals of *Hipposcarus longiceps*, *Lethrinus obsoletus*, *Naso lituratus*, *Naso unicornis* and *Siganus lineatus* were observed in 2014 than in 1990–1991; a result that is likely due to the introduction of minimum legal mesh sizes for gillnets, surround nets and *kesokes* nets under the Marine Protection Act of 1994. However, considerable differences in length frequencies were observed for *Lutjanus gibbus*. Most noticeable was a reduction in large fish, an increase in smaller fish and a general shift in the length frequencies to smaller sized individuals in 2014 compared to 1990–1991, consistent with fisher perceptions.

The amount and description of fish purchased from fishers by HFM in August 2014 were documented from receipt books held within the marketplace. A total of 164 catches were purchased from fishers over the month, totalling 11.84 t and equating to a total purchase price of USD 43,965. Of this, general reef fish (excluding parrotfish, rabbitfish and *N. unicornis*) comprised 44% of the total amount purchased (5.21 t), while parrotfish and *N. unicornis* comprised 29% and 13% of the total amount purchased (3.45 t and 1.59 t, respectively). On average, 383 kg of fish was purchased by the HFM on a daily basis. Assuming the data collected for August 2014 is representative of any given month, these figures equate to approximately 142.11 t) of fish passing through the HFM on an annual basis.

Demographic assessments focused on five of the most common finfish species observed in the catches, namely *Cephalopholis argus* (*Mengardechelucheb*), *L. obsoletus* (*Udech*), *L. gibbus* (*Keremlal*), *N. lituratus* (*Erangel*) and *N. unicornis* (*Um*). Key biological parameters, including growth parameters, age structures, mortality rates and length-and-age at maturity were determined for each species (where possible) to provide a baseline for future comparisons. Fishing mortality of *N. lituratus* was found to be well above the recommended rate, indicating that this species is fished beyond its optimum level, while *L. gibbus* was fished near a maximum recommended level.

1. Introduction

1.1 Background

The Republic of Palau (hereafter Palau) is an island archipelago lying at the western end of Micronesia approximately 600 km east of the Philippines and north of Irian Jaya. Palau is composed of 12 inhabited islands and 700+ islets, and has an estimated land area of 494 km^2 and an exclusive economic zone (EEZ) of 605,506 km^2 (Bell et al. 2011). The population at the last census was 17,445, with approximately 20% of the population aged 0–14 years old, and more than 75% of the population living in and around the capital city of Koror (SPC 2013). Projections estimate the population will rise to 18,300 in 2020 and 18,600 in 2030 (SPC 2013).

Palau has extensive areas of coral reef (2,496 km^2), with smaller seagrass areas (80 km^2) and mangrove forests (45 km^2) (Bell et al. 2011). Palau's coral reefs are widely recognised as being among the richest and most diverse in the world, and as such are regarded as one of the nation's most valuable natural resources. The rich and diverse marine environments of Palau support a growing tourism industry, with 83,000 tourists visiting the country in 2006, increasing to 139,000 in 2014 (Palau National Government 2015).

Coastal fisheries provide an important source of protein, livelihood and cultural identity to the people of Palau. Recent surveys under the Pacific Regional Oceanic and Coastal Fisheries Development Programme (PROCFish) coordinated by SPC revealed that, at Koror, per capita consumption of fresh fish was found to be approximately 77 kg $person^{-1}$ $year^{-1}$, more than double the regional average of 35 kg $person^{-1}$ $year^{-1}$, while invertebrate consumption was also relatively high with approximately 4 kg consumed per person per year (Friedman et al. 2009).

As is common in many Pacific Islands, a wide range of species is harvested for consumption in Palau. A variety of fishing methods is used to target coastal fish stocks. They include netting (and in particular the V-shaped stationary barrier net, known locally as *kesokes*), handlining, trolling, and night-time spearfishing, which is the dominant fishing method as it is elsewhere in Micronesia and the broader Pacific (Johannes 1981; Gillet and Moy 2006; Rhodes et al. 2008). In addition to the strong local demand for fish, the growing tourism and associated restaurant industry form a substantial market for reef fish. Further, a rising demand for reef fish from overseas markets, in particular Guam and Saipan, has led to the development of a significant, yet largely unquantified, export industry (Kitalong and Dalzell 1994).

Fishers in Palau have expressed concern over diminishing fish stocks since at least the mid-1970s (Johannes 1981; Kitalong and Dalzell 1994). A recent consultation in the northern states by The Nature Conservancy (TNC) found that most fishers perceive that catches today are generally less than half what they were seven years ago, that reef fish in general are much smaller now, and that local reefs are now exhausted by the current level of local-, tourism- and export-driven demand for fresh fish (Gleason et al. 2014).

1.2 Fisheries management in Palau

Management systems for finfish fisheries in Palau are a mix of input and output controls, regulated under the Marine Protection Act of 1994. They include the following:

- a closed season on the possession and sale of five grouper species (*Epinephelus fuscoguttatus*, *E. polyphekadion*, *Plectropomus areolatus*, *P. laevis* and *P. leopardus*) from April to October to protect these species during their spawning aggregation periods;
- a ban on the possession (including harvest, sale and export) of bumphead parrotfish, *Bolbometopon muricatum*, and humphead wrasse, *Chelinus undulatus*;
- a ban on the harvest, sale and purchase of rabbitfish from February to March;
- a ban on using any form of underwater breathing apparatus other than a snorkel for fishing;
- a minimum legal mesh size of three inches (measured diagonally) for gillnets and surround nets;
- a prohibition on fishing with a *kesokes* net with no bag portion or with the bag portion having a mesh size of less than three inches measured diagonally;
- a prohibition on the retention or abandonment of a *kesokes* net having a mesh size of less than three inches measured diagonally; and

- a prohibition on fishing with poisons or explosives.

In addition, there are a number of marine protected areas in Palau.

No licensing measures are in place for local boats or fishers in Palau and fishing in Palau is currently open access. Markets set prices for fish purchases from fishers and public sale, and no fishing cooperatives are currently active.

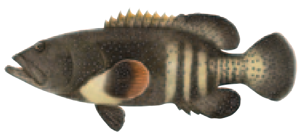
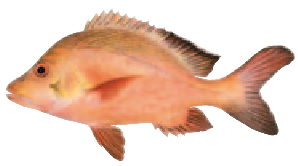
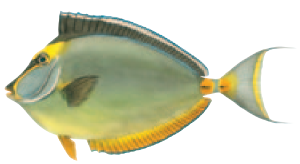
1.3 Objectives of this study

In 2013 The Nature Conservancy and Palau's Bureau of Marine Resources (BMR) requested assistance from the Secretariat of the Pacific Community's Coastal Fisheries Programme in conducting training in creel (fisher) surveys and biological sampling and in establishing baseline data on the status of coastal finfish resources of southern Palau based on these methods. Training took place over a three week period in September 2014 and involved four BMR staff and five state rangers. In this report we provide a preliminary assessment of the status of the coastal finfish resources based on the two different types of data collected during the training period, namely:

1. creel survey assessments of coastal fishing activities, including catch compositions, catch per unit effort, and length frequencies; and
2. age-based demographic assessments, including examination of age structures, age and growth parameters, length-and-age at maturity, and mortality rates, of selected species with sufficient sample sizes collected over the three-week training period (Table 1).

In addition, we provide an assessment of the volume of fish purchased from fishers at a single Koror fish market over the course of one month in 2014 and recommendations for management, monitoring and future research on the coastal finfish resources of Palau.

Table 1. Finfish species assessed and parameters investigated in this study.

Illustration	Local name	Common name	Scientific name
	*Mengardechelucheb*	Peacock grouper	*Cephalopholis argus*
	*Udech*	Orangestripe emperor	*Lethrinus obsoletus*
	*Keremlal*	Humpback red snapper	*Lutjanus gibbus*
	*Erangel*	Orangespine surgeonfish	*Naso lituratus*
	*Um*	Bluespine surgeonfish	*Naso unicornis*

2. Methods

2.1 Creel surveys

2.1.1 Data collection

Creel survey training in Palau focused on fishers landing at the Happy Fish Market (HFM) dock in Koror, and primarily focused on commercial gillnet fishing, handline / bottom fishing, and daytime and night-time spearfishing. The creel surveys had the following objectives:

1. to document fisher demographics and fishing behaviour (e.g. age, number of fishers per trip, number of trips per week, locations fished);
2. to provide a 'snapshot' of species composition of each fishery;
3. to document catch (including lengths and weights of all individuals caught) and effort (including trip duration, time spent fishing, distances travelled and gear used) for monitoring purposes.
4. to document fishers' perceptions of the status of fisheries resources.

Fishers were met at the landing dock at the HFM, mostly between 6 a.m. and 10 a.m. and between 4 p.m. and 7 p.m. The entire catch was quantified, including fish destined for the market as well as those kept for personal consumption. All fish caught were identified as to species level, measured to the nearest millimetre, and weighed to the nearest 10 g, unless damaged. During the survey, the lead fisher was asked questions relating to the fishing trip, including the number of fishers who took part, the fishing method(s) used, the locations fished, the distance travelled, and the costs involved. Fishers were shown laminated maps of Palau to determine their fishing area and distances travelled. Their historical fishing patterns, and perceptions of the state of resources, were also documented. Perceptions were documented once only for each lead fisher, regardless of how many times that fisher was surveyed. A copy of the survey form used in the creel surveys is included as Appendix 1.

2.1.2 Data analysis

Summary statistics, including mean number of fishers per trip, mean trip duration, mean catch (individual fish and kg) were compiled for the total catch and for each individual fishing method. Where weight data were not recorded (i.e. when a fish was damaged) weights were estimated from length-weight relationships in FishBase (Froese and Pauly 2013). Length-frequency plots were established for key target species and were compared against lengths-at-maturity (where known) to estimate the percentage of immature individuals in the catch. The percentage of the catch under the length at 50% maturity (L_{50}) was assessed relative to the common reference value of ≤30% being immature. Length frequencies of key species were compared with those from 1990–1991 collated by Kitalong and Dalzell (1994).

Catch per unit effort (CPUE) was calculated for each fishing method, and was based on number ($CPUE_N$) and weight ($CPUE_W$) of fish caught per fisher per hour spent fishing. A guide to the minimum number of landings to be met to be able to detect a change in $CPUE_N$ and $CPUE_W$ at a level of precision of 0.2 in future surveys was calculated for each fishing method using the formula:

$$n = (SD\ /\ (P^*avg))^2$$

where n = number of replicates required, SD = standard deviation, P = level of precision, and avg = average $CPUE_N$ or $CPUE_W$ of each fishing method. $CPUE_N$ and $CPUE_W$ estimates were compared against those collected using identical methods elsewhere in the region (Moore et al. 2014, 2015).

2.2 Monthly fish purchases by the Happy Fish Market

Fish purchased from fishers by the HFM for the month of August 2014 were documented from receipt books held within the marketplace. For each sale, the following information was available: date, fisher's name, weight (recorded in lbs[1], itemised by type of fish), unit price and total price (both itemised by type of fish).

[1] For the purposes of this report, weights have been converted to metric (kg, t).

While the market has kept sales records since at least 2006, since 2011 it has recorded fish types in a number of broad categories, including:

- *chum* (*um* – *Naso unicornis*)
- parrotfish
- rabbitfish
- general reef fish (excluding *Naso unicornis*, parrotfish and rabbitfish)
- lobster
- tuna
- *sebus* and *dudul* (deepwater snapper species, e.g. *Etelis*, *Pristipomoides*)
- *desui* (rainbow runner – *Elagatis bipinnulata*)
- wahoo (*Acanthocybium solandri*)

Summary statistics, including the total weight purchased, the percentage and total of each fish category purchased, the average total and categorised weight purchased per day and the average number of fishers selling per day were calculated from the collated data.

2.3 Demographic assessments

2.3.1 Sample collection

Finfish samples used for demographic assessments were collected from fishers during creel survey operations or from the HFM where the date, location and method of collection was known. Collected fish were taken to the laboratory at the Palau International Coral Reef Centre (PICRC) for processing. Fork length (FL), total length (TL) and stretched total length (STL) were measured to the nearest millimetre for each fish, unless damaged, and whole wet weight (W) was measured to the nearest 1 g. Sex and maturity stage were determined from a macroscopic examination of the gonads. The gonads were removed, trimmed of excess tissue and weighed to the nearest 0.001 g. Sagittal otoliths (hereafter referred to as otoliths) were removed, cleaned, dried and stored in plastic vials until processing for use in age-based demographic analyses.

2.3.2 Otolith processing

Unless broken, a single otolith from each fish was weighed to the nearest 0.001 g using an electronic balance. Otoliths were used to estimate fish age. These otoliths were processed using standard sectioning protocols. Briefly, a single otolith from each individual was embedded in resin and sectioned on the transverse axis using a slow-speed diamond edge saw. Sections were approximately 300 μm thick, and care was taken to ensure that the primordium of the otolith was included in the sections. The sections were cleaned, dried and mounted onto clear glass microscope slides under glass coverslips, using resin.

Mounted otolith sections from all species were examined under a stereo microscope with reflected light. Opaque increments observed in the otolith were assumed to be annuli for all species examined. Supportive evidence for annual periodicity in opaque increment formation in otoliths has been demonstrated in the majority of cases for tropical reef fish, including *Lutjanus gibbus* (Nanami et al. 2010) and *Naso lituratus* and *N. unicornis* (Taylor et al. 2014) and many other closely related species to those examined here (Choat and Axe 1996; Newman et al. 2000; Shimose and Nanami 2014). The annuli count was accepted as the final age of the individual, with no adjustment made of birth date or date of capture.

2.3.3 Data analysis

Length and age frequency distributions were constructed to examine population structures of each species. Chi-squared tests were used to compare age frequency distributions between sexes and fishing methods, using R (R Core Team 2013). The relationship between length and weight was described using a power function of the form:

$$W = a \times FL^{b}$$

To examine growth patterns, the von Bertalanffy growth function (VBGF) was fitted by nonlinear least-squares regression of length (FL or TL) on age, using the solver function in MS Excel. The form of the VBGF used to model length-at-age data was as follows:

$$L_t = L_\infty [1 - e^{-K(t - t_0)}]$$

where L_t is the length of fish at age t, L_∞ is the hypothetical asymptotic length, K is the growth coefficient or rate at which L_∞ is approached, and t_0 is the hypothetical age at which a fish would have a length of zero. Due to a lack of smaller, younger fish in the samples, t_0 was constrained to zero to improve precision and account for early growth trajectories in the models. A single VBGF was fitted for hermaphroditic species (*Cephalopholis argus* and *Lethrinus obsoletus*), while sex-specific VBGFs were initially fitted for gonochoristic species (*Lutjanus gibbus*, *Naso lituratus* and *N. unicornis*). Likelihood ratio tests were used to test for differences in VBGF parameters between sexes, using the solver function in MS Excel. A common range of age classes was used in each analysis to assure validity of the comparisons (Haddon 2001).

