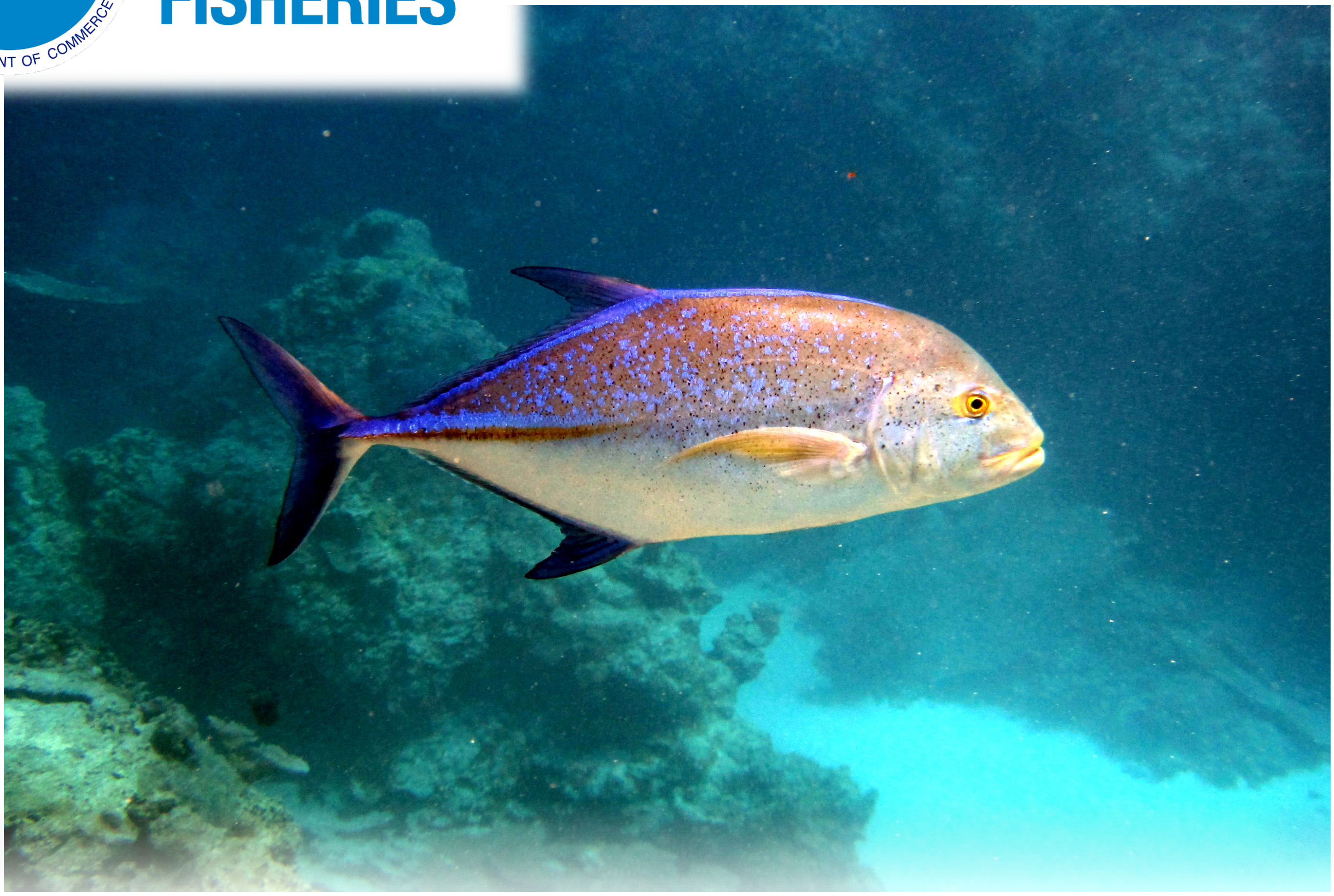


An Evaluation of the Status and Management Option for 7 Species of Reef Fish in Guam

Robert Ahrens and Marc Nadon

NOAA Technical Memorandum NMFS-PIFSC-155
Pacific Islands Fisheries Science Center
National Oceanographic and Atmospheric Administration
U.S. Department of Commerce
December 2023

An Evaluation of the Status and Management Option for 7 Species of Reef Fish in Guam

Robert Ahrens[1], Mark Nadon[1]

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

NOAA Technical Memorandum NMFS-PIFSC-155

December 2023

U.S. Department of Commerce
Gina Raimondo, Secretary

National Oceanic and Atmospheric Administration
Richard W. Spinrad, Ph.D., NOAA Administrator

National Marine Fisheries Service
Janet Coit, Assistant Administrator for Fisheries

About this report

The Pacific Islands Fisheries Science Center of NOAA's National Marine Fisheries Service uses the NOAA Technical Memorandum NMFS-PIFSC series to disseminate scientific and technical information that has been scientifically reviewed and edited. Documents within this series reflect sound professional work and may be referenced in the formal scientific and technical literature.

Cover photo: NOAA Fisheries

Recommended citation

Ahrens, R.A., Nadon, M. 2023. An evaluation of the status and management option for 7 species of reef fish in Guam. U.S. Dept. of Commerce, NOAA Technical Memorandum NMFS-PIFSC-155, 71 71p. doi:10.25923/hks1-gr20

Copies of this report are available from

Pacific Islands Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
1845 Wasp Boulevard, Building #176
Honolulu, Hawaii 96818

Or online at

https://repository.library.noaa.gov/

Contents

List of Figures

List of Tables

Executive Summary

This Technical Memorandum assesses and presents the potential outcomes of various management strategies for 7 reef species, *Bolbometopon muricatum, Caranx melampygus, Cheilinus undulatus, Epinephelus merra, Lethrinus olivaceus, Lutjanus fulvus*, and *Scarus schlegeli*. These have been identified as priority species by Guam's Department of Agriculture (DoAg) Division of Aquatic and Wildlife Resource**s** (DAWR) as part of the development of a Jurisdictional Coral Reef Fishery Management Plan (JCR FMP). Given the data limited nature of the fisheries, a meta-analytic data-poor approach to impute life history parameters for some species, combined with a growth-type-group length-based spawning potential ratio model (GTG LBSPR) was used to assess current status. We then simulated the potential outcomes of conventional management tactics such as length and bag limits to limit fishing mortality such as effort reductions or the establishment of catch limits. *Bolbometopon muricatum,* could not be assessed due to insufficient length frequency data. The assessment results for the other species were mixed and depended on the input life history characteristics. Across all life history characteristics, only *Lethrinus olivaceus* and *Lutjanus fulvus* were assessed to be experiencing overfishing. Assessments where life history characteristics were obtained from a meta-analytical approach produce results that indicated higher exploitation rates. Approximately 50% of the assessment for *Caranx melampygus* and *Scarus schlegeli* resulted in an SPR less than 30%, and ~40% of assessment for *Cheilinus undulatus* and *Epinephelus merra* showed an SPR under 30%. As a general rule, establishing a bag limit of 6-8 individuals per fishing trip would reverse overfishing. When species were assessed as experiencing overfishing, length limits were noticeably larger than the assessed selectivity parameters. For species experiencing overfishing, fishing mortality reductions would need to be reduced by 20–50%. Increasing the area of marine protected zones would potentially allow SPR to be increased. If 30% of a population was protected, SPR would increase by 0.1.

Introduction

NOAA Fisheries Pacific Islands Regional Office (PIRO) and Pacific Islands Fisheries Science Center (PIFSC) are providing support to Guam's Department of Agriculture (DoAg) Division of Aquatic and Wildlife Resources (DAWR) as they develop a jurisdictional coral reef fisheries management plan (JCR-FMP). Defining the current conditions and establishing strategies to meet sustainable management targets for priority coral reef species is a key step in the JCR-FMP development. Recent work has suggested that the establishment of an FMP would create a guiding document to help DAWR establish and meet conservation objectives since there are indications that some species may be below standard fishery management reference points. Nadon (2019) evaluated the status of 12 of the most commonly exploited coral-reef fish species in the waters of Guam: *Naso unicornis, Carangoides orthogrammus*, *Caranx melampygus*, *Lethrinus olivaceus*, *Lethrinus xanthochilus*, *Monotaxis grandoculis*, *Lutjanus fulvus*, *Lutjanus gibbus*, *Chlorurus microrhinos*, *Hipposcarus longiceps*, *Scarus altipinnis*, *Scarus rubroviolaceus.* Using a meta-analytical data-poor approach to impute life history parameters for some species, combined with a growth-type-group length-based spawning potential ratio model (GTG LBSPR), 4 of the 12 species were estimated to have a high probability of experiencing overfishing (assessed using an F_{30} benchmark proxy). F_{30} is the fishing mortality that reduces spawning stock biomass (SSB) to 30% of that expected in an unfished state (the spawning potential ratio (SPR) is 30%). Three of the species had fishing mortalities close to F_{30}. These results indicate a need to further understand the status of reef species in Guam and to establish the potential outcomes of implementing certain management strategies and tactics. Reef species in Guam are generally considered data poor due to the scale of the fishery and associated sampling programs as well as the paucity of local life history information. As a result, evaluating management strategy performance in relation to short-term population changes is not productive due to the high uncertainty in underlying stock-specific production functions. Assessments are also likely to employ data limited approaches, such as LBSPR, that assume some degree of stability (equilibrium) in the fishery over the time period assessed. Given these challenges, we have opted to use the same equilibrium methods to explore the potential outcomes of various management tactics.

Nature Analytics (Reid et al., 2022) provided technical assistance in conducting projection modeling of various management options for Guam priority species: *Acanthurus lineatus, Naso lituratus, Chlorurus frontalis, Kyphosus cinerascens,* and *Monotaxis grandoculis*. Focusing on the catch impacts of a range of size limits as well as fishing effort reduction, they generally found that reductions in fishing effort and shifting selectivity to larger sizes would produce positive changes in the long-term harvest of the species under consideration.

This report adds to the body of work exploring management strategies for coral species in Guam. Seven species were considered: *Bolbometopon muricatum, Caranx melampygus, Cheilinus undulatus, Epinephelus merra, Lethrinus olivaceus, Lutjanus fulvus*, and *Scarus schlegeli* (Table 1). Data for *Bolbometopon muricatum* were so deficient that they could not be assessed, but management options are discussed within this context. As in Nadon (2019), an SPR based reference point is adopted where overfishing is defined as F is greater than F_{30} or F / F_{30} is greater than 1 where F_{30} is the fishing mortality that produces an SPR of 30% or that the lifetime expected egg production per recruit is 30% of that expected if no fishing occurred (Restrepo et al. 1998). Given the relative stability of catches in the Guam fisheries, an SPR below 30% can also be interpreted to indicate that a stock is overfished where SSB is below 30% of SSB in the unfished state.

Table 1. List of species evaluated including the scientific name, English common name, Chamorro name (juvenile / adult), and short identifier code.

Scientific Name	English Common	Chamorro	Short Code
Bolbometopon muricatum	Humphead parrotfish	Pachak / Fumo / Atuhong	BOMU
Caranx melampygus	Bluefin trevally	i'e' / Tarakitu	CAME
Cheilinus undulatus	Humphead wrasse	Tåsen guåguan / Tangison	CHUN
Epinephelus merra	Honeycomb grouper	Gådao	EPME
Lethrinus olivaceus	Longface emperor	Lililok	LELO
Lutjanus fulvus	Blacktail snapper	Bu‘a	LUFU
Scarus schlegeli	Yellowband parrotfish	Palakse' / Laggua	SCSC

Description of the fishery

Guam is a large island (50 km long and 12 km wide) located at the southern end of the Mariana Archipelago. This unincorporated U.S. territory with an estimated population of 170,534[1] was first settled by Chamorros approximately 3,500 years ago; reef fish communities have been exploited since that time (Amesbury & Hunter-Anderson, 2008). The present-day coral reef fishery involves mixed purpose (commercial and non-commercial) shore- and boat-based fishing. Nearly all Guam domestic fishers have other occupations (Myers, 1993) though almost two thirds of Guam households are involved in fishing activities (Allen and Bartram, 2008). The fishery is culturally and socially important to the local population, especially the tradition of sharing fish catches among the community (Allen and Bartram, 2008). Estimated catch from creel programs indicates that catch primarily comes from boat-based fisheries (85%: Figure 1) and total catch has fluctuated around ~43 metric tons per year. The primary families in the catch (boat-based and shore-based combined) in decreasing order are jacks, emperors, surgeonfishes, rabbitfishes, goatfishes, parrotfishes, snappers, and groupers (Nadon, 2019).

[1] datacatalog.worldbank.org

The shallow waters around Guam Island (0–200 m depth) which make up the habitat of the 7 species in this report are almost entirely within territorial jurisdiction limits and comprise 19,000 ha. The large banks to the southwest of the island (e.g., Santa Rosa, Galvez) contain almost as much reef habitat (15,000 ha). 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. It is not entirely clear to what level the reef fish populations around the southern Mariana Islands are connected or 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), it is likely that the reef fish populations in these areas are connected to some extent. 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. In this report, **all 7 stocks were analyzed at the scale of the island of Guam only** due to these data limitations. All Guam Island sea floor area between 0 to 200 m depths falls within the 3 nautical miles territorial water limits.

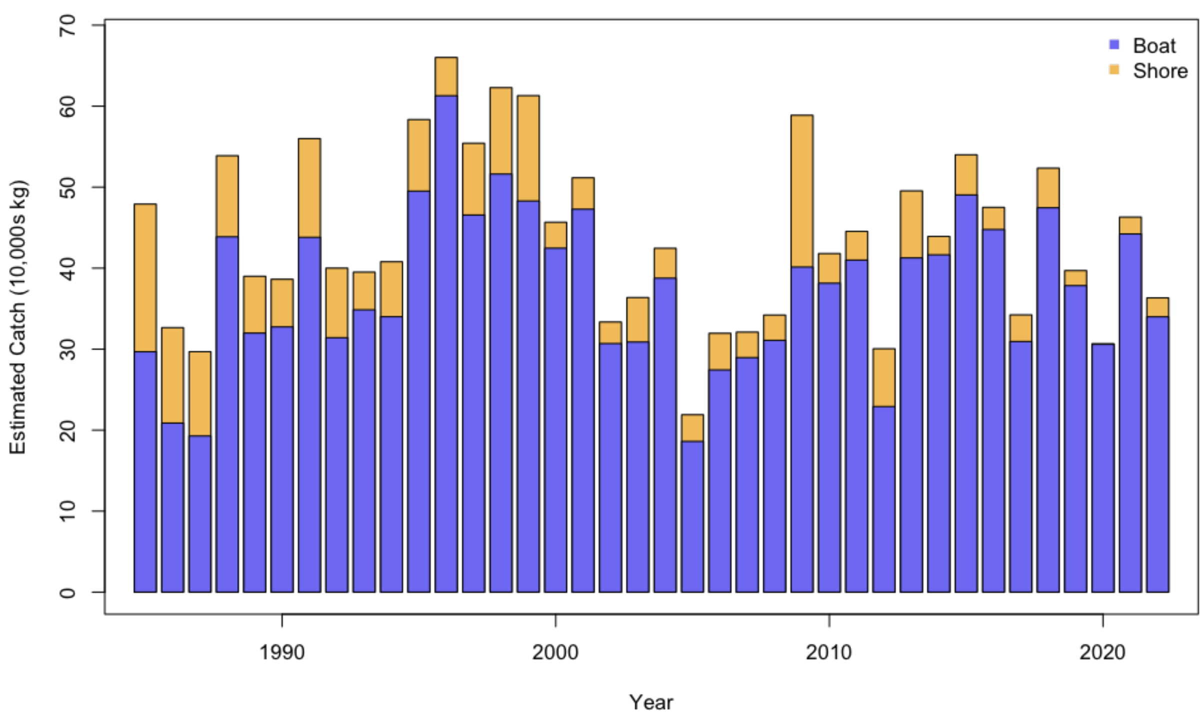


Figure 1. Annual estimated total catch from the shore- and boat-based creel programs.

Approach rational

Although there are monitoring programs in place in Guam, the scale of fisheries results in data streams that have low sample sizes can be highly variable. For any given species, this would generally result in a data poor designation for assessment purposes. There are 4 main data streams that have the potential to contribute to assessments: (1)

the boat- (Pacific Islands Fisheries Science Center 2023a) and shore-based (Pacific Islands Fisheries Science Center 2023c) creel programs which are used to estimate total catch and provide information of fisher catch rates and fish lengths; (2) the National Coral Reef Monitoring Program diver surveys (Pacific Islands Fisheries Science Center 2023d, 2023e) which provide estimates of density and sizes; (3) the Guam Commercial Fisheries BioSampling (CFBS) program (Pacific Islands Fisheries Science Center 2023b) that provide information on lengths and structure for life history characteristics; and (4) regional estimates of life history characteristics for some species. Each of these data streams contributed in some way to the analysis presented here. Given the nature of the available data, a length-based equilibrium approach was chosen to assess and provide the potential outcomes of management tactics for the species listed above.

Equilibrium approaches assume some degree of stability in the fishery in the recent past. In general, catch patterns show stability (Nadon, 2019) although catch has declined for a few species recent years. Even with these recent declines, the lack of certainty around factors that drive short-term population dynamics make equilibrium approaches more tractable. Length composition data for each year are sparse and need to be aggregated across years to reach reasonable sample sizes. There is insufficient contrast in the abundance of the stocks to estimate a stock recruitment relationship resulting in any dynamic assessment or simulation being highly dependent on assumed stock-recruit productivity assumptions. While it is possible to obtain estimates from meta-analyses, the insight gained from the highly uncertain time dynamics is minimal.

For this study the length-based spawning potential ratio (LBSPR) method developed by Hordyk et al. (2016) is used. This approach uses a length-structured version of the LBSPR model where a population is separated into growth-type-groups (GTG), given an estimate of growth variation, and can account for the erosion of growth characteristics due the differential removal of faster growing individuals under size-based selectivity (Rosa Lee Phenomenon (Lee, 1912)). When this effect is ignored, fishing mortality is overestimated leading to a negative bias in estimates of SPR. Conditioned on growth, maturity, and natural mortality estimates, LBSPR estimates the logistic selectivity parameters and fishing mortality rates that best characterize an observed length frequency. The fishing mortality and selectivity parameters can then be used to explore various management tactics to achieve desired reference points. LBSPR was implemented using the R package LBSPR (Hordyk, 2021).

Life history parameter sources

More sophisticated data poor methods such as LBSPR rely on basic life history information being known. Natural mortality, growth, and maturity schedules are basic inputs into these approaches. Life history characteristics used in the LBSPR model are detailed in the species-specific section of this report. Local life history information was available for *Caranx melampygus, Cheilinus undulatus,* and *Scarus schlegeli* though we note some concerns in the species-specific sections as the estimated asymptotic mean max length from local growth studies is low compared to observed lengths in the catch. Local life history characteristics for *Bolbometopon muricatum, Epinephelus merra, Lethrinus olivaceus,* and *Lutjanus fulvus* were not available but were imputed using values found in the primary literature. Imputing can complicate the interpretation of length-based assessments because of their sensitivity to underlying growth parameters. We searched the scientific literature for studies from similar thermal regimes that were geographically close; however, these may not be an appropriate substitute for local characteristics due to differences in local productivity and population densities. In addition to literature values or local characteristics, the stepwise life history (SWLH) imputation approach described in Nadon and Ault (2016) as well as Erickson and Nadon (2021) was used to obtain parameters for *Caranx melampygus, Cheilinus undulatus, Epinephelus merra, Lethrinus olivaceus, Lutjanus fulvus,* and *Scarus schlegeli*. This meta-analytic approach uses a local estimate of maximum length to generate family-specific probability distributions for life history parameters describing growth, maturity, and longevity (A_{max}). The maximum length used for this approach was the 99th percentile observation of a length data set to filter out potentially erroneous or unrepresentative extreme length observations. When local information was available or when literature values were used, natural mortality estimates were derived using the equation in Hamel and Cope (2022), where $M = \frac{5.4}{A_{max}}$ the natural mortality which is different that used in Nadon (2019) which employed the equation from Nadon et al. (2015) $M = \frac{-ln(0.43)}{A_{max}}$ and slightly different that the commonly used Then et al. (2015) $M = 4.899 A_{max}^{-0.916}$. Post hoc, life history parameter combinations that resulted in no estimate of fishing mortality ($F = 0$) were discarded from the analysis given the known history of exploitation (i.e., these combinations are impossible given the information contained in the observed length data and should be discarded).

A few of the species are known (*Epinephelus merra, Scarus schlegeli, Cheilinus undulatus Cheilinus undulatus*) to be or suspected (*Bolbometopon muricatum, Lethrinus olivaceus*) to be protogynous, maturing to male later and at a larger size. The potential for males to become scarce and reduce stock productivity has not been accounted for in the LBSPR model which was developed for gonochoristic species. Given the plasticity in maturation to male that is exhibited by these species and the importance of female reproductive output, explicitly accounting for protogyny was considered unnecessary (Brooks et al., 2008).

Size composition and catch

Length composition data came from the creel program and from diver surveys collected in 2016 to present. Length data from the creel program were gear-specific and tested to determine if samples could be combined to create a single length frequency (Figure 2). In general, length frequencies were similar across gears for each species and all species combined. A simple ANOVA was used to determine if the lengths captured in different gears were similar enough to be combined. In general, there was little difference between the gears and lengths were combined across gears. Length observations from creel and diver surveys were also combined (Figure 3) to create a final single length data set to be used in the LBSPR analysis.

Details of the Guam Division of Aquatic and Wildlife Resources (DAWR) creel program and the approach used to estimate species-specific catch can be found in Ma et al.

(2022). Both creel surveys consist of fisher interviews as well as participation surveys. During interviews, individual fish are also measured for length and weight. This information is then used to develop and estimate total catch (Figure 4). Catch for many species was highest in the 80s and 90s and has somewhat stabilized in recent years. For this assessment, catch data from 2012 through 2022 were used to estimate the mean and variance in annual catch for each species to meet the assumption that the fishing mortality that produced the most recent length frequencies was generated over this time frame and has been relatively stable.

