Improving Understanding of Fish Stocks: Fishery-Independent Monitoring

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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 suggests that the abundance and size of many principle fisheries species in the region have declined (Prince et al. 2015). In response to these declines, both the states of Ngarchelong and Kayangel in the northern reefs region of Palau passed fisheries regulations for 14 species between 2015 to 2018. These regulations include both temporary moratoriums on harvest and or length-based size limits (Table 1).

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 fisheries independent underwater surveys across the costal reefs of Ngarchelong and Kayangel annually between 2015 to 2017. These surveys provide time series data on the size frequency distributions of the region's import fisheries species from which the status of their stock can be evaluated with a data limited, length-based stock assessment methodology known as the Spawning Potential Ratio (SPR). The following is a description of the work that was completed to survey the status of the northern reef fish stocks between 2015 to 2017, 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.

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

Species	Ngarchelong			Kayangel		
	Minimum size (cm)	**Implementation date**	**Moratorium**	**Minimum size (cm)**	**Implementation date**	**Moratorium**
Lutjanus bohar	40	May 2017	-	46	April 2016	-
Lethrinus olivaceus	40	May 2017	-	46	April 2016	-
Cetoscarus ocellatus	28	May 2017	-	33	April 2016	-
Chlorurus microrhinos	28	May 2017	-	33	April 2016	-
Hipposcarus longiceps	25	May 2017	-	30	April 2016	-
Lutjanus gibbus	25	May 2017	-	30	April 2016	-
Naso unicornis	-	-	-	40	April 2016	-
Lethrinus xanthochilus	-	-	-	33	April 2016	-
Plectropomus leopardus	28	After 3-year ban	July 2015 – July 2018	33	After 3-year ban	August 2015 – August 2018
Plectropomus areolatus	36	After 3-year ban	July 2015 – July 2018	40	After 3-year ban	August 2015 – August 2018
Plectropomus laevis	56	After 3-year ban	July 2015 – July 2018	61	After 3-year ban	August 2015 – August 2018
Epinephelus fuscoguttatus	36	After 3-year ban	July 2015 – July 2018	40	After 3-year ban	August 2015 – August 2018
Epinephelus polyphekadion	36	After 3-year ban	July 2015 – July 2018	40	After 3-year ban	August 2015 – August 2018
Variola louti	25	May 2017	-	-	-	August 2015 – August 2018

Methods

Fisheries independent surveys

Fisheries independent underwater surveys were conducted annually between 2015 to 2017 on the reefs at Ngarchelong and Kayangel. At each survey location, a 15-minute timed swim was done along the reef by a team of divers in two different depth categories, one being “deep” (i.e., 15-20 m) and the other “shallow” (i.e., 5-10 m) and each depth was counted as a separate sample site. During each survey, a diver recorded all the fish present along the transect with 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 EventMeasure 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 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).