Age-based catch curves (Ricker 1975) were used to estimate the instantaneous rate of total mortality (Z) for each species. Catch curves were generated by fitting a linear regression to the natural log-transformed number of fish in each age class against fish age. The slope of this regression is an estimate of the rate of annual mortality. Regressions were fitted from the first modal age class, presumed to be the first age class fully selected by the sampling gear, to the oldest age class that was preceded by no more than two consecutive zero frequencies. Following Newman and Dunk (2002), instantaneous natural mortality rates (M) were derived using the general regression equation of Hoenig (1983) for fish:

$$\ln(M) = 1.46 - 1.01 \times \ln t_{max}$$

where t_{max} is the maximum known age, in years. Estimates of fishing mortality (F) were derived by subtraction, since F = Z – M. The harvest strategy of F_{opt} = 0.5 M was adopted in this study as the optimum fishing mortality rate for sustainable exploitation. This reference point seeks to ensure adequate egg production and therefore the maintenance of recruitment (Walters 2000) and is used routinely as a mortality reference point for tropical, data-poor fisheries (Newman and Dunk 2002).

Length- and age-at-maturity was determined by logistic regression analysis, using the following equation:

$$P_m = 1 \,/\, [1 + \exp(-\ln(19)\,(m - m_{50}) \,/\, (m_{95} - m_{50}))]$$

where P_m = the proportion of mature fish in each age or 10 mm FL or TL class m, and m_{50} and m_{95} are the lengths or ages at which 50% and 95% of the population is mature, respectively. The data (immature or mature) were randomly re-sampled and analysed using solver in MS Excel to create 50 sets of bootstrap estimates for the parameters of the logistic equation and of the probability of maturity within the recorded lengths and ages. The point estimates for each parameter and of each probability of maturity were taken as the medians of the bootstrap estimates. A similar design was used to estimate the length- and age-at-sex change in the protogynous hermaphrodite *C. argus*.

3. Results and discussion

3.1 Creel surveys

3.1.1 Overview

A total of 23 landings were met during the September 2014 training (Table 2). Over the course of the training period, a total of 2,042 individual fish were recorded, weighing an estimated 1.26 t. Ninety-three species from 14 families were observed in the catch. Night-time spearfishing was responsible for 48% of the total catch by abundance and 38% of the total catch by weight, while handlining was responsible for 28% of the total catch by abundance and 26% of the total catch by weight. Parrotfish (Scaridae) constituted 17% of the total catch by abundance and weight, while surgeonfish (Acanthuridae) constituted 17% of the total catch by abundance and 16% of the total catch by weight (Fig. 1). The average $CPUE_N$ (all methods combined) was 4.25 ±0.16 individuals fisher^{-1} hour^{-1}, while the average $CPUE_W$ was 2.47 ±0.08 kg fisher^{-1} hour^{-1}. The average furthest distance travelled during the fishing trips was 26.6 km.

Table 2. Data summary for creel surveys conducted at Koror, September 2014.

Fishing method	Gillnetting	Handlining	Daytime spearfishing	Night-time spearfishing
No. landings where method encountered	3	14	3	9
Total number of fishers surveyed	13	24	9	18
Mean time spent fishing (hrs)	4.7 ±0.9	4.0 ±0.2	8.5 ±0.3	3.7 ±0.3
Mean no. of fishers per trip	4.3 ±1.5	1.7 ±0.2	3.0 ±0.6	2.0 ±0.2
Average catch (number of fish) per trip	117 ±41	40 ±9	49 ±15	109 ±22
Average catch (kg) per trip	55 ±8	24 ±4	93 ±30	54 ±11
Average $CPUE_N$ by abundance (individuals fisher^{-1} hour fishing^{-1})	9.0 ±4.1	5.2 ±0.8	4.2 ±0.5	14.8 ±2.1
Average $CPUE_W$ by weight (kg fisher^{-1} hour fishing^{-1})	3.7 ±1.3	3.2 ±0.4	7.8 ±0.8	7.4 ±1.1
No. of landings needed to survey to detect change in $CPUE_N$ at precision of 0.1, 0.15 and 0.2*	-	37, 17, 9	-	19, 9, 5
No. of landings needed to survey to detect change in $CPUE_W$ at precision of 0.1, 0.15 and 0.2*	-	18, 8, 5	-	20, 9, 5

* Estimates of precision were not calculated for gillnetting and day spearing due to low numbers of landings met.

Gillnetting

Three landings of gillnet fishing were met at Koror (Table 2). The total catch recorded was 352 individual fish, weighing an estimated 165 kg. The average catch from gillnetting was 117 ±41 individual fish, or 55 ±8 kg per trip. The average number of fishers involved in gillnet trips was 4.3 ±1.5, and trips lasted on average 5.7 ±0.9 hours. Average $CPUE_N$ was 9.0 ±4.1 individuals fisher^{-1} hour^{-1}, while the average $CPUE_W$ was 3.7 ±1.3 kg fisher^{-1} hour^{-1} (Fig. 2).

Nineteen species from nine families were observed in the gillnet catch (Appendix 2). Members of the Siganidae (rabbitfish), Acanthuridae (surgeonfish) and Lethrinidae (emperors) dominated the total catch in terms of both abundance and weight (Fig. 3). The most common finfish species in the gillnet catch were the rabbitfish *Siganus lineatus* (265 individuals observed, representing 75% of the total catch by abundance and 56% of the total catch by weight), the surgeonfish *Naso unicornis* (24 individuals: 7% of the total catch by abundance and 26% of the total catch by weight) and the emperors *Lethrinus lentjan* (19 individuals: 5% of the total catch by both abundance and weight) and *Lethrinus harak* (15 individuals: 4% of the total catch by both abundance and weight) (Appendix 2).

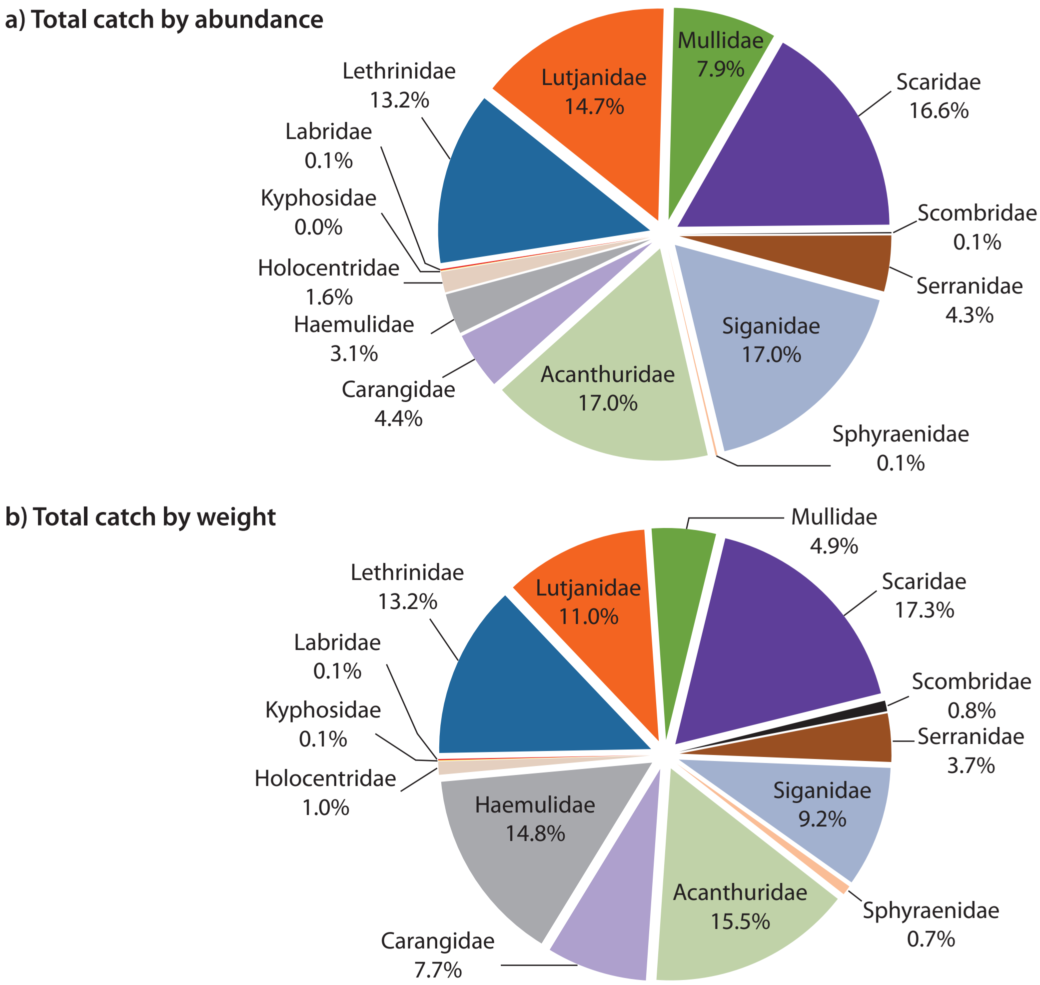


Figure 1. Percentage contribution by abundance (a) and weight (b) of families caught by fishers landing at the Happy Fish Market, Koror, September 2014 (all fishing methods combined).

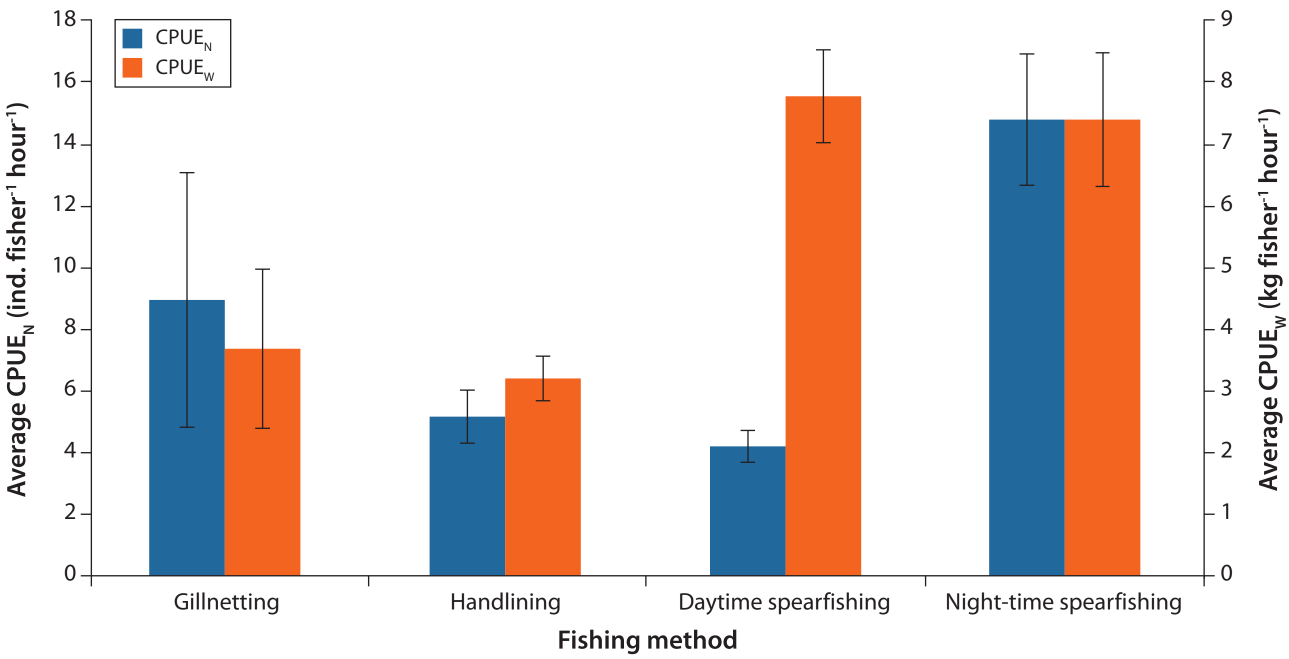
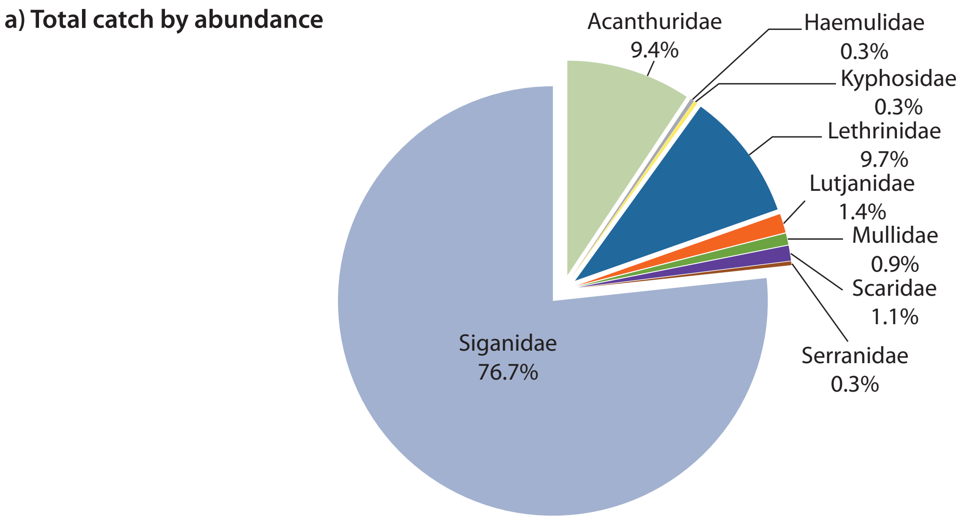


Figure 2. Average catch per unit effort (CPUE) (±SE) for each fishing method of landings surveyed at Koror, September 2014.



