Palau's reef fisheries: changes in size and spawning potential from past to present

Dr. Steven Lindfield
Coral Reef Research Foundation
PO Box 1765, Koror, Palau
Ph: 778 4095 / 488 5255
steve.lindfield@yahoo.com

February 2017

Produced with funding from Rare Micronesia

www.coralreefpalau.org

Suggested citation: Lindfield, S.J., 2017. Palau's reef fisheries: changes in size and spawning potential from past to present. Technical report, Coral Reef Research Foundation, 23pp.

Background:

The size of fish is a useful indicator to detect fishing impacts over time and track the potential recovery of stocks. In Palau there have been two past fish length measuring projects by the then 'Division of Marine Resources' in 1982-1984 and 1991-1992. More recently in 2014-2015 the current Bureau of Marine Resources (BMR) have established ongoing creel and market surveys where they have been measuring the size of reef fish at the main landing site in Koror, the JR5 central market (also known as Happy fish market). In this report, length frequencies and spawning potential ratios for the main reef fishery species are compared to track the magnitude of change over time. These data highlight that the majority of fishery-targeted species are currently at a low level of reproductive potential or are quickly approaching a level where potential for stock replenishment is impaired. These data will provide a good baseline to track the hopeful recovery of reef fish stocks into the future with increased fisheries management and awareness of the previous declines. This report accompanies "Summary of the 2015 fishery creel and market survey in Palau", which summaries the catch data from a 3-month creel survey conducted by the BMR and provides recommendations for continuing and improving the creel and market surveys.

Introduction:

Reef fish are an important resource in Micronesia. They provide food for subsistence, a commercial sale item, whilst fishing remains a fundamental cultural activity. In Palau, like many other Pacific Islands, there is concern and consensus that fish stocks are declining, especially at the current time with booming tourism markets and increased demand for fresh seafood. A recent scientific paper by Prince et al. (2015) showed that the coral reef fish populations in the northern reefs of Palau, indeed have been heavily fished with most of the twelve species assessed having spawning potential ratios (SPRs) <20 %. This level of spawning potential will result in a continued decline in fishery stocks if left unmanaged. Fortunately, awareness amongst Palau's residents has prompted a renewed interest in fisheries management, as expressed at a recent Fishermen's Forums in July 2015 and April 2016.

After the Fishermen's Forum meeting in July 2015, resolutions were adopted by a Joint House Resolution (No. 9-105-12) which supports recommendations to (1) create a list of ten priority near-shore fish species that will be the targets of legislative reform proposals; (2) determining optimal, scientifically derived size limits for each of these species as a biological reference point based on at least 20% spawning potential; (3) identifying spawning seasons, spawning sites, and other critical habitats for these species, and developing strategies for adequate enforcement; exploring marine use zoning options that delineate areas for conservation, reseeding activities, and specific types of fishing. It is hoped that these activities will help set reef fish stocks back on the path of recovery.

To help sustain the world's fisheries, there is a need to develop simple data-driven management policies that are understood by all stakeholders. With this recognition, data-poor stock assessment techniques have been developed to help bridge the gap between the expensive data-rich assessments conducted only for the most valuable fisheries in the world, and the vast majority of smaller fisheries, especially those on coral reefs that support millions of fishers. Conventional assessment methods on which fisheries management is based require large amounts of data, including good biological information for the exploited stock and historical time series of catch and effort data, with the annual costs per assessed stock ranging from 50,000 to millions of US dollars (Pauly et al. 2013). By some estimates, 90% of the world's fisheries, which directly support 14 - 40 million fishers and indirectly support approximately 200 million people, are un-assessable with conventional methods (Andrew et al. 2007). Therefore, there has been a great interest in developing data-poor stock assessment methods in recent years, which are typically based on the size structure of the population (Hordyk et al. 2014; Nadon et al. 2015).

Data-poor stock assessment techniques such as length-based assessments of spawning potential ratio (LB-SPR) require life-history ratios of natural mortality to growth rate (M/k) and the length at maturity to asymptotic length (L_m/L_∞), along with the size frequency structure of the population, and an estimate of local size at maturity and or asymptotic length (Hordyk et al. 2014; Prince et al. 2015). It is through these input parameters that the spawning potential ratio (SPR), a widely used reference point for fishery stock assessments, can be estimated. Generic SPR-based reference points have been developed and have been recognized in international fisheries law; SPR 40% is generally considered a conservative proxy for maximum sustainable yield, and SPR 20% is the proxy for when recruitment rates are likely to be impaired for fish.

Through previous work by Dr. Jeremy Prince on the fisheries of Palau's Northern Reefs the life-history parameters of the main species of reef fish caught in Palau have been determined from: 1) studies to determine the local size at maturity from community participation in fish gonad inspection and data collection, and 2) a synthesis of all published information on life histories of the species caught in Palau. A summary of these data collection programs can be found in the published paper by Prince et al. (2015) and a more recent unpublished report where some of the parameters were refined from new evidence. It is through these analyses by Dr. Prince that allow the current assessment to be completed.

Methods:

Past data on reef fisheries in Palau

The main source of data was from fish measuring programs implemented in 1982-1984 and again in 1990-1991 by staff at the then 'Division of Marine Resources', now the 'Bureau of Marine Resources (BMR)'. The 1980s data was collect as part of the 'Palau reef fish production study' as documented in the report by Perron et al. (1983). These data and that of the 1990-1991 are summarized in a report from 1994 by Anne Kitalong and Paul Dalzel published by the Secretariat of the Pacific Community (SPC) (Kitalong & Dalzell 1994). The original hard copy of this report contains the raw length frequency data for more species than the technical document published online. Data were scanned and copied into a spreadsheet then converted into a long list of lengths using R code, before being used to create graphs and analyzed for SPR analysis.

Most of this historical data was collected at the Palau Federation of Fishing Association (PFFA) fish market located on Malakal Island, Koror. However some data was also collected from several other smaller markets. The data from the 1990s was collected between February 1990 and April 1991 and lengths measured to the nearest 0.1 cm from the tip of the snout to the fork, except where fish had a rounded or truncate tail where total length was measured. These lengths were then aggregated to 1 cm length classes and stored as length frequency tables in the report. As these lengths were grouped in 1 cm bins and the 2014-15 data was recorded to the nearest mm, to make sure the data was comparable between time periods for the SPR analysis we increased the historical data by 0.5 cm so it would be the midpoint of the 1 cm length class.

Present data on reef fisheries in Palau:

This data collection program utilized new technology, stereo-video, for recording the species composition and lengths of reef fish. The use of a compact 3D camera for filming at the fish market was first trialed in 2014 by Steven Lindfield and Jeremy Prince. Since then the use of this stereo-video system has also been used to monitor fishing catches for the Northern Reef Fisheries Management Project in Palau. It has proven to be an efficient way to collect data on the species and sizes of fish landed with minimal interference to fishers at the landing site.

