# Status of the U.S. sablefish resource in 2015

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# Contents

# Executive summary

## Stock

This assessment update reports the status of the sablefish (*Anoplopoma fimbria*, or 'black cod') resource off the coast of the United States (U.S.) from southern California to the U.S.-Canadian border using data through 2014. The resource is modeled as a single stock, however sablefish do disperse to some degree to and from offshore seamounts and along the coastal waters of the continental U.S., Canada, Alaska, and across the Aleutian Islands to the western Pacific and this is not explicitly accounted for in this analysis.

## Catches

Historical sablefish landings were reconstructed from a variety of sources, and are generally more reliable than those for many other groundfish due to the consistent identification of sablefish by species. Uncertainty in historical landings (i.e., fish brought to market), primarily in the Washington-based fishery, stems from poor identification of fishing location (coastal U.S. waters, Canadian waters, or Alaskan waters). Given that sablefish are found from the southern tip of Baja Calfifornia to the north- central Bering Sea, fish landed in Washington ports are not necessarily caught off the coast of Washington. Revised reconstructions from California and Oregon, as well as a more limited analysis using Washington sources, for the 2011 assessment resulted in almost no change from landings used in previous sablefish assessments. Because discarding is explicitly modeled in the stock assessment, total catches (i.e., discards, drop offs, landings, etc.) are estimated simultaneously with other model parameters and derived quantities of management interest. Using an internal estimation approach, such as the one used here, can result in total mortality estimates that differ from those used by previous management and/or estimated using other methods.

Sablefish landings were small (<5,000 mt), and were primarily harvested by hook-and-line fisheries until the end of the 1960s. A very large catch by foreign vessels, fishing pot gear, in 1976 resulted in the largest single-year removal of over 25,000 mt from the stock. A rapid rise in domestic pot and trawl landings followed this peak removal, such that on average, nearly 14,000 mt of sablefish were landed per year between 1976 and 1990. Annual landings have remained below 10,000 mt in subsequent years, divided approximately 45% from hook-and-line, 17% from pot, and 38% from trawl gear during the most recent decade. In the last three years, since the implementation of the trawl catch share program, relative landings from the pot fishery have increased while trawl landings have decreased. Model estimates of discarding result in total dead catches that are an average of 5.08% larger than reported landings over the last decade. However, due to a lack of data regarding changes in selectivity and retention during the historical period (prior to the current observer program, which began in 2002), total catch and age and length composition of landings and discards for much of the time-series represent an important source of uncertainty in this stock assessment.

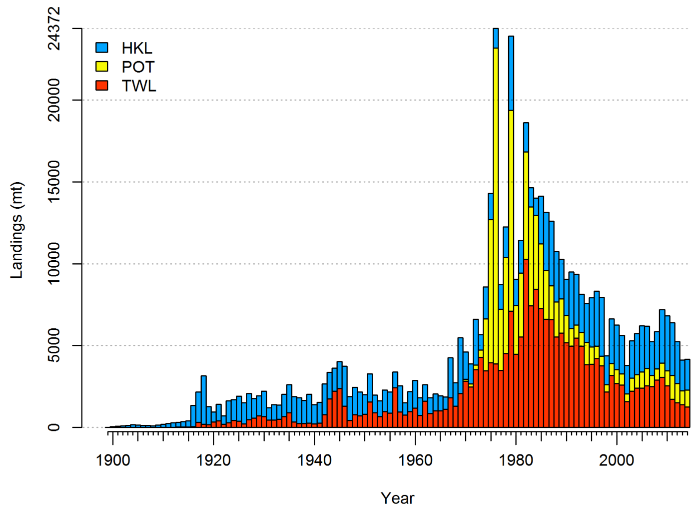


Figure 1: Sablefish landings history, 1900-2014. Fleet names indicate gear type (HKL = Hook-and-line, POT = Pot, and TWL = Trawl). Foreign fleets are included and are largely responsible for the peak landings in 1976 and 1979.

Table 1: Recent sablefish landings (mt) by fleet.

| | **Hook-and-Line** | | **Pot** | | **Trawl** | |
|---|---|---|---|---|---|---|
| Year | mt | % | mt | % | mt | % |
| 2001 | 2362 | 3.03 | 673 | 0.86 | 2596 | 3.33 |
| 2002 | 1749 | 2.25 | 472 | 0.61 | 1568 | 2.01 |
| 2003 | 2283 | 2.93 | 799 | 1.03 | 2213 | 2.84 |
| 2004 | 2515 | 3.23 | 816 | 1.05 | 2411 | 3.10 |
| 2005 | 2807 | 3.60 | 997 | 1.28 | 2399 | 3.08 |
| 2006 | 2604 | 3.34 | 1053 | 1.35 | 2538 | 3.26 |
| 2007 | 2060 | 2.65 | 688 | 0.88 | 2489 | 3.20 |
| 2008 | 2301 | 2.95 | 675 | 0.87 | 2892 | 3.71 |
| 2009 | 3274 | 4.20 | 863 | 1.11 | 3061 | 3.93 |
| 2010 | 3379 | 4.34 | 910 | 1.17 | 2539 | 3.26 |
| 2011 | 3231 | 4.15 | 1449 | 1.86 | 1724 | 2.21 |
| 2012 | 2561 | 3.29 | 1179 | 1.51 | 1498 | 1.92 |
| 2013 | 1865 | 2.39 | 846 | 1.09 | 1402 | 1.80 |
| 2014 | 1868 | 2.40 | 1032 | 1.32 | 1256 | 1.61 |

## Data and assessment

This stock assessment is an update of the 2011 sablefish assessment, using the same data streams and general data analysis methods, structural choices, and assumptions as in that assessment. This assessment update did, however, make use of the most recent version of the Stock Synthesis modeling platform (3.24u, released 29 August, 2014). Primary data sources include landings and length- and age-frequency data from both the retained and, in recent years the discarded portion of the commercial catch. Discard rates as well as mean observed individual body weight in the discards are also included. The National Marine Fisheries Service (NMFS) Northwest Fisheries Science Center (NWFSC) Shelf-Slope trawl survey relative biomass index is the primary source of stock trend information, updated to cover the period 2003-2014 and include depths from 55-1,280 m. Other (discontinued) survey indices contributing information on trend and sablefish demographics include: the NWFSC slope survey conducted from 1998-2002, the Alaska Fisheries Science Center (AFSC) slope survey (1997-2001), and the AFSC/NWFSC triennial shelf trawl survey (1980-2004). Environmental time-series including both sea-surface height (used in previous sablefish assessments) and zooplankton abundance were also investigated.

All externally estimated model parameters, including those defining the weight- length relationship, maturity schedule, and fecundity relationships, have been revisited and, in some cases, revised from the values used in previous assessments. The assessment explicitly estimates parameters describing dimorphic growth and mortality differences between male and female sablefish. Recruitment uncertainty is included via a full time-series of estimated deviations from the stock-recruit curve. Uncertainty in leading parameters such as natural mortality, the unexploited equilibrium level of the stock-recruit function, and catchability coefficients of the survey indices are explicitly included in the model results. Due to the one-way-trip nature of the time-series it was not possible to estimate the steepness parameter ($h$) of the stock-recruitment relationship, so this quantity was fixed at a value of 0.6 and explored via sensitivity analyses. Aging error, including both precision and accuracy, was extensively investigated during the 2011 assessment. The potential for underestimating the age of the oldest fish was not resolved with available data, and therefore aging bias also remains an important source of uncertainty. Sablefish are caught throughout the depth and geographic range of the survey and calculation of the relative biomass in the southern area is of particular management interest. To account for both the spatial and temporal variation in sablefish density and irregularity in sampling a delta-Generalized Linear Mixed Effects Model (delta-GLMM) with Gaussian Markov random fields was used to provide an index of abundance. The delta-GLMM method accommodates both spatial and spatiotemporal variation through the use of Gaussian Markov random fields.

During the 2011 full assessment, a vast number of historical management actions were condensed down to those that seemed most likely to have had a direct influence on fishery behavior (either sorting and retention, selectivity, or both) to reduce the complexity in modeling fishery dynamics. The 2011 base-case model, which forms the basis for this this update, attempted to parsimoniously represent these changes in selectivity and retention with the fewest number of parameters possible, requiring that among-parameter correlations remained low and estimation behavior robust. Furthermore, the time-block for retention, with respect to the trawl fishery, was updated to assume full retention to match the adoption of the West Coast Groundfish Trawl Catch Share Program in 2011.

## Stock biomass

Sablefish are estimated to have been exploited at a modest level through the first half of the $20^{th}$ century. Following a period of recruitments, estimated to have been above average, but highly uncertain, the spawning stock biomass rebounded to nearly unexploited levels in the late 1970s. Large harvests during those years, and lower average recruitment throughout the 1980s and early-1990s, are estimated to have caused the stock to decline continuously between 1976 and 2001, despite harvest rates that were below the current OFL rate from 1983 through 2001. Following higher recruitments in 1995, 1999, and 2000, the spawning biomass increased slightly during the early-2000s, but has continued to decline since 2005, due, in large part, to extremely poor recruitments from 2002 to 2007. The relative spawning biomass is estimated to be at only 33% of unexploited levels in 2015; however this value is highly uncertain (~95% intervals range from 2.23-5.85%). Although the relative trend in spawning biomass is quite robust to uncertainty in the leading model parameters, the productivity of the stock is highly uncertain due to confounding of mortality, absolute stock size, and productivity. The estimated spawning biomass in 2015 is 54,330 mt, however, the ~95% interval ranges broadly from 22,570 to 86,090 mt reflecting little information in the data about absolute stock size. SB was projected to fall by 6% from 2011 to 2015 in the last assessment, and the current assessment estimates that the decline was actually 9%. But since, $SB_0$ is 19% lower in the current assessment, the stock is somewhat less depleted than was estimated in 2011, even with the greater rate of decline. The higher rate of decline in the current assessment appears primarily due to the 2010-11 recruitments being estimated at only 58% of their combined numbers in the 2011 assessment.

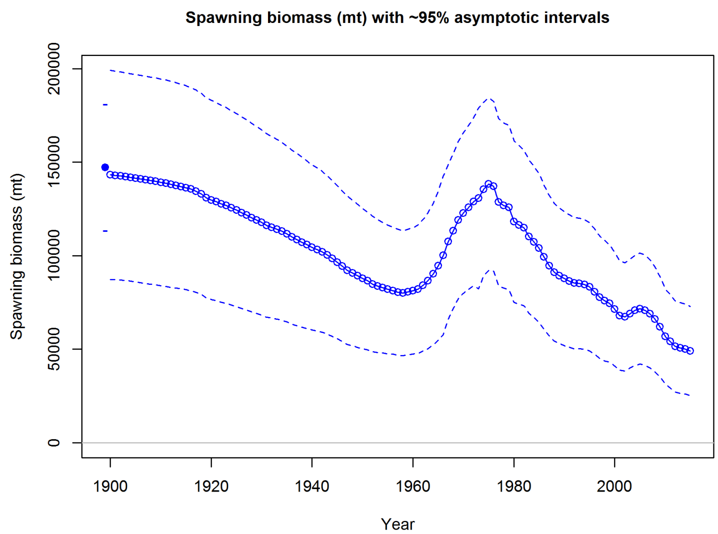


Figure 2: Estimated spawning biomass time-series (1900-2015) for the base-case model (circles) with with ∼95% intervals (dashed lines).

Table 2: Recent trend in estimated sablefish spawning biomass, recruitment, and relative depletion level.

| Year | Spawning biomass (mt) | ∼95% interval | Estimated recruit-ment (1000s) | ∼95% interval | Estimated depletion | ∼95% interval |
|---|---|---|---|---|---|---|
| 2005 | 71,638 | 41,998-101,279 | 588 | 185-991 | 49 % | 33-64 % |
| 2006 | 70,829 | 41,392-100,265 | 1,672 | 895-2,449 | 48 % | 33-64 % |
| 2007 | 68,893 | 39,969-97,818 | 1,198 | 515-1,880 | 47 % | 32-62 % |
| 2008 | 66,028 | 38,018-94,038 | 27,163 | 17,233-37,093 | 45 % | 30-60 % |
| 2009 | 62,042 | 35,195-88,889 | 1,704 | 706-2,701 | 42 % | 28-56 % |
| 2010 | 56,828 | 31,319-82,337 | 16,589 | 9,821-23,356 | 39 % | 25-52 % |
| 2011 | 54,188 | 29,234-79,143 | 5,275 | 2,747-7,804 | 37 % | 24-50 % |
| 2012 | 51,457 | 27,137-75,776 | 4,061 | 1,760-6,363 | 35 % | 22-48 % |
| 2013 | 50,631 | 26,414-74,848 | 41,745 | 22,626-60,863 | 34 % | 22-47 % |
| 2014 | 50,044 | 25,961-74,127 | 3,482 | 70-6,895 | 34 % | 21-47 % |
| 2015 | 49,071 | 25,206-72,936 | 12,624 | 0-36,706 | 33 % | 21-46 % |

## Recruitment

Sablefish recruitment is estimated to be quite variable over the historical record; however uncertainty in individual recruitment events is large. Within this variability, the average recruitment is estimated to have declined steadily between the 1970s and 2007. Recruitments during the 1980s were, on average, roughly an order of magnitude higher than the very poor recent cohorts estimated between 2002 and 2005. It appears that large 1995, 1999, and 2000 year classes briefly slowed the rate of stock decline in the early 2000s and above-average cohorts from 2008, 2010, and 2013 are currently moving through the population. More specifically, the 2013 cohort appears to be one of the top ten largest recruitments events in the history of the fishery. However, only the 2008 cohort has begun to mature and thus their contribution to the trend in spawning biomass remains minimal. Furthermore, the size of the 2010 cohort has been downgraded by 20% in the current assessment compared to the estimate from 2011, and the current estimate of the 2011 year class is less than one-third of the average-recruitment amount assumed in the last assessment.

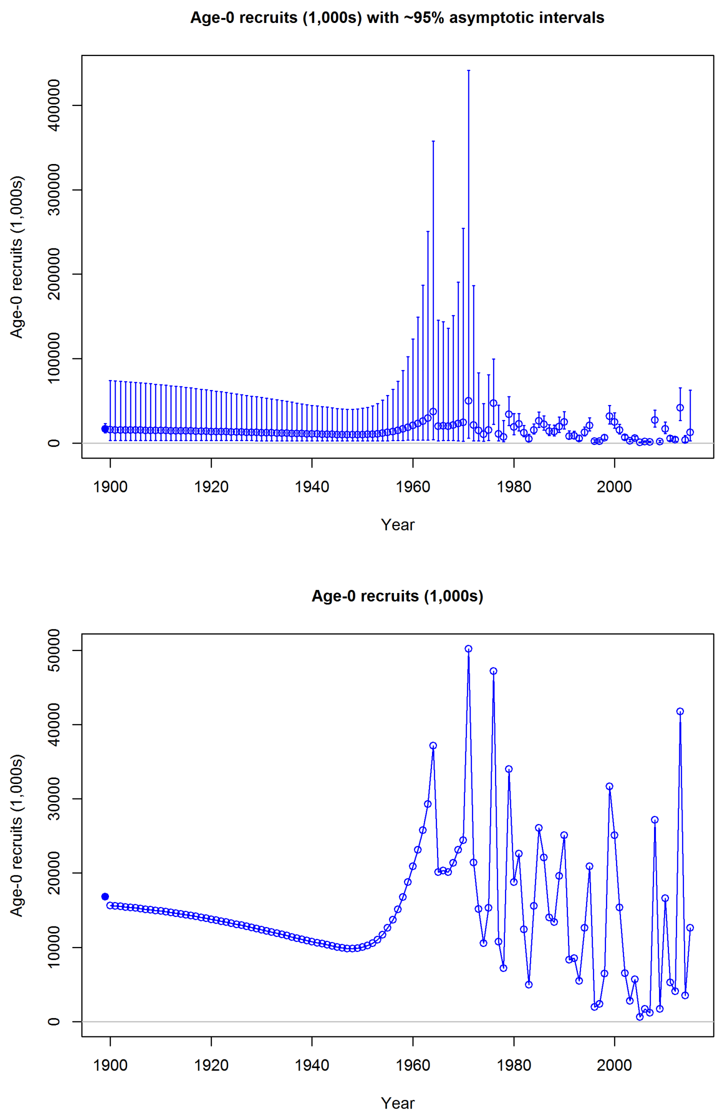


Figure 3: Time series of estimated sablefish recruitments for the base-case model (solid line) with ∼95% intervals (vertical lines; upper panel) and without intervals (lower-panel) to better visualize recent estimated trends.

## Reference points

Unfished female spawning biomass was estimated to be 147,209 mt, but this value is highly uncertain (∼95% interval: 113,472-180,946 mt). The management target stock size ($SB_{40\%}$) is therefore 58,884 mt, and the overfished threshold ($SB_{25\%}$) is 36,802 mt. Total and age-4+ biomass at unexploited equilibrium were estimated to be 432,047 and 405,032 mt respectively. Because the steepness parameter is not estimated in this assessment, the uncertainty in equilibrium yields at the following reference points is grossly underestimated. Maximum sustainable yield (MSY), conditioned on current fishery selectivity and allocations, was estimated to occur at a spawning stock biomass of 43,149 (29% of unfished female spawning biomass), and produce a dead MSY catch (excluding discarded fish that are predicted to have survived) of 7,639 mt. However, the yield MSY varies almost linearly with steepness. Maximum sustainable yield is estimated to be achieved at an SPR of 41. This is very close to the yield, 7,290 mt, generated by the SPR (50%) that stabilizes the stock at the $SB_{40\%}$ target. The fishing mortality target/overfishing level (SPR = 45%) results in an intermediate equilibrium yield of 7,565 mt at a spawning biomass of 50,051 mt (34 % of the unfished equilibrium).

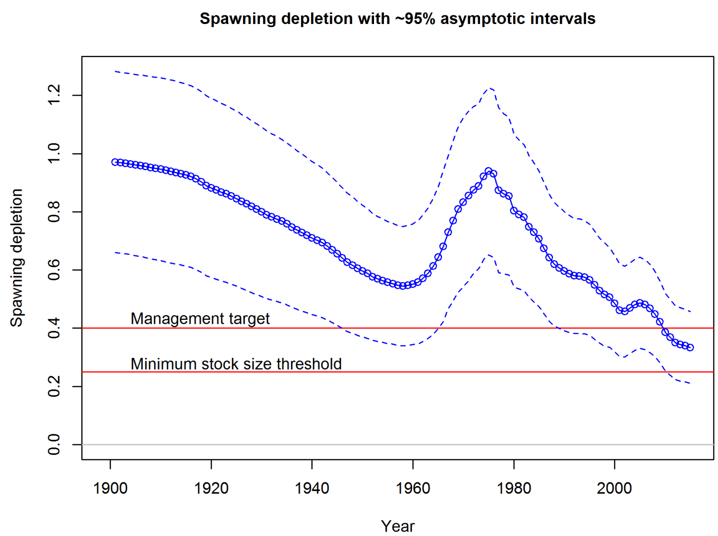


Figure 4: Time series of estimated relative spawning depletion from the base-case model (circles) with $\sim$ 95% interval (dashed lines).

## Exploitation status

The coast-wide abundance of sablefish was estimated to have dropped below the $SB_{40}\%$ management target between 2009 and 2010 and is currently declining. The cause of this trend appears to be primarily due to relatively poor recruitments, as the fishing intensity remained below relative SPR target rates between 1988 and 2008. Although the estimated productivity and absolute scale of the stock are very poorly informed by the available data and are therefore highly sensitive to changes in model structure and treatment of data, all sensitivity or alternate models evaluated showed a current declining trend in biomass and increasing trend in fishing mortality.

Table 3: Recent trend in relative spawning potential ratio (1-SPR/1-SPR$_{Target=0.45}$) and relative exploitation rate (catch/biomass of age-4 and older fish).

| Year | Relative SPR | ∼95% interval | Relative exploitation rate | ∼95% interval |
|---|---|---|---|---|
| 2005 | 78% | 55-102% | 2.8% | 1.7-4% |
| 2006 | 80% | 56-104% | 2.9% | 1.7-4.1% |
| 2007 | 74% | 51-97% | 2.6% | 1.5-3.7% |
| 2008 | 87% | 62-112% | 3% | 1.8-4.3% |
| 2009 | 109% | 82-136% | 4.1% | 2.3-5.8% |
| 2010 | 112% | 85-140% | 4.2% | 2.3-6% |
| 2011 | 113% | 85-140% | 4.2% | 2.3-6.2% |
| 2012 | 101% | 73-130% | 3.3% | 1.8-4.7% |
| 2013 | 85% | 58-113% | 2.7% | 1.5-4% |
| 2014 | 84% | 56-112% | 2.7% | 1.5-4% |

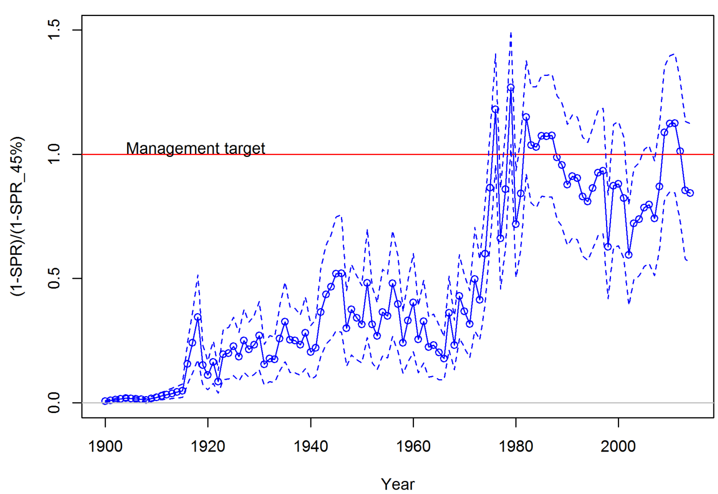


Figure 5: Time series of estimated relative spawning potential ratio (1-SPR/1-SPR$_{Target=0.45}$) for the base-case model (round points) with ∼95% intervals (dashed lines). Values of relative SPR above 1.0 (100% in the table above) reflect harvests in excess of the current overfishing proxy.

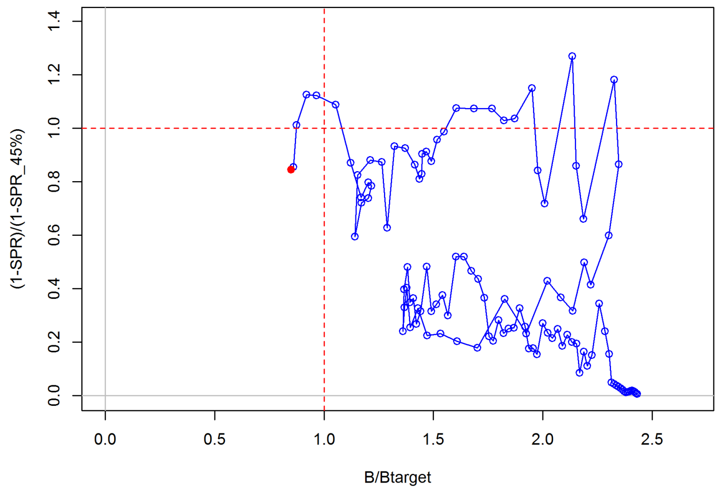


Figure 6: Estimated relative spawning potential ratio relative to the proxy target/limit of 45% vs. estimated spawning biomass relative to the proxy 40% level from the base-case model. Higher spawning output occurs on the right side of the x-axis, higher exploitation rates occur on the upper side of the y-axis. The filled circle indicates 2014.

## Management performance

The sablefish fishery has been managed with a rich history of seasons, size-limits, trip-limits, and a complex permit system. Coast-wide yield-targets have been divided among the different gears (hook-and-line, pot, and trawl), fishery sectors (including both limited entry and open access), as well as north and south of 36° latitude. Peak catches occurred in the late 1970s just prior to the imposition of the first catch limits. Since 2005, the total estimated dead catch has been only 63% of the sum of the OFLs (ABCs at the time) and 74% of the ACLs (OYs at the time). In only one year of the last 10 years, 2008, does the dead catch estimated in the assessment exceed the ACL (and OFL) by 4% (2%).

Table 4: Recent trend in sablefish landings and estimated total dead catch (mt) relative to OFL (ABCs at the time) and ACLs (OYs at the time).

| Year | OFL (mt)[1] | ACL (mt)[1] | Landings (mt) | Estimated dead catch (mt)[2] |
|---|---|---|---|---|
| 2005 | 8471 | 7761 | 6203 | 6537.77 |
| 2006 | 8175 | 7634 | 6195 | 6508.40 |
| 2007 | 6210 | 5934 | 5237 | 5493.03 |
| 2008 | 6058 | 5934 | 5868 | 6158.67 |
| 2009 | 9914 | 8423 | 7198 | 7718.91 |
| 2010 | 9217 | 7729 | 6828 | 7273.60 |
| 2011 | 8808 | 6813 | 6404 | 6733.72 |
| 2012 | 8623 | 6605 | 5238 | 5497.94 |
| 2013 | 6621 | 5451 | 4113 | 4311.34 |
| 2014 | 7158 | 5909 | 4156 | 4453.90 |
| 2015 | 7857 | 6512 | | |

[1]Includes both the southern and northern management areas where separate values were applied.

[2]Includes discards estimated within the stock assessment and therefore may differ from total mortality reports used by management.

