Stock Assessment of Guam Coral Reef Fish, 2019

Marc O. Nadon

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Marc Nadon[1,2]

[1]Pacific Islands Fisheries Science Center
National Marine Fisheries Service
1845 Wasp Boulevard
Honolulu, HI 96818

[2]Joint Institute for Marine and Atmospheric Research
University of Hawaii
1000 Pope Road
Honolulu, Hawaii 96822

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RDML Tim Gallaudet, Ph.D., USN Ret., Acting NOAA Administrator

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National Oceanic and Atmospheric Administration
1845 Wasp Boulevard, Building #176
Honolulu, Hawaii 96818

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Species photos for *C. melampygus* was taken by the author for NOAA-PIFSC. All other species photos are from Randall, J.E. 1997. Randall's underwater photos. Collection of almost 2,000 underwater photos. Unpublished. Accessed through fishbase.org.

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Executive Summary

This report contains single-species assessments of 12 reef-associated fish stocks around the island of Guam using data from various sources focusing on the 2013–2017 period. Previous management actions have set overfishing limits (*OFL*) at the family level using either a percentile of historical catches or a catch-MSY approach. Here, we used life history data, fishery-independent and -dependent size composition and abundance data, and total catch estimates to calculate current fishing mortality rates (F), spawning potential ratios (*SPR*), and *SPR*-based sustainable fishing rates (F_{30}: F resulting in *SPR* = 30%). We used the growth-type-group length-based spawning potential ratio model (GTG LBSPR) to obtain both current mortality rates and various stock status metrics. A meta-analytical data-poor approach was used to estimate life history parameters for 6 species with either no or inadequate growth and maturity studies. We used Monte Carlo simulations to incorporate all sources of uncertainty (i.e. life history parameters, size structure, abundance, and catch). Of the 12 assessed species, 4 had median F/F_{30} ratios greater than 1 and therefore median *SPR* values below the minimum overfishing limit of 30%. Another 3 species were close to this limit (30% ≤ *SPR* ≤ 35%). This suggests that 4 assessed species may be experiencing overfishing and 3 others may be close to experiencing overfishing (e.g. 48% risk of overfishing for *Monotaxis grandoculis*). *SPR* values among species within any given family varied. Typically, species with low *SPR* values were the ones with longer lifespans (e.g. *Naso unicornis*, *Scarus rubroviolaceus*, and emperors) and/or commonly reported (e.g. *Caranx melampygus*). Finally, for 5 species for which catch and/or biomass data were deemed of sufficient reliability, catch levels corresponding to F_{30} (C_{30}) were calculated by combining F_{30} estimates with current population biomass estimates derived directly from diver surveys or indirectly from the total catch. The overfishing limit (usually defined as the catch level corresponding to a 50% risk of overfishing) was calculated here as the median of the C_{30} distribution. Overfishing probability distributions for a range of catch limits were generated.

Introduction

The 2006 re-authorization of the Magnuson-Stevens Fishery Conservation and Management Act calls for annual catch limits (ACLs) to be set for all exploited stocks in the United States and its territories in order to, among other goals, insure sustainable harvesting practices. In the U.S. western Pacific, exploited stocks include a multitude of coral reef-associated finfish species inhabiting shallow-water areas around a large number of islands and atolls. The high species diversity, the mixture of commercial and noncommercial fishing effort, and the spatially diffused nature of the fisheries result in a comparatively data-poor situation for these stocks. This has led the Western Pacific Regional Fishery Management Council (WPRFMC) to set ACLs using basic approaches at the family level such as using the 75th percentile of historical catches, or using catch-based methods (Sabater and Kleiber, 2013). However, efforts in fisheries-independent surveys and life history research by the Pacific Islands Fisheries Science Center (PIFSC) have improved this situation to the point where length-based assessment approaches can now be applied to individual coral-reef fish stocks.

This report builds off the recent Hawaii coral reef fish stock assessment methods (Nadon, 2017) to evaluate the status of 12 of the most commonly exploited coral-reef fish species of Guam. These analyses use a length-based model to obtain current mortality rates and stock status metrics. We obtained estimates of fishing mortality (F) and spawning potential ratio (SPR) over the recent time period, associated F at SPR = 30% (F_{30}). For 5 species for which catch and/or biomass data were sufficiently reliable, additional values were calculated: catch associated with F_{30} (C_{30}), and overfishing risk tables for a range of catch limits (including a proxy overfishing limit, OFL, defined as the median C_{30} level which results in a 50% chance of overfishing; see Table 1 for the definition of all parameters).

For the purposes of our SPR-based approach, we used a default definition of overfishing as recommended by Restrepo et al. (1998):

- Overfishing limit: F at SPR = 30% (F_{30}), with overfishing defined as $F > F_{30}$ or $F/F_{30} > 1$.

For this approach, we used fishery-independent size composition and abundance data provided by NOAA diver surveys, as well as fishery-dependent data from both the biosampling program at the Fishermen's Cooperative Association and creel surveys conducted by the Guam Division of Aquatic and Wildlife Resources (DAWR) in partnership with PIFSC.

The 12 species assessed here were chosen based on a larger species list provided by the WPRFMC, whittled down to those species for which sufficient and reliable data sources were available and/or whose fishery characteristics could be accounted for using these methods. For all 12 species, stock status is calculated. Only 5 of these 12 species were deemed to have sufficient data to estimate an overfishing limit and an overfishing probability distribution for a range of catch limits following an independent peer review (Franklin, 2018).

Description of the Fisheries

The Mariana Archipelago follows an 870 km-long arc centered on the 145°E meridian, extending between 12°N and 21°N (Figure 1 inset). The archipelago is composed of 15 islands which are divided between 2 broad regions: a mostly inhabited southern group of 5 limestone islands and a northern volcanic group composed of mostly uninhabited smaller islands. Guam, an unincorporated U.S. territory, is a large island located at the southern end of the Archipelago. It is approximatively 50 km-long and 12 km-wide and has a human population of about 162,000. The island was first settled by the indigenous Chamorros at least 3,500 years ago and reef fish communities have been exploited since that time (Amesbury and Hunter-Anderson, 2008). The northern group of islands is lightly inhabited but still face some level of fishing pressure. The three northernmost islands are included in the Mariana Trench Marine National Monument.

The coral reef fishery around the island of Guam involves both inshore and offshore (i.e. boat-based) fishing. Fishing activities are a mix of commercial and noncommercial (recreational, cultural, and/or subsistence). Nearly all Guam domestic fishers have secondary occupations; Myers, 1993). Almost two thirds of Guam households are involved in fishing activities (Allen and Bartram, 2008). The noncommercial sector is composed of (mostly) shore-based fishers using a variety of gears such as spears, hook-and-line, and small gill and cast nets. There is also a traditional net fishery targeting seasonal runs of juvenile jacks, rabbitfish, goatfish, and scads. Data from boat-based and shore-based creel surveys indicate that fishing effort appears to have significantly increased from the late 1980s to the early 2000s, especially for the 2 dominant fishing gears (boat-based trolling and shore-based hook and line; Figure 2). Fishing effort for all gear types appears to have stabilized during the last 10 years (Figure 2). The primary families in the catch (boat-based and shore-based together), in decreasing order, are jacks, emperors, surgeonfishes, rabbitfishes, goatfishes, parrotfishes, snappers, and groupers.

The direct monetary value of the near-shore fishery is relatively minor, but it is culturally and socially important to the local population, especially the tradition of sharing fish catches among the community (Allen and Bartram, 2008).

Methods

The general assessment approach used in the present document recognizes that most coral-reef fish stocks in the U.S. Pacific are relatively data-poor. We selected this approach as it focuses on the best data sources available which are 1) the ongoing NOAA-PIFSC diver surveys (total biomass, individual size data), 2) the biosampling program (individual size data), and 3) the boat- and shore-based creel survey program (size data and total catch estimate). The length-based assessment approach used for the current analyses assumed relatively constant fishing mortality and recruitment over the time period of the analyses. The validity of this assumption was investigated for each species by looking at temporal trends in average length in the catch and abundance index from diver surveys as illustrated in the Species Report section at the end of this document. Furthermore, the lack of stock-recruitment relationships meant that we had to rely on a biological reference point (BRP) based on per-recruit spawning stock biomass (SSBR) and the ratio of current SSBR to un-exploited SSBR known as spawning potential ratio, *SPR*, a measure of the spawning potential of a stock.

The approach consisted of two main steps: 1) the use of life history and length structure data in the growth-type-group length-based spawning potential ratio model (GTG-LBSPR) to calculate current fishing mortality rates (F), spawning potential ratios (SPR), and sustainable fishing rates (F_{30} or fishing mortality rate resulting in SPR = 30%), and for a few select species, 2) the calculation of catch limits (C_{30}) associated with a given F_{30} by combining the F_{30} estimate with an estimate of current population biomass (derived directly from diver surveys or indirectly by relating the current total catch with the current F). The median of the C_{30} distribution is reported here as the overfishing limit (*OFL*), since it corresponds to a 50% chance of overfishing. A Monte Carlo procedure was used to integrate the uncertainty in each individual parameter related to length, population size, and life history for both main steps. A schematic of these steps and decisions are presented in Figure 3. The following sections explain this approach in greater details and describe the various data sources.

Stock Area

The first step of any stock assessment is to define the geographical extent of the stocks being analyzed. The shallow waters around Guam Island (0-200 m depth) which make up the habitat of the 12 species in this report are almost entirely within territorial jurisdiction limits and comprise 19,000 ha. However, the large banks to the southwest of the island (e.g. Santa Rosa, Galvez) contain almost as much reef habitat (15,000 ha; see Table 2 and Figure 1). These banks are only 10 nautical miles (20 km) away from Guam at their nearest point and the reef fish populations are likely connected to some degree (see Discussion for more details). It is not entirely clear to what level the reef fish populations around the southern Mariana Islands are connected and if significant larval exchange or adult movement exist. Given the relatively short distance between Guam Island and the large banks extending to the south (20 km, Figure 1), it is likely that the reef fish populations in these areas are connected to some extent (see Discussion section for details). However, no diver surveys were conducted on these banks and there is only a limited amount of length data from the boat-based creel survey for the banks (see Data Sources section). In this report, **all 12 stocks were analyzed at the scale of the island of Guam only** (Figure 1) due to these data limitations. Further stock connectivity studies may suggest that future stock assessments be conducted at different spatial scales for certain species, if data becomes available.

Another consideration for these assessments was the extent of each species' geographical range that fell in federal vs. territorial waters. All Guam Island sea floor area between 0 to 200 m depths falls within the 3 nautical miles territorial water limits (Table 3). Conversely, all sea floor area in the 0-200 m depth range on the banks is in federal waters. For each species, we obtained depth range estimates from Baited Remote Underwater Video (BRUV) and bottomfish camera (BotCam) exploratory surveys conducted by PIFSC (J. Asher, pers. comm.) and the University of Hawaii (J. Drazen, pers. comm.). We also used the mesophotic deep diving exploratory work conducted by Pyle et al. (2016) in Hawaii. We did not attempt to quantify abundance-at-depth given the limited coverage of these surveys. We simply reported the maximum depth that individual species can inhabit, which may be fairly marginal in certain cases, and calculated the sea floor area to this depth. In the Species Report section, we provide both the maximum depth and the percentage of sea floor area in Guam (territorial) vs. the Banks (federal) for all species (see Table 3 and Figure 1 for a summary).

Data Sources

For our analyses, abundance and size data were selected from the 2014-2017 time period (4 years) which included some extensive diver surveys conducted in 2017. The total catch estimate was obtained by combining 4 years of data from 2013 to 2016 (2017 was not included since that year's catch data was not complete at the time of this report). Selecting the last 4 years of data was necessary to obtain sufficient observations to run the analyses while lowering the risk of violating the equilibrium assumption by selecting a relatively short time period. Abundance and size data from diver and creel surveys were first summarized by island sector (East and West; Figure 1 and Table 2) before being combined using each's sector respective area weight (East: 0.39 and West: 0.61, obtained from the Pacific Islands Benthic Habitat Mapping Center). This was done to account for potential differences in abundance and size structure linked to uneven fishing pressure (inferred from accessibility) and uneven sampling effort between sectors.

Size composition, density, and total biomass from diver surveys

Fisheries-independent data were available from the diver surveys conducted by the Pacific Islands Fisheries Science Center's Ecosystem Sciences Division (ESD). The diver surveys provided size structure and abundance data. Size structure data is used for SPR calculation, and abundance data is used to derive total population biomass estimates for those select species that have an OFL calculation. Below is a brief description of the survey protocol. An in-depth description is available in Ayotte et al. (2015).

Starting in 2009, trained divers from the NOAA Pacific Islands Fisheries Science Center (PIFSC) have been conducting visual surveys around Guam following a stratified random design. Survey sites were randomly selected within strata defined by depth bins (shallow, 0–6 m; mid, 6–18 m; and deep, 18–30 m). All coastlines around Guam were easily accessible since the survey effort used small boats deployed from a research vessel. For practical and safety reasons, surveys were limited to depths above 30 m. During a typical survey day, a NOAA ship deployed 3 to 4 small dive boats that sampled pre-determined random sites along a large section of coastline. The entire island could easily be covered in 2 or 3 deployment days. At each site, stationary fish counts were implemented by two paired divers inside contiguous 15-m diameter cylinders that extended from the bottom to the surface (Brandt et al., 2009; Smith et al., 2011; Williams et al., 2011). Divers first listed all observed fish species during an initial 5-minute period and then went through this list, one species at the time, recording number of individuals and estimating sizes of all fish seen within the cylinder. Fish sizes were recorded as total lengths to the nearest cm. Individuals from species not listed during the initial 5-minute period but observed later in the survey were also recorded but classified in a different data category (i.e. non-instantaneous count). Divers were continuously trained between cruises in size estimation using fish cut-outs of various sizes. Diver performance during research cruises was evaluated by comparing size and count estimates between paired divers.

From this data set, it was possible to obtain an estimate of population size structure. Average length in the exploited phase ($\overline{L}$) was obtained by averaging the diver size structure above length at full selectivity (L_{S95}), which was obtained using the GTG-LBSPR model (see below). The standard deviations of the size structure and $\overline{L}$ estimates were obtained by bootstrapping the diver survey data set by re-sampling survey sites within sector (Figure 1).

Total numerical density estimates (individuals per 100 m^2) were obtained by dividing fish counts in each survey by the survey area (353 m^2 from two 15-m diameter survey cylinders) and multiplying by 100. An individual survey consisted of the combined fish counts from the two divers deployed at a single site. To obtain fishery-targeted numerical density, we multiplied total numerical density at a given size by species-specific selectivity coefficients generated using Eq. (1) and the L_{S50} and L_{S95} parameters obtained from the GTG-LBSPR model (see section below for definitions and more details). The overall fishery-targeted numerical density was obtained by (1) averaging site-level density estimates within a coastline sector and by (2) averaging all sector-level density estimates together using sector weights. Standard deviations were obtained by bootstrapping the diver survey data set by re-sampling survey sites within sector from 2014-2017 and applying the weighted mean procedure described above to generate a distribution of mean numerical density. Finally, it is important to note that only instantaneous fish counts were kept for this calculation to obtain an abundance estimate close to "true" density. The implied assumption here is that the "catchability" (q) of an individual underwater survey is the fraction of the total hard-bottom population area (6,625 ha) covered by a single survey (353 m^2; $q = 5.3\times10^{-6}$). We used hard-bottom area since all species in this report are heavily associated with this habitat type. Note that Table 2 and Table 3 include soft- and hard-bottom in its area calculation due to bottom-type information not being available at all depths and on the bank area, which precluded us form presenting only hard-bottom information, which would have been preferable.

Fishery-targeted biomass density (kg per 100m^2) was calculated directly from fishery-targeted numerical density by converting fish lengths to mass using a length-weight relationship ($W=\alpha \times L^{\beta}$). The α and β parameters are listed for each species in the Species Reports section as LW-alpha and LW-beta. Total fishery-targeted stock biomass was obtained by multiplying sector-specific biomass density by total habitat area within sector, and summing biomass across sectors. The standard deviations of total fish biomass were obtained through bootstrapping in a similar fashion as for numerical density using 2014-2017 data. Note that we also present biomass density per year as figures in the Species Reports section to help evaluate the equilibrium assumption.

One limitation of this data set was the potential impact of fish behavior on the assumed catchability coefficient (5.3×10^{-6}) for population biomass calculations. Cryptic behavior and diver avoidance (or attraction) will have an effect on this assumed value and this will differ between species. Although the biomass calculations for all species were done assuming this value, we discuss potential biomass estimate biases for certain species in the Species Report section.

Another limitation of this data set is the potential mismatch between the survey domain (limited to 30-m depth) and the greater depth range of certain species. For species occurring at depths greater than 30 m, we did not attempt to assign a population abundance to the un-sampled sea floor area, given our limited knowledge of the amount of suitable habitat at these depths. We do however discuss this potential bias and implications for the relevant species in the Species Report section.

Size composition and total catch from the creel survey and biosampling program

The Guam Division of Aquatic and Wildlife Resources (DAWR) in partnership with PIFSC has been running a boat-based and shore-based creel survey program since 1985 (Jasper et al., 2016). Both creel survey methods consist of participation counts to determine total effort (number of trips) combined with random fisher interviews to determine average catch per trip. The fisher interviews occur at vessel harbors (boat-based survey) and around the island with randomly intercepted fishers (shore-based survey). The interviews record species composition, fishing gear, fish count, length, and weight. The average catch estimates obtained from these interviews are expanded to total catch using the total effort estimate derived from the participation counts. For the shore-based survey, the participation counts consists of surveyors driving along the coastline on a set route and recording all shored-based fishing effort (e.g. deployed fishing rods, spearfishing floats, etc.). For the boat-based survey, the participation counts consists of surveyors recording effort as boat trips at the 3 main port areas combined with boat trailer counts reported during the normal shore-based survey drive (Jasper et al., 2016). The participation counts occur during both week days and week-ends. There is also an aerial survey that complements the normal participation counts by including coastlines not easily accessible to surveyors. More in-depth information concerning these surveys is available (Oram et al., 2013a; Oram et al., 2013b; Jasper et al., 2016). Total expanded catch estimates per species were obtained from the Western Pacific Fisheries Information Network database at PIFSC and the standard deviations around these estimates were derived by bootstrapping (WPacFIN, T. Matthews, unpubl.).

PIFSC developed and funds a biosampling program on Guam in partnership with the Guam Fishermen's Co-op Association (GFCA). This biosampling program collects fish samples for life history studies as well as a large number of length measurements which can be used to parameterize length-based models. The general area where these fish samples are collected are reported which allows the data to be weighted by island sector, similarly to the other data sets. The Guam biosampling program is focused on the fish brought to GFCA in Hagatña. Boat-based scuba spearfishing is the dominant fishing method in the biosampling program (75% of the catch).

Length data from both the creel and biosampling program were combined and classified by 3 main fishing methods (spear, line, and net fishing). Size structure graphs were generated to visually compare the selectivity pattern of the main gears for each species (see Species Reports). If the selectivity patterns of the main gears appeared different, the gear with the smallest length at first selectivity was selected to better capture the full fishery-targeted size structure for the

GTG-LBSPR analyses. Selecting size data from a fishing gear with a narrow selectivity window would bias the L_{S50} and L_{S95} estimates as well as the F and SPR estimates by underestimating the true size/age range in which individual fish experience fishing mortality. If the selectivity patterns of the different fishing gears were similar, then data from the gear with the most size observations were used (typically line or spear fishing). Similarly to how the diver data were treated, length observations were weighted by sector before being combined. Average lengths for the main fishing gears were also calculated and presented in figures for each species.

Life history parameter sources

The scientific literature was reviewed for published life history parameters related to growth, longevity, and maturity. This search was not restricted to local studies given the paucity of peer-reviewed literature on coral reef fish biology. If multiple growth or maturity studies were available for a species, we prioritized using local studies, followed by the most recent, in-depth studies (even if from a different geographical area). If no life history study was available or if the parameters were non-sensical (i.e. local maximum length much larger than the L_{inf} obtained from a non-local study), we used the data-poor life history estimation approach described in Nadon and Ault (2016). In short, this approach uses a local estimate of maximum length to provide family-specific probability distributions for all main life history parameters. The maximum length used for this approach was the 99$^{\text{th}}$ percentile observation of a length data set (L_{99}) which was selected to filter out potentially erroneous extreme length observations. Where possible, we used the diver length data set from the lightly fished Northern Mariana Islands to obtain an estimate of maximum length. The standard deviations of life history parameters were obtained by one of the following methods, presented in order of preference based on reliability: 1) bootstrapping the raw length, age, or maturity data, when available, or 2) using the coefficient of variations at different sample sizes from Kritzer et al. (2001) for growth and Nadon (unpublished) for maturity (Table 4), or 3) from the stepwise approach itself, if it was used to generate life history parameters (Nadon and Ault 2016). See Figure 3 for a summary of life history steps within this assessment framework. The CV L_{inf} parameter was obtained directly from the growth model when raw data was available or was obtained from published growth figures using the following equation: $[(\text{max length}-L_{\text{inf}}) \div 1.96] \div L_{\text{inf}}$. This equation assumes that the distance between max length and L_{inf} encompasses 95% of individual fish L_{inf} values.

GTG-LBSPR Model

The recent PIFSC Hawaii reef fish assessments (Nadon, 2017) used an average length mortality estimator to determine fishing mortality rates. In contrast, the current assessments used the growth-type-group length-based spawning potential ratio approach (GTG-LBSPR) to calculate fishing mortality rates and obtain stock status metrics (Hordyk et al., 2016). The main differences between the two approaches are 1) the GTG-LBSPR model fits to the entire size structure data (as opposed to mean length), 2) the GTG-LBSPR model estimates the selectivity parameters, but requires an extra life history parameter ($CV\,L_{\text{inf}}$; see description further in this section), and 3) the use of growth-type groups allow the GTG-LBSPR model to control for differences in fishing mortality rates within the same age-class due to the combination of size-dependent selectivity and variability in growth trajectories (i.e. Lee's phenomenon; Lee, 1912). The section below describes the key components of this model. A more complete description can be found in Hordyk et al. (2016).

The GTG-LBSPR model relies on the Von Bertalanffy growth equation (VBGE), fishing and natural instantaneous mortality rates, and size-based selectivity to predict the size structure of exploited stocks at equilibrium. By assuming constant recruitment and mortality rates, it can describe the number-per-recruit in individual length classes using the recursive equation:

$$N_{L+dL} = N_L \left(\frac{L_{\inf} - L - dL}{L_{\inf} - L} \right)^{\frac{Z_L}{K}} \qquad \text{Eq. 1}$$

where N_L is the number of fish in length class L, dL is a small increment in length, $L_{\inf}$ and K are parameters of the VBGE, and Z_L is the total mortality rate at length class L (equal to the sum of fishing mortality rate at length L (F_L) and natural mortality rate M which is assumed constant, see below for more details). F_L is assumed to be size-dependent and can be described using a logistic selectivity equation:

$$F_L = \frac{1}{1 + e^{\left[-\ln(19) \frac{L - L_{S50}}{L_{S95} - L_{S50}} \right]}} F \qquad \text{Eq. 2}$$

where L_{S50} and L_{S95} are the size at 50% and 95% selectivity, and F is the background fishing mortality rate.

The cumulative per-recruit density between length class L and $L+dL$ can then be described as

$$\tilde{D}_{L+dL} = \frac{\frac{1}{Z_L}(N_L - N_{L+dL})}{\sum_L \frac{1}{Z_L}(N_L - N_{L+dL})} \qquad \text{Eq. 3}$$

which is standardized to sum to 1.

The equations described above are for an individual growth trajectory (i.e. a single $L_{\inf}$ value). By varying $L_{\inf}$ using the CV $L_{\inf}$ parameter (coefficient of variation associated with individual variability in $L_{\inf}$), we can use these equations to calculate the density at length vector $\tilde{D}_L$ for a number of different growth-type groups (G). It is then possible to obtain the expected length structure by summing the density for all individual length classes across the G growth-type groups:

$$\ddot{D} = \sum_1^G \tilde{D}_{L+dL,g} \qquad \text{Eq. 4}$$

The length-based model described here can also be used to calculate the spawning potential ratio, alleviating the need for a separate age-based model as used in Nadon (2017). Assuming that egg production is proportional to weight, we can describe fecundity-at-length (Fec_L) as

$$Fec_L = Mat_L L^{\beta} \qquad \text{Eq. 5}$$

where Mat_L is maturity-at-length which can be described using a logistic function of format similar to Eq. 2 (replacing L_{S50} and L_{S95} with L_{mat50} and L_{mat95}). The β parameter is from the length-weight relationship ($W=\alpha \cdot L^{\beta}$). In the current report, length-at-maturity was assumed to be knife-edged given that most life history studies used for this report only report length at 50% maturity (L_{mat}). Using this equation, it is now possible to calculate spawner-biomass-per-recruit (*SSBR*) for each length class and ultimately obtain *SPR* by summing *SSBR* across all length classes and all growth-type groups for both the exploited stock (numerator) and the pristine stock (denominator):

$$SPR = \frac{\sum_g \sum_L \frac{1}{(M+F_L)}(N_{L,g} - N_{L,g+dL})Fec_L}{\sum_g \sum_L \frac{1}{M}(N_{L,g} - N_{L,g+dL})Fec_L} \qquad \text{Eq. 6}$$

With estimates of L_{inf}, K, $CV\ L_{inf}$, and L_{mat} (again, assuming knife-edged maturity), it is now possible to estimate F, L_{S50}, and L_{S95} from a population size structure by minimizing the multinomial negative log-likelihood (NLL) following the function:

$$NLL = \underset{F, L_{S50}, L_{S95}}{\arg\min} \sum_i O_i \ln \frac{\tilde{P}_i}{\tilde{O}_i} \qquad \text{Eq. 7}$$

where O_i and $\tilde{O}_i$ are the observed number- and proportion-at-length (respectively) in each i length class and $\tilde{P}_i$ is the estimated proportion-at-length for each i which can be calculated by multiplying the $\ddot{D}$ in Eq. 4 by the estimated selectivity curve.

The GTG-LBSPR model makes similar assumptions to other relatively simple length-based approaches (e.g. mean length-SPR), mainly that the stock is in a mostly steady-state (recruitment- and mortality-wise) and that the VBGE appropriately describes fish growth. The current implementation of this model also assumed logistic selectivity, knife-edged length-at-maturity, and constant natural mortality at all sizes.

Estimated *SPR*s were evaluated in relation to the recommended 30% *SPR* threshold, a standard threshold recommended for less well-known stocks (Gabriel et al., 1989; Restrepo et al., 1998; Clark, 2002). F_{30}, the fishing mortality required to obtain an *SPR*=30%, was also estimated using the GTG-LBSPR model. To do so, we used an iterative procedure which calculated *SPR* at incrementing F values (keeping all other parameters fixed) until the *SPR*=30% level was reached. An identical procedure was used to obtain Lc_{30} (the knife-edge size limit resulting in SPR=30% at current fishing mortality rate). *SPR*, proportion of *SPR* iterations that resulted in $SPR < 0.30$, Lc_{30}, F_{30}, and F/F_{30} values are provided in the Species Report section. The final distribution of derived values (including *SPR* and any life history parameters) were obtained by incorporating all described sources of uncertainty (data and parameters) using a Monte Carlo approach.

Note: Eq 6 presented above is derived from equation 31 in the original Hordyk et al. (2016) manuscript which contains an error where the D parameters should be N, as above (this was confirmed by personal communication with the author, A. Hordyk).

Natural Mortality Models

The GTG-LBSPR model requires an estimate of natural mortality (*M*) which we obtained using the procedure of Alagaraja (1984), similar to (Hoenig, 1983) and Hewitt and Hoenig (2005), assuming that 4% of a cohort survives to the observed maximum age (a_λ), also known as longevity:

$$M = \frac{-\ln(0.04)}{a_\lambda} \qquad \text{Eq. 8}$$

We used the 4% cohort survivorship value based on the analyses of (Nadon et al., 2015) which showed that this is an appropriate survivorship value for coral reef fishes. We did not have independent estimates of *M per se* and had to rely on this longevity-based approach. Although there are other data-poor methods for estimating natural mortality, involving other parameters (e.g. K, L_{inf}, L_{mat}, water temperature), two recent scientific papers on the subject clearly suggest that longevity-only methods are better performing (Kenchington, 2014; Then et al., 2015). It is important to consider the potential difficulty in obtaining a representative longevity value in heavily exploited stocks. To reduce this concern as much as possible, we always selected the oldest recorded age, regardless of geographical location, as our measure of longevity. It was, unfortunately, impossible to only select longevity estimates from un-exploited stocks given that there are few life history studies on such stocks. The Species Report section provides details of parameters selected and their sources, and output parameter values and associated uncertainty.

Overfishing Limit Calculation

The sections above present the data sources and models used to obtain various population parameters (mortality rates, *SPR*, F_{30}, Lc_{30}). For a few select species, to obtain overfishing limit estimates (*OFL*, the catch limit that results in a 50% chance of overfishing), we first needed to obtain an estimate of current population biomass (*B*). This could be obtained in two ways depending on data reliability and availability for each species: 1) obtaining total biomass directly from the diver-surveys, as explained earlier, and 2) by using the estimates of total catch (*C*), natural mortality, and length-derived fishing mortality in the Baranov catch equation:

$$B = C \div \frac{F}{F+M}\left(1-e^{-(F+M)}\right) \qquad \text{Eq. 9}$$

From one or both of these estimates of current population biomass, we derived the catch level corresponding to F_{30} (C_{30}) by using the Baranov equation and our estimates of sustainable fishing mortality rate (F_{30}):

$$C_{30} = B \cdot \frac{F_{30}}{F_{30}+M}\left(1-e^{-(F_{30}+M)}\right) \qquad \text{Eq. 10}$$

Similar to the approach for derived *SPR* and life history parameters, the final distribution of C_{30} estimates were obtained by incorporating all described sources of uncertainty (data and parameters) using a Monte Carlo approach. In short, we drew a random value from the probability distributions of each data source (size structure, life history parameters, diver-derived population biomass, and total catch) and ran all the steps necessary to calculate C_{30} using these random values (Figure 3). The Monte Carlo draws for parameters that could not be negative (e.g. catch) were bounded at zero if they were drawn from probability distributions that allowed negative values. The Monte Carlo procedure was repeated 15,000 times to generate distributions of C_{30} and other derived values. The median of the C_{30} distribution represented the catch level corresponding to a 50% chance of overfishing (*OFL*).

It is important to note that randomly drawn combinations of life history parameters could lead to a biologically impossible scenario where the observed size structure is composed of size classes that are larger than the pristine size structure predicted by these parameters. For these random draws, F will be negative and *SPR* will go above 1. This can be a fairly common situation for lightly fished stocks with a size structure close to its pristine composition and is not necessarily an indication of incorrect life history parameter distributions. Instead, it is the result of a lack of a proper *a priori* covariance structure between these parameters that should have limited certain parameter combinations. For example, a very high M value, combined with a low K and low L_{inf} values can lead to a pristine size structure that is unrealistically small and therefore smaller than the observed one. To correct this issue, for an observed size structure, we rejected life history parameter combinations that led to negative F values. An alternative approach would have been to prevent the maximum likelihood optimization procedure from selecting F below zero (e.g. using a log-normal distribution for F), but that would simply lead to the GTG-LBSPR model not converging on a maximum likelihood estimate of F. It is more straight-forward to diagnose poor model convergence due to a size structure that is too large by observing (and rejecting) negative F values in the output than to diagnose poor model convergence through likelihood gradients.

Decision Process for Multiple Data Sources

Throughout the process used to generate *OFL* estimates (Figure 3), there were several steps where decisions had to be made regarding data sources. To reduce the subjectivity of these decisions, we created a decision table presented in Figure 3. In short, there were 3 main decision steps: 1) selecting a specific fishing gear data set for the size structure, 2) choosing a local study, external study or the Nadon and Ault (2016) approach as a source of life history parameters, and 3) choosing a bootstrap procedure on raw data or the meta-analysis of Kritzer et al. (2001) and Nadon (unpubl.) to generate uncertainty of life history parameters. For select species, both the C_{30} distributions (and *OFLs*) generated from diver-survey biomass or from catch-based biomass are discussed and presented in the Species Reports section; the choice of which to use is ultimately left to managers.

Analyses Work Flow

The following section describes the data and analyses work flow used to generate the final tables and figures presented in the individual species reports (Figure 4).

The raw diver survey data were provided by the PIFSC ESD (file named "all_rea_fish_raw.rdata"), the biosampling program length data were provided by the PIFSC Life History Program ("biosampling.xlsx"), and the raw creel data and expanded catch per species were obtained from PIFSC WPacFIN staff. Four R scripts were used to process these raw data sets ("process_uvs.r", "process_creel.r", "process_biosampling.r", and "get_catch.r"). Other R scripts were used to obtain various metrics and their associated distributions: average length and size structure ("get_size.r"), population biomass ("get_biomass.r"), and L_{99} for the stepwise approach ("get_l99.r").

The overall approach to fit the GTG-LBSPR model and generate population status metrics (F, F_{30}, and SPR) and the C_{30} distributions (Figure 3) was implemented in the R programming language (R Core Team, 2017) using the Template Model Builder (TMB) library (Kristensen et al., 2016) for the model itself. This code was implemented as an R package named TMB.LBSPR. This package requires inputs in the form of probability distribution parameters (e.g. mean, standard deviation) for 1) the life history parameters, 2) average length, 3) total catch (if available), and 4) population biomass from diver surveys (if available). These are entered in a separate excel spreadsheet ("lh par.xlsx"). In the case of the stepwise approach (Nadon and Ault, 2016), the StepwiseLH R package (Nadon and Ault, 2016) can be called which requires L_{99} distribution parameters and a species' family-level taxonomic group. Other required parameters are entered as fixed values: length-weight parameters (β) and the number of Monte Carlo iterations.

Once launched, the TMB.LBSPR package will draw random samples from the input distributions and run the calculations showed in Figure 3: 1) calculate M from longevity (if necessary), 2) generate an estimate of F, SPR, F_{30}, and L_{c30} from the GTG-LBSPR model, and 3) calculate C_{30} from the diver surveys (if available) and from the catch data (if available). The program outputs a data table containing all parameter values for each Monte Carlo iteration. This table is processed with an R function contained in the TMB.LBSPR R package (process.results) that will generate the standard suite of figures and tables displayed in each species report.

Results

This section provides a brief overview of the assessment of the Guam reef fish included in this report. Table 5 presents a summary of selected stock status metrics for each species, and overfishing limits for select species. In-depth results, comments, and specific concerns can be found in the Species Reports section at the end of this manuscript.

Based on their depth range, all 12 species in this report occur only in territorial waters around the island of Guam. However, they are also found on the nearby banks which are entirely in federal waters (> 3 nm offshore; Figure 1). If we combine both Guam Island and offshore bank habitat, these 12 reef species occur significantly in federal waters (23% to 44% of their total habitat). However, it was not possible to include the bank area in our analyses due to a lack of data. It is important to note, again, that we assessed the reef fish on Guam Island only, and not on the associated banks.

We found local life history parameters for 5 species and had to use parameters from studies conducted elsewhere in the Indo-Pacific region for 1 species. The remaining 6 species had either no (n=4) or inadequate (n=2) published life history studies and we used the stepwise approach presented in Nadon and Ault (2016) to obtain estimates of these parameters (Table 5). As expected, the assessment results conducted with these estimates were more variable than those conducted with life history parameters from actual studies due to the additional level of uncertainty associated with this meta-analytical approach.

Of the 12 assessed species, 4 had median *SPR* values below the 0.3 overfishing threshold recommended by (Restrepo et al., 1998). Three other species had median *SPR* values close to this limit (< 0.35; Table 5). Typically, species with low *SPR*s were the ones with longer lifespans (i.e. *Naso unicornis*, *Scarus rubroviolaceus*, and the emperors) and/or commonly reported (e.g. *Caranx melampygus*). Species with shorter lifespans (i.e. small parrotfishes) fared generally better.

For species with overfishing limit calculations, biomass estimates obtained from diver surveys were always more precise than those derived from the catch. Consequently, C_{30} distributions derived from diver-biomass were more precise as well. Of the 5 species with biomass estimates from both data sources, 4 had reasonably similar estimates, with differences ranging from 17% to 60% (Table 5). One species (*L. gibbus*) had a much larger catch-derived biomass vs. diver-survey biomass (i.e. 5 times larger).

Discussion

The assessment approach used in this report focused on fisheries-independent diver-survey data (size structure, biomass for select species) as well as fisheries-dependent data from creel surveys (size structure, total catch for select species) and biosampling program (size structure). The growth-type-group length-based spawning potential ratio (GTG-LBSPR) population model used in this report is relatively simple and only requires size data and life history parameters. This model and other length-based ones are well-tested and appropriate for the data-poor situation that characterize coral-reef fisheries (Ehrhardt and Ault, 1992; Ault et al., 2005; Hordyk et al., 2015; Nadon et al., 2015; Hordyk et al., 2016). Several assumptions and caveats apply to this type of length model.

First, we assumed the stocks analyzed in the current study were at equilibrium in terms of both mortality and recruitment rates (i.e. relatively constant over the last few years). Hordyk et al. (2016) showed that mortality rates derived from the GTG-LBSPR model are reasonably robust to moderate levels of recruitment variation. In the case of an extreme recruitment event, we would have expected average lengths to decrease dramatically for a few years followed by a quick upward rebound before a return to the long-term equilibrium. In the case of a long-term increasing trend in fishing mortality, we would have expected a slow, constant decline in average length. For the most part, we did not observe such patterns in average length over time in our study and this suggests that temporal fluctuations in recruitment or fishing mortality were not significant enough to affect our length-based mortality estimates.

A second key assumption was that size composition, abundance, and catch data were representative of the true fish populations around the island of Guam. For the most part, the general agreement between diver, biosampling, and creel survey size structures supports this assumption. One clear exception was the surgeonfish *Naso unicornis* which showed a drastic shift in size structure from 2012 to 2014, followed by a return to the original pattern in 2015-2016. As explained in the Species Reports section, this was likely related to the closure of a boat ramp on the east side which shifted co-operative fishermen fishing effort to deeper areas off Apra Harbor where larger fish were caught, thus violating this assumption (M. Duenas and E. Cruz, personal comm.). The closure of that fishing area around 2015 likely explains the return to the original size structure for that species.

