

Status of quillback rockfish (*Sebastes maliger*) in U.S. waters off
the coast of Oregon in 2021 using catch and length data

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1 Introduction

1.1 Basic Information

This assessment reports the status of quillback rockfish (*Sebastes maliger*) off the Oregon coast using data through 2020.

The stock off the Oregon coast was assessed as a separate stock from other populations off the U.S. West Coast based on the fairly sedentary nature of quillback rockfish (Hannah and Rankin 2011; Tolimieri et al. 2009), which likely limits movement of fish between Oregon and California and Oregon and Washington. The substrate of the southern Washington coast is typically sandy bottom, a poor substrate for quillback rockfish, which creates a natural separation between the Oregon and Washington populations. Additionally, the exploitation history and magnitude of removals off the Oregon coast differ from those in Washington and California.

1.2 Life History

Quillback rockfish are a medium- to large-sized nearshore rockfish found from southern California to the Gulf of Alaska (Love et al. 2002). Off the U.S. West Coast quillback rockfish are primarily located north of central California, with few observations south of Point Conception. Quillback rockfish have historically been part of both commercial and recreational fisheries throughout their range.

Quillback rockfish are found in waters less than 274 meters in depth in nearshore kelp forests and rocky habitat (Love et al. 2002). The diets of quillback rockfish consist primarily of benthic and pelagic crustaceans and fish (Murie 1995). The body coloring of adult quillback rockfish is brown with yellow to orange blotching and light-colored dorsal saddle patches (Love et al. 2002). As their name suggests, quillback rockfish have long dorsal fin spines.

Limited studies have evaluated genetic variation in quillback rockfish across the U.S. West Coast. Genetic work has revealed significant differences between Puget Sound and coastal stocks of quillback rockfish (Stout et al. 2001; Seeb 1998), however Seeb (1998) did not find significant differentiation in populations of quillback rockfish between coastal Washington and Alaska. Significant population sub-division along the U.S. West Coast has been detected for the closely related, and more well-studied copper rockfish (*Sebastes caurinus*), indicating limited oceanographic exchange among geographically proximate locations (Seeb 1998; Buonaccorsi et al. 2002; Johansson et al. 2008). High site-fidelity (Hannah and Rankin

2011) and relatively small home ranges (Tolimieri et al. 2009) for quillback rockfish suggests patterns of isolation-by-distance as found for other rockfish.

Quillback rockfish are a long-lived rockfish estimated to live up to 95 years (Yamanako and Lacko 2001; Love et al. 2002). Quillback rockfish was determined to have a vulnerability ($V = 2.22$) of major concern in a productivity susceptibility analysis (Cope et al. 2011). This analysis calculated species specific vulnerability scores based on two dimensions: productivity characterized by the life history, and susceptibility characterized by how the stock is likely affected by the fishery in question.

1.3 Historical and Current Fishery Information

Quillback rockfish off the coast of Oregon is caught in both the commercial and recreational fisheries (Table 1 and Figure 1). The reported landings from the commercial fishery extend back to 1892 and, other than a small peak in the late 1930s through the 1940s, were minimal until the late-1960s. Currently, quillback rockfish is one of several rockfish species included in a nearshore, primarily live-fish, fixed-gear fishery centered on Oregon's southern coast. Following the development of the nearshore commercial fishery in the late 1990s, Oregon Department of Fish and Wildlife (ODFW) implemented a state-permitted limited access fishery that regulated fleet size, period landing limits, and established harvest guidelines (Rodomsky et al. 2020). Quillback rockfish is one of 11 species in the Other Nearshore Rockfish category managed under a single state harvest guideline. Within this management category, China, quillback, and copper rockfish are the three primary species landed. Data on landings from the recreational fishery off the coast of Oregon began in 1979 and removals from the recreational fleet have increased across time and now represent the majority of landings for quillback rockfish off the coast of Oregon. Recreational landings were large in the year that data were first available, and were expected to be minimal prior to the 1970s. Consequently a linear ramp in recreational landings was applied from 1970 to 1979.

1.4 Summary of Management History and Performance

Quillback rockfish is managed by the Pacific Fishery Management Council (PFMC) as a part of the Minor Nearshore Rockfish North and Minor Nearshore Rockfish South complexes. The North and South complexes are split at N. 40° 10' Lat. off the U.S. West Coast. Each complex is managed based on a complex-level overfishing limit (OFL) and annual catch limit (ACL) that are determined by summing the species-specific OFL and ACL (ACLs set equal to the Acceptable Biological Catch) contributions for all stocks managed in the complex. Removals for species within each complex are managed and tracked against the complex total OFL and ACL, rather than on a species by species basis.

Quillback rockfish was most recently assessed in 2010 using Depletion-Based Stock Reduction Analysis (DB-SRA) to provide estimates of coastwide OFLs (Dick and MacCall 2010). The coastwide OFL was then apportioned to each management area based on the proportion of historical catches North and South of N. 40° 10' Lat. DB-SRA does not assess overfished status, but rather assumes that current depletion is distributed around the management target (e.g. 40%). The 2010 assessment found there was a 52% chance that quillback rockfish was experiencing overfishing, as recent coastwide catch of quillback rockfish slightly exceeded the median coastwide OFL estimate at the time.

The current OFL contribution and implied ACL contribution for quillback rockfish North of 40° 10' Lat. N., the state specific ACL allocation (58.4% for Oregon; Groundfish Management Team, pers. comm.), and the total removals are shown in Table 2.

2 Data

The following types and sources of data were used in this assessment. Fishery catch and composition data were specific to Oregon, however biological data were estimated coastwide and included Washington, Oregon, and California sources.

1. Commercial landings, and length, weight, and age data obtained from PacFIN and the ODFW. Age compositions were not fit directly in the model, but age and weight data were used to estimate biological parameters which were fixed inputs to the model.
2. Estimates of commercial discard length frequencies and fraction discarded in the fishery obtained from the West Coast Groundfish Observer Program (WCGOP).
3. Recreational landings, discards, and length, weight, and age data obtained from RecFIN and the ODFW. Age compositions were not fit directly in the model, but age and weight data were used to estimate biological parameters which were fixed inputs to the model.
4. Fishery independent biological data (length, weight, and age) from the Northwest Fisheries Science Center (NWFS) West Coast Groundfish Bottom Trawl Survey (WCGTBS). These data were used to estimate biological parameters which were fixed inputs to the model.
5. Estimates of fecundity, maturity, and natural mortality from various sources.

A description of each data type is provided below, with timing of catch and composition data used in the base model shown in Figure 2.

2.1 Fishery-Dependent Data

2.1.1 Commercial Fishery

2.1.1.1 Landings

Historical commercial landings from 1892 to 1986 were provided by ODFW (Karnowski et al. 2014). Historical landings were consistent but minimal (< 1 mt in all years except 1943) until the mid-1960s, at which point landings increased to a high of 3.5 mt in 1978. Primary gear types during this historical period included longline and troll gears. However, ODFW commercial samplers suggest that these troll landings were primarily landed on hook and line gear, but not separated by gear type on the fish tickets (pers. comm. M. Freeman, ODFW).

Landings from 1987 – 1999 were compiled from a combination of PacFIN, which is the central repository for West coast commercial landings (extracted on 10/13/2020), and a separate ODFW reconstruction that delineated species-specific landings in the unspecified categories on PacFIN (e.g. URCK and POP1, ODFW 2017). Quillback rockfish landings from this reconstruction were substituted for the URCK and POP1 landings available from PacFIN, and added to PacFIN landings from other categories for a complete time series during this time period. Commercial landings from 2000 – 2020 are available on PacFIN (extracted on 10/13/2020 and 02/18/2021). Quillback rockfish is one of several rockfish species targeted by a nearshore, primarily live-fish fixed-gear fishery centered on Oregon’s southern coast. Quillback rockfish have been landed primarily with hook and line gear, though a substantial portion have been landed with bottom longline gear as well. Overall, 94.2% of quillback rockfish landings are from these two gear types (2000 – 2020). In the most recent years, longline landings have eclipsed hook and line landings. Landings from other gear types, including fish pot and trawl, are sporadic and minimal relative to hook and line and longline gears. Commercial landings for quillback rockfish increased from the mid-1960s to 1974 and have since fluctuated between approximately 0.4 and 4.5 mt annually. From 2003 to 2020, landings have averaged 1.6 mt annually, and represent approximately one third of the total removals. Commercial landings were aggregated across gear types into a single fleet for the base model. Length compositions aggregated across years for each of the two main commercial gears were similar, indicating the choice to combine across gears would not mask differences in selectivity.

The input catches in the model represent total removals: landings plus discards (Table 1 and Figure 1). Discards totals for the commercial fleet from 2002-2019 were determined based on WCGOP data provided in the Groundfish Expanded Mortality Multiyear (GEMM) product. The total coastwide observed discards in trawl and fixed gears were allocated by state and area based on the total observed landings observed by WCGOP. Discards were added to landings to obtain total removals for 2002-2019. Total removals from 1990 - 2002, and for

2020 where no WCGOP data were yet available, were calculated using the average discard rates of only fixed gears from WCGOP in 2002-2018 for Oregon (5.7 percent). The discard rate for fixed gears was used instead of the discard rate for all gears because trawl catches were lower before the 2000s than after the 2000s, and therefore using a fixed gear discard rate for historical discards better reflected the gear in use at the time. No discarding was assumed prior to 1990.

2.1.1.2 Length Compositions

Commercial quillback rockfish length samples are available from PacFIN from 1998 – 2020 (Table 3, extracted 2/23/2021). Approximately 44.3% of these samples are females ($n = 1,361$) and 54.2% are males ($n = 1,664$). There were 46 unsexed fish. The majority of length samples (77.2%) are from the southern Oregon coast, centered in Port Orford (65.3%) and Gold Beach (11.9%), where the majority of permit holders for the commercial nearshore fishery are based and where most of the landings are made. The majority of length samples are from quillback rockfish landed live (57.4%). Additionally, special projects length samples collected from the commercial fishery are available from PacFIN from 1999 – 2001, 2003 – 2006, 2008, 2010, 2012, 2015, and 2017 – 2019 ($n = 210$; extracted on 12/11/2020), but were not used due to concerns over non-random sampling.

The distribution of lengths in the commercial data ranged between 21 - 54 cm (the maximum length data bin size, Figure 3). The mean size observed by the commercial fishery was relatively variable from year to year with the mean length occurring between 35 - 41 cm for all but the first two years, which had particularly low sample sizes, and where mean length was 27 and 29 cm (Figure 4). The length observations in 1998 were not fit in the base model due to very low (four) annual sample size, and so mean length in 1998 is not shown in Figure 4. Length observations for 1998 were used in the model as a ‘ghost’ fleet, not fit by the model but implied fits reflected in diagnostic output Appendix.

The input sample sizes for the commercial length data were calculated via the Stewart method (Ian Stewart, personal communication) which incorporate the number of trips and fish by year:

$$\begin{aligned} \text{Input effN} &= N_{\text{trips}} + 0.138 * N_{\text{fish}} \text{ if } N_{\text{fish}}/N_{\text{trips}} \text{ is } < 44 \\ \text{Input effN} &= 7.06 * N_{\text{trips}} \text{ if } N_{\text{fish}}/N_{\text{trips}} \text{ is } \geq 44 \end{aligned}$$

2.1.2 Recreational Fishery

2.1.2.1 Landings

Historic Ocean Boat Landings (1979 – 2000)

Recently, the ODFW undertook an effort to comprehensively reconstruct all marine fish recreational ocean boat landings prior to 2001 (A. Whitman, ODFW, pers. comm.). Reconstructed catch estimates from the Oregon Recreational Boat Survey (ORBS) improve upon estimates from the federal Marine Recreational Fisheries Statistical Survey (MRFSS), which have known biases related to effort estimation and sampling (Van Voorhees et al. 2000) that resulted in catch estimates considered implausible by ODFW. However, the ORBS sample estimates are known to lack the comprehensive spatial and temporal coverage of MRFSS. Addressing this coverage issue is a major part of this reconstruction. In general, the base data and methodology for these reconstructed estimates are consistent with recent assessments for other nearshore species (Dick et al. 2016, 2018; Haltuch et al. 2018; Cope et al. 2019).

Prior to 2001, ORBS monitored marine species in both multi-species categories, such as rockfish, flatfish, and other miscellaneous fishes, and as individual species, such as lingcod or halibut. For this comprehensive reconstruction, four species categories were selected to reconstruct, including rockfish, lingcod, flatfish and miscellaneous, which constitute the bulk of the managed marine fish species. Quillback rockfish are a component of the rockfish species category.

Category-level estimates were expanded to account for gaps in sampling coverage in two separate pathways. First, estimates from five major ports were expanded to include unsampled winter months in years lacking complete coverage. Expansions were based on available year-round sampling data and excluded years where regulations may have impacted the temporal distribution of catch. Second, all other minor port estimates were expanded to include seasonal estimates in years lacking any sampling based on the amount of minor port catch as compared to all major port estimates. A subset of landings were sampled by ORBS for species compositions within these categories. Once category-level landings were comprehensive in space and time, species compositions were applied for the three multi-species categories, including rockfish, flatfish and miscellaneous fish. Borrowing rules for species compositions were specific to the category and determined based on a series of regression tree analyses that detailed the importance of each domain (year, month, port and fishing mode) to variability in compositions.

Ocean boat estimates from 1979 – 2000 in numbers of quillback rockfish from the above described methods were converted to biomass using biological samples from MRFSS (A. Whitman, ODFW, pers. comm.). MRFSS biological data are available from 1980 – 1989 and 1993 – 2000. An annual average weight was applied to the total annual number of fish to obtain an annual landings estimate. Several of the years missing biological data (1979, 1990 – 1992) were filled in using neighboring years or interpolation. These landings in biomass were provided by ODFW and do not include an estimate of discarded fish. Landings during this time period gradually increased from 1979 to a peak of 7.1 mt in 1992, and fluctuated

annually. Recreational landings were large in 1979, the year that data were first available, and were expected to be minimal prior to the 1970s. Consequently a linear ramp in recreational landings was applied from 1970 to 1979 for this assessment.

Modern Ocean Boat Landings (2001 – 2020)

Recreational landings for ocean boat modes from 2001 – 2020 are available from RecFIN. Estimates of mortality from both retained and released fish are included, though retained mortality constitutes the vast majority of total fishing mortality. Release mortality is estimated from angler-reported release rates and the application of discard mortality rates from the PFMC. From 2001 – 2020, landings averaged 4.6mt, ranging from 0.7 to 9.5 mt. In 2020, ocean boat landings were 6.3 mt.

Shore and Estuary Landings (1979 – 2020)

Shore and estuary landings are much smaller than other recreational modes. ODFW provided reconstructed estimates of shore and estuary landings for quillback rockfish from 1979 – 2020, using methodology similar to recent assessments (Berger et al. 2015; Dick et al. 2018; Cope et al. 2019). Data sources include MRFSS and the Oregon Shore and Estuary Boat Survey (SEBS). Numbers of fish were provided by MRFSS from 1980 – 1989 and 1993 – June 2003, and by SEBS from July 2003 – June 2005. An annual mode-specific average weight was applied to numbers of quillback rockfish from 1980 – 1989 and 1993 – 2005. Separate weights were calculated for shore and estuary boat modes, and excluded extreme outliers and imputed values. This reconstruction also applied two scaling factors to remove bias towards freshwater sampling and underestimation of estuary boats, as detailed in Dick (2018). To estimate quillback rockfish landings from July – December 2005, an expansion was developed using the three year average of the ratio between the first six months of the year and the total annual landings from MRFSS and SEBS landings from 2002 - 2004. Separate expansions were developed for shore mode and estuary boat modes. A three year average (1980 - 1982) was used to estimate shore and estuary boat landings for 1979. The ODFW does not currently sample shore and estuary boat fishing trips, and so a 10 year average landing (1996 – 2005; 0.024 mt/year) was used to estimate shore and estuary boat landings during 2006 – 2020. Shore and estuary boat landings for quillback rockfish were sporadic. Shore and estuary boat landings averaged 0.07 mt annually from 1980 – 2003.

Recreational removals were aggregated across modes into a single fleet in the model (Table 1 and Figure 1). Values from 2001-2020 represent total removals consisting of both landings and estimated discard mortality. Values prior to 2001 also represent total removals, however no recreational discarding was assumed for these years, because the bag limits (15 fish bag limit) are thought to not have been restrictive enough to induce appreciable size based discarding of quillback rockfish.

2.1.2.2 Length Compositions

Recreational length samples were obtained from two sources: MRFSS and RecFIN (ORBS). From 1980 – 1989 and from 1993 – 2000, the MRFSS program collected samples from both ocean and inland (estuary) areas. ODFW provided MRFSS samples with the addition of a column that flagged length values imputed from weights to allow for selection of directly measured values; however, sample size was limited and therefore, imputed lengths were used. From 1980 – 1989, total lengths (mm) were collected by MRFSS, which were converted to fork length. From 1993 – 2000, fork length (mm) was collected. Length samples from 2001 – 2020 from the ORBS sampling program are available on RecFIN. All ORBS samples are by fork length (mm). The vast majority (78%) of these samples are from ocean trips, or do not distinguish inland from ocean (21%). Special projects samples collected by ODFW staff from the recreational fishery are also available from 1998 – 2001 and 2013 - 2015 ($n = 150$), but were not used due to concerns about non-random sampling. Table 4 details sample sizes used by year in the base model. Retention of quillback rockfish was not allowed under recreational state regulations in 2015 or 2016, limiting the number of samples in those years. Furthermore, released samples ($n = 121$), of which 60 occurred in 2015 and 2016, were not used in length compositions for the base model.

The distribution of the lengths in the recreational data ranged between 20 and 54 cm (the maximum length data bin size, Figure 5). The mean length by year in the recreational data was more variable prior to 2000, after which the mean lengths observed by year became relatively stable with tight 95 percent confidence intervals, with the exception of 2015, which had small sample sizes (Figure 6).

The input sample sizes for the recreational length data were set equal to the number of length samples available by year.

2.2 Fishery-Independent Data

No fishery-independent data sources that are commonly incorporated in West Coast groundfish assessments (as required by the data moderate Terms of Reference) had adequate sample sizes of quillback rockfish off the Oregon coast to include abundance indices for this assessment. The WCG BTS, and previously the Triennial survey, collect data off the Oregon coast on rockfish biology and abundance. There were no more than ten positive tows of quillback rockfish in any one year coastwide in the WCG BTS, and typically fewer than five. Similarly there were no more than five positive tows of quillback rockfish in any one year coastwide for the Triennial survey. Given indices of abundance were not calculated due to small sample sizes, length composition data from the WCG BTS ($n = 102$) and Triennial Survey ($n = 5$) off Oregon were not included in the model. Biological data from the WCG BTS survey was used in external calculations of biological parameters, including growth and weight-at-length relationships. No ages or weights for quillback rockfish were available from the Triennial survey.

Oregon has a number of state-specific small-scale fishery-independent surveys and datasets considered by ODFW to have adequate samples of quillback rockfish. These include two abundance estimates, one from underwater video lander data and the other from remotely-operated vehicle surveys, and a catch-per-unit-effort time series from hook and line surveys in Oregon’s marine reserves network. Given these surveys are not commonly incorporated into West Coast groundfish assessments, and are not explicitly conducted as a state-wide estimate of relative or absolute abundance, we do not include the data in the model for quillback rockfish. However, we do compare estimates from these surveys to the our assessment model in Appendix.

2.3 Biological Data

This assessment modeled quillback rockfish as a single sex. Growth and length-weight relationships were similar across sexes, and the literature provided limited evidence of sexual dimorphism in length (Lenarz and Echeverria 1991). The sections below therefore describe combined male and female biological data.

2.3.1 Natural Mortality

Hamel (2015) developed a method for combining meta-analytic approaches relating instantaneous natural mortality rate (M) to other life-history parameters such as longevity, size, growth rate, and reproductive effort to provide a prior on M . Then et al. (2015) provided an updated data set of estimates of M and related life history parameters across a large number of fish species from which to develop an M estimator for fish species in general. They concluded by recommending M estimates be based on maximum age alone, based on an updated Hoenig non-linear least-squares estimator $M = 4.899A_{max}^{-0.916}$. The approach of basing M priors on maximum age alone was one that was already being used for West Coast rockfish assessments. However, in fitting the alternative model forms relating M to A_{max} , Then et al. (2015) did not consistently apply their transformation. In particular, in real space, one would expect substantial heteroscedasticity in both the observation and process error associated with the observed relationship of M to A_{max} . Therefore, it would be reasonable to fit all models under a log transformation. This was not done. Re-evaluating the data used in Then et al. (2015) by fitting the one-parameter A_{max} model under a log-log transformation (such that the slope is forced to be -1 in the transformed space Hamel (2015)), the point estimate for M is:

$$M = \frac{5.4}{A_{max}}$$

The above is also the median of the prior suggested by Hamel (2015). The prior is defined as a log-normal distribution with parameters $\mu = \ln(5.4/A_{\max})$ and $\sigma = 0.438$. Using a maximum age of 95 years, the point estimate and median of the prior for M is 0.057 per year.

The maximum age assumed for calculating natural mortality in the base model was 95 years. The maximum age of 95 years was based on literature values for the U.S. West Coast examining the longevity of female quillback rockfish (Yamanako and Lacko 2001; Love et al. 2002; Palsson et al. 2009). Yamanako and Lacko (2001) found male longevity to be 76 years. Literature estimates were larger than the oldest aged quillback rockfish (73, 70, and 69) among data used in this assessment. These ages were from fish caught off the coast of Washington in 1999.

2.3.2 Maturation and Fecundity

Maturity-at-length estimates were based on the work of Hannah and Blume (2011) which estimated the 50% size-at-maturity of 29.2 cm off the coast of Oregon with maturity asymptoting to 1.0 for larger fish (Figure 7). A length at 50% maturity of 29.2 cm is consistent with other studies for quillback rockfish, which provide a range of 26-32 cm (Rosenthal et al. 1982; Echeverria 1987).

The fecundity-at-length was based on research by Dick et al. (2017). The fecundity relationship for quillback rockfish was estimated equal to $3.93e-07L^{3.7}$ in millions of eggs where L is length in cm. Fecundity-at-length is shown in Figure 8.

2.3.3 Length-Weight Relationship

The length-weight relationship for quillback rockfish was estimated outside the model using available coastwide biological data collected from fishery-independent and fishery-dependent data sources (Figure 9). Sources included the WCG BTS, and recreational and commercial samples from all states (Table 5). Only directly measured weight and length values were used; any values with more than two decimal places were assumed to be calculated from another measurement and were excluded. This occurred for 32 percent of lengths and 20 percent of the weights in the MRFSS-era recreational samples. Weights from Oregon special projects samples taken from the Oregon recreational and commercial fleets ($n = 241$) were not included. The estimated length-weight relationship for quillback rockfish was $W = 1.963e-05L^{3.02}$ where L is fork length in cm and W is weight in kg (Figures 10).

2.3.4 Growth (Length-at-Age)

The length-at-age relationship for quillback rockfish was estimated outside the model using data collected from fishery-dependent sources off the coast of Oregon and Washington collected between 1998-2019, and from a single coastwide fishery-independent source (WCG BTS) collected between 2005-2019 (Table 6). Ages from Oregon special projects samples taken from the Oregon commercial fleet ($n = 30$) were not included. Age data were generally sparse for quillback rockfish from any one source (Figure 11). The fishery-dependent data had limited observations of young fish less than 5 years of age, but had observations of fish up to 73 years of age. The fishery-independent data had limited observations of old fish greater than 40 years of age, but had observations of fish as young as one year of age. Growth parameters for quillback rockfish were estimated at the following values:

$$L_{\infty} = 43.04 \text{ cm}; k = 0.199; t_0 = -0.067 \text{ cm}$$

These values were fixed within the base model. The coefficient of variation (CV) around young and old fish was fixed at a value of 0.10. The length-at-age curve with the CV around length-at-age is shown in Figure 12. The estimate of L_{∞} is comparable to literature values, while the estimate of k is on the higher side of literature values which vary from 0.06 - 0.19 (Yamanako and Lacko 2001; Pálsson et al. 2009; West et al. 2014).

Table 7 shows the length-at-age, weight-at-age, maturity-at-age, and spawning output (the product of fecundity and maturity) assumed in the base model.

3 Assessment Model

3.1 Summary of Previous Assessments

Quillback rockfish was last assessed in 2010 (Dick and MacCall 2010). The stock was assessed using Depletion-Based Stock Reduction Analysis (DB-SRA) which is a data-limited approach that incorporates catch data with priors on select parameters including natural mortality, the ratio of fishing mortality at maximum sustainable yield to natural mortality, current depletion, and the depletion at maximum sustainable yield to estimate overfishing status, but not overfished status. Quillback rockfish was assessed as a single coastwide stock to generate an overall OFL that was then apportioned to each management area based on the proportion of historical catches North and South of 40° 10' Lat. N.. Assuming that current depletion was at the management target on average (e.g. 40%), the 2010 assessment found that quillback rockfish had a 52% chance of experiencing overfishing coastwide.

3.1.1 Bridging Analysis

A direct bridging analysis was not conducted because the previous assessment was structured as a single coastwide model. The previous assessment also used DB-SRA, which uses different assumptions and data than the model used for this assessment, making a direct bridging analysis intractable.

3.2 Selection of Method

Quillback rockfish was assessed using a catch and length-based (SS-CL) data moderate method, as allowed within the Terms of Reference. Fishery-independent indices had inadequate sample sizes, as described in Section 2.2 above, so index-based methods were not selected.

3.3 Model Structure and Assumptions

Oregon quillback rockfish was assessed using a one-sex model with life history parameters combined across sexes. The model assumed two fleets: 1) commercial and 2) recreational fleets with removals beginning in 1892. Selectivity for the commercial fleet was specified to be asymptotic using a six-parameter double normal parameterization. The ascending width and beginning size of maximum selectivity parameters were estimated for the commercial fleet. The selectivity for the recreational fleet was also specified using the six-parameter double normal parameterization with the ascending width and beginning size of maximum selectivity parameters estimated, and reduced selectivity for the largest fish was allowed (i.e., allowed to be dome-shaped). Annual recruitment deviations were estimated within the base model.

3.3.1 Modeling Platform and Structure

Stock Synthesis (SS) version 3.30.16 was used to estimate the parameters in the model (Methot and Wetzel 2013). The R package `r4ss`, version 1.41.0 (Taylor et al. 2021), along with R version 4.0.2 (R Core Team 2020) were used to investigate and plot model fits. The NWFSC developed R packages `nwfscSurvey_2.0` and `PacFIN.Utilities_0.0.2.0000` were used for synthesis and processing of data for use in Stock Synthesis.

3.3.2 Priors

Fixed parameter values for natural mortality and steepness, based on prior distributions, were used in the base model. The prior distribution for natural mortality was based on the Hamel (2015) meta-analytic approach with an assumed maximum age of 95 years. The prior assumed a log-normal distribution for natural mortality with a median of 0.057 and a standard deviation of 0.438.

The prior for steepness assumed a beta distribution with mean of 0.72 and standard deviation of 0.158. The prior parameters are based on the Thorson-Dorn rockfish prior (commonly used in past West Coast rockfish assessments) conducted by James Thorson (personal communication, NWFSC, NOAA) which was reviewed and endorsed by the Scientific and Statistical Committee (SSC) in 2017. However, this approach was subsequently rejected for future analysis in 2019 when the new meta-analysis resulted in a mean value of approximately 0.95. In the absence of a new method for generating a prior for steepness the default approach reverts to the previously endorsed method, the 2017 value.

3.3.3 Data Weighting

Length composition data for the commercial fishery started with a sample size determined from the equation listed in Section 2.1.1 (Table 3). The input sample size for the recreational fishery length composition data was set equal to the number of length samples by year (Table 4).

The base model was weighted using the Francis method, which was based on equation TA1.8 in Francis (2011). The weightings applied using the Francis method are provided in Table 8. This formulation looks at the mean length or age by year and the standard error of the mean to determine if, across years, the variability is adequately explained by the model. If the standard error of the mean does not encompass the model predictions, then that data source should be down-weighted. This method accounts for correlation in the data (i.e., the multinomial distribution). Sensitivities were performed examining the difference in weighting using McAllister-Ianelli Harmonic Mean Weighting (McAllister and Ianelli 1997) and the Dirichlet Multinomial Weighting (Thorson et al. 2017).

3.3.4 Estimated and Fixed Parameters

There were 89 estimated parameters in the base model. These included one parameter for R_0 , 5 parameters for selectivity, 71 annual recruitment deviations, and 12 forecast recruitment deviations (Table 9).

Fixed parameters in the model were as follows. Steepness was fixed at 0.72, and natural mortality was fixed at 0.057, as described above in Section 3.3.2. Growth, maturity-at-length, and length-at-weight were fixed as described above in Section 2.3. The standard deviation of recruitment deviates was fixed at 0.6. Likelihood profiles were performed for steepness, natural mortality, length at maximum size, vonBertalanffy growth coefficient, and the CV at maximum length.

Dome-shaped selectivity was explored for all fleets within the model. Older and larger quillback rockfish may be found in deeper waters and may move into areas that limit their availability to fishing gear as they mature. Dome shaped selectivity can also occur under heterogeneous fishing pressure across space by fleets (Waterhouse et al. 2014).

The final base model estimated dome-shaped selectivity for the recreational fishery. The selectivity for the commercial fishery was fixed as asymptotic. During initial model development, the descending width and width of maximum selectivity parameters for the recreational and commercial fleets were estimated to identify appropriate fixed values consistent with the data, and then fixed at those estimates.

3.4 Model Selection and Evaluation

The base assessment model for quillback rockfish was developed to balance parsimony and realism, with the goal of estimating a spawning output trajectory for the population of quillback rockfish off Oregon. The model contains many assumptions to achieve parsimony and uses many different sources of data to estimate reality. A series of investigative model runs were done to achieve the final base model.

3.5 Base Model Results

The base model parameter estimates along with approximate asymptotic standard errors are shown in Table 9 and the likelihood components are shown in Table 10. Estimates of derived reference points and approximate 95 percent asymptotic confidence intervals are shown in Table 11. Estimates of stock size and status over time are shown in Table 12.

3.5.1 Parameter Estimates

Estimated parameter values are provided in Table 9. The $\ln(R_0)$ was estimated at 2.14. The selectivity curves for the commercial and recreational fleet are shown in Figure 13. The

selectivity was fixed to be asymptotic for the commercial fleet with a peak in maximum selectivity starting at 32.7 cm. Selectivity for the commercial fleet was steep and nearly knife-edged. The selectivity for the recreational fleet was estimated to be dome-shaped at the largest sizes. The peak of the selectivity curve by the recreational fleet was estimated to start at 40.9 cm and decline at 43 cm.

After discussions with individuals knowledgeable about the recreational fishery, we theorized that the dome-shape in selectivity could arise due to older and larger fish moving deeper and being unavailable to the recreational fishery, which often operates nearshore and often targets rockfish in the water column, such as black or blue/deacon rockfishes, rather than quillback rockfish, which is typically strongly associated with the bottom. Additionally, in most recent years, the recreational fishery has also been restricted to extreme nearshore waters ($<20 - 40\text{fm}$) to reduce impacts on overfished rockfishes, primarily yelloweye rockfish. Sensitivities to the shape and potential time blocking of the recreational selectivity were explored (see below in Section 3.6.4).

The estimated annual recruitment and recruitment deviations are shown in Figures 14 and 15. Strong recruitment events were estimated to have occurred in 1993, 1995, 1999, and 2012 which resulted in a substantial increase in biomass during the late 1990s and early to mid 2000s. While the largest recruitment deviations were estimated to have occurred in these four specific years, the surrounding years in the 1990s also have above average recruitment estimated, whereas the surrounding years in the 2000s have lower than average recruitment estimated. Bias adjustment was applied to the annual estimates of recruitment deviations following the pattern of transformed variances in recent years as shown in Figure 16.

The large recruitment pulses in the 1990s show up in the composition data for the commercial and recreational fleets in some years as a pulse of young fish, but more so as a steady increasing trend in mean size that help support the increasing catches over the time. The steadily increasing mean size in the recreational fleet along with minimal catches of smaller fish in the composition data supports the estimated below average recruitment in the 2000s, until 2012. The 2012 large recruitment pulse shows up in the composition data for both the commercial and recreational fleets as pulses of smaller fish that are also reflected by declines in mean size.

3.5.2 Fits to the Data

Fits to the length data are shown based on the Pearson residuals-at-length, the annual mean lengths, and aggregated length composition data for the commercial and recreational fleets. Fits to the length composition data by year are provided in Appendix A.

The Pearson residuals for the commercial fishery have no discernible pattern of misfit to the length data across cohorts but show areas of misfit over time (Figure 17). The residuals show that the peak of the composition is being underfit for many years. These years have lower sample size, and for years with high sample size such as 2000, 2002, and 2017, compositions are being fit well. The largest residuals were observed in 1999 or when missing small spikes of small fish in the compositions (2009, 2017, 2020) (see Appendix A for details). The mean lengths observed by the commercial fishery were variable by year but with generally consistent confidence intervals across years and showed an increase in mean length followed by a period of stability and then decline (Figure 18).