Table 2. Parameter symbols, and descriptions.

Parameter	Definition
M	Instantaneous natural mortality rate
F	Instantaneous fishing mortality rate
L_{∞}	von Bertalanffy mean asymptotic maximum length
K	von Bertalanffy metabolic growth parameter
L_{50}	Length at which 50% of females are maturity
L_{95}	Length at which 95% of females are maturity
SPR	Spawning potential ratio
SPR_{30}	Spawning potential ratio of 30%
F_{30}	The fishing mortality that would achieve SPR_{30}
$\frac{F}{F_{30}}$	The ratio of current fishing mortality to the fishing mortality that would achieve SPR_{30}
SL_{50}	Length at which 50% of individuals are selected by the suite of fishing gears
SL_{95}	Length at which 95% of individuals are selected by the suite of fishing gears
$SL_{50}F_{30}$	SL_{50} that would achieve F_{30}
A_{max}	The maximum age in the population
sel_a	Selectivity at age
p_{mpa}	Proportion of a population within an MPA
l_a	Survivorship at age
E_a	Eggs produced at age

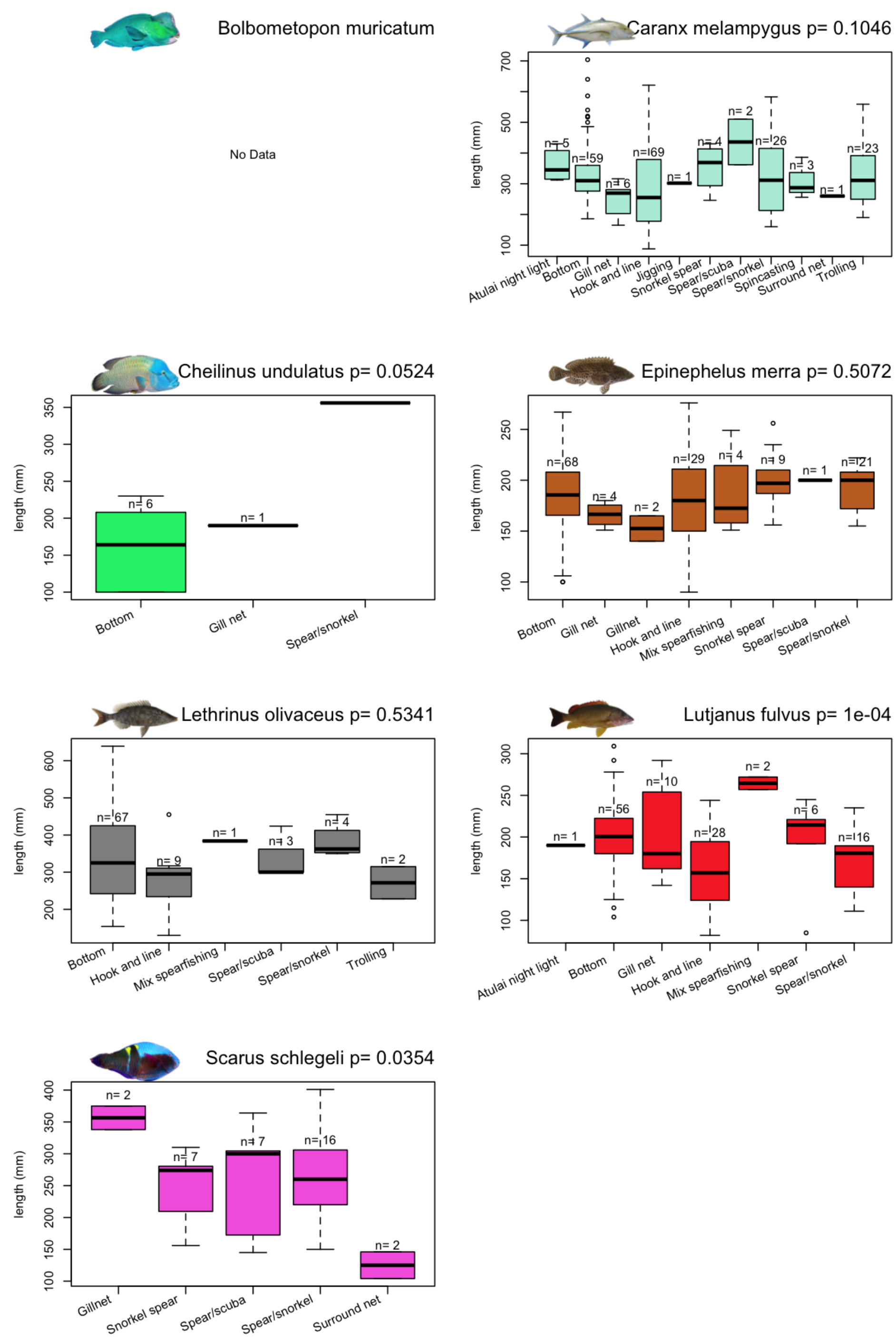


Figure 2. Boxplots showing the range of sizes captured by each gear from the shore and boat-based creel programs. Sample sizes are indicated above each box and the p value was generated using a simple ANOVA.

.

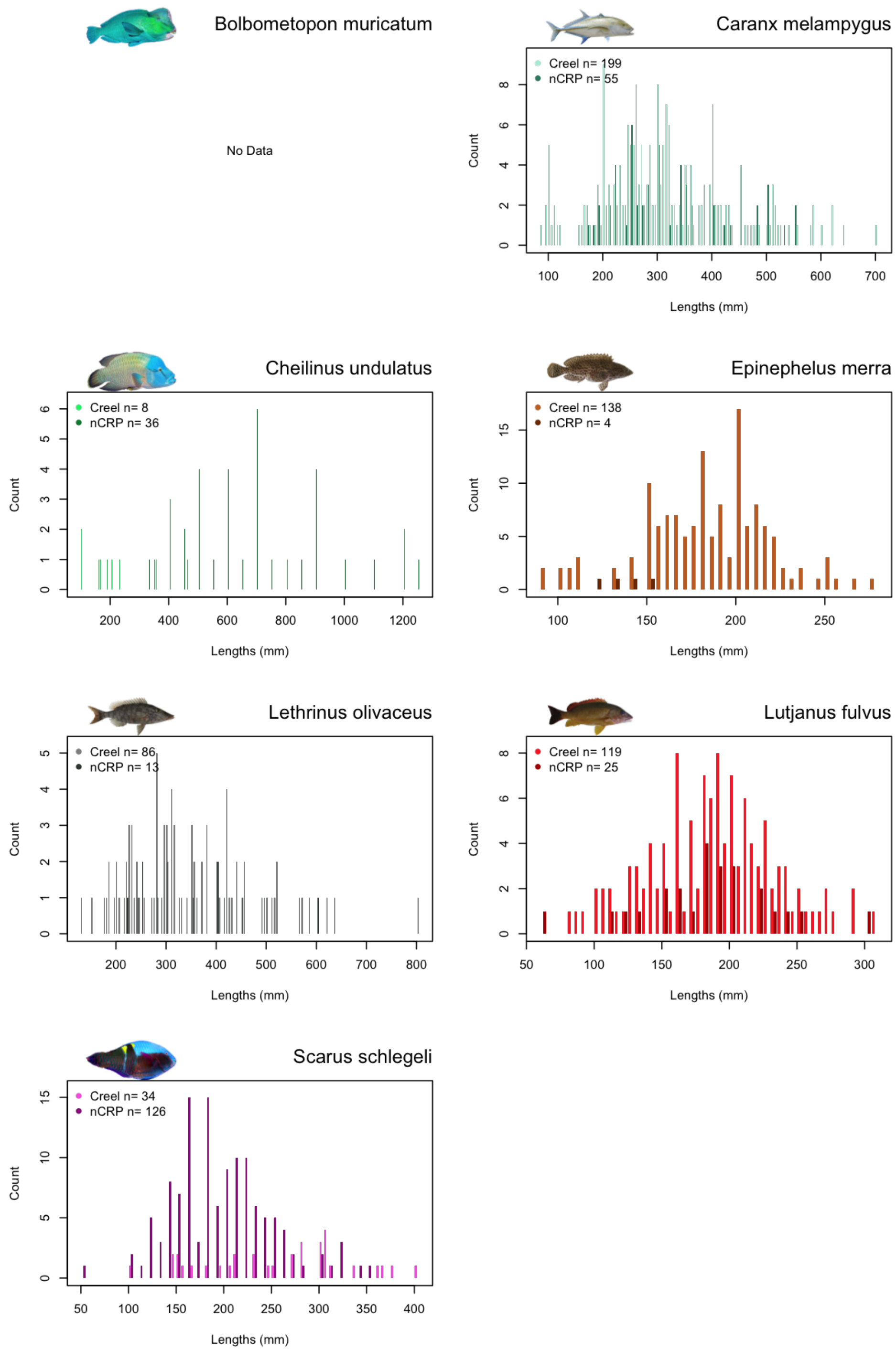


Figure 3. Histograms showing the range of sizes captured gear combined creel data and diver surveys.

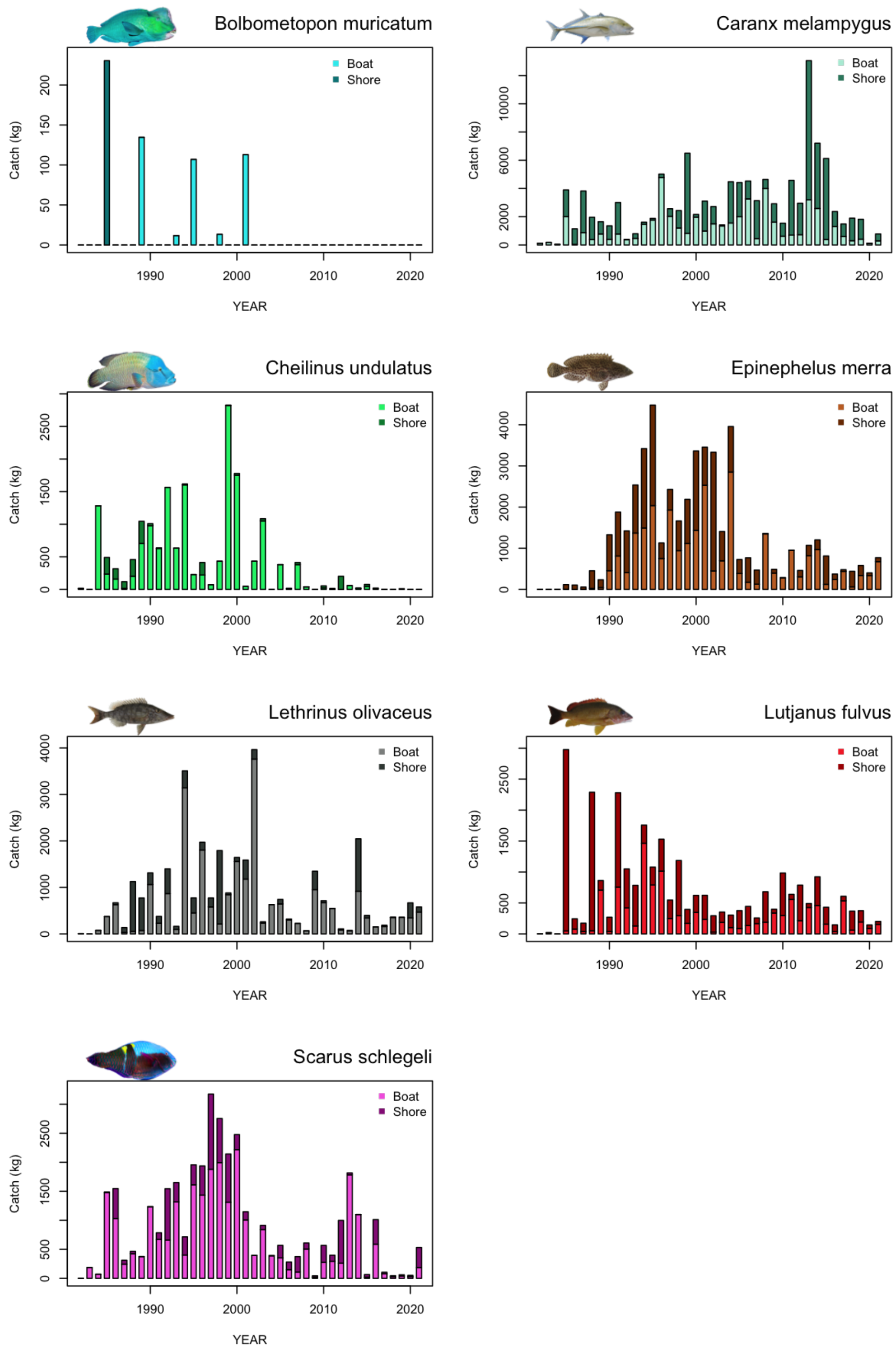


Figure 4. Catch by species since 1985, estimated from shore and boat creel programs.

Implementing the LBSPR framework

The growth-type-group length-based spawning potential ratio approach (GTG-LBSPR) was used to obtain estimates of recent fishing mortality (F) and the 50% and 95 % (SL_{50}, SL_{95}) cumulative logistic probability values that define a selectivity ogive. These in turn were used to estimate F_{30} and other management metrics of interest. The GTG-LBSPR model requires natural morality, the 50% and 95 % (L_{50}, L_{95}) cumulative logistic probability values that define a maturity ogive, von Bertalanffy growth parameters (L_∞ - mean asymptotic length, K—a metabolically determine constant), as well as the coefficient of variation in L_∞. The coefficient of variation in L_∞ determines the variability across growth type groups in the model. Because of the uncertainty in these parameters, a Monte Carlo approach was adopted and 1,000 draws from lognormal distributions for each input parameter were used. In all cases, the coefficient of variation in L_∞ was assumed to be 13%.

The use of growth-type groups allows 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. 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:

(Equation 1) $N_{L+\Delta L} = N_L \left(\frac{L_\infty - L - \Delta L}{L_\infty - L}\right)^{\frac{Z_L}{K}}$

where N_L is the number of fish in length class L, ΔL is a small increment in length, L_∞ 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:

(Equation 2) $F_L = \left(1 + exp\left(-\, ln\, ln\, (19)\ \frac{L - SL_{50}}{SL_{95} - SL_{50}}\right)\right)^{-1}$

where SL_{50} and SL_{95} are the sizes at 50% and 95% selectivity, and F is the background fishing mortality rate.

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

(Equation 3) $\widetilde{D}_{L+\Delta L} = \frac{\frac{1}{Z_L}(N_L - N_{L+\Delta L})}{\sum_L \frac{1}{Z_L}(N_L - N_{L+\Delta L})}$

which is standardized to sum to 1.

The equations described above are for an individual growth trajectory (i.e., a single L_∞ value). By varying L_∞ using the CV L_∞ parameter (coefficient of variation associated with individual variability in L_∞), we can use these equations to calculate the density at length vector $\widetilde{D}_L$ 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:

(Equation 4) $\ddot{D} = \sum_1^G \widetilde{D}_{L+\Delta L}$

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. Assuming that egg production is proportional to weight, we can describe fecundity-at-length (Fec_L) as:

(Equation 5) $Fec_L = Mat_L L^\beta$

where Mat_L is maturity-at-length which can be described using a logistic function of format similar to Equation 2 (replacing SL_{50} and SL_{95} with L_{50} and L_{95}). The β parameter is from the length-weight relationship ($W = \alpha \cdot L^\beta$). 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):

(Equation 6) $SPR = \frac{\sum_g \sum_L (M+F)^{-1}(N_{L,g} - N_{L+\Delta L,g})Fec_L}{\sum_g \sum_L (M)^{-1}(N_{L,g} - N_{L+\Delta L,g})Fec_L}$

With estimates of L_∞, *K*, *CV* L_∞, L_{50}, and L_{95}, it is now possible to find the maximum likelihood estimates of *F*, SL_{50}, and SL_{95} by comparing the observed proportions at length to those predicted by the LBSPR-GTG model using a multinomial likelihood. The GTG-LBSPR model makes 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.

Given these values, the current estimate of SPR can be made and the F_{30} value can be calculated. The ratio of F/F_{30} provides insight into how fishing effort needs to be adjusted to achieve the desired SPR = 30% target. If F is fixed and SL_{50} is adjusted to achieve an SPR of 30%, insight can be gained into how length limits could be modified to achieve a SPR target. Given an assumed steepness of the stock-recruitment curve (i.e., 0.7), it is possible to explore the relative relationship between current catch levels (C) and that obtained when SPR is 30 % (C_{30}). This relationship can be used compared to current catch levels to determine the potential benefits of implementing management measures to achieve an SPR of 30%. Within the LBSPR framework, catch (C_{Fx}) at a fishing mortality rate (Fx) at equilibrium is proportional to yield per recruit (YRP_{Fx}) times relative recruitment ($R_{rel,Fx}$) (Equation 7). Given an assumed stock recruitment steepness, the ratio of catch (C_{Fcur}) given the current fishing mortality (F_{cur}) to the catch (C_{F30}) given the fishing mortality that would result in an SPR of 30% (F_{30}) can be calculated (Equation 8).

(Equation 7) $C_{Fx} = YPR_{Fx} * R_{rel,Fx}$

(Equation 8) $\frac{C_{Fcur}}{C_{F30}} = \frac{YPR_{Fcur} * R_{rel,Fcur}}{YPR_{F30} * R_{rel,F30}}$

To explore the possible impact of bag limits on reference points, historic catch rate information from the creel was used to develop an understanding of the underlying distribution of angler catchabilities (q_i)(Figure 5). If angler interviews are collected randomly, then the distribution of catch rates (y_i) is proportional to the distribution of angler catchabilities. This information can then be used to estimate how fishing mortality (F) would change if a bag limit was imposed. Since average population size ($\underline{B}$) is generally unknown, it is not possible to estimate q_is directly; however, changes in the mean expected catch rate as a result of the imposition of a bag limit are proportional to changes in the mean catchability (Equation 9). To determine the mean catch rate that results from a certain bag limit, the proportion (p_i) of anglers achieving specific catch rates can be estimated directly from interviews or by fitting a probability distribution (e.g., poisson or negative binomial) to the observed catch rate data. To account for the effects of a bag limit, the catch rate of anglers above the bag is capped at the bag and the resulting new catch rate is estimated assuming stationarity in the underlying distribution of angler catchability proportions (Equation 10). The ratio of the catch rate after the establishment of a bag limit to the current catch rate can be used to scale fishing mortality (Equation 11).

(Equation 9) $\underline{y}_{now} = \underline{q}\underline{B}_{now} = \sum_{i=1}^{\infty} p_i q_i \underline{B}_{now}$

(Equation 10) $\hat{\underline{y}}_{bag} = \sum_{i=0}^{\infty} p_i y_i | y_i = argmin(y_i, y_{bag})$

(Equation 11) $F_{new} = F_{now} * \frac{\hat{\underline{y}}_{bag}}{\underline{y}_{now}}$

To estimate how bag limits could change fishing mortality, a negative binomial distribution truncated at 1 was fit to the positive catch rate data for each species. Bag limits were then adjusted from 20 or the 95% quantile of the observed catch rate distribution down to 1 per trip to determine how F could be changed. While such an exploration provides some insight into the utility of bag limits, it requires a number of constraining assumptions. The underlying distribution of fisher characteristics that gives rise to the q_is is assumed to be stationary and nonresponsive to the establishment of a bag limit or changes in population size. Effort is also assumed not to change in response to the establishment of a bag limit or change in population size. These are challenging assumptions because the establishment of a bag limit is likely to alter fishers' perceptions of utility, and the adoption of a bag is intended to change population size. However, without additional studies on angler preference and skill, this is a necessary assumption.

Exploring the impact of marine protected areas

The effectiveness of marine protected areas (MPAs) depends on the mobility of a species and the time spent exposed to fishing mortally. To understand the potential effect of MPAs on achieving SPR targets, a simple equilibrium simulation was developed to look at the potential absolute SPR benefit of protecting a proportion of a stock within MPAs. The simulation uses a simplifying assumption of no movement out of the MPA and therefore produced ideal results. The simulation calculates SPR without (SPR_f REF _$Ref148685128$ \h (Equation 12)) and with MPA (SPR_{mpa} REF _$Ref148685141$ \ h (Equation 13)) where l_a^f and l_a^{mpa} are the survivorship to age (*a*) and E_a is the age-specific number of eggs produced. The difference between the without MPA survivorship (Equation 14) and with MPA survivorship (Equation 15) is that the effect of fishing only impacts the proportion of the population outside the MPA (1-p_{mpa}). In the survivorship equations, *M* is the natural mortality rate, sel_a is the age-specific selectivity, and *F* is the fishing mortality rate. The survivorship in the first age class is 1. A basic life history is used with a longevity of 20 years, fecundity proportional to body weight after maturity is reached, and a fishery selectivity that captures individuals slightly before they mature. Simulations were run over a range of fishing mortality rates and proportions of the population in the MPA.