Furthermore, there was a lack of fishery-dependent or -independent data from the large offshore banks south of the island (Figure 1). This prevented us from including the fish population around these banks in the current analyses, but the results would only differ if the fish populations around the banks differed in terms of size structure and density. These banks comprised 15,000 ha of shallow water habitat (depth < 200 m; 44% of reef habitat in the region, Table 2). It is not entirely clear to what level the fish populations around Guam Island are connected to these offshore banks, but they are likely connected to some degree given their relatively close proximity. For example, a recent genetic parentage analyses of two coral reef fish species in Australia found parent-offspring pairs at distances up to 250 km, with a median dispersal distance of 110 km and 190 km (Williamson et al., 2016). Another recent study showed a mean dispersal of 37 km between parent-offspring for a butterflyfish in the Philippines (Abesamis et al., 2017). As shown in Table 2, the closest bank, Galvez, is only about 20 km from Guam and the other banks are separated from one another by even shorter distances. Furthermore, a recent study of passive pelagic particle connectivity in the Mariana Archipelago, based on pelagic larval durations between 10 and 100 days, showed potential connections among southern islands, although the dominant surface current is westward (North Equatorial Current; (Kendall and Poti, 2014; Kendall and Poti, 2015). Population connectivity within the Guam region is still an open question and further research is required to answer this question.

Regarding the data available for Guam Island, both the diver surveys and creel data sets had strengths and weaknesses. The scuba divers did not reach depths beyond 30 m due to safety and time constraints, thus likely underestimating total population abundance and biomass for species with depth ranges extending beyond this depth. However, diver surveys were able to sample remote and exposed areas of Guam that are visited less frequently by fishers. This includes the marine protected areas (MPAs), which comprise about 15% of the reef habitat around Guam. The size composition and abundance data for the visual diver survey data set was thus more representative of shallower, nearshore (< 30 m deep) communities but encompassed the entire nearshore waters around Guam. On the other hand, size composition data from the creel surveys likely included some information on deeper fish communities but were less likely to be representative of inaccessible coastlines and theoretically excluded MPAs. Despite these potential biases, the size composition information from these two disparate data sets were similar suggesting that the length data used in the current report were reasonably representative of the current fish population size structures. It is also important to note that the population abundance estimates from the diver surveys used for select species assumed a catchability coefficient equal to the area of a single survey divided by the total hard-bottom habitat area above 30 m. In other words, we did not assume any detectability bias which could have an impact of overestimating population biomass estimates for more mobile species (jacks, snappers, larger parrotfishes) or an opposite bias of underestimating population biomass estimates for more cryptic species.

The total catch estimates used in this report for select species came from the shore- and boat-based creel surveys. This creel survey program is one of the best available in U.S. Pacific islands and generated what appeared to be realistic catch estimates when placed in relation to diver survey biomass. Most of the biomass estimates derived from the catch data were within 15% to 60% of the diver survey-estimated biomass which is reasonable given the uncertainty involved with this type of data. However, the diver survey biomass was on average much higher than the catch-derived biomass for species predominantly caught through spear fishing (i.e. parrotfishes, with the notable exception of *Scarus altipinnis*). This suggests some systematic underestimation of spear fishing catch by the creel survey. This was also evident when comparing the effort-expanded total catch estimate from the creel surveys to the un-expanded reported landings from the biosampling program. For example, parrotfish biosampling catches from the Guam Fishermen cooperative (mainly boat-based spear fishing) average about 1,500 kg per year which is almost equivalent to the total catch estimate from the creel survey program (2,000 kg per year). For many species, the creel survey catch estimates decrease after 2004 and this could be related to staff turnover and/or difficulty in obtaining catch interviews with spear fishers around that time. Given these issues and the higher variability associated with the catch-derived biomass estimates, diver-survey derived C_{30} and OFL estimation were likely more reliable for most species (but see details for each species in Species Reports). Some exceptions could be mobile predators or species with larger depth range, where the catch-derived biomass estimate may be more representative.

A third important assumption was that the life history parameters used in our analyses were adequate. For 5 of the 12 species, we had extensive local studies providing estimates of growth, maturity, and longevity, mainly from the work of B. Taylor and colleagues (see full citations in References section). We had to use life history parameters from another Pacific area for a single species and it is possible that these values were inappropriate for Guam given the different geography and environmental conditions (Choat an Robertson, 2002; Gust et al., 2002, although see Donovan et al., 2013). Further, for species with no published life history parameters, we used the approach presented in Nadon and Ault (2016) to generate estimates. This approach used a local estimate of maximum length (L_{99}) which may be negatively biased in heavily fished stocks and thus result in biased life history parameters. This is less of an issue in the current report given that length data in the lightly fished Northern Mariana Islands were often available to generate L_{99} estimates. Finally, we estimated natural mortality (M) parameters using a longevity-based model which assumed a reasonable knowledge of cohort survivorship at oldest recorded age (Hewitt and Hoenig, 2005; Then et al., 2015). A study conducted in a pristine region of the Hawaiian Islands used independent estimates of M to evaluate this parameter at 0.04 for coral reef fishes (Nadon et al. 2015). This is the value we used in the current study.

Future directions

The continued and new collection of several data sources will be useful for future stock assessments. Continued monitoring of fisheries, via creel surveys or other methods, would provide useful information on catch, effort, gear, size, and area. The continuation of fisheries-independent diver surveys would also provide useful information on fish sizes by area. These two data sets would eventually have a time-series of sufficient length to run more advanced, non-equilibrium models (e.g. stock synthesis, LIME; (Rudd and Thorson, 2018). Deep-water surveys using underwater cameras have provided useful information on depth distributions, and their continued deployments could hopefully also provide abundance and size composition data for a section of the reef fish populations that is not accessible by diver survey (deeper than 30 m) and may be different. These camera system deployments are also generating deep-water habitat information and could be deployed on the offshore banks. More studies on growth, maturity, and longevity of fish in the U.S. Pacific would lead to more appropriate and local life history parameters and result in less reliance on the meta-analytical approach to obtain these parameters. Finally, studies addressing population connectivity in the Guam region could help determine the impact of not including offshore banks in future stock assessments; however, more data on fish from the offshore banks would be required to consider them in any stock assessment.

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Tables and figures

Table 1. List of input and output parameters.

Parameter	Definition
a_λ	Oldest recorded age (i.e. longevity)
a_0	Theoretical age at which length equals zero from the von Bertalanffy growth curve
B	Total population biomass
C_{30}	Catch limit resulting in SPR = 0.3
F	Instantaneous annual fishing mortality rate
F_{30}	Instantaneous annual fishing mortality rate resulting in SPR = 0.3
K	Brody growth coefficient of the von Bertalanffy growth curve
L_{bar} or $\overline{L}$	Average length in the exploited size range of a stock
Lc_{30}	Size-at-first-capture limit resulting in SPR = 0.3, assuming knife-edge selectivity
L_{inf} or L_∞	Expected length at infinite age from the von Bertalanffy growth curve
$CV\ L_{\mathrm{inf}}$	Coefficient of variation of individual fish L_{inf} (metric of variability in growth)
L_{mat}	Length at which 50% of females reach maturity
L_{99}	Longest length in a growth study or 99th percentile of lengths in a population survey
L_{S50}	Length at 50% selectivity
L_{S95}	Length at 95% selectivity
M	Instantaneous annual natural mortality rate
OFL	Overfishing limit, defined as the median of the C_{30} distribution
S	Survivorship at maximum recorded age
SPR	Spawning potential ratio
Z	Instantaneous annual total mortality rate

Table 2. Information summary of Guam Island and the nearby 5 main offshore banks. Reef area is up to 200-m depth and includes soft bottom habitat. Source: Pacific Islands Benthic Habitat Mapping Center and T. Acoba.

Zone	Human population (2017)	Reef area (ha)	Percent of total reef in region	Human # per reef area (#/ha)	Distance to nearest reef (km)
Guam Island total	**174,000**	**19,458**	**56**	**8.9**	**20**
West sector	-	11,869	34	-	-
East sector	-	7,589	22	-	-
Banks total	**0**	**15,086**	**44**	**0**	**20**
11-mile Bank	-	153	< 1	-	20
Galvez Bank	-	4,079	12	-	2
South Galvez Bank	-	1,238	4	-	2
Santa Rosa Bank	-	3,686	11	-	3
SW Santa Rosa Bank	-	5,930	17	-	3

Table 3. Area of sea floor in the Guam area by depth zones, in territorial and federal waters (both soft and hard bottom). Depth range extends to 200 m which is close to the maximum recorded depths for the species included in this report. This stock assessment was conducted for Guam Island data only, given a lack of data from the banks. Source: Pacific Islands Benthic Habitat Mapping Center and T. Acoba.

Depth (m)		Hectares of sea floor			Cumulative percent in fed. waters for Guam Isl. and banks
Min	Max	Guam Island (all territorial waters)	Banks (all federal waters)	Total	
0	30	9,439	2,785	12,224	23
30	40	10,853	4,234	15,087	28
40	50	12,041	5,051	17,092	30
50	60	12,920	5,758	18,678	31
60	70	13,785	6,387	20,171	32
70	80	14,556	7,010	21,566	33
80	90	15,207	7,610	22,817	33
90	100	15,789	8,206	23,995	34
100	150	17,772	11,462	29,234	39
150	200	19,458	15,086	34,544	44

Table 4. Coefficient of variation of 4 life history parameters at various sample sizes. L_{inf}, K, and a_{max} from Kritzer et al. (2001), and L_{mat} from Nadon (unpubl.).

Sample size	CV $L_{inf\ error}$*	CV K	CV L_{mat}	CV a_{max}
25	0.167	0.568	0.070	0.190
50	0.111	0.299	0.048	0.168
75	0.078	0.250	0.036	0.147
100	0.060	0.222	0.031	0.129
125	0.050	0.190	0.027	0.118
150	0.045	0.172	0.025	0.113
200	0.040	0.142	0.021	0.092
300	0.030	0.120	0.017	0.074
500	0.021	0.095	0.013	0.056

* This is the CV of the standard deviation of the mean L_{inf} parameter. This is different from the CV L_{inf} parameter specified in the Species Report section, which pertains to growth variability for individual fish.

Table 5. Species summary of selected stock metrics. Bold text indicates stocks considered under overfishing condition according to the *SPR* = 30% biological reference point, and italic text indicates stocks near this limit. Overfishing is defined as $F/F_{30} > 1$.

Species	LH source[a]	Main gear	Max depth (m)	Percent sea floor in fed. Waters[b]	F/F_{30}	Prob. of overfish.	*SPR*	Pop. from catch (kg)	Pop. from divers (kg)	OFL from catch (kg)	OFL From Diver (kg)
Acanthuridae (surgeonfish)											
Naso unicornis	L	Spear	120	36	0.9	37	0.34	-	-		
Carangidae (jack)											
Carangoides orthogrammus	S	Spear	235	44	0.8	40	0.38	-	-		
Caranx melampygus	S	Line	230	44	**1.9**	**72**	**0.15**	-	-		
Lethrinidae (emperor)											
Lethrinus olivaceus	S	Line	100	34	**1.6**	**75**	**0.18**	-	-		
Lethrinus xanthochilus	S	Line	100	34	1.0	49	0.31	-	-		
Monotaxis grandoculis	S	Line	101	34	1.0	48	0.31	1,330	1,600	220	265
Lutjanidae (snapper)											
Lutjanus fulvus	S	Line	128	37	**1.6**	**66**	**0.19**	1,960	2,671	321	432
Lutjanus gibbus	E	Line	150	39	0.4	5	0.53	3,020	560	533	111
Scaridae (parrotfish)											
Chlorurus microrhinos	L	Spear	39	28	0.8	36	0.36	1,350	3,617	324	972
Hipposcarus longiceps	L	Spear	35	28	0.5	9	0.52	4,130	5,051	1,060	1,420
Scarus altipinnis	L	Spear	30	23	0.3	5	0.60	-	-		
Scarus rubroviolaceus	L	Spear	68	32	**1.4**	**65**	**0.21**	-	-		

[a] L=local, E=external, S=stepwise approach
[b] All sea floor habitat in federal water is on the offshore banks, which were not included in this stock assessment. All territorial water is located around Guam Island.

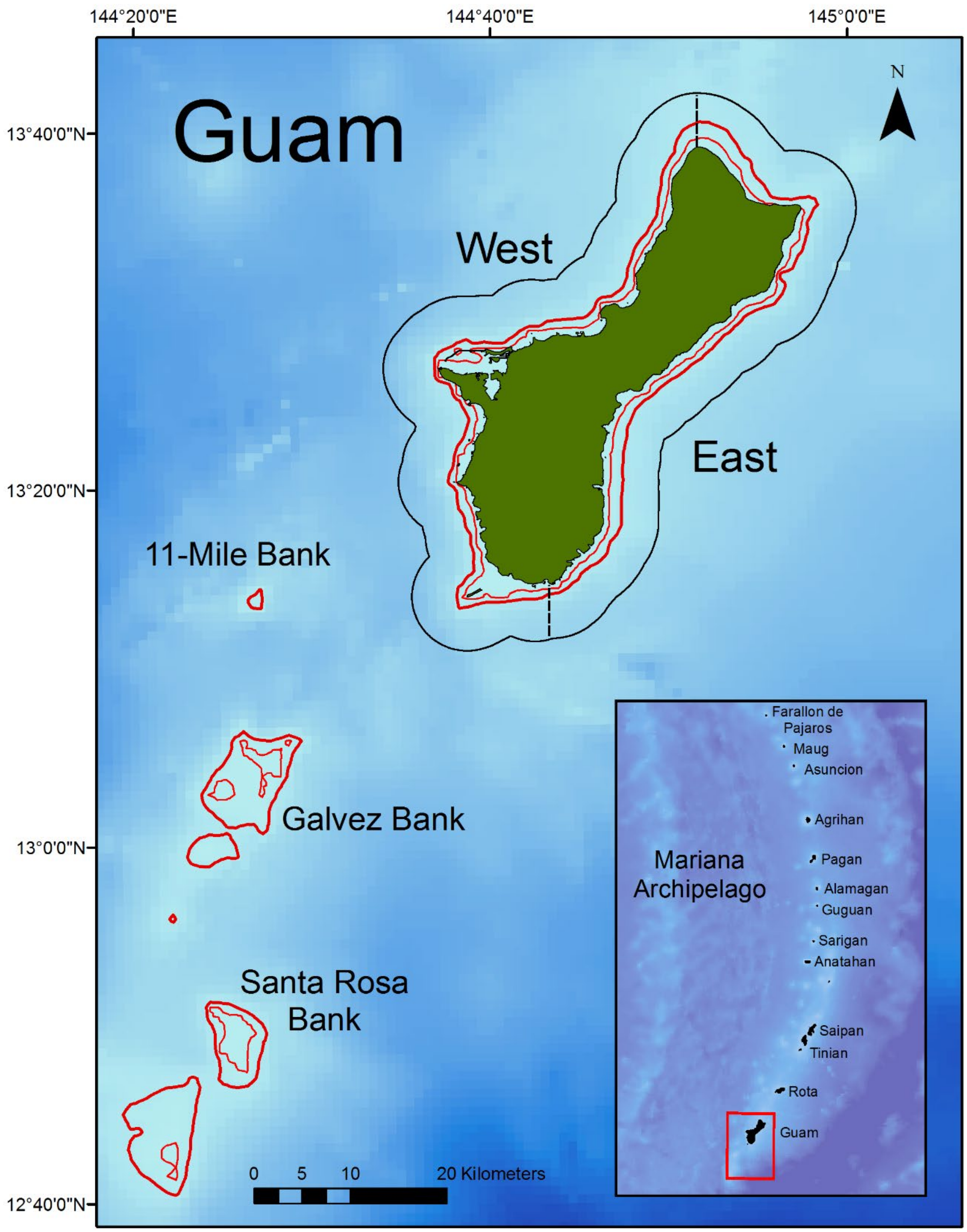
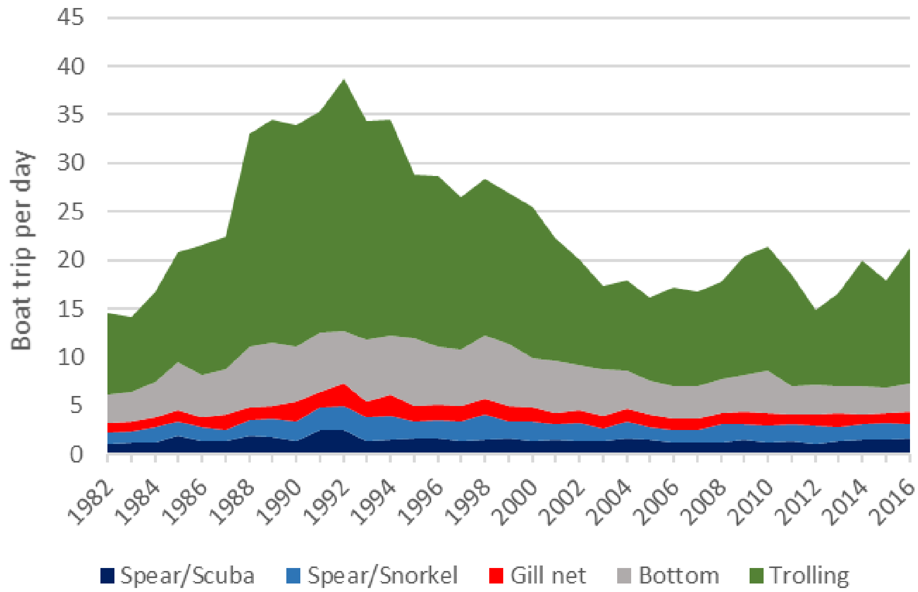


Figure 1. Map of the Guam area with 30-m (inner thin red line) and 200-m (outer thick red line) depth contours. Solid black line is the 3 nautical mile territorial water limit. The East and West sectors used in the analyses are demarcated. Due to a lack of data, the banks were excluded from this stock assessment. Inset: map of the Mariana Archipelago. Data source: T. Acoba and Pacific Islands Benthic Habitat Mapping Center.



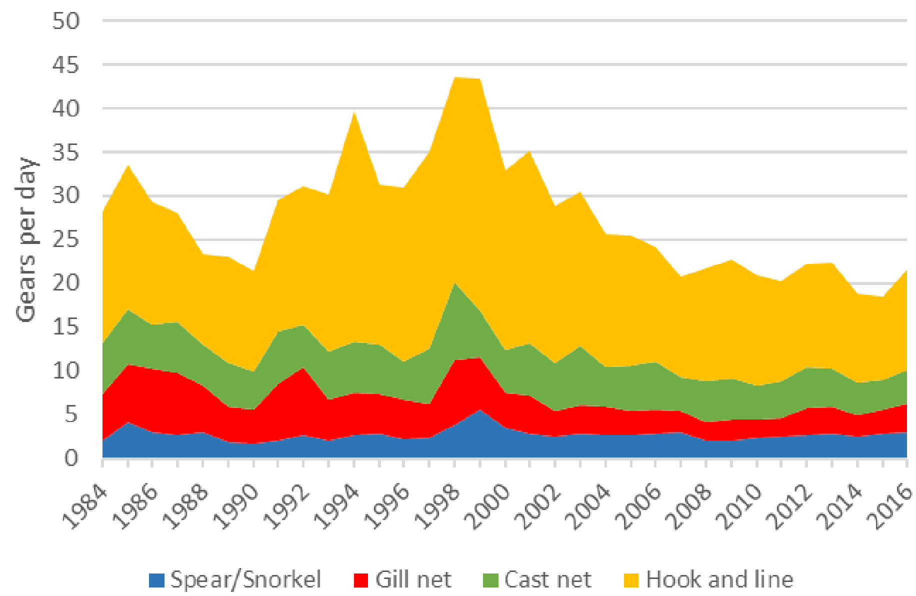


Figure 2. Fishing effort by fishing gear for both boat-based (top) and shore-based (bottom) activities. Data obtained from expanded creel survey fishery effort data.

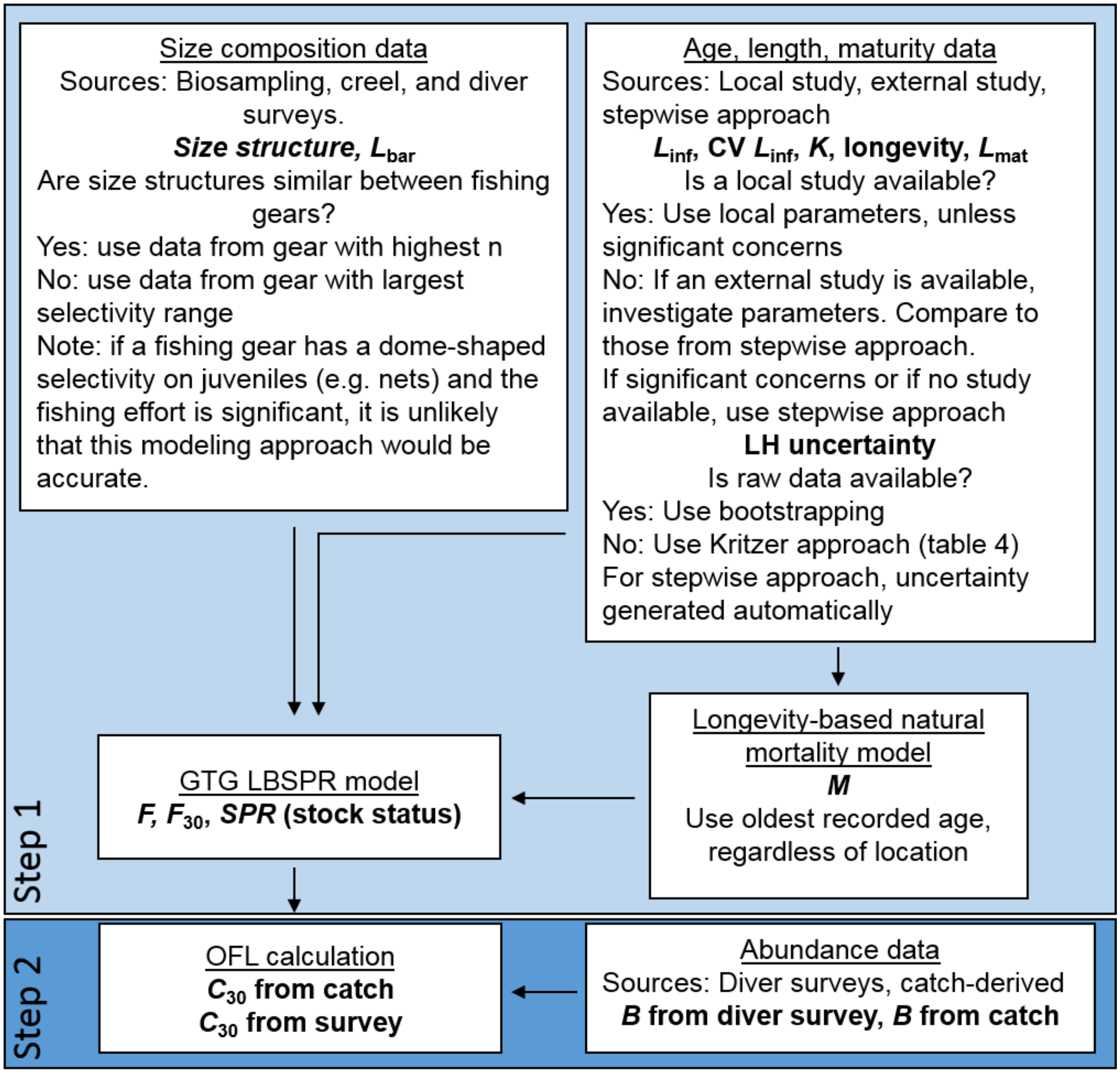


Figure 3. Overall approach and decision points used to calculate stock status using SPR and, for some species, calculate overfishing limits (*OFL*).

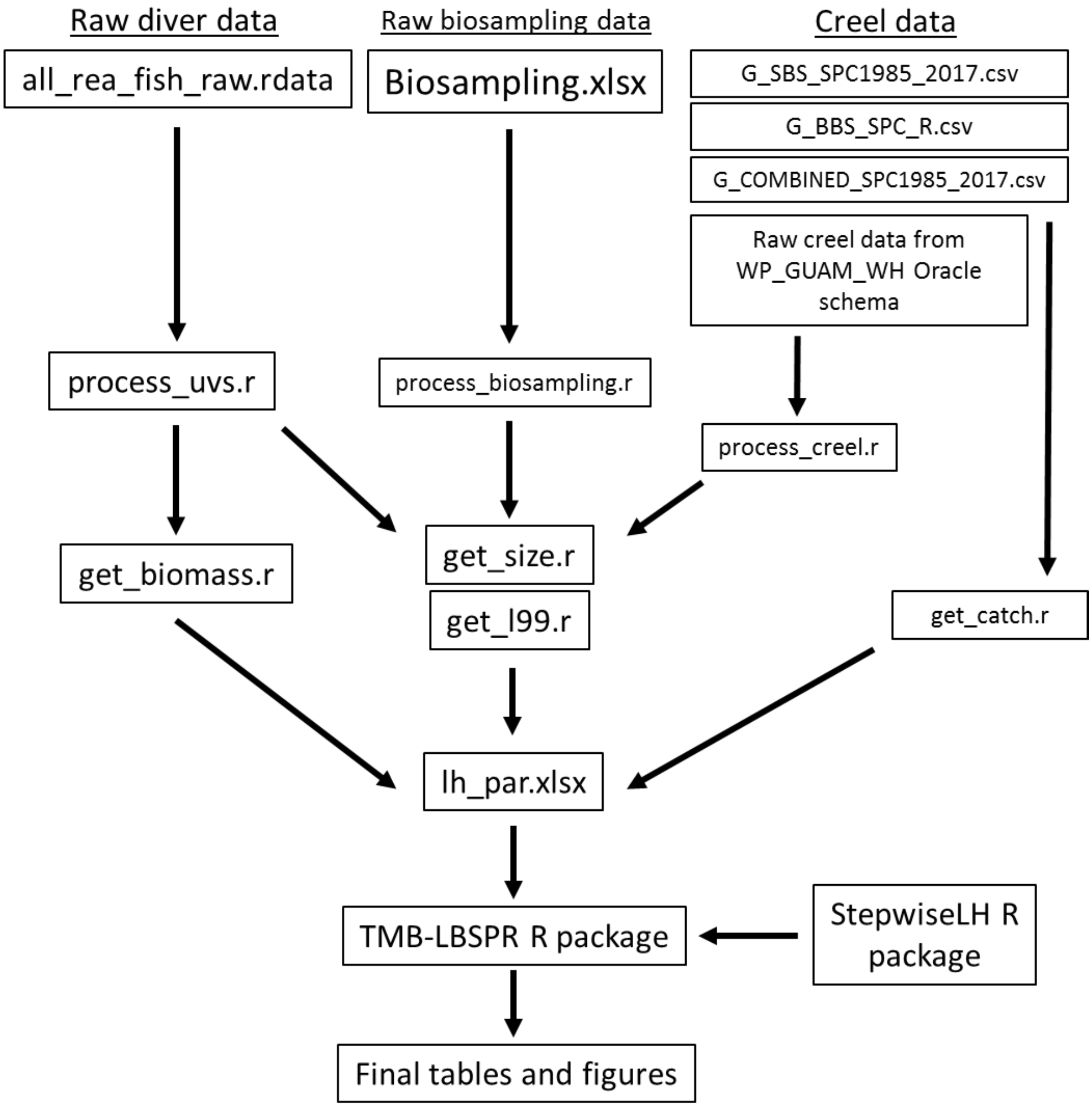


Figure 4. Analysis workflow showing inputted data sources and R scripts used to process the raw data and generate final tables and figures for the report.

Species Reports

Naso unicornis

Bluespine unicornfish, *tataga'*
Acanthuridae (surgeonfishes)

Life history and other input parameters

Parameter	Value	SD	Unit	n	Source
L_{inf}	493	17	mm	247	Mean and SD: Taylor et al. (2014)
K	0.22	0.029	yr^{-1}		
a_0	-0.48	-	yr		
L_{mat}	292	25	mm	98	Mean and SD: Taylor et al. (2014)
CV L_{inf}	0.085	0.001	-	-	Mean and SD: Taylor et al. (2014)
Longevity	23	1.9	yr	534	Mean and SD: Taylor et al. (2014)
LW-alpha	5.38e-5	-	-	-	Taylor et al. (2014)
LW-beta	2.829				
Max. depth	120	-	m	-	Pyle et al. (2016)

Stock status and other output parameters

Parameter	Median	SD	Unit
M	0.14	0.01	yr^{-1}
F	0.16	0.07	yr^{-1}
L_{S50}	274	8	mm
L_{S95}	348	16	mm
F_{30}	0.18	0.02	yr^{-1}
F/F_{30}	0.90	0.39	-
SPR	0.34	0.13	-
SPR < 0.30 iterations	37	-	%

Parameter	Median	SD	Unit
B from catch	-	-	kg
B from divers	-	-	kg
Boat-based catch	-	-	kg
Shore-based catch	-	-	kg
Total catch	-	-	kg
C_{30} from catch	-	-	kg
C_{30} from divers	-	-	kg
Lc_{30}	250	-	mm

General comments

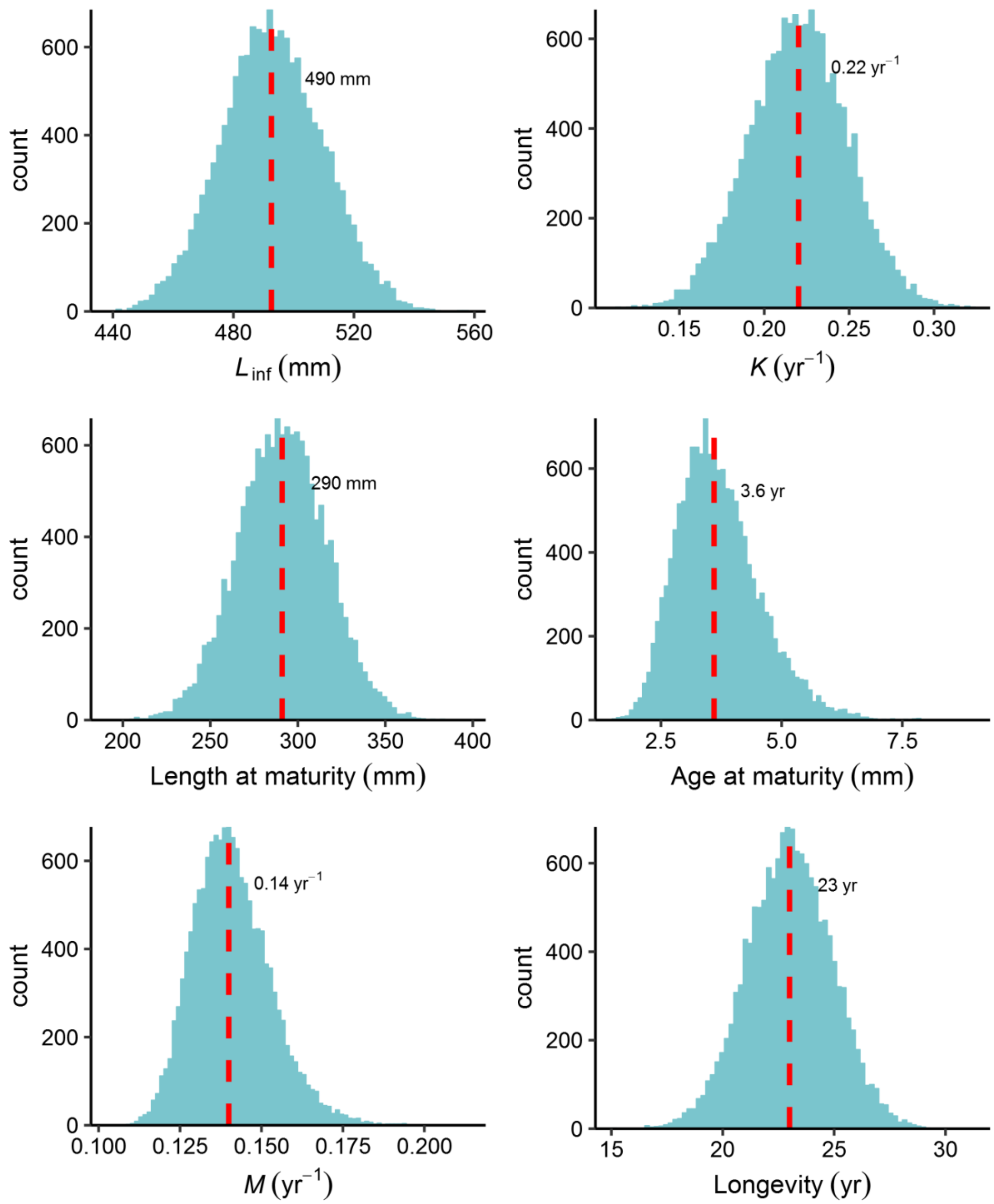
The total catch for this species has been fairly variable, with yields as high as 25,000 kg occurring before 2000 followed by a decline to about 4,000 kg in recent years. From 1985 to 2000, this species was caught by a mix of spear and line fishing but is now mostly caught through spear fishing. A few years between 2005 and 2010 show some peak catches in net fishing landings, but this species is not commonly caught with this gear. The biosampling size structure data showed a distinct shift towards larger individuals in 2012 – 2014 before reverting back to the old pattern in 2015-2016. According to local fishermen and scientists, the closure of the Ylig boat ramp in 2012 shifted some of the fishing effort to areas outside Apra Harbor where larger sized *N. unicornis* were typically caught before this area was closed to fishing with the expansion of the safety zone around that harbor. Due to concerns with the impact of this shift on the length-based model, we only used the last 2 years of spear fishing length data for this species which are more representative of the *N. unicornis* population as a whole.

The catch in recent years has been relatively stable although population abundance appears to be slightly declining. Interestingly, average length seems to have remained relatively stable throughout the years, despite the drastic changes in estimated total catch.

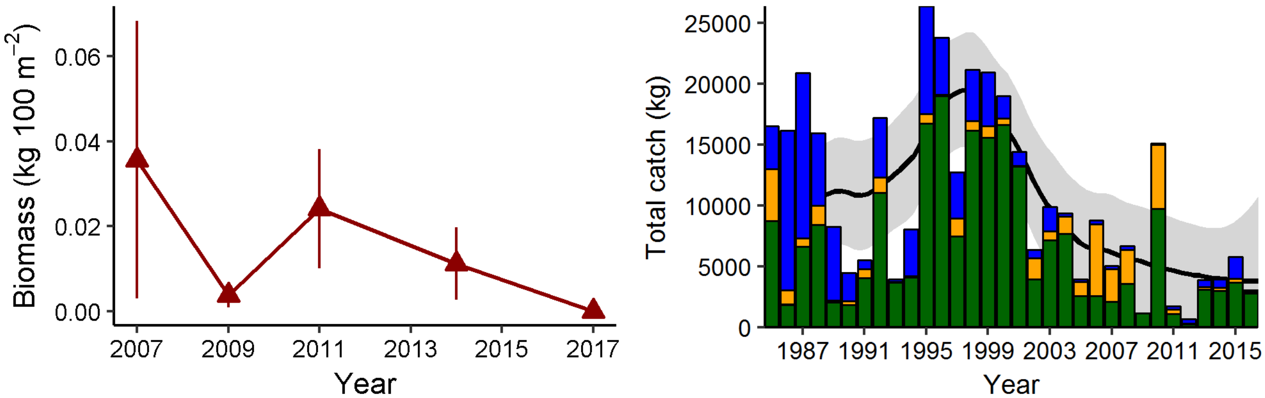
The life history parameters for this species come from a reliable local source with a high sample size. The longevity value recorded around Guam (23 years) is much lower than the one recorded in Hawaii (50 years; Andrews, 2016). The lower longevity around Guam could be related to higher sea temperature (B. Taylor, pers. comm.). We selected longevity from the Guam study given an upcoming study which appears to confirm the strong relationship between temperature and longevity for this species (B. Taylor, pers. comm.). A sensitivity run with the Guam max age of 50 years generated the following results: F_{30}: 0.10, F: 0.24, and SPR: 0.12. The higher longevity increased the F estimate and consequently lowered the SPR below the overfishing limit.

C_{30} and OFL estimates for this species were deemed too uncertain and are not presented here.