The Pearson residuals for the recreational length data were variable by year and indicate no discernible pattern of misfit to the length data (Figure 19). A period of positive residuals from 2005-2014 show that the peak of the composition is being underfit, however visual inspections suggest overall good fit (see Appendix A for details). The residual patterns for 2017-2020, which are the largest residuals outside misfits to very high and very low lengths in low sample size years (before 1990), show the model has difficulty fitting the bimodal patterns in these years, which is not unexpected. Throughout the mid-2000s the mean length increases to a larger size (around 40 cm in 2015) with a substantial decrease in variation of the observed lengths compared to pre-2000 lengths (Figure 20). The mean length was highly uncertain in 2015 due to low sample size (Table 4)

Aggregate fits by fleet are shown in Figure 21. The model fits the aggregated lengths for the recreational fleet well. The fit to the commercial fleet is poorer. Both fleets show similar ranges of sizes measured and an aggregated peak around 40 cm. The commercial fleet shows proportionally less catch of intermediate size fish between 30-40 cm compared to the recreational fleet. The model overfits the proportion of intermediate fish in the commercial fishery and underestimates the proportion of fish selected at their peak. The poor fit to commercial aggregate lengths appears to be due to periods with catches of small fish (1999-2002, and 2015-2020) that contribute to the peak at small sizes, and periods of catches of larger fish (2003-2014) that contribute to the peak at larger sizes. The periods where small fish were caught correspond to years where estimated large recruitments would appear in the catch. The base model fits the data best with a very steep selectivity curve for the commercial fleet, matching the left edge of aggregate composition for the commercial fleet (Figure 21). The near knife-edge selectivity at small sizes was somewhat unexpected given that along with longline gear, commercial fishing occurs on hook and line similar to the hook and line gear used in the recreational fleet. Thus, peak selectivity nearer to the estimate for the recreational selectivity was expected. A sensitivity blocking commercial length compositions in years without bimodal distributions (2003-2014) was explored to see the effect of these years on estimates of selectivity for the commercial fishery.

3.5.3 Population Trajectory

The predicted spawning output (in millions of eggs) is given in Table 12 and plotted in Figure 22. The estimates of spawning output across time are uncertain with the base model estimating a spawning output of 9.21 in 2021 with a 95 percent asymptotic confidence interval ranging from 3.14 - 15.28 millions of eggs. The predicted spawning output from the base model declines until 1995, and steadies due to several above average recruitment events that occurred in the early- to mid-1990s. The population then increases dramatically in the early 2000s due to the very large recruitment event in 1995. The population increase slows in the late 2000s, and then declines in the 2010s due to below average recruitment through the 2000s. The estimate of total biomass over time is shown in Figure 23.

The 2021 spawning output relative to unfished equilibrium spawning output is above the target of 40 percent of unfished spawning output (0.47, Figure 24). Approximate 95% confidence interval based on the asymptotic variance estimates show that the uncertainty in the estimated spawning output is large, ranging between approximately 20 - 75 percent of unfished equilibrium spawning output.

The slight dome shape in the final selectivity for the recreational fleet results in a fraction of large fish being unavailable in recent years (Figure 25). The fraction of large fish unavailable averaged five percent of the overall biomass since 1970, and in theory would be available for selection from the commercial fishery, which has asymptotic selectivity.

The stock-recruit curve resulting from a value of steepness fixed at 0.72 is shown in Figure 26. The estimated annual recruitment is shown in Figure 14.

3.6 Model Diagnostics

3.6.1 Convergence

Proper convergence was determined by starting the minimization process from dispersed values of the maximum likelihood estimates and adjusting phases of the estimated parameters to determine if the model found a better minimum. Starting parameters were jittered by 10 percent. This was repeated 100 times with 33 out of 100 runs returning to the base model likelihood. A lower negative log-likelihood model fit was not found and all runs converged. Early exploration runs did reveal some convergence issues that were identified through jittering, and were resolved by updating data weighting values suggested from a run starting with the the initial values set at parameter estimates. Alternative phasing was done over five models by setting phases of all parameters other than R_0 to 2, setting all selectivity

parameters to phase 2 and phase 3, and setting all recruitment deviation parameters to phase 2 and phase 4. No model with lower log-likelihood was found through alternative phasing. Through the jittering done as explained, likelihood profiles (described below), and alternative phasing, we are confident that the base model as presented represents the best fit to the data given the assumptions made. There were no difficulties in inverting the Hessian to obtain estimates of variability throughout initial model attempts and all explorations resulted in a positive-definite Hessian.

3.6.2 Likelihood Profiles

Likelihood profiles were conducted for R_0 , steepness, natural mortality, L_∞ , growth coefficient (k), and CV at maximum length values separately. These likelihood profiles were conducted by fixing the parameter at specific values and estimating the remaining parameters based on the fixed parameter value.

In regards to values of R_0 , the negative log-likelihood was minimized at the base model estimate of $\ln(R_0)$ 2.14 with support from 2.0 to 2.2 (Figure 27). The recreational data supported lower $\ln(R_0)$ values whereas the commercial data supported higher $\ln(R_0)$ values. Increasing R_0 relative to the base model value resulted in an increase in unfished and recent spawning output (Figure 28) and increase in stock status (Figure 29).

For steepness, values from approximately 0.9 to 1.0 were supported with the lowest negative log-likelihood occurring at the upper bound of 1.0 (Figure 30). The pattern followed that of the recreational data. The commercial data supported lower estimates of steepness. Assuming higher or lower steepness values had little impact on recent spawning output for all but the lowest values (Figure 31). The estimated relative final stock status was above 0.40 of unfished biomass across all but the lowest steepness values (0.30 and 0.40; Figure 32).

The negative log-likelihood profile across natural mortality supported values between approximately 0.05 and 0.10 which included the fixed value of 0.057 and was minimized at a value of 0.07 (Figure 33). Assuming higher values of natural mortality resulted in generally similar estimates of unfished spawning output but larger estimates of recent spawning output (Figures 34). Consequently a wide range of stock status was observed across values for M from below, within, and above the management precautionary zone, which is between 0.25 - 0.40 (Figure 35).

The negative log-likelihood profile across values of L_∞ showed strong support for values near the fixed value of 43.04 (Figure 36). The recreational data supported slightly higher L_∞ values whereas the commercial data supported slightly lower L_∞ values. The stock scale was variable across alternative L_∞ values where assuming lower values resulted in lower estimates

of unfished spawning output and higher estimates of recent spawning output (Figure 37), resulting in a wide range of stock status estimates (Figure 38).

The negative log-likelihood profile over values of k showed support for values between 0.15 and 0.2, and was minimized at 0.165 with support from both the recreational and commercial data (Figure 39). The k value in the base model was fixed at 0.199. The stock scale (Figure 40) and status (Figure 41) increased under lower k values. Explorations over finer values of k showed that local minima occurred over the profile, indicating the parameter space across k values is jagged.

The negative log-likelihood profile across values for the CV at maximum length was minimized at a value of 0.07, lower than the base model value of 0.1 (Figure 42). Both the commercial and recreational composition data supported 0.07. Lower variation around maximum length (i.e. lower values of CV) resulted in higher unfished and recent spawning output (Figure 43), and less depletion (Figure 44).

3.6.3 Retrospective Analysis

A five-year retrospective analysis was conducted by running the model using data up to 2015, 2016, 2017, 2018, and 2019. The estimated spawning output (Figure 45) and stock status (Figure 46) declined in comparison with the base model as recent years of data were removed. Removing the first 1-4 years of data resulted in a steady decline in spawning output relative to the base model likely due to reducing the information about the recruitment pulse in 2012 from the lengths comps (Figures 47). The effect of removing the fifth year was inconsistent with other years likely given the limited information in 2016 when retention was prohibited in the Oregon recreational fishery.

3.6.4 Sensitivity Analyses

A number of sensitivity analyses were conducted. Sensitivities were conducted as a single exploration from the base model assumptions and/or data, and were not performed in a cumulative fashion. The exception was with estimating both L_∞ and k in one sensitivity. There were challenges in obtaining a converged base model, as described in Section 3.6.1. Initial sensitivities for growth parameters did not align with profiles so additional explorations were done to obtain converged sensitivities for growth parameters. Other sensitivities may not be converged, but the sensitivities for natural mortality and coefficient of variation in length of older fishes align with their profiles.

1. Deterministic recruitment from the stock recruitment curve.
2. Data weighting according to the McAllister-Ianelli method (MI DW) using the weighting values shown in Table 8.
3. Data weighting according to the Dirichlet Multinomial method (DM DW) where the estimated parameters are shown in Table 8.
4. Estimate L_{∞} .
5. Estimate k .
6. Estimate L_{∞} and k .
7. Estimate the coefficient of variation in length of older fishes.
8. Estimate natural mortality.
9. Exclude composition data prior to 2001 for the recreational fleet
10. Fix recreational selectivity form to be asymptotic.
11. Allow commercial selectivity form to be dome-shaped.
12. Estimate recreational selectivity block: 1892-2000 with asymptotic selectivity curve and 2001-2020 with dome-shaped selectivity.
13. Estimate commercial selectivity block for years without bimodal length compositions (2003-2014).

Likelihood values and estimates of key parameters from each sensitivity are available in Table 13. Plots of the estimated time-series of spawning output, relative spawning output, and recruitment are shown in Figures 48, 49, and 50, respectively.

The largest change from the base model resulted when recruitment was fixed to be deterministic, and when selectivity for the recreational fleet was set to be asymptotic. Assuming deterministic recruitment resulted in a higher stock scale, and different population trajectory, but a comparable stock status relative to the base model. Results were similar regardless of whether data weighting was updated. Assuming asymptotic selectivity for the recreational fleet resulted in a reduction in the scale and status of the stock, such that stock status was close to the threshold of 25 percent.

Most sensitivities resulted in either changes in unfished and recent spawning output of greater than 10 percent from the base model or had stock status between the management precautionary zone (between the target and threshold ratio values). Estimating k resulted in similarly low estimates of unfished spawning output as the sensitivity with asymptotic selectivity for the recreational fleet, but resulted in comparable declines in recent spawning output, and thus stock status was similar to the base model. Estimating L_{∞} and k resulted in higher estimates of unfished and recent spawning output compared to the base, and a more optimistic view of stock status. Assuming dome-shaped selectivity for commercial

selectivity resulted in a more pessimistic view of stock status compared to the base model, with stock status estimated between the threshold and target ratios. Data weighting with the McAllister-Ianelli (MI) approach and the sensitivity blocking commercial selectivity in years without bimodal length distributions also resulted in stock status being between the threshold and target ratios, due to a lower estimate of recent spawning output compared to the base model. When natural mortality was estimated, recent spawning output was larger than the base model, and stock status less depleted. Estimating variation in length for older fish resulted in an increased stock scale but similar stock status as the base model, while blocking recreational selectivity resulted in a decrease in recent spawning output but similar stock status as the base model. Data weighting with the Dirichlet-Multinomial and excluding early recreational length comps produced similar results as the base model.

The sensitivity blocking commercial selectivity in years where composition data did not have proportionally higher catches of smaller fish resulted in estimates of commercial selectivity near to that of recreational selectivity. The fit to the aggregate lengths is unsurprisingly shifted more rightward, yet the general pattern in the recruitment deviations are similar (Figure 50). Despite difference between this sensitivity and the base model, due to the lack of clear evidence for blocks within the commercial fleet from 2003-2014, and the added complexity with applying blocks, we chose not to include a block in the base model.

3.6.5 Unresolved Problems and Major Uncertainties

There were four primary uncertainties in the model given current data availability and model assumptions.

1. First, selectivity patterns were a source of uncertainty. When estimating asymptotic selectivity for the recreational fleet the scale of the population was affected and relative stock size was estimated near the lower edge of the management precautionary zone. We assumed dome-shaped selectivity based on discussion with those knowledgeable about the fishery, depth restrictions in the fishery, and assumed habits of older and larger fish. Sensitivities where the peak in selectivity for the commercial fleet was estimated at larger values nearer to selectivity of the recreational fleet, and therefore fitting nearer the middle of the aggregate commercial lengths, resulted in estimates of stock status within the management precautionary zone.
2. Second, the magnitude of recruitment deviations was a source of uncertainty. Strong recruitment pulses in 1993, 1995, 1999, and 2012 were often estimated during model exploration with some years being stronger in some runs compared to others. Recruitment deviations in other years during the 1990s were typically variable, and sometimes greatly so as shown in (Figure 15). These were likely due to limited samples

and variable length in the recreational length compositions. This variation influences the magnitude of the increase in biomass in the late 1990s and 2000s as well as the magnitude of the decrease in the 2010s. Omitting recruitment deviations altogether changes the scale of the model as well.

3. The magnitude of recruitment was also affected by the data weighting values, which is the third uncertainty. Data weighting using McAllister-Ianelli reduced the amount of information coming from the recreational fleet, affecting the magnitude of recruitment, and resulting in a more pessimistic stock status. Francis and the Dirichlet-Multinomial weighting resulted in similar results.
4. The final uncertainty is with estimating growth parameters. The fixed value for k for quillback rockfish is on the higher end of other published studies, ranging between 0.06-0.19, and results in a low M/k ratio, but one within the range of Beverton (1992) for *Sebastes*. Profiles and sensitivities for L_∞ and k suggest the model has a difficult time converging when estimating these parameters, especially for k . Estimation results in estimates of k nearer to the middle of the range of literature values and L_∞ near to or above the fixed estimate. We decided to keep the fixed values in the base model given the range of plausible k values from the profile included the fixed estimate, concerns over whether length data on its own without age data can inform k , that the growth curve using estimated k and L_∞ values poorly fit the age and length data, and that growth estimates used in the model were based on data with young fish from the surveys to inform the estimate of k .

4 Management

4.0.1 Reference Points

Reference points were calculated using the estimated selectivity and catch distributions among fleets in the most recent year of the model (2020, Table 11). Sustainable total yields were 3.08 mt when using an $SPR_{50\%}$ reference harvest rate. The spawning output equivalent to 40 percent of the unfished spawning output ($SB_{40\%}$) was 8.79 millions of eggs.

The 2021 spawning output relative to unfished equilibrium spawning output is above the target of 40 percent of unfished spawning output (Figure 24). The fishing intensity, $1 - SPR$, has been above the harvest rate limit ($SPR_{50\%}$) in nearly all years from 1977-2001, and in all but 2015 and 2016 since 2011 (Table 12 and Figure 51). Figure 52 shows the phase plot of relative spawning output and fishing intensity. Table 11 shows the full suite of estimated

reference points for the base model and Figure 53 shows the equilibrium curve based on a steepness value fixed at 0.72.

4.1 Harvest Projections and Decision Tables

A ten year projection of the base model was estimated for years 2023-2032, with catches equal to the estimated Acceptable Biological Catch (ABC), which was equivalent the Annual Catch Limit (ACL), based on the category 2 time-varying sigma and $P^* = 0.45$ for years 2023-2032 (Table 14). The removals in 2021 and 2022 were set based on recommended values from the PFMC Groundfish Management Team (GMT, personal communication). The removals for 2023-2032 were apportioned to recreational and commercial catches based on the apportionment of the GMT provided 2022 catches, which was 60% recreational and 40% commercial.

The axis of uncertainty for the decision table was based on a low and high state of nature for alternative values of unfished recruitment ($\ln(R0)$). Following guidance from the TOR, the 12.5 and 87.5 percentiles (i.e. 1.15 standard deviations) of spawning output in 2021, based on the uncertainty around the spawning output in 2021 ($\sigma = 0.33$), were used to determine the values of $\ln(R0)$ corresponding to the states of nature. Once the values of 2021 spawning output at the 12.5 and 87.5 percentiles were identified, a search across unfished recruitment values was done to obtain the identified spawning output values. The values of $\ln(R0)$ corresponding to the low and high states of nature were 2.01 (low) and 2.28 (high).

The same catch values from the base model projections were applied to the low and high states of nature to provide a range of projected catch quantities given alternative assumptions for $\ln(R0)$ (Table 15). Across alternative states, the fraction of unfished at the end of the 10 year projection period ranges 0.34 - 0.60. Under the low state of nature, fraction of unfished is below the management target, but above the management limit, after 10 years.

4.2 Evaluation of Scientific Uncertainty

The estimated uncertainty in the base model around the 2021 spawning output is $\sigma = 0.33$ and the uncertainty in the base model around the 2021 OFL is $\sigma = 0.32$. The estimated model uncertainty was less than the category 2 groundfish data moderate assessment default value of $\sigma = 1.0$.

5 Research and Data Needs

The ability to estimate additional process and biological parameters for quillback rockfish was limited by data. Collecting the following data would be beneficial to future assessments of the stock:

- Continue collecting length and otolith samples from recreational and commercial catches, as well as from surveys, which capture small quillback rockfish.
- Improved understanding of where recreational fishing is commonly occurring (areas and depths) and the range of sizes available by depth would be beneficial to better inform the selectivity form.
- Recruitment patterns showed lower than average recruitment in the 2000s. Additional data to support such patterns in recruitment would provide additional support for model estimates.

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8 Tables

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

Year	OR Commercial	OR Recreational	Total Catch
1892	0.06	0.00	0.06
1893	0.06	0.00	0.06
1894	0.06	0.00	0.06
1895	0.01	0.00	0.01
1896	0.00	0.00	0.00
1897	0.00	0.00	0.00
1898	0.00	0.00	0.00
1899	0.00	0.00	0.00
1900	0.00	0.00	0.00
1901	0.01	0.00	0.01
1902	0.01	0.00	0.01
1903	0.01	0.00	0.01
1904	0.01	0.00	0.01
1905	0.01	0.00	0.01
1906	0.01	0.00	0.01
1907	0.01	0.00	0.01
1908	0.02	0.00	0.02
1909	0.02	0.00	0.02
1910	0.02	0.00	0.02
1911	0.02	0.00	0.02
1912	0.02	0.00	0.02
1913	0.02	0.00	0.02
1914	0.02	0.00	0.02
1915	0.03	0.00	0.03
1916	0.03	0.00	0.03
1917	0.03	0.00	0.03
1918	0.03	0.00	0.03
1919	0.03	0.00	0.03
1920	0.03	0.00	0.03
1921	0.03	0.00	0.03
1922	0.04	0.00	0.04
1923	0.04	0.00	0.04
1924	0.04	0.00	0.04
1925	0.04	0.00	0.04
1926	0.04	0.00	0.04
1927	0.04	0.00	0.04
1928	0.07	0.00	0.07
1929	0.21	0.00	0.21

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

Year	OR Commercial	OR Recreational	Total Catch
1930	0.27	0.00	0.27
1931	0.16	0.00	0.16
1932	0.03	0.00	0.03
1933	0.06	0.00	0.06
1934	0.07	0.00	0.07
1935	0.05	0.00	0.05
1936	0.20	0.00	0.20
1937	0.42	0.00	0.42
1938	0.47	0.00	0.47
1939	0.49	0.00	0.49
1940	0.66	0.00	0.66
1941	0.55	0.00	0.55
1942	0.70	0.00	0.70
1943	1.19	0.00	1.19
1944	0.81	0.00	0.81
1945	0.82	0.00	0.82
1946	0.91	0.00	0.91
1947	0.33	0.00	0.33
1948	0.64	0.00	0.64
1949	0.63	0.00	0.63
1950	0.27	0.00	0.27
1951	0.24	0.00	0.24
1952	0.41	0.00	0.41
1953	0.15	0.00	0.15
1954	0.11	0.00	0.11
1955	0.27	0.00	0.27
1956	0.14	0.00	0.14
1957	0.30	0.00	0.30
1958	0.04	0.00	0.04
1959	0.10	0.00	0.10
1960	0.11	0.00	0.11
1961	0.22	0.00	0.22
1962	0.14	0.00	0.14
1963	0.21	0.00	0.21
1964	0.07	0.00	0.07
1965	0.56	0.00	0.56
1966	0.35	0.00	0.35
1967	1.01	0.00	1.01
1968	0.96	0.00	0.96
1969	1.89	0.00	1.89

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

Year	OR Commercial	OR Recreational	Total Catch
1970	0.87	0.00	0.87
1971	1.94	0.39	2.34
1972	2.52	0.78	3.30
1973	2.71	1.17	3.89
1974	3.43	1.57	5.00
1975	1.79	1.96	3.75
1976	2.41	2.35	4.76
1977	2.92	2.74	5.66
1978	3.56	3.13	6.69
1979	2.65	3.52	6.17
1980	2.30	1.72	4.02
1981	1.54	6.54	8.08
1982	1.85	5.51	7.36
1983	2.51	0.47	2.98
1984	2.12	3.70	5.82
1985	3.05	2.31	5.36
1986	3.36	2.86	6.22
1987	3.55	3.04	6.58
1988	3.28	2.41	5.69
1989	3.34	3.91	7.25
1990	4.35	4.04	8.39
1991	2.03	2.26	4.29
1992	1.49	7.10	8.59
1993	4.49	6.36	10.85
1994	0.89	3.50	4.39
1995	0.87	1.73	2.60
1996	2.68	2.12	4.80
1997	2.71	5.00	7.71
1998	2.26	5.39	7.65
1999	0.61	1.38	1.99
2000	2.54	2.11	4.65
2001	2.80	3.15	5.95
2002	0.81	3.36	4.18
2003	0.50	3.62	4.12
2004	1.74	2.42	4.16
2005	0.38	3.11	3.49
2006	3.00	4.55	7.55
2007	1.17	4.70	5.88
2008	1.82	3.99	5.81
2009	1.90	3.59	5.49

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

Year	OR Commercial	OR Recreational	Total Catch
2010	0.74	4.20	4.94
2011	2.16	5.62	7.78
2012	2.18	8.87	11.05
2013	2.23	5.50	7.73
2014	1.57	3.44	5.01
2015	0.80	0.95	1.76
2016	1.11	0.69	1.80
2017	2.03	7.03	9.06
2018	2.14	9.57	11.71
2019	3.17	8.70	11.87
2020	3.34	6.34	9.68

Table 2: The OFL and ACL for quillback rockfish within the Minor Nearshore Rockfish North complex, the ACL allocated to Oregon, and the total removals.

Year	OFL	ACL	OR ACL	OR Removals
2011	8.70	7.26	4.24	7.78
2012	8.70	7.26	4.24	11.05
2013	7.37	6.15	3.59	7.73
2014	7.37	6.15	3.59	5.01
2015	7.37	6.15	3.59	1.76
2016	7.37	6.15	3.59	1.80
2017	7.37	6.15	3.59	9.06
2018	7.37	6.15	3.59	11.71
2019	7.37	6.15	3.59	11.87
2020	7.37	6.15	3.59	9.68

Table 3: Summary of the commercial length samples by number of trips and lengths by sex per year.

Year	N Trips	N Fish Female	N Fish Male	N Fish Unsexed
1998	1	1	3	0
1999	9	10	15	0
2000	43	83	117	0
2001	63	97	117	0
2002	47	23	36	0
2003	22	23	25	0
2004	42	56	78	0
2005	12	5	15	0
2006	34	68	72	0
2007	34	52	75	0
2008	26	24	31	2
2009	31	22	42	0
2010	34	29	40	0
2011	85	92	99	0
2012	59	69	82	0
2013	90	99	115	0
2014	74	75	109	6
2015	65	53	49	0
2016	42	32	43	2
2017	97	93	88	33
2018	97	109	89	1
2019	138	164	190	1
2020	68	82	134	0

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

Year	All Fish	Sexed Fish	Unsexed Fish
1980	10	0	10
1981	5	0	5
1982	12	0	12
1983	3	0	3
1984	9	0	9
1985	21	0	21
1986	7	0	7
1987	8	0	8
1988	8	0	8
1989	15	0	15
1993	47	0	47
1994	52	0	52
1995	17	0	17
1996	16	0	16
1997	55	0	55
1998	116	0	116
1999	157	0	157
2000	67	0	67
2001	376	0	376
2002	816	0	816
2003	883	0	883
2004	498	0	498
2005	1021	91	930
2006	1376	343	1033
2007	1384	309	1075
2008	1480	363	1117
2009	1069	245	824
2010	1291	372	919
2011	1381	333	1048
2012	1713	475	1238
2013	1036	283	753
2014	677	193	484
2015	10	0	10
2017	952	227	725
2018	1690	349	1341
2019	1598	392	1206
2020	39	0	39

Table 5: Summary of the number of samples by year from the NWFSC WCG BTS, and the commercial (com) and recreational (rec) fisheries by state used to estimate weight-at-length parameters.

	CA NWFSC WCG- BTS	CA Rec	OR Com	OR NWFSC WCG- BTS	OR Rec	WA Com	WA NWFSC WCG- BTS	WA Rec
1993	0	50	0	0	47	0	0	0
1994	0	28	0	0	43	0	0	0
1995	0	17	0	0	16	0	0	0
1996	0	37	0	0	13	0	0	0
1997	0	9	0	0	49	0	0	0
1998	0	7	0	0	115	0	0	0
1999	0	21	0	0	152	0	0	0
2000	0	38	20	0	59	0	0	0
2001	0	11	8	0	372	0	0	0
2002	0	4	45	0	811	0	0	18
2003	0	14	17	0	882	0	0	16
2004	0	21	65	0	498	0	0	26
2005	0	82	20	0	930	0	2	67
2006	0	118	73	2	1033	0	1	73
2007	15	203	127	1	1074	0	0	41
2008	0	163	56	22	1115	0	0	21
2009	0	119	59	3	824	0	0	10
2010	0	49	63	1	918	0	1	0
2011	0	70	191	6	1044	0	0	0
2012	0	173	129	0	1238	0	26	0
2013	0	167	211	1	752	0	0	0
2014	4	61	157	4	484	0	17	65
2015	0	113	102	5	10	0	3	14
2016	0	148	72	8	0	0	1	33
2017	2	385	214	5	724	0	9	10
2018	0	367	199	16	1341	8	5	25
2019	0	364	351	11	1206	1	5	61
2020	0	0	216	0	39	0	0	0

Table 6: Summary of the number of samples by year from the NWFSC WCG BTS, and the commercial (com) and recreational (rec) fisheries by state used to estimate length-at-age parameters.

	CA NWFSC WCG- BTS	OR Com	OR NWFSC WCG- BTS	OR Rec	WA Com	WA NWFSC WCG- BTS	WA Rec
1998	0	0	0	0	0	0	50
1999	0	0	0	0	0	0	162
2000	0	0	0	0	0	0	26
2002	0	2	0	0	0	0	0
2003	0	9	0	0	0	0	0
2004	0	63	0	0	0	0	0
2005	0	1	0	91	0	2	0
2006	0	63	2	336	0	1	0
2007	15	0	1	0	0	0	0
2008	0	0	22	356	0	0	0
2009	0	0	3	0	0	0	0
2010	0	0	1	0	0	1	0
2011	0	0	6	0	0	0	0
2012	0	0	0	0	0	26	0
2013	0	0	1	0	0	0	0
2014	4	0	3	0	0	17	0
2015	0	0	5	0	0	3	0
2016	0	0	8	0	0	1	0
2017	2	0	5	0	9	9	0
2018	0	0	16	0	4	5	0
2019	0	0	11	0	19	5	0

Table 7: Age, length, weight, maturity, and spawning output by age (product of maturity and fecundity) at the start of the year. Output for ages 51-95 is truncated as these ages have the same length, weight, maturity, and spawning output as at age 50.

Age	Length (cm)	Weight (kg)	Maturity	Spawning Output
0	4.00	0.00	0.00	0.00
1	8.23	0.01	0.00	0.00
2	14.51	0.06	0.00	0.00
3	19.66	0.16	0.00	0.00
4	23.88	0.29	0.05	0.00
5	27.34	0.44	0.30	0.03
6	30.17	0.59	0.60	0.09
7	32.49	0.73	0.79	0.14
8	34.40	0.87	0.89	0.19
9	35.96	1.00	0.94	0.23
10	37.23	1.11	0.97	0.27
11	38.28	1.20	0.98	0.30
12	39.14	1.29	0.98	0.32
13	39.84	1.36	0.99	0.35
14	40.42	1.42	1.00	0.37
15	40.89	1.47	1.00	0.38
16	41.28	1.51	1.00	0.40
17	41.60	1.55	1.00	0.41
18	41.86	1.58	1.00	0.42
19	42.07	1.60	1.00	0.42
20	42.25	1.62	1.00	0.43
21	42.39	1.64	1.00	0.44
22	42.51	1.65	1.00	0.44
23	42.60	1.66	1.00	0.44
24	42.68	1.67	1.00	0.45
25	42.75	1.68	1.00	0.45
26	42.80	1.68	1.00	0.45
27	42.84	1.69	1.00	0.45
28	42.88	1.69	1.00	0.46
29	42.91	1.70	1.00	0.46
30	42.93	1.70	1.00	0.46
31	42.95	1.70	1.00	0.46
32	42.97	1.70	1.00	0.46
33	42.98	1.71	1.00	0.46
34	42.99	1.71	1.00	0.46
35	43.00	1.71	1.00	0.46
36	43.01	1.71	1.00	0.46
37	43.01	1.71	1.00	0.46

Table 7: Age, length, weight, maturity, and spawning output by age (product of maturity and fecundity) at the start of the year. Output for ages 51-95 is truncated as these ages have the same length, weight, maturity, and spawning output as at age 50. (*continued*)

Age	Length (cm)	Weight (kg)	Maturity	Spawning Output
38	43.02	1.71	1.00	0.46
39	43.02	1.71	1.00	0.46
40	43.03	1.71	1.00	0.46
41	43.03	1.71	1.00	0.46
42	43.03	1.71	1.00	0.46
43	43.03	1.71	1.00	0.46
44	43.03	1.71	1.00	0.46
45	43.03	1.71	1.00	0.46
46	43.04	1.71	1.00	0.46
47	43.04	1.71	1.00	0.46
48	43.04	1.71	1.00	0.46
49	43.04	1.71	1.00	0.46
50	43.04	1.71	1.00	0.46

Table 8: Data weights applied by each alternative data weighting method. The Dirichlet Multinomial weight is $\theta/(1+\theta)$

Method	Commercial Lengths	Recreational Lengths
Francis	0.2881790	0.1974770
McAllister-Ianelli	0.4550210	0.0237120
Dirichlet Multinomial	0.9801535	0.5145631

Table 9: 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	SD	Prior (Exp.Val, SD)
NatM p 1 Fem GP 1	0.057	-2	(0.01, 0.2)	NA	NA	Log Norm (-2.8647, 0.438)
L at Amin Fem GP 1	8.230	-2	(0, 10)	NA	NA	None
L at Amax Fem GP 1	43.040	-2	(25, 60)	NA	NA	None
VonBert K Fem GP 1	0.199	-2	(0.03, 0.3)	NA	NA	None
CV young Fem GP 1	0.100	-2	(0.01, 1)	NA	NA	None
CV old Fem GP 1	0.100	-2	(0.01, 1)	NA	NA	None
Wtlen 1 Fem GP 1	1.963e-05	-9	(0, 0.1)	NA	NA	None
Wtlen 2 Fem GP 1	3.016	-9	(2, 4)	NA	NA	None
Mat50% Fem GP 1	29.230	-9	(10, 60)	NA	NA	None
Mat slope Fem GP 1	-0.800	-9	(-2, 0)	NA	NA	None
Eggs scalar Fem GP 1	0.000	-9	(-3, 3)	NA	NA	None
Eggs exp len Fem GP 1	3.702	-9	(0, 6)	NA	NA	None
CohortGrowDev	1.000	-9	(0, 1)	NA	NA	None
FracFemale GP 1	0.500	-9	(0.01, 0.99)	NA	NA	None
SR LN(R0)	2.140	1	(1, 20)	OK	0.0903554	None
SR BH steep	0.720	-7	(0.2, 1)	NA	NA	Full Beta (0.72, 0.158)
SR sigmaR	0.600	-99	(0.15, 0.9)	NA	NA	None
SR regime	0.000	-99	(-2, 2)	NA	NA	None
SR autocorr	0.000	-99	(0, 0)	NA	NA	None
Early RecrDev 1950	-0.020	5	(-5, 5)	act	0.5937800	dev (NA, NA)
Early RecrDev 1951	-0.021	5	(-5, 5)	act	0.5934220	dev (NA, NA)
Early RecrDev 1952	-0.022	5	(-5, 5)	act	0.5930310	dev (NA, NA)
Early RecrDev 1953	-0.024	5	(-5, 5)	act	0.5926030	dev (NA, NA)
Early RecrDev 1954	-0.025	5	(-5, 5)	act	0.5921300	dev (NA, NA)
Early RecrDev 1955	-0.027	5	(-5, 5)	act	0.5916030	dev (NA, NA)
Early RecrDev 1956	-0.029	5	(-5, 5)	act	0.5910100	dev (NA, NA)
Early RecrDev 1957	-0.031	5	(-5, 5)	act	0.5903370	dev (NA, NA)
Early RecrDev 1958	-0.034	5	(-5, 5)	act	0.5895680	dev (NA, NA)