(Equation 12) $$SPR_f = \frac{\sum_a l_a^f E_a}{\sum_a l_a^0 E_a}$$

(Equation 13) $$SPR_{mpa} = \frac{\sum_a l_a^{mpa} E_a}{\sum_a l_a^0 E_a}$$

(Equation 14) $$l_a^f = l_{a-1}^f exp(-M - sel_a F)$$

(Equation 15) $$l_a^{mpa} = l_{a-1}^{mpa} exp(-M - (1 - p_{mpa}) sel_a F)$$

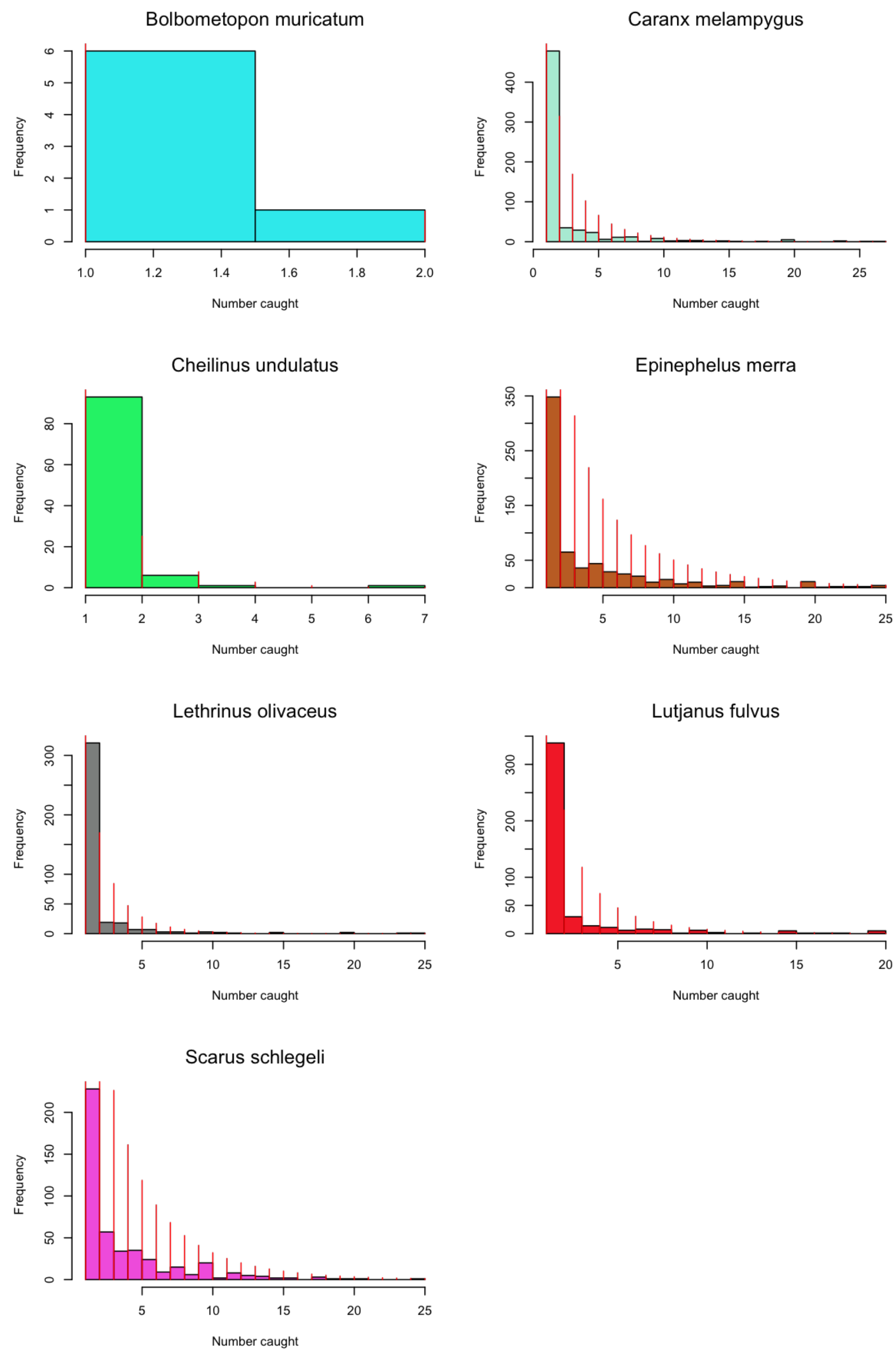


Figure 5. Histograms of catch rate per trip from the shore and boat-based creel. Vertical red lines show the best fitting 1 truncated negative binomial distribution.

General findings and potential management options.

General results

For the species that could be evaluated (*Bolbometopon muricatum* excluded) using the GTG LBSPR assessment approach and the base data, 2 (*Lethrinus olivaceus*, *Lutjanus fulvus*) of 6 were determined to be experiencing overfishing with more than 90% of the simulations indicating SPR was less than SPR 30% (Table 3). The other species (*Caranx melampygus*, *Cheilinus undulatus*, *Epinephelus merra*, *Scarus schlegeli*) had very little to no simulations indicating SPR values below 30%. Using the SWLH approach, assessments were generally more pessimistic. *Caranx melampygus* and *Scarus schlegeli* assessment results shifted to ~50% of simulations indicating SPR less than 30%. The proportion of simulations with SPR less than 30% increased for *Cheilinus undulatus* and *Epinephelus merra* to ~30% while there was a decrease for *Lethrinus olivaceus* and *Lutjanus fulvus* to ~60%. When local life history data were used, assessment results were less pessimistic—L_∞ and max age inputs tended to be lower than those produced with the SWLH approach.

In all instances, achieving the SPR 30% reference point would increase catch either by initially reducing harvest to recover the population or when under exploited, increase the harvest. Establishing management measures to achieve SPR 30% targets would have a positive impact on realized catch. In a high proportion of assessments, size limits were effective at achieving SPR 30% targets though there was substantial variability. Bag limits were also a suitable option achieving SPR targets in the majority of assessments. Where comparison between the SWLH assessment and Nadon (2019) could be made, the results were similar though more pessimistic in the latter. This is due to the more conservative *M* estimate used in Nadon (2019) compared to the value from Hamel and Cope (2022) used in this assessment.

Potential management options

Many of the assessments indicate that a reduction in fishing mortality would improve catch outcomes and achieve SPR 30%; there are a number of general options that could be considered to achieve that target. Because size limits are tightly linked to life history, they need to be species-specific and it is best to focus on those that are easily targeted and have low discard mortality rates. If size limits were used, assessments suggested they would be well above the current estimated SL_{50} and, though discarding would occur, discard mortality was not factored into these assessments.

There was a general pattern in bag limits that warrants presentation. For most species, ~5% of observed trips have high catch rates. If these trips were not allowed to occur and bag limits were set so that 95% of other trips were not impacted, the assessment result indicates that the SPR target of 30% could be achieved in most instances. The adoption of a general bag limit of 6–8 per trip, regardless of the number of anglers, would achieve SPR 30% targets except for larger, less common species such as *Cheilinus undulatus* and likely *Bolbometopon muricatum*. One would expect to set more specific regulations for these iconic and prized species such as harvest tags or special occasion permits.

Table 3. Summary table of status and management options using the LBSPR model with base data and results from the stepwise life history (SWLH). SPR is the mean spawning potential ratio. SPR < SPR_{30} indicates the probability of the stock being below the SPR_{30} reference point. F / F_{30} indicates the percentage that current F is relative to the F that would achieve a SPR_{30} target. C / C_{30} indicates the percentage that current mean catch is of what could be achieved if an SPR_{30} target was reached. SL_{50} is the mode of the distribution of estimated 50% selectivity. $SL_{50}F_{30}$ is the mean size limit that would achieve the SPR30 reference point with the percentage in backets indicating the number of assessments that generated an estimate. In instances where the percentage is not 100%, assessments had no size limit. Bag limit indicates the largest bag per trip that would achieve an SPR_{30} target and the percent of time the SPR target is achieved in parentheses. Missing values for bag limit indicate a bag was not calculated or had no impact on achieving an SPR30% target.

Scientific Name	SPR	SPR <SPR_{30}	F / F_{30}	C / C_{30}	SL_{50} (mm)	$SL_{50}F_{30}$ (mm)	Bag limit
BASE							
Bolbometopon muricatum	-	-	-	-	-	-	-
Caranx melampygus	0.53	1.4%	45%	90.8%	176	100 (10%)	8 (86%)
Cheilinus undulatus	0.84	0%	13%	13.5%	330	-	-
Epinephelus merra	0.81	0%	8%	42.1%	178	53 (18%)	-
Lethrinus olivaceus	0.15	99.5%	180%	40.3%	201	392 (100%)	6 (53%)
Lutjanus fulvus	0.24	93.6%	122%	86%	138	155 (100%)	8 (61%)
Scarus schlegeli	0.80	0%	16%	17.8%	110	-	-
SWLH							
Bolbometopon muricatum		-	-	-	-	-	-
Caranx melampygus	0.64	49.7%	130%	54.1%	204	362 (59%)	8 (97%)
Cheilinus undulatus	0.48	30.2	86%	70%	309	564(37%)	3(97%)
Epinephelus merra	0.42	39.1	110%	71%	173	168 (81%)	14 (97%)
Lethrinus olivaceus	0.32	59%	140%	57.7%	190	357 (67%)	6 (95%)
Lutjanus fulvus	0.41	64.3%	200%	47.8%	149	195 (79%)	8 (86%)
Scarus schlegeli	0.34	54.7%	124%	64.1%	121	185 (67%)	12 (93%)

Scientific Name	SPR	SPR <SPR30	F / F30	C / C30	SL50 (mm)	SL50F30 (mm)	Bag limit
Nadon (2019)							
Caranx melampygus	0.15	72%	190%	-	235	395	-
Lethrinus olivaceus	0.18	75%	160%	-	189	409	-

Other management options were not explicitly considered in the assessment as they tend to depend on the seasonal and spatial patterns inherent to each species. There is the potential to explore seasonal closure for species that are more vulnerable to harvest due to seasonal aggregations for spawning. This approach requires specific knowledge of where and when fishers target such aggregation. If the majority of such trips are resulting in the high catch rates observed, then this would be addressed using the general bag limit, but consideration could be given to adopting seasonal closure during spawning periods. When overfishing was assessed, F / F_{30} ratios indicate that effort reduction due to seasonal closures would need to be by 20–50%.

An alternative to temporal closures is to expand the network of MPAs currently in place in Guam; the design and expanse of these areas depends on species-specific habitat preferences and movement rates. Such areas are likely not practical to protect more mobile species with poorly defined home ranges and an expansion would create significant enforcement challenges. Under an ideal scenario (no illegal fishing and no species movement out of the MPA), the change in SPR that could be achieved if a proportion of the population was protected in an MPA can be calculated as an absolute SPR benefit given the life history of the species in question (Figure 6). In general, as the proportion of the stock protected increases SPR will increase while the SPR gain, in turn, depends on the fishing mortality rate. For the species simulated, the SPR benefit is the greatest when fishing mortality is equal to natural mortality. Under this condition, if 30% of the population is protected, there would be a positive 0.1 change in SPR. Therefore, under ideal circumstances, a species assessed with an SPR of 0.2 should increase to 0.3 with 30% population protected. As the F/M ratio increases the benefit is reduced. For species assessed with overfishing, the F/M ratio is in the 1–2 range. Currently MPAs around Guam (Nadon, 2019) are comprised of about 15% of reef habitat which would equate to around 0.03–0.05 SPR decrease for each species if they were removed and assuming ideal protection.

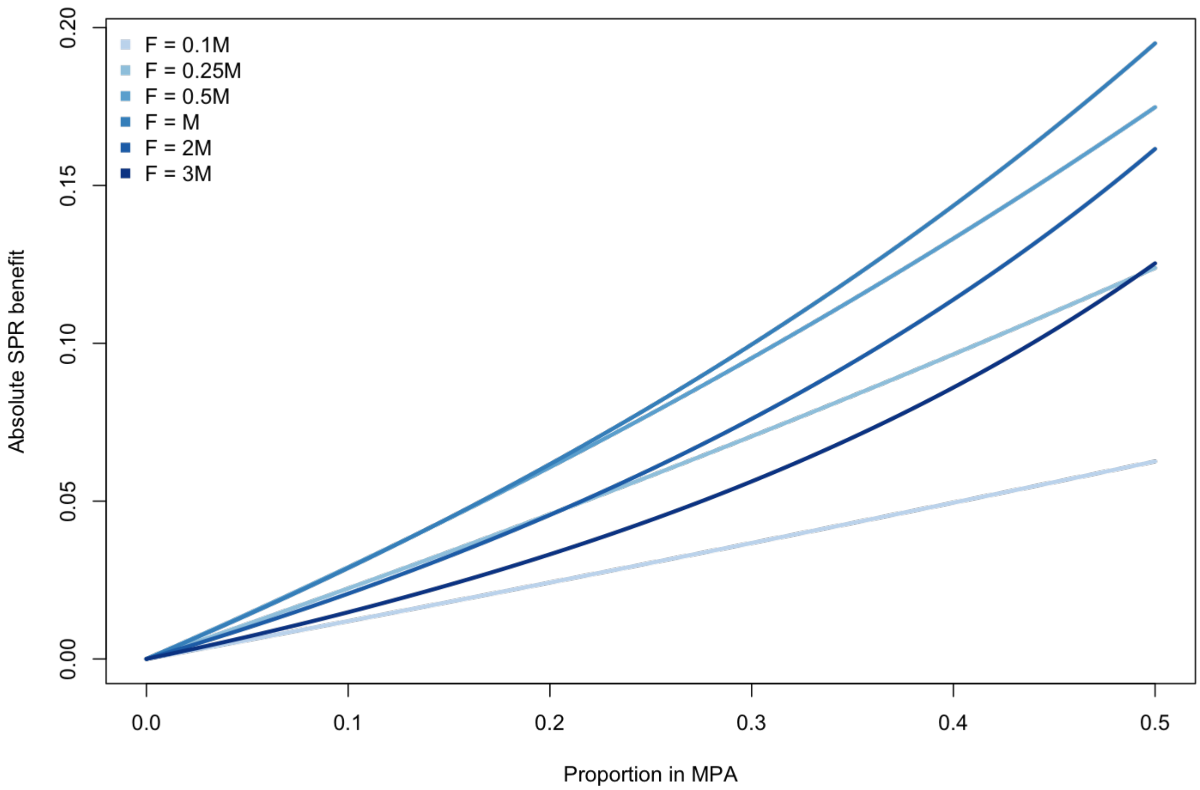


Figure 6. The ideal effect of having a proportion of a population in an MPA on the absolute change in SPR that could be achieved.

Cautions

One of the key assumptions of the GTG LBSPR model is that the length frequencies used in the assessments are representative of a population fluctuating around an equilibrium. The GTG LBSPR model is reasonably robust to variability (Hordyk et al. 2016) and estimated catch has been relatively stable for the fishery as a whole. At the species level, there has been some greater variability in recent years but no indication of major recruitment events that would skew the length frequency data.

Length-based spawning potential ratio assessments are sensitive to the input data. Small changes in the asymptotic mean length and other input parameters can result in different determinations of status relative to reference points. Some of this uncertainty is captured with the Monte Carlo iterations and results should be viewed with risk tolerance levels in mind. The design of sampling programs intended to produce growth model estimates or collect length frequencies from the catch need to be carefully considered when interpreting the result. Growth models fit to opportunistic data will have inherent bias as they are less likely to be representative across ages of the mean size at age in the vulnerable population. This effect can be exacerbated when data are collected from areas with high exploitation and age structures are truncated resulting in a paucity of older ages and faster growers. Bias can also occur in creel or bio-sampling programs if sample selections of trips and individual fish caught are not randomized.

Imputing (borrowing) life history characteristics for other locations can also introduce bias since these characteristics are often particular to local environmental conditions. Natural mortality for the species assessed has not been estimated but derived from empirical meta-analyses. To alleviate some of this potential bias, longevity has been used to estimate natural mortality as opposed to von Bertalanffy growth parameters. This is not a perfect solution since sample sizes need to be large for max ages to be detected; for heavily exploited populations, the observations may be biased to lower ages though there is some suggestion that small sample sizes are not a significant issue (Hamel and Cope, 2022).

The data collected from the fishery can be thought of as a weighted sample where the weights relative to the stocks in question depend on the spatial distribution of the fishery or monitoring programs. If these programs are not representatively sampling stocks—such as disproportionately fewer samples coming from stock components on the windward side of the island—then the assessment results presented are not a reflection of the status of the entire stock but the weighted component that is sampled. This is not necessarily a problem since this is the component that contributes to the fishery, but the sampling effect should be considered when interpreting the results. Both creel and diver survey information have been combined to produce the results observed. The diver surveys are limited to 30 m and are potentially truncating the size structure as larger individuals tend to occur at greater depths, but the program covers areas that are more difficult to access including marine protected areas. The creel data likely cover greater depths but would be more restricted spatially.

Future considerations

This data limited management strategy evaluation relied heavily on life history information and the collection of length frequency data. In many instances, the sample sizes were below what would be considered ideal, and there is certainly room to improve and target the collection of such information. The allocation of resources should consider the relative benefits to the monitoring and management of the reef community in general. The use of indicator species as outlined in the Magnuson-Stevens Act can help to focus discussion on which species should take priority to attain adequate samples for life history refinement and length composition information to use in assessments. How the information presented in this memo will contribute to the management of reef fisheries in Guam will depend on how feasible it is to implement the potential management strategies and the stated management objectives.

Acknowledgements

The data and the production of life history characteristics used in this tech memo came from various divisions at NOAA PIFSC, DAWR staff, and B. Taylor lab at the University of Guam. We thank all these individuals for their time and expertise. We also thank the individuals at PIFSC in the Fisheries Monitoring Program and the Fisheries Reporting and Bycatch Program for providing access to and maintaining the databases that were used.

Species-specific results and management options

Species-specific results are presented for up to 3 different assessments where the input data varied. As previously indicated, the base runs used input values taken from the literature with the references provided or from local studies. Life history inputs for *Caranx melampygus* and *Cheilinus undulatus* come from unpublished local data. SWLH runs use input values derived from the stepwise life history estimation approach described in Nadon and Ault (2016). The results from Nadon (2019) are also included where similar species were assessed. Within the species-specific tables, the results indicated as Base / SWLH / Nadon (2019). Standard error (SE log) values are only presented for the base runs with the value indicating the standard deviation used around the mean in log space. Standard deviations (SD) for output parameters are presented for each assessment but are not necessarily from symmetric distributions.

For each species except *Bolbometopon muricatum*, figures for the input data and output results of the base assessments and simulations. Where applicable, the SWLH assessments and simulations are presented, and Nadon (2019) is referenced for those figures. The input figures have 6 panels showing the distribution of (a) the asymptotic mean length (L_∞) of the von Bertalanffy growth model, (b) length at 50% and 95 % maturity for females represented using a cumulative logistic probability distribution, (c) the distribution of recent harvest, (d) the instantaneous natural mortality rate (M), (e) the metabolic constant of the von Bertalanffy growth model (K), and (f) the observed length frequency. Note that in Nadon (2019), length frequencies were boot strapped but here they are not; therefore, the histogram is from the raw data.

Each output figure has 8 panels showing the distribution of (a) the spawning potential ratio (SPR) estimated using GTG LBSPR, (b) the estimated fishing mortality in recent years, (c) the ratio of current fishing mortality to natural mortality, (d) the ratio of current fishing mortality to the fishing mortality that would result in an SPR of 30%, € the ratio of the current catch to the catch that could be obtained if an SPR 30% target was achieved, (f) the GTG LBSPR estimated selectivity parameters, (g) the estimated 50% selectivity relative to the selectivity that would achieve a fishing mortality (F_{30}) that would result in an SPR of 30%, and (h) boxplots of the SPR values that could be achieved if bag limits at various levels were adopted. The results are boxplots where the bark line presents the median, the boxes are the inner quartiles, and the whiskers are the 95% quartiles. The horizontal red dashed line demarks the SPR 30% reference points. The plot also contains an area indicating catch rates that are not observed in 95% of the creel interviews conducted in recent years

Bolbometopon muricatum

Humphead parrotfish

Pachak / Fumo / Atuhong

Family Scaridae

Life history inputs base (Base)

Parameter	Value	SE log	Unit	Source
L_∞	1070	0.018	mm	Taylor et al. (2018)
CV L_∞	0.13			Assumed
K	0.15	0.047	yr^{-1}	Taylor et al. (2018)
L_{50}	640	0.015	mm	Taylor et al. (2018)
L_{95}	700		mm	Assumed
Longevity	29		yr	Taylor et al. (2018)
M	0.186	0.1	yr^{-1}	
LW - a	1.168e-9		mm to kg	Taylor et al. (2018)
LW - b	3.409			Taylor et al. (2018)
Catch	0		Kg	

Stock status outputs (Base / SWLH / Nadon (2019))

Parameter	Median	SD
SPR	-	-
SPR < 0.3	-	-
F / F_{30}	-	-
C / C_{30}	-	-

General comments

Due to an absence of length data, *Bolbometopon muricatum* could not be assessed. Historically there were some captures of this species (Figure 4). It is likely that this species is predominantly captured at night using spear (Kobayashi et al. 2011) and given the timing of creel surveys, harvest is unlikely to be detected. With the ban of SCUBA spearfishing in Guam, harvest pressure has likely been reduced. The combination of poor harvest tracking and apparent historic depletion would suggest that special consideration be given to the management of *Bolbometopon muricatum*. A very limited harvest tag program or an outright ban on harvest would be warranted until a better understanding of the management goals and status of this species can be determined.

Caranx melampygus

I'e' / Tarakitu

Bluefin Trevally

Family Carangidae

Life history inputs (Base / SWLH / Nadon (2019))

Parameter	**Value**	**SE log**	**Unit**	**Source**
L_∞	518.1 / 674 / 688	0.02	mm	Reed (2023) unpublished
CV L_∞	0.13 / 0.13 / 0.17			Assumed
K	0.433 / 0.26 / 0.25	0.08	yr^{-1}	Reed (2023) unpublished
L_{50}	276.8 / 373.7 / 385	0.015	mm	Reed (2023) unpublished
L_{95}	321.4 / 418.3 / -	0.015	mm	Reed (2023) unpublished
Longevity	13 / 9.6 / 9.4		yr	Reed (2023) unpublished
M	0.415 / 0.55 / 0.34	0.1		
LW - a	2.763e-9		mm to kg	Reed (2023) unpublished
LW - b	2.931			Reed (2023) unpublished
Catch	3782		kg	

Stock status outputs (Base / SWLH / Nadon (2019))

Parameter	**Median**	**SD**
SPR	0.53 / 0.64 / 0.15	0.13 / 0.38 / 0.23
SPR < 0.3	1.4% / 49.7% / 72%	
F / F_{30}	0.45 / 1.3 / 1.9	0.21 / 1.22 / 1.8
C / C_{30}	0.91 / 0.54 / -	0.17 / 0.39 / -

General comments

Using local life history inputs (Figure 7), *Caranx melampygus* showed only a 1.3% chance of returning an SPR below 30%. This would suggest that it is not experiencing overfishing and the adoption of any management measures would not result in significant improvement to the catch (Figure 8). This result is in contrast to the SWLH input data (Figure 9) that suggests almost 50% of assessments return an SPR below 30% (Figure 10) or Nadon (2019) who estimated 72%. The difference is mainly caused by the input value of L_∞, which is much larger in the SWLH and Nadon assessments, as well as differences in how M was estimated. The local life history estimates are based on a small sample size (n = 102; Reed, 2023) and may have potential to come from a depleted population. Much larger sample sizes are generally preferred when establishing life history estimates as older individuals and larger individuals are often difficult to obtain which can bias estimates of L_∞ and A_{max}. Jacks are one of the most common species caught in Guam and are likely experiencing more than light fishing pressure. There has also been an observed length of ~700 mm recorded in the creel which would suggest the L_∞ estimated from local data is an underestimate as is the estimate of A_{max}. Further, divers' length observations from the NOAA coral reef surveys indicate *C. melampygus* commonly reach 75 cm. If the SWLH input life history parameters are a better approximation, then *Caranx melampygus* is likely at a point where management intervention could improve catch outcomes by adopting size of bag limits or other measures to reduce fishing mortality. This advantage will depend on risk tolerance. If more conservative risk levels are preferred, then establishing a size limit greater than the current SL_{50} or the adoption of 8 per trip bag limit would be advantageous.

