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DRAFT Stock Assessment of the Squarespot Rockfish (*Sebastes hopkinsi*) along the California U.S. West Coast in 2021 using catch, length, and fishery-independent abundance data

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1 Introduction

1.1 Basic Information

This assessment reports the status of squarespot rockfish (*Sebastes hopkinsi*) off the U.S. West Coast using data through 2020. Squarespot rockfish is a relatively small rockfish found from Mexico to southern Oregon, with a core distribution in southern California. This species is treated as one stock, as there is no evidence of population structure.

1.2 Life History

Squarespot rockfish is a dwarf species of rockfish commonly found in depths between 60 - 123 m (33-68 fm), hovering over or sheltering in rocky reef habitat and aggregating with other smaller rockfishes (M. Love, Yoklavich, and Thorsteinson 2002). Squarespot rockfish are yellow-brown, brown, or tan on the back and sides with lighter colored bellies. Squarespot rockfish has sex-specific growth with females reaching larger sizes (29 cm) than males (23 cm).

1.3 Historical and Current Fishery Information

Squarespot rockfish are generally undesirable in the recreational and commercial fishery due to their small size (maximum length of 29 cm; M. Love, Yoklavich, and Thorsteinson (2002)). Females grow larger than males, and only nearing their maximum length do they reach a size that is marginally acceptable to anglers, thus the landings are primarily composed of older females. While there is some anecdotal evidence of directed commercial fishing using small hooks, they are often discarded as bycatch and commercial catch is relatively low over the entire catch history. The stock has been managed as part of the Minor Shelf Rockfish South Complex since 2000, for which access for both the commercial and recreational fisheries have been restricted with rockfish conservation areas (RCAs) to rebuild overfished stocks (Appendix A).

In the early part of the 20th century the California recreational fishery was focused on nearshore waters near ports, but expanded further from port and into deeper depths over time (Miller et al. 2014). Prior to the rebuilding period for overfished species after the groundfish fishery disaster was declared in 2000, there was access to all depths and seasons for groundfishes (Appendix A). Most of the catch of squarespot rockfish in the recreational fishery comes from south of Point Conception, consistent with the species range. For areas north of Point Conception to Pigeon Point near Santa Cruz (the northern extent of squarespot rockfish range), the shallow depth limit of the Rockfish Conservation Area was 40 fm (73 m) and was increased to 50 fm (91 m) in 2017, both provides some protection for squarespot rockfish. South of Point Conception the depth restrictions were 20 to 60 fm (36-110 m) after 2000, providing more access compare to the north, until 2019 when depth restrictions started at 75 fm (137 m), then to 100 fm (183 m) in 2021. This depth restriction change was due to the rebuilding of cowcod, providing access to the majority of the squarespot rockfish depth range as they are found as deep as 123 fm, but are common to 83 fm (M. Love, Yoklavich, and Thorsteinson 2002).

1.4 Summary of Management History and Performance

Squarespot rockfish is managed by the Pacific Fishery Management Council (PFMC) as a part of the Minor Shelf Rockfish North and South complexes. The North and South areas are split at N. 40° 10' Lat. N. off the West Coast. While squarespot rockfish is included in the Shelf Rockfish North complex, the OFL contribution from squarespot rockfish is extremely low ($<$ 0.5 mt) because the vast majority of the distribution of the stock is in the southern region of California. The Shelf Rockfish complex is managed based on a complex level overfishing limit (OFL) and annual catch limit (ACL). The complex OFLs and ACLs are determined by summing the species specific OFLs and ACLs managed within the complex. Removals for species within the Minor Shelf Rockfish complex are managed and tracked against the complex total OFL and ACL, rather than on a species by species basis.

The OFL and ACLs contributions for squarespot rockfish South of 40° 10' Lat. N. management area and the total removals south of Pt. Conception are shown in Table 2.

2 Data and Parameters

Data used in the model are shown in Figure 1.

2.1 Fishery-Dependent Data

2.1.1 Recreational Fishery

2.1.1.1 Removals

The recreational removals prior to 1980 were obtained from the historical reconstruction starting in 1928 (Ralston et al. 2010). Recreational removals from 1980 - 2003 were obtained from MRFSS and provide total mortality (observed landings plus dead discarded and unavailable fish). Missing years of removals (1990-1992) were assumed by applying a linear ramp in removals based on 1989 and 1993 removals. Removals in years 2004 - 2020 were derived from samples taken by the California Recreational Fisheries Survey (CRFS). CRFS reported removals combine estimates of retained, dead discarded, and unreported landings. Both the MRFSS and CRFS reported removals were downloaded from RecFIN.

Estimates of recreational discard mortality for the period 1980 - 2020 are based on angler reported discards that can underestimate removals of less desirable species. Underestimation may occur because recall of encounters with undesirable species can be low, as well as *Sebastes* indentification issues among anglers (at least 36 rockfishes are regularly encountered in the recreational fishery). Since 2008, efforts have been made to improve anglers' species identification skills by distributing over 20,000 laminated groundfish identification guides and posters to CPFVs to improve compliance with species specific regulations.

Onboard observers record species of fish retained and discarded for a subset of anglers along each drift. Comparisons of the discard rates calculated from retained and discarded catch estimates to those calculated from onboard sampling observations of the composition of retained and discarded fish tallied by the observer the actual discard of squarespot by up to a factor of 3. Two model sensitivities to discard rates were performed: 1) increasing the discard by a factor of 3 (the average disard rate across years 2005-2016) applied to the entire timeseries; 2) Increase discards by a factor of 10.5 through 2008 (based on the average discard rate from 2005-2008), after which discards are increased by 2.7 (based on the average discard rate from 2009-2016).

2.1.1.2 Length Compositions

Length data (Figure 4) for retained recreational catches sourced by MRFSS (1980-2003) and CRFS (2004-2020) were downloaded from the RecFIN website. The lengths of discarded fish measured by samplers onboard CPFVs prior to being released (Type 3d data) from 2003 to 2020 were also downloaded from the RecFIN website. The number of length observations by year are shown in Table 4. The highest samples by year occurred within the last 16 years of the modeled period. The recreational lengths provide little information regarding recruitment strength in the length data as only the largest individuals (with a broad range of unknown age) are taken (Figure 4). The mean size observed ranged between about 20 to 25 cm (Figure 5). The small size of squarespot rockfish and typical hook size used in the recreational fishery likely limits the ability of hook and line gear to observe smaller fish. Input sample sizes were assumed equal to the number of length samples available by year.

2.1.2 Commercial Fishery

2.1.2.1 Removals

The commercial removals for squarespot rockfish are extremely sparse throughout the time series (Figure 2). The small size of squarespot rockfish individuals makes squarespot rockfish an undesirable fish to market and to capture by trawl or commercial hook and line gears. Its affinity for rocky reefs also makes it difficult to access with trawl gear. Commercial landings prior to 1969 were queried through the SWFSC California Catch Reconstruction database (Ralston et al. 2010). Landings in this database are divided into 'trawl,' 'non-trawl,' and 'unknown' gear categories. Commercial landings between 1969 - 1980 were queried from the CALCOM database. Commercial fishery landings from 1981-2020 were pulled from the PacFIN database, extracted 22 February, 2021.

The input catches in the model represent total removals: landings plus discards. Discards totals for the commercial fleet from 2002-2019 were determined based on West Coast Groundfish Observer Program (WCGOP) data provided in the Groundfish Expanded Mortality Multiyear (GEMM) product. The historical commercial discard mortality was calculated based on the average discard rates from WCGOP of 28 percent and used to adjust the landings data from 1916 to 2001 to account for total removals.

Given the extremely small commercial landings and minimal sampling of lengths (see below), the recreational and commercial catches were combined into a single fleet by aggregating across gear types (Table 1 and Figure 3).

2.1.2.2 Length Compositions

The annual length samples from the commercial fishery were quite limited (Table 3). The limited sizes observed were generally between 20 - 30 cm (Figure 7 and Figure 8). Given the small number of samples by year and the lack of commercial catches in the removal time series, the commerical removals were added to the recreational samples and the commercial lengths were excluded from the reference model.

A sensitivity to using 2 fleets (commerical and recreational) as opposed to a combined 1 fleet was explored. This scenario separated the removals into two fleets and used the limited commerical lengths to estimate commerical selectivity.

2.2 Fishery-Independent Data

2.2.1 NWFSC Hook and Line Survey

Since 2004, the NWFSC has conducted an annual hook and line survey targeting shelf rockfishes (genus *Sebastes*) at fixed stations (e.g., sites, Figure 9) in the Southern California Bight. Key species of rockfish targeted by the NWFSC Hook and Line Survey (Hook and Line Survey) are bocaccio (*S. paucispinis*), cowcod (*S. levis*), greenspotted (*S. chlorostictus*), and vermilion/sunset (*S. miniatus* and *S. crocotulus*) rockfishes, although a wide range of rockfish species have been observed by this survey. During each site visit, three deckhands simultaneously deploy 5-hook sampling rigs (this is referred to as a single drop) for a maximum of 5 minutes per line, but individual lines may be retrieved sooner at the angler's discretion (e.g., to avoid losing fish). Five drops are attempted at each site for a maximum possible catch of 75 fish per site per year (3 anglers x 5 hooks x 5 drops). Further details regarding the sample frame, site selection, and survey methodology are described by Harms et al. (J. Harms, Benante, and Barnhart 2008).

Squarespot rockfish have been observed at multiple sampling sites by the Hook and Line Survey each year between 2004 - 2019 (Table 5). The number of positive observations increased sharply starting in 2014 which coincided with when the Hook and Line Survey began sampling sites located within the Cowcod Conservation Area (CCA, Figure 10). The increased observation rate starting in 2014 appeared to occur both outside and inside the CCA, rather than being due to the commencement of sampling within the CCA. The increased observations of squarespot rockfish outside the CCA indicates that this change may be driven by recent strong year classes rather than a change in sampling location (John Harms, NOAA NWFSC, pers. comm.).

The squarespot rockfish observed by the Hook and Line Survey are primarily mature females which is likely due to the small size of male squarespot rockfish, competition among other rockfishes, and hook size (Figure 11). The mean size of fish observed by the Hook and Line Survey has been relatively stable (Figure 12). The small size of squarespot rockfish may also make it an inconsistently collected species in this survey, but it was considered worth evaluating an index of abundance. The input sample sizes of lengths that accompany the survey samples were set equal to the number of length samples available by year.

An annual index of abundance was calculated from the Hook and Line Survey data following the methods put forth in Harms et al. (2010) based on the AIC criterion. The index of abundance was calculated using a binomial generalized-linear model. The final index includes year, site, number of hooks, fisher, drop number, and moon fullness (as a polynomial) as covariates. The single index of abundance was calculated using both observation outside and within the CCA (Table 6 and Figure 13). The index of abundances was low and relatively flat until 2014 when the index sharply increases, hitting a high in 2018. There seems to be no significant difference between indices that include or exclude samples from the CCA (Figure 12).

2.2.2 NWFSC West Coast Groundfish Bottom Trawl Survey

The NWFSC West Coast Groundfish Bottom Trawl Survey (WCGBTS) is based on a random-grid design; covering the coastal waters from a depth of 55-1,280 m (Bradburn, Keller, and Horness 2011). This design generally uses four industry-chartered vessels per year assigned to a roughly equal number of randomly selected grid cells and divided into two ‘passes’ of the coast. Two vessels fish from north to south during each pass between late May to early October. This design therefore incorporates both vessel-to-vessel differences in catchability, as well as variance associated with selecting a relatively small number (approximately 700) of possible cells from a very large set of possible cells spread from the Mexican to the Canadian borders.

The WCGBTS has observed squarespot rockfish each year of the survey, however, the number of positive tows are limited (Table 7). Since the WCGBTS uses trawl gear to sample sandy bottom areas off the West Coast, it is not expected to be an informative data source for squarespot rockfish which are small and closely associated with rock substrate. The limited tows by year where squarespot rockfish were observed within this area, preventing the calculation of an index of abundance using spatial temporal methods (e.g., VAST) for squarespot rockfish. A design-based index calculated resulted in high variability and uncertainty by year (Figure 16). With limited length observations and in the absence of a VAST index of abundance to link these data to, this data set was not used in the base model.

Although these data were not used as an abundance index in the assessment, biological data from this survey were used to develop life history parameters. The WCGBTS captured smaller fish relative to Hook and Line Survey with both males and females observed (Figure 15), particularly useful for estimating growth parameters. Samples collected by the WCGBTS were used to estimate sex specific length-at-weight, growth parameters, and to determine a prior value for natural mortality (see the Biological Data section below for more information).

2.2.3 Triennial Survey

The AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey) had limited observations of squarespot rockfish (Table 8). Given the few positive tows these data were not used in the assessment.

2.3 Biological Parameters

2.3.1 Growth (Length-at-Age)

The length-at-age was estimated for female and male squarespot rockfish using data collected from fishery-independent data sources off the coast of California that were collected from 2004-2019 (Table 9 and Figure 18). Males are smaller than females, but much less susceptible to capture by hook and line, so the trawl fishery provided an important source of small individuals. Figure 19 shows the lengths and ages for all years by data source as well as predicted von Bertalanffy fits to the data. Females grow larger than males and sex-specific growth parameters were estimated at the following values:

$$\text{Females } L_\infty = 26.7 \text{ cm; } k = 0.124\text{; } t_0 = \text{-2.85}$$
$$\text{Males } L_\infty = 20.8 \text{ cm; } k = 0.246\text{; } t_0 = \text{-1.66}$$

The length-at-age by sex and the coefficient of variation by size used in the model is shown in Figure 20.

2.3.2 Maturation and Fecundity

Maturity-at-length based on the work of Love et al (1990) which estimated the 50 percent size-at-maturity of 14 cm off the coast of California, though the slope of the maturity curve was not estimated. Most rockfishes have slopes somewhere between -0.6 and -1 (though some go down to -0.25). In the absence of a literature value of -0.95 was assumed. A sensitivity run using -0.6 was also explored and showed essentially no change in results. Maturity was assumed to stay asymptotic for larger fish (Figure 21).

The fecundity-at-length was based on research by Dick et al.(2017). The fecundity relationship for squarespot rockfish was estimated equal to Fec=4.32e-07$L^{3.55}$ in millions of eggs where L is length in cm. Fecundity-at-length is shown in Figure 22.

2.3.3 Natural Mortality

Natural mortality was not directly measured, so life-history based empirical relationships were used. The Natural Mortality Tool (NMT; https://github.com/shcaba/Natural-Mortality-Tool), a Shiny-based graphical user interface allowing for the application of a variety of natural mortality estimators based on measures such as longevity, size, age and growth, and maturity, was used to obtain estimates of natural mortality. The NMT currently provides 19 options, including the Hamel (2015) method, which is a corrected form of the Then et al. (2015) functional regression model and is a commomly applied method for west coast groundfish. The NMT also allows for the construction of a natural mortality prior weighted across methods by the user.

We assumed the age of 45 years to represent the practical longevity for both females and males based on 90% of the age of the oldest sampled individual (a 50 year old female; oldest male was 49), as was done in the 2015 yelloweye assessement (Gertseva and Cope 2017). Empirical M estimators using the von Bertalanffy growth parameters were also considered (Figure 23), but they produced unreasonably high estimates (2-3 times higher than the longevity estimates). This is likely explained by the fact that while squarespot rockfish are a smaller rockfish species, they still have protracted longevity comparable to stocks that are twice their maximum size. Additionally, the FishLife (Thorson, Munch, et al. 2017) estimate was included, though, given the source of FishLife data is FishBase, there is a good chance the estimates of M are also from methods using longevity, though the actual value of longevity used was unknown. The final composite M distributionn (Figure 24) are based on 4 empirical estimators, and result in a median value of 0.133 (mean of 0.136), with a CV of 0.22. We explore sensitivity to these assumptions of natural mortality through likelihood profiling.

2.3.4 Length-Weight Relationship

The length(cm)-weight(kg) relationship for squarespot rockfish was estimated outside the model using all coastwide biological data available from fishery-independent data sources.

The estimated length-weight relationship for female fish was W=1.08e-05$L^{3.09}$ and males at W=1.17e-05$L^{3.04}$ (Figures 17).

2.3.5 Sex Ratio

No information on the sex ratio at birth was available so it was assumed to be 50:50.

2.3.6 Steepness

The Thorson-Dorn rockfish prior (developed for use West Coast rockfish assessments) conducted by James Thorson (personal communication, NWFSC, NOAA) and reviewed and endorsed by the Scientific and Statistical Committee (SSC) in 2017, has been a primary source of information on steepness for rockfishes. This approach, however, was subsequently rejected for future analysis in 2019 when the new meta-analysis resulted in a mean value of approximately 0.95. In the absense of a new method for generating a prior for steepness the default approach reverts to the previously endorsed method, the 2017 prior for steepness (h; beta distribution with μ=0.72 and σ=0.15) is retained.

3 Assessment Model

3.1 Summary of Previous Assessments

Depletion Corrected Average Catch (DCAC) was used to set annual catch limits (ACLs) for squarespot rockfish since 2010 (Dick and MacCall 2010) which estimate the mean sustainable yield as 5.7 mt (median of 5.9 mt). This method assumed squarespot rockfish relative stocks status was at 40% in 2009.

3.1.1 Modelling Platform

Stock Synthesis version 3.30.16 was used as the statistical catch-at-age modelling framework. The SS-DL tool (https://github.com/shcaba/SS-DL-tool) was used for model exploration, likelihood profiling, and sensitivity analyses. The companion R package r4ss, version 1.38.0, along with R version 4.0.5 were used to investigate and plot model fits.

3.1.2 Bridging Analysis

No bridgining analysis between the DCAC model and Stock Synthesis was conducted given the significant structural differences (e.g., DCAC is an analytical approach) between the methods.

3.2 Model Structure and Assumptions

The model assumes a "data-moderate" category 2 approach, meaning removal histories, length compositions and fishery-independent abundancies are the approved data inputs. Other data types (e.g., ages) can be used external to the assessment model to inform parameter values. The squarespot rockfish model assessment assumes a single removal fleet (mainly recreational that includes the very small commercial catches) with removals beginning in 1916. The NWFSC Hook and Line survey is the one fishery-independant data source used to measure abundance trends. Selectivities for the fleet and survey were specified using the double normal parameterization within SS where selectivity was fixed to be asymptotic with the ascending slope and size of maximum selectivity parameters estimated. Life history parameters are sex-specific, with one growth type, and assumed stationary. Recruitment assumes a Beverton-Holt stock-recruit relationship and is deterministic.

3.2.1 Estimated and Fixed Parameters

All life history parameters are fixed to values described in the Biology section (2.3). Estimated parameters in the model are the two selectivity parameters each for the fleet and survey selectivities, and the log of the initial recruitment ($logR_0$). Sensitivity scenarios and likelihood profiles were used to explore uncertainty in the values of the natural mortality and growth parameters. When estimating parameters, the prior for natural mortality was assumed lognormal with a standard deviation of 0.22 (based on the prior developed using the Natural Mortality Tool (see Biology section for more details)), and the prior for the growth parameters (L_∞ and k) was assumed normal with the mean equal to the fixed value with a CV of 10% (this is equal to assumed CV at length in the reference model, and maintains the ratio of variance between L_∞ and k).

3.2.2 Data Weighting

The reference model estimates additional variance on the NWFSC Hook and Line survey data to allow the model to balance model fit to that data while acknowledging that variances may be underestimated in the index standardization. The input CVs range from 30%-70% (Table 6). A sensitivity was run with no extra variance estimated, as well as removal of the index data.

Initial sample sizes for the recreational length compositions and NWFSC Hook and Line survey were based on the number of fish sampled. The method of Francis ((2011), equation TA1.8) was then used to balance the length composition data among other data inputs and likelihood components. The Francis method treats mean length as an index, with effective sample size defining the variance around the mean. If the variability around the mean does not encompass model predictions, the length data should be down-weighted until predictions fit within the intervals. This method accounts for correlation in the data (i.e., the multinomial distribution), but can be sensitive to years that are outliers, as the amount of down-weighting is applied to all years within a data source, and are not year-specific. Sensitivities were performed examining different data-weighting treatments: 1) the Dirichlet-Multinomial approach (Thorson, Johnson, et al. 2017), 2) the McAllister-Ianelli Harmonic Mean approach (McAllister and Ianelli 1997), or 3) no data-weighting of lengths.

3.3 Model Selection and Evaluation

The base assessment model for squarespot rockfish was developed to balance parsimony and realism, and the goal was to estimate a spawning output trajectory and realtive stock status for the population of squarespot rockfish in federal waters off California. The model contains many assumptions to achieve parsimony and uses different data types and sources to estimate reality. A series of investigative model runs were done to achieve the final base model. These include considerations of model structure, data and parameter treatment, estimation phasing, and jittered starting values to achieve a converged and balanced model that provides sensible parameter estimates and derived quantities.

3.4 Reference Model Diagnostics and Results

3.4.1 Model convergence and acceptability

While there is no definitive measure of model convergence, several measures are routinely applied. These criteria include a low maximum gradient (5.81943×10^{-5}), inversion of the Hessian (passed), reasonable parameter values (passed), and acceptable fits to data (passed).

An extra effort was given to ensure the model did not rest on a local likelihood minimum. This was done by starting the minimization process from dispersed parameter values away from the maximum likelihood estimates to determine if the approach found a better model fit (i.e., minimum negative log-likelihood value). Starting parameters used a jitter shift value of 0.1. This was repeated 100 times with 92 out of 100 runs returned to the reference model likelihood (Figure 26). Another exploration using a jitter shift at 0.2 was used, but it returned 94 out of 100 runs equal to the reference model. A better fit, lower negative log-likelihood model was not found in any of these runs. The model did not experience convergence issues when provided reasonable starting values. Through the jittering and likelihood profiles, the present reference model represents the best fit to the data given the assumptions made.

3.4.1.1 Fits to the Data

Fits to the length data are examined based on the Pearson residuals-at-length, the annual mean lengths, and aggregated length composition data for the commercial and recreational fleets. Annual length composition fits are shown in Appendix B. Lengths are generally sampled better post 2004 in the CRFS sampling period, though the MRFSS period contains several years of decent sampled sizes.

Pearson residuals of the fishery length data are generally low with no distinct pattern of misfitting (Figure 27). Despite the lack of recruitment estimation, there are no obvious patterns of missed recruitment. Fits to the fishery mean lengths, assuming Francis data-weighting, show a relatively stable mean length index, with a drop in size in the most recent years (Figure 28). This observed decline in mean lengths was well fit despite the rigid nature (e.g., few estimated parameters and deterministic recruitment) of the model.

Pearson residuals for the survey data are larger than the better sampled fishery data, but in general also do not present any distinct residual pattern (Figure 29). Largest residuals were with male samples at bigger sizes, where the model assumed fewer males were expected than observed, though those males are exceptionally large (near 30 cm) given there asymptotic size of <22 cm . This discrepancy, outside the issue with Pearson residuals being sensitive to small samples, could also be due to either sex-misidentification or the need for a higher CV at length for males, though is not a major source of uncertainty in the squarespot rockfish assessment. Fits to the survey mean lengths (Figure 30) again support relatively stable mean lengths with littel contrast. The male lengths provide little information on stock status, as only the largest males near L_∞ are taken. The female data, from which the spawning stock status is measured, provides more information as mean length is below, but included in the uncertainty of, the L_∞ value.

Aggregate fits by fleet are shown in Figure 31. The model fits the aggregate lengths for the unsexed fishery fleet and survey female length data well, with an acceptable, but noticeabley poorer fit to the male survey lengths. The biologically smaller males are encountered with much less frequency given the selectivity of the hook and line gear, and thus males samples sizes are much smaller and sporadic over time compared to the other data sources. This leads to spiky and less resolved length compositions, though the overall fit is reasonable under the circumstances. The mode of the aggregate female lengths is larger than the unsexed fishery data, though given the lack of sex-specific fishery lengths and prominent sex-specific growth, it is not apparent whether the Hook-and-Line survey acutally catches bigger fish than the recreational fishery.

The fit to the Hook and Line survey index is generally poor, as the index is much more dynamic and indicative of a general increase in the most recent few years (Figure 32). This opposes the trend in the fishery and survey lengths mostly showing a small decrease in the most recent years. The survey values are very low and the CVs are intially large (30-40% CV), but the model adds twice as much variance (0.85), limiting the influence of the survey in the model. Given the competition for hook space with bigger individuals and the geographically limited sampling of squarespot rockfish habitat, this result is not unreasonable.

3.4.2 Reference Model Outputs

The reference model parameter estimates along with asymptotic standard errors are shown in Table 10 and the likelihood components are shown in Table 11. Estimates of derived reference points and approximate 95 percent asymptotic confidence intervals are shown in Table 16. Estimates of stock size and status over time are shown in Table 12.

3.4.2.1 Parameter Estimates

A total of six parameters were estimated: initial recruitment size, extra variance on the survey index and two parameters each for the fishery and survey. The $logR_0$ was estimated at 5.94. The selectivity curves for the fishery fleet and Hook and Line survey are shown in Figure 25. Both selectivity curves are very similar, with the Hook and Line Survey intepreted to catch larger individuals.

3.4.3 Population Trajectory

The predicted spawning output (in millions of eggs) is given in Table 12 and plotted in Figure 33. Estimated spawning output shows a large decline starting in the 1970s, with a continued decline into the 1980s. This tracks the large removals during this time period. A large decline in removals starting in the mid-1980s and into the 1990s is reflected in a population that begins a steady increase into the early 2010s. Recent high removals (the largest in the recorded removal history) have again caused a stark population decline. The estimate of total biomass over time, which tracks that of spawning output, is shown in Figure 34.

Relative spawning output declined below the management target ($SB_{40\%}$) in the early 1980s and again fell below the target starting in 2019 (Figure 35). The relative stock status at the start of 2021 is estimated to be below the rockfish relative biomass target of 40 percent (0.37) but above the management threshold of 25 percent. Uncertainty intervals indicate the population never goes below the management limit ($SB_{25\%}$) and is near the target after a very low catch in 2020 (likely attributable to the COVID-19 pandemic). The very low catches in 2020 allowed the population to rebound under the assumption of determnistic recruitment.

Recruitment was treated as deterministic (Figure 36) and the overall yearly age-0 numbers declined slightly over time (Figure 37).

3.4.4 Reference Points

Reference points were calculated using the estimated fishery selectivity and removals in the most recent year of the model (2020, Table 16). Sustainable total yields were 9.04 mt when using an $SPR_{50\%}$ reference harvest rate. The spawning output equivalent to 40 percent of the unfished spawning output ($SB_{40\%}$) was 9.21 millions of eggs.

The 2021 spawning output relative to unfished equilibrium spawning output is below the squarespot rockfish relative biomass target of 40 percent but greater that the management limit of 25 percent (Figure 35). The fishing intensity, $1 - SPR$, was above the harvest rate limit ($SPR_{50\%}$) between the 1970s and early 1980s, below the target for much of the time from the mid-1980s to early 2010s, and most of the recent several years have exceeded the target (Table 12 and Figure 38). Table 16 shows the full suite of estimated reference points for the base model and Figure 39 shows the equilibrium curve based on a steepness value fixed at 0.72.

3.5 Uncertainty exploration

3.5.1 Sensitivity Analyses

Sensitivity analyses were conducted to evaluate model sensitivity to alternative data treatment and model specifications.

3.5.1.1 Data treatment sensitivities

Data treatments explored were as follows:

1. Data removal
    - Fishery length data only (no catches)
    - Remove fishery length data
    - No survey data
    - No extra variance estimated for the survey
2. Data weighting
    - Dirichlet data-weighting
    - McAllister-Ianelli data weighting
    - No data-weighting
3. Removal history
    - Alternative discards I: 3 times discard rate
    - Alternative discards II: 10.5 (up to 2009), then 2.7 times discard rate thereafter

Likelihood values and estimates of key parameters and derived quantities from each sensitivity are available in Table 13. Derived quantities relative to the reference model are provided in Figure 40. Time series of spawning output and relative spawning output are shown in Figures 41 and 42.

The decision to allow the model to find a compromised fit between the weighted length data and the Hook and Line survey index via added variance on the index showed the largest relative change. A model that did not downweight the Hook and Line index showed a more optimistic relative spawning output, with the scale of the population outside the confidence intervals of the reference model (Figure 40). The scaleless length-only model provides a very similar estimate of final relative spawning output to the reference model (36.9% vs 37.5%), thus showing the influence of the length information. The scenario that removes all lengths resulted in a lower relative stock size, but has nothing to inform the removal selectivity, thus the results are highly dependent on the starting values of an unstable model.

