Status of vermilion rockfish (*Sebastes miniatus*) off the waters of Oregon state.

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Executive Summary

Stock

This assessment reports the status of vermilion rockfish (*Sebastes miniatus*) off the US West - Oregon coast using data through xxxx.

Landings

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Data and Assessment

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Stock Biomass

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Recruitment

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Exploitation Status

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Reference Points

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Management Performance

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Unresolved Problems and Major Uncertainties

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Decision Table

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Research and Data Needs

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1 Introduction

1.1 Basic Information

This assessment reports the status of vermilion rockfish (*Sebastes miniatus*) off the waters of Oregon state using data through 2020. Vermilion rockfish range from Prince William Sound, Alaska, to central Baja California at depths of 6 m to 436 m (Love, Yoklavich, and Thorsteinson 2002). They are most commonly found from southern Oregon to Punta Baja, Mexico (Hyde and Vetter 2009) at depths of 50 m to 150 m (Hyde and Vetter 2009). Hyde and Vetter (2009) describe an additional cryptic species related to vermilion rockfish, the sunset rockfish (*Sebastes crocotulus*). They note that Vermilion rockfish are residents of shallower depths (<100 m) versus sunset rockfish. Sunset rockfish tend to be more southerly, and are not commonly encountered in Oregon, so this assessment focuses only on vermilion rockfish. Adult fish tend to cluster on high relief rocky outcrops (Love, Yoklavich, and Thorsteinson 2002) and kelp forests (Hyde and Vetter 2009). North of Point Conception, some adults are shallower, living in caves and cracks (Love, Yoklavich, and Thorsteinson 2002). Vermilion rockfish have shown high site fidelity (Robert W. Hannah and Rankin 2011 (only tagged 1 vermilion); Lea, McAllister, and VenTresca 1999), and low average larval dispersal distance (Hyde and Vetter 2009). Lowe et al. (2009) [Lowe2009] suggested vermilion rockfish to have a lower site fidelity than previously believed, but they acknowledged that their observations of movements to different depths may have been due to the reality of a shallower species and a deeper species.

The stock designation of Oregon waters was based on the California stock having a separate explotation history as well as a much larger stock density. Vermilion rockfish are not as abundant north of Califoria, but still provide some fishing opportunities (Robert W. Hannah and Kautzi 2012). The separation of Oregon and Washington into distinct mangement units, and thus separate stock assessments, were based on the observation that most vermilion in Oregon are taken off southern Oregon, while most of the habitat and take of vermilion off Washington was in the very northern portion of the Washington coast (Figure 1). Ninty percent of the total mortality in Oregon is from the southern part of the state (south of Pt. Arago), while ninty-seven percent comes from the northern portion of Washington (Figure 2). This large area separation, low movement of larvae and adults, and the biogeographic barriers of the Columbia River outfall and lack of rocky habitat in southern Washington all support separate Oregon-Washington management units.

1.2 Life History

Approximate lifespan for vermilion rockfish is 60 years, with females living longer and growing larger than their male counterparts. 50% are mature at 5 years and about 37 cm, with males probably maturing at shorter lengths than females (Love, Yoklavich, and Thorsteinson 2002).

Vermilion rockfish are viviparous, and release 63,000 to 2,600,000 eggs per season. In southern California, vermilion rockfish larvae are released between July and March. In central and northern California, this release occurs in September, December, and April-June (Love, Yoklavich, and Thorsteinson 2002). In Oregon, fertilized females with ripe ovaries are encountered from April to Ocotber (Robert W. Hannah and Kautzi 2012), with larval release sometime during and after that period. Larval release in fall and winter is not common among other rockfish species. Hyde and Vetter (2009) suggest that low larval dispersal may be due to weak poleward flow of nearshore waters corresponding with peak vermilion larval release.

Young-of-the-year (YOY) vermilion rockfish settle out of the plankton during two recruitment periods per year, first from February to April and a second from August to October, and settlement has been observed in May off southern California (Love, Yoklavich, and Thorsteinson 2002). There is no information on YOY settlement in Oregon. Larvae measure about 4.3 mm. Both young-of-the-year vermilion and sunset rockfish are mottled brown with areas of black, and older juveniles turn a mottled orange or red color (Love et al. 2012). Juvenile fish are found individually from 6 m to 36 m, living near sand and structures. After two months, juveniles travel deeper and live on low relief rocky outcrops and other structures (Love, Yoklavich, and Thorsteinson 2002).

Adult vermilion rockfish predominantly eat smaller fish, though sometimes they pursue euphausiids and other various macroplankton (Phillips 1964). Love (2002) noted their diet to include octopus, salps, shrimps, and pelagic red crabs.

1.3 Ecosystem Considerations

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1.4 Historical and Current Fishery Information

Off the coast of Oregon, vermilion rockfish is caught in both commercial and recreational fisheries. The landings from the commercial fishery were minimal until the mid-1960s. 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_2019_2020?**). Vermilion rockfish is one of multiple rockfish species that are commonly landed as a part of the nearshore commercial groundfish fishery. Currently, this commercial fishery is centered on the southern Oregon coast, where most of the vermilion rockfish commercial landings occur. Two types of state limited entry permits are issued for this fishery, with and without a nearshore endorsement. Limited entry permit holders without a nearshore endorsement may land commercial quantities of black and blue rockfish under state trip limits, with an additional total of 15 lbs per day of any combination of other nearshore groundfish species and two rockfish species with Federal designation as shelf rockfish. These include tiger and vermilion rockfish. Vessels that have a nearshore endorsement permit may land commercial quantities of other nearshore groundfish species up to the state's cumulative trip limits and the Federal limits for tiger and vermilion rockfish. There are no state trip limits set for vermilion rockfish.

This analysis assesses the stock off the Oregon coast as a separate stock from other populations off the West Coast based on the sedentary nature of vermillion rockfish, which likely limits flow of fish between California and Washington. The substrate of the northern Oregon and southern Washington coast is primarily sandy bottom and combined with the Columbia River plume between Oregon and Washington these factors create a natural separation between the Oregon and Washington populations. Additionally, the exploitation history and magnitude of removals off the Oregon coast has been dramatically lower than removals off the California coast. The recreational fishery off the coast of Oregon developed during the 1970s, with the first recorded landings of vermillion rockfish in 1979. Vermilion rockfish is not commonly encountered in the recreational fishery, but recreational removals have generally increased across time as this fishery has developed (Table **??**).

1.5 Summary of Management History and Performance

Vermilion rockfish is managed by the Pacific Fishery Management Council (PFMC) as a part of the Shelf Rockfish North and Shelf Rockfish South complexes. The North and South areas are split at N. 40°10' Lat. N. off the West Coast. The complex is managed based on a complex level overfishing limit (OFL) and annual catch limit (ACL). The OFL and ACL values for the complex are determined by summing the species specific OFLs and ACLs managed within the complex. Removals for species within the Rockfish complex are managed and tracked against the complex total OFL and ACL, rather than on a species by species basis. The OFL and ACLs for vermilion rockfish North of 40°10' Lat. N. management area, the state/specific ACL allocation (49 percent for Oregon, Groundfish Management Team, personal communication), and the total removals are shown in Table XX.

2 Data and Model Inputs

A description of each data source is provided below (Figure 3).

2.1 Fishery-Dependent Data

2.1.1 Commercial

2.1.1.1 Landings

In Oregon, historical commercial landings from 1892 to 1986 were provided by ODFW (Karnowski et al. 2014). Historical landings were consistent but minimal (< 1 mt) until the mid-1960s, except for a period from the mid-1930s to the late 1940s, during which landings increased to a high of 2.8 mt and declined again to under one mt. From 1965 to 1986, landings averaged 6.6 mt annually. 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, the central repository for West coast commercial landings (extracted on 11/17/2020), and a separate ODFW reconstruction that delineated species-specific landings in the unspecified categories on PacFIN (e.g. URCK and POP1, ODFW 2017). Vermilion 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 11/17/2020 and 02/18/2021). Vermilion rockfish is one of several rockfish species landed by a nearshore, primarily live-fish fixed gear fishery centered on Oregon's southern coast. Following the development of this nearshore commercial fishery in the late 1990s, ODFW implemented a state-permitted limited access fishery that regulated fleet size, period landing limits and established harvest guidelines (Rodomsky et al. 2020). Vermilion rockfish are landed almost exclusively with hook and line and bottom longline gear. On average, 99.8% of vermilion rockfish landings are from these two gear types (2000 – 2020). Landings from all other gear types, including fish pot and trawl, are minimal relative to jig and longline gears and sporadic. Commercial landings peaked in 1993 at 13.9 mt before declining and fluctuating between 1.5 and 4.8 mt (2000 – 2020). Landings in 2020 were 3.3 mt.

Discards So I can't remember what we did with commercial discards…!

2.1.1.2 Lengths

Commercial vermilion rockfish length samples are available from PacFIN from 1999 – 2020 (n = 2,355). These samples were extracted on 02/24/2021. Approximately 47.9% of these samples are females (n = 1,129) and 51.9% are males (n = 1,222). Only four fish were unsexed. The majority (93.3%) are from the southern Oregon coast, centered in Port Orford (67.4%) and Gold Beach (25.8%), 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 vermilion rockfish landed to the fresh (dead) market (93.5%). Additionally, special projects length samples collected from the commercial fishery are available from PacFIN from 2000 - 2006, 2008 - 2009, and 2012 (n = 381; extracted on 02/24/2021). Special projects samples were not included in the length compositions used in this model. Table X shows sample size by year and fleet.

2.1.1.3 Ages

There were 896 commercial age samples available from 2004 and 2007 - 2020. Approximately, 50.1% of samples were males (n = 449) and 49.9% were females (n = 447). As with the length samples, the vast majority of samples are from the southern Oregon coast (95.8%, n = 858), including Port Orford (73.4%) and Gold Beach (22.3%).

2.1.2 Recreational

2.1.2.1 Removals

2.1.2.1.1 Historic Ocean Boat Landings (1979 – 2000)

Recently, the Oregon Department of Fish and Wildlife (ODFW) undertook an effort to comprehensively reconstruct all marine fish recreational ocean boat landings prior to 2001 (pers. comm. A. Whitman, ODFW). 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; Dick et al. 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. Vermilion 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 fish of vermilion rockfish from the above described methods were converted to biomass using biological samples from MRFSS (pers. comm. A. Whitman, ODFW). 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 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 discards. In order to account for historical discards, 6% was added to landings from 1979 – 2000. This discard mortality estimate is an average of the annual discard mortality from 2001 – 2020 available on RecFIN. Landings during this time period gradually increase to a peak of 13.0 mt in 1993 and fluctuate between four and six mt following that peak.

2.1.2.1.2 Modern Ocean Boat Landings (2001 – 2020)

Recreational landings for ocean boat modes from 2001 – 2020 are available from RecFIN. Both retained and released estimates of mortality are included, though retained mortality contributes the vast majority to total 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 5.8 mt, ranging from 3.2 to 9.3 mt. In 2020, ocean boat landings were 8.9 mt.

2.1.2.1.3 Shore and Estuary Landings (1980 – 2020)

The ODFW does not currently sample shore and estuary boat fishing trips, and in recent assessments, ODFW has provided reconstructed species-specific estimates of shore and estuary landings from 1980 – 2020 (Berger et al. 2015, Dick et al. 2018, Cope et al. 2019). When investigating shore and estuary data for this species, there were virtually no records of shore and estuary landings of vermilion rockfish, and so these were not included for this assessment.

2.1.2.2 Lengths

Recreational length samples were obtained from three sources: MRFSS, RecFIN (ORBS) and ODFW special project sampling. From 1980 – 1989 and from 1993 – 2000, the MRFSS program collected samples from ocean areas only (n = 403). 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 (n =11,081). All ORBS samples are by fork length (mm). All samples are from ocean trips. Special projects samples collected by ODFW staff from the recreational fishery are provided from 1998 – 2001 (n = 54) but were not used in the length compositions for the assessment model. Table X details sample sizes by year and fleet.

2.1.2.3 Ages

There were 1,196 recreational age samples available from 2005 – 2020 (Table X). Approximately, 45.8% of samples were males (n = 548) and 53.9% were females (n = 645). There were three unsexed samples (0.25%). As with the length samples, the vast majority of samples are from the southern Oregon coast (93.3%, n = 1,116), primarily from Charleston (24.1%), Gold Beach (19.3%), Bandon (18.4%), and Brookings (18.0%).

2.1.3 Index of Abundance

2.1.3.1 Oregon ORBS Dockside Index (2001-2020)

Trip-level catch-per-unit-effort data from ORBS dockside sampling was obtained from ODFW on 04/15/2021. To mitigate the confounding of hourly effort associated with these trips with travel, the travel time was subtracted from the hours fished. Travel time was stratified by boat type (charter and private) and was calculated as boat type-specific speeds (13 mph for charter boat trips and 18 mph for private boat trips) multiplied by twice the distance between the port of origin and the reef that was fished. CPUE, expressed in terms of fish per angler-hour, was calculated by multiplying the number of anglers and the adjusted travel time. The database contains information on catch by species (number of retained fish), effort (angler hours), sample location (port where data were collected), date, bag limits, boat type (charter or private), and trip type (e.g., bottom associated fish).

2.1.3.1.1 ORBS CPUE Data Preparation, Filtering, and Sample Sizes

In order to define effective fishing effort for Vermilion (i.e. identify trips that were likely to catch the species), the method of Stephens and MacCall (2004) was used to predict the probability of catching a Vermilion given the occurrence of other species in the catch. The unfiltered data set contained 411,528 trips. Multiple standardized filters are applied to ORBS trip-level data in order to remove outliers and data unsuitable for an index. These filters include trips with incorrect interview times, which impact calculation of effort, unreasonably long or short trips, and retaining bottomfish target trips. There were 117,042 trips available for the application of the Stephens-MacCall filter (Table XX). Species that are rarely encountered will provide little information about the likelihood of catching Vermilion, and so 47 "indicator" species that were caught in at least 30 Oregon trips (Figure XX). Catch of these commonly-encountered species in a given trip was coded as presence/absence (1/0) and treated as a categorical variable in the Stephens-MacCall logistic regression analysis.

The top six species with a high probability of co-occurrence with Vermilion include Other Rockfish, Olive Rockfish, Copper Rockfish, Quillback Rockfish, Lingcod and China Rockfish, all of which are commonly associated with rocky reef and kelp habitats in nearshore waters. The top six species were all strongly associated with Vermilion (significantly different from zero at the alpha = 0.05 level). The six species with the lowest probability of co-occurrence were Buffalo Sculpin, Butter Sole, Greenstriped Rockfish, Striped Seaperch, Jack Mackerel, and Sand Sole. These species are not commonly caught during the same trip as Vermilion, presumably due to different habitat associations and fishing techniques. The Area Under the Characteristics curve (AUC) for this model is 0.7931; Figure XX), a significant improvement over a random classifier (AUC = 0.5). AUC represents the probability that a randomly chosen observation of presence would be assigned a higher ranked prediction than a randomly chosen observation of absence. Stephens-MacCall proposed filtering (excluding) trips from the index standardization based on a criterion of balancing the number of false positives (FP) and false negatives (FN). The FN trips were retained, assuming that catching a Vermilion indicates that a nonnegligible fraction of the fishing effort occurred in habitat where the species occurs. Only "true negatives" (the 103,762 trips that neither caught a Vermilion, nor were predicted to catch them by the model) were excluded from the index standardization.

After filtering for species composition, further filters were explored for fishing closures and catches exceeding bag limits, but these were not needed. The final dataset also excluded data from several ports with extremely small sample sizes and finally, trips that met criteria for irrational effort reporting (i.e., implausible values) or extreme catch rates (Table XX).

2.1.3.1.2 ORBS CPUE Standardization: Model Selection, Fits, and Diagnostics

Data at the port level were sparse for all months and years, so trips to north and south 'subregions' and to season (a compilation of winter and summer months) in order to facilitate data categories conducive to exploring interactions between subregion and year. Vermilion are somewhat rarely encountered by the recreational fleet. In order to focus any signal coming from this index, the above filtered dataset was further refined by retaining only trips that occurred in the southern megaregion, where the majority of the recreational and commercial catch occurs, and during the summer months (May – September; Figure XX). Raw catch rate data suggested that trends in CPUE over time diverged substantially by subregion. Further, ports in the south coast generally have difficult bars in the winter, restricting most of the recreational effort to summertime. A delta-Generalized Linear Model (GLM) approach was used to model CPUE. Apart from differences in catch rate among month, and year, we also considered changes associated with boat type (charter and private; Figure XX), the bag limit for Vermilion rockfish, and the depths available to the recreational fleet for fishing. The binomial component for catch occurrence was modeled using a logit link function while the log of positive CPUE was modeled with a Gaussian distribution and an identity link function. Based on the Akaike Information Criterion (AIC), the binomial model selected as the best predictor of ORBS catch rates included year, boat type, and the open depths available to fishing (Table XX). Residuals from the binomial component of the delta-model are not expected to be normally distributed, so quantile residuals (Dunn and Smyth 1996) were simulated using the R package DHARMa. Effective sample sizes prevented the direct comparison of the model predicted values to the standardized residuals (Figure X, right panel); however, examination of the QQ plot residuals and the results of tests for outliers and differing distributions indicated no significant issues (Figure XX, left panel), indicating that despite a small sample size, the model approximated the data reasonably well. The positive model selected, again based on AIC, included year, boat type, month and an interaction term with year: boat type (Table XX). Again, effective sample sizes prevented the comparison of model predicted values to the standardized residuals (Figure X, right panel) but no other significant issues were identified (Figure XX, left panel). Given that only a single subregion was included in this model selection procedure, an area-weighted model was not utilized for Vermilion, as has been used for other nearshore species in recent assessments, such as cabezon (Cope et al. 2019) or blue rockfish (Dick et al. 2018).

To estimate the uncertainty in the final index of abundance, it is necessary to account for the correlation structure between parameters within the binomial and lognormal components of the model, as well as with the combined (binomial and lognormal components) delta-model. The rstanarm package in R was used to replicate the best models using diffuse prior distributions that replicated point estimates from the maximum likelihood fits. The advantage of this approach is that the calculation of the index (summing relevant model parameters and combining model components) can be applied to posterior draws, preserving the correlation structure and propagating uncertainty into the final index (Figure XX; Table XX). As an additional diagnostic, replicate data sets were generated from the posterior predictive distribution, and compared the maximum likelihood estimates from the model components to the median estimates from the posterior distribution. As expected, the model closely matches the distribution from replicate data (Figure XX).

2.2 Fishery-Independent Data

2.2.1 AFSC Slope Survey

The AFSC Slope Survey (Slope Survey) operated during the months of October to November aboard the R/V *Miller Freeman*. Partial survey coverage of the US west coast occurred during the years 1988-1996 and complete coverage (north of 34°30'S) during the years 1997 and 1999-2001. Typically, only these four years that are seen as complete surveys are included in assessments.

2.2.2 AFSC/NWFSC West Coast Triennial Shelf Survey

The AFSC/NWFSC West Coast Triennial Shelf Survey (Triennial Survey) was first conducted by the Alaska Fisheries Science Center (AFSC) in 1977, and the survey continued until 2004 (Weinberg et al. 2002). Its basic design was a series of equally-spaced east-to-west transects across the continential shelf from which searches for tows in a specific depth range were initiated. The survey design changed slightly over time. In general, all of the surveys were conducted in the mid summer through early fall. The 1977 survey was conducted from early July through late September. The surveys from 1980 through 1989 were conducted from mid-July to late September. The 1992 survey was conducted from mid July through early October. The 1995 survey was conducted from early June through late August. The 1998 survey was conducted from early June through early August. Finally, the 2001 and 2004 surveys were conducted from May to July.

Haul depths ranged from 91-457 m during the 1977 survey with no hauls shallower than 91 m. Due to haul performance issues and truncated sampling with respect to depth, the data from 1977 were omitted from this analysis. The surveys in 1980, 1983, and 1986 covered the US West Coast south to 36.8°N latitude and a depth range of 55-366 m. The surveys in 1989 and 1992 covered the same depth range but extended the southern range to 34.5°N (near Point Conception). From 1995 through 2004, the surveys covered the depth range 55-500 m and surveyed south to 34.5°N. In 2004, the final year of the Triennial Survey series, the Northwest Fisheries Science Center (NWFSC) Fishery Resource and Monitoring division (FRAM) conducted the survey following similar protocols to earlier years.

2.2.3 NWFSC West Coast Groundfish Bottom Trawl Survey

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

2.3 Biological Parameters

2.3.1 Growth (Length-at-Age)

The length-at-age was estimated for female and male vermilion rockfish using data from collections sampling the commerical and recreational fisheries off the coast of Oregon from years 2004-2020 (Table **??**. Figure 4 shows the lengths and ages for all years by sex and data source as well as predicted von Bertalanffy growth function (VBGF) fits to the data. Females grow larger than males and sex-specific growth parameters were estimated at the following values:

$$\text{Females } L_\infty = 57.2 \text{ cm}; k = 0.146; t_0 = \text{-}0.65$$
$$\text{Males } L_\infty = 54.2 \text{ cm}; k = 0.18; t_0 = 0$$

The estimated VBGF parameters provided initial values for the estimation of growth in the model, as all age and length data are included in the model. The resultant growth curves estimated by the model are presented in Figure 5. Sensitivity to the treatment of growth parameters (fixed or estimated) are explored through sensitivity analyses.

2.3.2 Ageing Precision and Bias

Counting ages from ageing structures in long-lived temparate fishes is challenging. Ages derived from these structures can be hard to reproduce within and between readers (i.e., imprecision), and may not contain the true age (i.e., bias). Stock assessment outputs can be affected by bias and imprecision in ageing, thus it is important to quantify and integrate this source of variability when fitting age data in assessments. In Stock Synthesis, this is done by including ageing error matrices that include the mean age (row 1) and standard deviation in age (row 2). Ageing bias is implemented When the inputted mean age deviates from the expected middle age for any given age bin (e.g., 1.75 inputted versus 1.5 being the true age); ageing imprecision is given as the standard deviation for each age bin (row 2).

Ageing error matrices for commerical and recreational fisheries respectively were calculated using multiple reads within each reader (n = 181 for commercial; n = 237 for recreational). An additional ageing error matrix was constructed from the Committee of Age Reading Experts (CARE) otolith exchange, where an exchange of 43 individuals was done amonth ODFW, WDFW, SWFSC, and NWFSC. The ODFW internal reads were used in the reference model, with the CARE comparison explored in a sensitivity model run.