For this report, the data collection focused on landings within Koror state, as we assume would be more comparable to the historical landings that other locations in Palau. There is also more data from the Northern Reefs of Palau (see Prince et al 2015) and ongoing projects monitoring the landings in Ngarchelong state, but we did not include those data, in favor of using data from the JR5 central market (previously Happy Fish Market) and the bottomfish catch from the annual Palau Sports Fishing Association fishing tournament, the Etpison Cup

The majority of data was collected during a 3-month period from the 11th May to the 14th August 2015. This was part of a creel and market survey with the Bureau of Marine Resources at Palau's most popular fish market, the JR5 central market. This survey provided information on the fishery, the species caught, the size of reef fish and quantity of fish landed. The survey built upon a previous training conducted by the Secretariat of the Pacific Community (SPC) in September 2014, but used a 3D camera for filming the landings to determine species composition and lengths. The full details for this survey is presented in an accompanying report "Summary of the 2015 fishery creel and market survey in Palau" by Steven Lindfield.

To increase sample sizes of the main species measured, we also used length data from the creel and market survey training by SPC for the Bureau of Marine Resources. Full details of this survey can be found in the report "Creel survey and demographic assessments of coastal finfish fisheries of southern Palau" by Moore et al. (2015).

Other data collection took place at the Palau Sports Fishing Association's (PSFA) annual fishing tournament, ft. Etpison Cup. This is held in May each year and the landings of bottomfish were recorded with a 3D camera in 2014 and 2015. Data collection is focused on the 'Delta Dock' where fishers bring their catch for inspection for the chance of winning a prize. We also included bottomfish that were weighed into the competition data as part of the Women's bottom fishing category. Data collection takes place in collaboration with the Bureau of Marine Resources, Palau Conservation Society and volunteers from other organizations such as the CAT team and Delta Airlines. The monitoring of the landings at the fishing tournament is also used as a way to track changes in fishing catches over time. Reports summarizing the landings are available on request.

Equipment for surveying catches in 2015

The Fujifilm 3D-W3 camera is currently the best compact stereo-camera that can effectively be used to film fish landings. The camera lenses are separated 7.5 cm apart, allowing measurements to approx. 2 m distance. These compact 3D cameras (Fig. 1) can take stills or video in stereo, which can be uploaded into a computer and split into left and right images. These images are then able to be analysed using EventMeasure-Stereo software (www.seagis.com.au). See Figure 2 for an example of the fish measuring process using EventMeasure.

Figure 1. The Fujifilm 3D-W3 camera used to record fish landings

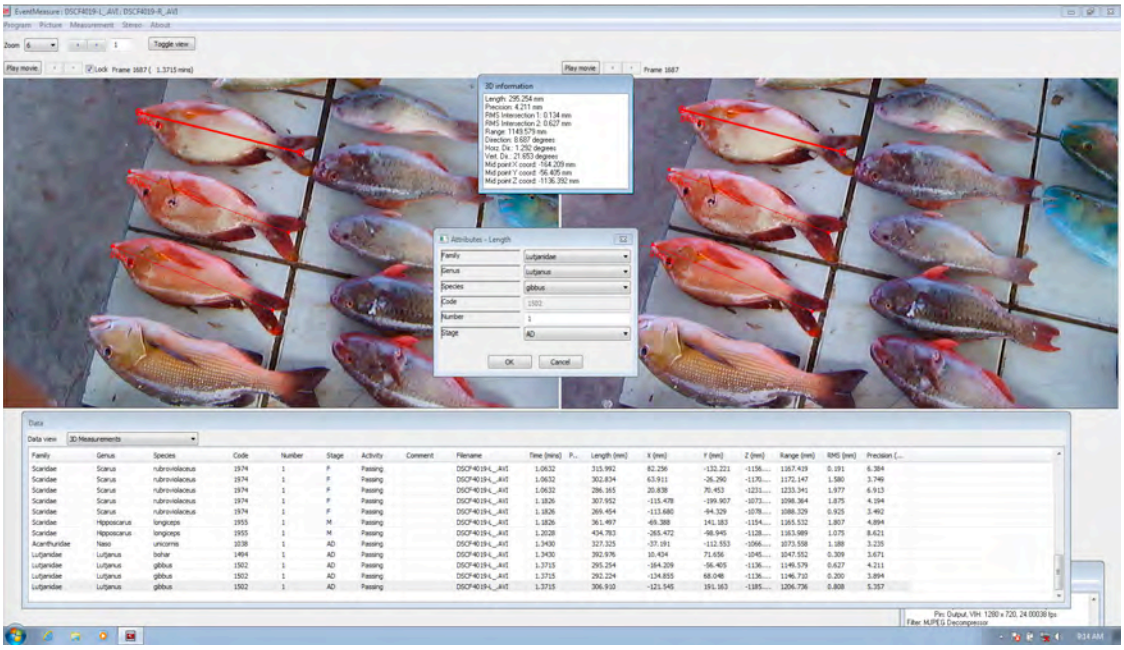


Figure 2: Frame grab from the EventMeasure software used to measure the size of fish from the left and right images from the Fujifim3DW3 camera.

Survey protocol

The fish market survey requires at least one surveyor to be present at the market when fish are landed, either by boat or delivered by truck. The unloading of fish from the boat or truck typically transfers fish from an icebox/cooler to a plastic baskets used at the market. This transfer of fish provides a time where each fish can be filmed using the stereo-video camera without interrupting the normal flow of market operation. This way the fish do not need to be touched and can be completed in several minutes or less depending on the volume. However, the downside is that not all fish will land in the basket in a way that allows measurements and large fish will need to be measured separately if they do not land flat in the basket.

For details on the camera settings and step-by-step instructions for the use of this camera system and the survey protocol, please refer to a separate document "Monitoring fish landings in Palau with a stereo-video camera - standard operating procedures". This document can be provided on request.

Comparing length frequencies across the three time periods

To visualize how the sizes of fish have changed over time, length frequency distributions were created for each time period and arranged vertically to show how the average sizes and shape of the probability density curves change over time. The probably density curves convert the frequency distribution to a density so they are the same height with differing sample sizes. This aids visualization but the y-axis values are on a scale that is dependent on the number of length classes, which is less intuitive than an actual number. Therefore the sample size (n) is shown in the top left corner of each graph and average length shown as a dashed vertical line.

Calculating the Length Based Spawning Potential Ratio (LB-SPR)

The LB-SPR method was developed by Jeremy Prince and Adrian Hordyk and have since been used to assess fish stocks in the Northern Reefs of Palau (Prince et al. 2015). More details on the assessment methodology can be found in scientific publications by Hordyk (2014, 2015). These techniques were developed to assess small-scale 'data-poor' fisheries where only minimal data inputs are necessary, particularly the length structure of the population and size at maturity of each species of fish.

The LB-SPR assessment technique utilizes the fact that size structure and spawning potential ratio (SPR) in an exploited population are a function of the ratio of fishing mortality to natural mortality (F/M), and the two life history ratios M/k and $Lm/L\infty$; where M is the rate of natural mortality, k is the von Bertalanffy growth co-efficient, Lm is the size of maturity (SoM) and $L\infty$ is asymptotic size (Hordyk et al. 2014). These life history parameters have previously been collated and applied to the main species of reef fish in Palau and details found in Prince et al. (2015) and a more recent unpublished report. Therefore the details on the assessment methodology and justification for the chosen parameters will not be covered in detail here. The exception is for this report, the M/k value of 0.44 for *Lethrinus obsoletus* (published in Taylor 2010) was used rather than the average value for all Lethrinid species.