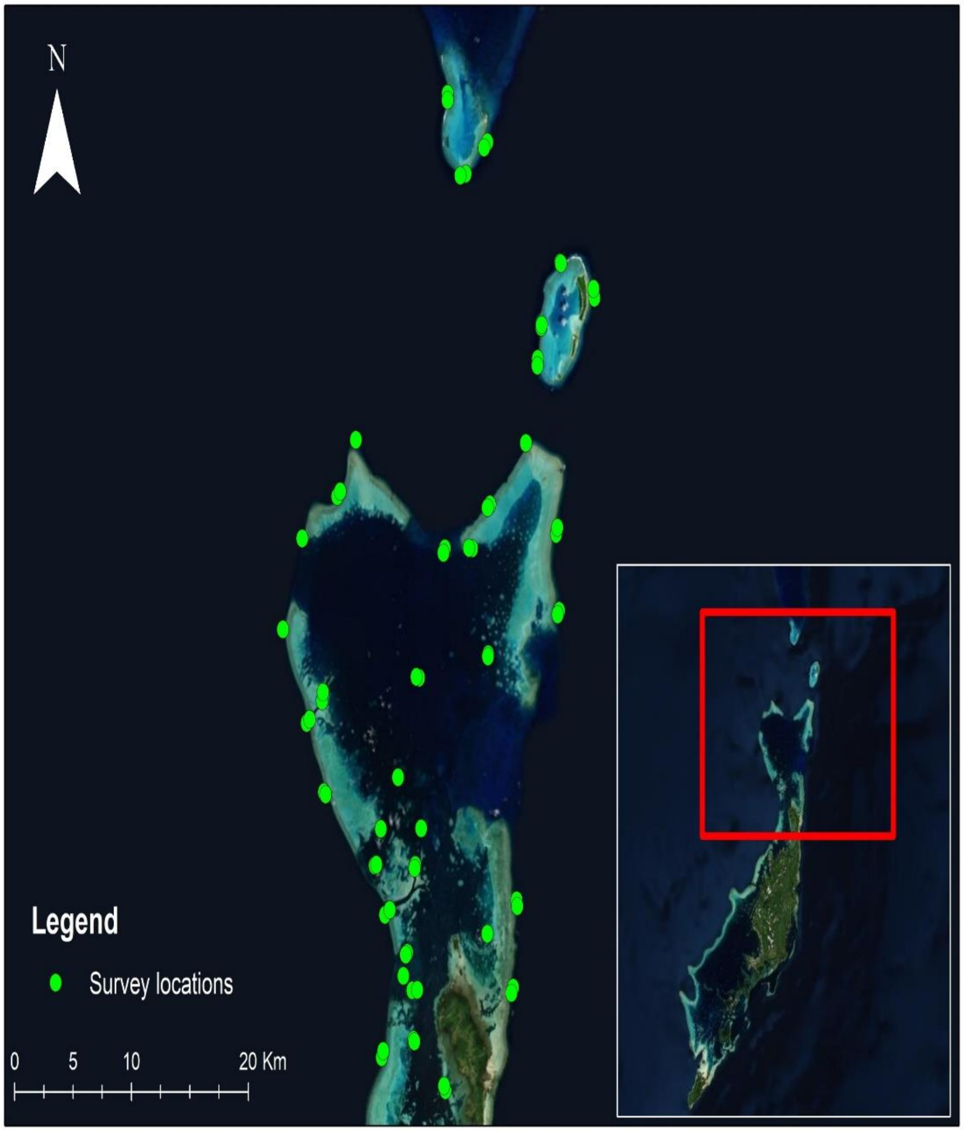

Figure 1: The 64 survey sites in the northern reefs of Palau that were surveyed consecutively between 2015 to 2017 and included in the analysis of fisheries independent underwater survey data.

Statistical analysis

The change in biomass across the three sampling years for each state of the northern reefs 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 total annual biomass of the survey locations in 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 that are prerequisites required to conduct a length-based stock assessment. Because reliable life history data was not available for all 14 regulated species and limited sample sizes, SPR was not estimated for all species. In lieu of a length-based stock assessment, the mean annual biomass was 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 reefs region, we filtered the data to exclude all 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 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}), 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 reefs 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 measured 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).