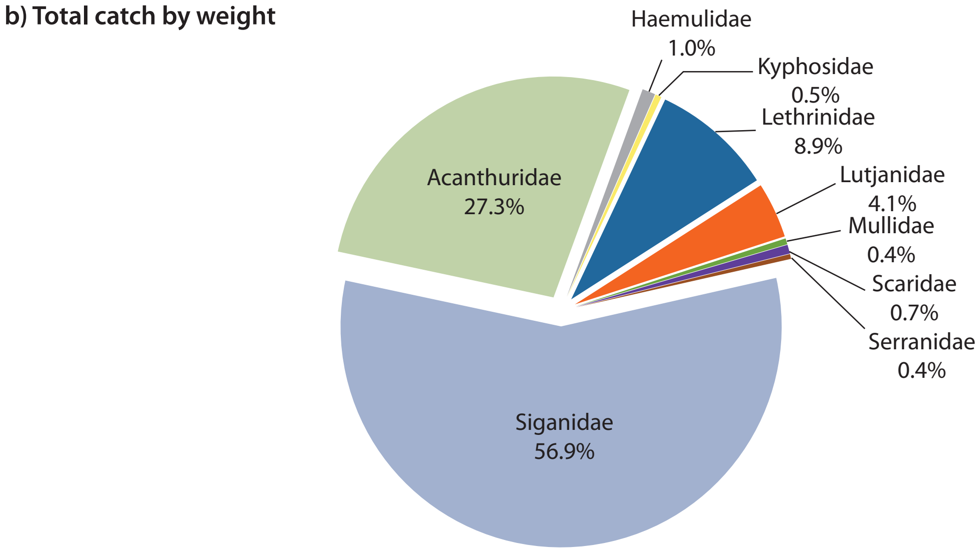


Figure 3. Percentage contribution by abundance (a) and weight (b) of families caught by gillnetting, Koror, September 2014.

Handline / bottom fishing

Handline / bottom fishing activities were encountered on 14 of the 23 landings met (Table 2). The total catch recorded from the three landings was 565 individual fish, weighing an estimated 333 kg. The average catch from handlining was 40 ±9 individual fish, or 24 ±4 kg per trip. An average of 1.7 ±0.2 fishers were involved in handline fishing per trip. The average trip duration was 9.9 ±3.6 hours, with 4.0 ±0.2 hours spent fishing. The average $CPUE_N$ was 5.2 ±0.8 individuals fisher^{-1} hour^{-1}, while the average $CPUE_W$ was 3.2 ±0.4 kg fisher^{-1} hour^{-1} (Fig. 2). The minimum number of surveys required to detect a change in average $CPUE_N$ at precision levels of 0.10, 0.15 and 0.20 was estimated as 37, 17 and 10 surveys, respectively, while the estimated minimum number of surveys required to detect a change in average $CPUE_W$ at precision levels of 0.10, 0.15 and 0.20 precision was estimated as 18, 8 and 5 surveys, respectively.

A total of 41 species from seven families was observed in the handline catch (Appendix 2). Members of the Lutjanidae (snappers), Lethrinidae (emperors) and Carangidae (jacks) dominated the total catch in terms of both abundance and weight (Fig. 4). The most common finfish species in the handline catch were the snappers *Lutjanus gibbus* (127 individuals observed, representing 22% of the total catch by abundance and 12% of the total catch by weight), *Lutjanus vitta* (58 individuals: 10% of the total catch by abundance and 3% of the total catch by weight) and *Lutjanus bohar* (57 individuals: 10% of the total catch by abundance and 13% of the total catch by weight), and the emperors *Lethrinus lentjan* (68 individuals: 12% of the total catch by abundance and 11% of the total catch by weight), *Lethrinus obsoletus* (66 individuals: 12% of the total catch by abundance and 6% of the total catch by weight) and *Lethrinus xanthochilus* (38 individuals: 7% of the total catch by abundance and 11% of the total catch by weight) (Appendix 2).

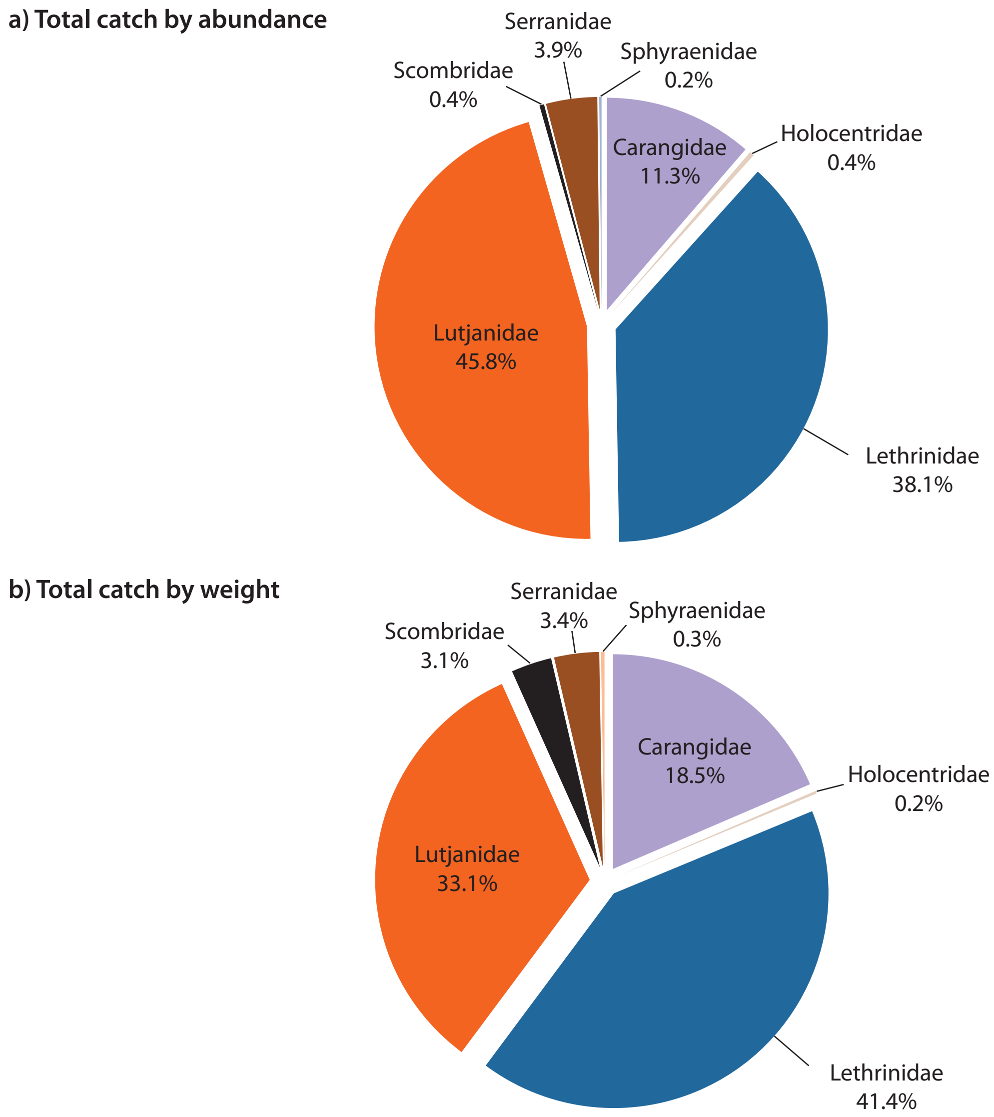


Figure 4. Percentage contribution by abundance (a) and weight (b) of families caught by handline/bottom fishing, Koror, September 2014.

Spearfishing – daytime

Three landings of daytime spearfishing were met at Koror, where the catches of nine individual fishers were quantified (Table 2). The total catch recorded from the three landings was 148 individual fish, weighing an estimated 278 kg. On average, daytime spearfishing trips caught 49 ±15 individual fish, or 93 ±30 kg. The average $CPUE_N$ was 4.2 ±0.5 individuals fisher^{-1} hour^{-1}, while the average $CPUE_W$ was 7.8 ±0.8 kg fisher^{-1} hour^{-1} (Fig. 2). The average furthest distance travelled was 41.7 ±3.3 km.

Members of the families Haemulidae (sweetlips), Carangidae (jacks) and Scaridae (parrotfish) dominated the catch in terms of both abundance and weight (Fig. 5). Twenty-six species were observed in the daytime spearfishing catch. Dominant species were the large-bodied sweetlips *Plectorhinchus albovittatus* (27 individuals: 18% of the total catch by abundance and 50% of the total catch by weight) and *Plectorhinchus lineatus* (26 individuals: 18% of the total catch by abundance and 11% of the total catch by weight), and the jack *Carangoides orthogrammus* (15 individuals: 10% of the total catch by abundance and 5% of the total catch by weight) (Appendix 2).

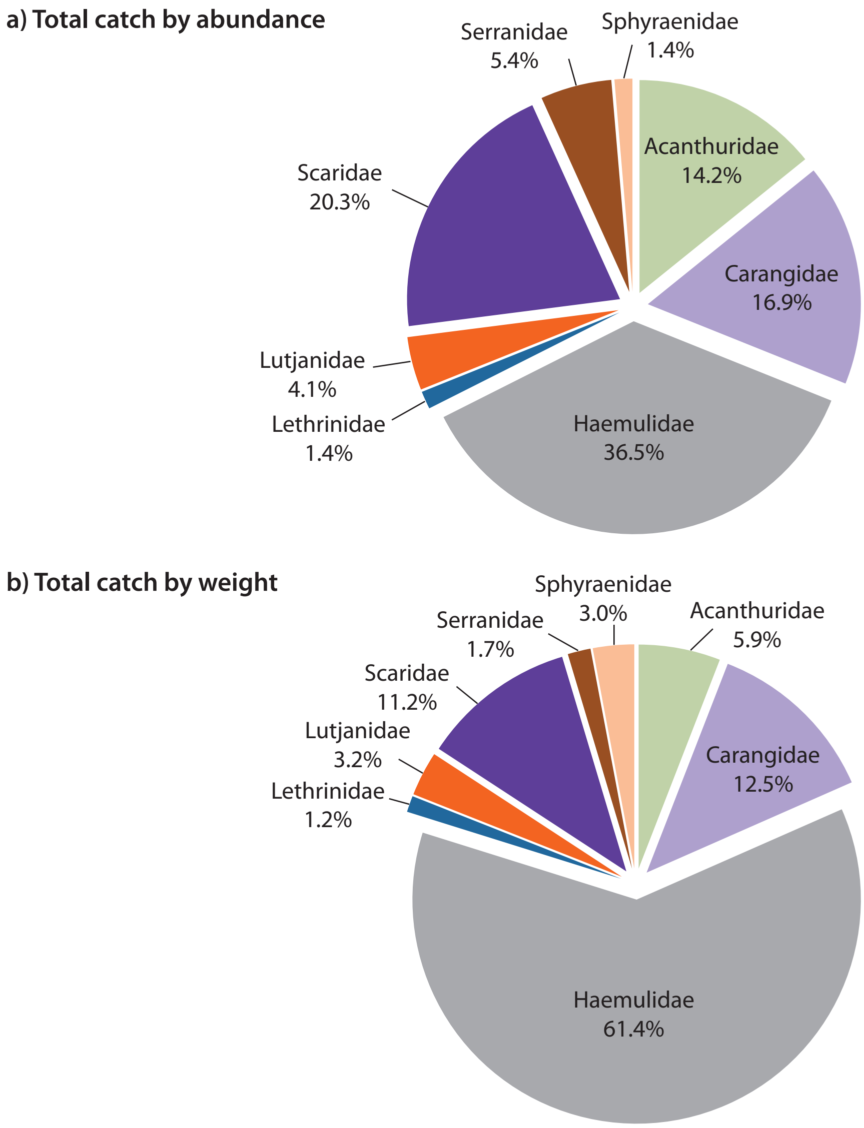


Figure 5. Percentage contribution by abundance (a) and weight (b) of families caught by daytime spearfishing, Koror, September 2014.

Spearfishing – Night-time

Nine landings of night-time spearfishing were met at Koror, during which the catches of 18 individual fishers were quantified (Table 2). On average, night-time spearfishing trips involved 2.0 ±0.2 fishers with an average of 3.7 ±0.3 hours spent fishing. The average catch per landing was 109 ±22 individual fish, or 54 ±11 kg. The average $CPUE_N$ was 14.8 ±2.1 individuals fisher^{-1} hour^{-1}, while the average $CPUE_W$ was 7.4 ±1.1 kg fisher^{-1} hour^{-1} (Figs 2 and 6). These estimates are slightly higher than those estimated for night-time spearfishing activities in Pohnpei ($CPUE_N$ = 11.51 ±1.36 individuals fisher^{-1} hour^{-1} or $CPUE_W$ = 4.50 ±0.85 kg fisher^{-1} hour^{-1}) and significantly higher than those estimated for Majuro Atoll in Marshall Islands (Fig. 6). The average furthest distance travelled was 23.9 ±4.3 km. The minimum number of surveys required to detect a change in average $CPUE_N$ at precision levels of 0.10, 0.15 and 0.20 was estimated as 19, 9 and 5 surveys, respectively, while the estimated minimum number of surveys required to detect a change in average $CPUE_W$ at precision levels of 0.10, 0.15 and 0.20 precision was estimated as 20, 9 and 5 surveys, respectively.

A total of 977 individual fish were observed from the night-time spearfishing catch landed at Koror, which weighed an estimated 483 kg. A diverse array of species was recorded, with 55 species from ten families observed (Appendix 2). The catch composition of night-time spearfishing was considerably different to that of daytime spearing, with small-bodied members of the Scaridae (parrotfish), Acanthuridae (surgeonfish), Mullidae (goatfish) and Siganidae (rabbitfish) dominating the total catch in terms of both abundance and weight (Fig. 7). The most common finfish species in the night-time spearfishing catch were the parrotfish *Hipposcarus longiceps* (225 individuals recorded, representing 23% of the total catch by abundance and 27% of the total catch by weight); the surgeonfish *Naso lituratus* (158 individuals recorded, representing 16% of the total catch by abundance and 10% of the total catch by weight) and *Acanthurus nigricauda* (84 individuals: 9% of the total catch by abundance and 5% of the total catch by weight); and the goatfish *Parupeneus barberinus* (146 individuals: 15% of the total catch by abundance and 12% of the total catch by weight) (Appendix 2). The average weight of individual fish in the night-time spearfishing catch was significantly lower than that of the daytime spearfishing catch (0.49 kg vs. 1.88 kg per individual fish captured for night and day spearfishing, respectively), indicating that daytime spearfishers are selecting larger fish, and night-time spearfishers are selecting smaller fish.