As these models work more accurately with greater sample sizes, the data from 1982-84 and 1990-91 were pooled together. These assessments work best when there is several hundred fish measured for each species, but can be done with caution with at least 100 fish in the population. Here, assessments were only conducted when there were at least 100 fish measured in the historical (1982-1991) and present (2014-15) time periods. Although the species *Siganus argenteus* and *Parupeneus barberinus* fit this criterion, there were unfortunately no reliable life history parameters available to use in the model. See Table 1 for the sample sizes of each species over the three time periods.

To run the LB-SPR models, I used the application on the barefoot ecologist website (http://barefootecologist.com.au/lbspr). This provides an interface to the code for calculating the SPR values from the length frequency data and life-history parameters for each species.

Results and discussion:

Size structure changes from the 1980s to present:

There were eight species of fish consistently recorded over the three time periods from 1983- 2015. The parrotfish Ngyaoch/Berkisim (*Hipposcarus longiceps*) was the most abundant with over 1500 fish measured. The next most abundant was the rabbitfish Meyas (*Siganus fuscesens* – previously known as *Siganus canaliculatus*), however this species was not commonly recorded in 2015 surveys and is mainly caught by fishers specifically targeting them with nets. The next most abundant were the snapper, Keremlal (*Lutjanus gibbus*) with over 1200 fish measured, followed by the unicornfishes Um (*Naso unicornis*) and Erangel (*Naso lituratus*). The rabbitfish Klsebuul (*Siganus lineatus*) the emperorfishes Udech (*Lethrinus obsoletus*) and Mechur (*Lethrinus xanthochilus*) were also consistently measured over these time periods. Whereas two of the main species of grouper Ksau Temekai (*Epinephelus polyphekadion*) and Tiau (*Plectropomus areolatus*) were only recorded in the historical data as the 2014-15 surveys were during the grouper closed season from 1st April – 31st October. Table 1 summaries the number of fish measured during each time period.

Table 1: The top 30 fish measured from each species in Palau during three time periods and ranked by their total number.

	Number of fish measured			
Taxa	1983-1985	1990-1991	2014-15	*Total*
Hipposcarus longiceps	184	530	828	*1542*
Siganus fuscesens	152	1229	4	*1381*
Lutjanus gibbus	144	523	582	*1249*
Naso unicornis	187	594	290	*1071*
Naso lituratus	93	420	378	*891*
Siganus lineatus	72	412	275	*759*
Lethrinus obsoletus	101	488	115	*704*
Siganus argenteus		415	111	*526*
Parupeneus barberinus		139	368	*507*
Lethrinus xanthochilus	142	146	125	*413*
Epinephelus polyphekadion	230	168		*398*
Lethrinus olivaceus		148	75	*223*
Bolbometopon muricatum	57	156		*213*
Monotaxis grandoculis		106	68	*174*
Chlorurus microrhinos		35	133	*168*
Acanthurus nigricauda			167	*167*
Scarus rubroviolaceus			164	*164*
Cetoscarus ocellatus		91	52	*143*
Siganus punctatus			141	*141*
Plectropomus areolatus	52	88		*140*
Cheilinus undulatus	9	120		*129*
Lethrinus harak		113	15	*128*
Lutjanus bohar	39		81	*120*
Mulloidichthys flavolineatus		110		*110*
Lethrinus lentjan			106	*106*
Lutjanus vitta			102	*102*
Syphyraena barracuda		101		*101*
Atule mate			95	*95*
Sargocentron spiniferum			90	*90*
Epinephelus fuscoguttatus	16	48		*64*

From the thirty main species measured, for most there were not adequate sample sizes to analyze between time periods, as length samples were either lacking in the historical data or the more recent assessments. The data reported in Kitalong and Dalzell (1994) provided a great reference to determine a baseline for 8 species, but had some species that were grouped under one Palauan name. For example the blue/green parrotfish known locally as Mellemau and Butilang were likely translated to *Scarus oviceps,* but it is unlikely that all those fish reported were actually *S. oviceps,* as this fish is not as frequency caught as other parrotfish. It is likely that some of the other larger parrotfish that dominate catches now, such as *Scarus rubroviolaceaus* were in that group and could not be analysed to track changes over time. Other species that could not be analysed were due to the 2014-15 data collection occurring over the closed season for groupers and other species such as *Cheilinus undulatus* and *Bolbometopon muricatum* which have since been protected from fishing.

To compare how the lengths of these main species of fish changed over these three time periods, length frequency plots were created and stacked in-line with a dashed vertical line showing the average length for each time period (Figure 3). The average size of parrotfish Ngyaoch/Berkism, *Hipposcarus longiceps* actually increased slightly over these years from 284 to 306 mm, but there was little change in the shape of the length frequency distribution. Whereas Keremlal *Lutjanus gibbus* declined in average size in each time period from 287 mm average size to 272 mm. Here, there was an obvious lack of larger fish around 350 mm that were present in 1984 and such the shape of the distribution has changed in relation to the larger fish missing from the population.

a)