Estimation of ageing error matrices for each lab used the approach of Punt et al. (2008). The ageing error matrix offers a way to calculate both bias and imprecision in age reads. Reader 1, the primary reader of the ages used in the stock assessment, is always considered unbiased, but may be imprecise. Several model configurations are available for exploration based on either the functional form (e.g., constant CV, curvilinear standard deviation, or curvilinear CV) of the bias in reader 2 or in the precision of the readers. Model selection uses AIC corrected for small sample size (AICc), which converges to AIC when sample sizes are large. Bayesian Information Criterion (BIC) was also considered when selecting a final model. Table 2 provides model selection results.

The ODFW interlab comparison supported imprecision with a curvilinear standard deviation for the recretaional fishery, and a linear one for commercial. The CARE comparison was also linear, with a bit higher standard deviation. The functional forms for each matrix are given in Figure 6.

2.3.3 Natural Mortality

Natural mortality was not directly measured, so life-history based empirical relationships were used. The Natural Mortality Tool (NMT; https://github.com/shcaba/Natural-Mortality-Tool), a Shiny-based graphical user interface allowing for the application of a variety of natural mortality estimators based on measures such as longevity, size, age and growth, and maturity, was used to obtain estimates of natural mortality. The NMT currently provides 22 options, including the Hamel (2015) method, which is a corrected form of the Then et al. (2015) functional regression model and is a commonly applied method for west coast groundfish. The NMT also allows for the construction of a natural mortality prior weighted across methods by the user.

We assumed the age of 54 years to represent the practical longevity (i.e., 90% of the commonly seen maximum age of 60) for both females and males, though the absolute oldest age in OR was >60 years. In the larger biomass, higher sampled area of California, ages 80+ were even encountered. Empirical M estimators using the von Bertalanffy growth parameters were also considered, but they produced unreasonably high estimates (2-3 times higher than the longevity estimates). This is likely explained by the fact that while vermilion rockfish have protracted longevity at L_∞. Additionally, the FishLife (**thorson_predicting_2017?**) estimate was included, though, given the source of FishLife data is FishBase, there is a good chance the estimates of M are also from methods using longevity, though the actual source of longevity in FishLife was unknown. The final composite M distributionn (Figure 9) are based on 4 empirical estimators, and result in a median value of 0.1. We assume a lognormal distribution with a standard deviation of 0.438 (Hamel (2015)) for the purposes of the prior used to estimate M. This creates a wide prior to allow the data in the model to also influence the final estimated value of M.We also explore sensitivity to these assumptions of natural mortality through likelihood profiling.

2.3.4 Maturation and Fecundity

Maturity-at-length is based on the work of Hannah and Kautzi (2012) which estimated the 50 percent size-at-maturity of 39.4 cm off Oregon, though the slope of the maturity curve was not provided. Looking at the data provided in the reference, and length at 95% maturity was assumed at 48cm, resulting in a slope of -0.34. Maturity was assumed to stay asymptotic for larger fish (Figure 7) as no functional maturity estimate was availale (Head, Cope, and Wulfing 2020).

The fecundity-at-length was based on research by Dick et al.(2017). The fecundity relationship for vermilion rockfish was estimated equal to Fec=4.32e-07$L^{3.55}$ in millions of eggs where L is length in cm. Fecundity-at-length is shown in Figure 8.

2.3.5 Length-Weight Relationship

The length(cm)-weight(kg) relationship for vermilion rockfish was estimated outside the model using all coastwide biological data available from commercial data sources that provided the only sex-specific information on length and weight (Figure 10). The estimated length-weight relationship for female fish was W=2.60642e-05$L^{2.93}$ and males at W=3.7636e-05$L^{2.83}$.

2.3.6 Sex Ratio

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

2.3.7 Steepness

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

3 Assessment Model

3.1 Summary of Previous Assessments

Vermilion rockfish in Oregon has not been previously assessed in full, so this is the first benchmark for this management unit. Depletion Corrected Average Catch (DCAC) was used to set annual catch limits (ACLs) for vermilion rockfish since 2010 (**dick_estimates_2010?**) which estimate the mean sustainable yield as 5.7 mt (median of 5.9 mt). This method assumed vermilion rockfish relative stocks status was at 40% in 2009.

3.1.1 Modelling Platform

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

3.1.2 Bridging Analysis

No bridgining analysis between the DBSRA model and Stock Synthesis was conducted given the significant differences (DBSRA is provided the depletion value) between the methods. It is well documented already that SS can mimic DBSRA approaches (Cope (2013)).

3.2 Model Structure and Assumptions

Stock Synthesis is an age-structured modelling framework that allow for the inclusion of removal histories, length and age compositions and abundance indices. The Oregon vermilion rockfish model assessment assumes a two removal fleets (mainly a recreational fihsery in the contemporary period, though commercial removals are present and were more prominant historically) with removals beginning in 1892. The Oregon Recreational abundance index is the one fishery-dependant data source used to measure abundance trends. Selectivities for the fleet and survey were specified using the double normal parameterization within SS where selectivity was fixed to be asymptotic with the ascending slope and size of maximum selectivity parameters estimated. Life history parameters are sex-specific, with one growth type, and assumed stationary. Recruitment assumes a Beverton-Holt stock-recruit relationship and is deterministic.

3.2.1 Estimated and Fixed Parameters

All life history parameters are estimated except the CV at length at t_0. Estimated parameters in the model are natural mortality, L_∞, k, t_0, CV at L_∞, the two selectivity parameters for each fleet and the survey, the log of the initial recruitment ($logR_0$), and recruitment deviations. Sensitivity scenarios and likelihood profiles were used to explore uncertainty in the values of the natural mortality and growth parameters. When estimating parameters, the prior for natural mortality was assumed lognormal with a standard deviation of 0.438 (based on the prior developed using the Natural Mortality Tool (see Biology section for more details)); growth parameters were estiamted with no priors.

3.2.2 Data Weighting

The reference model estimates additional variance on the Oregon recreational survey data to allow the model to balance model fit to that data while acknowledging that variances may be underestimated in the index standardization. The input CVs range from 1%-7%, which is very small (Table **??**). A sensitivity was run with no extra variance estimated, as well as removal of the index data.

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

3.3 Model Selection and Evaluation

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

3.4 Summary of Previous Assessments and Reviews

There are no previous assessments for the Oregon vermilion rockfish management unit, thus no summary of previous assessments or reviews.

3.4.1 History of Modeling Approaches

The previous treatment of vermilion rockfish that contained the area of Oregon was the application of DBSRA in order to determine OFLs, and was not a model to provide estimates of stock status.

3.4.2 Most Recent STAR Panel and SSC Recommendations (not required for an update assessment)

There are no recent STAR or SSC recommendations regarding Oregon vermilion rockfish.

3.5 Reference Model Diagnostics and Results

3.5.1 Model convergence and acceptability

While there is no definitive measure of model convergence, several measures are routinely applied. These criteria include a low maximum gradient (1.38574×10^{-4}), inversion of the Hessian (passed), reasonable parameter values (passed), and acceptable fits to data (passed).

An extra effort was given to ensure the model did not rest on a local likelihood minimum. This was done by starting the minimization process from dispersed parameter values away from the maximum likelihood estimates to determine if the approach found a better model fit (i.e., minimum negative log-likelihood value). Starting parameters used a jitter shift value of 0.1. This was repeated 100 times with 92 out of 100 runs returned to the reference model likelihood (Figure 12). Another exploration using a jitter shift at 0.2 was used, but it returned 94 out of 100 runs equal to the reference model. A better fit, lower negative log-likelihood model was not found in any of these runs. The model did not experience convergence issues when provided reasonable starting values. Through the jittering and likelihood profiles, the present reference model represents the best fit to the data given the assumptions made.

3.5.1.1 Fits to the Data

3.5.1.1.1 Lengths

Fits to the length data are examined based on the Pearson residuals-at-length, the annual mean lengths, and aggregated length composition data for the commercial and recreational fleets. Annual length composition fits are shown in Appendix A. Lengths are generally sampled better in the recreational fishery and after year 2000.

Pearson residuals of fits to the commerical fishery length data are generally low with no distinct pattern of misfitting despite lower sample sizes (Figure 13). Fits to the commercial fishery mean lengths, assuming Francis data-weighting, show increasing female and males lengths until after 2009, after which mean lengths are relatively stable, with a small drop in size in the most recent year (Figure 14).

Pearson residuals of fits to the combined sex recreational fishery length data are also generally low, though with small bands of misfitting (Figure 13). These small bands are not deemed concerning given the small residuals and that recruitments are estimated. Fits to the recreational fishery mean lengths, assuming Francis data-weighting, show a very similar trend as the commercial mean lengths, with increasing lengths until after 2009, after which mean lengths are relatively stable, with a drop in size in the most recent year (Figure 15).

Aggregate fits by fleet are shown in Figure 16. The model fits the aggregate lengths for the sexed commerical fishery fleet and unsexed recreational female length data well. The commerical fishery data are fit less well given the smaller sample sizes.

3.5.1.1.2 Conditional Age at Length

Fits to the conditioanl age at length data are examined based on the age-at-length Pearson residuals, the annual mean ages, and mean age at length by year for the commercial and recreational fleet samples. The maximum size of the Pearson residuals for both fleets was large (maximum = 30.56 and 30.63 for commercial and recretaional samples, respectively; Appendix B), due to the inclusion of very small but aged as older fish. Most of the residuals were small and unnoteworthy and demonstrate the expected shape of the growth curve. As with the lengths, the mean age by year increased then leveled off, though the recreational mean ages continue to increase in the most recent years (Figures 17 and 18). The mean age for commercial stocks were generally around 15 years old, whereas the recretional ages are around 18 years old. Fits to the mean ages by length bins show acceptable fits consistent with model expectations Appendix C.

3.5.1.1.3 ORBS Survey Index of Abundance

The fit to the ORBS recreational survey index are generally good and consistent with other model sources as the trend shows a population increasing in the early 2000s then leveling off and dropping over recent years (Figure 19). The decreasing trend is more consistent over the last decade than indicated in the lengths or ages. Inital variance for the survey is extremely small, though it only took a small about of added variance to fit the index (0.08). The catchability coefficient (q) 0.003 was analytically solved for and very small relative to the total an absoute measure (q=1), a typical result of a fishery-based abundance index.

3.5.2 Selectivity

3.5.3 Reference Model Outputs

3.5.3.1 Parameter Estimates

A total of sixteen primary parameters were estimated, along with sixty recruitment deviations. The reference model parameter estimates along with asymptotic standard errors are shown in Table 5 and the likelihood components are shown in Table 6. Estimates of derived reference points and approximate 95 percent asymptotic confidence intervals are provided in Table 7.

The natural mortality for females and males was estimated at 0 and 0.073 yr^{-1}, respectively. These values are below the mean prior value, but not unrreasonable given the corresponding longevities would be between 67 and 75 year old and the sampled max ages of 68 come from a fished population.

The estimates of sex-specific growth parameters were different from the externally estimated starting values (Table **??** and Figure **??**). The estimated k for female and male fish were greater than the values estimated externally using only available survey data (0.146 for females and 0.175 yr^{-1} for males). The majority of female and male vermilion rockfish growth occurs at younger ages, reaching near maximum length by age 20-25, depending upon sex, with female vermilion rockfish reaching larger maximum lengths (Figure **??**).

The estimated logistic selectivity curves for the commericial and recreational fishery look plausible (i.e., as a model convergence check for realism, the selectivity curves are not overtly outrageous) for each fishery and are very similar to each other (Figure 20). Selectivity at 50% maturity (commercial = 43.67cm; recreational = 44.443cm) was between the length at

50% (39.4cm) and 95% maturity (48cm). Future assessments could opt for parsimony and combine these two fisheries into one combined selectivity, though the model had no issue adding two more parameters given the available length data.

The time series of estimated recruitments and annual recruitment deviations are shown in Figures 24 and 25. Years with the highest recruitment deviations were estimated to have occurred in 1993-1994, 1998, 2005, and 2015. The variance check on the recruitment deviations indicates well informed recruitments from 1980 to 2015, providing justifation for the estimation of recruitment. Recruitment deviations after 2015 are relatively uninformed with estimated deviations near zero where recruitment is estimated primarily based on the spawner-recruit curve (Figure 27). The recruitment bias adjustment applied within the model across years is shown in Figure 28.

3.5.3.2 Population Trajectory

The predicted spawning output (in millions of eggs) is provided in Table 8 and plotted in Figure 21. Estimated spawning output shows a large decline starting in the 1970s, with a continued decline into the late 1990s. This tracks the time period of major removals, though removals have stayed somewhat elevated since. Strong recruitments in the 1990s The estimate of total biomass over time, which tracks that of spawning output, is shown in Figure 22.

Relative spawning output declined below the management target ($SB_{40\%}$) in the early 1980s and again fell below the target starting in 2019 (Figure 23). The relative stock status at the start of 2021 is estimated to be below the rockfish relative biomass target of 40 percent (0.73) but above the management threshold of 25 percent. Uncertainty intervals indicate the population never goes below the management limit ($SB_{25\%}$) and is near the target after a very low catch in 2020 (likely attributable to the COVID-19 pandemic). The very low catches in 2020 allowed the population to rebound under the assumption of determnistic recruitment.

Recruitment was treated as deterministic (Figure 27) and the overall yearly age-0 numbers declined slightly over time (Figure 24).

3.5.3.3 Reference Points

Reference points were calculated using the estimated fishery selectivity and removals in the most recent year of the model (2020, Table 7). Sustainable total yields were 7.95 mt when using an $SPR_{50\%}$ reference harvest rate. The spawning output equivalent to 40 percent of the unfished spawning output ($SB_{40\%}$) was 13.04 millions of eggs.

The 2021 spawning output relative to unfished equilibrium spawning output is below the vermilion rockfish relative biomass target of 40 percent but greater that the management limit of 25 percent (Figure 23). The fishing intensity, $1 - SPR$, was above the harvest rate limit ($SPR_{50\%}$) between the 1970s and early 1980s, below the target for much of the time from the mid-1980s to early 2010s, and most of the recent several years have exceeded the target (Table 8 and Figure 30). Table 7 shows the full suite of estimated reference points for the base model and Figure 32 shows the equilibrium curve based on a steepness value fixed at 0.72.

3.6 Model Diagnostics

Describe all diagnostics

3.6.1 Convergence

3.6.2 Sensitivity Analyses

3.6.3 Retrospective Analysis

3.6.4 Likelihood Profiles

3.6.5 Unresolved Problems and Major Uncertainties

4 Management

4.1 Reference Points

4.2 Unresolved Problems and Major Uncertainties

4.3 Harvest Projections and Decision Tables

4.4 Evaluation of Scientific Uncertainty

4.5 Research and Data Needs

5 Acknowledgments

Here are all the mad props!

6 References

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7 Tables

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

Year	Commercial	Recreational	Total Catch
1892	0.00	0.00	0.00
1893	0.00	0.00	0.00
1894	0.00	0.00	0.00
1895	0.00	0.00	0.00
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	0.00	0.00	0.00
1902	0.00	0.00	0.00
1903	0.00	0.00	0.00
1904	0.00	0.00	0.00
1905	0.00	0.00	0.00
1906	0.00	0.00	0.00
1907	0.00	0.00	0.00
1908	0.00	0.00	0.00
1909	0.00	0.00	0.00
1910	0.00	0.00	0.00
1911	0.00	0.00	0.00
1912	0.00	0.00	0.00
1913	0.00	0.00	0.00
1914	0.00	0.00	0.00
1915	0.00	0.00	0.00
1916	0.00	0.00	0.00
1917	0.00	0.00	0.00
1918	0.00	0.00	0.00
1919	0.00	0.00	0.00
1920	0.00	0.00	0.00
1921	0.00	0.00	0.00
1922	0.00	0.00	0.00
1923	0.00	0.00	0.00
1924	0.00	0.00	0.00
1925	0.00	0.00	0.00
1926	0.00	0.00	0.00
1927	0.00	0.00	0.00
1928	0.00	0.00	0.00
1929	0.32	0.00	0.32
1930	0.58	0.00	0.58
1931	0.28	0.00	0.28
1932	0.00	0.00	0.00
1933	0.06	0.00	0.06
1934	0.09	0.00	0.09
1935	0.00	0.00	0.00
1936	0.33	0.00	0.33

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

Year	Commercial	Recreational	Total Catch
1937	1.08	0.00	1.08
1938	1.26	0.00	1.26
1939	1.52	0.00	1.52
1940	1.81	0.00	1.81
1941	1.21	0.00	1.21
1942	1.46	0.00	1.46
1943	1.65	0.00	1.65
1944	2.28	0.00	2.28
1945	2.57	0.00	2.57
1946	2.78	0.00	2.78
1947	0.92	0.00	0.92
1948	1.87	0.00	1.87
1949	2.00	0.00	2.00
1950	0.72	0.00	0.72
1951	0.65	0.00	0.65
1952	1.29	0.00	1.29
1953	0.44	0.00	0.44
1954	0.29	0.00	0.29
1955	0.83	0.00	0.83
1956	0.41	0.00	0.41
1957	0.87	0.00	0.87
1958	0.09	0.00	0.09
1959	0.27	0.00	0.27
1960	0.35	0.00	0.35
1961	0.65	0.00	0.65
1962	0.36	0.00	0.36
1963	0.63	0.00	0.63
1964	0.36	0.00	0.36
1965	1.82	0.00	1.82
1966	1.14	0.00	1.14
1967	3.26	0.00	3.26
1968	3.10	0.00	3.10
1969	6.04	0.00	6.04
1970	2.83	0.00	2.83
1971	6.42	0.00	6.42
1972	8.31	0.00	8.31
1973	9.02	0.00	9.02
1974	11.53	0.00	11.53
1975	5.97	0.00	5.97
1976	7.98	0.00	7.98
1977	11.21	0.00	11.21
1978	11.75	0.00	11.75
1979	7.70	0.30	8.00
1980	8.16	0.48	8.64
1981	4.37	1.66	6.03

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

Year	Commercial	Recreational	Total Catch
1982	4.94	2.02	6.96
1983	6.03	0.85	6.88
1984	5.60	1.52	7.12
1985	8.53	0.64	9.17
1986	10.38	3.18	13.56
1987	9.63	0.12	9.75
1988	10.11	1.26	11.37
1989	9.98	6.26	16.23
1990	10.87	5.20	16.07
1991	3.60	2.36	5.96
1992	4.30	5.05	9.35
1993	13.90	13.00	26.90
1994	4.07	4.66	8.72
1995	1.78	2.26	4.04
1996	5.41	2.35	7.76
1997	4.55	4.04	8.59
1998	4.71	6.40	11.11
1999	1.44	1.57	3.01
2000	2.99	2.59	5.58
2001	4.80	3.24	8.04
2002	2.08	3.21	5.28
2003	2.20	4.21	6.41
2004	1.76	3.50	5.26
2005	1.68	6.07	7.74
2006	2.42	5.42	7.85
2007	2.06	6.85	8.91
2008	3.99	5.66	9.64
2009	4.08	3.98	8.06
2010	1.64	4.78	6.42
2011	2.95	6.10	9.05
2012	2.79	9.15	11.94
2013	3.42	6.30	9.73
2014	2.28	3.95	6.23
2015	1.47	4.65	6.12
2016	2.02	3.69	5.71
2017	3.26	8.80	12.06
2018	3.09	9.20	12.29
2019	3.86	9.25	13.11
2020	3.05	8.24	11.29

Table 2: Ageing error models and resultant model selection (AICc) values for 9 models of bias and precision explored for each lab used in the vermilion rockfish assessments. Gray bars indicate the chosen model. Model codes: 0= unbiased; 1 = Constant CV; 2 = Curvilinear SD; 3= Curvilinear CV

Model	Bias	Precision	Bias	Precision	AICc	ΔAICc	BIC	ΔBIC
1	0	1	0	1	0	26	0	25
2	0	2	0	2	0	4	0	4
3	**0**	**3**	**0**	**3**	**0**	**0**	**0**	**0**
4	0	1	1	1	0	16	0	16
5	0	2	1	2	0	15	0	16
6	0	3	1	3	0	15	0	16
7	0	1	2	1	0	24	0	25
8	0	2	2	2	0	24	0	26
9	0	3	2	3	0	28	0	30

Model	Bias	Precision	Bias	Precision	AICc	ΔAICc	BIC	ΔBIC
1	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**
2	0	2	0	2	0	4	0	6
3	0	3	0	3	0	4	0	6
4	0	1	1	1	0	0	0	3
5	0	2	1	2	0	4	0	8
6	0	3	1	3	0	8	0	12
7	0	1	2	1	0	39	0	42
8	0	2	2	2	0	10	0	14
9	0	3	2	3	0	9	0	14

Table 4: Ageing error models and resultant model selection (AICc) values for 9 models of bias and precision explored for each lab used in the vermilion rockfish assessments. Gray bars indicate the chosen model. Model codes: 0= unbiased; 1 = Constant CV; 2 = Curvilinear SD; 3= Curvilinear CV *(continued)*

Model	Bias	Precision	Bias	Precision	AICc	ΔAICc	BIC	ΔBIC
1	0	1	0	1	0	73	0	64
2	0	2	0	2	0	61	0	54
3	0	3	0	3	0	57	0	50
4	**0**	**1**	**1**	**1**	**0**	**0**	**0**	**0**
5	0	2	1	2	0	17	0	18
6	0	3	1	3	0	7	0	8
7	0	1	2	1	0	1	0	3
8	0	2	2	2	0	13	0	16
9	0	3	2	3	0	10	0	13

Table 5: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (mean and SD).