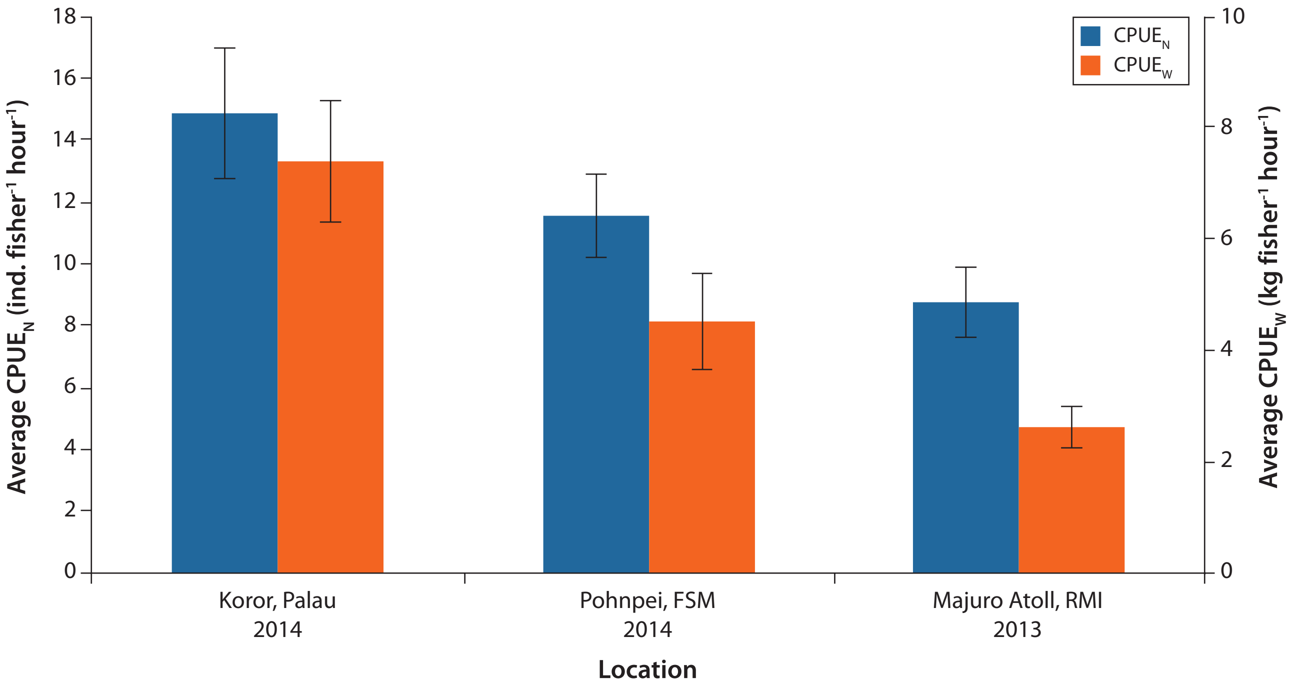


Figure 6. Comparison of average CPUE$_N$ and CPUE$_W$ (±SE) among locations in Micronesia. Pohnpei data (FSM, Federated States of Micronesia) are from Moore et al. (2015); Majuro Atoll data (RMI, Republic of the Marshall Islands) are from Moore et al. (2014).

3.1.2 Length data

Length frequencies of the most commonly encountered species are presented in Figure 8. Harvested individuals of most species were considered to be over the length at 50% maturity (L_{50}) (Fig. 8; Table 3). However, 42% of all individuals of the parrotfish *Cetoscarus ocellatus*, 85% of the parrotfish *Chlorurus microrhinos* and 39% of the parrotfish *Hipposcarus longiceps* landed at Koror were estimated to be under the length at 50% maturity (Table 3), with all individuals (immature or otherwise) caught by spearfishing. Similarly, 91% of the *Lutjanus bohar*, 50% of *Lethrinus olivaceus* and 50% of *Lutjanus gibbus* landed were considered to be under L_{50} (Table 3). For *Lutjanus bohar*, all individuals were captured by handlining. For *Lethrinus olivaceus*, 88% of the immature individuals were caught by handlining. For *Lutjanus gibbus*, 88% of the immature individuals landed were caught by handlining, while 53% of all *L. gibbus* in the handlining catch were under the length at 50% maturity (67 of 127 individuals), with the vast majority taken by handlining fishing on patch reefs within the lagoon.

Few differences were evident in length frequencies of key species between the 1990–1991 catch and the 2014 catch (Fig. 9). Slightly fewer small individuals of *Hipposcarus longiceps*, *Lethrinus obsoletus*,[2] *Naso lituratus*,

[2] This species was referred to as *Lethrinus ramak* by Kitalong and Dalzell (1994). *Lethrinus ramak* has since been used synonymously with *L. obsoletus*.

Naso unicornis and *Siganus lineatus* were observed in 2014 than in 1990–1991, a result that likely reflects the introduction of minimum legal mesh sizes for gillnets, surround nets and *kesokes* nets (as outlined in Section 1) in 1994.

Considerable differences in length frequencies were observed for *L. gibbus* between 1990–1991 and the current survey. Most notably, there was a general shift in the length frequencies to smaller sized individuals. The maximum size of fish observed decreased from the 38.0–38.9 cm FL category to the 33.0–33.9 cm FL length category, while the modal length class decreased from 26.0–26.9 cm FL to 23.0–23.9 cm FL (Fig. 9).

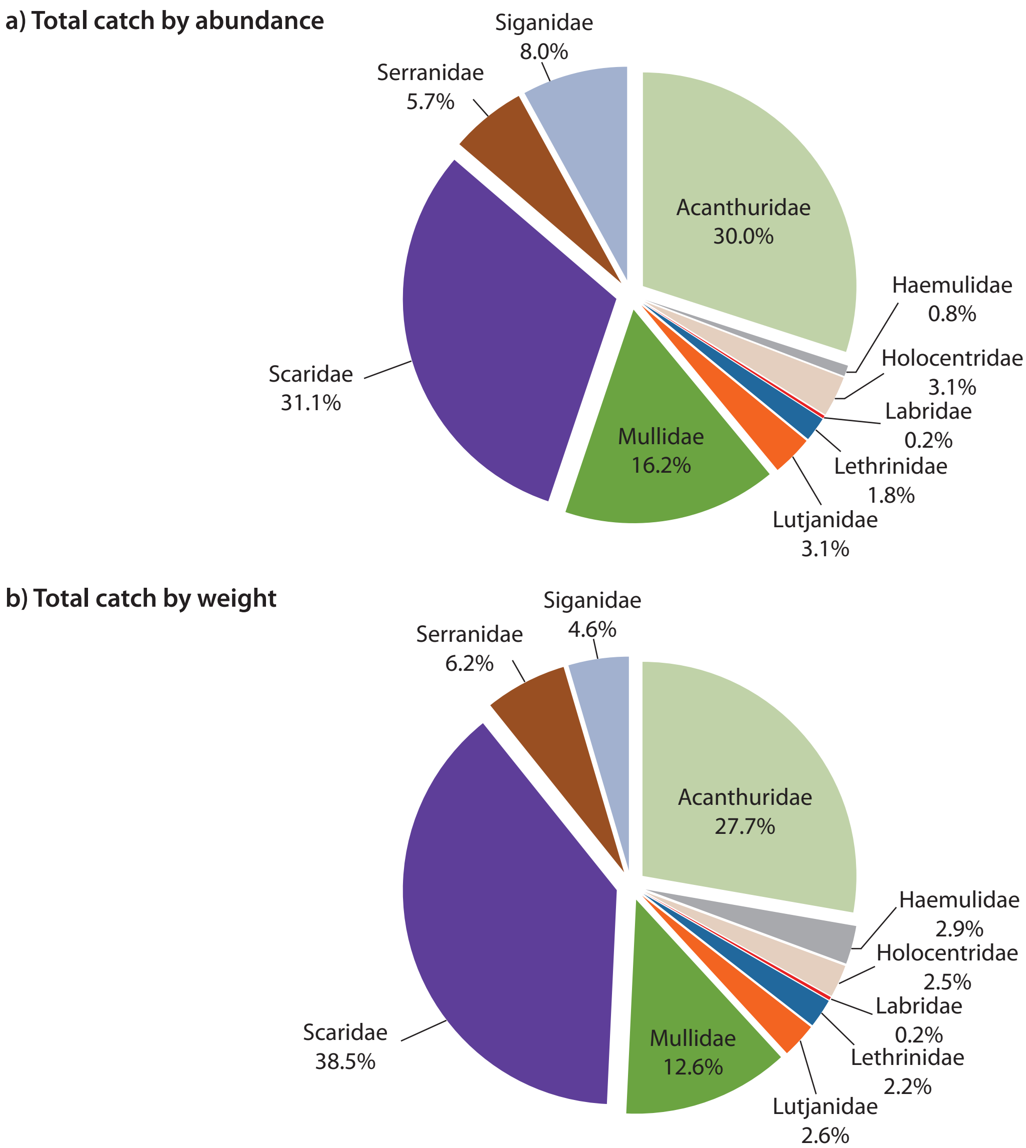


Figure 7. Percentage contribution by abundance (a) and weight (b) of families caught by night-time spearfishing, Koror, September 2014.

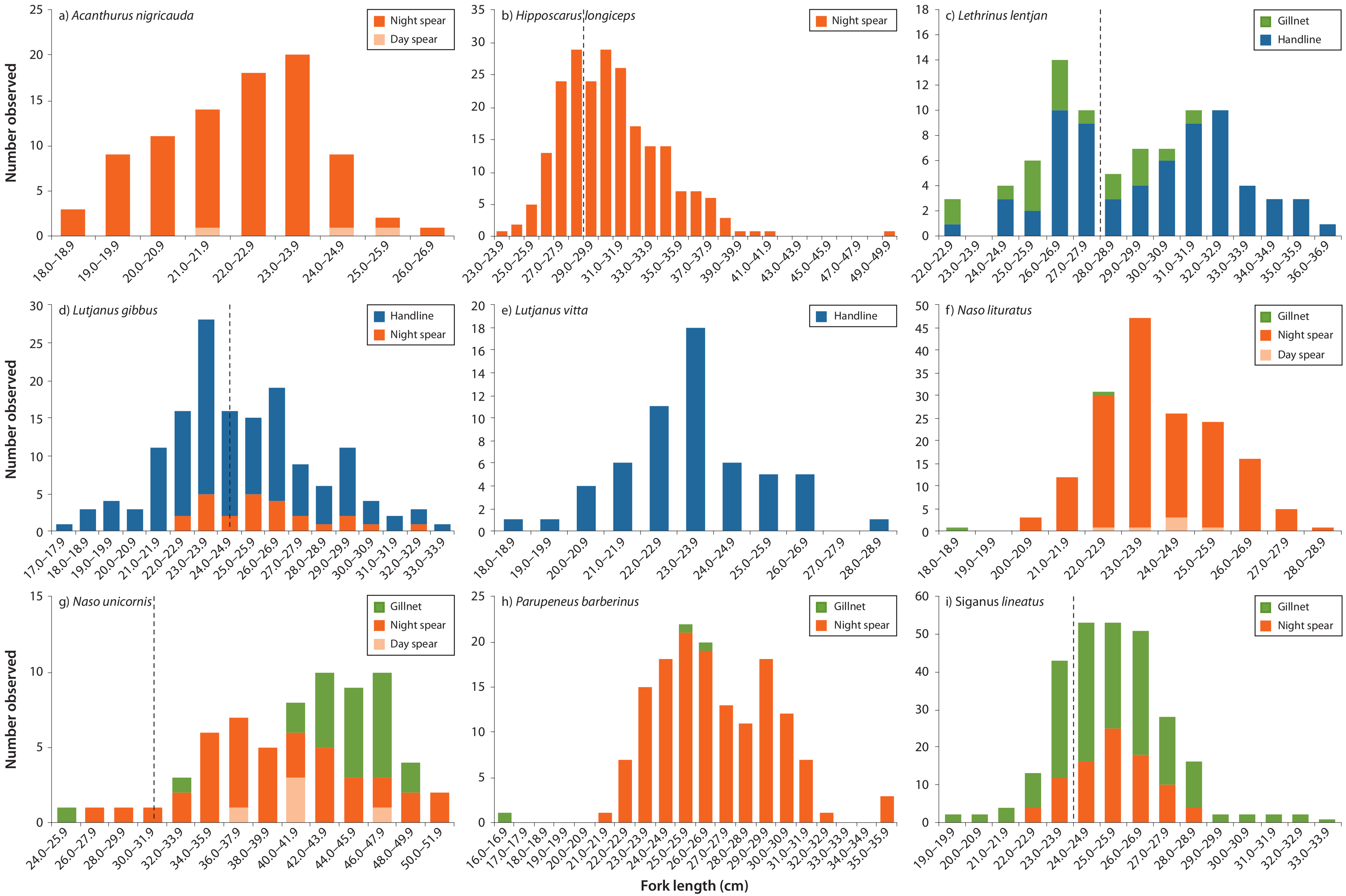


Figure 8. Length frequencies for nine of the most commonly observed finfish species during creel surveys in Koror, September 2014, by fishing method. Dashed lines indicate estimated lengths at 50% maturity (see Table 2 for references).

Table 3. Species commonly encountered during the creel surveys, their corresponding lengths at 50% maturity (L_{50}) and percentage of the catch (all methods) under L_m. Orange type indicates that more than 30% of the catch was considered to be under the length at 50% maturity. n/a = no estimate available.

Local name	Species	L_{50} (reference)	Percentage of catch <L_{50} (all methods)
Esengel	*Acanthurus nigricauda*	14 cm FL (SPC, unpublished data)	0%
Mengardecheluchеb	*Cephalopholis argus*	22 cm TL (SPC, unpublished data)[3]	0%
Beyadel (female); *Ngesngis* (male)	*Cetoscarus ocellatus*	35 cm FL (Barba 2010)	**42%**
Udoudungelel	*Chlorurus microrhinos*	38 cm FL (Barba 2010)	**85%**
Ngyaoch (small); *Berkism* (large)	*Hipposcarus longiceps*	29.5 cm FL (SPC, unpublished data)	**39%**
Itotech	*Lethrinus harak*	21 cm FL (Taylor and McIlwain 2010)	0%
Udech	*Lethrinus obsoletus*	21 cm FL (Taylor 2010)	0%
Melangmud	*Lethrinus olivaceus*	42.6 cm FL (Prince, unpublished data)	**50%**
Mechur	*Lethrinus xanthochilus*	30 cm FL (May and Robinson 2005)	0%
Kotongel (small-medium); *Kedesau* (large)	*Lutjanus bohar*	43 cm FL (Marriot et al. 2007)	**91%**
Keremlal	*Lutjanus gibbus*	24.6 cm FL (this study)	**50%**
Dodes	*Lutjanus vitta*	16 cm FL (Ramachandran et al. 2014)	0%
Erangel	*Naso lituratus*	20 cm FL (Moore and Malimali, in prep)	1%
Um	*Naso unicornis*	31 cm FL (Taylor et al. 2014)	4%
Bang	*Parupeneus barberinus*	14 cm FL (Longenecker et al. 2011)	0%
Bikl	*Plectorhinchus albovittatus*	n/a	0%[4]
Yaus	*Plectorhinchus lineatus*	32 cm FL (Longenecker et al. 2011)	0%
Mellemau	*Scarus frenatus*	22 cm FL (Barba 2010)	0%
Beduut	*Siganus argenteus*	19 cm FL (Moore and Malimali, in prep)	0%
Klsebuul	*Siganus lineatus*	24 cm FL (Longenecker et al. 2011)	23%

[3] Based on regional dataset.