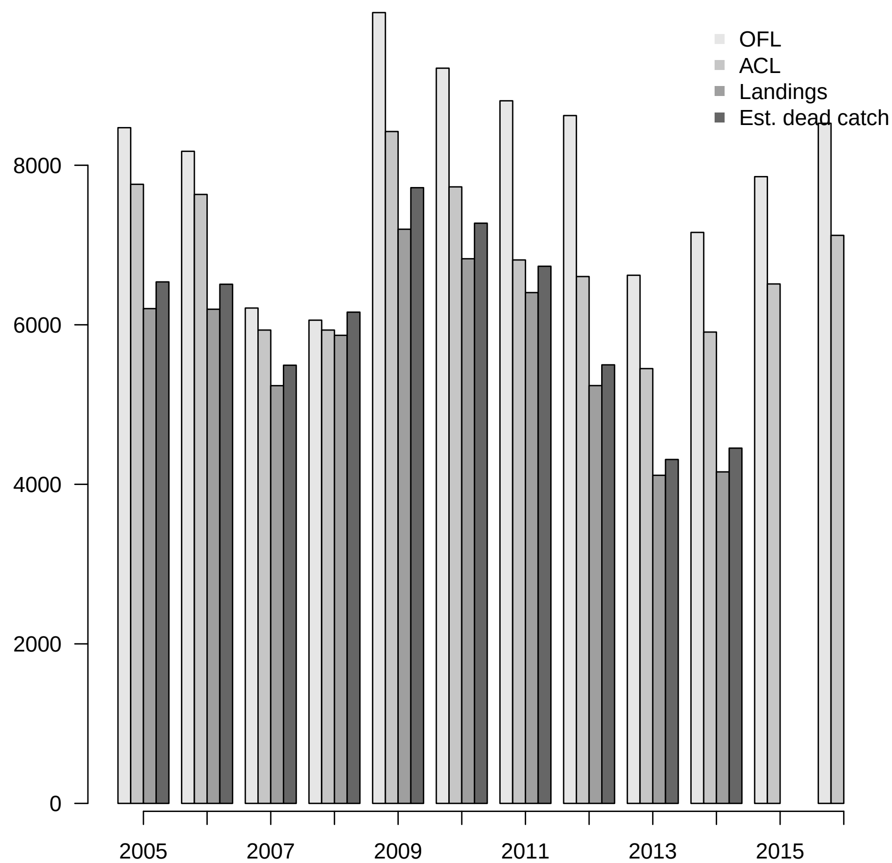


Figure 7: Recent (and current) sablefish OFLs (ABCs prior to 2011), and ACLs (OYs prior to 2011), in relation to recent total landings and estimated total dead catch (excludes discarded fish that are predicted to have survived) from the base-case model.

## Unresolved problems and major uncertainties

The available data for sablefish are largely uninformative about the absolute size and productivity of the stock. This is largely due to the one-way-trip nature of the historical series: a slow and steady decline in spawning biomass consistent with a larger less productive stock, a smaller more productive stock, or many combinations in between. Historical catches provide some information about the minimum stock size needed to have supported the observed time-series but little information about the upper bounds for the stock size. Likelihood profiles, parameter estimates, and general model behavior illustrate that small changes in many parameters can result in differing point estimates for management reference points, however the uncertainty about these estimates remains large unless leading model parameters, such as natural mortality, survey catchability, as well as historical recruitments, are fixed at arbitrarily selected values. This assessment includes the uncertainty for these unknown quantities, with the exception of steepness. This uncertainty will remain until a more informative time-series and better quality demographic and biological information is accumulated for the stock.

Uncertainty in the properties of current aging methods (both potential bias and imprecision), as well as relatively sparse fishery sampling, result in age data that are less reliable than would be preferred. Similarly, because sablefish grow very rapidly and reach near-asymptotic length in their first decade of life, length-frequency data is not particularly informative about historical patterns in recruitment. The patterns observed in historical sablefish recruitment suggest that the stock trajectory (via shifts in recruitment strength) is closely linked to productivity regimes in the California current. Uncertainty in future environmental conditions, changes in the timing, dynamics, and productivity of the California current ecosystem, via climate change, or cycles similar to the historical period, should be considered a significant source of uncertainty in all projections of stock status.

The ongoing NWFSC Shelf-Slope trawl survey is a fairly precise relative index of abundance over a broad demographic component of the sablefish stock (although not the entire stock, as some of the stock resides in waters deeper than 1260 m, the limit of the survey, and is therefore unobserved). This index has the potential to inform future stock assessments about the scale of the sablefish population relative to the catches being removed (assuming these are enumerated reasonably accurately), however such information will require contrast in the observed declining survey trend. Therefore, although there is the potential to considerably reduce the current uncertainty in sablefish stock size and dynamics, it will likely take several years of contrasting trend in the survey to do so.

## Forecasts

The reported forecasts are based on the application of the 40-10 harvest control rule and the $F_{45}\%$ overfishing limit/target (OFL). In addition, a reduction to the OFL of 8.7% was applied representing the application of a $P*$ of 0.40 and the Category 1 stock proxy uncertainty $\sigma$ of 0.36 (but without applying an additional buffer for management uncertainty). These values reflect the Pacific Fishery Management Council (PFMC) decisions made during the November 2011 meeting.

This projection is intended to provide a yardstick with which to gauge the likely trajectory of the stock. Catch allocation used for the forecast reflects the average distribution of fishing intensity among fleets (hook-and- line, pot, and trawl) during 2012-2014 and it is also assumed that discarding and retention behavior does not differ from recent years (supplementary analyses provided to the GMT did indicate some sensitivity to these assumptions). A representation of the uncertainty about projected stock sizes is presented in the decision table along with two markedly different alternative catch streams.

Current forecasts predict a slow increase in the spawning stock, with a relatively large probability that the stock will remain below the target spawning biomass for several more years as the 2008, 2010, and 2013 cohorts fully mature. Forecast values are highly uncertain, and given this uncertainty, and the number of years the stock is projected to remain at low levels, it is possible that the stock will be assessed to be below the overfished threshold during the next several cycles. However, additional trawl survey observations may help to better inform the estimate of the 2008, 2010, and 2013 cohort sizes. The full implications of the current uncertainty in stock trajectory and scale can be best evaluated in the decision table in the following section (the central panel of which duplicates the following table).

Table 5: Projection of potential sablefish OFL, ACL, and estimated spawning biomass and depletion for the base-case model based on the 40:10 correction to the $F_{45}\%$ overfishing limit/target (OFL) and an 8.7% reduction to approximate the P* approach. Catch allocation used for the forecast reflects the average distribution of fishing intensity among fleets (hook-and-line, pot, and trawl) during 2012-2013.

| Year | OFL[1] (mt) | ABC[1] (mt) | ACL[1] (mt) | Spawning biomass (mt) | Relative depletion |
|---|---|---|---|---|---|
| 2015 | 7857 | 7173 | 6512 | 6512 | 33% |
| 2016 | 8526 | 7784 | 7121 | 7121 | 35% |
| 2017 | 7596 | 6935 | 6602 | 51469 | 35% |
| 2018 | 7879 | 7194 | 6902 | 52503 | 36% |
| 2019 | 8050 | 7350 | 7086 | 53162 | 36% |
| 2020 | 8217 | 7502 | 7253 | 53544 | 36% |
| 2021 | 8286 | 7565 | 7323 | 53727 | 36% |
| 2022 | 8185 | 7473 | 7238 | 53812 | 37% |
| 2023 | 8105 | 7400 | 7172 | 53913 | 37% |
| 2024 | 8070 | 7368 | 7148 | 54039 | 37% |
| 2025 | 8043 | 7343 | 7131 | 54182 | 37% |
| 2026 | 8018 | 7320 | 7116 | 54330 | 37% |

[1]OFL/ABC/ACL values for 2015 and 2016 have already been adopted, and are not based on the results of this assessment.

## Decision Table

The decision table reports 12-year projections for alternate states of nature (columns) and management options (rows) beginning in 2017. The results of this table are conditioned on the already-specified ACLs for 2015 and 2016 being achieved exactly. It is common to select an 'axis of uncertainty' from leading parameters, model structure or historical catch levels, to best bracket the range of possible states of nature. For this assessment, due to the explicit inclusion of uncertainty in natural mortality, survey catchability, and scale of the stock-recruit function, asymptotic intervals are very broad. In 2011, steepness was evaluated as a possible axis of uncertainty, but even a broad range (from 0.3-0.9) underrepresented the forecast uncertainty relative to that implied by the parameter uncertainty already included. Therefore, the percentiles of the asymptotic distribution are used to describe the relative probabilities among the states of nature. Low and high columns are based on the $12.5^{th}$ and $87.5^{th}$ percentiles of the distribution about the maximum likelihood estimates for: depletion, relative SPR (in reverse order to match depletion; i.e., larger values implying greater relative fishing intensity are reported first), and spawning biomass from the base-case model. Catch allocation used for the forecast reflects the average distribution of fishing intensity among fleets (hook-and-line, pot, and trawl) during 2012-2013.

The probability that the stock is already overfished ($<25\%B_0$) in 2015, based upon the estimated status and asymptotic uncertainty is 8%) (Table 9). Further, given any status much below the estimated current spawning biomass, the stock is not projected to increase appreciably over the duration of these forecasts.

Table 6: Decision table of 12-year projections for alternate states of nature (columns) and management options (rows) beginning in 2017. The percentiles of the asymptotic distribution are used to describe the relative probabilities among the states of nature. Values of relative SPR that exceed 100% indicate overfishing; order is reversed to maintain the 'lower-to-higher' pattern consistent with other quantities, i.e., larger values implying greater relative fishing intensity are reported on the left side of the table. The results of this table are conditioned on the already-specified ACLs for 2015 and 2016 being achieved exactly.

| **Management alt** | | | **State of nature** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $12.5^{th}$ pctl | | | Max likelihood est. | | | $87.5^{th}$ pctl | | |
| | Year | Dead catch (mt) | Depl | Rel SPR | Spawning biomass (mt) | Depl | Rel SPR | Spawning biomass (mt) | Depl | Rel SPR | Spawning biomass (mt) |
| $12.5^{th}$ | 2017 | 4053 | 27% | 80% | 36215 | 35% | 64% | 51469 | 43% | 49% | 66724 |
| pctl | 2018 | 4389 | 28% | 81% | 37517 | 36% | 66% | 53472 | 45% | 50% | 69427 |
| 40:10 | 2019 | 4659 | 29% | 83% | 38423 | 37% | 67% | 55174 | 46% | 50% | 71925 |
| catch | 2020 | 4914 | 29% | 85% | 38913 | 38% | 67% | 56605 | 48% | 49% | 74296 |
| | 2021 | 5091 | 29% | 87% | 39061 | 39% | 68% | 57816 | 49% | 49% | 76572 |
| | 2022 | 5143 | 29% | 89% | 38994 | 40% | 68% | 58878 | 51% | 48% | 78761 |
| | 2023 | 5188 | 29% | 91% | 38849 | 41% | 69% | 59869 | 52% | 47% | 80890 |
| | 2024 | 5244 | 29% | 92% | 38682 | 41% | 69% | 60813 | 54% | 47% | 82944 |
| | 2025 | 5293 | 29% | 93% | 38521 | 42% | 70% | 61717 | 55% | 47% | 84913 |
| | 2026 | 5334 | 29% | 94% | 38375 | 43% | 70% | 62583 | 56% | 46% | 86792 |
| | 2017 | 6602 | 27% | 110% | 36215 | 35% | 91% | 51469 | 43% | 73% | 66724 |
| | 2018 | 6902 | 27% | 111% | 36565 | 36% | 92% | 52518 | 44% | 73% | 68470 |
| 40:10 | 2019 | 7086 | 27% | 113% | 36440 | 36% | 92% | 53190 | 45% | 71% | 69939 |
| catch | 2020 | 7253 | 27% | 114% | 35897 | 36% | 92% | 53587 | 46% | 70% | 71277 |
| | 2021 | 7323 | 26% | 116% | 35050 | 37% | 92% | 53796 | 47% | 68% | 72542 |
| | 2022 | 7238 | 26% | 118% | 34052 | 37% | 92% | 53909 | 48% | 67% | 73765 |
| | 2023 | 7172 | 25% | 119% | 33057 | 37% | 92% | 54027 | 49% | 65% | 74997 |
| | 2024 | 7148 | 24% | 120% | 32105 | 37% | 92% | 54162 | 49% | 64% | 76219 |
| | 2025 | 7131 | 24% | 121% | 31210 | 37% | 92% | 54312 | 50% | 63% | 77414 |
| | 2026 | 7116 | 23% | 122% | 30366 | 37% | 92% | 54469 | 51% | 63% | 78572 |
| $87.5^{th}$ | 2017 | 9151 | 27% | 130% | 36215 | 35% | 111% | 51469 | 43% | 92% | 66724 |
| pctl | 2018 | 9415 | 27% | 132% | 35614 | 35% | 112% | 51564 | 43% | 92% | 67513 |
| 40:10 | 2019 | 9514 | 26% | 134% | 34466 | 35% | 112% | 51213 | 44% | 90% | 67959 |
| catch | 2020 | 9592 | 25% | 137% | 32913 | 34% | 113% | 50593 | 44% | 89% | 68274 |
| | 2021 | 9556 | 24% | 139% | 31101 | 34% | 113% | 49821 | 44% | 87% | 68541 |
| | 2022 | 9334 | 22% | 141% | 29207 | 33% | 113% | 49009 | 44% | 85% | 68811 |
| | 2023 | 9157 | 21% | 143% | 27394 | 33% | 113% | 48276 | 45% | 83% | 69157 |
| | 2024 | 9051 | 20% | 145% | 25685 | 32% | 113% | 47619 | 45% | 82% | 69553 |
| | 2025 | 8968 | 19% | 146% | 24071 | 32% | 114% | 47023 | 45% | 81% | 69975 |
| | 2026 | 8897 | 17% | 148% | 22535 | 32% | 114% | 46471 | 46% | 80% | 70407 |

## Research and Data Needs

The following research could improve the ability of this assessment to reliably model sablefish population dynamics in the future:

1. Continue the annual NWFSC Shelf-Slope trawl survey time-series. Future improvements in the precision of estimates of absolute stock size and productivity are reliant upon observing some contrast in stock trend (other than a one-way trip) with an unbroken survey index. Only a longer, more informative survey time-series will provide stock-specific and data-based information on the steepness parameter governing the sablefish stock and recruitment relationship.

2. Investigate aging methods that could prove more precise than current break-and-burn methods. If age data were more accurate, cohorts could be better tracked to older ages and estimates of historical year-class strengths may be improved. Further studies to investigate the potential for bias in aging methods should be conducted; these results will have a strong effect on natural mortality estimates.

3. Evaluate potential causes of residual patterns in the fit to larger cohorts in the age data (particularly the 1999 and 2000 cohorts) and for residual patterns in the fit to the size data.

4. Model results were quite sensitive to changes in the maturity schedule, yet the available information is very outdated, in addition to being variable among sources, years and regions. The routine collection of samples to refine estimates of biological parameters, particularly maturity and fecundity would greatly benefit the reliability of this assessment.

5. Age sampling from the commercial fishery has generally been sparse compared to other groundfish and relative to the importance of this stock to west coast fisheries. Work toward further standardization of state and federal biological sampling programs would make the data more informative, by reducing sampling variability. For example, during most of the last 30 years at least one state has collected sexed-length observations, while at least one has not. If an increased fraction of both the catch was available for sampling at-sea, or in-port in a non-dressed form, then more consistent demographic information could result.

6. Continued refinement of the historical landings estimates for Washington, subsequent to the large data entry of historical fish-ticket information currently underway, will likely produce a more accurate time-series of mortality and would complement the completed efforts to reconstruct California and Oregon landings.

7. Given the migratory nature and broad distribution of sablefish along the Pacific Rim, it is important to continue to evaluate the spatial aspects of the assessments, including the northern boundary with Canada, and the

connectivity with offshore seamounts. A joint assessment with Canadian and Alaskan scientists could be warranted, following the approach taken by the International Pacific Halibut Commission.

8. Continue to evaluate methods to capture information regarding environmental and ecosystem variability in stock assessments. Further, historical records of particularly large year classes (e.g., 1947 reported by sport fishermen in central California) could be investigated to better inform the historical period.

9. Assessments prior to 2011 relied upon independent databases for collecting and analyzing biological sampling from the three states. Washington, California, and Oregon have now loaded all available data into PacFINs Biological Data System, where it can be retrieved and analyzed in a consistent and documented format. However, information is still missing from some records, and a small number of samples were unsuitable for analysis due to incomplete or jumbled records. An effort to either repair or remove any unreliable information could improve the speed and accuracy of future analyses.

10. There is uncertainty in the accuracy of the dressed to whole weight conversions used in some situations to estimate fishery landings. Following Oregons lead, this topic should be investigated, and total landed catch estimates adjusted, according to the best available conversion information (Table 7).

Table 7: Summary of sablefish reference points from the base-case model. Yields include discard mortality. Because steepness is a fixed parameter, the uncertainty in these reference points is grossly underestimated.

| Quantity | Estimated value | ~95% interval |
|---|---|---|
| Unfished total biomass (mt) | 432,047 | 367,420-496,674 |
| Unfished 4+ biomass (mt) | 405,032 | 344,894-465,170 |
| Unfished spawning biomass ($SB_0$, mt) | 147,209 | 127,408-167,010 |
| Unfished recruitment ($R_0$, thousands) | 16,832 | 13,584-20,079 |
| **Reference points based on** $SB_{40\%}$ | | |
| $MSY$ Proxy spawning biomass ($SB_{40\%}, mt$) | 58,884 | 50,963-66,804 |
| Relative spawning depletion at $SB_{40\%}$ | 40% | |
| SPR resulting in $SB_{40\%}$ | 50% | |
| Exploitation rate resulting in $SB_{40\%}$ | 4% | 3.6-4.1% |
| Yield with $SPR_{SB40\%}$ (mt) | 7,290 | 6,029-8,552 |
| **Reference points based on** $SPR$ **proxy for** $MSY$ | | |
| Spawning biomass at $SPR_{MSY-proxy}$ ($SPR_{SPR}$, mt) | 50,051 | 43,319-56,783 |
| Relative spawning depletion at $SPR_{SPR}$ | 34% | |
| $SPR_{MSY-proxy}$ | 41% | |
| Exploitation rate corresponding to $SPR$ | 5% | 4.2-4.9% |
| Yield with $SPR_{MSY-proxy}$ at $SB_{SPR}$ (mt) | 7,565 | 6,256-8,873 |
| **Reference points based on estimated** $MSY$ **values** | | |
| Spawning biomass at $MSY$ ($SB_{MSY}$, mt) | 43,149 | 37,313-48,984 |
| Relative spawning depletion at $SB_{MSY}$ | 29% | |
| $SPR_{MSY}$ | 41% | 41-41.2% |
| Exploitation rate corresponding to $SPR_{MSY}$ | 5% | 4.9-5.6% |
| $MSY$ (mt) | 7,639 | 6,319-8,960 |

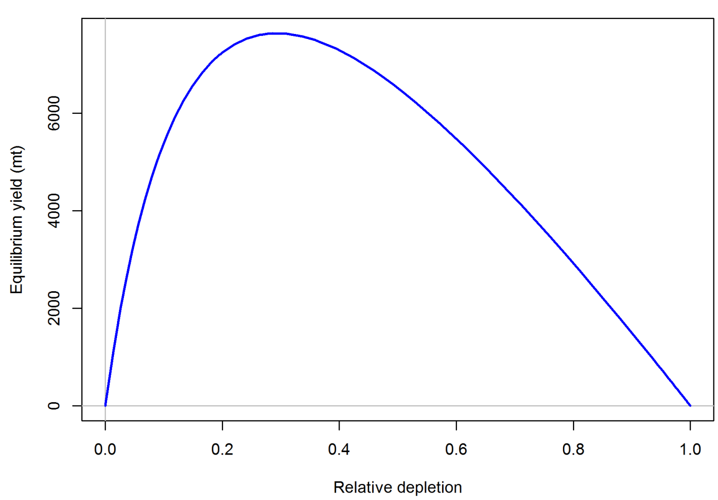


Figure 8: Equilibrium yield curve (total dead catch) for the base-case model.

# 1 Introduction

## 1.1 Distribution and stock structure

Sablefish (*Anoplopoma fimbria*, or black cod) are distributed in the Northeastern Pacific Ocean from the southern tip of Baja California, northward to the north-central Bering Sea and in the Northwestern Pacific Ocean from Kamchatka, southward to the northeastern coast of Japan (Hart 1973, Eschmeyer and Herald 1983). The resource in U.S. waters off California, Oregon, and Washington is modeled as a single stock, however there is some dispersal to and from offshore seamounts and along the coastal waters of the continental U.S., Canada, Alaska (Shaw and Parks 1997, Morita et al. 2012), and across the Aleutian Islands to the western Pacific which is not explicitly accounted for in this analysis (e.g., Fujioka et al. 1988, Heifetz and Fujioka 1991). Previous analyses have suggested the existence of several stocks of sablefish in the Eastern Pacific, including a southern California stock, a central California through Washington stock and a British Columbia to Gulf of Alaska (Schirripa 2007; and earlier assessments). Recent (2010) recovery of three tags at large off the U.S. west coast for 19-24 years illustrates the uncertainty in stock structure and movement rates: one tag moved from southern California to northern California (600 miles north), one tag moved from southern Oregon to Central California (>500 miles south), and the third tag was recovered within 15 miles of the location of release. Furthermore, differences in maximum body size (larger to the north) and growth rates (slower to the north) are apparent; however environmental effects cannot easily be isolated from stock structure.

Sablefish are ubiquitously distributed in California current waters, with smaller younger individuals generally found in shallower water, but show a characteristic ontogenetic shift to a fully mixed (adult and juvenile) demographic near the shelf-slope break (100-300 m). Beyond the shelf-slope break, the adult population is dominated by older (but generally not larger) individuals (well-explored in historical stock assessments; e.g., Methot 1994, Methot 1995), and younger fish become increasingly rare (see description of survey data below). Importantly for all modeling efforts, the stock is distributed beyond the greatest depth sampled by any of the trawl surveys and beyond the deepest commercial fishing areas. Fish in the deepest areas tend to be the oldest individuals, but not the largest individuals, suggesting that age rather than size dictates depth distribution. However, the interaction of environmental conditions and seasonal movements that produce an increase in age with depth are largely unknown. The deeper habitats occupied by sablefish span the EEZ boundary and extend across seamounts and ridges around the Pacific.

There are relatively fewer sablefish in Puget sound and the Strait of Georgia, therefore connectivity among these areas and the open coast is likely much less important to this stock assessment than along the open coast, especially between British Columbia and the U.S. west coast.

## 1.2 Life history and ecosystem considerations

Sablefish off the U.S. west coast exhibit a protracted spawning period from October through April, with peak spawning occurring in January and February. Sablefish spawn along the continental slope in deep waters, generally greater than 500 m. This winter-time spawning appears to result in reduced availability to the commercial fishery during the winter months. Eggs ($\sim$2.1 mm in diameter) are buoyant and rise to the surface waters. After hatching, post-larval sablefish are believed to continue to inhabit surface waters offshore. Within a few months they begin to migrate inshore, where they become largely demersal and are captured by trawl surveys as small juveniles (cigars). In parallel with the above mentioned ontogenetic shift in distribution, sablefish generally grow rapidly reaching nearly asymptotic size and beginning to mature after 5-7 years and reach full size and maturity in their first decade of life (see maturity and discussion of estimated growth curves below). These life-history traits show a strong latitudinal gradient, with slower growth and maturity schedules moving north along the distribution, as well a high degree of variability among studies.

Female sablefish generally reach larger sizes than males; however the sex-ratio tends to be skewed toward males at the oldest ages implying a lower natural mortality rate for males relative to females. The oldest sablefish in current records was captured off Washington in 2006 and aged (with observation error) at 102 years. This female was only 68 cm long, nowhere near the largest individual (117 cm).

Adult sablefish are fast swimming fish, capable of feeding on a diverse array of prey species including fishes, cephalopods, and crustaceans (Low et al. 1976; Shaw 1984). The cohabitation of adult and juvenile sablefish may result in some cannibalism, and large changes in predator biomass (such as the rebuilding of lingcod, Ophiodon elongatus, in recent years) could have a strong feedback to juvenile survival and therefore stock productivity.

Many groundfish have shown decadal changes in productivity linked to ocean conditions. For sablefish, the correlation between productivity in the California current and recruitment success is well-documented (Schirripa and Colbert 2006, Schirripa et al. 2009) and has been included in recent stock assessments (Schirripa 2002, Schirripa and Colbert 2005, Schirripa 2007). This source of information is discussed in further detail below. Future environmental conditions, changes in the timing, dynamics, and productivity of the California current ecosystem have a very high potential to directly affect the sablefish stock through recruitment success. However, with no ability to accurately predict these conditions, climate change should be considered a significant source of uncertainty in all projections of stock status. Further (and unknown) effects on individual growth, life history, or stock distribution also increase un-modeled prediction uncertainty.