Table 9: 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	SD	Prior (Exp.Val, SD)
Early RecrDev 1959	-0.037	5	(-5, 5)	act	0.5886780	dev (NA, NA)
Early RecrDev 1960	-0.040	5	(-5, 5)	act	0.5876400	dev (NA, NA)
Early RecrDev 1961	-0.044	5	(-5, 5)	act	0.5864190	dev (NA, NA)
Early RecrDev 1962	-0.050	5	(-5, 5)	act	0.5849770	dev (NA, NA)
Early RecrDev 1963	-0.056	5	(-5, 5)	act	0.5832640	dev (NA, NA)
Early RecrDev 1964	-0.063	5	(-5, 5)	act	0.5812350	dev (NA, NA)
Early RecrDev 1965	-0.073	5	(-5, 5)	act	0.5788450	dev (NA, NA)
Early RecrDev 1966	-0.083	5	(-5, 5)	act	0.5760620	dev (NA, NA)
Early RecrDev 1967	-0.096	5	(-5, 5)	act	0.5728290	dev (NA, NA)
Early RecrDev 1968	-0.111	5	(-5, 5)	act	0.5691880	dev (NA, NA)
Early RecrDev 1969	-0.127	5	(-5, 5)	act	0.5652580	dev (NA, NA)
Early RecrDev 1970	-0.143	5	(-5, 5)	act	0.5613140	dev (NA, NA)
Early RecrDev 1971	-0.158	5	(-5, 5)	act	0.5576670	dev (NA, NA)
Early RecrDev 1972	-0.169	5	(-5, 5)	act	0.5547560	dev (NA, NA)
Early RecrDev 1973	-0.174	5	(-5, 5)	act	0.5529570	dev (NA, NA)
Early RecrDev 1974	-0.172	5	(-5, 5)	act	0.5522280	dev (NA, NA)
Early RecrDev 1975	-0.173	5	(-5, 5)	act	0.5521910	dev (NA, NA)
Early RecrDev 1976	-0.160	5	(-5, 5)	act	0.5540660	dev (NA, NA)
Early RecrDev 1977	-0.114	5	(-5, 5)	act	0.5584530	dev (NA, NA)
Early RecrDev 1978	-0.099	5	(-5, 5)	act	0.5621780	dev (NA, NA)
Early RecrDev 1979	-0.065	5	(-5, 5)	act	0.5638940	dev (NA, NA)
Main RecrDev 1980	-0.216	2	(-5, 5)	act	0.5560900	dev (NA, NA)
Main RecrDev 1981	-0.263	2	(-5, 5)	act	0.5486350	dev (NA, NA)
Main RecrDev 1982	-0.268	2	(-5, 5)	act	0.5481230	dev (NA, NA)
Main RecrDev 1983	-0.254	2	(-5, 5)	act	0.5505630	dev (NA, NA)
Main RecrDev 1984	-0.217	2	(-5, 5)	act	0.5533730	dev (NA, NA)
Main RecrDev 1985	-0.217	2	(-5, 5)	act	0.5503930	dev (NA, NA)
Main RecrDev 1986	-0.252	2	(-5, 5)	act	0.5477640	dev (NA, NA)
Main RecrDev 1987	-0.236	2	(-5, 5)	act	0.5489110	dev (NA, NA)

Table 9: 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	SD	Prior (Exp.Val, SD)
Main RecrDev 1988	-0.131	2	(-5, 5)	act	0.5678180	dev (NA, NA)
Main RecrDev 1989	0.126	2	(-5, 5)	act	0.6212200	dev (NA, NA)
Main RecrDev 1990	0.517	2	(-5, 5)	act	0.6755810	dev (NA, NA)
Main RecrDev 1991	0.374	2	(-5, 5)	act	0.7426210	dev (NA, NA)
Main RecrDev 1992	0.549	2	(-5, 5)	act	1.0475800	dev (NA, NA)
Main RecrDev 1993	1.591	2	(-5, 5)	act	0.6926550	dev (NA, NA)
Main RecrDev 1994	0.114	2	(-5, 5)	act	0.6816430	dev (NA, NA)
Main RecrDev 1995	3.035	2	(-5, 5)	act	0.1553480	dev (NA, NA)
Main RecrDev 1996	0.097	2	(-5, 5)	act	0.6626920	dev (NA, NA)
Main RecrDev 1997	0.217	2	(-5, 5)	act	0.6851780	dev (NA, NA)
Main RecrDev 1998	0.358	2	(-5, 5)	act	0.7740230	dev (NA, NA)
Main RecrDev 1999	1.439	2	(-5, 5)	act	0.4140170	dev (NA, NA)
Main RecrDev 2000	-0.068	2	(-5, 5)	act	0.5904850	dev (NA, NA)
Main RecrDev 2001	-0.434	2	(-5, 5)	act	0.4949760	dev (NA, NA)
Main RecrDev 2002	-0.473	2	(-5, 5)	act	0.4771330	dev (NA, NA)
Main RecrDev 2003	-0.240	2	(-5, 5)	act	0.4645800	dev (NA, NA)
Main RecrDev 2004	-0.381	2	(-5, 5)	act	0.4525250	dev (NA, NA)
Main RecrDev 2005	-0.834	2	(-5, 5)	act	0.4322680	dev (NA, NA)
Main RecrDev 2006	-0.943	2	(-5, 5)	act	0.4189020	dev (NA, NA)
Main RecrDev 2007	-0.826	2	(-5, 5)	act	0.4179180	dev (NA, NA)
Main RecrDev 2008	-0.774	2	(-5, 5)	act	0.4255780	dev (NA, NA)
Main RecrDev 2009	-0.848	2	(-5, 5)	act	0.4307390	dev (NA, NA)
Main RecrDev 2010	-0.742	2	(-5, 5)	act	0.4502570	dev (NA, NA)
Main RecrDev 2011	-0.278	2	(-5, 5)	act	0.5257220	dev (NA, NA)
Main RecrDev 2012	1.898	2	(-5, 5)	act	0.2349670	dev (NA, NA)
Main RecrDev 2013	-0.356	2	(-5, 5)	act	0.5140880	dev (NA, NA)
Main RecrDev 2014	-0.517	2	(-5, 5)	act	0.4831150	dev (NA, NA)
Main RecrDev 2015	-0.240	2	(-5, 5)	act	0.5090740	dev (NA, NA)
Main RecrDev 2016	-0.167	2	(-5, 5)	act	0.5644370	dev (NA, NA)

Table 9: 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	SD	Prior (Exp.Val, SD)
Main RecrDev 2017	-0.139	2	(-5, 5)	act	0.5846230	dev (NA, NA)
Late RecrDev 2018	0.000	6	(-5, 5)	act	0.5998300	dev (NA, NA)
Late RecrDev 2019	0.000	6	(-5, 5)	act	0.6000000	dev (NA, NA)
Late RecrDev 2020	0.000	6	(-5, 5)	act	0.6000000	dev (NA, NA)
Size DblN peak OR Commercial(1)	32.741	2	(15, 50)	OK	0.7384900	None
Size DblN top logit OR Commercial(1)	-3.025	-2	(-7, 7)	NA	NA	None
Size DblN ascend se OR Commercial(1)	2.199	3	(-10, 10)	OK	0.4329720	None
Size DblN descend se OR Commercial(1)	-2.232	-4	(-10, 10)	NA	NA	None
Size DblN start logit OR Commercial(1)	-20.000	-9	(-20, 30)	NA	NA	None
Size DblN end logit OR Commercial(1)	10.000	-3	(-10, 10)	NA	NA	None
Size DblN peak OR Recreational(2)	40.897	2	(15, 50)	OK	0.1684250	None
Size DblN top logit OR Recreational(2)	-2.396	-2	(-7, 7)	NA	NA	None
Size DblN ascend se OR Recreational(2)	4.418	3	(-10, 10)	OK	0.0572554	None
Size DblN descend se OR Recreational(2)	0.296	-4	(-10, 10)	NA	NA	None
Size DblN start logit OR Recreational(2)	-20.000	-9	(-20, 30)	NA	NA	None
Size DblN end logit OR Recreational(2)	0.192	3	(-10, 10)	OK	0.1770950	None

Table 10: Likelihood components by source.

Label	Total
TOTAL	245.28
Catch	0.00
Equil catch	0.00
Length comp	214.79
Recruitment	30.49
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 11: Summary of reference points and management quantities, including estimates of the 95 percent intervals.

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Output	19.71	16.22	23.2
Unfished Age 3+ Biomass (mt)	158.49	130.43	186.56
Unfished Recruitment (R0)	8.5	7	10.01
Spawning Output (2021)	9.21	3.14	15.28
Fraction Unfished (2021)	0.47	0.21	0.72
Reference Points Based SB40\%	-	-	-
Proxy Spawning Output SB40\%	7.88	6.49	9.28
SPR Resulting in SB40\%	0.46	0.46	0.46
Exploitation Rate Resulting in SB40\%	0.05	0.05	0.05
Yield with SPR Based On SB40\% (mt)	3.24	2.67	3.8
Reference Points Based on SPR Proxy for MSY	-	-	-
Proxy Spawning Output (SPR50)	8.79	7.24	10.35
Exploitation Rate Corresponding to SPR50	0.04	0.04	0.04
Yield with SPR50 at SB SPR (mt)	3.08	2.54	3.62
Reference Points Based on Estimated MSY Values	-	-	-
Spawning Output at MSY (SB MSY)	5.32	4.38	6.26
SPR MSY	0.34	0.34	0.34
Exploitation Rate Corresponding to SPR MSY	0.07	0.07	0.07
MSY (mt)	3.46	2.85	4.06

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

Year	Total Biomass (mt)	Spawn- ing Output	Total Biomass 3+ (mt)	Frac- tion Un- fished	Age-0 Re- cruits	Total Mortal- ity (mt)	1-SPR	Ex- ploita- tion Rate
1892	159.10	19.71	158.49	1.00	8.51	0.06	0.01	0.00
1893	159.05	19.70	158.44	1.00	8.51	0.06	0.01	0.00
1894	158.99	19.69	158.38	1.00	8.51	0.06	0.01	0.00
1895	158.94	19.69	158.33	1.00	8.51	0.01	0.00	0.00
1896	158.93	19.68	158.32	1.00	8.51	0.00	0.00	0.00
1897	158.94	19.68	158.33	1.00	8.51	0.00	0.00	0.00
1898	158.94	19.68	158.33	1.00	8.51	0.00	0.00	0.00
1899	158.95	19.69	158.34	1.00	8.51	0.00	0.00	0.00
1900	158.95	19.69	158.34	1.00	8.51	0.00	0.00	0.00
1901	158.96	19.69	158.35	1.00	8.51	0.01	0.00	0.00
1902	158.96	19.69	158.35	1.00	8.51	0.01	0.00	0.00
1903	158.96	19.69	158.35	1.00	8.51	0.01	0.00	0.00
1904	158.96	19.69	158.35	1.00	8.51	0.01	0.00	0.00
1905	158.96	19.69	158.35	1.00	8.51	0.01	0.00	0.00
1906	158.96	19.69	158.35	1.00	8.51	0.01	0.00	0.00
1907	158.96	19.69	158.35	1.00	8.51	0.01	0.00	0.00
1908	158.95	19.69	158.34	1.00	8.51	0.02	0.00	0.00
1909	158.95	19.69	158.34	1.00	8.51	0.02	0.00	0.00
1910	158.94	19.68	158.33	1.00	8.51	0.02	0.00	0.00
1911	158.93	19.68	158.32	1.00	8.51	0.02	0.00	0.00
1912	158.92	19.68	158.32	1.00	8.51	0.02	0.00	0.00
1913	158.91	19.68	158.30	1.00	8.51	0.02	0.00	0.00
1914	158.90	19.68	158.29	1.00	8.51	0.02	0.00	0.00
1915	158.89	19.68	158.28	1.00	8.51	0.03	0.00	0.00
1916	158.88	19.68	158.27	1.00	8.51	0.03	0.00	0.00
1917	158.86	19.67	158.26	1.00	8.51	0.03	0.00	0.00
1918	158.85	19.67	158.24	1.00	8.51	0.03	0.00	0.00
1919	158.83	19.67	158.22	1.00	8.50	0.03	0.00	0.00
1920	158.82	19.67	158.21	1.00	8.50	0.03	0.00	0.00
1921	158.80	19.67	158.19	1.00	8.50	0.03	0.00	0.00
1922	158.78	19.66	158.18	1.00	8.50	0.04	0.00	0.00
1923	158.77	19.66	158.16	1.00	8.50	0.04	0.01	0.00
1924	158.75	19.66	158.14	1.00	8.50	0.04	0.01	0.00
1925	158.73	19.66	158.12	1.00	8.50	0.04	0.01	0.00
1926	158.71	19.65	158.10	1.00	8.50	0.04	0.01	0.00
1927	158.69	19.65	158.08	1.00	8.50	0.04	0.01	0.00
1928	158.67	19.65	158.06	1.00	8.50	0.07	0.01	0.00
1929	158.62	19.64	158.01	1.00	8.50	0.21	0.03	0.00

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

Year	Total Biomass (mt)	Spawn- ing Output	Total Biomass 3+ (mt)	Frac- tion Un- fished	Age-0 Re- cruits	Total Mortal- ity (mt)	1-SPR	Ex- ploita- tion Rate
1930	158.44	19.62	157.83	1.00	8.50	0.27	0.04	0.00
1931	158.20	19.59	157.59	0.99	8.50	0.16	0.02	0.00
1932	158.08	19.57	157.47	0.99	8.50	0.03	0.00	0.00
1933	158.09	19.57	157.49	0.99	8.50	0.06	0.01	0.00
1934	158.08	19.57	157.47	0.99	8.50	0.07	0.01	0.00
1935	158.05	19.57	157.44	0.99	8.50	0.05	0.01	0.00
1936	158.05	19.57	157.44	0.99	8.50	0.20	0.03	0.00
1937	157.91	19.55	157.30	0.99	8.50	0.42	0.06	0.00
1938	157.55	19.50	156.94	0.99	8.50	0.47	0.06	0.00
1939	157.15	19.45	156.54	0.99	8.50	0.49	0.06	0.00
1940	156.75	19.40	156.14	0.98	8.49	0.66	0.08	0.00
1941	156.20	19.33	155.59	0.98	8.49	0.55	0.07	0.00
1942	155.78	19.27	155.17	0.98	8.49	0.70	0.09	0.00
1943	155.23	19.20	154.62	0.97	8.48	1.19	0.14	0.01
1944	154.21	19.06	153.61	0.97	8.48	0.81	0.10	0.01
1945	153.60	18.98	153.00	0.96	8.48	0.82	0.11	0.01
1946	153.01	18.90	152.40	0.96	8.47	0.91	0.12	0.01
1947	152.36	18.82	151.75	0.95	8.47	0.33	0.04	0.00
1948	152.30	18.81	151.69	0.95	8.47	0.64	0.08	0.00
1949	151.95	18.76	151.34	0.95	8.47	0.63	0.08	0.00
1950	151.63	18.72	151.02	0.95	8.30	0.27	0.04	0.00
1951	151.66	18.72	151.06	0.95	8.29	0.24	0.03	0.00
1952	151.73	18.73	151.14	0.95	8.28	0.41	0.06	0.00
1953	151.62	18.72	151.03	0.95	8.27	0.15	0.02	0.00
1954	151.75	18.74	151.16	0.95	8.25	0.11	0.02	0.00
1955	151.90	18.77	151.31	0.95	8.24	0.27	0.04	0.00
1956	151.87	18.77	151.28	0.95	8.23	0.14	0.02	0.00
1957	151.95	18.78	151.36	0.95	8.21	0.30	0.04	0.00
1958	151.85	18.77	151.26	0.95	8.19	0.04	0.00	0.00
1959	152.00	18.80	151.41	0.95	8.16	0.10	0.01	0.00
1960	152.05	18.81	151.47	0.95	8.13	0.11	0.02	0.00
1961	152.08	18.81	151.50	0.95	8.10	0.22	0.03	0.00
1962	151.98	18.80	151.40	0.95	8.06	0.14	0.02	0.00
1963	151.94	18.80	151.36	0.95	8.01	0.21	0.03	0.00
1964	151.82	18.79	151.24	0.95	7.95	0.07	0.01	0.00
1965	151.81	18.79	151.23	0.95	7.87	0.56	0.07	0.00
1966	151.29	18.73	150.72	0.95	7.79	0.35	0.05	0.00
1967	150.96	18.70	150.40	0.95	7.69	1.01	0.13	0.01
1968	149.96	18.58	149.41	0.94	7.57	0.96	0.12	0.01

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

Year	Total Biomass (mt)	Spawn- ing Output	Total Biomass 3+ (mt)	Frac- tion Un- fished	Age-0 Re- cruits	Total Mortal- ity (mt)	1-SPR	Ex- ploita- tion Rate
1969	149.01	18.46	148.46	0.94	7.44	1.89	0.22	0.01
1970	147.12	18.22	146.58	0.92	7.31	0.87	0.11	0.01
1971	146.23	18.12	145.70	0.92	7.20	2.34	0.26	0.02
1972	143.88	17.83	143.36	0.90	7.11	3.30	0.34	0.02
1973	140.58	17.41	140.07	0.88	7.06	3.89	0.39	0.03
1974	136.75	16.92	136.24	0.86	7.05	5.00	0.46	0.04
1975	131.89	16.30	131.38	0.83	7.02	3.75	0.40	0.03
1976	128.34	15.85	127.83	0.80	7.08	4.76	0.47	0.04
1977	123.88	15.27	123.38	0.78	7.38	5.66	0.53	0.05
1978	118.67	14.60	118.16	0.74	7.45	6.69	0.58	0.06
1979	112.63	13.81	112.10	0.70	7.65	6.17	0.58	0.06
1980	107.31	13.10	106.78	0.66	6.54	4.02	0.47	0.04
1981	104.35	12.70	103.82	0.64	6.21	8.08	0.67	0.08
1982	97.51	11.79	97.04	0.60	6.12	7.36	0.66	0.08
1983	91.59	11.02	91.15	0.56	6.14	2.98	0.44	0.03
1984	90.16	10.85	89.72	0.55	6.35	5.82	0.62	0.06
1985	85.94	10.32	85.50	0.52	6.30	5.36	0.61	0.06
1986	82.27	9.86	81.81	0.50	6.03	6.22	0.66	0.08
1987	77.82	9.30	77.37	0.47	6.07	6.58	0.69	0.09
1988	73.10	8.69	72.67	0.44	6.66	5.69	0.67	0.08
1989	69.38	8.20	68.93	0.42	8.51	7.25	0.74	0.11
1990	64.27	7.54	63.75	0.38	12.36	8.39	0.79	0.13
1991	58.35	6.75	57.69	0.34	10.45	4.29	0.66	0.07
1992	56.96	6.48	56.10	0.33	12.33	8.59	0.82	0.15
1993	51.98	5.71	51.15	0.29	33.85	10.85	0.88	0.21
1994	45.64	4.72	44.53	0.24	7.33	4.39	0.75	0.10
1995	47.42	4.63	45.04	0.23	135.20	2.60	0.62	0.06
1996	52.82	4.86	50.85	0.25	7.27	4.80	0.76	0.09
1997	61.42	4.98	53.50	0.25	8.25	7.71	0.84	0.14
1998	71.27	5.04	70.73	0.26	9.53	7.65	0.83	0.11
1999	82.96	5.49	82.31	0.28	28.40	1.99	0.48	0.02
2000	99.94	7.66	99.05	0.39	6.73	4.65	0.61	0.05
2001	113.77	10.35	112.03	0.53	4.87	5.95	0.61	0.05
2002	124.54	12.51	124.09	0.63	4.76	4.18	0.47	0.03
2003	134.54	14.26	134.19	0.72	6.04	4.12	0.43	0.03
2004	142.00	15.70	141.65	0.80	5.23	4.16	0.41	0.03
2005	146.87	16.88	146.46	0.86	3.31	3.49	0.34	0.02
2006	150.12	17.75	149.78	0.90	2.94	7.55	0.54	0.05
2007	147.35	17.75	147.12	0.90	3.31	5.88	0.47	0.04

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

Year	Total Biomass (mt)	Spawn- ing Output	Total Biomass 3+ (mt)	Frac- tion Un- fished	Age-0 Re- cruits	Total Mortal- ity (mt)	1-SPR	Ex- ploita- tion Rate
2008	144.44	17.65	144.22	0.90	3.51	5.81	0.48	0.04
2009	140.15	17.34	139.91	0.88	3.28	5.49	0.47	0.04
2010	135.08	16.87	134.83	0.86	3.67	4.94	0.45	0.04
2011	129.75	16.32	129.50	0.83	5.87	7.78	0.59	0.06
2012	121.20	15.28	120.79	0.78	51.72	11.05	0.70	0.09
2013	109.54	13.76	108.60	0.70	5.41	7.73	0.63	0.07
2014	103.08	12.63	100.01	0.64	4.59	5.01	0.54	0.05
2015	101.03	11.85	100.65	0.60	6.05	1.76	0.29	0.02
2016	103.19	11.60	102.84	0.59	6.54	1.80	0.30	0.02
2017	105.61	11.82	105.17	0.60	6.80	9.06	0.71	0.09
2018	100.77	11.50	100.29	0.58	7.85	11.71	0.78	0.12
2019	93.15	10.80	92.65	0.55	7.84	11.87	0.79	0.13
2020	85.15	9.93	84.59	0.50	7.77	9.68	0.76	0.11
2021	79.06	9.21	78.50	0.47	7.67	10.58	0.79	0.13
2022	71.95	8.31	71.39	0.42	7.52	10.58	0.81	0.15
2023	64.81	7.39	64.26	0.38	7.34	2.24	0.46	0.03
2024	65.87	7.51	65.33	0.38	7.36	2.26	0.46	0.03
2025	66.93	7.63	66.40	0.39	7.39	2.29	0.46	0.03
2026	67.96	7.76	67.43	0.39	7.42	2.32	0.45	0.03
2027	68.95	7.90	68.42	0.40	7.44	2.35	0.45	0.03
2028	69.90	8.02	69.37	0.41	7.47	2.36	0.45	0.03
2029	70.80	8.14	70.26	0.41	7.49	2.38	0.45	0.03
2030	71.65	8.25	71.12	0.42	7.51	2.38	0.45	0.03
2031	72.48	8.36	71.94	0.42	7.53	2.39	0.44	0.03
2032	73.27	8.46	72.73	0.43	7.55	2.39	0.44	0.03

Table 13: Sensitivities relative to the base model.

	Base model	No rec devs	DW MI	DW DM	Est Linf	Est K	Est Linf, K	Est Old CV	Est M	No early rec comps	Rec asympt. selex.	Com dome- shaped selex.	Rec block selex.	Com block selex.
Total Likelihood	245.28	578.05	132.40	907.68	244.56	242.33	236.38	213.97	244.92	197.25	272.81	255.55	240.63	250.34
Length Likelihood	214.79	578.05	117.94	863.43	214.45	217.27	209.57	186.94	215.10	171.87	242.59	225.62	213.34	220.52
Recruitment Likelihood	30.49	0.00	14.46	41.91	30.11	25.06	26.81	27.02	29.76	25.38	30.22	29.92	27.28	29.82
Forecast Recruitment Likelihood	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Parameter Priors Likelihood	0.00	0.00	0.00	2.31	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00
Parameter Bounds Likelihood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
log(R0)	2.14	2.61	2.18	2.08	2.11	2.30	2.35	2.27	2.37	2.12	2.02	2.07	2.14	2.08
SB Virgin	19.71	31.61	20.60	18.61	19.57	17.13	21.84	21.95	19.48	19.31	17.43	18.35	19.74	18.62
SB 2021	9.21	12.62	6.65	9.35	8.25	8.51	13.12	9.70	11.36	9.27	4.36	6.50	8.09	6.70
Fraction Unfished 2021	0.47	0.40	0.32	0.50	0.42	0.50	0.60	0.44	0.58	0.48	0.25	0.35	0.41	0.36
Total Yield at SPR 50	3.08	4.88	3.22	2.94	3.02	2.95	3.18	3.41	3.53	3.09	2.97	2.96	3.15	2.97
Steepness	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Natural Mortality	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.06	0.06	0.06	0.06
Length at Amin	8.23	8.23	8.23	8.23	8.23	8.23	8.23	8.23	8.23	8.23	8.23	8.23	8.23	8.23
Length at Amax	43.04	43.04	43.04	43.04	43.32	43.04	44.52	43.04	43.04	43.04	43.04	43.04	43.04	43.04
Von Bert. k	0.20	0.20	0.20	0.20	0.20	0.12	0.13	0.20	0.20	0.20	0.20	0.20	0.20	0.20
CV young	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
CV old	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.07	0.10	0.10	0.10	0.10	0.10	0.10
Peak commercial selex	32.74	31.84	32.78	32.86	32.75	45.07	32.96	31.96	32.77	33.35	42.45	40.23	33.23	33.42
Peak recreational selex	40.90	40.63	40.84	42.01	40.85	46.09	40.93	35.82	40.91	42.23	43.60	42.23	42.18	42.10

Table 14: Projections of potential OFLs (mt), ABCs (mt), resulting ACLs (mt) based on 40-10 rule, estimated spawning output, and fraction unfished for 2023-2032, with assumed removals in 2021 and 2022 based on recommended values from the Groundfish Management Team. The OFL North and ACL North for 2021 and 2022 reflect adopted management limits for quillback rockfish for the area north of 40 degrees 10 minutes Latitude N, while the OR ACL North is the Oregon specific allocation of the total ACL.

Year	OFL North	ACL North	OR ACL North	As- sumed re- movals	OFL	Buffer	ABC	ACL	Spawn- ing Out- put	Frac- tion Un- fished
2021	7.37	5.73	3.35	6.52	-	-	-	-	9.21	0.47
2022	7.37	5.74	3.35	2.43	-	-	-	-	8.81	0.45
2023	-	-	-	-	3.14	0.874	2.74	2.74	8.90	0.45
2024	-	-	-	-	3.15	0.865	2.73	2.73	8.94	0.45
2025	-	-	-	-	3.17	0.857	2.71	2.71	9.00	0.46
2026	-	-	-	-	3.18	0.849	2.7	2.7	9.05	0.46
2027	-	-	-	-	3.19	0.841	2.69	2.69	9.10	0.46
2028	-	-	-	-	3.21	0.833	2.67	2.67	9.15	0.46
2029	-	-	-	-	3.23	0.826	2.66	2.66	9.20	0.47
2030	-	-	-	-	3.24	0.818	2.65	2.65	9.25	0.47
2031	-	-	-	-	3.26	0.81	2.64	2.64	9.30	0.47
2032	-	-	-	-	3.27	0.803	2.63	2.63	9.35	0.47

Table 15: Decision table summary of 10 year projections for low (2.01) and high (2.28) states of nature around $\ln(R_0)$. Columns range over low, base, and high states of nature, and rows range over different catch level assumptions. The current catch level assumption is the ACL from the base model where $P^* = 0.45$.

			$\ln(R_0) = 2.01$		$\ln(R_0) = 2.14$		$\ln(R_0) = 2.28$	
	Year	Catch (mt)	Spawning Biomass	Fraction Unfished	Spawning Biomass	Fraction Unfished	Spawning Biomass	Fraction Unfished
ACL $P^*=0.45$	2021	6.52	5.76	0.33	9.21	0.47	13.49	0.60
	2022	2.43	5.33	0.31	8.81	0.45	13.17	0.58
	2023	2.74	5.38	0.31	8.90	0.45	13.32	0.59
	2024	2.73	5.41	0.31	8.94	0.45	13.40	0.59
	2025	2.71	5.46	0.32	9.00	0.46	13.46	0.59
	2026	2.70	5.51	0.32	9.05	0.46	13.52	0.60
	2027	2.69	5.56	0.32	9.10	0.46	13.56	0.60
	2028	2.67	5.61	0.32	9.15	0.46	13.60	0.60
	2029	2.66	5.66	0.33	9.20	0.47	13.63	0.60
	2030	2.65	5.71	0.33	9.25	0.47	13.65	0.60
	2031	2.64	5.76	0.33	9.30	0.47	13.67	0.60
	2032	2.63	5.81	0.34	9.35	0.47	13.69	0.60

9 Figures

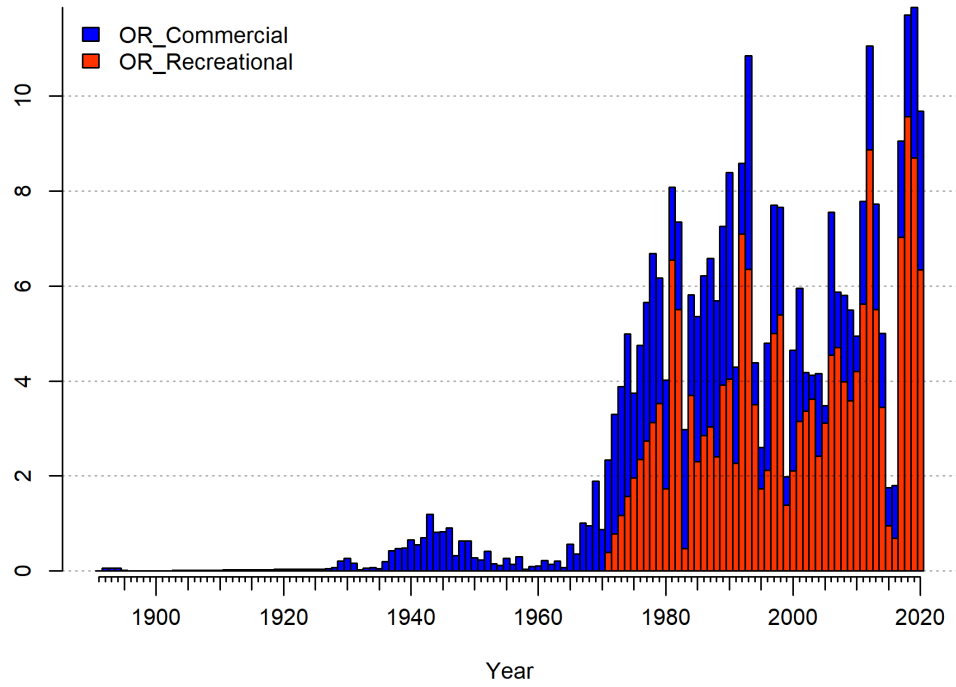


Figure 1: Total removals (mt) by fleet used in the base model.

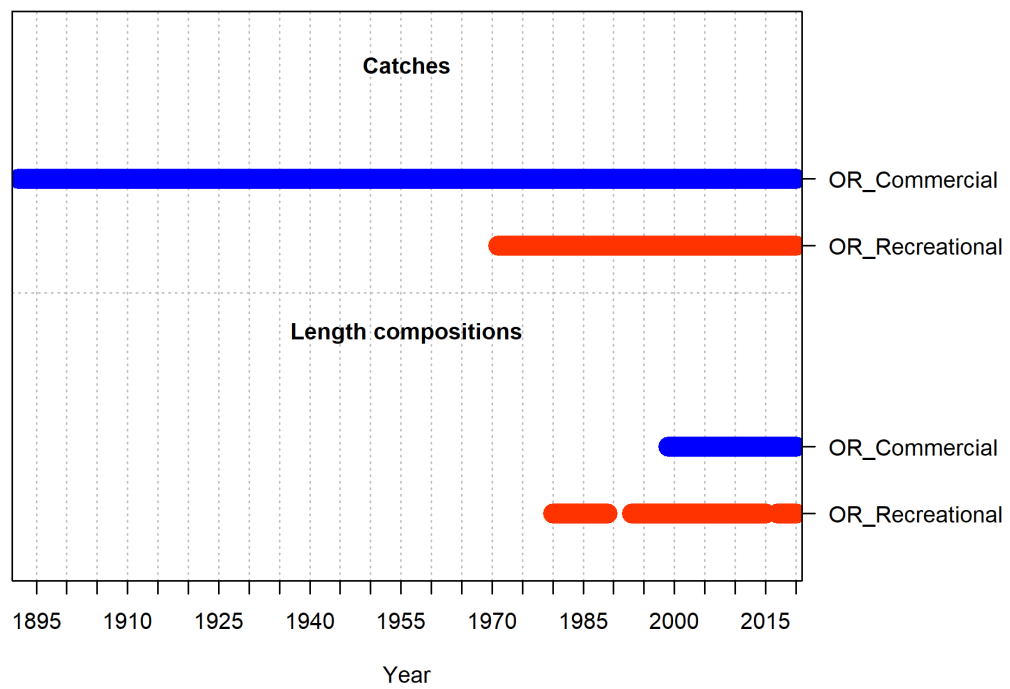


Figure 2: Summary of data sources used in the base model.