Data-weighting choice had very little influence on model output. This also highlights that the simple fleet structure, limited additional data types, and fixed life history parameters puts a focus on the signal contained in the fishery length data. There was little influence in any derived quantities when adding three times more discards in the contemporary time frame (Figure 40). There was a little more sensitivity in the population scale adding 10 times more discards prior to 2009. This is a typical results when the catch history is adjusted upwards, which simply scales the popualtion size up as well. The model also added a little less variance to the Hook and Line index (Table 13), but in general even adding 10 times more discards had very little impact in model results. Overall, the effects of all these data treatments are small.

3.5.1.2 Model specification sensitivities

Model specifications looked at the estimation of indiviual and combinations of life history parameters, the estimation of recruitment, and the use of two fleets (commercial and recreational) instead of one, and the hypothesis of five growth platoons instead of one. Each of the five life history estimation model specifications listed below were done for both sexes, just females and just males, for a total of 15 scenarios. All scenarios match the reference model specificatins in all other aspects unless otherwised stated.

1. Life history estimation

- Estimate natural mortality (M)
- Estimate L_∞
- Estimate k
- Estimate L_∞ and k
- Estimate M, L_∞ and k

2. Recruitment estimation and variability (σ_R). All years are estimated with bias correction applied.

    - $\sigma_R = 0.45$
    - $\sigma_R = 0.6$
    - $\sigma_R = 0.75$
    - $\sigma_R = 0.6$ with no extra variance

3. Miscellaneous

    - 2 fleets (commerical and recreational instead of just one lumped fleet)
    - 5 growth platoons instead of just one

Likelihood values and estimates of key parameters and derived quantities from each sensitivity are available in Tables 14 and 15. Any attempt to estimate female M and or k led to unrealistic life history parameters estimates or population sizes (Table 14), so these runs are not included in the sensitivity figures in order to maintain an informative presentation. Derived quantities relative to the reference model are provided in Figure 43. Time series of spawning output and relative spawning output are shown in Figures 44 and 45.

Life history estimation involving female growth values tended to increase stock scale and current relative stock status, while male estimation tended to drop the estimate of unfished stock size, with slight overall increases in current relative stock status.

A reference model that included recruitment estimation (assuming $\sigma_R = 0.6$) was under consideration, but the model showed very little information in estimating recruitment (Figure 46). This is unsurprising given the fishery only takes the largest females, thus selectivity greatly weakens any recruitment signal. Estimating recruitment caused stock scale to decrease to around the bottom end of the reference model confidence intervals, but with a slight decrease in relative stock status. Downweighting the survey, as done in the reference model, causes the current biomass to increase with a significant increase in relative stock status.

For the final two sensitivities, breaking the fishery data into two fleets made little difference, thus supporting the parsimony of using one fleet. Hypothesizing five growth platoons instead of just one led to the notable result of higher stock scale and relative stock status. This approach causes two of five proposed female growth platoons to be below and two above the average (i.e., equivalent to the reference model) growth response. Given the fishery only takes the largest individuals, the smaller growth platoons are no longer available to the fishery, thus the population gains overall stock size and relative stock status.

Overall, there were no model specification sensitivity scenarios that caused the population to drop significantly below the reference model estimate of stock status. If stock scale differed, unfished stock size had the biggest uncertainty and was usually less than the reference model, excepting the hypothesis of five growth platoons.

3.5.2 Likelihood Profiles

Likelihood profiles were conducted for $log(R_0)$, steepness (h), female and male natural mortality (M) values separately and varying together, female and male maximum length (L_∞), female and male growth coefficient (k), female and male variability of size at maximum age. In addition, joint profiles over L_∞ and k (that maintains a -0.9 correlation structure between the parameters) were done for females and males separately as well as for female and male natural mortality. Likelihood profiles were conducted by fixing the featured parameter(s) at specific values across a range of values and estimating the remaining parameters. A likelihood profile offers insight into model information on a given parameter or parameter pairing, while providing an additional way to describe uncertainty in the parameter by indentifying the range of parameters within 1.96 likelihood units of the refrence model.

The $log(R_0)$ profiles show strong support for the maximum likelhood value of 5.94 (Figure 47). Population size expectedly increases as $log(R_0)$ increases, with the increase in current biomass happening quicker than initial biomass, thus relative stock status increase towards unfished at high $log(R_0)$ values. This is explained by the harvest rate decreasing because the removal history is fixed and becomes relatively smaller compared to the overall biomass. Length data dominated the information content in the profile, with the index indicating a higher $log(R_0)$, partially explaining the increased stock status when the index is given more weight.l

The steepness profile showed data supported values from 0.45 to 1, with ranges of relative stock status from 30% to 40% (Figure 48). SB_0 showed the biggest change across steepness values, though the most informed portion of the profile did not change greatly. Length data dominated the information in the profile (Figure 48).

Natural mortality profiles for females (Figure 49) and males (Figure 50) highlight two important issues: 1) the inability for the data in this model to inform either of these parameters and 2) model derived values are sensitive to the value, mainly female M. Natural mortality values at the minimum likelihood values either goes toward unrealistically high (Figure 49) or low (Figure 50) M values. The combined profile that varies female and male M together at the same changing value behave diretionally most like the female likelihood, though with less change across values (Figure 51). Scale and relative stock status are most affected by the assumption of females rather than male M, as the females interact the most with the fishery.

Female growth profiles show a similar lack of information to estimate L_∞, k, or CV at maximum age. Length compositions support a smaller L_∞ when k is fixed (Figure 52) and a lower k when L_∞ is fixed (Figure 53). A more realistic profile maintains the negative correlation bewtween L_∞ and k showing the lower L_∞ value is preferred over a lower k value (Figure 54). Changing either value has a large affect on stock scale and relative stock status. The profile over the variability at maximum age supported a lower value than in the model (Figure 55). The lower values increased overall popluation size (particularly current biomass) and derived a noticeably higher current relative stock status.

Male growth profiles showed more information and less overall sensitivity than the female profiles. Length compositions from the fishery and survey strongly supported a slightly larger L_∞ when k is fixed (Figure 56) and a much higher k when L_∞ is fixed (Figure 57), though there is essentially no information in estimating male k. Relative stock status changes little across L_∞ and k values, but the population scale change is more pronounced. The joint L_∞-k profile showing the higher L_∞ value is preferred over a higher k value (Figure 58). Changing either value has a relatively small affect on stock scale and relative stock status. Overall, the influence of male growth values is smaller than females. The model supported values of the variability at maximum age between 0.1 and 0.14 (Figure 55). Larger values decreased overall popluation size a little, with more of an affect on the more recent biomass estimates, and had only small affect on relative stock status.

3.5.3 Retrospective Analysis

A ten-year retrospective analysis was conducted by running the model and sequentially removing one year of data. Retrospective spawning output estimates were gnerally within the confidence intervals of the reference model (Figure 60), which also lead to consistent estimates of stock status among the retrospective scenarios, with no strong pattern (Figure 61).

4 Management

A salient aspect of the squarespot rockfish stock assessment is how much the female portion of the population is affected by the fishery. Given any removal levels set will mostly influence spawning biomass directly, additional consideration about this asymmetry should be considered when setting catch levels.

4.1 Harvest Projections and Decision Tables

A ten year projection of the reference model with removals in 2021 and 2022 equal to the recent average removals from 2017-2019 were run based on the category 2 time-varying buffer using $P^* = 0.45$ for years 2023-2032 is provided in Table 17.

A decision table with uncertainty axes and proposed catch levels will be determined later.

4.2 Evaluation of Scientific Uncertainty

The estimated uncertainty in the base model around the 2021 spawning output is $\sigma = 0.17$ and the uncertainty in the base model around the 2021 OFL is $\sigma = 0.21$. The estimated model uncertainty was less than the category 2 groundfish data moderate assessment default value of $\sigma = 1.0$.

4.3 Future Research and Data Needs

Squarespot rockfish is a relatively data-limited rockfish. More research and data collection would improve future assessments and address some sources of uncertainty. Below is a list of specific suggestions for future research:

1. More age and length data would continue to improve growth estimates, especially for females, and allow for the estimation of growth within the model.
2. The maturity estimate used is old (30+ years ago) and was missing both the slope parameter or estimate of 95% maturity. An updated measure of functional maturity that gives a more complete consideration of the length or age-based maturity would be a major improvement.
3. More work on dead discard estimates in recreational fisheries could benefit multiple rockfish species, especially smaller-sized species that are more prone to being thrown back and unidentified.
4. The Hook and Line survey proved questionable for squarespot given their size. A survey for squarespot may be difficult to design given their small size and depths. Smaller hook size or other considerations will need to be evaluated in the event a survey for smaller rockfishes is desireable.
5. Hyperstability in length composition data (i.e., only catching the biggest individuals, thus unable to detect a decrease in relative stock size) should be explored via simulation testing in order to understand when catch and length models could suffer from the lack of contrast needed to detect stocks status.

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7 Tables

Table 1: Catches (mt) by fleet for all years and total catches (mt) by year summed by year.

Year	Comm Rec	Total Catch
1916	0.07	0.07
1917	0.12	0.12
1918	0.11	0.11
1919	0.06	0.06
1920	0.07	0.07
1921	0.06	0.06
1922	0.06	0.06
1923	0.08	0.08
1924	0.11	0.11
1925	0.12	0.12
1926	0.15	0.15
1927	0.12	0.12
1928	0.14	0.14
1929	0.18	0.18
1930	0.21	0.21
1931	0.32	0.32
1932	0.19	0.19
1933	0.32	0.32
1934	0.26	0.26
1935	0.29	0.29
1936	0.31	0.31
1937	0.41	0.41
1938	0.39	0.39
1939	0.33	0.33
1940	0.33	0.33
1941	0.31	0.31
1942	0.16	0.16
1943	0.16	0.16
1944	0.12	0.12
1945	0.16	0.16
1946	0.28	0.28
1947	0.49	0.49
1948	1.15	1.15
1949	1.38	1.38
1950	1.65	1.65
1951	1.55	1.55
1952	1.89	1.89
1953	2.03	2.03
1954	4.22	4.22
1955	8.12	8.12
1956	9.44	9.44
1957	5.29	5.29
1958	3.14	3.14
1959	2.21	2.21
1960	2.22	2.22

Table 1: Catches (mt) by fleet for all years and total catches (mt) by year summed by year. *(continued)*

Year	Comm Rec	Total Catch
1961	2.40	2.40
1962	2.30	2.30
1963	2.21	2.21
1964	2.77	2.77
1965	3.49	3.49
1966	5.93	5.93
1967	7.79	7.79
1968	8.23	8.23
1969	7.63	7.63
1970	10.72	10.72
1971	10.32	10.32
1972	13.48	13.48
1973	15.70	15.70
1974	20.17	20.17
1975	19.03	19.03
1976	15.62	15.62
1977	14.74	14.74
1978	12.99	12.99
1979	17.20	17.20
1980	15.07	15.07
1981	8.21	8.21
1982	6.70	6.70
1983	17.65	17.65
1984	20.47	20.47
1985	6.88	6.88
1986	13.26	13.26
1987	0.77	0.77
1988	4.83	4.83
1989	3.14	3.14
1990	3.22	3.22
1991	3.31	3.31
1992	3.39	3.39
1993	3.71	3.71
1994	6.39	6.39
1995	2.68	2.68
1996	16.92	16.92
1997	14.19	14.19
1998	7.11	7.11
1999	6.25	6.25
2000	1.78	1.78
2001	0.33	0.33
2002	1.16	1.16
2003	2.63	2.63
2004	3.67	3.67
2005	4.04	4.04

Table 1: Catches (mt) by fleet for all years and total catches (mt) by year summed by year. *(continued)*

Year	Comm Rec	Total Catch
2006	0.94	0.94
2007	1.64	1.64
2008	2.28	2.28
2009	3.27	3.27
2010	2.02	2.02
2011	5.88	5.88
2012	4.61	4.61
2013	16.73	16.73
2014	14.30	14.30
2015	22.03	22.03
2016	22.14	22.14
2017	17.15	17.15
2018	23.36	23.36
2019	24.09	24.09
2020	1.29	1.29

Table 2: The shelf rockfish complex OFL and ACL for south of 40.10 Latitude N., the squarespot rockfish specific OFL and ACL, and removals

Year	Complex OFL	Complex ACL	OFL	ACL	Removals
2011	2238	714	5.77	4.81	5.88
2012	2243	714	5.77	4.81	4.61
2013	1910	714	11.08	9.24	16.73
2014	1913	714	11.08	9.24	14.30
2015	1918	1624	11.08	9.24	22.03
2016	1919	1625	11.08	9.24	22.14
2017	1917	1623	11.08	9.24	17.15
2018	1918	1624	11.08	9.24	23.36
2019	1919	1625	11.08	9.24	24.09
2020	1919	1625	11.08	9.24	1.29

Table 3: Summary of the commercial length samples used in the stock assessment.

Year	Tows	Fish
1985	7	16
1986	1	2
1992	1	1
1993	2	3
1994	3	5
1995	2	2
1997	2	3
1998	2	6
1999	1	1
2008	2	3
2009	3	19
2010	4	22
2011	1	1
2014	2	5
2015	1	7
2016	5	43
2017	1	2

Table 4: Summary of the recreational length samples used in the stock assessment.

Year	All Fish	Sexed Fish	Unsexed Fish	Sample Size
1980	142	0	142	142
1981	99	0	99	99
1982	88	0	88	88
1983	672	0	672	672
1984	579	0	579	579
1985	208	0	208	208
1986	213	0	213	213
1987	17	0	17	17
1988	35	0	35	35
1989	47	0	47	47
1993	47	0	47	47
1994	64	0	64	64
1995	20	0	20	20
1996	225	0	225	225
1997	244	0	244	244
1998	243	0	243	206
1999	323	0	323	323
2000	88	0	88	88
2001	9	0	9	9
2002	43	0	43	43
2003	77	0	77	77
2004	53	1	52	53
2005	79	0	79	79
2006	97	0	97	97
2007	70	0	70	70
2008	85	0	85	85
2009	94	0	94	94
2010	72	4	68	72
2011	40	1	39	40
2012	558	0	558	558
2013	1708	0	1708	1708
2014	1491	1	1490	1491
2015	1683	0	1683	1683
2016	1385	0	1385	1385
2017	1249	0	1249	1249
2018	1217	0	1217	1217
2019	1528	0	1528	1528

Table 5: Summary of the NWFSC Hook and Line length samples used in the stock assessment.

Year	Site	All Fish	Sexed Fish	Unsexed Fish
2004	4	6	6	0
2005	17	28	26	2
2006	13	35	35	0
2007	8	10	10	0
2008	21	64	63	1
2009	12	20	20	0
2010	8	28	28	0
2011	13	24	24	0
2012	4	4	4	0
2013	7	8	8	0
2014	27	86	81	5
2015	36	145	145	0
2016	45	221	220	1
2017	55	265	265	0
2018	67	343	343	0
2019	59	191	191	0

Table 6: Index of abundance for the NWFSC Hook and Line survey.

Year	Index	SE
2004	0.0008	0.691
2005	0.0026	0.494
2006	0.0039	0.558
2007	0.0014	0.518
2008	0.0069	0.396
2009	0.0025	0.445
2010	0.0051	0.426
2011	0.0032	0.423
2012	0.0005	0.665
2013	0.0011	0.535
2014	0.0064	0.376
2015	0.0083	0.333
2016	0.0130	0.355
2017	0.0169	0.351
2018	0.0239	0.340
2019	0.0109	0.362

Table 7: Summary of the NWFSC WCGBTS length samples. These data were not used in the assessment.

Year	Tows	All Fish	Sexed Fish	Unsexed Fish	Sample Size
2003	2	30	30	0	4
2004	5	159	141	18	11
2005	13	245	219	26	30
2006	6	152	151	1	14
2007	13	424	333	91	30
2008	10	239	234	5	23
2009	16	490	487	3	38
2010	13	185	181	4	30
2011	6	77	64	13	14
2012	6	32	28	4	14
2013	10	524	517	7	23
2014	9	232	17	215	21
2015	9	247	223	24	21
2016	18	329	172	157	42
2017	11	322	277	45	26
2018	11	240	193	47	26
2019	6	206	187	19	14

Table 8: Summary of the Triennial length samples. These data were not used in the assessment.

Year	Tows	All Fish	Sexed Fish	Unsexed Fish	Sample Size
1989	1	211	211	0	2
1992	1	12	12	0	2
1995	1	34	34	0	2
2001	3	48	48	0	7
2004	1	10	10	0	2

Table 9: Summary of the number of samples by year and source used to estimate length-at-age parameters.

Year	NWFSC HKL F	NWFSC HKL M	NWFSC WCGBTS F	NWFSC WCGBTS M	NWFSC WCGBTS U
2004	1	0	0	1	0
2005	4	0	22	17	2
2006	6	1	5	5	0
2007	4	3	16	17	0
2008	6	1	12	24	0
2009	4	0	11	23	0
2010	3	0	3	12	2
2011	1	1	3	7	0
2012	0	0	2	3	0
2013	2	0	13	7	1
2014	14	6	3	3	0
2015	14	2	15	12	7
2016	18	7	18	20	21
2017	31	14	24	19	19
2018	170	4	9	7	1
2019	23	4	14	8	0

Table 10: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (mean and SD).

Parameter	Value	Phase	Bounds	Status	Prior (Exp.Val, SD)
NatM p 1 Fem GP 1	0.133	-1	-	-	Log Norm (-2.92, 0.22)
L at Amin Fem GP 1	0.000	-3	-	-	None
L at Amax Fem GP 1	26.740	-2	-	-	None
VonBert K Fem GP 1	0.124	-3	-	-	None
CV young Fem GP 1	0.100	-4	-	-	None
CV old Fem GP 1	0.100	-4	-	-	None
Wtlen 1 Fem GP 1	0.000	-99	-	-	None
Wtlen 2 Fem GP 1	3.090	-99	-	-	None
Mat50% Fem GP 1	14.000	-99	-	-	None
Mat slope Fem GP 1	-0.950	-99	-	-	None
Eggs scalar Fem GP 1	0.000	-3	-	-	None
Eggs exp len Fem GP 1	3.548	-3	-	-	None
NatM p 1 Mal GP 1	0.133	-1	-	-	Log Norm (-2.92, 0.22)
L at Amin Mal GP 1	-7.081	-3	-	-	None
L at Amax Mal GP 1	20.820	-2	-	-	None
VonBert K Mal GP 1	0.246	-3	-	-	None
CV young Mal GP 1	0.100	-4	-	-	None
CV old Mal GP 1	0.100	-4	-	-	None
Wtlen 1 Mal GP 1	0.000	-99	-	-	None
Wtlen 2 Mal GP 1	3.040	-99	-	-	None
CohortGrowDev	1.000	-1	-	-	None
FracFemale GP 1	0.500	-99	-	-	None
SR LN(R0)	5.942	1	OK	0.0699588	None
SR BH steep	0.720	-1	-	-	Log Norm (0.72, 0.24)
SR sigmaR	0.700	-6	-	-	None
SR regime	0.000	-99	-	-	None
SR autocorr	0.000	-99	-	-	None
ForeRecr 2021	0.000	-	-	-	dev (NA, NA)

Table 10: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (mean and SD). *(continued)*

Parameter	Value	Phase	Bounds	Status	Prior (Exp.Val, SD)
InitF seas 1 flt 1Comm Rec	0.000	-1	-	-	None
LnQ base HKL(2)	-9.155	-1	-	-	None
Q extraSD HKL(2)	0.848	3	OK	0.233647	None
Size DblN peak Comm Rec(1)	23.850	1	OK	0.298703	None
Size DblN top logit Comm Rec(1)	15.000	-1	-	-	None
Size DblN ascend se Comm Rec(1)	2.534	2	OK	0.101892	None
Size DblN descend se Comm Rec(1)	-15.000	-1	-	-	None
Size DblN start logit Comm Rec(1)	-15.000	-2	-	-	None
Size DblN end logit Comm Rec(1)	15.000	-1	-	-	None
Size DblN peak HKL(2)	24.502	2	OK	0.627565	None
Size DblN top logit HKL(2)	15.000	-1	-	-	None
Size DblN ascend se HKL(2)	2.287	2	OK	0.247638	None
Size DblN descend se HKL(2)	-15.000	-1	-	-	None
Size DblN start logit HKL(2)	-15.000	-2	-	-	None
Size DblN end logit HKL(2)	15.000	-1	-	-	None

Table 11: Likelihood components by source.

Label	Total
TOTAL	129.38
Catch	0.00
Equil catch	0.00
Survey	12.24
Length comp	117.14
Recruitment	0.00
InitEQ Regime	0.00
Forecast Recruitment	0.00
Parm priors	0.00
Parm softbounds	0.00
Parm devs	0.00
Crash Pen	0.00

Table 12: Time series of population estimates from the base model.

Year	Total Biomass (mt)	Spawning Output	Total Biomass 3 (mt)	Fraction Unfished	Age-0 Recruits	Total Catch (mt)	1-SPR	Exploitation Rate
1916	229.41	20.64	215.38	1.00	380.94	0.07	0.00	0.00
1917	229.35	20.63	215.32	1.00	380.93	0.12	0.01	0.00
1918	229.26	20.62	215.22	1.00	380.91	0.11	0.01	0.00
1919	229.18	20.61	215.14	1.00	380.89	0.06	0.00	0.00
1920	229.16	20.60	215.12	1.00	380.88	0.07	0.00	0.00
1921	229.13	20.60	215.09	1.00	380.87	0.06	0.00	0.00
1922	229.11	20.60	215.07	1.00	380.87	0.06	0.00	0.00
1923	229.09	20.59	215.06	1.00	380.86	0.08	0.00	0.00
1924	229.06	20.59	215.03	1.00	380.86	0.11	0.01	0.00
1925	229.01	20.58	214.97	1.00	380.84	0.12	0.01	0.00
1926	228.95	20.58	214.92	1.00	380.83	0.15	0.01	0.00
1927	228.88	20.56	214.84	1.00	380.81	0.12	0.01	0.00
1928	228.83	20.56	214.80	1.00	380.80	0.14	0.01	0.00
1929	228.78	20.55	214.74	1.00	380.79	0.18	0.01	0.00
1930	228.69	20.54	214.66	1.00	380.77	0.21	0.01	0.00
1931	228.58	20.53	214.55	0.99	380.74	0.32	0.02	0.00
1932	228.40	20.50	214.36	0.99	380.70	0.19	0.01	0.00
1933	228.34	20.49	214.30	0.99	380.68	0.32	0.02	0.00
1934	228.17	20.47	214.14	0.99	380.64	0.26	0.01	0.00
1935	228.07	20.46	214.04	0.99	380.62	0.29	0.02	0.00
1936	227.95	20.44	213.93	0.99	380.59	0.31	0.02	0.00
1937	227.83	20.43	213.80	0.99	380.56	0.41	0.02	0.00
1938	227.63	20.40	213.61	0.99	380.52	0.39	0.02	0.00
1939	227.47	20.38	213.45	0.99	380.48	0.33	0.02	0.00
1940	227.37	20.37	213.35	0.99	380.45	0.33	0.02	0.00
1941	227.29	20.35	213.26	0.99	380.43	0.31	0.02	0.00
1942	227.22	20.35	213.20	0.99	380.42	0.16	0.01	0.00
1943	227.30	20.36	213.28	0.99	380.43	0.16	0.01	0.00
1944	227.36	20.36	213.34	0.99	380.45	0.12	0.01	0.00
1945	227.46	20.38	213.44	0.99	380.47	0.16	0.01	0.00
1946	227.51	20.38	213.49	0.99	380.48	0.28	0.01	0.00
1947	227.46	20.38	213.43	0.99	380.47	0.49	0.03	0.00
1948	227.23	20.35	213.20	0.99	380.42	1.15	0.06	0.01
1949	226.45	20.25	212.43	0.98	380.24	1.38	0.07	0.01
1950	225.55	20.13	211.53	0.98	380.02	1.65	0.08	0.01
1951	224.50	19.99	210.49	0.97	379.76	1.55	0.08	0.01
1952	223.62	19.88	209.62	0.96	379.54	1.89	0.09	0.01
1953	222.53	19.74	208.54	0.96	379.27	2.03	0.10	0.01
1954	221.42	19.59	207.44	0.95	378.99	4.22	0.19	0.02
1955	218.55	19.22	204.58	0.93	378.25	8.12	0.30	0.04
1956	212.60	18.46	198.66	0.89	376.65	9.44	0.34	0.05
1957	206.06	17.62	192.16	0.85	374.77	5.29	0.24	0.03

Table 12: Time series of population estimates from the base model. *(continued)*

Year	Total Biomass (mt)	Spawning Output	Total Biomass 3 (mt)	Fraction Unfished	Age-0 Recruits	Total Catch (mt)	1-SPR	Exploitation Rate
1958	203.60	17.31	189.76	0.84	374.01	3.14	0.16	0.02
1959	203.20	17.25	189.40	0.84	373.87	2.21	0.12	0.01
1960	203.64	17.30	189.85	0.84	374.00	2.22	0.12	0.01
1961	204.04	17.36	190.25	0.84	374.13	2.40	0.13	0.01
1962	204.25	17.39	190.46	0.84	374.21	2.30	0.13	0.01
1963	204.54	17.43	190.74	0.84	374.30	2.21	0.12	0.01
1964	204.87	17.47	191.08	0.85	374.42	2.77	0.15	0.01
1965	204.70	17.46	190.91	0.85	374.38	3.49	0.18	0.02
1966	203.94	17.37	190.14	0.84	374.16	5.93	0.26	0.03
1967	201.16	17.02	187.38	0.82	373.31	7.79	0.32	0.04
1968	197.05	16.51	183.28	0.80	372.00	8.23	0.34	0.04
1969	192.91	16.00	179.18	0.78	370.61	7.63	0.33	0.04
1970	189.62	15.60	175.94	0.76	369.46	10.72	0.41	0.06
1971	184.02	14.92	170.39	0.72	367.39	10.32	0.41	0.06
1972	179.22	14.34	165.65	0.69	365.51	13.48	0.47	0.08
1973	172.17	13.51	158.68	0.65	362.55	15.70	0.52	0.10
1974	163.86	12.54	150.46	0.61	358.71	20.17	0.59	0.13
1975	152.52	11.26	139.26	0.55	352.77	19.03	0.60	0.14
1976	143.03	10.24	129.95	0.50	347.13	15.62	0.58	0.12
1977	137.07	9.63	124.19	0.47	343.33	14.74	0.58	0.12
1978	132.25	9.17	119.54	0.44	340.17	12.99	0.57	0.11
1979	129.17	8.90	116.58	0.43	338.20	17.20	0.63	0.15
1980	122.84	8.30	110.36	0.40	333.50	15.07	0.62	0.14
1981	118.59	7.92	106.23	0.38	330.27	8.21	0.52	0.08
1982	120.09	8.13	107.85	0.39	332.08	6.70	0.47	0.06
1983	122.67	8.44	110.46	0.41	334.68	17.65	0.65	0.16
1984	116.19	7.81	103.94	0.38	329.29	20.47	0.69	0.20
1985	107.80	7.01	95.61	0.34	321.30	6.88	0.51	0.07
1986	110.78	7.34	98.76	0.36	324.78	13.26	0.63	0.13
1987	108.43	7.14	96.54	0.35	322.75	0.77	0.12	0.01
1988	116.24	7.97	104.26	0.39	330.66	4.83	0.41	0.05
1989	120.33	8.41	108.28	0.41	334.41	3.14	0.31	0.03
1990	125.55	8.96	113.27	0.43	338.72	3.22	0.29	0.03
1991	130.40	9.48	117.98	0.46	342.34	3.31	0.29	0.03
1992	134.90	9.96	122.34	0.48	345.42	3.39	0.28	0.03
1993	139.09	10.40	126.40	0.50	348.06	3.71	0.29	0.03
1994	142.78	10.78	129.99	0.52	350.23	6.39	0.39	0.05
1995	144.05	10.89	131.18	0.53	350.81	2.68	0.22	0.02
1996	148.34	11.34	135.41	0.55	353.17	16.92	0.58	0.12
1997	140.60	10.42	127.66	0.50	348.20	14.19	0.56	0.11
1998	135.69	9.84	122.78	0.48	344.67	7.11	0.43	0.06
1999	136.98	9.96	124.20	0.48	345.44	6.25	0.40	0.05
2000	138.92	10.16	126.20	0.49	346.68	1.78	0.17	0.01

Table 12: Time series of population estimates from the base model. *(continued)*

Year	Total Biomass (mt)	Spawning Output	Total Biomass 3 (mt)	Fraction Unfished	Age-0 Recruits	Total Catch (mt)	1-SPR	Exploitation Rate
2001	144.43	10.77	131.66	0.52	350.17	0.33	0.04	0.00
2002	150.79	11.48	137.93	0.56	353.86	1.16	0.11	0.01
2003	156.03	12.07	143.05	0.58	356.65	2.63	0.20	0.02
2004	159.69	12.48	146.59	0.60	358.46	3.67	0.25	0.03
2005	162.23	12.76	149.05	0.62	359.62	4.04	0.26	0.03
2006	164.28	12.98	151.04	0.63	360.51	0.94	0.08	0.01
2007	168.78	13.49	155.50	0.65	362.49	1.64	0.12	0.01
2008	172.38	13.90	159.05	0.67	363.99	2.28	0.15	0.01
2009	175.18	14.22	161.79	0.69	365.09	3.27	0.20	0.02
2010	176.96	14.41	163.52	0.70	365.74	2.02	0.14	0.01
2011	179.65	14.71	166.18	0.71	366.73	5.88	0.30	0.04
2012	178.91	14.60	165.41	0.71	366.36	4.61	0.25	0.03
2013	179.29	14.62	165.78	0.71	366.44	16.73	0.52	0.10
2014	169.49	13.42	156.01	0.65	362.22	14.30	0.50	0.09
2015	162.50	12.57	149.09	0.61	358.83	22.03	0.60	0.15
2016	149.68	11.08	136.43	0.54	351.84	22.14	0.63	0.16
2017	137.81	9.77	124.75	0.47	344.23	17.15	0.61	0.14
2018	130.96	9.06	118.15	0.44	339.38	23.36	0.68	0.20
2019	119.58	7.92	107.03	0.38	330.29	24.09	0.71	0.23
2020	108.43	6.89	96.14	0.33	320.05	1.29	0.19	0.01
2021	116.20	7.73	104.16	0.37	328.54	6.42	0.48	0.06

Table 13: Likelihood, parameter and derivied quantities from data treatment sensitivities.