[4] Although little information is available on the L_{50} of *Plectorhinchus albovittatus*, all individuals encountered were considered mature, based on observations of ripe ovaries and testes upon dissection at the market.

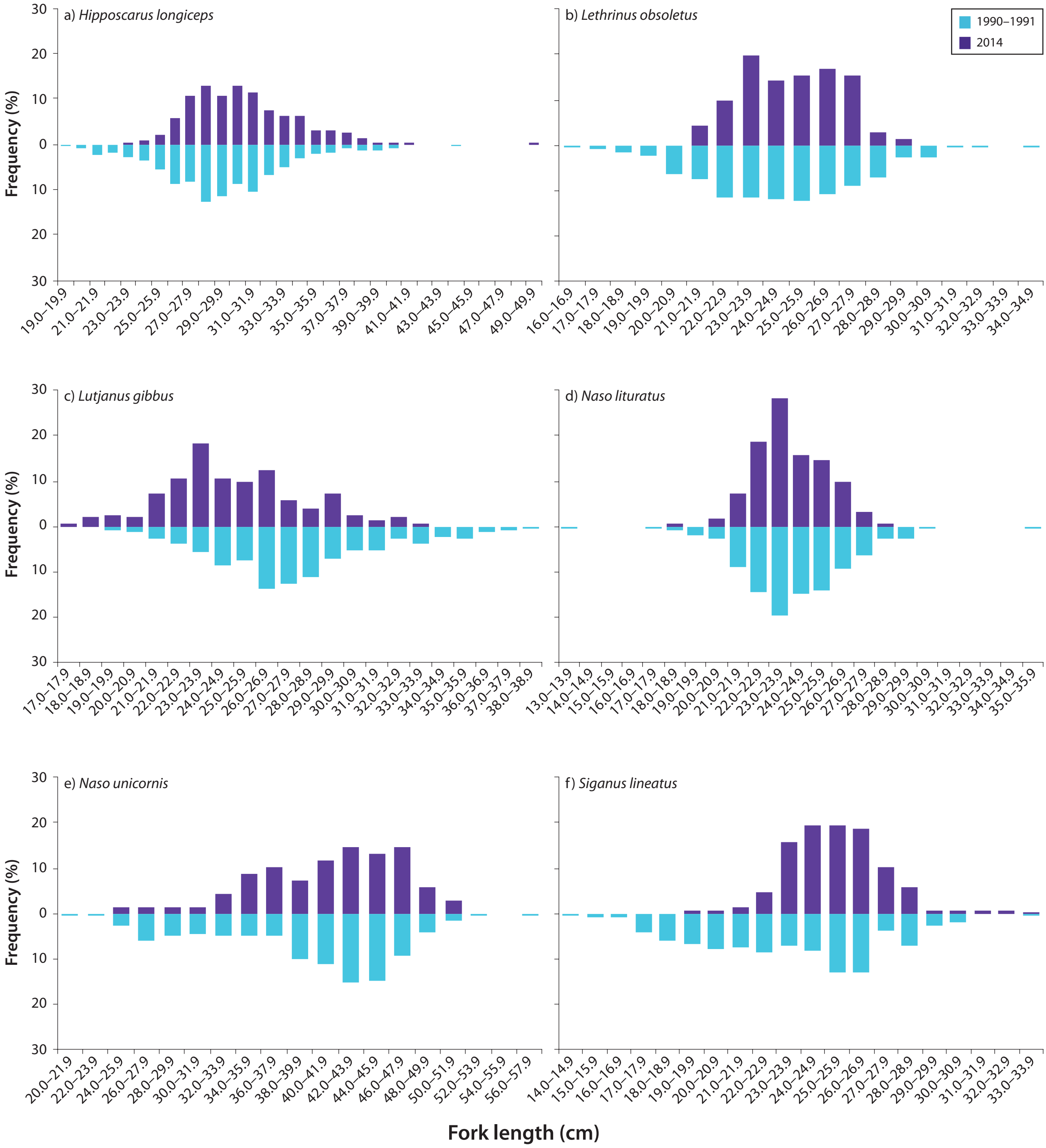


Figure 9. Length frequencies for six coastal finfish species landed by commercial fishers in Koror, in 2014 (purple bars) and 1990–1991 (blue bars).

3.1.3 Fisher perceptions

Perception data were collected from 15 lead fishers.[5] All fishers from whom perceptions were documented were male. The majority of fishers interviewed stated that they had seen changes in the fishery in the last few years, with 73% of all respondents stating that the quantity of fish caught had decreased over the last five years, and 80% stating that the size of fish had decreased in the same period (Fig. 10).

During the creel survey the fishers were asked their concerns. These were:

- overfishing;
- habitat destruction and geophysical changes on the reef caused by storms and typhoons;
- the effects of climate change on coastal resources; and
- the effects of increased tourist numbers to reefs and fisheries.

Some of the more common suggestions for management included:

- increasing community awareness and outreach programmes;
- increasing the number of species subject to temporal closures; and
- development of management measures to prevent the capture and/or sale of small (immature) fish.

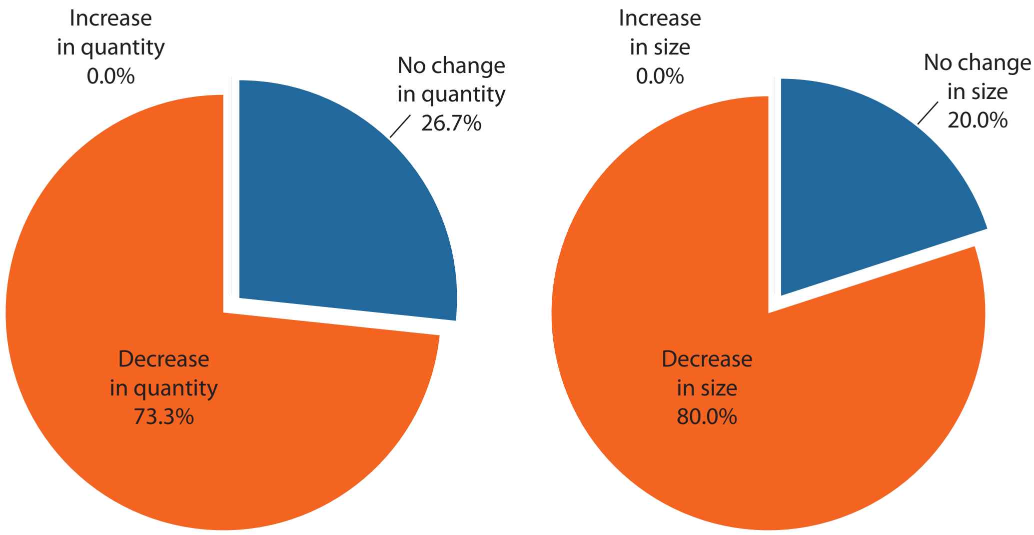


Figure 10. Responses of lead fishers to questions on perceptions on whether catch quantity (left) or fish size (right) have changed over the last five years.

3.2 Monthly fish purchases by the Happy Fish Market

In August 2014, a total of 164 purchases of fish from fishers were made by the HFM, totalling 11.84 t and equating to a purchase price of USD 43,965. Of this, general reef fish comprised 44% of the total amount purchased (5.21 t), while parrotfish and *Um* (*Naso unicornis*) comprised 29% and 13% of the total amount purchased (3.45 t and 1.59 t, respectively) (Fig. 11). On average, 383 kg of fish was purchased by the HFM on a daily basis during August 2014, with the majority sold to customers on the day of purchase. Assuming the data collected for August 2014 are representative of any given month, these figures equate to approximately 142.11 t of fish passing through the HFM on an annual basis.

Fish were purchased from fishers every day of the week, with Tuesdays typically having the lowest average number of fishers selling to the market (= lowest number of landings purchased) and the lowest total weight purchased of any day and Thursdays having the highest average number of boats selling to the market (Fig. 12).

[5] Perception data were only collected once for each lead fisher, regardless of how many times that lead fisher was surveyed.

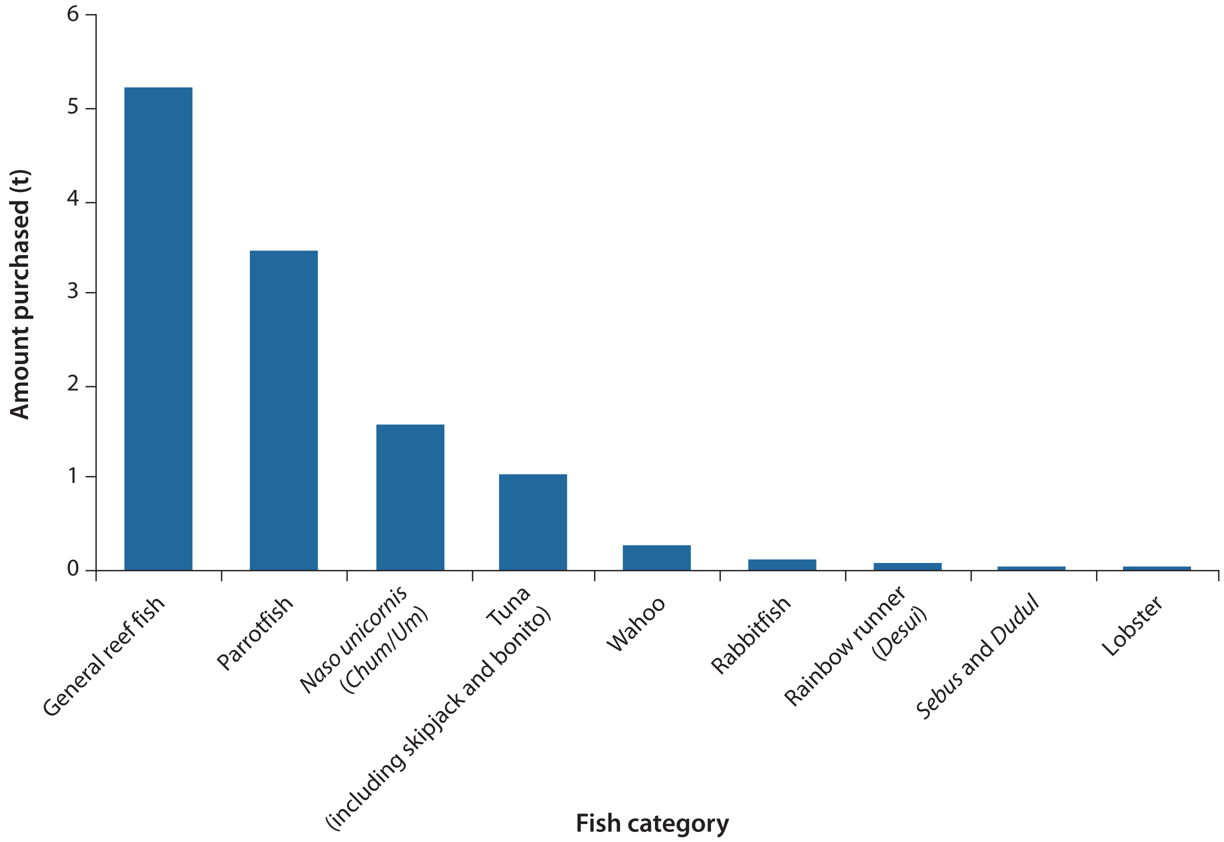


Figure 11. Amount of fish purchased by the Happy Fish Market, by fish category, in August 2014.

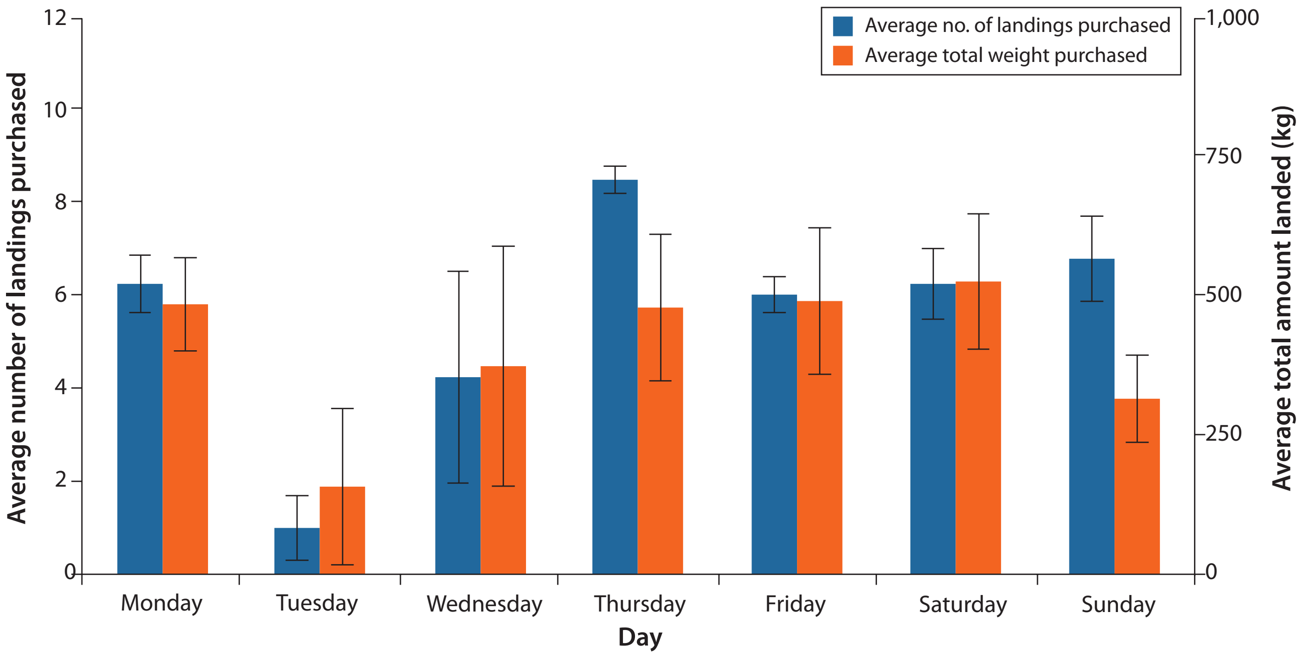


Figure 12. Average number (±SE) of landings and total weight of fish purchased per day of the week at the Happy Fish Market, Koror, August 2014.