## 1.3 Historical and current fishery

Sablefish catches are recorded back to the beginning of the 20th century, primarily in California, but appreciable quantities were not landed until 1916-1919, and landings remained below 5,000 mt through 1969 (Table 8; Figure 9). An early peak around World War II, likely due to a relaxed degree of species sorting (because of the associated decrease in manpower rather than a dramatic increase in fishing effort, mentioned indirectly in Washington grey literature), was fueled by the demand for domestic sources of protein (Browning 1980). This lack of species identification for reported catches increases the uncertainty in the historical catch reconstructions and thus the uncertainty in the size of the stock prior to fishing. Sablefish landings during this period were primarily harvested by hook-and-line fisheries. The fishery increased dramatically during the 1970s, a combination of foreign vessels at first (Van Houten Lynde 1986, McDevitt 1987), then transitioning to a domestic fleet. This corresponds to the introduction of a pot fishery and then an increasing percentage of the catch from the trawl sector, with only minor increases in the hook-and-line sector until the mid-1980s. A very large catch by foreign vessels, fishing pot gear, in 1976 resulted in the largest single-year removal of over 25,000 mt from the stock. A rapid rise in domestic pot and trawl landings followed this peak removal, such that on average, nearly 14,000 mt of sablefish were landed per year between 1976 and 1990. Annual landings have remained below 10,000 mt in subsequent years, divided approximately 45% from hook-and-line, 17% from pot, and 38% from trawl gear during the most recent decade. The decline in domestic landings through the 1980s was likely due to a combination of reduced Asian market strength and increasing fishery regulations. Subsequently, annual landings have remained below 10,000 mt.

Historical sablefish landings were reconstructed from a variety of sources, and are generally far more reliable than those for many other groundfish due to the consistent identification of sablefish by species. Uncertainty in historical catches, primarily in the Washington fishery, stems from poor identification of where fishing occurred (coastal U.S. waters, Canadian waters, or Alaskan waters) relative to the subsequent port of landing. Revised reconstructions from California and Oregon (Karnowski et al. 2011, Ralston et al. 2010), as well as a more limited analysis performed by Ian Stewart, the 2011 assessment author, using all available Washington sources resulted in almost no change (Stewart et al. 2011) from landings used in previous sablefish assessments (Schirripa 2007). The previously extrapolated period prior to 1930 was populated with actual landings estimates, applying only a small amount of extrapolation of very small landings during the period before 1920.

Because discarding is explicitly modeled in the stock assessment, total catches are estimated simultaneously with other model parameters and derived quantities of management interest. This can result in total mortality estimates that differ from those used by recent management and/or estimated using other methods. Due to a lack of data regarding changes in selectivity and retention during the historical period (prior to the current observer program, which began in 2002), total catch and discards for much of the time-series represent an important source of uncertainty in this stock assessment.

Since 2002, the trawl fishery has encountered a relatively continuous distribution of catches across deeper shelf and slope waters from Point Conception north to the U.S. Canadian border (Figure 10, Figure 11). The fixed gear fishery (including all sectors using pot and hook-and-line gear) has shown a somewhat more patchy distribution, focusing on areas with slightly higher catch-rates, and extending (albeit with lower total catch) through the waters south of Point Conception (Figure 12, Figure 13). The ex-vessel value of the sablefish fishery was estimated to be 24.1 million dollars in 2014 (http://pacfin.psmfc.org/).

## 1.4 Management history and performance

From the early 1900s to the early 1980s, management of the sablefish fishery was the responsibility of the individual coastal states (California, Oregon, and Washington). Since the adoption of the Groundfish Fishery Management Plan by the PFMC in 1982, responsibility has rested with the federal government and the PFMC. From 1977 to the mid-1980s, commercial fishers from the U.S. took advantage of their newly protected fishing grounds (i.e., the Fishery Conservation and Management Act was enacted in 1976, recently renamed to Magnuson Stevens Fishery Conservation and Management Act) recording high catches of sablefish to meet the demands of flourishing export (primarily Asian countries) and domestic markets.

The first coast-wide-established regulations on the sablefish fishery off the U.S. Pacific coast were implemented as trip limits in October 1982, followed by a rich history of management via seasons, size-limits, trip-limits, and a complex permit system (Table 9; See Appendix A for a comprehensive list of management actions). Beginning in 1983, trip limits were imposed on landings of sablefish less than 22 inches in length. Sablefish were first allocated between trawl and non-trawl fleets in 1987.

The fixed-gear sablefish fishery was managed a derby fishery, characterized by increasing reductions in season lengths beginning in the late-1980s. In 1991, the fully open season lasted seven weeks, from April 1 through May 23. In 1992, about 1,300 mt were landed under early season trip limits of up to 1,500 lb/day, and the fully open season lasted from May 12 through May 26. In 1993, there was a 250 lb/day trip limit prior to the open season which extended from May 12 through June 1. In 1994, the fully open season was shorted to May 15 through June 3. In 1995, the open season lasted one week, from August 3 to August 13. The open season spanned only six days in 1996, from September 1 to September 6. In 1997, 9 days (August 25 to September 3) were set aside for the open season, with a mop-up period from October 1-15. In the more recent period, the limited- entry fixed-gear fishery has been managed primarily through the use of tiered cumulative limits (allocated on the basis of historical landings) which can be landed throughout a 7-month season. The remaining open-access fishery and some limited-entry non-trawl vessels are allowed to make smaller landings that are subject to daily/weekly limits and 2-month cumulative caps.

Sablefish are harvested by the trawl fishery in association with a variety of other species which are distributed to domestic and foreign markets. Prior to 2011, the trawl fishery was managed primarily through the use of trip limits. These evolved from simple per-trip limits in the 1980s to cumulative periodic (monthly or bi-monthly) limits by the mid-1990s. In addition to sablefish- specific limits, various limits existed for the overall landings of deep-water complex species (See Stewart et al. (2011) for more detail of specific management actions).

Coast-wide yield-targets were divided among the different gears (hook-and-line, pot, and trawl), fishery sectors (including both limited entry and open access) as well as north and south of 36° latitude. The overfishing level (OFL, formerly the ABC) for sablefish has ranged from 49,071 (2015) to 71,638 mt (2005) during the last decade (Table 9). Catch targets (ACLs, formerly OYs) ranged from 25,206-72,936 (2015) to 41,998-101,279 mt (2005) over the same period. Landings were estimated to be below the ACLs in all years. Total mortality (including discards predicted to not survive) in the context of management limits and targets is discussed in section 3 below.

An Individual Fishing Quota (IFQ) program, referred to as catch shares, was implemented for the U.S. West Coast trawl fleet beginning in 2011 (with gear switching allowed, such that pot gear can be used to catch sablefish under the trawl IFQ). This has resulted in changes in fleet behavior, the distribution of fishing effort, and discarding rates.

### 1.5 Fisheries in Canada and Alaska

Historically, Alaskan catches were much larger than those on the U.S. west coast. Catches in Alaska have reached as high as 17,720 mt in the last decade, but declined steadily from 2004 to 2014, with 2012 catches of 11,476, the lowest since 1980 (Hanselman et al. 2014). Recent Alaskan catches were mainly comprised of a relatively strong 2000 year class. Slow increases in spawning stock were estimated from 2000 to 2010 but the increasing trend was predicted to decline from 2010-2020.

In British Columbian waters, estimates of catches range from 2,354 to 3,614 mt from 2001-2004, with a steady decline since 1999. The 2003 catch was the lowest since 1967 (Haist et al. 2005). Steep declines in vulnerable biomass were estimated from the mid-1990s to 2000, with a relatively stable or slightly decreasing trend since then (Haist et al. 2005).

## 2 Assessment

The following sources of data were used in building this assessment update:

1. Fishery independent data: including relative abundance indices, length and age data from the NWFSC Shelf-Slope bottom trawl survey (2003-2014), the NWFSC slope bottom trawl survey (1998-2002), the AFSC

slope bottom trawl survey (1997-2002), and the AFSC Triennial shelf bottom trawl survey (1980-2004).

2. Estimates of fecundity, maturity, length-weight relationships, and ageing imprecision from various sources.

3. Informative priors on male and female natural mortality based upon meta-analytical relationships with other life-history parameters derived from data across a number of fish stocks.

4. Commercial landings estimates (1900-2014).

5. Commercial fishery biological data (age and length) from port sampling programs (1978-2014).

6. Commercial fishery biological data (length and mean weight) and discard rates from at-sea observer sampling programs (2002-2014).

7. Environmental indices of sea-surface height and zooplankton abundance.

Data availability by source and year is presented Figure 14. A description of each of the specific data sources is presented below.

## 2.1 Fishery-Independent data

### 2.1.1 NWFSC Shelf-Slope bottom trawl survey

The NWFSC shelf and slope trawl survey time series has maintained a consistent stratified random survey design over the period 2003-2014, including depths from 55-1,280 m. Sablefish are captured in a very high proportion of survey hauls over most of the west coast shelf and slope depths (Figure 15, Table 11).

NWFSC trawl data are used to estimate an index of abundance for several groundfish species including sablefish. Data were analyzed using a delta-Generalized Linear Mixed Model (delta-GLMM), which explicitly models both the zero (using logistic regression) and non-zero (using a generalized linear model) catches and allows for skewness in the distribution of catch rates through the use of a gamma or lognormal error structure (Maunder and Punt 2004). The product of these two components yields an estimate of overall abundance (Pennington 1983).

For this assessment, delta-GLMM analyses were conducted using an open source software package from Thorson and Ward (2013) implemented in the R statistical software environment. Whereas the previous assessment and all 2011 groundfish assessments used a delta-GLMM approach following the methods of Helser et al. (2004) using in OpenBUGS (http://www.openbugs.info/), an offshoot of WinBUGS, implemented in the R and conducted by John Wallace (personal com.). The change in methods was reviewed and endorsed by the PFMCs Scientific and Statistical Committee (SSC). The use of the delta-GLMM facilitates the inclusion of vessel:year interactions as random effects, which is necessary because vessels used for the survey are not consistent across years and are instead selected from all possible commercial vessels via an open-bid sampling contract (Helser et al. 2004). In 2011, both lognormal and gamma errors structures were considered for the model component representing positive catches and in all cases gamma errors were found to perform best. Consequently, only models using gamma distributed errors were investigated for this update. A Bernoulli error structure was assumed for the presence/absence model component. Three potential effects (stratum, vessel, and year) were investigated, for a total of fivemodel structures, each with a different combination of fixed and random effects:

Model 1: Strata and year as fixed effects and the interaction of year and vessel as random effects.

Model 2: Strata and year and the interaction between strata and vessel as fixed effects.

Model 3: Strata and year as fixed effects and the interactions between year and vessel and strata and vessel as random effects.

Model 4: Strata and year as fixed effects.

Model 5: Strata and year as fixed effects with correlated interactions between year and vessel and strata and vessel.

Additionally, all models included survey pass as covariate to account for the incomplete sampling which occurred in 2013, during the second pass of the NWFSC shelf and slope trawl survey. The survey was cut short and no stations south of 37°N were sampled (Figure 15). Because of this, the data for strata between 34°N and 40.5°N (i.e. strata I, J, K and L) in pass 2 were not considered representative, and while strata M, N, and O were not sampled at all in that pass they were not included in the GLMM.

Convergence of each delta-GLMM model was evaluated using the effective sample size of all estimated parameters (>500 was sought) and visual inspection of trace plots and autocorrelation plots (where a maximum 0.2 was sought for the lag-1 autocorrelation). Model goodness-of-fit was evaluated using Bayesian posterior predictive checks and Q-Q plots.

When implementing the GLMM approach, it is recommended that there be at least three positive tows in each strata:year combination. Stratification of the survey abundance index was performed via a priori inspection of trends in size across latitude and depth, an evaluation of the presence or absence of sablefish in certain depth- or latitudinal areas, the boundaries of survey design changes, and the requirement of a sufficient number of positive tows in each strata:year combination for the estimation model to perform adequately. For sablefish, a rapid increase in average fish size was identified over the shallowest depths to roughly 183 m, thus defining the maximum depth for the first depth strata (Figure 15). Due to the very large number of positive tows in the deeper depths, it was possible to further divide the strata at depths of 549 m and 900 m (Figure

15). No catches were observed deeper than 1,280 m, which represents the outer strata boundary (Figure 15). Across latitude, the boundary at 34.5°N captured the lack of juvenile (age-0 and age-1) fish in the southern zone and represents the southernmost break (Figure 15; Figure 17). Further stratification breaks at 40.5°N and 45°N were easily supported by the quantity of observations (Figure 15). The strata south of Point Conception, and shallower than 183 m, was found to have no sablefish observations, except for a very few at the northern boundary (between 34°N and 34.5°N). Thus to avoid extrapolating biomass into areas with no fish, , a shallow break at 34°N was used for the strata less than 183 m deep and south of 40.5°N. The final stratification resulted in 15 strata that could be applied to all of the trawl surveys (albeit by removing unsampled areas for historical AFSC surveys) and appeared to adequately capture the most dominant demographic trends in size and age.

The biomass index shows a relatively precise and strong declining trend over the period 2003-2008, stabilization from 2008 through 2013, and an increasing trend between 2013 and 2014 (Figure 18). The 2011 assessment found the declining trend to be robust to alternate stratifications and to the analysis via delta-GLMM or design-based estimators. Therefore, this assessment re-ran the delta-GLMM including the most recent survey index data and the same stratifications. Model results were similar across all investigated fixed- and random-effect structures and were insensitive to software frameworks (Figure 19). A model including fixed-effects for year and strata and random-effects for positive or zero tows by strata:year and vessel:year interactions (Model 3) fit the data well and was most similar to the index used in 2011 and was thus carried forward for subsequent analyses (Figure 18).

Thirty-six bins from <22 to 90+ cm were used to summarize the length frequency of the survey catches in each year, the first bin including all observations less than 22 cm and the last bin including all fish 90 cm or larger. These bins are populated with a large quantity of sampling: 307-463 tows and 3,280-5,798 fish per year (Table 11). Broadly, the aggregate length frequency distributions for the NWFSC survey from 2003-2014 show modes for age-0 fish (20-30 cm), age-1 fish (30-40 cm) and adults to ~80 cm (Figure 20). In the annual length distributions, there is a very clear cohort at age-0 in 2008, age-1 in 2009 and age-2 in 2010 visible for both male and female sablefish (Figure 21). The same pattern is observed for age-0 in 2010 and 2013, age-1 in 2011 and 2014, and age-2 in 2012.

Age-frequency data from the NWFSC survey was compiled as conditional age-at- length distributions by sex and year. Individual length- and age-observations can be thought of as entries in an age-length key (matrix), with age across the columns and length down the rows. The approach consists of tabulating the sums within rows as the standard length-frequency distribution and, instead of also tabulating the sums to the age margin the distribution of ages in each row of the age-length key are treated as separate observations, conditioned on the rows (length) from which they came. This approach has several benefits for analysis compared to the standard use of marginal age compositions. First, age structures are generally collected as a subset of the fish that have been measured for length. If the ages are to be used to create an external age- length key to transform the lengths to ages, then the uncertainty due to sampling and missing data in the key is not included in the resulting age- compositions used in the stock assessment. Furthermore, if marginal age compositions are used along with length compositions, the information content on sex-ratio and year class strength is largely double-counted as the same fish are contributing to likelihood components assumed to be independent. Using conditional age-distributions for each length bin allows only the additional information provided by the limited age data (relative to the generally far more numerous length observations) to be captured, without creating a double-counting of the data in the total likelihood. The second major benefit to using conditional age-composition observations is that in addition to being able to estimate the basic growth parameters (Lenth at age and $K$) inside the assessment model, the distribution of lengths at a given age, usually governed by two parameters – the CV of length at some young age and the CV of length at a much older age – are also quite reliably estimated. Without the use of conditional age-composition data, CVs could only be derived from accurately aged and measured marginal age- and length-composition observations where very strong and well-separated cohorts existed; rare conditions at best. By fully estimating the growth specifications within the stock assessment model, this major source of uncertainty is included in the assessment results.

Age distributions included 36 bins from age 0 to age 35, with the last bin including all fish of greater age. Approximately one-quarter as many fish were sampled and have been subsequently aged as were measured for length, but these fish were collected from a similar number of tows (Table 11). These distributions show the rapid growth trajectory over the first several years of life, as well as the larger abundance of males in the aggregate bin at age-35 (Figure 22). Dimorphic growth is also quite pronounced, with virtually all sablefish above 70 cm being female. It is often helpful for visual interpretation to compute the marginal age-compositions, and include these in the assessment model (with the likelihood contribution turned off, so they do not affect model fit in any way) for comparison of the implied fit to the age margin of the age-length key. The marginal age compositions allow for easier visual tracking of strong cohorts (although this information is still imparted to the model using conditional age-at-length observations, it is harder to visualize) and offer a view of the data more familiar for those accustomed to diagnosing model fit based on marginal age-composition data. NWFSC Shelf-Slope survey age distributions also clearly show the pronounced 2009 and 2010 cohorts, as well as a recent population dominated by the 1999 and 2000 cohorts, but with an appreciable number of age-35+ individuals (Figure 23).

#### 2.1.2 NWFSC Slope bottom trawl survey

The same stratification as the NWFSC Shelf-Slope survey was used to analyze the NWFSC slope survey, conducted from 1998-2002. However, the southern and shallow strata were not sampled during this time-period and so were excluded from the analysis. There were fewer tows available for analysis, but a similar proportion of positive tows, from which length samples were collected (Table 12). The fraction of tows with ages collected and subsequently analyzed was much lower.

The biomass index shows a relatively flat trajectory over the survey period (Figure 68). The newer delta-GLMM method estimates are nearly identical to the those produced from the GLMM, and also very close to those used in the 2007 assessment.

The length-frequency distributions for the NWFSC slope survey show the 1999 cohort as age-1, -2, and -3, but did not observe them at age-0 (Figure 24); this is expected since generally the age-0 fish are present only over shallower depths. The pattern of dimorphic growth is also visible in this series of length-frequency observations, as well as in the conditional age-at-length distributions (Figure 25). The marginal age distributions corroborate the strong 1999 year-class, and show some evidence for a 1995 cohort, as well as a protracted distribution of ages between 8 and 35 (Figure 26).

### 2.1.3 AFSC Slope bottom trawl survey

The AFSC slope survey was conducted over depths from 183-1,280 m, north of 34.5°N from 1997 and 1999-2001. Limited sampling in earlier years covered only relatively small (and inconsistent) portions of the coast and are therefore was insufficient to provide an index of abundance. The same stratification as the NWFSC slope survey was used to analyze the AFSC slope survey. This survey had a very high degree of both positive tows and biological sampling (Table 13). The AFSC slope biomass index also shows a relatively flat trajectory over the survey period (Figure 68), albeit one with differing peaks from the NWFSC slope survey (Figure 68). Similar to the NWFSC slope survey biological data, the length-frequency distributions for the AFSC slope survey show a strong 1999 cohort as well as a few age-0 fish in 2000 and 2001 (Figure 27). The conditional age-at-length distributions are similar as well, with the exception of a seemingly anomalous number of males at the largest sizes, perhaps implying some error in the identification of sex for these fish (Figure 28).

### 2.1.4 AFSC Triennial Shelf bottom trawl survey

Previously, the triennial shelf bottom trawl surveys conducted by the AFSC in 1980, 1983, 1986, 1989, 1992, 1995, 1998, 2001, and 2004 provided the longest time series of information regarding abundance of sablefish, especially younger fish occurring at the shallowest depths. Survey methods are described in a series of NOAA Tech. Memos (e.g., Weinberg et al. 2002). Sampling occurred over depths from 55 to 366 m (500m after 1992), and from 36.5°N (34.5°N after 1992) to the Canadian border. Lengths were collected for a large number of fish; however age-sampling was relatively sparse (Table 14).

In general, all of the surveys were conducted from mid-summer through early fall; however during the 2007 assessment cycle a marked shift in the timing of surveys was identified, with the surveys occurring much earlier in 1995 and after (Figure 29). To address this change in design, subsequent groundfish assessments have estimated catchability separately for the two portions of the time-series. Similarly, a retrospective analysis of catch rates for benthic material identified a large number of water-hauls (Zimmermann et al. 2001, 2003) in the early years of the AFSC shelf survey, leading groundfish assessments to exclude these hauls in stock assessment analyses and to exclude the survey conducted in 1977 entirely.

The AFSC shelf survey biomass index shows an increasing trend from 1992 to the last year of the time series in 2004. The same increase was not picked up in the previously described indexes that overlapped in the early 2000s. Future assessments may wish to update this index using the newest available methods, as the magnitude of the trend decreased when updated in the previous assessment.

Sablefish were not reliably identified to sex during the 1983 and 1986 surveys, so the length-frequency observations were aggregated among males and females and show little clear information (Figure 30). Length frequencies for subsequent years are quite variable, and conspicuously missing any age-0 sablefish (Figure 30). Conditional age-at-length distributions show some of the largest female sablefish caught by any survey, but a very rapidly truncated age structure (Figure 30). The latter pattern is expected given the very limited depth range covered by the survey.

### 2.1.5 Other fishery-independent data

Pot surveys were conducted by NMFS in 1979-1981, 1983, 1985, 1987, and 1989 in northern International North Pacic Fisheries Commission (INPFC) areas (U.S. Vancouver and Columbia) and in 1984, 1986, 1988, and 1991 in southern INPFC areas (Eureka, Monterey, and Conception). Catch information (number of fish/pot) and biological data were collected according to grade-specific categories: large fish (>68 cm); medium (62-67 cm); small (52-61 cm); and extra-small (<51 cm). Specific details concerning survey methods are described in Parks and Hughes (1981), Parks and Shaw (1983b, 1985, 1987, 1989), and Kimura and Balsiger (1985). Early sablefish stock assessments had little choice but to use the geographically limited and variable pot surveys as indices of abundance. Over time, growing time-series of trawl survey indices, conflicting abundance trends and incomplete spatial coverage within the pot surveys has led to their exclusion from all recent stock assessments. These indices have not been revisited for this assessment, but future work could be done to re-evaluate the possibility that there is some useful information that can be captured from these data-sets through updated analysis or modeling methods.

### 2.1.6 Environmental indices

The correlation between sablefish recruitment strength and environmental conditions in the California current has been the topic of extensive research

(Schirripa and Methot 2001, Schirripa and Colbert 2006, Schirripa et al. 2009). The relationship has been modeled both via a direct offset to the expected value for recruitment (Maunder and Watters 2003, Schirripa and Colbert 2005), and as an index of recruitment deviations (Schirripa 2007). The former method makes it difficult to determine the appropriate degree of recruitment variability for the deviations themselves, and also requires that the environmental series be treated as if it is known without error. The latter method allows for observation error in the environmental series, as well as for tuning of the uncertainty so that forecast uncertainty is consistent with the degree of correspondence observed within the time-series. Although it has received much attention in recent assessments and reviews, the link between recruitment strength and environmental conditions has generally been contentious, and ultimately has not greatly influenced model results or predictions (Schirripa 2007, Stewart et al. 2011).

The topic of model-selection, robustness and validation for the sablefish recruitment-environment relationship has been a recurrent theme in STAR panels and with the SSC since its use in the stock assessment began in 2002. Most recently, the covariate of annual series of average sea surface heights over the spring months was the focus of much research. A number of covariates at several temporal and regional aggregations appear to have been tested, resulting in a total of almost 900 unique possible combinations. However, not all of these series are independent. In fact, SSH appears to have been selected, in part, as a replacement for the copepod index on the basis of the correlation between the two and the more complete time series of the former.

Exercises were conducted in the previous assessment (Stewart et al. 2011) to test these questions. The results indicated that for small numbers of candidate covariates there is little chance of selecting a randomly generated time-series with the observed $R^2$, which supports the hypothesis that the relationship between sablefish recruitment and SSH was probably not spuriously identified. However, the relatively small number of years over which the correlation has continued, beyond what is predicted at random, should be noted. The time series of SSH was extended to 2014, and converted to a standard normal then scaled such that the SD matched the r used for recruitment deviations (see below). This updated series was subsequently evaluated via sensitivity testing (see section below).

An index of relative zooplankton abundance in the California current was also made available for the 2011 stock assessment (J. Fisher, W. Peterson, personal communication, 2015). A similar metric of zooplankton abundance was previously evaluated in the sablefish assessment via sensitivity analysis (Stewart et al. 2011). This series represented the output of a principal component analysis for summer (June-August) zooplankton abundance, and again transformed, with observation uncertainty reflected via the month-to-month SD in the results.

The two environmental variables produced similar patterns in the resulting indices (Figure 91). Both capture the general patterns in recent recruitment (1999 and 2008 are above average). There are at least two aspects of the use of these series that are left to be fully reconciled: 1) The assumption must be made that the period over which both recruitment deviations and the indices are compared is centered on the S-R curve, which will be reasonable for very long time-series, but subject to small sample size issues for shorter ones; 2) The spatial and temporal scale over which the indices are calculated is relatively small compared with the distribution of the sablefish stock. The influence of each environmental series on the stock assessment results is explored via sensitivity testing reported below.

## 2.2 Biological data

A number of biological parameters were estimated outside the assessment model. These values are treated as fixed, and therefore uncertainty reported for the stock assessment results does not include any uncertainty associated with these quantities (however some were investigated via sensitivity testing). Input values for such parameters are provided in Table 15, and the methods are described below.

### 2.2.1 Weight-length relationship

The weight-length relationship used for this assessment is based on survey data from 24,602 fish sampled in California, Oregon, and Washington between 1978 and 2014 with information on both length and weight. Male (n = 13,001) and female (n = 11,172) curves were fit separately using a normal error assumption for the log-linear relationship $W = aL^b$. Parameter estimates derived from this analysis (Table 15) are consistent with other published studies (and the values used in previous sablefish assessments). Estimated parameters fit the data well, and indicate little difference in the weight of female vs. male sablefish (Figure 32).