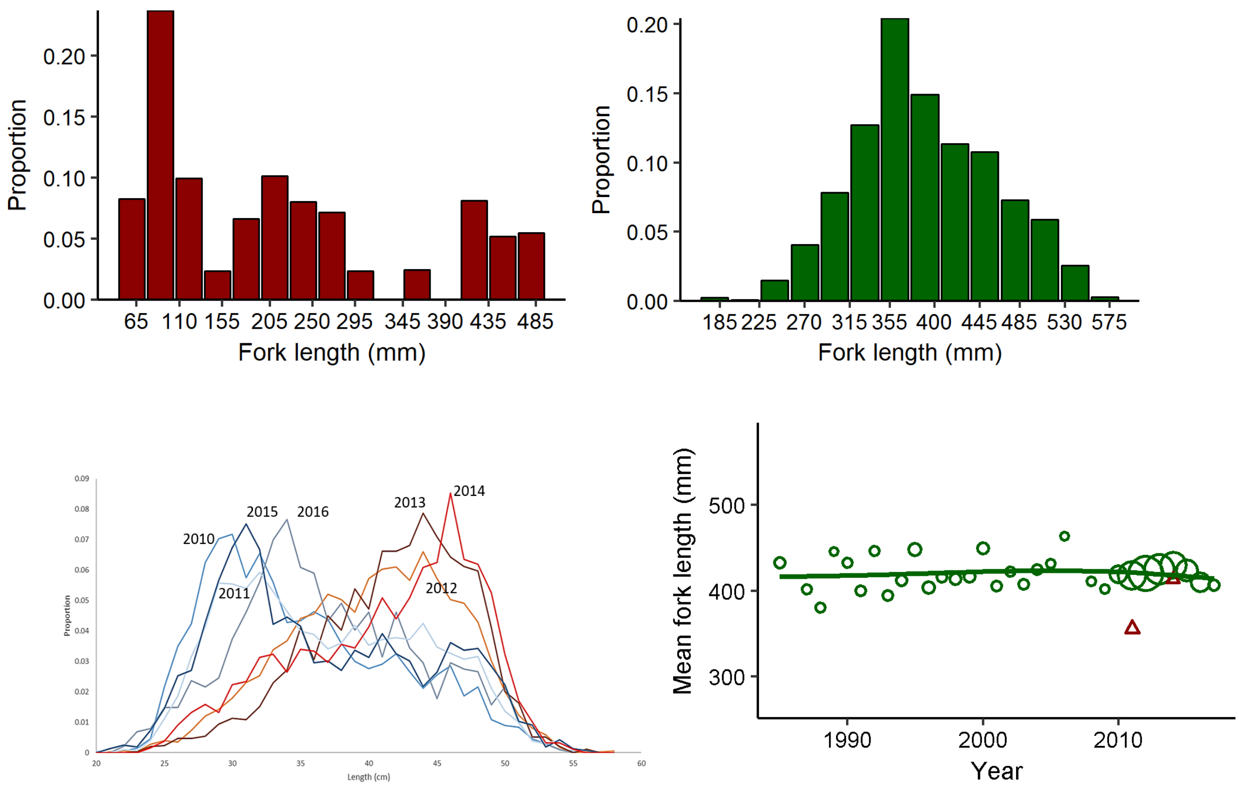
Naso unicornis



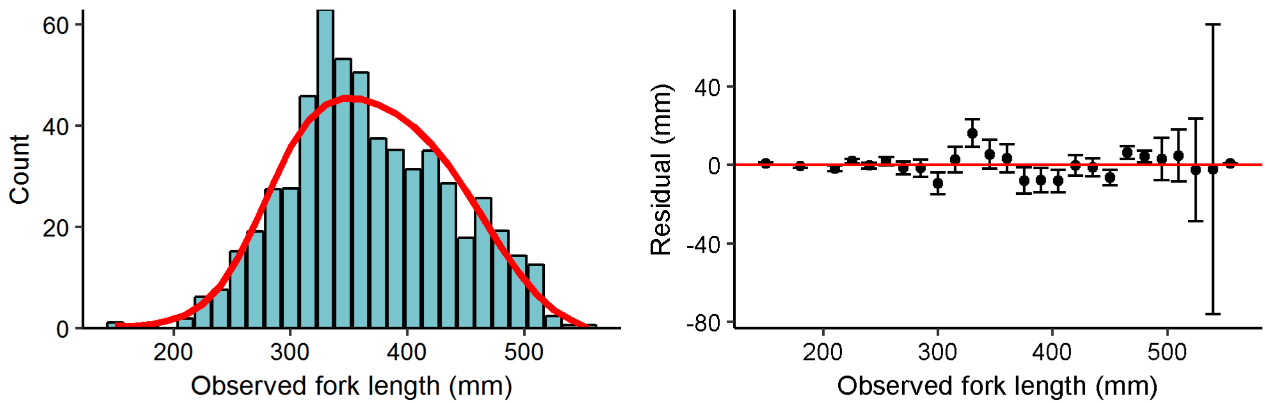
Life history parameter distributions. Red line indicates median value.



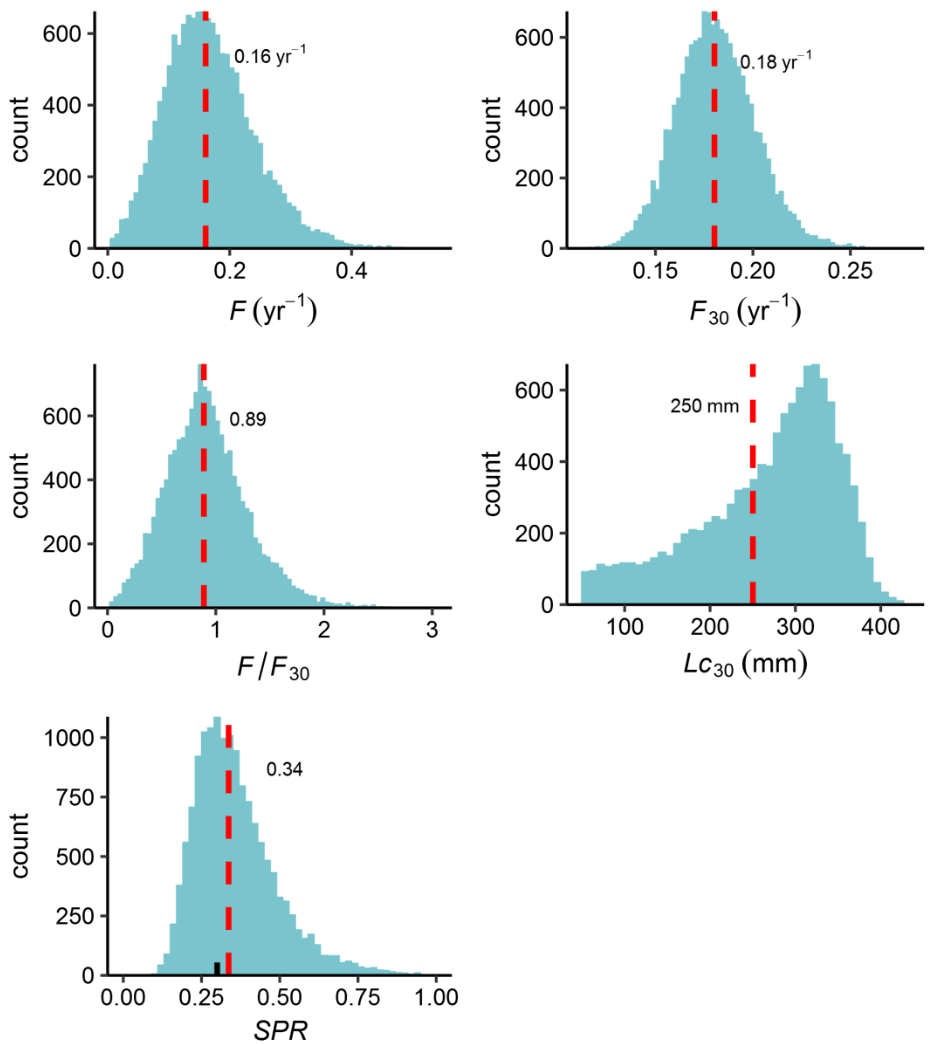
Abundance index from diver surveys (left; red triangles, ±SE) and total catch time series (right) from hook-and-line (blue), spear (green), and net (orange) fishing gears. Black line shows loess fit for total catch with 95% confidence interval (gray area).



Size structure from diver surveys (top left) and from the catch by fishing gear (top right; spear gear). Average length time series (bottom right; spear gear: green circles, diver surveys: red upright triangles). Size of icons is proportional to sample size. Bottom left graph shows the annual variability in size structure between 2010 and 2016 (see text for details).



LBSPR model fit (left) and residual (right).



Stock status parameter distributions (*SPR*: small bar shows 0.30 level). Red line indicates median value.

Probability of overfishing at various minimum sizes.

Overfishing probability	Lc_{30} (mm)	Overfishing probability	Lc_{30} (mm)
0.05	366	0.28	311
0.06	363	0.29	309
0.07	360	0.30	307
0.08	356	0.31	305
0.09	353	0.32	302
0.10	350	0.33	300
0.11	347	0.34	297
0.12	345	0.35	295
0.13	342	0.36	293
0.14	340	0.37	291
0.15	338	0.38	289
0.16	335	0.39	286
0.17	333	0.40	283
0.18	331	0.41	281
0.19	329	0.42	278
0.20	327	0.43	275
0.21	325	0.44	271
0.22	323	0.45	268
0.23	321	0.46	265
0.24	319	0.47	261
0.25	317	0.48	258
0.26	315	0.49	254
0.27	313	0.50	250

Carangoides orthogrammus

Island jack, *tarakitu*
Carangidae (jacks)

Life history and other input parameters

Parameter	Value	SD	Unit	n	Source
L_{inf}	576	73	mm	-	Mean and SD: Nadon and Ault (2016) L99 from creel: 505 (36) mm
K	0.30	0.11	yr^{-1}		
a_0	-0.8	-	yr		
L_{mat}	337	57	mm	-	Mean and SD: Nadon and Ault (2016)
CV L_{inf}	0.09	0.01	-	-	Mean and SD: Estimated.
Longevity	9.1	2.9	yr	-	Mean and SD: Nadon and Ault (2016)
LW-alpha	2.34e-5	-	-	-	Kamikawa (2015)
LW-beta	2.98				
Max. depth	235	-	m	-	BotCam surveys in Hawaii

Stock status and other output parameters

Parameter	Median	SD	Unit
M	0.36	0.11	yr^{-1}
F	0.21	0.27	yr^{-1}
L_{S50}	197	20	mm
L_{S95}	280	53	mm
F_{30}	0.26	0.08	yr^{-1}
F/F_{30}	0.80	1.1	-
SPR	0.38	0.27	-
SPR < 0.30 iterations	40	-	%

Parameter	Median	SD	Unit
B from catch	-	-	kg
B from divers	-	-	kg
Boat-based catch	-	-	kg
Shore-based catch	-	-	kg
Total catch	-	-	kg
C_{30} from catch	-	-	kg
C_{30} from divers	-	-	kg
Lc_{30}	0	-	mm

General comments

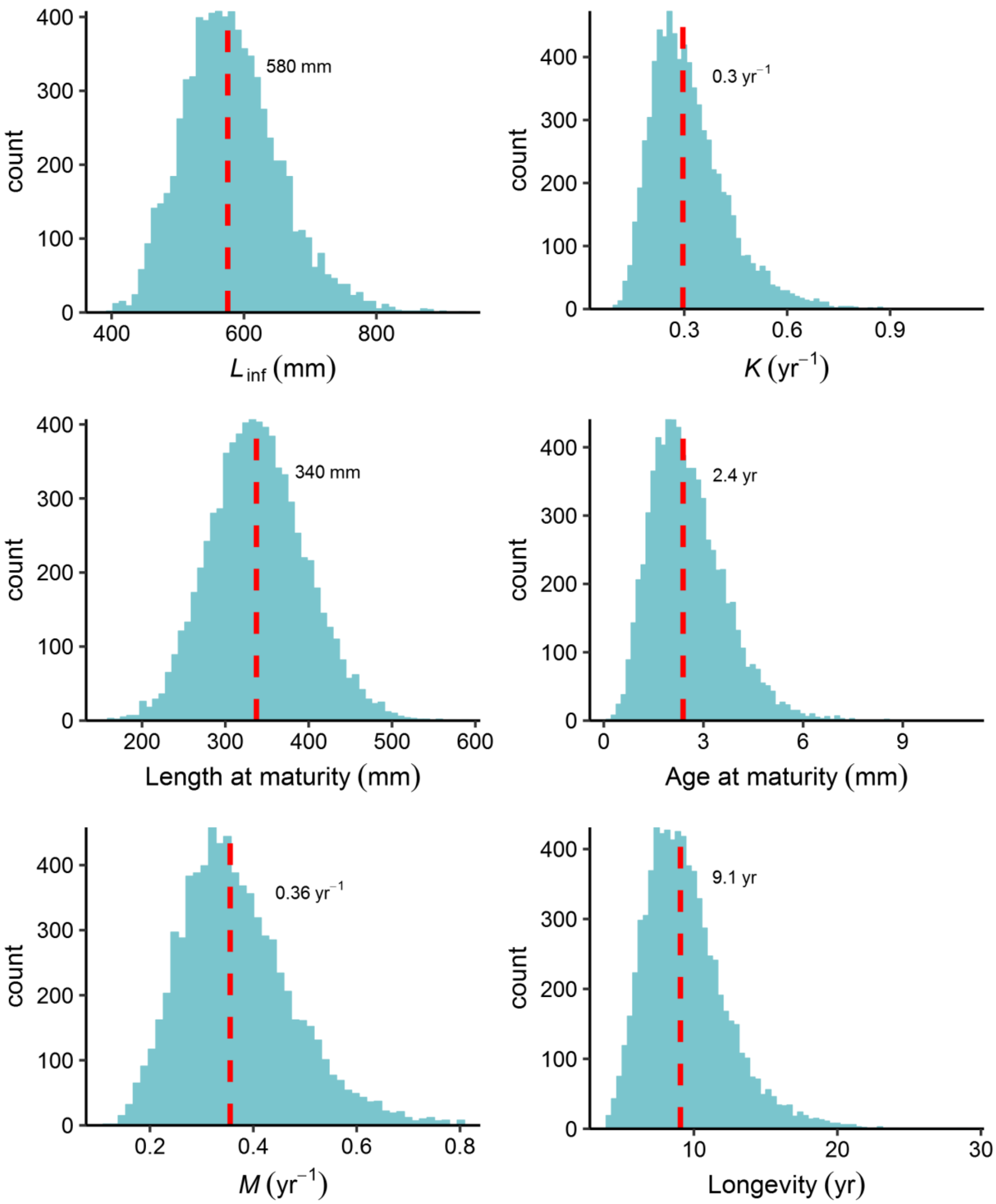
This species is not often recorded on diver surveys, especially around Guam. Therefore only fishery-dependent data (creel surveys and biosampling) were used for this assessment. This species is almost entirely caught by boat-based line fishing with occasional peaks in net fishing likely related to recruitment events. Length data from line fishing was used in the LBSPR analyses. Due to the low length observation sample size, length observations going back to 2006 were used for this species (vs. the usual 2014-2017 range). This seems appropriate given that average lengths were mostly stable during that period at around 400 mm.

Aside from the occasional net fishing peaks, total catch for this species was relatively stable between 1985 and 2005 at around 1,000 kg, before declining to around 300 kg in recent years. There were two large peaks in total catch in 2003 (6,000 kg) and 2014 (3,000 kg) related to net fishing. Average lengths have been mostly stable since 1985 at around 400 mm.

There are currently no life history parameters available for this species. The parameters used in this assessment were obtained using the stepwise approach with an L_{99} value obtained from the creel survey (505 mm). There was an insufficient amount of diver observations to obtain a separate L_{99} estimate. As a side note, this species' L_{99} value from the northern Hawaiian Island was estimated at 685 mm (Nadon, 2017) which suggests that this species can grow even larger in other regions.

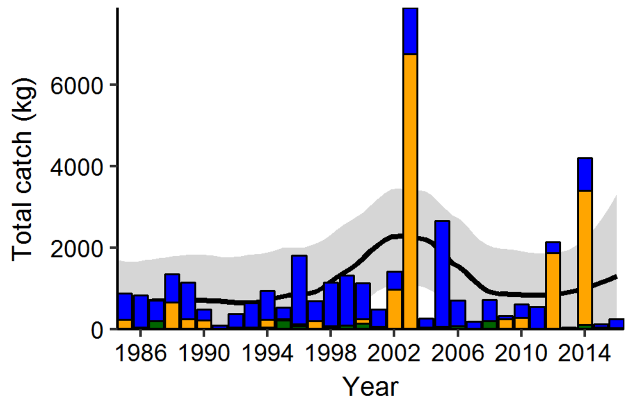
C_{30} and OFL estimates for this species were deemed too uncertain and are not presented here.

Carangoides orthogrammus

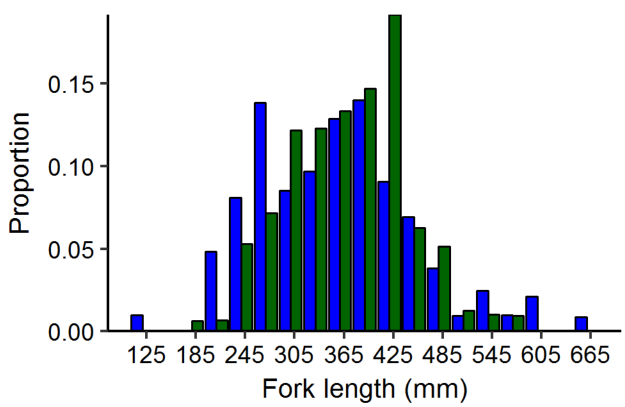


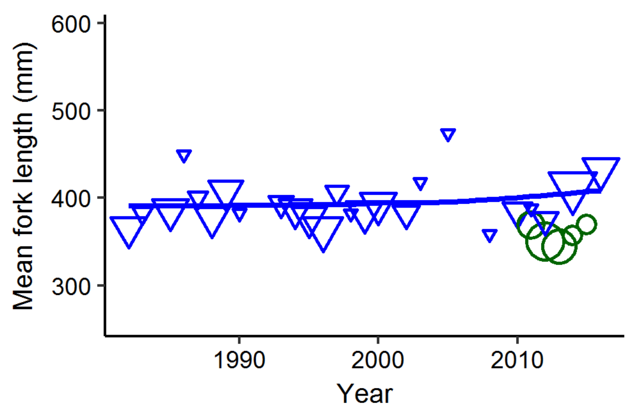
Life history parameter distributions. Red line indicates median value.

Carangoides orthogrammus



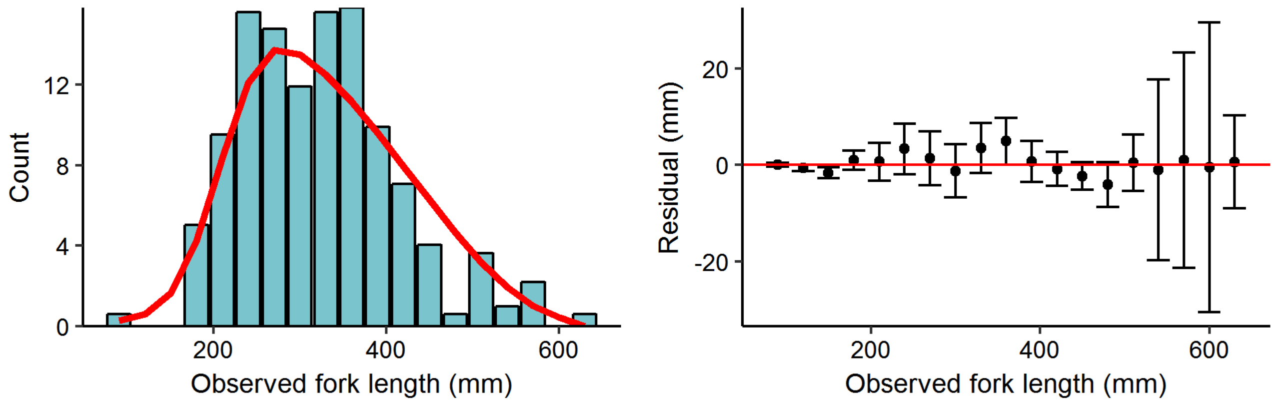
Total catch time series from hook-and-line (blue), spear (green), and net (orange) fishing gears. Black line shows loess fit for total catch with 95% confidence interval (gray area).



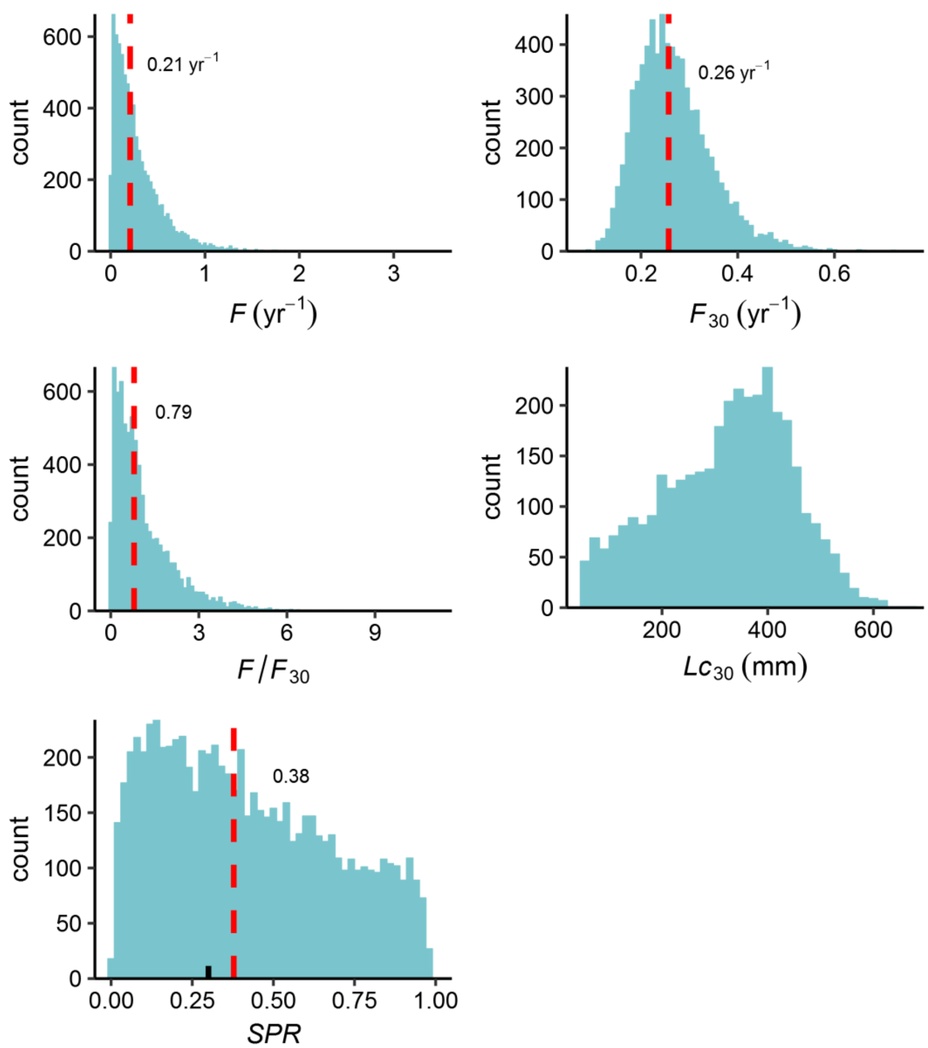


Size structure from fishing gears (left) (blue: hook-and-line, green: spear) and average length time series (right; hook-and-line gear: blue inverse triangles, spear: green circles). Size of icons is proportional to sample size.

Carangoides orthogrammus



LBSPR model fit (left) and residuals (right).



Stock status parameter distributions (*SPR*: small bar shows 0.30 level). Red line indicates median value.

Probability of overfishing at various minimum sizes.

Overfishing probability	Lc_{30} (mm)	Overfishing probability	Lc_{30} (mm)
0.05	465	0.28	309
0.06	455	0.29	300
0.07	445	0.30	292
0.08	437	0.31	284
0.09	430	0.32	276
0.10	422	0.33	266
0.11	416	0.34	257
0.12	409	0.35	249
0.13	404	0.36	237
0.14	398	0.37	226
0.15	393	0.38	214
0.16	387	0.39	203
0.17	382	0.40	191
0.18	376	0.41	177
0.19	370	0.42	162
0.20	364	0.43	143
0.21	357	0.44	126
0.22	351	0.45	106
0.23	345	0.46	87
0.24	338	0.47	68
0.25	331	0.48	0
0.26	325	0.49	0
0.27	317	0.50	0

Caranx melampygus

Bluefin trevally, *tarakitu*
Carangidae (jacks)

Life history and other input parameters

Parameter	Value	SD	Unit	n	Source
L_{inf}	688	97	mm	-	Mean and SD: Nadon and Ault (2016) L99 from North. Marianas: 650 (40) mm
K	0.25	0.10	yr^{-1}		
a_0	-0.8	-	yr		
L_{mat}	385	71	mm	-	Mean and SD: Nadon and Ault (2016)
CV L_{inf}	0.17	0.02	-	-	Mean and SD: Smith and Parrish (2002)
Longevity	9.4	3.2	yr	-	Mean and SD: Nadon and Ault (2016)
LW-alpha	2.56e-5	-	-	-	Kamikawa (2015)
LW-beta	2.95				
Max. depth	230	-	m	-	Pyle et al. (2016)

Stock status and other output parameters

Parameter	Median	SD	Unit
M	0.34	0.11	yr^{-1}
F	0.44	0.40	yr^{-1}
L_{S50}	235	7	mm
L_{S95}	280	13	mm
F_{30}	0.25	0.08	yr^{-1}
F/F_{30}	1.9	1.8	-
SPR	0.15	0.23	-
SPR < 0.30 iterations	72	-	%

Parameter	Median	SD	Unit
B from catch	-	-	kg
B from divers	-	-	kg
Boat-based catch	-	-	kg
Shore-based catch	-	-	kg
Total catch	-	-	kg
C_{30} from catch	-	-	kg
C_{30} from divers	-	-	kg
Lc_{30}	395	-	mm

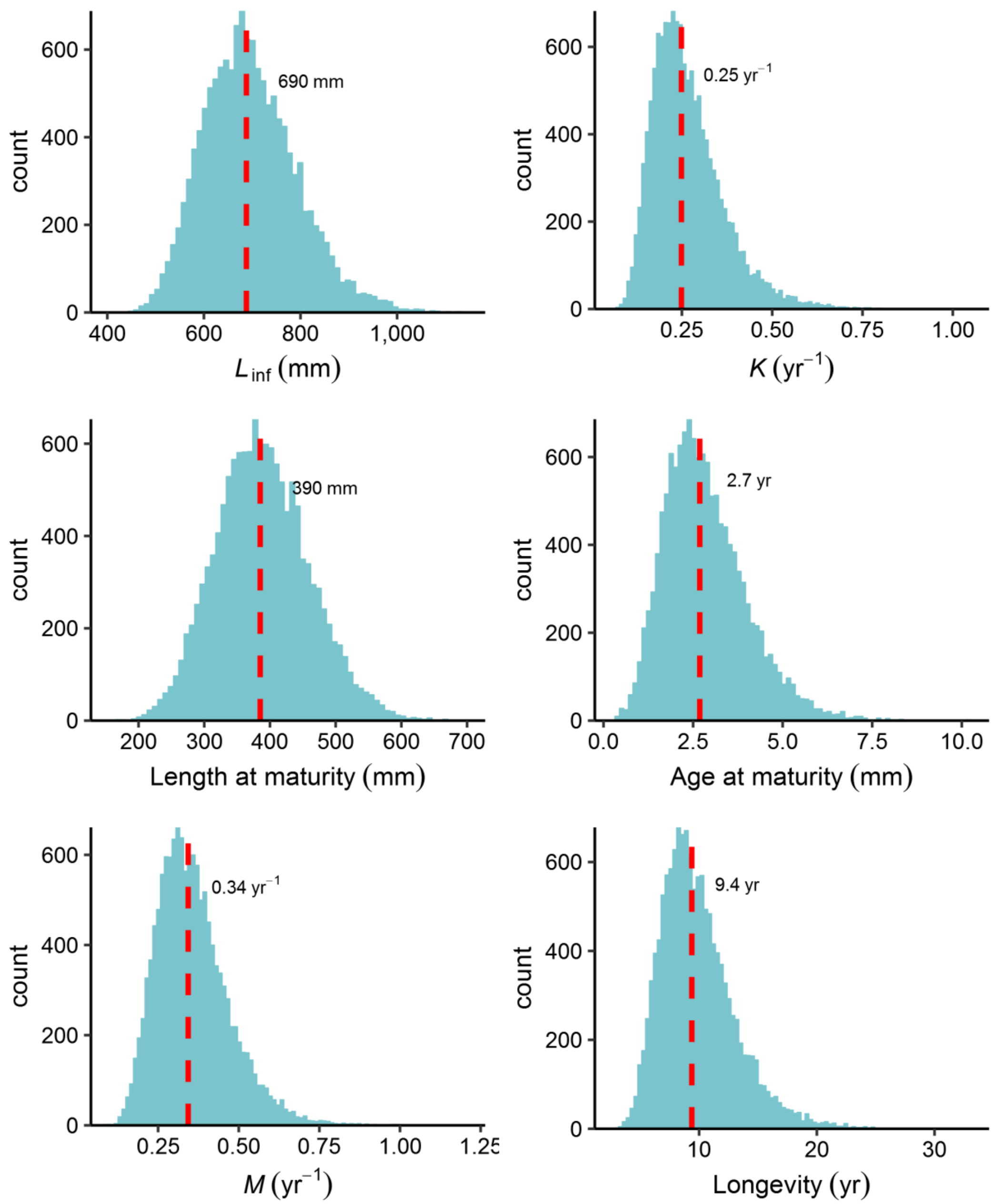
General comments

Total catch for this species has been fairly constant since 1985, oscillating between 1,000 kg and 5,000 kg per year, with an anomalous catch event in 2011 (~23,000 kg) and 2013 (~15,000 kg) which could be related to strong recruitment pulses. The predominant gear has been line fishing for almost every year in the catch time-series, with one extreme net fishing peak in 2011. Selectivity patterns were similar between line and spear fishing and the catch size structure was consistent with the diver observations as well. The spear fishing length data was used for the LBSPR analyses given this similarity and the higher observation numbers. Population abundance and average lengths have been stable since 2011 (although the line data average length is fairly variable).

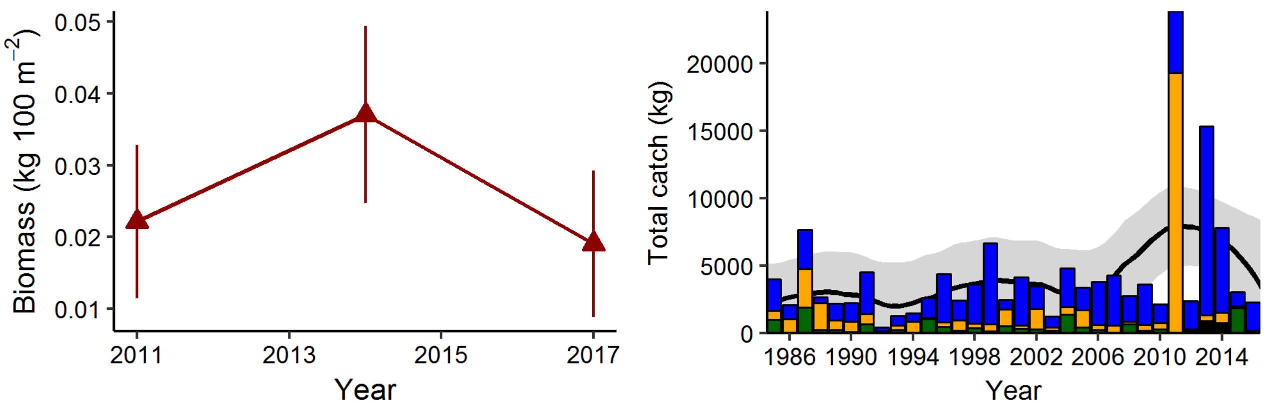
The life history parameters for this species were obtained from the stepwise approach. A pair of life history studies from Hawaii does exist but it has a low sample size (n=20). A sensitivity run using Smith and Parrish (2002) and Sudekum (1991) generated the following results: L_{inf}: 999 mm, K: 0.17, M: 0.46, F_{30}: 0.25, F: 0.66, and SPR: 0.08. These results show the stock status to be at an even lower level (higher F, lower SPR).

Note: there is high variability in shore-based catch related to a spike in line fishing catch in 2013 (see figure below). The average catch used in the analyses is strongly influenced by the 2013 reported total catch. The average catch in recent years, excluding this value, is closer to 3,000 kg.

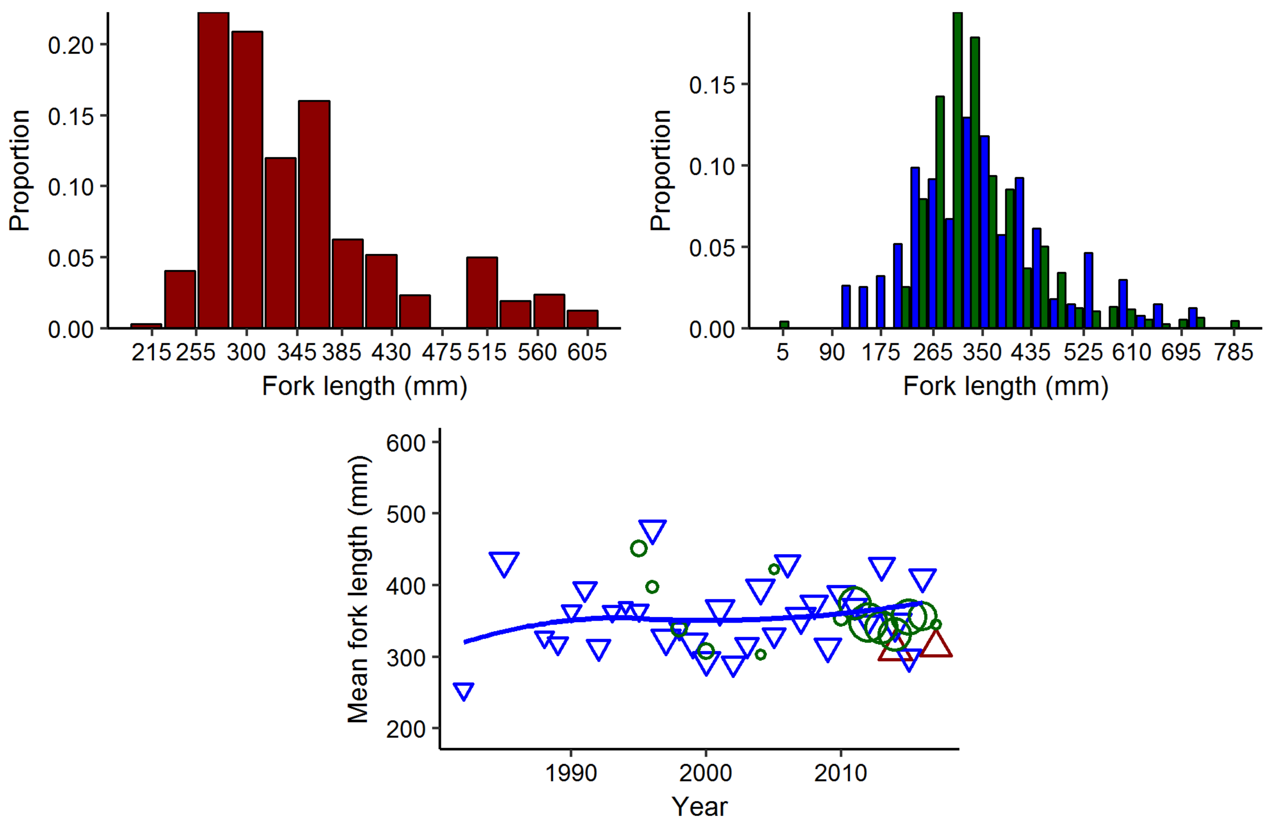
C_{30} and OFL estimates for this species were deemed too uncertain and are not presented here.



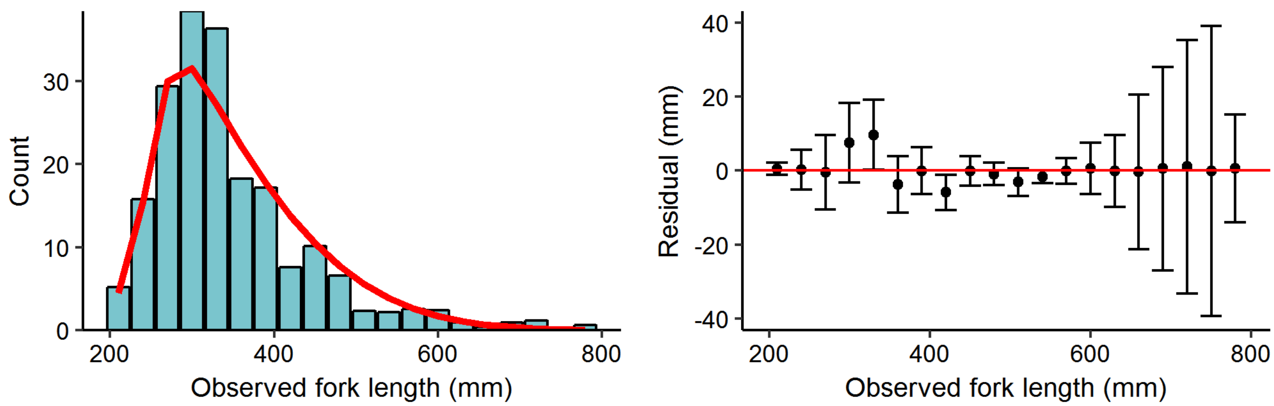
Life history parameter distributions. Red line indicates median value.