3.3 Demographic assessments

3.3.1 Cephalopholis argus

Sixty-one *Cephalopholis argus* were sampled from the spearfishing (n = 47) and handlining (n = 14) catch landed at Koror. Lengths ranged from 24.9–36.1 cm TL, with a modal length class of 30.0–30.9 cm TL (Table 4). The average length was 30.9 ±0.4 cm TL. The length-weight relationship was $W = 0.0229 \times TL^{2.9281}$ ($r^2 = 0.84$).

Ages were assigned to 47 of the *C. argus* sampled. Estimated ages ranged from 5–19 years, with a modal age of nine years (Fig. 13; Table 4). The maximum age was slightly higher than that observed for populations in neighbouring Pohnpei (15 years; Moore et al. 2015). No significant difference was detected in age frequencies of individuals caught by handline or spearfishing ($X^2 = 17.9$, df = 14, p = 0.21).

Total mortality was estimated at 0.193 yr^{-1}. The estimate of M from fitting Hoenig's (1983) equation using the maximum observed age of 25 years, based on the maximum age reported from Hawaii (Donovan et al. 2013), was 0.167 yr^{-1}. Accordingly, fishing mortality was calculated as 0.026 yr^{-1}: well below the maximum recommended fishing mortality rate of 0.083 yr^{-1} (Table 5).

Due to low numbers of immature individuals, no estimate of length- or age-at-maturity was established for this species. The length and age at which 50% of the population changed sex to males was estimated at 31.0 cm TL (95% CI = 29.7–32.0 cm TL) and 11.9 years (95% CI = 11.0–13.0 years), while 95% of the population were estimated to have changed sex by 37.7 cm TL (95% CI = 34.0–41.0 cm TL) and 17.2 years (95% CI = 15.4–18.7 years).

3.3.2 Lethrinus obsoletus

Eighty-seven *Lethrinus obsoletus* were sampled from the commercial fishers of Palau, all of which were assigned an age. The sex ratio was largely skewed towards females, with males representing 29 of the 87 individuals observed (0.3 males: 1 female). The average length of sampled individuals was 24.8 ±0.2 cm FL. The length-weight relationship was $W = 0.0215 \times FL^{2.9514}$ ($r^2 = 0.90$).

Estimated ages for *L. obsoletus* at Palau ranged from 2–12 years, with a first modal age of three years. While no previous assessment of the biology of this species had been conducted in Palau, the maximum observed age (12 years) is generally consistent with observations of this species in nearby Guam (11 years; Taylor 2010), although slightly less than the maximum age observed for this species in Tonga (16 years; Moore and Malimali, in prep). No significant difference was detected in the age frequencies of individuals caught by handline or spearfishing ($X^2 = 12.4$, df = 9, p = 0.19). Growth of *L. obsoletus* was initially rapid. After this initial rapid period, *L. obsoletus* were relatively slow growing, consistent with observations of this species elsewhere (e.g. Ebisawa and Ozawa 2009; Taylor 2010; Moore and Malimali, in prep).

Total mortality was estimated at 0.290 yr^{-1}. Natural mortality, estimated from the Hoenig (1983) equation using a maximum age of 21 years (Ebisawa and Ozawa 2009), was 0.200 yr^{-1}. Fishing mortality (F) was estimated at 0.091, slightly under the recommended maximum fishing mortality rate of 0.099. While these estimates suggest that *L. obsoletus* in southern Palau are not overfished at present, ongoing monitoring is recommended to ensure that fishing mortality for this species does not increase.

Due to low numbers of immature individuals, no estimate of length- or age-at-maturity was established for this species. This suggests that the majority of *L. obsoletus* captured in the fisheries of southern Palau are mature: a result that is generally consistent with that observed from the creel survey data (Fig. 8; Table 3).

3.3.3 Lutjanus gibbus

One hundred and sixty-seven *Lutjanus gibbus* were sampled from the handline catch landed at Koror, 166 of which were assigned an age. The sex ratio was close to 1:1, with 87 females and 79 males (0.91 males: 1 female). Length of sampled individuals ranged from 17.4–34.0 cm FL. The average length was 25.9 ±0.3 cm FL. The average length of males was slightly more than that of females (27.7 ±0.4 cm FL for males vs. 24.1 ±0.2 cm FL for females). The length-weight relationship was $W = 0.0217 \times FL^{2.9713}$ ($r^2 = 0.97$).

Estimated ages ranged from 2–16 years, with a modal age of four years. The average age of males was slightly higher than females (5.9 ±0.3 years for males compared to 5.0 ±0.3 years for females). No significant difference was detected in age frequencies of individuals caught by handline or spearfishing ($X^2 = 12.4$, df = 13, p = 0.50). Constrained growth curves differed markedly between sexes, with males reaching a greater length at a given age than females ($X^2 = 79.5.0$, df = 2, $p<0.05$).

The estimate of total mortality (Z) for *L. gibbus* was 0.329 yr^{-1}, which is lower than the rate of 0.434 yr^{-1} estimated for populations in Pohnpei but higher than the rate of 0.289 yr^{-1} estimated for populations at Majuro Atoll in Marshall Islands (Moore et al. 2014, 2015). The estimate of M from fitting Hoenig's (1983) equation using a maximum age of 18 years (based on samples from elsewhere in Micronesia; Moore et al. 2014) was 0.232 yr^{-1}. Accordingly, fishing mortality was calculated at 0.096 yr^{-1}: slightly under the recommended maximum fishing mortality rate of 0.116 yr^{-1}. These results indicate that *L. gibbus* populations in southern Palau are close to being fished beyond a biologically sustainable level, and that future management intervention will be required to reduce fishing mortality for this species.

Length- and age-at-maturity was established for both female and male *L. gibbus* landed at Koror. For females, length at which 50% of the population became mature was approximately 23.2 cm FL (95% CI = 22.6–23.5 cm FL), while 95% of the population was estimated to be mature at 25.2 cm FL (95% CI = 24.2–26.1 cm FL). The length at which 50% of males became mature was 24.6 cm FL (95% CI = 23.6–25.6 cm FL), while 95% of males were mature at 27.4 cm FL (95% CI = 25.8–28.5 cm FL). The age at which 50% of females became mature was 3.5 years (95% CI = 3.1–3.9 years), while 95% of females were mature at 5.8 years (95% CI = 4.6–6.3 years. The age at which 50% of males were mature was 3.7 years (95% CI = 2.6–4.3 years), while 95% of the male population was mature at 6.6 years (95% CI = 5.5–8.2 years).

3.3.4 Naso lituratus

One hundred and twenty-eight *Naso lituratus* were sampled from the commercial spearfishers landing at Koror. The sex ratio was 1 male: 1 female. Lengths of sampled individuals ranged from 20.9–27.5 cm FL, with a modal length class of 23.0–23.9 cm FL. The average length was 23.8 ±0.1 cm FL. The average length of males was slightly more than that of females (24.7 ±0.2 cm FL for males vs. 23.0 ±0.1 cm FL for females). The length-weight relationship was $W = 0.0865 \times FL^{2.579}$ ($r^2 = 0.83$).

Ages were assigned to 124 of the 128 *N. lituratus* collected. They ranged from 1–13 years, with a modal age of five years (Fig. 13; Table 4). No significant difference was observed in the age frequency distributions between sexes ($X^2 = 20.7$, df = 12, p = 0.06). Growth in both sexes was initially rapid, consistent with observations of this species elsewhere across its distribution (Taylor et al. 2014; Moore et al. 2014). Likelihood ratio tests revealed that growth of *N. lituratus* differed significantly between sexes ($X^2 = 79.5$, df = 2, $p<0.05$), with males typically reaching a greater length-at-age and a greater asymptotic length than females.

The estimate of total mortality (Z) for *N. lituratus* was high at 0.414 yr^{-1}, and was comparable to estimates reported from elsewhere in Micronesia (e.g. 0.33 and 0.40 yr^{-1} for Pohnpei and Guam respectively; Taylor et al. 2014). The estimate of M from fitting Hoenig's (1983) equation using a maximum age of 20 years (based on samples from elsewhere in Micronesia; Moore et al. 2014) was 0.209 yr^{-1}. Accordingly, fishing mortality was calculated at 0.205 yr^{-1}: more than double the recommended maximum fishing mortality rate of 0.104 yr^{-1}. These results indicate that *N. lituratus* populations in southern Palau are fished beyond a sustainable level, suggesting that urgent management action to reduce fishing pressure on this species is required (Table 5).

No immature females and only three immature males were observed from the 128 *N. lituratus* sampled. Accordingly, due to low numbers of immature individuals, no estimates of length- or age-at-maturity were established for this species. This suggests that the majority of *N. lituratus* captured in the fisheries of southern Palau are mature: a result that is consistent with that observed from the creel survey data (Fig. 8; Table 3).

3.3.5 Naso unicornis

Eighty-two *Naso unicornis* were sampled from the commercial gillnet (n = 15) and spearfishing (n = 67) catch landed at Koror. The sex ratio was 0.37 males: 1 female (22 males to 60 females). Lengths of sampled individuals ranged from 27.2–51.3 cm FL, with an average length of 41.2 ±0.7 cm FL. The average length of females was slightly more than that of males (42.2 ±0.7 cm FL for females vs. 38.4 ±1.5 cm FL for males). The length-weight relationship was $W = 0.0598 \times FL^{2.6897}$ ($r^2 = 0.97$).

Ages were assigned to 75 of the 82 *N. unicornis* sampled. Ages ranged from 1–32 years, with a first modal age of five years (Fig. 13; Table 4). The maximum observed age (32 years) was considerably higher than that reported for *N. unicornis* in nearby Pohnpei and Guam (16 and 23 years respectively; Taylor et al. 2014) where fishing pressure on this species is high, but is comparable with the maximum age of >30 years observed on the Great Barrier Reef, Australia, where fishing pressure on this species is minimal (Choat and Axe 1996).

Significant differences were observed in the age frequencies by fishing method, with spearfishers selecting considerably younger individuals than those captured by gillnetting ($X^2 = 43.6$, df = 20, p = 0.002).

As with the congener *N. lituratus*, growth of *N. unicornis* was initially rapid, although it was slower than the 'square' growth curve observed for many species of acanthurids in the region, in particular *Ctenochaetus striatus* (Trip et al. 2008; Moore et al. 2014). Little variation in growth was observed between sexes ($X^2 = 0.34$, df = 2, p = 0.84).

Total mortality for *N. unicornis* was estimated as 0.161 yr^{-1}. The estimate of M from fitting Hoenig's (1983) equation using the maximum observed age of 32 years was 0.130 yr^{-1}. Accordingly, fishing mortality was calculated as 0.031 yr^{-1}: below the recommended maximum fishing mortality reference point of 0.065 yr^{-1} (Table 5). While these estimates suggest that *N. unicornis* in southern Palau are not overfished at present, monitoring is recommended to evaluate ongoing effects of fishing pressure on this species, particularly given this species' key ecological role as a macroalgae browser and as the demand for fresh fish grows with increasing populations.

Only three immature females and five immature males were observed from the 82 individuals collected. Accordingly, due to low numbers of immature individuals, no estimates of length- or age-at-maturity were established for this species. As with *N. lituratus*, this suggests that the majority of *N. unicornis* captured in the fisheries of southern Palau are mature: a result that is generally consistent with that observed from the creel survey data (Fig. 8; Table 3).

Table 4. Demographic parameter estimates for selected reef fish species from southern Palau, September 2014. VBGF parameters are based on constrained ($t_0 = 0$) estimates. L_∞ is the hypothetical asymptotic length; K is the growth coefficient or rate at which L_∞ is approached.

Species	No. collected	No. aged to date	Size range (cm)	Age range	L_∞ (males / females)[6]	K (males / females)
Cephalopholis argus	61	47	24.9–36.1 TL	5–19	35.1	0.20
Lethrinus obsoletus	87	87	21.1–28.9 FL	2–12	26.2	0.68
Lutjanus gibbus	167	166	17.4–34.0 FL	2–16	31.2 / 25.7	0.44 / 0.72
Naso lituratus	128	124	20.9–27.5 FL	1–13	25.2 / 23.2	1.34 / 1.42
Naso unicornis	82	75	27.2–51.3 FL	1–32	44.2 / 45.5	0.56 / 0.53

Table 5. Estimates of mortality for monitored species using catch curve and Hoenig (1983) estimators. Maximum ages used in the equation of Hoenig (1983) and age ranges used for total mortality (Z) calculations are indicated. Fishing mortality rates (F) in green are below estimated maximum optimal rates (F_{opt}), while fishing mortality rates in orange exceed maximum recommended rates.

Species	Maximum age (yr)	Age range	Total mortality (Z) Catch curve	Natural mortality (M) Hoenig (1983)	Fishing mortality (F)	F_{opt}
Cephalopholis argus	25 (Donovan et al. 2013)	9–19	0.193	0.167	0.026	0.083
Lethrinus obsoletus	21 (Ebisawa and Ozawa 2009)	2–12	0.290	0.199	0.091	0.099
Lutjanus gibbus	18 (Moore et al. 2014)	4–16	0.329	0.232	0.096	0.116
Naso lituratus	20 (Moore et al. 2014)	5–13	0.414	0.209	0.205	0.104
Naso unicornis	32 (this study)	5–20	0.161	0.130	0.031	0.065

[6] Estimates of L_∞ and K for *Cephalopholis argus* and *Lethrinus obsoletus* are based on male and female data combined.