	Reference	Lengths only	-catch lengths	-extra var	-survey	Dirichlet	MI	-data-weight	3x discards	Discards 2008 change
AIC	270.76	2354.00	109.28	341.92	163.85	2575.14	263.47	3353.08	268.51	262.40
deltaAIC	0.00	2083.24	-161.48	71.17	-106.91	2304.38	-7.29	3082.32	-2.25	-8.36
Survey likelihood										
HKL	12.24	-	10.75	42.65	11.03	12.50	12.55	12.82	12.15	10.88
Survey lambda										
HKL	1.00	-	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00
Length likelihood										
Total	117.14	1172.74	37.89	123.31	75.92	1264.71	113.18	1657.71	116.11	114.31
Comm_Rec	76.81	1172.74	1118.45	83.92	75.92	1032.90	96.19	1422.36	75.90	75.15
HKL	40.33	-	40.33	37.89	332.22	231.81	16.99	235.35	40.21	39.16
Length lambda										
Comm_Rec	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HKL	1.00	-	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00
Parameters										
Log(R0)	5.94	10.77	6.09	6.25	5.85	5.91	5.90	5.87	6.04	6.20
HKL logQ	-9.15	-	-9.30	-9.60	-10.08	-9.05	-9.04	-8.93	-9.21	-9.28
HKL extra SD	0.85	0.84	0.73	-	0.85	0.87	0.87	0.90	0.84	0.74
Comm_Rec peak selectivity	23.85	25.44	9.51	23.50	24.07	23.97	23.94	24.00	23.89	24.04
Comm_Rec asc lt)	2.53	2.76	4.00	2.51	2.55	2.58	2.54	2.55	2.54	2.55
HKL peak selectivity	24.50	-	23.58	23.63	19.00	24.66	24.62	24.83	24.55	24.68
HKL asc lt	2.29	-	2.08	2.08	4.00	2.32	2.31	2.35	2.30	2.35
ln(DM_theta) fishery	-	-	-	-	-	-0.53	-	-	-	-
ln(DM_theta) survey	-	-	-	-	-	3.90	-	-	-	-
Derived quantities										
SB0	20.64	-	23.93	28.03	18.75	19.94	19.79	19.21	22.65	26.60
SSB_2021	7.73	-	6.67	14.80	6.03	7.08	6.95	6.44	8.27	10.87
Bratio_2021	0.37	0.37	0.28	0.53	0.32	0.35	0.35	0.33	0.37	0.41
MSY_SPR	9.04	-	7.59	12.22	8.24	8.73	8.68	8.43	9.93	11.68
F_SPR	0.21	0.35	0.06	0.19	0.22	0.21	0.21	0.21	0.21	0.22

Table 14: Likelihood, parameter and derivied quantities from life history model specification sensitivities.

	Reference	Est M	Est Linf	Est k	Est Linf,k	Est. M,Linf,k	F: Est M	F: Est Linf	F: Est k	F: Est Linf,k	F: Est. M,Linf,k	M: Est M	M: Est Linf	M: Est k	M: Est Linf,k	M: Est M,Linf,k
AIC	270.76	236.36	272.13	228.49	264.84	235.03	236.44	231.02	227.00	227.00	229.00	254.20	258.03	240.66	254.17	248.89
deltaAIC	0.00	-34.4	1.37	-42.3	-5.92	-35.7	-34.3	-39.7	-43.7	-43.7	-41.7	-16.6	-12.7	-30.1	-16.6	-21.8
Survey likelihood																
HKL	12.24	8.74	9.37	9.00	8.74	8.74	8.74	9.12	8.74	8.74	8.74	11.07	12.11	11.23	11.93	11.29
Length likelihood																
Total	117.14	97.40	118.70	97.24	113.68	96.75	97.98	99.38	96.76	96.76	96.76	104.44	109.90	102.10	107.15	100.99
HKL	40.33	37.99	50.68	39.05	48.93	38.35	37.83	38.88	38.28	38.28	38.28	39.94	39.76	40.79	39.83	39.69
Comm_Rec	76.81	59.41	68.01	58.19	64.75	58.40	60.15	60.50	58.48	58.48	58.48	64.51	70.15	61.31	67.32	61.31
Parameters																
Female M	0.13	0.23	0.13	0.13	0.13	0.13	0.26	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Female L_{infty}	26.74	26.74	24.19	26.74	26.16	25.70	26.74	23.79	25.49	25.49	25.49	26.74	26.74	26.74	26.74	26.74
Female k	0.12	0.12	0.12	0.06	0.07	0.06	0.12	0.12	0.05	0.05	0.05	0.12	0.12	0.12	0.12	0.12
Male M	0.13	0.10	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.07	0.13	0.13	0.13	0.08
Male L_{infty}	20.82	20.82	21.39	20.82	21.21	21.04	20.82	20.82	20.82	20.82	20.82	20.82	22.20	20.82	21.97	21.79
Male k	0.25	0.25	0.25	0.30	0.32	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	2.00	0.30	0.25
Log(R0)	5.94	19.82	7.33	8.46	19.95	19.97	19.87	7.92	19.98	19.98	19.98	5.64	5.81	5.61	5.74	5.56
HKL logQ	-9.15	-23.1	-10.3	-11.2	-23.2	-22.5	-22.6	-10.5	-22.1	-22.1	-22.1	-9.47	-9.29	-9.55	-9.35	-9.53
HKL extra SD	0.85	0.58	0.63	0.60	0.58	0.58	0.58	0.61	0.58	0.58	0.58	0.75	0.84	0.77	0.82	0.77
Comm_Rec peak selectivity	23.85	25.89	24.45	26.57	25.32	26.30	25.65	25.03	27.73	27.73	27.72	24.68	23.42	24.50	23.52	23.76
Comm_Rec asc lt)	2.53	3.05	2.81	3.11	3.01	3.07	2.92	2.86	3.22	3.22	3.22	2.83	2.55	3.17	2.61	2.74
HKL peak selectivity	24.50	24.56	26.99	25.41	25.12	25.62	24.95	28.02	25.73	25.73	25.72	24.17	24.25	23.90	24.19	23.97
HKL asc lt	2.29	2.32	2.95	2.44	2.44	2.47	2.39	3.10	2.41	2.41	2.41	2.23	2.23	2.14	2.22	2.17
Derived quantities																
SB0	20.64	HIGH	55.87	64.13	HIGH	HIGH	HIGH	94.25	HIGH	HIGH	HIGH	15.20	18.02	14.86	16.91	14.02
SSB_2021	7.73	HIGH	47.15	59.56	HIGH	HIGH	HIGH	85.12	HIGH	HIGH	HIGH	6.88	6.90	6.49	6.69	6.21
Bratio_2021	0.37	1.00	0.84	0.93	1.00	1.00	1.00	0.90	1.00	1.00	1.00	0.45	0.38	0.44	0.40	0.44
MSY_SPR	9.04	HIGH	38.47	109.45	HIGH	HIGH	HIGH	65.25	HIGH	HIGH	HIGH	9.85	9.18	10.38	9.40	9.58
F_SPR	0.21	1.09	0.37	1.23	0.60	1.37	1.58	0.50	3.63	3.63	3.62	0.22	0.18	0.18	0.18	0.18

Table 15: Likelihood, parameter and derivied quantities from model specification sensitivities that consider recruitment, fleet and growth platoon treatments.

Type	Reference	sR=0.45	sR=0.6	sR=0.75	sR=0.6, no extraSD	2 fleets	5 GTG
AIC	270.76	510.81	507.95	498.38	529.92	322.32	276.47
deltaAIC	0.00	240.05	237.19	227.62	259.16	51.56	5.71
Survey likelihood							
HKL	12.24	10.32	10.10	9.26	19.37	12.14	11.52
Length likelihood							
Total	117.14	126.49	125.20	121.07	121.04	141.02	120.72
HKL	40.33	48.52	48.38	48.05	50.79	40.72	38.38
Comm_Rec	76.81	77.97	76.81	73.02	70.24		82.34
Commercial	-	-	-	-	-	21.65	-
Recreational	-	-	-	-	-	78.65	-
Parameters							
Female M	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Female L_{infty}	26.74	26.74	26.74	26.74	26.74	26.74	26.74
Female k	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Male M	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Male L_{infty}	20.82	20.82	20.82	20.82	20.82	20.82	20.82
Male k	0.25	0.25	0.25	0.25	0.25	0.25	0.25
log(R0)	5.94	5.74	5.74	5.73	5.77	5.96	6.27
sigmaR	-	0.45	0.60	0.75	0.60	-	-
HKL logQ	-9.15	-8.21	-8.13	-7.82	-7.83	-9.19	-9.62
HKL extra SD	0.85	0.70	0.68	0.62	-	0.84	0.79
Comm_Rec peak selectivity	23.85	24.76	24.83	25.07	25.08	-	23.99
Comm_Rec asc lt)	2.53	2.66	2.66	2.68	2.67	-	2.58
HKL peak selectivity	24.50	26.52	26.67	27.22	27.26	24.47	24.48
HKL asc lt	2.29	2.78	2.81	2.88	2.88	2.28	2.32
Comm. peak selectivity	-	-	-	-	-	28.60	-
Comm. asc lt	-	-	-	-	-	3.01	-
Rec. peak selectivity	-	-	-	-	-	23.83	-
Rec. asc lt	-	-	-	-	-	2.53	-
Derived quantities	-	-	-	-	-	-	
SB0	20.64	16.92	16.85	16.76	17.46	20.92	28.27
SSB_2021	7.73	5.75	5.78	6.26	9.79	8.00	13.66

Table 15: Likelihood, parameter and derivied quantities from model specification sensitivities that consider recruitment, fleet and growth platoon treatments. *(continued)*

Type	Reference	sR=0.45	sR=0.6	sR=0.75	sR=0.6, no extraSD	2 fleets	5 GTG
Bratio_2021	0.37	0.34	0.34	0.37	0.56	0.38	0.48
MSY_SPR	9.04	7.48	7.45	7.43	7.74	9.20	10.97
F_SPR	0.21	0.25	0.26	0.27	0.27	0.26	0.20

Table 16: Summary of reference points and management quantities, including estimates of the 95 percent intervals.

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Output	20.64	17.81	23.47
Unfished Age 3+ Biomass (mt)	215.38	185.84	244.91
Unfished Recruitment (R0)	380.76	328.56	432.97
Spawning Output (2021)	7.73	5.12	10.34
Fraction Unfished (2021)	0.37	0.30	0.45
Reference Points Based SB40 Percent			
Proxy Spawning OutputSB40 Percent	8.26	7.12	9.39
SPR Resulting in SB40 Percent	0.46	0.46	0.46
Exploitation Rate Resulting in SB40 Percent	0.26	0.23	0.28
Yield with SPR Based On SB40 Percent (mt)	9.67	8.38	10.96
Reference Points Based on SPR Proxy for MSY			
Proxy Spawning Output (SPR50)	9.21	7.95	10.47
Exploitation Rate Corresponding to SPR50	0.21	0.19	0.22
Yield with SPR50 at SB SPR (mt)	9.04	7.83	10.26
Reference Points Based on Estimated MSY Values			
Spawning Output at MSY (SB MSY)	4.85	4.23	5.47
SPR MSY	0.31	0.31	0.31
Exploitation Rate Corresponding to SPR MSY	0.64	0.57	0.71
MSY (mt)	11.08	9.64	12.52

Table 17: Projections of potential OFLs (mt), ABCs (mt), estimated spawning output, and fraction unfished. The adopted OFL and ACL,for 2021 and 2022 reflect adopted management limits for the area South of 40.10 Latitude N.

Year	Complex OFL	Complex ACL	Adopted OFL	Adopted ACL	OFL	ABC	Buffer	Spawning Output	Fraction Unfished
2021	1919	1438	11.08	8.64	-	-	-	7.73	0.37
2022	1842	1428	11.1	8.64	-	-	-	6.90	0.33
2023	-	-	-	-	5.33	4.14	0.777	6.14	0.30
2024	-	-	-	-	5.98	4.8	0.803	6.74	0.33
2025	-	-	-	-	6.58	5.39	0.819	7.26	0.35
2026	-	-	-	-	7.12	5.9	0.829	7.69	0.37
2027	-	-	-	-	7.57	6.32	0.835	8.04	0.39
2028	-	-	-	-	7.95	6.63	0.834	8.33	0.40
2029	-	-	-	-	8.25	6.82	0.827	8.57	0.42
2030	-	-	-	-	8.5	6.95	0.818	8.77	0.42
2031	-	-	-	-	8.71	7.06	0.811	8.95	0.43
2032	-	-	-	-	8.89	7.14	0.803	9.11	0.44

8 Figures

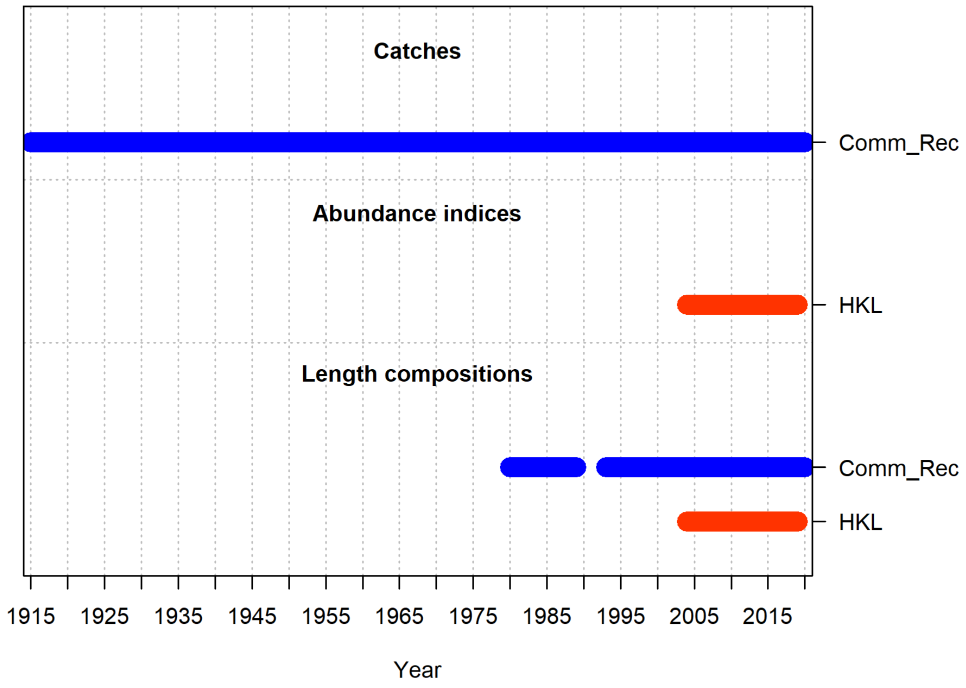

Figure 1: Summary of data sources used in the base model.

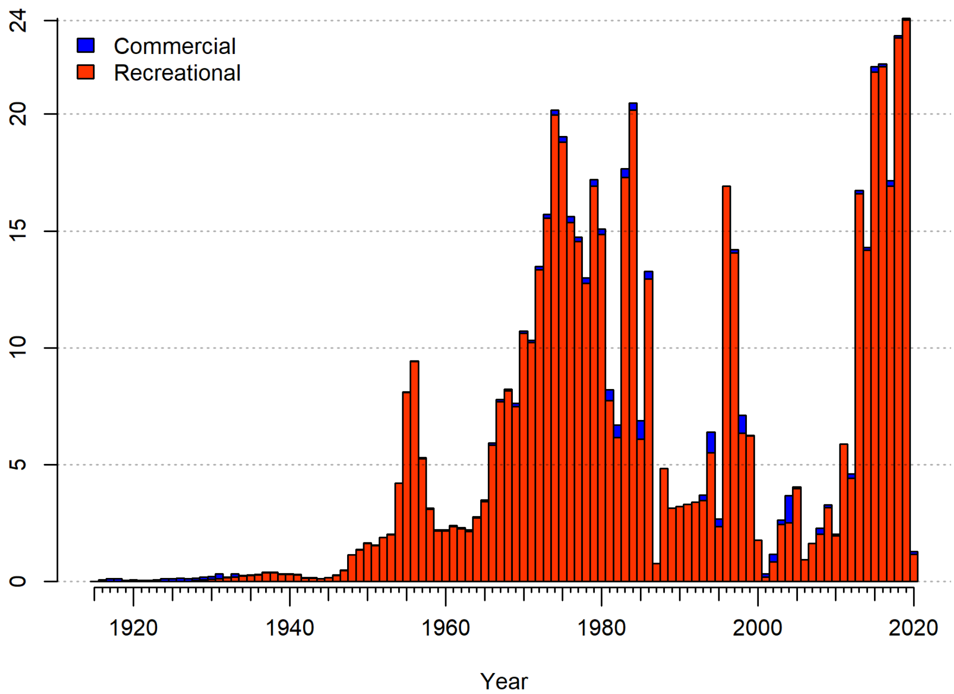

Figure 2: Commerical and recreational removals.

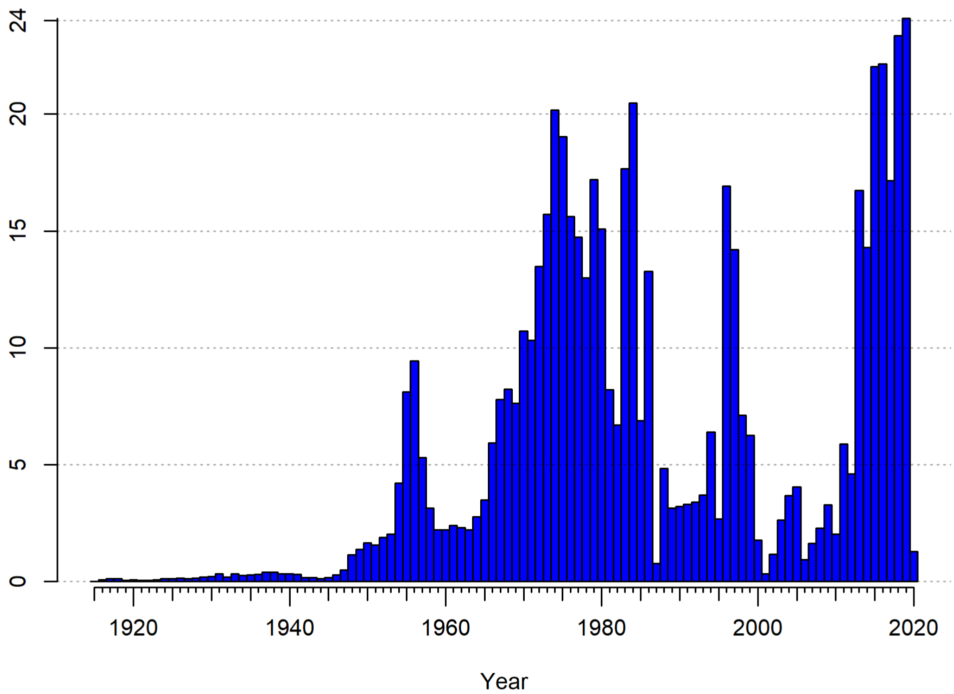

Figure 3: Removals by fleet used in the base model.

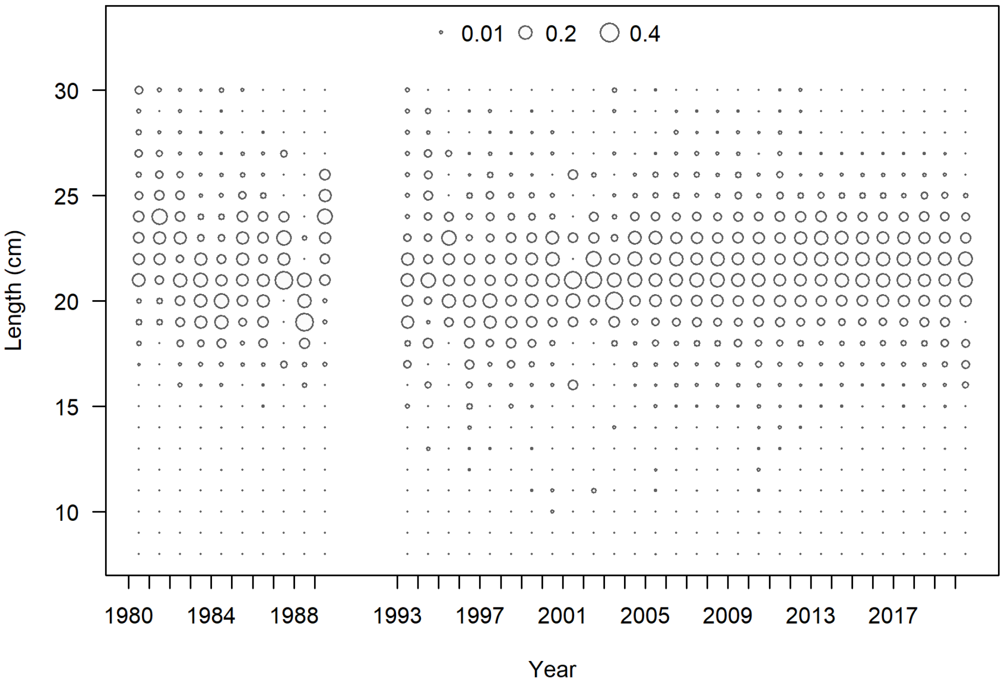

Figure 4: Length composition data from recreational fleet.

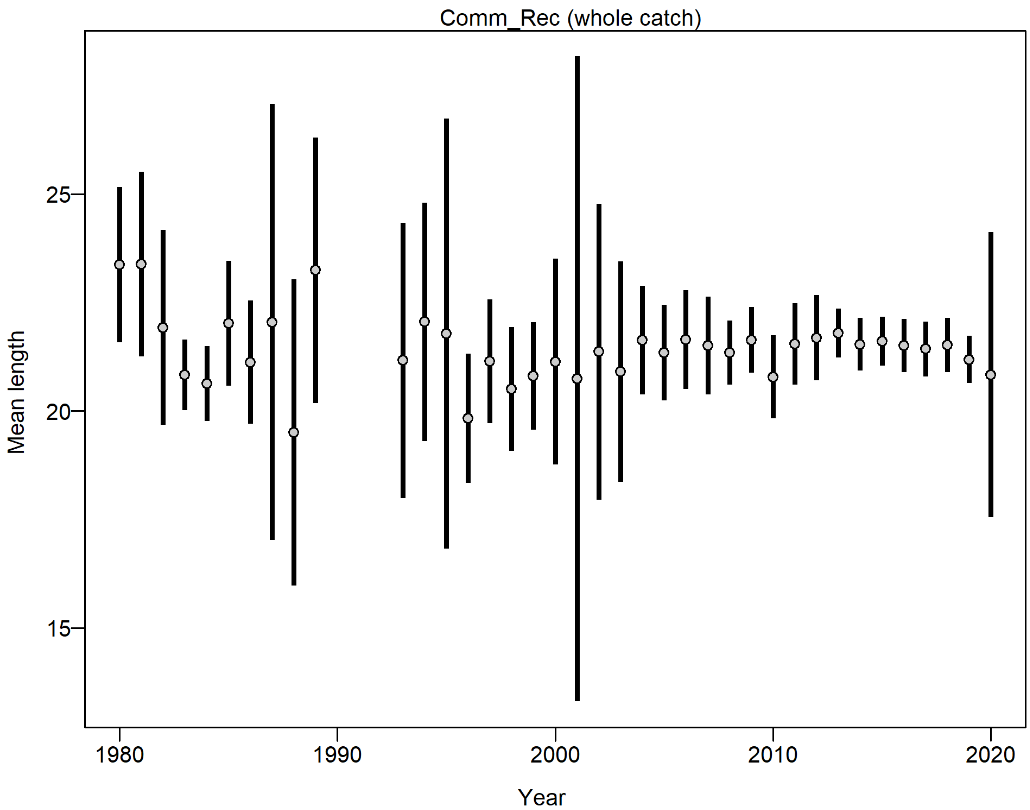

Figure 5: Mean length for the recreational fleet with 95 percent confidence intervals.

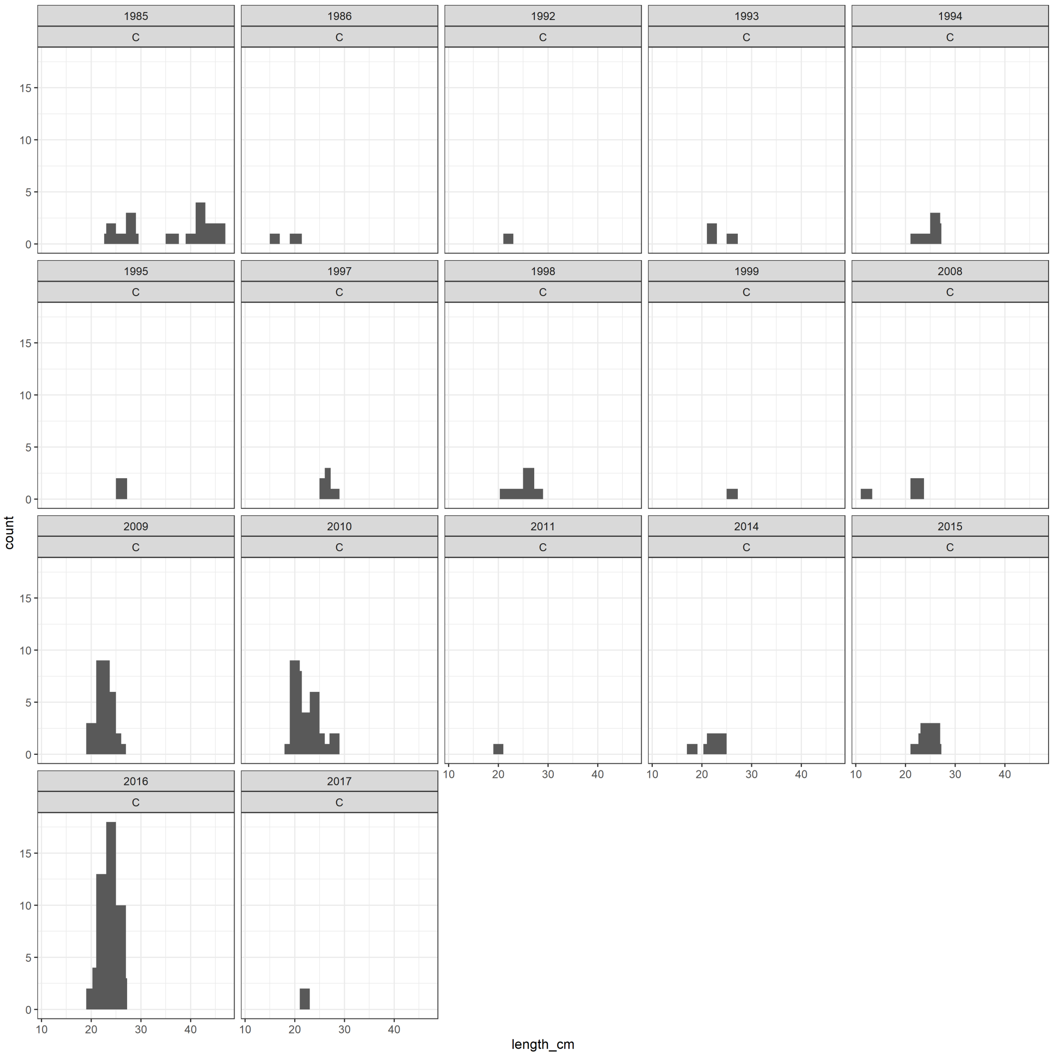

Figure 6: Sqaurespot rockfish commerical length sample frequencies by year.