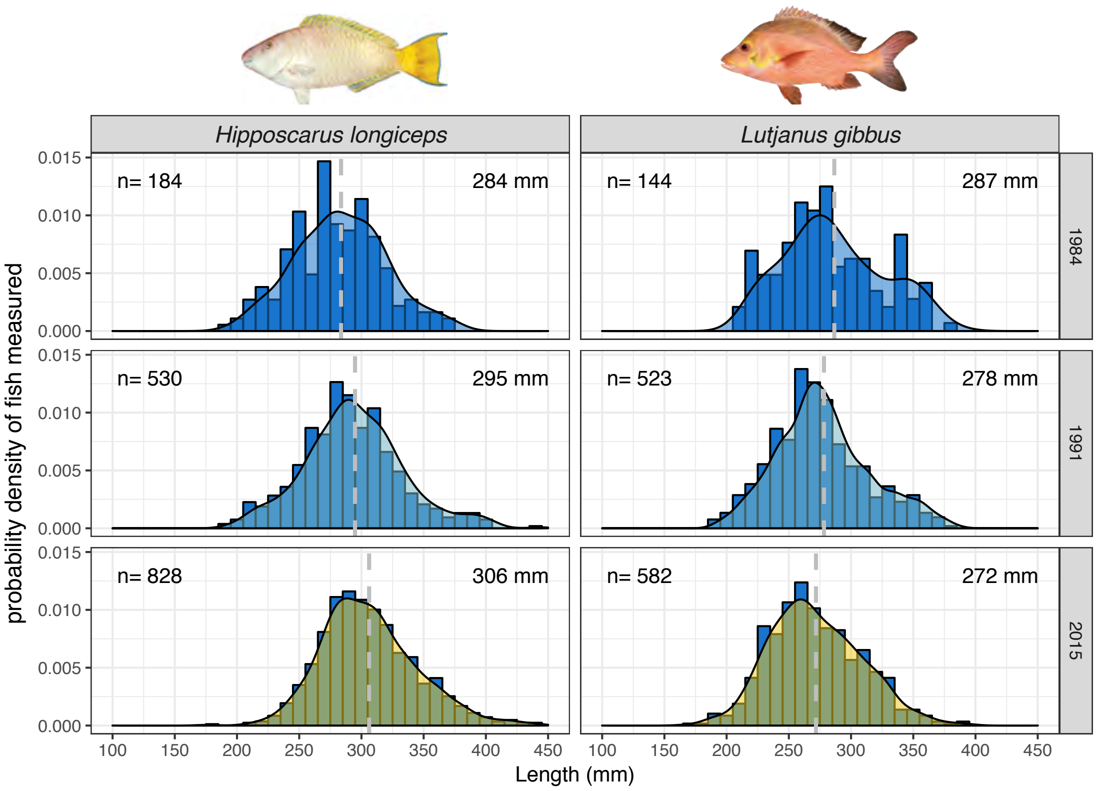
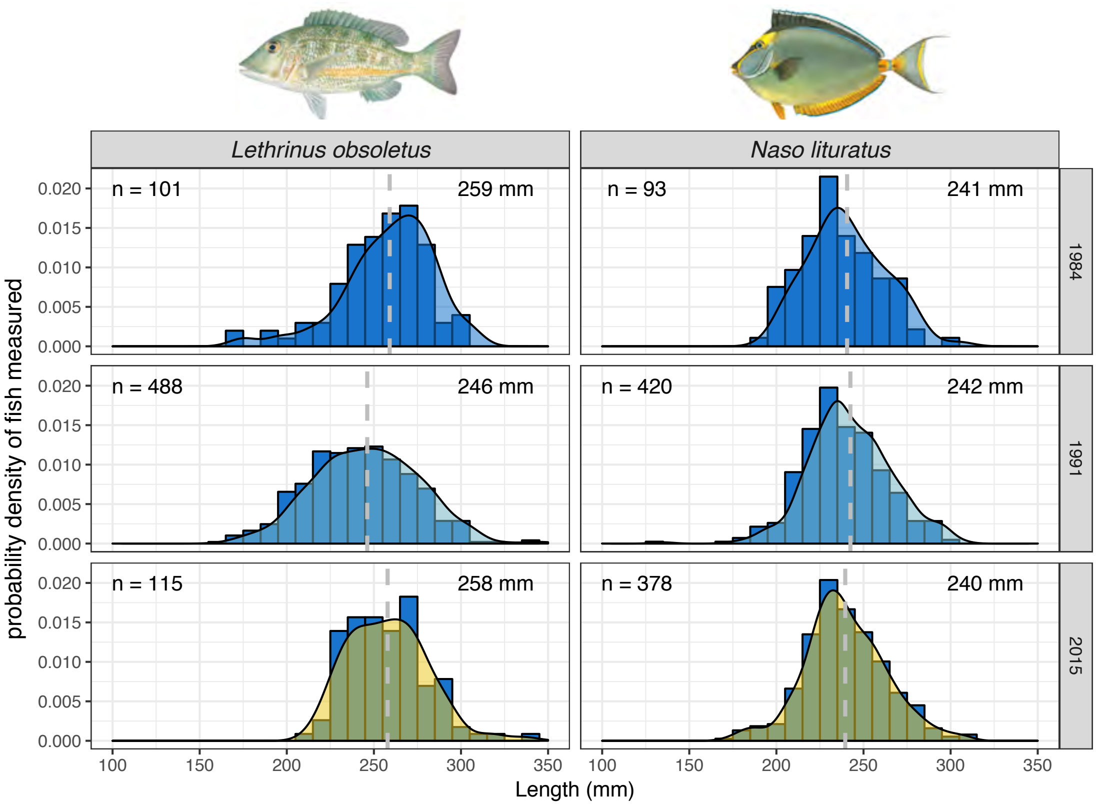


Figure 3a: Length frequency distribution two similarly sized fishes, each time period (1982-84 = blue, 1990-91 = green, and 2014-15 = yellow) are represented in boxes arranged vertically. The colored probability density curves are arranged over the length frequency distribution. The sample size (number of fish measured; n) is shown in the top left and the average size (shown as the dotted line) is displayed in the top right corner of each graph.

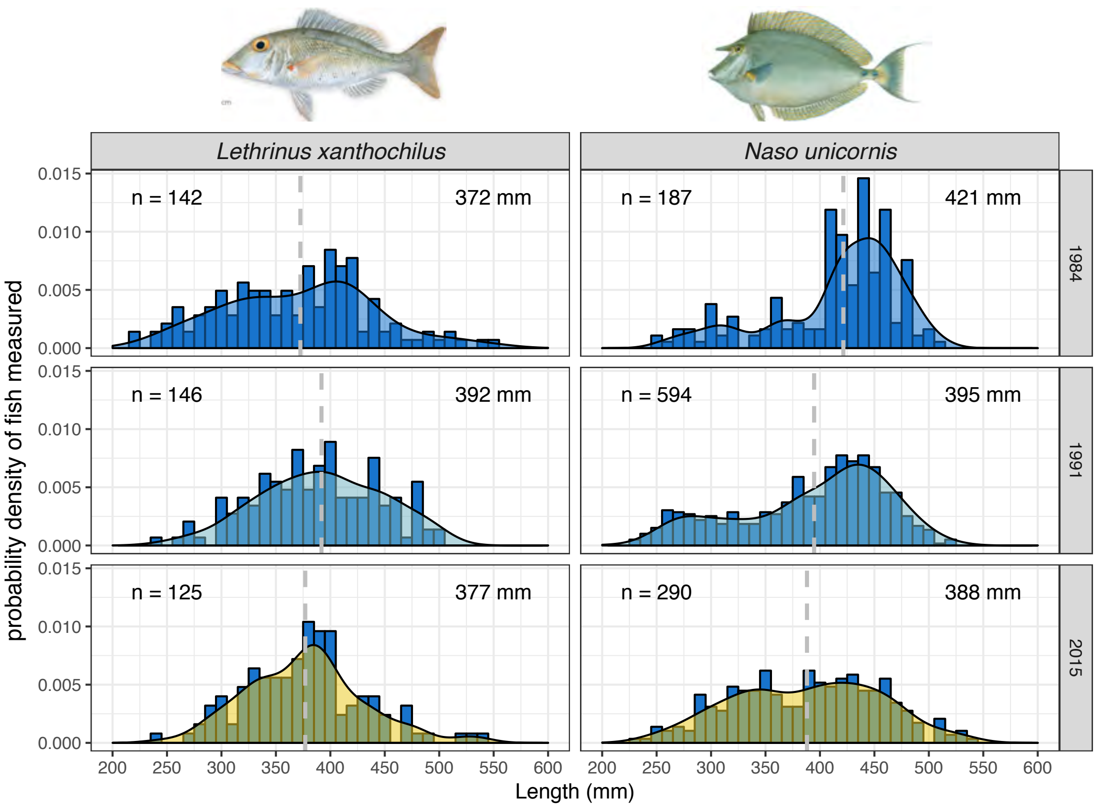
The size of Udech *Lethrinus obsoletus* and Erangle *Naso lineatus* were similar between 1984 and 2015, however smaller Udech were sampled in 1991 where there were also much larger sample sizes. This may have been due to different fishing practices such as netting which may have caught more small fish.

b)