### 2.2.2 Maturity schedule

Sablefish studies across Alaska, Canada, and the U.S. west coast (i.e. Washington, Oregon, and California) provide numerous parameter estimates for modeling maturity as a logistic function of length, where the probability that individual i is mature is based on the length of individual $i$ ($L_i$); the length at 50% maturity ($L_{50\%}$); and, a rate parameter ($\beta$). Most studies report estimates of $L_{50\%}$ while fewer report estimates of $\beta$. In general, $L_{50\%}$ is greater for sablefish in Alaska and Canada than for those off the U.S. west coast (Parks and Shaw 1983b, McFarlane and Beamish 1990). Estimates of $L_{50\%}$ are smaller for sablefish in deeper waters (Fujiwara and Hankin 1988) and for older individuals (Methot 1995); these latter effects are linked due to the likely ontogenetic movement of mature individuals offshore. Additionally, stressed individuals (such as those with tags) appear to have higher $L_{50\%}$ (McFarlane and Beamish 1990). In general, even similar studies estimating $L_{50\%}$ for female sablefish off the U.S. west coast demonstrate considerable variability in $L_{50\%}$ estimates among studies (Parks and Shaw 1987, 1988), between areas within a given year and sampling design (Parks and Shaw 1983b), and between years within a given area and sampling design (McFarlane and Beamish 1990). This variability could represent sampling error, variability in the biological processes influencing maturity, or both. In aggregate, variability among areas, years, and studies appears to represent a range of 2-4 cm between lower and upper estimates of $L_{50\%}$.

Historical estimates of $L_{50\%}$ for female sablefish off the U.S. west coast range from approximately 56 cm (Parks and Shaw 1983a, Fujiwara and Hankin 1988, Methot 1995) to 60 cm (Hunter et al. 1989). Here, we use an intermediate value of $L_{50\%} = 58$ cm (Table 15) as in the 2011 full assessment. Given sparse reporting for estimates of $\beta$, we use the value $\beta = 0.13$ from Fujiwara and Hankin (1988). The composite maturity schedule suggests a slightly more protracted size range over which sablefish mature than has been estimated in recent assessments (Figure 33). A recent study, which included 477 female sablefish, found $L_{50\%}$ to decrease from north to south and with increasing depth (Head et al. 2014). Coast-wide estimates of $L_{50\%}$ were somewhat smaller than historical estimates at 54.64 cm. Sensitivity analysis of the model results to the maturity schedule is reported below.

### 2.2.3 Fecundity

Available data suggests that sablefish are determinate spawners (i.e. total advanced oocytes at the beginning of the spawning season is equivalent to total annual spawning output) and spawn 3-4 times per year (Hunter et al. 1989, Macewicz and Hunter 1994). The total number of oocytes at the beginning of the spawning season appears to be linearly proportional to weight (Hunter et al. 1989), implying that spawning output for a mature female is also proportional to weight. This assumption has been used in previous sablefish stock assessments and is retained here (Table 15) in the absence of new information. However, there is no data to assess the likelihood of skip-spawning behaviors, environmental effects, or other factors that could cause fecundity to vary nonlinearly with weight.

### 2.2.4 Natural mortality

Since 1992, a fixed value for natural mortality, equal for males and females, of 0.07 was assumed in all stock assessments (Schirripa 2007). Improvements in our understanding of the importance of natural morality estimates on stock assessment model uncertainty, and the growing number of assessments identifying differences in mortality among male and female groundfish, make this fixed value approach undesirable. Sablefish have been aged at over 100 years, but recent survey and commercial catch are largely dominated by much younger individuals. Prior probability distributions for males and females were developed based on a hybrid method including both Hoenigs (1983) method using maximum observed age and Paulys (1980) meta-analysis of natural mortality for a wide range of fish species. The method calculates prediction intervals based on the two methods, using input information including the maximum observed age, average temperature, and growth parameters (Hamel 2015; Then et al. 2015). Results for this analysis were relatively insensitive to the choice of specific input parameters and generally quite uncertain: ln(M) = -2.1791, SD = 0.3384 for females and ln(M) = -2.0565, SD = 0.3375 for males (Figure 34). Both priors resulted in a substantial probability density over the range 0.06-0.2. This is somewhat higher than might be expected, largely because sablefish grow very rapidly relative to most other long-lived fish, especially males.

### 2.2.5 Ageing bias and imprecision

Observed sablefish ages are derived from visually counting rings on otoliths after they have been 'broken-and-burned'. Because sabelfish are long-lived, these counts can be large, and the repeatability of individual age estimates is imperfect, especially for older fish. The observed age can therefore differ (sometimes substantially) from the true age of a fish (called 'reading error'). Aging error can be decomposed into the difference between true age and average-read age ('bias') and variability around that average read age ('precision'). The bias and precision for aging methods or labs for west coast groundfish is generally estimated as a hierarchical model using readily available software (Punt et al. 2008) and data consisting of comparisons among and within methods or labs ('cross-reads' or 'double-reads').

We compiled a database of all available age comparisons for sablefish, which included 6,959 reads for 2,619 unique otoliths, with a large number of reasonably old (>40 years) fish in the sample (Figure 35). Data included 15 individuals with known ages (i.e., no bias and perfect precision) obtained from tag-recapture studies in Alaska. Other reads were obtained from thirteen readers in four laboratories (NWFSC: seven readers; AFSC: two readers; ADFG: two readers; DFO: two readers), and we assumed that reading errors for all readers within a laboratory had identical precision and bias.

Initial inspection of the data in 2011 revealed that NWFSC ages were quite biased (low) relative to the small sample of tagged fish, which appeared to be aged much more accurately by the AFSC (Figure 36). We then analyzed these data using the ageing-error model from Punt et al. (2008), which estimates (1) the true proportion-at-age in the sample, and (2) the bias and precision for each of four laboratories that were assumed to have ageing error. This model treats the 'true' age for each otolith as a random effect, and estimates the marginal likelihood of all other fixed effects while integrating across these random effects. We used stepwise (i.e. forward and backward) model selection to select among all combinations of three precision models (i.e. linear and a Hollings- form for either standard deviation or coefficient of variation for precision) and two bias models (i.e. linear or Hollings-form) for each laboratory, as well as the maximum age for which a proportion-at-age parameter was estimated (possibly ranging from 2 yr to 80 yr). Model comparisons were conducted using the Akaike Information Criterion (AIC) which is often used for selection of fixed effects in maximum likelihood models with random effects. Stepwise model selection identified a model with Hollings-form bias and Hollings-form standard deviation of precision for each laboratory. Biases were very large and negative (i.e. reads were lower than the true age) and the standard deviation was increasing with true age for all laboratories (Figure 37).

In the 2011 assessment, a substantial amount of preliminary modeling was performed using the estimates that ages were both highly imprecise and very biased. This modeling revealed that the degree of bias estimated from initial ageing error analyses was incompatible with observed cohorts moving through the population and produced poor residual patterns and unrealistically low estimates of natural mortality. Based on these findings the information used to estimate ageing error properties was re-evaluated.

Of particular interest was whether the tagged fish, which originated in Alaska, showed similar patterns to fish from the west coast, where the NWFSC age-readers would presumably be more comfortable with patterns observed on the otoliths. A comparison of a much larger sample (also containing much older fish) of otoliths collected during trawl survey operations revealed that there was likely a much greater consistency among labs for west coast fish (Figure 38). It was concluded that the perfect ages derived from the tagging experiment were not broadly representative of the aging methods for the fishery and survey samples available, and that the initial analysis of bias was heavily influenced by these few fish.

In contrast to the ageing imprecision applied in the 2007 assessment, double-reads from the NWFSC did produce an estimate of imprecision suggesting that by age 50 observed ages can easily differ from true ages by as much as 10-12 years (Figure 39). This result is quite consistent with the comments made by age- reading staff indicating that sablefish can be quite difficult to age consistently. Because of the uncertainty in the ageing process and the lack of a true age validation study for west coast sablefish, several alternate treatments of ageing bias and impression were evaluated via sensitivity testing during the 2011 assessment. No additional investigation was performed regarding new and/or improved aging methods for this assessment update, though both new and/or improved aging methods and related studies are identified as important recommendations for future research.

## 2.3 Fishery-Dependent data

### 2.3.1 Historical commercial landings

The historical commercial catch reconstruction used for this assessment update represents a complete reconstruction from basic sources for California, Oregon, and Washington, based on information used in the 2011 assessment. The general sources and methods used for this reconstruction are summarized by state below (Table 8; Figure 9).

For the state of California, commercial landings for the period 1916-1968 relied on estimates from the recent reconstruction efforts by SWFSC and California Department of Fish and Game (CDFG) scientists (Ralston et al. 2010). This effort utilized spatial information regarding groundfish landings back to

1931. This method is probably quite reliable for sablefish, because sablefish are identified as a separate market category. Prior to 1931 landings estimates were available from published California DFG Bulletins back to 1916. Fisheries statistics of the U.S., published by the U.S. Fish Commission, extended the series back to 1908. Catch from 1908 was estimated to be less than 16 mt and this was extrapolated linearly to zero in 1900. The cumulative catch during this period was relatively small, and although there is uncertainty in apportionment to gear type (it was split between hook-and-line and trawl based on the earliest ratio recorded), it was unimportant to the results of the 2011 assessment and thus used for this assessment update. The most recent historical catches (from 1981 to 2014) were extracted from PacFIN in February 2015.

For the state of Oregon, there was also a comprehensive reconstruction of historical catches that extended back to 1927 (Karnowski et al. 2011). Low et al. (1976) provided total landings from 1915-1926. Prior to 1915 no statistics were available, so a linear extrapolation from the 10 mt estimate for 1916 to 0 mt in 1900 was applied. Oregon catches from 1987 (the last year of the reconstruction) to 2014 were also re-summarized from PacFIN in February 2015.

For the state of Washington there was no comprehensive historical reconstruction that could be used directly for this assessment update, although efforts are underway. The main concern with catches landed in Washington lies in determining the location of fishing: the U.S. west coast, Canada, Alaska, or Puget Sound. A number of unpublished summary tables were made available to the author of the 2011 assessment by Washington Department of Fish and Wildlife (WDFW) scientists (G. Lippert and D. Bacon; personal communication). These tables, summaries, and bulletins included various portions of the time-series that were reported by gear type, catch location, and port of landing. Very little sablefish were historically caught in Puget Sound waters (unlike many of the flatfish). Working backward in through the record the following sources and methods were utilized: PacFIN catches were downloaded in February 2015 covering the period 1981-2014; WDFW maintains a fisheries statistics program that includes sablefish landings from state waters, by gear type during the period 1970-1980 (T. Tsou; personal communication). The above-mentioned summary tables, aggregate fish- ticket records, and season summaries were sufficient to reconstruct the landings and apportion out Canadian and Alaskan catches from 1926-1969, with a few gaps pieced in via the Pacific Coast Fisheries Bulletin, or the Washington Department of Fisheries annual reports. Low et al. (1976) was again used for the period 1915-1925. Prior to 1916 there were negligible trawl catches (pot gear being absent prior to 1970). Hook-and-line catches from 1900-1914 were interpolated from sparse records available in Sette and Fiedler (1928); however the largest landings in this period were estimated to be less than 400 mt.

There are ongoing efforts to key-punch a large quantity of historical fish ticket data for the state of Washington. These records will provide a trip-by- trip record of where fish were landed, species composition information for market categories, and a much more reliable historical record. Future sablefish assessments will likely benefit from this work, when it becomes available.

This assessment update did not attempt to update the methods used for the previously outlined catch reconstructions. Given that the net result of the 2011 reconstruction was nearly identical to that used in 2007 stock assessments (Stewart et al. 2011), future stock assessments should wait to revisit this issue until more recent data is made available for Washington.

#### 2.3.2 Foreign catches

Foreign catches are included in the landings estimates for commercial fleets by state (Table 8), and were very large in the late 1970s. The values reconstructed for the 2011 assessment (and used in this assessment update) were identical to those used in 2007, and were based on the records in the HAL database (Van Houten Lynde 1986).

#### 2.3.3 Fishery catch-per-unit-effort

Trawl fishery logbook data have been collected by the states of California (CDFG), Oregon (Oregon Department of Fish and Wildlife), and Washington (WDFW) since the 1970s. Records provide tow-by-tow information regarding groundfish species including sablefish. The 1997 sablefish assessment (Crone et al. 1997) considered the use of a time series of standardized catch per unit effort (CPUE) based on the GLM analyses described in Brodziak (1997). That effort filtered the raw tow data for a deep-water catch strategy (DTS, or Dover, thornyheads, and sablefish; Brodziak 1997; Crone et al. 1997). Variable trends, patterns were observed, and these were speculatively linked to management changes. Given the varied management history, inherent uncertainties associated with the use of fishery-dependent CPUE, and conflicting trends identified in earlier analyses, a commercial CPUE series has not been included in any recent sablefish stock assessment. The topic was not revisited for this assessment update.

Another potential source of fishery-dependent information is the bycatch of sablefish in the mid-water whiting fishery. Bycatch of sablefish is documented for this fishery (Sampson et al. 1997), and anecdotal reports indicate that it encounters many small fish in years of above average recruitment. During the 2011 assessment, a preliminary investigation revealed that the length-frequencies from this source did indeed show small fish associated with the 1999 and 2008 cohorts; however beyond general corroboration of modeled patterns it seemed unlikely that a reliable quantitative index of recruitment strength exists.

#### 2.3.4 Fishery biological data

Considerable variability in the analysis and weighting of commercial biological data has been present over historical sablefish stock assessments. In recent years, biological sampling was summarized in an independent database, populated directly from state records. For 2011, all three states made a concerted effort to upload all biological data to the Pacific Fisheries Information Networks (PacFIN) Biological Data System (BDS), making it possible to extract these data in a single format, with well-documented fields and standardized lists of codes describing each field. This effort made analysis much more straightforward and more consistent with analyses of other groundfish than was previously the case.

The complicating factor for sablefish is that many landings are sorted into size-grades while at sea and therefore require information about the magnitude of catch within each size-grade to appropriately weight the biological information to reflect the total, unsorted, landed catch. Broadly, the weighting of commercial biological samples was conducted via the following method:

1. Expand the number of lengths (or ages) from the subsample consisting of one or more baskets of fish to the estimated total catch in that market category (or trip for ungraded samples). This step accounts for differences in the fraction of each landing (or market category) that was actually sampled and is important during periods where there are some differences in the number of baskets or fish that comprise a ‘sample’.

2. Sum the expanded values within gear and state combinations. Large landings account for more weight in the sum, better reflecting the total catch.

3. Normalize the compositions and then aggregate again across states based on the total landed catch in each state. This step ensures that if one state samples landings very heavily, but is responsible for only a small fraction of the total landings it will not be weighted too heavily (as would be the case for an unweighted analysis) in the final length- or age-compositions.

State recorded values for sample weights and category landings estimates were utilized for step 1 above. Where one or both of these was unavailable, sample weights were derived from gender specific length-weight relationships and median category landings estimates from similar landings. For step three, reconstructed landings by state and gear were used to weight the normalized proportions at length or age. This method was intended to match that used in nearly all west coast groundfish stock assessment analyses.

Age-compositions were calculated for each sex and all unsexed fish less than 71 cm were equally assigned to males and females, consistent with the survey age-frequency distributions. Conversely, length compositions were aggregated without regard to sex, as was done in the previous assessment, to limit the exclusion of data and allow for a longer time series of length data (back to 1978; Table 16) relative to the earliest data used in 2007 (from 1986). Most of the sablefish lengths were observed from whole fish, but some were extrapolated via a dorsal-to-fork length conversion applied by the individual states. Year and fleet combinations with less than three tows were removed from the analysis. A summary of the number of trips contributing to the fishery biological data is provided in Table 16. Generally far more trips (and fish) have been sampled for length than for age, and the number of samples is relatively small when compared to the sampling of other groundfish species.

Aggregate length-frequency distributions show the broadest size spectrum captured by the hook-and-line fishery, the largest individuals observed in the pot fishery, and the smallest sablefish landed by the trawl fishery (Figure 40). Annual distributions show a relatively stable size distribution for the hook- and-line fishery with some evidence of a bimodal distribution in many years (Figure 41). The pot fishery shows a much larger average size of fish retained, with almost no small sablefish below roughly 45 cm during any part of the time-series; an increase in the average size of fish is also prominent between the late 1990s and roughly 2004 (Figure 43). For the trawl fishery, the early years are quite variable due to small sample-sizes, but an increase in the average size of sablefish landed is visible between the early 1990s and the end of the 20th century (Figure 45). The trawl fishery appears to routinely land a much larger fraction of fish less than 40 cm, giving a very slight indication of the 1999 cohort in 2000 and 2001, and perhaps a 1991 cohort in 1992. The presence of sablefish in the 40 cm range in 2010 is consistent with a prominent 2008 year-class.

Length-frequency distributions from sablefish that were discarded at sea were available from the West Coast Groundfish Observer Program (WCGOP) for the period 2002-2014. These samples were analyzed using a weighting method consistent with that applied to port samples described above. In aggregate, these samples reflect the sorting out of smaller fish from the retained catch, with all gears discarding sablefish at age-1 and above and several observations of age-0 fish in the trawl and pot gears (Figure 47). Annual distributions from all three gear types are highly variable due to limited sample sizes and probably only informative about the general size ranges that are discarded (Figure 48, Figure 50, and Figure 52). It is important to note that all three gears do discard some sablefish 50-60+ cm in length. Since these fish are large enough to be valuable (and at least as large as the average retained sablefish) this implies that size-based sorting is not the only reason for discarding and that no age or size is likely to be completely retained under all conditions. With the implementation of the trawl catch share program discarding is now directly accounted for and more than likely different than years prior to 2011.

Unlike the trawl surveys, marginal age compositions were derived for the commercial fishery fleets using the same weighting methods as the length- frequency distributions. Using marginal age compositions is one way to account for non-stationarity in age-at-length within a year, which is generally present in fishery data because the more protracted season than for the surveys and to speed the computation time of model runs. In aggregate, generally more females are observed in the fishery age compositions than males; however the male distributions contain relatively more of the oldest sablefish (Figure 54). The annual fishery age distributions provide a reasonably clear picture of several prominent cohorts identified in other data sets, despite the lack of very young fish. A 1991 cohort can be seen in the mid-1990s in the hook-and-line age compositions for both sexes, as well as a 1994 or 1995 cohort, the 1999 and 2000 cohorts and a reasonably large number of two year olds in 2010 consistent with the 2008 year class (Figure 55). The pot fishery also shows these cohorts (Figure 57), along with more inter-annual variability, potentially attributable to spatial and depths changes in where the fishery was concentrated during different periods of time (anecdotally, the fishery operated in relatively deep water during the late 1980s when the oldest fish were observed). Because the trawl fishery tends to retain the smallest sablefish, tracking cohorts in the age data for the trawl fishery provides the clearest window on the above-average year-classes common to all series (Figure 59).

Also available from the WCGOP program were mean body weight observations from the discarded catch, 2002-20014. These were available for some hauls where length data were not collected, as they were calculated via the sample weight divided by the count of fish in that haul. Hook-and-line annual values ranged from 1.76-2.69 kg, implying somewhat larger sablefish than observed in the length frequencies. The observed mean weights for the pot fishery also had a similar range (1.47-2.06 kg). The smallest average fish weights were recorded for the trawl fishery discards, ranging from 0.59-1.08 kg. The time-series of values for each fleet are plotted along with predicted values in the results section below.

### 2.3.5 Discard ratio estimates

The WCGOP provided data on the total discards by gear type (pot, hook-and-line, or trawl), fishery (e.g., open access, limited entry), and state (WA, OR, and CA). These data were available for the period 2002-2013, and explicitly accounted for the introduction of the catch share program. The ratios for each strata (discard ratio by gear type, state, and fishery) were computed as:

$$\rho_{s,y} = \frac{d_{s,y}}{r_{s,y}}$$

where $\rho_{s,y}$ is the estimated discard rate for stratum $s$ in year $y$, $r_{s,y}$ is the weight of the the sample retained for stratum $s$ in year $y$, and $d_{s,y}$ is the weight of the sampled discards for stratum $s$ in year $y$. To aggregate these ratios into the fleets modeled in this assessment (discard ratios by gear), each state, fishery, and gear combination was weighted by the total estimated retained catch using:

$$D_{s,y} = \rho_{s,y} C_{s,y}$$

where $C_{s,y}$ is the landed catch in stratum $s$ in year $y$ and $D_{s,y}$ is the total estimated discards for stratum $s$ and year $y$. The total estimated discards and catch were then summed across strata to estimated an expanded discard rate by gear, accounting for catch and differences between states and fishery sectors:

$$\phi_y = \frac{\sum_s D_{s,y}}{\sum_s C_{s,y} + \sum_s D_{s,y}}$$

where $\phi_{g,y}$ is the discard rate by gear $g$ and year $y$. These methods are different than the methods used by WCGOP to estimate total discards, but explicitly considers the difference in catch by sector, state, and gear.

Uncertainty in these values was quantified via bootstrapping the individual observations and then aggregating to the total estimate, providing a distribution of the discard rate. From this distribution a SE was provided. With the introduction of catch shares in 2011, it was necessary to combine the bootstrap samples from the non-catch shares with the single observation from the catch-share stratas. Futhermore, because of the small sample sizes for the trawl fleet beginning in 2011, it was necessary to use a single standard error for all three years (2011-2013) for this strata.

Discard rates for the trawl fleet were computed for previous sablefish stock assessments from two additional sources the Pikitch study conducted from 1985-1987 (Pikitch et al. 1988) and the Enhanced Data Collection Program (EDCP; Sampson 2002) conducted from 1996-2000. These estimates were used by Schirripa (2007), and were not re-analyzed for this assessment. For this assessment update, discard rates and their corresponding standard errors for 1986-1988 were taken directly from Pikitch (1988).

Discard rates have ranged from 9-26% for the hook-and-line fishery over the period 1986-2013. For the pot fishery, discards have ranged between 11-39%. The early estimates of discard rates for the trawl fishery from the 1980s averaged 36.3%. More recent trawl estimates have ranged from 5.5% in 2008 to 59.0% in 2002. After the implementation of the catch share program in 2011, discard rate estimates for the trawl feet have dropped as low as 0.5% in 2012, with the highest observed rate of 1.1% in 2013. These estimates are also plotted with predicted values below.

### 2.3.6 Discard mortality estimates

Discard mortality rates have been the subject of numerous research studies and analyses supporting historical sablefish stock assessments. What is currently understood is that sablefish, lacking a swim-bladder (and therefore the propensity for severe barotrauma), have a good chance of survival after capture, depending on the specific conditions that they experience during the process. Generally, warmer water results in higher mortality, as the physiological stress of transitioning from very cold bottom temperatures to warmer surface water and air temperatures can be great (Davis et al. 2001). Further, some gears, such as pot and hook-and-line are less physically damaging to sablefish than, for example, spending an extended period in a trawl cod-end with a large catch volume. Treatment and handing of captured fish, including time-on-deck are also quite likely to be important for subsequent survival.

Analysis of discard mortality is hampered by the lack of available temperature information. Substantial efforts as part of the 2005 assessment resulted in a detailed model-based approach that used seasonal average water temperatures to predict variable annual discard mortality rates over the historical time- series, corrected for estimated differences among gear types (Schirripa and Colbert 2005). Ultimately the approach was discarded as too complex to be supported by the available observed data, with which to assign temperature, and other individual fishing trip variables.

This topic was not investigated further; however in 2011, discard mortality estimates were corrected to be consistent with those used by the PFMCs Groundfish Management Team (GMT) in predicting in-season total mortality and for NOAAs annual calculation of total mortality for comparison with harvest regulations. These values are: 20% discard mortality for sablefish captured with hook-and-line and pot gear and 50% discard mortality for sablefish captured with trawls. An exception to this is age-0 fish for which discard mortality is assumed to be 100%.

## 2.4 History of modeling approaches

### 2.4.1 Previous assessments

Stock assessments of sablefish began in 1984 and have been conducted frequently since then (Francis 1984, 1985, McDevitt 1987, Methot and Hightower 1988, 1989, 1990, Methot 1992, 1994, Crone et al. 1997, Schirripa and Methot 2001, Schirripa 2002, Schirripa and Colbert 2005, Schirripa 2007, Stewart et al. 2011).

Francis (1984) examined catch-per-unit-effort (CPUE) data generated from the NMFS pot survey conducted from 1979 to 1983. The 1985 assessment utilized an age-structured simulation model, estimating natural mortality, average weight- at-age, recruitment, and relative age-specific catchability. Simulation analysis was used to examine the maximum sustainable yield. The model relied on research survey data, trawl and pot surveys, and parameter estimates generated from independent research studies. The 1987 sablefish assessment extended the existing survey time-series and primarily consisted of a modified yield-per-recruit focusing on the minimum size limit (22 in) that had been in place since 1983.

In 1988 (Methot and Hightower), implemented the first separable catch-at-age analysis using an early version of the Stock Synthesis modeling framework, the framework which forms the basis for all subsequent assessments. The 1988 model included two fleets, trawl and fixed gear, and two years of biological data from the fishery. Trawl and pot surveys provided indices of abundance, and estimates of exploitation rate were based on tag recapture information generated from a tagging study that began in 1971. The 1989 sablefish stock assessment followed similar approach (Methot and Hightower 1989); revisions in the age determination criteria for sablefish caused an increase in the observed proportion of old fish and a decrease in the estimate of natural mortality from 0.15 to 0.09. The 1990 sablefish assessment (Methot and Hightower 1990) explicitly modeled stock structure with a northern population (U.S. Vancouver and Columbia INPFC areas) and a southern population (Eureka, Monterey, and Conception INPFC areas). This change was motivated by differences in area growth rates as well as the perception that migration rates were low. It also allowed for slope survey data from only the northern area to be more readily compared with model results.