Parameter	Value	Phase	Bounds	Status	Prior (Exp.Val, SD)
NatM p 1 Fem GP 1	0.080	3	OK	0.00812246	Log Norm (-2.30259, 0.438)
L at Amin Fem GP 1	-17.078	3	OK	3.33389	None
L at Amax Fem GP 1	57.184	3	OK	0.341133	None
VonBert K Fem GP 1	0.146	3	OK	0.00585385	None
CV young Fem GP 1	0.100	-4	-	-	None
CV old Fem GP 1	0.054	4	OK	0.00178057	None
Wtlen 1 Fem GP 1	0.000	-99	-	-	None
Wtlen 2 Fem GP 1	2.930	-99	-	-	None
Mat50% Fem GP 1	39.400	-99	-	-	None
Mat slope Fem GP 1	-0.342	-99	-	-	None
Eggs scalar Fem GP 1	0.000	-3	-	-	None
Eggs exp len Fem GP 1	3.548	-3	-	-	None
NatM p 1 Mal GP 1	0.073	3	OK	0.00789027	Log Norm (-2.30259, 0.438)
L at Amin Mal GP 1	-29.898	3	OK	5.2875	None
L at Amax Mal GP 1	54.193	3	OK	0.245592	None
VonBert K Mal GP 1	0.180	3	OK	0.00749103	None
CV young Mal GP 1	0.100	-4	-	-	None
CV old Mal GP 1	0.045	4	LO	0.00166169	None
Wtlen 1 Mal GP 1	0.000	-99	-	-	None
Wtlen 2 Mal GP 1	2.830	-99	-	-	None
CohortGrowDev	1.000	-1	-	-	None
FracFemale GP 1	0.500	-99	-	-	None
SR LN(R0)	2.793	1	OK	0.243905	None
SR BH steep	0.720	-1	-	-	None
SR sigmaR	0.600	-6	-	-	None
SR regime	0.000	-99	-	-	None
SR autocorr	0.000	-99	-	-	None
Early RecrDev 1961	0.401	3	act	0.502983	dev (NA, NA)
Main RecrDev 1962	-0.310	1	act	0.5281	dev (NA, NA)

Table 5: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (mean and SD). *(continued)*

Parameter	Value	Phase	Bounds	Status	Prior (Exp.Val, SD)
Main RecrDev 1963	-0.146	1	act	0.525021	dev (NA, NA)
Main RecrDev 1964	-0.181	1	act	0.523987	dev (NA, NA)
Main RecrDev 1965	-0.361	1	act	0.516361	dev (NA, NA)
Main RecrDev 1966	-0.377	1	act	0.512917	dev (NA, NA)
Main RecrDev 1967	-0.403	1	act	0.507653	dev (NA, NA)
Main RecrDev 1968	-0.419	1	act	0.50438	dev (NA, NA)
Main RecrDev 1969	-0.265	1	act	0.489923	dev (NA, NA)
Main RecrDev 1970	-0.469	1	act	0.494869	dev (NA, NA)
Main RecrDev 1971	-0.514	1	act	0.487127	dev (NA, NA)
Main RecrDev 1972	-0.542	1	act	0.48257	dev (NA, NA)
Main RecrDev 1973	-0.416	1	act	0.470845	dev (NA, NA)
Main RecrDev 1974	-0.447	1	act	0.463433	dev (NA, NA)
Main RecrDev 1975	-0.617	1	act	0.470639	dev (NA, NA)
Main RecrDev 1976	-0.413	1	act	0.457774	dev (NA, NA)
Main RecrDev 1977	-0.246	1	act	0.457334	dev (NA, NA)
Main RecrDev 1978	0.083	1	act	0.462145	dev (NA, NA)
Main RecrDev 1979	0.918	1	act	0.329273	dev (NA, NA)
Main RecrDev 1980	0.053	1	act	0.446429	dev (NA, NA)
Main RecrDev 1981	-0.293	1	act	0.459389	dev (NA, NA)
Main RecrDev 1982	0.096	1	act	0.359725	dev (NA, NA)
Main RecrDev 1983	-0.696	1	act	0.438068	dev (NA, NA)
Main RecrDev 1984	-0.544	1	act	0.405129	dev (NA, NA)
Main RecrDev 1985	-0.319	1	act	0.406255	dev (NA, NA)
Main RecrDev 1986	0.271	1	act	0.312356	dev (NA, NA)
Main RecrDev 1987	-0.120	1	act	0.387596	dev (NA, NA)
Main RecrDev 1988	-0.149	1	act	0.349932	dev (NA, NA)
Main RecrDev 1989	-0.394	1	act	0.402682	dev (NA, NA)
Main RecrDev 1990	-0.037	1	act	0.336222	dev (NA, NA)
Main RecrDev 1991	-0.035	1	act	0.407393	dev (NA, NA)

Table 5: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (mean and SD). *(continued)*

Parameter	Value	Phase	Bounds	Status	Prior (Exp.Val, SD)
Main RecrDev 1992	0.976	1	act	0.27623	dev (NA, NA)
Main RecrDev 1993	1.904	1	act	0.155751	dev (NA, NA)
Main RecrDev 1994	1.855	1	act	0.14828	dev (NA, NA)
Main RecrDev 1995	0.794	1	act	0.264997	dev (NA, NA)
Main RecrDev 1996	0.668	1	act	0.216913	dev (NA, NA)
Main RecrDev 1997	0.384	1	act	0.262629	dev (NA, NA)
Main RecrDev 1998	1.758	1	act	0.0976628	dev (NA, NA)
Main RecrDev 1999	0.759	1	act	0.166544	dev (NA, NA)
Main RecrDev 2000	-0.383	1	act	0.254929	dev (NA, NA)
Main RecrDev 2001	-0.524	1	act	0.228807	dev (NA, NA)
Main RecrDev 2002	-0.626	1	act	0.234313	dev (NA, NA)
Main RecrDev 2003	-0.957	1	act	0.256931	dev (NA, NA)
Main RecrDev 2004	-0.783	1	act	0.249366	dev (NA, NA)
Main RecrDev 2005	1.258	1	act	0.102519	dev (NA, NA)
Main RecrDev 2006	0.247	1	act	0.174997	dev (NA, NA)
Main RecrDev 2007	-0.449	1	act	0.227476	dev (NA, NA)
Main RecrDev 2008	-0.599	1	act	0.254319	dev (NA, NA)
Main RecrDev 2009	-0.052	1	act	0.202398	dev (NA, NA)
Main RecrDev 2010	-0.311	1	act	0.237927	dev (NA, NA)
Main RecrDev 2011	-0.730	1	act	0.312447	dev (NA, NA)
Main RecrDev 2012	0.514	1	act	0.184045	dev (NA, NA)
Main RecrDev 2013	-0.360	1	act	0.324163	dev (NA, NA)
Main RecrDev 2014	0.823	1	act	0.273872	dev (NA, NA)
Main RecrDev 2015	1.738	1	act	0.293244	dev (NA, NA)
Main RecrDev 2016	-0.324	1	act	0.544964	dev (NA, NA)
Main RecrDev 2017	-0.064	1	act	0.596996	dev (NA, NA)
Main RecrDev 2018	-0.075	1	act	0.594571	dev (NA, NA)
Main RecrDev 2019	-0.075	1	act	0.594573	dev (NA, NA)
Main RecrDev 2020	-0.075	1	act	0.594573	dev (NA, NA)

Table 5: List of parameters used in the base model, including estimated values and standard deviations (SD), bounds (minimum and maximum), estimation phase (negative values not estimated), status (indicates if parameters are near bounds), and prior type information (mean and SD). *(continued)*

Parameter	Value	Phase	Bounds	Status	Prior (Exp.Val, SD)
ForeRecr 2021	0.000	5	act	0.6	dev (NA, NA)
ForeRecr 2022	0.000	5	act	0.6	dev (NA, NA)
InitF seas 1 flt 1Commercial	0.000	-1	-	-	None
InitF seas 1 flt 2Recreational	0.000	-1	-	-	None
LnQ base Recreational(2)	-5.723	-1	-	-	None
Q extraSD Recreational(2)	0.081	3	OK	0.0227712	None
Size DblN peak Commercial(1)	43.670	2	OK	0.713312	None
Size DblN top logit Commercial(1)	15.000	-1	-	-	None
Size DblN ascend se Commercial(1)	3.728	2	OK	0.182659	None
Size DblN descend se Commercial(1)	-15.000	-1	-	-	None
Size DblN start logit Commercial(1)	-15.000	-2	-	-	None
Size DblN end logit Commercial(1)	15.000	-1	-	-	None
Size DblN peak Recreational(2)	44.443	2	OK	0.828114	None
Size DblN top logit Recreational(2)	15.000	-1	-	-	None
Size DblN ascend se Recreational(2)	4.298	2	OK	0.153315	None
Size DblN descend se Recreational(2)	-15.000	-1	-	-	None
Size DblN start logit Recreational(2)	-15.000	-2	-	-	None
Size DblN end logit Recreational(2)	15.000	-1	-	-	None

Table 6: Likelihood components by source.

Label	Total
TOTAL	2701.16
Catch	0.00
Equil catch	0.00
Survey	-32.83
Length comp	449.80
Age comp	2260.95
Recruitment	22.83
InitEQ Regime	0.00
Forecast Recruitment	0.00
Parm priors	0.40
Parm softbounds	0.00
Parm devs	0.00
Crash Pen	0.00

Table 7: Summary of reference points and management quantities, including estimates of the 95 percent intervals.

	Estimate	Lower Interval	Upper Interval
Unfished Spawning Output	29.24	22.19	36.29
Unfished Age 3+ Biomass (mt)	354.37	278.67	430.07
Unfished Recruitment (R0)	16.33	8.52	24.13
Spawning Output (2021)	21.35	10.06	32.65
Fraction Unfished (2021)	0.73	0.48	0.98
Reference Points Based SB40\%	NA	NA	NA
Proxy Spawning Output SB40\%	11.70	8.88	14.51
SPR Resulting in SB40\%	0.46	0.46	0.46
Exploitation Rate Resulting in SB40\%	0.06	0.05	0.07
Yield with SPR Based On SB40\% (mt)	8.32	5.57	11.07
Reference Points Based on SPR Proxy for MSY	NA	NA	NA
Proxy Spawning Output (SPR50)	13.04	9.90	16.19
SPR50	0.50	NA	NA
Exploitation Rate Corresponding to SPR50	0.05	0.04	0.06
Yield with SPR50 at SB SPR (mt)	7.95	5.32	10.57
Reference Points Based on Estimated MSY Values	NA	NA	NA
Spawning Output at MSY (SB MSY)	8.04	6.28	9.81
SPR MSY	0.35	0.34	0.35
Exploitation Rate Corresponding to SPR MSY	0.09	0.07	0.11
MSY (mt)	8.82	5.89	11.76

Table 8: Time series of population estimates from the base model.

Year	Total Biomass (mt)	Spawning Output	Total Biomass 3+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	1-SPR	Exploitation Rate
1892	439.44	29.24	354.37	1.00	16.33	0.00	0.00	0.00
1893	439.44	29.24	354.37	1.00	16.33	0.00	0.00	0.00
1894	439.44	29.24	354.37	1.00	16.33	0.00	0.00	0.00
1895	439.44	29.24	354.37	1.00	16.33	0.00	0.00	0.00
1896	439.44	29.24	354.37	1.00	16.33	0.00	0.00	0.00
1897	439.44	29.24	354.37	1.00	16.33	0.00	0.00	0.00
1898	439.44	29.24	354.37	1.00	16.33	0.00	0.00	0.00
1899	439.45	29.24	354.38	1.00	16.33	0.00	0.00	0.00
1900	439.45	29.24	354.38	1.00	16.33	0.00	0.00	0.00
1901	439.46	29.24	354.39	1.00	16.33	0.00	0.00	0.00
1902	439.46	29.24	354.39	1.00	16.33	0.00	0.00	0.00
1903	439.47	29.24	354.40	1.00	16.33	0.00	0.00	0.00
1904	439.47	29.24	354.40	1.00	16.33	0.00	0.00	0.00
1905	439.48	29.24	354.40	1.00	16.33	0.00	0.00	0.00
1906	439.48	29.24	354.41	1.00	16.33	0.00	0.00	0.00
1907	439.49	29.24	354.41	1.00	16.33	0.00	0.00	0.00
1908	439.49	29.24	354.42	1.00	16.33	0.00	0.00	0.00
1909	439.50	29.24	354.42	1.00	16.33	0.00	0.00	0.00
1910	439.50	29.24	354.43	1.00	16.33	0.00	0.00	0.00
1911	439.50	29.24	354.43	1.00	16.33	0.00	0.00	0.00
1912	439.51	29.24	354.43	1.00	16.33	0.00	0.00	0.00
1913	439.51	29.24	354.44	1.00	16.33	0.00	0.00	0.00
1914	439.51	29.24	354.44	1.00	16.33	0.00	0.00	0.00
1915	439.52	29.24	354.44	1.00	16.33	0.00	0.00	0.00
1916	439.52	29.24	354.44	1.00	16.33	0.00	0.00	0.00
1917	439.52	29.24	354.45	1.00	16.33	0.00	0.00	0.00
1918	439.52	29.24	354.45	1.00	16.33	0.00	0.00	0.00
1919	439.52	29.24	354.45	1.00	16.33	0.00	0.00	0.00
1920	439.53	29.25	354.45	1.00	16.33	0.00	0.00	0.00
1921	439.53	29.25	354.46	1.00	16.33	0.00	0.00	0.00
1922	439.53	29.25	354.46	1.00	16.33	0.00	0.00	0.00
1923	439.53	29.25	354.46	1.00	16.33	0.00	0.00	0.00
1924	439.53	29.25	354.46	1.00	16.33	0.00	0.00	0.00
1925	439.54	29.25	354.46	1.00	16.33	0.00	0.00	0.00
1926	439.54	29.25	354.46	1.00	16.33	0.00	0.00	0.00
1927	439.54	29.25	354.46	1.00	16.33	0.00	0.00	0.00
1928	439.54	29.25	354.46	1.00	16.33	0.00	0.00	0.00
1929	439.54	29.25	354.46	1.00	16.33	0.32	0.02	0.00
1930	439.22	29.22	354.15	1.00	16.33	0.58	0.03	0.00
1931	438.65	29.17	353.60	1.00	16.33	0.28	0.01	0.00
1932	438.41	29.15	353.36	1.00	16.33	0.00	0.00	0.00
1933	438.46	29.15	353.41	1.00	16.33	0.06	0.00	0.00

Table 8: Time series of population estimates from the base model. *(continued)*

Year	Total Biomass (mt)	Spawning Output	Total Biomass 3+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	1-SPR	Exploitation Rate
1934	438.45	29.15	353.41	1.00	16.33	0.09	0.00	0.00
1935	438.42	29.14	353.38	1.00	16.33	0.00	0.00	0.00
1936	438.48	29.15	353.43	1.00	16.33	0.33	0.02	0.00
1937	438.21	29.13	353.16	1.00	16.33	1.08	0.05	0.00
1938	437.20	29.04	352.18	0.99	16.32	1.26	0.06	0.00
1939	436.04	28.93	351.06	0.99	16.32	1.52	0.07	0.00
1940	434.68	28.81	349.73	0.99	16.31	1.81	0.09	0.01
1941	433.09	28.67	348.18	0.98	16.30	1.21	0.06	0.00
1942	432.17	28.58	347.28	0.98	16.30	1.46	0.07	0.00
1943	431.05	28.48	346.20	0.97	16.29	1.65	0.08	0.00
1944	429.80	28.37	344.98	0.97	16.28	2.28	0.11	0.01
1945	427.98	28.20	343.20	0.96	16.27	2.57	0.12	0.01
1946	425.95	28.02	341.23	0.96	16.26	2.78	0.13	0.01
1947	423.81	27.83	339.15	0.95	16.25	0.92	0.05	0.00
1948	423.64	27.81	338.99	0.95	16.25	1.87	0.09	0.01
1949	422.55	27.71	337.93	0.95	16.25	2.00	0.10	0.01
1950	421.39	27.60	336.80	0.94	16.24	0.72	0.04	0.00
1951	421.58	27.61	336.99	0.94	16.24	0.65	0.03	0.00
1952	421.86	27.64	337.26	0.95	16.24	1.29	0.07	0.00
1953	421.49	27.60	336.90	0.94	16.24	0.44	0.02	0.00
1954	422.00	27.65	337.40	0.95	16.24	0.29	0.02	0.00
1955	422.66	27.71	338.04	0.95	16.25	0.83	0.04	0.00
1956	422.74	27.71	338.12	0.95	16.25	0.41	0.02	0.00
1957	423.26	27.76	338.62	0.95	16.25	0.87	0.04	0.00
1958	423.28	27.77	338.64	0.95	16.25	0.09	0.00	0.00
1959	424.09	27.84	339.43	0.95	16.25	0.27	0.01	0.00
1960	424.68	27.89	340.00	0.95	16.26	0.35	0.02	0.00
1961	465.90	27.94	340.47	0.96	24.28	0.65	0.03	0.00
1962	403.55	27.95	340.62	0.96	11.93	0.36	0.02	0.00
1963	414.94	27.99	341.04	0.96	14.00	0.63	0.03	0.00
1964	412.88	28.01	342.91	0.96	13.46	0.36	0.02	0.00
1965	402.11	28.05	343.41	0.96	11.20	1.82	0.09	0.01
1966	399.83	27.98	342.35	0.96	10.99	1.14	0.06	0.00
1967	397.07	28.00	341.48	0.96	10.66	3.26	0.15	0.01
1968	392.07	27.85	337.60	0.95	10.45	3.10	0.14	0.01
1969	396.16	27.68	333.20	0.95	12.13	6.04	0.26	0.02
1970	376.60	27.20	325.25	0.93	9.83	2.83	0.14	0.01
1971	368.96	26.93	319.96	0.92	9.35	6.42	0.28	0.02
1972	358.26	26.27	311.10	0.90	9.04	8.31	0.34	0.03
1973	352.81	25.38	299.94	0.87	10.17	9.02	0.37	0.03
1974	338.80	24.40	287.94	0.83	9.78	11.53	0.45	0.04
1975	316.25	23.17	273.44	0.79	8.17	5.97	0.29	0.02
1976	316.49	22.45	264.80	0.77	9.94	7.98	0.37	0.03

Table 8: Time series of population estimates from the base model. *(continued)*

Year	Total Biomass (mt)	Spawning Output	Total Biomass 3+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	1-SPR	Exploitation Rate
1977	314.55	21.54	254.31	0.74	11.64	11.21	0.47	0.04
1978	323.21	20.35	240.64	0.70	16.00	11.75	0.50	0.05
1979	413.67	19.12	227.10	0.65	36.42	8.00	0.41	0.04
1980	297.90	18.26	218.18	0.62	15.18	8.64	0.45	0.04
1981	268.33	17.37	210.27	0.59	10.61	6.03	0.37	0.03
1982	291.22	16.76	210.62	0.57	15.51	6.96	0.41	0.03
1983	246.19	16.13	209.35	0.55	6.96	6.88	0.42	0.03
1984	250.72	15.67	208.18	0.54	8.03	7.12	0.43	0.03
1985	259.52	15.43	207.85	0.53	9.99	9.17	0.50	0.04
1986	296.13	15.23	204.04	0.52	17.92	13.56	0.61	0.07
1987	257.76	14.78	195.29	0.51	12.00	9.75	0.52	0.05
1988	251.00	14.61	189.96	0.50	11.59	11.37	0.57	0.06
1989	231.49	14.23	184.27	0.49	8.99	16.23	0.68	0.09
1990	238.90	13.32	173.25	0.46	12.64	16.07	0.70	0.09
1991	226.99	12.35	162.55	0.42	12.44	5.96	0.44	0.04
1992	335.74	12.24	161.47	0.42	33.99	9.35	0.57	0.06
1993	592.34	11.88	157.56	0.41	85.18	26.90	0.84	0.17
1994	538.07	10.10	136.62	0.35	77.90	8.72	0.60	0.06
1995	285.19	9.83	138.76	0.34	26.68	4.04	0.39	0.03
1996	287.86	9.98	159.65	0.34	23.52	7.76	0.57	0.05
1997	277.97	9.95	185.00	0.34	17.64	8.59	0.59	0.05
1998	564.54	10.23	206.97	0.35	69.84	11.11	0.64	0.05
1999	362.64	11.06	226.47	0.38	26.07	3.01	0.25	0.01
2000	303.04	13.29	251.43	0.45	8.60	5.58	0.34	0.02
2001	324.23	15.88	282.33	0.54	7.68	8.04	0.39	0.03
2002	341.87	18.32	304.89	0.63	7.06	5.28	0.27	0.02
2003	351.42	20.74	324.24	0.71	5.16	6.41	0.29	0.02
2004	369.98	22.91	337.53	0.78	6.22	5.26	0.24	0.02
2005	593.10	25.03	346.87	0.86	48.35	7.74	0.30	0.02
2006	440.52	26.65	348.61	0.91	17.71	7.85	0.30	0.02
2007	396.51	27.72	346.04	0.95	8.86	8.91	0.33	0.03
2008	388.82	28.12	347.92	0.96	7.65	9.64	0.35	0.03
2009	413.30	27.96	345.16	0.96	13.20	8.06	0.31	0.02
2010	394.31	27.64	341.49	0.95	10.18	6.42	0.27	0.02
2011	373.11	27.41	337.52	0.94	6.69	9.05	0.35	0.03
2012	449.25	27.04	330.37	0.92	23.17	11.94	0.43	0.04
2013	369.24	26.42	318.92	0.90	9.65	9.73	0.38	0.03
2014	470.14	25.87	308.01	0.88	31.41	6.23	0.28	0.02
2015	702.32	25.47	302.94	0.87	78.28	6.12	0.28	0.02
2016	360.67	24.94	296.21	0.85	11.62	5.71	0.27	0.02
2017	378.90	24.38	294.20	0.83	15.03	12.06	0.47	0.04
2018	375.26	23.26	298.55	0.80	14.79	12.29	0.48	0.04
2019	373.86	22.25	297.20	0.76	14.71	13.11	0.51	0.04

Table 8: Time series of population estimates from the base model. *(continued)*

Year	Total Biomass (mt)	Spawning Output	Total Biomass 3+ (mt)	Fraction Unfished	Age-0 Recruits	Total Mortality (mt)	1-SPR	Exploitation Rate
2020	372.12	21.47	295.82	0.73	14.64	11.29	0.47	0.04
2021	377.77	21.35	295.77	0.73	15.77	11.86	0.47	0.04
2022	376.26	21.60	294.11	0.74	15.79	12.21	0.47	0.04

8 Figures

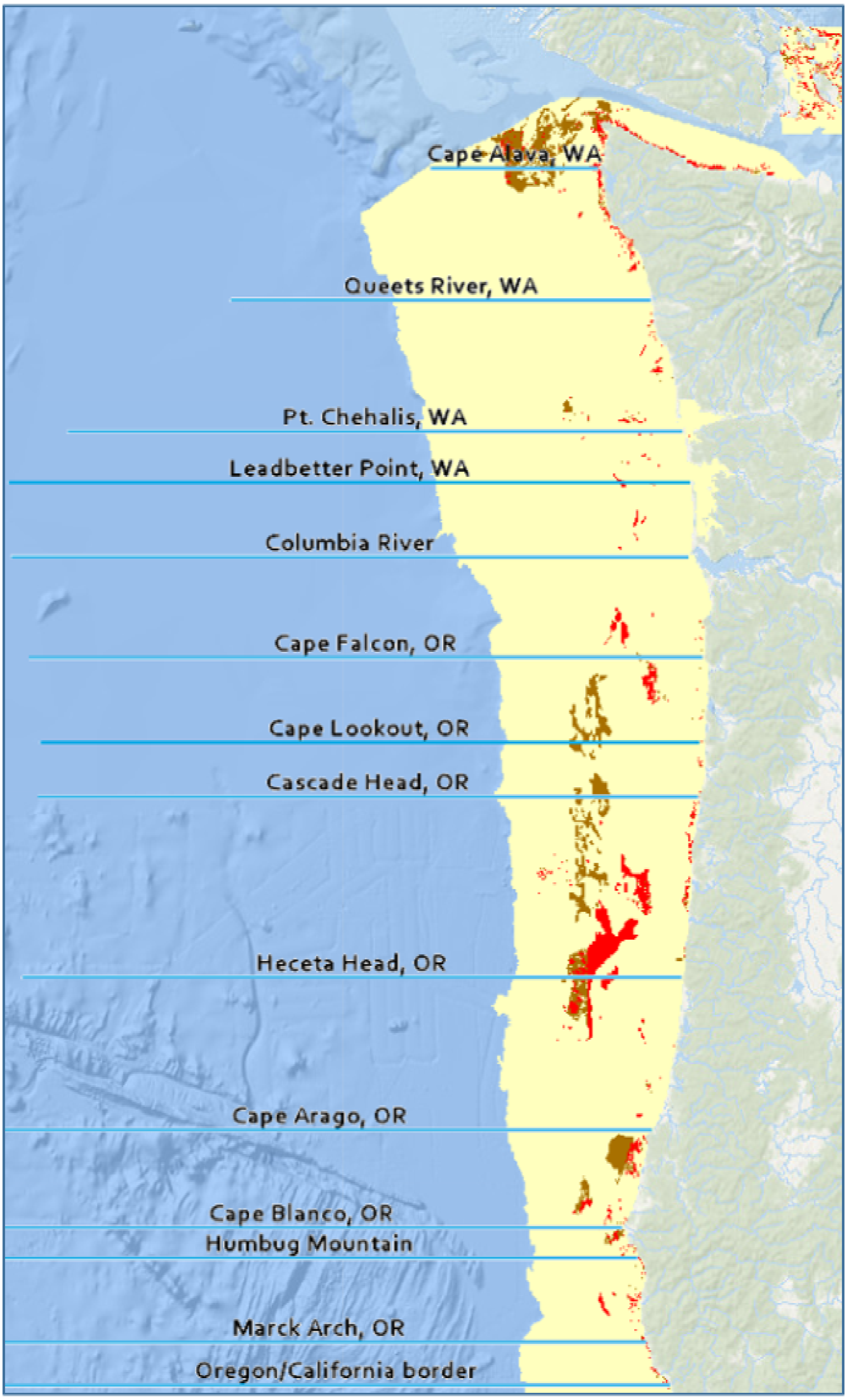

Figure 1: Oregon and Washington coastlines with rocky habitat indicated by brown shaded areas. Circled areas represent areas of primary vermilion rockfish occurence..