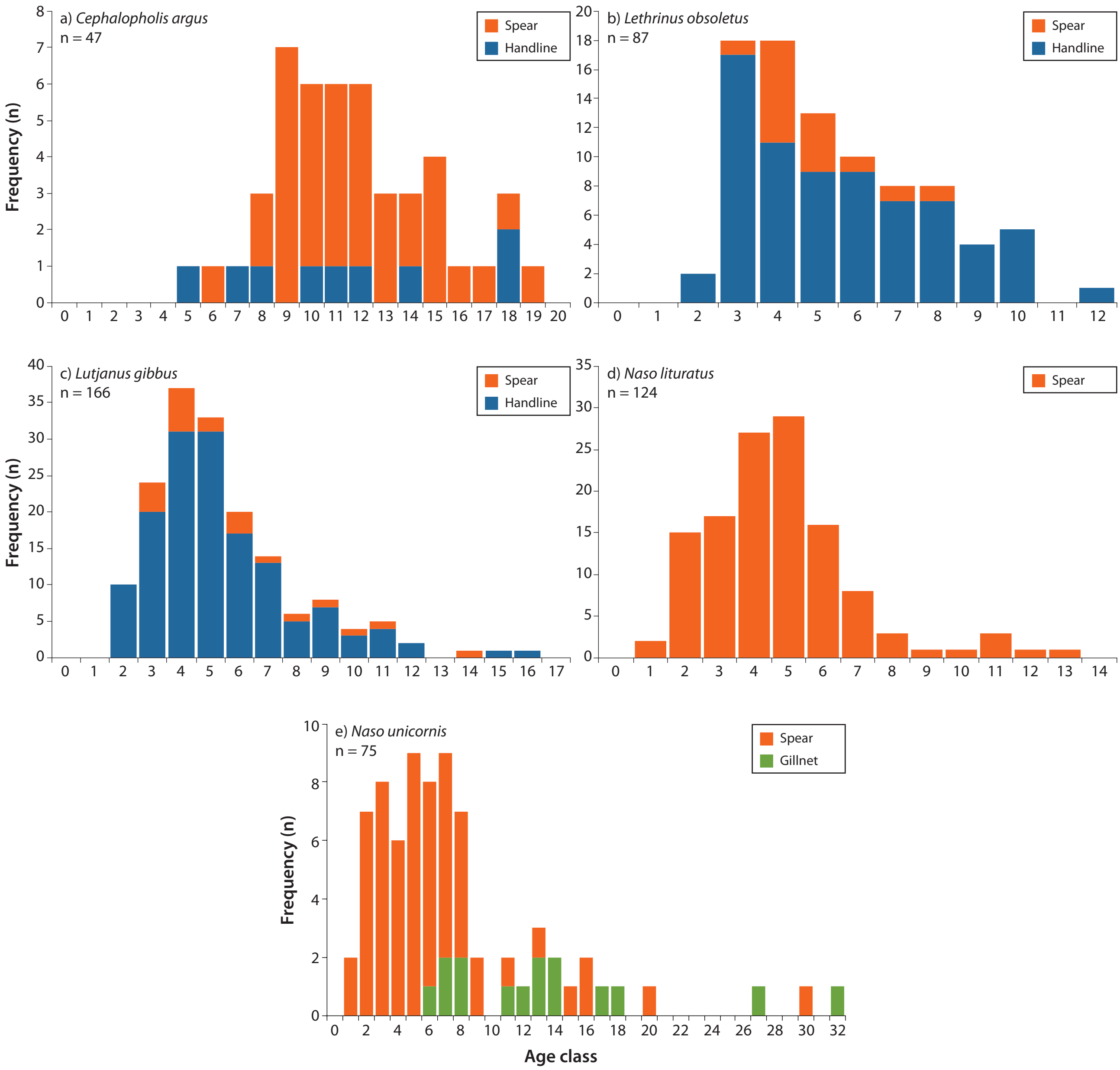


Figure 13. Age frequency distribution of five exploited finfish species from Palau, September 2014.

4. Conclusions and recommendations for management, monitoring and future research

4.1 Conclusions

Results from this baseline assessment suggest that the coastal finfish fisheries of Palau appear to be moderately healthy, at least when compared to elsewhere in the region. Overall catch rates and maximum ages of key species were generally comparable or higher than those reported elsewhere in Micronesia, while mortality rates were generally lower. Moreover, historical management arrangements designed to reduce the harvest of small, immature individuals, such as the minimum legal mesh size of three inches for gillnets and surround nets introduced under the Marine Protection Act of 1994, appear to be largely effective, as evidenced by the low number of immature individuals observed in the current catches and the significant reduction in the proportion of smaller fish compared to approximately 25 years ago.

Nevertheless, there are some areas for concern. Based on age structures and estimated mortality rates, fishing pressure from night-time spearfishing on *Naso lituratus* was considered too high, and needs to be reduced. While not considered overfished at present, given the high demand for *Naso unicornis* and its extended longevity, there is a high potential for this species to be overfished should fishing efforts increase. Both *N. lituratus* and *N. unicornis* are macroalgae browsers with low functional redundancy,[7] and play an important functional role in reducing coral overgrowth and shading by macroalgae, and in preventing and reversing coral-algal phase shifts (Green and Bellwood 2009). Accordingly, diminished populations and reductions in size of remaining individuals of these species may hinder the capacity of reefs in Palau to avoid or reverse phase shifts from coral-dominated systems to macroalgae-dominated systems.

Similarly, the large proportion of immature individuals of the parrotfish *Cetoscarus ocellatus*, *Chlorurus microrhinos* and *Hipposcarus longiceps* observed in the night-time spearfishing catch is cause for concern, as it indicates that these individuals are not getting the chance to spawn – and thus contribute to the replenishment of the population – before they are harvested. These medium to large-bodied parrotfish each play an important ecological role in scraping / excavating benthic substrate and removing dead coral, exposing hard reef matrix for settlement by coral and coralline algae, and in helping to promote reef recovery after disturbance (Green and Bellwood 2009). As with the two *Naso* spp., diminished populations of these species as a result of heavy fishing pressure on immature individuals may hinder the capacity of reefs in Palau to avoid or revert from coral-algal phase shifts.

The large number of immature individuals of *Lutjanus bohar*, *L. gibbus* and *Lethrinus olivaceus* observed in the handline catch also need management attention, as it indicates that these individuals are not getting the chance to spawn before they are harvested. Moreover, for *Lutjanus gibbus*, the significant declines in length frequencies observed between 1990–1991 and 2015, the heavy fishing pressure on this species as indicated by high quantities in the catches, and the observation that fishing mortality for this species is close to the optimum recommended mortality reference point all indicate that this species requires management intervention to prevent further overfishing.

A number of Pacific Island countries are moving towards introducing minimum size limits to reduce fishing pressure on young, immature individuals. Such an approach may work in Palau, where locals have already expressed support over the implementation of size limits (J. Prince, Biospherics Pty Ltd, September 2014 pers. comm.). Other potential strategies for reducing fishing pressure, and promoting population replenishment, include (but are not limited to):

- protection of juvenile habitats through spatial (or rotational) closures;
- additional seasonal closures of key species around their spawning times, or seasonal gear restrictions;
- implementation of maximum size limits for key species with the aim of protecting the largest individuals of the population, given that these individuals contribute a disproportionate amount towards population replenishment through the production of more and fitter eggs and sperm than smaller mature individuals;

[7] A species' functional redundancy essentially refers to whether other species are able to fill its functional role (e.g. browsing of macroalgae). Low functional redundancy means that there are few species to fill a species' ecological role in its absence, while a high functional redundancy means there are numerous suitable candidates to fill its ecological role.

- limiting overseas exports of reef fish;
- strengthening traditional management schemes; and
- expanding the existing marine protected area network to account for the connectivity of essential habitat types needed for many species during their ontogenetic development and home range sizes or migratory behaviours of key species.

Like most Pacific Island locales, Palau is subject to a thriving coral reef fishery that is largely unmonitored and marginally managed, with few rules or restrictions on harvests. Given the high dependence of Palauans on marine resources for food and livelihoods and the multi-species nature of coastal fisheries in Palau, it is strongly recommended that a coastal fisheries management plan be developed as a priority measure to support and formalise community-based initiatives. This plan should address various fishing activities (e.g. fishing method and practices), restrictions on species' harvests (e.g. size limits, seasonal closures during spawning season), the export of coastal resources, and community management practices.

4.2 Recommendations for future assessments and monitoring

While the results of the current study provide much useful information for management and monitoring purposes, it should be reinforced that the information presented here is a single 'snapshot' of data collected during the September 2014 training. Accordingly, the results presented here are unlikely to be representative of the catches across a full year. Indeed, previous surveys in Palau and elsewhere in the region have documented significant changes in species compositions and catch rates across seasons, and particularly in response to species closures, with such shifts presumed to maintain overall catches and income (Rhodes et al. 2008). For example, Bejarano Chavarro et al. (2014) documented a shift towards the selective harvesting of smaller *N. unicornis* and an increase in fishing pressure on smaller-bodied herbivores that are usually caught opportunistically or otherwise avoided during the seasonal grouper closure in Palau. Similarly, Rhodes et al. (2008) documented increased catches of parrotfish, emperors and goatfish during the March–April sales ban of groupers in Pohnpei. Ongoing creel surveys are therefore recommended to assess spatial and temporal variations in catches. The design of a creel survey programme largely depends on the questions that are asked and the resources at hand. For example, if the objective of undertaking creel surveys is to provide information on total annual catches and value, we recommend that surveys be conducted 1–2 days per week for an extended period (e.g. one year). If using creel surveys as a monitoring tool (e.g. for length frequencies, CPUE etc.) a 'snapshot' approach may be more appropriate, with surveys conducted quarterly at a minimum. Based on the results of the precision analyses, we recommend that around 15–20 surveys each of handline and spearfishing be conducted each quarter, or at least at times within and outside the grouper seasonal closure. For each landing met, data should be collected on fisher demographics and fishing behaviour (Slice C1 in Appendix 1), lengths of each individual (Slice C3 in Appendix 1), and effort (Slice C5 in Appendix 1) (Fig. 14). Survey days over the quarter should be randomised, so that fishing and thus the survey is not biased by any particular event (e.g. poor weather, unsuitable tide, moon phase, etc.). This will provide a robust dataset from which to monitor key parameters such as catches (including total number and total weight, and catch compositions), average lengths and length frequencies, and $CPUE_N$ and $CPUE_W$ with sufficient power to detect changes should they occur.

Recently, considerable interest has been shown in the use of length-based metrics as alternative approaches for estimating biological reference points such as mortality rates and spawning potential ratios for exploited stocks in small-scale, data-poor fisheries. These approaches initially seem very attractive, as length is one of the easiest and most affordable metrics to collect. However, results of these approaches need to be treated with caution, particularly where data for key input parameters (e.g. growth rates, hypothetical asymptotic lengths, lengths at 50% maturity and maximum ages, etc.) have been derived for distant populations. For example, Heupel et al. (2010) reported a maximum age of 12 years for *Lutjanus gibbus* on the Great Barrier Reef, Australia, while the maximum age observed for this species in New Caledonian waters exceeds 36 years (SPC unpublished data), and a maximum age of 16 years was recorded for this species during the present study. Accordingly, using demographic parameters estimates from other locations would potentially bring large uncertainty and error into the length-based models. Future research effort should, therefore, target gaps in understanding of local demographic parameters of key species in the catches for input into length-based models, in order to build upon data collected here for southern Palau and on the work undertaken by The Nature Conservancy and partners in the northern states.

It is highly recommended that purchases, exports and sales of coastal fish (including both finfish and invertebrates) to hotels and resorts be documented and monitored. Given that a basic record of purchases and commercial exports is maintained at the HFM in Koror, documenting and monitoring these should be fairly easy to accomplish, at least from this market. We recommend that historical purchase and export data first be collated and examined to provide an extended time series from which to examine future temporal trends. Thereafter, monthly purchase and export data could easily be collated by assigning a single staff member to review the purchases and export receipts at the HFM for 1–2 days per month. Monitoring sales of fish from fishers to hotels could potentially be achieved directly through the hotels themselves.

To provide a more holistic estimation of the volume of reef fish extracted from local reefs, it is highly recommended that assessments of subsistence fishers be conducted. In some Pacific Island locales, subsistence fisheries account for up to ten times the amount of fish taken by the commercial sectors (Zeller et al. 2006). In Palau, Kitalong and Dalzell (1994) estimated that subsistence fisheries production was in the order of 500–1,100 t per year. While these estimates are more than 20 years old and are now likely to be inaccurate, they suggest that estimates of commercial activity may considerably underestimate actual catch volumes.

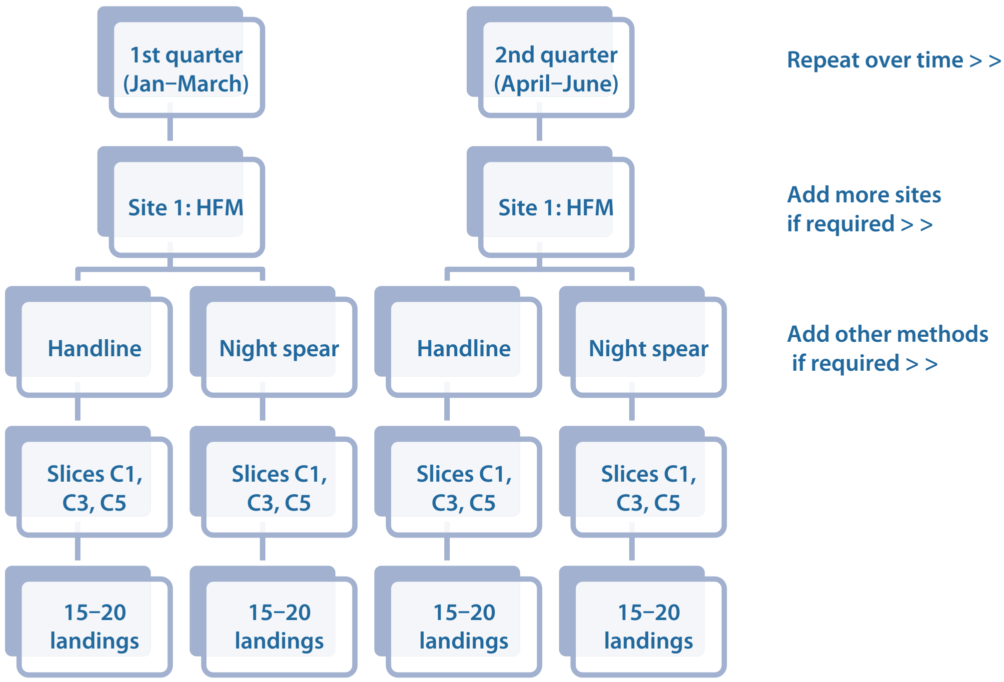


Figure 14. Proposed creel survey design for monitoring handline and night-time spearfishing catches at a single site in Palau.

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Appendix 1.

Creel survey form used in this assessment

Creel survey carried out by: ***[Enter organisation / department]***		***Landing no.:***
Type of creel survey: (if stratifying)		
Province / Island + Country:		
Date of this replicate (Day / Month / Year):		Currency used:
Survey Site:		
Latitude (DD):		Longitude (DD):
Interviewers / surveyor names:	1.	2.
	3.	4.