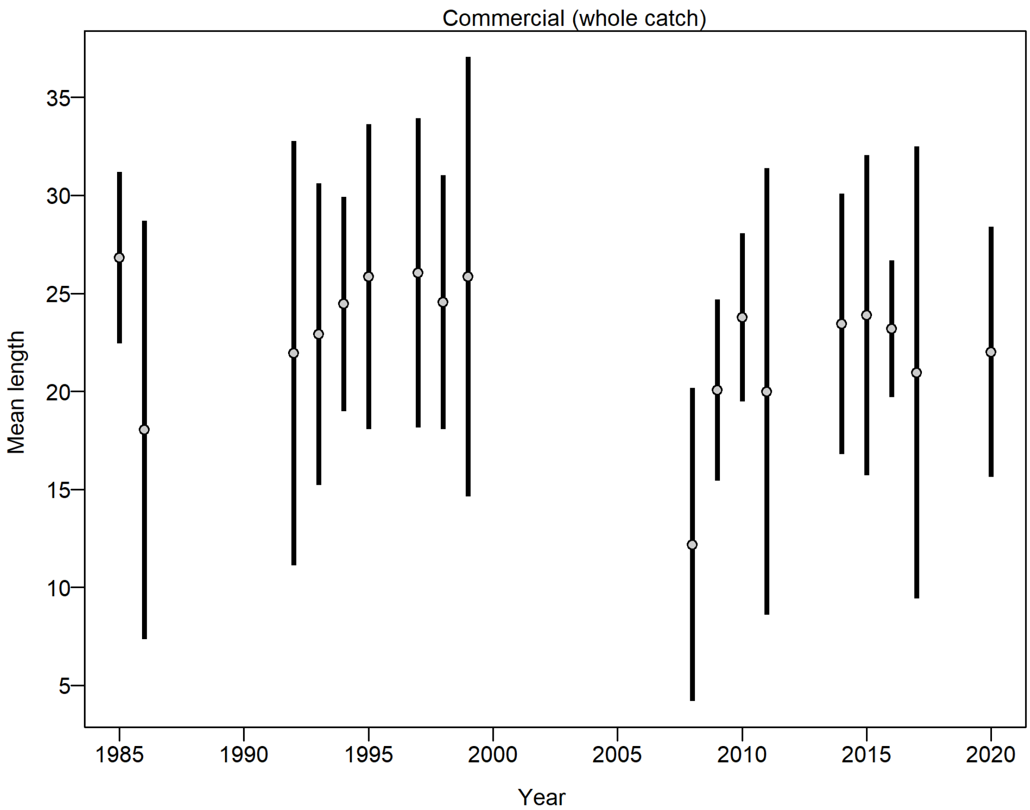

Figure 7: Mean length for the commercial fleet with 95 percent confidence intervals.

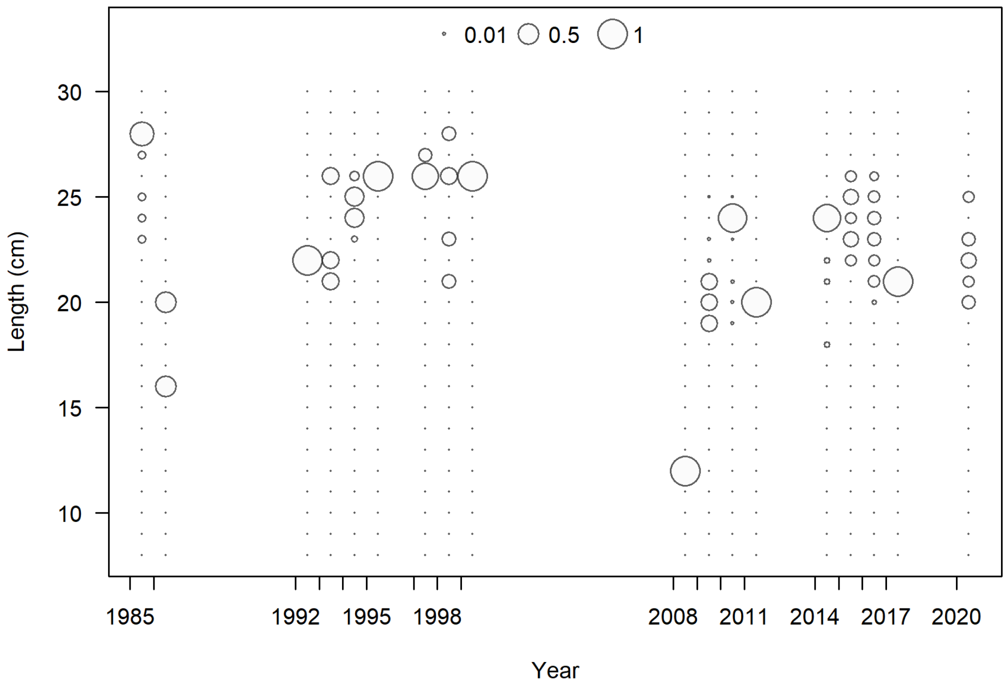

Figure 8: Bubble plot of length compositions for the commercial fleet with 95 percent confidence intervals.

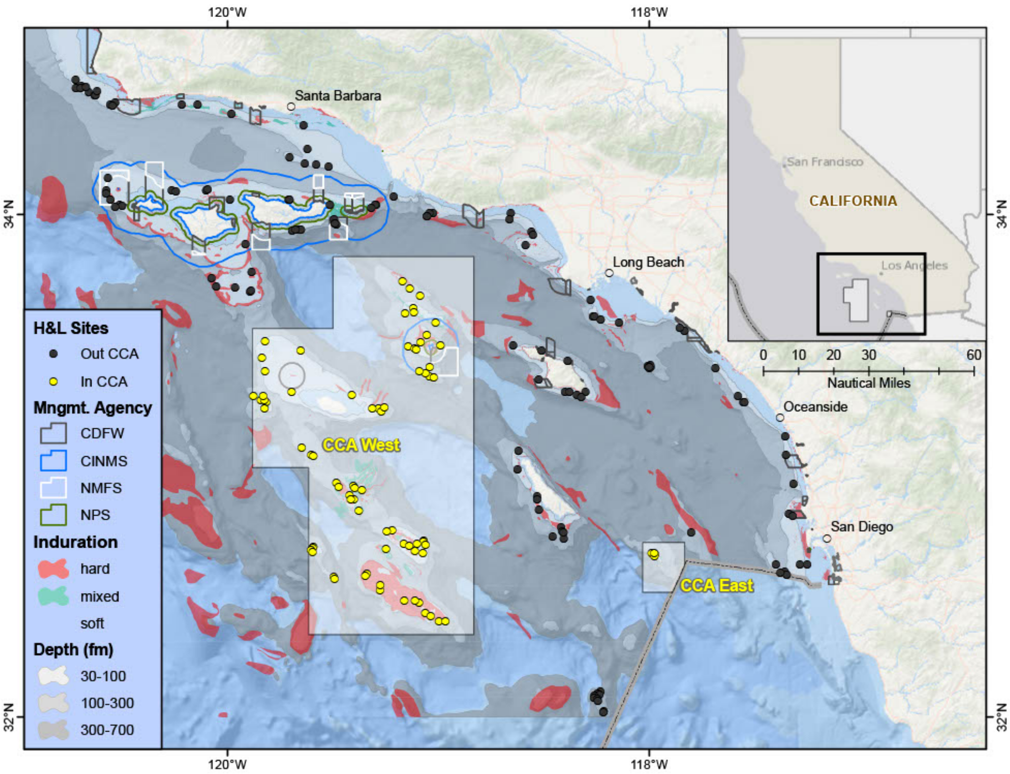

Figure 9: NWFSC Hook and Line survey sampling sites where yellow sites indicate locations inside Cowcod Conservation Areas. Additionally, known substrate structure, depths, and areas under various management regulations are shown for the area south of Point Conception.

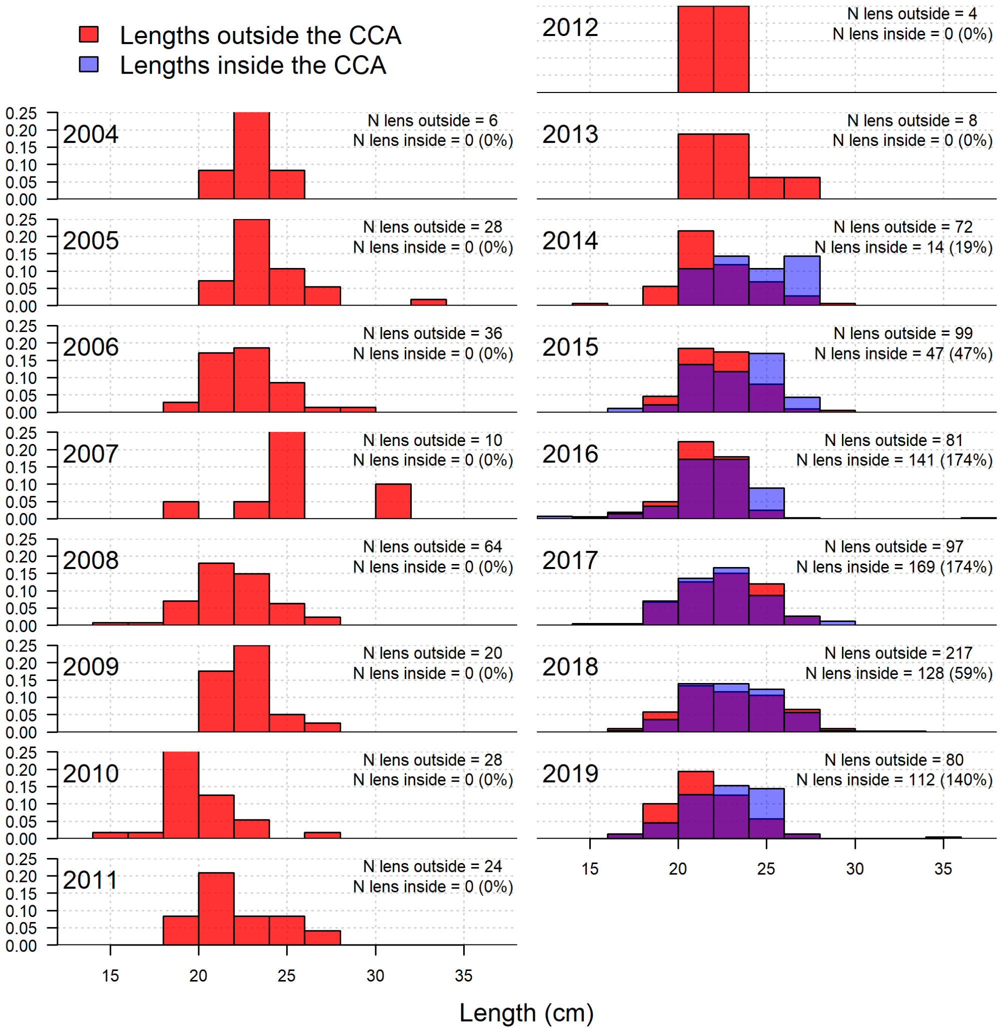

Figure 10: NWFSC Hook and Line survey observations by year outside and inside the cowcod conservation area.

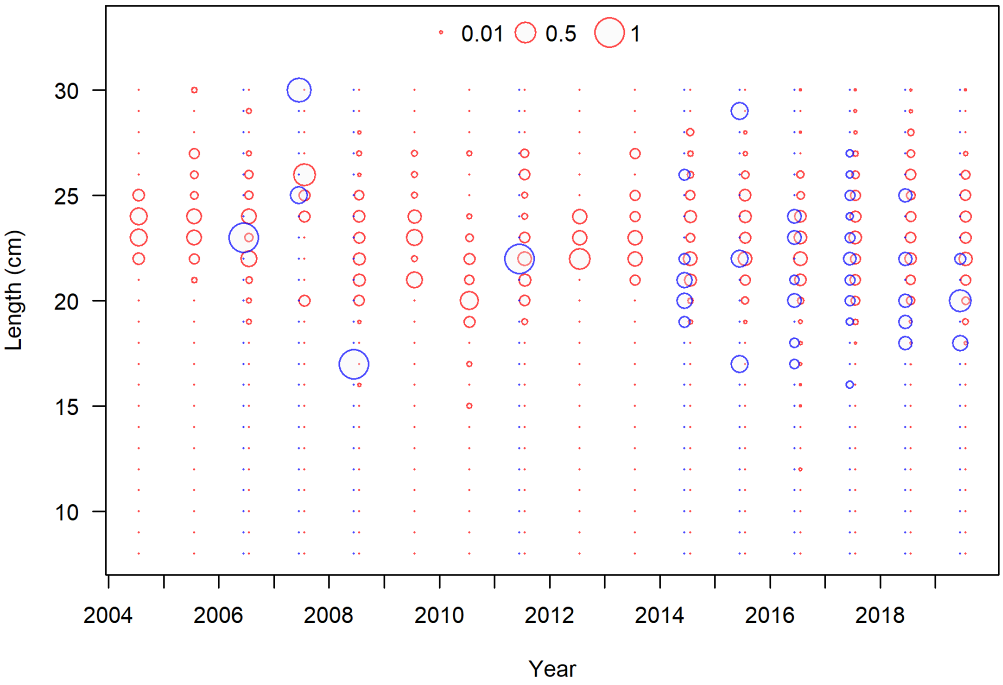

Figure 11: Length composition data from the NWFSC Hook and Line survey.

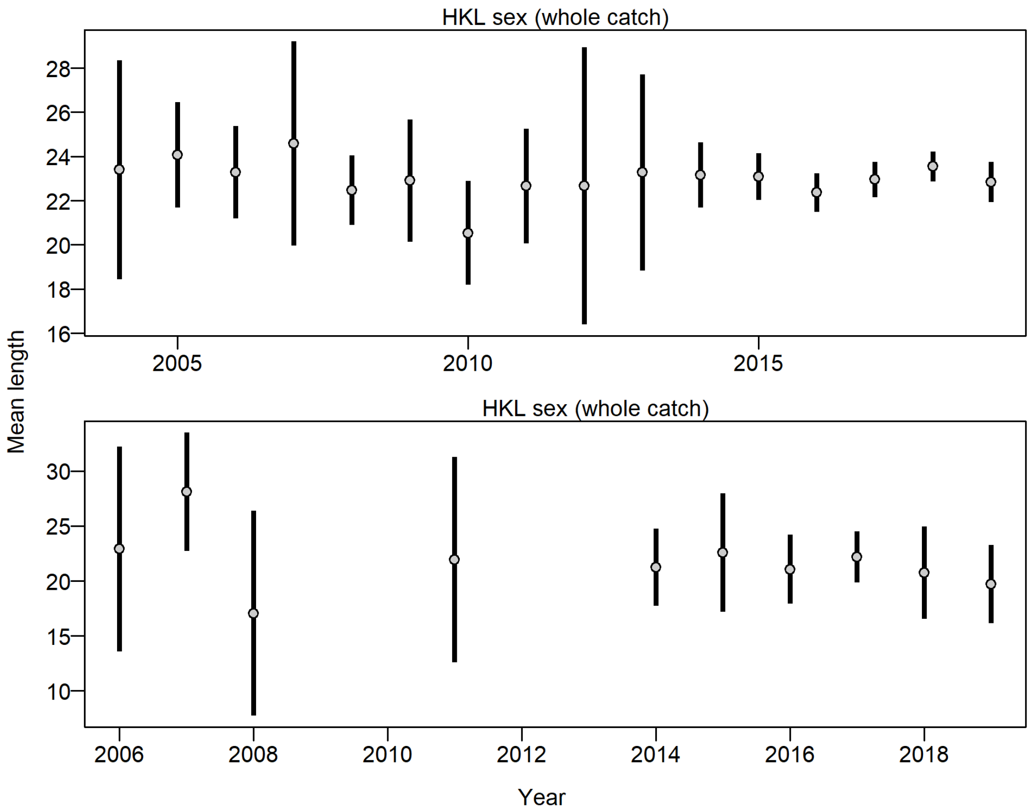

Figure 12: Mean length for NWFSC Hook and Line survey with 95 percent confidence intervals.

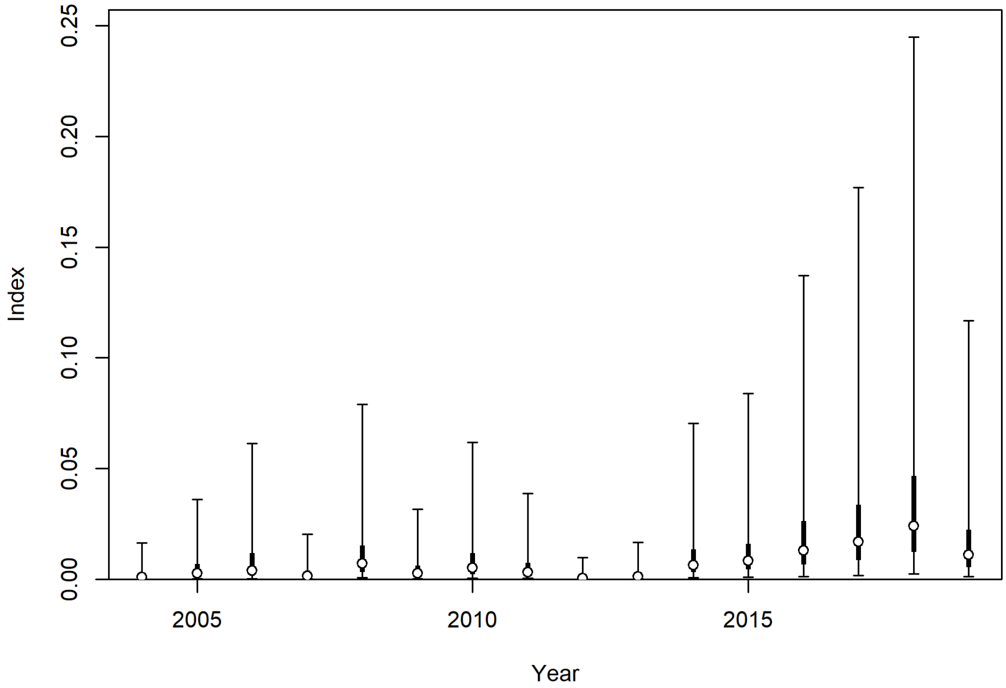

Figure 13: Index of abundance for the NWFSC Hook and Line survey. Lines indicate 95 percent uncertainty interval around index values based on the model assumption of lognormal error. Thicker lines indicate input uncertainty before addition of estimated additional uncertainty parameter.

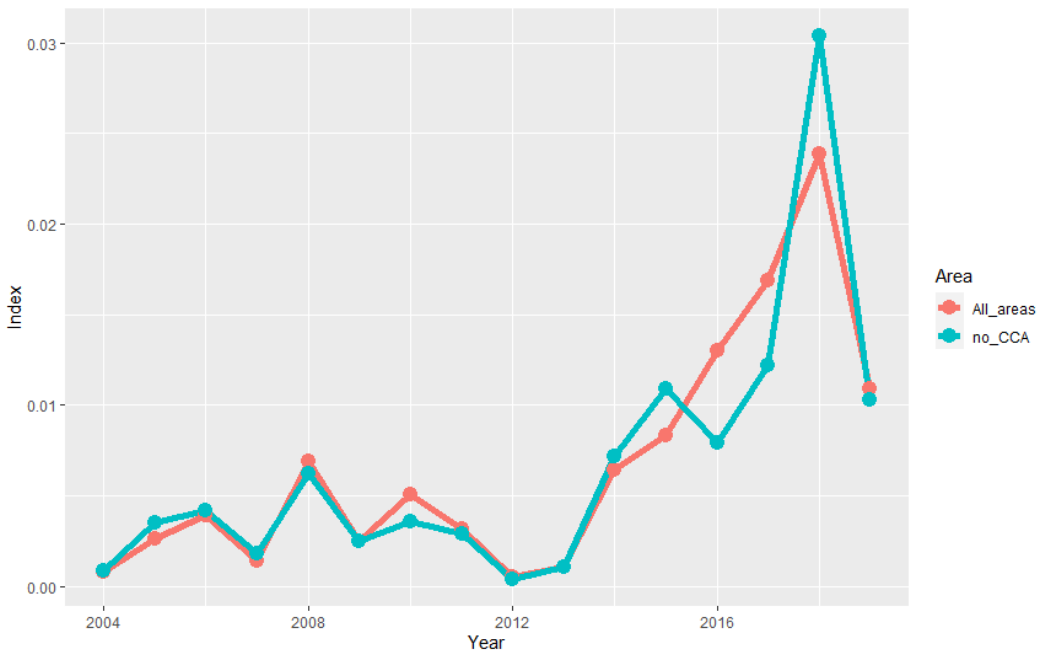

Figure 14: Comparison of NWFSC Hook and Line survey index time series using all areas compared to just using non-CCA samples.

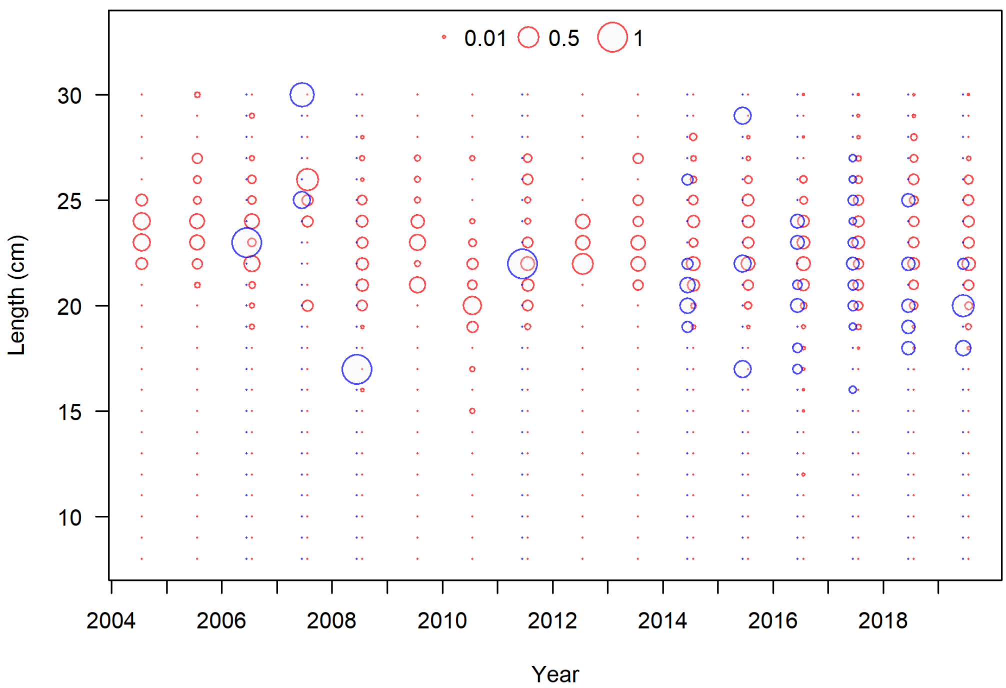

Figure 15: Length composition data from the NWFSC WCGBT survey.

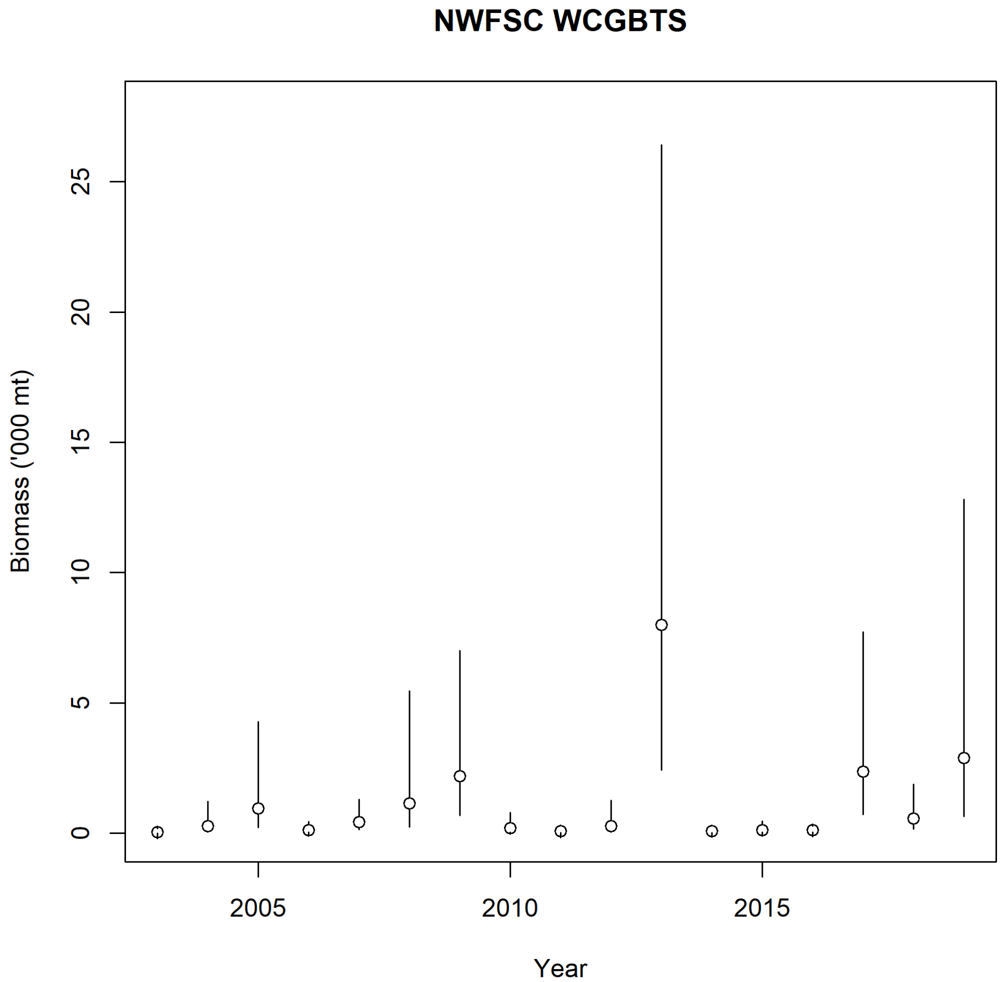

Figure 16: Design-based index of abundance for the NWFSC WCGBT survey.

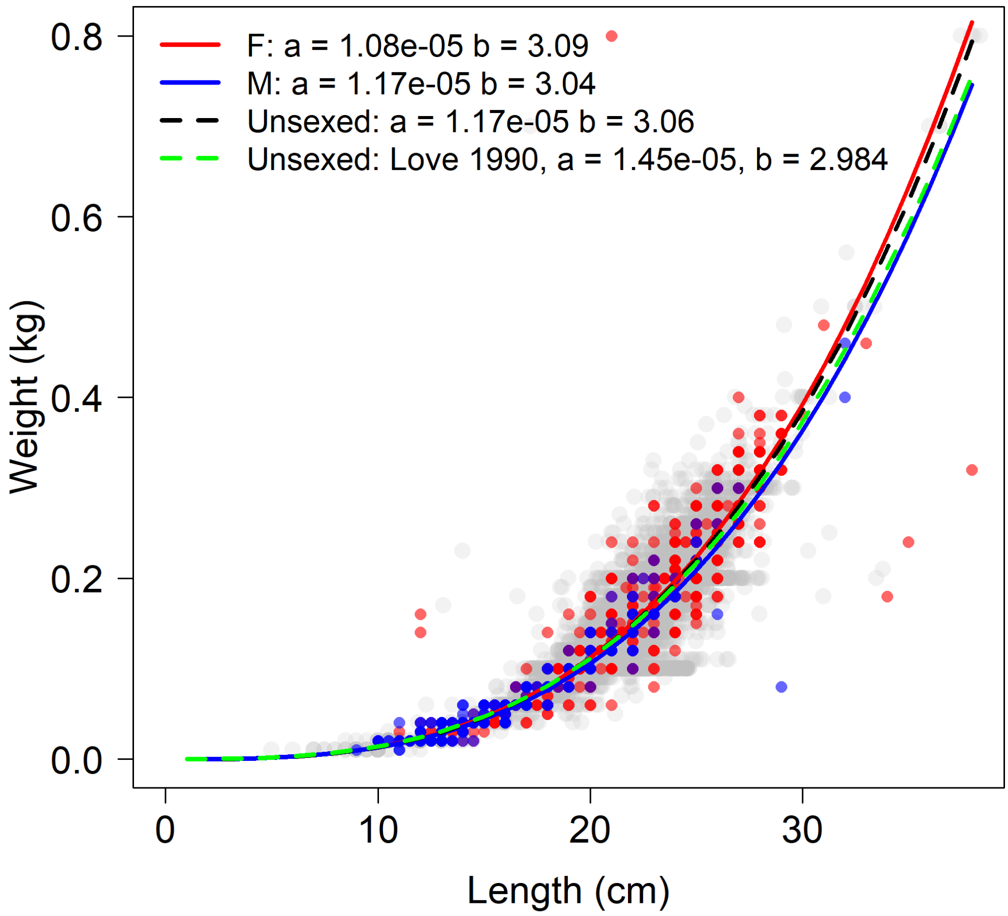

Figure 17: Survey length-at-weight data with sex specific estimated fits and comparison to literature length-at-weight values.