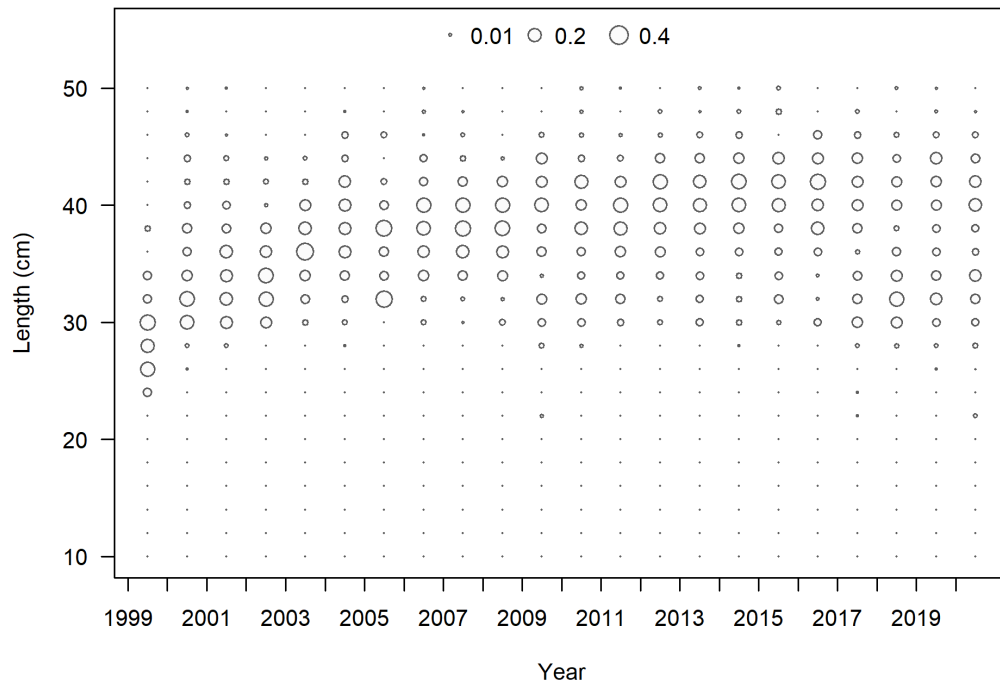


Figure 3: Length composition data from the commercial fleet.

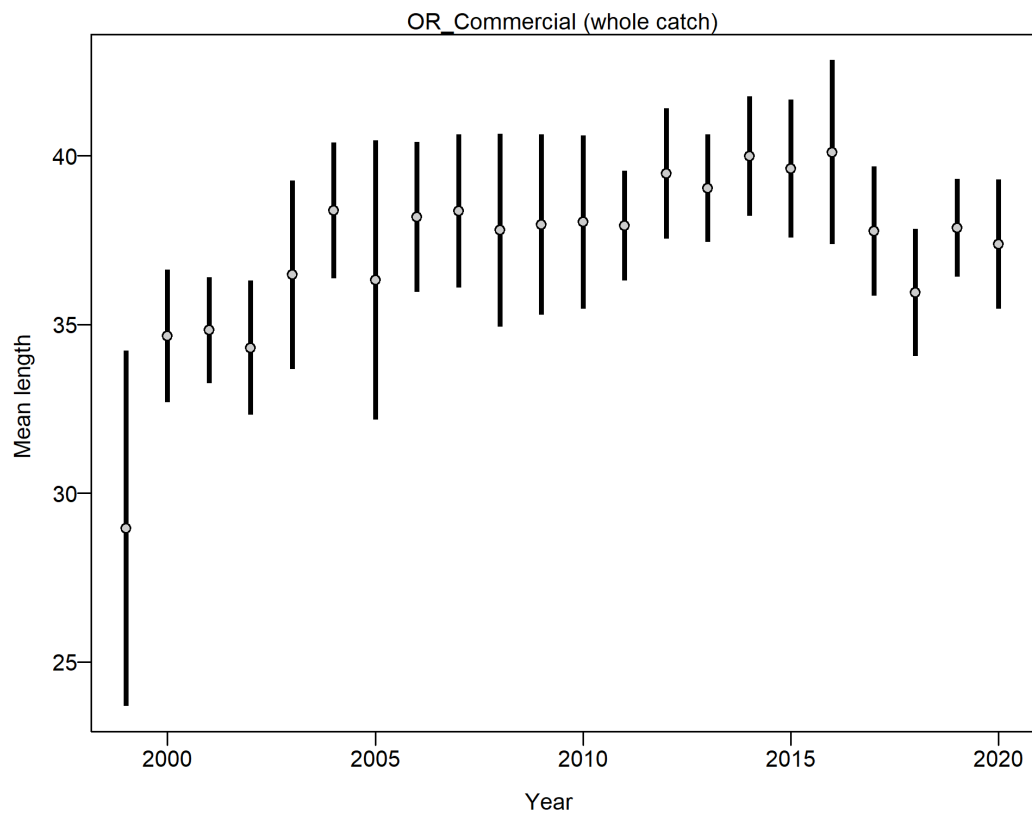


Figure 4: Mean length for commercial fleet with 95 percent confidence intervals.

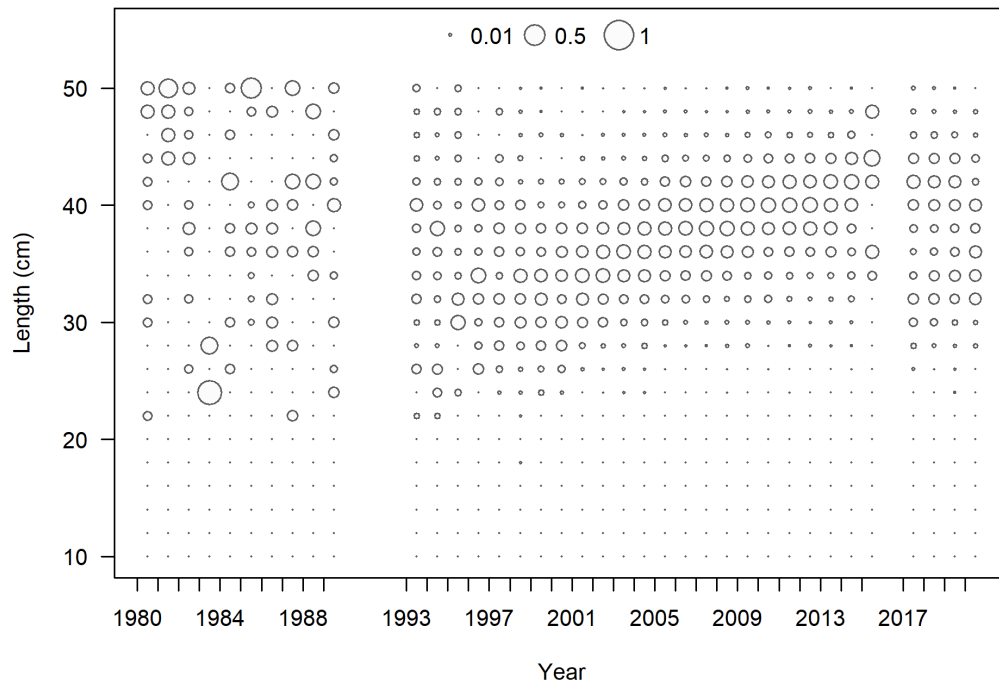


Figure 5: Length composition data from the recreational fleet.

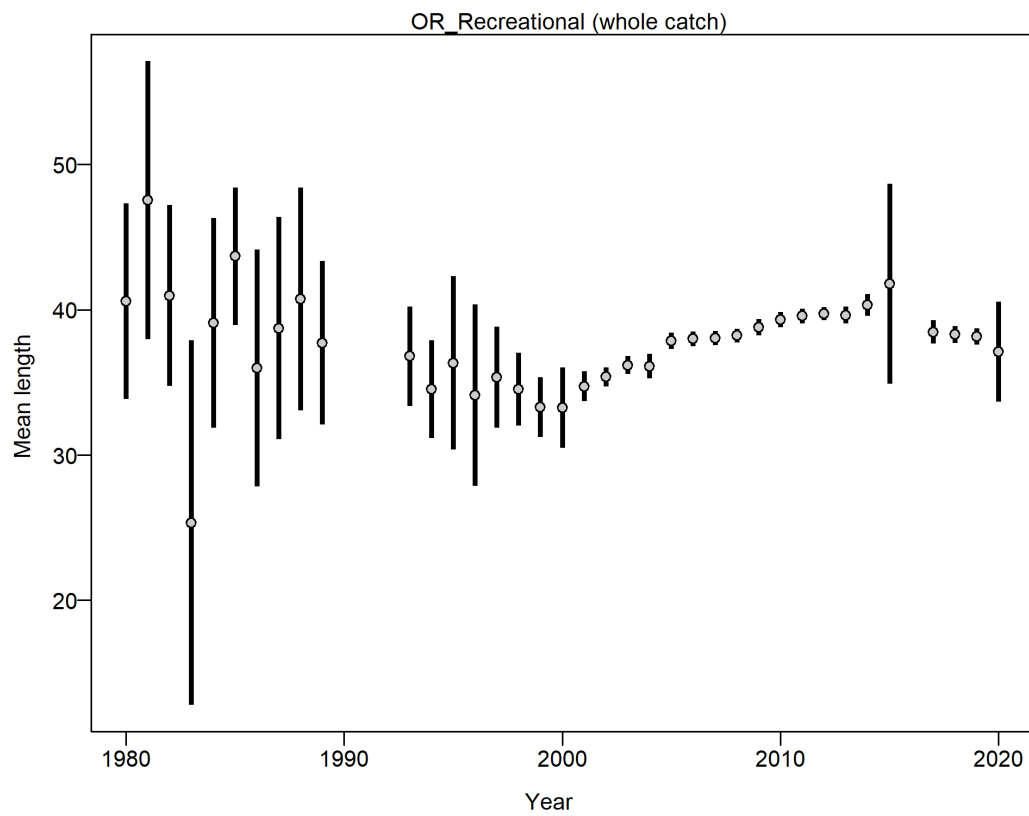


Figure 6: Mean length for recreational fleet with 95 percent confidence intervals.

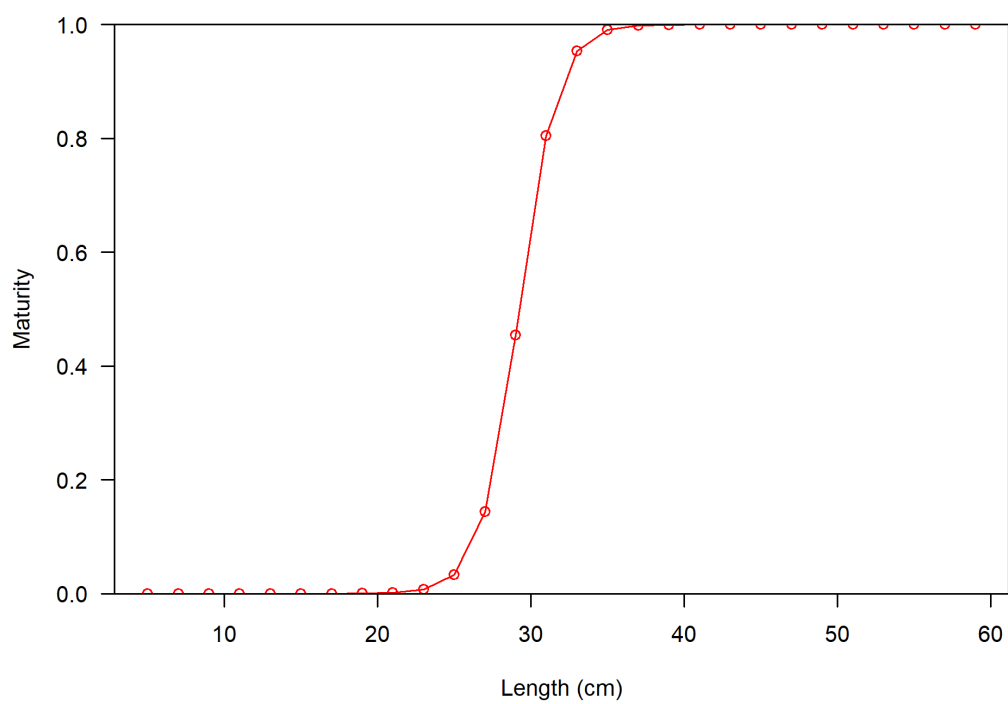


Figure 7: Maturity as a function of length.

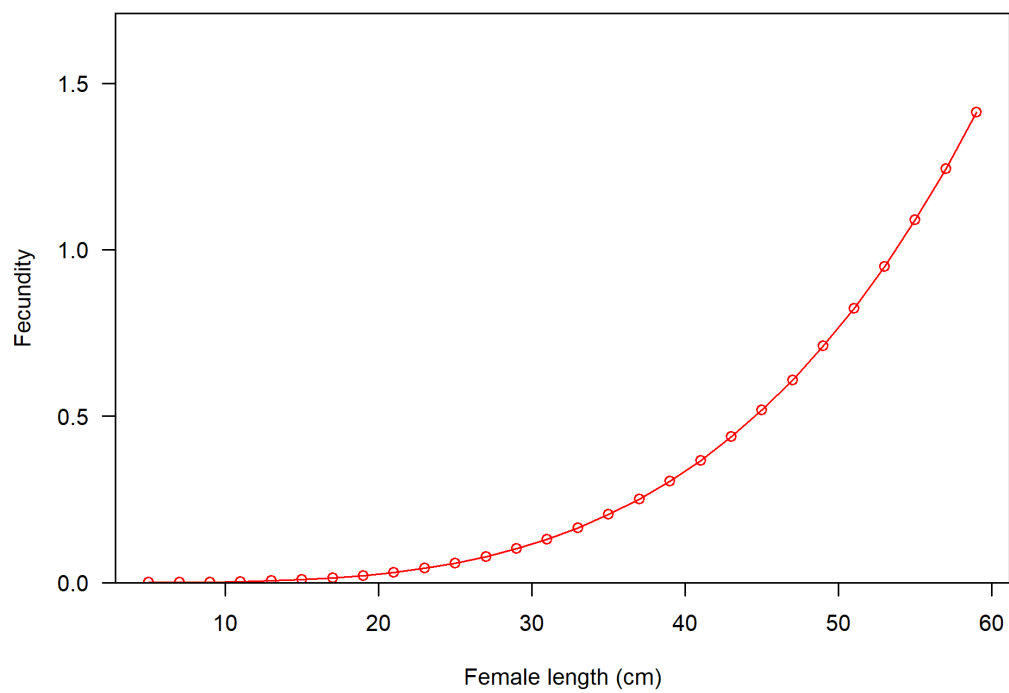


Figure 8: Fecundity as a function of length.

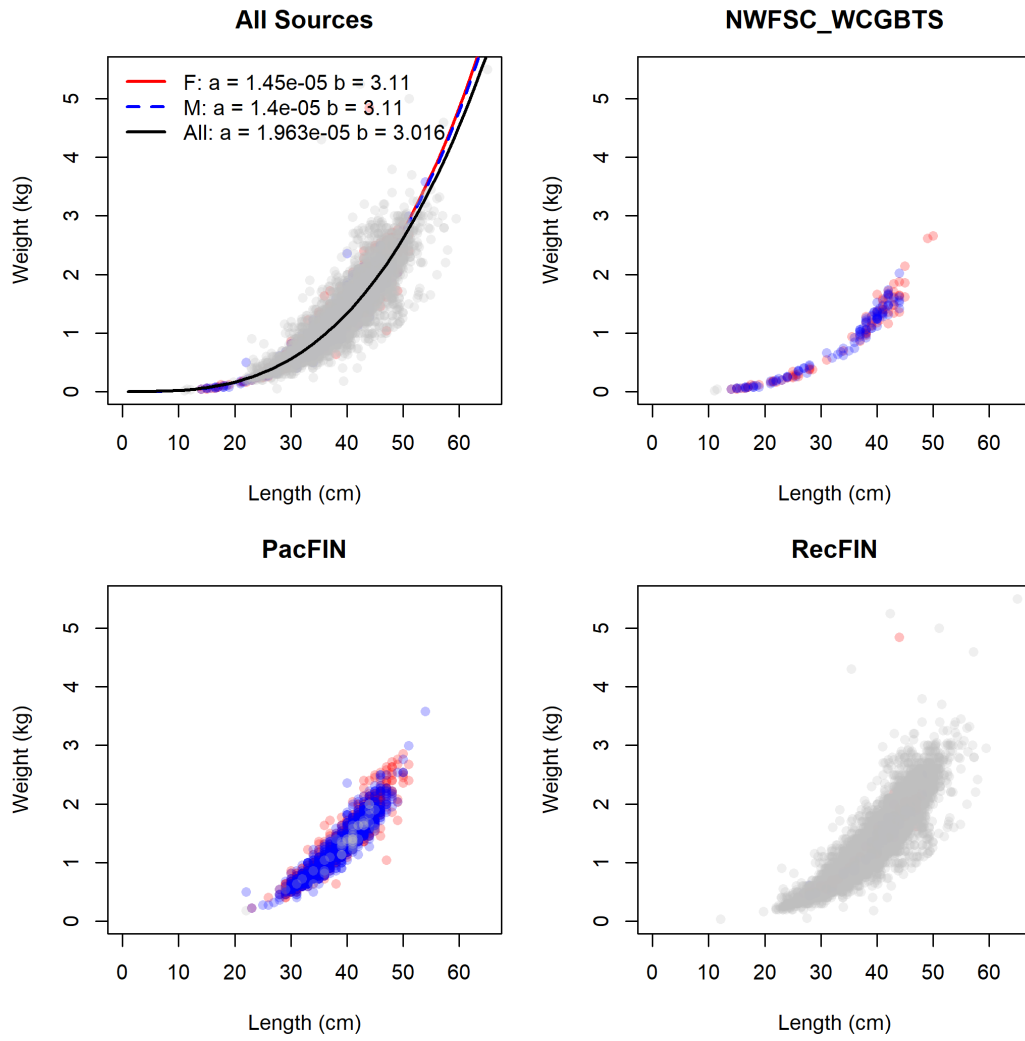


Figure 9: Observed sex-specific (red is female, blue is male, gray is unsexed) weight-at-length data from the individual sources with length and weight data, along with all sources combined with the estimated weight-at-length curves.

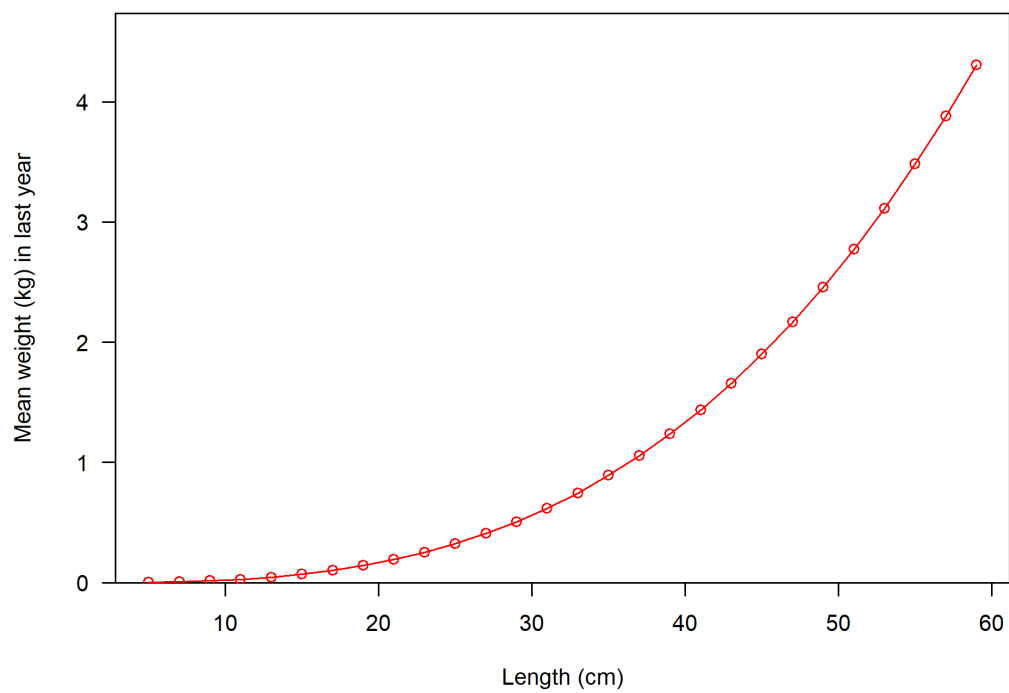


Figure 10: Weight-at-length relationship used in the model.

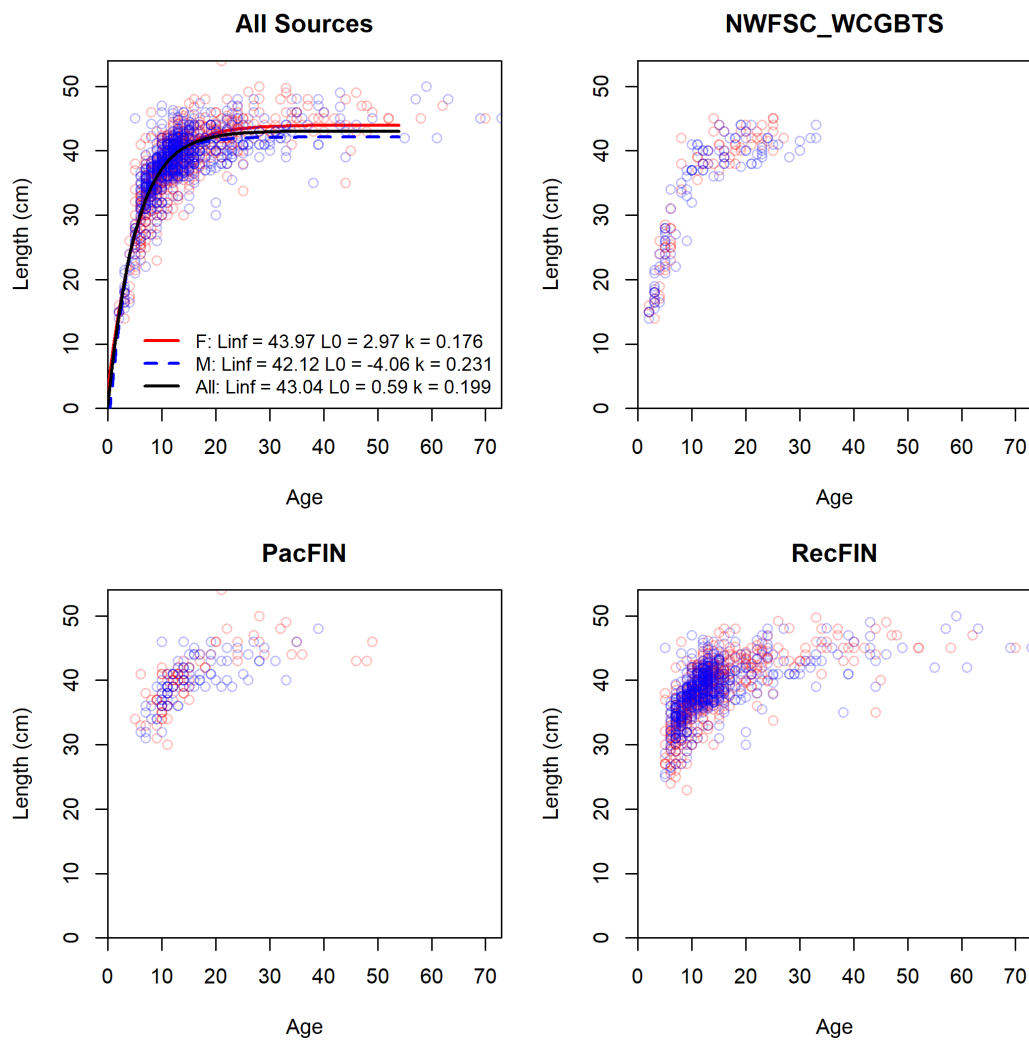


Figure 11: Observed sex-specific (red is female, blue is male, gray is unsexed) length-at-age data from the individual sources with length and age data, along with all sources combined with the estimated length-at-age curves.

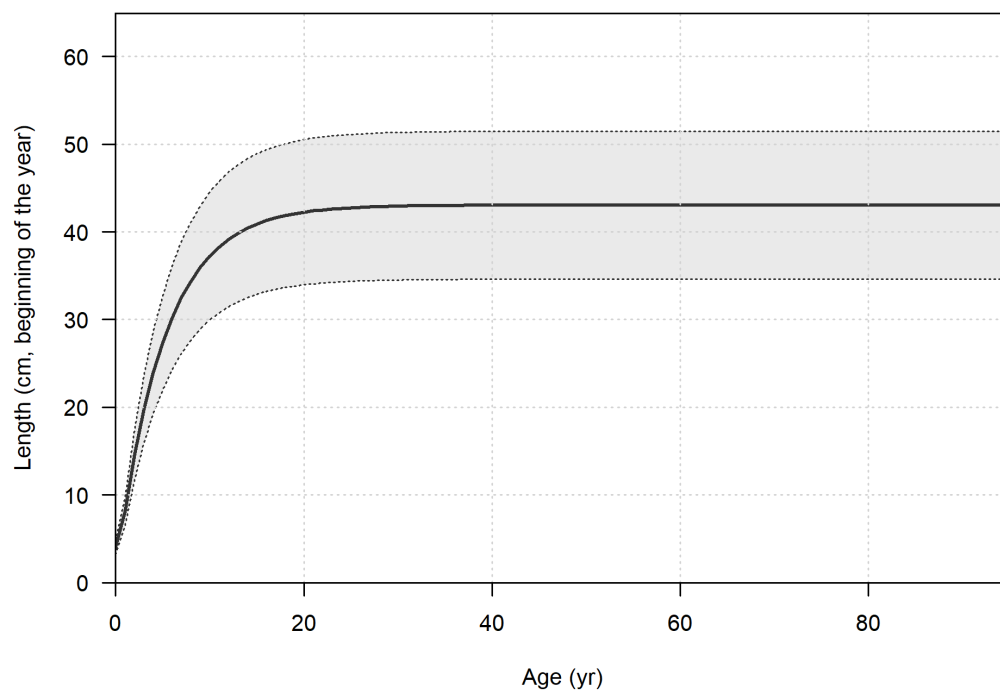


Figure 12: Length at age in the beginning of the year in the ending year of the model.

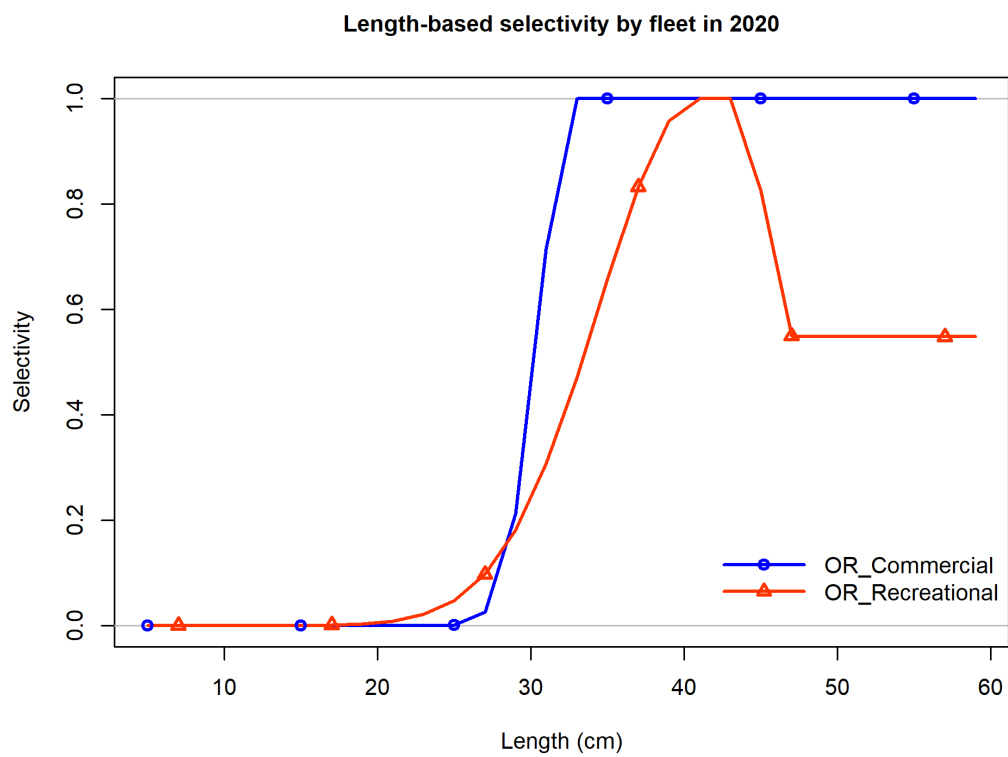


Figure 13: Selectivity at length by fleet.

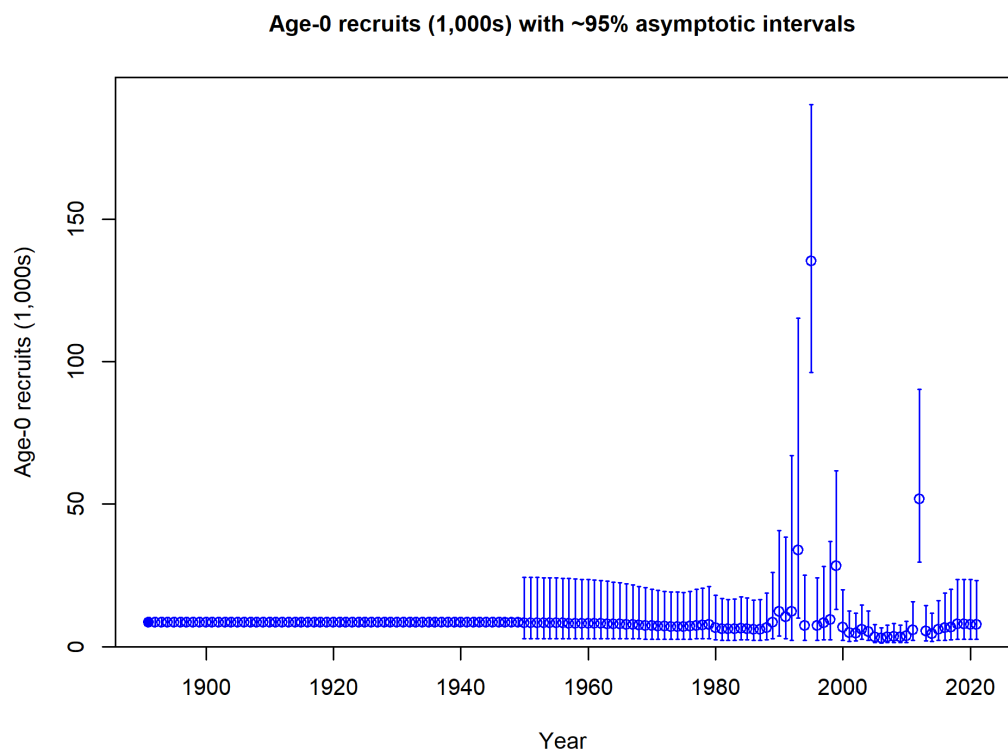


Figure 14: Estimated time series of age-0 recruits (1000s).

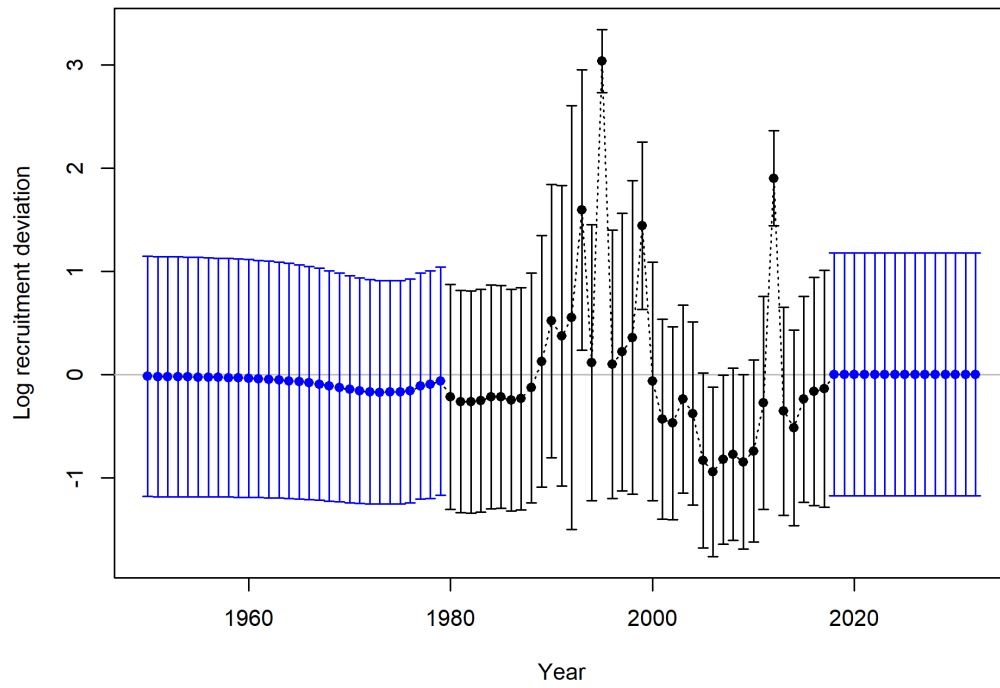


Figure 15: Estimated time series of recruitment deviations.