In the 1992 sablefish assessment (Methot 1992) reverted to a single stock area. However, the Conception INPFC area was not included in the analysis. The 1992 assessment utilized slope trawl survey data explicitly, extrapolating the estimates to the entire assessment area (Monterey through U.S. Vancouver INPFC areas). The assessment focused on exploring the trade-off in fitting the slope trawl survey biomass and the trend from the pot survey. Analysis of depth stratified age- and length-composition data suggested that the movement of sablefish into deep water was more closely related to their age than size. The 1994 sablefish assessment was similar to the 1992 analysis. The slope trawl survey was used as absolute measures of biomass after extrapolation to the coast-wide level. The 1997 assessment added catch-per-unit-effort (CPUE) generated along with existing survey indices. No single model was found that fit all indices well. The assessment in 1998 again focused on the inclusion and exclusion of the pot survey index and the use of commercial logbook CPUE as an index.

The 2001 assessment (Schirripa and Methot 2001) focused on evaluating the sensitivity of the results to treatment of the survey data and trade-offs among pot survey and logbook indices of abundance. This assessment was the first to introduce the possibility that sablefish recruitment may be linked to environmental factors. The 2002 assessment (Schirripa 2002) was an update to the 2001 analysis, and therefore focused mainly on newly available data from existing sources. It was the first assessment to detect the relatively strong incoming cohorts from 1999 and 2000 present in the 2001 data, following ten years of below average recruitment. A significant relationship between recruitment and sea surface height was identified.

In 2005 (Schirripa and Colbert 2005) several important changes were made to the sablefish assessment. Landings (and the modeled time-period) were extended back to the year 1900. Trawl surveys were allowed to have separate selectivity curves and slope survey years of limited geographic coverage were removed from the model. Discard data from the relatively new observer program were included and discard mortality was investigated (as described above). Sea surface height was used as an explicit offset to expected recruitment.

The 2007 (Schirripa 2007) assessment extended the available data series and adjusted the treatment of the environmental index of recruitment to be an index, and therefore subject to observation error, rather than an offset to recruitment. The assessment made the explicit assumption that catchability for the NWFSC trawl survey (which was, at the time extended from 1998-2006 by separating and modeling separately the shelf depths) was equal to a value of 0.56. Uncertainty was investigated and reported primarily through alternate values for catchability. Further details of this stock assessment model are described below, in conjunction with changes made for the 2011(Stewart et al. 2011) stock assessment.

The 2011 stock assessment put in a considerable amount of effort to reduce the number of parameters used to model fishery dynamics. First, historical management actions included in the model were condensed to those that had a strong influence on fishery behavior (sorting and retention, selectivity, or both). Second, previously fixed leading parameters, including natural mortality and trawl survey catchability, were estimated, leading to a much more realistic perception of the uncertainty around stock size estimates. Model complexity, particularly with regard to the estimation of a large number of deviations about annual growth and annual selectivity curves, was substantially reduced, with the net effect that uncertainty in the aggregate results was realistically increased. The sensitivity of model results to these parameters and steepness (estimated prior to 2011) was investigated via likelihood profiles. Additional sensitivity analyses were performed for the remaining fixed parameters, such as the maturity schedule, discard rates and ageing imprecision.

Estimation of catchability for the trawl survey was facilitated by only including sampled geographic strata. Included strata consisted of depths from 55-1,280 m, from the Canadian to the Mexican border. The time-series required no extrapolation and provided a relatively precise and highly informative (regarding trend) time-series.

In aggregate these assessments have largely drawn the same conclusions regarding historical trends: that the sablefish resource declined rapidly due to low recruitment and high fishing intensity during 1970s and 1980s (Figure 51). There is a considerable amount of retrospective uncertainty regarding the absolute scale of the sablefish population, and there has also been a general pattern of each subsequent assessment tending to be slightly more optimistic than those before.

### 2.4.2 Response to STAR Panel recommendations in 2011

The STAR panel report from 2011 identified a number of recommendations for future assessments. Although all these recommendations could not be addressed for 2015, progress on each is summarized below:

1. *Complete and review the Washington catch reconstruction and review the California and Oregon catch reconstructions. The accuracy and wide availability of consistent basic information is essential to the development of Pacific coast assessments. In addition to the raw data, the reliability and availability of more spatially dis-aggregated forms of the data should be investigated to determine if they could be used to develop more spatially or temporally explicit models without causing sacrifices in accuracy.*

   Work within the PFMC is ongoing with regard to historical catch reconstruction. In particular, WDFW has contracted with Dr. Ray Conser to perform a historical reconstruction for Washington, but this information was not available for the 2015 assessment update. Thus, catches from historical catch reconstructions are the same as was used in the 2011 assessment.

2. *Include in future versions of Stock Synthesis the capability to explore alternative error distribution assumptions for compositional data. Currently the multinomial distribution is the only type of error distribution available in Stock Synthesis for length or age information. It appears that this may*

*have some impact with respect to underestimating strong year-classes. It would be helpful to be able to explore alternative error assumptions in order to analyse composition information, in particular where the effective sample size estimates (which control the variance in the composition data) may be related to perceived stock abundance.*

It is well known that the multinomial likelihood does not account for overdispersion nor allows for correlation among adjacent categories. Work is currently being conducted by Dave Fournier, James Ianelli, and Steve Martel to include an alternative to the multinomial in ADMB. When the alternative will be available in Stock Synthesis is unknown. Thus, for this assessment update, no work was performed with respect to investigating a more appropriate error structure for composition data.

3. *Develop guidelines for use of the Lorenzen model for age-dependent natural mortality. The panel investigated the use of age dependent M in both the Dover sole and sablefish assessments. In each case one of the reasons for exploring different mortality schedules was the potential imbalance between the genders in the age- and length composition information, either in the sex ratio at older ages (Dover sole) or in the ratio of young to old fish (Sablefish). The use of the Lorenzen M model, which is based on a decline in M with age by the inverse of the growth rate, implies a link with size-based predation. However, with likely wider use of this model feature there should be development of some guidance on the appropriateness of the implementation in other stock assessments.*

   It is unclear how to scale the Lorenzen curve to the appropriate magnitude for a given species. In practice, data are often too noisy or the contrast in fishing mortality is too little to precisely estimate age-specific natural mortality. Before age-specific natural mortality is investigated within the sablefish stock assessment, a significant effort should be put forward using a simulation framework to properly characterize best practices on how to implement a Lorenzen curve within Stock Synthesis.

4. *Conduct new studies of maturity by length and age based on more comprehensive coastwide and depth-based sampling and using histological techniques for determining maturity stage. Given that there is uncertainty regarding the temporal stability of maturity schedules, there should be periodic monitoring to explore for changes in maturity.*

   A recent study by Head et al. (2014) provided new estimates of critical life- history parameters for sablefish based on data specific to the U.S. west coast. Specifically, length and age at maturity was investigated for 477 female sablefish on both a coast-wide and regional level. Age at 50% maturity decreased going south to north and perhaps more importantly was estimated at a value smaller than what was previously included in sensitivity analyses regarding sablefish maturity parameters. Furthermore, the estimated slope of the maturity curve (-0.44) was less than any previously reported value. The new estimates were investigated via sensitivity analyses (see below).

5. *Modify the Stock Synthesis code to allow changes to the plus-group age. The Panel found it very helpful to be able to modify the plus-group in the age-composition data to investigate the influence of old versus young age composition data. This feature could also be used to explore the influence of aging errors. The current version of SS requires restructuring of the input data if the plus-group is changed.*

   It was outside of the scope of this analysis to modify Stock Synthesis.

6. *Further investigate potential inaccuracy in using maximum likelihood estimates and the normal distribution to approximate confidence limits for estimates of spawning biomass. The current assessments measures of uncertainty in spawning biomass are based on the assumption that the errors can be adequately approximated by normal distributions. The current model for sablefish is sufficiently simple that it may be feasible to conduct a full Bayesian analysis of uncertainty. There is concern that asymmetries in the error distributions, which the normal distribution cannot account for, may be creating a biased view of stock status.*

   Although Stock Synthesis can operate using Monte Carlo Markov Chain methods, this was not done here. Instead, methods followed previous assessments and a sequence of Stock Synthesis runs were performed across a range of fixed values for several of the leading fixed parameters. Likelihood profiles are provided later in this document.

7. *Conduct new studies on maturity and age-reading error. A major uncertainty in the sablefish assessment relates to the maturity schedule and in age determination. Better maturity and age-at-length data could reduce uncertainty and help resolve issues of cohort size.*

   Major efforts were put in place to age backlogged samples, but no additional studies were performed with respect to age-reading error. For updated regarding maturity please reference (4) from above.

## 2.5 Model description

### 2.5.1 Link from the 2011 to the 2015 assessment model

This stock assessment is an update of the 2011 sablefish assessment and therefore heavily relies the previous framework, using the same data streams and general data analysis methods, structural choices, and assumptions as in that assessment. This assessment update did, however, make use of the most recent version of the Stock Synthesis modeling platform (3.24u, released 29 August, 2014; Figure 99) and generalized code provided by the NWFSC to work up survey and fishery composition data that was previously unavailable. The following list (in general order of magnitude of influence on model results) documents the most important changes and a brief rationale for each (Figure 100):

1. Utilize standardized code to generate fishery length- and age-composition data. **Rationale**: Newly available data from the fishery (2011-2014 and previously un-aged historical samples) were included in the fishery length- and age-compositions provided to SS. In addition to including new data, the compositions were created from the raw data using standardized code (Andi Stephens, personal communication). The standardized code uses the same general method as was used in 2011, but is more consistent across fleets, particularly with respect to generating the expansion factor. For instance, data from all states were weighted by the expansion factor only utilizing fish with lengths or fish with age rather than both, whereas in the previous assessment, across states, it was inconsistent how this was done. Additionally, a sex-specific weight-length relationship was used to generate the expansion factor for sexed-fish rather than only utilizing the relationship from unsexed fish. This assessment update uses the number of tows as an input sample size, which is the same method as the previous assessment, although the text referenced number of trips, which was inconsistent with the data files input into SS.

2. Revise the delta-GLMM used in 2011 to create the NWFSC Shelf-Slope survey index of abundance, which previously included vessel-specific differences in catchability utilizing a gamma error structure. As well as include four additional years of data (2011-2014). **Rationale**: The delta-GLMM method used here facilitates the use of interactions between fixed and random effects, is consistent with other groundfish stock assessments, and was reviewed and endorsed by the PFMCs Scientific and Statistical Committee. An interaction between vessel and year was included because vessels used for the survey are not consistent across years and are instead selected from all possible commercial vessels via an open-bid sampling contract (Helser et al. 2004). Furthermore, vessels may change characteristics over time that lead to temporal changes in catchability, which could not be accounted for with the previous framework. Furthermore, the newly available delta-GLMM method can account for spatial and spatiotemporal variation through the use of Gaussian Markov random fields. Including a spatial component in the index of abundance for sablefish is ideal as they are caught throughout the depth and geographic range of the survey and calculation of the relative biomass in the southern area is of particular interest to management. The previously used delta-GLMM did not include a spatial component and extrapolation of survey results in un-sampled areas was an issue. Five delta-GLMM models were compared and the model with the structure most similar to that used in 2011 (Model 3) was used for this assessment, even though it did not provide the best fit.

3. Implemented a time block for retention of older, large fish for the trawl

fishery to match the implementation of the catch share program. **Rationale**: Discarding is prohibited within the catch share program, thus the retention parameter for the trawl fishery was updated accordingly.

4. Tune $\sigma_r$, and update the relative bias correction over modeled time-periods to be consistent with the degree of estimated recruitment variability. **Rationale**: Recent simulation work has shown that utilizing the bias adjustment routine within SS facilitates that the estimated log-normally distributed recruitments are mean unbiased, which leads to mean unbiased estimates of biomass and unbiased parameter estimates (Methot et al. 2011). The most recent data (2011-2014) on recruitment variability was included in the bias adjustment calculation, and thus data on recruitment in 2011-2013 were included in the bias adjustment calculation, though the maximum bias adjustment did not change appreciably. With the most updated data and bias adjustment correction the RMSE of recruitment deviations was less than the input value for $\sigma_R$, thus the input value was decreased to better match the derived value generated by SS.

5. Utilize standardized code to generate survey length- and age-composition data. **Rationale**: Newly available data from the NWFSC Shelf-Slope survey (2011-2014 and previously un-aged historical samples) were included in the fishery length- and age-compositions provided to SS. In addition to including new data, the compositions were created from the raw data using standardized code (www.github.com/nwfsc-assess/nwfscSurvey). The code was developed for use by scientists at the NWFSC and is intended to increase the reproducibility of survey composition data and increase the use of standardized methods across assessments. Additionally, sex-specific rather than un-sexed marginal age-compositions were included for the surveys. Fits to these data are provided for evaluation only (mentioned here for completeness), but not included in the model likelihood.

6. Update the W-L relationship. **Rationale**: The weight-length relationship is input as fixed parameters in SS and must be determined externally, and was therefore calculated using survey data in the R software environment. The previous assessment used both fishery and survey information to calculate the weight-length relationship. Here, only survey data was used, to minimize the effect of selectivity inherent in fishery-dependent data. The change in parameter estimates proved trivially small.

7. Upgrade to the newest version of SS. **Rationale**: This is standard practice to capitalize on newly developed features, corrections to older versions of the code and increases in computational efficiency. Model results were nearly identical before and after this change. Changes to the input data facilitating using the newest version of SS included changing the ballpark year used for estimating fishing mortality off, whereas before it was initially included in the likelihood only to be later removed, and changing how composition data that are not to be included in the likelihood are entered into the data file.

Despite the very large number of changes made to data sources and model configuration, the results of this assessment (see below) are generally consistent with those from previous analyses in terms of the general trend over the last several decades. The biggest difference is the absolute scale of the total stock abundance, along with the estimated size of some recruitments.

### 2.5.2 Summary of fleets

Fishery removals were divided among three fleets, identical to those used in 2011: 1) the pot fishery, 2) the hook-and-line fishery, and 3) the trawl fishery. Selectivity and retention schedules are treated separately for each fleet. Furthermore, each trawl survey is treated as a separate fleet with independently estimated selectivity and catchability parameters reflecting differences in depth and latitudinal coverage, design, methods, and equipment among them.

### 2.5.3 Modeling software

This assessment used the Stock Synthesis modeling framework written by Dr. Richard Methot at the NWFSC. The most recent version (3.24u, released 29 August, 2014) was used, because it included many improvements and corrections to older versions used during the 2011 and earlier assessments.

### 2.5.4 Priors

Uniform priors (which are intended to be noninformative) were applied to all estimated parameters in the base-case model with only three exceptions: male and female natural mortality (described in section 2.2.4 above), and steepness, described below. Parameter bounds were selected to be sufficiently wide to avoid truncating the searching procedure during maximum likelihood estimation. A list of parameter bounds and priors are provided in this document (Table 17).

In addition to the priors for natural mortality, an (infinitely) informative prior (fixed at 0.6) for stock-recruitment steepness ($h$) is used for the base-case model. This assessment, like many, has had trouble with unreasonably low steepness estimates in previous iterations, likely due to the one-way trip nature of the time-series and the high degree of confounding between population scale (via equilibrium recruitment), mortality, and steepness. Further, much of the perceived information about steepness was likely derived from the rigid assumption of production-model dynamics (no historical recruitment deviations) in models previous to 2011. Estimation in this assessment led to unreasonably low estimates (at or near 0.20). Values in the range of 0.2 are considered to be ecologically implausible given the theoretical work of He et al. (2006). Even using a prior that approximated the probability distribution from that work, given natural mortality and recruitment variability values from this assessment (Figure 61), produced extremely low parameter estimates (see sensitivity analyses below). The use of a fixed value grossly underestimates the uncertainty in $MSY$ and equilibrium yield, however, since both and $F$ and $SB_{proxy}$ are used for management the importance of this is somewhat reduced. A likelihood profile and summary of the implications of the parameter range for steepness revealed that uncertainty from this source was well inside the global estimation uncertainty captured via the asymptotic intervals about the maximum likelihood estimates.

### 2.5.5 Sample weighting

The approach to sample weighting used here attempts to achieve consistency between the degree of uncertainty in each data set and the models ability to fit those data. Variances and sample sizes were first derived from the raw data sources. Variances and sample sizes were then iteratively re-weighted to ensure consistency between the input sample sizes (or standard errors) and the effective sample sizes (and root-mean-squared-errors) based on model fit. This approach attempts to reduce the potential for particular data sources to have a disproportionate effect of total model fit, while creating estimates of uncertainty that are commensurate with the uncertainty inherent in the input data. Iterative re-weighting was applied to the length data, starting from a conservative metric of sample size (the number of tows sampled), and then multiplying the year-specific input sample sizes by a single constant for each data set that made the mean input sample size for compositional data roughly equal to the harmonic mean effective sample size based on model fit. The same method was applied to the age data. For both types of data, the input sample sizes were not further increased; thus they were considered to be minimum estimates of the true variance. Variance estimates for discard ratio data were estimated via an additive component to the input standard error in log-space. This achieves the same result as iterative reweighting and has the additional benefit that it propagates the weighting uncertainty into the model results. These choices reflect the post-hoc nature of model tuning and generally avoid the potential for increasing weight on those data sources that are consistent with model predictions, thereby reducing the perceived uncertainty in model results. Added variances for mean body weight were set to zero for the base-model of this assessment.

Generally composition data was down-weighted in an intuitive fashion, given a reasonable degree of clustering in the underlying population, which can make individual tows not completely independent (Table 18). However, the exception seemed to be the AFSC slope survey age data, for which the weighting was substantially reduced, largely due to a few outlying observations (see model results below). Additional variance components could be added to the hook and line fleet with respect to mean body weight, though the remaining fleets appear to fit the data well without any additional variance (Table 19).

As described above, the variance estimates from design-based or GLMM-based survey index analyses can be reasonably considered minimum estimates at best. For this assessment an additive constant was freely estimated for each survey. Estimating the additional variance components speeds the process of iterative reweighting among data sources and propagates the uncertainty about the true survey index variance into the model results. Estimated values appear to be within expected ranges, except for the NWFSC Shelf-Slope bottom trawl survey, for which the estimated added variance was negative. Instead of decreasing the variance for this index, the added variance parameter was fixed at zero.

### 2.5.6 General model specifications

Stock synthesis has a broad suite of structural options available for each application. There are no true default settings for most of these options; each application must be customized to best represent the life-history, dynamics, data-complexity, and estimation approach (Bayesian or maximum likelihood) most appropriate.

This assessment is structured to be sex-specific, including separate growth curves for males and females, and therefore tracking the spawning biomass of only females for use in calculating management quantities. Growth parameters describing the von Bertalanffy growth equation, as well as the spread of lengths for a given age, were estimated for each sex, except that the length and spread of length at age-1 was forced to be identical for males and females. The parameterization used by Stock Synthesis allows the user to specify the age for the two growth parameters (rather than the length at age zero and the implied length at infinite age). Ages 0.5 and 30 were selected to be close to the range of observed data. Based on an analysis done in 2011, the choice of age has little effect on estimated growth curves. A list of the growth parameters, bounds, and priors is given in Table 17. Natural mortality was estimated, with the informative priors described above, for each sex, based on the a priori evidence that it might differ for males and females.

For the internal population dynamics, ages 0-50 are individually tracked, with the accumulator age of 50 determining when the plus-group calculations are applied. This is a relatively large age, but was necessary to ensure that little growth would be predicted to occur (but not be modeled) at and beyond this age, because SS does not allow growth to continue in the plus-group.

Recruitment dynamics are governed by a Beverton-Holt stock-recruit function. This relationship is parameterized to include two estimated quantities: the log of unexploited equilibrium recruitment ($R0$) and steepness ($h$). A full time-series of recruitment deviations, including the initial age-structure in 1900 are estimated to adequately propagate uncertainty in the historical period and avoid imparting the perception of information through 'overly rigid' conditions prior to the most recent and informed time-period.

No seasons are used to structure removals or biological predictions, thus data collection is assumed to be relatively continuous throughout the year. Fishery removals occur instantaneously at the mid-point of each year and recruitment on the 1st of January. The sex-ratio at birth is fixed at 1:1, although sex-specific natural mortality, and selectivity, can result in significant departure from equality due to differential mortality over age and sex.

### 2.5.7 Estimated and fixed parameters

A full list of all estimated parameters and values for key fixed parameters is provided in Table 17.

Selectivity curves for the fishing fleets were modeled as being age-based using a cubic spline over age with an offset for male vs. female selectivity. This choice, made in 2011, was motivated by the desire to substantially reduce the complexity of previous approaches which utilized both age- and length-based selectivity schedules to capture the relatively complex interactions created by the combination of dimorphic growth and age-based ontogenetic movement out of the heavily fished areas. Further complicating any a priori expectation of a more parametric shape to selectivity curves is the fact that each modeled fleet represents the amalgamation of several distinct fisheries operating at different depths and in different areas, quite plausibly resulting in realized selectivity curves that are multi-modal. Briefly, the cubic spline function requires specification of n nodes spread over ages captured by each fishery. The parameterization then estimates a starting and ending gradient and a selectivity value at each node, using a smoothing function to connect the nodes. The smoothing function dramatically reduces the influence of exactly where each node is located (these are parameters but cannot be reliably estimated). In 2011, an iterative approach was taken to node choice, adding, removing and moving selectivity nodes, until the derived selectivity schedule became largely stationary, and the parameter correlations were generally not greater than 80%. Although the choice of updated nodes was investigated for this assessment, the results were similar to the base-model and thus the same nodes were used. A simple two-parameter offset for male relative to female selectivity was also estimated for each fishery. This approach included one estimated parameter describing the relative selectivity for males near the peak of the selectivity curve and another the offset at the maximum age. This allows for differences in both overall scale across ages and in the relative selectivity of older fish between the sexes.

Time blocks for fishery selectivity and retention schedules were based on previous research with respect influential management 'milestones' and the recent introduction of catch shares within the trawl fishery. 'Milestones' included are: full retention of age-1+ sablefish during WWII; introduction of trip-limit induced discarding (not just size-sorting) for the trawl fleet in 1982 and for fixed-gear fleets in 1997; a change in selectivity in 2003 resulting from large scale movements of all fleets in response to large spatial closures (Rockfish Conservation Areas; RCAs), and full retention of older, marketable sablefish within the trawl fishery with the implementation of the catch share program. To allow selectivity to shift in 2003 for each fishery, the two parameter values at nodes near the peak of each selectivity curve were estimated independently for each time period. Fishery retention schedules were estimated via a logistic curve defined by an inflection, slope, and asymptote. To accommodate the temporal changes in retention identified above, the asymptote, parameters were fixed to be equal to 1.0 prior to 1982 and after 2010 for the trawl fishery and prior to 1997 for the fixed-gear fisheries. The inflection parameter was fixed at 25 cm for all fleets during WWII, implying retention of all fish greater than age-0.

For fish not estimated to have been retained, fishery discard mortality was assumed to be equal to 100% for age-0 sablefish less than 28 cm and then to decline rapidly to 20% for the hook-and- line and pot fisheries and 50% for the trawl fishery (for 29 cm and above, while splitting the difference at 28 cm (i.e., 60% for fixed gear and 75% for trawl)). This is consistent with the values used by the PFMC for management purposes.

Survey selectivity also follows the simplified method adopted in 2011, utilizing a double normal parameterization, which allows for an initial selectivity at age-0, an ascending slope, a peak and width of the peak, a descending slope, and a selectivity at the oldest age. The double normal allows for dome-shaped selectivity within the surveys accommodating the knowledge that the surveys do not extend into the deepest water inhabited by sablefish (nor do the fisheries for that matter).

As expected, surveys covering the shelf depths captured a large fraction of age-0 and age-1 sablefish, and most of the catch was comprised of sablefish less than 10 years old, with relatively low selectivity for older individuals. Since the surveys covering shelf depths (NWFSC shelf- slope and AFSC Triennial shelf) surveys showed a peak selectivity at very young ages ($\sim$1.5 years) it was redundant to estimate the ascending width parameters in addition to the initial selectivity values; these were therefore fixed at reasonable values. Sharply dome-shaped curves made estimation of the width parameters also redundant (estimates always returned to the lower bound in preliminary modeling conducted in 2011).

In total for the base-case model there were 12 growth, mortality and stock-recruitment parameters, 6 catchability and survey variance parameters (and 3 analytic solutions which could have been treated as estimated parameters), and 48 estimated parameters describing selectivity and retention schedules.

## 2.6 Model selection and evaluation

### 2.6.1 Key assumptions and structural choices

All structural choices for stock assessment models are likely to be important under some circumstances. In the 2011 assessment, and therefore in this update, these choices are generally made to 1) be as objective as possible, and 2) follow generally accepted methods of approaching similar models and data. The most important source of structural uncertainty in this assessment is the fixed value used for steepness (discussed above) and its importance is investigated via sensitivity analysis.

The use of a static (but sex-specific) estimated value for natural mortality over time and age is also a very important assumption. In reality, natural mortality is quite likely to vary over time (and possibly space) and may be non-stationary, where predation or environmental factors have directional instead of random effects on survival during the modeled period. However this degree of complexity is clearly beyond the information content of the available data.

Growth is also assumed to be time- and space-invariant, which does produce some residual patterns in the length data, reflecting slightly different growth trajectories among some cohorts. Sablefish in U.S. waters do not exist independently of the portion of the total population occurring in British Columbian and Alaskan waters to the north. The degree to which recruitment linkages and adult movement may be contributing to the observed dynamics of the stock off the west coast is unknown. Potential shifts in spatial distribution in response to changes in density outside our waters or climate change could substantially reduce our ability to model and predict current and future trends.