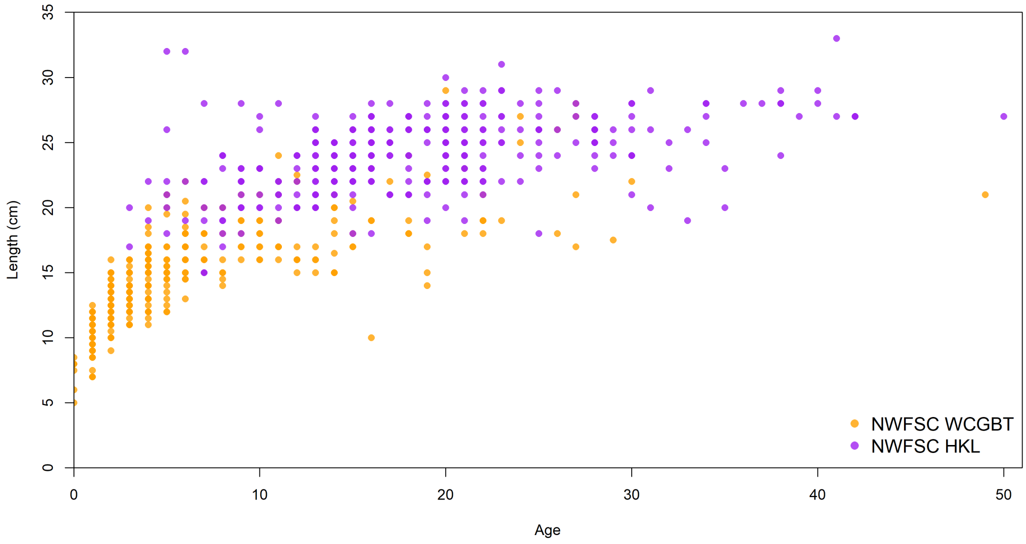

Figure 18: Observed length-at-age by data source.

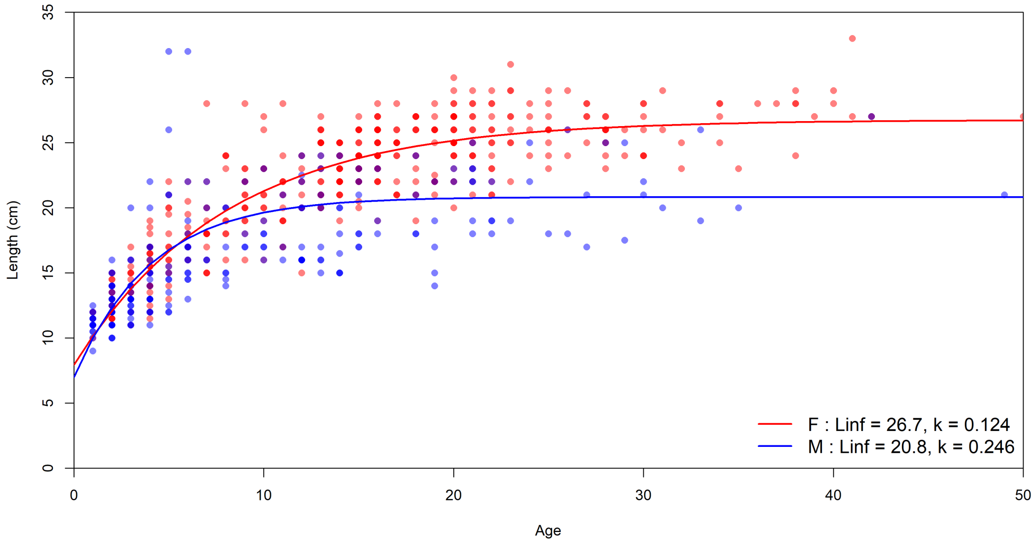

Figure 19: Length-at-age estimated from the NWFSC WCGBT and Hook and Line survey data with sex specific estimated growth.

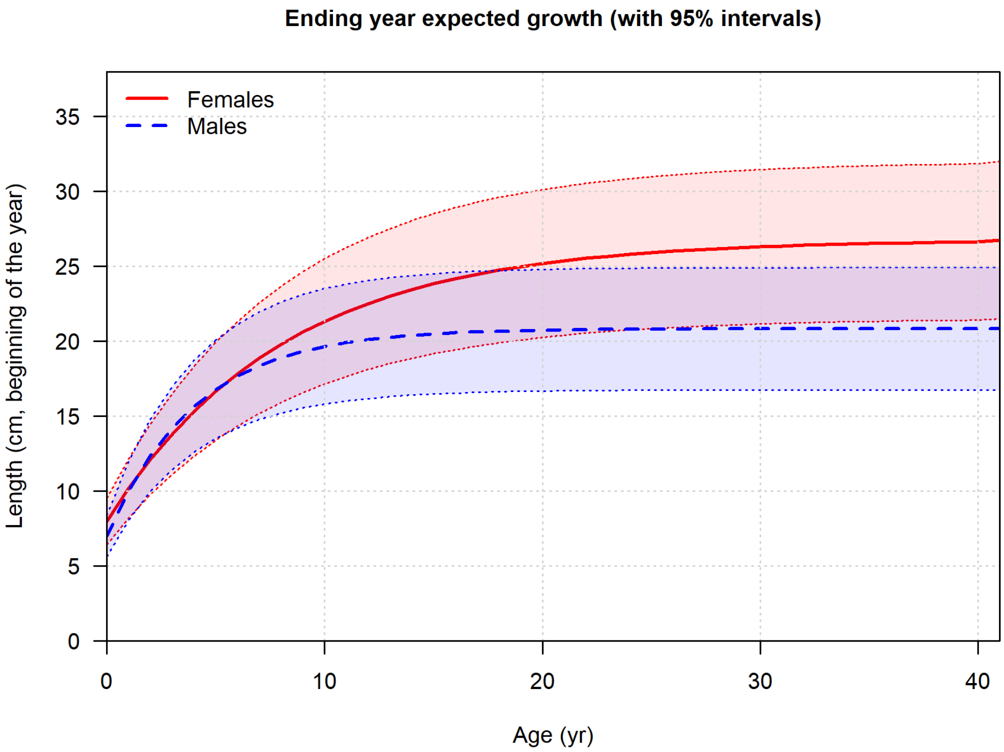

Figure 20: Length at age in the beginning of the year in the ending year of the model.

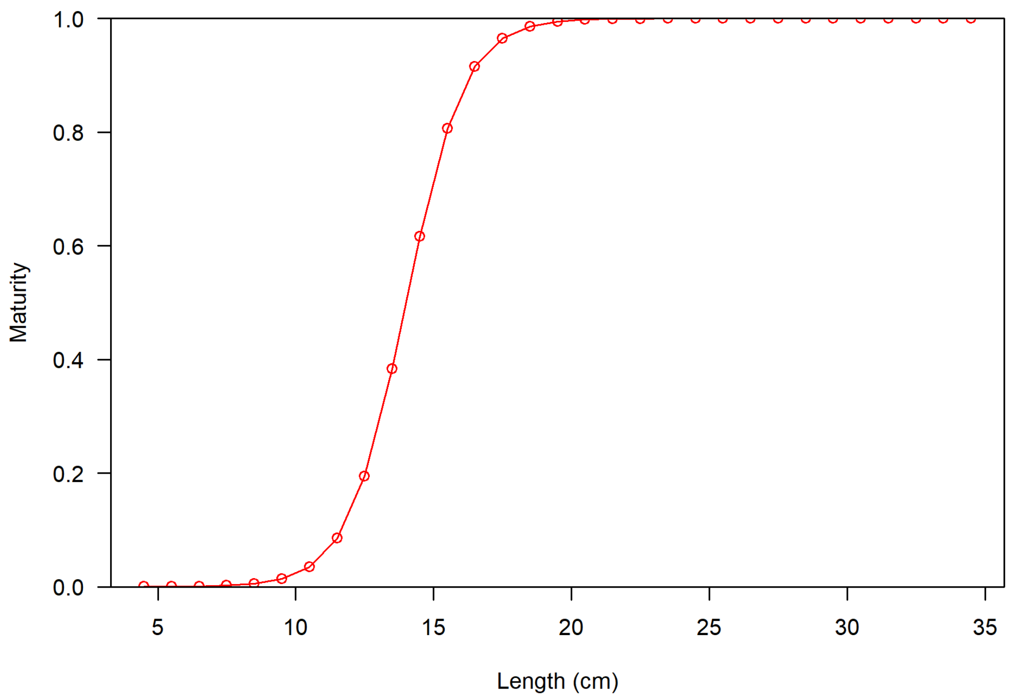

Figure 21: Maturity as a function of length.

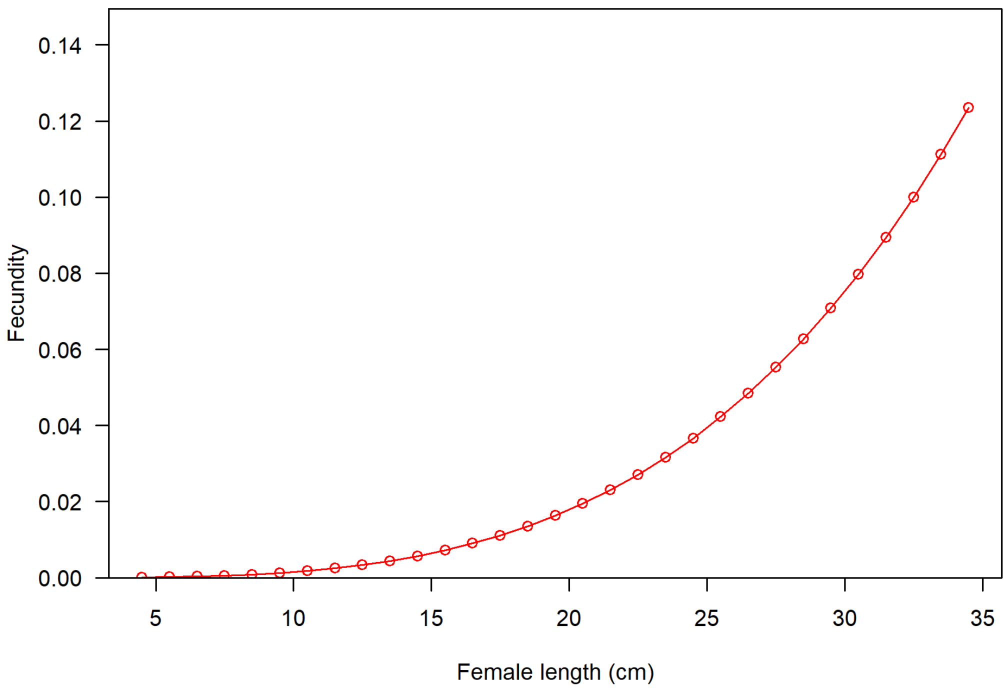

Figure 22: Fecundity as a function of length.

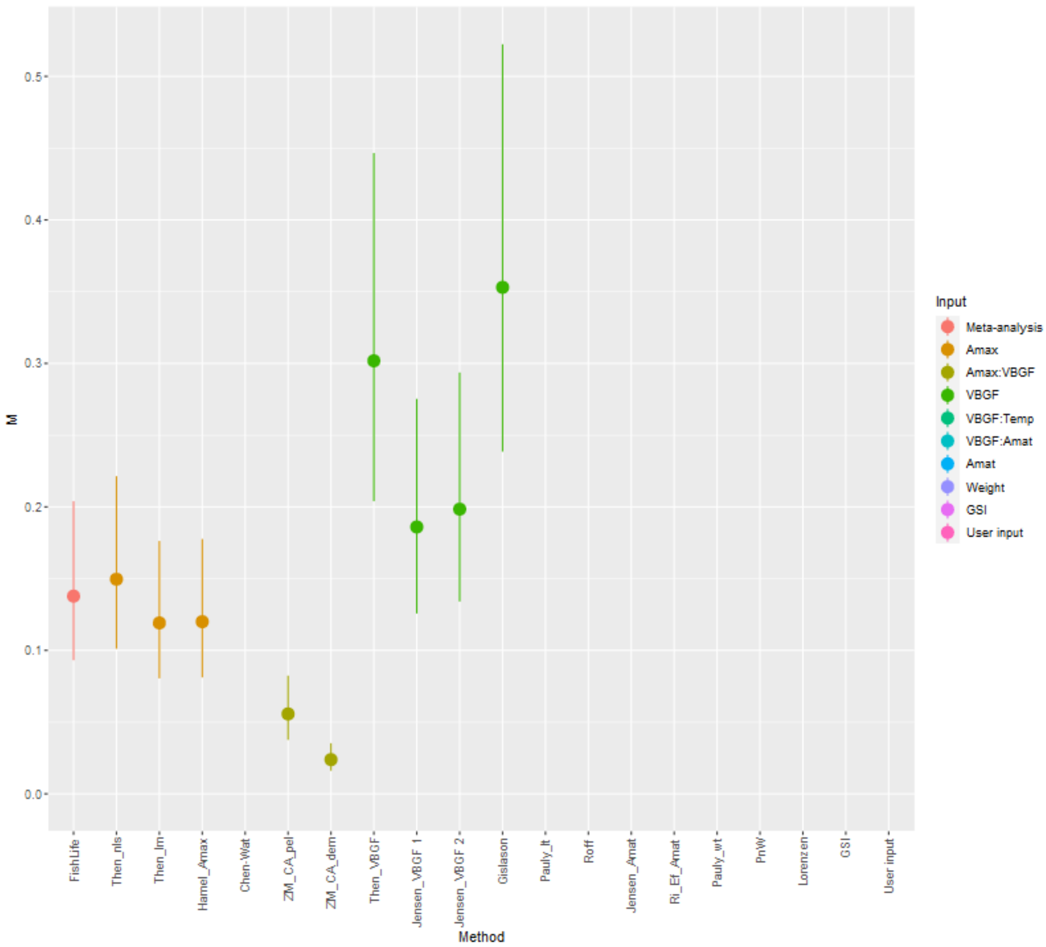

Figure 23: Estimates of natural mortality for *S.hopkinsi* using longevity = 45 years and female VBGF parameters. Error bars are based on a lognormal distribution with SD = 0.2.

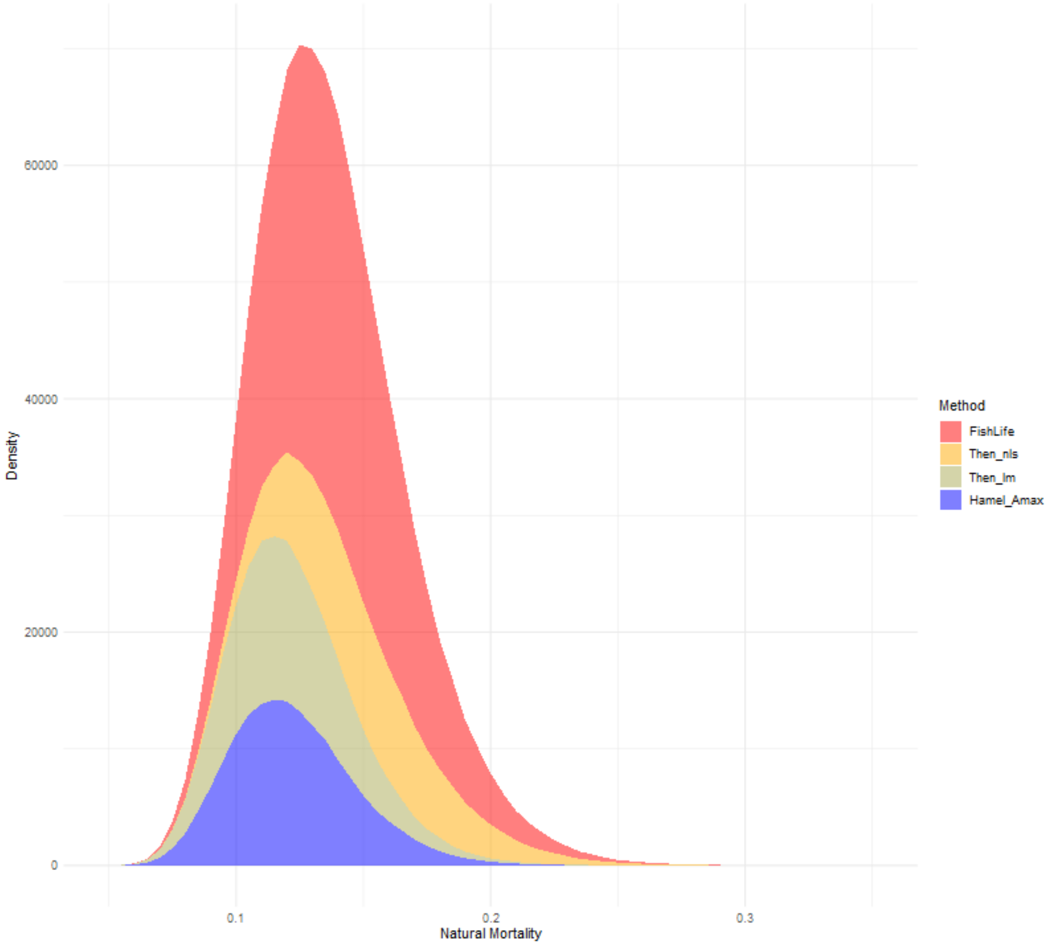

Figure 24: Composite natural mortality distriubtion for *S.hopkinsi* using four longevity estimators each with a SD = 0.2 presuming a lognomral error distibution.

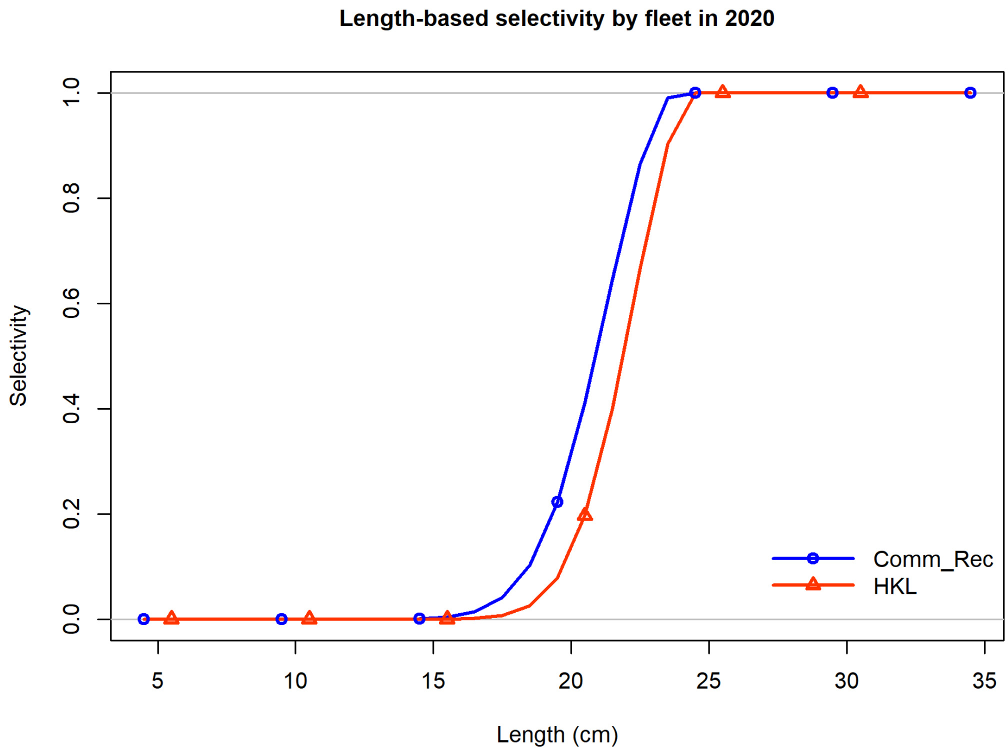

Figure 25: Selectivity at length by fleet.

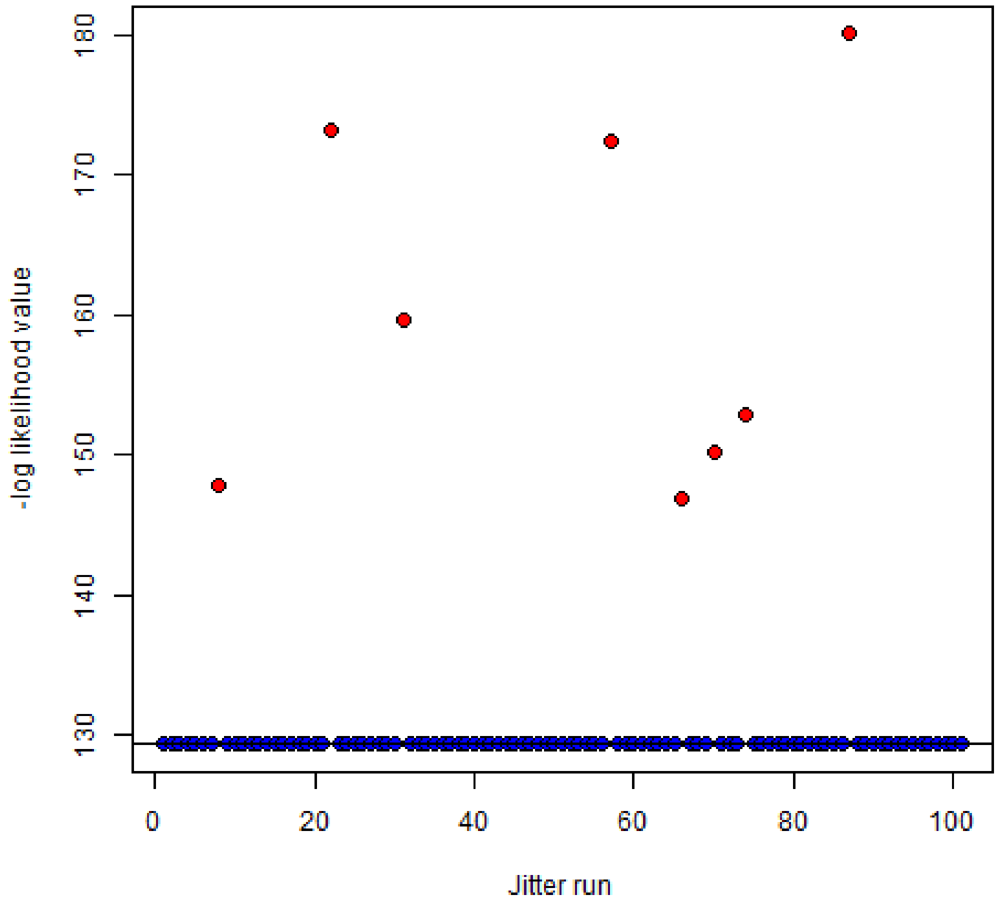

Figure 26: Jitter runs for the squarespot rockfish reference model, with jitter run number on the x-axis and -log likelihood value on the y-axis. Blue dot are models that match the likelihood value of the reference model, while red dots deviate from the reference model. All red dots are above the blue dots, indicating no better fit to the reference model was found.

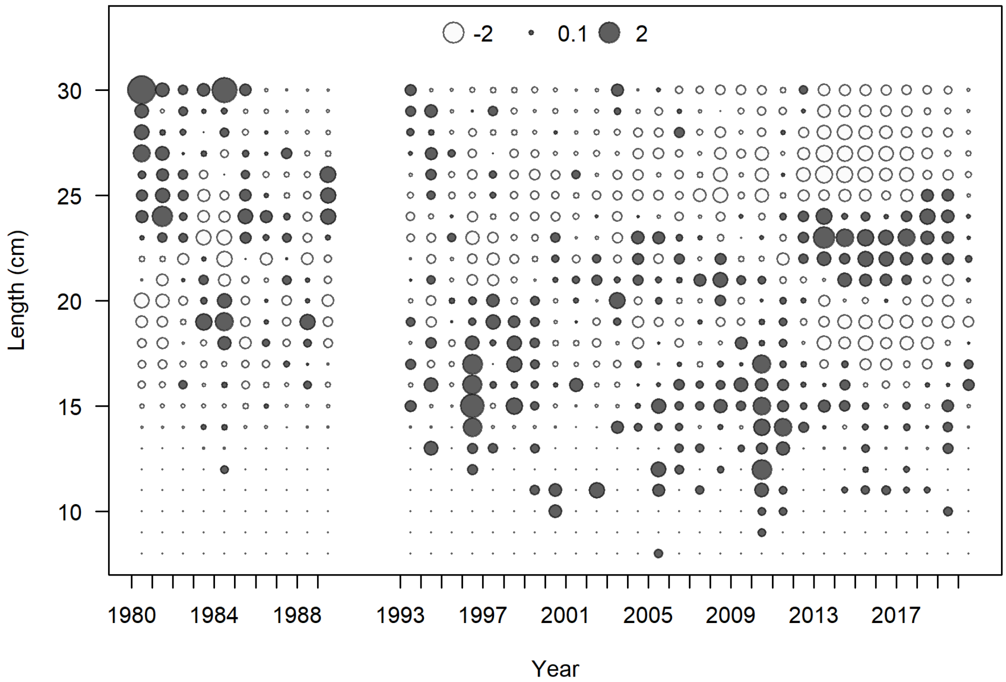

Figure 27: Pearson residuals for combind recreational and commercial fleet. Closed bubble are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

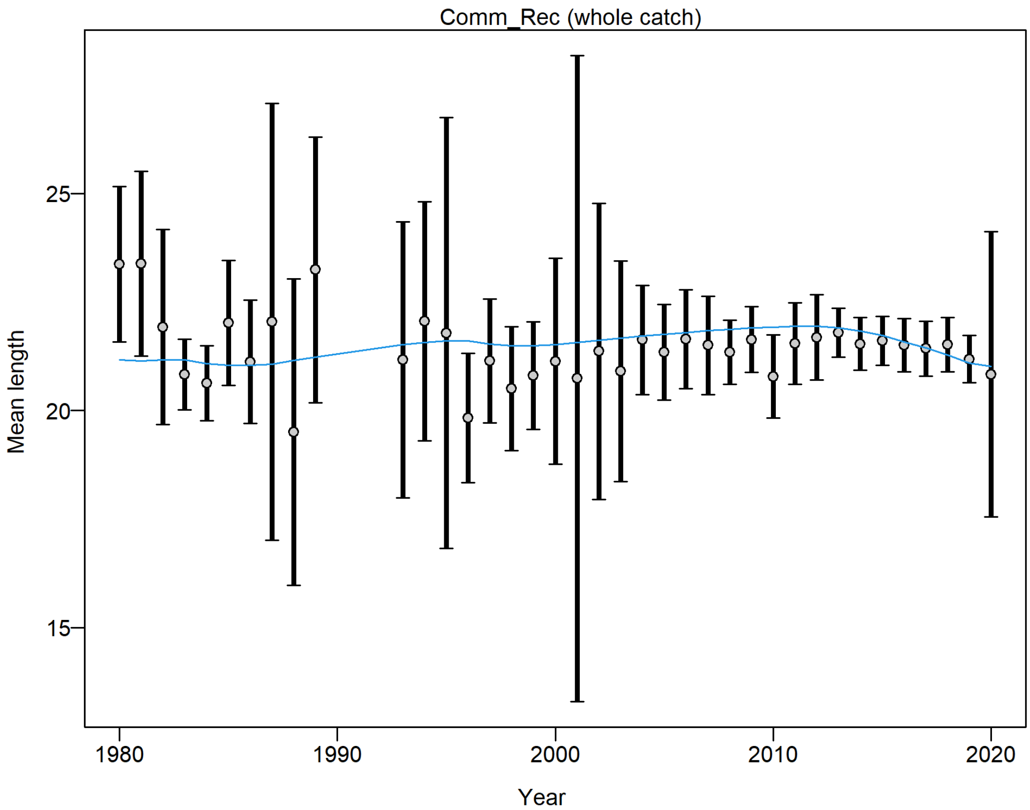

Figure 28: Mean length for combined recreational and commercial lengths with 95 percent confidence intervals based on current samples sizes.