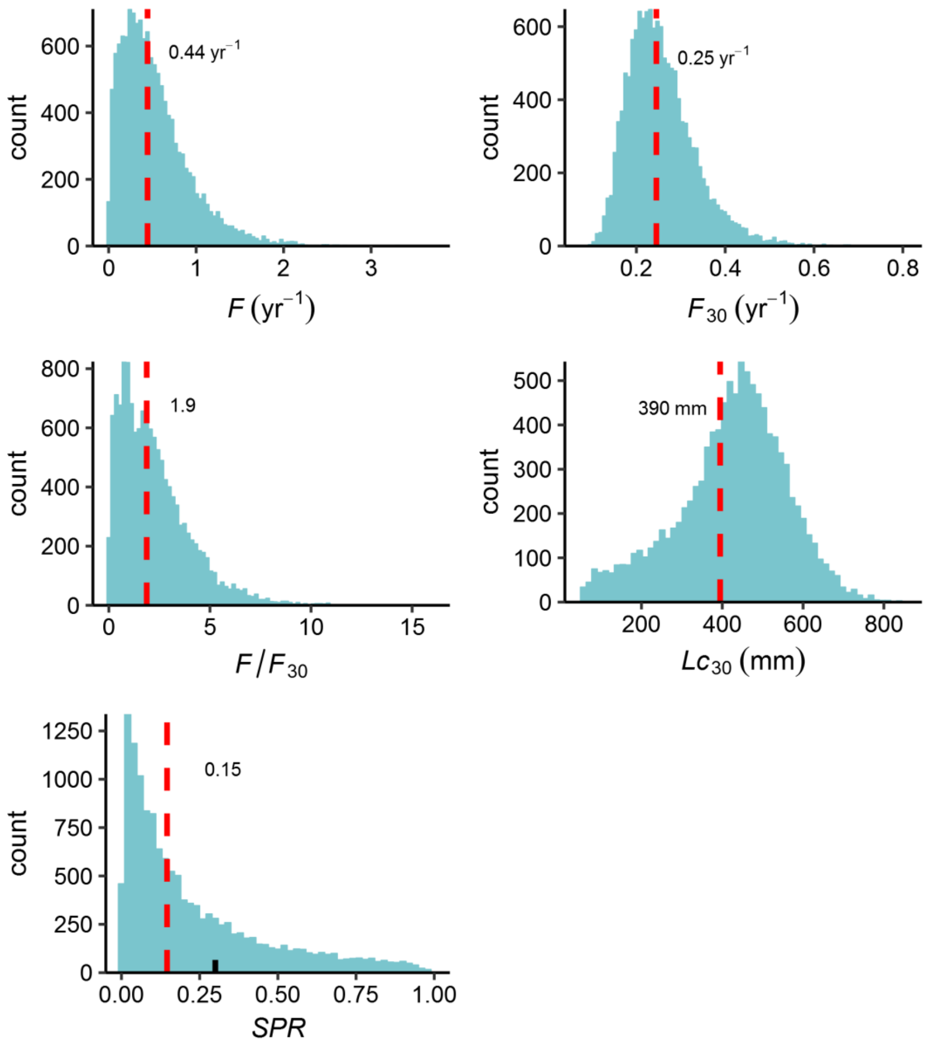
Abundance index from UVS (left; red triangles, ±SE) and total catch time series (right) from hook-and-line (blue), spear (green), and net (orange) fishing gears. Black line shows loess fit for total catch with 95% confidence interval (gray area).



Size structure from diver surveys (top left) and from the catch by fishing gear (top right) (hook-and-line: blue, spear: green). Average length time series (bottom) (hook-and-line: blue inverse triangles, spear: green circles, and diver surveys: red upright triangles). Size of icons is proportional to sample size.



LBSPR model fit (left) and residuals (right).



Stock status parameter distributions (*SPR*: small bar shows 0.30 level). Red line indicates median value.

Probability of overfishing at various minimum sizes.

Overfishing probability	Lc_{30} (mm)	Overfishing probability	Lc_{30} (mm)
0.05	613	0.28	479
0.06	602	0.29	475
0.07	593	0.30	472
0.08	583	0.31	468
0.09	575	0.32	464
0.10	567	0.33	460
0.11	561	0.34	457
0.12	555	0.35	453
0.13	549	0.36	450
0.14	543	0.37	446
0.15	538	0.38	443
0.16	532	0.39	439
0.17	527	0.40	435
0.18	523	0.41	432
0.19	517	0.42	427
0.20	513	0.43	423
0.21	508	0.44	420
0.22	504	0.45	416
0.23	499	0.46	412
0.24	495	0.47	407
0.25	491	0.48	404
0.26	487	0.49	399
0.27	483	0.50	395

Lethrinus olivaceus

Longface emperor, *lililok*
Lethrinidae (emperors)

Life history and other input parameters

Parameter	Value	SD	Unit	n	Source
L_{inf}	606	20	mm	-	Mean and SD: Nadon and Ault (2016) L99 from biosampling: 686 (12) mm
K	0.28	0.15	yr^{-1}		
a_0	-0.8	-	yr		
L_{mat}	440	29	mm	-	Mean and SD: Nadon and Ault (2016)
CV L_{inf}	0.1	0.01	-	-	Mean and SD: Estimated.
Longevity	23	11	yr	-	Mean and SD: Nadon and Ault (2016)
LW-alpha	2.09e-5	-	-	-	Kamikawa (2015)
LW-beta	2.93				
Max. depth	100	-	m	-	Mesophotic cruise 2014

Stock status and other output parameters

Parameter	Median	SD	Unit
M	0.14	0.07	yr^{-1}
F	0.19	0.16	yr^{-1}
L_{S50}	189	18	mm
L_{S95}	273	40	mm
F_{30}	0.12	0.05	yr^{-1}
F/F_{30}	1.6	0.9	-
SPR	0.18	0.17	-
SPR < 0.30 iterations	75	-	%

Parameter	Median	SD	Unit
B from catch	-	-	kg
B from divers	-	-	kg
Boat-based catch	-	-	kg
Shore-based catch	-	-	kg
Total catch	-	-	kg
C_{30} from catch	-	-	kg
C_{30} from divers	-	-	kg
Lc_{30}	409	-	mm

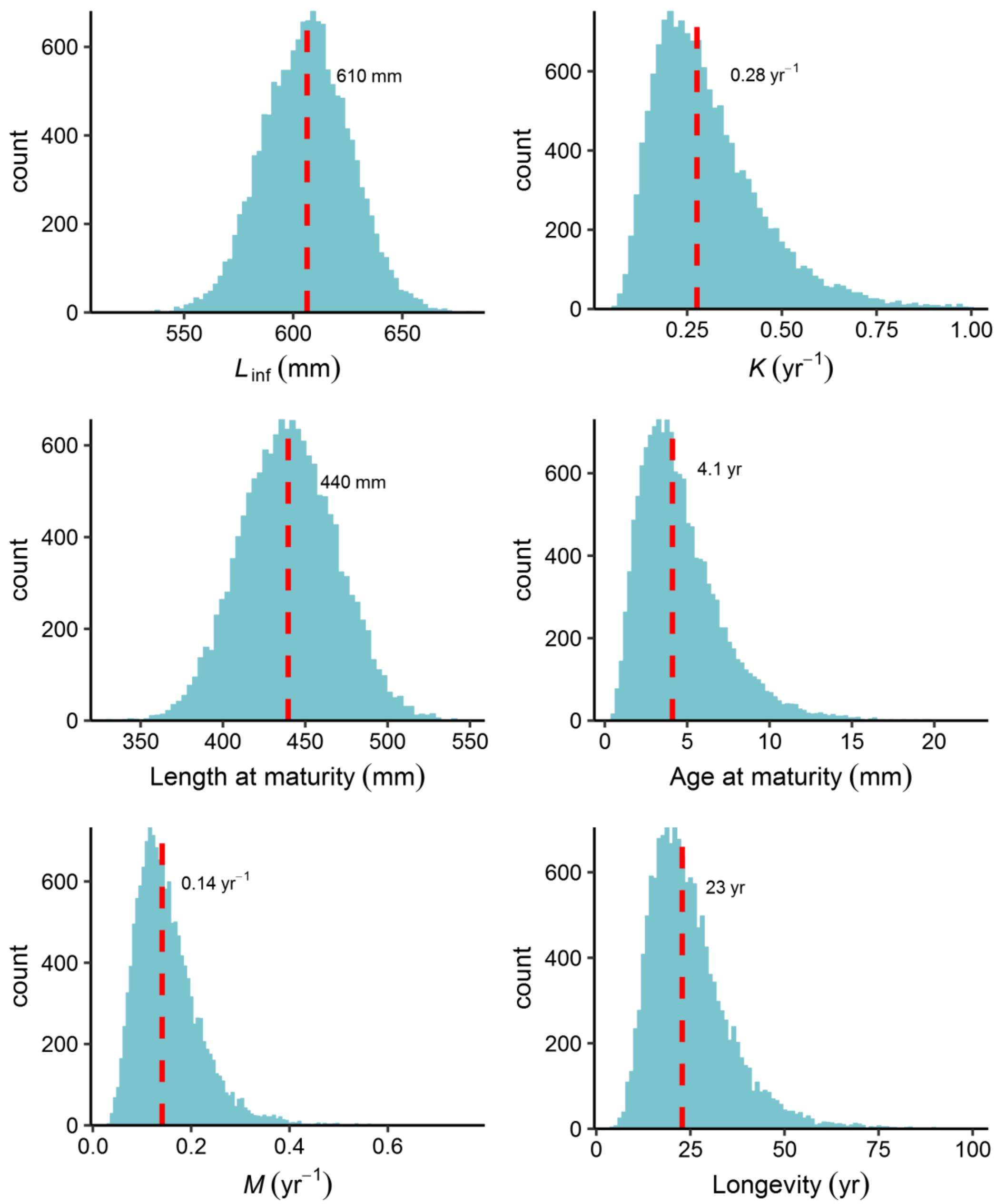
General comments

This species is almost never encountered by divers and therefore only fishery-dependent data (creel surveys, biosampling) were used for this assessment. It is almost exclusively caught by line fishing, except for a few peaks in net fishing, likely related to some recruitment events. Length data from line fishing were used in the LBSPR analyses. Yearly total catch increased from 1985 before peaking in 2002 (> 4,000 kg). Catch in recent years have been generally below 1,000 kg, with a peak in 2014. Average lengths from line fishing have decreased from 1985 to 2000, but appear stable since then.

There are no published life history parameters for this species and we therefore used the stepwise approach. The only available estimate of L_{99} was from the line fishing creel survey data set (692 mm) and biosampling (686 mm). There is some data from the diver surveys around Guam which suggest that these estimates are reasonable (651 mm), but this value is highly variable (SD: 118 mm).

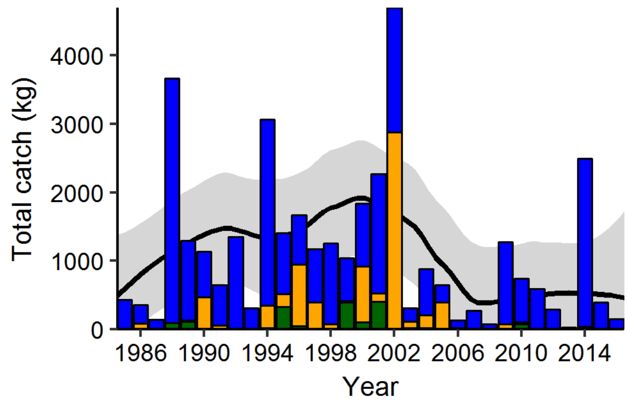
C_{30} and OFL estimates for this species were deemed too uncertain and are not presented here.

Lethrinus olivaceus

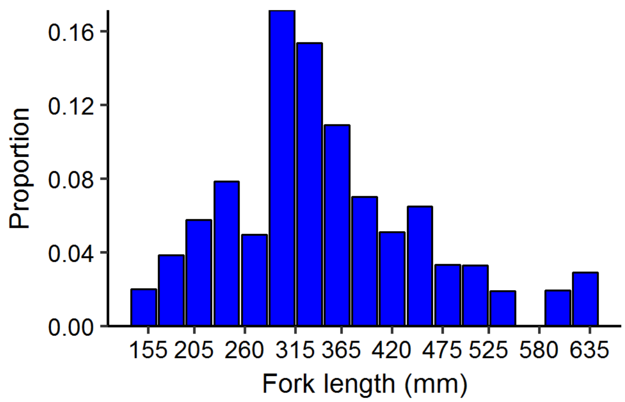


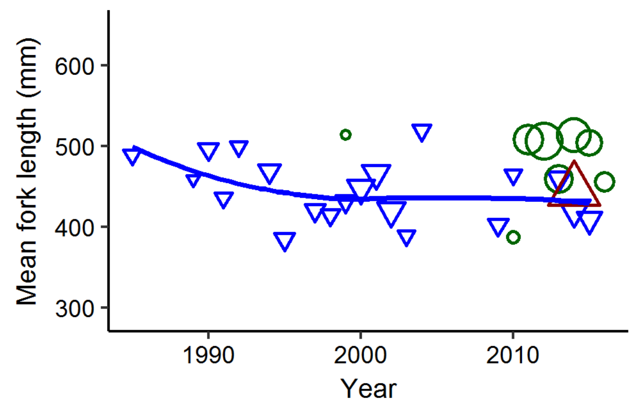
Life history parameter distributions. Red line indicates median value.

Lethrinus olivaceus



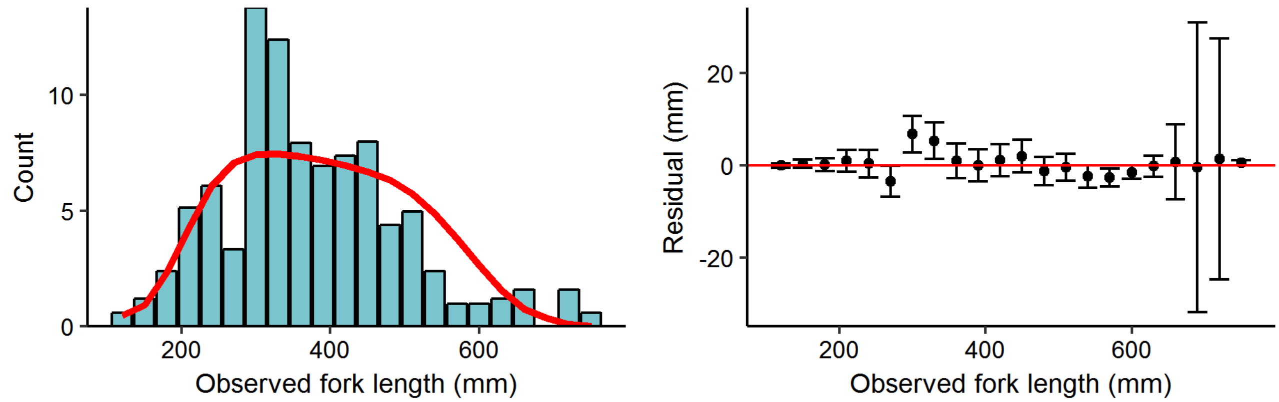
Total catch time series from hook-and-line (blue), spear (green), and net (orange) fishing gears. Black line shows loess fit for total catch with 95% confidence interval (gray area).



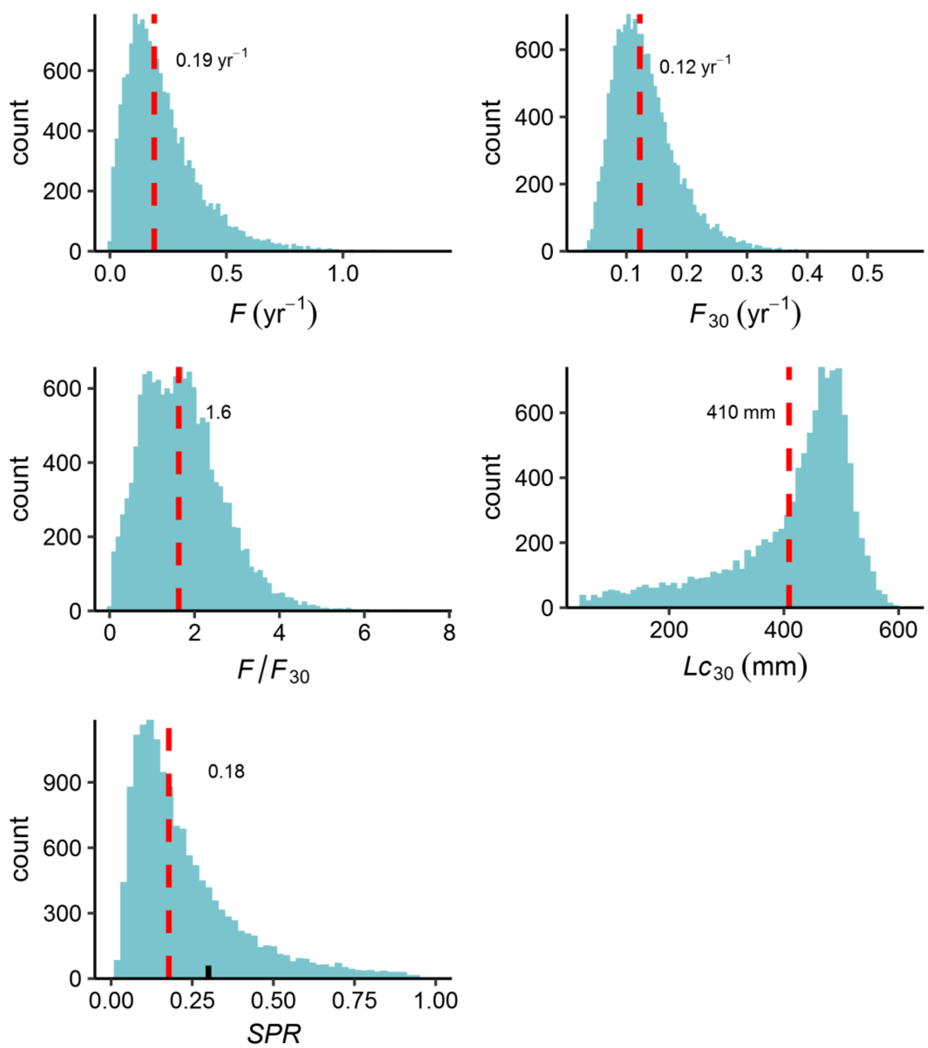


Size structure from fishing gear (left; hook-and-line). Average length time series (right) (hook-and-line: blue inverse triangles, spear: green circles, diver surveys: red upright triangles). Size of icons is proportional to sample size.

Lethrinus olivaceus



LBSPR model fit (left) and residuals (right).



Stock status parameter distributions (*SPR*: small bar shows 0.30 level). Red line indicates median value.

Probability of overfishing at various minimum sizes.

Overfishing probability	Lc_{30} (mm)	Overfishing probability	Lc_{30} (mm)
0.05	525	0.28	471
0.06	521	0.29	469
0.07	517	0.30	467
0.08	514	0.31	465
0.09	511	0.32	463
0.10	508	0.33	461
0.11	505	0.34	459
0.12	503	0.35	457
0.13	501	0.36	454
0.14	499	0.37	452
0.15	497	0.38	449
0.16	495	0.39	446
0.17	493	0.40	444
0.18	491	0.41	441
0.19	489	0.42	438
0.20	487	0.43	435
0.21	485	0.44	432
0.22	483	0.45	429
0.23	481	0.46	426
0.24	479	0.47	422
0.25	477	0.48	418
0.26	475	0.49	414
0.27	473	0.50	409

Lethrinus xanthochilus

Yellowlip emperor, *lililok*
Lethrinidae (emperors)

Life history and other input parameters

Parameter	Value	SD	Unit	n	Source
L_{inf}	506	20	mm	-	Mean and SD: Nadon and Ault (2016) L99 from biosampling: 580 (11) mm
K	0.34	0.16	yr^{-1}		
a_0	-0.8	-	yr		
L_{mat}	374	27	mm	-	Mean and SD: Nadon and Ault (2016)
CV L_{inf}	0.1	0.01	-	-	Mean and SD: Estimated.
Longevity	20	9	yr		Mean and SD: Nadon and Ault (2016)
LW-alpha	1.79e-5	-	-	-	Kamikawa (2015)
LW-beta	3.00				
Max. depth	100	-	m	-	Mesophotic cruise 2014

Stock status and other output parameters

Parameter	Median	SD	Unit
M	0.16	0.07	yr^{-1}
F	0.14	0.14	yr^{-1}
L_{S50}	168	14	mm
L_{S95}	250	21	mm
F_{30}	0.14	0.06	yr^{-1}
F/F_{30}	1.0	0.8	-
SPR	0.31	0.22	-
SPR < 0.30 iterations	49	-	%

Parameter	Median	SD	Unit
B from catch	-	-	kg
B from divers	-	-	kg
Boat-based catch	-	-	kg
Shore-based catch	-	-	kg
Total catch	-	-	kg
C_{30} from catch	-	-	kg
C_{30} from divers	-	-	kg
Lc_{30}	87	-	mm

General comments

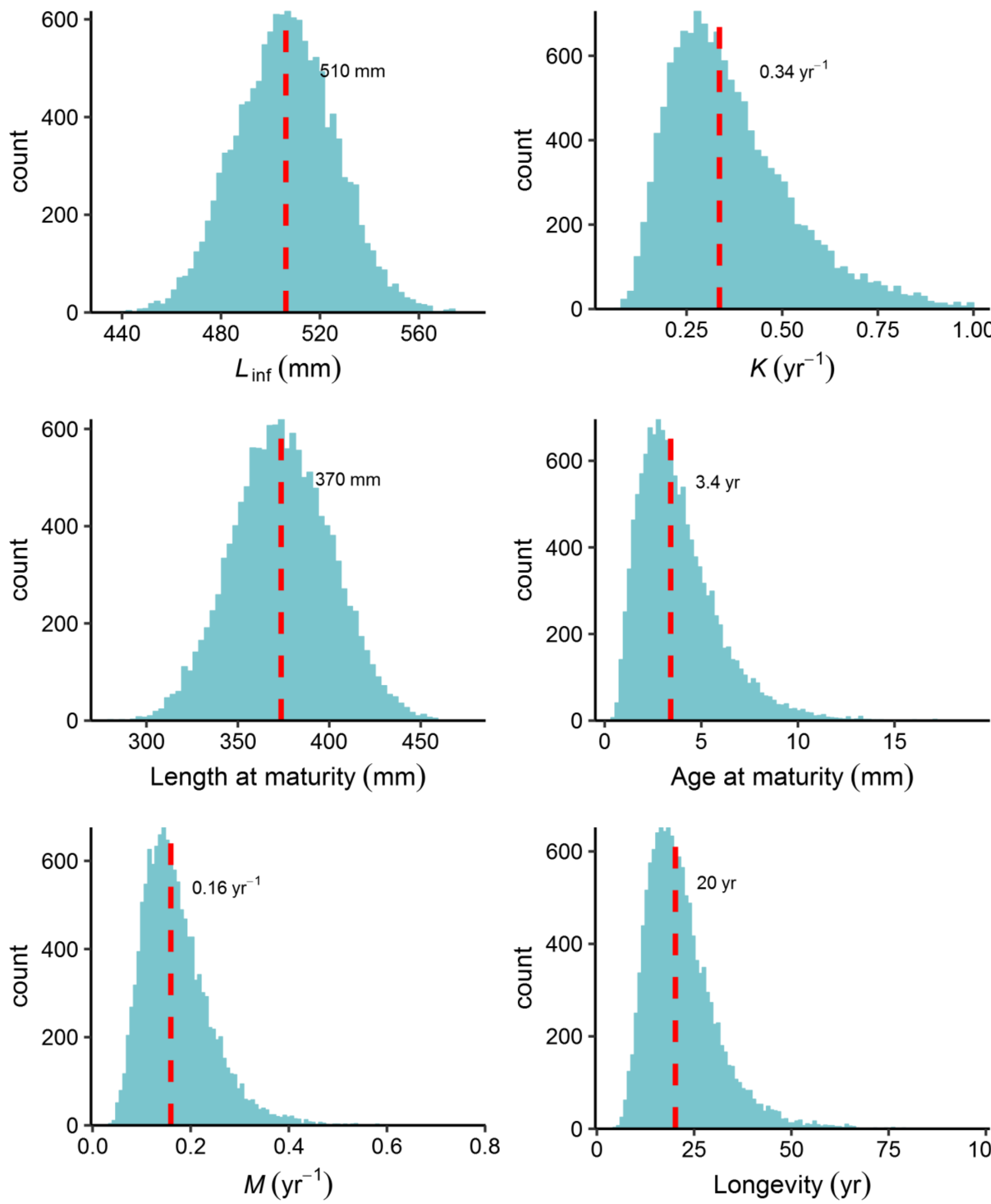
This species is almost never encountered by divers and therefore only fishery-dependent data (creel survey, biosampling) were used for this assessment. There was some net fishing for this species in the early years of the catch record, but this gear is not as commonly used for this species recently, and line fishing is the predominant gear (length data from this gear was used in the LBSPR analyses). The catch for this species is highly variable, jumping from several thousand kg per year to less than 1,000 kg in certain years.

Average lengths from line fishing are fairly variable due to a relatively small sample size, varying mostly between 350 mm and 400 mm for the last 30 years.

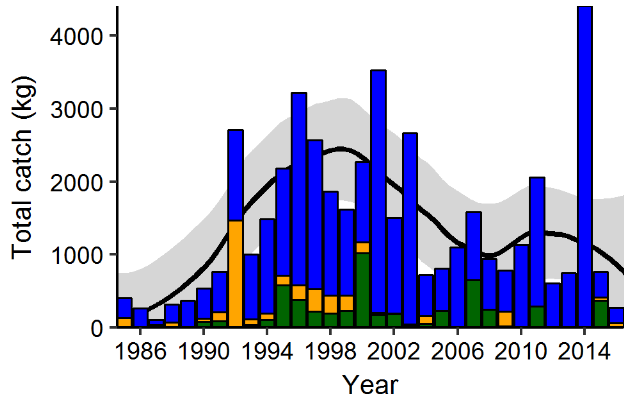
Some life history parameters are available from American Samoa for this species (Taylor, unpublished), but these appear unsuitable for Guam (L_{inf} from America Samoa is 402 mm while this species can reach 580 mm around Guam). The stepwise approach was used to obtain life history parameter estimates, using a maximum length from the biosampling data. This max length estimate was identical to one obtained from diver surveys in the northern Marianas (580 mm).

C_{30} and OFL estimates for this species were deemed too uncertain and are not presented here.

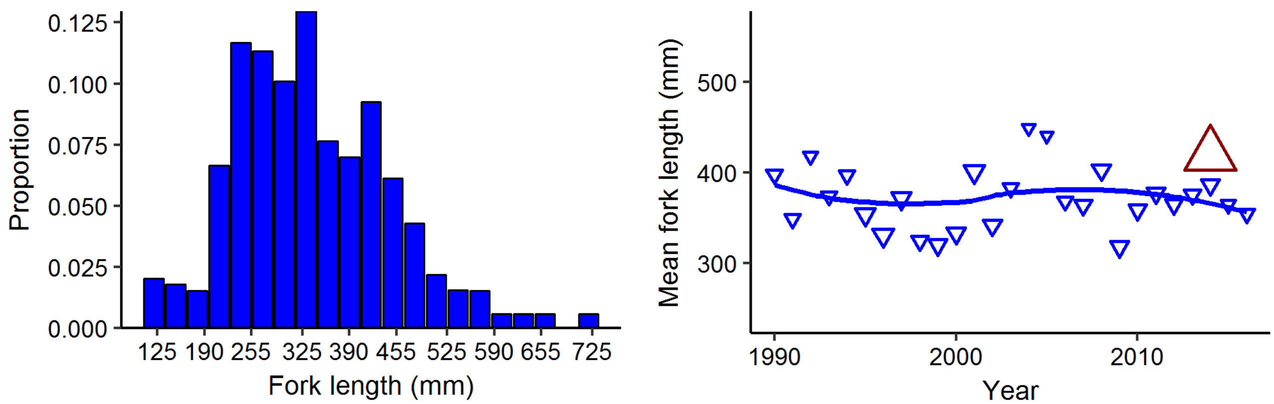
Lethrinus xanthochilus



Life history parameter distributions. Red line indicates median value.

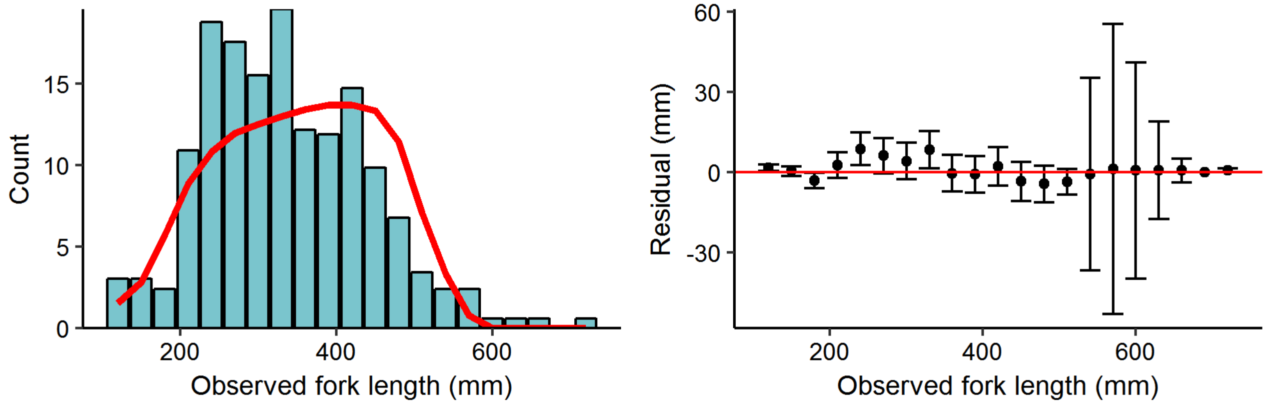


Total catch time series from hook-and-line (blue), spear (green), and net (orange) fishing gears. Black line shows loess fit for total catch with 95% confidence interval (gray area).

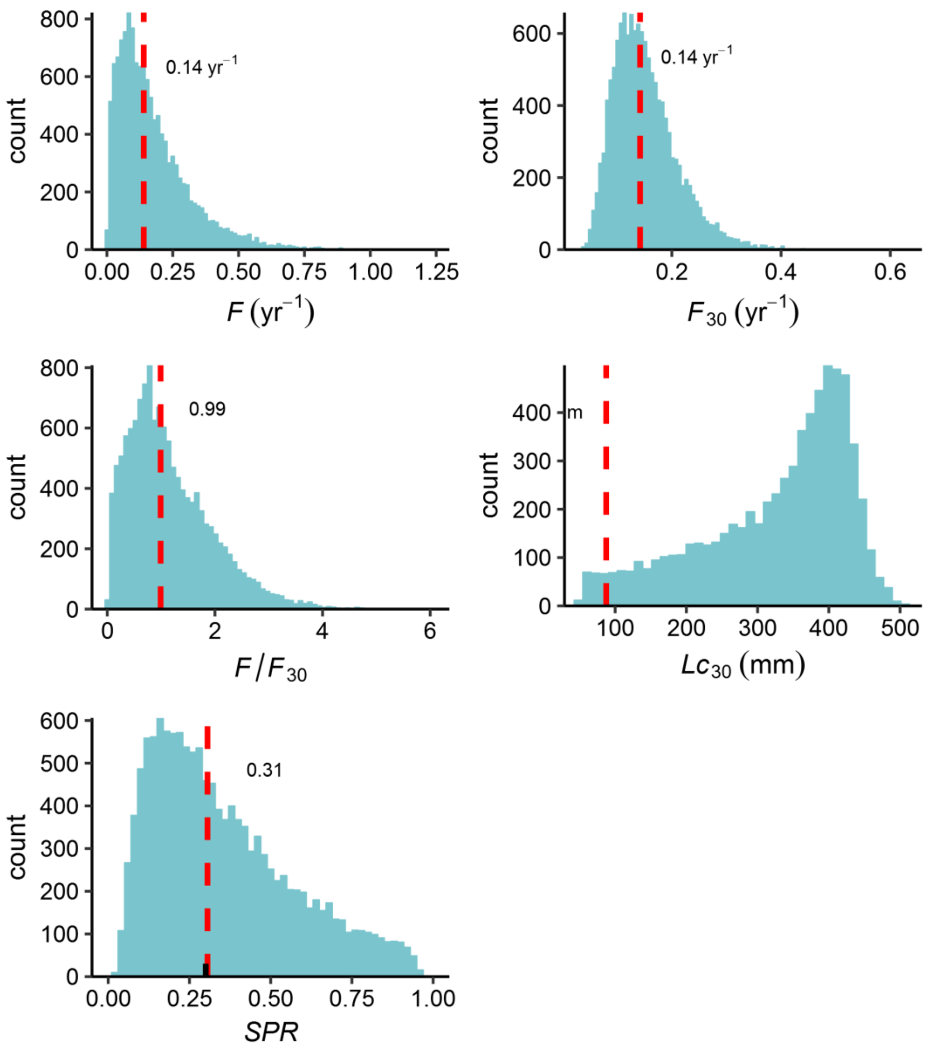


Size structure from fishing gear (left; hook-and-line). Average length time series (right) (hook-and-line: blue inverse triangles, diver surveys: red upright triangles). Size of icons is proportional to sample size.

Lethrinus xanthochilus



LBSPR model fit (left) and residuals (right).



Stock status parameter distributions (*SPR*: small bar shows 0.30 level). Red line indicates median value.

Probability of overfishing at various minimum sizes.

Overfishing probability	Lc_{30} (mm)	Overfishing probability	Lc_{30} (mm)
0.05	432	0.28	346
0.06	429	0.29	340
0.07	425	0.30	334
0.08	422	0.31	327
0.09	419	0.32	320
0.10	415	0.33	313
0.11	412	0.34	305
0.12	409	0.35	295
0.13	405	0.36	288
0.14	402	0.37	278
0.15	399	0.38	268
0.16	396	0.39	258
0.17	393	0.40	248
0.18	389	0.41	236
0.19	386	0.42	223
0.20	382	0.43	211
0.21	378	0.44	198
0.22	374	0.45	182
0.23	370	0.46	168
0.24	366	0.47	151
0.25	361	0.48	132
0.26	357	0.49	109
0.27	351	0.50	87

Monotaxis grandoculis

Big-eye bream, *m'atan hagan* Lethrinidae (emperors)

Life history and other input parameters

Parameter	Value	SD	Unit	n	Source
L_{inf}	379	16	mm	-	Mean and SD: Nadon and Ault (2016) L99 from biosampling: 432 (4) mm
K	0.43	0.18	yr^{-1}		
a_0	-0.8	-	yr		
L_{mat}	289	25	mm	-	Mean and SD: Nadon and Ault (2016)
CV L_{inf}	0.1	0.01	-	-	Mean and SD: Estimated.
Longevity	16	7	yr	-	Mean and SD: Nadon and Ault (2016)
LW-alpha	3.83e-5	-	-	1581	Kamikawa (2015)
LW-beta	2.84				
Max. depth	101	-	m	-	Pyle et al. (2014)

Stock status and other output parameters

Parameter	Median	SD	Unit
M	0.20	0.08	yr^{-1}
F	0.20	0.19	yr^{-1}
L_{S50}	206	8	mm
L_{S95}	252	15	mm
F_{30}	0.21	0.08	yr^{-1}
F/F_{30}	0.98	0.81	-
SPR	0.31	0.22	-
SPR < 0.30 iterations	48	-	%

Parameter	Median	SD	Unit
B from catch	1,330	7,200	kg
B from divers	1,600	860	kg
Boat-based catch	252	-	kg
Shore-based catch	54	-	kg
Total catch	306	273	kg
C_{30} from catch	220	1,160	kg
C_{30} from divers	265	165	kg
Lc_{30}	137	-	mm

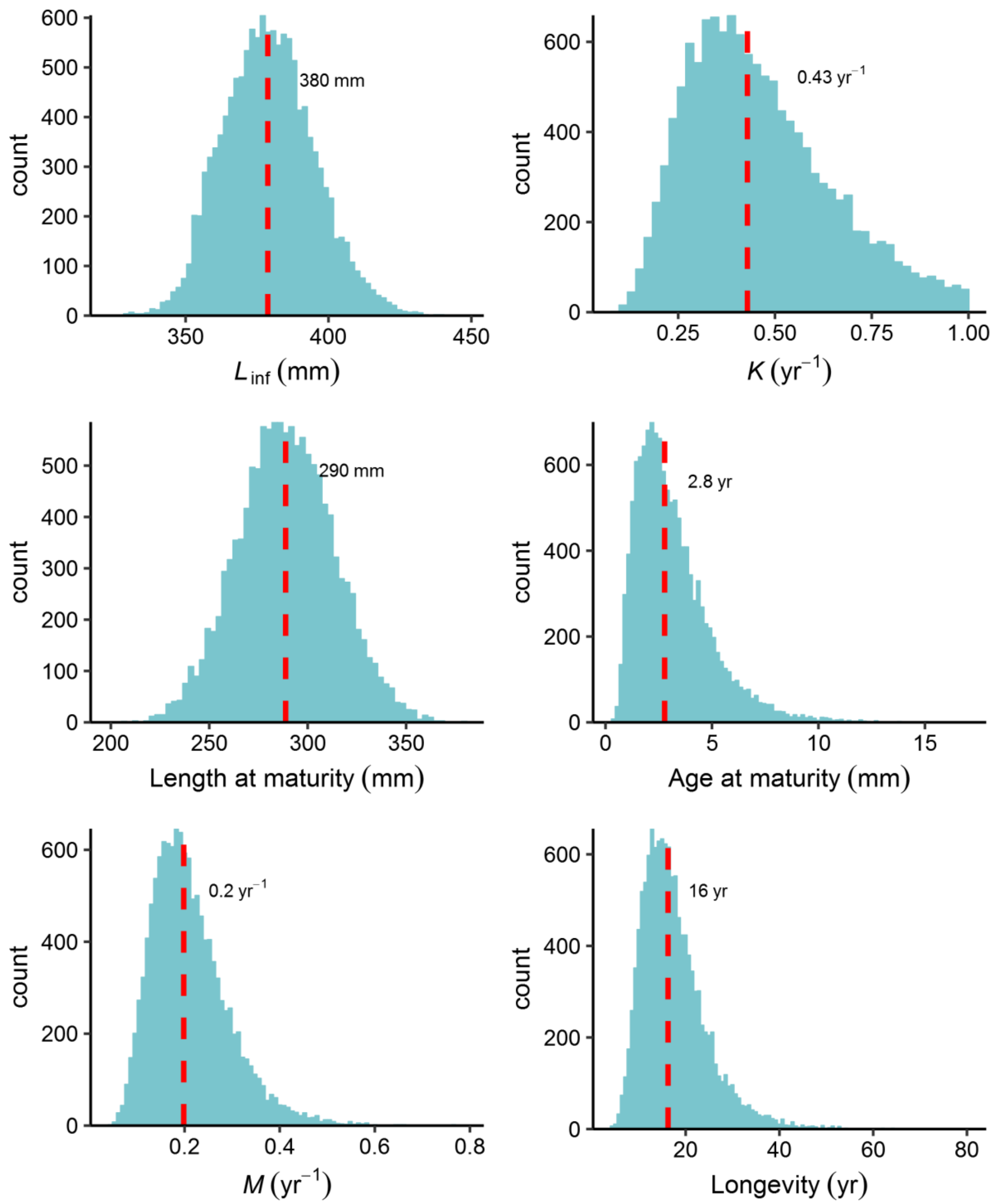
General comments

Total catch for this species can be highly variable from year to year, often exceeding 2,000 kg in the years prior to 2000. Landings in recent years have been lower, at around 300 kg per year. Spear fishing was the main fishing gear prior to 2000 while line fishing has been mostly used in recent years. Selectivity for both gears and from the diver surveys were similar. The spear fishing length data was used for the LBSPR analyses given this similarity and the higher observation numbers. Average length was higher between 1990 and 2000 at around 350 mm (it currently sits at around 300 mm). Population abundance has been relatively stable except for a peak in 2011.