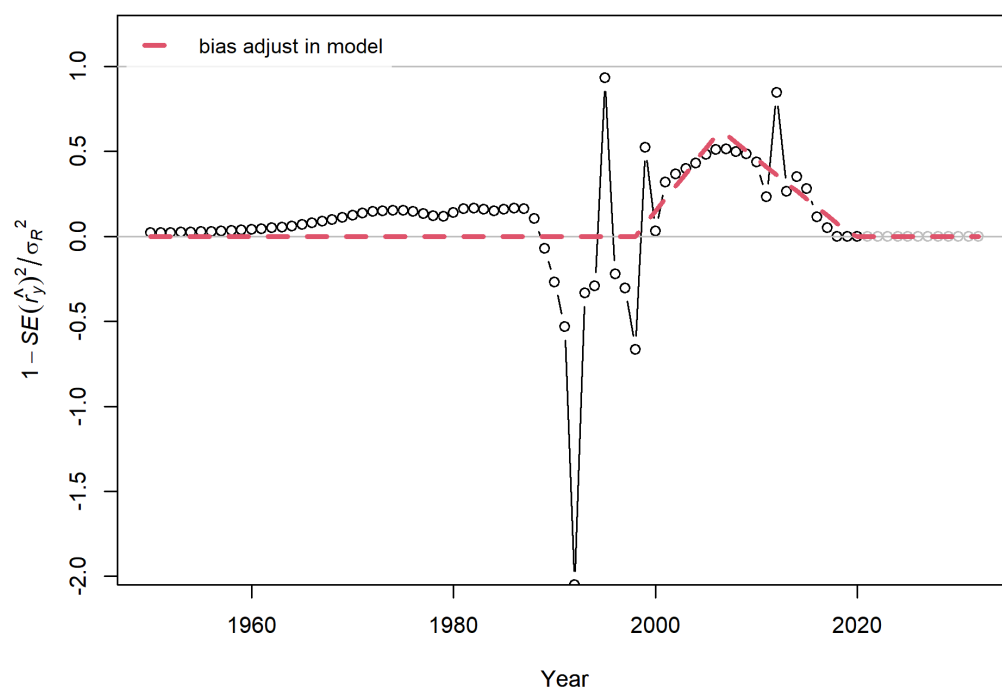


Figure 16: Recruitment bias adjustment applied in the base model.

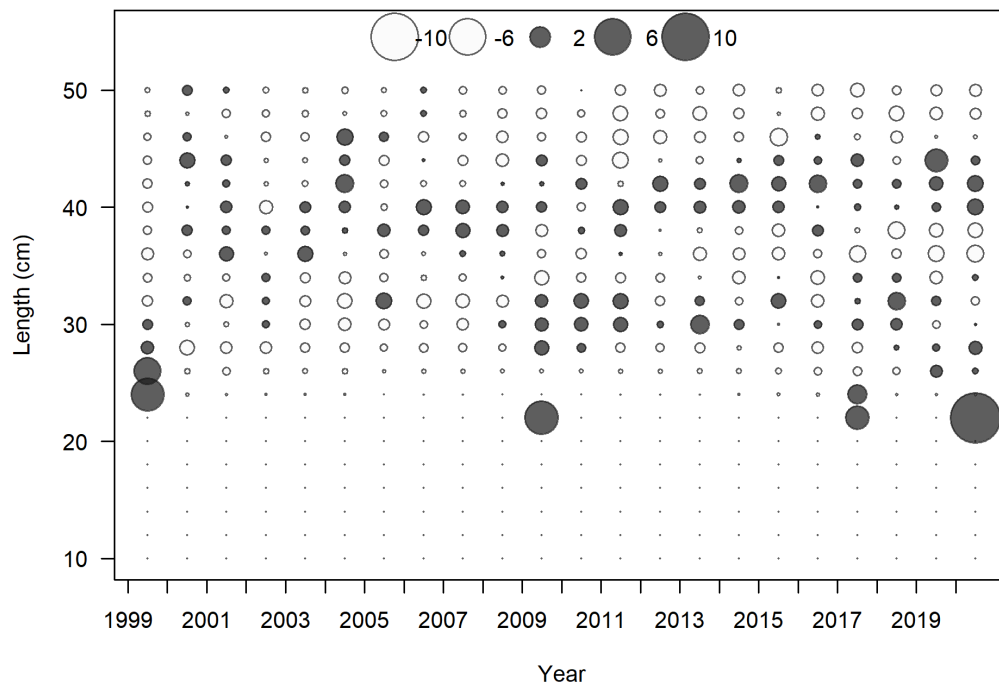


Figure 17: Pearson residuals for commercial fleet. Closed bubble are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

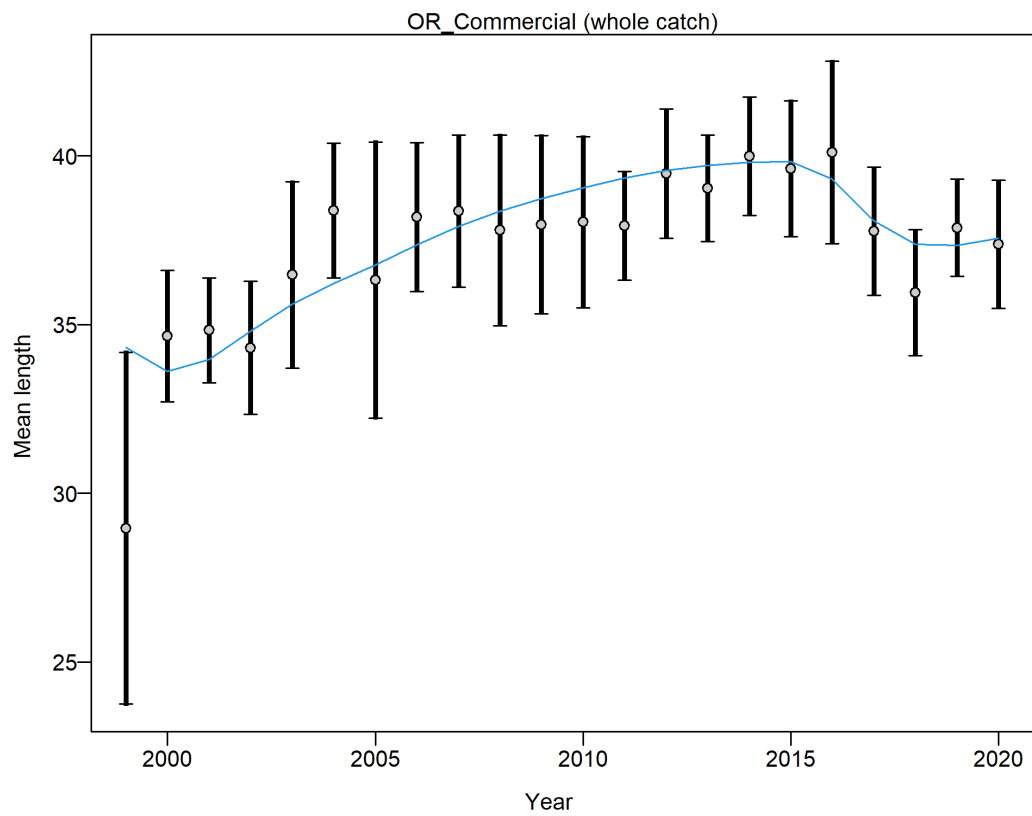


Figure 18: Model estimated mean length in cm (blue line) overlaid on mean length of commercial lengths (gray circles) with 95 percent confidence intervals based on current samples sizes.

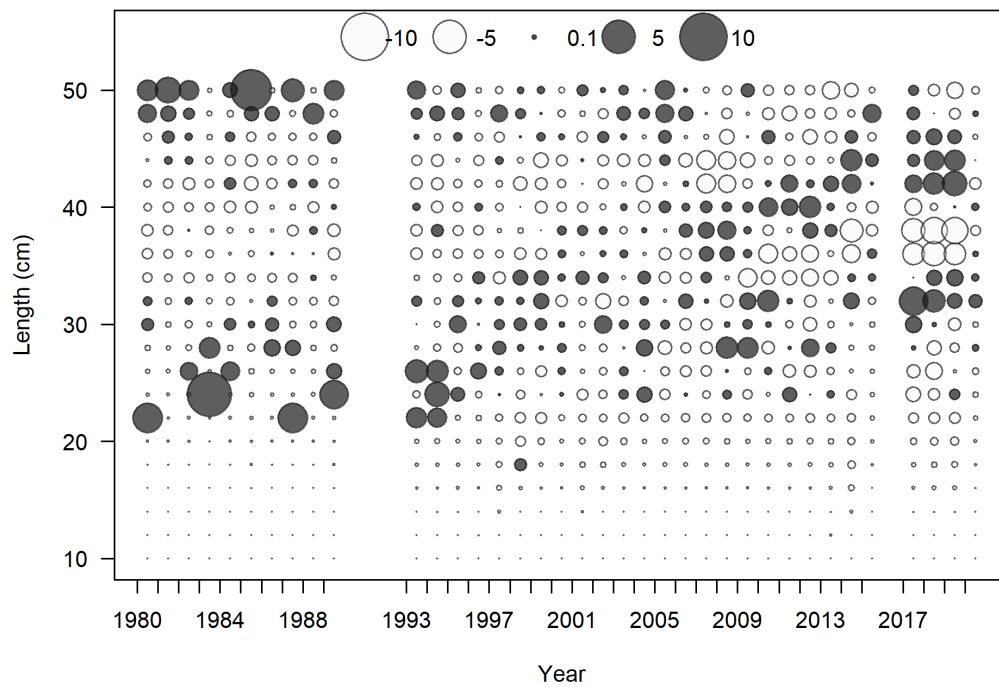


Figure 19: Pearson residuals for recreational fleet. Closed bubble are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

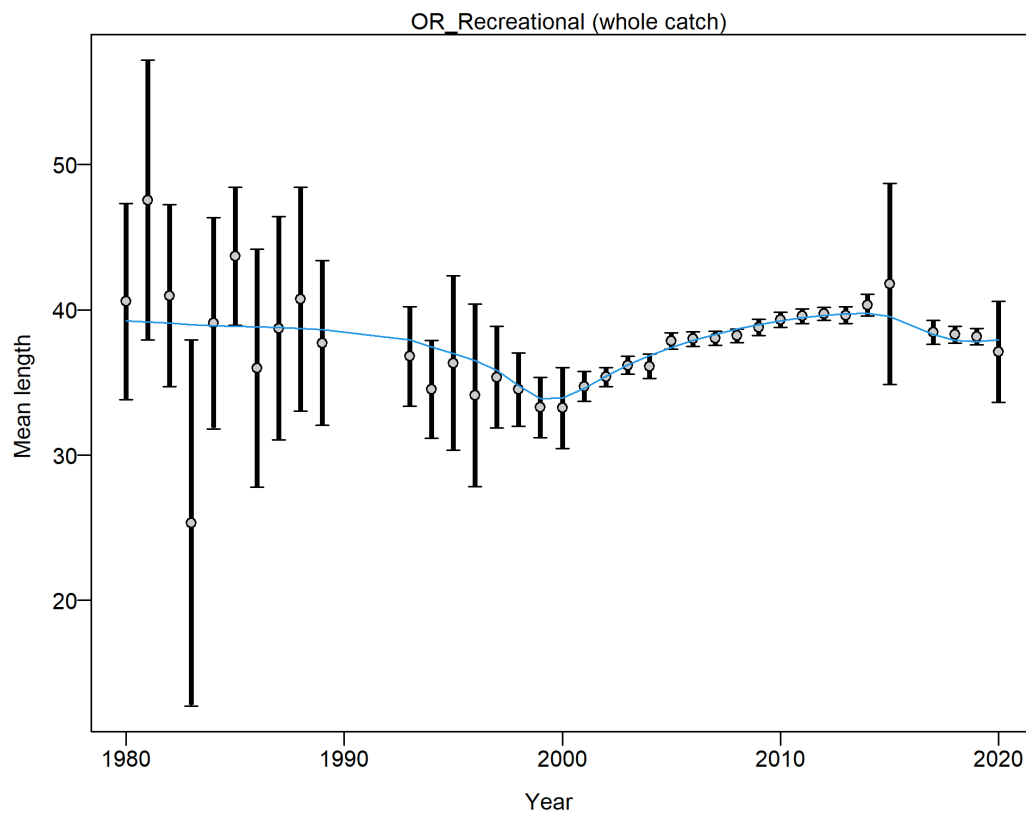


Figure 20: Model estimated mean length in cm (blue line) overlaid on mean length for recreational lengths (gray circles) with 95 percent confidence intervals based on current samples sizes.

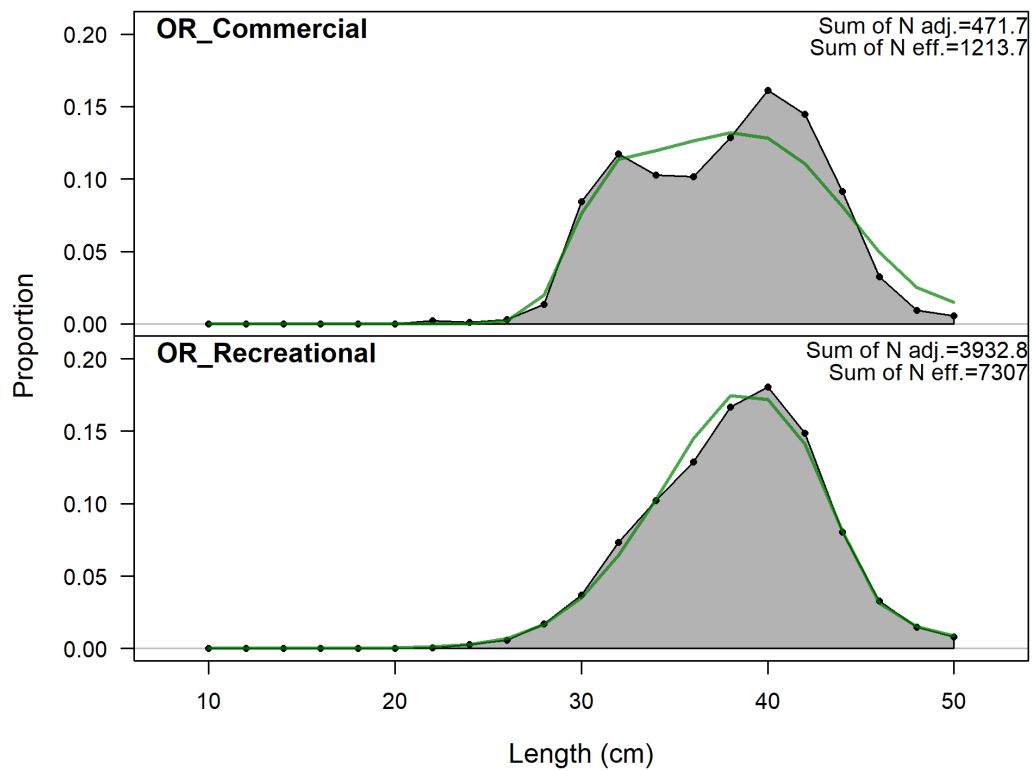


Figure 21: Aggregated length comps over all years.

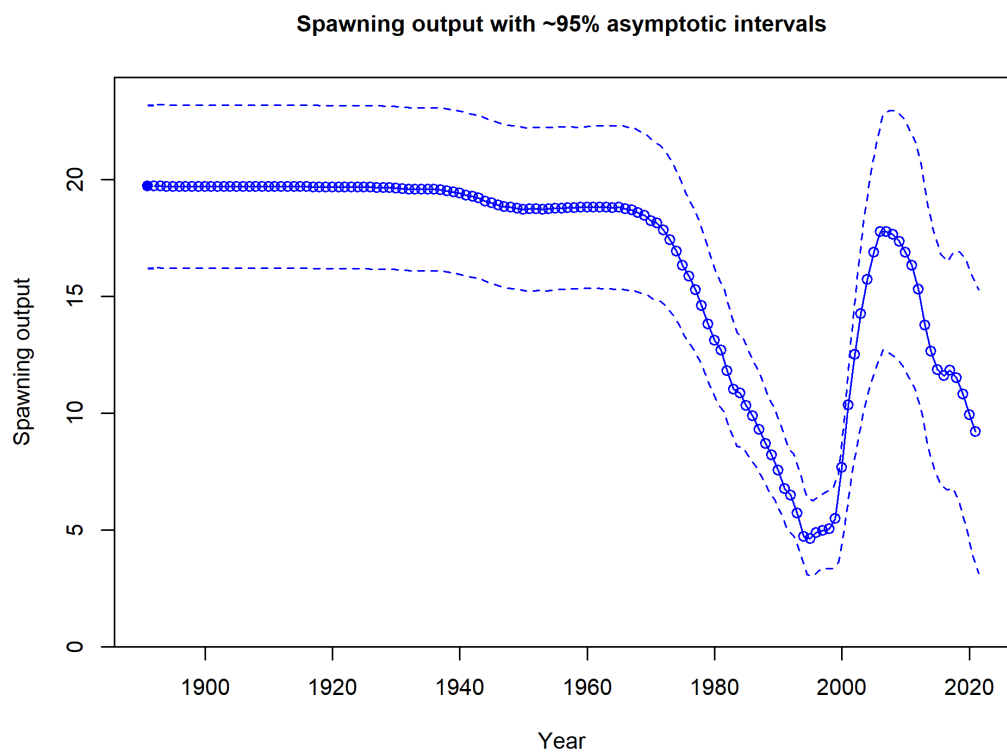


Figure 22: Estimated time series of spawning output (million of eggs).

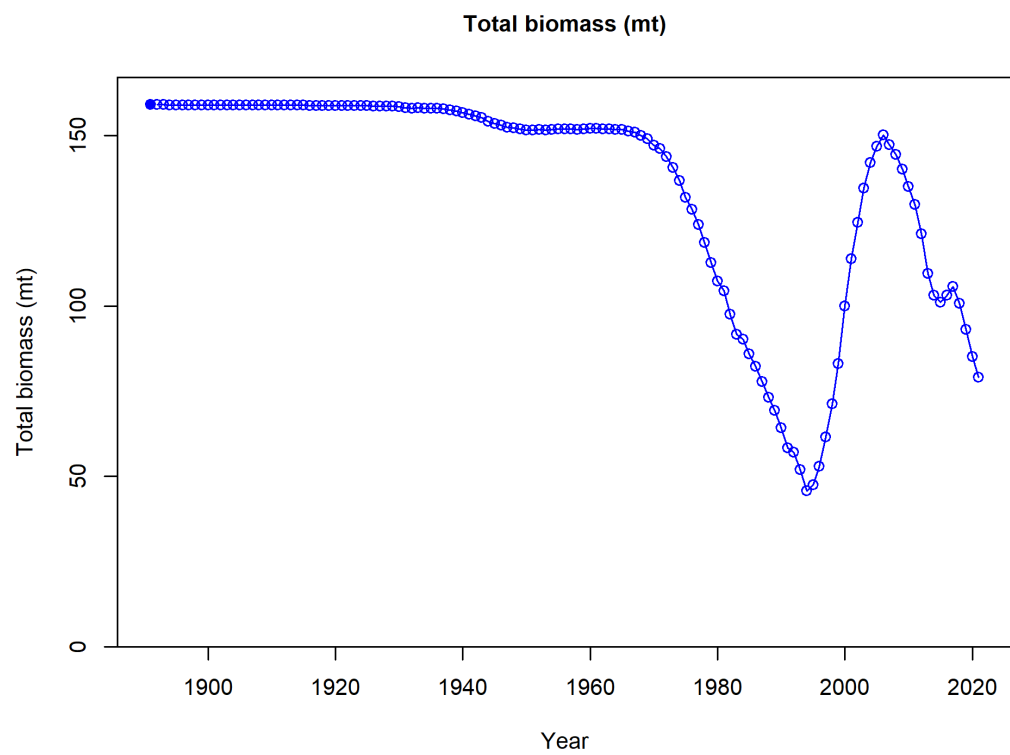


Figure 23: Estimated time series of total biomass.

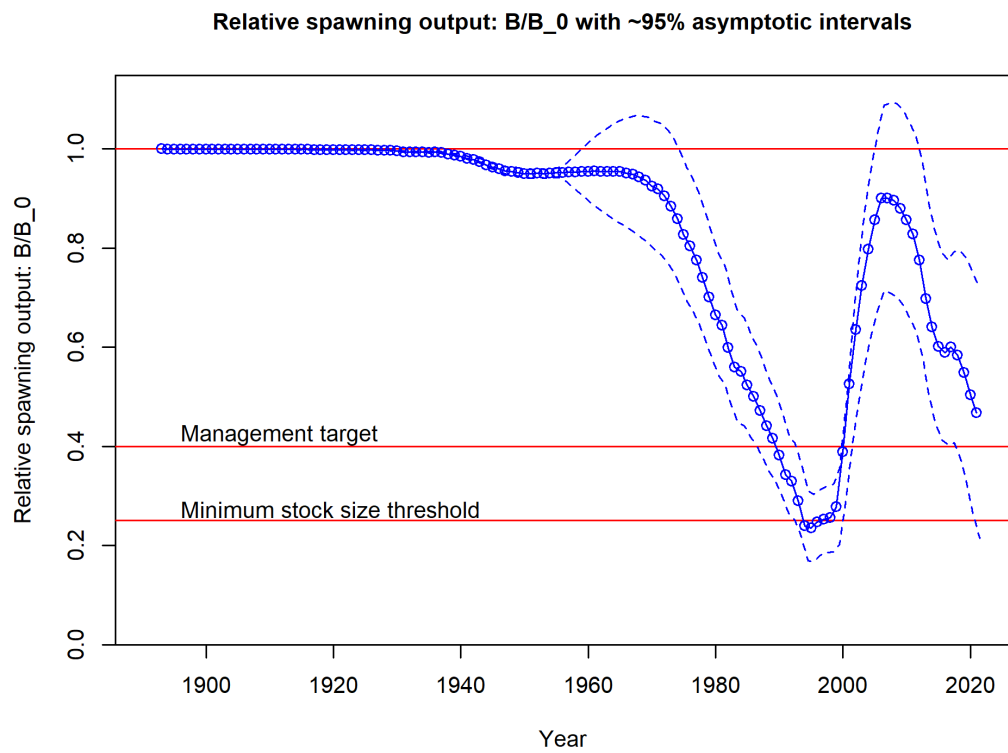


Figure 24: Estimated time series of relative spawning output.

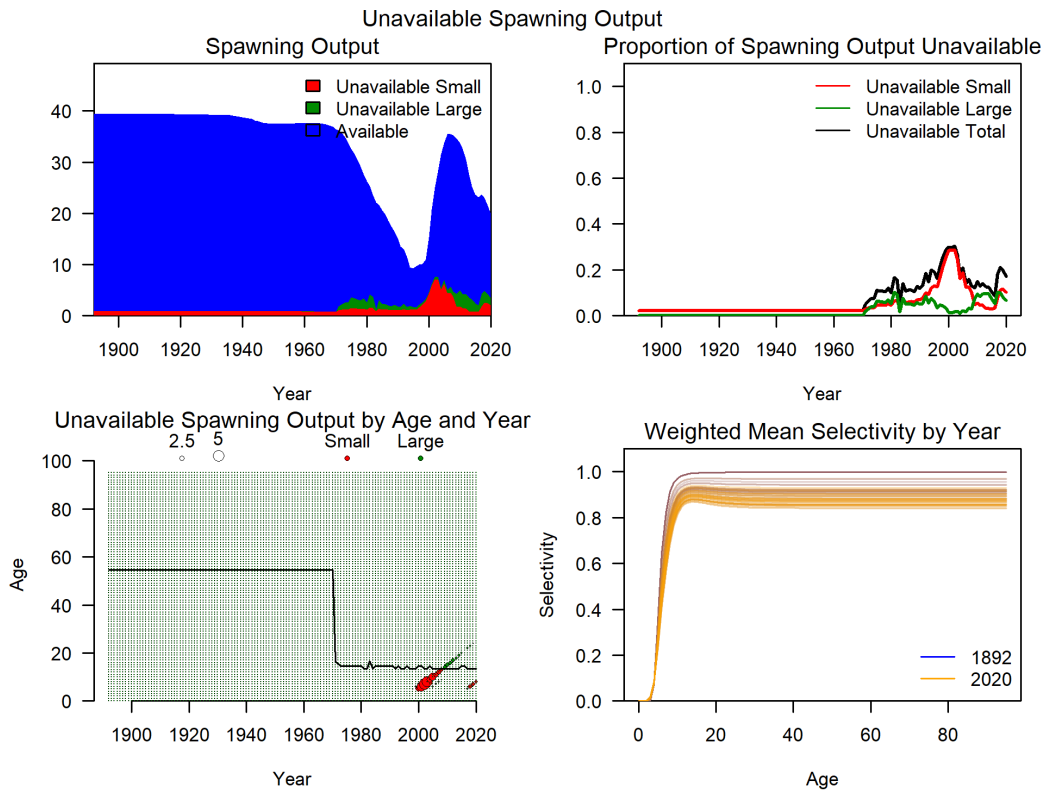


Figure 25: Proportion of biomass unavailable due to selectivity for small and large fish.

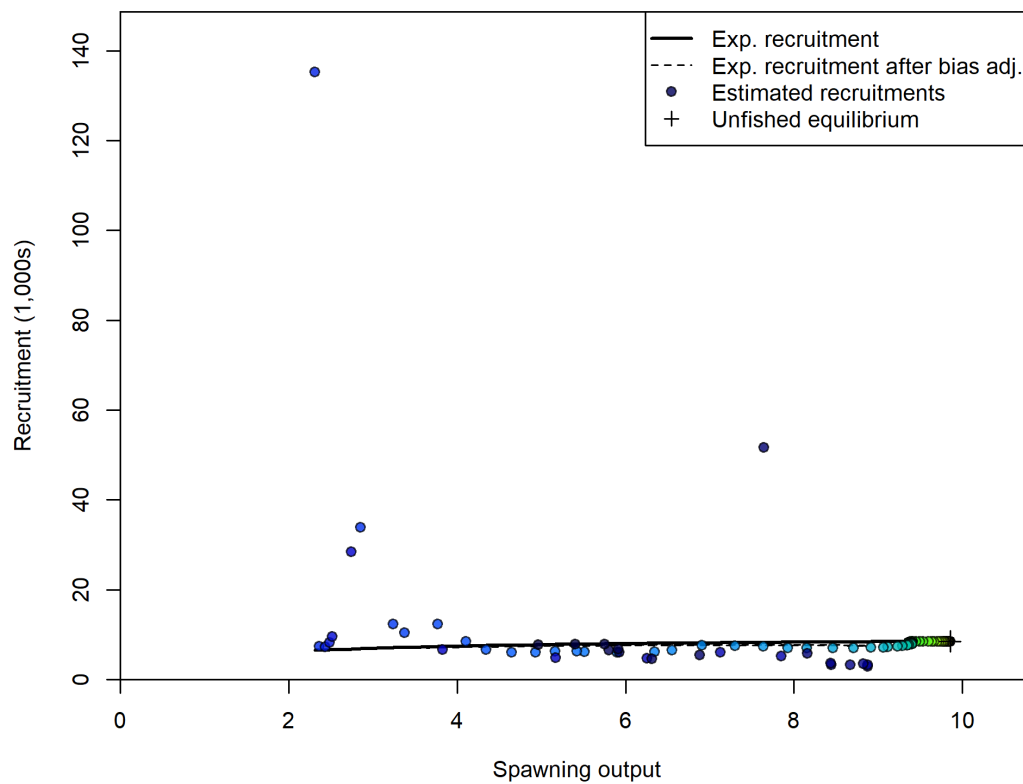


Figure 26: Stock-recruit curve. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

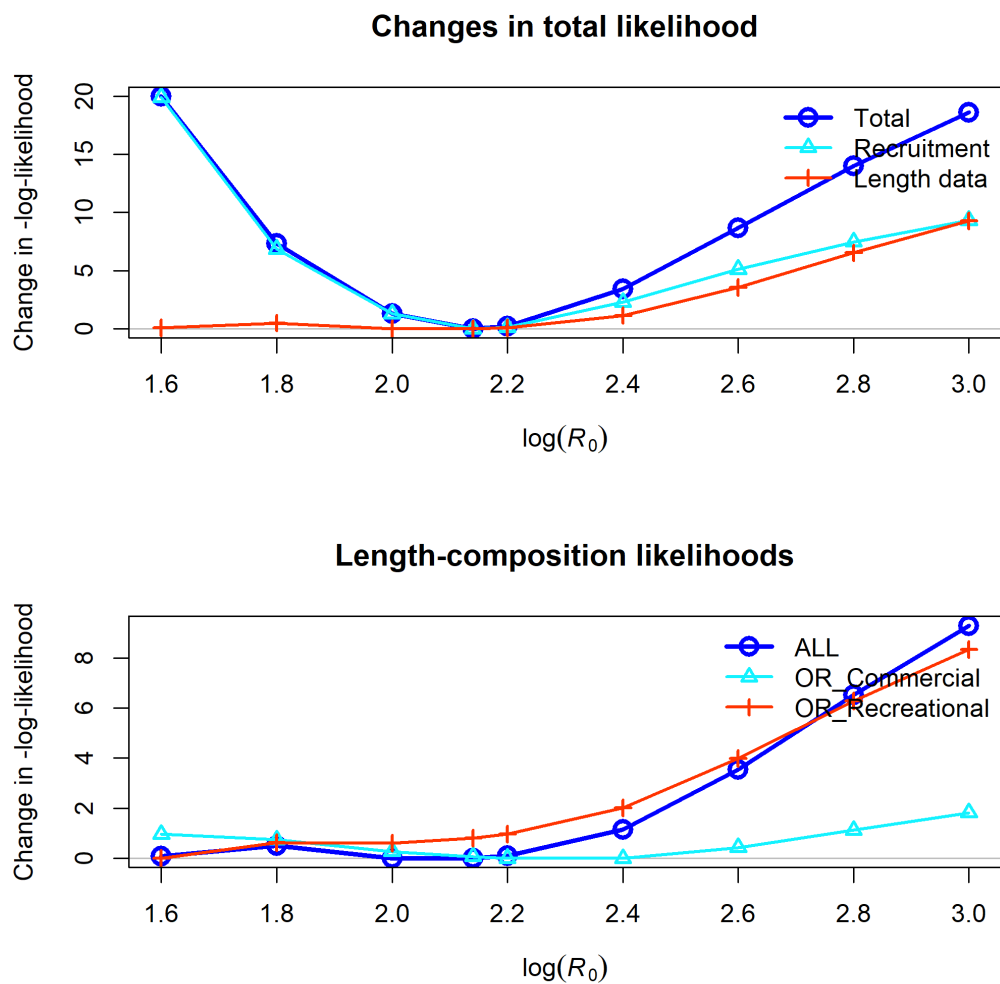


Figure 27: Change in the negative log-likelihood across a range of $\ln(R_0)$ values.

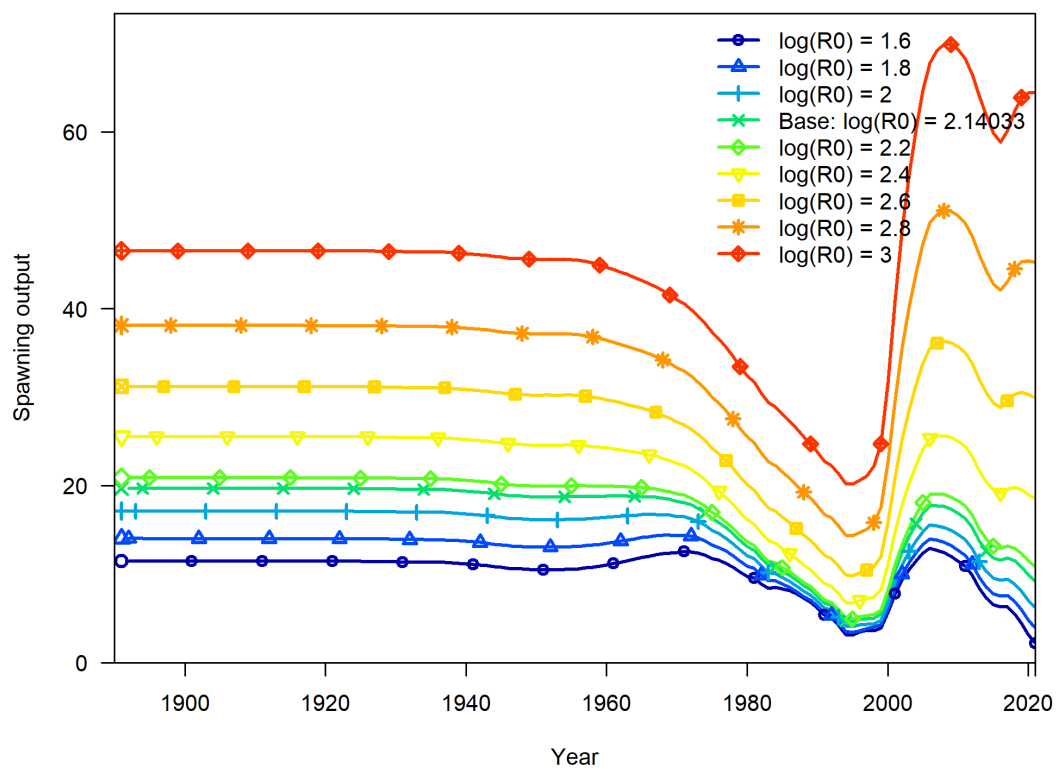


Figure 28: Change in the estimate of spawning output across a range of $\ln(R_0)$ values.