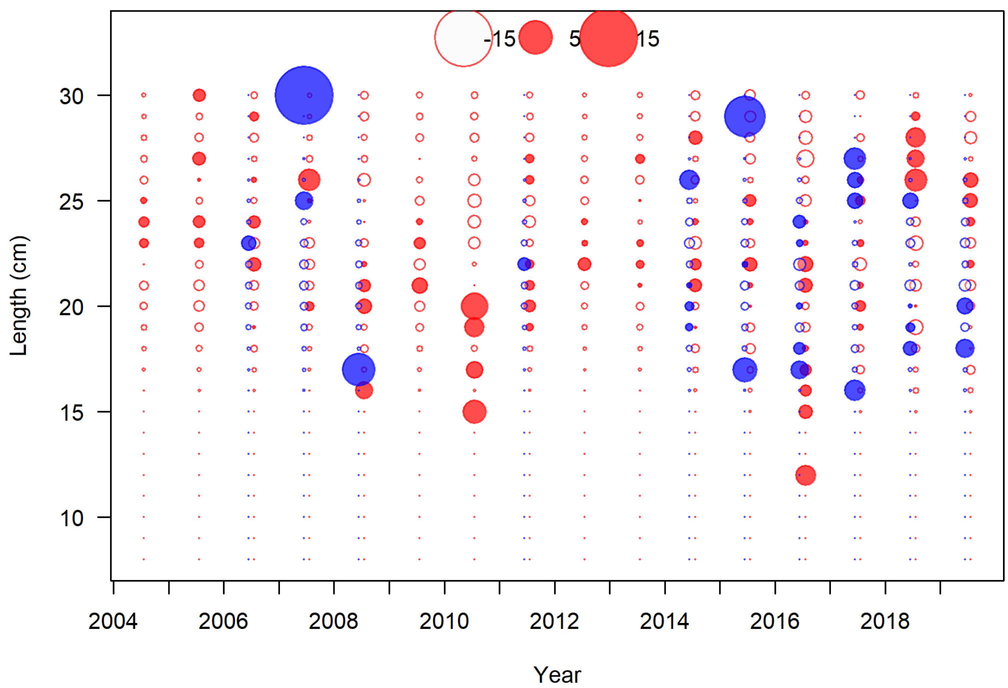

Figure 29: Pearson residuals for NWFSC Hook and Line survey. Closed bubble are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

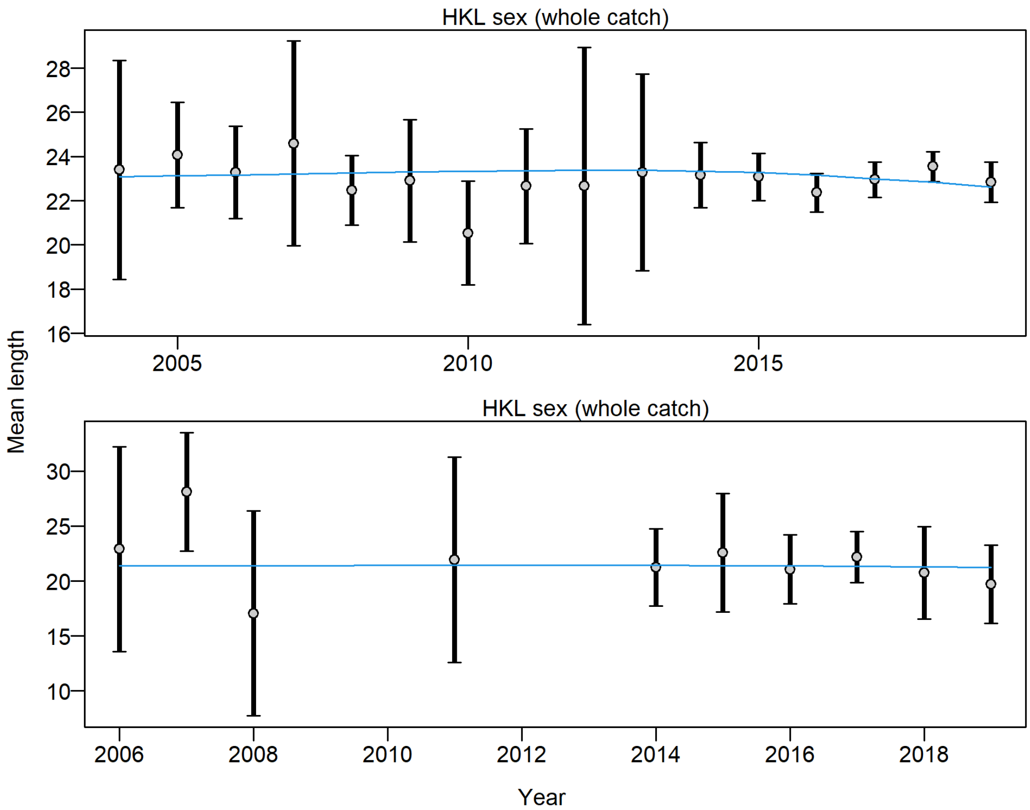

Figure 30: Mean length for NWFSC Hook and Line survey lengths with 95 percent confidence intervals based on current samples sizes.

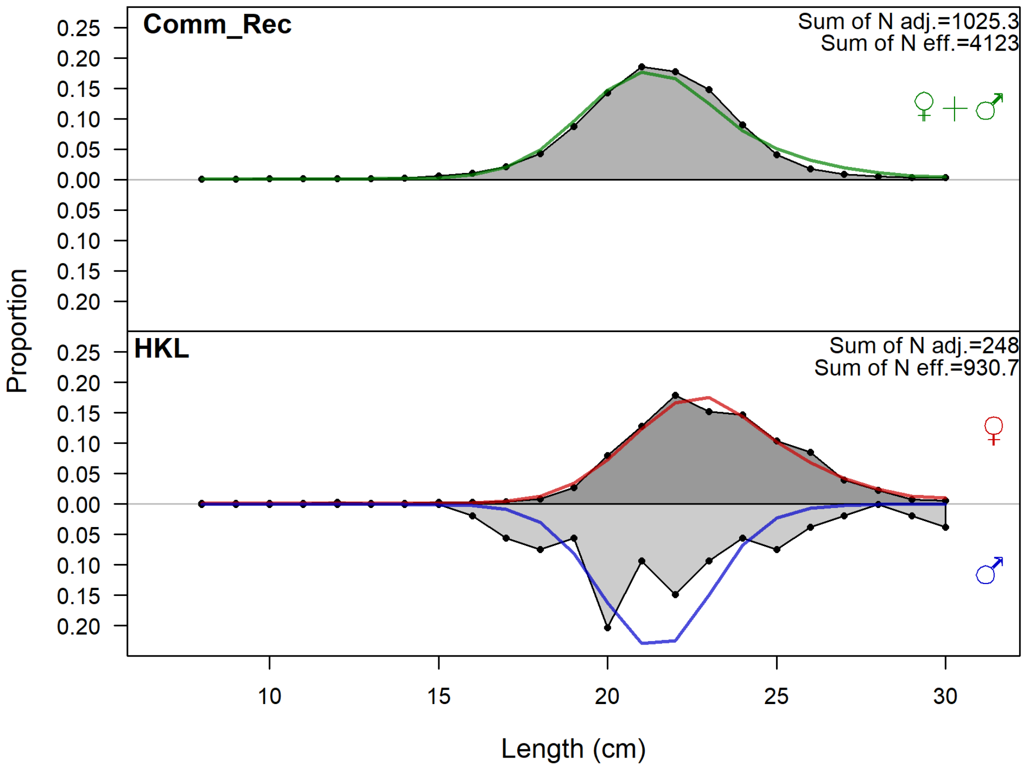

Figure 31: Aggregated length comps over all years.

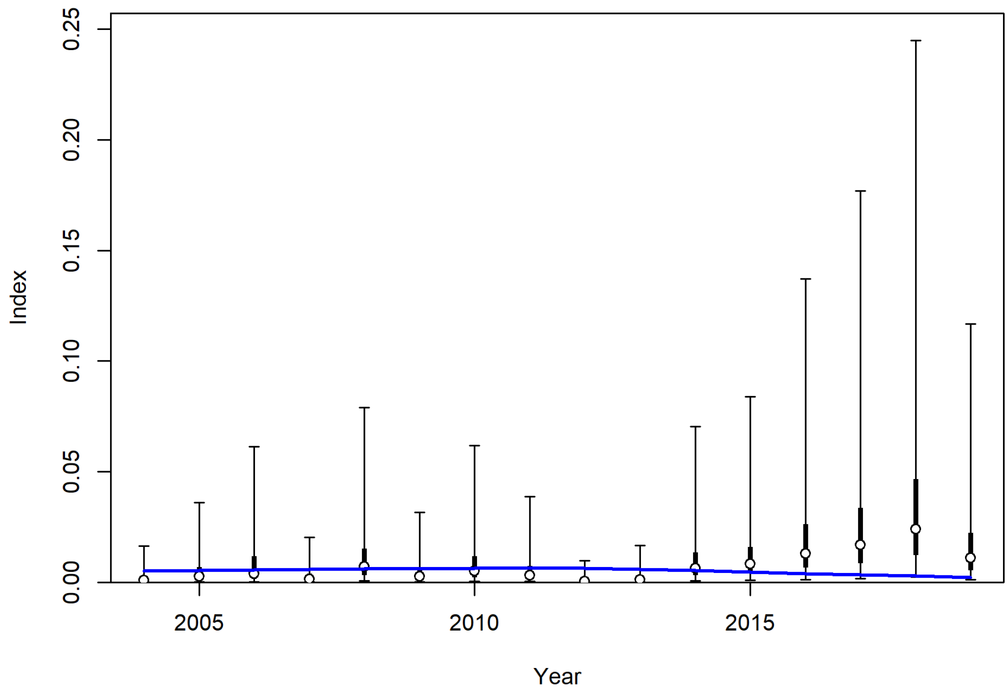

Figure 32: Fit to the NWFSC Hook and Line survey index of abundance.

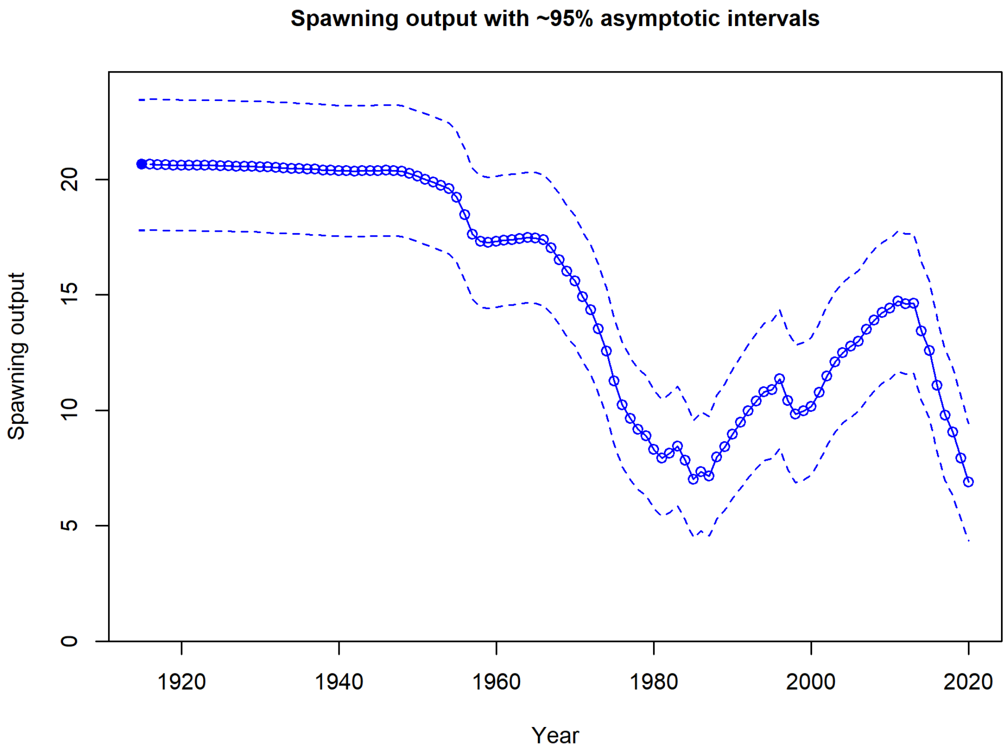

Figure 33: Estimated time series of spawning output.

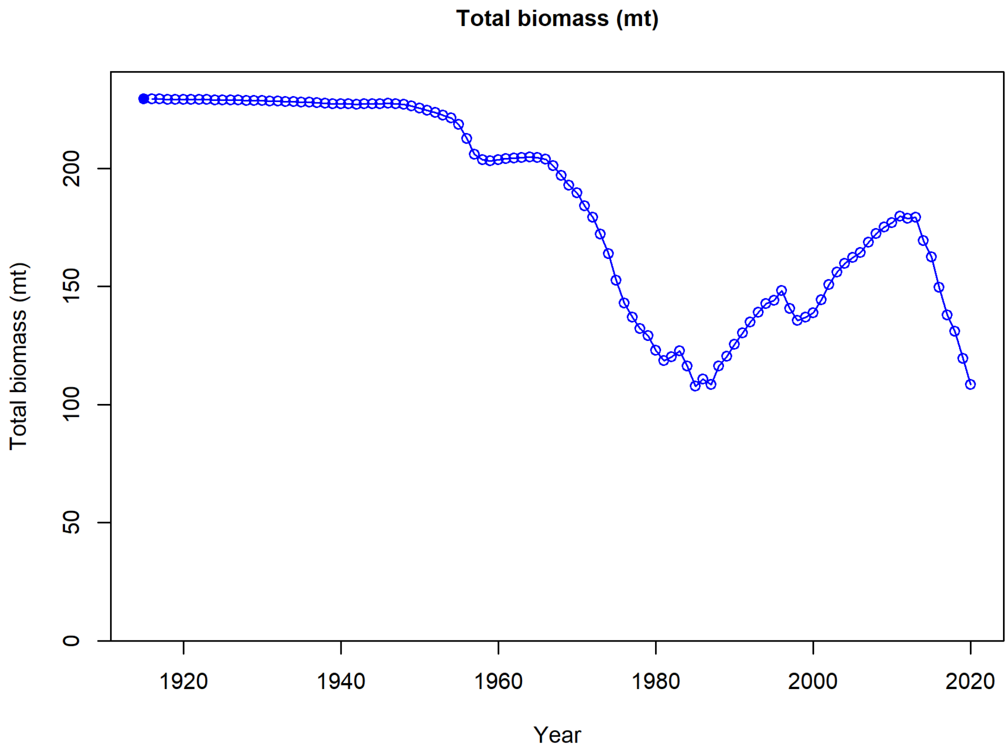

Figure 34: Estimated time series of total biomass.

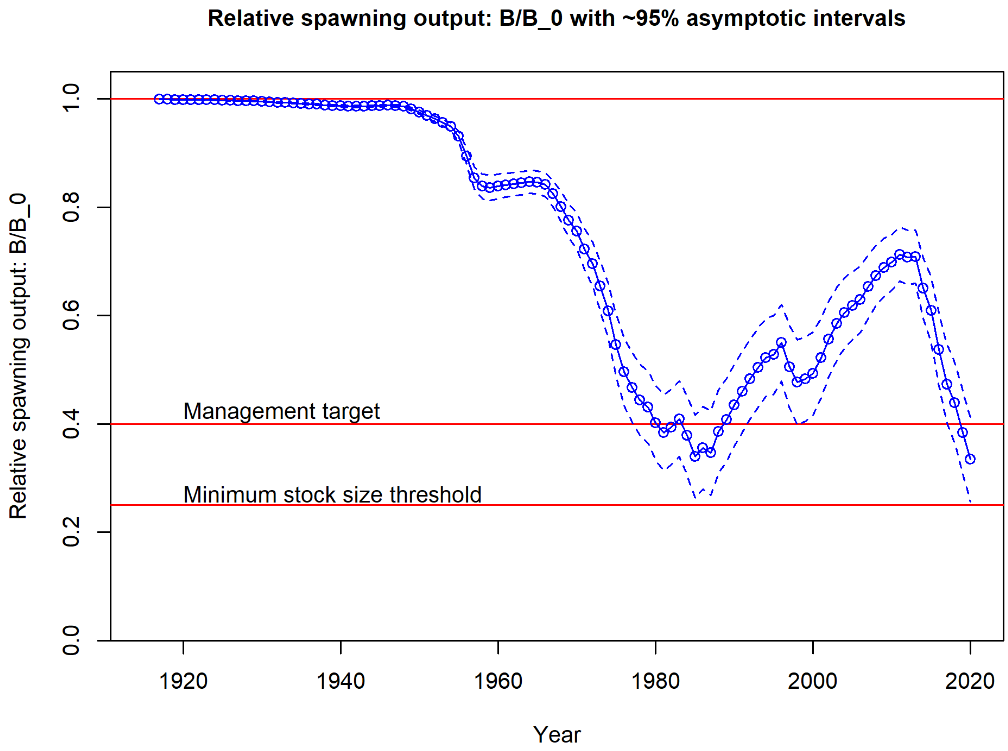

Figure 35: Estimated time series of fraction of unfished spawning output.

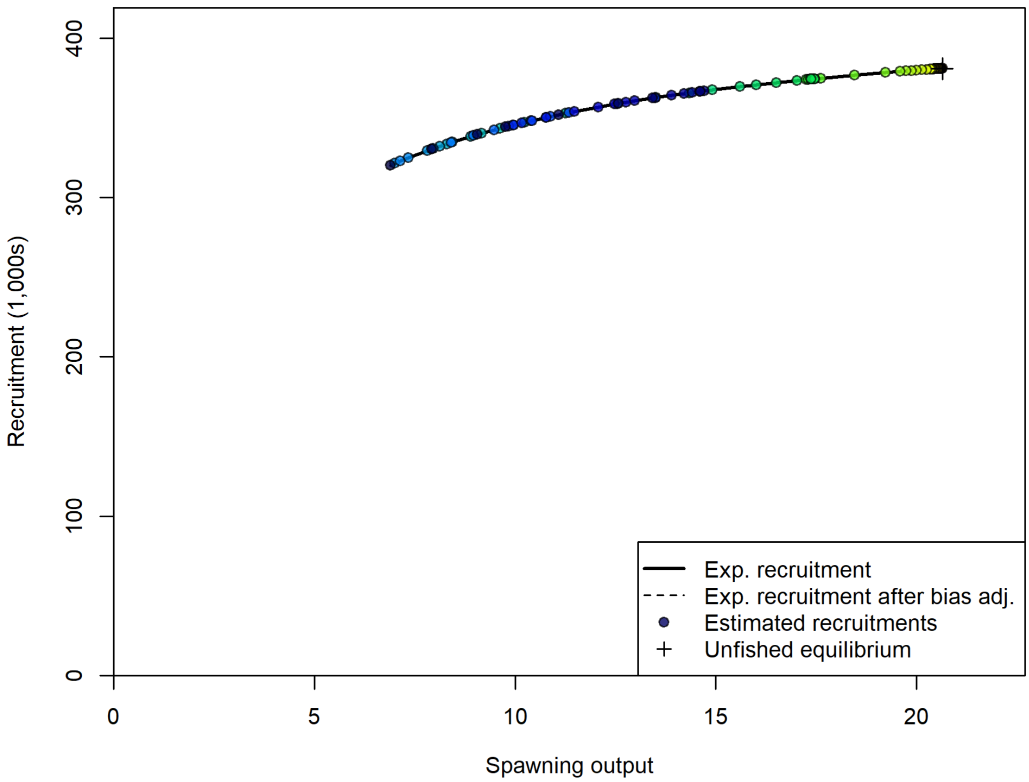

Figure 36: Stock-recruit curve. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

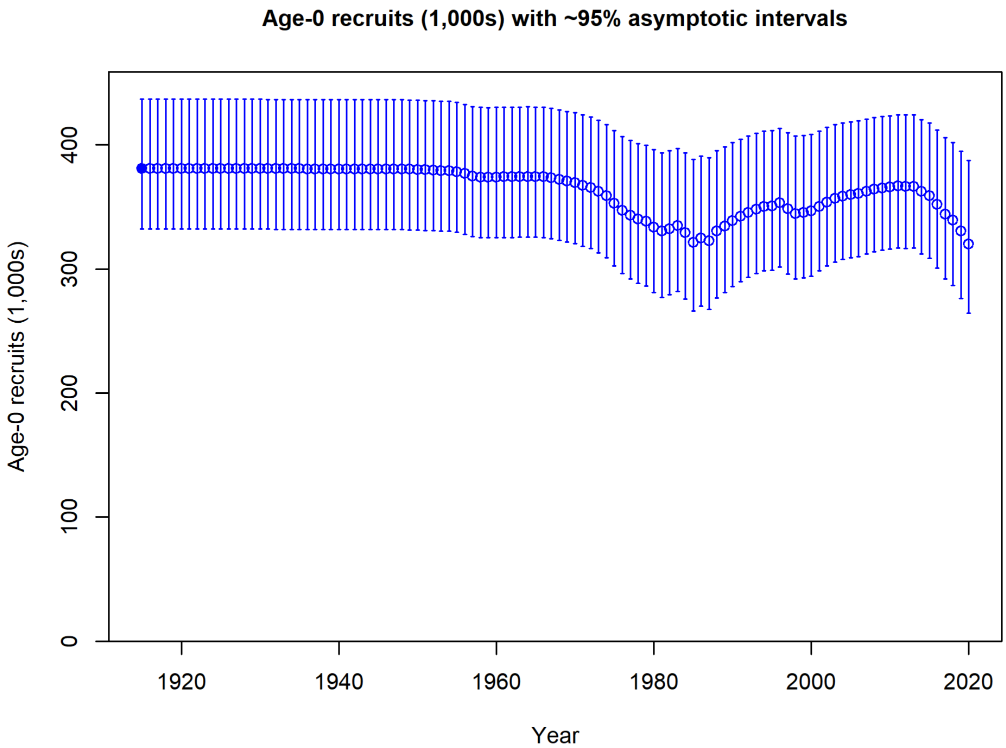

Figure 37: Estimated time series of age-0 recruits (1000s).

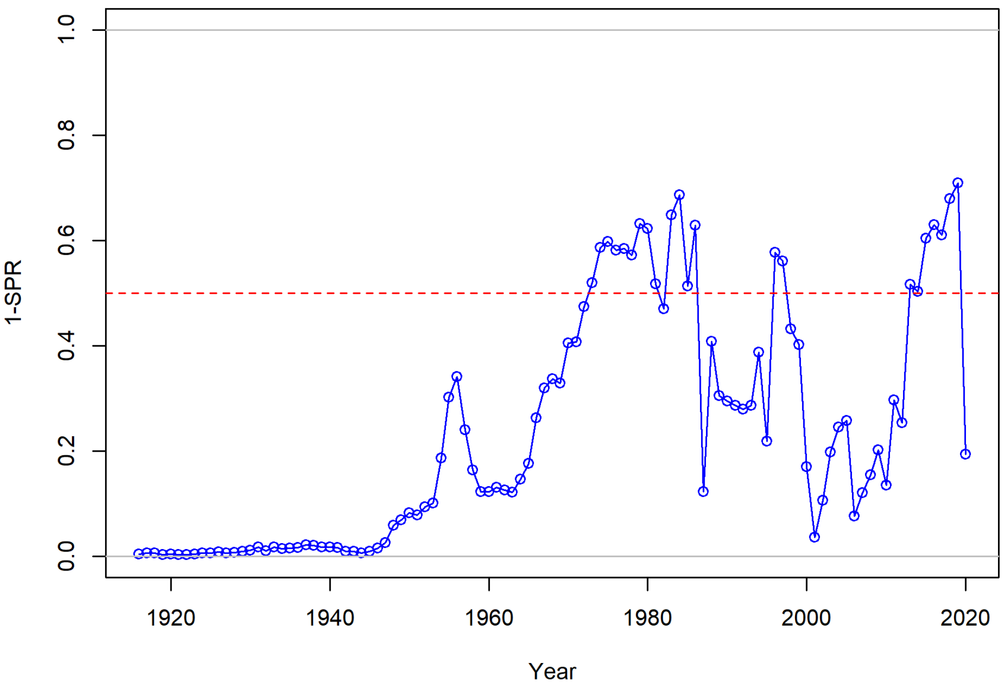

Figure 38: Estimated 1 - relative spawning ratio (SPR) by year.

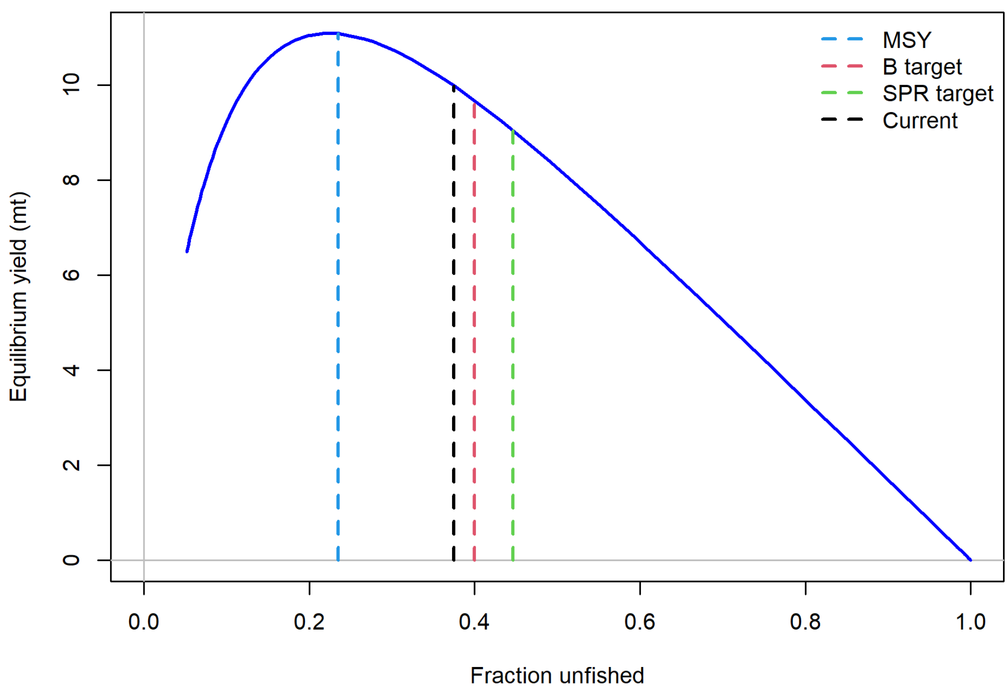

Figure 39: Equilibrium yield curve for the base case model. Values are based on the 2020 fishery selectivity and with steepness fixed at 0.72.

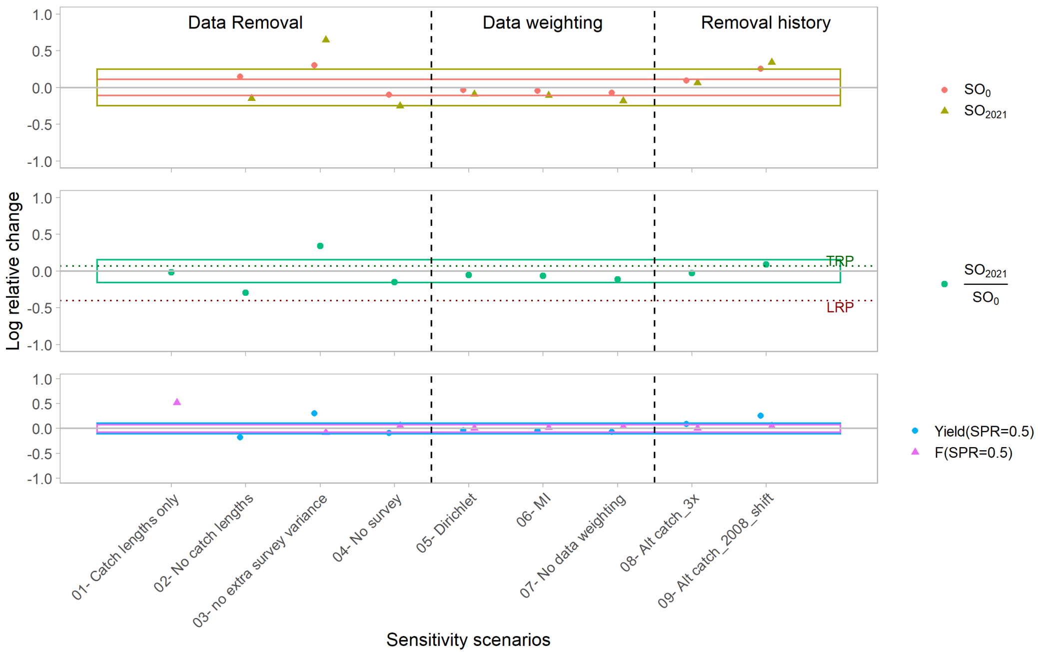

Figure 40: Log relative change (log((Model_sensi-Model_ref)/Model_ref) in data treatment for 5 derived quantities. Colored boxes indicate 95 percent confidence interval of the reference model.