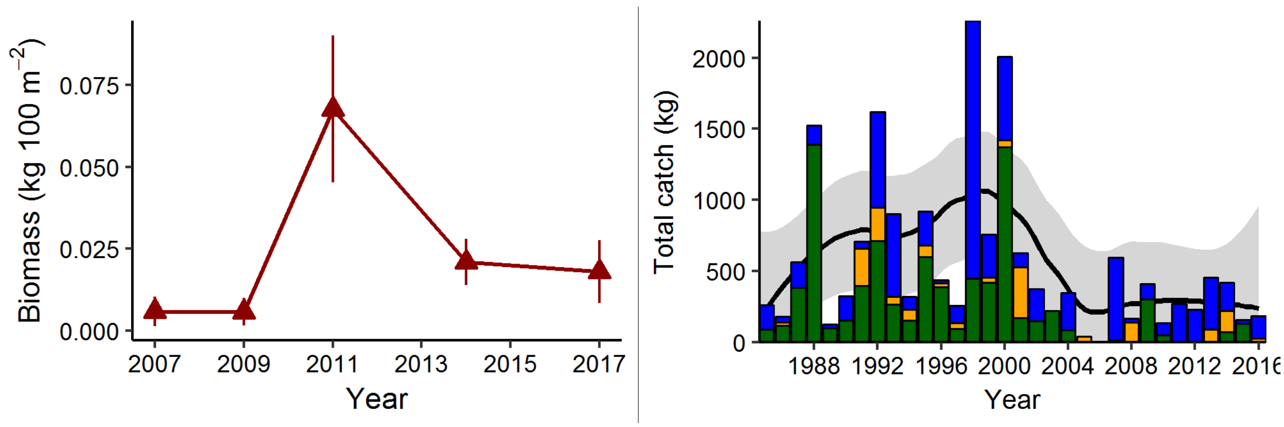
There are no published life history parameters for this species and we therefore relied on the stepwise approach using a L_{99} estimate from the biosampling data. A lower L_{99} was obtained from the diver surveys in the northern Mariana islands at 395 mm. Running the analyses with this value generated the following metrics: L_{inf}: 364 mm, K: 0.49, M: 0.20, F_{30}: 0.22, F: 0.13, and SPR: 0.47. It is not clear why the L_{99} in the northern island from the diver surveys was significantly lower than the Guam L_{99} for both diver surveys (412 mm) and biosampling data (432 mm). This could be related to the sample size (n=203).

Population biomass estimate from the catch was similar to the diver survey-derived estimate. The diver-derived estimates are likely more reliable for this species given that this is an easily identified species that is regularly observed. True biomass is likely even higher given the depth limitation of the diver surveys is shallower than this species' depth range (30 m vs. 101 m).

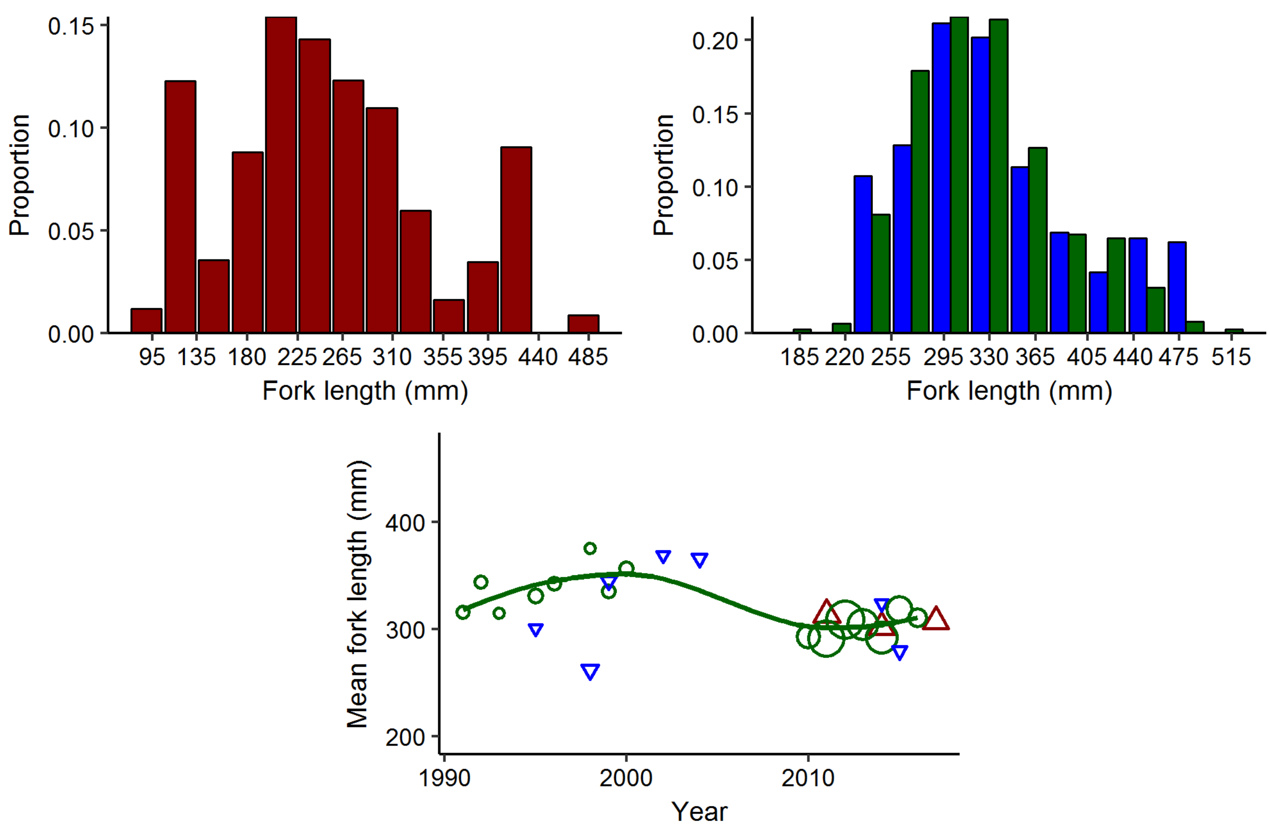
Monotaxis grandoculis



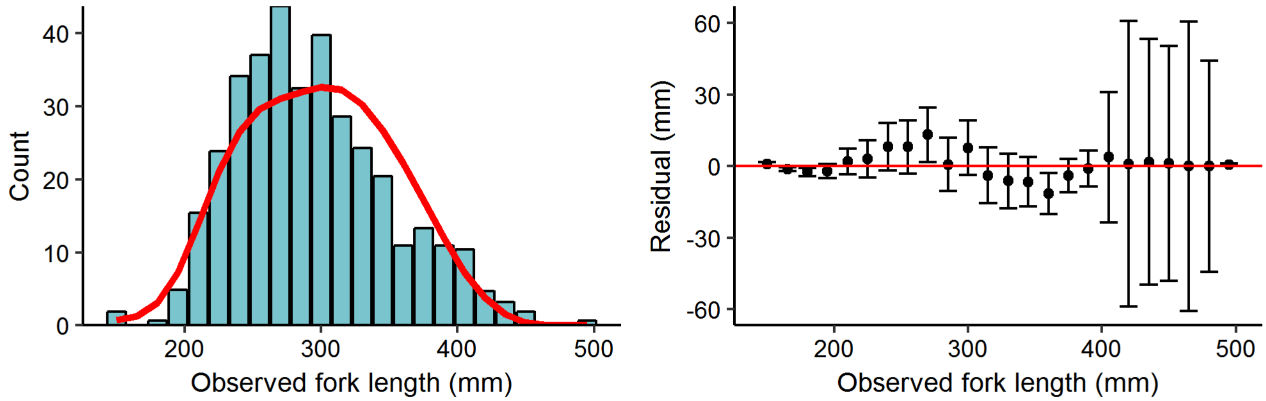
Life history parameter distributions. Red line indicates median value.



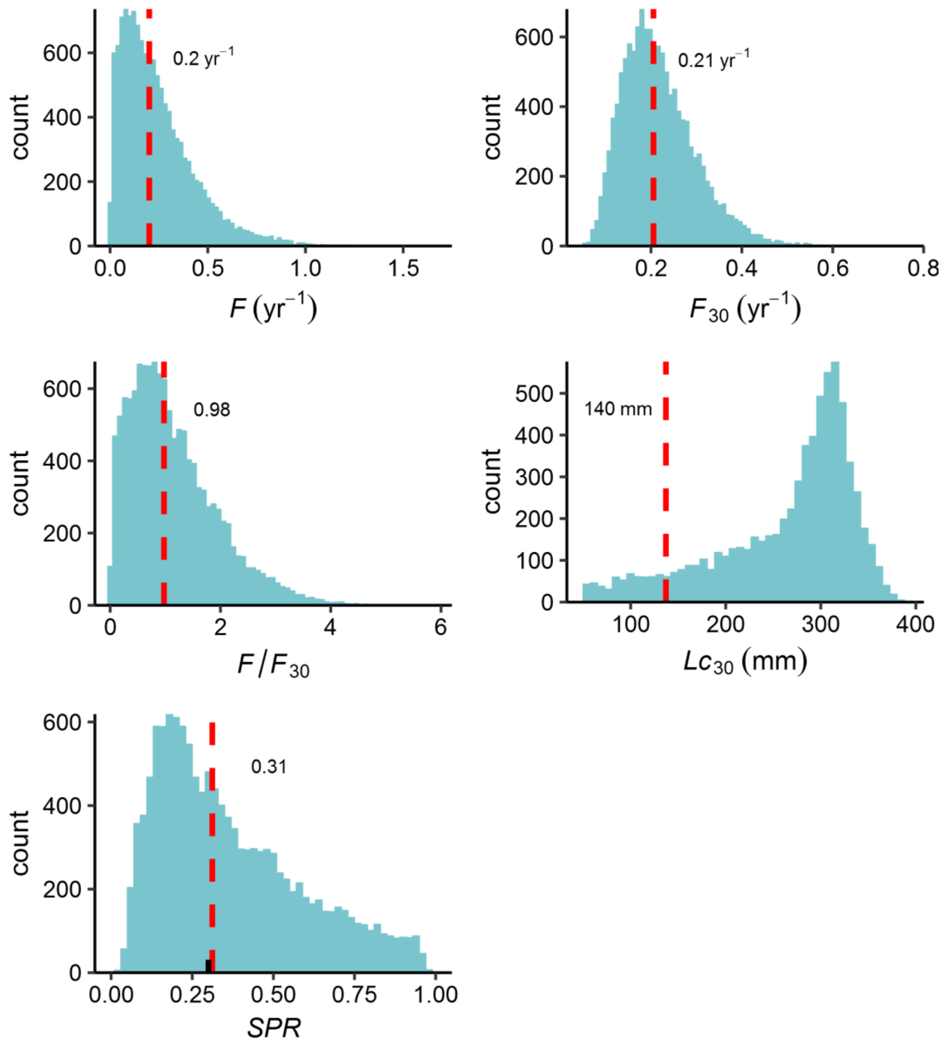
Abundance index from diver surveys (left; red triangles, ±SE) and total catch time series (right) from hook-and-line (blue), spear (green), and net (orange) fishing gears. Black line shows loess fit for total catch with 95% confidence interval (gray area).



Size structure from diver surveys (top left) and from the catch by fishing gear (top right) (hook-and-line: blue, spear: green). Average length time series (bottom; hook-and-line: blue inverse triangles, spear: green circles, diver surveys: red upright triangles). Size of icons is proportional to sample size.

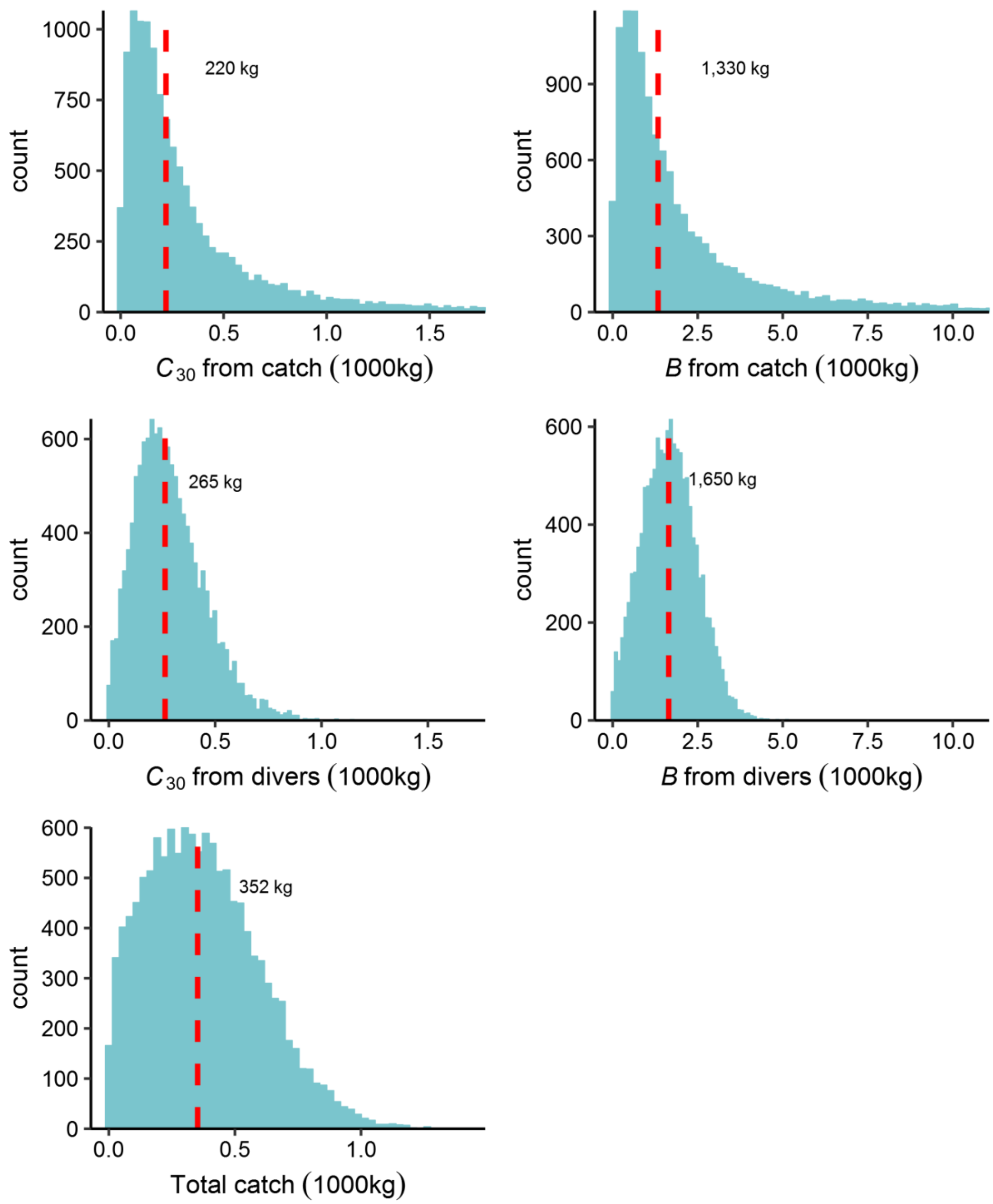


LBSPR model fit (left) and residuals (right).

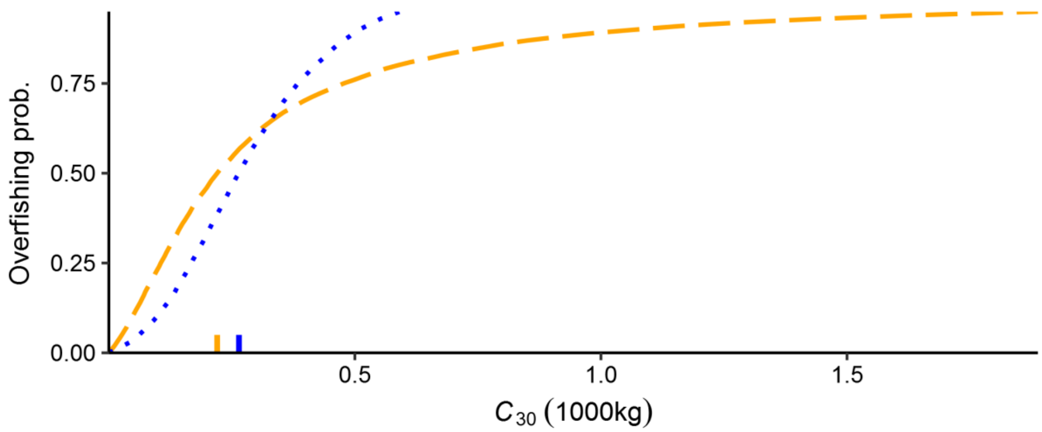


Stock status parameter distributions (*SPR*: small bar shows 0.30 level). Red line indicates median value.

Monotaxis grandoculis



Distributions of C_{30} from catch (top left), C_{30} from diver survey biomass (middle left), and current total catch (bottom left), biomass from catch (top right), and biomass from diver surveys (middle right). Red line indicates median value.



Overfishing probabilities for a range of C_{30} levels (derived from catch - orange dashed line, diver surveys - blue dotted line). *OFLs* are represented by small vertical bars.

Probability of overfishing for various C_{30} levels (reported in pounds).

Overfishing probability	C_{30} from catch (1000 lbs)	C_{30} from diver survey (1000 lbs)	Overfishing probability	C_{30} from catch (1000 lbs)	C_{30} from diver survey (1000 lbs)
0.05	0.060	0.137	0.28	0.258	0.395
0.06	0.068	0.154	0.29	0.267	0.403
0.07	0.079	0.168	0.30	0.276	0.412
0.08	0.086	0.185	0.31	0.284	0.421
0.09	0.095	0.201	0.32	0.295	0.430
0.10	0.106	0.214	0.33	0.304	0.437
0.11	0.115	0.227	0.34	0.311	0.448
0.12	0.123	0.240	0.35	0.322	0.456
0.13	0.132	0.251	0.36	0.331	0.463
0.14	0.141	0.265	0.37	0.342	0.470
0.15	0.148	0.276	0.38	0.351	0.478
0.16	0.157	0.287	0.39	0.362	0.487
0.17	0.163	0.295	0.40	0.370	0.498
0.18	0.172	0.304	0.41	0.379	0.505
0.19	0.181	0.315	0.42	0.390	0.514
0.20	0.190	0.324	0.43	0.403	0.522
0.21	0.198	0.333	0.44	0.414	0.531
0.22	0.207	0.344	0.45	0.425	0.540
0.23	0.216	0.353	0.46	0.439	0.547
0.24	0.225	0.359	0.47	0.450	0.556
0.25	0.234	0.370	0.48	0.461	0.562
0.26	0.243	0.377	0.49	0.472	0.573
0.27	0.251	0.388	0.50	0.485	0.582

Probability of overfishing at various minimum sizes.

Overfishing probability	Lc_{30} (mm)	Overfishing probability	Lc_{30} (mm)
0.05	337	0.28	288
0.06	333	0.29	285
0.07	330	0.30	282
0.08	327	0.31	279
0.09	325	0.32	276
0.10	323	0.33	272
0.11	321	0.34	268
0.12	319	0.35	263
0.13	317	0.36	258
0.14	316	0.37	252
0.15	314	0.38	246
0.16	312	0.39	240
0.17	310	0.40	233
0.18	308	0.41	227
0.19	306	0.42	219
0.20	305	0.43	211
0.21	303	0.44	203
0.22	301	0.45	194
0.23	299	0.46	186
0.24	297	0.47	175
0.25	295	0.48	163
0.26	292	0.49	151
0.27	290	0.50	137

Lutjanus fulvus

Blacktail snapper, *kaka'ka'*
Lutjanidae (snappers)

Life history and other input parameters

Parameter	Value	SD	Unit	n	Source
L_{inf}	289	23	mm	-	Mean and SD: Nadon and Ault (2016) L99 from biosampling: 317 (12) mm
K	0.48	0.18	yr^{-1}		
a_0	-0.8	-	yr		
L_{mat}	210	33	mm	-	Mean and SD: Nadon and Ault (2016)
CV L_{inf}	0.09	0.01	-	-	Mean and SD: Estimated.
Longevity	16	7	yr	-	Mean and SD: Nadon and Ault (2016)
LW-alpha	1.02e-5	-	-	-	Kamikawa (2015)
LW-beta	3.12				
Max. depth	128	-	m	-	Pyle et al. (2014)

Stock status and other output parameters

Parameter	Median	SD	Unit
M	0.21	0.09	yr^{-1}
F	0.32	0.33	yr^{-1}
L_{S50}	135	18	mm
L_{S95}	192	37	mm
F_{30}	0.20	0.07	yr^{-1}
F/F_{30}	1.6	1.7	-
SPR	0.19	0.23	-
SPR < 0.30 iterations	66	-	%

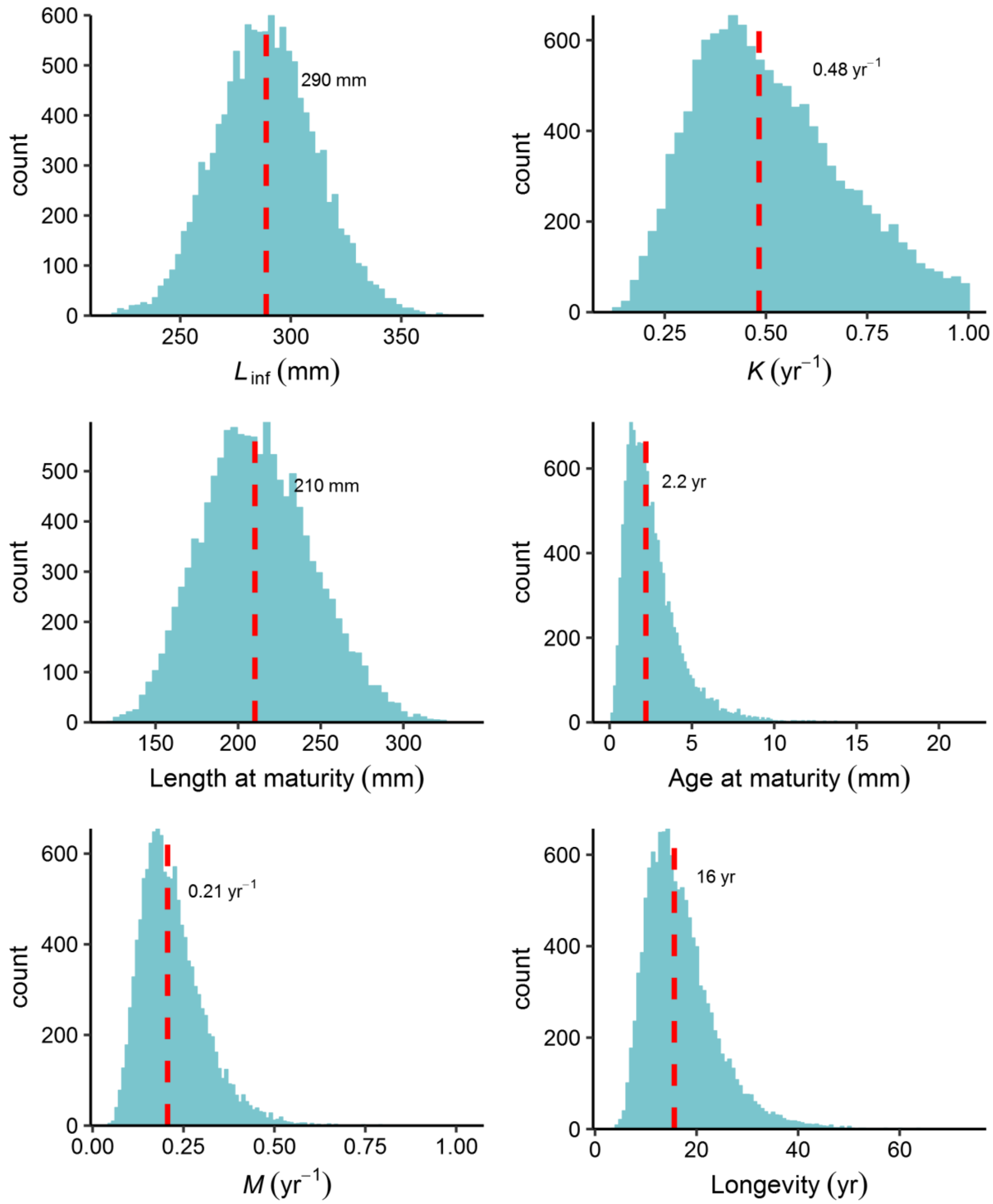
Parameter	Median	SD	Unit
B from catch	1,960	16,300	kg
B from divers	2,671	1,077	kg
Boat-based catch	260	-	kg
Shore-based catch	227	-	kg
Total catch	487	973	kg
C_{30} from catch	321	2,700	kg
C_{30} from divers	432	225	kg
Lc_{30}	149	-	mm

General comments

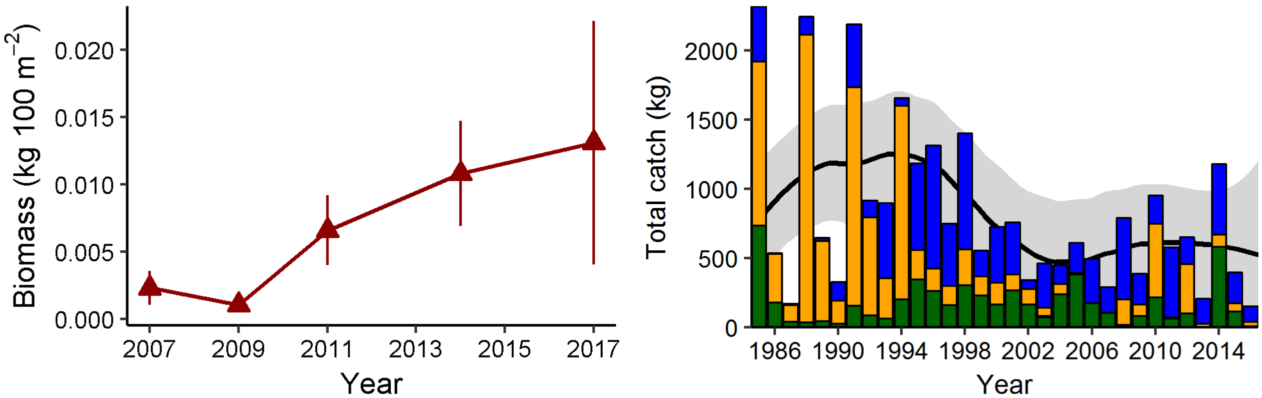
Total catch for this species has been in decline since the start of the time series in 1985, starting from a range of 1,000 kg to 2,000 kg, to around 500 kg in recent years. Since 1995, the main gear used to catch this species is line fishing, with some spear fishing. In the 1980s and early 1990s, large numbers of *L. fulvus* were caught by nets (also note the small spikes in 2010 and 2012). Population abundance appears to be increasing in recent years, while average length appears to have been mostly stable. The selectivity for line fishing compared to spear fishing starts at a lower size, and line fishing data were selected for the analyses.

There are no published life history parameters for this species and we therefore used the stepwise approach. The L_{99} for the biosampling data was similar to the diver survey value (317 mm vs. 291 mm). The northern Mariana diver survey had an even larger L_{99} (343 mm), but this may be affected by the sample size (n = 47). Using this L_{99} value would lead to even higher F (0.52) and lower SPR (0.09).

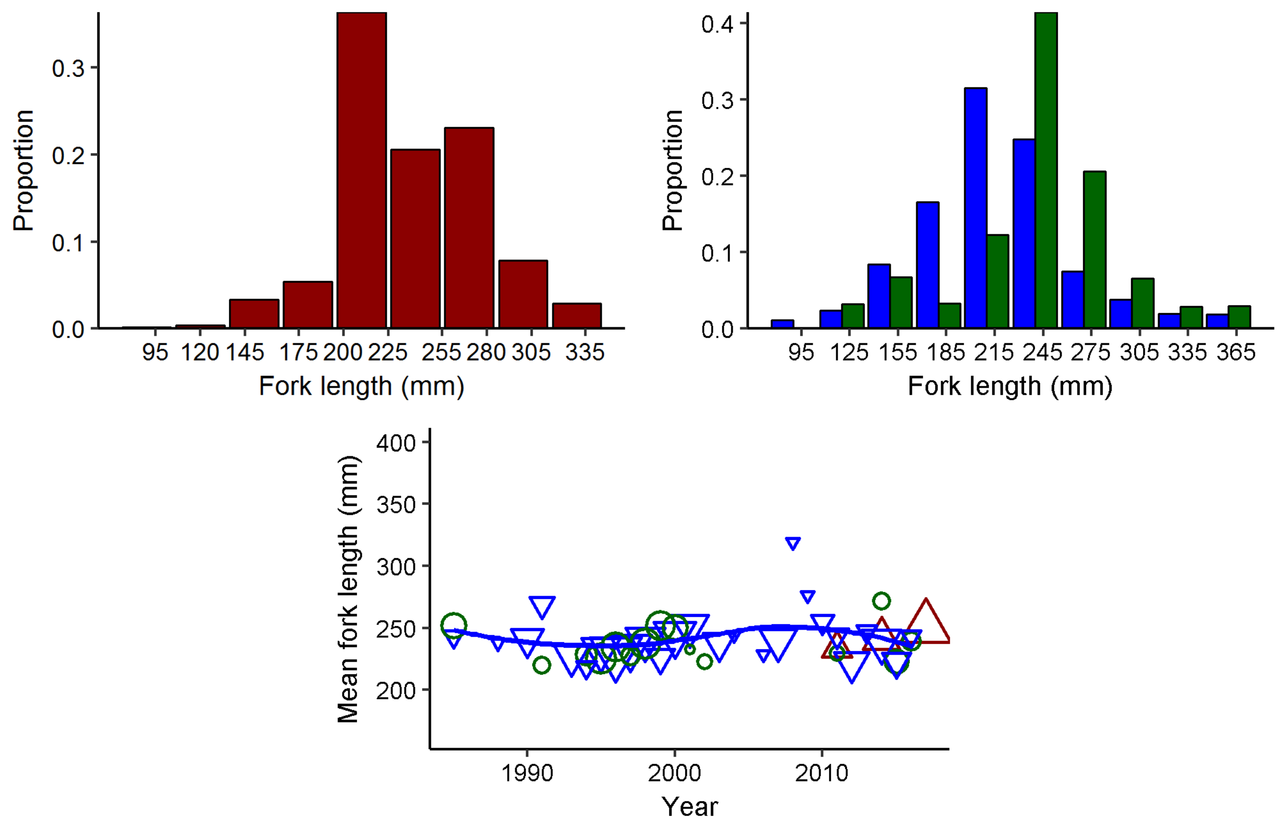
The population biomass estimates derived from catch vs. diver surveys (1,960 kg vs. 2,671 kg) were relatively close. The diver survey-derived biomass estimate (and the associated *OFL*) should be more reliable given that this is an easily identified species which is commonly encountered by divers. It is likely that true population biomass is even higher given the depth-limitation of the diver surveys is shallower than the species range (30 m vs. 128 m).



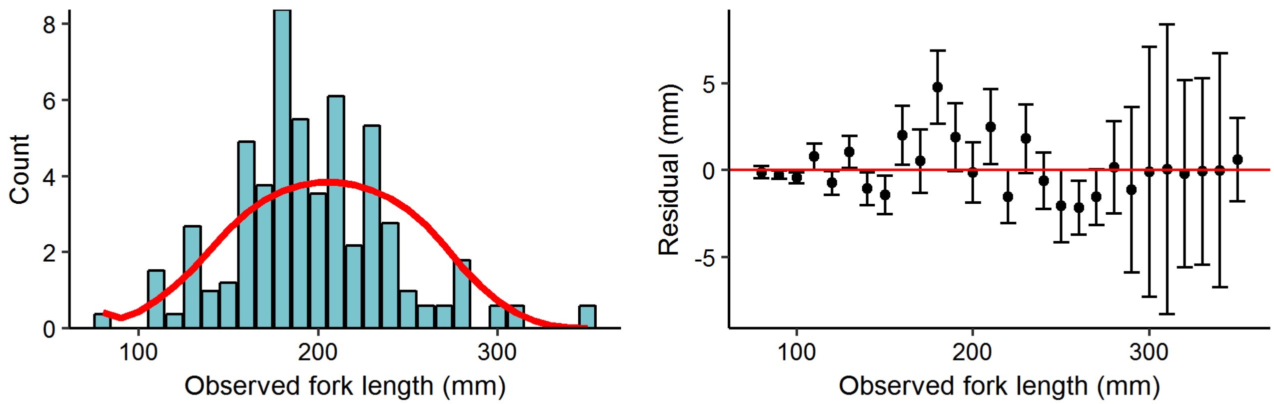
Life history parameter distributions. Red line indicates median value.



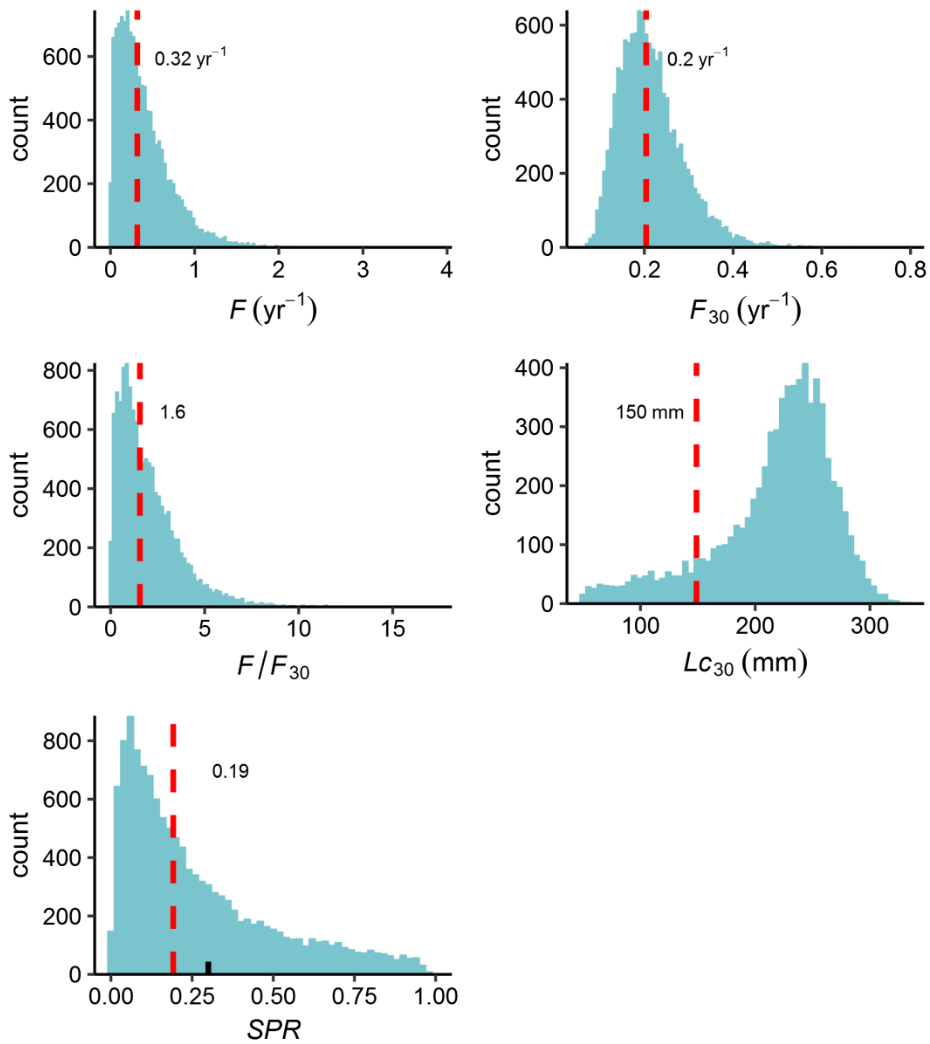
Abundance index from diver surveys (left; red triangles, ±SE) and total catch time series (right) from hook-and-line (blue), spear (green), and net (orange) fishing gears. Black line shows loess fit for total catch with 95% confidence interval (gray area).



Size structure from diver surveys (top left) and from the catch by fishing gear (top right) (hook-and-line: blue, spear: green). Average length time series (bottom) (hook-and-line: blue inverse triangles, spear: green circles, diver surveys: red upright triangles). Size of icons is proportional to sample size.