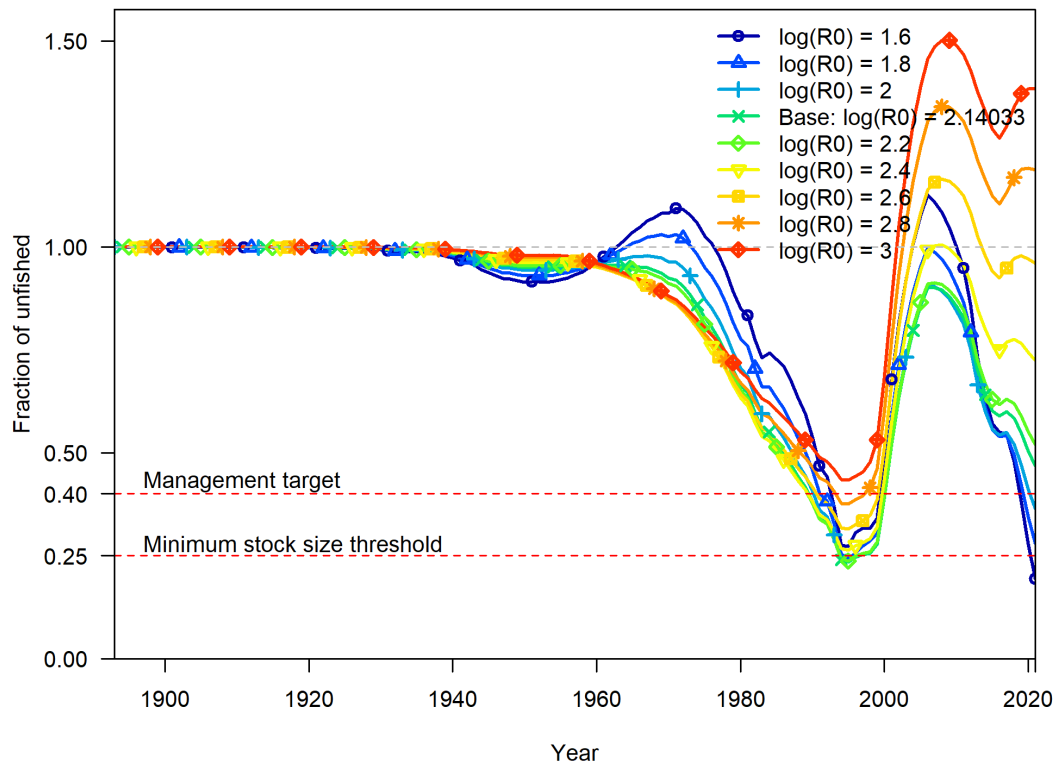


Figure 29: Change in the estimate of fraction unfished across a range of $\ln(R_0)$ values.

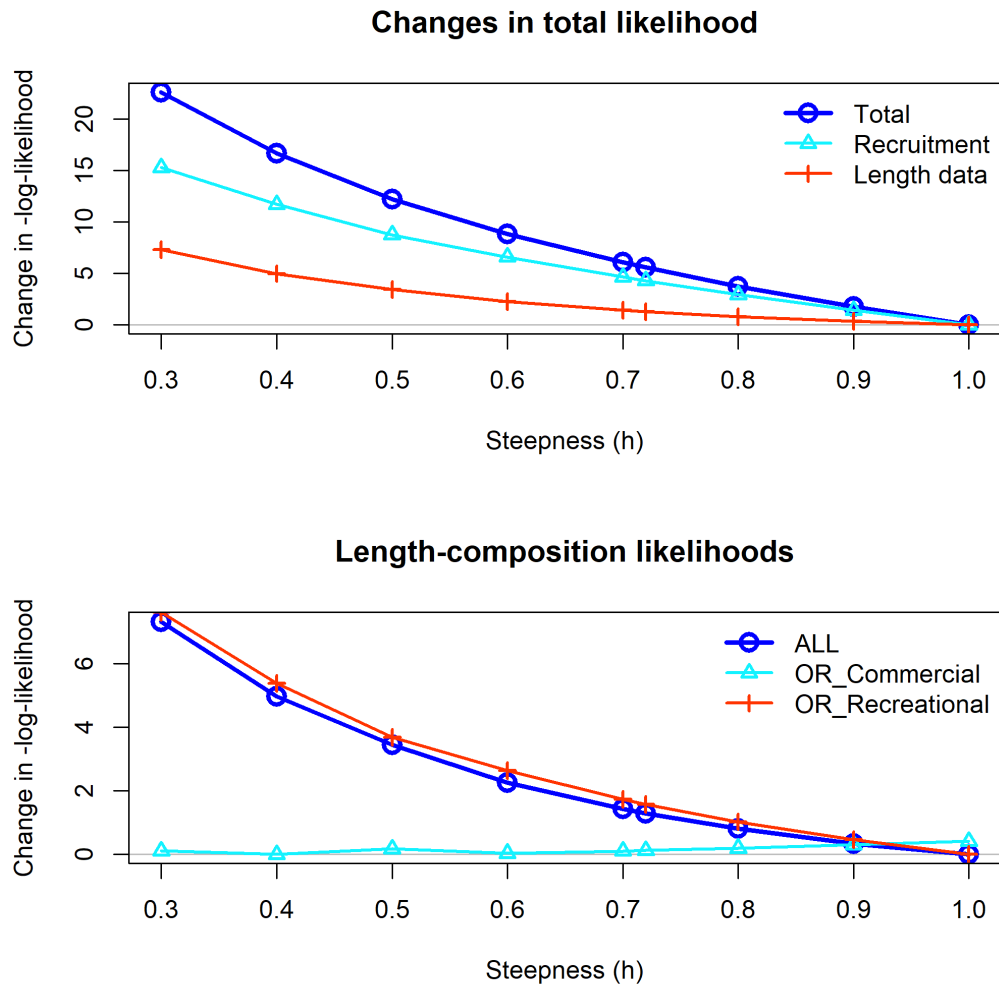


Figure 30: Change in the negative log-likelihood across a range of steepness values.

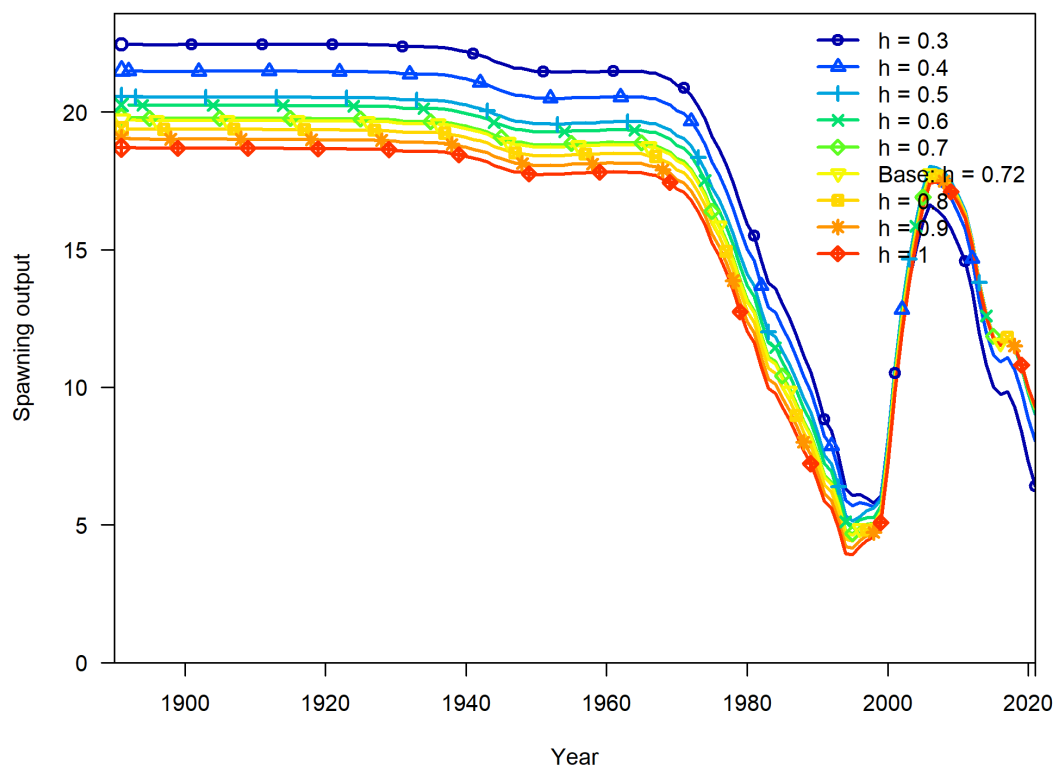


Figure 31: Change in the estimate of spawning output across a range of steepness values.

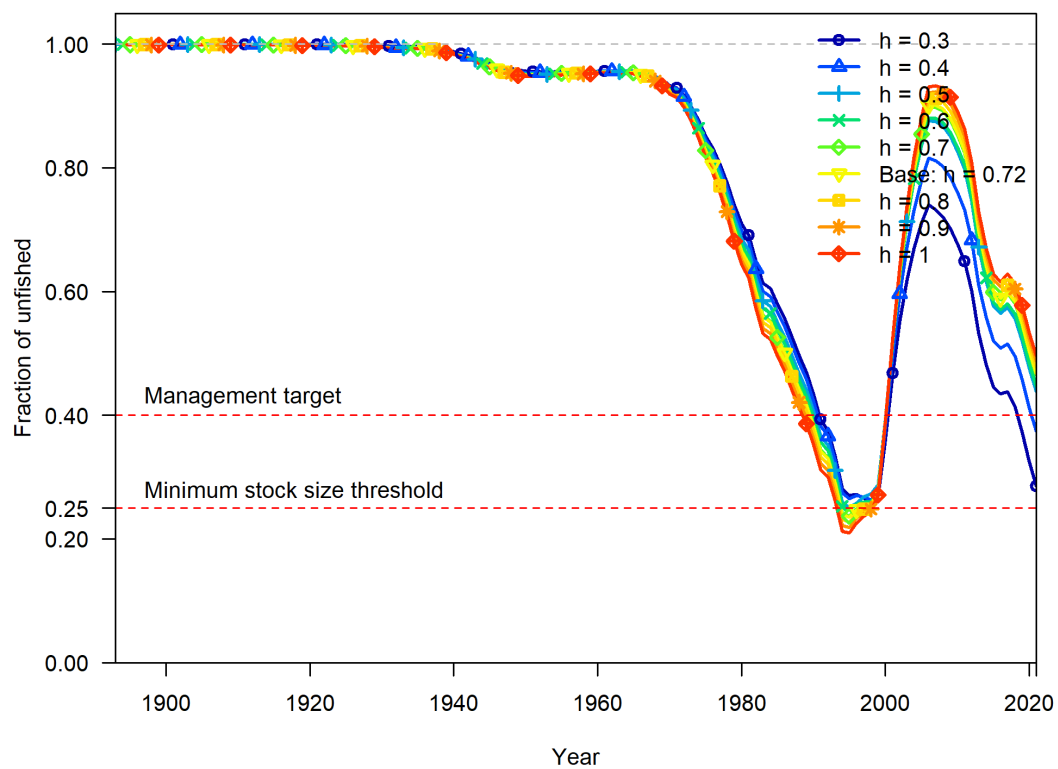


Figure 32: Change in the estimate of fraction unfished across a range of steepness values.

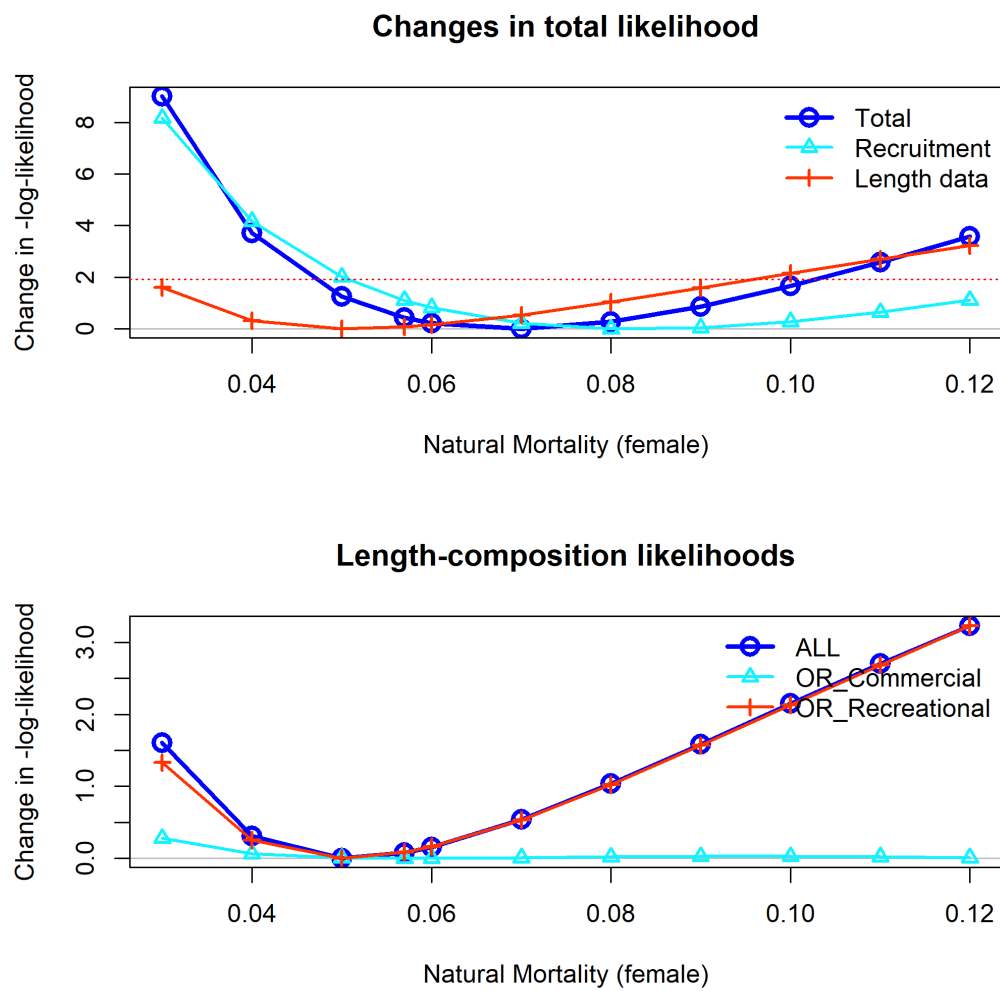


Figure 33: Change in the negative log-likelihood across a range of natural mortality values.

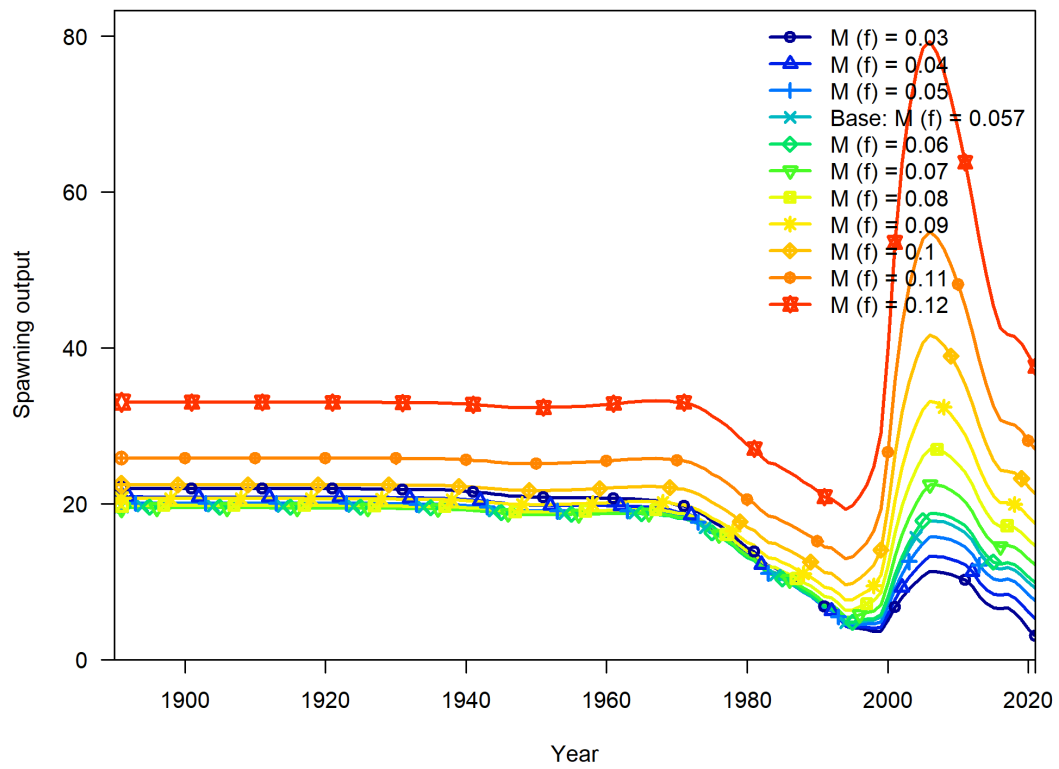


Figure 34: Change in the estimate of spawning output across a range of natural mortality values.

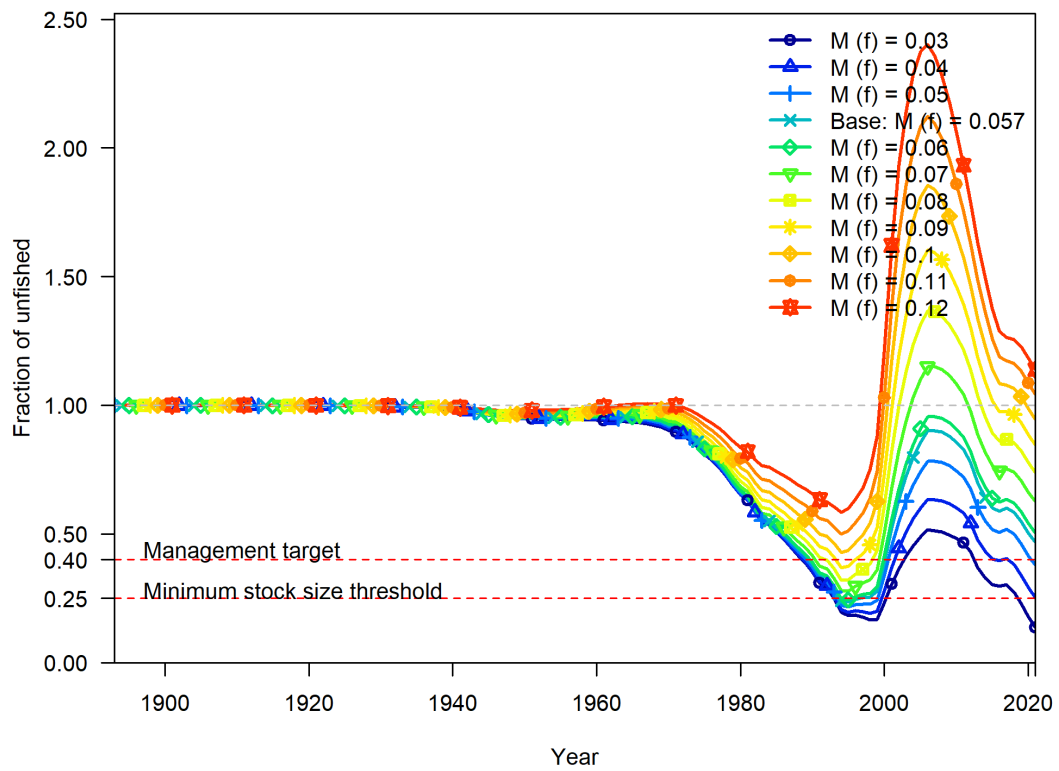


Figure 35: Change in the estimate of fraction unfished across a range of natural values.

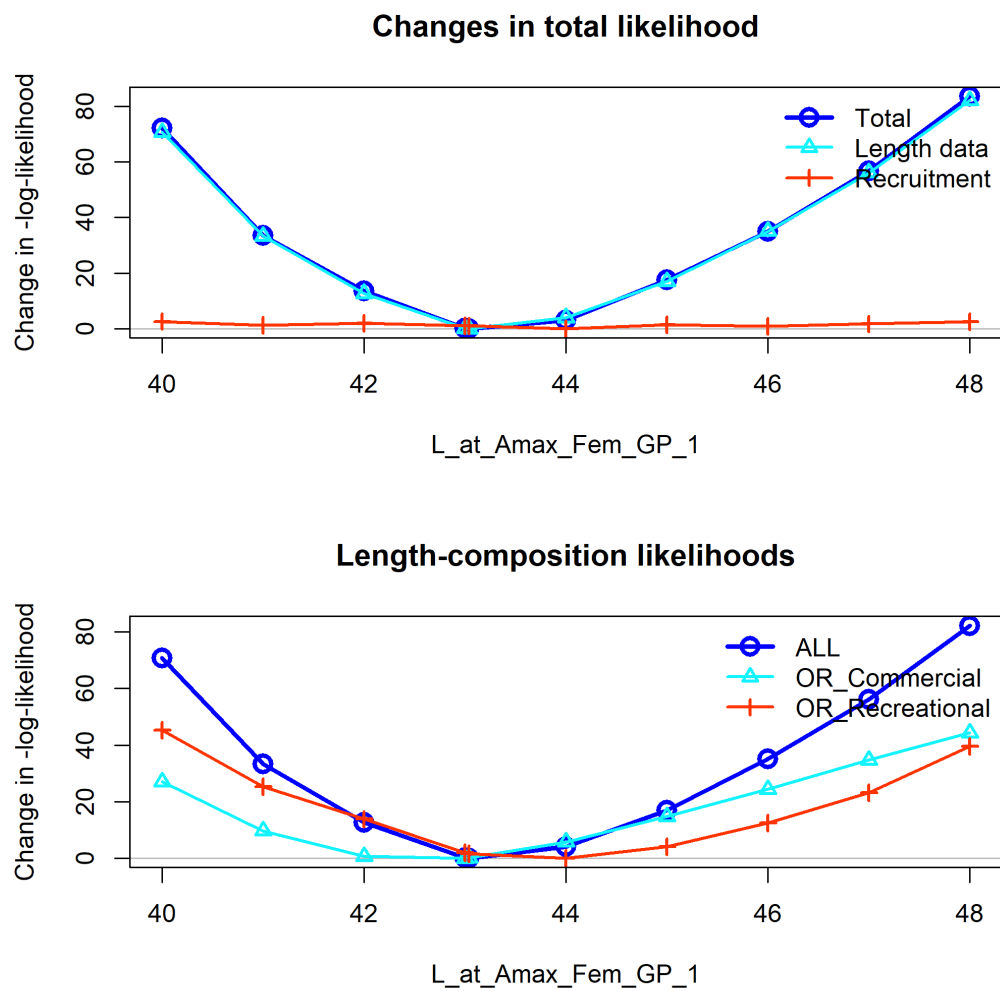


Figure 36: Change in the negative log-likelihood across a range of maximum length values.

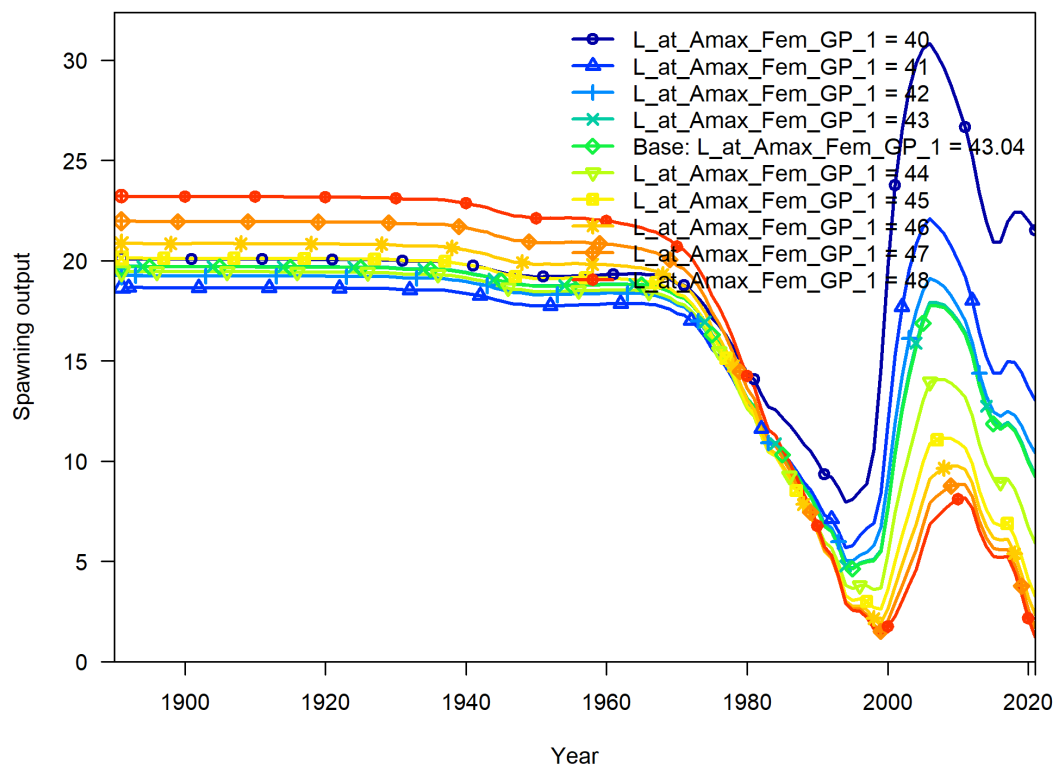


Figure 37: Change in the estimate of spawning output across a range of maximum length values.

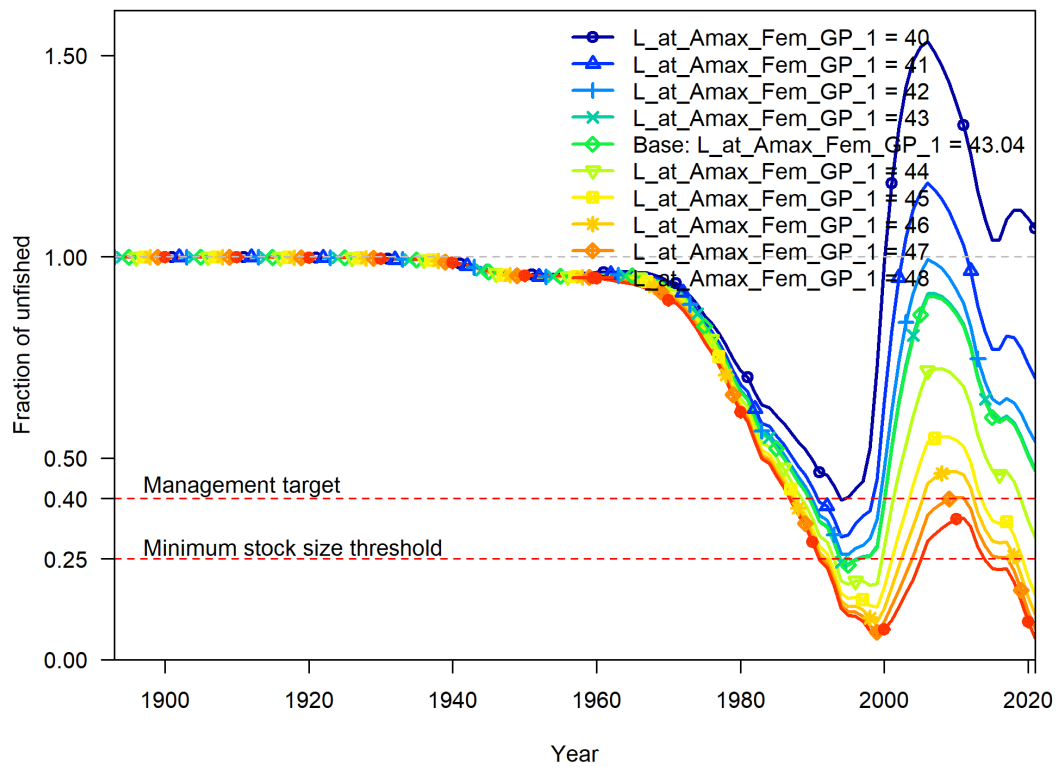


Figure 38: Change in the estimate of fraction unfished across a range of maximum length values.

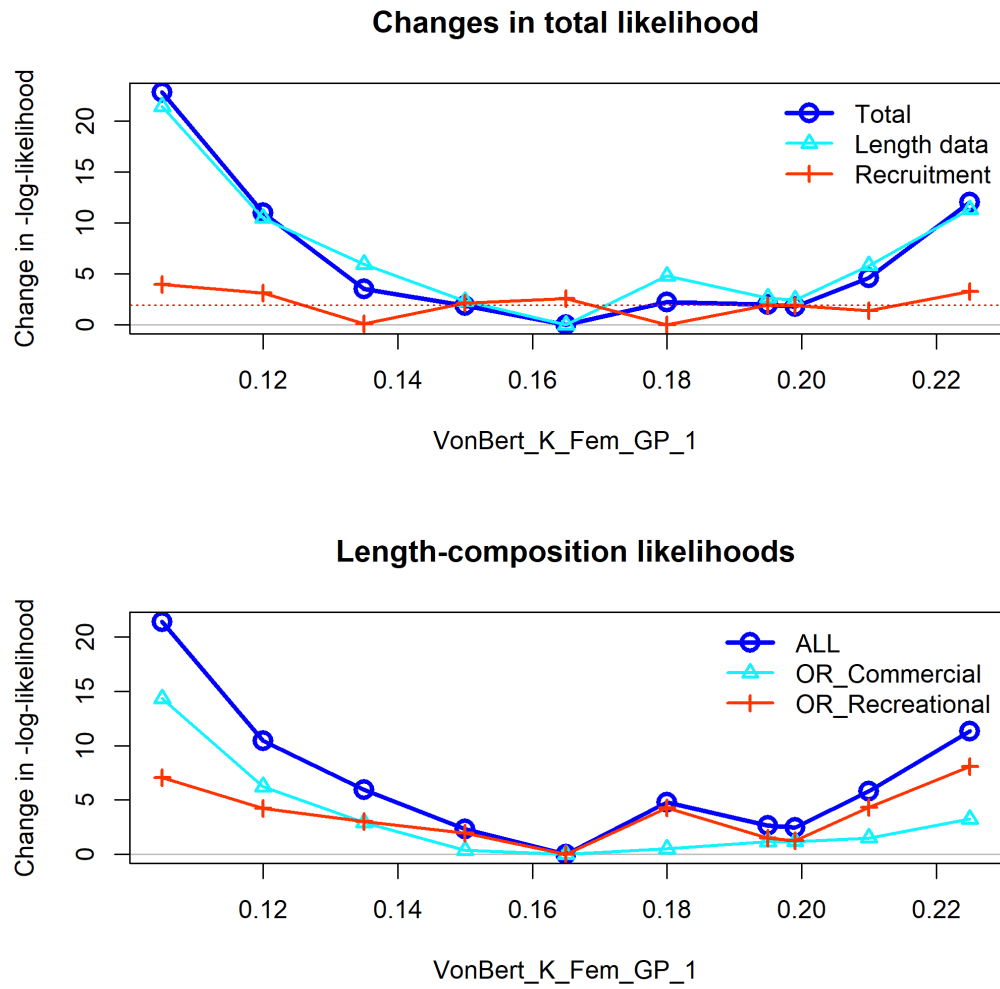


Figure 39: Change in the negative log-likelihood across a range of k values.

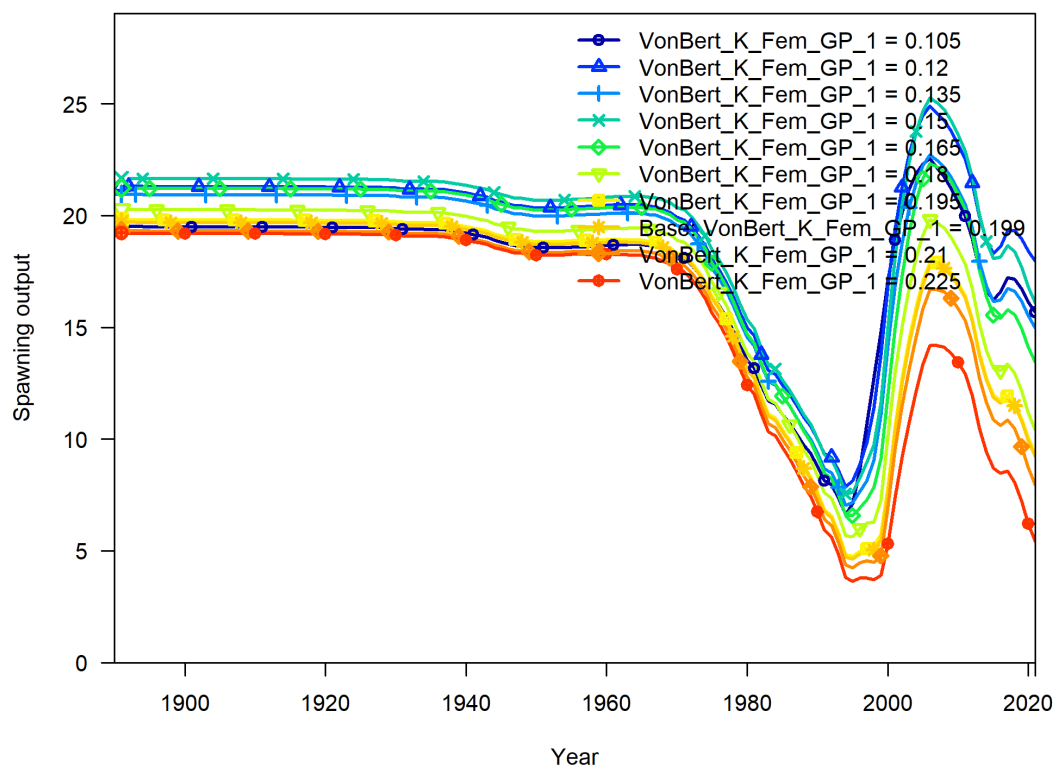


Figure 40: Change in the estimate of spawning output across a range of k values.