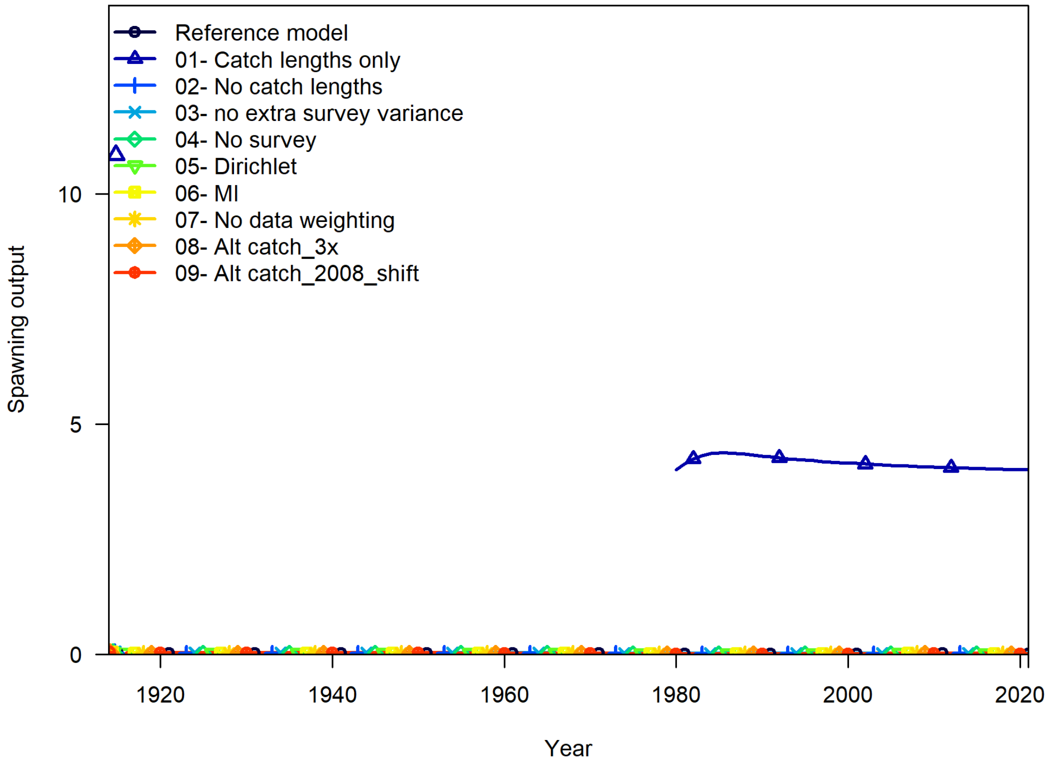

Figure 41: Spawning biomass time series by data treatment compared to the reference model.

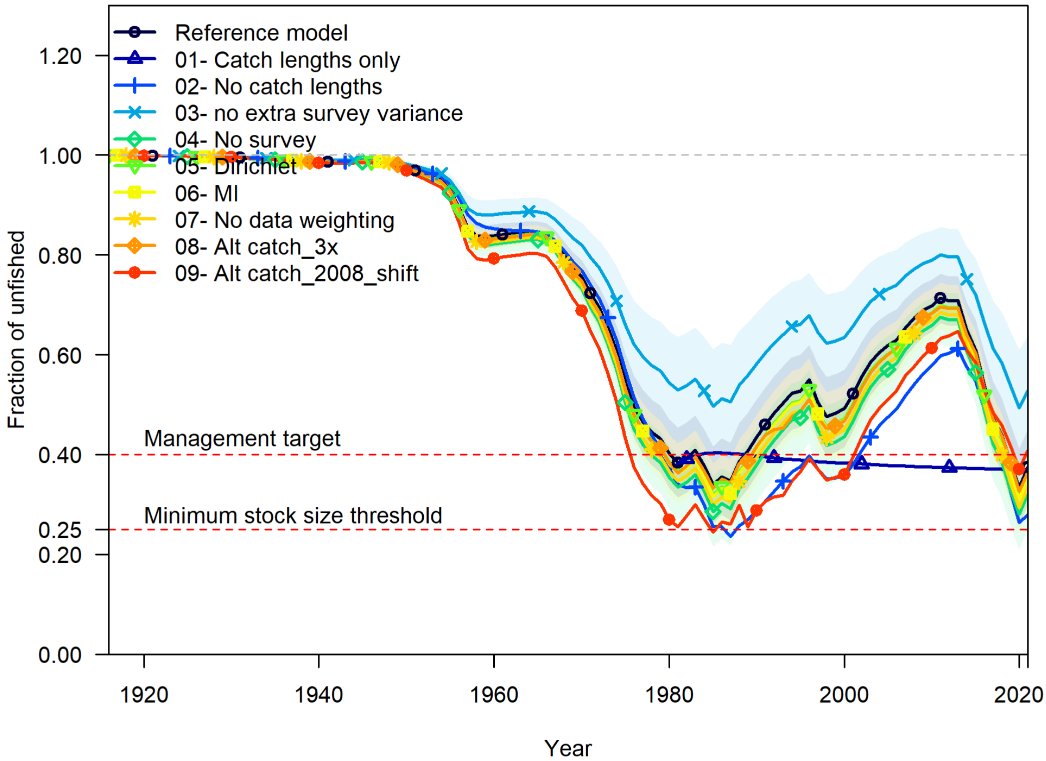

Figure 42: Relative spawning biomass time series by data treatment compared to the reference model.

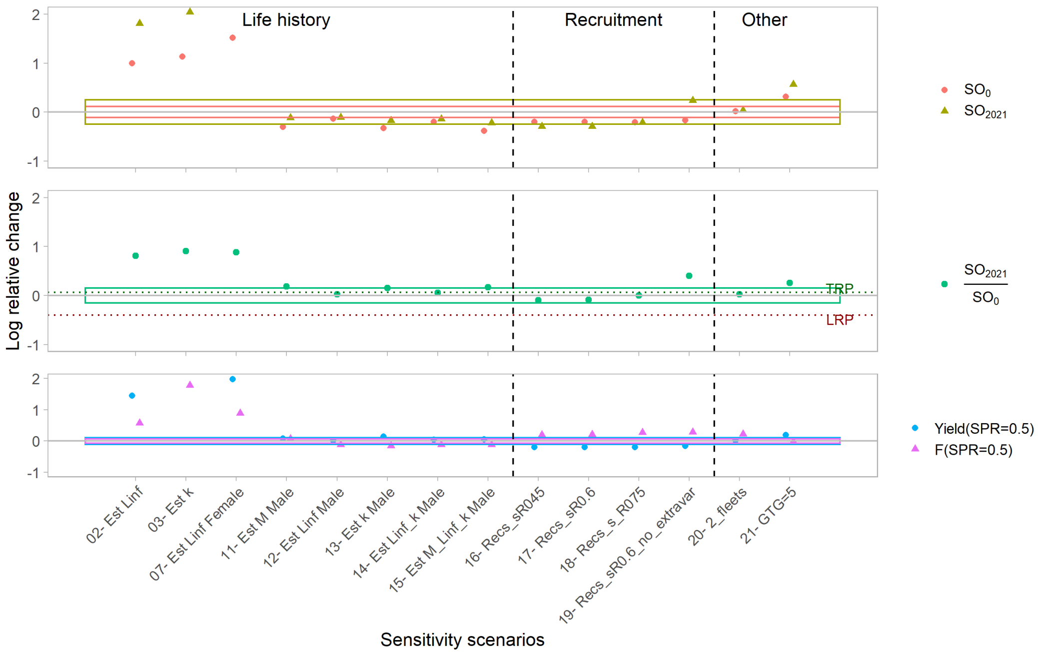

Figure 43: Log relative change (log((Model_sensi-Model_ref)/Model_ref) in data treatment for 5 derived quantities. Colored boxes indicate 95 percent confidence interval of the reference model.

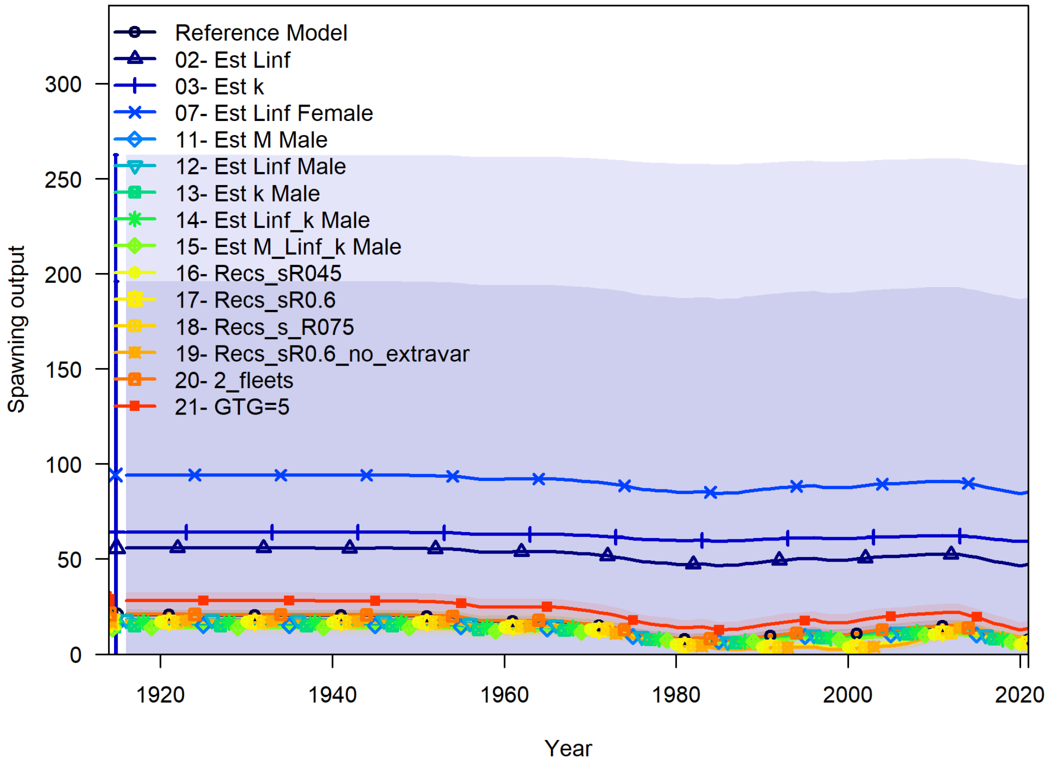

Figure 44: Spawning biomass time series by data treatment compared to the reference model.

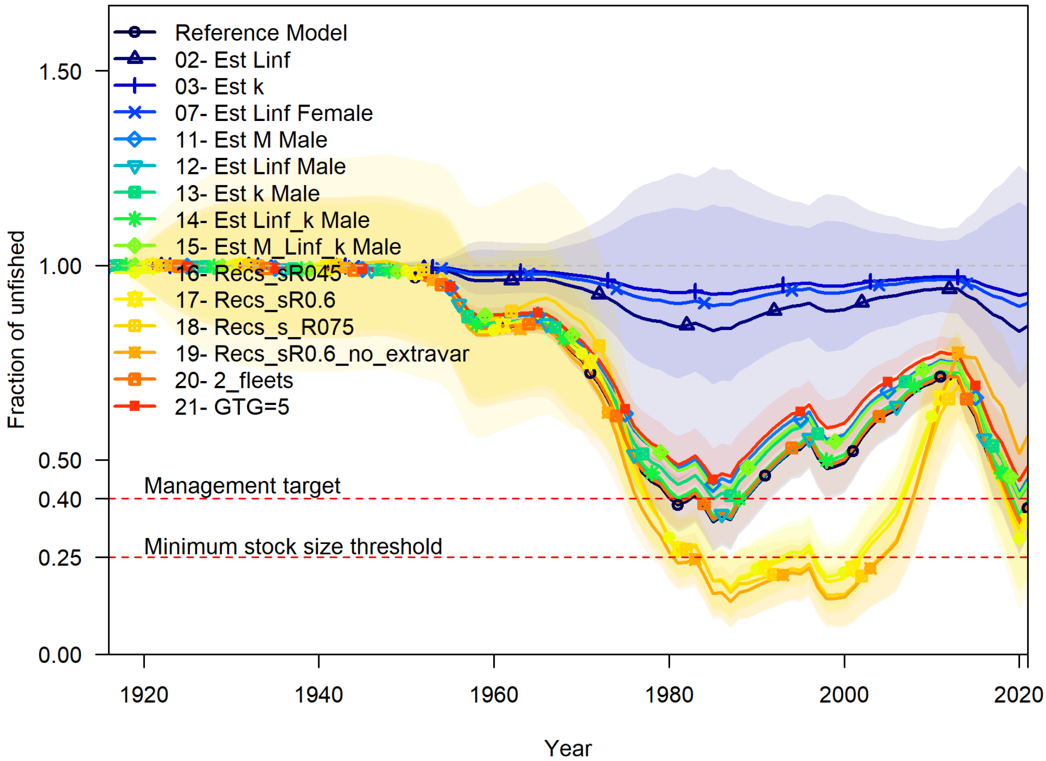

Figure 45: Relative spawning biomass time series by data treatment compared to the reference model.

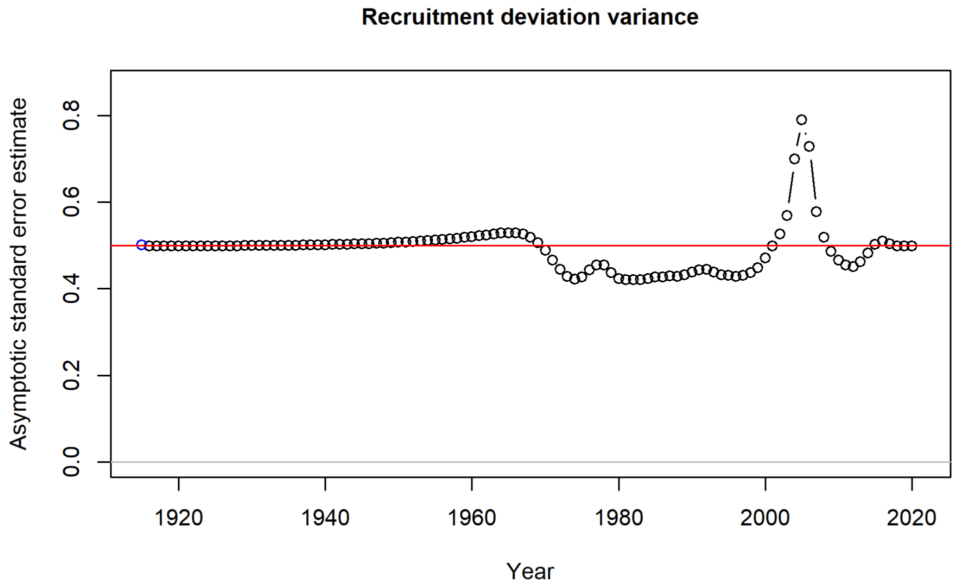

Figure 46: Asymptotic error in recruitment deviations when recruitment is estimated for all years. A drop in the asymptotic error (i.e., value approaches zero) is expected when data inform recruitment.

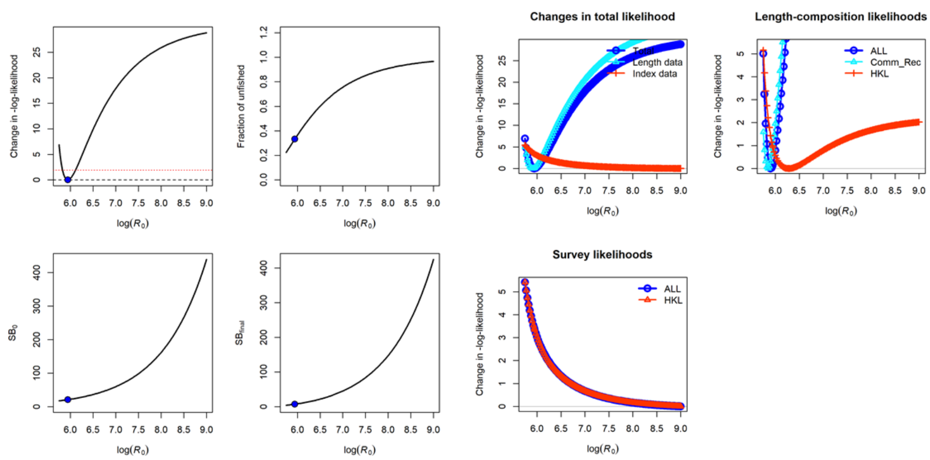

Figure 47: $Log(R0)$ likelihood profiles (change in the negative log-likelihood across a range of $log(R0)$ values) and derived quantities (left four figures) and likelihood component contributions (right three figures). Red line in the top left most figure indicates the significance level in likelihood difference.

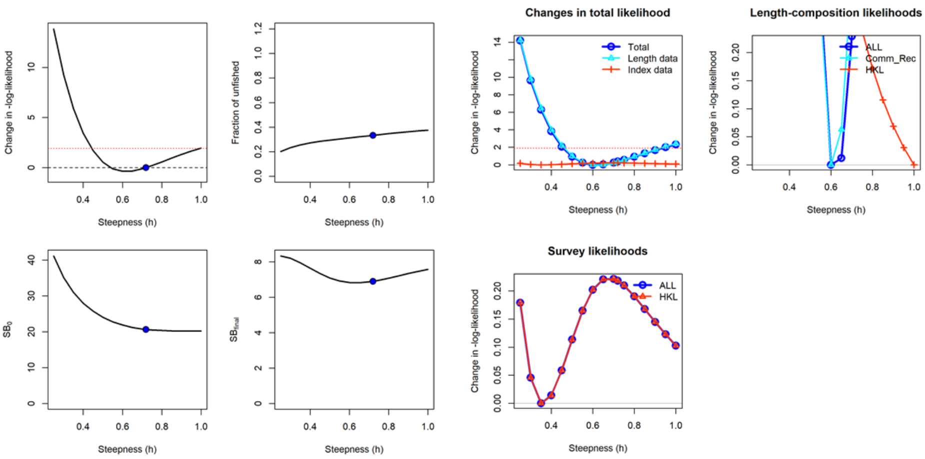

Figure 48: Steepness likelihood profiles (change in the negative log-likelihood across a range of steepness values) and derived quantities (left four figures) and likelihood component contributions (right three figures).

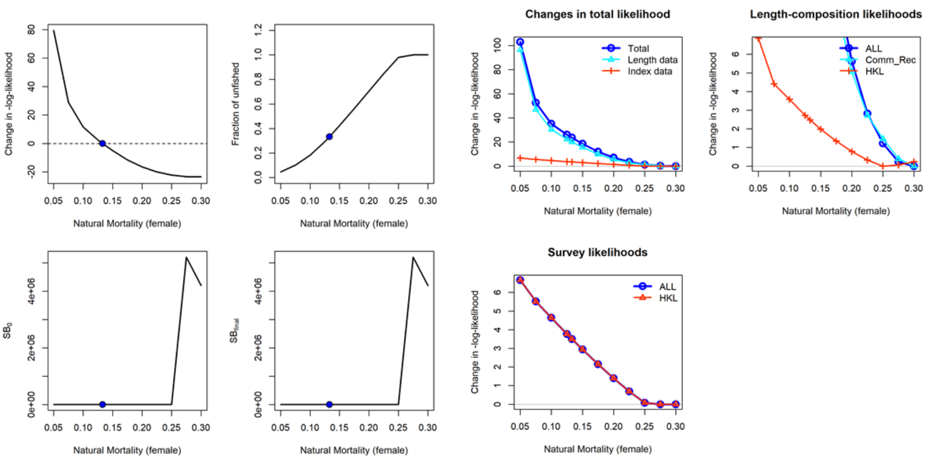

Figure 49: Female M likelihood profiles (change in the negative log-likelihood across a range of M values) and derived quantities (left four figures) and likelihood component contributions (right three figures).

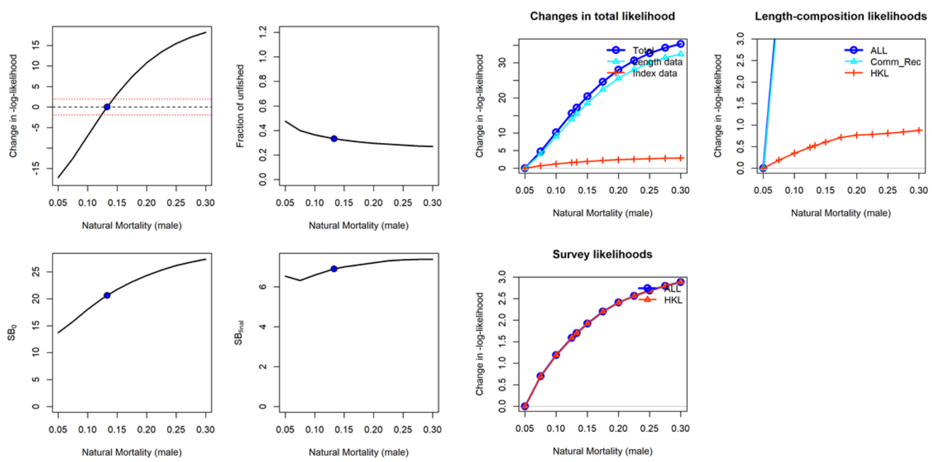

Figure 50: Male M likelihood profiles (change in the negative log-likelihood across a range of M values) and derived quantities (left four figures) and likelihood component contributions (right three figures).

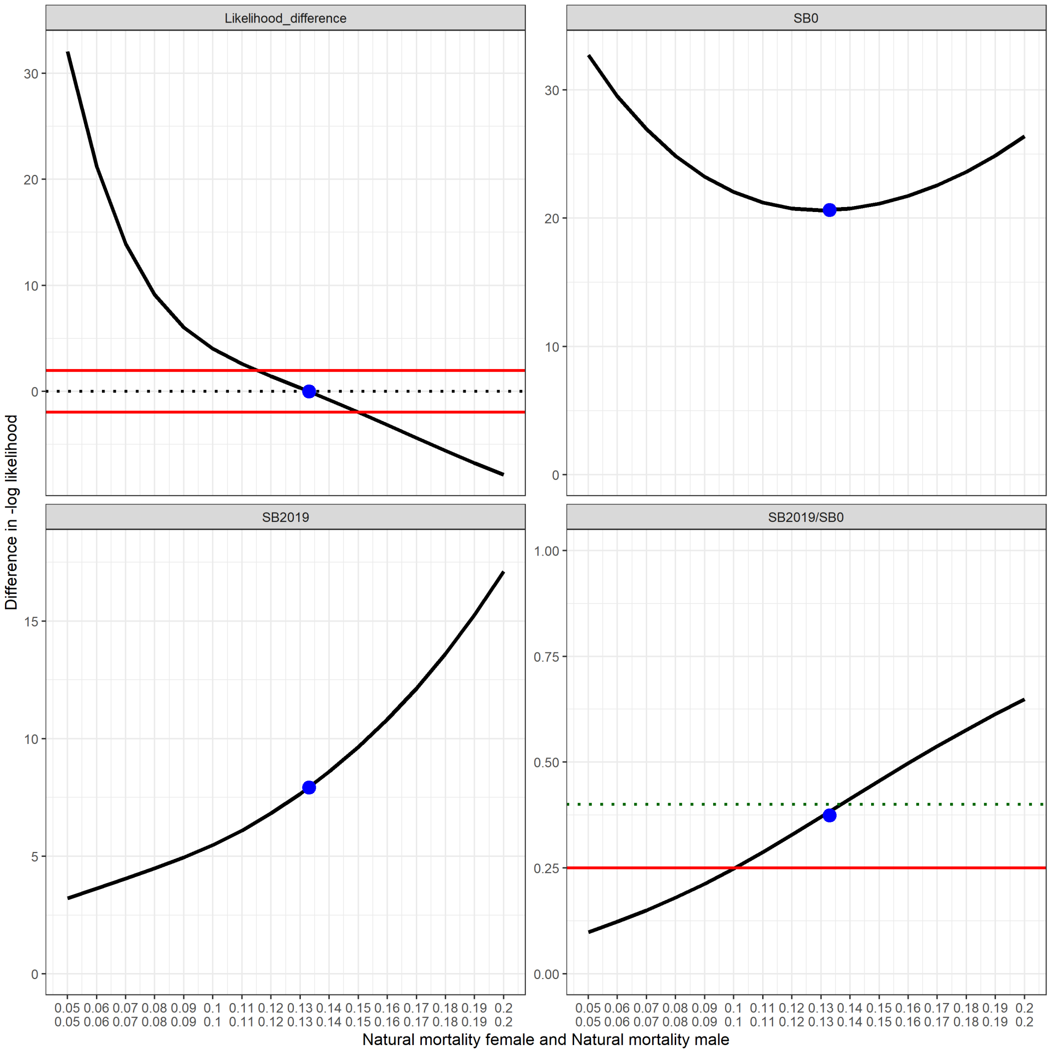

Figure 51: Female and male M multi-parameter likelihood profiles and derived quantities. Red lines in the top left figure indicate significantly similar values compared to the reference model. Broken and solid lines in the bottom right figure indicate target and limit referene points, respectively.

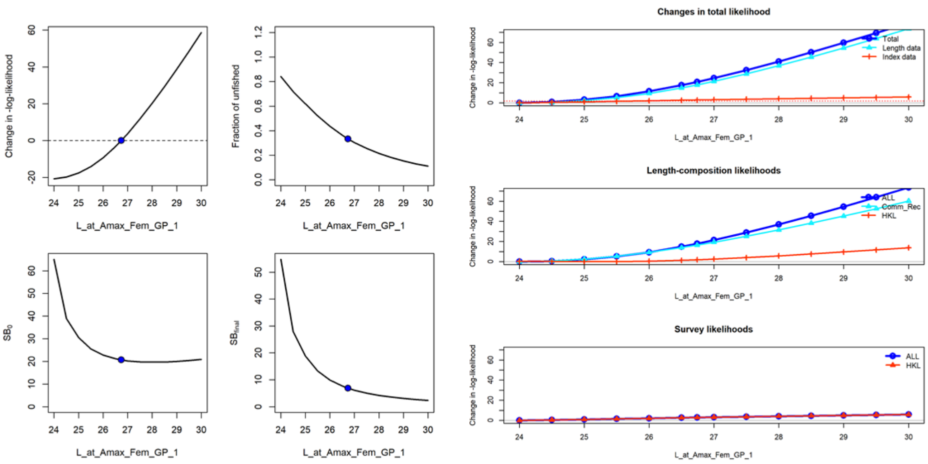

Figure 52: Female $Linf$ likelihood profiles (change in the negative log-likelihood across a range of L_inf values) and derived quantities (left four figures) and likelihood component contributions (right three figures).

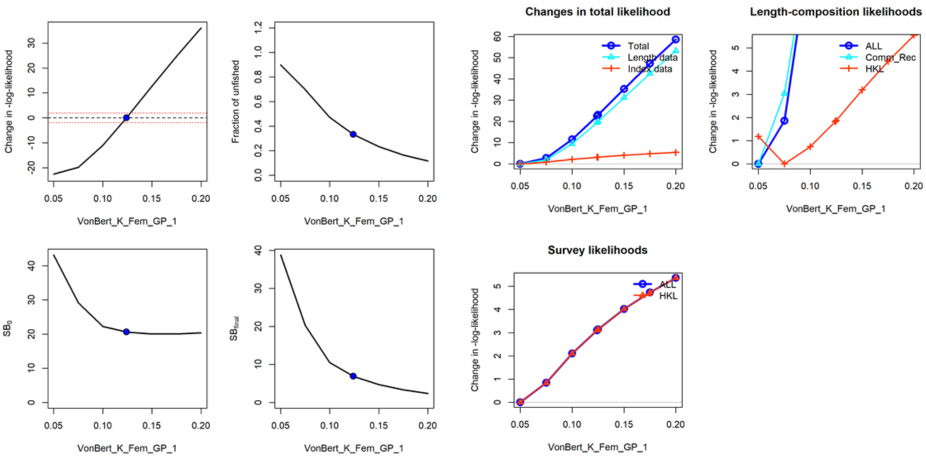

Figure 53: Female k likelihood profiles (change in the negative log-likelihood across a range of k values) and derived quantities (left four figures) and likelihood component contributions (right three figures).