### 2.6.2 Convergence status

To test for convergence prior to the STAR review, 100 trials were performed using a jitter value (Methot 2009) of 0.1 for the base-case model. This perturbs the initial values used for minimization with the intention of causing the search to traverse a broader region of the likelihood surface. All of these trials returned to exactly the same objective function value as in the base-case

## 2.7 Response to SSC recommendations

If the SSC determines that additional analysis is warranted, this work will be completed subsequent to the September 2015 PFMC meeting.

## 2.8 Base-Case model results

The biological (growth and mortality) parameters estimated from the base-case and alternate models appear to be reasonable, relatively precise and very consistent with those from previous sablefish stock assessments (Table 20) and commensurate with inspection of the raw data. Female and male sablefish showed similar rapid growth trajectories; with females growing to a slightly larger size at age 30 (64.151 cm) than males (56.282 cm) and showing a broader distribution of length at a given age (Figure 62). The estimated natural mortality rates for females (0.076) and males (0.061) were very close to the value used in previous assessments (0.08 and 0.065 respectively).

Estimated selectivity curves for the trawl surveys were broadly similar, with the NWFSC Shelf-Slope survey sampling the broadest demographic portion of the sablefish population, and the AFSC shelf survey the most limited (Figure 63). The hook-and-line fishery showed a bimodal selectivity curve in the early years, somewhat reduced after 2003; males were roughly half as selected as females and individuals beyond ages 10-15 were much less available to the fishery on a relative basis (Figure 64). The pot fishery showed a similar pattern, and a shift to slightly older fish in 2003 (Figure 64). The trawl fishery is estimated to select far more younger sablefish, and showed much less difference between males and females and after 2003 (Figure 64). Retention schedules showed rapidly increasing retention of age-1 fish for the hook-and-line fishery and a maximum of 87% retention of the largest individuals (Figure 65). The pot fishery estimates suggested far more sorting out of small sablefish and full retention of the largest individuals (%, Figure 66). Full retention of the largest individuals is assumed since 2011 for the trawl fishery (Figure 67). Estimated values and confidence intervals for selectivity and retention parameters are provided in Table 21.

The base-case model fit the trend (decline then stabilization) in the NWFSC Shelf-Slope survey extremely well (Figure 69), such that the added increase in the log standard deviation was turned off during the tuning phase of the base-model. Fit to the NWFSC slope and AFSC slope surveys was generally flat (Figure 70, Figure 71), as might be expected for such short time-series even with relatively low extra SD estimates of and (Table 21) respectively. With the offset estimate for the AFSC Triennial shelf survey beginning in 1995, predicted survey values are also relatively flat over this period (Figure 72), although the estimated extra SD of suggests a relatively poorer fit to these data than those from other surveys. Catchability values for the most fully selected ages (~1.5-4 years old) in each survey ranged from 0.32726 (early AFSC Triennial shelf survey) to 0.891818 (NWFSC Shelf-Slope).

The base-case model fit the aggregate length distributions from trawl surveys reasonably well (Figure 73). The best fits were to the NWFSC survey length-frequency data (Figure 74), with residual patterns (Figure 75) primarily generated through small mismatches in the model structure, likely due differences in growth, environmental conditions, or timing rather than misspecification of year-classes. The fit to the NWFSC slope survey did not capture the modes for female sablefish particularly well or the mode for males in 2001. Unsurprisingly, the survey failed to pick up the strong 1999 year class at age-0 (Figure 76, Figure 77). Fits to AFSC length data were also variable, but the strongest modes for age-0 and age-1 cohorts were captured as well as the mean of the distribution for both males and females (Figure 78, Figure 79). AFSC shelf survey length distributions tended to be variable (likely due to lower sampling intensity), but no obvious residual patterns appeared to be present (Figure 78, Figure 79).

Aggregate fits to the pot and trawl fishery length-frequency distributions, over all years, were very good for the retained catch (Figure 40), and fairly reasonable given noisy data for the discarded catch (Figure 47). The poorest fits were to the retained hook-and-line lengths. A pattern that is consistent with the previous assessment. Annual fits to the hook and line length data showed too few small fish predicted in the retained catch (Figure 41, Figure 42), perhaps because these fish were observed in the discarded catch (Figure 48, Figure 49). Fits to the retained lengths for the pot fishery showed some residual patterns through time (Figure 43, Figure 44). Anecdotally, these trends appear to correspond to shifts in the general depth distribution of most of the fishing activity. The biggest residuals in the discard lengths from the pot fishery are a number of age-0 fish from 2006-2007 (Figure 50, Figure 51). The residuals were present in the previous assessment and their source should probably be investigated in the future. With the exception of a few years with very low sample sizes, the fits to the trawl fishery retained-fish length data were very good (Figure 45, Figure 46). As with the other two fleets, fits to the discard lengths from the trawl fleet were quite noisy (Figure 52, Figure 53), though the general pattern appears to be represented.

No obvious patterns were observed in the fit to the NWFSC Shelf-Slope conditional age-at-length data, suggesting that the estimated growth curves represented the data quite well (Figure 22). Although not included in the objective function, the implied fit to the NWFSC marginal age distributions was also very good (Figure 82). The NWFSC slope survey also showed no glaring residual patterns in the age data (Figure 25). The AFSC slope survey showed some large residual fits to the conditional age-at-length data in 1999 and 2000, more so than any other fleet. Additionally, output from the Francis re-weighting method indicates a poor fit to the 1998 data for this fleet. The selection of only the youngest sablefish (but including the full size range) was quite evident for the AFSC shelf survey (Figure 31).

Fits to the aggregate age-frequency distributions for the three fisheries were again best for the trawl fleet and poorest for the hook-and-line fleet (Figure 54). However, except for ages 1-3, the residual patterns for the hook-and- line fishery were reasonable (Figures 55, 56). The fits to the age data for the pot fishery showed some lack of fit to the 1999-2000 cohorts for females (Figure 57, 58), however this pattern was not present for males, which had generally too few older fish in the late 1980s (Figure 57, 58). The trawl ages were fit much better than the other two fleets (Figures 59, 60). Both the hook-and-line and pot fishery mean body weight in the discards were underestimated consistently (Figures 83 and 83); however the trawl observations fit much better (Figure 83). Discard fractions for all three fleets were also fit very well, considering the retention schedules were time- invariant over the period for which data were available (Figures 84, 84, 84).

The deviations about the estimated stock-recruitment function, as expected, had a very large amount of uncertainty prior to the mid-1970s, when the data first become informative about incoming cohort strengths. Therefore the relative bias adjustment was ramped to the maximum value 0.9588 during this period (Figure 85). Sablefish recruitment is estimated to be quite variable over the historical record; however uncertainty in individual recruitment events is large. Within this variability, the average recruitment is estimated to have declined steadily between the 1970s and 2007 (Figure 86). Recruitments during the 1980s were, on average, roughly an order of magnitude higher than the very poor cohorts estimated between 2002 and 2005. It appears that large 1994, 1995, 1999, and 2000 year classes briefly slowed the rate of stock decline in the early 2000s and above-average cohorts from 2008, 2010, and 2013 are currently moving through the population. However, only the 2008 cohort has begun to mature and thus their contribution to the trend in spawning biomass remains minimal. Given a relatively high degree of recruitment variability, the estimated stock-recruit function predicts a wide range of cohort sizes over the observed range of spawning biomass (Figure 87).

The estimated time-series of total, age-4+ (Figure 88) and spawning biomass (Figure 89) track one another very closely (Figure 22). Sablefish are estimated to have been exploited at a modest level through the first half of the 20th century. Following a period of recruitments estimated to have been above average, but highly uncertain, the spawning stock biomass rebounded to nearly unexploited levels in the late 1970s. Large harvests during those years, and throughout the 1980s, are estimated to have caused the stock to decline nearly monotonically to the present. It appears that large 1999 and 2000 year classes briefly slowed the rate of stock decline between 2002 and 2005. Three cohorts from years with above-average recruitment (2008, 2010, and 2013) are currently moving through the population, however they have yet to mature, and therefore are only minorly contributing to the trend in spawning biomass. The relative spawning biomass is estimated to be at only 33% of unexploited levels in 2015; however this value is highly uncertain (Figure 90; ∼95% intervals range from 21-46 %). Although the relative trend in spawning biomass is quite robust to uncertainty in the leading model parameters, the productivity of the stock is highly uncertain due to confounding of mortality, absolute stock size and productivity. The estimated spawning biomass in 2015 is 49,071 mt, however, the ∼95% interval ranges broadly between 25,206-72,936 mt, reflecting little information in the data about absolute stock size. The full matrix of predicted numbers at age by sex is provided in Appendix B.

## 2.9 Uncertainty and sensitivity analysis

The available data for sablefish are largely uninformative about the absolute size and productivity of the stock. This is largely due to the one-way-trip nature of the historical series: a slow and steady decline in spawning biomass consistent with a larger, less productive stock, a smaller more productive stock, or many combinations in between. Historical catches provide some information about the minimum stock size needed to have supported the observed time-series but little information about the upper bounds for the stock size. Likelihood profiles, parameter estimates, and general model behavior illustrate that small changes in many parameters can result in differing point estimates for management reference points, however the uncertainty about these estimates remains large unless leading model parameters, such as natural mortality, survey catchability, as well as historical recruitments, are fixed at arbitrarily selected values. This assessment includes the uncertainty for these unknown quantities, with the exception of steepness. This uncertainty will remain until a more informative time-series and better quality demographic and biological information are accumulated for the stock.

Uncertainty in the properties of current aging methods (both potential bias and imprecision), as well as relatively sparse fishery sampling, result in age data that are less reliable than would be preferred. Similarly, because sablefish grow very rapidly and reach near-asymptotic length in their first decade of life, length-frequency data are not particularly informative about historical patterns in recruitment. The patterns observed in historical sablefish recruitment suggest that stock trajectory (via shifts in recruitment strength) is closely linked to productivity regimes in the California current. Uncertainty in future environmental conditions, changes in the timing, dynamics, and productivity of the California current ecosystem, via climate change, or cycles similar to the historical period, should be considered a significant source of uncertainty in all projections of stock status.

The ongoing NWFSC Shelf-Slope trawl survey is a relatively precise index over a broad demographic component of the sablefish stock (although not the entire stock, as some of it occurs in deep water and is therefore unobserved). This index has the potential to inform future stock assessments about the scale of the sablefish population relative to the catches being removed (assuming these are enumerated reasonably accurately), however such information will require contrast in the observed declining survey trend. Therefore, although there is the potential to considerably reduce the current uncertainty in sablefish stock size and dynamics, it will likely take several years of contrasting trend in the survey to do so.

### 2.9.1 Sensitivity analysis

The results reported in this section are by no means meant to be a comprehensive comparison of all possible aspects of model uncertainty, nor do they reflect even the full range of models considered in developing the base-case. These results are intended to provide more information about relatively obvious questions for any stock assessment such as sensitivity to priors, key structural choices and potential conflict in signal among data sources. The order in which they are presented is not intended to reflect their importance; each run included here provided important information for developing or evaluating the base-case model and alternate states of nature. (More results to come.)

Although it is not frequently investigated, due to the uncertainty in and outdated analyses upon which the maturity schedule is based it seemed appropriate to test the sensitivity of the assessment results to changes in the externally derived relationship. The recent publication of Head, et al. (2014) prompted a reevaluation of sensitivity to female length at 50% maturity. This study estimated length at 50% maturity for females at 54.64 cm. The Head et al. paper also suggested a maturity slope parameter at -0.44, much lower than the previous value of 0.13 (Fujiwara and Hankin, 1988). Results show little difference in fit to the data for length at 50% female maturity or maturity slope values. Length at 50% maturity showed an almost linear scaling effect on spawning biomass values (Figure 93). These results are consistent with the sensitivity analysis on female maturity from the 2011 assessment.

### 2.9.2 Retrospective analysis

A 5-year retrospective analysis was conducted by running the base-case model using data only through 2009 ('5 year'), 2010, 2011, 2012, and 2013 (Figure 92). Little evidence of a retrospective pattern was present. Estimates of spawning biomass from the retrospective runs were slightly lower and less uncertain than estimates from the current assessment update, particularly for 1979 and adjacent years.

### 2.9.3 Parametric bootstrap using Stock Synthesis

There is a built-in option to create bootstrapped data-sets using Stock Synthesis. This feature performs a parametric bootstrap using the error assumptions and sample sizes from the input data to generate new observations about the fitted model expectations. It is therefore not strictly a variance estimation exercise, but an exploration of the question: If the assessment was true, and the same relative quantity and quality of data were available, how reliably could the parameters and derived quantities be re-estimated? There was insufficient time to use this powerful diagnostic tool for this assessment, but it should be considered a standard method for full assessments where time permits. Its use is particularly important for cases where the asymptotic (or posterior) intervals about model estimates are used as the primary representation of uncertainty.

# 3 Reference points

The coast-wide abundance of sablefish was estimated to have dropped below the $SB_{40}\%$ management target between 2009 and 2010 and is currently declining. The cause of this trend appears to be primarily due to relatively poor recruitments, as the fishing intensity remained below relative SPR target rates between 1988 and 2008 (Figure 94). Although the estimated productivity and absolute scale of the stock are very poorly informed by the available data and are therefore highly sensitive to changes in model structure and treatment of data, all sensitivity or alternate models evaluated showed a current declining trend in biomass and increasing trend in fishing mortality. Relative SPR exceeded $\text{SPR}_{45\%}$ in 2009-20012, but for 2013-2014 has been at about 85% of $\text{SPR}_{45\%}$.

Unfished female spawning biomass was estimated to be 147,209 mt, but this value is highly uncertain (~95% interval: 113,472-180,946 mt). The management target stock size ($SB_{40\%}$) is therefore 58,884 mt, and the overfished threshold ($SB_{25\%}$) is 36,802 mt. Total and age-4+ biomass at unexploited equilibrium were estimated to be 432,047 and 405,032 mt respectively. Because the steepness parameter is not estimated in this assessment, the uncertainty in equilibrium yields at the following reference points is grossly underestimated. Maximum sustained yield ($MSY$), conditioned on current fishery selectivity and allocations, was estimated to occur at a spawning stock biomass of 43,149 mt and produce a dead MSY catch (excluding discarded fish that are predicted to have survived) of 7,639 mt (Figure 97). However, the yield at MSY varies almost linearly with the value for steepness. Maximum sustainable yield is estimated to be achieved at an SPR of 0%. This is very close to the yield, 7,290 mt, generated by the SPR (50%) that stabilizes the stock at the $SB_{40\%}$ target. The fishing mortality target/overfishing level (SPR = 45%) results in an intermediate equilibrium yield of 7,290 mt at a spawning biomass of 50,051 mt ( 34% of the unfished level).

Although the estimated productivity and absolute scale of the stock are very poorly informed by the available data and are therefore highly sensitive to changes in model structure and treatment of data, all sensitivity or alternate models evaluated showed a current declining trend in biomass and increasing trend in fishing mortality.

# 4 Harvest projections and decision tables

The forecast reported here is based on application of the '40-10' harvest control rule and the $F_{45\%}$ overfishing limit/target (OFL). In addition, a reduction to the OFL of 8.7% was applied representing the application of a P* of 0.40 and the Category 1 stock proxy uncertainty $\sigma$ of 0.36 (but without applying an additional buffer for management uncertainty). These values reflect the PFMC decisions made during the November 2011 meeting.

This projection is intended to provide a 'yardstick' with which to gauge the likely trajectory of the stock. Projections assume the ACLs of 7,173 and 7,784 mt are achieved exactly in 2015 and 2016. Catch allocation used for the forecast reflects the average distribution of fishing intensity among fleets (hook-and-line, pot, and trawl) during 2012-2013 and it is also assumed that discarding and retention behavior does not differ from recent years.

Current forecasts predict a slow increase in the spawning stock, with a relatively large probability that the stock will remain below the tarrget spawning biomass for several more years as the 2008, 2010, and 2013 cohorts fully mature (Table 24). Projected increases beyond 2014 are small and reliant upon expected recruitment levels from the stock-recruitment relationship, despite many recent years of below average recruitment. Forecast values are highly uncertain, and given this uncertainty, and the number of years the stock is projected to remain at low levels, it is still possible that the stock will be assessed to be below the overfished threshold during the next several cycles. However, additional trawl survey observations may help to better inform the estimate of the 2008 cohort size. The full implications of this uncertainty can be best evaluated in the decision table.

The decision table reports 12-year projections for alternate states of nature (columns) and management options (rows) beginning in 2017. The results of this table are conditioned on the already-specified ACLs for 2015 and 2016 being achieved exactly. It is common to select an axis of uncertainty from leading parameters, model structure or historical catch levels, to best bracket the range of possible states of nature. For this assessment, due to the explicit inclusion of uncertainty in natural mortality, survey catchability and scale of the stock-recruit function, asymptotic intervals are very broad. Steepness was evaluated as a possible axis of uncertainty, but even a broad range (from 0.3-0.9) under-represented the forecast uncertainty relative to that implied by the parameter uncertainty already included. Therefore, the percentiles of the asymptotic distribution are used to describe the relative probabilities among the states of nature. Low and high columns are based on the 12th, and 87.5th percentiles of the distribution about the maximum likelihood estimates for: depletion, relative SPR (in reverse order to match depletion; i.e., larger values implying greater relative fishing intensity are reported first) and spawning biomass from the base-case model. Catch allocation used for the forecast reflects the average distribution of fishing intensity among fleets (hook-and-line, pot, and commercial) during 2007-2009.

The decision table results show that there is a relatively large probability (>25%) that the stock is already overfished (Table 9). Further, given any status much below the estimated current spawning biomass, the stock is not projected to increase appreciably over the duration of these forecasts, even under harvest alternatives that are much lower than current ACLs. However, if the stock is actually above current estimates, it is projected to increase over all harvest alternatives.

# 5 Regional management considerations

Recent sablefish management has relied upon allocations north and south of an arbitrary line at 36°N. Although this does not likely correspond to any meaningful biological boundary, it has led to an increased interest in the fraction of the coast-wide stock that is present to the south of this line. This assessment update cannot explicitly estimate this fraction, however an approximation can be generated using an analysis of recent NWFSC survey catches north and south of Point Conception (the closest survey stratification line to the management break) to aid managers in evaluating relevant decisions. Because the NWFSC survey is estimated to have non-uniform (and quite dome-shaped) selectivity, these results should be interpreted with caution, as they only represent the relative distribution of the sablefish population observed by the survey, not the entire population.

The total biomass over the entire surveyed time-period (2003-2014) has been distributed 10.11% over the shelf north of Point Conception, 74.80% over the slope north of Point Conception, and 15.09% over the slope south of Point Conception (Figure 98). In the previous assessment, 16.2% of the biomass was found south of Point Conception and 83.8% to the north. The decrease in biomass south of Point Conception runs counter to the previously observed increasing trend in the southern biomass despite a declining trend in survey abundance over the entire coast.

Use of an average ratio for management purposes requires that the relative distribution of sablefish biomass along the coast has not changed appreciably over the period from which the average was created. The strata used to create the delta-GLMM-based index of abundance show that the spatial distribution appears to be relatively stable, particularly starting in 2008 until the present, with no dramatic changes in relative distribution (Figure 98).

# 6 Research needs

The following research could improve the ability of this assessment to reliably model sablefish population dynamics in the future:

1. Continue the annual NWFSC Shelf-Slope trawl survey time-series. Future improvements in the precision of estimates of absolute stock size and productivity are reliant upon observing some contrast in stock trend (other than a one-way trip) with an unbroken survey index. Only a longer, more informative survey time-series will provide stock-specific and data-based information on the steepness parameter governing the sablefish stock and recruitment relationship.

2. Investigate aging methods that could prove more precise than current break-and-burn methods. If age data were more accurate, cohorts could be better tracked to older ages and estimates of historical year-class strengths may be improved. Further studies to investigate the potential for bias in aging methods should be conducted; these results will have a strong effect on natural mortality estimates.

3. Evaluate potential causes of residual patterns in the fit to larger cohorts in the age data (particularly the 1999 and 2000 cohorts) and for residual patterns in the fit to the size data.

4. Model results were quite sensitive to changes in the maturity schedule, yet the available information is very outdated, in addition to being variable among sources, years, and regions. The routine collection of samples to refine estimates of biological parameters, particularly maturity and fecundity, would greatly benefit the reliability of this assessment.

5. Age sampling from the commercial fishery has generally been sparse compared to other groundfish and relative to the importance of this stock to west coast fisheries. Work toward further standardization of state and federal biological sampling programs would make data more informative, by reducing sampling variability. For example, during most of the last 30 years at least one state has collected sexed-length observations, while at least one has not. If an increased fraction of both the catch was available for sampling at-sea, or in-port in a non-dressed form, then more consistent demographic information could result.

6. Continued refinement of the historical landings estimates for Washington, subsequent to the large data entry of historical fish-ticket information currently underway, will likely produce a more accurate time-series of mortality and would complement the completed efforts to reconstruct California and Oregon landings.

7. Given the migratory nature and broad distribution of sablefish along the Pacific Rim, it is important to continue to evaluate the spatial aspects of

the assessments, including the northern boundary with Canada, and the connectivity with offshore seamounts. A joint assessment with Canadian and Alaskan scientists could be warranted, following the approach taken by the International Pacific Halibut Commission.

8. Continue to evaluate methods to capture information regarding environmental and ecosystem variability in stock assessments. Further, historical records of particularly large year classes (e.g., 1947 reported by sport fishermen in central California) could be investigated to better inform the historical period.

9. There is uncertainty in the accuracy of the dressed to whole weight conversions used in some situations to estimate fishery landings. Following Oregons lead, this topic should be investigated, and total landed catch estimates adjusted, according to the best available conversion information.

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# 9 Tables

Table 8: Total landings (mt) of sablefish by fleet (Hook-and-line (HKL), pot (POT), and trawl (TWL)) used in the assessment model. Foreign landings are included in totals. See text for description of sources.

| Year | HKL | POT | TWL | Year | HKL | POT | TWL | Year | HKL | POT | TWL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1900 | 50 | 0 | 0 | 1939 | 1757 | 0 | 258 | 1978 | 1868 | 5859 | 4526 |
| 1901 | 76 | 0 | 1 | 1940 | 1187 | 0 | 216 | 1979 | 4535 | 12269 | 7105 |
| 1902 | 103 | 0 | 3 | 1941 | 1251 | 0 | 272 | 1980 | 1596 | 2987 | 4469 |
| 1903 | 129 | 0 | 4 | 1942 | 1888 | 0 | 775 | 1981 | 1981 | 3914 | 5524 |
| 1904 | 156 | 0 | 6 | 1943 | 1613 | 0 | 1747 | 1982 | 1789 | 6574 | 10265 |
| 1905 | 138 | 0 | 7 | 1944 | 1412 | 0 | 2224 | 1983 | 1181 | 6045 | 7426 |
| 1906 | 121 | 0 | 8 | 1945 | 1638 | 0 | 2390 | 1984 | 1066 | 4500 | 8449 |
| 1907 | 103 | 0 | 10 | 1946 | 2431 | 0 | 1308 | 1985 | 2909 | 3950 | 7273 |
| 1908 | 86 | 0 | 11 | 1947 | 1451 | 0 | 436 | 1986 | 3546 | 2986 | 6618 |
| 1909 | 129 | 0 | 12 | 1948 | 1667 | 0 | 782 | 1987 | 3946 | 2082 | 6574 |
| 1910 | 173 | 0 | 14 | 1949 | 1461 | 0 | 711 | 1988 | 3070 | 2146 | 5528 |
| 1911 | 216 | 0 | 15 | 1950 | 1190 | 0 | 808 | 1989 | 2438 | 2074 | 5772 |
| 1912 | 260 | 0 | 16 | 1951 | 1711 | 0 | 1567 | 1990 | 2213 | 1679 | 5173 |
| 1913 | 303 | 0 | 18 | 1952 | 1073 | 0 | 901 | 1991 | 3458 | 1068 | 4975 |
| 1914 | 347 | 0 | 19 | 1953 | 952 | 0 | 672 | 1992 | 3103 | 802 | 5456 |
| 1915 | 390 | 0 | 20 | 1954 | 1318 | 0 | 975 | 1993 | 2334 | 848 | 4964 |
| 1916 | 1309 | 0 | 42 | 1955 | 1297 | 0 | 880 | 1994 | 2379 | 1371 | 3829 |
| 1917 | 1856 | 0 | 318 | 1956 | 973 | 0 | 2425 | 1995 | 2996 | 1067 | 3852 |
| 1918 | 2941 | 0 | 204 | 1957 | 1605 | 0 | 936 | 1996 | 3363 | 751 | 4203 |
| 1919 | 1117 | 0 | 168 | 1958 | 767 | 0 | 752 | 1997 | 3587 | 584 | 3771 |
| 1920 | 628 | 0 | 324 | 1959 | 1242 | 0 | 960 | 1998 | 1761 | 442 | 2170 |
| 1921 | 997 | 0 | 416 | 1960 | 1686 | 0 | 1185 | 1999 | 2713 | 738 | 3170 |
| 1922 | 508 | 0 | 194 | 1961 | 1061 | 0 | 742 | 2000 | 2714 | 853 | 2689 |
| 1923 | 1344 | 0 | 294 | 1962 | 1016 | 0 | 1607 | 2001 | 2362 | 673 | 2596 |
| 1924 | 1258 | 0 | 434 | 1963 | 954 | 0 | 850 | 2002 | 1749 | 472 | 1568 |
| 1925 | 1519 | 0 | 384 | 1964 | 1014 | 0 | 1025 | 2003 | 2283 | 799 | 2213 |
| 1926 | 1272 | 0 | 227 | 1965 | 913 | 0 | 1012 | 2004 | 2515 | 816 | 2411 |
| 1927 | 1610 | 0 | 466 | 1966 | 742 | 0 | 1121 | 2005 | 2807 | 997 | 2399 |
| 1928 | 1213 | 0 | 560 | 1967 | 2458 | 0 | 1812 | 2006 | 2604 | 1053 | 2538 |
| 1929 | 1233 | 0 | 710 | 1968 | 1421 | 0 | 1308 | 2007 | 2060 | 688 | 2489 |
| 1930 | 1564 | 0 | 657 | 1969 | 3406 | 0 | 2068 | 2008 | 2301 | 675 | 2892 |
| 1931 | 763 | 0 | 449 | 1970 | 1653 | 114 | 2837 | 2009 | 3274 | 863 | 3061 |
| 1932 | 928 | 0 | 461 | 1971 | 1228 | 181 | 2475 | 2010 | 3379 | 910 | 2539 |
| 1933 | 865 | 0 | 499 | 1972 | 2810 | 273 | 3534 | 2011 | 3231 | 1449 | 1724 |
| 1934 | 1370 | 0 | 665 | 1973 | 945 | 453 | 4273 | 2012 | 2561 | 1179 | 1498 |
| 1935 | 1714 | 0 | 897 | 1974 | 1948 | 3180 | 3463 | 2013 | 1865 | 846 | 1402 |
| 1936 | 1553 | 0 | 327 | 1975 | 1593 | 8747 | 3949 | 2014 | 1868 | 1032 | 1256 |
| 1937 | 1579 | 0 | 232 | 1976 | 1185 | 19308 | 3879 | | | | |
| 1938 | 1418 | 0 | 243 | 1977 | 1522 | 3731 | 3480 | | | | |