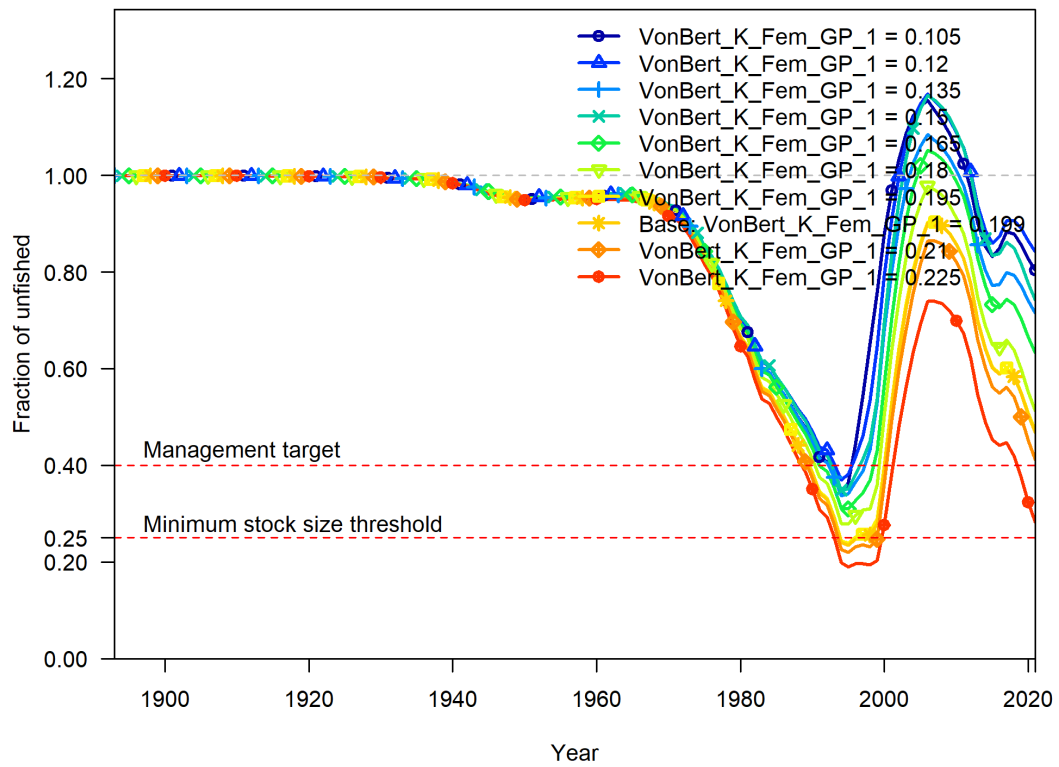


Figure 41: Change in the estimate of fraction unfished across a range of k values.

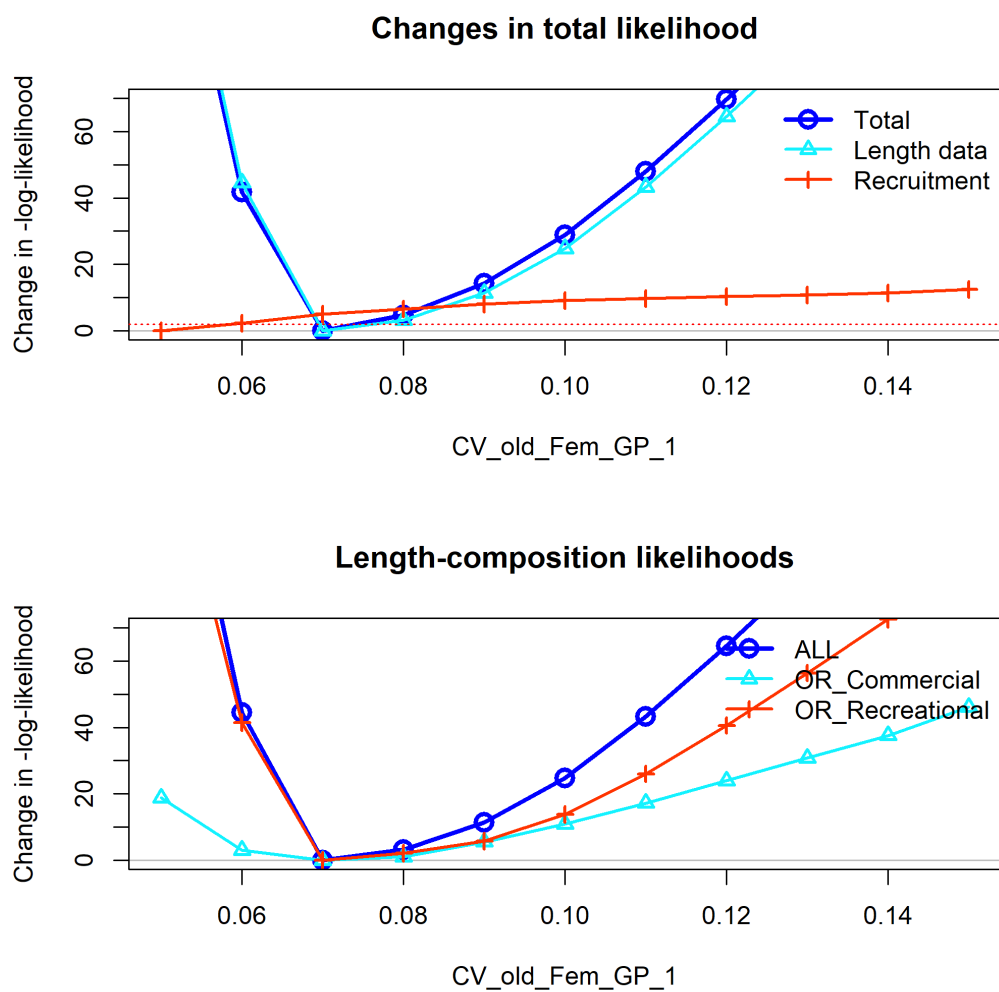


Figure 42: Change in the negative log-likelihood across a range of CV at maximum length values.

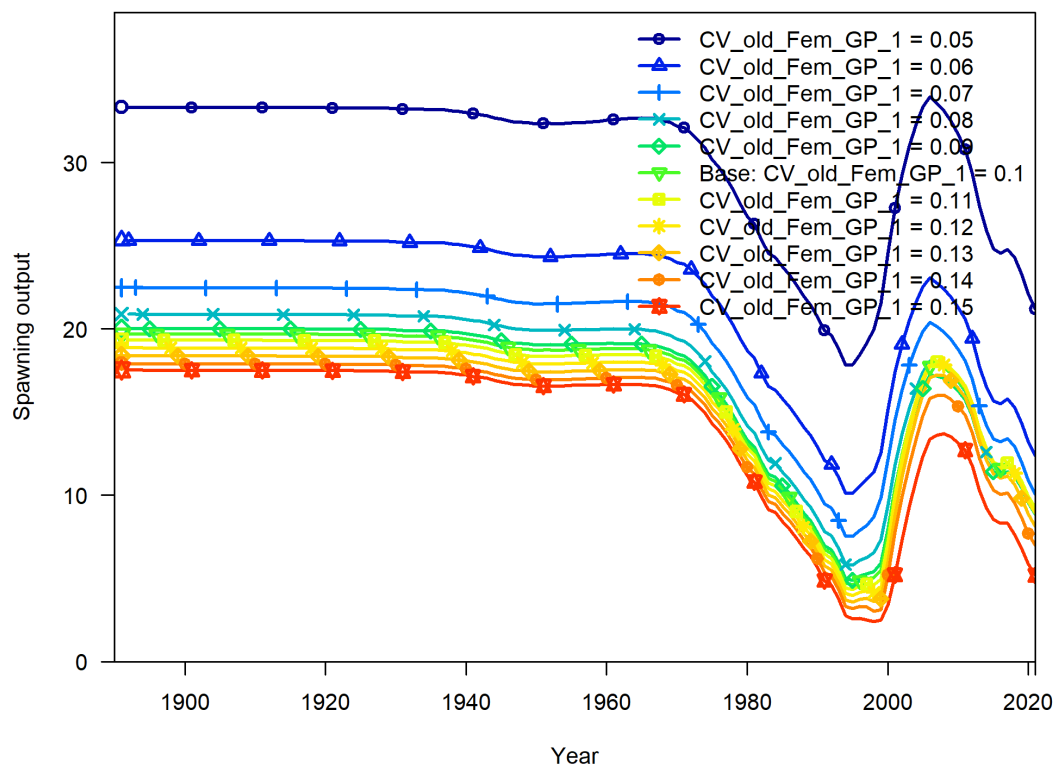


Figure 43: Change in the estimate of spawning output across a range of CV at maximum length values.

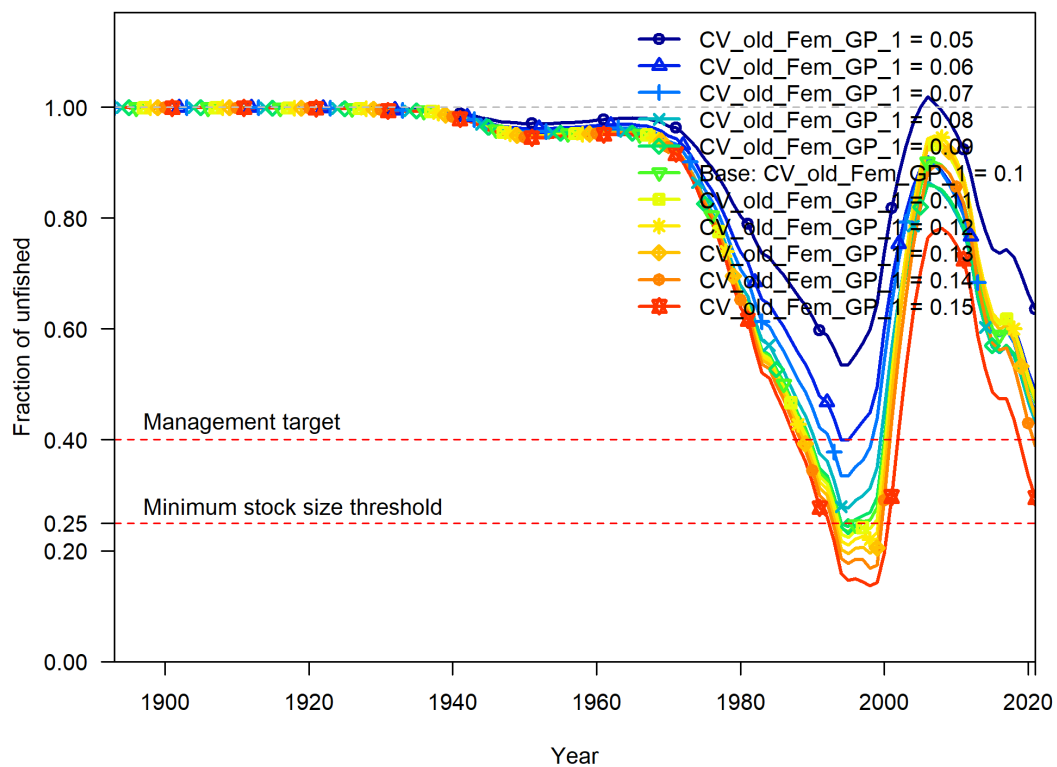


Figure 44: Change in the estimate of fraction unfished across a range of CV at maximum length values.

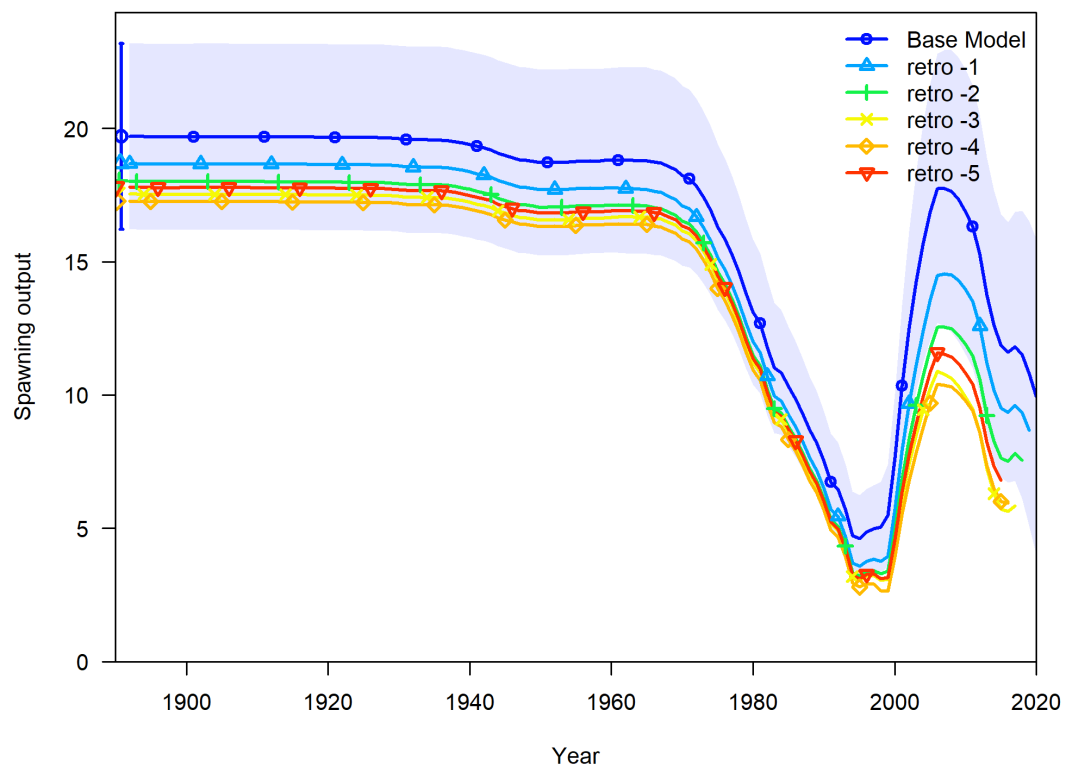


Figure 45: Change in the estimate of spawning output when the most recent 5 years of data are removed sequentially.

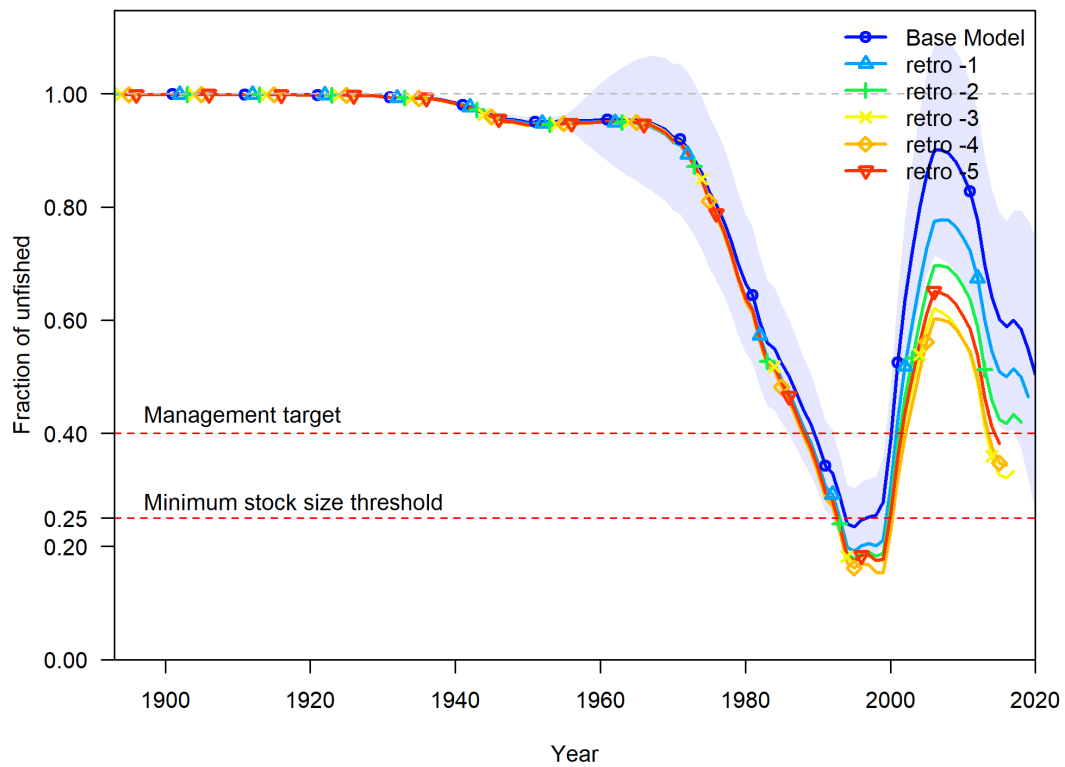


Figure 46: Change in the estimate of fraction unfished when the most recent 5 years of data are removed sequentially.

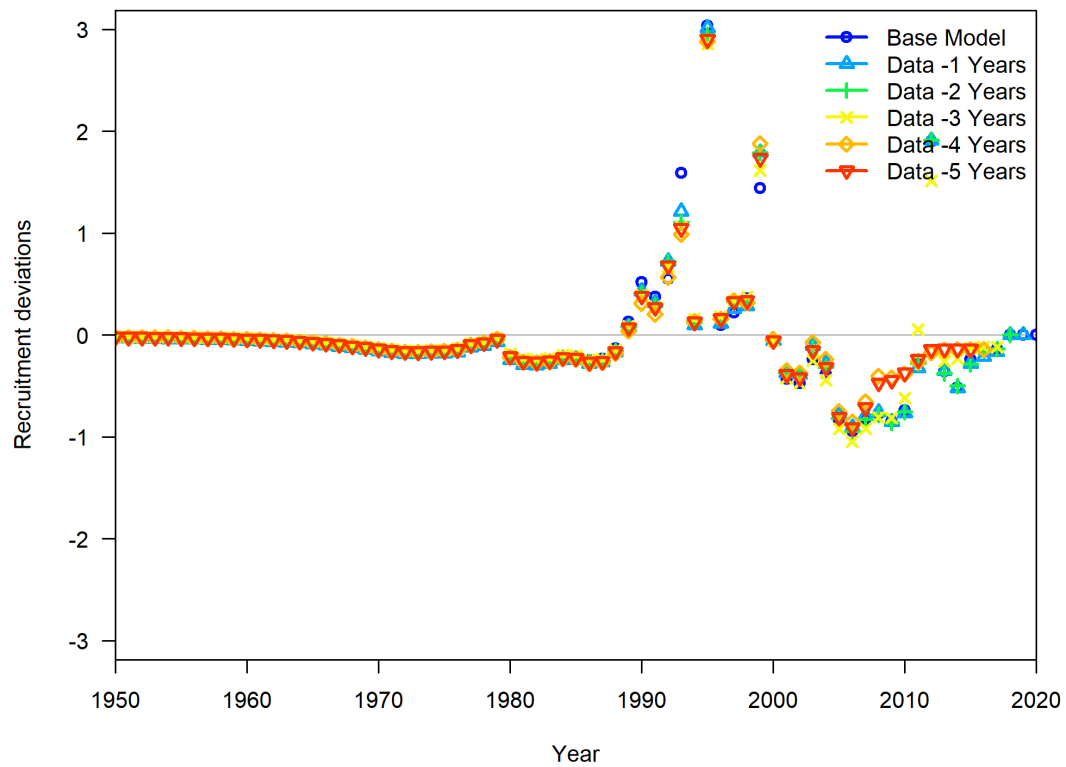


Figure 47: Change in the estimate of annual recruitment deviations when the most recent 5 years of data are removed sequentially.

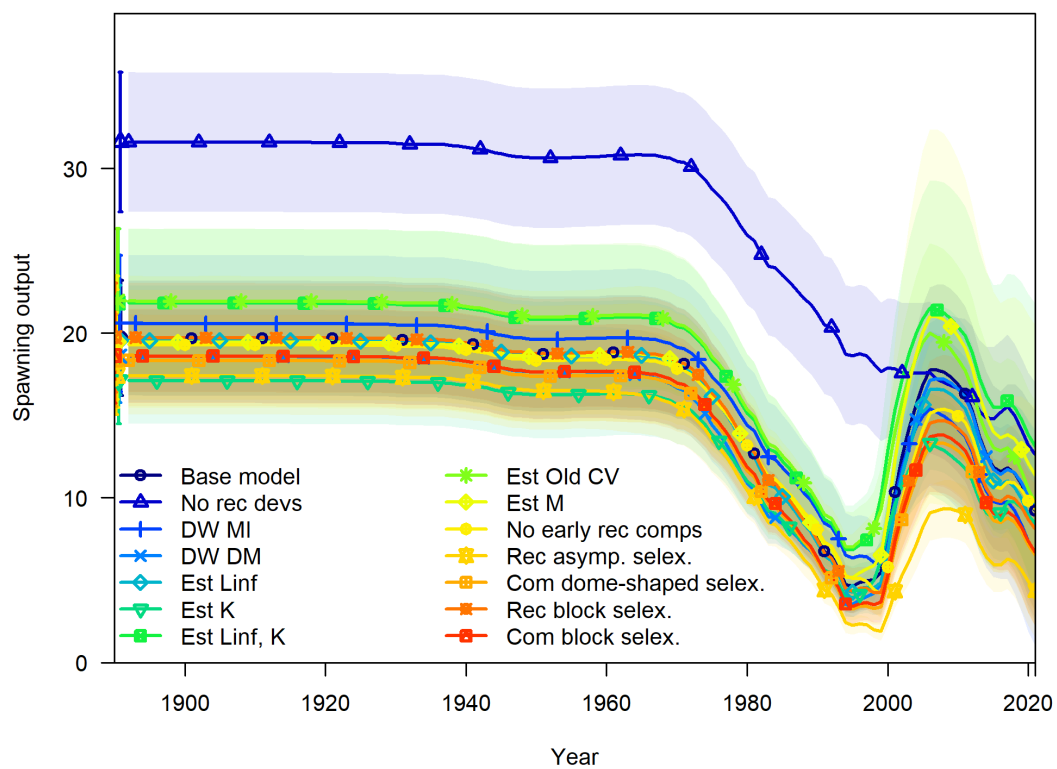


Figure 48: Change in estimated spawning output by sensitivity.

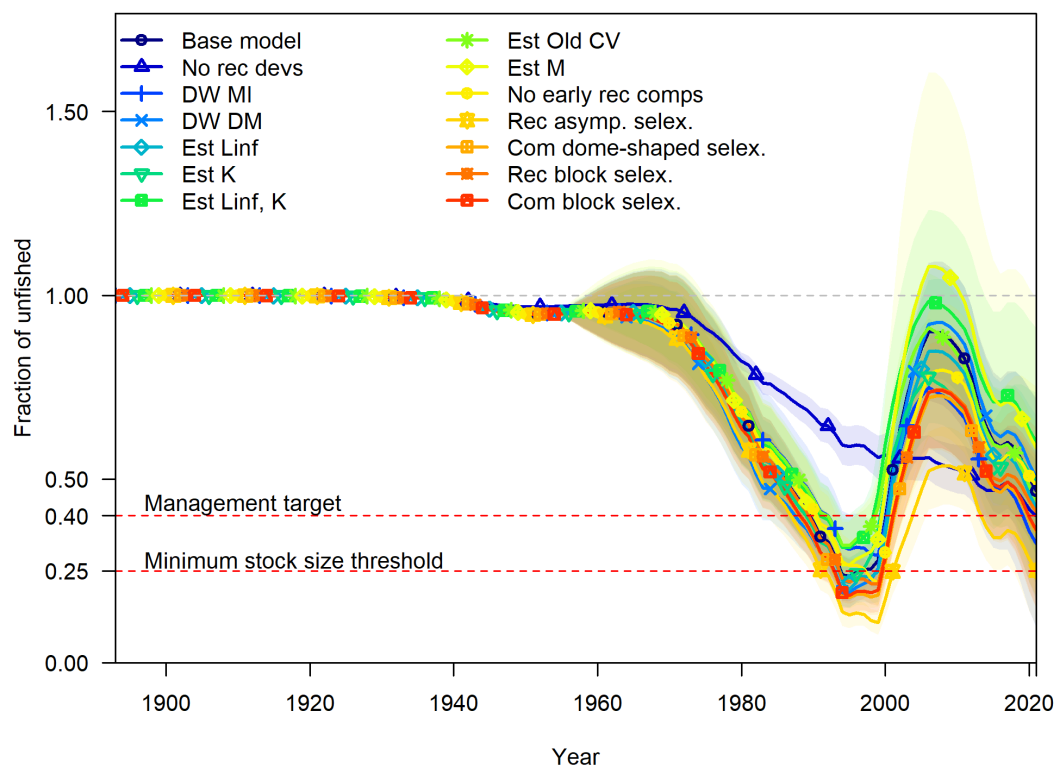


Figure 49: Change in estimated fraction unfished by sensitivity.

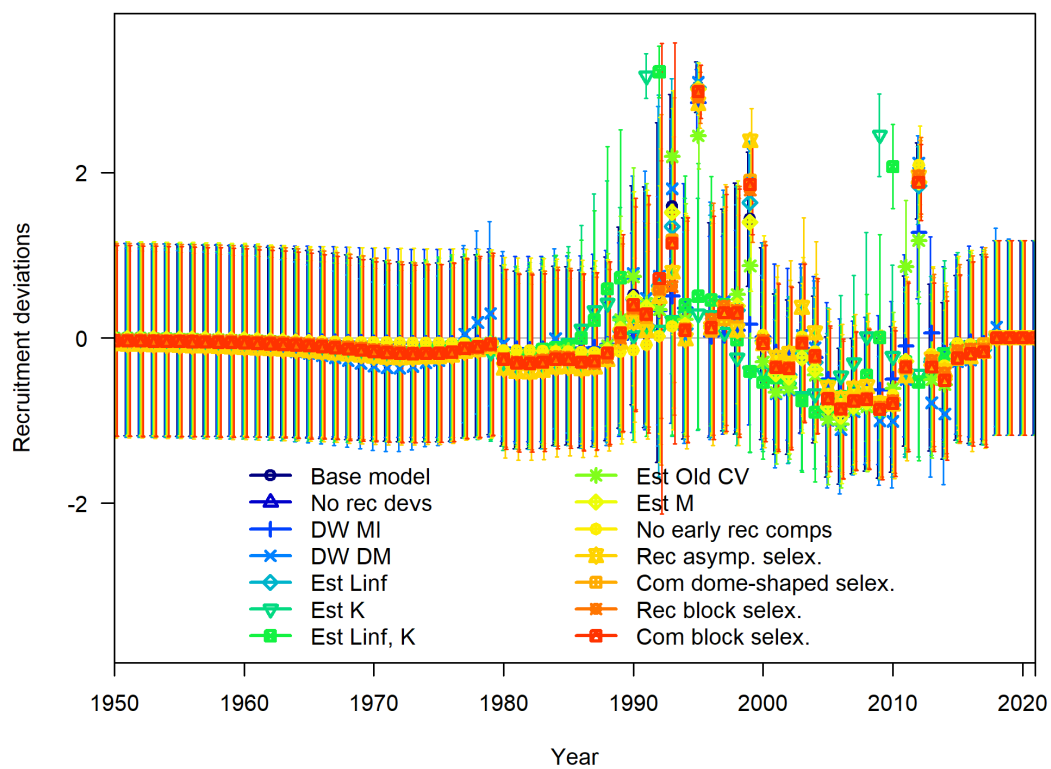


Figure 50: Change in estimated annual recruitment deviation by sensitivity.

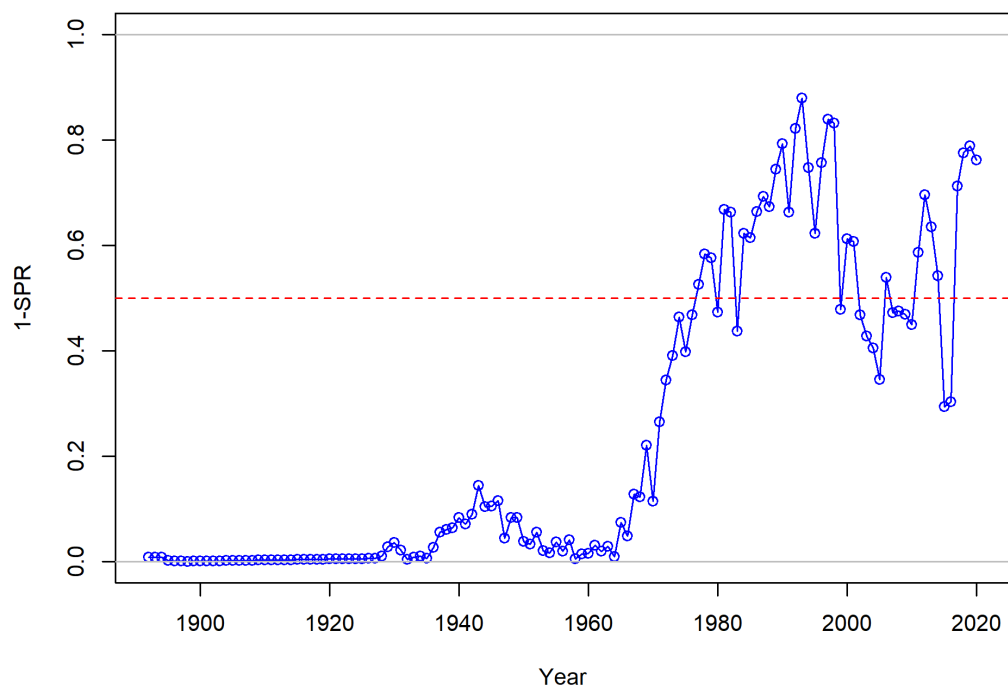


Figure 51: Estimated 1 - relative spawning ratio (SPR) by year.

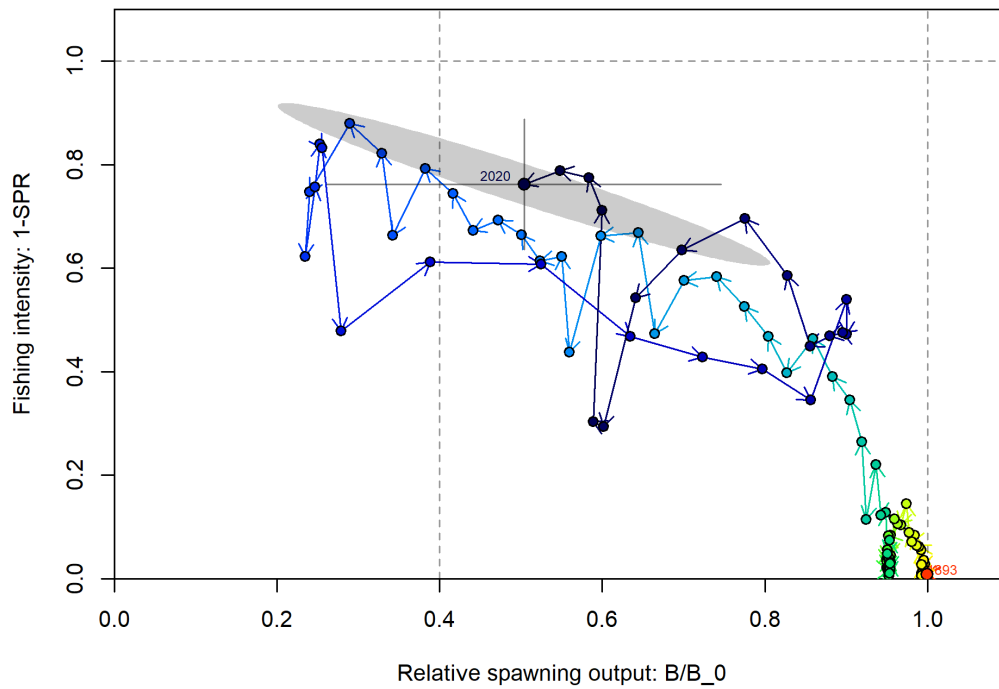


Figure 52: Phase plot showing the fraction unfished versus fishing intensity for each year. Each point shows the spawning output relative to the unfished spawning output and the SPR ratio for each year. Lines through the final point show the 95 percent confidence intervals based on the asymptotic uncertainty for each dimension. The shaded ellipse is a 95 percent confidence region which accounts for the estimated correlations between the spawning output and SPR ratios.