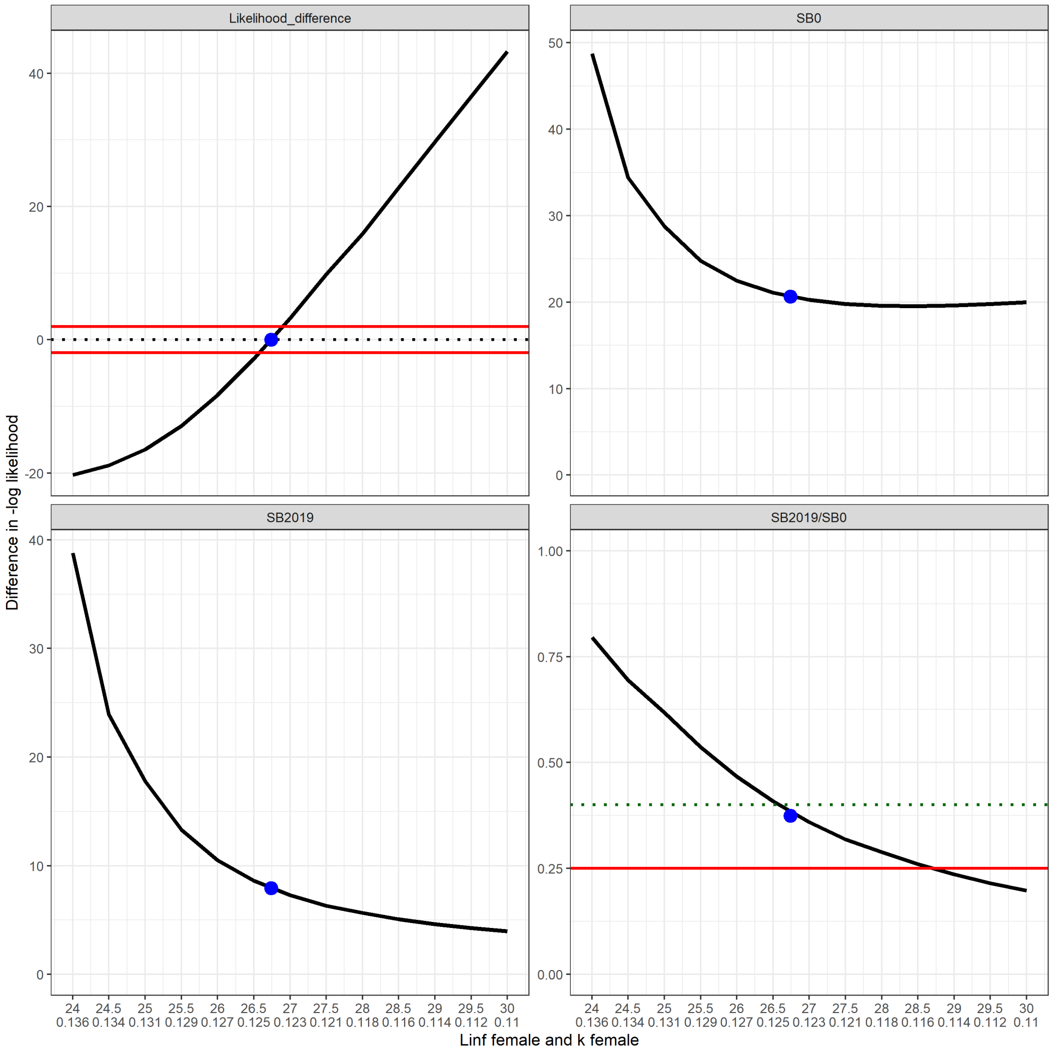

Figure 54: Female *Linf* and *k* multi-parameter likelihood profiles and derived quantities. Red lines in the top left figure indicate significantly similar values compared to the reference model. Broken and solid lines in the bottom right figure indicate target and limit referene points, respectively.

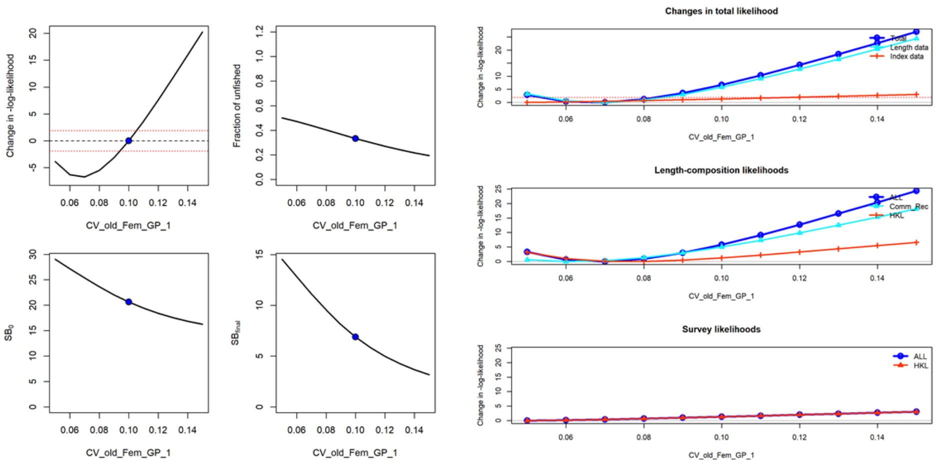

Figure 55: Female variability at maximum age likelihood profiles (change in the negative log-likelihood across a range of CV at maximum age values) and derived quantities (left four figures) and likelihood component contributions (right three figures).

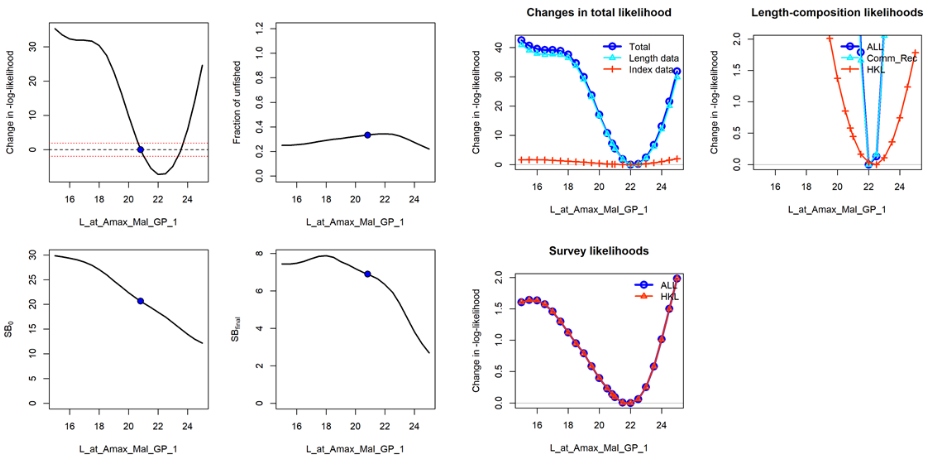

Figure 56: Male *Linf* likelihood profiles (change in the negative log-likelihood across a range of L_inf values) and derived quantities (left four figures) and likelihood component contributions (right three figures).

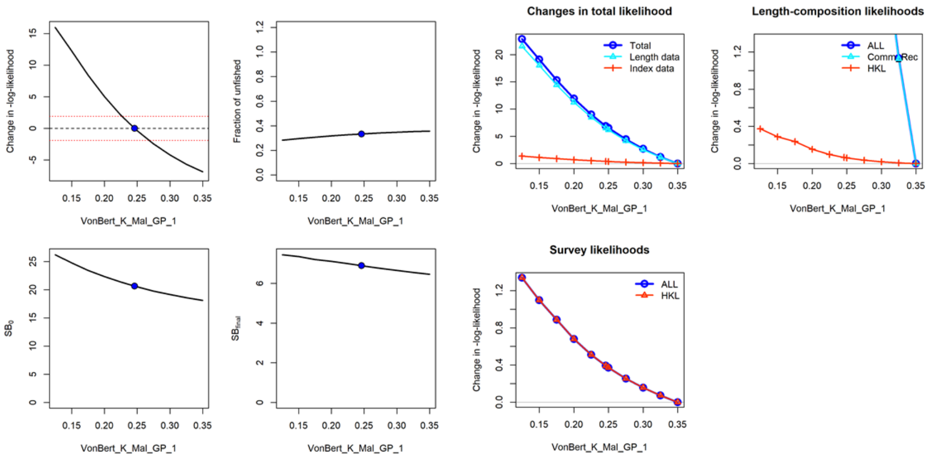

Figure 57: Male k likelihood profiles (change in the negative log-likelihood across a range of k values) and derived quantities (left four figures) and likelihood component contributions (right three figures).

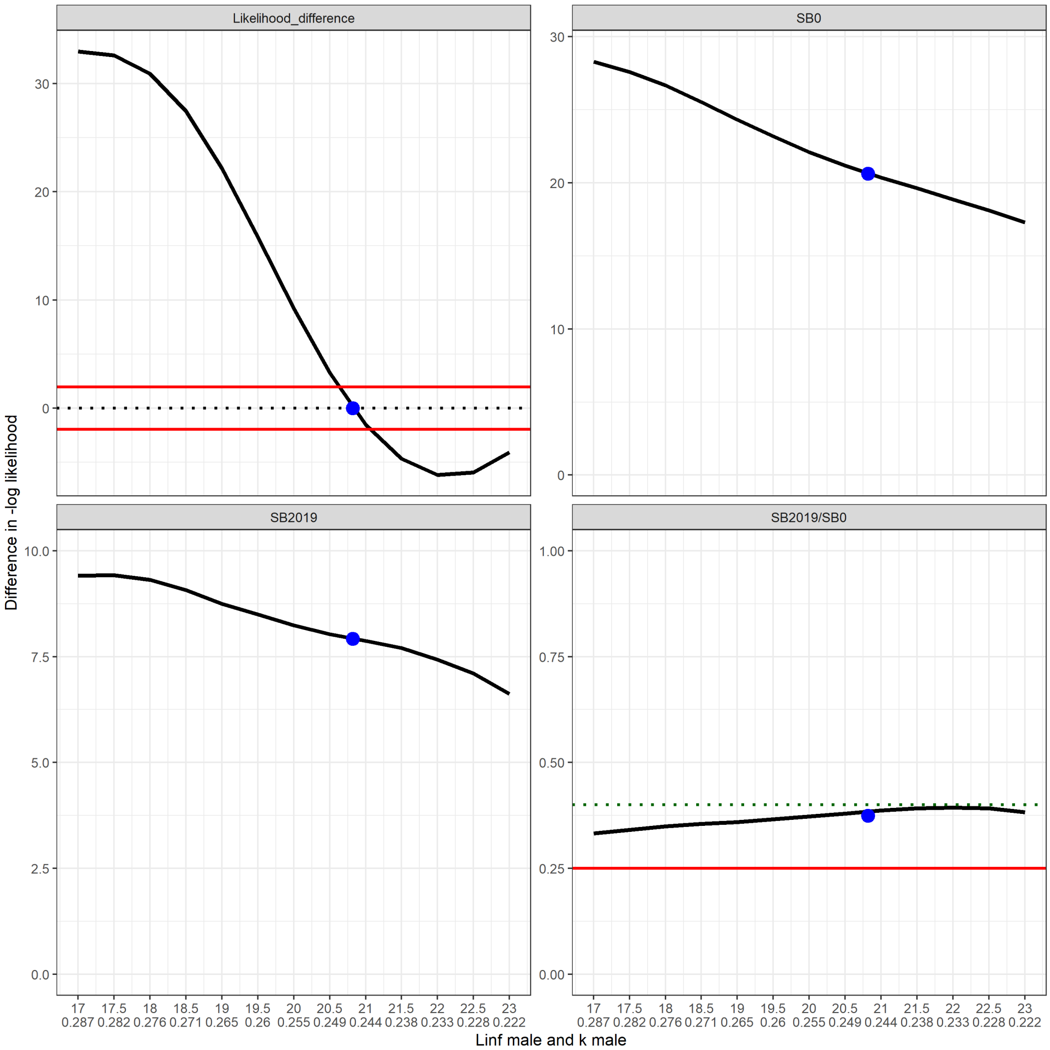

Figure 58: Male L_inf and k multi-parameter likelihood profiles and derived quantities. Red lines in the top left figure indicate significantly similar values compared to the reference model. Broken and solid lines in the bottom right figure indicate target and limit referene points, respectively.

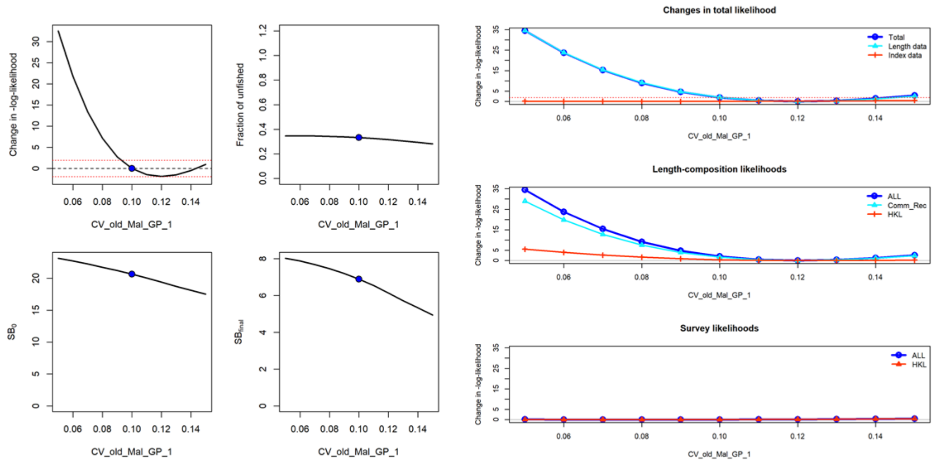

Figure 59: Male variability at maximum age likelihood profiles (change in the negative log-likelihood across a range of CV at maximum age values) and derived quantities (left four figures) and likelihood component contributions (right three figures).

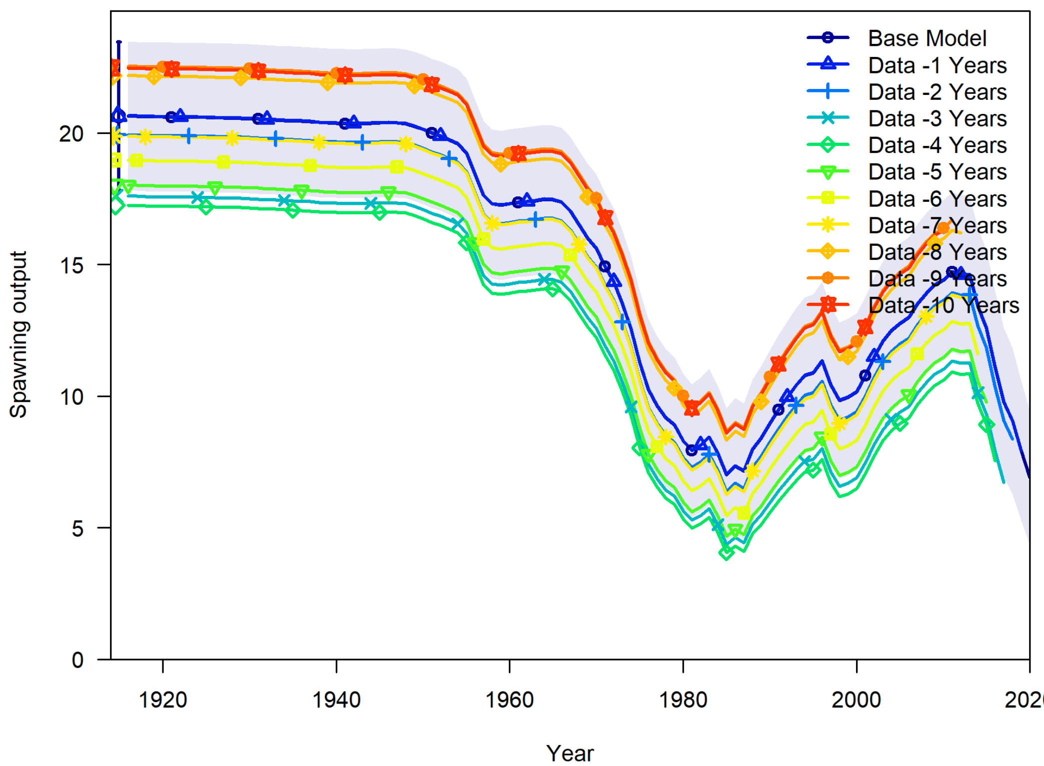

Figure 60: Change in the estimate of spawning output when the most recent 10 years of data area removed sequentially.

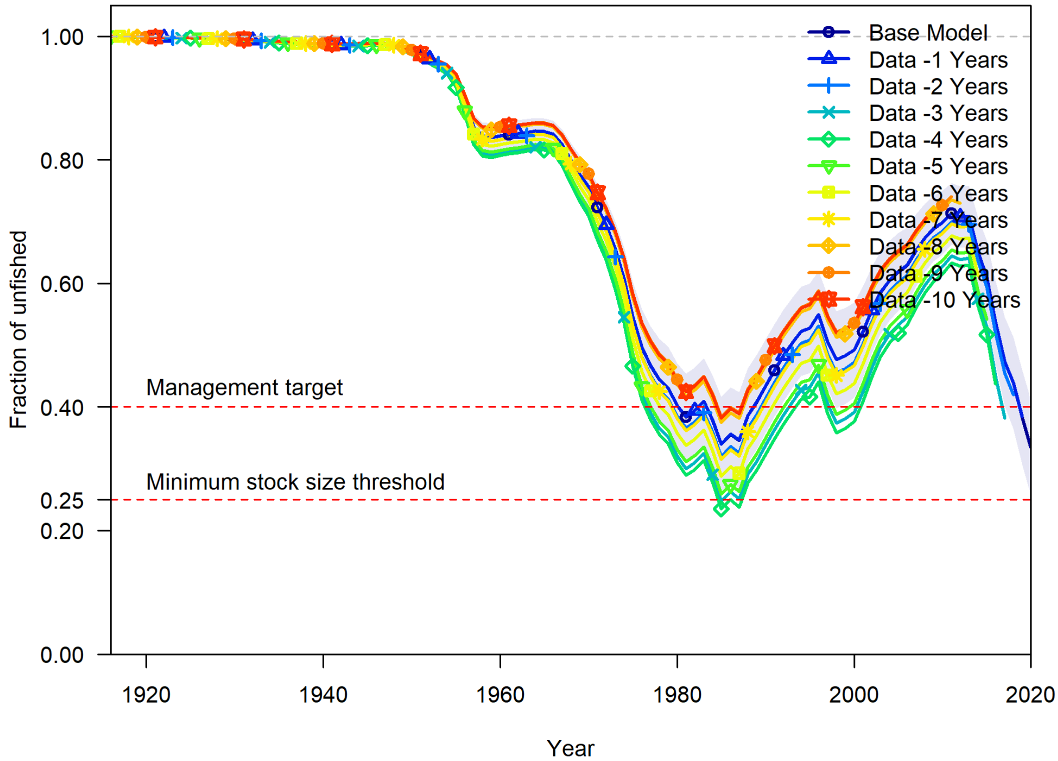

Figure 61: Change in the estimate of fraction unfished when the most recent 10 years of data area removed sequentially.

9 Appendix A. Summary of California Management Measures

Appendix A can be found in the separate file “California Nearshore Regulation History.pdf.”

10 Appendix B. Detailed Fit to Length Composition Data

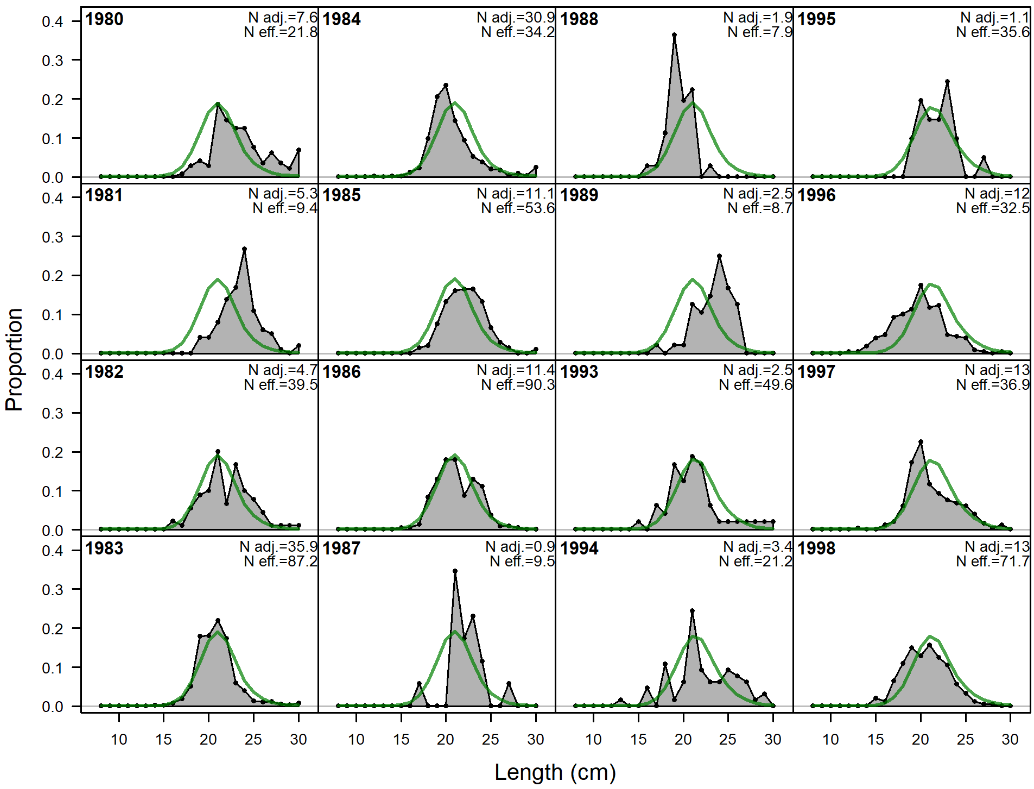

Figure 62: Length comps, whole catch, Comm_Rec (plot 1 of 3).‘N adj.’ is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Iannelli tuning method..

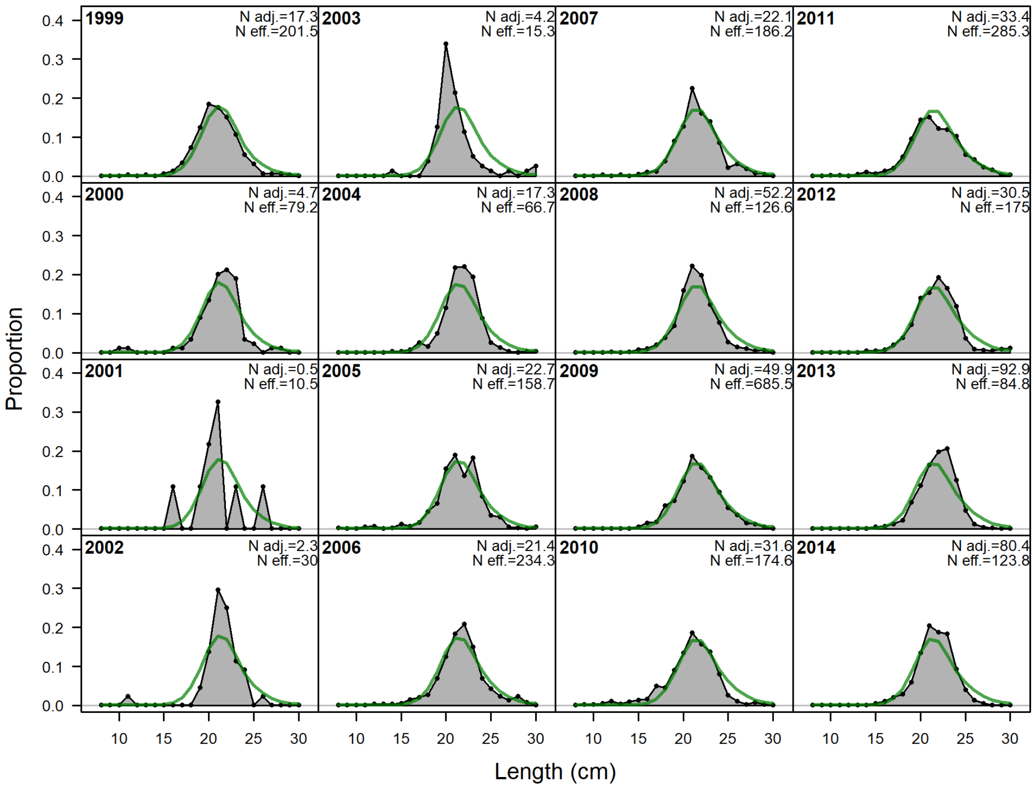

Figure 63: Length comps, whole catch, Comm_Rec (plot 2 of 3).

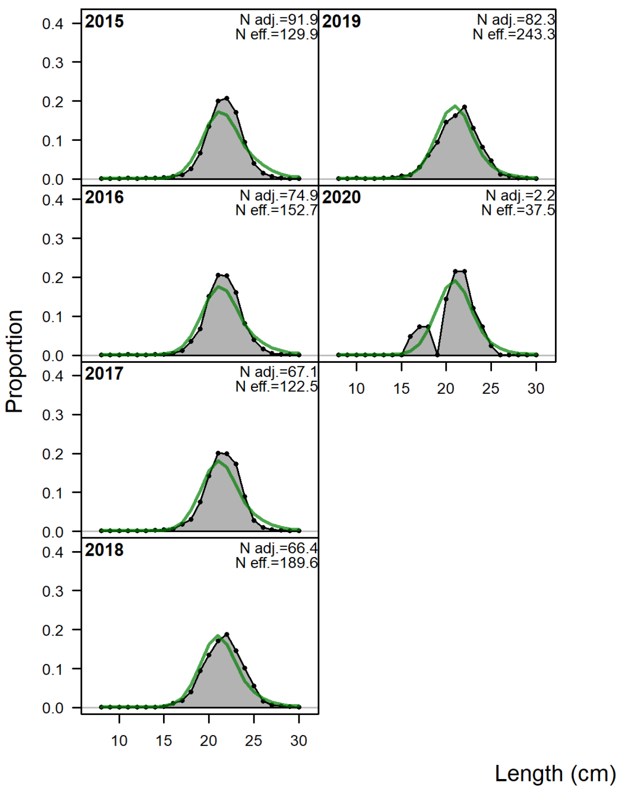

Figure 64: Length comps, whole catch, Comm_Rec (plot 3 of 3).

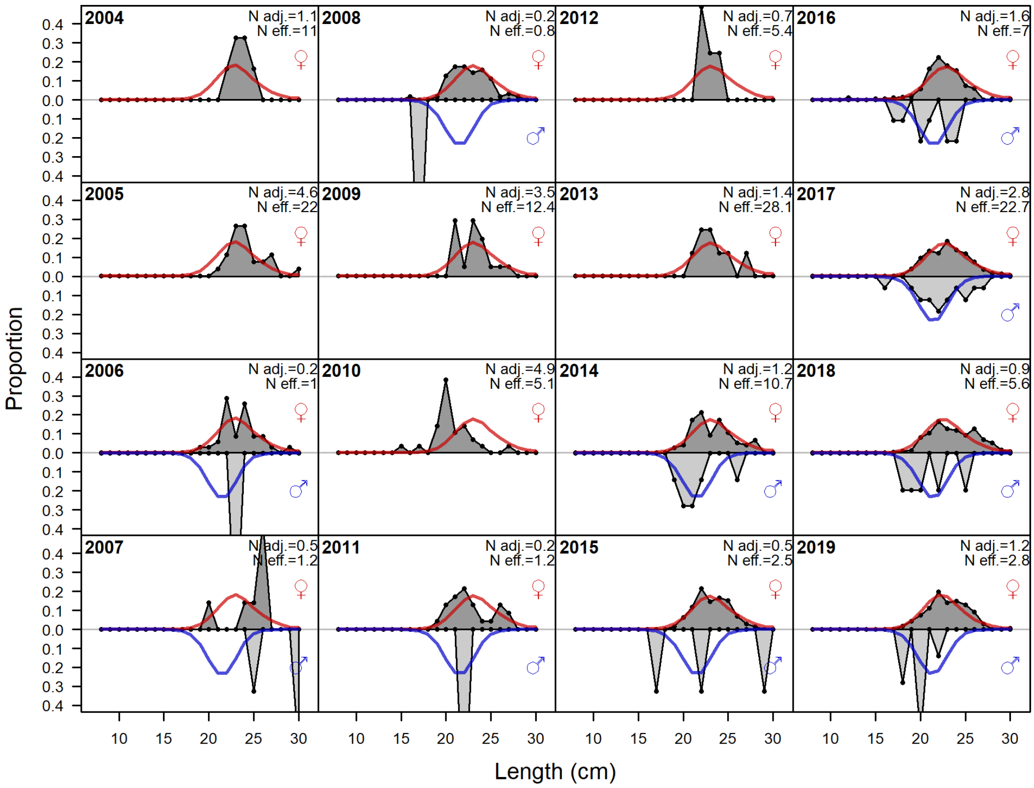

Figure 65: Length comps, whole catch, HKL.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Iannelli tuning method..