Table 9: Summary of key events in the sablefish fishery and management history. See appendix A for more complete summary of management actions since 1982.

| Year | Source |
|---|---|
| 1942 - 1946 | Market demands likely increase retention of previously unmarketable sablefish. |
| 1955 | First minimum size limit (26 inches, in OR and WA, later removed). |
| 1982 | First trip limits imposed on the trawl fishery. |
| 1983 | 22 inch minimum size limit north of Point Conception (allowance for some smaller fish). |
| 1990-1993 | Increasingly shorter fixed-gear seasons. |
| 1997-1999 | Sequential reductions in landings limits begin. |
| 2003 | Rockfish conservation areas close large portions of the shelf to trawling and fixed-gear fleets. |
| 2011 | Rationalization of the trawl fishery. |

Table 10: Recent trend in sablefish landings and estimated total dead catch (mt) relative to OFL (ABCs at the time) and ACLs (OYs at the time).

| Year | OFL (mt)[1] | ACL (mt)[1] | Landings (mt) | Estimated dead catch (mt)[2] |
|---|---|---|---|---|
| 2005 | 8471.00 | 7761.00 | 6203.00 | 6537.77 |
| 2006 | 8175.00 | 7634.00 | 6195.00 | 6508.40 |
| 2007 | 6210.00 | 5934.00 | 5237.00 | 5493.03 |
| 2008 | 6058.00 | 5934.00 | 5868.00 | 6158.67 |
| 2009 | 9914.00 | 8423.00 | 7198.00 | 7718.91 |
| 2010 | 9217.00 | 7729.00 | 6828.00 | 7273.60 |
| 2011 | 8808.00 | 6813.00 | 6404.00 | 6733.72 |
| 2012 | 8623.00 | 6605.00 | 5238.00 | 5497.94 |
| 2013 | 6621.00 | 5451.00 | 4113.00 | 4311.34 |
| 2014 | 7158.00 | 5909.00 | 4156.00 | 4453.90 |

Table 11: Summary of data used to produce NWFSC Shelf-Slope bottom trawl survey biomass index, length-, and age-composition data between 2003 and 2014.

| Year | N hauls | N positive hauls | N hauls w/ lengths | N lengthed fish | N hauls w/ ages | N aged fish |
|---|---|---|---|---|---|---|
| 2003 | 541 | 421 | 419 | 5,798 | 382 | 1,388 |
| 2004 | 470 | 332 | 328 | 4,511 | 278 | 1,086 |
| 2005 | 637 | 447 | 445 | 5,567 | 415 | 1,575 |
| 2006 | 641 | 399 | 398 | 4,833 | 369 | 1,363 |
| 2007 | 688 | 430 | 422 | 4,470 | 396 | 1,258 |
| 2008 | 681 | 421 | 421 | 3,979 | 369 | 1,194 |
| 2009 | 682 | 419 | 419 | 3,688 | 383 | 1,181 |
| 2010 | 714 | 458 | 457 | 4,204 | 421 | 1,265 |
| 2011 | 697 | 457 | 455 | 4,674 | 382 | 773 |
| 2012 | 701 | 428 | 428 | 4,381 | 395 | 1091 |
| 2013 | 471 | 307 | 307 | 3,280 | 285 | 992 |
| 2014 | 685 | 465 | 463 | 4,323 | 383 | 793 |

Table 12: Summary of data used to produce NWFSC slope bottom trawl survey biomass index, length-, and age-composition data.

| Year | N hauls | N positive hauls | N hauls w/ lengths | N lengthed fish | N hauls w/ ages | N aged fish |
|---|---|---|---|---|---|---|
| 1998 | 299 | 252 | 196 | 1,672 | 115 | 648 |
| 1999 | 322 | 293 | 293 | 3,032 | 127 | 475 |
| 2000 | 321 | 296 | 294 | 3,173 | 150 | 737 |
| 2001 | 328 | 303 | 298 | 2,863 | 135 | 596 |
| 2002 | 362 | 378 | 341 | 3,794 | 179 | 1,490 |

Table 13: Summary of data used to produce AFSC slope bottom trawl survey biomass index, length-, and age-composition data.

| Year | N hauls | N positive hauls | N hauls w/ lengths | N lengthed fish | N hauls w/ ages | N aged fish |
|---|---|---|---|---|---|---|
| 1997 | 180 | 174 | 173 | 5,182 | 153 | 1,485 |
| 1999 | 199 | 193 | 193 | 3,619 | 157 | 472 |
| 2000 | 207 | 206 | 206 | 4,740 | 198 | 1,622 |
| 2001 | 207 | 206 | 206 | 4,674 | 124 | 472 |

Table 14: Summary of data used to produce AFSC triennial bottom bottom trawl survey biomass index, length-, and age-composition data.

| Year | N hauls | N positive hauls | N hauls w/ lengths | N lengthed fish | N hauls w/ ages | N aged fish |
|---|---|---|---|---|---|---|
| 1980 | 332 | 209 | 16 | 1,944 | 0 | 0 |
| 1983 | 513 | 357 | 205 | 5,767 | 20 | 914 |
| 1986 | 484 | 372 | 104 | 4,896 | 1 | 68 |
| 1989 | 447 | 321 | 290 | 5,183 | 21 | 475 |
| 1992 | 445 | 307 | 222 | 6,919 | 43 | 536 |
| 1995 | 479 | 364 | 334 | 7,673 | 75 | 340 |
| 1998 | 511 | 298 | 267 | 7,442 | 79 | 432 |
| 2001 | 497 | 397 | 369 | 12,790 | 121 | 434 |
| 2004 | 382 | 297 | 296 | 8,753 | 233 | 477 |

Table 15: Summary of fixed biological parameters estimated externally and used as input for this stock assessment.

| Quantity | Value | Source |
|---|---|---|
| Fecundity eggs/kilogram intercept | 1.00 | Various published studies (see text) |
| Fecundity slope | 0.00 | |
| Female maturity logistic slope | -0.13 | Various published studies (see text) |
| Female length at 50% maturity | 58.00 | |
| Female weight-length coefficient (a) | 0.00000326728 | All available survey data |
| Male weight-length coefficient (a) | 0.00000332942 | |
| Female weight-length exponent (b) | 3.27596000000 | |
| Male weight-length exponent (b) | 3.27292000000 | |

Table 16: Summary of fishery sampling (tows) used to create commercial fishery length- and age-frequency distributions for the assessment model. Year and gear combinations with two or fewer tows were removed as they were extremely noisy. At-sea sampling of retained catch by observers is included with port samples.

| | **Lengths (retained)** | | | **Ages (retained)** | | | **Lengths (discard)** | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | HKL | POT | TWL | HKL | POT | TWL | HKL | POT | TWL |
| 1978 | 0 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1979 | 0 | 7 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1980 | 0 | 7 | 42 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1981 | 3 | 0 | 31 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1982 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1983 | 0 | 15 | 11 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1985 | 0 | 4 | 25 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1986 | 47 | 33 | 190 | 24 | 20 | 138 | 0 | 0 | 0 |
| 1987 | 82 | 37 | 174 | 71 | 33 | 145 | 0 | 0 | 0 |
| 1988 | 33 | 15 | 122 | 23 | 6 | 90 | 0 | 0 | 0 |
| 1989 | 23 | 59 | 155 | 7 | 25 | 83 | 0 | 0 | 0 |
| 1990 | 39 | 33 | 173 | 9 | 10 | 77 | 0 | 0 | 0 |
| 1991 | 57 | 27 | 168 | 8 | 14 | 45 | 0 | 0 | 0 |
| 1992 | 21 | 6 | 18 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1993 | 206 | 33 | 187 | 0 | 6 | 26 | 0 | 0 | 0 |
| 1994 | 175 | 16 | 157 | 0 | 4 | 27 | 0 | 0 | 0 |
| 1995 | 134 | 43 | 143 | 11 | 7 | 26 | 0 | 0 | 0 |
| 1996 | 93 | 22 | 119 | 26 | 17 | 45 | 0 | 0 | 0 |
| 1997 | 161 | 36 | 142 | 47 | 29 | 69 | 0 | 0 | 0 |
| 1998 | 129 | 21 | 130 | 15 | 0 | 22 | 0 | 0 | 0 |
| 1999 | 188 | 26 | 158 | 38 | 15 | 19 | 0 | 0 | 0 |
| 2000 | 198 | 33 | 152 | 28 | 16 | 69 | 0 | 0 | 0 |
| 2001 | 140 | 17 | 145 | 49 | 14 | 71 | 0 | 0 | 0 |
| 2002 | 110 | 17 | 141 | 25 | 11 | 23 | 0 | 0 | 0 |
| 2003 | 154 | 21 | 162 | 15 | 10 | 28 | 0 | 0 | 0 |
| 2004 | 98 | 26 | 131 | 11 | 6 | 36 | 0 | 0 | 5 |
| 2005 | 174 | 20 | 150 | 29 | 7 | 35 | 1 | 0 | 2 |
| 2006 | 240 | 41 | 173 | 31 | 5 | 65 | 36 | 33 | 171 |
| 2007 | 177 | 37 | 179 | 82 | 15 | 81 | 74 | 48 | 162 |
| 2008 | 302 | 65 | 156 | 8 | 0 | 8 | 80 | 33 | 171 |
| 2009 | 310 | 92 | 121 | 42 | 16 | 31 | 55 | 43 | 309 |
| 2010 | 309 | 81 | 121 | 45 | 11 | 33 | 170 | 61 | 204 |
| 2011 | 336 | 74 | 111 | 33 | 11 | 29 | 131 | 59 | 130 |
| 2012 | 372 | 109 | 135 | 79 | 3 | 4 | 121 | 45 | 124 |
| 2013 | 331 | 76 | 148 | 30 | 10 | 33 | 49 | 30 | 153 |
| 2014 | 118 | 41 | 77 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 17: Description of model parameters in the base-case assessment model. A total of 12 mortality, growth, and stock recruit, 54 survey and fishery dynamics, and 176 recruitment deviation parameters are estimated.

| Parameter | N est. | Lower bound | Upper bound | Prior | mean | SD |
|---|---|---|---|---|---|---|
| Natural mortality ($M$, female) | 1 | 0.01 | 0.11 | Log(Normal) | -2.1791 | 0.3384 |
| Natural mortality ($M$, male) | 1 | 0.01 | 0.11 | Log(Normal) | -2.0565 | 0.3375 |
| Stock and recruitment | | | | | | |
| $Ln(R_0)$ | 1 | 8 | 12 | Uniform | | |
| Steepness ($h$) | - | NA | NA | Fixed | 0.6 | |
| Recruitment SD ($\sigma_r$) | - | NA | NA | Iterated | 0.95 | |
| Initial age deviations (ages 1-49 at age-0) | 49 | -4 | 4 | Normal | 0 | $\sigma_r$ |
| Time-series recruitment deviations (1900-2014) | 115 | -4 | 4 | Normal | 0 | $\sigma_r$ |
| Forecast recruitment deviations (2015-2026) | 12 | -4 | 4 | Normal | 0 | $\sigma_r$ |
| Survey catchability and variability | | | | | | |
| Ln($Q$) NWFSC Shelf-Slope | - | | | Analytic | | |
| Ln($Q$) AFSC shelf (1980-1992) | - | -3 | 0.5 | Uniform | | |
| Ln($Q$) AFSC shelf offset (1995-2004) | - | -2 | 3 | Uniform | | |
| Extra additive SD for survey index | - | 0.001 | 1.3 | Uniform | | |
| Selectivity, retention, & discard mortality | | | | | | |
| Survey selectivity (double-normal) (See text for detailed description) | 13 | | | | | |
| Fishery selectivity (cubic spline) (See text for detailed description) | 28 | | | | | |
| Fishery retention inflections | 3 | 25 | -60 | Uniform | | |
| Hook-&-line retention slope | - | NA | | Fixed | 1.0 | |
| Pot and trawl retention slope | 2 | 1 | 20 | Uniform | | |
| Hook-&-line and trawl retention asymptote | 2 | 0.6 | 1.0 | Uniform | | |
| Pot retention asymptote | - | NA | | Fixed | 1.0 | |
| Historical differences in retention (See text for detailed description) | - | NA | | Fixed | | |
| Hook-&-line and pot discard mortality | - | NA | | Fixed | 20% | |
| Trawl discard mortality | - | NA | | Fixed | 50% | |
| Fishery size at first survival | - | NA | | Fixed | 28 | |
| Individual growth | | | | | | |
| Females: | | | | | | |
| Length at age 0.5 | 1 | 22 | 30 | Uniform | | |
| Length at age 30 | 1 | 60 | 70 | Uniform | | |
| von Bertalanffy $K$ | 1 | 0.15 | 0.35 | Uniform | | |
| CV of length at age 0.5 | 1 | 0.03 | 0.15 | Uniform | | |
| CV of length at age 30 | 1 | 0.03 | 0.15 | Uniform | | |
| Males: | | | | | | |
| Length at age 0.5 offset to fem. | - | NA | | Fixed | 0.0 | |
| Length at age 30 | 1 | 50 | 60 | Uniform | | |
| von Bertalanffy $K$ | 1 | 0.2 | 0.45 | Uniform | | |
| CV of length at age 0.5 | 1 | NA | | Fixed | 0.0 | |
| CV of length at age 30 | 1 | 0.03 | 0.15 | Uniform | | |

Table 18: Input and effective sample sizes resulting from tuning the composition data in the base model.

| Data type | Fleet | Adj | Mean after adj. | Harmonic mean |
|---|---|---|---|---|
| Age | HKL | 29.48 | 32.90 | 0.94 |
| | POT | 28.83 | 29.08 | 2.25 |
| | TWL | 87.59 | 88.01 | 1.74 |
| | AKSHLF | 2.25 | 2.27 | 0.28 |
| | AKSLP | 1.00 | 0.40 | 0.00 |
| | NWSLP | 4.00 | 3.96 | 0.19 |
| | NWCBO | 5.31 | 5.31 | 0.24 |
| Length | HKL | 18.91 | 18.13 | 0.13 |
| | POT | 37.81 | 37.59 | 1.01 |
| | TWL | 30.63 | 30.60 | 0.25 |
| | AKSHLF | 43.74 | 43.88 | 0.19 |
| | AKSLP | 241.00 | 237.85 | 1.24 |
| | NWSLP | 160.18 | 160.48 | 0.55 |
| | NWCBO | 316.04 | 316.04 | 0.76 |

Table 19: Adjusted mean input standard errors and root-mean-squared error (RMSE) of fits to discard and mean body weight data resulting from tuning the base model.

| Fleet | SD adj. | Mean SD after adj. | RMSE |
|---|---|---|---|
| *Discard ratio*: | | | |
| Hook-and-line | 0.015 | 0.04 | 0.06 |
| Pot | 0.024 | 0.07 | 0.08 |
| Trawl | 0.097 | 0.17 | 0.13 |
| *Mean body weight*: | | | |
| Hook-and-line | 0 | 0.09 | 0.31 |
| Pot | 0 | 0.09 | 0.12 |
| Trawl | 0 | 0.18 | 0.12 |

Table 20: Sablefish stock-recruitment, mortality, and growth parameter estimates and ~95% interval from the base-case model.

| Parameter | Value | Lower ~95% | Upper ~95% |
|---|---|---|---|
| Equilibrium recruitment ($R_0$) | 0.08 | 0.07 | 0.07 |
| *Females:* | | | |
| Natural Mortality ($M$) | 0.08 | 0.07 | 0.07 |
| Length at age 0.5 (cm) | 26.10 | 25.82 | 25.82 |
| Length at age 30 (cm) | 64.15 | 63.67 | 63.67 |
| von Bertalanffy $K$ | 0.33 | 0.32 | 0.32 |
| CV of length at age 0.5 | 0.08 | 0.07 | 0.07 |
| CV of length at age 30 | 0.12 | 0.11 | 0.11 |
| *Males:* | | | |
| Natural Mortality ($M$) | 0.06 | 0.05 | 0.05 |
| Length at age 0.5 (cm) | 0.00 | | |
| Length at age 30 (cm) | 56.28 | 56.04 | 56.04 |
| von Bertalanffy $K$ | 0.42 | 0.40 | 0.40 |
| CV of length at age 0.5 | 0.00 | | |
| CV of length at age 30 | 0.08 | 0.08 | 0.08 |

Table 21: Sablefish estimated parameters (excluding recruitment deviations and growth parameters) and their ∼95% intervals in the base-case model.

| Parameter | Estimate | Lower 95% | Upper 95% |
|---|---|---|---|
| Q-extraSD-5-AKSHLF | 0.35 | 0.15 | 0.55 |
| Q-extraSD-6-AKSLP | 0.07 | -0.04 | 0.17 |
| Q-extraSD-7-NWSLP | 0.09 | -0.01 | 0.20 |
| LnQ-base-5-AKSHLF | -1.12 | -1.62 | -0.62 |
| Q-walk-5y-1995 | 0.68 | 0.11 | 1.25 |
| Retain-1P-1-HKL | 34.60 | 33.35 | 35.84 |
| Retain-1P-3-HKL | 0.87 | 0.85 | 0.89 |
| Retain-2P-1-POT | 50.28 | 48.47 | 52.09 |
| Retain-2P-2-POT | 7.21 | 6.43 | 7.99 |
| Retain-3P-1-TWL | 44.95 | 43.78 | 46.13 |
| Retain-3P-2-TWL | 2.61 | 2.28 | 2.93 |
| AgeSpline-GradLo-HKL-1 | 0.71 | 0.60 | 0.83 |
| AgeSpline-GradHi-HKL-1 | -0.58 | -0.80 | -0.35 |
| AgeSpline-Val-1-HKL-1 | -0.84 | -1.14 | -0.53 |
| AgeSpline-Val-3-HKL-1 | -0.16 | -0.56 | 0.25 |
| AgeSpline-Val-4-HKL-1 | -1.25 | -1.65 | -0.85 |
| AgeSel-1MaleatDogleg-HKL | -1.22 | -1.45 | -0.99 |
| AgeSel-1MaleatMaxage-HKL | -1.26 | -2.04 | -0.49 |
| AgeSpline-GradLo-POT-2 | 0.80 | 0.58 | 1.02 |
| AgeSpline-GradHi-POT-2 | -0.21 | -0.40 | -0.02 |
| AgeSpline-Val-1-POT-2 | -1.68 | -2.02 | -1.33 |
| AgeSpline-Val-2-POT-2 | -1.19 | -1.79 | -0.58 |
| AgeSpline-Val-4-POT-2 | -1.38 | -2.04 | -0.71 |
| AgeSel-2MaleatDogleg-POT | -1.20 | -1.42 | -0.99 |
| AgeSel-2MaleatMaxage-POT | -1.40 | -1.98 | -0.83 |
| AgeSpline-GradLo-TWL-3 | 0.70 | 0.41 | 0.99 |
| AgeSpline-GradHi-TWL-3 | -0.24 | -0.37 | -0.11 |
| AgeSpline-Val-1-TWL-3 | 0.17 | -0.26 | 0.60 |
| AgeSpline-Val-2-TWL-3 | 0.00 | -0.33 | 0.34 |
| AgeSpline-Val-4-TWL-3 | -0.14 | -0.51 | 0.23 |
| AgeSpline-Val-5-TWL-3 | -0.76 | -0.96 | -0.56 |
| AgeSel-3MaleatDogleg-TWL | 0.04 | -0.08 | 0.16 |
| AgeSel-3MaleatMaxage-TWL | -0.26 | -0.61 | 0.08 |
| AgeSel-5P-4-AKSHLF | 1.80 | 1.50 | 2.10 |
| AgeSel-5P-5-AKSHLF | -3.82 | -5.01 | -2.62 |
| AgeSel-6P-1-AKSLP | 2.75 | 2.45 | 3.04 |
| AgeSel-6P-4-AKSLP | 0.96 | -0.92 | 2.84 |
| AgeSel-6P-5-AKSLP | -1.14 | -1.56 | -0.72 |
| AgeSel-6P-6-AKSLP | -0.67 | -1.15 | -0.18 |
| AgeSel-7P-3-NWSLP | 1.44 | 0.89 | 1.99 |

Table 21: Sablefish estimated parameters (excluding recruitment deviations and growth parameters) and their ~95% intervals in the base-case model.

| Parameter | Estimate | Lower 95% | Upper 95% |
|---|---|---|---|
| AgeSel-7P-4-NWSLP | 0.91 | -0.49 | 2.30 |
| AgeSel-7P-5-NWSLP | -3.97 | -5.41 | -2.52 |
| AgeSel-7P-6-NWSLP | 0.27 | -0.25 | 0.79 |
| AgeSel-8P-4-NWCBO | 3.26 | 2.94 | 3.58 |
| AgeSel-8P-5-NWCBO | -1.10 | -1.38 | -0.83 |
| AgeSel-8P-6-NWCBO | -0.96 | -1.24 | -0.68 |
| Retain-3P-3-TWL-BLK2repl-1982 | 0.93 | 0.90 | 0.96 |
| AgeSpline-Val-3-HKL-1-BLK4repl-1900 | -0.24 | -0.69 | 0.22 |
| AgeSpline-Val-4-HKL-1-BLK4repl-1900 | -0.77 | -1.17 | -0.37 |
| AgeSpline-Val-2-POT-2-BLK4repl-1900 | 0.04 | -0.41 | 0.48 |
| AgeSpline-Val-4-POT-2-BLK4repl-1900 | -0.14 | -0.66 | 0.39 |
| AgeSpline-Val-2-TWL-3-BLK4repl-1900 | 0.15 | -0.10 | 0.40 |
| AgeSpline-Val-4-TWL-3-BLK4repl-1900 | -0.76 | -1.08 | -0.45 |

Table 22: Time series of population estimates from the base-case model.

| Year | Total biomass (mt) | Age4+ biomass (mt) | Spawning biomass (mt) | ~95% low | ~95% high | Age-0 Recruits (1000) | ~95% low | ~95% high |
|---|---|---|---|---|---|---|---|---|
| 1900 | 419,233 | 393,846 | 143,182 | 87,275 | 199,089 | 15,625 | 0 | 44,344 |
| 1901 | 418,351 | 393,066 | 142,893 | 87,141 | 198,645 | 15,563 | 0 | 44,127 |
| 1902 | 417,387 | 392,229 | 142,580 | 86,991 | 198,169 | 15,498 | 0 | 43,900 |
| 1903 | 416,339 | 391,333 | 142,233 | 86,751 | 197,715 | 15,429 | 0 | 43,662 |
| 1904 | 415,214 | 390,312 | 141,855 | 86,436 | 197,274 | 15,358 | 0 | 43,412 |
| 1905 | 414,013 | 389,220 | 141,445 | 86,055 | 196,835 | 15,282 | 0 | 43,150 |
| 1906 | 412,783 | 388,104 | 141,025 | 85,649 | 196,401 | 15,203 | 0 | 42,879 |
| 1907 | 411,527 | 386,966 | 140,598 | 85,236 | 195,960 | 15,123 | 0 | 42,602 |
| 1908 | 410,243 | 385,806 | 140,163 | 84,827 | 195,499 | 15,040 | 0 | 42,316 |
| 1909 | 408,933 | 384,623 | 139,722 | 84,431 | 195,013 | 14,955 | 0 | 42,022 |
| 1910 | 407,533 | 383,357 | 139,247 | 84,024 | 194,470 | 14,867 | 0 | 41,719 |
| 1911 | 406,042 | 382,004 | 138,736 | 83,604 | 193,868 | 14,776 | 0 | 41,407 |

Table 22: Time series of population estimates from the base-case model.