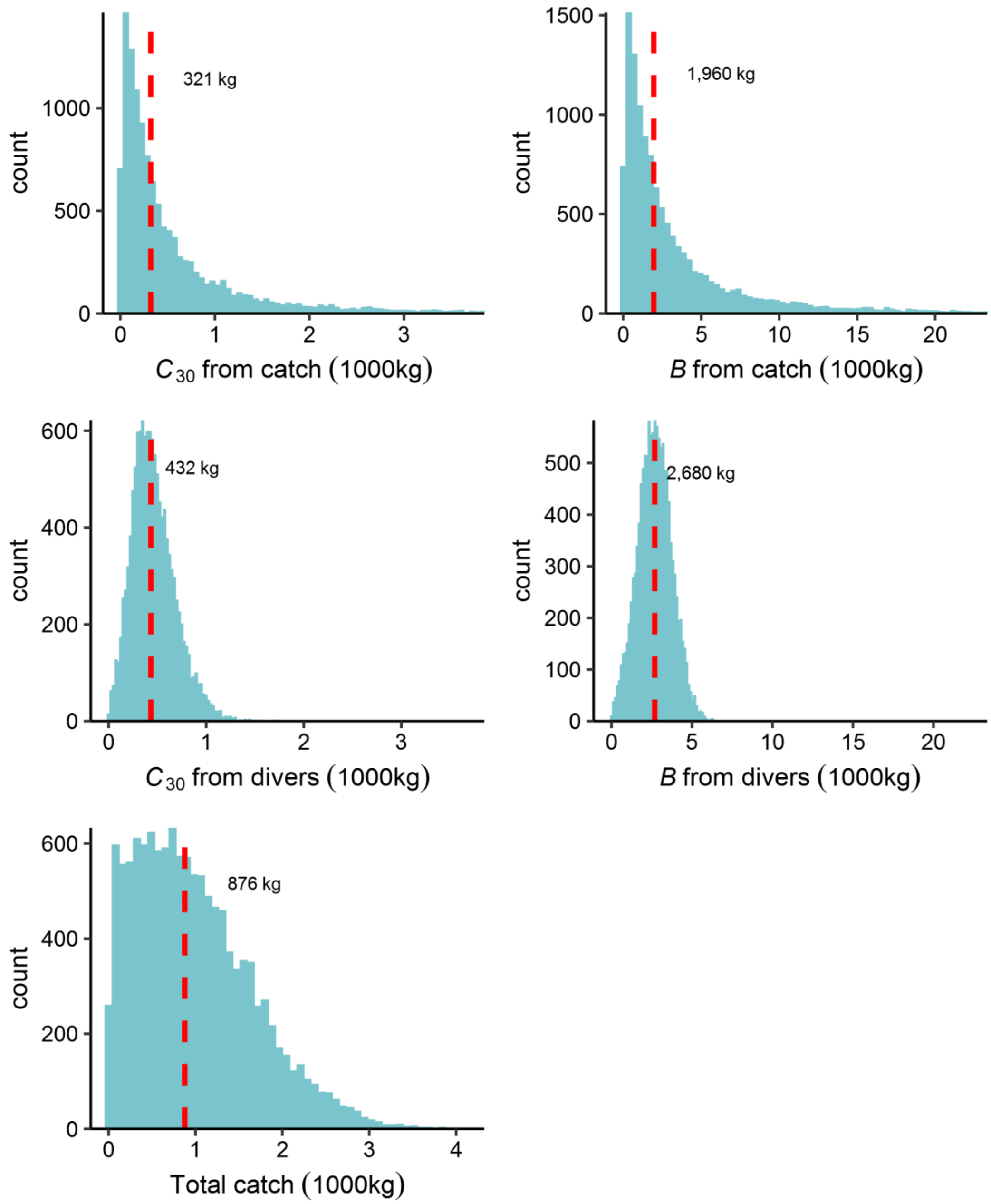


LBSPR model fit (left) and residuals (right).



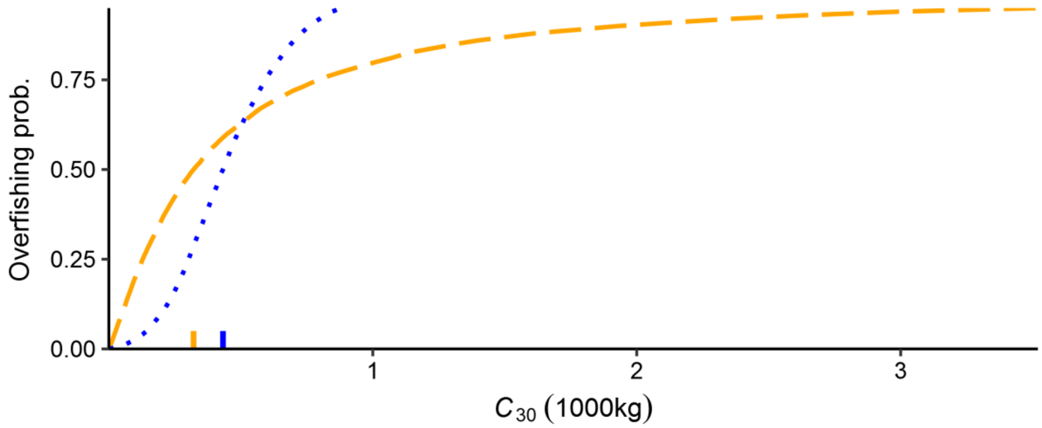
Stock status parameter distributions (*SPR*: small bar shows 0.30 level). Red line indicates median value.

Lutjanus fulvus



Distributions of *C*30 from catch (top left), *C*30 from diver survey biomass (middle left), and current total catch (bottom left), biomass from catch (top right), and biomass from diver surveys (middle right). Red line indicates median value.

Lutjanus fulvus



Overfishing probabilities for a range of C_{30} levels (derived from catch - orange dashed line, diver surveys - blue dotted line). *OFLs* are represented by small vertical bars.

Probability of overfishing for various C_{30} levels (reported in pounds).

Overfishing probability	C_{30} from catch (1000 lbs)	C_{30} from diver survey (1000 lbs)	Overfishing probability	C_{30} from catch (1000 lbs)	C_{30} from diver survey (1000 lbs)
0.05	0.057	0.315	0.28	0.324	0.701
0.06	0.066	0.344	0.29	0.337	0.712
0.07	0.077	0.368	0.30	0.353	0.723
0.08	0.088	0.395	0.31	0.368	0.734
0.09	0.101	0.419	0.32	0.384	0.747
0.10	0.112	0.443	0.33	0.397	0.758
0.11	0.123	0.465	0.34	0.412	0.769
0.12	0.134	0.481	0.35	0.428	0.783
0.13	0.143	0.500	0.36	0.441	0.791
0.14	0.154	0.516	0.37	0.456	0.802
0.15	0.165	0.536	0.38	0.474	0.814
0.16	0.176	0.549	0.39	0.492	0.827
0.17	0.187	0.562	0.40	0.507	0.838
0.18	0.198	0.578	0.41	0.525	0.849
0.19	0.209	0.591	0.42	0.542	0.862
0.20	0.223	0.604	0.43	0.562	0.873
0.21	0.234	0.617	0.44	0.580	0.884
0.22	0.247	0.631	0.45	0.600	0.897
0.23	0.260	0.642	0.46	0.619	0.908
0.24	0.271	0.655	0.47	0.639	0.917
0.25	0.282	0.666	0.48	0.664	0.928
0.26	0.295	0.677	0.49	0.683	0.939
0.27	0.311	0.688	0.50	0.708	0.952

Probability of overfishing at various minimum sizes.

Overfishing probability	Lc_{30} (mm)	Overfishing probability	Lc_{30} (mm)
0.05	273	0.28	229
0.06	270	0.29	228
0.07	267	0.30	226
0.08	265	0.31	224
0.09	262	0.32	223
0.10	260	0.33	221
0.11	258	0.34	218
0.12	256	0.35	216
0.13	254	0.36	214
0.14	253	0.37	212
0.15	251	0.38	209
0.16	250	0.39	207
0.17	248	0.40	203
0.18	246	0.41	200
0.19	244	0.42	197
0.20	243	0.43	192
0.21	241	0.44	188
0.22	239	0.45	183
0.23	238	0.46	178
0.24	236	0.47	172
0.25	234	0.48	165
0.26	233	0.49	157
0.27	231	0.50	149

Lutjanus gibbus

Humpback snapper, *fafa'et*
Lutjanidae (snappers)

Life history and other input parameters

Parameter	Value	SD	Unit	n	Source
L_{inf}	303	4	mm	166	Mean and SD: Nanami (2010)
K	0.25	0.03	yr^{-1}		
a_0	-3.25	-	yr		
L_{mat}	249	21	mm	88	Mean and SD: Taylor (unpublished)
CV L_{inf}	0.030	0.004	-	-	Mean and SD: Nanami (2010)
Longevity	27	2.5	yr	236	Mean and SD: Taylor (unpublished)
LW-alpha	1.53e-5	-	-	-	Kamikawa (2015)
LW-beta	3.06				
Max. depth	150	-	m	-	Pyle et al. (2014)

Stock status and other output parameters

Parameter	Median	SD	Unit
M	0.12	0.01	yr^{-1}
F	0.09	0.06	yr^{-1}
L_{S50}	249	7	mm
L_{S95}	291	11	mm
F_{30}	0.21	0.1	yr^{-1}
F/F_{30}	0.41	0.32	-
SPR	0.53	0.16	-
SPR < 0.30 iterations	5	-	%

Parameter	Median	SD	Unit
B from catch	3,020	8,740	kg
B from divers	560	532	kg
Boat-based catch	159	-	kg
Shore-based catch	59	-	kg
Total catch	218	303	kg
C_{30} from catch	533	1,380	kg
C_{30} from divers	111	98	kg
Lc_{30}	0	-	mm

General comments

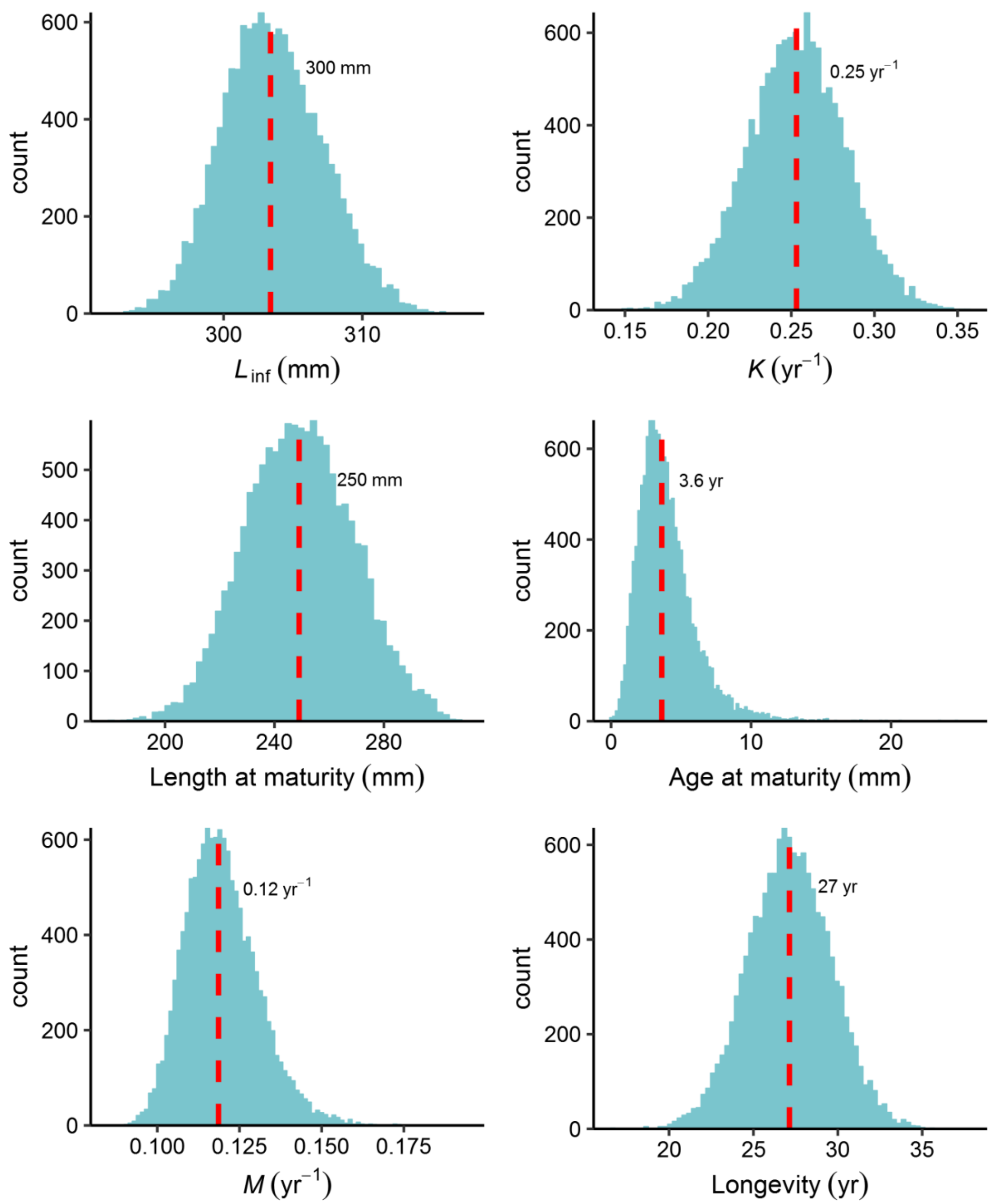
Total catch for this species can be highly variable from year to year, exceeding 1,000 kg a few times in the 1990s. Landings in recent years have been lower, at around 200 kg per year. Line fishing is the main fishing gear with a small peak in net fishing in 2013. Selectivity for both line and spear fishing were similar, allowing us to use the more abundant spear fishing data from the biosampling program. Average lengths were slightly higher between 1985 and 2000 and appear to have declined slightly since then. Population abundance from 2007 to 2017 has been mostly stable.

The life history parameters for this species are available from an Okinawa study (Nanami et al., 2010). Interestingly, this study showed clear growth differences between sexes, with males reaching much larger sizes than females (L_{inf} of 390 mm vs. 303 mm). This is apparent in the Guam size structure graph which shows a second peak corresponding to male counts. To correct for this, we obtained the sex ratio at size for this species from an unpublished data set from American Samoa (provided by B. Taylor, see below) and applied these size specific ratios to the Guam size structure data. The original vs. female-only size structure graphs are presented below. It was possible to apply the female growth curve from Nanami (2010) to the female-only size structure data to obtain an estimate of F and other metrics.

Population biomass estimate from the catch was higher than the diver survey-derived estimate. This difference may be explained by the high uncertainty associated with biomass obtained from the catch. Given this species' high mobility and depth range, it is likely that the higher catch-derived biomass estimate is more accurate.

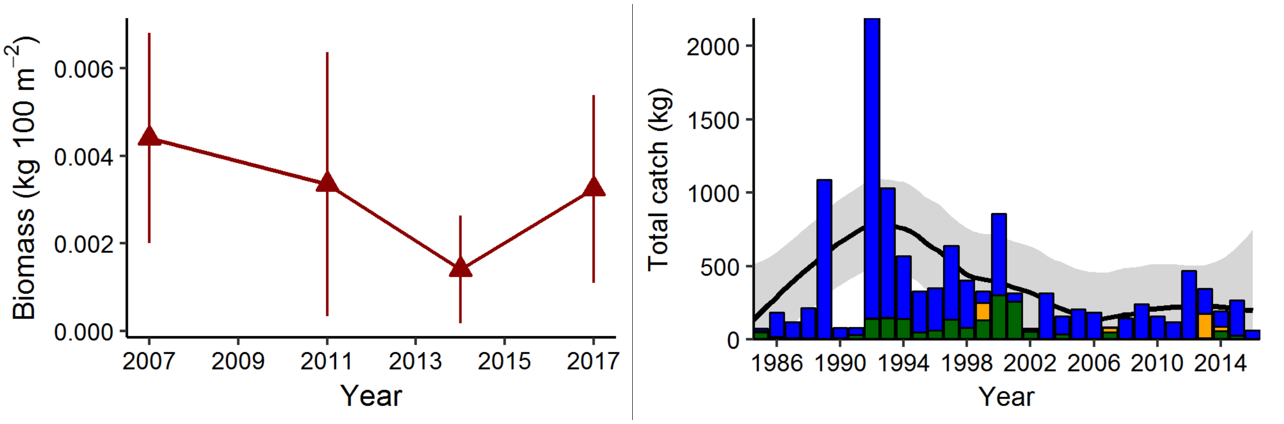
Note: size-specific female:male ratios from B. Taylor: 0-25cm: 0.50, 25-27cm: 0.72, 27-29cm: 0.85, 29-31cm: 0.57, 31-33cm: 0.35, and 33-45cm: 0.0.

Lutjanus gibbus

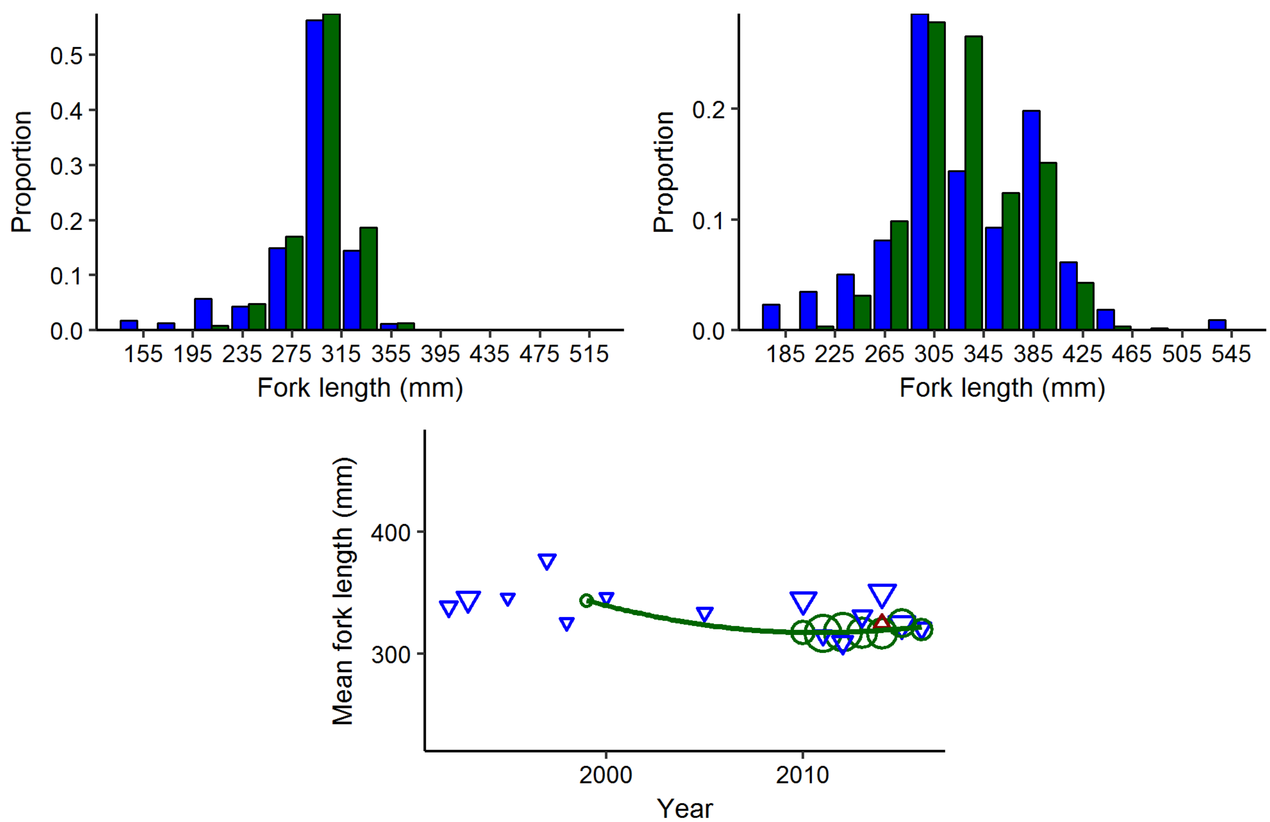


Life history parameter distributions. Red line indicates median value.

Lutjanus gibbus

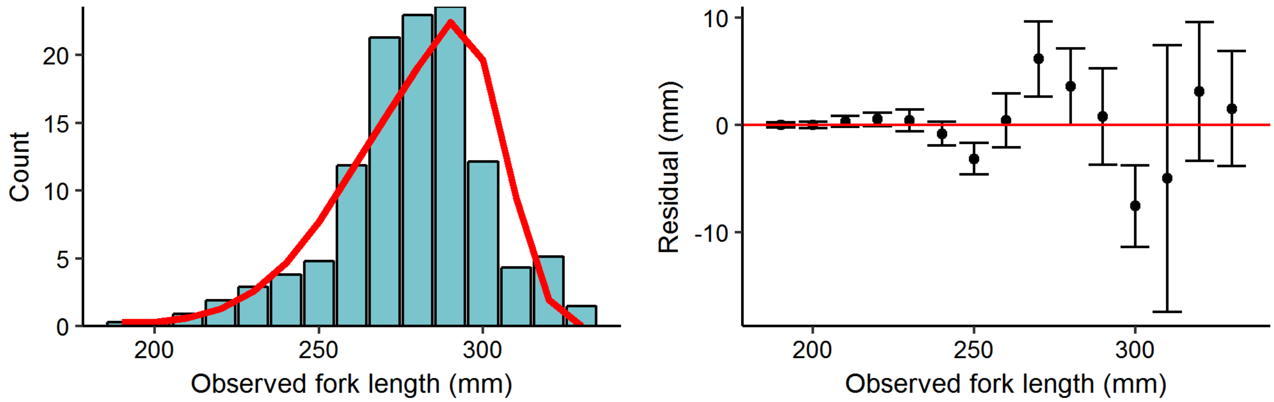


Abundance index from diver surveys (left; red triangles, ±SE) and total catch time series (right) from hook-and-line (blue), spear (green), and net (orange) fishing gears. Black line shows loess fit for total catch with 95% confidence interval (gray area).

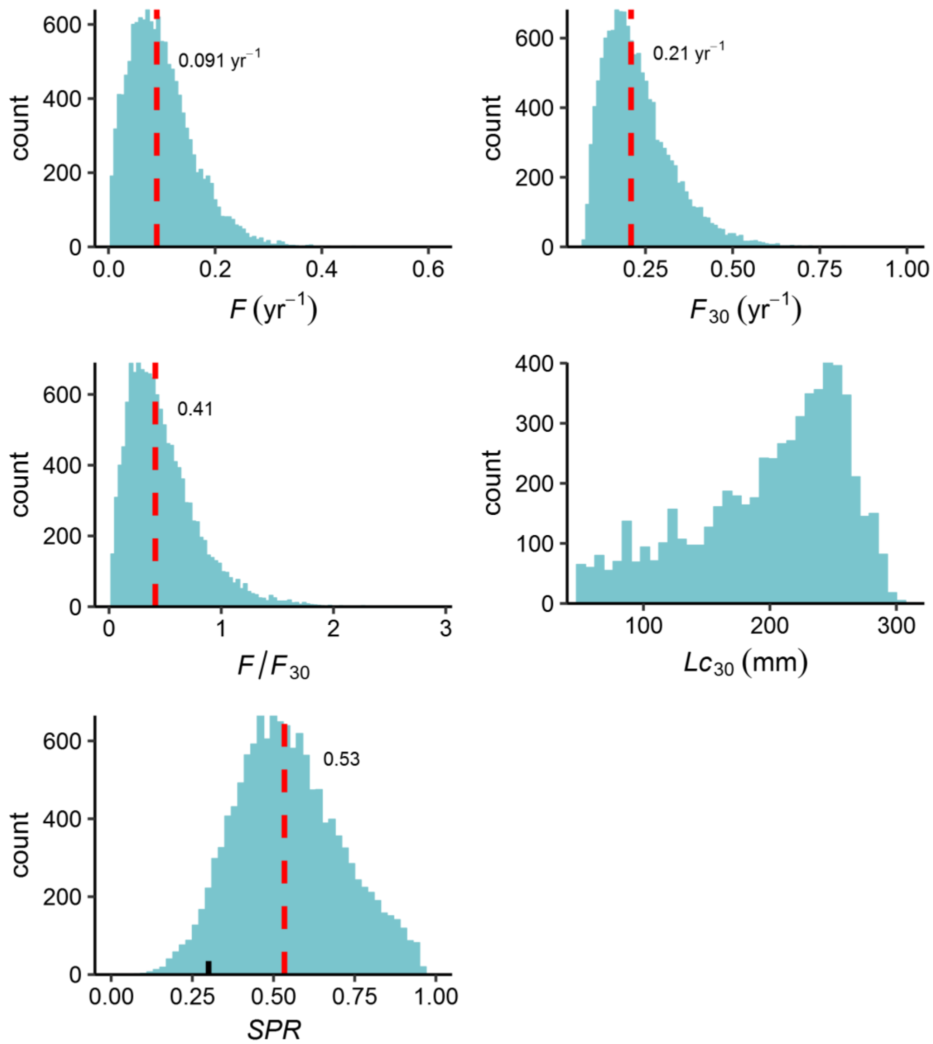


Size structure from the catch for females only (top left) and for both sexes (top right) by fishing gear (hook-and-line: blue, spear: green). Average length time series (bottom) (hook-and-line: blue inverse triangles, spear: green circles, diver surveys: red upright triangles). Size of icons is proportional to sample size.

Lutjanus gibbus

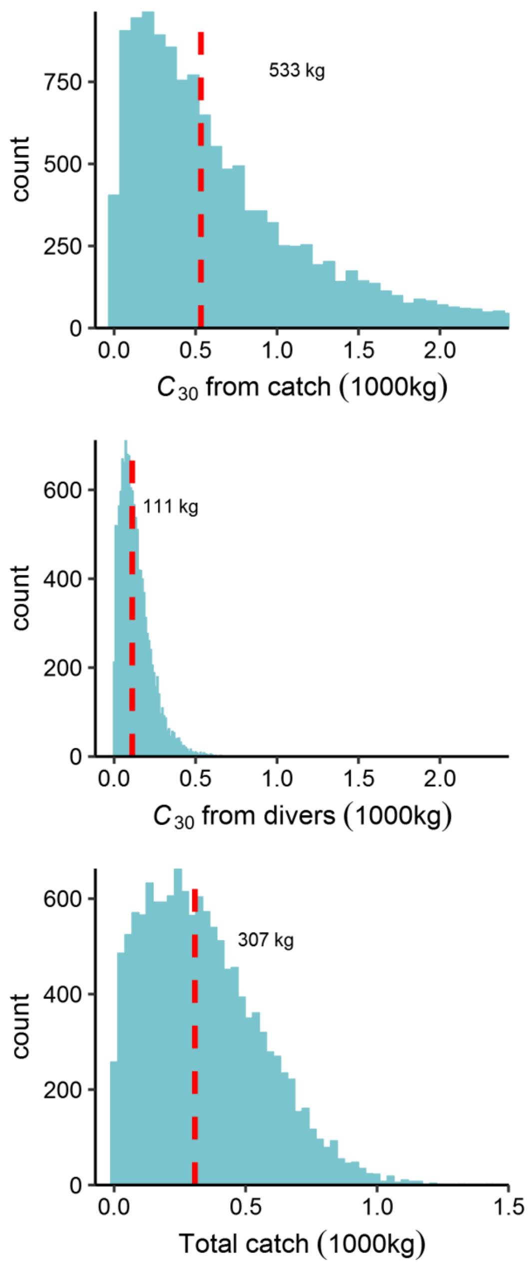


LBSPR model fit (left) and residuals (right).



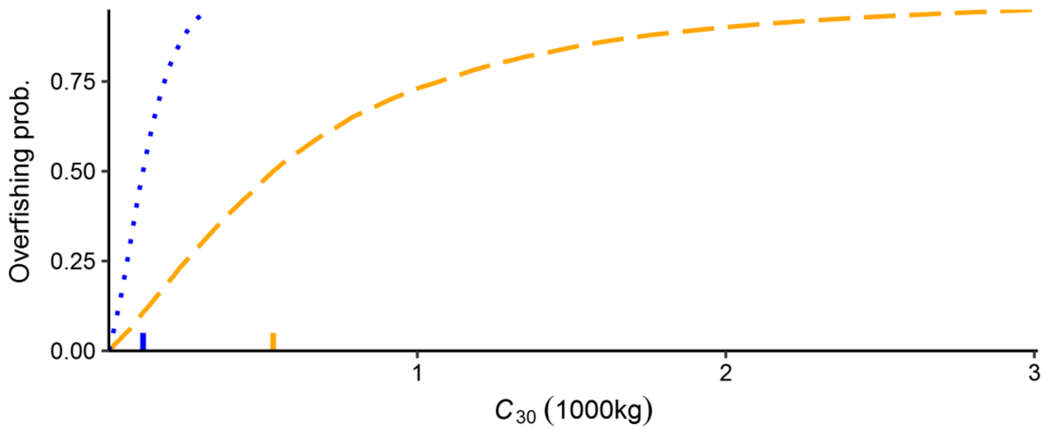
Stock status parameter distributions (*SPR*: small bar shows 0.30 level). Red line indicates median value.

Lutjanus gibbus



Distributions of C_{30} from catch (top left), C_{30} from diver survey biomass (middle left), and current total catch (bottom left), biomass from catch (top right), and biomass from diver surveys (middle right). Red line indicates median value.

Lutjanus gibbus



Overfishing probabilities for a range of C_{30} levels (derived from catch - orange dashed line, diver surveys - blue dotted line). *OFLs* are represented by small vertical bars.

Probability of overfishing for various C_{30} levels (reported in pounds).

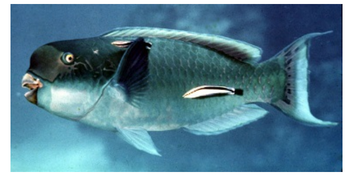
Overfishing probability	C_{30} from catch (1000 lbs)	C_{30} from diver survey (1000 lbs)	Overfishing probability	C_{30} from catch (1000 lbs)	C_{30} from diver survey (1000 lbs)
0.05	0.123	0.031	0.28	0.615	0.146
0.06	0.152	0.037	0.29	0.642	0.150
0.07	0.172	0.042	0.30	0.664	0.152
0.08	0.192	0.049	0.31	0.688	0.159
0.09	0.212	0.053	0.32	0.712	0.163
0.10	0.231	0.060	0.33	0.734	0.165
0.11	0.251	0.064	0.34	0.758	0.170
0.12	0.276	0.068	0.35	0.783	0.174
0.13	0.298	0.075	0.36	0.807	0.179
0.14	0.317	0.082	0.37	0.829	0.183
0.15	0.340	0.086	0.38	0.855	0.187
0.16	0.362	0.090	0.39	0.880	0.192
0.17	0.384	0.095	0.40	0.908	0.196
0.18	0.403	0.099	0.41	0.935	0.201
0.19	0.423	0.106	0.42	0.959	0.205
0.20	0.443	0.110	0.43	0.990	0.209
0.21	0.467	0.115	0.44	1.019	0.214
0.22	0.485	0.119	0.45	1.045	0.218
0.23	0.505	0.123	0.46	1.069	0.225
0.24	0.529	0.128	0.47	1.093	0.229
0.25	0.551	0.132	0.48	1.120	0.234
0.26	0.573	0.137	0.49	1.149	0.240
0.27	0.597	0.141	0.50	1.175	0.245

Lutjanus gibbus

Probability of overfishing at various minimum sizes.

Overfishing probability	Lc_{30} (mm)	Overfishing probability	Lc_{30} (mm)
0.05	263	0.28	194
0.06	260	0.29	189
0.07	258	0.30	184
0.08	255	0.31	179
0.09	252	0.32	174
0.10	250	0.33	169
0.11	248	0.34	162
0.12	245	0.35	156
0.13	243	0.36	149
0.14	241	0.37	140
0.15	238	0.38	132
0.16	235	0.39	123
0.17	232	0.40	114
0.18	230	0.41	103
0.19	226	0.42	95
0.20	224	0.43	84
0.21	220	0.44	71
0.22	217	0.45	59
0.23	213	0.46	0
0.24	211	0.47	0
0.25	206	0.48	0
0.26	202	0.49	0
0.27	198	0.50	0

Chlorurus microrhinos



Steephead parrotfish, *laggua*
Scaridae (parrotfishes)

Life history and other input parameters

Parameter	Value	SD	Unit	n	Source
L_{inf}	457	24	mm	80	Mean and SD: Taylor (2014)
K	0.34	0.04	yr^{-1}		
a_0	-0.097	-	yr		
L_{mat}	308	16	mm	80	Mean and SD: Taylor (2014)
CV L_{inf}	0.101	0.008	-	-	Mean and SD: Taylor (2014)
Longevity	11	2	yr	80	Mean and SD: Taylor (2014)
LW-alpha	1.48e-5	-	-	-	Kamikawa (2015)
LW-beta	3.07				
Max. depth	39	-	m	-	Mesophotic cruise 2014

Stock status and other output parameters

Parameter	Median	SD	Unit
M	0.29	0.06	yr^{-1}
F	0.27	0.17	yr^{-1}
L_{S50}	270	9	mm
L_{S95}	341	15	mm
F_{30}	0.31	0.06	yr^{-1}
F/F_{30}	0.8	0.5	-
SPR	0.36	0.19	-
SPR < 0.30 iterations	36	-	%

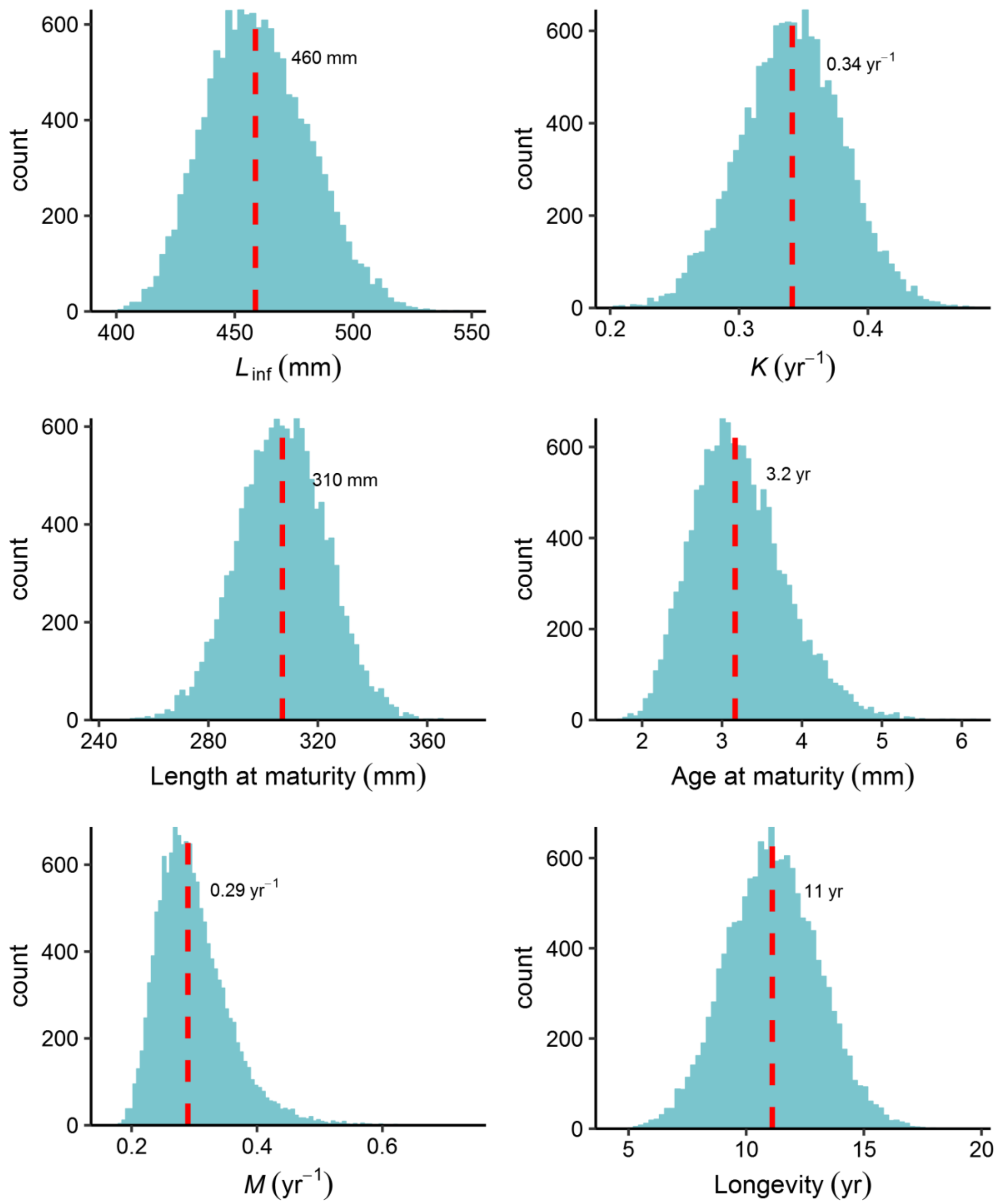
Parameter	Median	SD	Unit
B from catch	1,350	6,430	kg
B from divers	3,617	3,287	kg
Boat-based catch	121	-	kg
Shore-based catch	334	-	kg
Total catch	455	352	kg
C_{30} from catch	324	1,450	kg
C_{30} from divers	972	652	kg
Lc_{30}	230	-	mm

General comments

This species is caught almost exclusively through spear fishing (length data from this gear was used in the LBSPR analyses). Total catch per year for this species was relatively high between 1990 and 2005 at around 1,000 kg, but has been low in recent years (< 200 kg), except for an anomalous peak in 2013. Average length appears to have slowly decreased from 420 mm in 1985 to around 375 mm in recent years. Population abundance has been relatively stable since 2007, although the 2017 diver surveys reported a low biomass for that year.

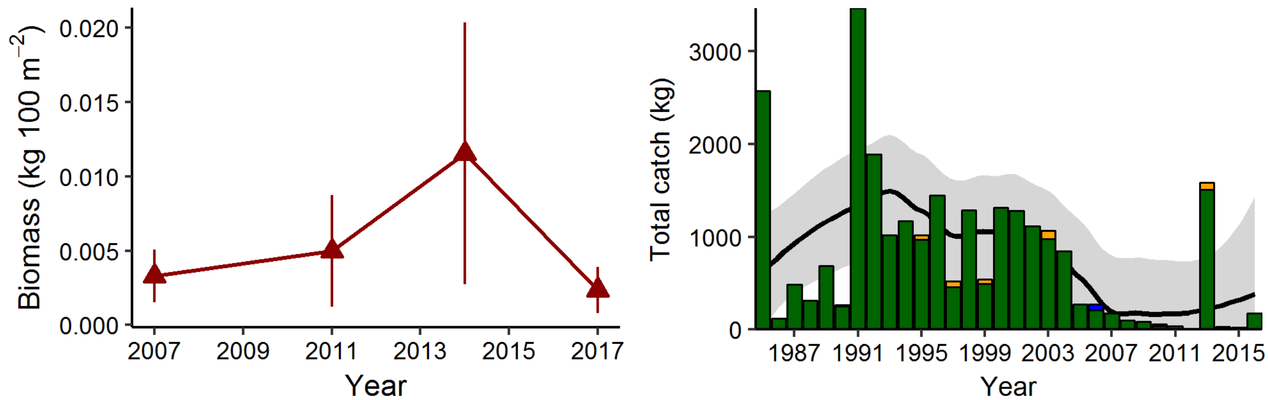
The life history parameters for this species come from a local study with a moderate sample size (n=80). The maximum age reported around Guam from that study was 11 years vs. 14 years for the Great Barrier Reef. This longevity difference could be related to the sample size, higher fishing pressure around Guam, and/or the higher local water temperature. A sensitivity run using a longevity of 14 years generated the following results: M: 0.23, F_{30}: 0.27, F: 0.32, SPR: 0.26, and diver-derived C_{30}: 899 kg.