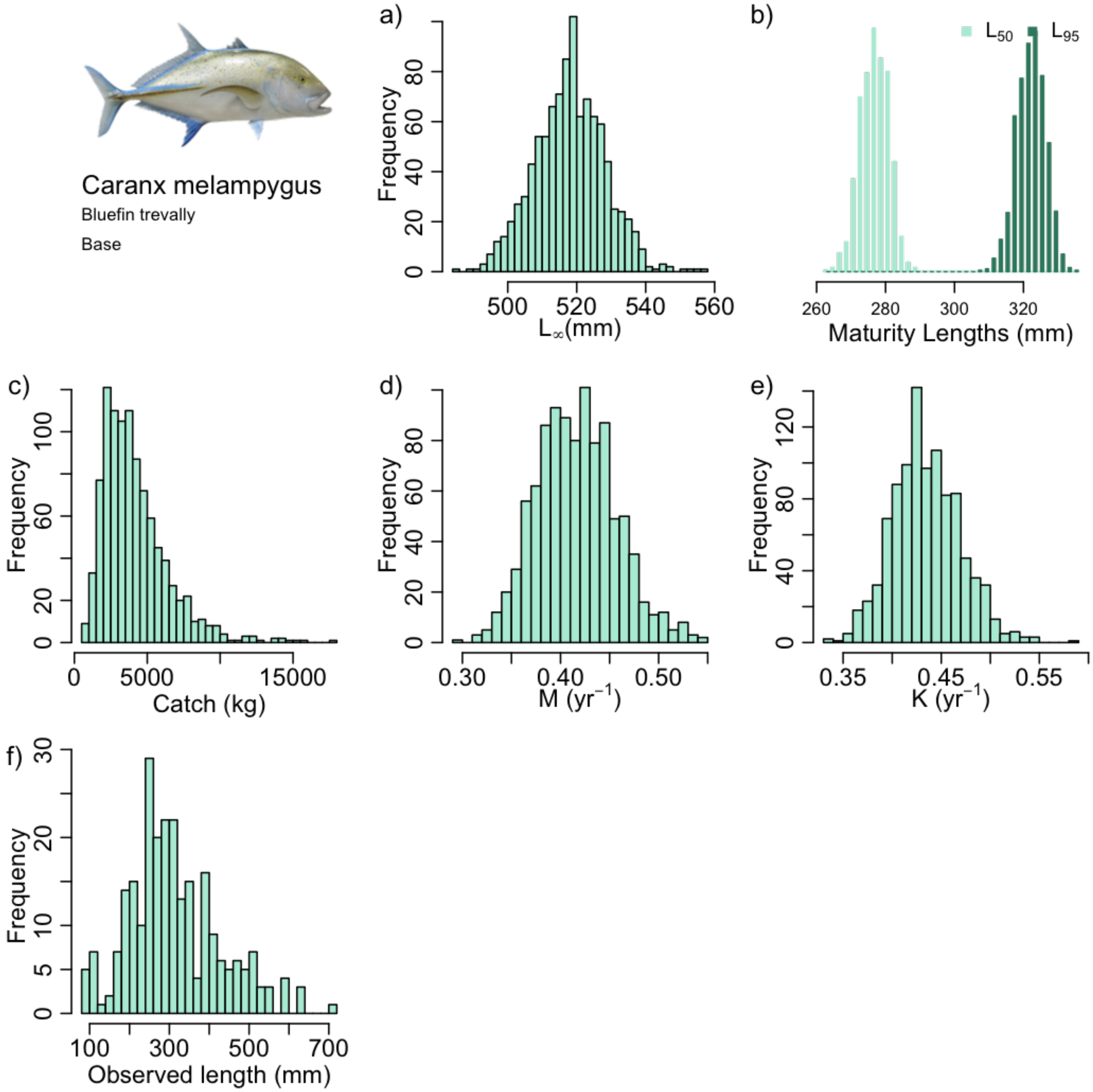


Figure 7. Input parameter distributions and data for *Caranx melampygus* in the base scenario.

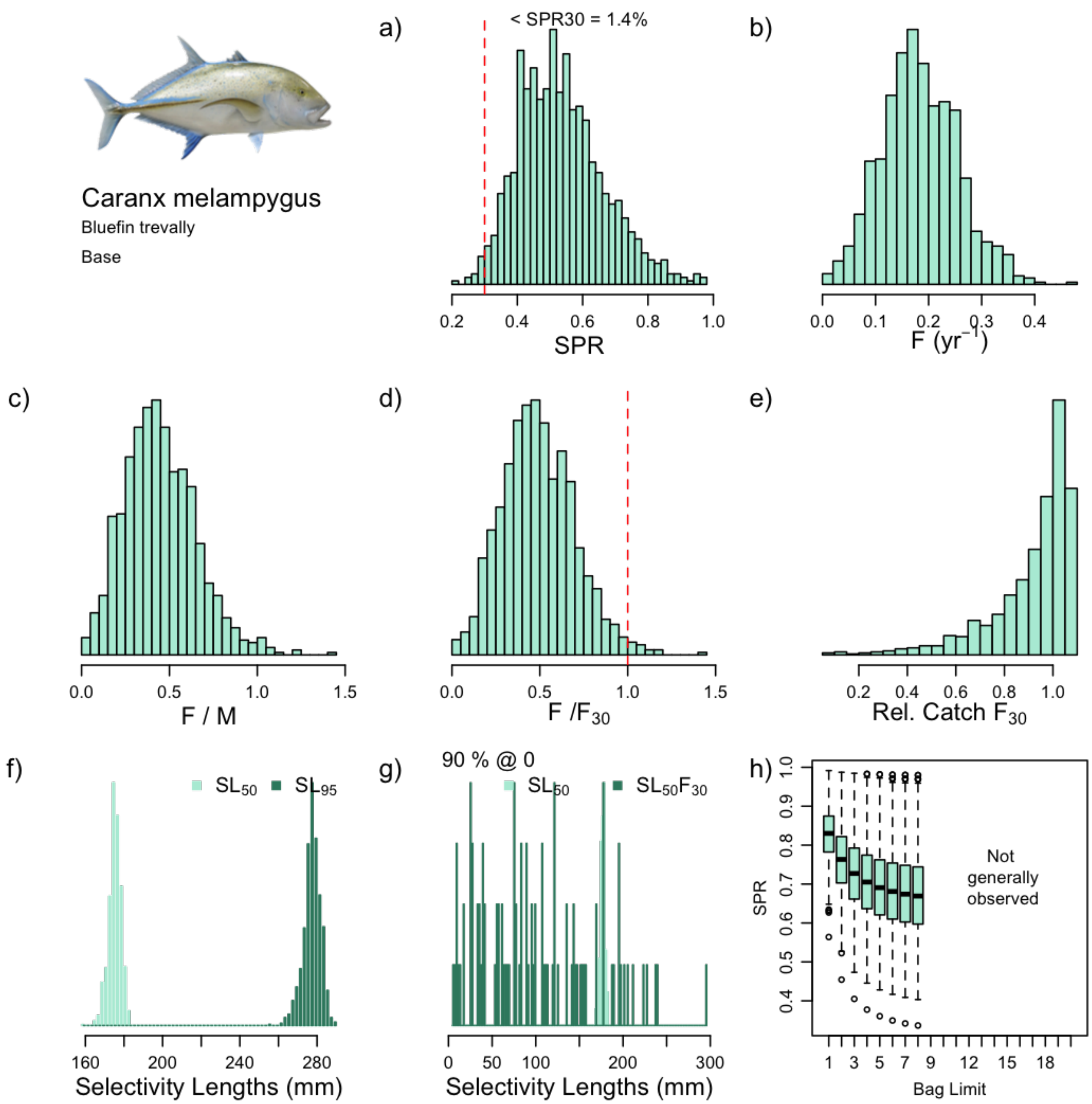


Figure 8. Output reference point and management tactic distributions *Caranx melampygus* in the base scenario.

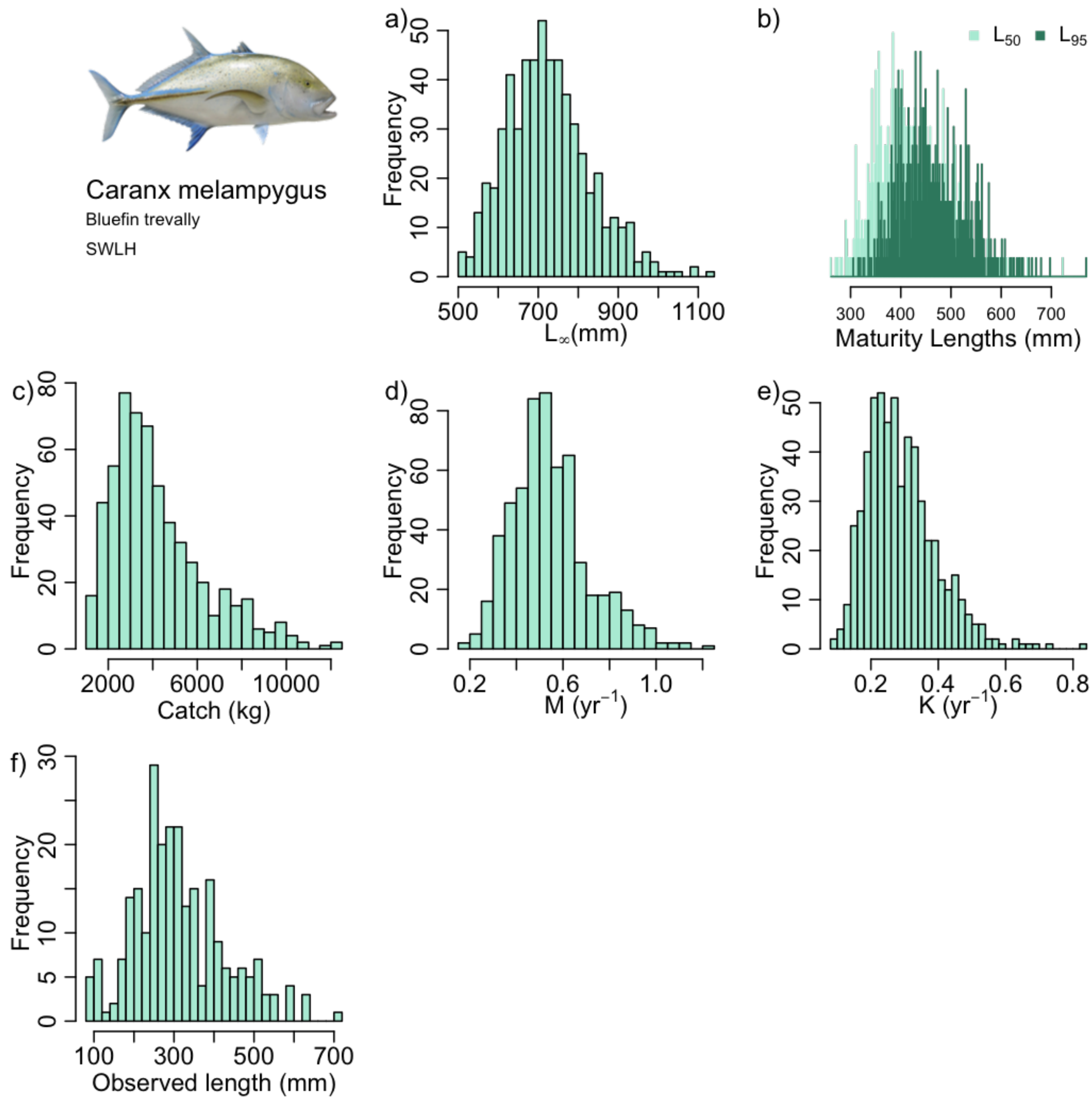


Figure 9. Input parameter distributions and data for *Caranx melampygus* in the SWLH scenario.

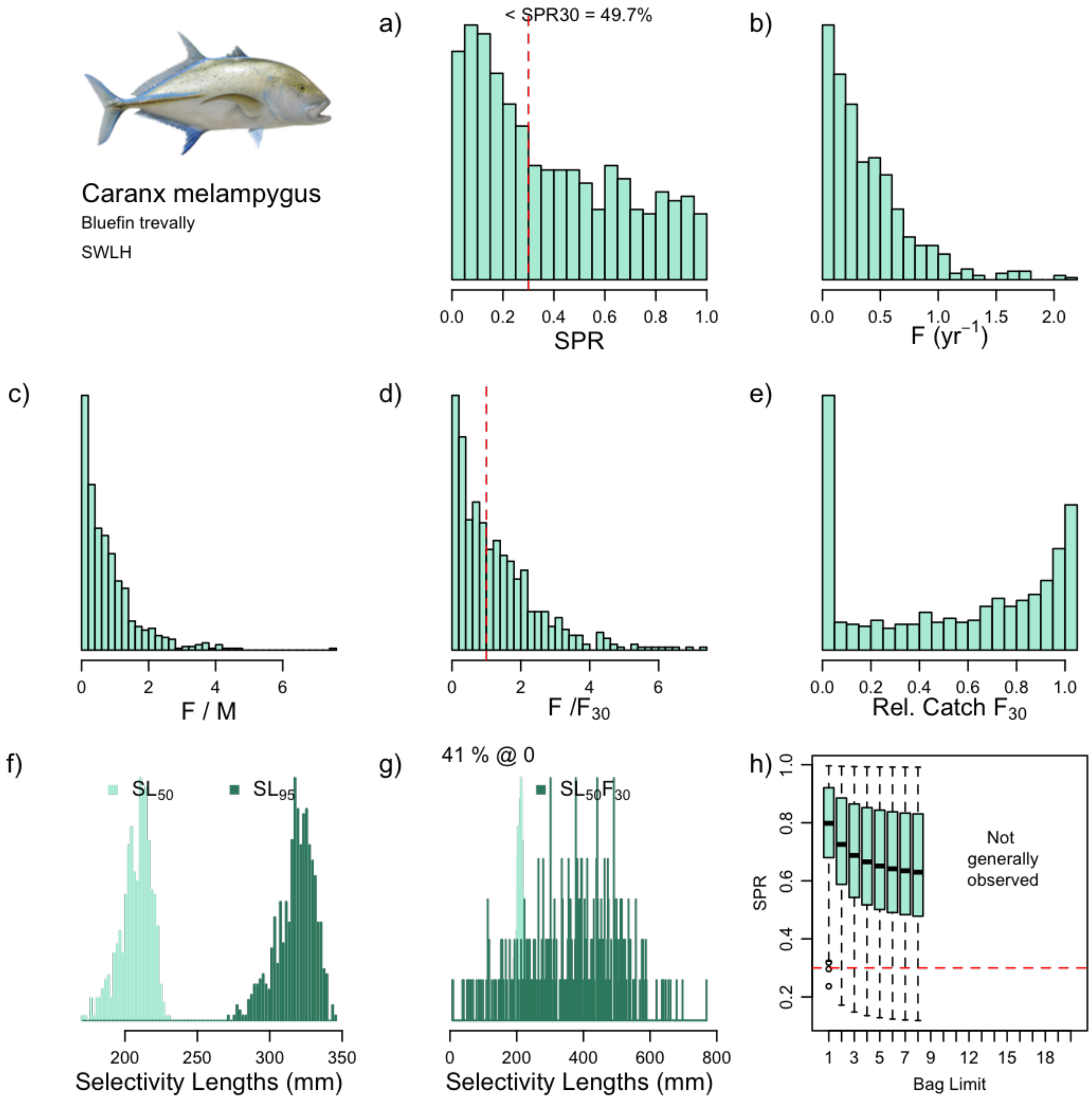


Figure 10. Output reference point and management tactic distributions *Caranx melampygus* in the SWLH scenario.

Cheilinus undulatus

Tåsen guåguan / Tangison

Humphead wrasse

Family Labridae

Life history inputs (Base / SWLH)

Parameter	**Value**	**SE log**	**Unit**	**Source**
L_∞	1382 / 1387	0.02	mm	Taylor (2023) unpublished
CV L_∞	0.13			
K	0.1 / 0.11	0.08	yr^{-1}	Taylor (2023) unpublished
L50	550 / 448	0.015	mm	Taylor (2023) unpublished
L95	590 / 488	0.015	mm	Assumed
Longevity	22 / 19		yr	Taylor (2023) unpublished
M	0.245 / 0.23	0.1		
LW - a	1.61e-9		mm to kg	Taylor (2023) unpublished
LW - b	3.0552			Taylor (2023) unpublished
Catch	55	0.2	kg	

Stock status outputs (Base)

Parameter	**Median**	**SD**
SPR	0.84 / 0.48	0.11 / 0.27
SPR < 0.3	0% / 30%	
F / F30	0.13 / 0.87	0.10 / 0.85
C / C30	0.43 / 0.70	0.26 / 0.37

General comments

The GTG LBSPR results for *Cheilinus undulatus* should be treated with a great deal of caution due to the sample sizes available for the length frequency distribution (n = 44) and the sample size used in the development of life history characteristics (n = 113). While this rough analysis shows little indication that this population is experiencing over fishing as 0% of iterations indicate an SPR less than 30% (Figure 12) in the base case and 30.2% of iterations indicate an SPR less than 30% (Figure 14) using SWLH parameters. Therefore, it would be unwise to put much weight on the results given these limitations.

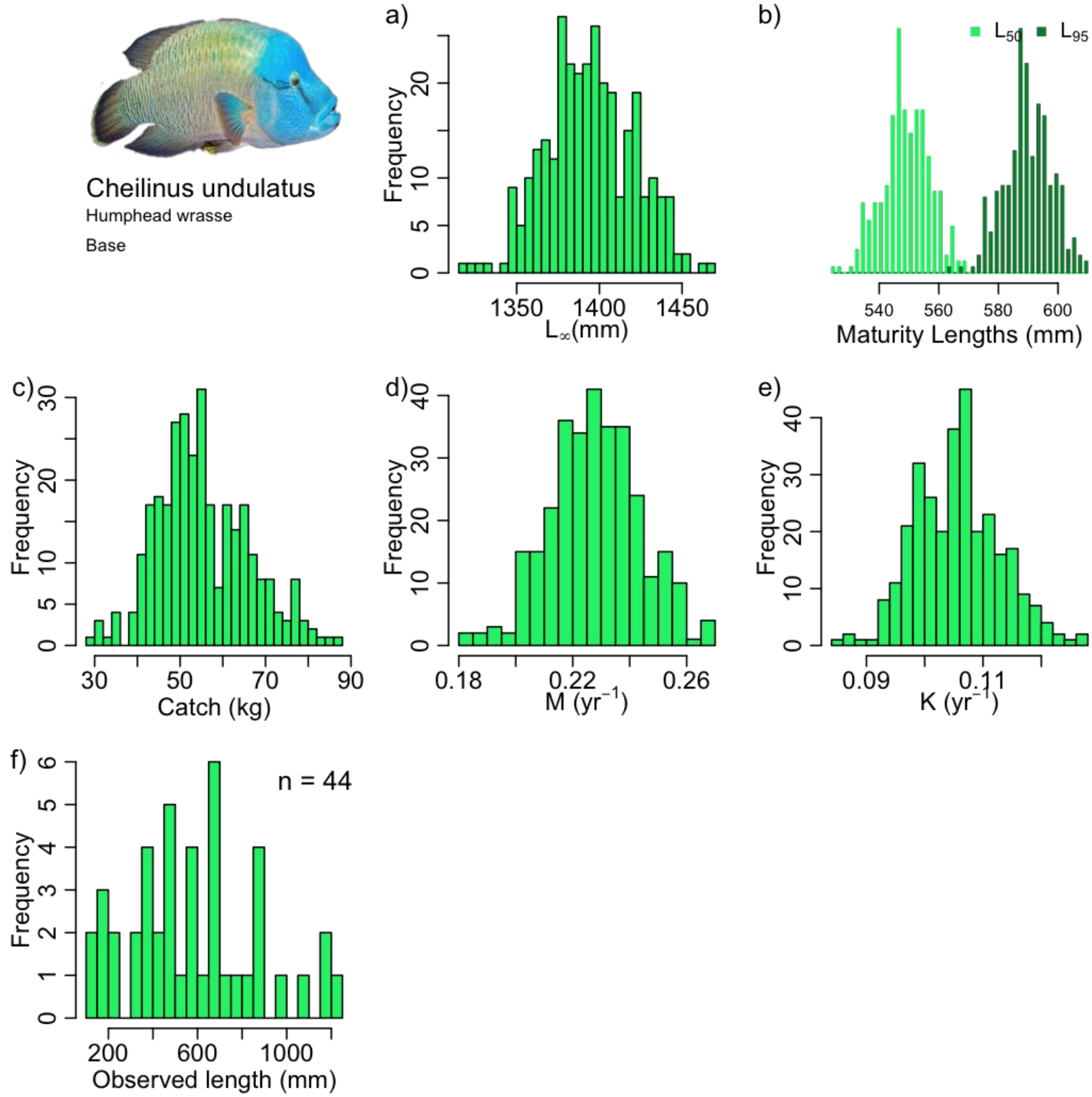


Figure 11. Input parameter distributions and data for *Cheilinus undulatus* in the base scenario.