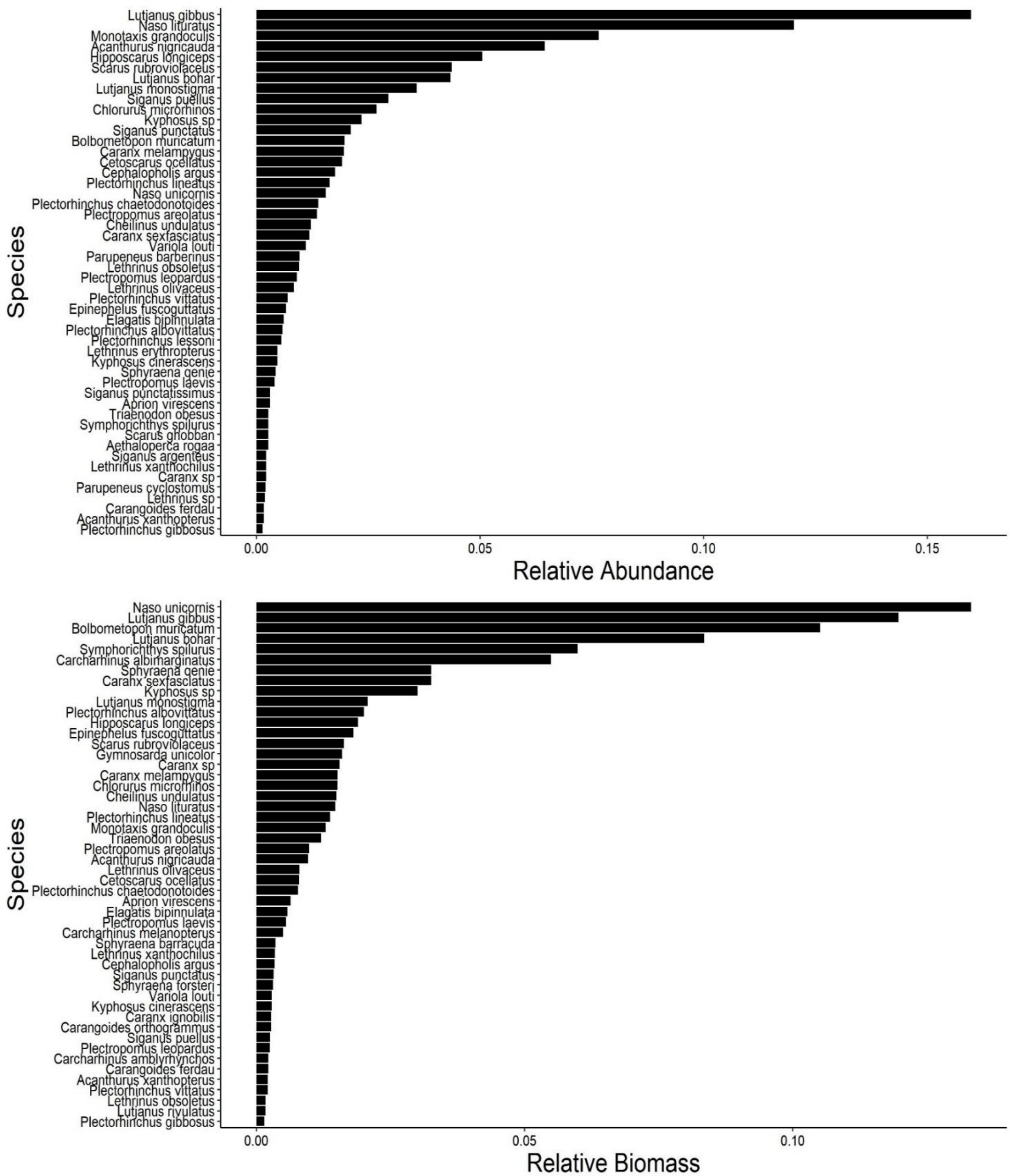

Figure 2: The relative abundance and relative biomass of the top 50 fishery species observed in diver operated stereo video surveys in the northern reefs from 2015 to 2017.

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 ± 21grams 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 to 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 suggests 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).