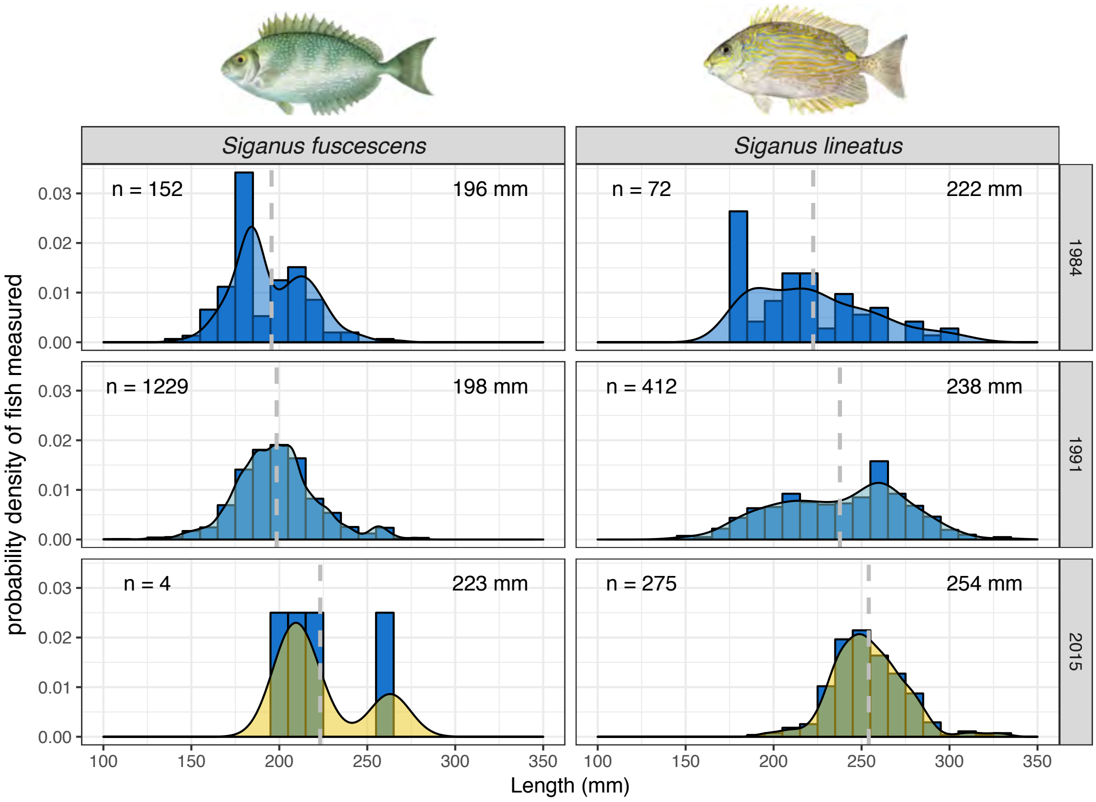
For Mechur (*Lethrinus xanthochilus*) and Um (*Naso unicornis*) there has been a reduction in the numbers of large fish caught. Although the average size of Mechur was smallest in 1982-1984, there was still some larger fish > 400mm that have since become less common in the catch. This truncated size structure pattern over time was most pronounced in Um, where modal size class was around 450 mm in the 1980-90s but has since declined severely in 2015.

c)



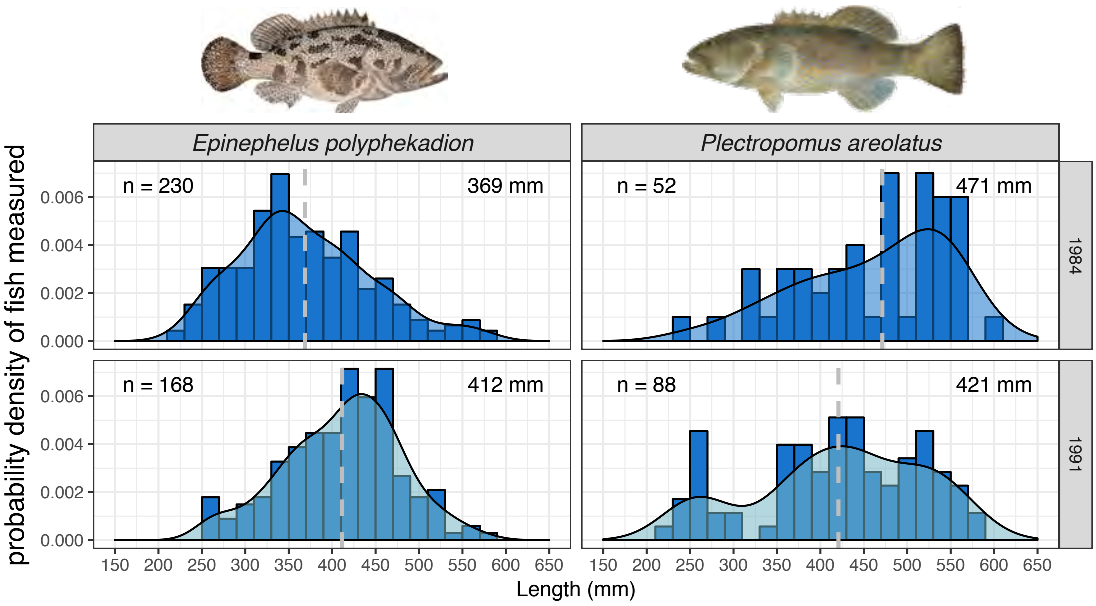
For Meyas (*Siganus fuscescens*) the size changed little between the 1980-1990s, however this species was not regularly caught in our 2015 surveys at the fish market and fishing competitions with only 4 fish measured. Targeted surveys for measuring this fish should be completed in the future. The size of Klsebuul (*Signaus lineatus*) has changed over time with an increase in average size of 3 cm. As these fish are caught by both gillnets and spearguns, this change in length frequency may be the response of a minimum net mesh size of 3 inches implemented in 1994 and/or more landings coming from spearfishers that are more selective and targeting the larger fish.

c)



Average size of Ksau Temekai (*Epinephelus polyphekadion*) increased between the two earlier time periods. However as these species form spawning aggregations and it is possible that the fish caught in 1991 were primarily caught from aggregations where a larger size would be expected from other reef fishes. In contrast there was a greater frequency of larger Tiau (*Plectropomus areolatus*) in the earlier time period, however sample sizes were lower with <100 fish. These species were not recorded in the 2014-15 surveys as was during the time of the grouper closed season.

d)



Changes in spawning potential ratio (SPR) from 1980/90s to 2015:

The spawning potential ratio (SPR) is a widely used reference point for fishery stock assessments. By using new length-based 'data-poor' stock assessment techniques, these models were applied to the length frequencies of the main species to track how the stocks have changed over time. Of the seven species assessed (for which had sample sizes of at least 100 fish is each time period), there were four species that declined in their spawning potential and three species that slightly increased (these data are summarised in Table 2). When fitting the LB-SPR model to the length frequency data, it provides the selectivity at length parameters (SL) for 50% and 95% of the catch and calculates the relative fishing mortality (F/M), which can then used to calculate SPR level (with a range of possible values).