The diver survey-derived biomass estimate was much larger than the one estimated from the catch (3,617 kg vs. 1,350 kg). The 2014 diver surveys generated a higher than usual biomass estimate which could be biasing our biomass estimate upward, if it was caused by a sampling error. Also, the unexpanded average biosampling catch per year for this species was only slightly lower than the expanded creel catch. This suggests that the creel survey spear fishing catch estimate may be underestimated, or that almost all spear fishing catch goes through one fisherman coop which is less likely (see Discussion section regarding issues with spear fishing creel surveys). The diver biomass estimate is probably more reliable than the one using catch data for this species.

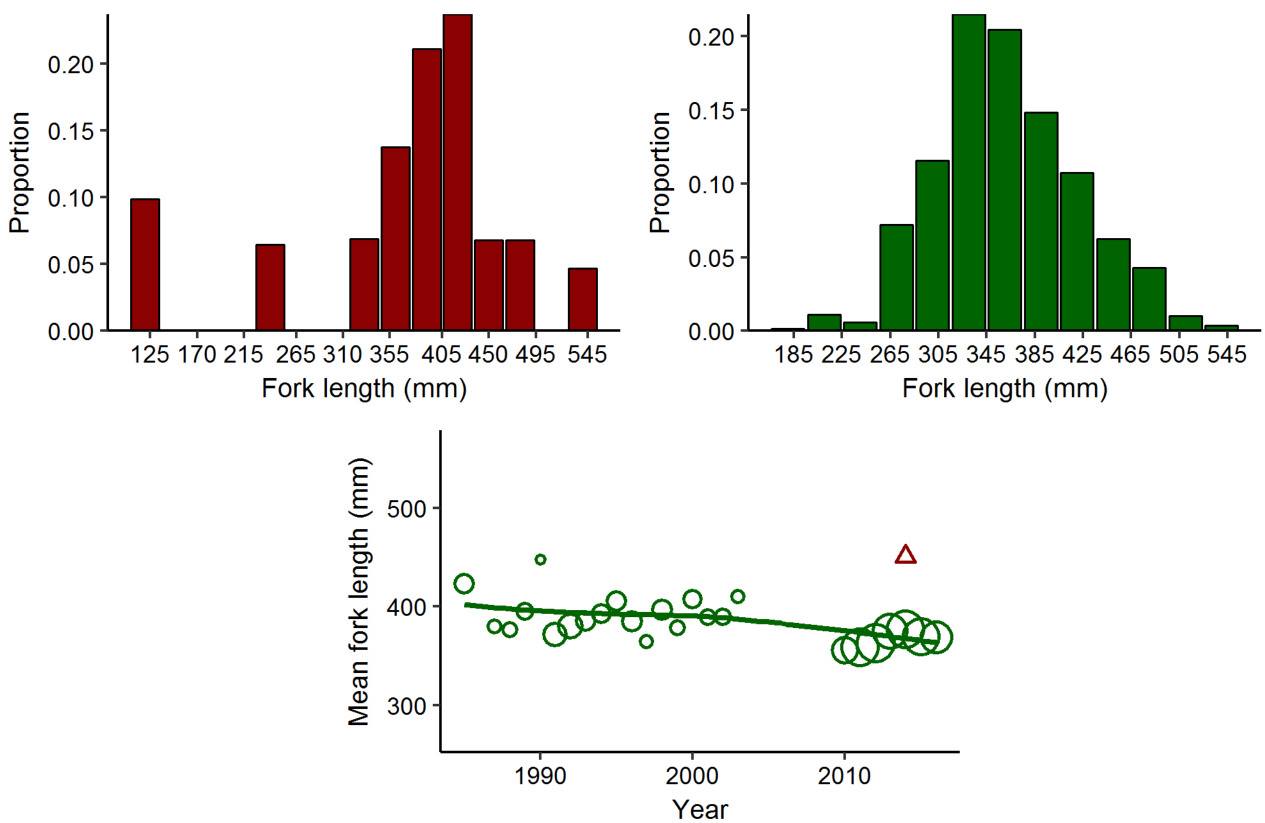


Life history parameter distributions. Red line indicates median value.

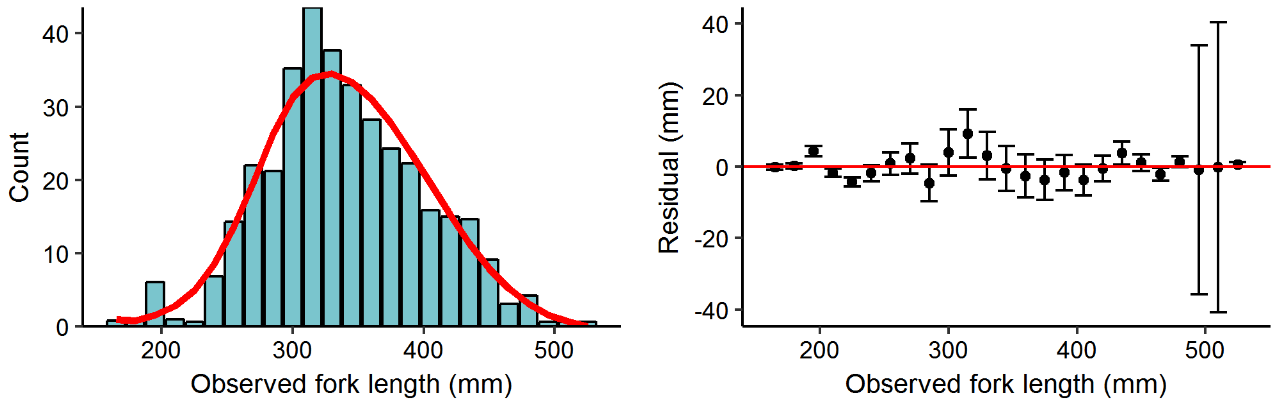
Chlorurus microrhinos



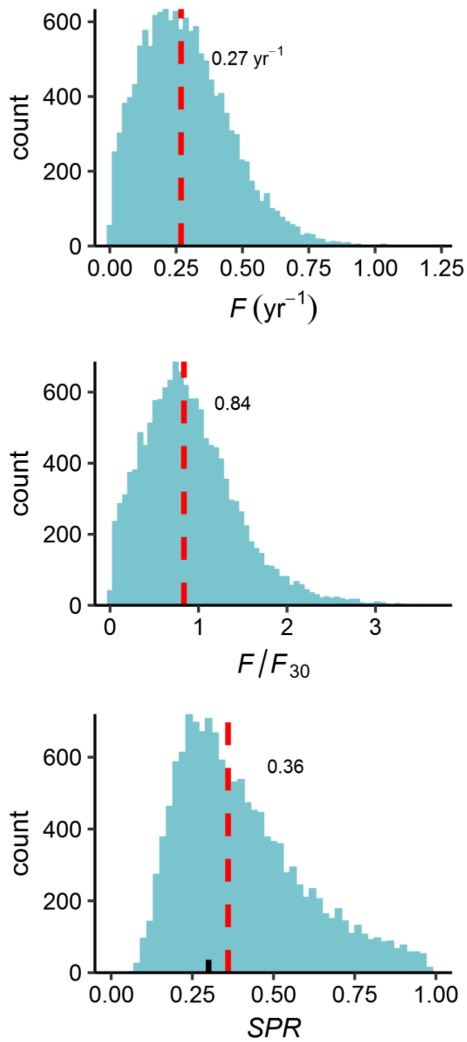
Abundance index from diver surveys (left; red triangles, ±SE) and total catch time series (right) from hook-and-line (blue), spear (green), and net (orange) fishing gears. Black line shows loess fit for total catch with 95% confidence interval (gray area).



Size structure from diver surveys (top left) and from the catch by fishing gear (top right) (hook-and-line: blue, spear: green, net: orange). Average length time series (bottom) (spear: green circles, diver surveys: red upright triangles). Size of icons is proportional to sample size.

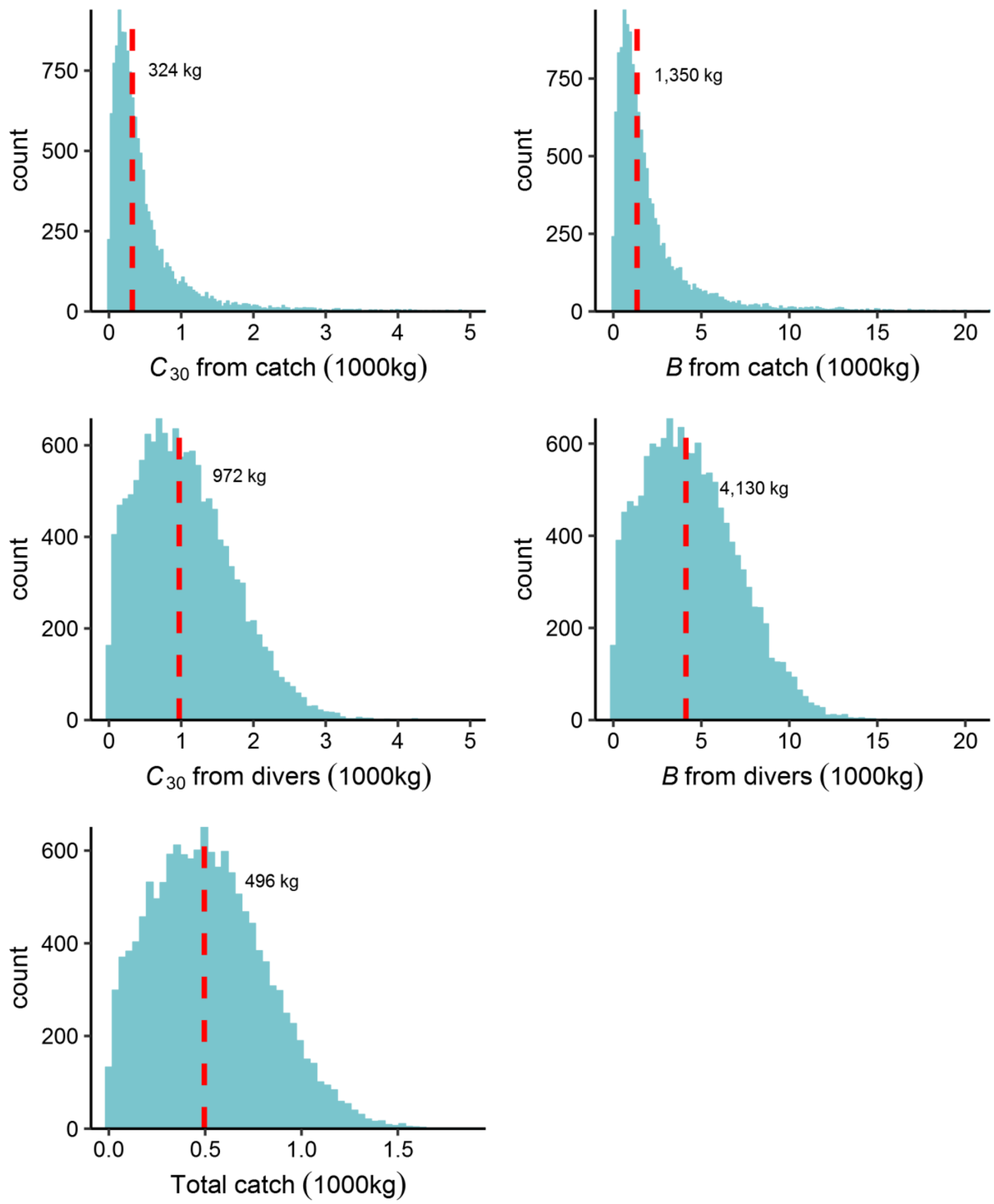


LBSPR model fit (left) and residuals (right).

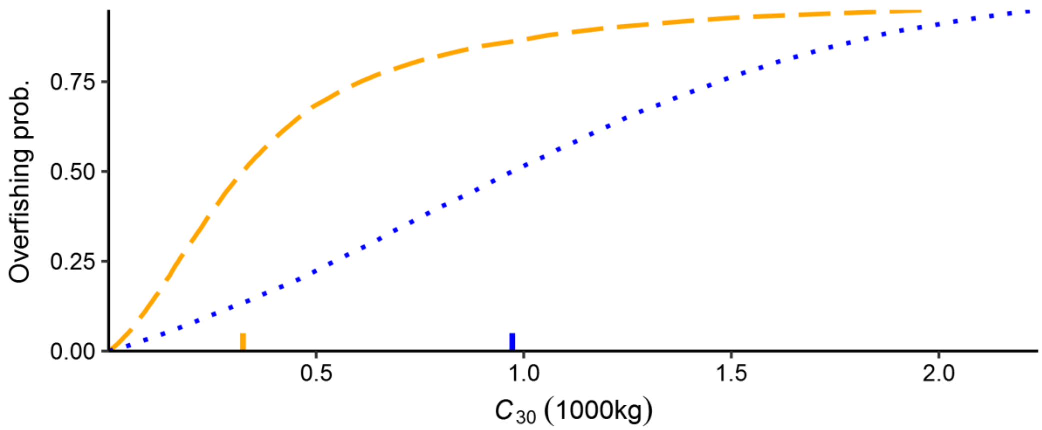


Stock status parameter distributions (*SPR*: small bar shows 0.30 level). Red line indicates median value.

Chlorurus microrhinos



Distributions of C_{30} from catch (top left), C_{30} from diver survey biomass (middle left), and current total catch (bottom left), biomass from catch (top right), and biomass from diver surveys (middle right). Red line indicates median value.



Overfishing probabilities for a range of C_{30} levels (derived from catch - orange dashed line, diver surveys - blue dotted line). *OFLs* are represented by small vertical bars.

Probability of overfishing for various C_{30} levels (reported in pounds).

Overfishing probability	C_{30} from catch (1000 lbs)	C_{30} from diver survey (1000 lbs)	Overfishing probability	C_{30} from catch (1000 lbs)	C_{30} from diver survey (1000 lbs)
0.05	0.104	0.300	0.28	0.408	1.316
0.06	0.119	0.351	0.29	0.421	1.356
0.07	0.134	0.401	0.30	0.434	1.400
0.08	0.150	0.450	0.31	0.448	1.431
0.09	0.163	0.498	0.32	0.461	1.462
0.10	0.179	0.547	0.33	0.474	1.497
0.11	0.194	0.595	0.34	0.487	1.534
0.12	0.205	0.642	0.35	0.500	1.574
0.13	0.220	0.688	0.36	0.511	1.609
0.14	0.234	0.741	0.37	0.525	1.642
0.15	0.247	0.785	0.38	0.536	1.684
0.16	0.260	0.829	0.39	0.549	1.717
0.17	0.273	0.873	0.40	0.564	1.755
0.18	0.287	0.922	0.41	0.580	1.799
0.19	0.298	0.966	0.42	0.593	1.839
0.20	0.311	1.010	0.43	0.606	1.878
0.21	0.324	1.047	0.44	0.619	1.922
0.22	0.335	1.089	0.45	0.635	1.958
0.23	0.346	1.122	0.46	0.650	1.991
0.24	0.357	1.162	0.47	0.666	2.030
0.25	0.370	1.199	0.48	0.679	2.066
0.26	0.381	1.237	0.49	0.697	2.103
0.27	0.395	1.276	0.50	0.714	2.143

Chlorurus microrhinos

Probability of overfishing at various minimum sizes.

Overfishing probability	Lc_{30} (mm)	Overfishing probability	Lc_{30} (mm)
0.05	355	0.28	309
0.06	352	0.29	307
0.07	349	0.30	305
0.08	346	0.31	303
0.09	344	0.32	300
0.10	342	0.33	298
0.11	340	0.34	295
0.12	338	0.35	293
0.13	336	0.36	290
0.14	334	0.37	287
0.15	332	0.38	283
0.16	330	0.39	280
0.17	329	0.40	277
0.18	327	0.41	274
0.19	325	0.42	270
0.20	324	0.43	266
0.21	322	0.44	261
0.22	320	0.45	257
0.23	318	0.46	252
0.24	317	0.47	247
0.25	315	0.48	242
0.26	313	0.49	236
0.27	311	0.50	230

Hipposcarus longiceps

Pacific longnose parrotfish, *gualafi*
Scaridae (parrotfish)

Life history and other input parameters

Parameter	Value	SD	Unit	n	Source
L_{inf}	461	14	mm	279	Mean and SD: Taylor (unpublished)
K	0.41	0.05	yr^{-1}		
a_0	-1.03	-	yr		
L_{mat}	327	17	mm	33	Mean and SD: Taylor (2014)
CV L_{inf}	0.07	0.005	-	-	Mean and SD: Taylor (unpublished)
Longevity	10	0.8	yr	279	Mean and SD: Taylor (unpublished)
LW-alpha	1.43e-5	-	-	-	Kamikawa (2015)
LW-beta	3.05				
Max. depth	35	-	m	-	Baited camera Guam

Stock status and other output parameters

Parameter	Median	SD	Unit
M	0.31	0.06	yr^{-1}
F	0.17	0.12	yr^{-1}
L_{S50}	287	11	mm
L_{S95}	371	18	mm
F_{30}	0.35	0.07	yr^{-1}
F/F_{30}	0.50	0.34	-
SPR	0.52	0.19	-
SPR < 0.30 iterations	9	-	%

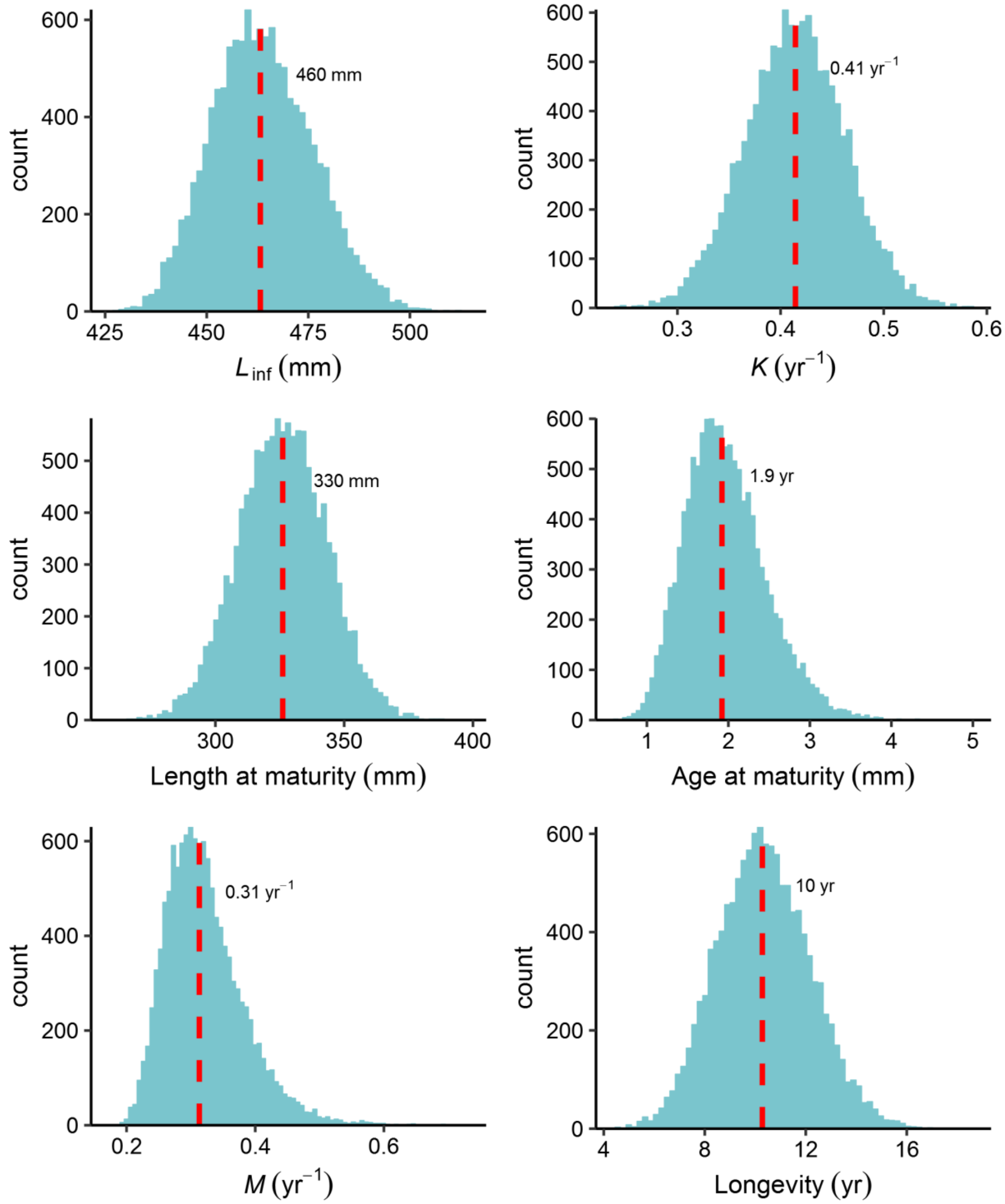
Parameter	Median	SD	Unit
B from catch	4,130	19,200	kg
B from divers	5,051	4,108	kg
Boat-based catch	526	-	kg
Shore-based catch	171	-	kg
Total catch	698	902	kg
C_{30} from catch	1,060	4,770	kg
C_{30} from divers	1,420	922	kg
Lc_{30}	0	-	mm

General comments

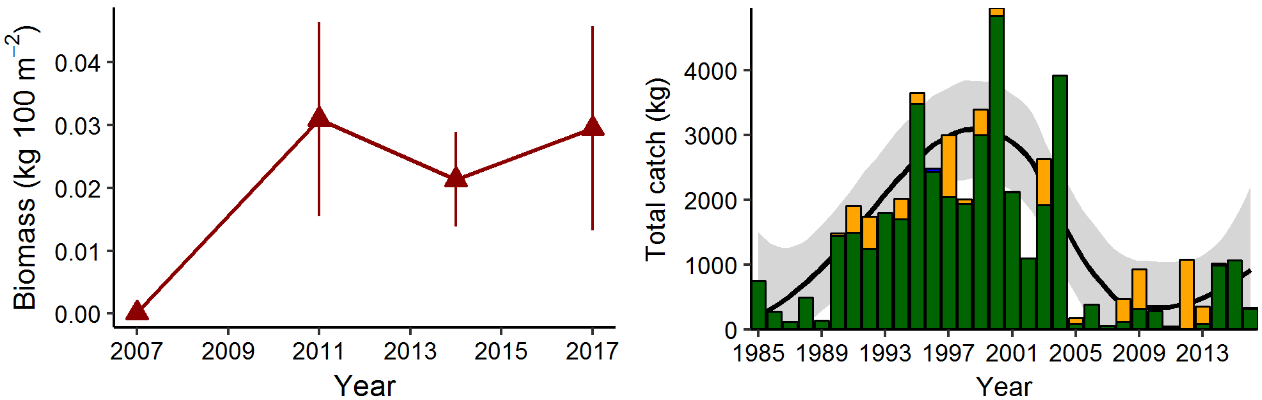
This species is caught almost entirely by spear fishing (length data from this gear was used in the LBSPR analyses). The yearly total catch increased dramatically starting in 1985, peaked around 1998 (~3,000 kg), before falling to very low values. The catch in recent years has been slightly increasing to about 700 kg. Population abundance has been mostly stable since 2011 (the low estimate in 2007 may be related to low sample size during the diver surveys for that year). Average length was higher in the 1990-2000 decade and appears to be declining slightly in recent years.

The life history parameters for this species come from an extensive local data set that is not yet published (B. Taylor).

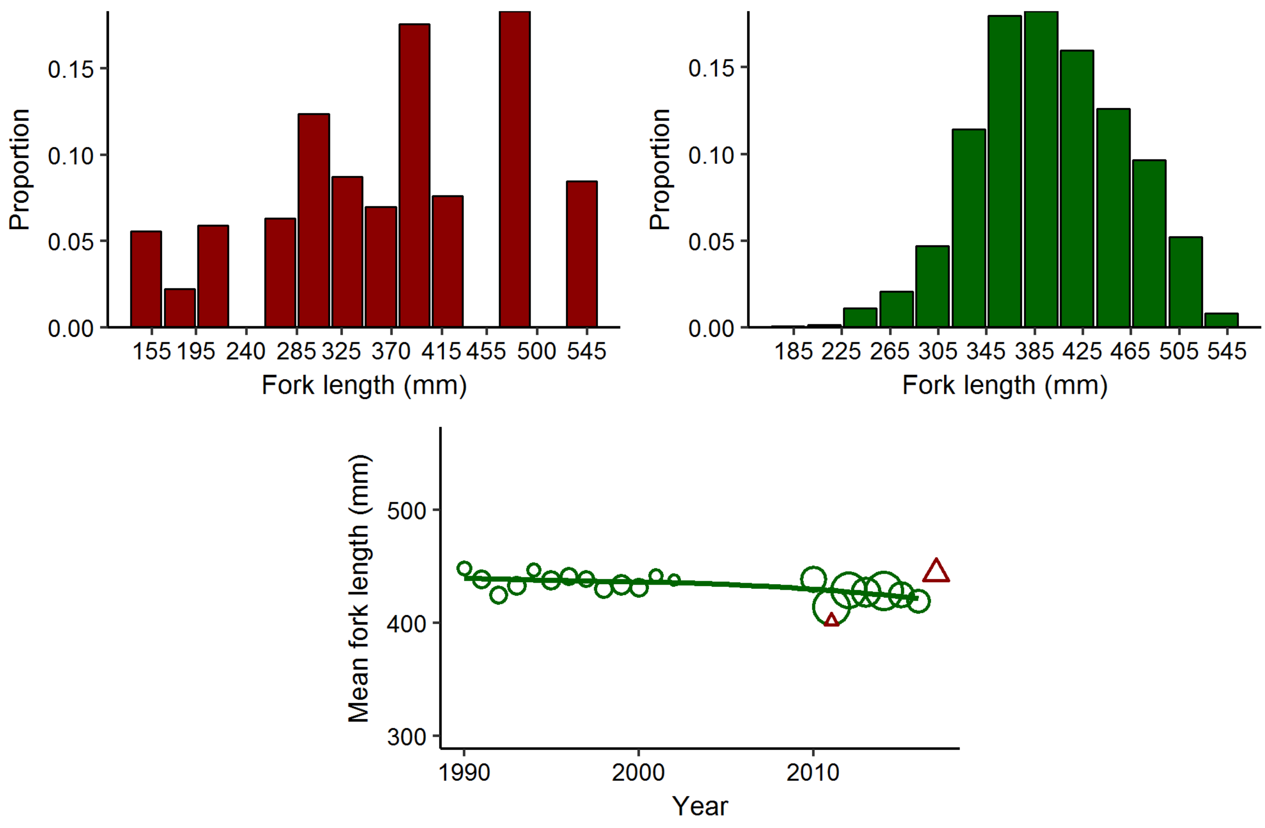
The diver survey-derived population biomass estimate was fairly closed to the catch-derived estimate. The diver biomass estimate is likely more reliable than the one using catch data for this species given that this is an easily identifiable species which is often encountered by divers.



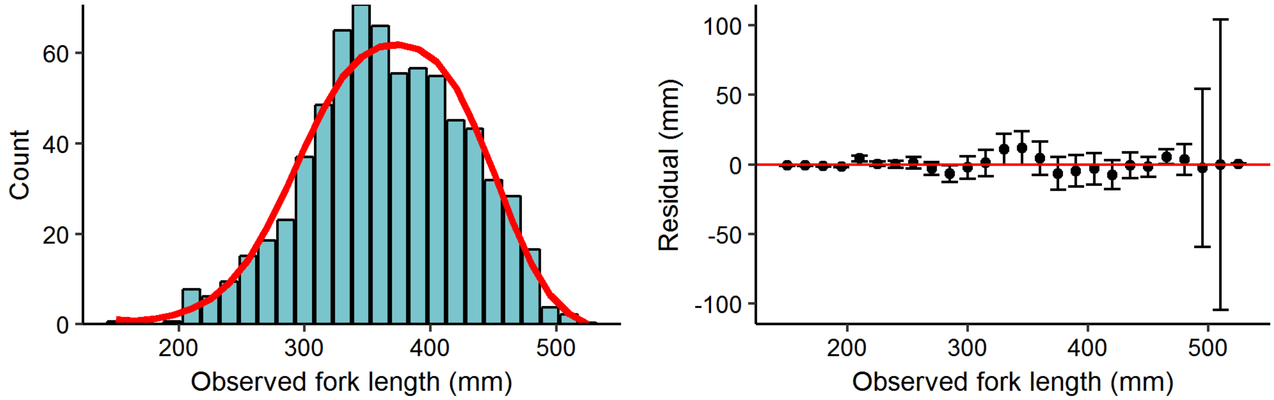
Life history parameter distributions. Red line indicates median value.



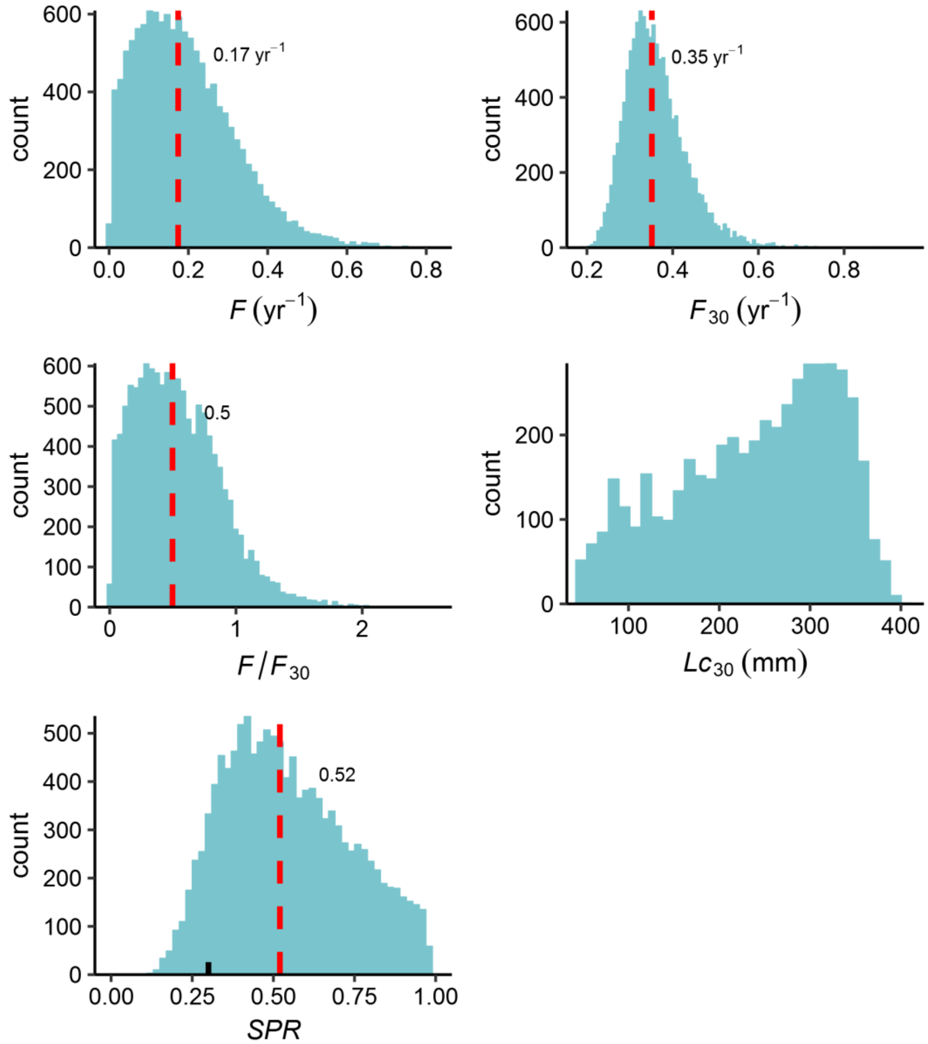
Abundance index from diver surveys (left; red triangles, ±SE) and total catch time series (right) from spear (green), and net (orange) fishing gears. Black line shows loess fit for total catch with 95% confidence interval (gray area).



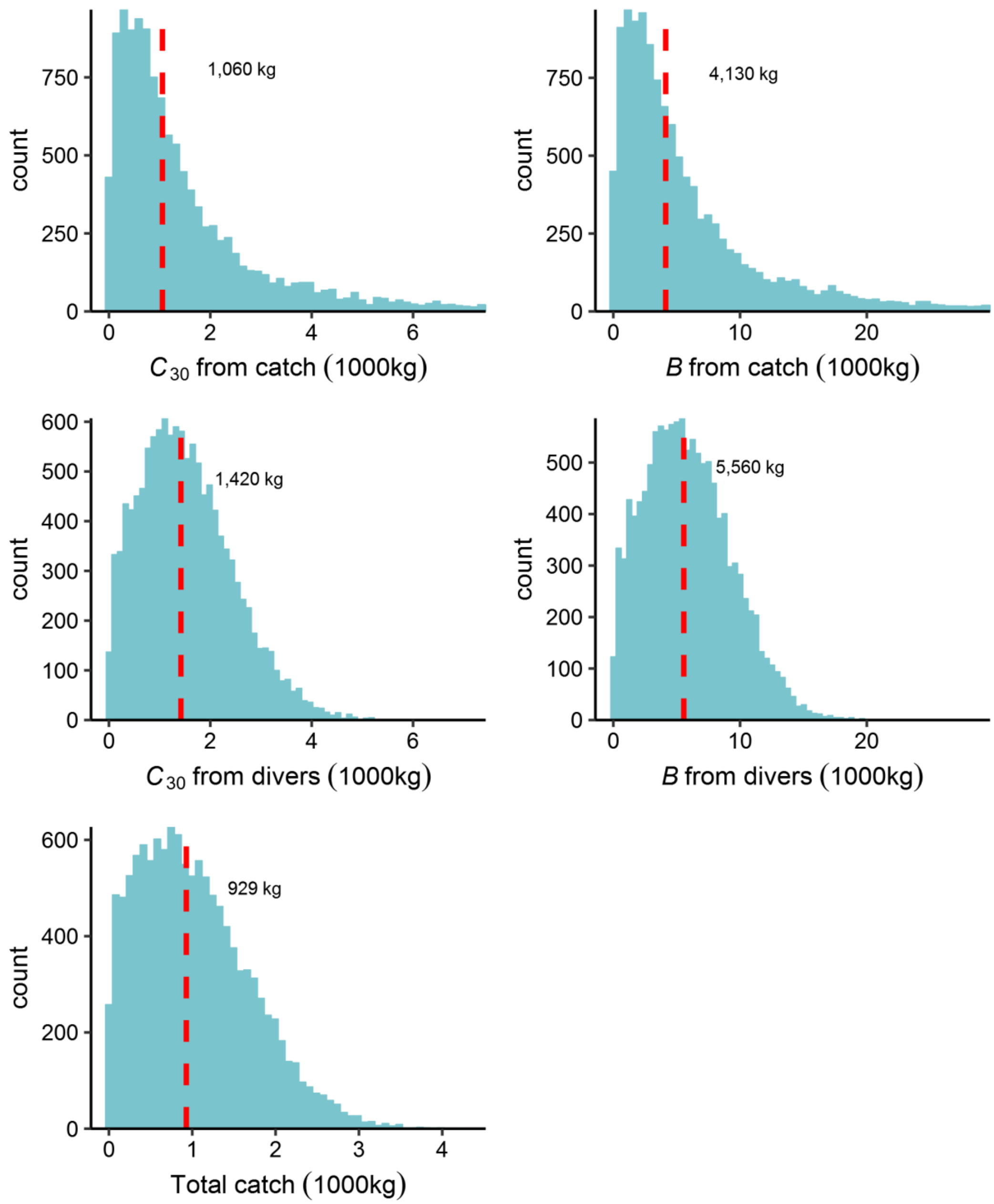
Size structure from diver surveys (top left) and from the catch by fishing gear (top right) (spear: green). Average length time series (bottom) (spear: green circles, diver surveys: red upright triangles). Size of icons is proportional to sample size.



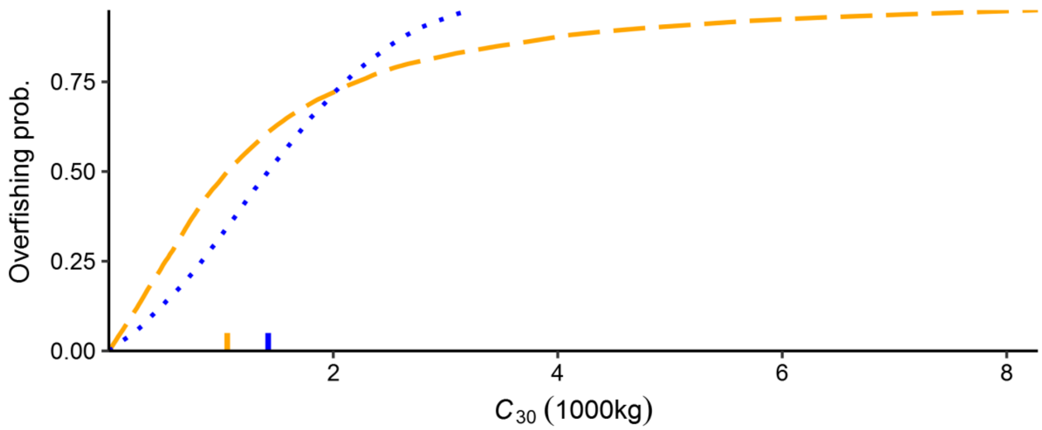
LBSPR model fit (left) and residuals (right).