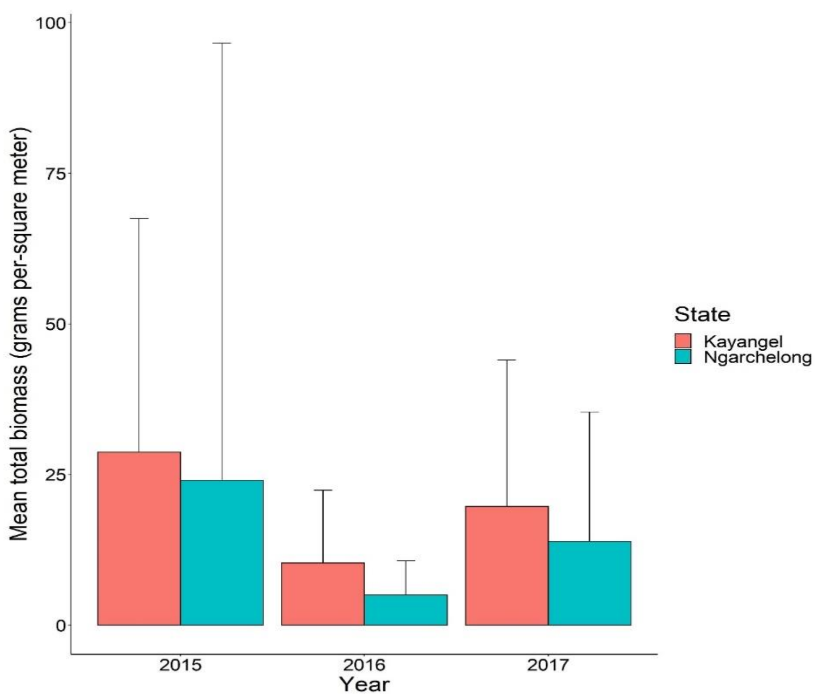

Figure 3: The mean total biomass of fishery species at each site observed during diver operated stereo video surveys in the states of Ngarchelong (green bars) and Kayangel (red bars) during 2015 to 2017 (error bars represent standard deviations from the mean).

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 Wilcox on 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).