The spawning potential ratio (SPR) of a stock is defined as the proportion of the unfished reproductive potential left at any given level of fishing pressure (Hordyk et al. 2014) and is commonly used to set target and limit reference points for fisheries. By definition, the SPR equals 100% in an unexploited stock, and zero in a stock with no spawning (e.g. all mature fish have been removed, or all female fish have been caught). SPR-based reference points have been recognized in international fisheries law, where SPR 40% is generally considered a conservative proxy for maximum sustainable yield (MSY) and SPR 20% is proxy for when recruitment rates are likely to be impaired for finfish. It is therefore important that the fish stocks should not fall below a level of 20%.

Of these species, three were calculated to have levels of SPR below 20%. Ngyaoch/Berkism (*Hipposcarus longicps*), Udech (*Lethrinus obsoletus*) and Klsebuul (*Signaus lineatus*). However, all these species have increased slightly in SPR over the time periods examined here, which is positive news. It should also be noted that the input parameters for these species, especially *L. obsoletus* and *S. lineatus* may not be the most accurate and therefore the percentage of SPR may fluctuate if there is new biological data emerging for these species. But at the moment, although SPR levels are low, the data shows increasing SPR so given a reduction in fishing pressure, these species should continue to recover.

The more concerning patterns are how some species have declined in SPR over time, particularly Keremlal (*Lutjanus gibbus*), Um (*Naso unicronis*) and Mechur (*Lethrinus xanthochilus*). Assessments from the most recent sampling period are reporting spawning potential ratios of 20-27%, which is close to the SPR level where the population will not be able to replenish itself given the current level of fishing pressure. It is for these species that management intervention is more urgently required.

Table 1: Summary of the LB-SPR input parameters that were used in the model for each of the seven species fish, along with the output results reporting the spawning potential ratio (SPR), the selectivity at length (SL) and the level of fishing mortality/natural mortality (F/M).

		LBSPR output				LBSPR input parameters			
Taxa	Period	SPR (range)	SL50	SL95	F/M (range)	M/k	Linf (mm)	L50 (mm)	L95 (mm)
Hipposcarus longiceps	84-91	0.13 (0.1 - 0.17)	265	318	2.55 (2.04 - 3.06)	1.07	423	300	330
	2015	0.22 (0.18 - 0.25)	270	310	1.77 (1.46 - 2.08)	1.07	423	300	330
Lutjanus gibbus	84-91	0.45 (0.37 - 0.52)	224	253	0.9 (0.64 - 1.16)	0.41	327	245	320
	2015	0.27 (0.23 - 0.32)	221	255	1.72 (1.35 - 2.09)	0.41	327	245	320
Lethrinus obsoletus	84-91	0.14 (0.11 - 0.18)	223	269	3.83 (2.9 - 4.76)	0.44	311	236	270
	2015	0.18 (0.09 - 0.26)	233	257	3.8 (1.36 - 6.24)	0.44	311	236	270
Naso lituratus	84-91	0.32 (0.27 - 0.37)	218	247	2.3 (1.7 - 2.9)	0.35	273	205	238
	2015	0.26 (0.22 - 0.31)	217	249	3.02 (2.16 - 3.88)	0.35	273	205	238
Naso unicornis	84-91	0.4 (0.34 - 0.46)	259	289	0.89 (0.69 - 1.09)	0.35	497	363	420
	2015	0.2 (0.14 - 0.26)	283	338	1.97 (1.42 - 2.52)	0.35	497	363	420
Lethrinus xanthochilus	84-91	0.32 (0.22 - 0.41)	314	399	1.39 (0.82 - 1.96)	0.62	502	326	360
	2015	0.21 (0.13 - 0.29)	329	397	2.57 (1.35 - 3.79)	0.62	502	326	360
Siganus lineatus	84-91	0.17 (0.1 - 0.25)	228	290	2.65 (1.42 - 3.88)	1.5	372	242	290
	2015	0.19 (0.15 - 0.22)	242	268	4.12 (2.93 - 5.31)	1.5	372	242	290

The average size of parrotfish Ngyaoch/Berkism, *Hipposcarus longiceps* is very close to the size at maturity, which implies that approximately 50% of the fish caught are immature. This corresponds to a low SPR level where they are being fished to a level where the population is struggling to recover. When comparing the two length frequency distributions, there are less of the smallest length classes of fish being caught in 2014-2015 and a slight increase in the numbers of larger fish around 350 mm which corresponds to a greater spawning potential ratio. Whereas Keremlal *Lutjanus gibbus* has shown a slight decrease in average size and a reduction in the proportion of larger fish around 350 mm. This removal of larger fish in the population has impaired the reproductive potential with a decline in SPR from 45% to 27%.

a)

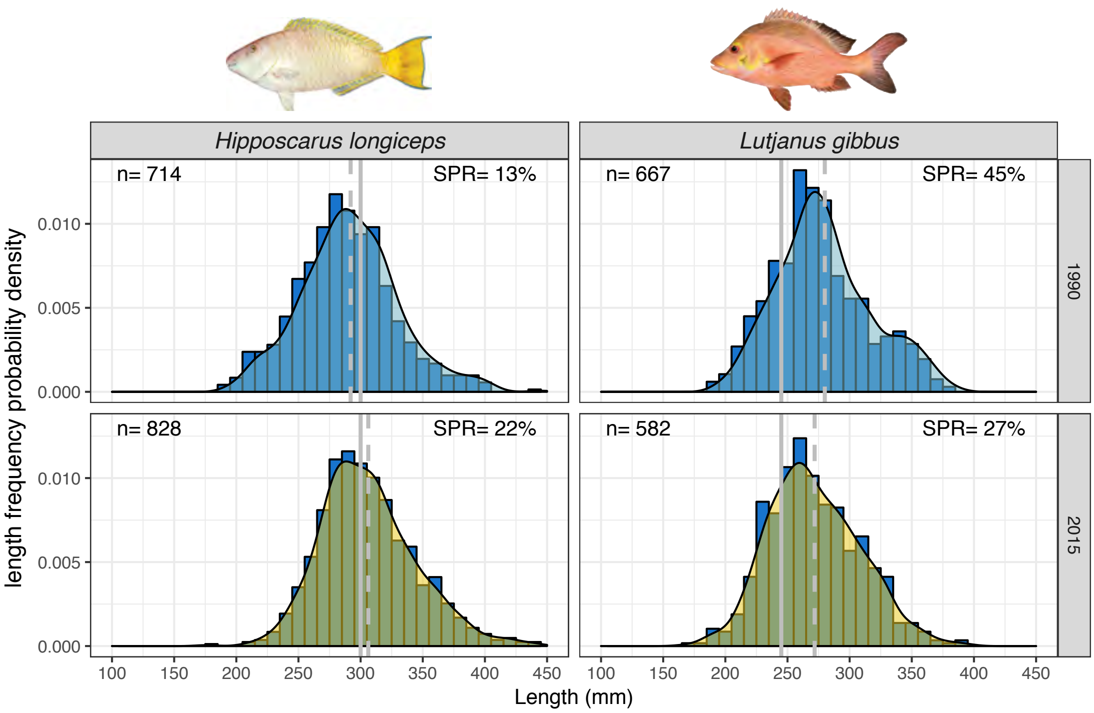
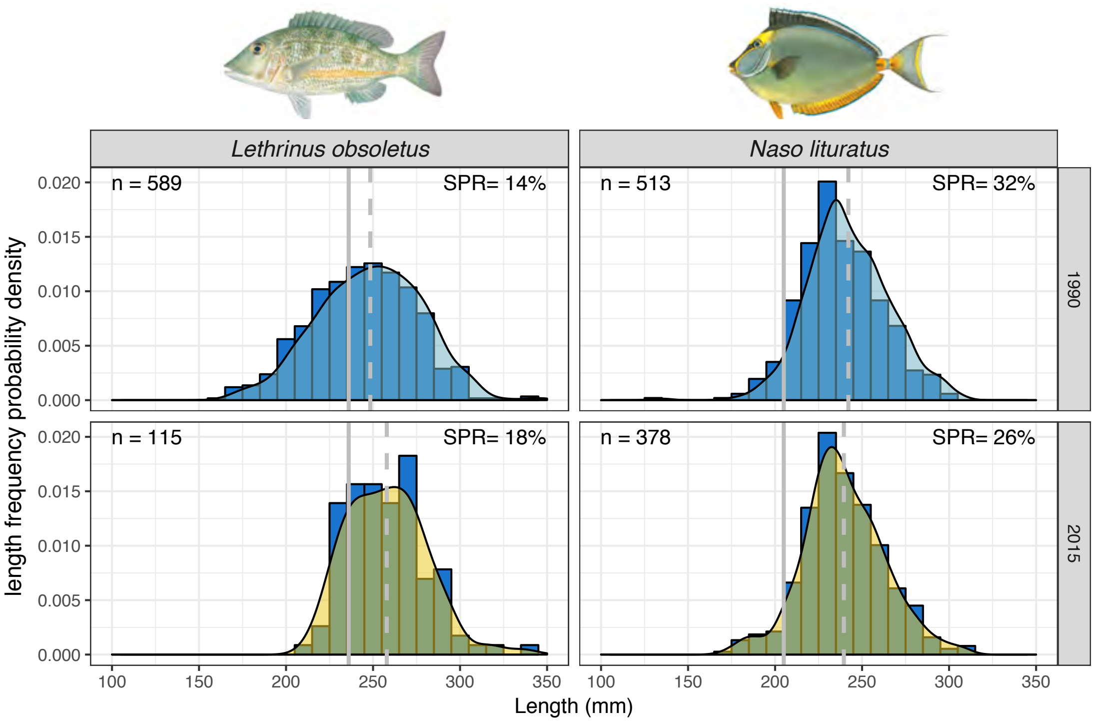