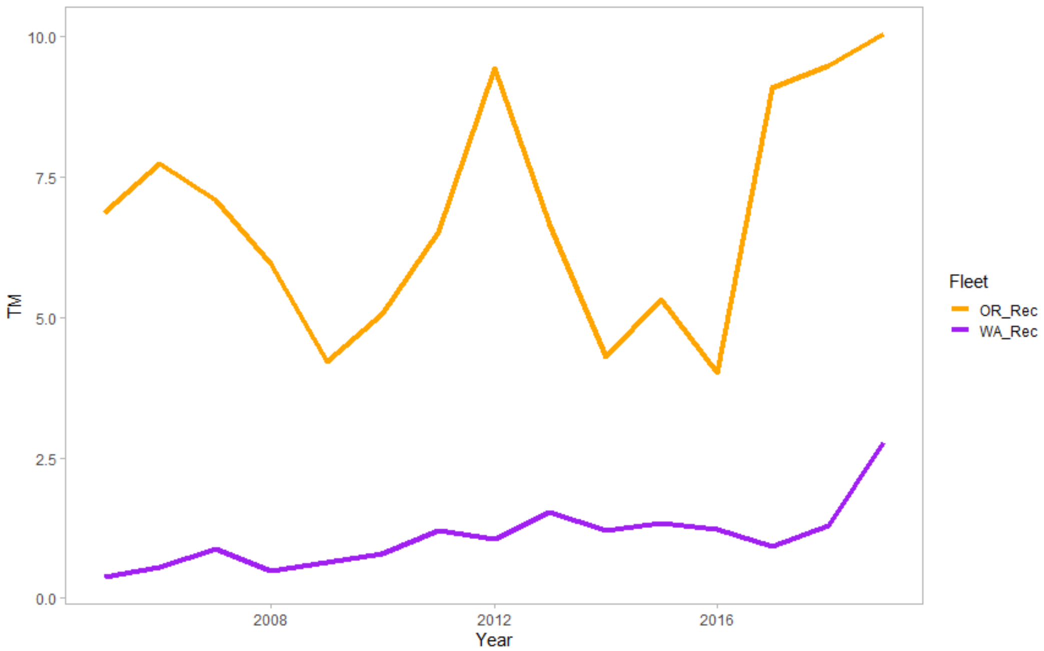

Figure 2: Total mortality from the southern Oregon and northern Washington recreational fisheries. These represent ninty and ninty-seven percent of the total vermilion removals in each state, respectively..

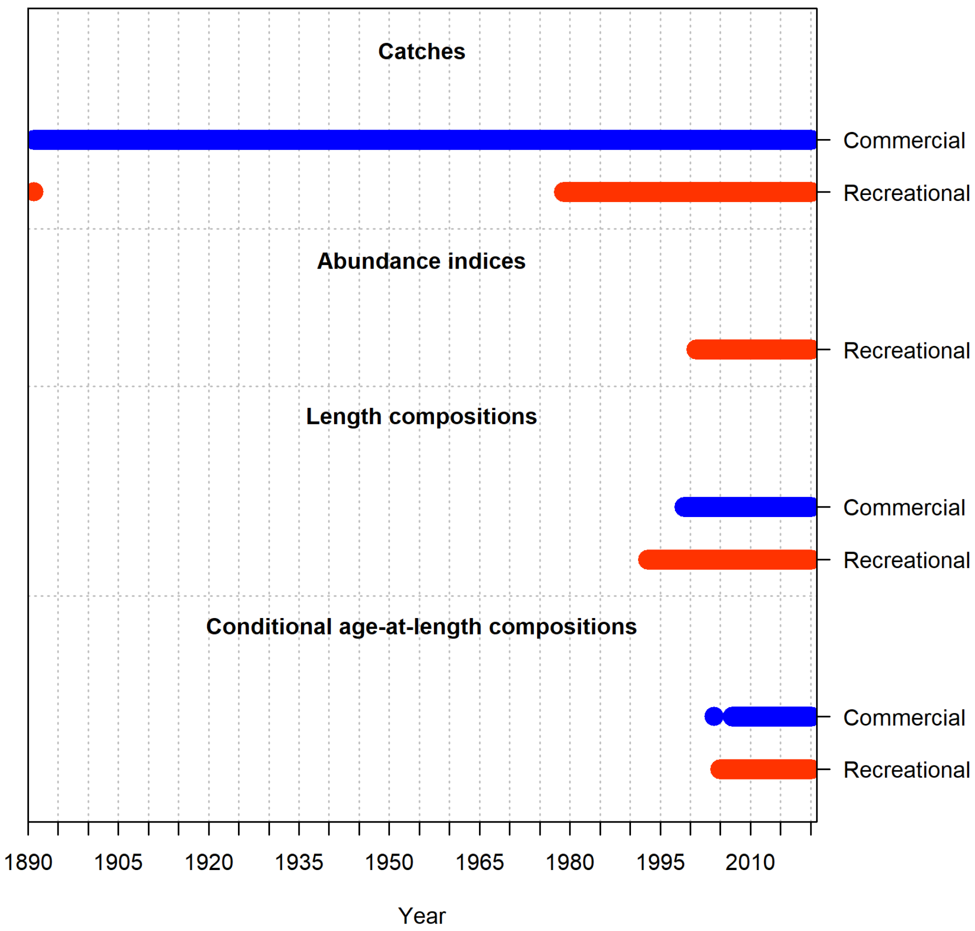

Figure 3: Summary of data sources used in the base model.

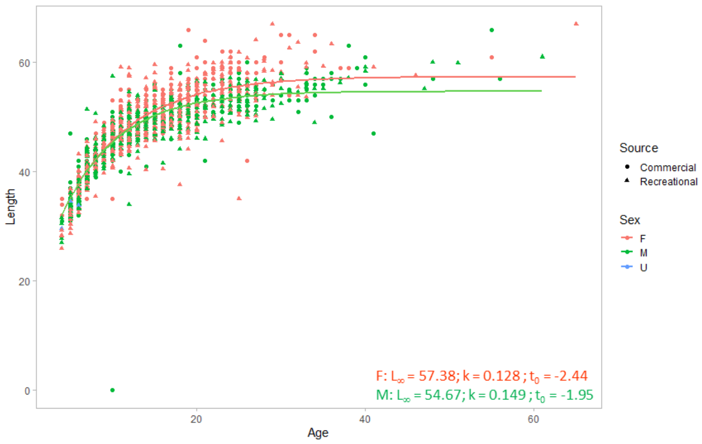

Figure 4: Observed length-at-age by data source and sex. Lines indicate fits to the von Bertalanffy growth equation, with parameter estimates provided in the bottom right corner of the figure.

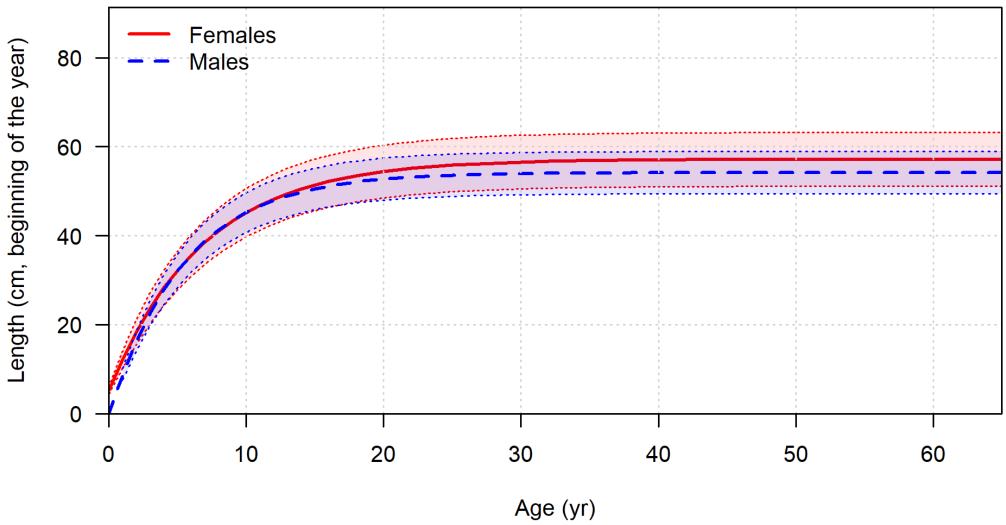

Figure 5: Length at age in the beginning of the year in the ending year of the model.

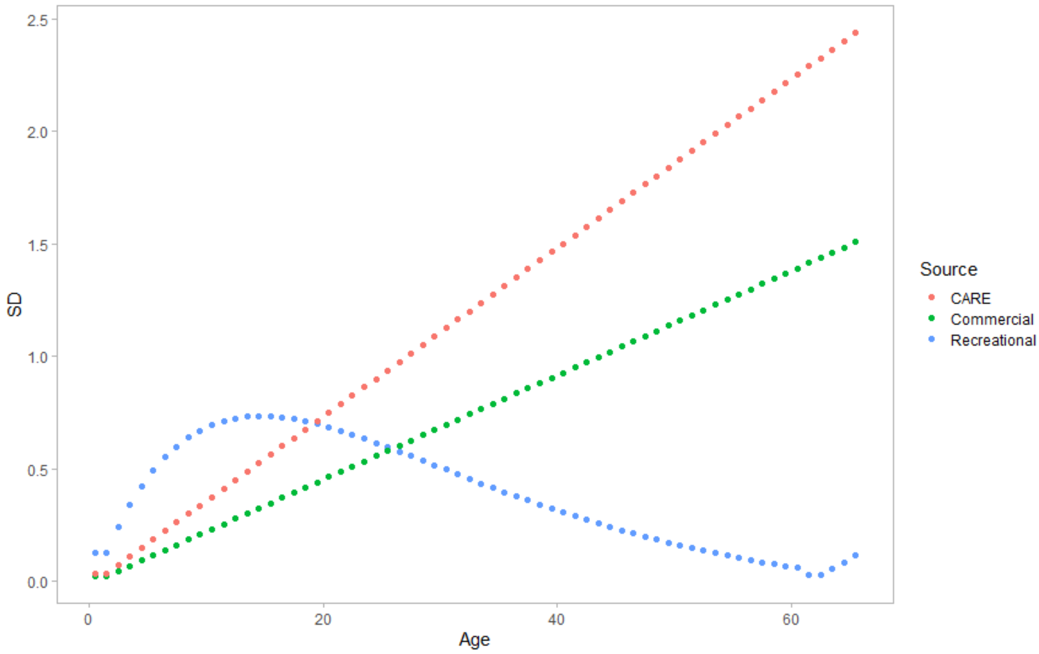

Figure 6: Agein error matrix (age by standard deviation) values by source. The commercial and recreational matrices are based on inter-reader comparisons.

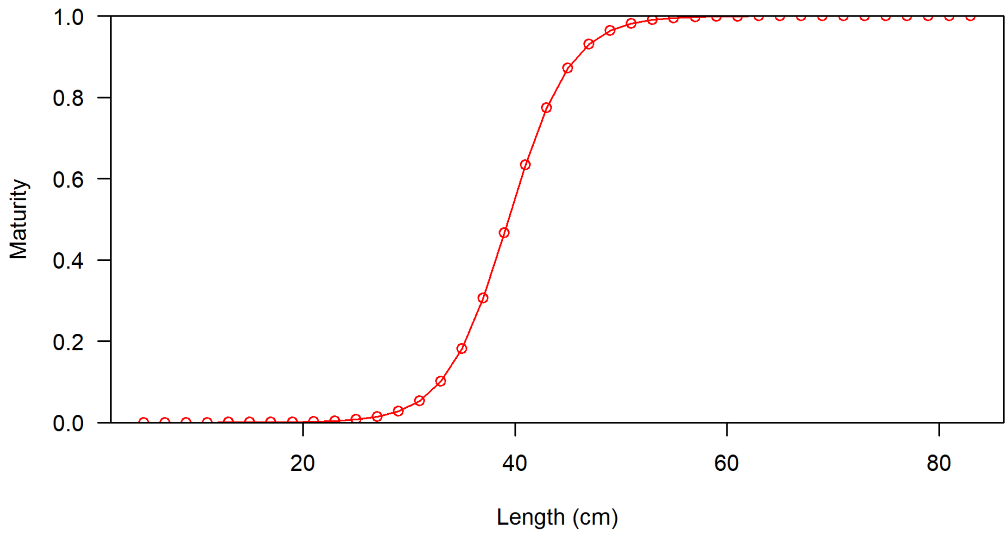

Figure 7: Maturity as a function of length.

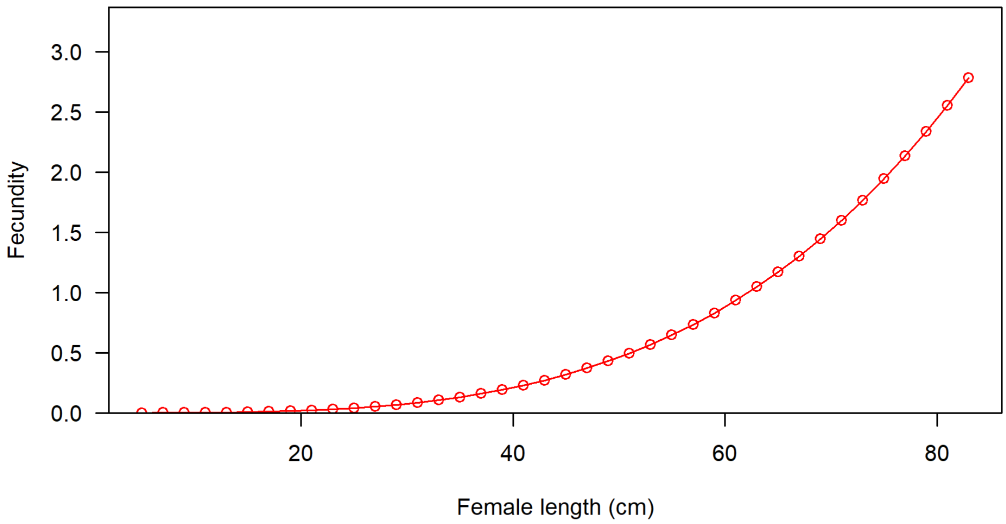

Figure 8: Fecundity as a function of length.

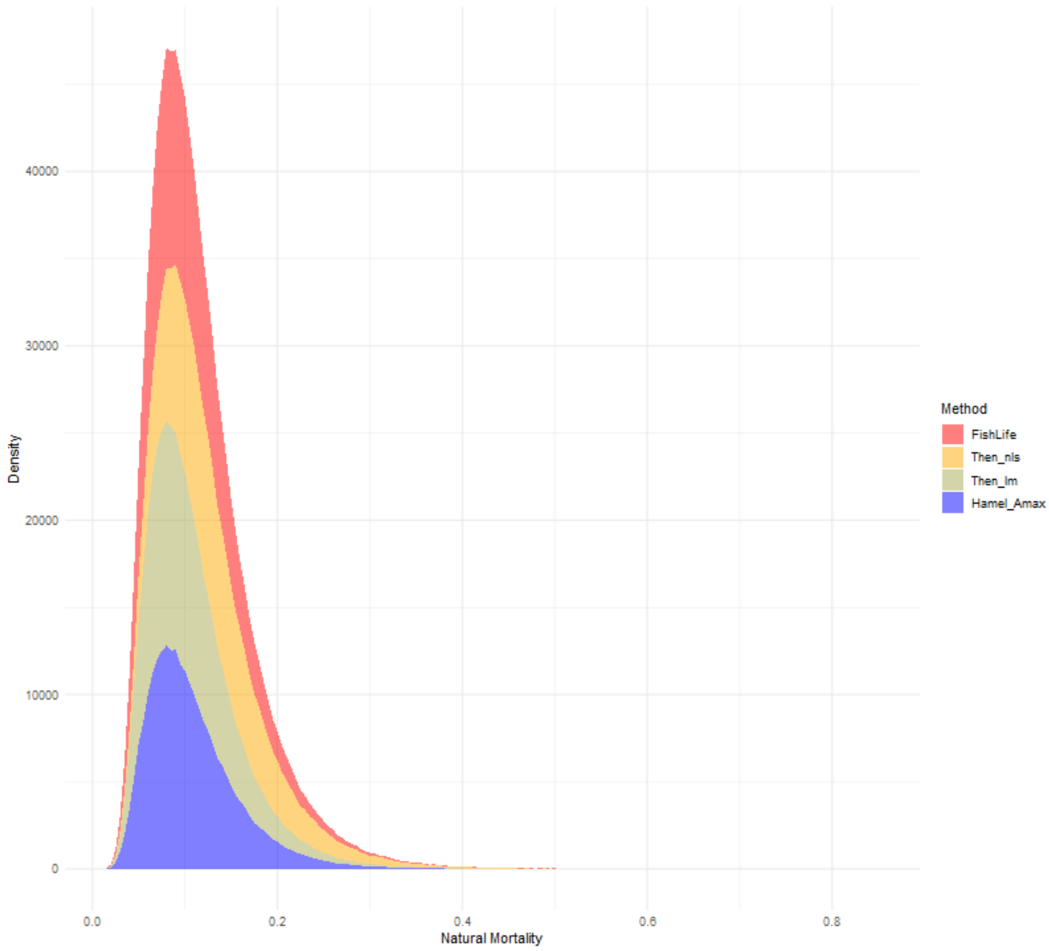

Figure 9: Composite natural mortality distriubtion for *S.hopkinsi* using four longevity estimators each with a SD = 0.2 presuming a lognomral error distibution.

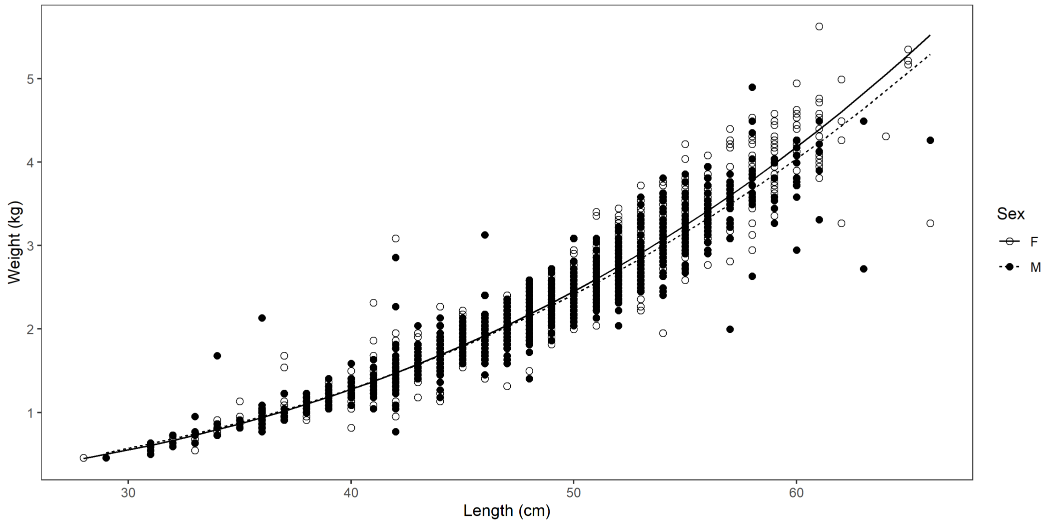

Figure 10: Length-weight data and fits to commercially-derived sex-specific vermilion samples.