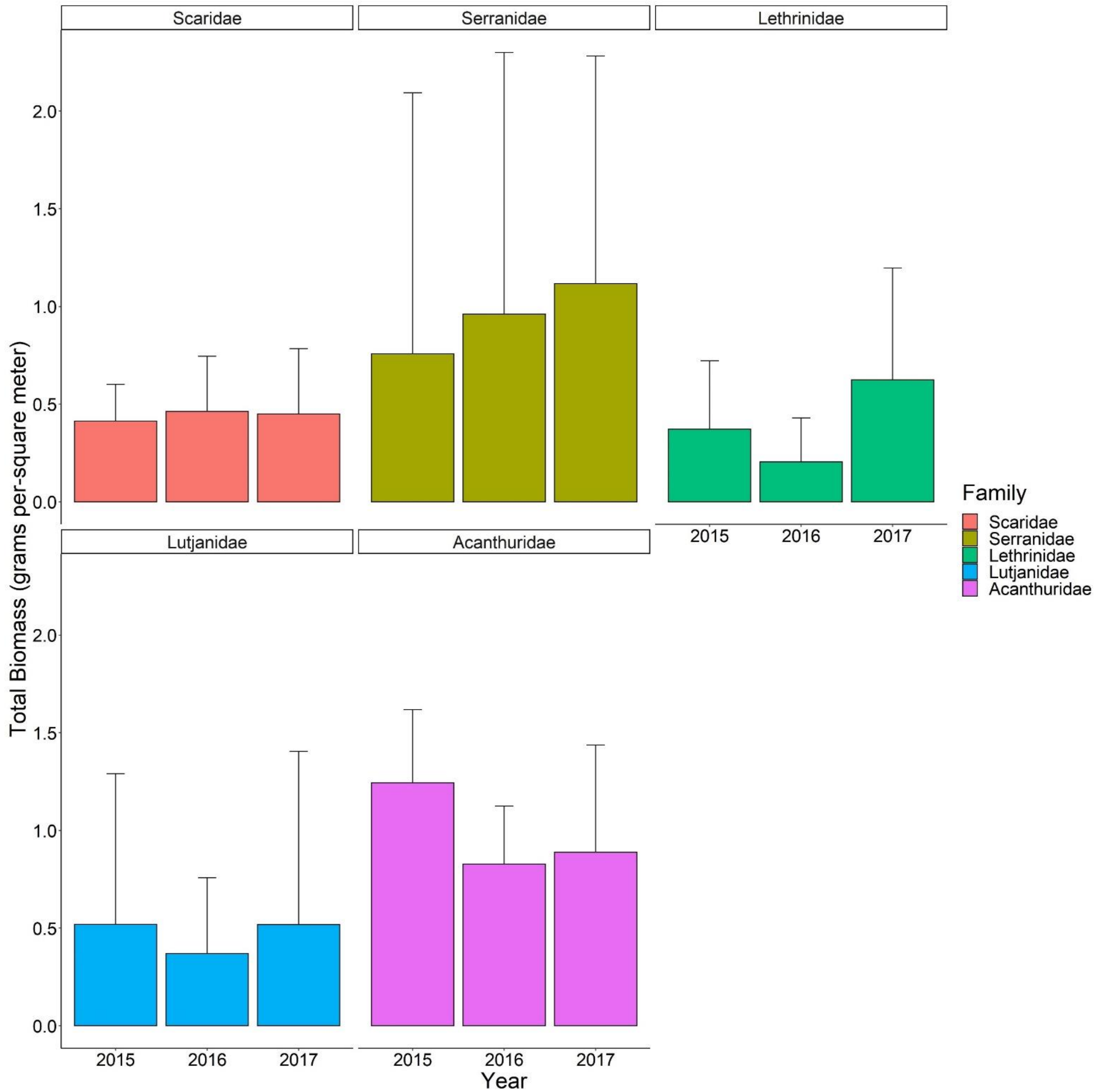

Figure 4: The mean biomass of regulated species from five Families obsevred during diver operated stereo video surveys in the states of the northern reefs during 2015 to 2017 (error bars represent standard deviations from the mean).