Figure 4a: Length frequency distribution two similarly sized fishes, each time period (1982-91 = green, and 2014-2015 = yellow) are represented in boxes arranged vertically. The colored probability density curves are arranged over the length frequency distribution so the shape of the distribution is the same height for all graphs. The average size is shown as the grey dotted line and the size at maturity is shown as the sold grey line. The sample size (number of fish measured; n) is shown in the top left and the spawning potential ratio (SPR) value is displayed in the top right corner of each graph.

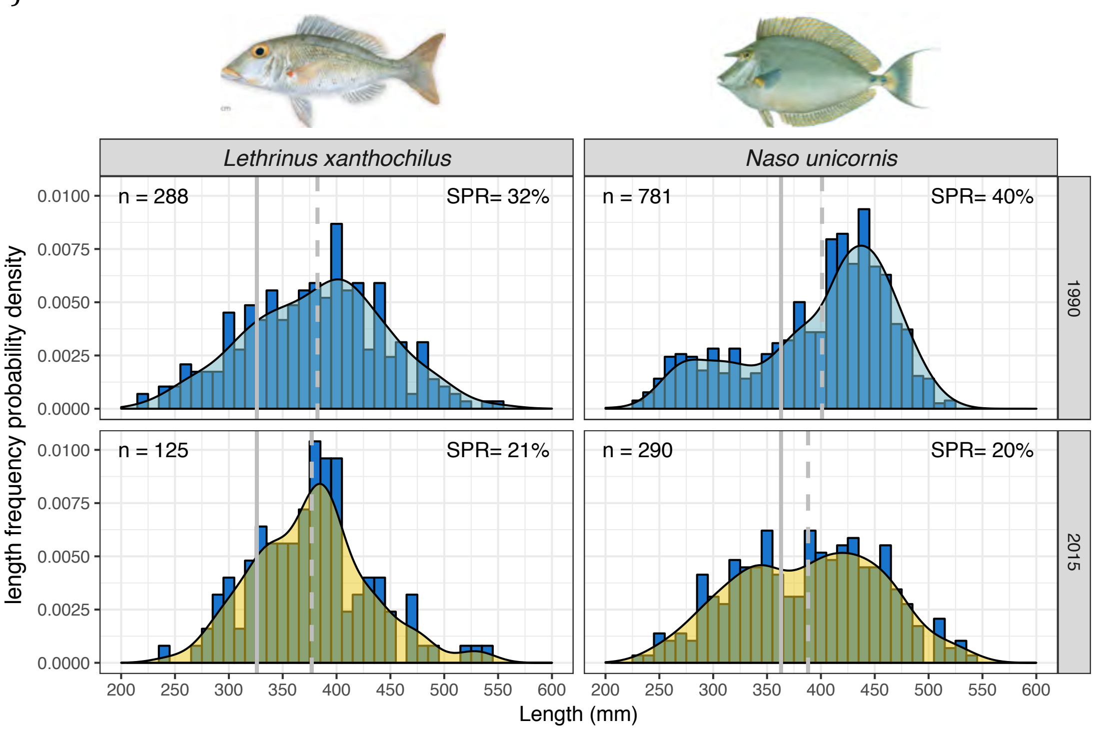
For Udech *Lethrinus obsoletus*, the SPR level is estimated to be below the 20% threshold, but it is positive that the SPR level has increased slightly in recent years. However it should be noted that sample sizes in 2014-15 are less than 1/5th of those in the 1980-90s and greater sample size would be preferred for accurate assessments. Also for this species, the life-history parameters are not well known so the level of SPR may be underestimated. For Erangle *Naso literatus* there was a slight decline in spawning potential but most of the fish caught are mature. It is not recommended for fishing pressure to be increased for this species.

b)