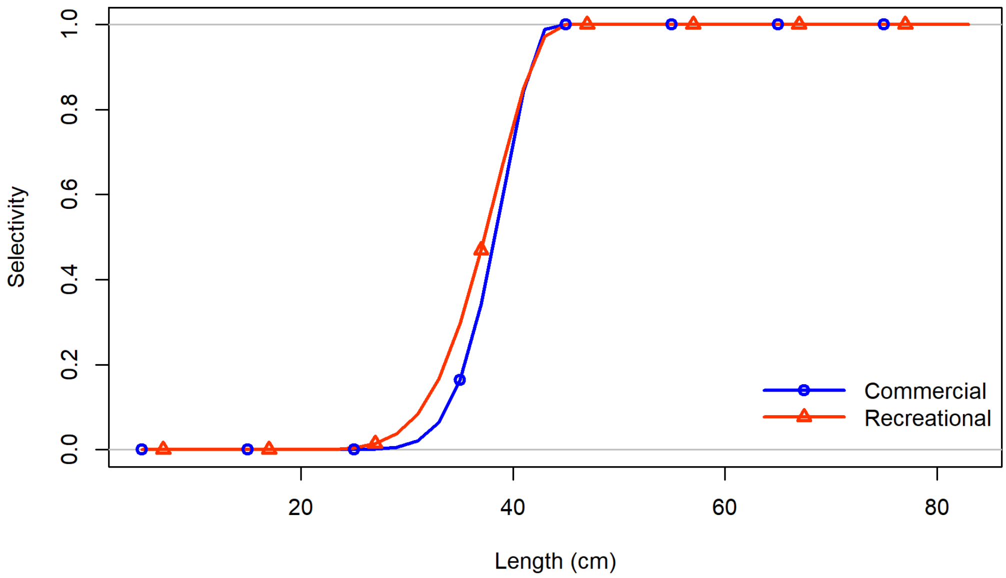

Figure 11: Selectivity at length by fleet.

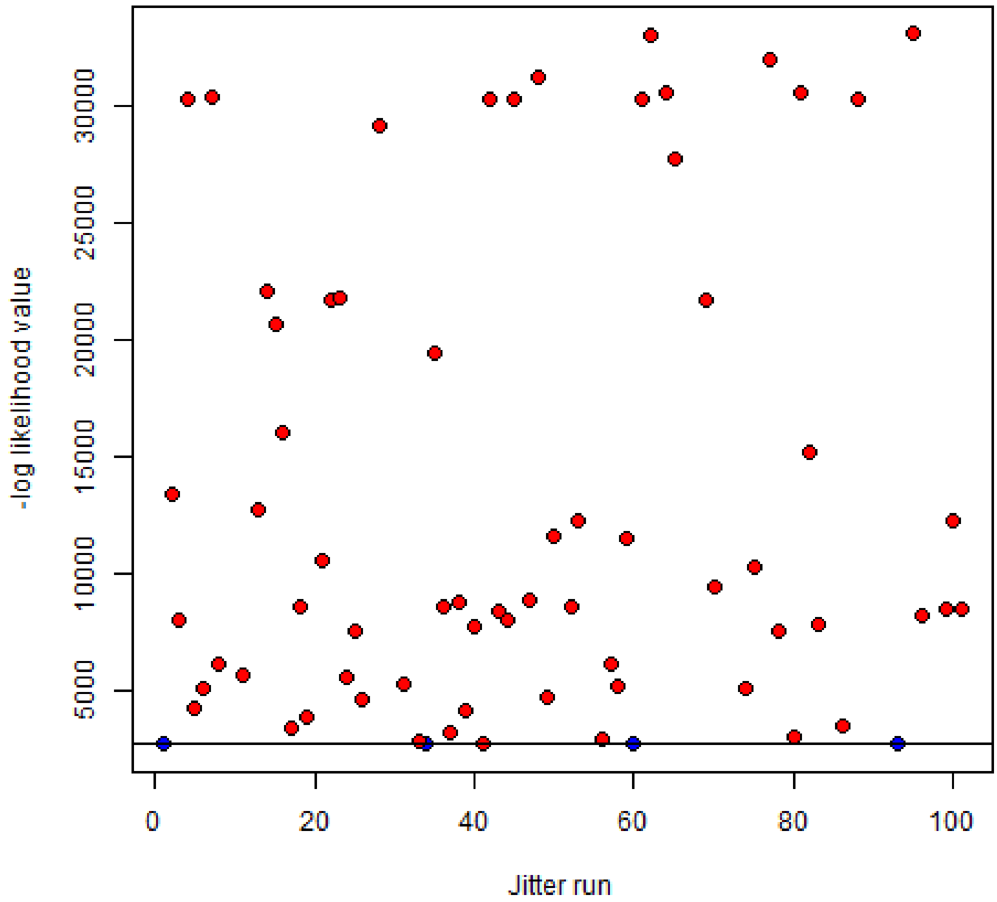

Figure 12: Jitter runs for the squarespot rockfish reference model, with jitter run number on the x-axis and -log likelihood value on the y-axis. Blue dot are models that match the likelihood value of the reference model, while red dots deviate from the reference model. All red dots are above the blue dots, indicating no better fit to the reference model was found.

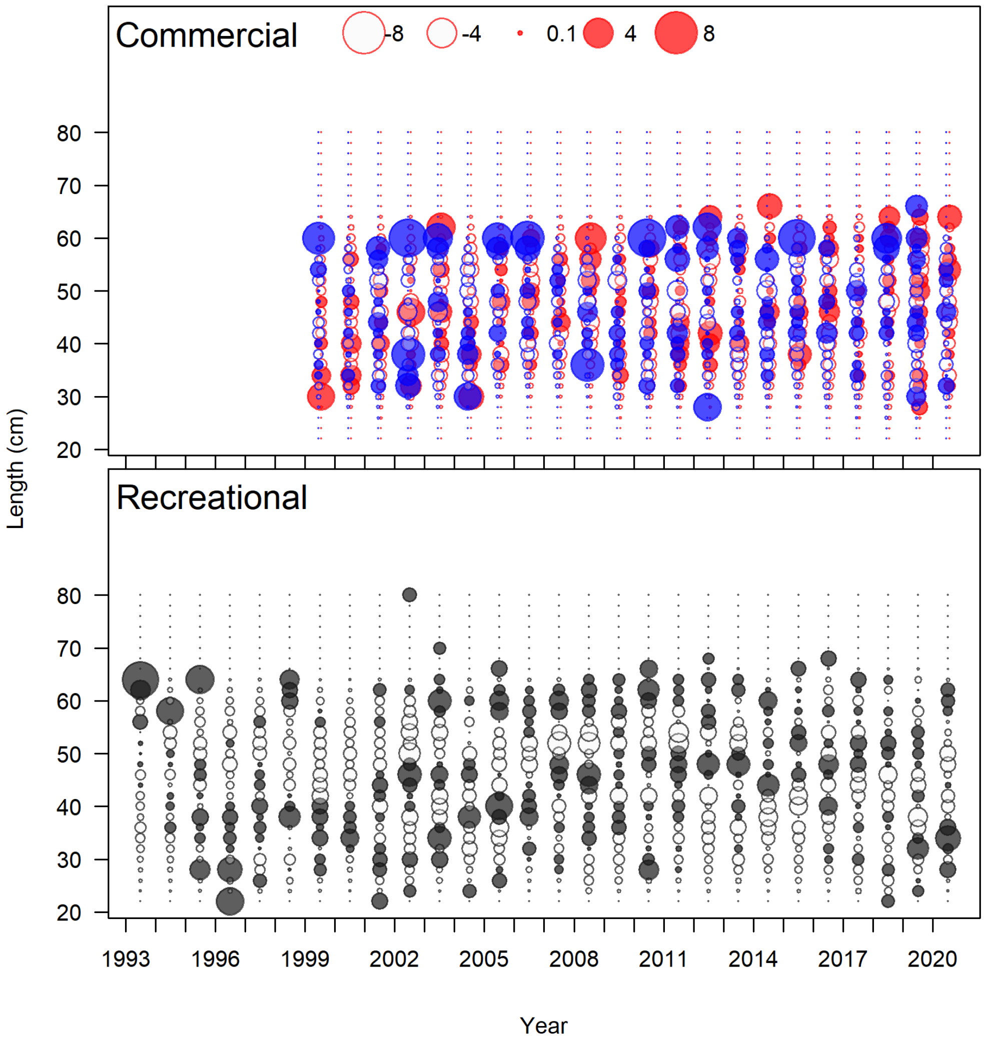

Figure 13: Pearson residuals for the commercial (top panel) and recreational (bottom panel) fleet. Closed bubble are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

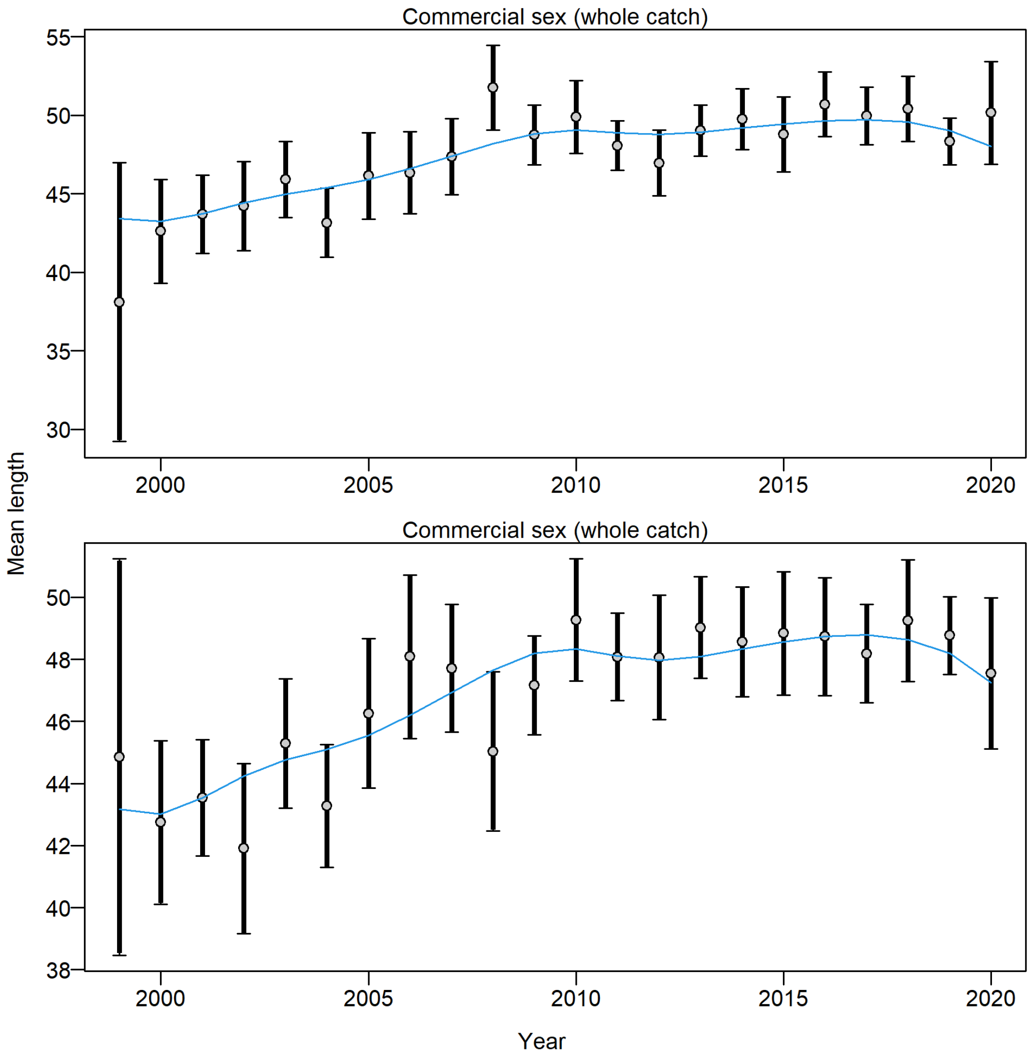

Figure 14: Mean length index from the commercial fishery with 95 percent confidence intervals based on sample sizes and data weighting.

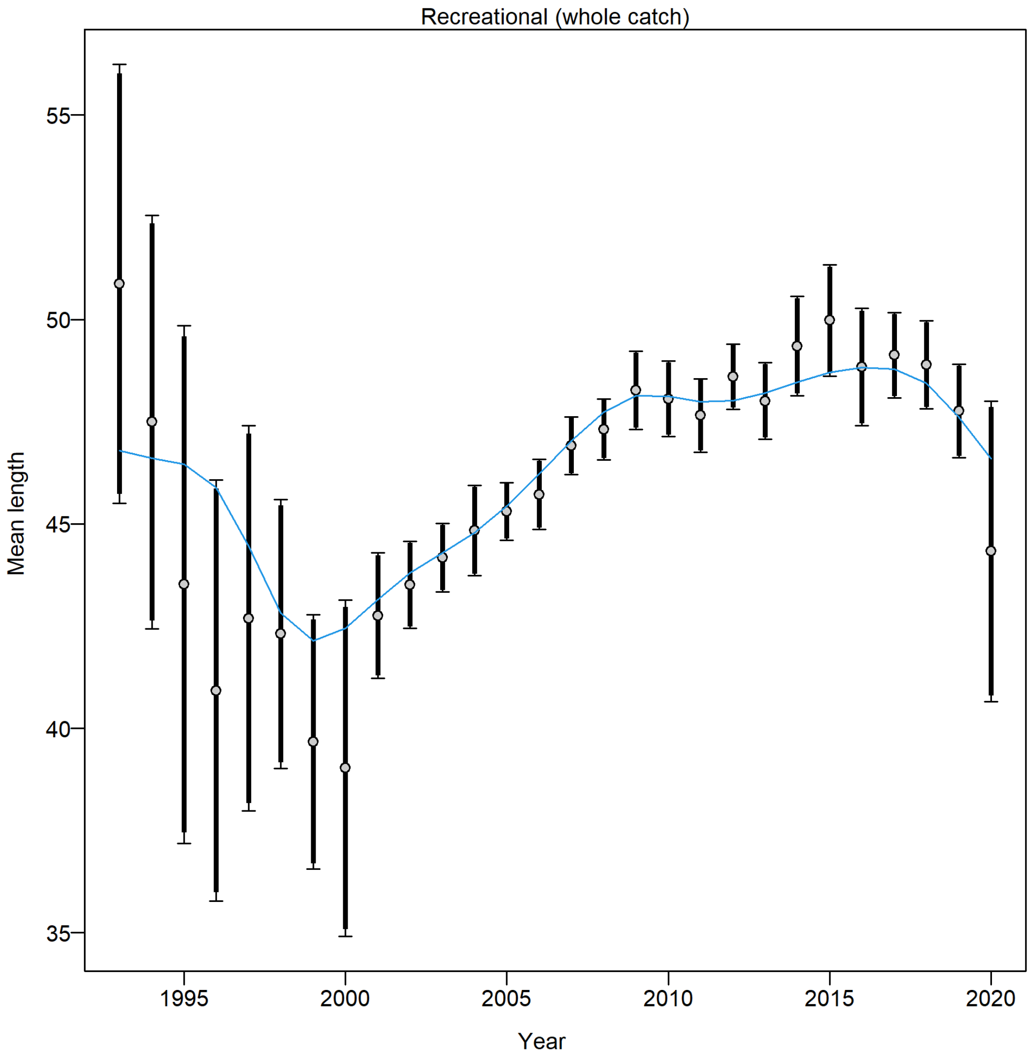

Figure 15: Mean length index from the recreational fishery with 95 percent confidence intervals based on sample sizes and data weighting.

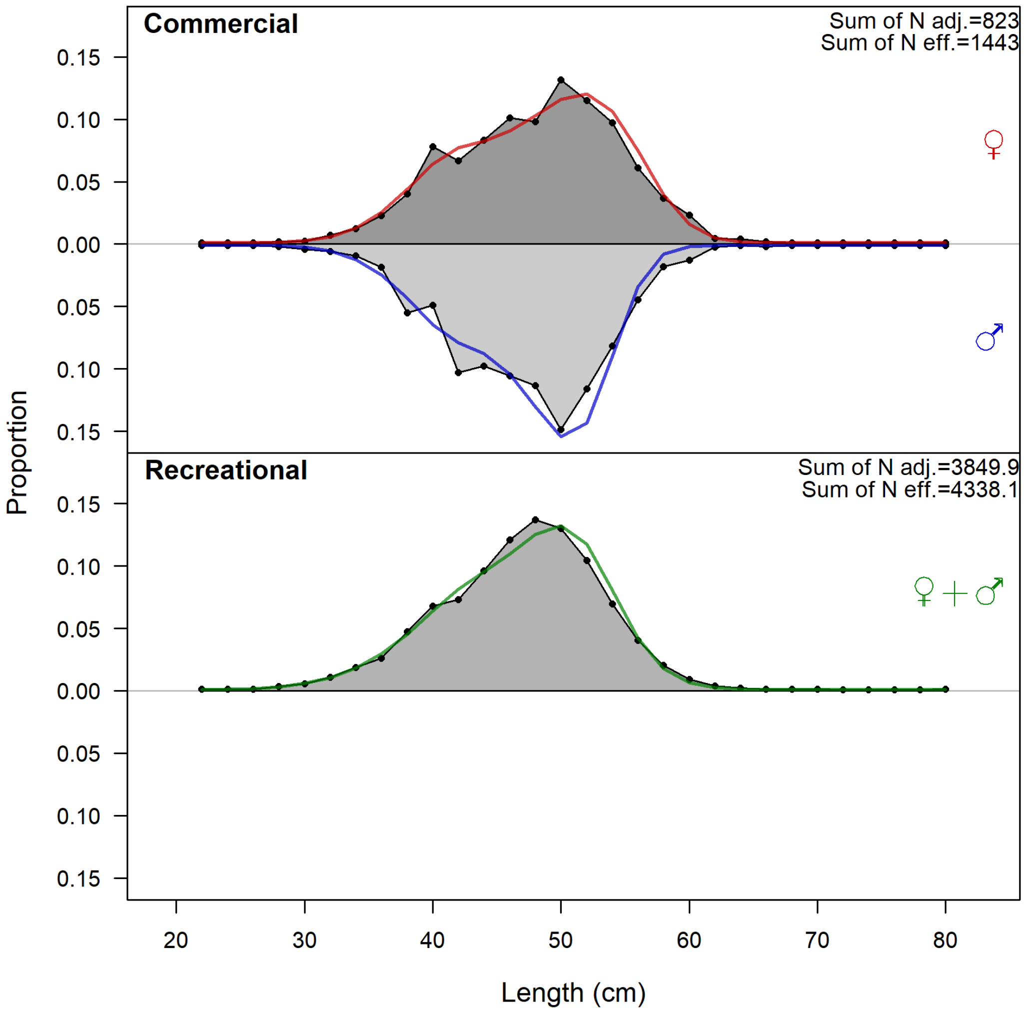

Figure 16: Aggregated length comps over all years.

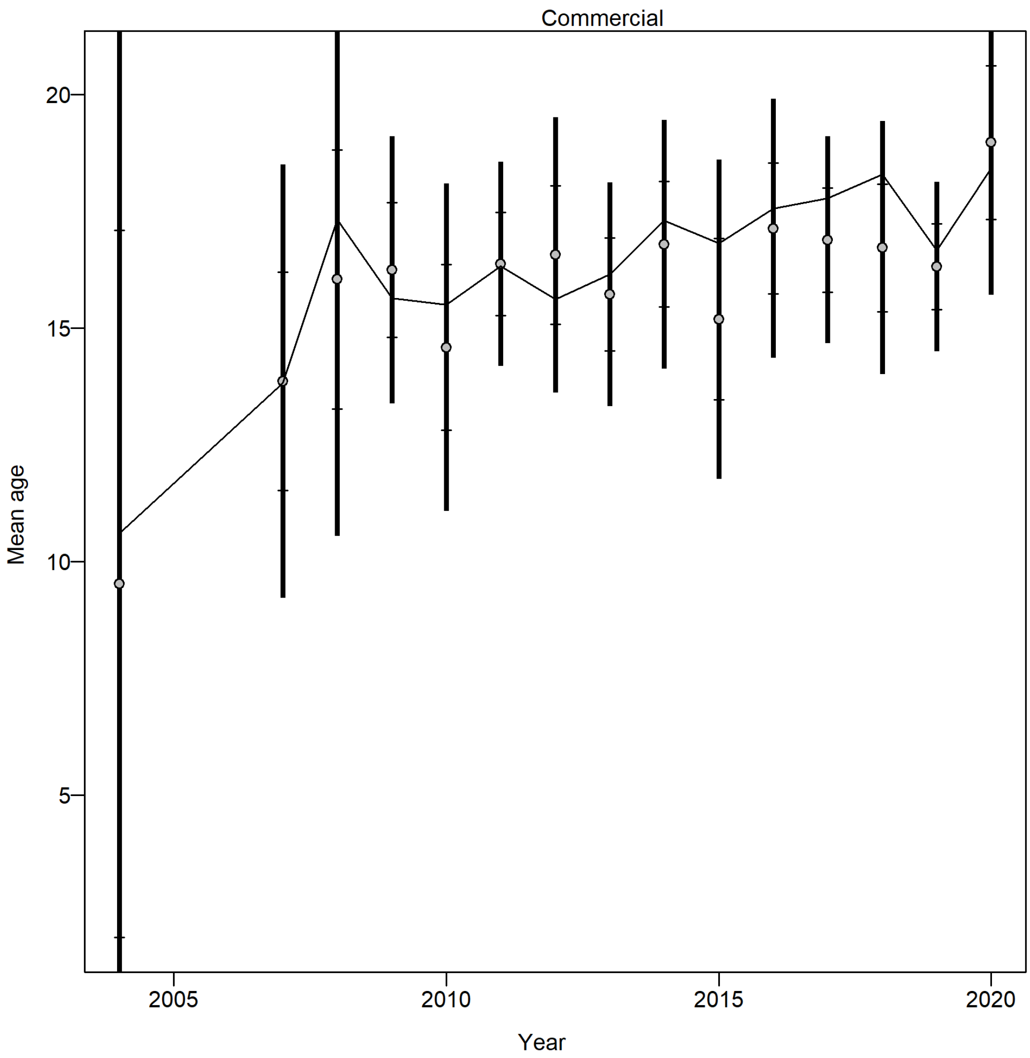

Figure 17: Mean age from conditional age-at-length data for the Commercial.