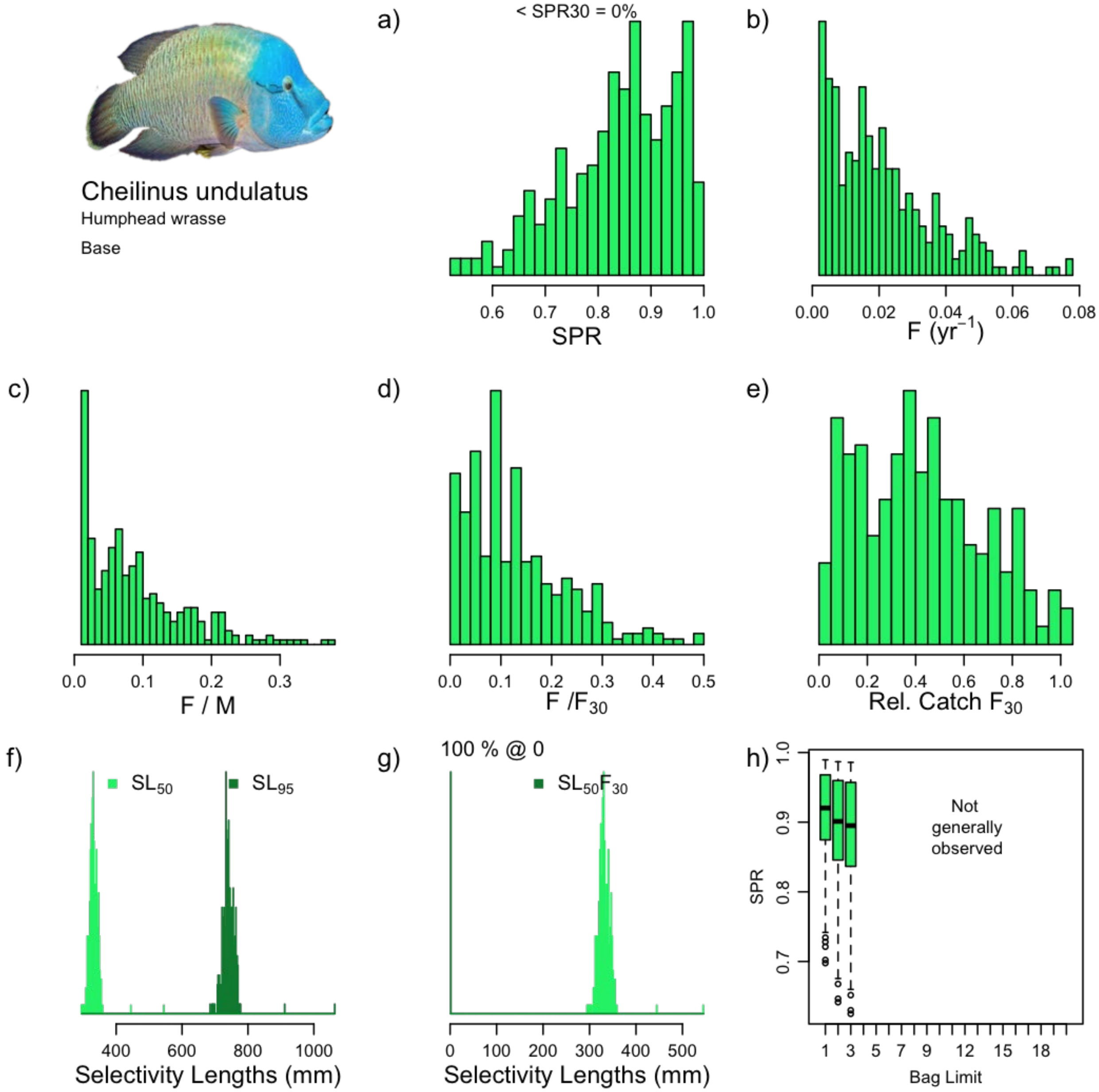


Figure 12. Output reference point and management tactic distributions *Cheilinus undulatus* in the base scenario.

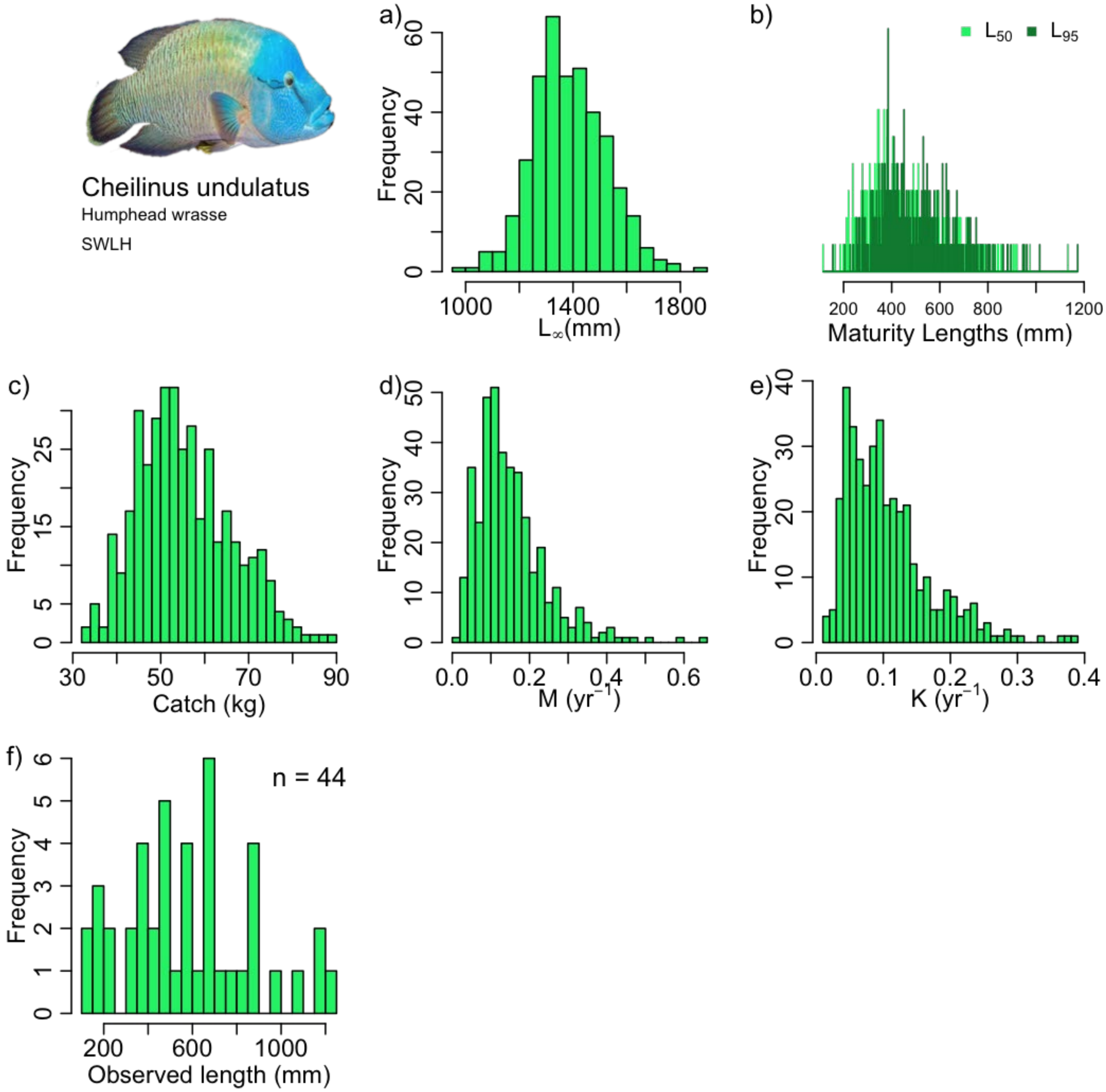


Figure 13. Input parameter distributions and data for *Cheilinus undulatus* in the SWLH scenario.

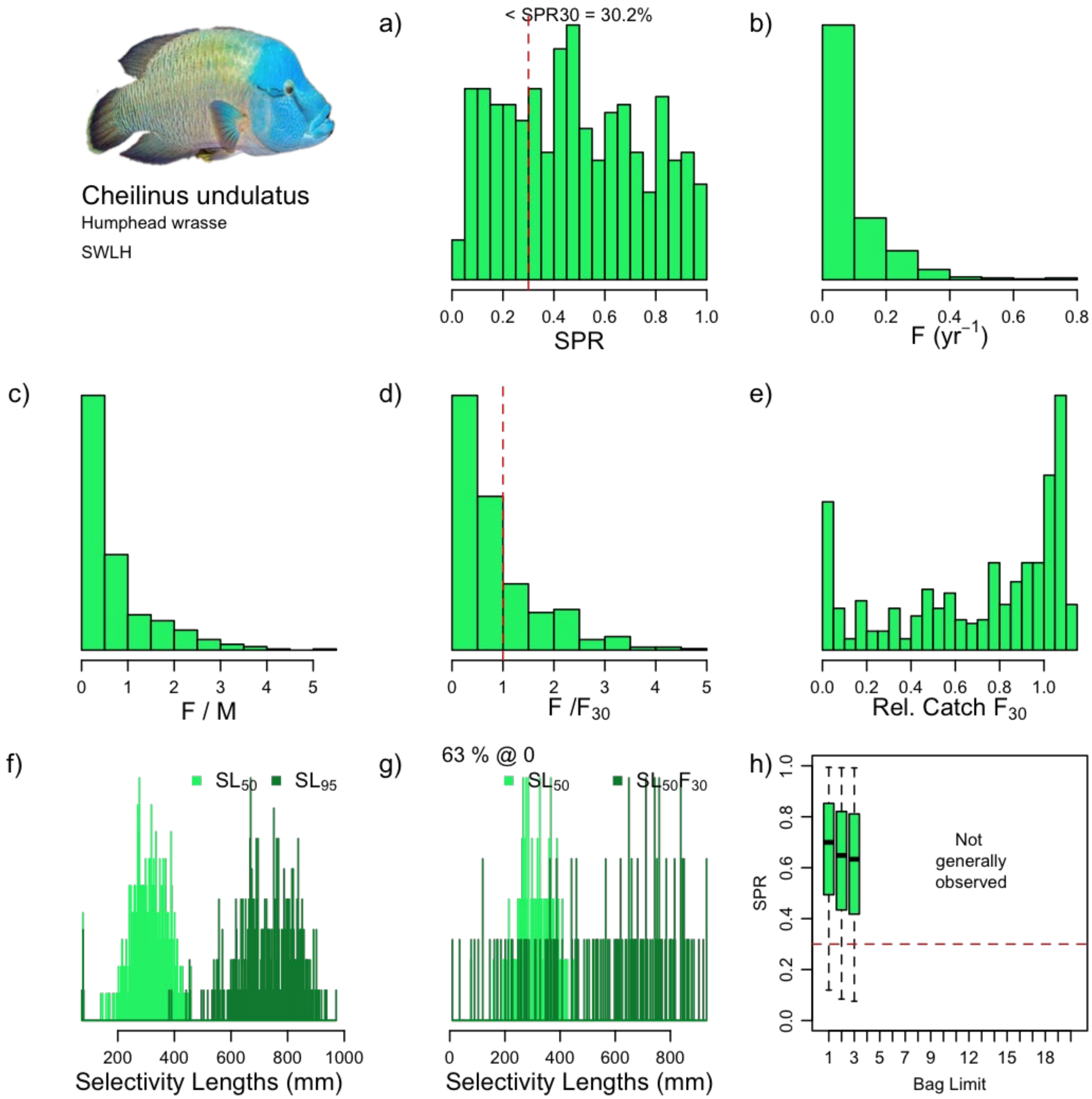


Figure 14. Output reference point and management tactic distributions *Cheilinus undulatus* in the SWLH scenario.

Epinephilus merra

Gådao

Honeycomb grouper

Family Serranidae

Life history inputs (Base/SWLH)

Parameter	Value	SE log	Unit	Source
L_∞	250 / 262	0.2	mm	Pothin et al. (2004)
CV L_∞	0.13			Assumed
K	0.43 / 0.40	0.1	yr^{-1}	Pothin et al. (2004)
L_{50}	180 / 179	0.015	mm	Pothin et al. (2004)
L_{95}	235 / 234	0.015	mm	Pothin et al. (2004)
Longevity	6 / 14		yr	Pothin et al. (2004)
M	0.9 / 0.42	0.1		
LW - a	1.97e-9		mm to kg	Pothin et al. (2004)
LW - b	3.015			Pothin et al. (2004)
Catch	660	0.42	kg	

Stock status outputs (Base / SWLH / Nadon (2019))

Parameter	Median	SD
SPR	0.81 / 0.42	0.10 / 0.25
SPR < 0.3	0% / 39.1%	
F / F_{30}	0.08 / 1.10	0.06 / 1.17
C / C_{30}	0.44 / 0.71	0.21 / 0.35

General comments

The life history parameters (Figure 15) used for *Epinephilus merra* were derived from a study at Reunion Island in the SW Indian Ocean where water temperatures are cooler than in Guam. Though the L_∞ used may be larger than what was determined for Guam, larger individuals are sought after by local fishermen in Reunion and fishing pressure likely caused a high biasing result downwards. All GTG LBSPR assessments (Figure 16) indicated SPR values above 30% and no benefit from management measures such as size of bag limits. These results show that harvest could be increased if the imputed life history characteristics are reflective of the Guam population. SWLH input parameters produced more pessimistic results, but the majority of simulations were still above the SPR 30% reference point (Figure 18). The input values from SWLH for *Epinephilus merra* had a high standard deviation resulting in the rejection of a large number of runs due to estimates of F=0 or F greater than 1.5. The longevity from SWLH was also considerably higher that the SW Indian Ocean study.

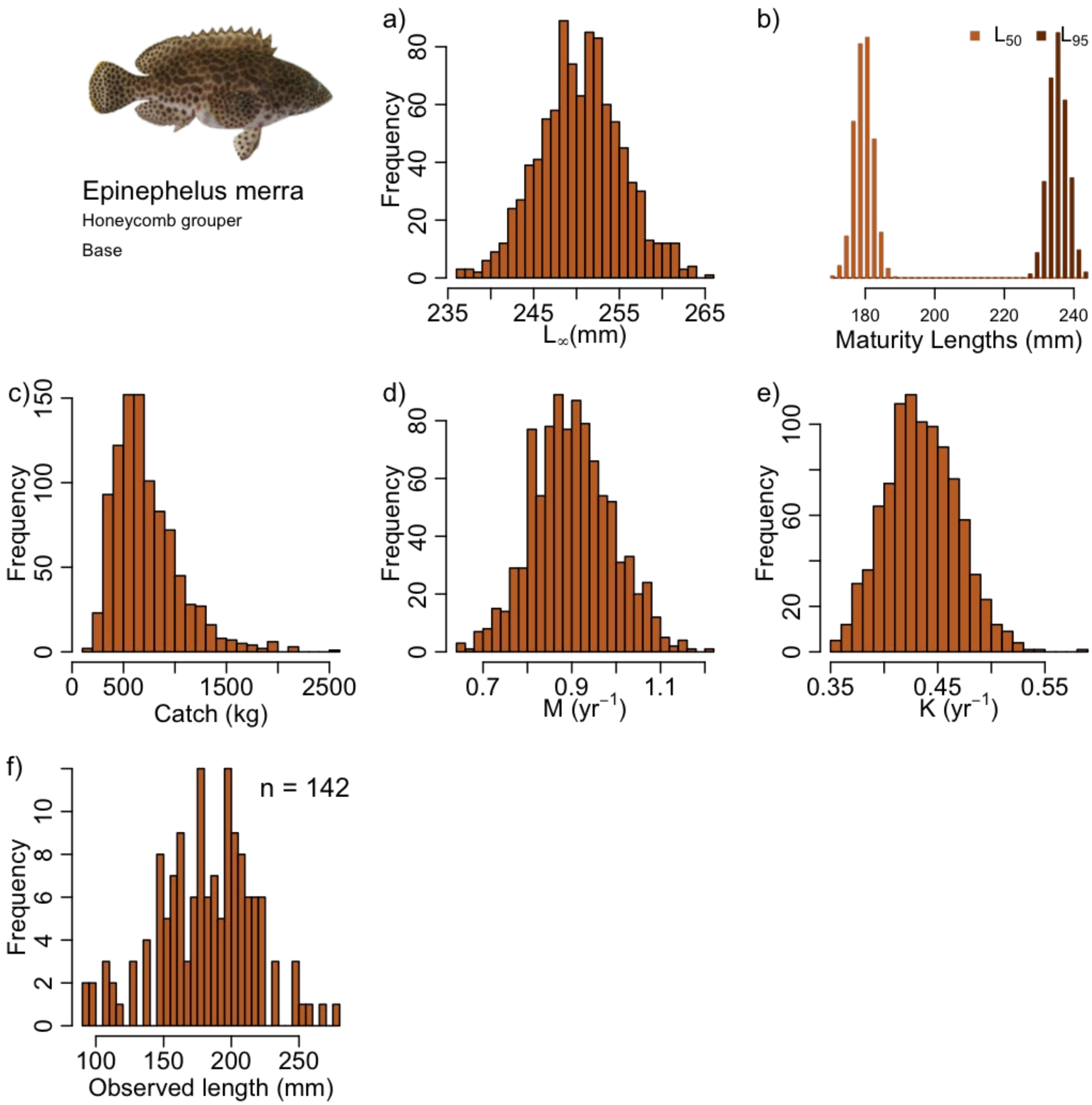


Figure 15. Input parameter distributions and data for *Epinephilus merra* in the base scenario.

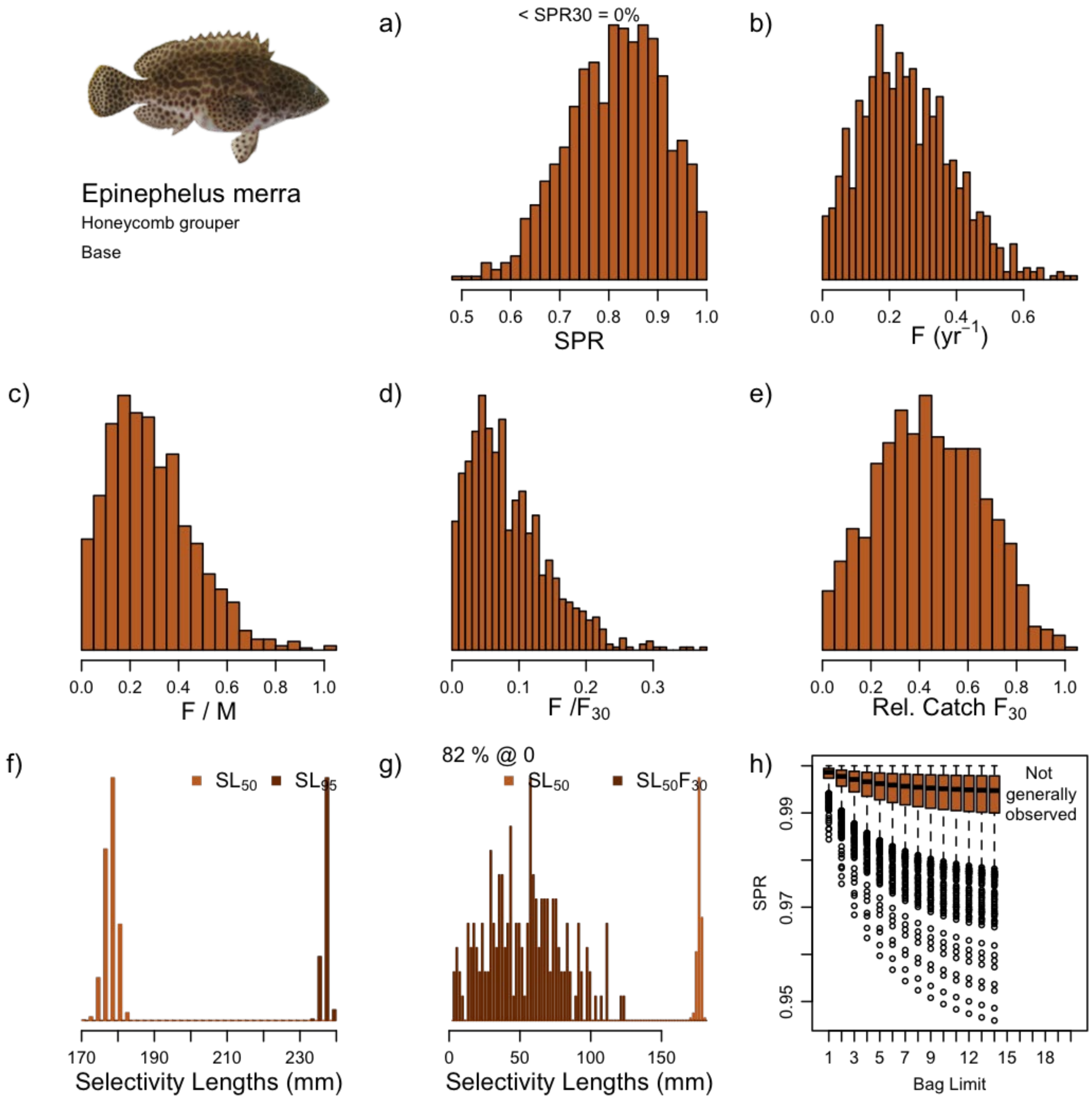


Figure 16. Output reference point and management tactic distributions for *Epinephelus merra* in the base scenario.