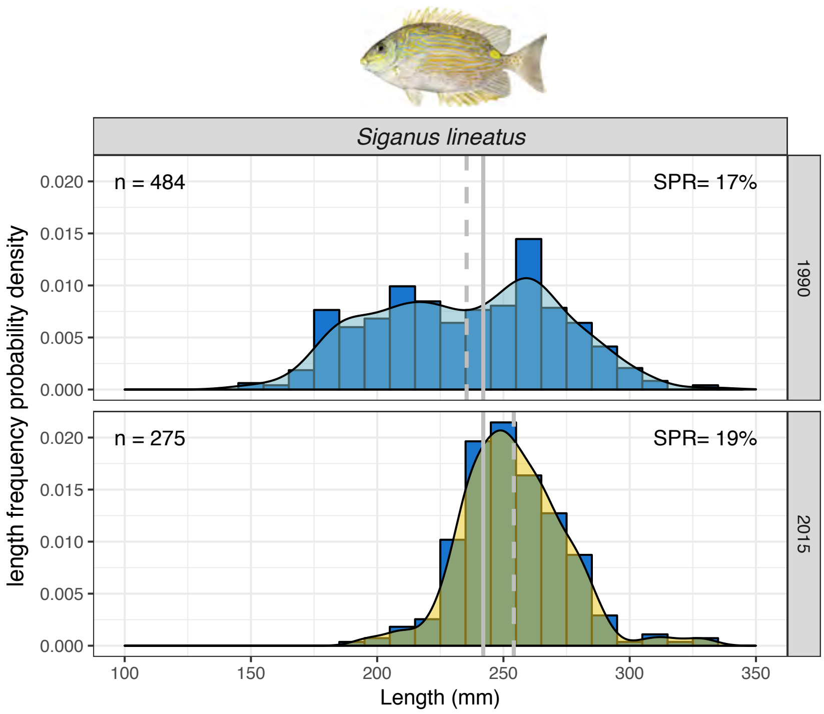
For Mechur (*Lethrinus xanthochilus*) and Um (*Naso unicornis*) there has been a reduction in the numbers of large fish caught. This truncated size structure pattern over time was most pronounced in Um, where modal size class was around 450 mm in the 1980-90s but has since declined in 2015. This reduction in large fish corresponded to pronounced declines in SPR with both species now at the borderline level of SPR 20% where the stocks may not be able to replace themselves. It will be important to decrease fishing pressure (through the implementation of size limits or reductions in effort) so the populations to not continue to decline to a point where it is difficult to recover and stocks may collapse.

c)



The size of Klsebuul (*Signaus lineatus*) has changed over time with both a reduction of small fish and large fish in the most recent surveys. The reduction of small fish may be in response to the minimum mesh size of 3 inches since 1994 as this species is frequently caught by gillnet. Nevertheless this species should be monitored and fishing pressure not increased as SPR is now estimated around 20%.

d)



Conclusion and recommendations

The relative simplicity of the data required for the LB-SPR assessment technique allowed robust stock assessments for seven species to track changes over time. These stocks could not have been assessed using conventional assessment techniques. This study also highlights the usefulness of historical data collection, which at the time may not have been directly informative but now provides a good baseline to assess changes over time (as predicted by Perron et al. 1983). But it is important to note that the data collection in the 80s and 90s occurred when there was already considerable fishing pressure in Palau. These times do not represent anywhere near unfished conditions. The works by Bob Johannes in the book 'Words of the Lagoon' (1981) mentioned that fishing had previously impacted the stocks of reef fish and at that time locals expressed concern about the declining abundance of certain species. This most recent data collection program with creel and market surveys at the JR5 market will provide another snapshot benchmark to assess the effectiveness of potential changes in fisheries management in the future.

As supported by data in this report, fishermen throughout the Republic of Palau have observed a steady reduction in nearshore fish populations, catch sizes, and average fish size. As a result, there has been a recent push for reforming the market process for reef fish in Palau and the increased fisheries management regulations such as size limits for more species and greater protection for fish spawning aggregation sites. With adopted resolutions and public awareness of the problem, it is hoped that over time we will see improvement in the reef fish stocks and the data generated now can be used to assess the effectiveness of these interventions.

For three of the main species, there has been a critical drop in spawning potential that now places these species on the brink where populations will not be able to replenish themselves given current levels of fishing pressure. Along with other species that have SPR levels below 20% there is a need for increased fisheries management to help the stocks of these species recover. Recent information suggests that the implementation of a minimum size limit based on protecting at least 20% SPR is recommended as the simplest and most effective management strategy for improving SPR levels and the sustainability of the fishery. The calculation of SPR 20% works out to be approximately 10% greater than the size at maturity (Prince and Hordyk unpublished data).

There are also several species that could not be assessed due to a lack of sample sizes from length measuring studies or the generation of life history parameters. It is therefore likely that many of these other fish species are currently fished at unsustainable levels, so it will be important to increase sampling to assess the SPR levels of these species. It would also be beneficial to increase studies on the size at maturity of fishes in Palau, as without this parameter a biologically relevant size limit cannot be recommended. More size at maturity studies can also be used to improve other estimates that were based on small samples sizes and maybe skewing the resulting SPR assessments (as reported in Prince at al. 2015).

In conclusion, this report highlights the benefits of fishery-dependent surveys of catches and the utility of data poor stock assessment techniques. As echoed by many fishermen in Palau, the stocks are declining and it is time to do something to address the problems if to increase the numbers of fish and support ecosystem services, food and the economy.

If any questions or suggestions to improve this report, please contact Steve Lindfield, Coral Reef Research Foundation, Palau – steve.lindfield@yahoo.com.

Acknowledgements:

Funding was provided by Rare Micronesia to support video analysis of the stereo-video footage and report writing. Jeremy Prince provided the basis for the LB-SPR assessment approach and the generating life history parameters for the main species in Palau. Adrian Hordyk developed the LB-SPR app online and assisted with codes to convert length frequency tables to lists of data. Percy Rechelluul and Lora Demei from the Bureau of Marine Resources were the main data collectors at the fish market and worked with SPC during the 2014 creel survey. The JR5 market and fishers supplied data and we appreciate their willingness to have landings surveyed. Anne Kitalong provided data for the historical length data from the 1980s and 90s. Thank you to all these individuals.

References:

Andrew NL, Béné C, Hall SJ, Allison EH, Heck S, Ratner BD. 2007. Diagnosis and management of small-scale fisheries in developing countries. Fish and Fisheries 8:227–240.

Hordyk A, Ono K, Valencia S, Loneragan N, Prince J. 2014. A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. ICES Journal of Marine Science doi: 10.1093/icesjms/fsu004.

Hordyk AR, Loneragan NR, Prince JD. 2015. An evaluation of an iterative harvest strategy for data-poor fisheries using the length-based spawning potential ratio assessment methodology. Fisheries Research.

Johannes RE. 1981. Words of the lagoon: fishing and marine lore in the Palau district of Micronesia. University of California Press, Los Angeles.

Kitalong A, Dalzell P. 1994. A preliminary assessment of the status of inshore coral reef fish stocks in Palau. South Pacific Commission, Nouméa, New Caledonia.

Moore B, Rechelluul P, Victor S, Secretariat of the Pacific Community. 2015. Creel survey and demographic assessments of coastal finfish fisheries of southern Palau, September 2014.

Nadon MO, Ault JS, Williams ID, Smith SG, DiNardo GT. 2015. Length-Based Assessment of Coral Reef Fish Populations in the Main and Northwestern Hawaiian Islands. PLOS ONE 10:e0133960.

Pauly D, Hilborn R, Branch TA. 2013. Fisheries: Does catch reflect abundance? Nature 494:303–306.

Perron F, Narvo A, Patris S. 1983. The Palau Reef Fish Production Study: A baseline study of the commercial reef fishing industry in Palau and a blueprint for the development of permanent fisheries managment system. Division of Marine Resources, Republic of Palau.

Prince J, Victor S, Kloulchad V, Hordyk A. 2015. Length based SPR assessment of eleven Indo-Pacific coral reef fish populations in Palau. Fisheries Research 171:42–58.
Taylor BM. 2010. Life-history and per-recruit assessment of *Lethrinus obsoletus* from Guam. Technical Report 128. University of Guam Marine Laboratory, Mangilao.