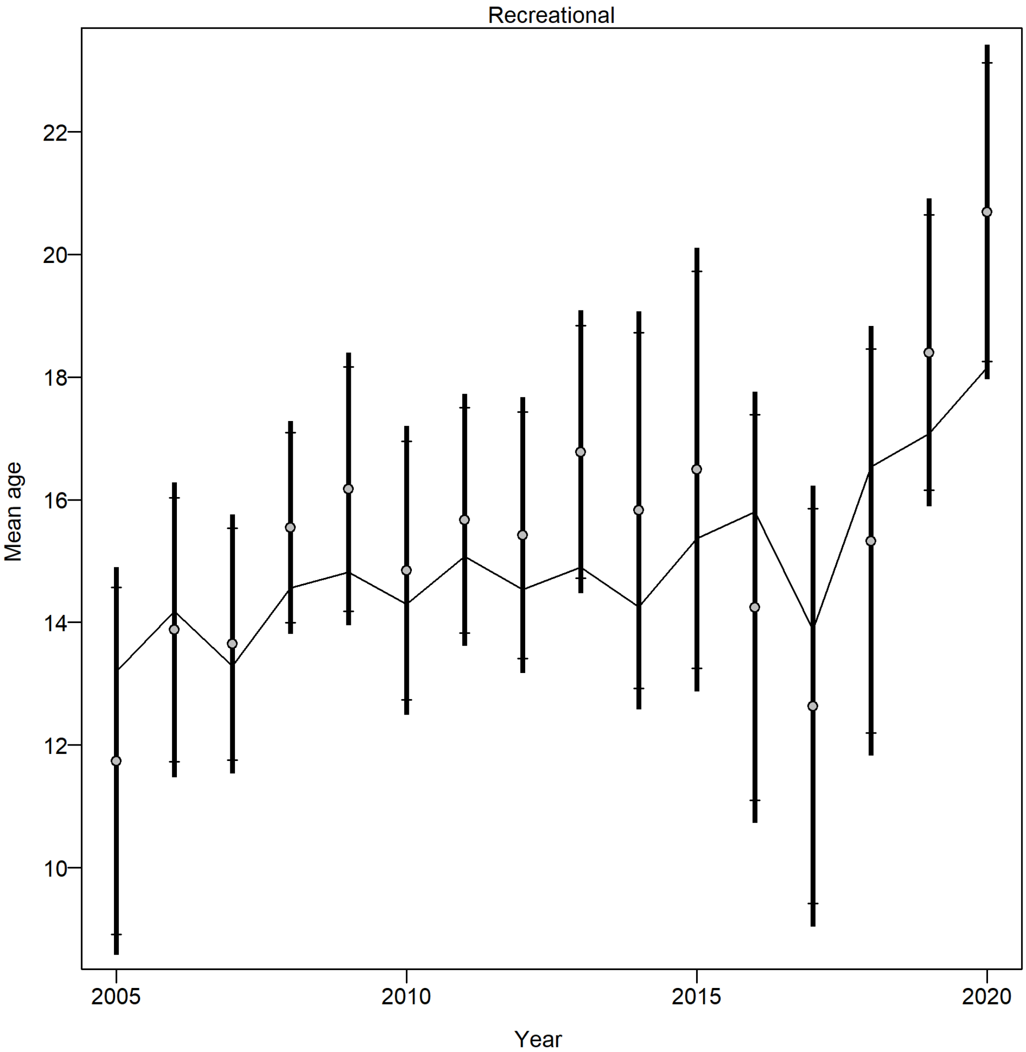

Figure 18: Mean age observations from the conditional age-at-length data from the Recreational fishery.

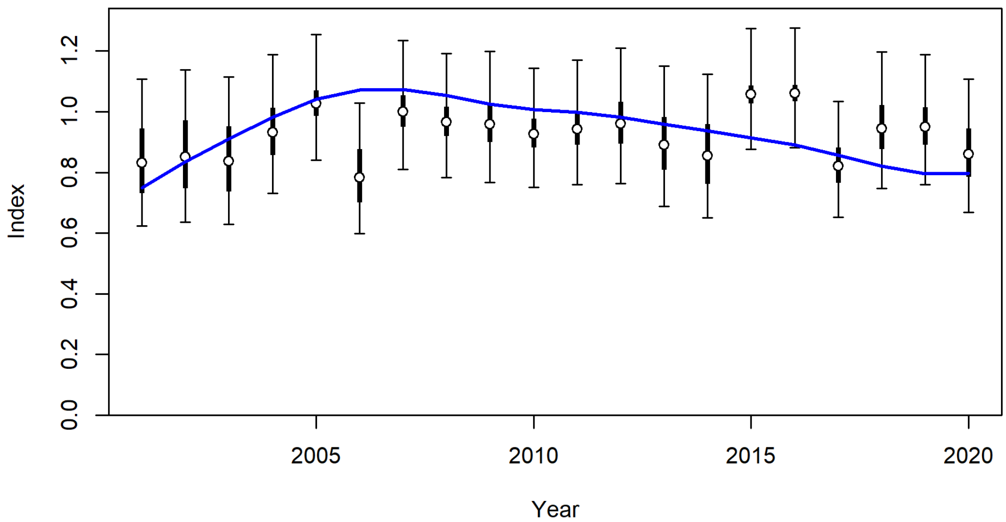

Figure 19: Fit to the ORBS recreational survey index of abundance.

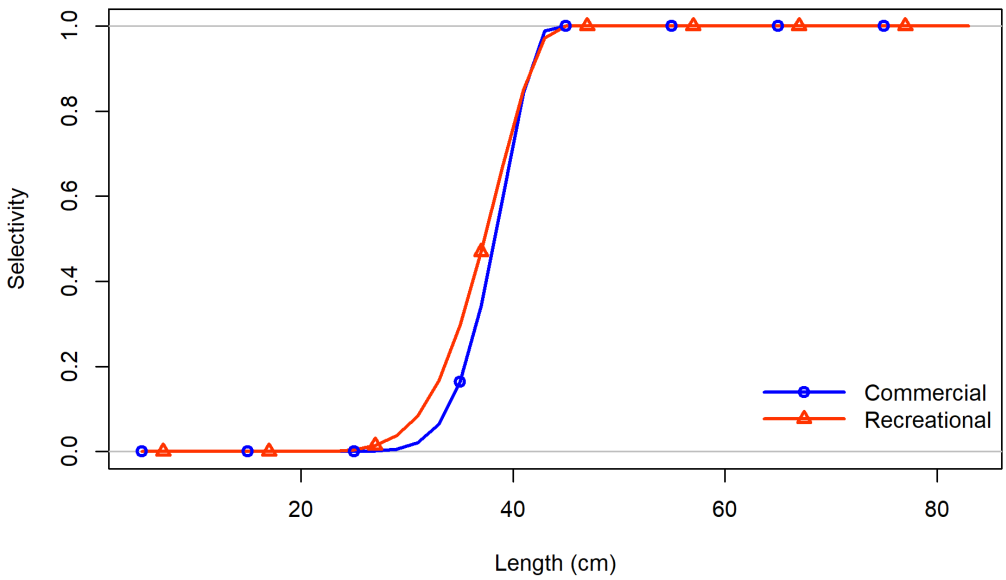

Figure 20: Length-based selectivity curves for the commercial and recreational fisheries.

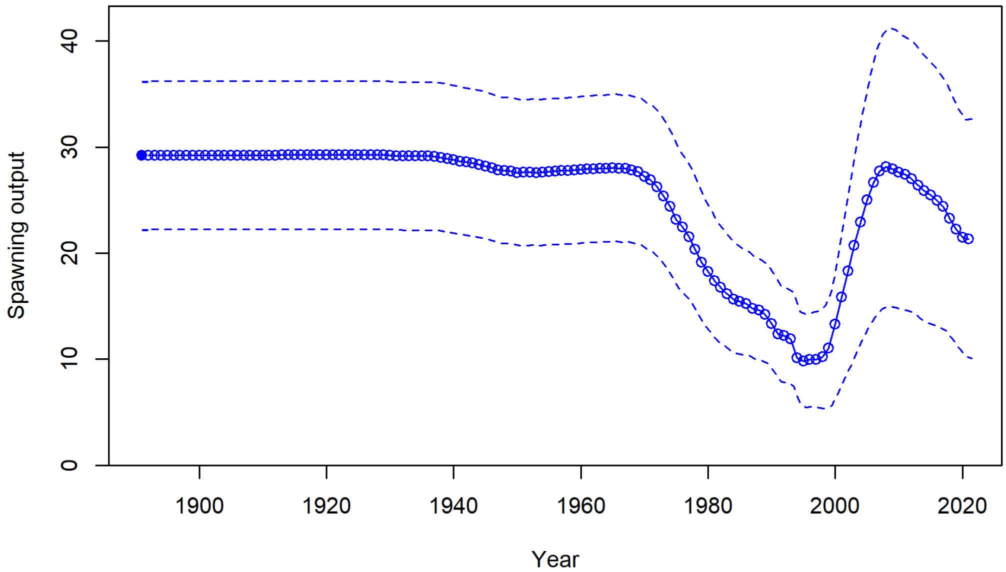

Figure 21: Estimated time series of spawning biomass.

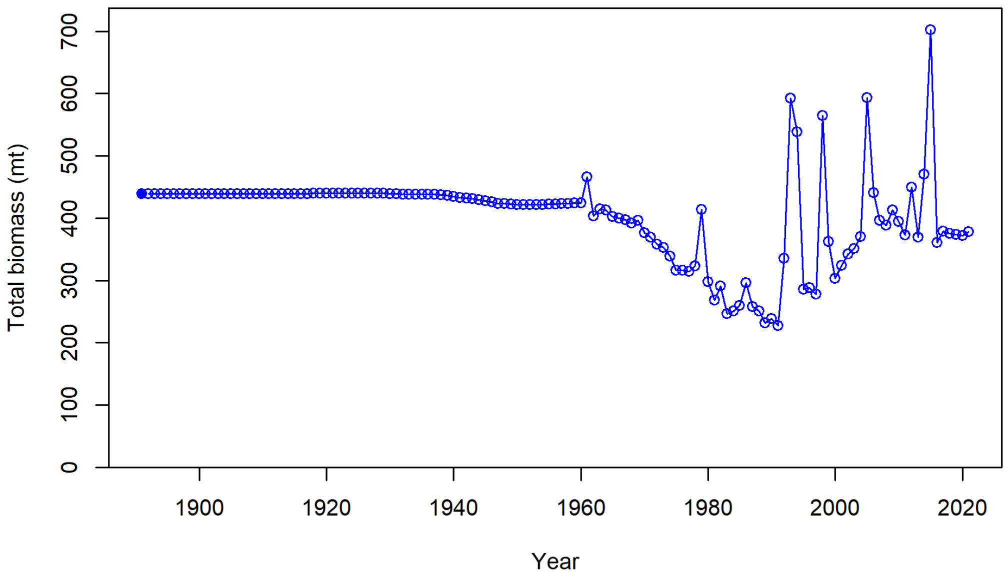

Figure 22: Estimated time series of total biomass.

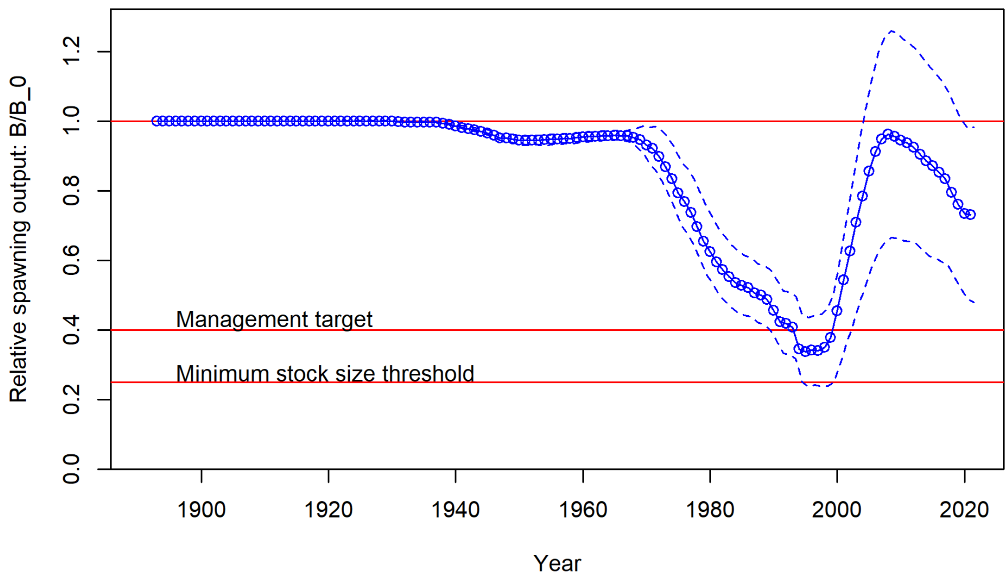

Figure 23: Estimated time series of fraction of unfished spawning biomass.

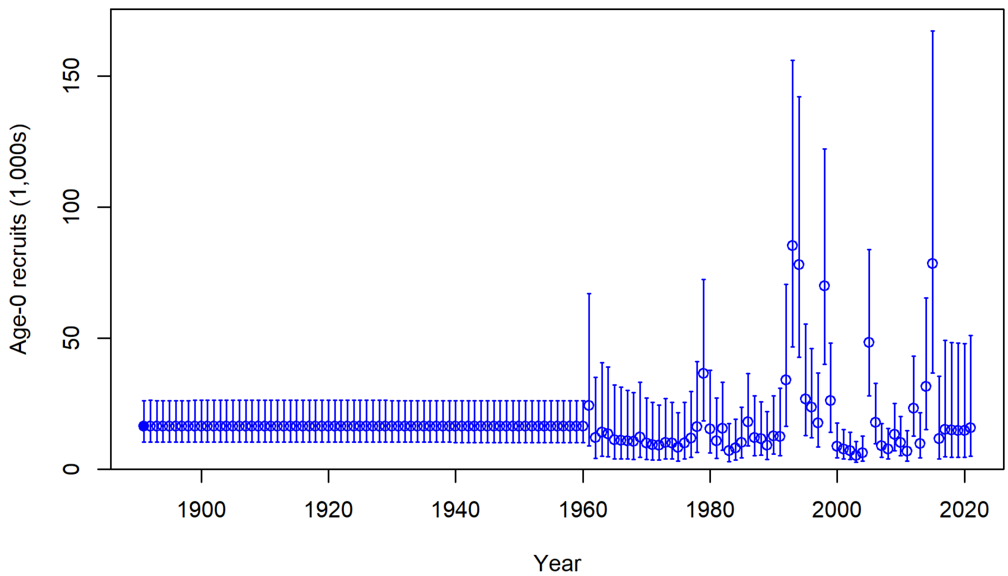

Figure 24: Estimated time series of age-0 recruits (1000s).

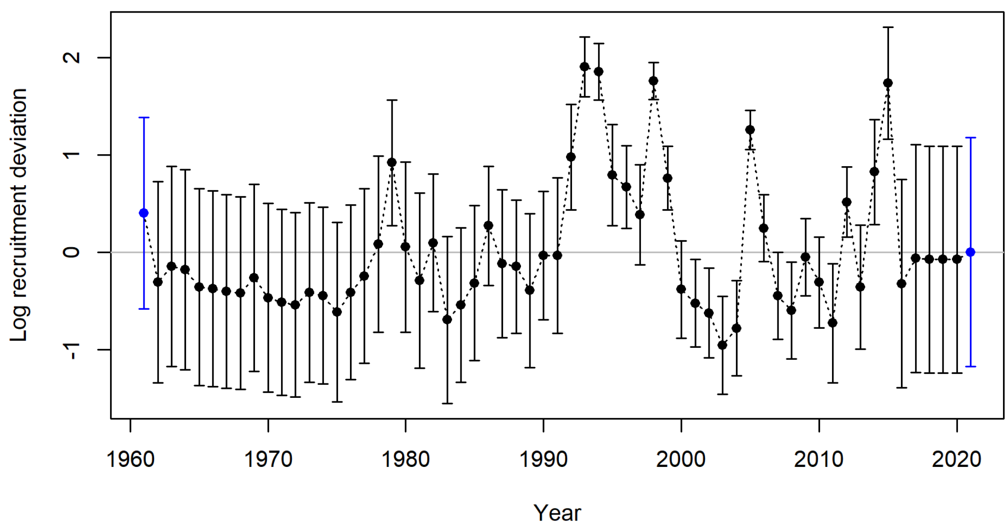

Figure 25: Estimated time series of recruitment deviations.

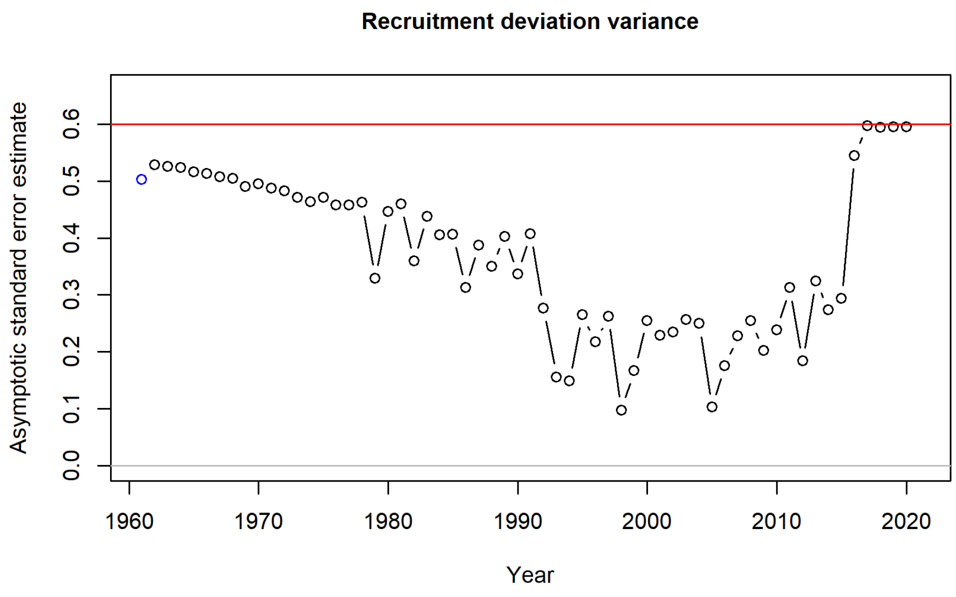

Figure 26: Recruitment deviations variance by year. This plot tracks the information content contained in each recruitment deviation. Values below the red line (assumed recruitment variability) indicates years with more informed recruitment deviations.

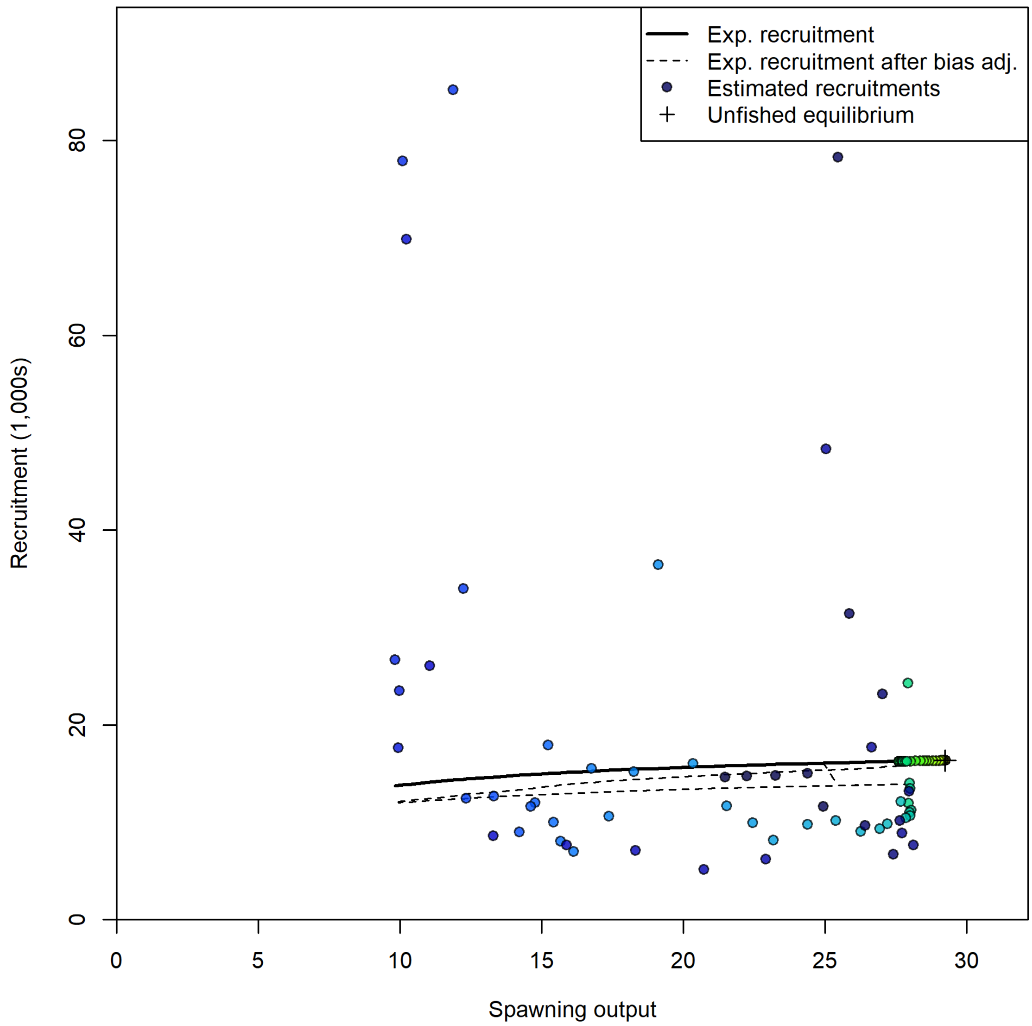

Figure 27: Stock-recruit curve. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years.

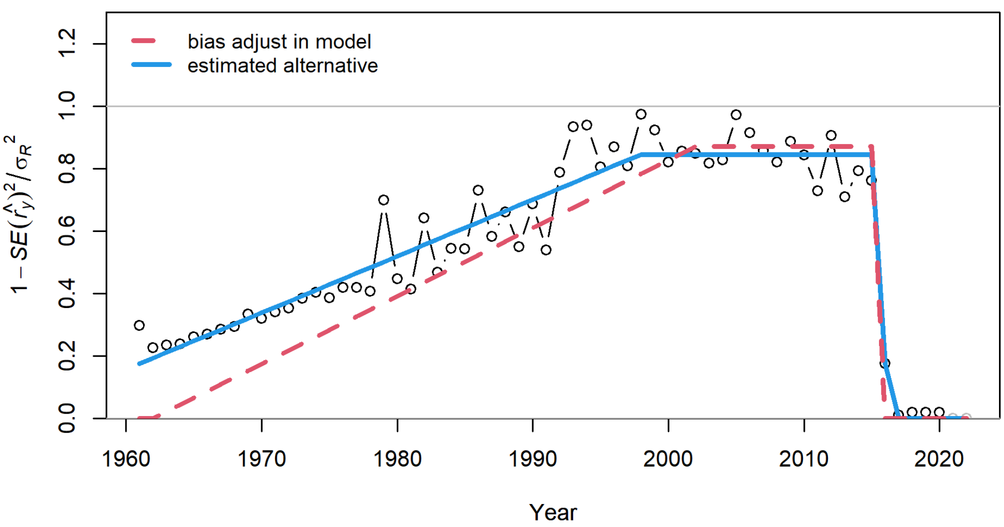

Figure 28: Recruitment bias adjustment applied in the base model.