Appendix 1. *(cont.)*

Slice C1 basic information on fishers		
Lead Fisher's name:		
Date of Birth (DOB):	Gender:	
Address as Village / Town / City:		
Is the fisher with others? Yes ☐ | No ☐		
Total number of fishers?		
-> (data on other fishers in the landing today)		
Name of other fisher 1:	DOB:	Gender:
Other fisher 2:	DOB:	Gender:
Other fisher 3:	DOB:	Gender:
Other fisher 4:	DOB:	Gender:
-> (back to Lead Fisher)		
How often do you go fishing per month? /month	How many months a year do you fish (i.e. exclude closed months) months fished	
What fishing methods do you usually use (not only this fishing trip)?	Method 1:	
Method 2:	Method 3:	
Method 4:	Method 5:	
Where else do you land your fish? What other site? List by priority		
Other site 1: (most often)	How often? /month	
Other site 2:	How often? /month	
Other site 3	How often? /month	
Other site 4	How often? /month	
Why do you go fishing? Subsistence ☐ | Income ☐ | Other ☐		
Please provide details:		
About how much of this catch will be eaten at home / sold?	% kept	% sold
What would you expect as income from this catch overall?	Value:	
What is your eye-estimate of the total weight of this catch? (Estimated by you, not the fisher)		kg

C2 Species composition / counts

What is the total count by species of all fishes / invertebrates / other landed?

Species name / Group	Fish product	Total number	Total weight (kg)	Fishing method

C3 Species size and C4 Species weight

All sizes in the catch in cm | All weights in kg

(Repeat this page if you need more space)

Species name	Size type	Size	Weight	Fishing method
e.g. *Lutjanus gibbus*	FL	23.2	0.25	Handline

C5 Effort data for CPUE				
How many hours spent on the fishing trip today?				Hrs
Fishing method / gear used for each species group (separate pelagic fish, reef fish, crabs, lobsters, etc) How many people involved and how much time spent doing each activity?				
Species group	Methods / gear used	No. people	No. hours	Period
1.				
2.				
3.				
4.				
Did you have any gear losses during this fishing trip? What and how much to replace or repair?				
Gear	What loss / damage?	Cost to replace / repair		
1.				
2.				
3.				
4.				
Please list any other costs of this fishing trip. Include fuel, wages, ice, food, drink, any other items				
Item		Purchase price:		
1.				
2.				
3.				
4.				
What is the distance to the furthest site you fished in today?				km
Where did you leave from?				
How many sites did you stop and fish in? Where are they?				
Site	Location (on map, lat/long, or distance to each fishing ground)			
1.				
2.				
3.				
4.				
What kind of boat used today?				
Construction:	Wood ☐ | Fibreglass ☐ | Plastic ☐ | Steel ☐ | Concrete ☐			
Type of boat:	No boat ☐ | Motor boat ☐ | Sail boat ☐ | Canoe ☐			
How is the boat powered?	Paddle ☐ | Sail ☐ | Inboard ☐ | Outboard: 2 stroke ☐ 4 Stroke ☐			
Length (m):		Engine (hp):		
What safety gear do you have onboard today? (tick all that apply)		Oars ☐ | Life jackets ☐ | Water ☐ | EPIRB ☐ | GPS ☐ Flares ☐ | Bailer / Bilge ☐ | Extra fuel ☐		

C6 Catch prices

Where will you use / sell this catch?	Home ☐ | Market ☐ | Buyer domestic ☐ | Buyer export ☐ Roadside ☐ | Resort / Restaurant ☐ | Retail Shop ☐

How are the items sold (units of sale) and what prices can you expect?

Item / Group	Unit of sale	No. per unit	Price / Unit of sale	Price / Item
e.g. Crabs	String	5	USD 25 / string	USD 5 / crab
1.				
2.				
3.				
4.				

C7 Perceptions of fishers		
What is the main fishing activity for this landing? Clam / Trochus fishery ☐ | Nearshore / Oceanic fishery ☐ | Other invertebrates fishery ☐ | Reef / Lagoon fishery ☐ Sea cucumber fishery ☐		
How long have you been fishing?		Years
How long have you been fishing in this fishery? (e.g. nearshore / oceanic fishery, reef / lagoon fishery, sea cucumber fishery)		Years
Have you participated in other fisheries in the past? (e.g. nearshore / oceanic fishery, reef / lagoon fishery, sea cucumber fishery)		
Are you fishing in other fisheries now? Yes ☐ | No ☐	Describe:	
Are you fishing in the same areas as 5 years ago? Yes ☐ | No ☐	Please explain:	
Are you catching the same quantities as 5 years ago? Same ☐ | Increase ☐ | Decrease ☐	Please explain:	
Are you catching the same size as 5 years ago? Same ☐ | Increase ☐ | Decrease ☐	Please explain:	
If catches are different, what has changed?		
Do you have any concerns about the resources?		

Appendix 2.

Number of individuals observed from various fishing methods during creel surveys at Koror, September 2014, and relative percentage contribution to the catch of that method

Fishing method	Species	No. observed	Total weight	% contribution by abundance	% contribution by weight
Gillnet	*Acanthurus olivaceus*	4	0.80	1.14	0.48
	Ctenochaetus striatus	2	0.27	0.57	0.16
	Epinephelus maculatus	1	0.59	0.28	0.36
	Kyphosus vaigiensis	1	0.74	0.28	0.45
	Lethrinus harak	15	6.66	4.26	4.04
	Lethrinus lentjan	19	8.07	5.40	4.89
	Lutjanus argentimaculatus	5	6.73	1.42	4.08
	Naso brachycentron	1	0.54	0.28	0.32
	Naso lituratus	2	0.33	0.57	0.20
	Naso unicornis	24	43.02	6.82	26.09
	Parupeneus barberinus	3	0.73	0.85	0.44
	Plectorhinchus lineatus	1	1.59	0.28	0.96
	Scarus dimidiatus	1	0.21	0.28	0.13
	Scarus frenatus	1	0.43	0.28	0.26
	Scarus globiceps	1	0.08	0.28	0.05
	Scarus schlegeli	1	0.36	0.28	0.22
	Siganus fuscescens	3	0.42	0.85	0.25
	Siganus lineatus	265	92.69	75.28	56.20
	Siganus punctatus	2	0.67	0.57	0.40
Handline	*Aethaloperca rogaa*	1	0.66	0.18	0.20
	Aphareus furca	5	4.71	0.88	1.42
	Carangoides chrysophrys	2	1.97	0.35	0.59
	Carangoides ferdau	1	1.76	0.18	0.53
	Carangoides gymnostethus	1	1.42	0.18	0.43
	Carangoides orthogrammus	10	9.62	1.77	2.90
	Caranx lugubris	2	4.57	0.35	1.38
	Caranx melampygus	3	4.27	0.53	1.28
	Caranx sexfasciatus	11	11.65	1.95	3.51
	Cephalopholis argus	7	3.42	1.24	1.03
	Cephalopholis miniata	1	0.55	0.18	0.17
	Cephalopholis urodeta	1	0.11	0.18	0.03
	Decapterus macarellus	3	0.55	0.53	0.17

Appendix 2. *(cont.)*

Fishing method	Species	No. observed	Total weight	% contribution by abundance	% contribution by weight
Handline	*Elagatis bipinnulata*	9	21.02	1.59	6.33
	Epinephelus areolatus	1	0.46	0.18	0.14
	Epinephelus coeruleopunctatus	1	0.88	0.18	0.27
	Epinephelus coioides	2	1.49	0.35	0.45
	Epinephelus maculatus	3	2.66	0.53	0.80
	Epinephelus merra	4	0.53	0.71	0.16
	Epinephelus tauvina	1	0.48	0.18	0.14
	Lethrinus atkinsoni	2	0.60	0.35	0.18
	Lethrinus erythracanthus	3	1.84	0.53	0.56
	Lethrinus erythropterus	1	1.86	0.18	0.56
	Lethrinus lentjan	68	35.30	12.04	10.62
	Lethrinus obsoletus	66	19.79	11.68	5.96
	Lethrinus olivaceus	29	37.92	5.13	11.41
	Lethrinus rubrioperculatus	7	2.26	1.24	0.68
	Lethrinus xanthochilus	38	36.52	6.73	10.99
	Lutjanus bohar	57	44.20	10.09	13.30
	Lutjanus fulvus	4	0.98	0.71	0.29
	Lutjanus gibbus	127	41.01	22.48	12.34
	Lutjanus malabaricus	1	3.54	0.18	1.07
	Lutjanus monostigma	5	2.51	0.88	0.76
	Lutjanus russellii	1	1.16	0.18	0.35
	Lutjanus semicinctus	1	0.29	0.18	0.09
	Lutjanus vitta	58	11.58	10.27	3.49
	Monotaxis grandoculis	1	1.60	0.18	0.48
	Sargocentron spiniferum	2	0.69	0.35	0.21
	Scomberomorus commerson	2	10.17	0.35	3.06
	Selar crumenophthalmus	22	4.78	3.89	1.44
	Sphyraena forsteri	1	0.88	0.18	0.26
Day spear	*Acanthurus bariene*	4	3.04	2.70	1.09
	Acanthurus nigricauda	3	1.24	2.03	0.45
	Acanthurus xanthopterus	3	3.20	2.03	1.15
	Aprion virescens	1	2.36	0.68	0.85
	Carangoides ferdau	5	12.49	3.38	4.49
	Carangoides fulvoguttatus	3	3.36	2.03	1.21
	Carangoides orthogrammus	15	14.70	10.14	5.28

Appendix 2. *(cont.)*

Fishing method	Species	No. observed	Total weight	% contribution by abundance	% contribution by weight
Day spear	*Cephalopholis argus*	8	4.61	5.41	1.66
	Cetoscarus ocellatus	4	4.24	2.70	1.52
	Chlorurus microrhinos	9	11.26	6.08	4.05
	Elagatis bipinnulata	1	2.49	0.68	0.90
	Lethrinus olivaceus	1	1.83	0.68	0.66
	Lethrinus xanthochilus	1	1.43	0.68	0.51
	Naso lituratus	6	1.77	4.05	0.64
	Naso unicornis	5	7.16	3.38	2.57
	Plectorhinchus albovittatus	27	138.07	18.24	49.62
	Plectorhinchus chaetodonoides	1	0.95	0.68	0.34
	Plectorhinchus lineatus	26	31.94	17.57	11.48
	Scarus ghobban	3	3.46	2.03	1.24
	Scarus prasiognathos	7	5.47	4.73	1.97
	Scarus quoyi	4	3.51	2.70	1.26
	Scarus rubroviolaceus	1	1.37	0.68	0.49
	Scarus tricolor	2	1.73	1.35	0.62
	Sphyraena qenie	2	8.26	1.35	2.97
	Symphorus nematophorus	5	6.58	3.38	2.37
	Trachinotus blochii	1	1.73	0.68	0.62
Night spear	*Acanthurus bariene*	2	0.58	0.20	0.12
	Acanthurus maculiceps	2	0.45	0.20	0.09
	Acanthurus nigricauda	84	25.37	8.60	5.25
	Acanthurus xanthopterus	7	7.69	0.72	1.59
	Calotomus carolinus	2	0.82	0.20	0.17
	Cephalopholis argus	46	24.94	4.71	5.16
	Cetoscarus ocellatus	8	7.90	0.82	1.63
	Cheilinus trilobatus	1	0.58	0.10	0.12
	Chlorurus microrhinos	4	1.98	0.41	0.41
	Chlorurus sordidus	1	0.65	0.10	0.13
	Choerodon anchorago	1	0.56	0.10	0.12
	Ctenochaetus binotatus	1	-	0.10	0.00
	Epinephelus areolatus	1	0.34	0.10	0.07
	Epinephelus maculatus	5	2.25	0.51	0.46
	Epinephelus tauvina	4	2.41	0.41	0.50
	Hipposcarus longiceps	225	132.93	23.03	27.49

Fishing method	Species	No. observed	Total weight	% contribution by abundance	% contribution by weight
Night spear	*Lethrinus atkinsoni*	2	0.44	0.20	0.09
	Lethrinus obsoletus	5	1.44	0.51	0.30
	Lethrinus olivaceus	2	1.67	0.20	0.35
	Lethrinus ornatus	1	0.29	0.10	0.06
	Lethrinus xanthochilus	2	2.39	0.20	0.49
	Lutjanus fulvus	1	0.19	0.10	0.04
	Lutjanus gibbus	25	9.06	2.56	1.87
	Lutjanus monostigma	1	0.24	0.10	0.05
	Lutjanus semicinctus	1	0.34	0.10	0.07
	Monotaxis grandoculis	6	4.36	0.61	0.90
	Mulloidichthys vanicolensis	1	0.34	0.10	0.07
	Naso lituratus	158	47.42	16.17	9.81
	Naso unicornis	39	52.60	3.99	10.88
	Parupeneus barberinus	146	56.31	14.94	11.65
	Parupeneus crassilabris	1	0.32	0.10	0.07
	Parupeneus cyclostomus	10	3.83	1.02	0.79
	Plectorhinchus albovittatus	2	7.73	0.20	1.60
	Plectorhinchus gibbosus	2	0.68	0.20	0.14
	Plectorhinchus lineatus	4	5.60	0.41	1.16
	Sargocentron spiniferum	30	11.88	3.07	2.46
	Scarus dimidiatus	6	1.93	0.61	0.40
	Scarus frenatus	6	3.26	0.61	0.67
	Scarus ghobban	11	9.56	1.13	1.98
	Scarus globiceps	3	0.92	0.31	0.19
	Scarus prasiognathos	8	6.34	0.82	1.31
	Scarus psittacus	3	1.17	0.31	0.24
	Scarus quoyi	5	1.98	0.51	0.41
	Scarus rivulatus	5	3.46	0.51	0.72
	Scarus rubroviolaceus	9	8.07	0.92	1.67
	Scarus schlegeli	4	1.56	0.41	0.32
	Scarus tricolor	4	3.64	0.41	0.75
	Siganus argenteus	36	8.16	3.68	1.69
	Siganus corallinus	1	0.28	0.10	0.06
	Siganus doliatus	1	0.27	0.10	0.06
	Siganus fuscescens	1	0.31	0.10	0.06

Fishing method	Species	No. observed	Total weight	% contribution by abundance	% contribution by weight
Night spear	*Siganus lineatus*	9	5.47	0.92	1.13
	Siganus puellus	10	1.75	1.02	0.36
	Siganus punctatus	20	5.82	2.05	1.20
	Symphorus nematophorus	2	2.95	0.20	0.61

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