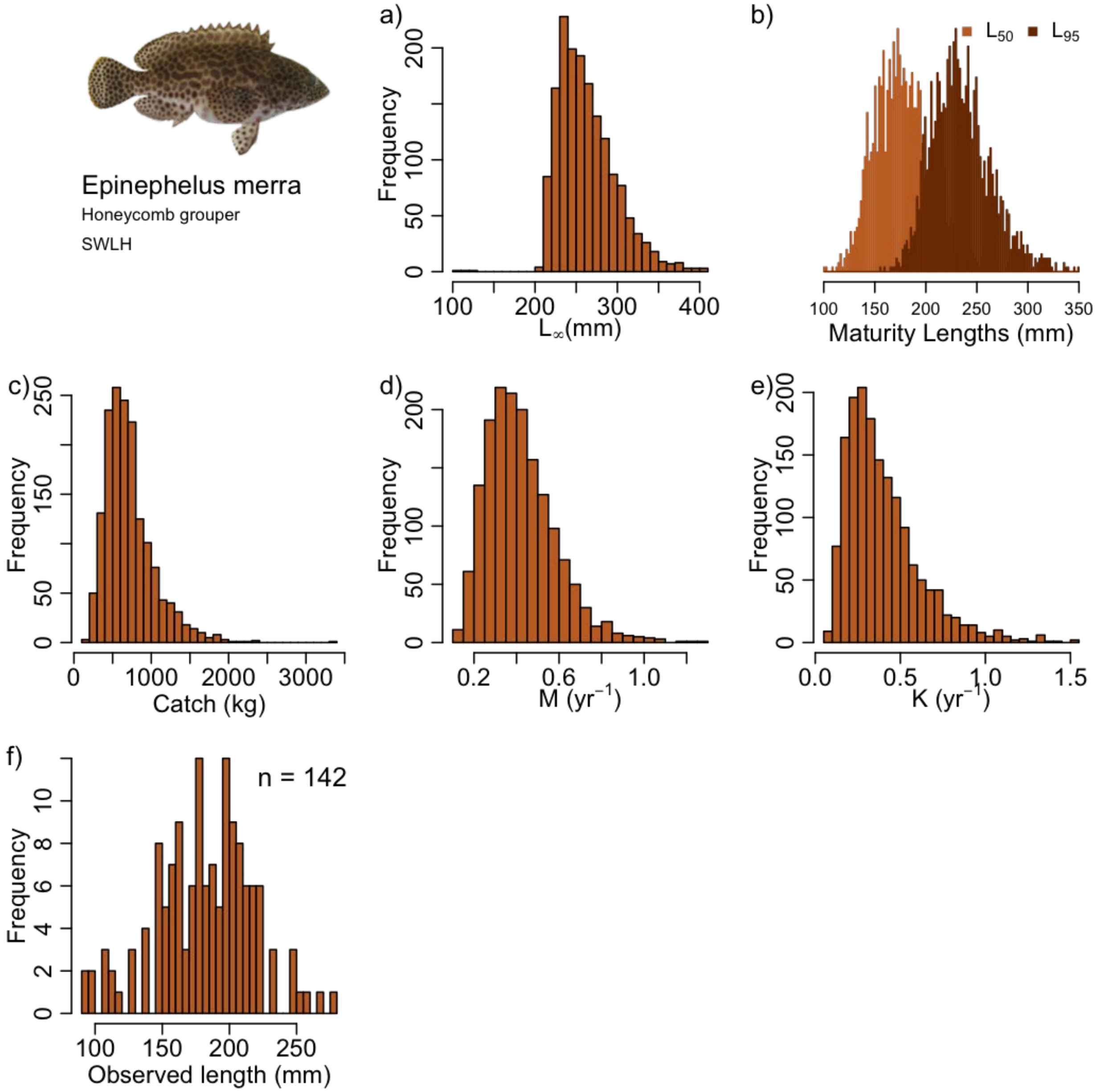


Figure 17. Input parameter distributions and data for *Epinephilus merra* in the SWLH scenario.

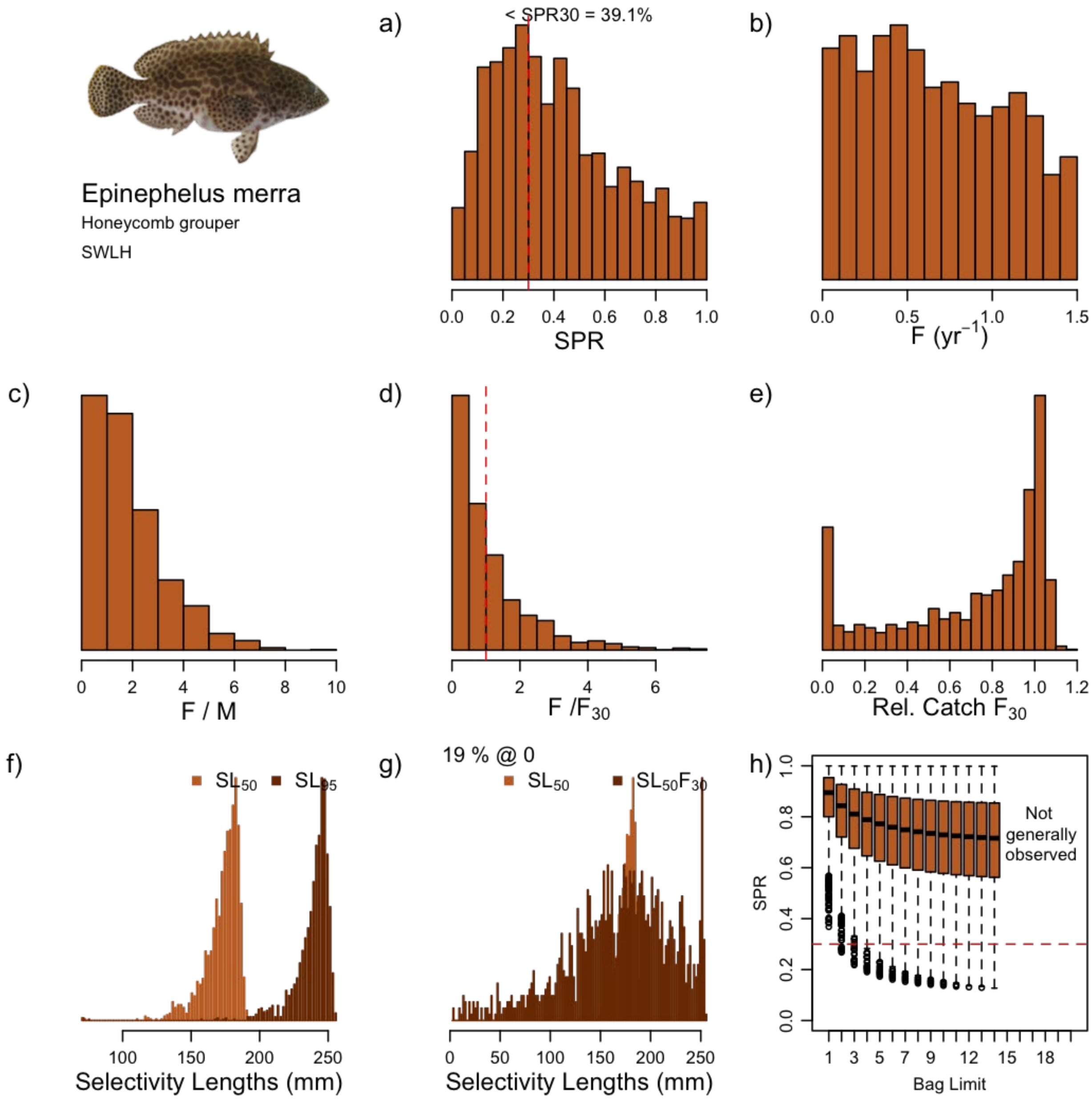


Figure 18. Output reference point and management tactic distributions for *Epinephilus merra* in the SWLH scenario.

Lethrinus olivaceus

Lililok

Longface emperor

Family Lethrinidae

Life history inputs (Base / SWLH / Nadon (2019))

Parameter	**Value**	**SE log**	**Unit**	**Source**
L_∞	800 / 578.2 / 606	0.04	mm	Filous et al. (2022)
CV L_∞	0.13 / 0.13 / 0.1			Assumed
K	0.18 / 0.32 / 0.28	0.015	yr^{-1}	Filous et al. (2022)
L_{50}	380 / 422 / 440	0.015	mm	Filous et al. (2022)
L_{95}	470 / 512 / -	0.015	mm	Filous et al. (2022)
Longevity	22 / 24 / 23		yr	Filous et al. (2022)
M	0.245 / 0.225 / 0.14	0.1		
LW - a	1.09e-9		mm to kg	Filous et al. (2022)
LW - b	2.99			Filous et al. (2022)
Catch	494	0.97	kg	

Stock status outputs (Base / SWLH / Nadon (2019))

Parameter	**Median**	**SD**
SPR	0.15 / 0.32 / 0.18	0.04 / 0.32 / 0.17
SPR < 0.3	99% / 59 % / 75%	
F / F30	1.8 / 1.4 / 1.6	0.33 / 0.24 / 0.9
C / C30	0.40 / 0.58 / -	0.28 / 0.39 / -

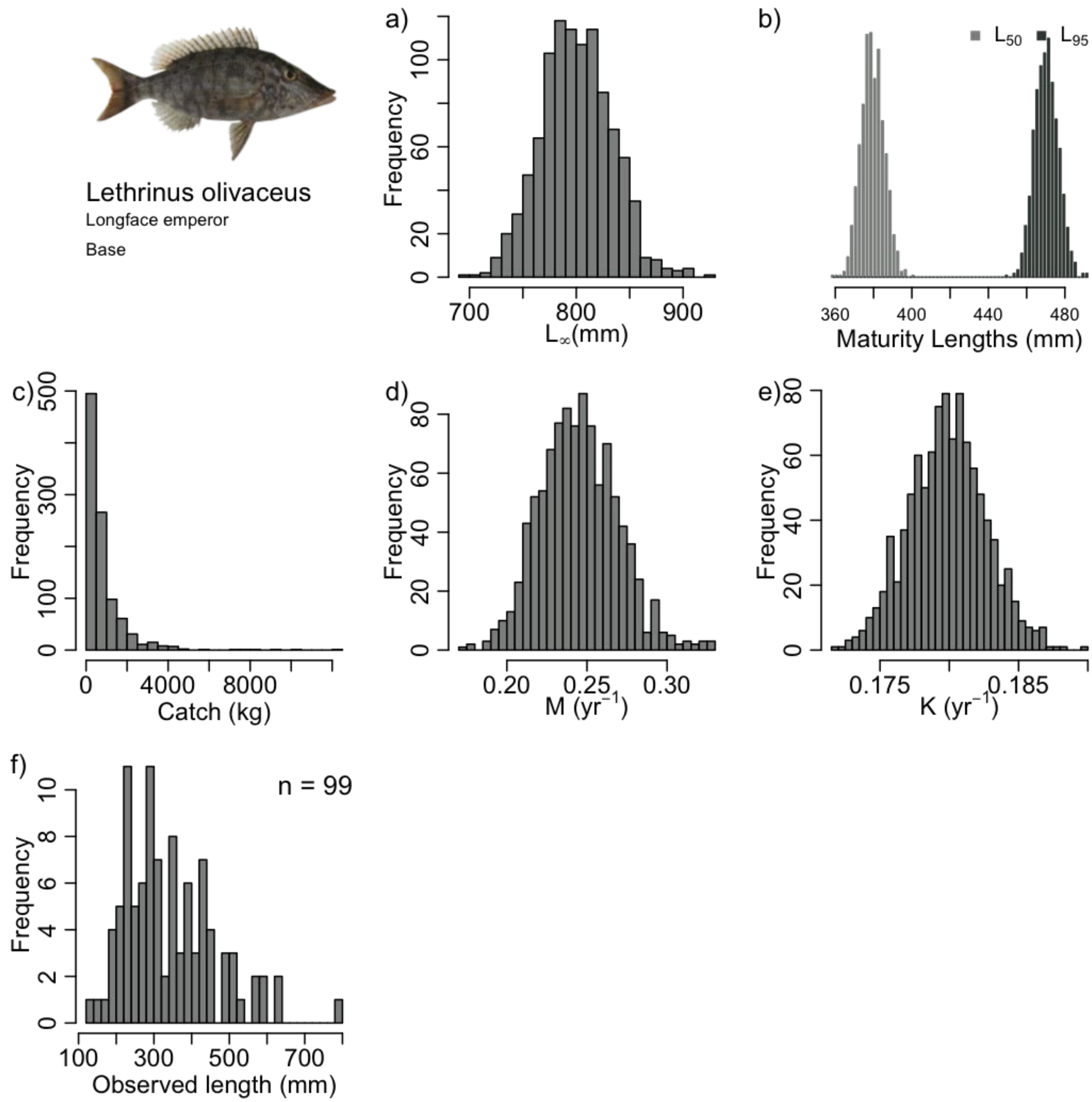


Figure 19. Input parameter distributions and data for *Lethrinus olivaceus* in the base scenario.

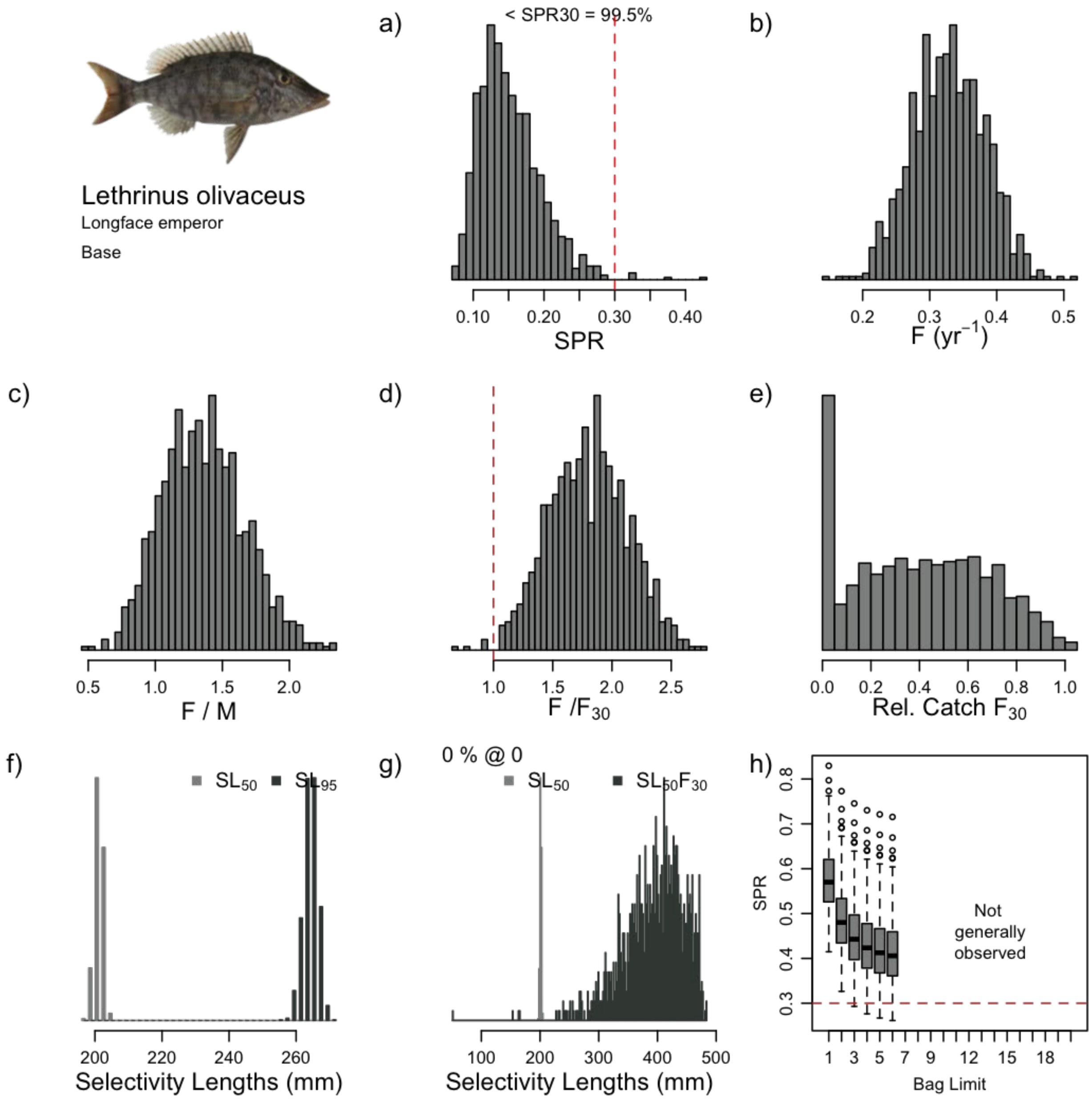


Figure 20. Output reference point and management tactic distributions *Lethrinus olivaceus* in the base scenario.

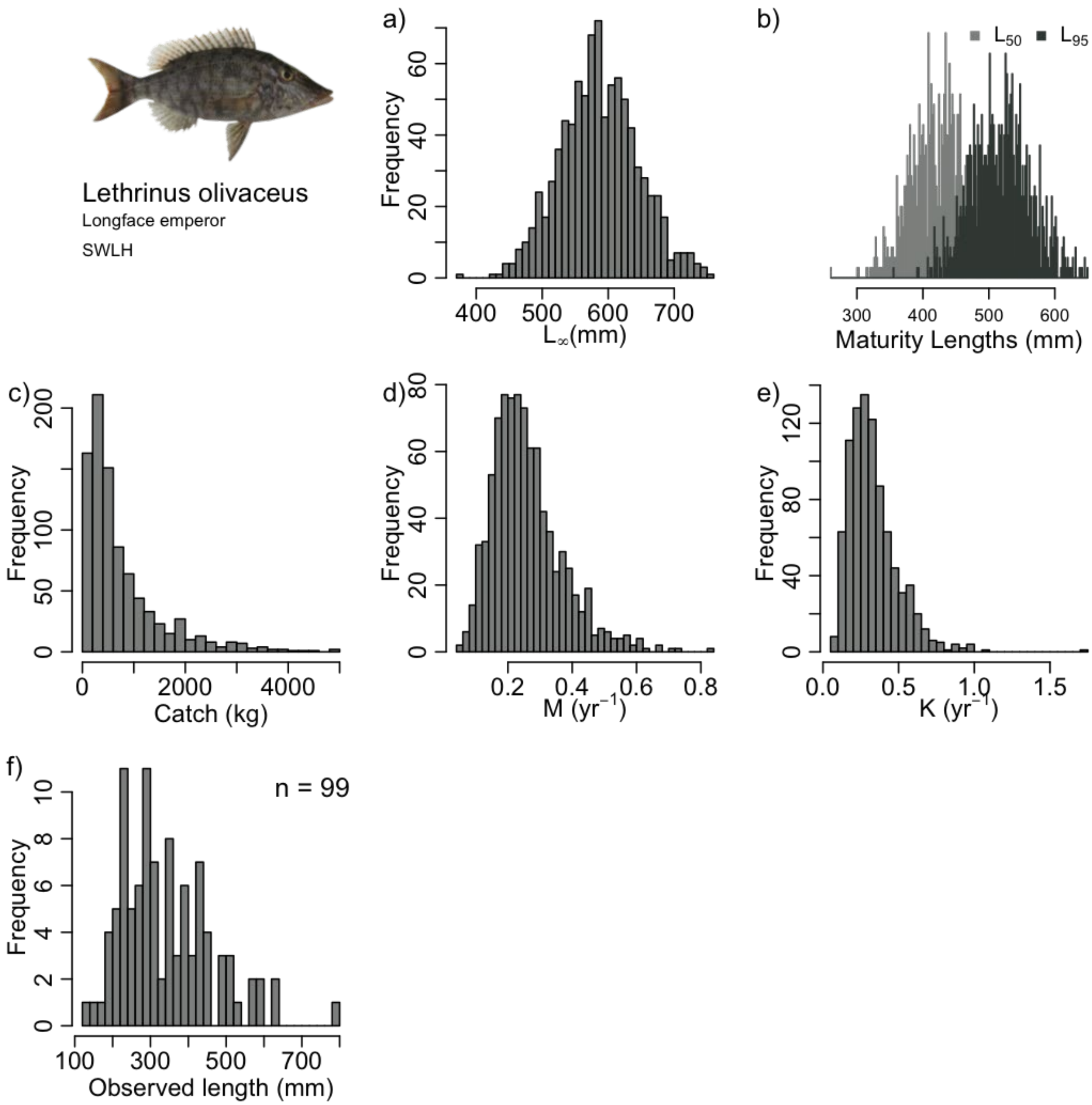


Figure 21. Input parameter distributions and data for *Lethrinus olivaceus* in the SWLH scenario.