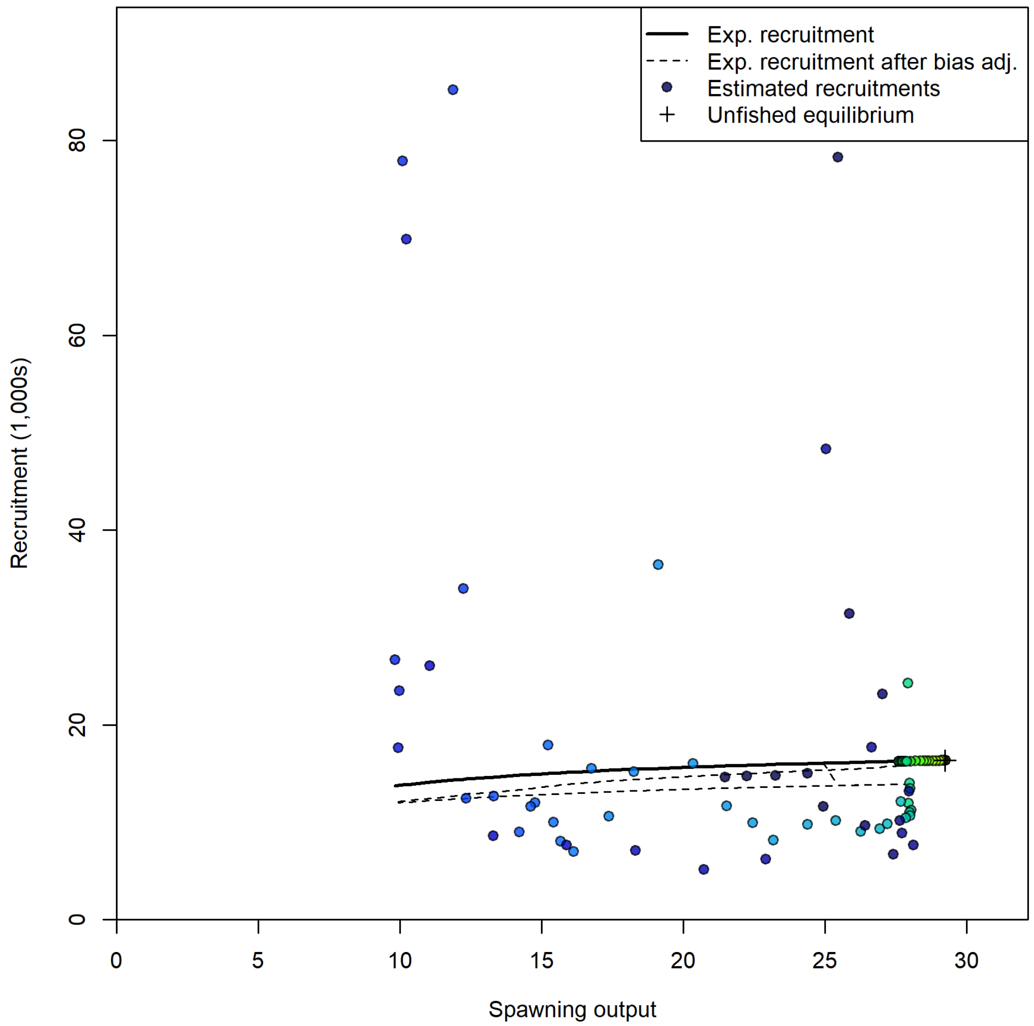

Figure 29: Stock recruit curve where point color indicate year, with warmer colors (yellow to green) indicating earlier years and cooler colors (blue) showing later years.

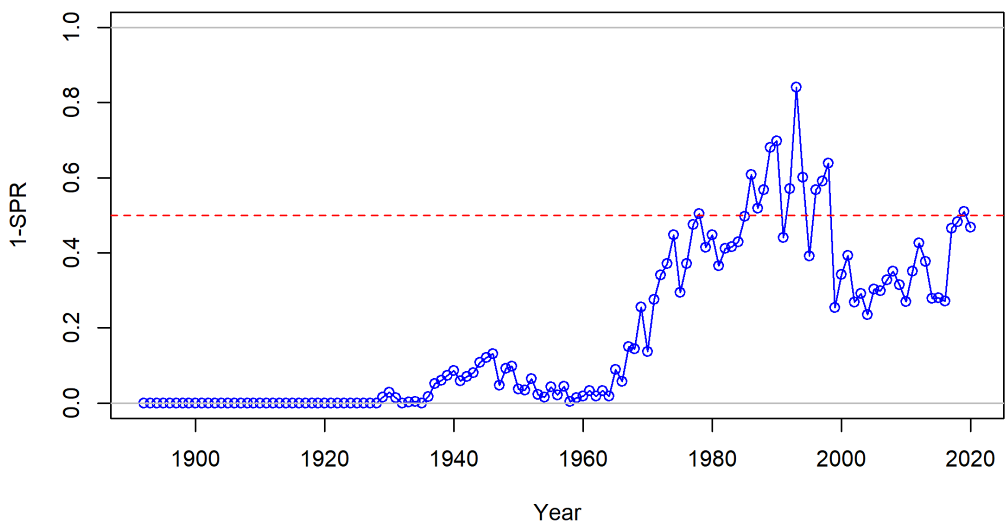

Figure 30: Estimated 1 - relative spawning ratio (SPR) by year.

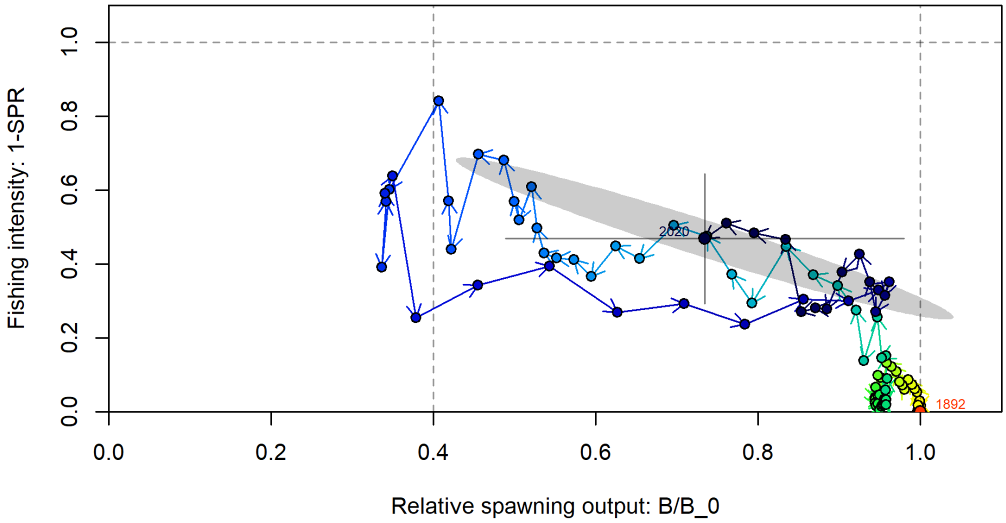

Figure 31: Phase plot of the relative biomass (also referred to as fraction unfished) versus the SPR ratio where each point represents the biomass ratio at the start of the year and the relative fishing intensity in that same year. Lines through the final point show the 95 percent intervals based on the asymptotic uncertainty for each dimension. The shaded ellipse is a 95 percent region which accounts for the estimated correlations between the biomass ratio and SPR ratio.

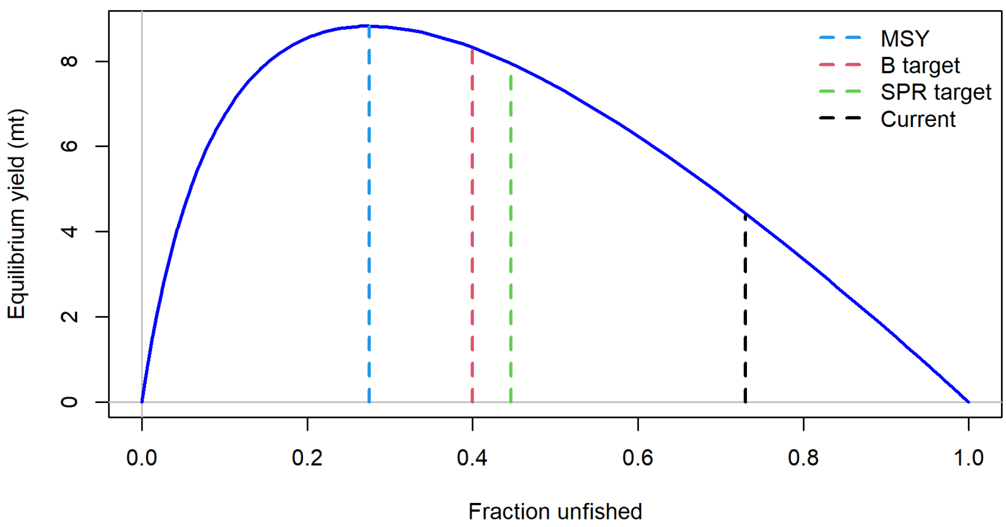

Figure 32: Equilibrium yield curve for the base case model. Values are based on the 2020 fishery selectivities and with steepness fixed at 0.80.

9 Appendix A: Detailed Fit to Length Composition Data

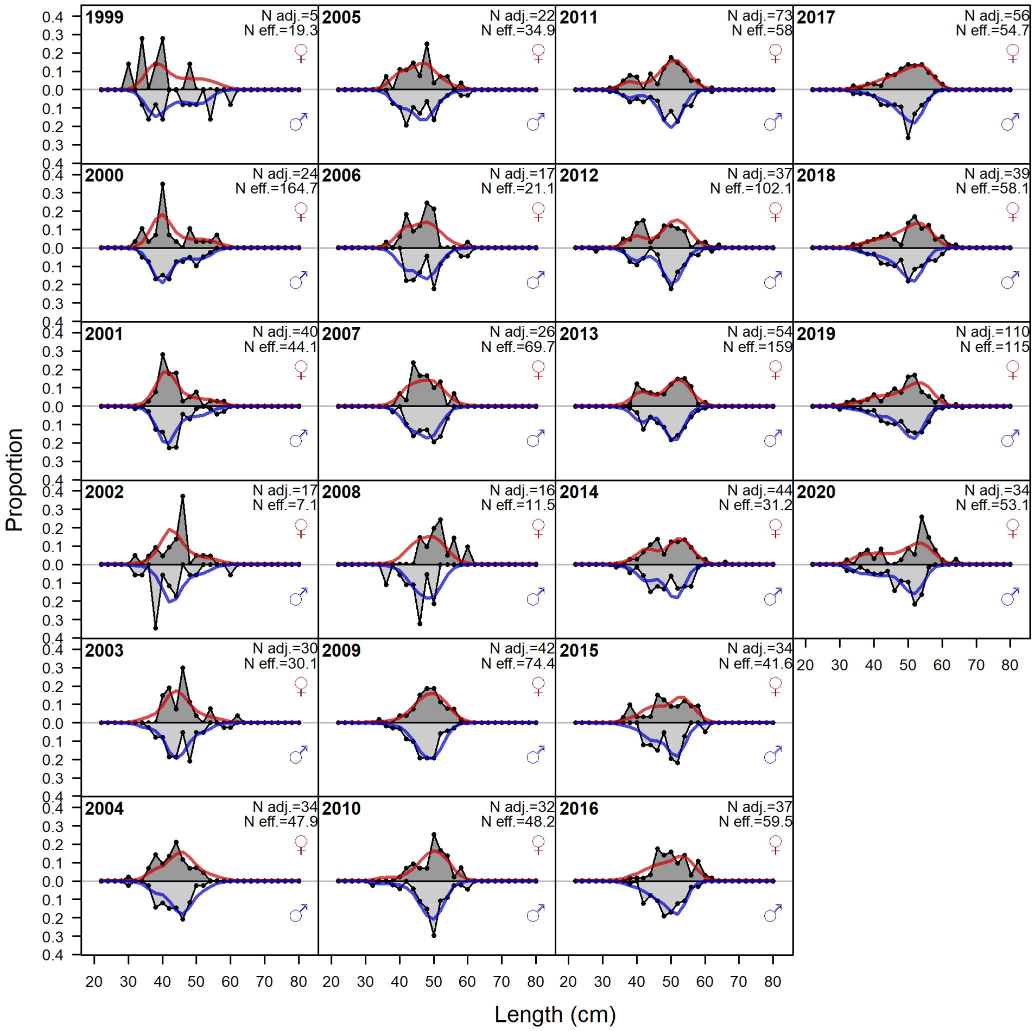

Figure 33: Length comps, whole catch, Commercial.'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method..

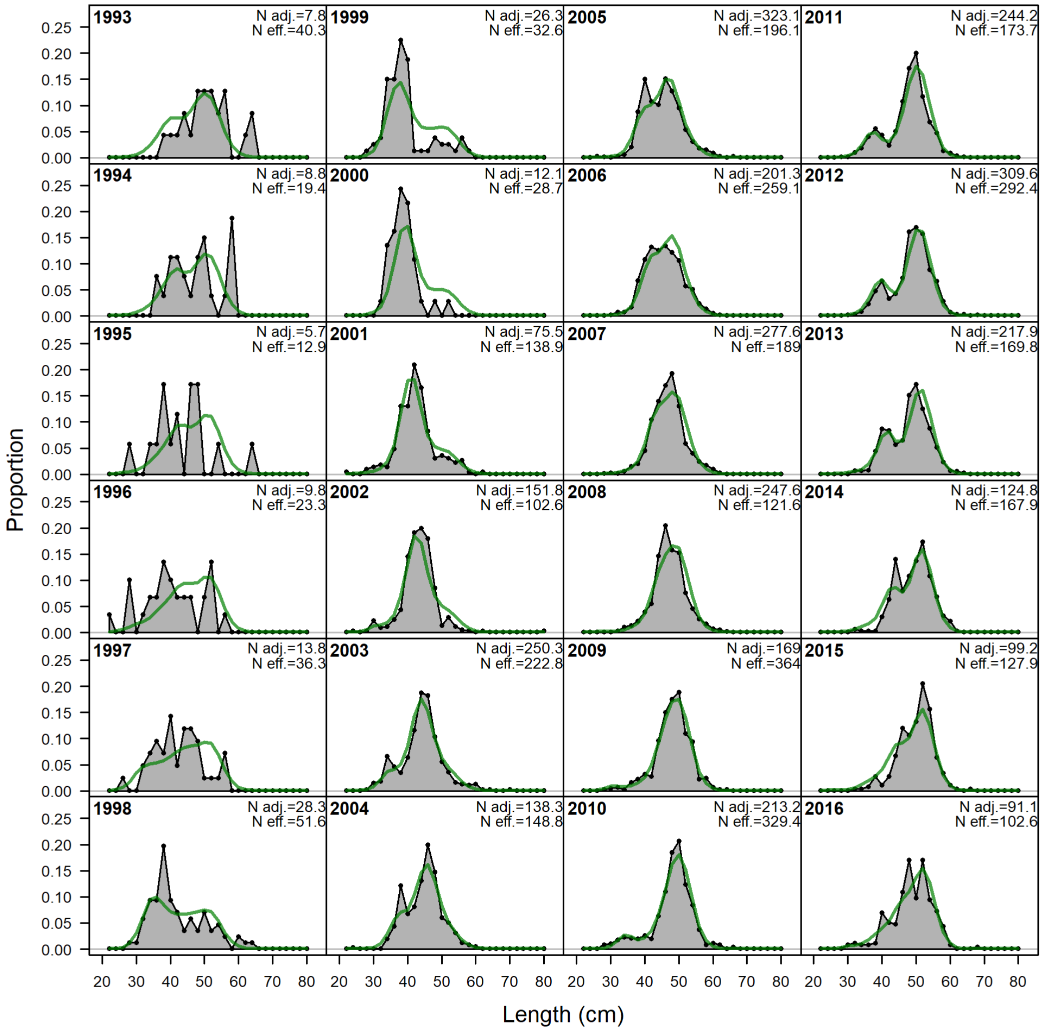

Figure 34: Length comps, whole catch, Recreational (plot 1 of 2).'N adj.' is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method..

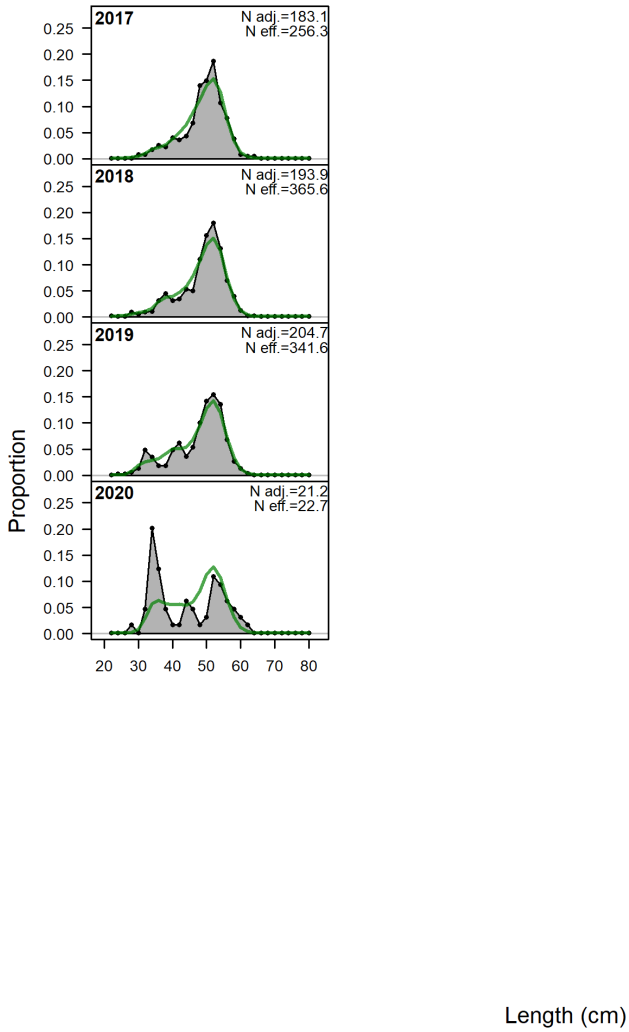

Figure 35: Length comps, whole catch, Recreational (plot 2 of 2).

10 Appendix B: Detailed Fit to Conditional-Age-at-Length Composition Data

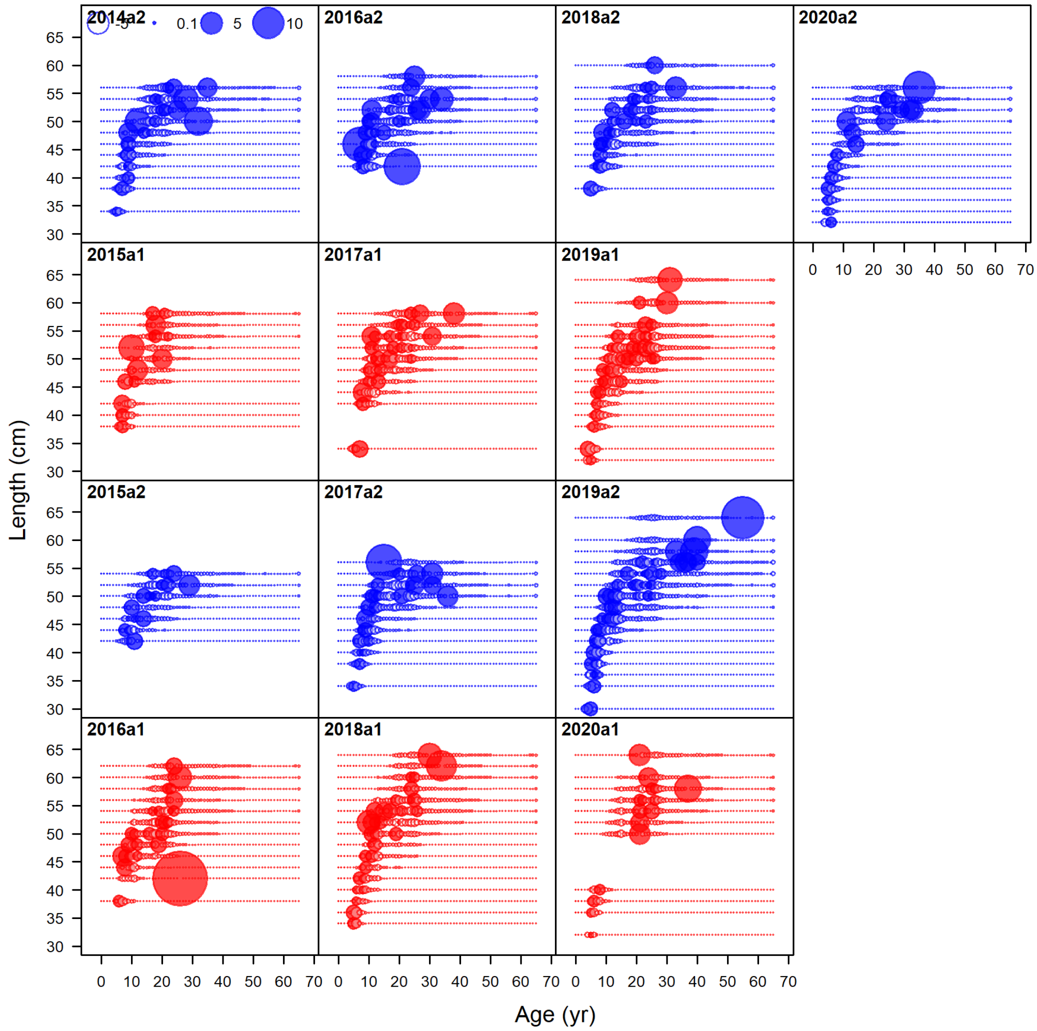

Figure 36: Pearson residuals, whole catch, Commercial (max=30.56) (plot 1 of 4) (plot 2 of 4).