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

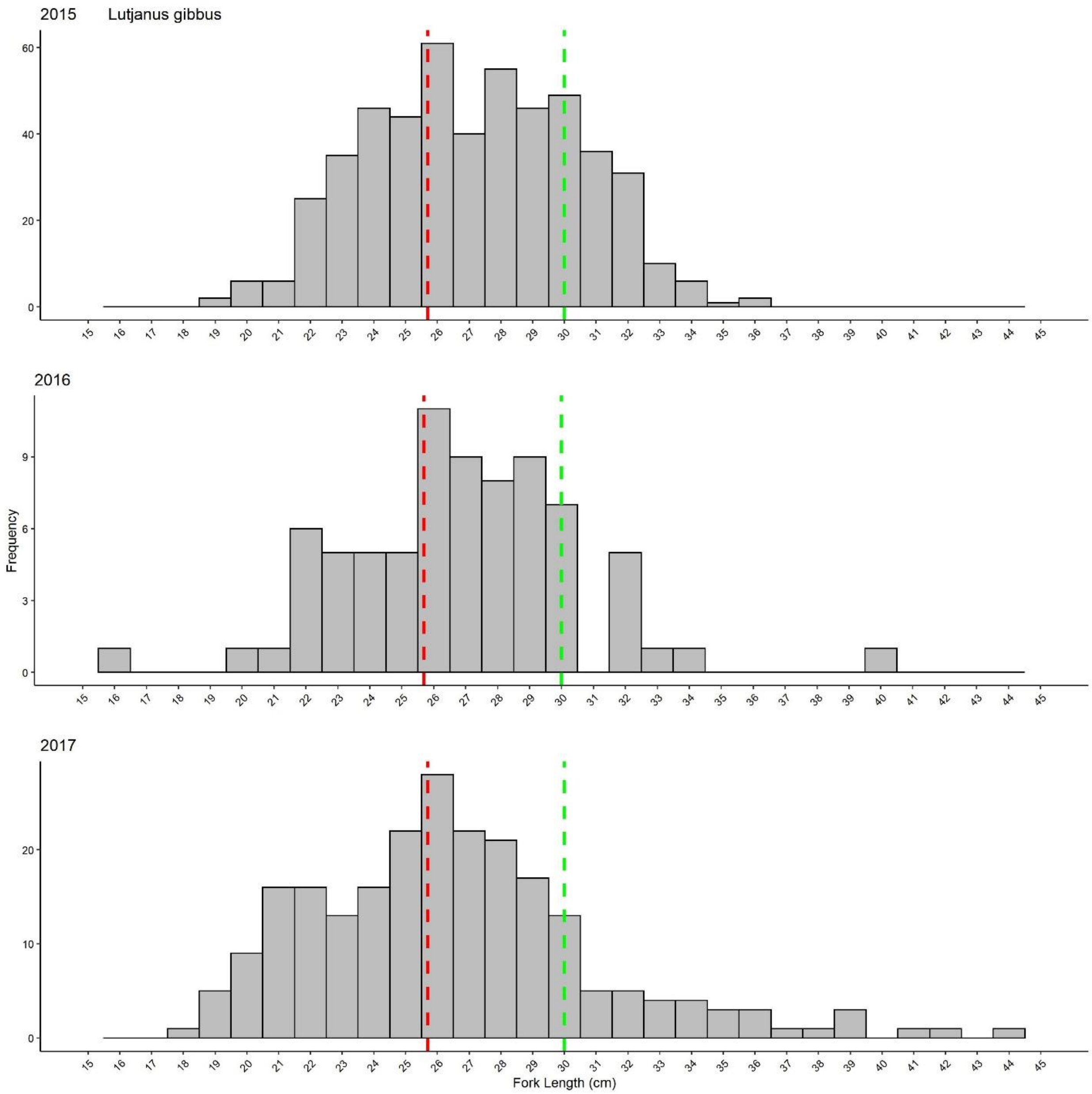

Figure 5: The size frequency distributions of *Lutjanus gibbus* in fork length (raw data, that was not resampled) observed in diver operated stereo video surveys of Palau's northern reefs from 2015 to 2017 and used to estimate the Spawning Potential Ratio of the species across the study period. The length 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.

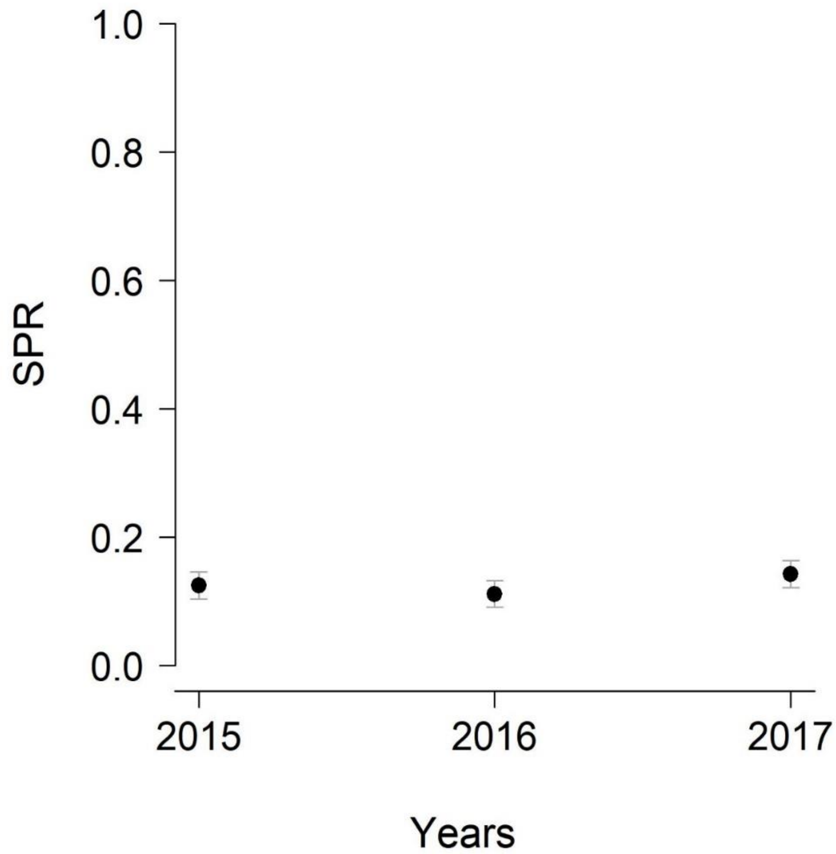

Figure 6: The bootstrapped estimates of Spawning Potential Ratios (SPRs) for *Lutjanus gibbus* in the northern reefs region of Palau from 2015-2017 (error bars represent the variance of the SPR estimates, see Table 3 for SPR estimates from raw data).

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

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

2017	*Lutjanus gibbus*	235	15	15

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 reefs 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 nighttime spearfishing (Taylor 2014; Andrews et al. 2016), and these results suggest 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. These results are positive, however there was insufficient sample size to estimate the SPR of these individual species and robust conclusions cannot be made on their status from this Family level analysis.

Lutjanus gibbus was the most abundant species numerically, represented 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 previous 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 (Karanassos et al. 2020) and the boot strapped estimates of SPR suggest the 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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