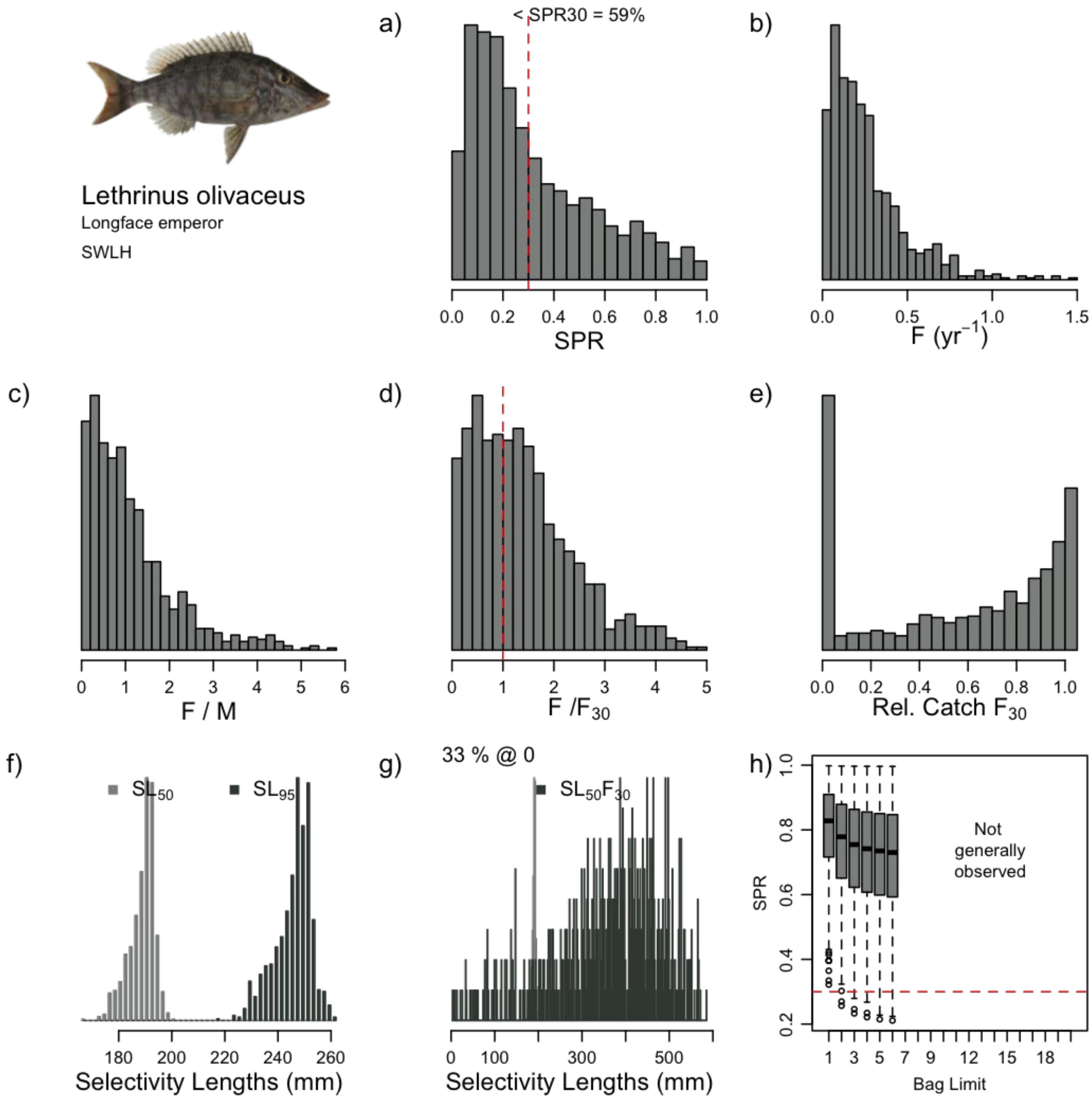


Figure 22. Output reference point and management tactic distributions *Lethrinus olivaceus* in the SWLH scenario.

Lutjanus fulvus

Bu’a

Blacktail snapper

Family Lutjanidae

Life history inputs (Base / SWLH)

Parameter	**Value**	**SE log**	**Unit**	**Source**
L_∞	265 / 273.6	0.015	mm	Shimose and Nanami (2014)
CV L_∞	0.13			Assumed
K	0.41 / 0.549	0.04	yr^{-1}	Shimose and Nanami (2014)
L_{50}	176 / 203	0.015	mm	Shimose and Nanami (2014)
L_{95}	216 / 243	0.015	mm	Assumed
Longevity	25 / 15.9		yr	Shimose and Nanami (2014)
M	0.216 / 0.244	0.1		
LW - a	1.209e-9		mm to kg	Shimose and Nanami (2014)
LW - b	3.09			Shimose and Nanami (2014)
Catch	448	0.65	kg	

Stock status outputs (Base / SWLH)

Parameter	**Median**	**SD**
SPR	0.24 / 0.41	0.04 / 0.36
SPR < 0.3	93.6% / 64.3%	
F / F_{30}	1.22 / 2.00	0.19 / 1.73
C / C_{30}	0.86 / 0.48	0.11 / 0.41

General comments

The base variation of GTG-LBSPR for *Lutjanus fulvus* resulted in 93.6% of assessments with an SPR less than 30% (Figure 24). The base life history parameters (Figure 23) were from a study located around Yaeyama Islands, Okinawa, Japan, where water temperatures are similar in the summer but 5 °C cooler in the winter. Given the observed length frequencies, the L_∞ estimated in this study is reasonable. With the current fishing mortality rate, the adoption of a size limit of around 160 mm would achieve an SPR of 30%. A bag limit of 8 per trip would also meet the SPR 30% requirement. If one of these measures were adopted, modest increase in catch could be achieved. SWLH assessment had much lower max ages and hence higher mortality rates (Figure 25). These input differences resulted in a less pessimistic assessment with 64.3% resulting in SPR values below 30% (Figure 26). The utility of size and bag limit management strategies were less clear with the SWLH input. There was some indication that a size limit around 200 mm would improve catch. Bag limits below 8 would also increase SPR.

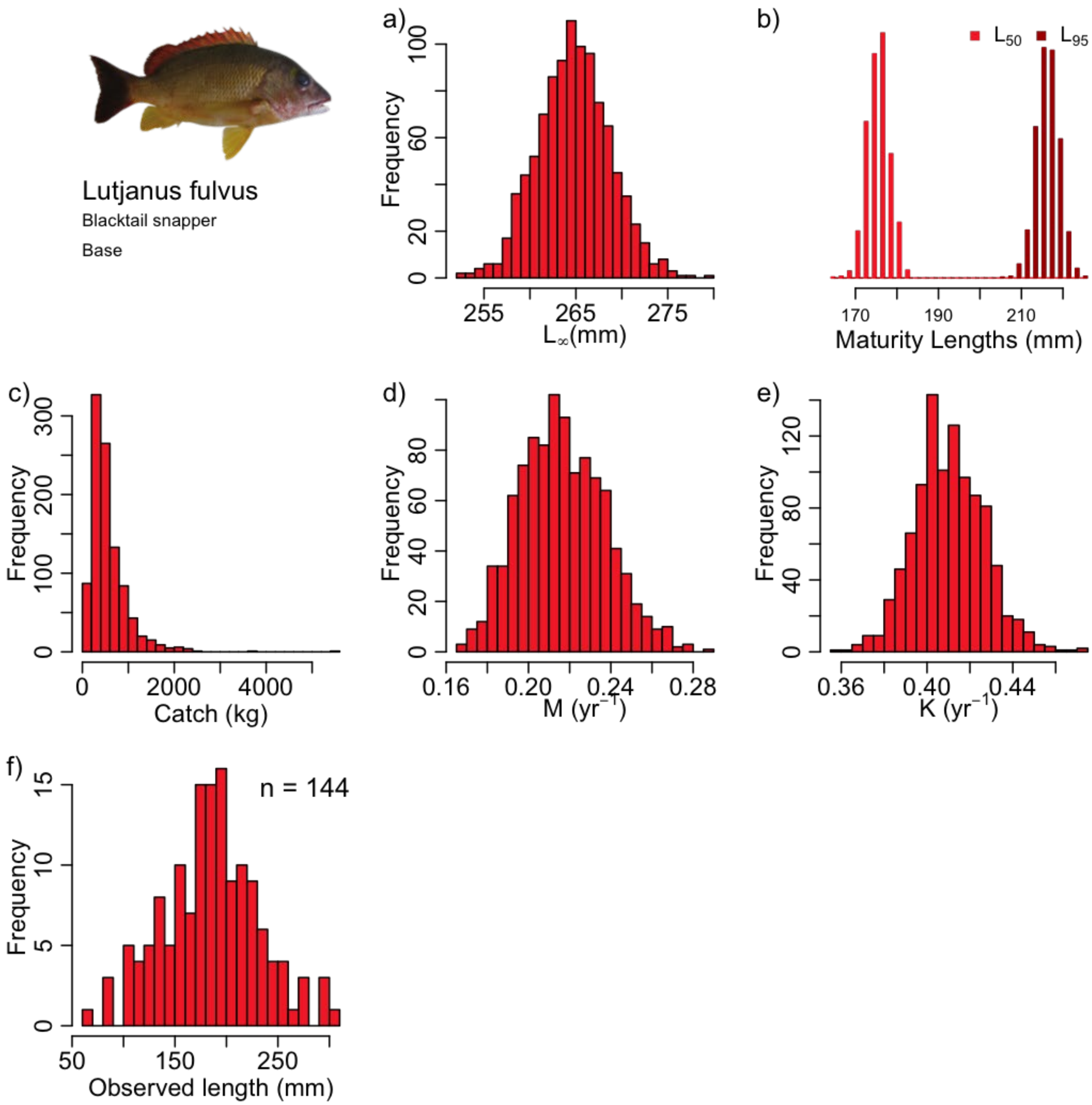


Figure 23. Input parameter distributions and data for *Lutjanus fulvus* in the base scenario.

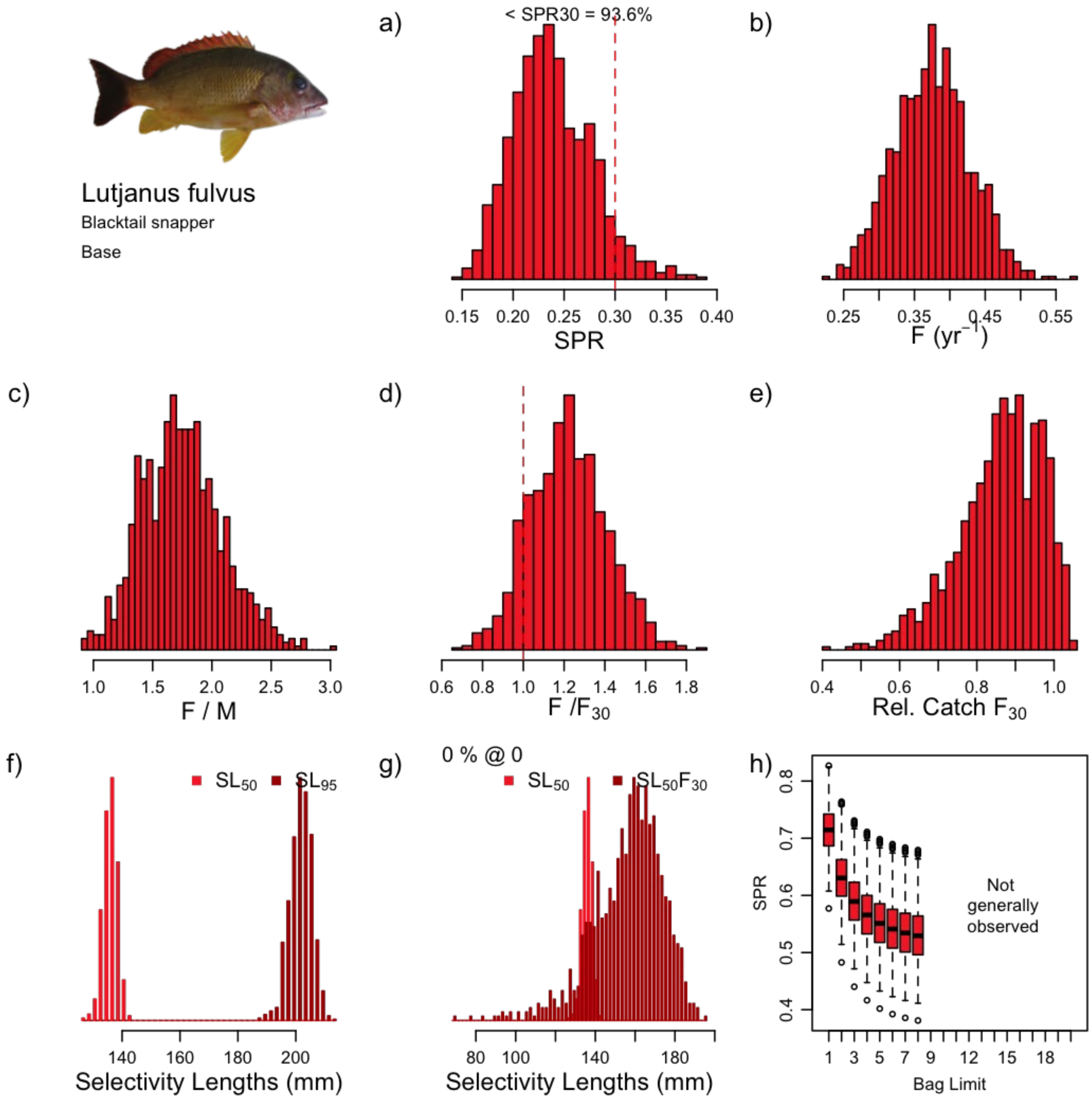


Figure 24. Output reference point and management tactic distributions *Lutjanus fulvus* in the base scenario.

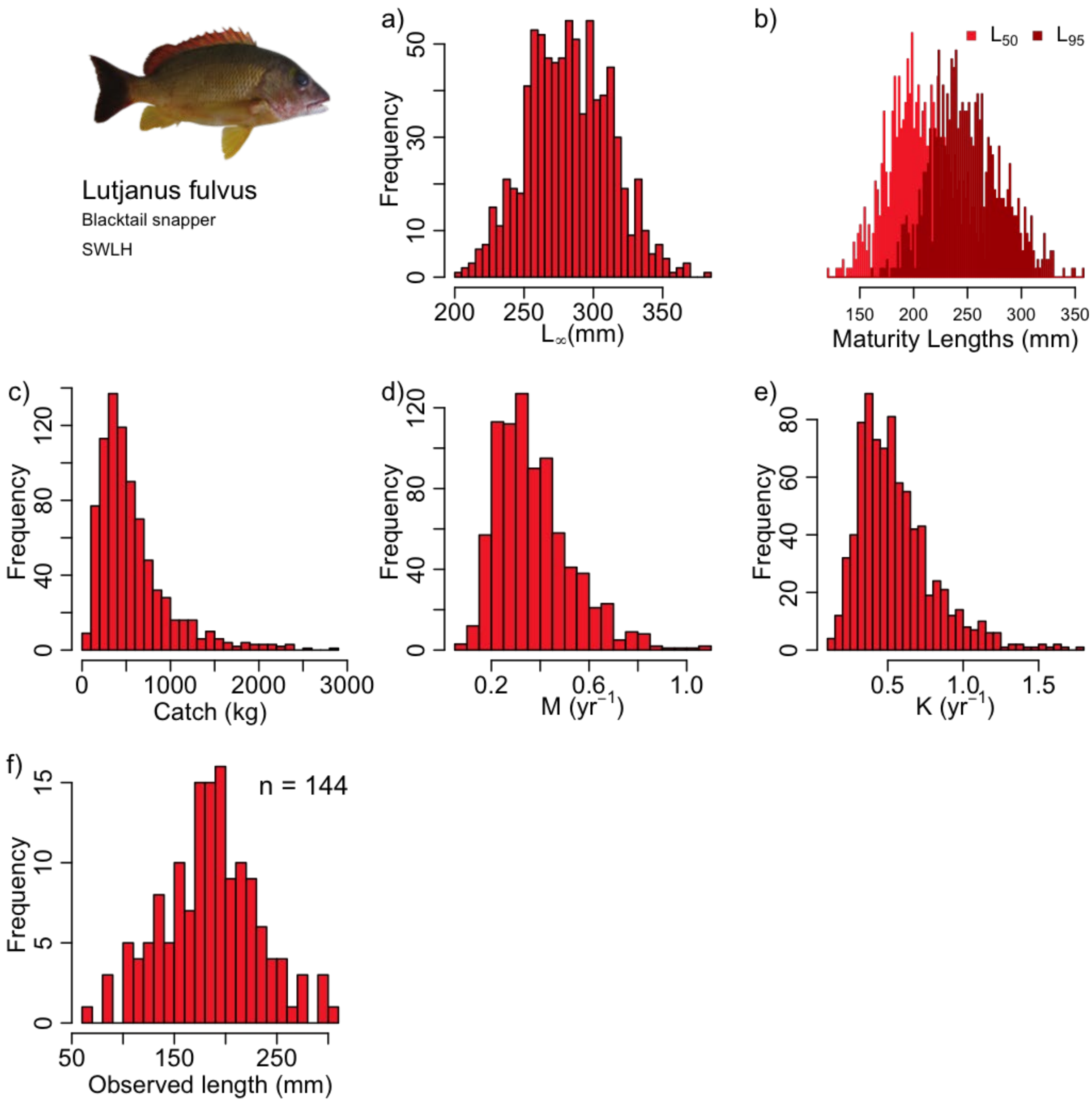


Figure 25. Input parameter distributions and data for *Lutjanus fulvus* in the SWLH scenario.

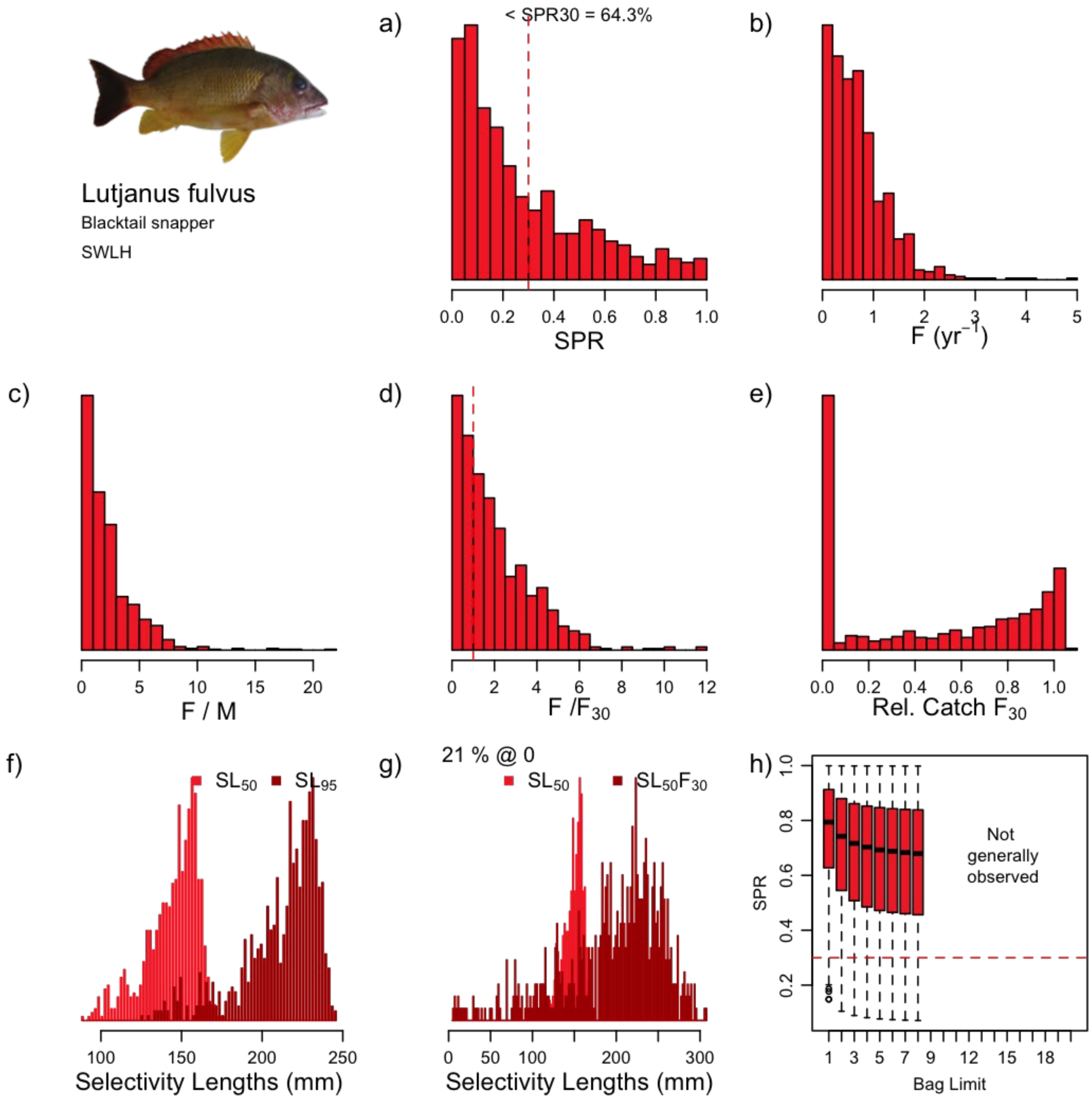
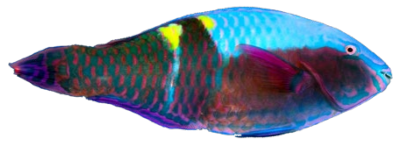


Figure 26. Output reference point and management tactic distributions *Lutjanus fulvus* in the SWLH scenario.

Scarus schlegeli



Palakse'

Yellowband parrotfish

Family Scaridae

Life history inputs (Base / SWLH)

Parameter	**Value**	**SE log**	**Unit**	**Source**
L_∞	252 / 323 / -	0.03	mm	Taylor and Choat (2014)
CV L_∞	0.13			Assumed
K	1.03 / 0.67 / -	0.1	yr^{-1}	Taylor and Choat (2014)
L_{50}	197 / 223 / -	0.015	mm	Taylor and Choat (2014)
L_{95}	220 / 246 /	0.015	mm	Taylor and Choat (2014)
Longevity	8 / 11.9		yr	Taylor and Choat (2014)
M	0.675 / 0.31	0.1		
LW - a	5.011e-9		mm to kg	Taylor and Choat (2014)
LW - b	2.843			Taylor and Choat (2014)
Catch	579	1.5	kg	

Stock status outputs (Base / SWLH)

Parameter	**Median**	**SD**
SPR	0.80 / 0.34	0.13 / 0.30
SPR < 0.3	0% / 54.7%	
F / F_{30}	0.16 / 1.24	0.05/ 0.86
C / C_{30}	0.42 / 0.64	0.26 / 0.37

General comments

Life history inputs (Figure 27) for the base assessment of *Scarus schlegeli* were developed from samples collected in Guam and Pohnpei. L_∞ estimates may be biased low since only 116 samples were used and the populations were exploited. Further, NOAA diver surveys in the Northern Mariana Islands typically show this species is up to 35 cm, which also suggests issues with the local growth curve. Base runs had 0% of assessments with SPR values below 30% (Figure 28). Management measures such as size and bag limits were not indicated to improve catch outcomes, and catches could be increased. These results are in contrast to the SWLH runs which had a higher mean value for L_∞ and a mean natural mortality rate much lower than the base runs (Figure 29). Given the observed length frequency for *Scarus schlegeli,* the SWLH estimate of L_∞ may be more reasonable though natural mortality more than likely falls between the two mean estimates. For SWLH runs, 54.7% of assessments had SPR values below 30% indicating that this stock is experiencing overfishing. There was some indication that size limits of around 200 mm would improve catch outcomes by increasing the SPR to 30%. A bag limit of 12 per trip would also increase the SPR. In the SWLH runs, there would be gain in catch should SPR 30% be reached.