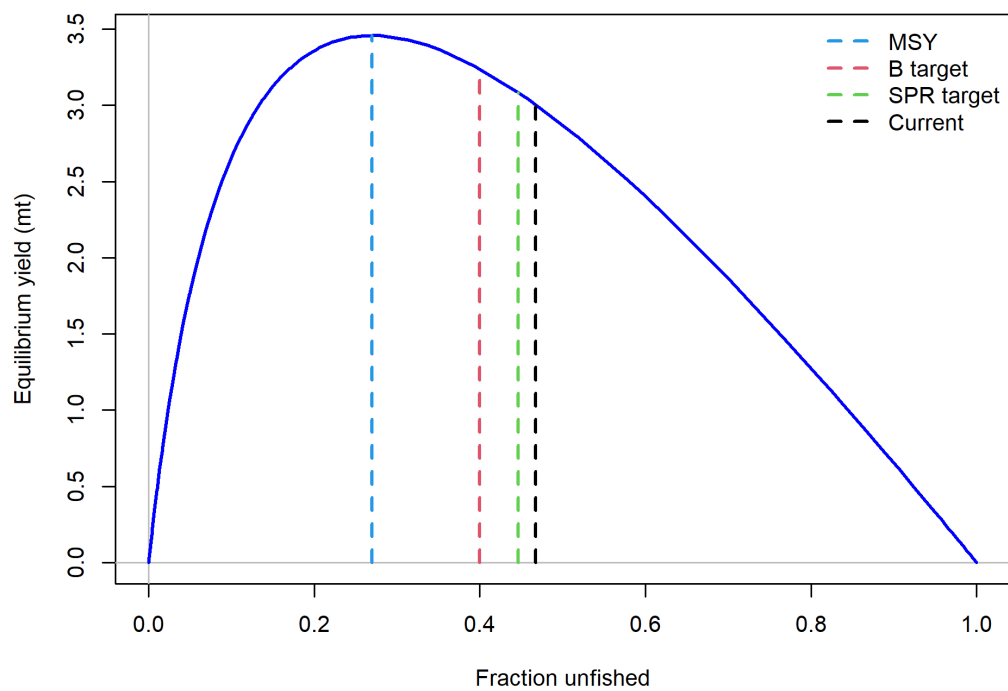


Figure 53: Equilibrium yield curve for the base case model. Values are based on the 2020 fishery selectivity and with steepness fixed at 0.72.

10 Appendix

10.1 Appendix A: Detailed Fit to Length Composition Data

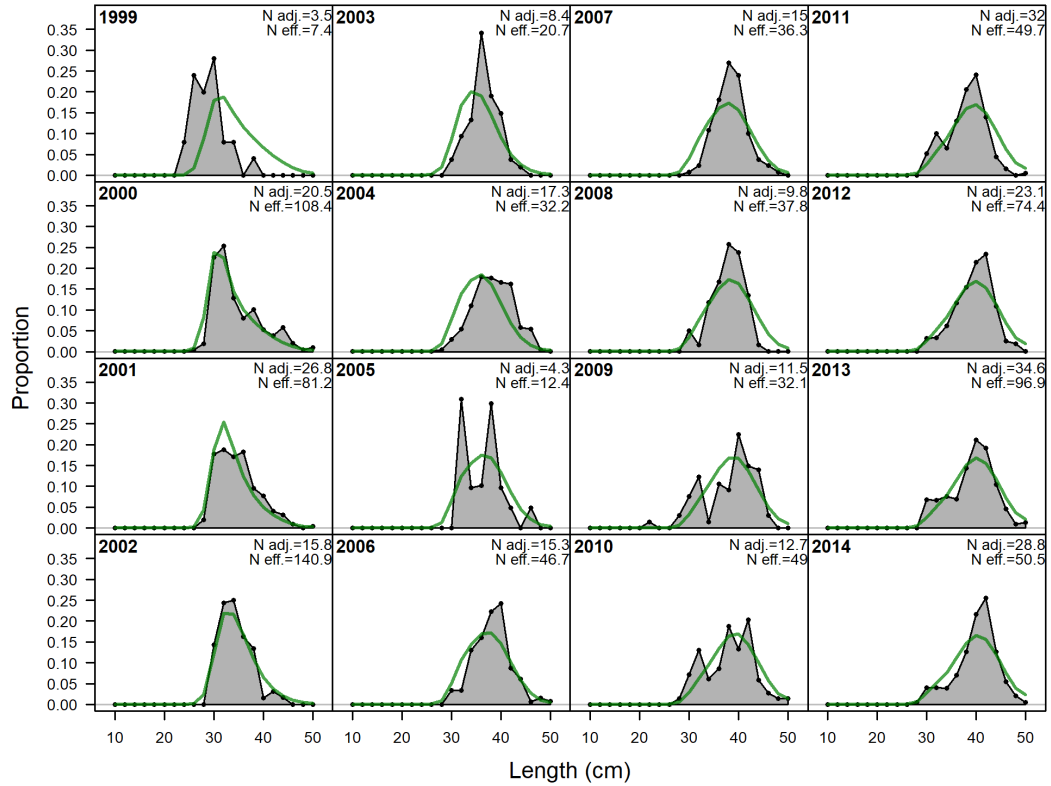


Figure 54: Length comps, whole catch, OR_Commercial (plot 1 of 2). 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Iannelli tuning method.

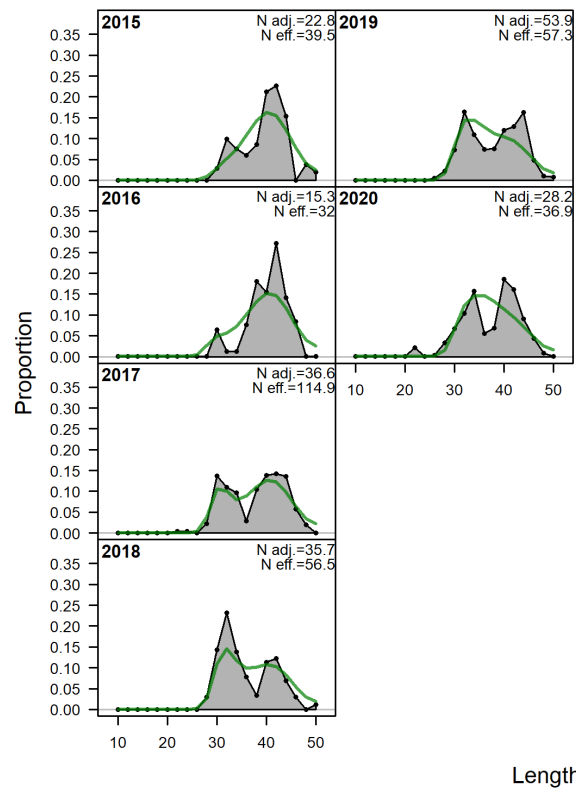


Figure 55: Length comps, whole catch, OR_Commercial (plot 2 of 2).

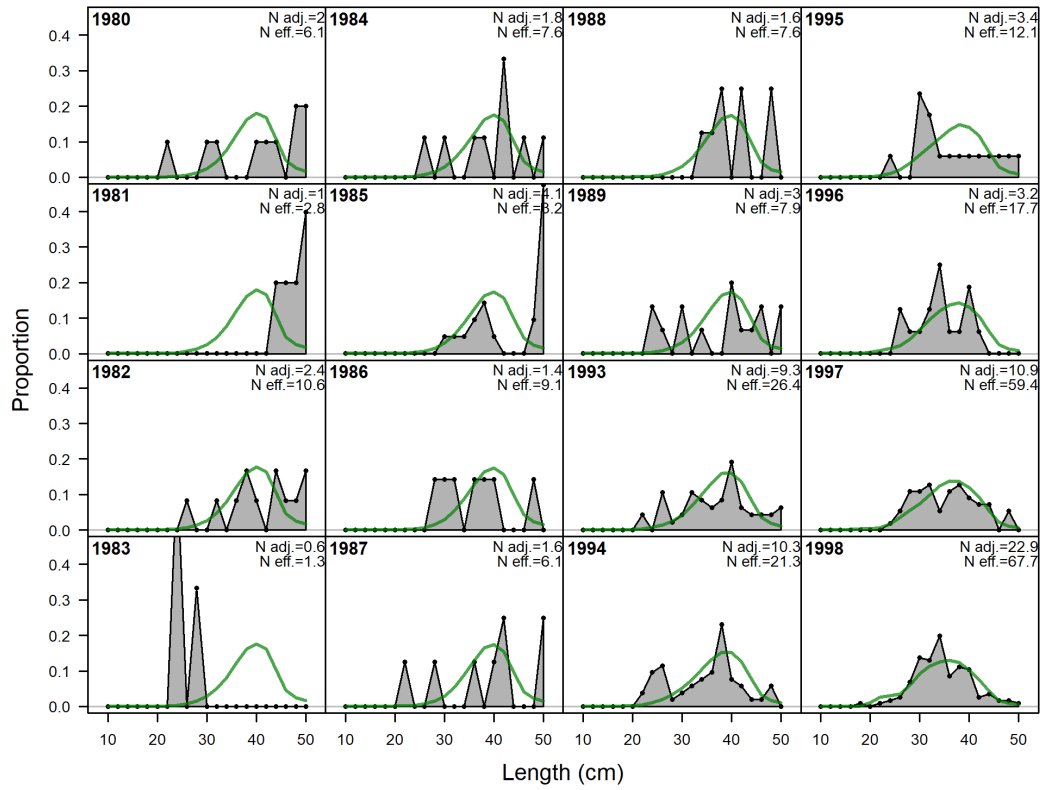


Figure 56: Length comps, whole catch, OR_Recreational (plot 1 of 3). 'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Iannelli tuning method.

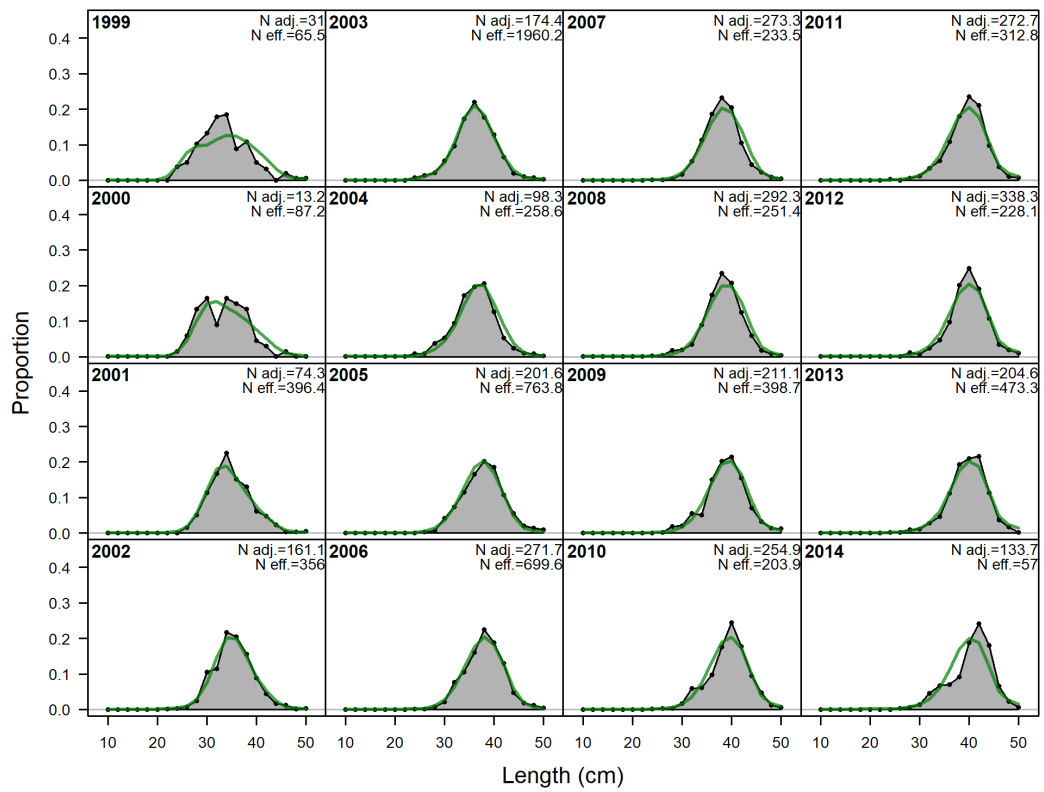


Figure 57: Length comps, whole catch, OR_Recreational (plot 2 of 3).

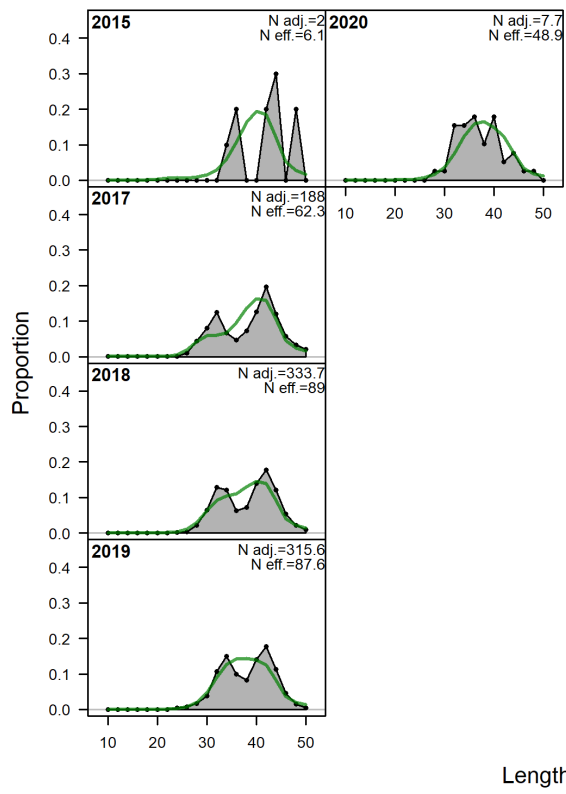
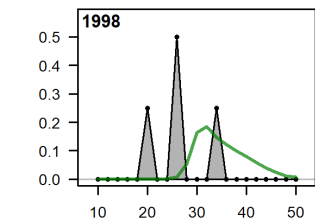


Figure 58: Length comps, whole catch, OR_Recreational (plot 3 of 3).



Proportion

Length (cm)

Figure 59: Ghost length comps, whole catch, OR_Commercial.'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.

10.2 Appendix B: ODFW Marine Reserve Hook and Line Survey

One source of information that fell outside the bounds of the current PFMC Groundfish Terms of Reference for Data Moderate assessment is the ODFW Marine Reserve Hook and Line Survey. This data source to date has not been used in any West Coast groundfish stock assessments, but will likely be considered in select future full rockfish assessments (e.g., black rockfish). Given that this is an existing data source that may prove useful for future rockfish assessments, we wanted to provide an overall summary of this data source and the available data for quillback rockfish.

The Marine Reserve Program in the ODFW has routinely monitored state marine reserves (MR) and associated comparison areas (CA) since 2011. Data from the hook and line survey from 2011 - 2019 are presented in this summary. Surveys in 2011 and 2012 only visited a single site, Redfish Rocks. Surveys from 2013 – 2019 include reserves and comparison areas from four sites: Redfish Rocks, Cape Falcon, Cape Perpetua and Cascade Head. Each of these four sites has a marine reserve and one to three comparison areas. Comparison areas are specifically selected for each marine reserve to be similar in location, habitat and depth to the reserve but are subject to fishing pressure. Not all sites are sampled in each year, due to both the gradual implementation of the reserve network and the available staff to execute surveys. Sites and areas sampled that are included in this dataset are below (Table 16).

Table 16: Sites and areas sampled by the Marine Reserve Program hook and line survey.

Site	Area	Years Sampled	Total Samples
Redfish Rocks	Humbug CA	2011 – 2019	8
Redfish Rocks	Redfish Rocks MR	2011 – 2019	8
Redfish Rocks	Orford Reef CA	2014, 2015, 2017, 2019	4
Cape Falcon	CA Adjacent to Cape Falcon MR	2014, 2015, 2017, 2019	4
Cape Falcon	Cape Falcon MR	2014, 2015, 2017, 2019	4
Cape Falcon	Cape Meares CA	2014, 2015, 2017, 2019	4
Cape Falcon	Three Arch Rocks CA	2014, 2015, 2017, 2019	4
Cape Perpetua	CA Outside Cape Perpetua MR	2016, 2018	2
Cape Perpetua	Cape Perpetua MR	2013, 2014, 2017, 2018	4
Cape Perpetua	Postage Stamp CA	2013, 2014, 2017, 2018	4
Cascade Head	Cape Foulweather CA	2015, 2016, 2018	3
Cascade Head	Cascade Head MR	2013 - 2016, 2018	5
Cascade Head	Cavalier CA	2013, 2015, 2016, 2018	4
Cascade Head	Schooner Creek CA	2013 - 2016, 2018	5

A 500 meter square grid overlaid on the sampling area defines the sample units or cells. Cells are randomly selected within a marine reserve or comparison area for each sampling event. Three replicate drifts are executed in each cell. The specific location of the drifts within the cell is selected by the captain. Over time, cells without appropriate habitat for the focus species, mainly groundfish, have been removed from the selection procedures, and those presented in this dataset include only those that are currently “active”. The number of cells visited in a day can vary slightly and range from three to five. Data are aggregated to the cell-day level.

10.2.1 Quillback Rockfish Summary

Of the 940 total-cell days at 14 areas, 164 (17.4 percent) of those had positive quillback rockfish catches with a total of 291 observations of quillback rockfish across all years and sites (Table 17). The number of quillback rockfish caught ranged from 1 to 10 fish in a cell-day.

Table 17: Summary of number of catch cell days and positive observations of quillback rockfish.

	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Number of Positive Catch Cell-Days	5	5	23	30	26	22	17	16	20	164
Total Cell-Days	44	52	97	141	167	112	103	116	108	940
Proportion of Positives	0.11	0.1	0.24	0.21	0.16	0.2	0.16	0.14	0.18	0.17
Total Number of Quillback Caught	9	9	51	52	34	55	22	27	32	291

Areas differ in both geographic location and the level of fishing pressure experienced or allowed. Staff from the Marine Reserves Program suggested that the treatment (reserve vs. comparison area) may not be a delineating factor for the catch of some species (e.g., cabezon) due to the recent implementation of the reserves. It was suggested that data could be aggregated to the site level, functioning at the level of a reef complex, to examine patterns at different locations along the coast. However, this may not be possible with the sample size available at some sites.

Observations of quillback rockfish were varied across sample sites and years. The number of observations of quillback rockfish was highest at Redfish Rocks ($N = 118$) and closely followed by Cape Perpetua ($N = 108$) (Table 18).

Table 18: Summary of sampling effort by year and site combined with the positive observations of quillback rockfish.

Site	Year	Number of Positive Catch Cell Days	Total Cell Days	Proportion of Positives	Total Number of Quillback Rockfish Caught
Cape Falcon	2014	0	18	0.000	0
	2015	3	51	0.059	4
	2017	1	47	0.021	1
	2019	3	42	0.071	6
	Total	7	158	0.044	11
Cape Perpetua	2013	8	34	0.235	23
	2014	13	34	0.382	31
	2016	11	42	0.262	40
	2018	7	41	0.171	14
	Total	39	151	0.258	108
Cascade Head	2013	4	35	0.114	5
	2014	6	43	0.140	7
	2015	12	59	0.203	15
	2016	10	63	0.159	14
	2018	9	75	0.120	13
Redfish Rocks	Total	41	275	0.149	54
	2011	5	44	0.114	9
	2012	5	52	0.096	9
	2013	11	28	0.393	23
	2014	11	46	0.239	14
	2015	11	57	0.193	15
	2016	1	7	0.143	1
	2017	16	56	0.286	21
	2019	17	66	0.258	26
	Total	77	356	0.216	118

Catch-per-unit-effort (CPUE) was calculated by the number of fish per angler hour (Figures 60 and 61). The number of anglers and hooks are standardized for each survey. Angler hours have been adjusted for non-fishing time (i.e., travel time, etc.).

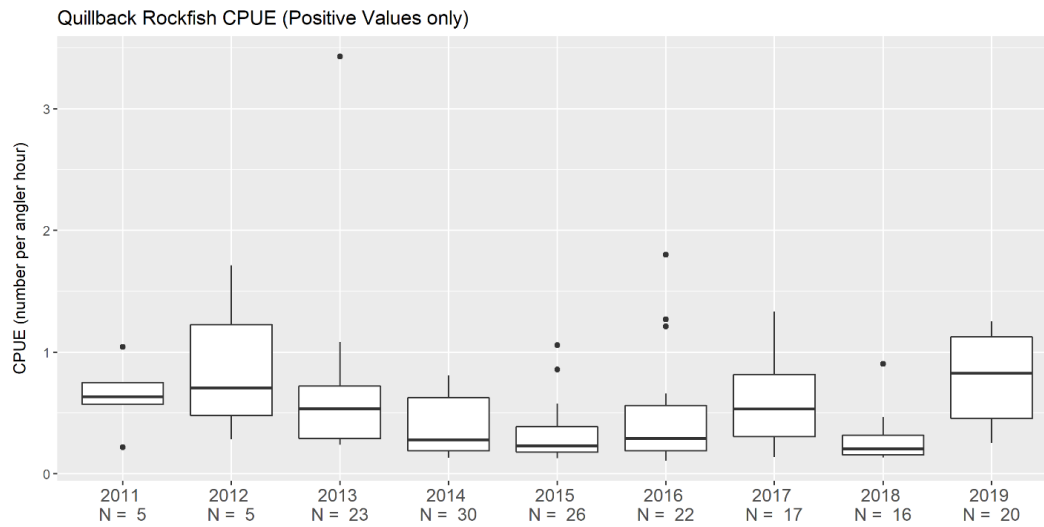


Figure 60: Quillback rockfish CPUE calculated based on positive values only.

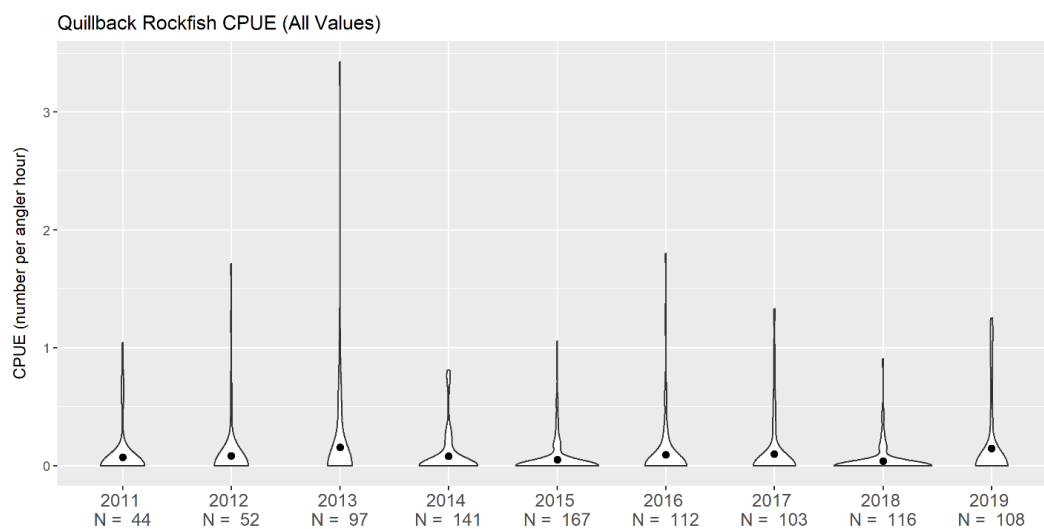


Figure 61: Quillback rockfish CPUE calculated based on all values.

Additional filtering may not be necessary, as the filtering for “active” cells has already likely removed any unsuitable sampling units, based on habitat, depth and local knowledge. Based on the annual proportion of positive cell-days and the relative rarity of quillback rockfish encounters, there are probably not enough data to move forward with a timeseries at a coastwide level. However, Redfish Rocks has been sampled in each year from 2011 - 2019, except for 2018. Though sample size is extremely limited, CPUE based on positive values at this site shows a variable and slightly declining trend from 2011 to 2015 followed by a slightly increasing trend from 2015 to 2020 for quillback rockfish (Figures 62). This differs from the trajectory from the base model, which shows a decline from 2016 to 2020 (Figure 23).

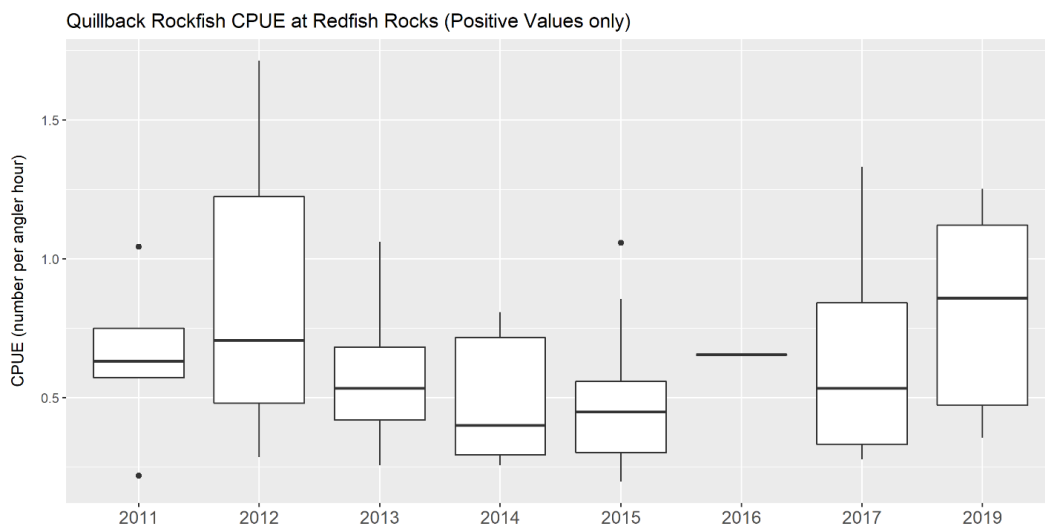


Figure 62: Quillback rockfish CPUE calculated at Redfish Rocks based on postive values only.

When all sites and all values are included, quillback rockfish appear to have a relatively stable trend from 2011 – 2019, with the annual mean CPUE oscillating around the long-term mean (Figures 63).

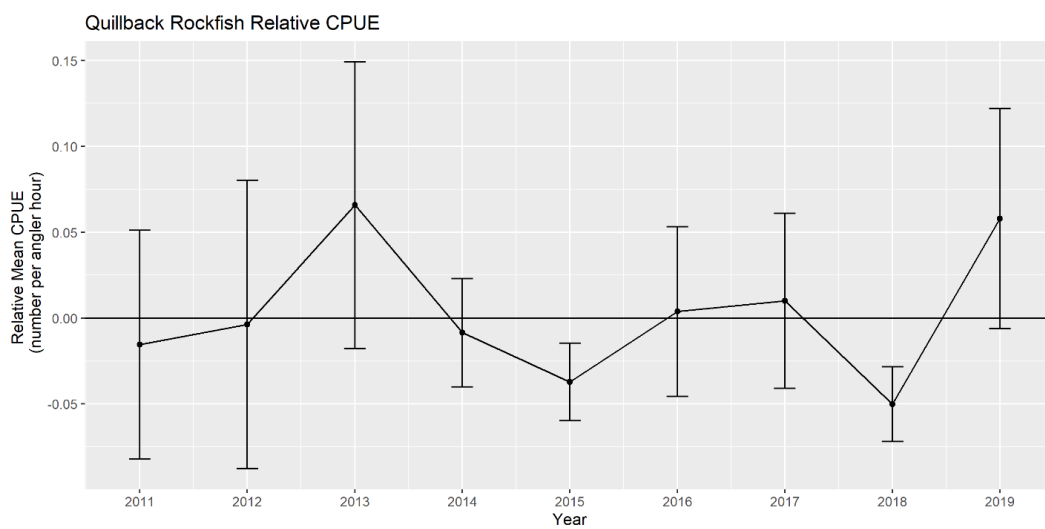


Figure 63: Quillback rockfish relative CPUE across all sample sites and with all data values.

10.3 Appendix C: Video Lander Population Estimate

Oregon Department of Fish and Wildlife (ODFW) provided density estimates and a range of estimated population abundances from underwater video lander data for quillback rockfish. The lander data was collected over nine years by the ODFW and summarized in Rasmuson et al. (2020). This large dataset is made up of ten independent studies carried out in both nearshore rocky reefs coastwide as well as select reef structures offshore of the central coast of Oregon. Underwater video landers are stationary platforms consisting of one to three video cameras. Landers used in deeper water employ advanced lighting systems for optimal viewing of fish and benthic habitat. Ambient light is used in shallow surveys. The variability in detection range by depth is an important factor to consider when deriving fish density from lander data. Therefore, a series of abundance estimates were provided to inform the quillback rockfish assessment. Methods are summarized below but a more detailed document is available by ODFW upon request.

Variability in range (and therefore, area viewed) directly influences fish abundance; therefore, fish density estimates were calculated using five different estimates of range. These include the average range, the range \pm one standard deviation from the mean, and the maximum and minimum ranges. The area viewed is calculated using both the range and the horizontal field of view. This viewed area was then combined with fish count data to generate fish densities. Count data were provided from Rasmuson et al. (2020). As expected, the viewed range has a large effect on the calculated density of the fish, with larger ranges resulting in a lower density of fish. Since there is no way to know which range model most accurately reflects the true density of fish, multiple range estimates were combined into a single density estimate using a weighted arithmetic mean. Although the arithmetic mean is simpler and more intuitive, the fact that the area viewed increases exponentially suggests a geometric mean may be more appropriate. As an alternative to the arithmetic mean, the geometric mean density was calculated in three different ways to address the zeros in the data. Abundance estimates (numbers of fish) were calculated by multiplying the density estimate by an estimate of the habitat area. Coastwide habitat area was limited to primary or secondary habitat containing hard substrate. The western boundary was defined as the 200 m contour based on the depth of the continental shelf-break. The eastern boundary was based on the shallowest lander observation for each species. Quillback rockfish were not observed on lander video in water <22 m, therefore the 20 m contour was used. It should be noted that while the depth range of the lander surveys conducted by ODFW extends to 212 m, the majority of lander surveys have been conducted in either nearshore rocky reefs or at Stonewall Bank RCA on the central Oregon coast.

Abundance estimates for the coastwide survey area are provided for quillback rockfish derived from each of the nine density estimates; five range models, the weighted arithmetic mean, and three weighted geometric mean methods. For quillback rockfish, density estimates ranged from 0.004 ± 0.029 (no. fish / $m^2 \pm SD$) from the maximum range method to 0.950 ± 1.366 for the third geometric mean method. The estimated habitat area was 1,840 thousand km^2 . Abundance estimates ranged from 7.3 ± 53.5 (millions of fish $\pm SD$) to $1,751 \pm 2,519$.

Estimates of abundance from the five range models produced similar results to the weighted arithmetic mean, ranging from 7.3 ± 53.5 (millions of fish \pm SD) for the maximum range to 36.9 ± 247.0 for the minimum range. These were generally considered more plausible than the results based on the geometric density means. Caveats to this abundance estimate are provided in the detailed document, but include considerations of the use of the lander dataset and the estimation of habitat area. Abundance estimates were much greater than the base model estimate for number of fish, which was 104.9 (thousands of fish) across all ages, and 82.7 (thousands of fish) across ages 3+.

10.4 Appendix D: ROV minimum population estimate

The ODFW has conducted remotely-operated vehicle (ROV) surveys for nearly 20 years, targeting nearshore rocky reef habitats and associated fish and invertebrate assemblages. Oregon ROV survey methods, analyses, and data were subjected to an SSC methodology review in 2019 and were determined to be suitable for use in west coast stock assessments, subject to assessment authors' evaluation of suitability for particular stocks and specific data uses. Oregon ROV data were used to estimate a minimum abundance of quillback rockfish within a subset of the total available nearshore habitat, as a reference point for the assessment, though these data are not included directly in the assessment model. A summary of the methodology to develop this estimate follows, and a more detailed document is in development and available upon request by ODFW.

ROV data from 2010 – 2019 were used for this abundance estimate, reflecting the period during which high-definition cameras were used. Sites were surveyed as funding and personnel allowed, and not all sites were surveyed in each year. Transect-level densities were aggregated by reef, regardless of year surveyed. Most transects were roughly 500m in length. These densities were derived from the rocky habitat portions of these transects only, excluding data from portions of transects over “soft” habitats (mud, sand, gravel). Total abundance (number of individuals) for the survey area was estimated by summing reef-level abundances. Each reef-level abundance was calculated as the weighted mean density of all transects conducted at the site across all years (weighted by the total view area of rock per transect) times the total area of mapped rock at the site within 20 – 70m range.

The total abundance estimate for quillback rockfish for the rock-only transect density expansion is 136,828 \pm 90,971 (SD) individuals. The total area included in this abundance estimate is 134.8 km², representing an estimated 74.8% of total rocky habitat within 20 – 70m in Oregon waters. A total of 490 transects were included in the calculation of the site-level mean densities. Several regions of potential quillback rockfish habitat along the Oregon coast were not included in this estimate due to a lack of survey data. In the study's 20 – 70m depth range, the most important of these is the coast south of Port Orford which holds over half of the remaining unsurveyed rocky reef area. Outside the study's depth range, the most important missing rocky habitats are the shallows between 0 – 20m, which

are typically difficult to survey using an ROV, and the expansive deeper ($> 70\text{m}$) portion of Arago Reef. Given these factors, the abundance estimate presented above is likely a minimum population estimate and intended to provide a reference point only for the scale of the population size in a portion of Oregon's nearshore rocky habitat. Despite this, the minimum estimate is greater than the base model estimate for number of fish, which was 104.9 (thousands of fish) across all ages, and 82.7 (thousands of fish) across ages 3+.