Stock status parameter distributions (*SPR*: small bar shows 0.30 level). Red line indicates median value.



Distributions of C_{30} from catch (top left), C_{30} from diver survey biomass (middle left), and current total catch (bottom left), biomass from catch (top right), and biomass from diver surveys (middle right). Red line indicates median value.



Overfishing probabilities for a range of C_{30} levels (derived from catch - orange dashed line, diver surveys - blue dotted line). *OFLs* are represented by small vertical bars.

Probability of overfishing for various C_{30} levels (reported in pounds).

Overfishing probability	C_{30} from catch (1000 lbs)	C_{30} from diver survey (1000 lbs)	Overfishing probability	C_{30} from catch (1000 lbs)	C_{30} from diver survey (1000 lbs)
0.05	0.234	0.481	0.28	1.257	1.986
0.06	0.280	0.571	0.29	1.296	2.037
0.07	0.324	0.655	0.30	1.340	2.103
0.08	0.373	0.728	0.31	1.380	2.152
0.09	0.412	0.789	0.32	1.422	2.196
0.10	0.459	0.860	0.33	1.464	2.249
0.11	0.505	0.933	0.34	1.501	2.297
0.12	0.553	1.003	0.35	1.545	2.352
0.13	0.593	1.076	0.36	1.587	2.405
0.14	0.637	1.138	0.37	1.634	2.458
0.15	0.679	1.208	0.38	1.682	2.511
0.16	0.719	1.281	0.39	1.728	2.555
0.17	0.758	1.347	0.40	1.775	2.608
0.18	0.802	1.418	0.41	1.819	2.659
0.19	0.847	1.473	0.42	1.872	2.707
0.20	0.895	1.541	0.43	1.922	2.765
0.21	0.937	1.601	0.44	1.980	2.818
0.22	0.988	1.664	0.45	2.033	2.859
0.23	1.027	1.722	0.46	2.099	2.917
0.24	1.067	1.775	0.47	2.161	2.974
0.25	1.111	1.825	0.48	2.216	3.025
0.26	1.164	1.881	0.49	2.271	3.075
0.27	1.204	1.936	0.50	2.326	3.131

Hipposcarus longiceps

Probability of overfishing at various minimum sizes.

Overfishing probability	Lc_{30} (mm)	Overfishing probability	Lc_{30} (mm)
0.05	338	0.28	185
0.06	332	0.29	178
0.07	327	0.30	168
0.08	322	0.31	154
0.09	316	0.32	143
0.10	311	0.33	133
0.11	305	0.34	116
0.12	300	0.35	105
0.13	295	0.36	96
0.14	289	0.37	79
0.15	284	0.38	61
0.16	278	0.39	0
0.17	272	0.40	0
0.18	265	0.41	0
0.19	257	0.42	0
0.20	249	0.43	0
0.21	243	0.44	0
0.22	236	0.45	0
0.23	228	0.46	0
0.24	220	0.47	0
0.25	212	0.48	0
0.26	203	0.49	0
0.27	194	0.50	0

Scarus altipinnis

Filament-finned parrotfish, *laggua*
Scaridae (parrotfishes)

Life history and other input parameters

Parameter	Value	SD	Unit	n	Source
L_{inf}	336	13	mm	53	Mean and SD: Taylor (unpubl.)
K	0.47	0.08	yr^{-1}		
a_0	-0.86	-	yr		
L_{mat}	251	11	mm	53	Mean and SD: Taylor (2014.)
CV L_{inf}	0.1162	0.0113	-	-	Mean and SD: Taylor (unpubl.)
Longevity	14	2.4	yr	53	Mean and SD: Taylor (2014)
LW-alpha	2.06e-5	-	-	-	Kamikawa (2015)
LW-beta	3				
Max. depth	30	-	m	-	Baited camera Guam

Stock status and other output parameters

Parameter	Median	SD	Unit
M	0.22	0.04	yr^{-1}
F	0.14	0.15	yr^{-1}
L_{S50}	268	10	mm
L_{S95}	315	15	mm
F_{30}	0.44	0.14	yr^{-1}
F/F_{30}	0.30	0.31	-
SPR	0.60	0.20	-
$SPR < 0.30$ iterations	5	-	%

Parameter	Median	SD	Unit
B from catch	-	-	kg
B from divers	-	-	kg
Boat-based catch	-	-	kg
Shore-based catch	-	-	kg
Total catch	-	-	kg
C_{30} from catch	-	-	kg
C_{30} from divers	-	-	kg
Lc_{30}	0	-	mm

General comments

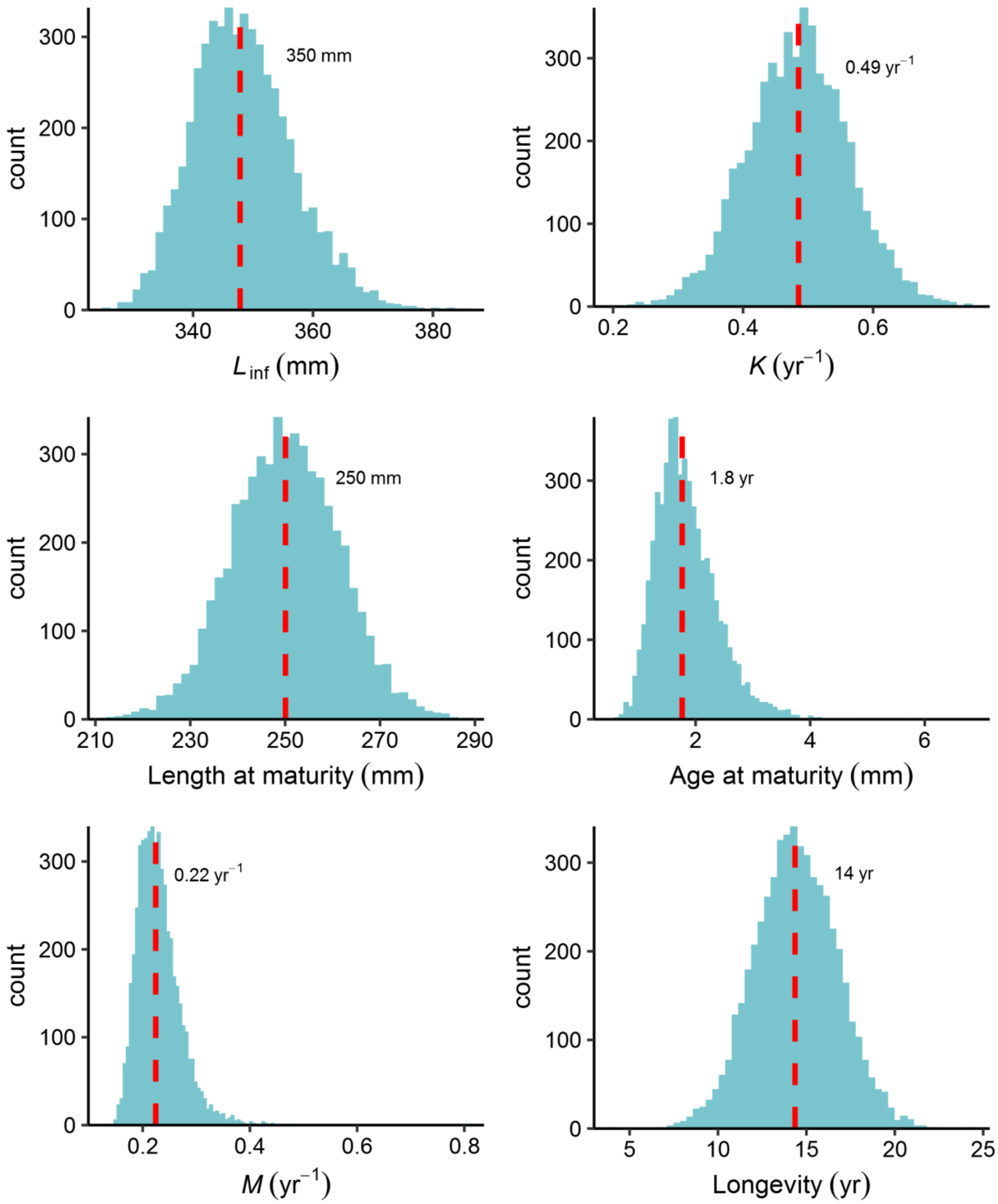
This species is caught almost entirely by spear fishing (length data from this gear was used in the LBSPR analyses). The yearly total catch increased dramatically from 1985 to around 2004, before falling to very low values. The catch in recent years seems to be increasing, but the yearly catches are highly variable (with an extreme value in 2013, which may be a sampling anomaly). Population abundance was fairly high in 2011, but this may also be due to a sampling error. Average length was higher in the 1990-2000 decade and appears to be declining slightly in recent years.

The life history parameters for this species come from an extensive local data set that is not yet published (B. Taylor).

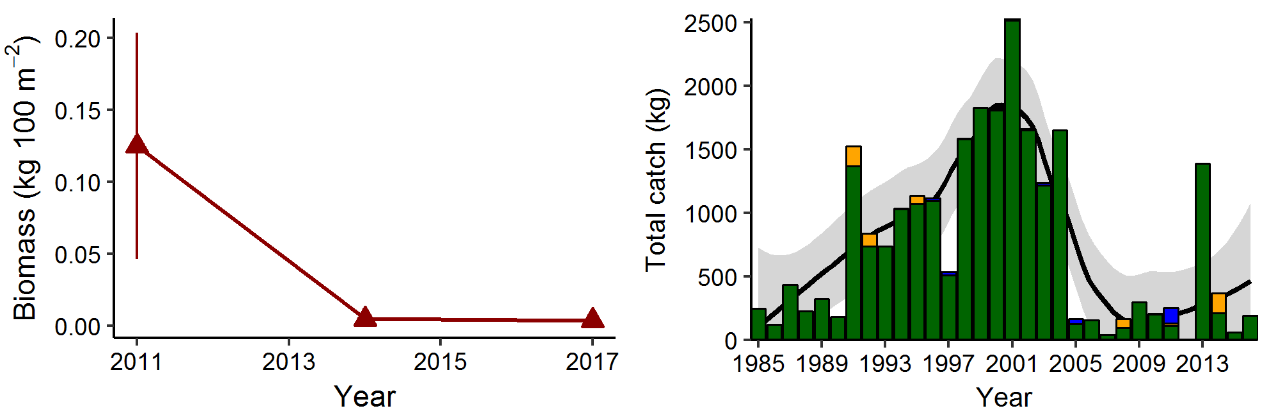
The catch-derived biomass estimate was much higher than the diver survey-derived biomass one. This is likely related to the high uncertainty associated with the catch-derived biomass estimates as well as the depth limitation of the diver surveys (note: the 30 m depth range estimated for this species is likely an underestimate, given that most parrotfish species occur below this depth).

C_{30} and OFL estimates for this species were deemed too uncertain and are not presented here.

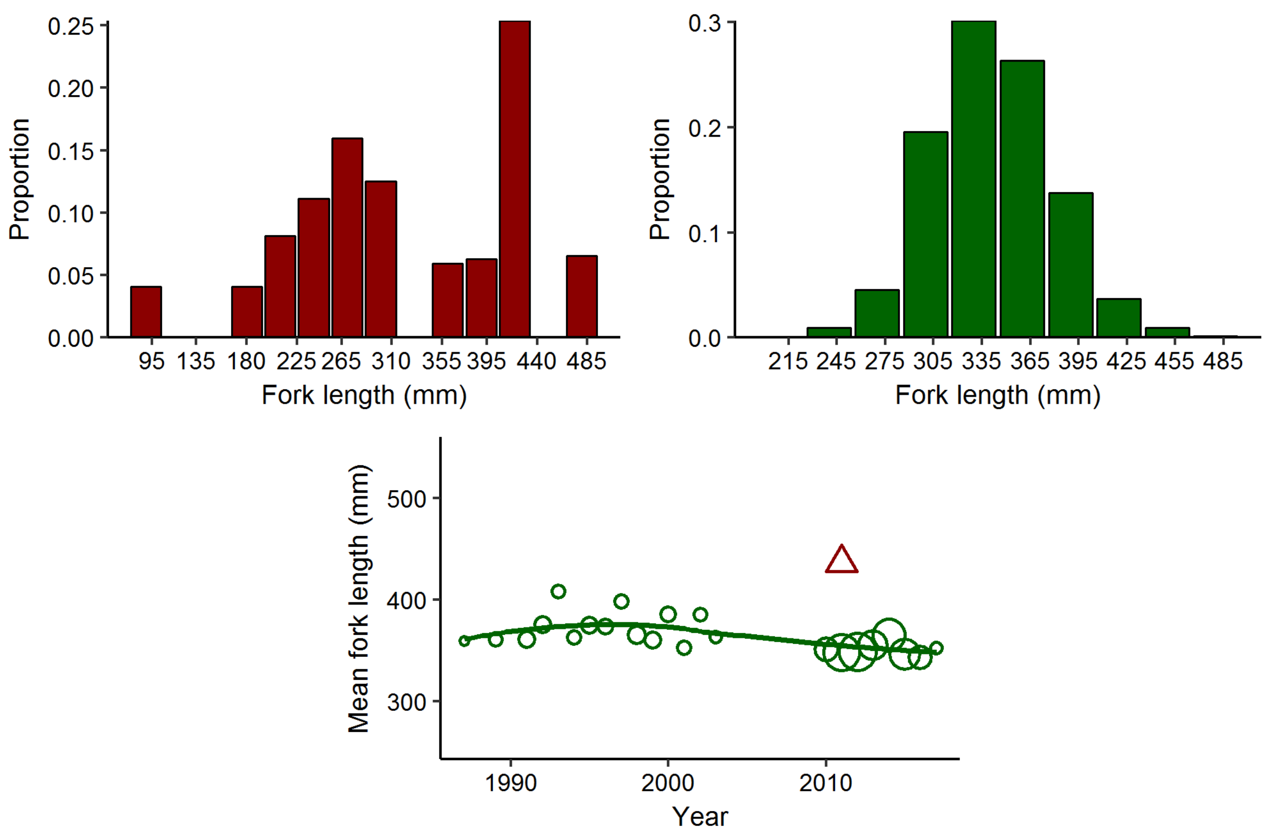
Scarus altipinnis



Life history parameter distributions. Red line indicates median value.

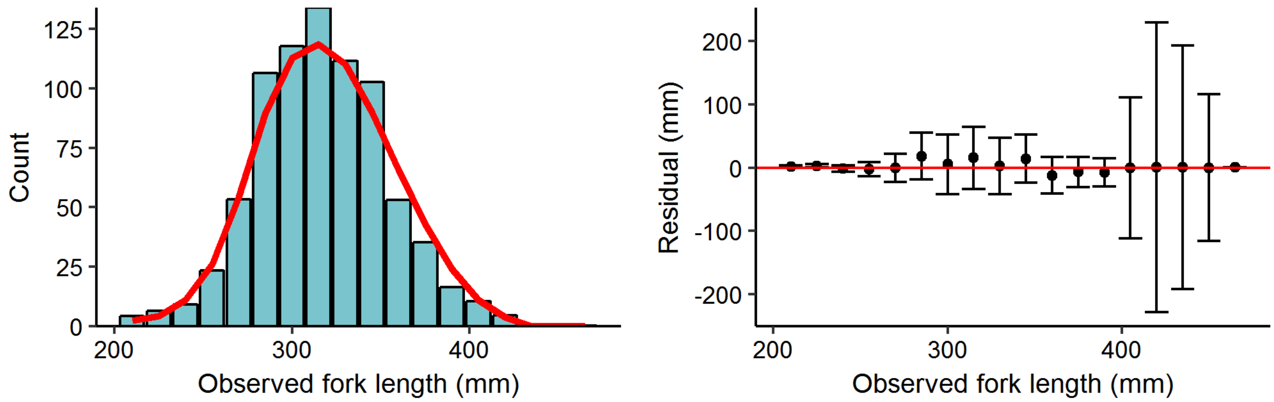


Abundance index from diver surveys (left; red triangles, ±SE) and total catch time series (right) from hook-and-line (blue), spear (green), and net (orange) fishing gears. Black line shows loess fit for total catch with 95% confidence interval (gray area).

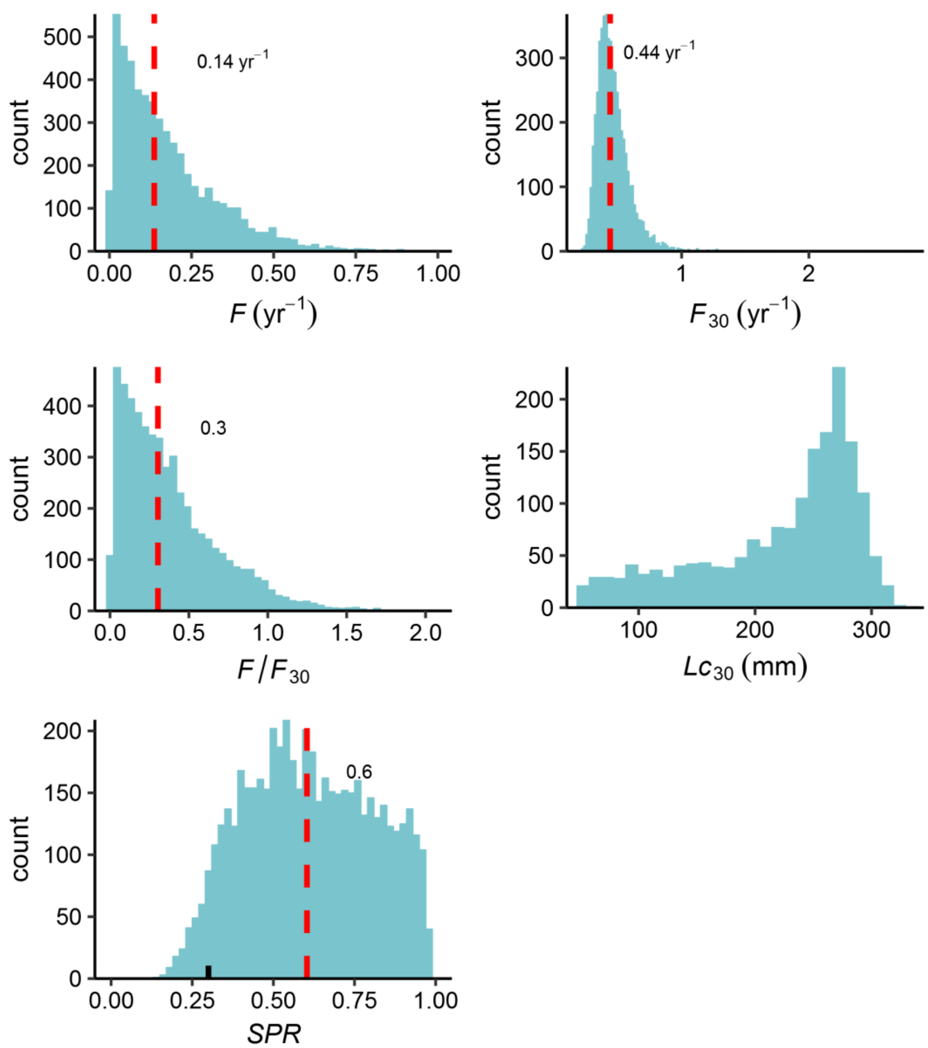


Size structure from diver surveys (top left) and from the catch by fishing gear (top right) (spear: green). Average length time series (bottom) (spear: green circles, diver surveys: red upright triangles). Size of icons is proportional to sample size.

Scarus altipinnis



LBSPR model fit (left) and residuals (right).



Stock status parameter distributions (*SPR*: small bar shows 0.30 level). Red line indicates median value.

Probability of overfishing at various minimum sizes.

Overfishing probability	Lc_{30} (mm)	Overfishing probability	Lc_{30} (mm)
0.05	283	0.28	144
0.06	279	0.29	130
0.07	276	0.30	111
0.08	274	0.31	96
0.09	271	0.32	81
0.10	269	0.33	61
0.11	266	0.34	0
0.12	263	0.35	0
0.13	260	0.36	0
0.14	257	0.37	0
0.15	253	0.38	0
0.16	250	0.39	0
0.17	246	0.40	0
0.18	241	0.41	0
0.19	234	0.42	0
0.20	228	0.43	0
0.21	220	0.44	0
0.22	213	0.45	0
0.23	203	0.46	0
0.24	195	0.47	0
0.25	184	0.48	0
0.26	171	0.49	0
0.27	156	0.50	0

Scarus rubroviolaceus

Redlip parrotfish, *laggua*
Scaridae (parrotfishes)

Life history and other input parameters

Parameter	Value	SD	Unit	n	Source
L_{inf}	424	40	mm	55	Mean and SD: Taylor (unpubl.)
K	0.31	0.11	yr^{-1}		
a_0	-1.34	-	yr		
L_{mat}	271	8	mm	55	Mean and SD: Taylor (2014)
CV L_{inf}	0.080	0.008	-	-	Mean and SD: Howard (2008)
Longevity	22	2	yr	182	Mean: Howard (2008), SD: Kritzer (2001)
LW-alpha	8.26e-5	-	-	-	Kamikawa (2015)
LW-beta	3.14				
Max. depth	68	-	m	-	Pyle et al. (2014)

Stock status and other output parameters

Parameter	Median	SD	Unit
M	0.15	0.01	yr^{-1}
F	0.35	0.38	yr^{-1}
L_{S50}	281	19	mm
L_{S95}	343	33	mm
F_{30}	0.23	0.04	yr^{-1}
F/F_{30}	1.4	1.5	-
SPR	0.21	0.21	-
SPR < 0.30 iterations	65	-	%

Parameter	Median	SD	Unit
B from catch	-	-	kg
B from divers	-	-	kg
Boat-based catch	-	-	kg
Shore-based catch	-	-	kg
Total catch	-	-	kg
C_{30} from catch	-	-	kg
C_{30} from divers	-	-	kg
Lc_{30}	318	-	mm

General comments

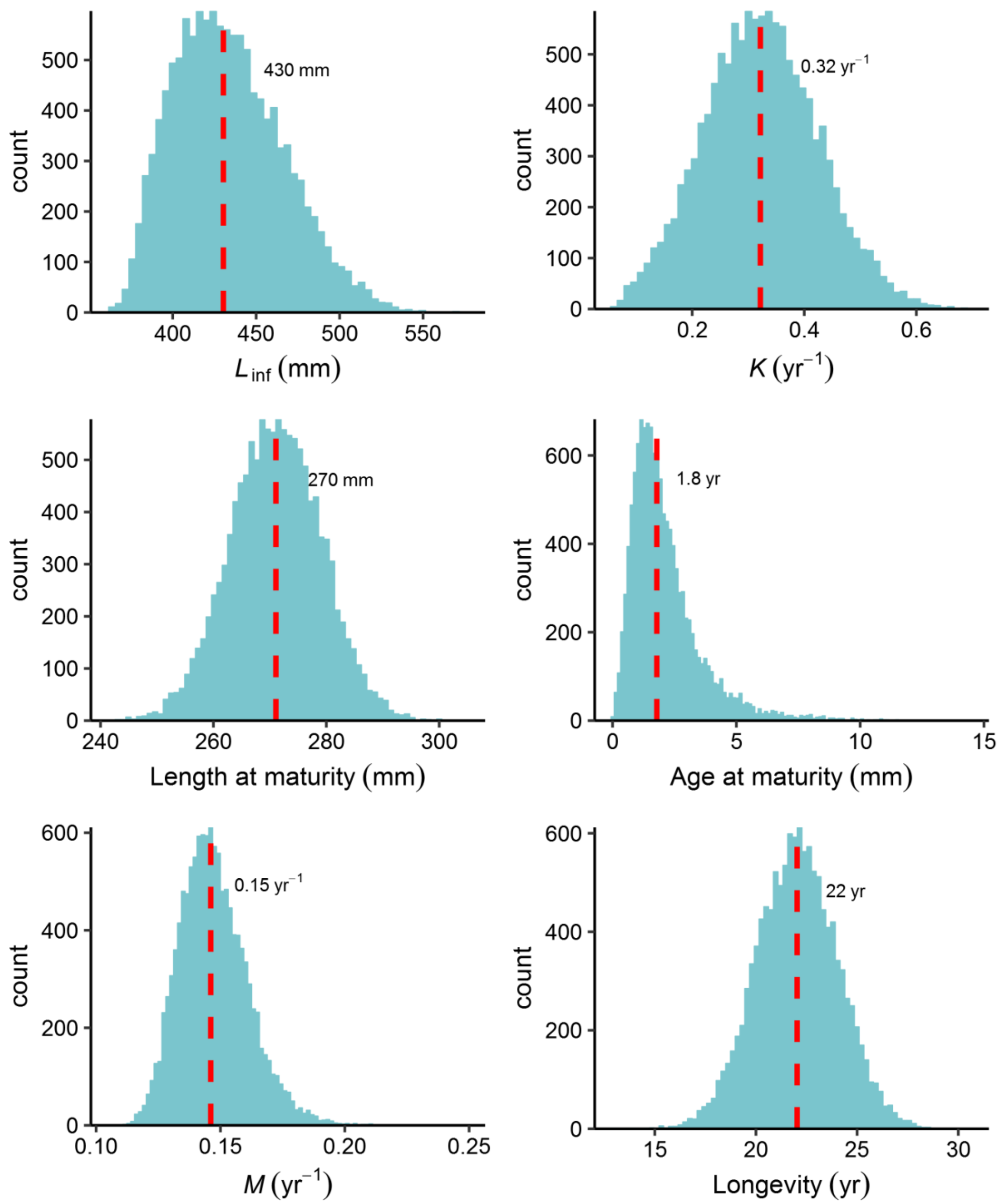
This species is caught almost entirely by spear fishing (length data from this gear was used in the LBSPR analyses). The total catch estimates were generally between 500 kg and 1,000 kg from 1985 to 2007 after which the species catch declines (current catch estimate is around 200 kg per year). This decline in catch may have been caused by a reported increased difficulty in obtaining spear fishing catch interviews. The biosampling data set shows yearly catches for this species between 40 kg and 431 kg per year in the last 6 years. These numbers are simply the sum of all reported *S. rubroviolaceus* in that data set and are not expanded by fishing effort; the real catch is likely even higher.

Population abundance in recent years appears relatively stable (the 2011 abundance peak is likely a sampling anomaly and this should be confirmed in future surveys). Average length from spear fishing has been declining since 1985 when it was 425 mm. but appears stable in recent years at around 390 mm.

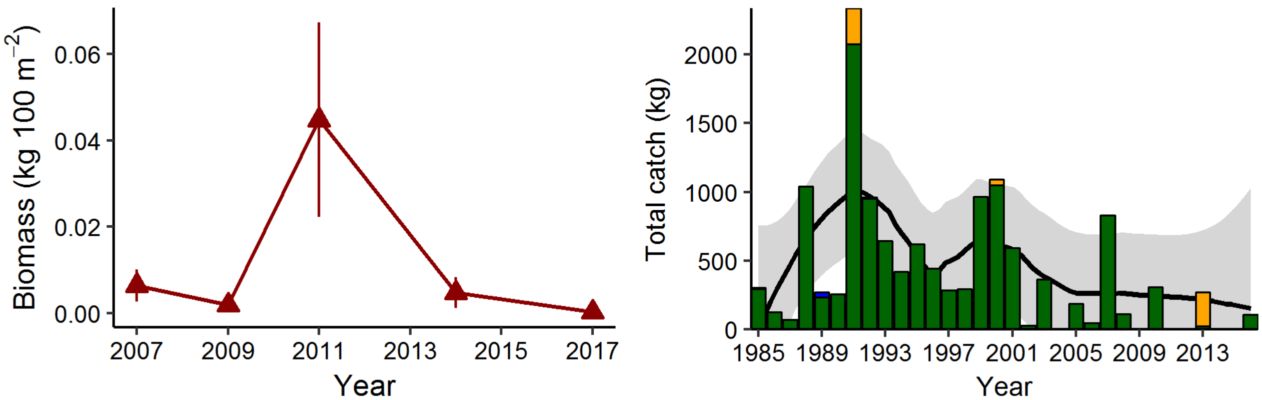
The life history parameters for this species were obtained from a local data set. The maximum age for this data set is unrealistically low at 6 years compared to 18 years in the Seychelles (Grandcourt, 2002) and 22 years in Hawaii (Howard, 2008). The maximum reported age of 22 years from Hawaii was used for this species.

C_{30} and OFL estimates for this species were deemed too uncertain and are not presented here.

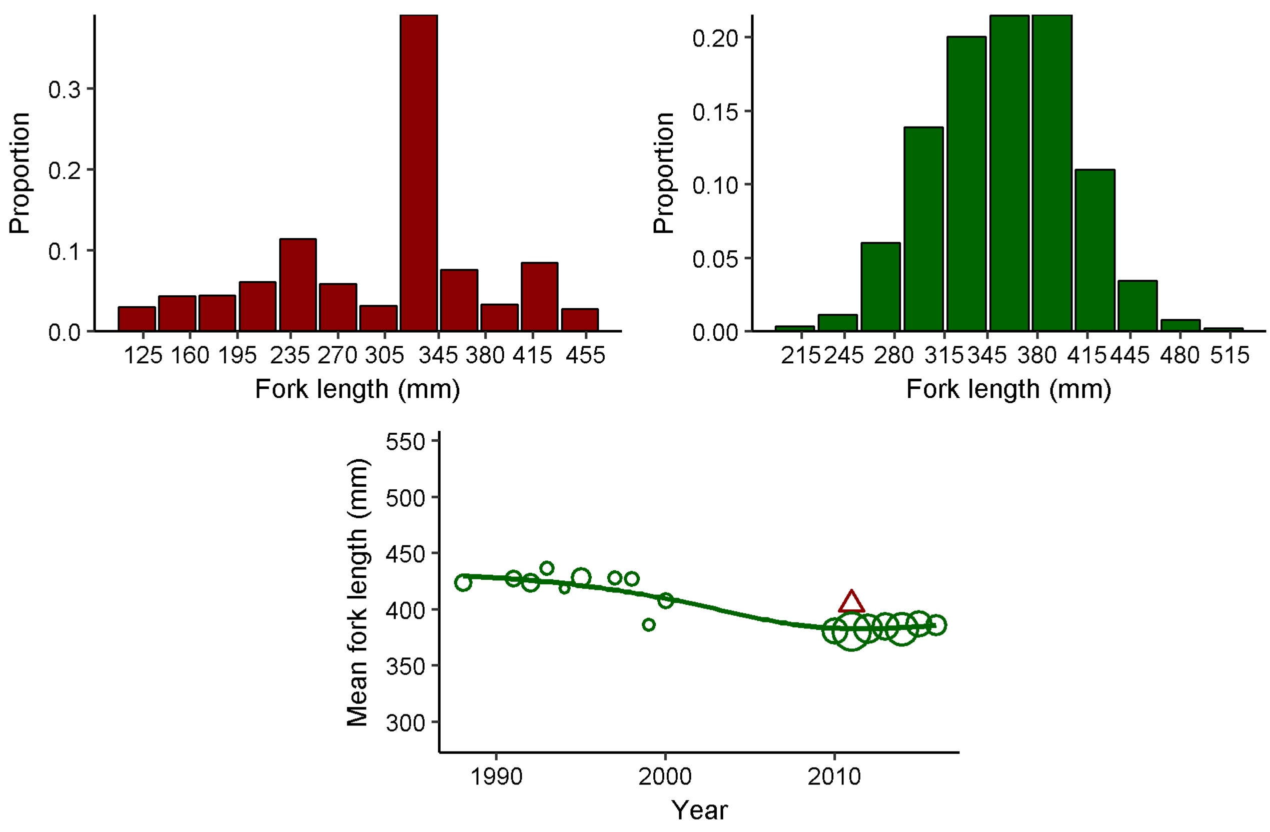
Scarus rubroviolaceus



Life history parameter distributions. Red line indicates median value.

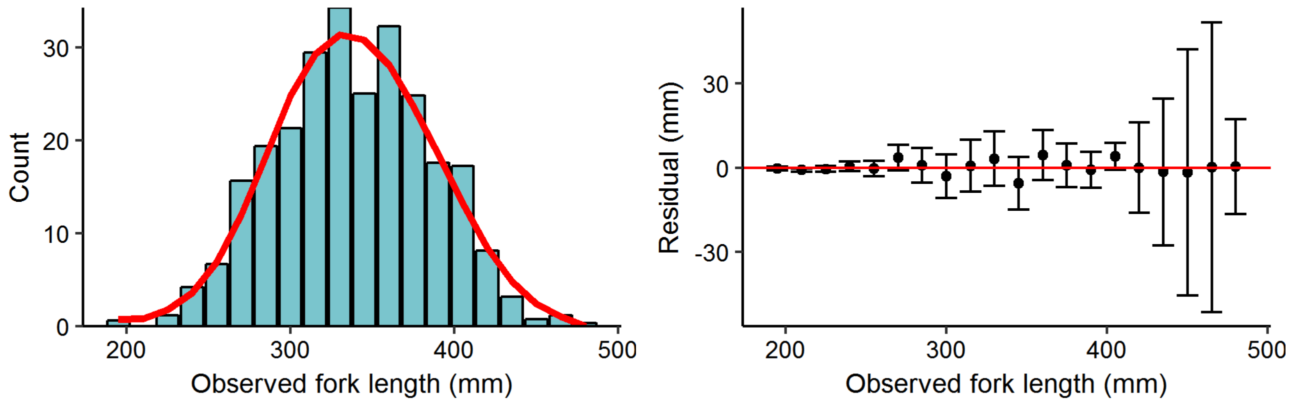


Abundance index from diver surveys (left; red triangles, ±SE) and total catch time series (right) from line (blue), spear (green), and net (orange) fishing gears. Black line shows loess fit for total catch with 95% confidence interval (gray area).

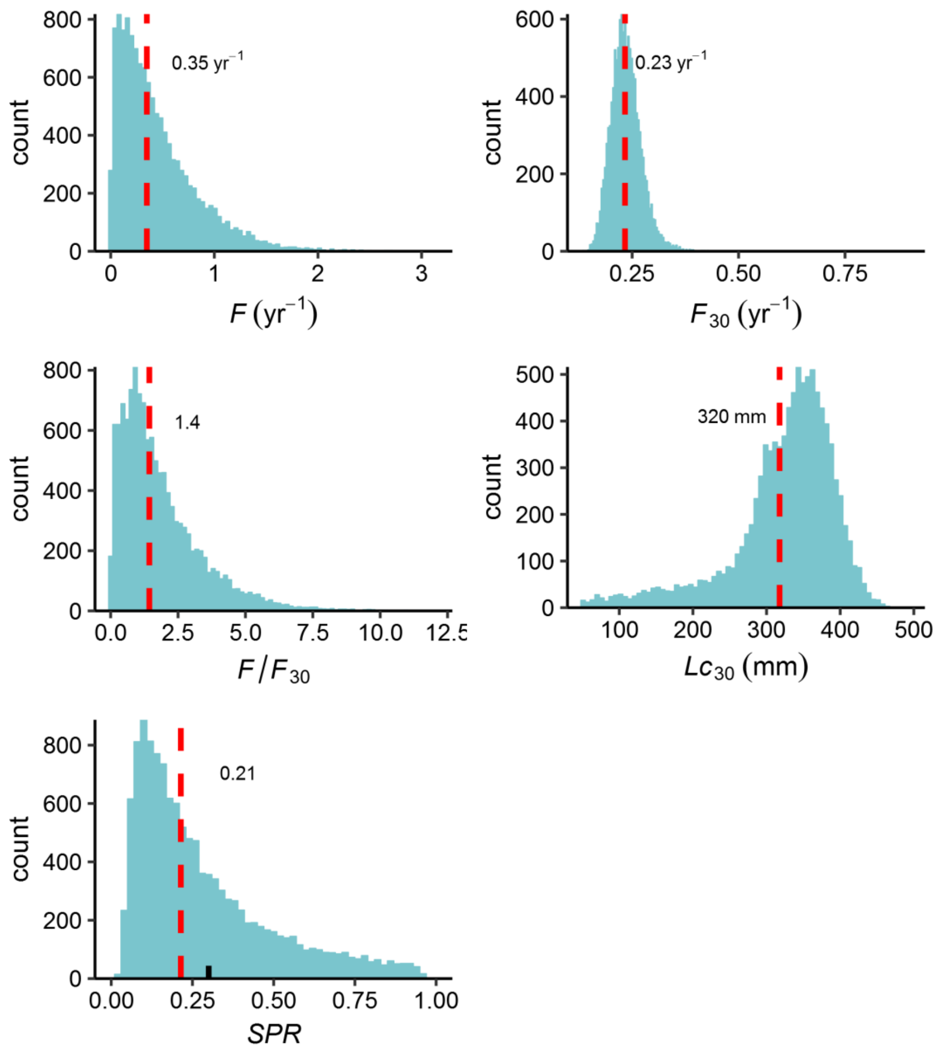


Size structure from diver surveys (top left) and from the catch by fishing gear (top right) (spear: green). Average length time series (bottom) (spear: green circles, diver surveys: red upright triangles). Size of icons is proportional to sample size.

Scarus rubroviolaceus



LBSPR model fit (left) and residuals (right).



Stock status parameter distributions (*SPR*: small bar shows 0.30 level). Red line indicates median value.

Probability of overfishing at various minimum sizes.

Overfishing probability	Lc_{30} (mm)	Overfishing probability	Lc_{30} (mm)
0.05	404	0.28	357
0.06	400	0.29	355
0.07	397	0.30	353
0.08	394	0.31	352
0.09	392	0.32	350
0.10	389	0.33	349
0.11	387	0.34	347
0.12	385	0.35	346
0.13	383	0.36	344
0.14	381	0.37	343
0.15	379	0.38	341
0.16	377	0.39	339
0.17	375	0.40	337
0.18	373	0.41	336
0.19	371	0.42	334
0.20	369	0.43	332
0.21	368	0.44	330
0.22	366	0.45	328
0.23	365	0.46	327
0.24	363	0.47	325
0.25	361	0.48	322
0.26	360	0.49	320
0.27	358	0.50	318