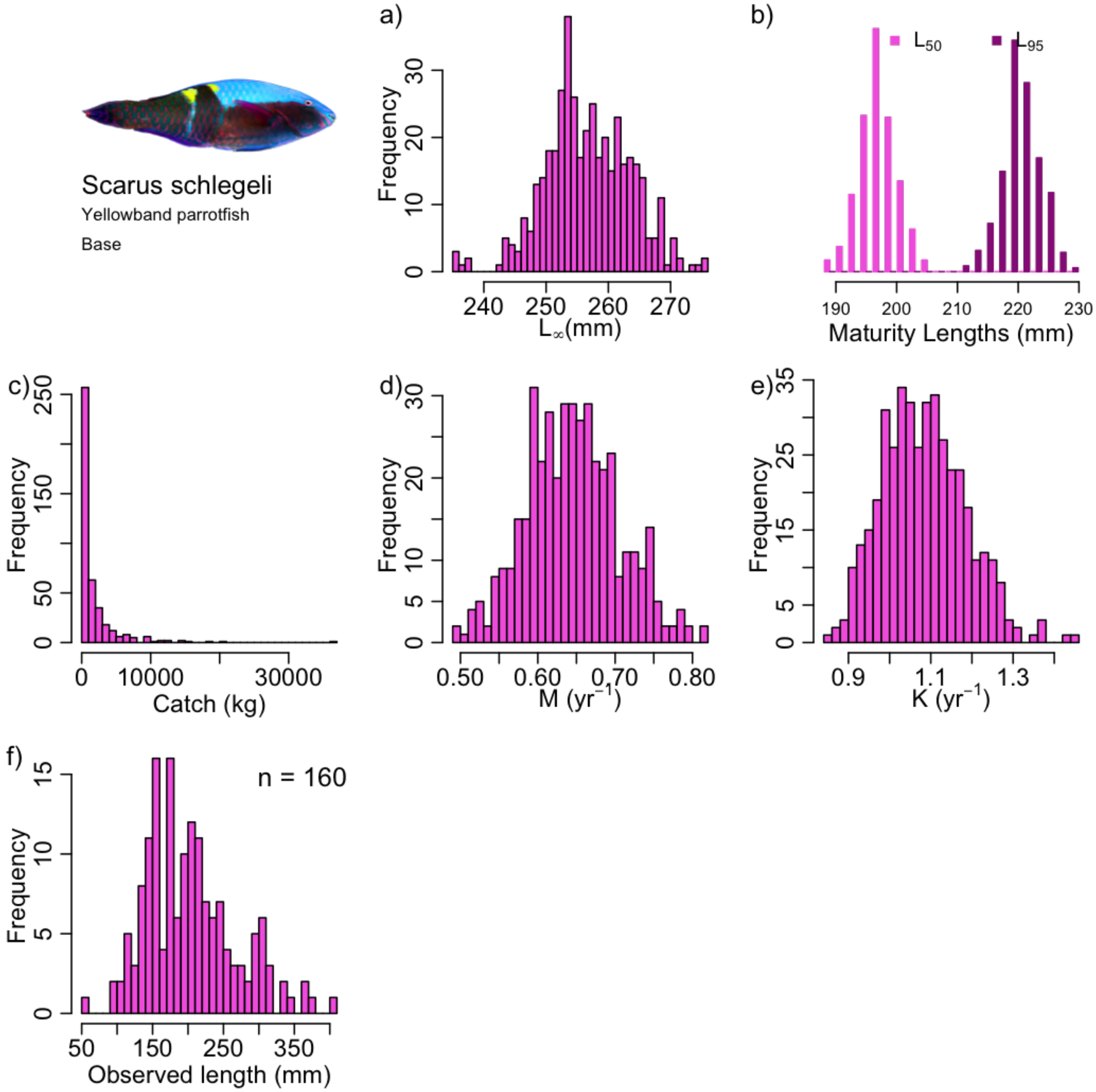


Figure 27. Input parameter distributions and data for *Scarus schlegeli* in the base scenario.

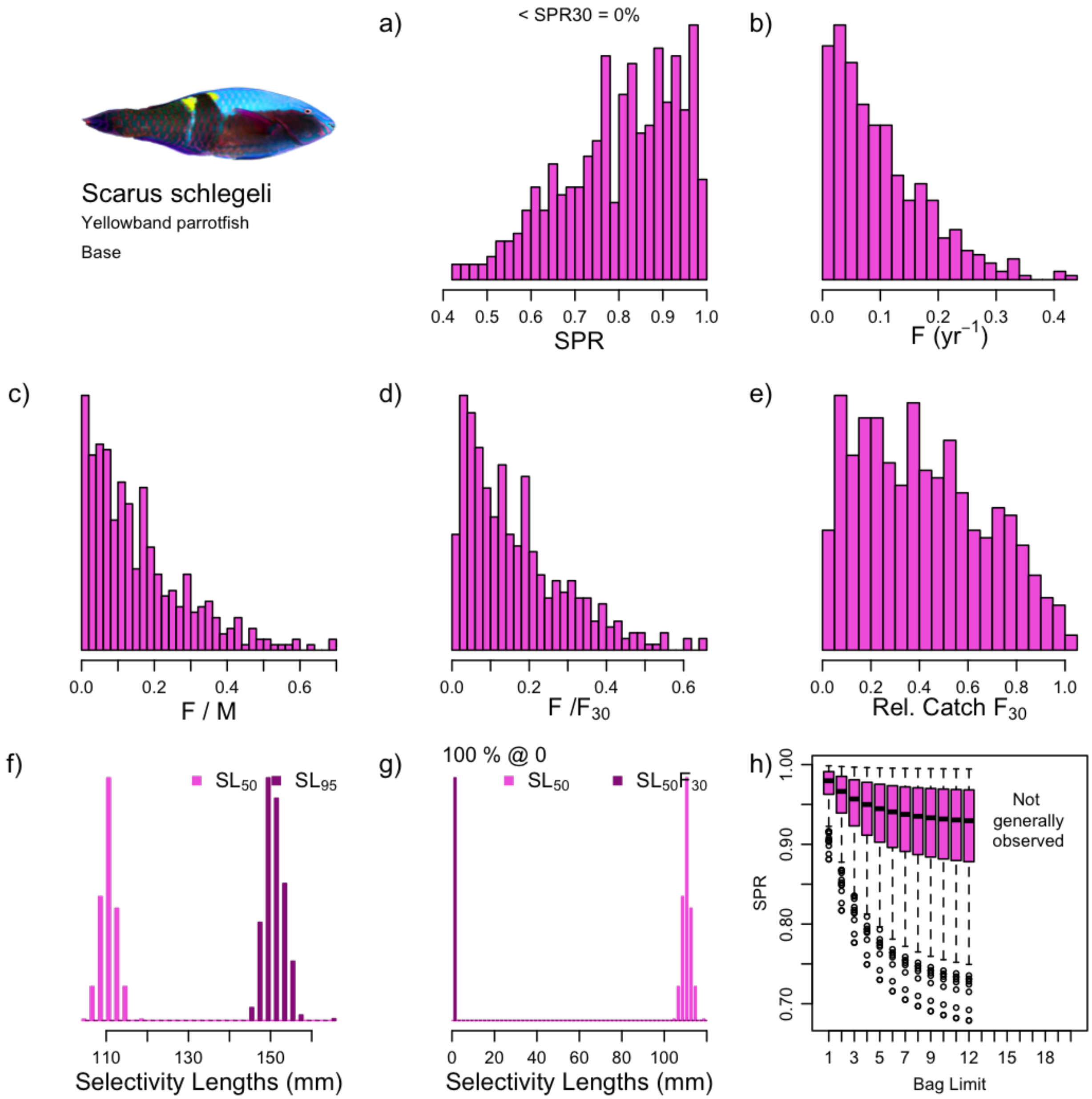


Figure 28. Output reference point and management tactic distributions *Scarus schlegeli* in the base scenario.

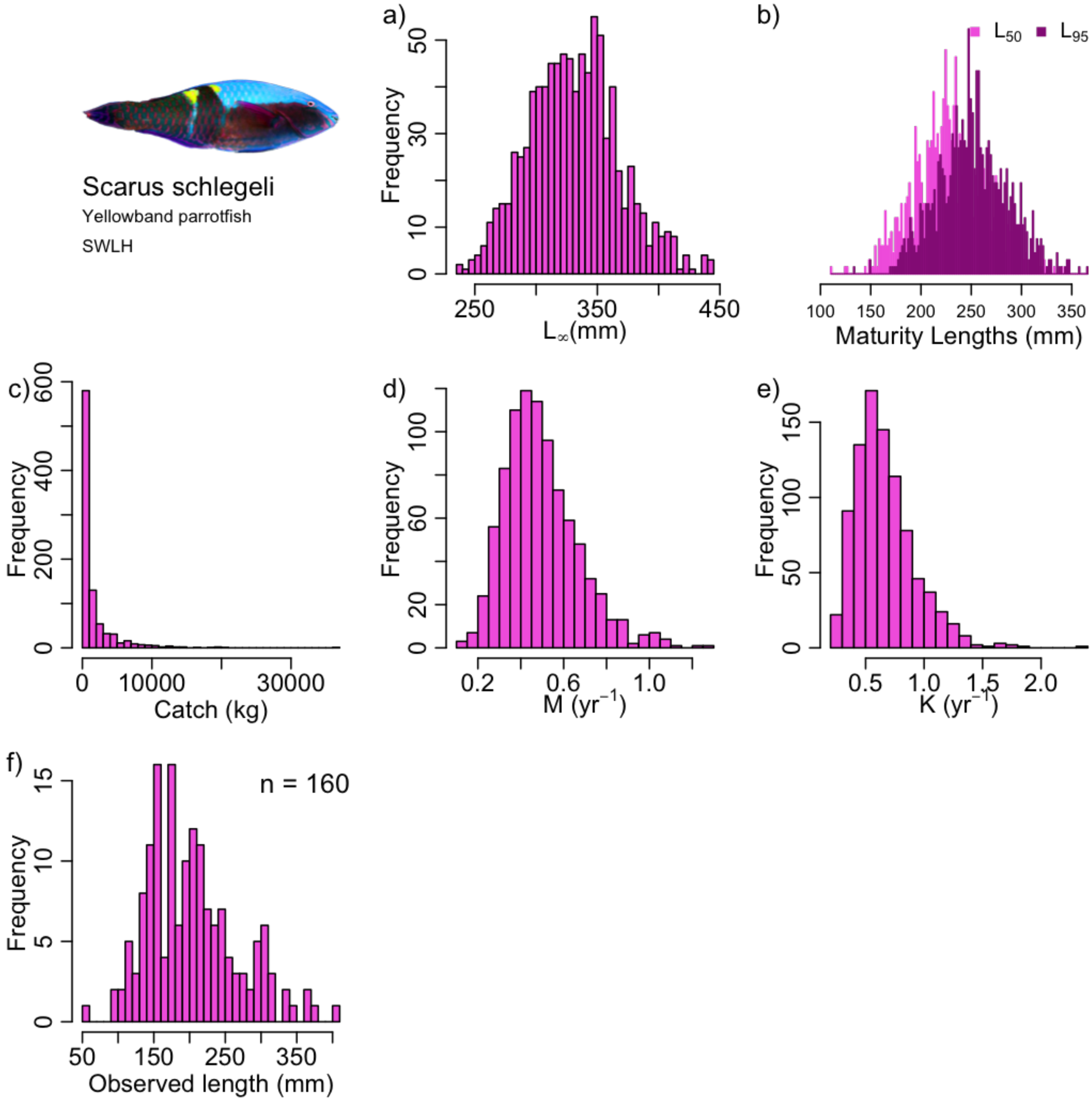


Figure 29. Input parameter distributions and data for *Scarus schlegeli* in the SWLH scenario.

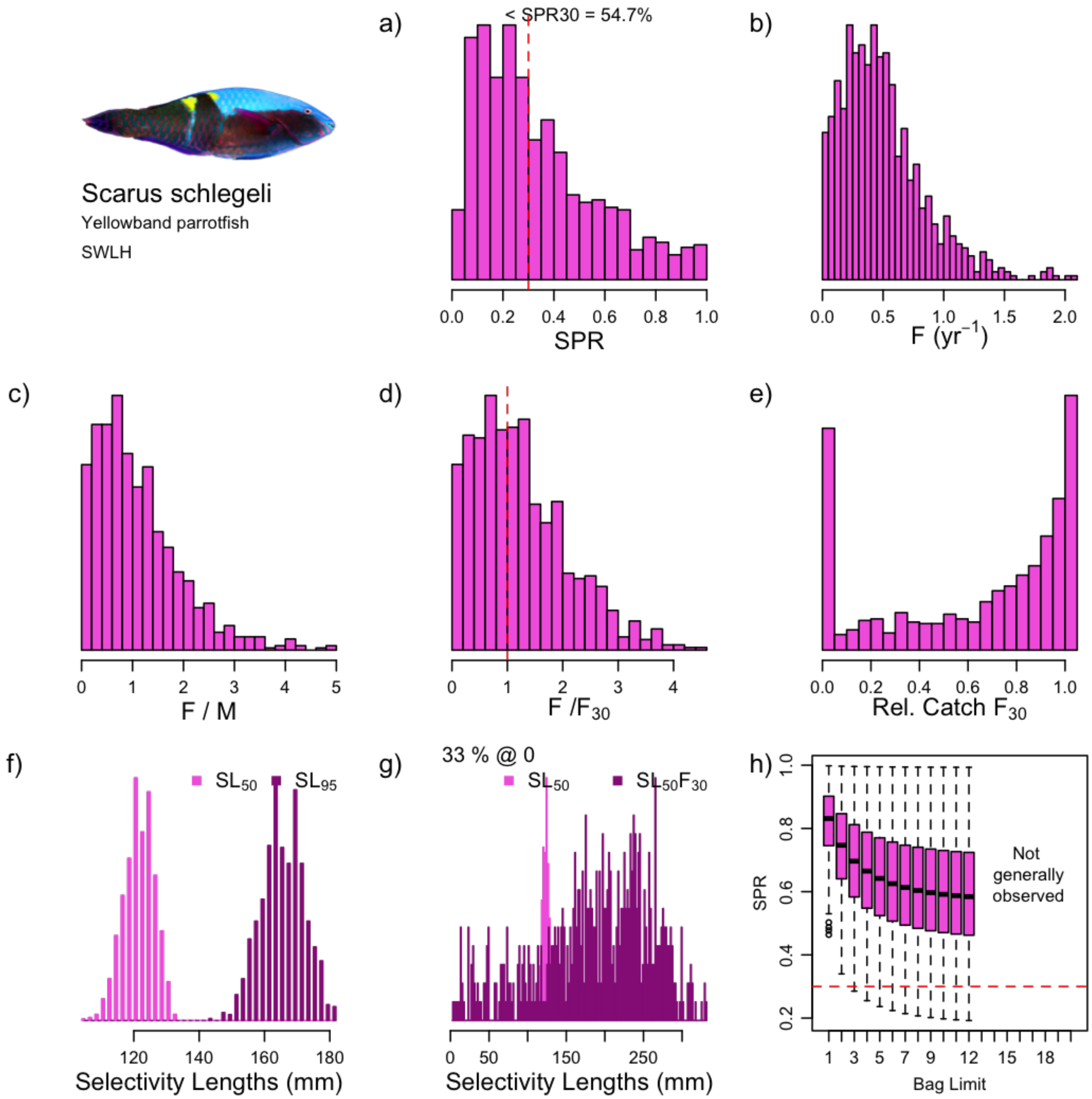


Figure 30. Output reference point and management tactic distributions *Scarus schlegeli* in the SWLH scenario.

References

Allen, S. D., & Bartram, P. K. (2008). Guam as a fishing community. Pacific Islands Fisheries Science Center Administrative Report H-08-01.

Amesbury, J. R., & Hunter-Anderson, R. L. (2008). An analysis of archaeological and historical data on fisheries for pelagic species in Guam and the Northern Mariana Islands. Report prepared for Pelagic Fisheries Research Program, University of Hawaii at Manoa. Micronesian Archaeological Research Services, Mangilao, 170.

Brooks, E. N., Shertzer, K. W., Gedamke, T., & Vaughan, D. S. (2008). Stock assessment of protogynous fish: evaluating measures of spawning biomass used to estimate biological reference points. Fish Bull. 106(1), 12–23.

Erickson, K. A., & Nadon, M. O. (2021). An extension of the stepwise stochastic simulation approach for estimating distributions of missing life history parameter values for sharks, groupers, and other taxa. Fish Bull. 119(1), 77–114.

Filous, A., Daxboeck, C., Beguet, T., & Cook, C. (2022). The life history of longnose emperors (Lethrinus olivaceus) and a data-limited assessment of their stock to support fisheries management at Rangiroa Atoll, French Polynesia. J Fish Biol. 100(3), 632–644.

Hamel, O. S., & Cope, J. M. (2022). Development and considerations for application of a longevity-based prior for the natural mortality rate. Fish Res.256, 106477.

Hordyk, A. (2021). LBSPR: Length-Based Spawning Potential Ratio. R package version 0.1.6 <https://CRAN.R-project.org/package=LBSPR>.

Hordyk, A. R., Ono, K., Prince, J. D., & Walters, C. J. (2016). A simple length-structured model based on life history ratios and incorporating size-dependent selectivity: application to spawning potential ratios for data-poor stocks. CJFAS, 73(12), 1787–1799.

Kobayashi, D. R., Friedlander, A. M., Grimes, C. B., Nichols, R. S., & Zgliczynski, B. (2011). Bumphead parrotfish (Bolbometopon muricatum) status review.

Lee, R. M. (1912). An investigation into the methods of growth determination in fishes. Publ. Circonst. Cons. Int. Explor. Mer., 63, 35.

Ma, H., Matthews, T., Nadon, M., & Carvalho, F. (2022). Shore-based and boat-based fishing surveys in Guam, the CNMI, and American Samoa: survey design, expansion algorithm, and a case study. NOAA Technical Memorandum NMFS-PIFSH; 126. DOI : https://doi.org/10.25923/c9hn-5m88

Myers, R. F. (1993). Guam's small-boat-based fisheries. Mar Fish Rev. 55(2), 117–128.

Nadon, M. O. (2019). Stock Assessment of Guam Coral Reef Fish, 2019. NOAA Technical Memorandum NMFS-PIFSC-82, 107. https://doi.org/10.25923/pyd6-7k49

Nadon, M. O., & Ault, J. S. (2016). A stepwise stochastic simulation approach to estimate life history parameters for data-poor fisheries. CJFAS, 73(12), 1874-1884.

Nadon, M. O., Ault, J. S., Williams, I. D., Smith, S. G., & DiNardo, G. T. (2015). Length-based assessment of coral reef fish populations in the main and Northwestern Hawaiian Islands. PloS one, 10(8), e0133960.

Pacific Islands Fisheries Science Center. (2023a). Guam Boat-based Creel Survey. NOAA National Centers for Environmental Information, https://www.fisheries.noaa.gov/inport/item/5620.

Pacific Islands Fisheries Science Center. (2023b). Guam Commercial Fisheries BioSampling (CFBS), https://www.fisheries.noaa.gov/inport/item/5625.

Pacific Islands Fisheries Science Center. (2023c). Guam Shore-based Creel Survey. NOAA National Centers for Environmental Information, https://www.fisheries.noaa.gov/inport/item/5621.

Pacific Islands Fisheries Science Center. (2023d). National Coral Reef Monitoring Program: Stratified Random Surveys (StRS) of Reef Fish, including Benthic Estimate Data of the Mariana Archipelago since 2014, https://www.fisheries.noaa.gov/inport/item/34518.

Pacific Islands Fisheries Science Center. (2023e). National Coral Reef Monitoring Program: Towed-diver Surveys of Large-bodied Fishes of the Pacific Remote Island Areas since 2014, https://www.fisheries.noaa.gov/inport/item/5568.

Pothin, K., Letourneur, Y., & Lecomte-Finiger, R. (2004). Age, growth and mortality of the tropical grouper Epinephelus merra (Pisces, Serranidae) on Reunion Island, SW Indian Ocean. Vie et Milieu/Life & Environment, 193-202.

Reed, E. (2023). Life history paramters for *Caranx melampygus* from the waters around Guam. In R. Ahrens (Ed.).

Reid, K., Moore, P., Vaughan, N., & Harford, W. (2022). Projection Modeling to Inform Sustainable Management of Coral Reef Species in American Samoa and Guam. Nature Analytics Report.

Restrepo, V., Thompson, G., Mace, P., Gabriel, W., Low, L., MacCall, A., Methot, R., Powers, J., Taylor, B., Wade, P., & Witzig, J. (1998). Technical guidance on the use of precautionary approaches to implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. NOAA Technical Memorandum, NMFS–F/SPO–31.

Shimose, T., & Nanami, A. (2014). Age, growth, and reproductive biology of blacktail snapper, Lutjanus fulvus, around the Yaeyama Islands, Okinawa, Japan. Ichthyol Res. 61, 322-331.

Taylor, B. (2023). Life history parameters for *Cheilinus undulatus* from waters around Guam. In R. Ahrens (Ed.).

Taylor, B., & Choat, J. (2014). Comparative demography of commercially important parrotfish species from Micronesia. J Fish Biol., 84(2), 383–402.

Taylor, B. M., Hamilton, R. J., Almany, G. R., & Howard Choat, J. (2018). The world's largest parrotfish has slow growth and a complex reproductive ecology. Coral Reefs, 37(4), 1197–1208.

Then, A. Y., Hoenig, J. M., Hall, N. G., Hewitt, D. A., & Jardim, H. e. E. (2015). Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES J Mar Sci. 72(1), 82–92.