Figure 37: Pearson residuals, whole catch, Commercial (max=30.56) (plot 1 of 4) (plot 2 of 4) (plot 3 of 4).

Figure 38: Pearson residuals, whole catch, Commercial (max=30.56) (plot 1 of 4) (plot 2 of 4) (plot 3 of 4) (plot 4 of 4).

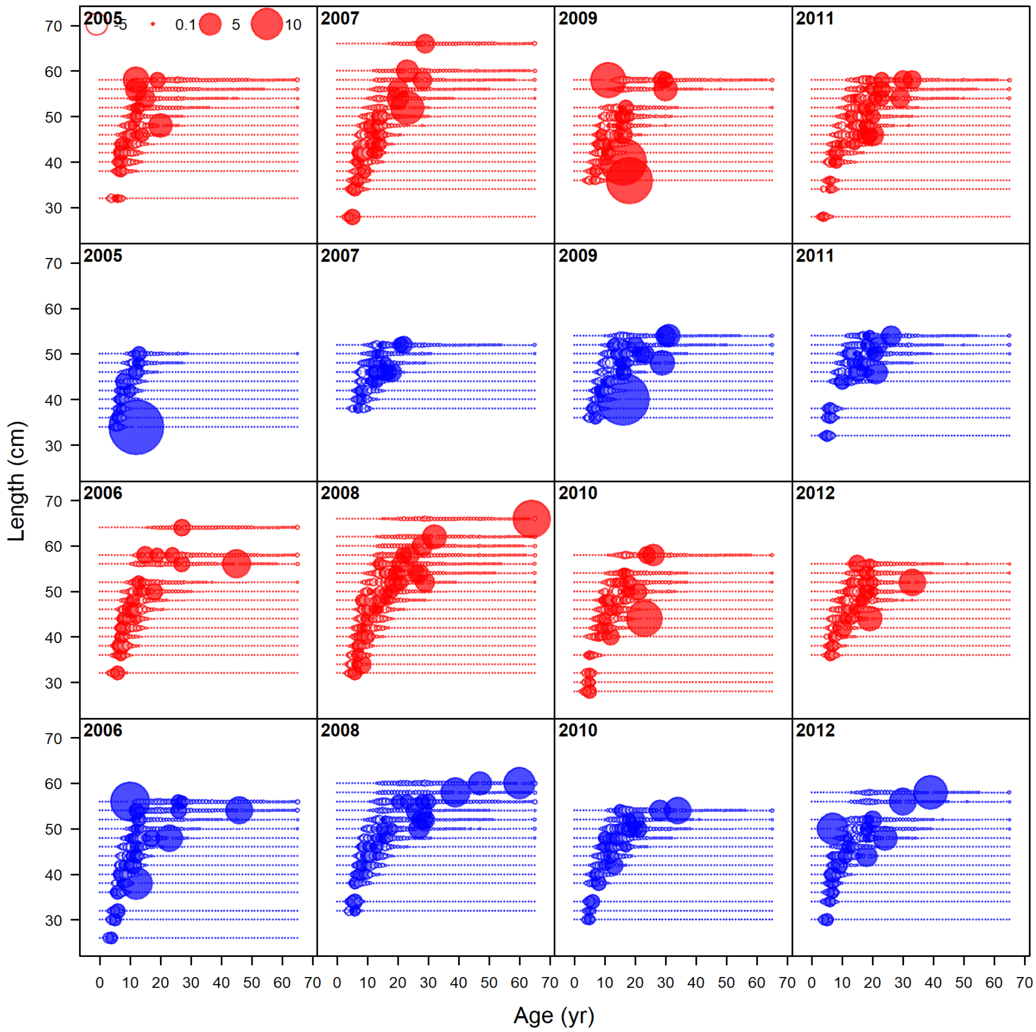

Figure 39: Pearson residuals, whole catch, Recreational (max=30.63) (plot 1 of 3).

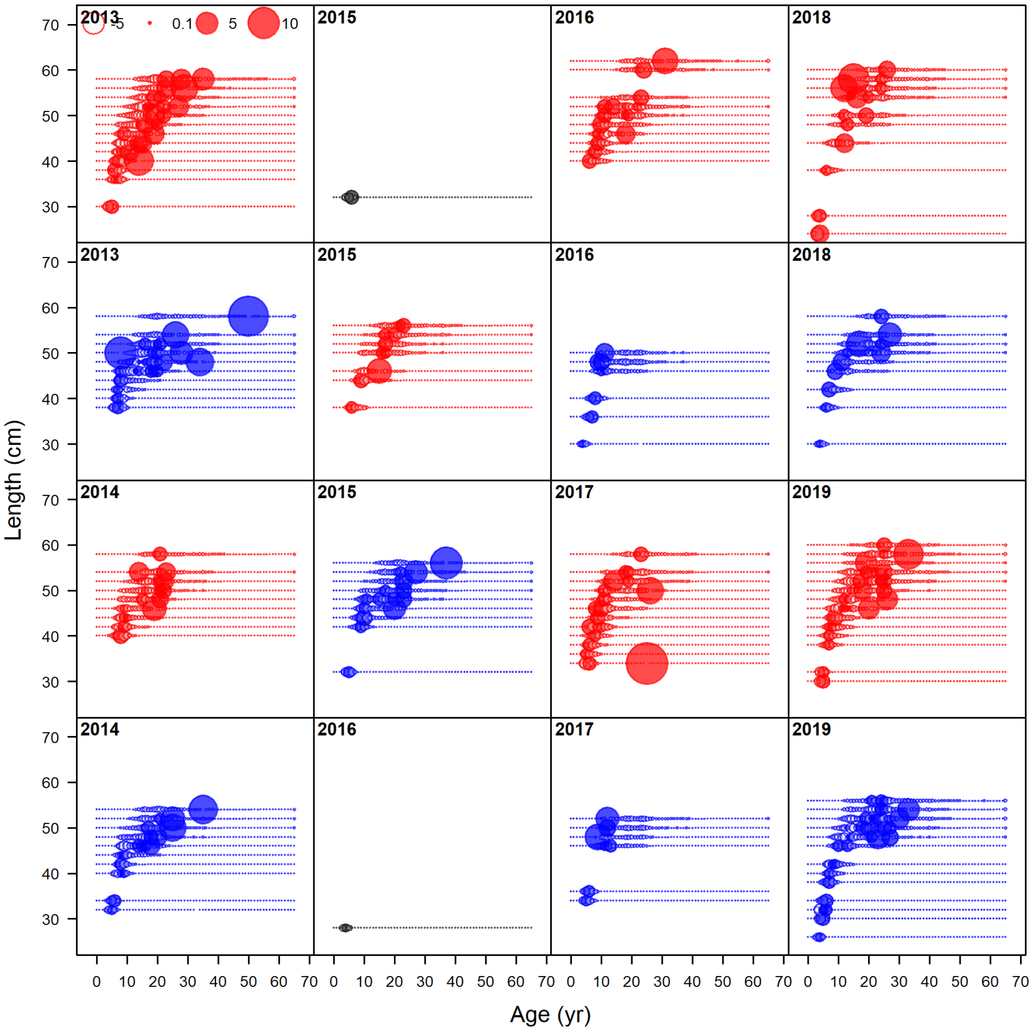

Figure 40: Pearson residuals, whole catch, Recreational (max=30.63) (plot 1 of 3) (plot 2 of 3).

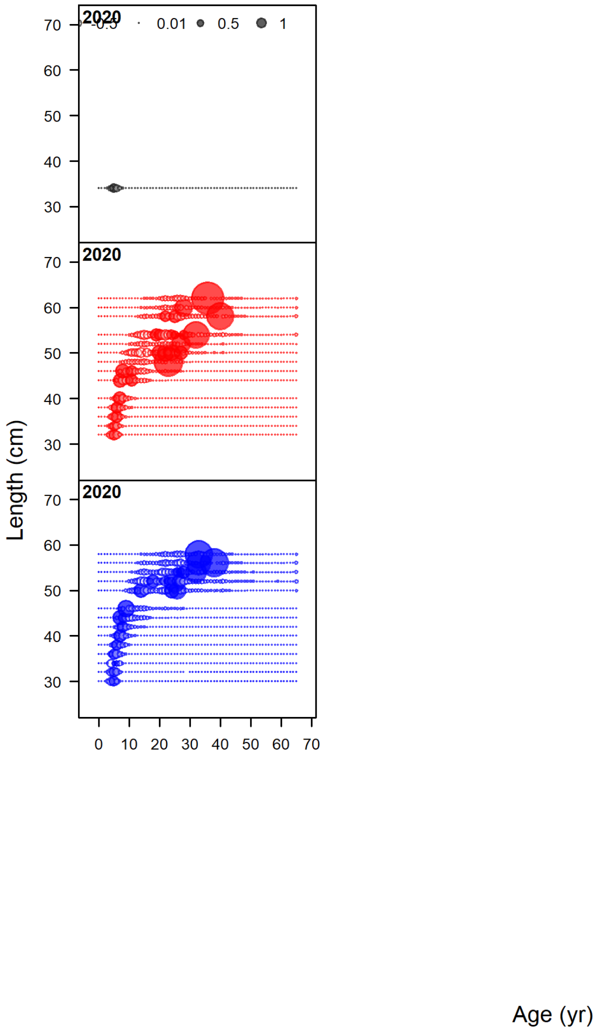

Figure 41: Pearson residuals, whole catch, Recreational (max=30.63) (plot 1 of 3) (plot 2 of 3) (plot 3 of 3).

11 Appendix C: Detailed Fit to Conditional-Age-at-Length Composition Data

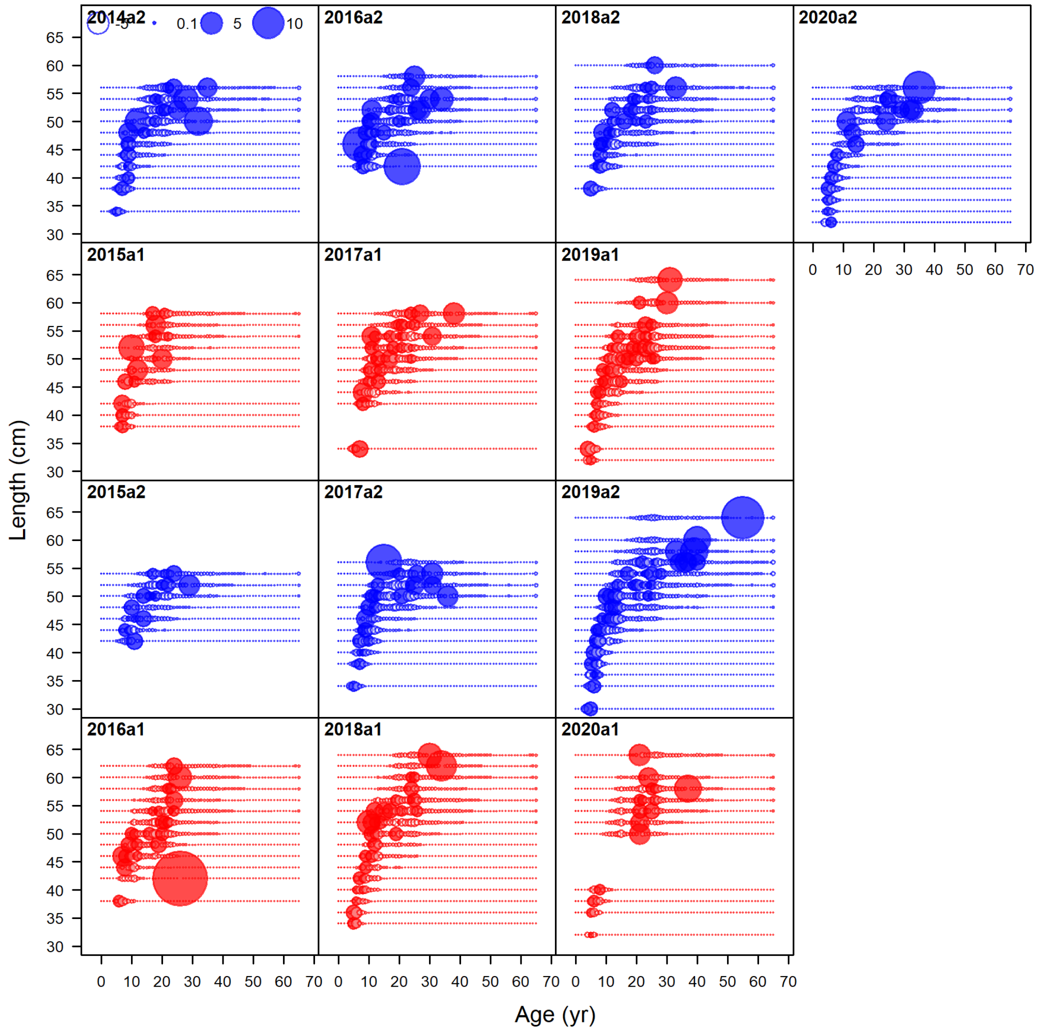

Figure 42: Pearson residuals, whole catch, Commercial (max=30.56) (plot 1 of 4) (plot 2 of 4).

Figure 43: Pearson residuals, whole catch, Commercial (max=30.56) (plot 1 of 4) (plot 2 of 4) (plot 3 of 4).

Figure 44: Pearson residuals, whole catch, Commercial (max=30.56) (plot 1 of 4) (plot 2 of 4) (plot 3 of 4) (plot 4 of 4).

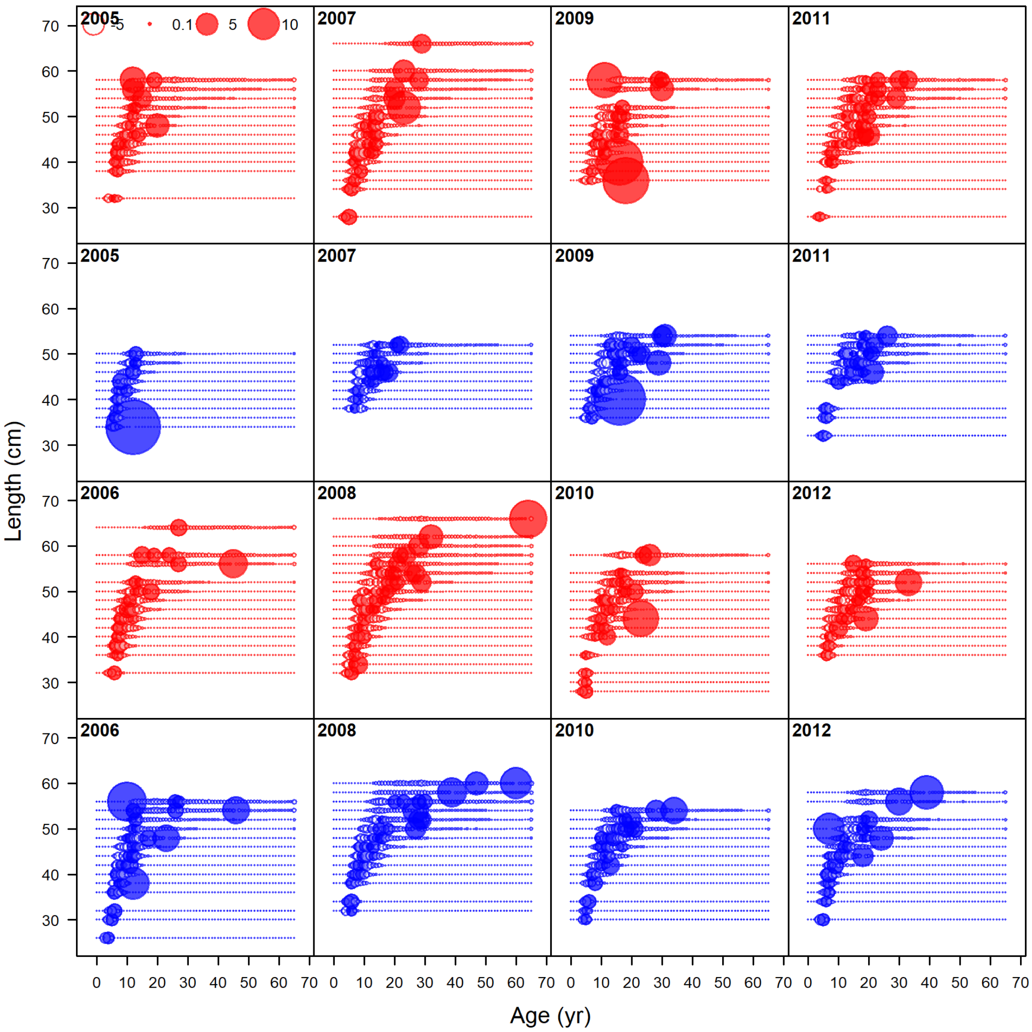

Figure 45: Pearson residuals, whole catch, Recreational (max=30.63) (plot 1 of 3).

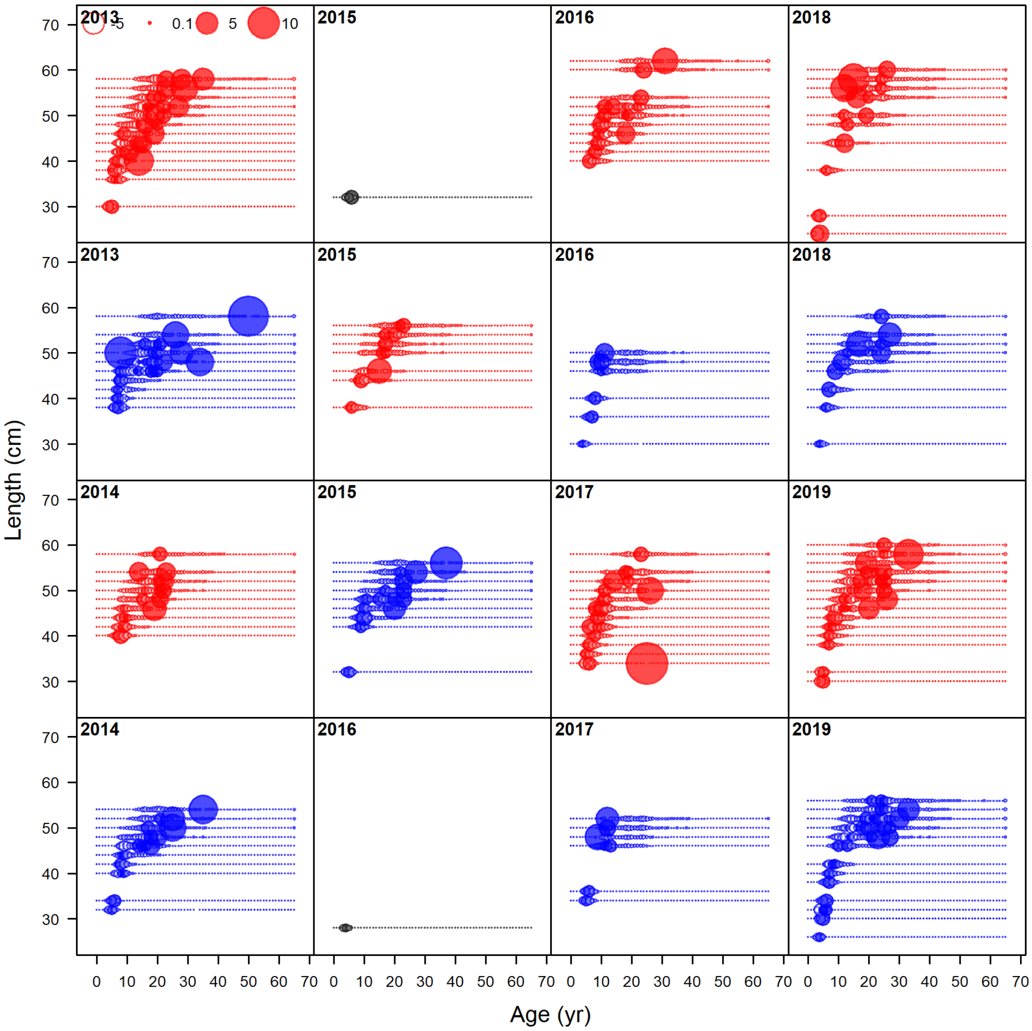

Figure 46: Pearson residuals, whole catch, Recreational (max=30.63) (plot 1 of 3) (plot 2 of 3).

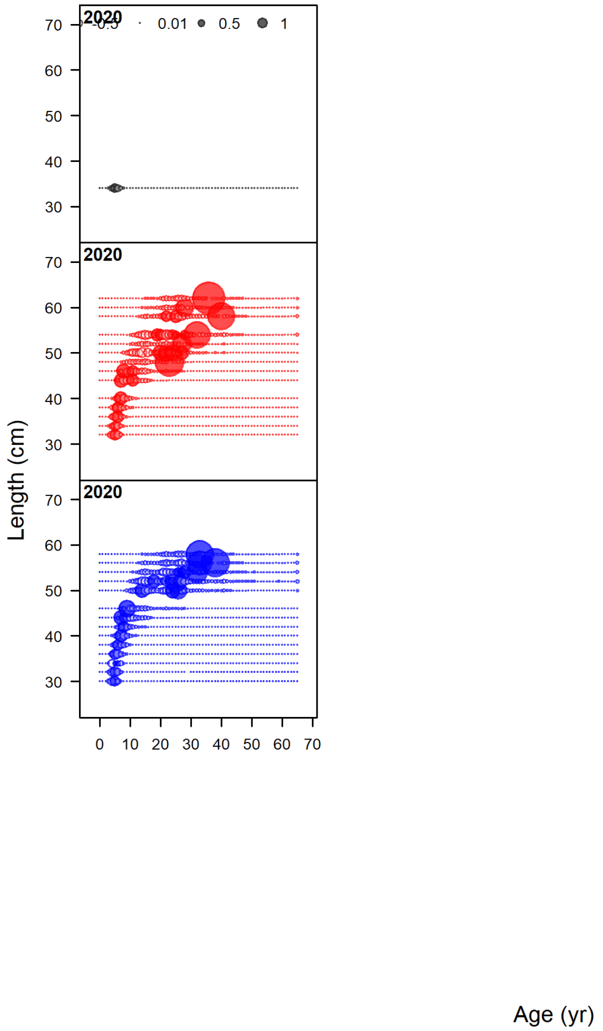

Figure 47: Pearson residuals, whole catch, Recreational (max=30.63) (plot 1 of 3) (plot 2 of 3) (plot 3 of 3).