| Year | Total biomass (mt) | Age4+ biomass (mt) | Spawning biomass (mt) | ~95% low | ~95% high | Age-0 Recruits (1000) | ~95% low | ~95% high |
|---|---|---|---|---|---|---|---|---|
| 1912 | 404,461 | 380,565 | 138,188 | 83,172 | 193,204 | 14,682 | 0 | 41,089 |
| 1913 | 402,788 | 379,039 | 137,604 | 82,728 | 192,480 | 14,588 | 0 | 40,766 |
| 1914 | 401,025 | 377,428 | 136,984 | 82,271 | 191,697 | 14,490 | 0 | 40,434 |
| 1915 | 399,174 | 375,730 | 136,327 | 81,800 | 190,854 | 14,388 | 0 | 40,087 |
| 1916 | 397,235 | 373,950 | 135,635 | 81,316 | 189,954 | 14,278 | 0 | 39,717 |
| 1917 | 394,308 | 371,223 | 134,493 | 80,402 | 188,584 | 14,154 | 0 | 39,305 |
| 1918 | 390,497 | 367,646 | 132,975 | 79,129 | 186,821 | 14,024 | 0 | 38,880 |
| 1919 | 385,689 | 363,084 | 130,968 | 77,385 | 184,551 | 13,887 | 0 | 38,435 |
| 1920 | 382,750 | 360,287 | 129,804 | 76,500 | 183,108 | 13,762 | 0 | 38,022 |
| 1921 | 380,153 | 357,874 | 128,838 | 75,836 | 181,840 | 13,637 | 0 | 37,610 |
| 1922 | 377,092 | 355,042 | 127,690 | 75,012 | 180,368 | 13,507 | 0 | 37,182 |
| 1923 | 374,749 | 352,870 | 126,856 | 74,518 | 179,194 | 13,378 | 0 | 36,757 |
| 1924 | 371,449 | 349,800 | 125,614 | 73,635 | 177,593 | 13,239 | 0 | 36,302 |
| 1925 | 368,063 | 346,647 | 124,358 | 72,750 | 175,966 | 13,099 | 0 | 35,846 |
| 1926 | 364,448 | 343,261 | 122,993 | 71,771 | 174,215 | 12,956 | 0 | 35,382 |
| 1927 | 361,230 | 340,246 | 121,793 | 70,972 | 172,614 | 12,812 | 0 | 34,915 |
| 1928 | 357,409 | 336,677 | 120,357 | 69,953 | 170,761 | 12,660 | 0 | 34,427 |
| 1929 | 353,870 | 333,378 | 119,070 | 69,097 | 169,043 | 12,506 | 0 | 33,933 |
| 1930 | 350,139 | 329,900 | 117,723 | 68,198 | 167,248 | 12,352 | 0 | 33,439 |
| 1931 | 346,113 | 326,135 | 116,241 | 67,178 | 165,304 | 12,198 | 0 | 32,947 |
| 1932 | 343,099 | 323,320 | 115,198 | 66,613 | 163,783 | 12,050 | 0 | 32,470 |
| 1933 | 339,898 | 320,353 | 114,086 | 65,997 | 162,175 | 11,895 | 0 | 31,975 |
| 1934 | 336,699 | 317,398 | 112,993 | 65,415 | 160,571 | 11,735 | 0 | 31,465 |
| 1935 | 332,788 | 313,767 | 111,606 | 64,555 | 158,657 | 11,565 | 0 | 30,931 |
| 1936 | 328,250 | 309,532 | 109,965 | 63,453 | 156,477 | 11,396 | 0 | 30,401 |
| 1937 | 324,446 | 305,955 | 108,577 | 62,618 | 154,536 | 11,226 | 0 | 29,867 |
| 1938 | 320,704 | 302,450 | 107,210 | 61,821 | 152,599 | 11,055 | 0 | 29,330 |
| 1939 | 317,095 | 299,100 | 105,915 | 61,111 | 150,719 | 10,889 | 0 | 28,809 |
| 1940 | 313,108 | 295,398 | 104,461 | 60,258 | 148,664 | 10,735 | 0 | 28,328 |
| 1941 | 309,717 | 292,253 | 103,282 | 59,694 | 146,870 | 10,601 | 0 | 27,907 |
| 1942 | 306,190 | 288,976 | 102,056 | 59,100 | 145,012 | 10,472 | 0 | 27,506 |
| 1943 | 301,508 | 284,625 | 100,381 | 58,074 | 142,688 | 10,328 | 0 | 27,065 |
| 1944 | 296,091 | 279,588 | 98,504 | 56,856 | 140,152 | 10,174 | 0 | 26,603 |
| 1945 | 290,369 | 274,213 | 96,540 | 55,560 | 137,519 | 10,021 | 0 | 26,148 |
| 1946 | 284,252 | 268,405 | 94,395 | 54,094 | 134,696 | 9,901 | 0 | 25,799 |
| 1947 | 278,483 | 262,798 | 92,212 | 52,599 | 131,825 | 9,841 | 0 | 25,632 |
| 1948 | 274,696 | 258,983 | 90,764 | 51,846 | 129,681 | 9,839 | 0 | 25,638 |
| 1949 | 270,520 | 254,873 | 89,166 | 50,953 | 127,379 | 9,894 | 0 | 25,821 |
| 1950 | 266,835 | 251,219 | 87,752 | 50,243 | 125,262 | 10,021 | 0 | 26,226 |
| 1951 | 263,569 | 247,888 | 86,504 | 49,687 | 123,322 | 10,230 | 0 | 26,887 |

Table 22: Time series of population estimates from the base-case model.

| Year | Total biomass (mt) | Age4+ biomass (mt) | Spawning biomass (mt) | ~95% low | ~95% high | Age-0 Recruits (1000) | ~95% low | ~95% high |
|---|---|---|---|---|---|---|---|---|
| 1952 | 259,276 | 243,525 | 84,841 | 48,693 | 120,990 | 10,551 | 0 | 27,915 |
| 1953 | 256,703 | 240,614 | 83,773 | 48,256 | 119,289 | 11,036 | 0 | 29,464 |
| 1954 | 254,999 | 238,384 | 82,959 | 48,031 | 117,887 | 11,709 | 0 | 31,644 |
| 1955 | 253,244 | 235,966 | 82,030 | 47,626 | 116,433 | 12,590 | 0 | 34,569 |
| 1956 | 252,411 | 234,168 | 81,320 | 47,352 | 115,287 | 13,707 | 0 | 38,382 |
| 1957 | 251,245 | 231,867 | 80,468 | 46,815 | 114,122 | 15,097 | 0 | 43,336 |
| 1958 | 252,262 | 231,184 | 80,098 | 46,613 | 113,582 | 16,780 | 0 | 49,649 |
| 1959 | 255,871 | 232,580 | 80,536 | 47,038 | 114,033 | 18,769 | 0 | 57,601 |
| 1960 | 260,619 | 234,816 | 81,177 | 47,435 | 114,919 | 20,908 | 0 | 67,006 |
| 1961 | 266,748 | 238,066 | 82,111 | 47,837 | 116,385 | 23,140 | 0 | 78,132 |
| 1962 | 276,287 | 244,215 | 84,110 | 48,982 | 119,238 | 25,769 | 0 | 93,201 |
| 1963 | 287,465 | 251,895 | 86,621 | 50,284 | 122,958 | 29,291 | 0 | 116,785 |
| 1964 | 302,472 | 262,716 | 90,218 | 52,298 | 128,139 | 37,165 | 0 | 159,036 |
| 1965 | 321,666 | 275,826 | 94,668 | 54,733 | 134,603 | 20,106 | 0 | 72,574 |
| 1966 | 340,336 | 291,915 | 100,238 | 57,753 | 142,723 | 20,331 | 0 | 72,417 |
| 1967 | 357,258 | 311,741 | 107,492 | 66,068 | 148,916 | 20,140 | 0 | 69,809 |
| 1968 | 369,078 | 337,084 | 113,332 | 71,862 | 154,802 | 21,372 | 0 | 76,094 |
| 1969 | 380,267 | 347,826 | 119,042 | 77,021 | 161,063 | 23,143 | 0 | 90,102 |
| 1970 | 387,373 | 354,082 | 122,653 | 79,779 | 165,527 | 24,431 | 0 | 109,738 |
| 1971 | 394,827 | 359,354 | 125,867 | 82,095 | 169,639 | 50,184 | 0 | 203,296 |
| 1972 | 409,613 | 365,307 | 128,897 | 83,871 | 173,923 | 21,435 | 0 | 86,282 |
| 1973 | 421,035 | 369,684 | 130,677 | 82,367 | 178,987 | 15,143 | 0 | 46,650 |
| 1974 | 430,082 | 375,927 | 135,541 | 89,085 | 181,997 | 10,563 | 0 | 28,897 |
| 1975 | 430,735 | 403,320 | 138,282 | 92,232 | 184,332 | 15,302 | 0 | 46,130 |
| 1976 | 421,541 | 400,225 | 137,050 | 91,637 | 182,463 | 47,167 | 10,693 | 83,641 |
| 1977 | 407,559 | 379,138 | 128,699 | 83,935 | 173,463 | 10,752 | 0 | 28,418 |
| 1978 | 407,261 | 367,852 | 126,783 | 82,605 | 170,961 | 7,162 | 0 | 17,709 |
| 1979 | 399,694 | 356,445 | 125,742 | 81,951 | 169,533 | 33,970 | 17,361 | 50,578 |
| 1980 | 382,882 | 362,338 | 118,283 | 75,031 | 161,535 | 18,792 | 6,900 | 30,684 |
| 1981 | 380,885 | 352,749 | 116,413 | 74,053 | 158,774 | 22,613 | 12,633 | 32,593 |
| 1982 | 377,367 | 336,117 | 114,902 | 73,187 | 156,617 | 12,407 | 5,918 | 18,896 |
| 1983 | 363,726 | 335,101 | 110,203 | 69,170 | 151,236 | 4,934 | 1,052 | 8,816 |
| 1984 | 350,276 | 326,146 | 107,314 | 66,856 | 147,772 | 15,562 | 9,686 | 21,439 |
| 1985 | 336,335 | 320,739 | 104,132 | 64,432 | 143,832 | 26,088 | 17,067 | 35,108 |
| 1986 | 324,855 | 306,452 | 99,273 | 60,658 | 137,887 | 22,082 | 13,732 | 30,431 |
| 1987 | 316,686 | 286,215 | 94,548 | 57,027 | 132,070 | 14,031 | 7,781 | 20,280 |
| 1988 | 309,211 | 275,370 | 91,176 | 54,419 | 127,933 | 13,395 | 7,246 | 19,544 |
| 1989 | 303,138 | 276,303 | 89,341 | 53,081 | 125,601 | 19,606 | 10,607 | 28,605 |
| 1990 | 298,237 | 275,873 | 87,771 | 51,961 | 123,582 | 25,067 | 15,018 | 35,116 |
| 1991 | 296,944 | 270,293 | 86,467 | 51,112 | 121,822 | 8,296 | 3,657 | 12,936 |

Table 22: Time series of population estimates from the base-case model.

| Year | Total biomass (mt) | Age4+ biomass (mt) | Spawning biomass (mt) | ~95% low | ~95% high | Age-0 Recruits (1000) | ~95% low | ~95% high |
|---|---|---|---|---|---|---|---|---|
| 1992 | 293,328 | 263,613 | 85,318 | 50,289 | 120,347 | 8,505 | 4,056 | 12,954 |
| 1993 | 287,524 | 262,555 | 85,161 | 50,177 | 120,146 | 5,472 | 2,429 | 8,515 |
| 1994 | 279,848 | 267,843 | 84,586 | 49,861 | 119,312 | 12,630 | 7,542 | 17,718 |
| 1995 | 272,075 | 259,557 | 83,303 | 49,032 | 117,573 | 20,905 | 13,452 | 28,358 |
| 1996 | 266,160 | 249,984 | 80,722 | 47,222 | 114,221 | 1,969 | 594 | 3,344 |
| 1997 | 257,657 | 236,871 | 77,827 | 45,133 | 110,521 | 2,364 | 1,115 | 3,614 |
| 1998 | 247,212 | 230,175 | 75,891 | 43,729 | 108,052 | 6,462 | 3,776 | 9,147 |
| 1999 | 239,305 | 234,865 | 74,461 | 43,099 | 105,823 | 31,651 | 20,672 | 42,630 |
| 2000 | 234,950 | 221,495 | 71,351 | 40,994 | 101,707 | 25,065 | 16,109 | 34,021 |
| 2001 | 235,963 | 207,923 | 67,937 | 38,679 | 97,194 | 15,378 | 9,627 | 21,128 |
| 2002 | 239,647 | 198,743 | 67,239 | 38,339 | 96,139 | 6,521 | 3,942 | 9,100 |
| 2003 | 243,714 | 214,768 | 68,965 | 39,902 | 98,029 | 2,759 | 1,550 | 3,968 |
| 2004 | 242,489 | 226,522 | 70,769 | 41,323 | 100,216 | 5,671 | 3,552 | 7,790 |
| 2005 | 237,683 | 229,741 | 71,638 | 41,998 | 101,279 | 587 | 184 | 990 |
| 2006 | 228,720 | 223,436 | 70,829 | 41,392 | 100,265 | 1,671 | 894 | 2,448 |
| 2007 | 217,244 | 212,169 | 68,893 | 39,969 | 97,818 | 1,197 | 515 | 1,879 |
| 2008 | 204,991 | 203,328 | 66,028 | 38,018 | 94,038 | 27,162 | 17,232 | 37,093 |
| 2009 | 197,869 | 188,859 | 62,042 | 35,195 | 88,889 | 1,703 | 706 | 2,701 |
| 2010 | 189,331 | 173,728 | 56,828 | 31,319 | 82,337 | 16,588 | 9,820 | 23,356 |
| 2011 | 184,534 | 159,316 | 54,188 | 29,234 | 79,143 | 5,275 | 2,746 | 7,803 |
| 2012 | 180,053 | 168,645 | 51,457 | 27,137 | 75,776 | 4,061 | 1,759 | 6,362 |
| 2013 | 175,768 | 159,436 | 50,631 | 26,414 | 74,848 | 41,744 | 22,626 | 60,862 |
| 2014 | 181,180 | 164,071 | 50,044 | 25,961 | 74,127 | 3,482 | 69 | 6,895 |
| 2015 | 185,770 | 159,471 | 49,071 | 25,206 | 72,936 | 12,624 | 0 | 36,705 |

Table 22: Time series of population estimates from the base-case model.

| Year | Total dead catch (mt) | Relative SPR (%) | ~95% low | ~95% high | Relative exploitation rate (%) | ~95% low | ~95% high |
|---|---|---|---|---|---|---|---|
| 1900 | 100 | 0.57 | 0.26 | 0.87 | 0.01 | 0.01 | 0.02 |
| 1901 | 152 | 0.87 | 0.40 | 1.34 | 0.02 | 0.01 | 0.03 |
| 1902 | 206 | 1.20 | 0.55 | 1.85 | 0.03 | 0.02 | 0.04 |
| 1903 | 258 | 1.51 | 0.69 | 2.32 | 0.03 | 0.02 | 0.05 |
| 1904 | 312 | 1.84 | 0.84 | 2.84 | 0.04 | 0.02 | 0.06 |
| 1905 | 276 | 1.65 | 0.75 | 2.55 | 0.04 | 0.02 | 0.05 |

Table 22: Time series of population estimates from the base-case model.

| Year | Total dead catch (mt) | Relative SPR (%) | ~95% low | ~95% high | Relative exploitation rate (%) | ~95% low | ~95% high |
|---|---|---|---|---|---|---|---|
| 1906 | 242 | 1.47 | 0.67 | 2.27 | 0.03 | 0.02 | 0.05 |
| 1907 | 206 | 1.29 | 0.58 | 1.99 | 0.03 | 0.02 | 0.04 |
| 1908 | 172 | 1.11 | 0.50 | 1.71 | 0.03 | 0.01 | 0.04 |
| 1909 | 258 | 1.62 | 0.73 | 2.51 | 0.04 | 0.02 | 0.05 |
| 1910 | 346 | 2.16 | 0.97 | 3.34 | 0.05 | 0.03 | 0.07 |
| 1911 | 432 | 2.68 | 1.21 | 4.14 | 0.06 | 0.04 | 0.09 |
| 1912 | 520 | 3.21 | 1.45 | 4.97 | 0.07 | 0.04 | 0.10 |
| 1913 | 607 | 3.75 | 1.70 | 5.81 | 0.09 | 0.05 | 0.12 |
| 1914 | 695 | 4.30 | 1.94 | 6.65 | 0.10 | 0.06 | 0.14 |
| 1915 | 781 | 4.83 | 2.19 | 7.48 | 0.11 | 0.06 | 0.16 |
| 1916 | 2,620 | 15.53 | 7.31 | 23.74 | 0.36 | 0.21 | 0.51 |
| 1917 | 3,715 | 24.02 | 11.81 | 36.24 | 0.59 | 0.34 | 0.84 |
| 1918 | 5,887 | 34.43 | 17.36 | 51.49 | 0.86 | 0.50 | 1.22 |
| 1919 | 2,236 | 15.14 | 7.06 | 23.21 | 0.36 | 0.21 | 0.51 |
| 1920 | 1,257 | 11.03 | 5.19 | 16.86 | 0.27 | 0.16 | 0.38 |
| 1921 | 1,996 | 16.33 | 7.80 | 24.85 | 0.40 | 0.23 | 0.57 |
| 1922 | 1,017 | 8.43 | 3.89 | 12.97 | 0.20 | 0.12 | 0.29 |
| 1923 | 2,690 | 19.42 | 9.26 | 29.58 | 0.47 | 0.27 | 0.67 |
| 1924 | 2,518 | 19.94 | 9.60 | 30.27 | 0.49 | 0.28 | 0.70 |
| 1925 | 3,041 | 22.67 | 10.95 | 34.40 | 0.56 | 0.32 | 0.79 |
| 1926 | 2,546 | 18.50 | 8.71 | 28.28 | 0.44 | 0.25 | 0.63 |
| 1927 | 3,223 | 24.94 | 12.15 | 37.73 | 0.62 | 0.35 | 0.88 |
| 1928 | 2,428 | 21.44 | 10.39 | 32.50 | 0.54 | 0.31 | 0.77 |
| 1929 | 2,468 | 23.37 | 11.46 | 35.27 | 0.60 | 0.34 | 0.85 |
| 1930 | 3,131 | 27.04 | 13.33 | 40.75 | 0.69 | 0.39 | 0.98 |
| 1931 | 1,527 | 15.35 | 7.27 | 23.42 | 0.38 | 0.22 | 0.54 |
| 1932 | 1,858 | 17.73 | 8.46 | 27.01 | 0.44 | 0.25 | 0.63 |
| 1933 | 1,732 | 17.48 | 8.38 | 26.58 | 0.44 | 0.25 | 0.62 |
| 1934 | 2,742 | 25.78 | 12.72 | 38.84 | 0.65 | 0.37 | 0.94 |
| 1935 | 3,431 | 32.59 | 16.53 | 48.64 | 0.85 | 0.48 | 1.22 |
| 1936 | 3,109 | 25.32 | 12.21 | 38.42 | 0.61 | 0.35 | 0.88 |
| 1937 | 3,161 | 24.96 | 11.96 | 37.96 | 0.60 | 0.34 | 0.86 |
| 1938 | 2,838 | 23.25 | 11.10 | 35.41 | 0.55 | 0.31 | 0.79 |
| 1939 | 3,517 | 28.17 | 13.71 | 42.63 | 0.68 | 0.39 | 0.97 |
| 1940 | 2,376 | 20.35 | 9.63 | 31.08 | 0.48 | 0.27 | 0.69 |
| 1941 | 2,504 | 22.10 | 10.60 | 33.61 | 0.53 | 0.30 | 0.75 |
| 1942 | 3,777 | 36.48 | 18.82 | 54.14 | 0.92 | 0.53 | 1.32 |
| 1943 | 3,227 | 43.54 | 23.55 | 63.52 | 1.18 | 0.67 | 1.69 |
| 1944 | 2,824 | 46.62 | 25.65 | 67.59 | 1.30 | 0.74 | 1.86 |

Table 22: Time series of population estimates from the base-case model.

| Year | Total dead catch (mt) | Relative SPR (%) | ~95% low | ~95% high | Relative exploitation rate (%) | ~95% low | ~95% high |
|---|---|---|---|---|---|---|---|
| 1945 | 3,277 | 51.90 | 29.00 | 74.81 | 1.47 | 0.83 | 2.10 |
| 1946 | 4,863 | 51.99 | 28.34 | 75.64 | 1.39 | 0.79 | 2.00 |
| 1947 | 2,905 | 29.90 | 14.66 | 45.13 | 0.73 | 0.41 | 1.05 |
| 1948 | 3,337 | 37.50 | 19.21 | 55.79 | 0.96 | 0.54 | 1.39 |
| 1949 | 2,925 | 34.13 | 17.30 | 50.96 | 0.87 | 0.49 | 1.25 |
| 1950 | 2,382 | 31.54 | 16.00 | 47.09 | 0.82 | 0.46 | 1.17 |
| 1951 | 3,425 | 48.17 | 26.31 | 70.03 | 1.36 | 0.77 | 1.96 |
| 1952 | 2,148 | 31.56 | 16.11 | 47.02 | 0.83 | 0.47 | 1.20 |
| 1953 | 1,906 | 26.80 | 13.41 | 40.19 | 0.69 | 0.39 | 1.00 |
| 1954 | 2,639 | 36.40 | 18.97 | 53.83 | 0.99 | 0.56 | 1.42 |
| 1955 | 2,597 | 34.87 | 18.01 | 51.74 | 0.95 | 0.54 | 1.36 |
| 1956 | 1,948 | 48.00 | 26.64 | 69.37 | 1.53 | 0.86 | 2.19 |
| 1957 | 3,214 | 39.71 | 20.59 | 58.83 | 1.13 | 0.64 | 1.62 |
| 1958 | 1,536 | 24.06 | 11.75 | 36.37 | 0.68 | 0.39 | 0.98 |
| 1959 | 2,488 | 33.00 | 16.52 | 49.47 | 0.98 | 0.55 | 1.41 |
| 1960 | 3,378 | 40.33 | 20.57 | 60.08 | 1.27 | 0.71 | 1.83 |
| 1961 | 2,126 | 25.51 | 12.07 | 38.95 | 0.79 | 0.44 | 1.14 |
| 1962 | 2,036 | 32.72 | 16.04 | 49.40 | 1.14 | 0.62 | 1.66 |
| 1963 | 1,912 | 22.37 | 10.30 | 34.44 | 0.75 | 0.41 | 1.10 |
| 1964 | 2,032 | 23.17 | 10.63 | 35.71 | 0.82 | 0.43 | 1.21 |
| 1965 | 1,829 | 20.20 | 9.23 | 31.18 | 0.74 | 0.37 | 1.11 |
| 1966 | 1,486 | 17.76 | 9.17 | 26.35 | 0.68 | 0.34 | 1.02 |
| 1967 | 4,921 | 36.12 | 21.21 | 51.04 | 1.42 | 0.71 | 2.13 |
| 1968 | 2,845 | 23.18 | 13.23 | 33.13 | 0.84 | 0.51 | 1.17 |
| 1969 | 6,819 | 42.93 | 26.17 | 59.68 | 1.62 | 1.00 | 2.24 |
| 1970 | 3,431 | 36.73 | 22.08 | 51.39 | 1.36 | 0.84 | 1.89 |
| 1971 | 2,653 | 31.68 | 18.27 | 45.09 | 1.14 | 0.70 | 1.58 |
| 1972 | 5,919 | 49.78 | 28.94 | 70.62 | 1.92 | 1.14 | 2.70 |
| 1973 | 2,374 | 41.45 | 25.24 | 57.66 | 1.66 | 0.94 | 2.37 |
| 1974 | 7,284 | 59.93 | 39.76 | 80.10 | 2.41 | 1.28 | 3.54 |
| 1975 | 12,507 | 86.51 | 63.84 | 109.18 | 3.74 | 2.44 | 5.04 |
| 1976 | 22,949 | 118.11 | 95.83 | 140.40 | 6.46 | 4.27 | 8.65 |
| 1977 | 7,007 | 66.07 | 45.76 | 86.38 | 2.45 | 1.58 | 3.32 |
| 1978 | 9,946 | 85.94 | 62.62 | 109.25 | 3.53 | 2.27 | 4.79 |
| 1979 | 22,128 | 126.92 | 103.95 | 149.88 | 7.05 | 4.47 | 9.62 |
| 1980 | 6,375 | 71.86 | 50.37 | 93.35 | 2.65 | 1.69 | 3.60 |
| 1981 | 8,129 | 84.14 | 61.94 | 106.34 | 3.44 | 2.20 | 4.68 |
| 1982 | 10,561 | 114.97 | 92.27 | 137.68 | 6.05 | 3.84 | 8.26 |
| 1983 | 8,784 | 103.69 | 80.28 | 127.10 | 4.74 | 3.00 | 6.48 |

Table 22: Time series of population estimates from the base-case model.

| Year | Total dead catch (mt) | Relative SPR (%) | ~95% low | ~95% high | Relative exploitation rate (%) | ~95% low | ~95% high |
|---|---|---|---|---|---|---|---|
| 1984 | 6,920 | 102.86 | 78.54 | 127.19 | 4.63 | 2.91 | 6.36 |
| 1985 | 10,026 | 107.42 | 83.11 | 131.73 | 4.71 | 2.95 | 6.48 |
| 1986 | 10,272 | 107.30 | 82.88 | 131.72 | 4.63 | 2.86 | 6.40 |
| 1987 | 10,109 | 107.54 | 82.86 | 132.21 | 4.78 | 2.91 | 6.64 |
| 1988 | 8,426 | 98.80 | 73.99 | 123.60 | 4.22 | 2.55 | 5.89 |
| 1989 | 7,093 | 95.64 | 70.78 | 120.50 | 4.02 | 2.43 | 5.62 |
| 1990 | 6,225 | 87.68 | 63.33 | 112.03 | 3.56 | 2.14 | 4.99 |
| 1991 | 8,060 | 91.17 | 66.49 | 115.85 | 3.80 | 2.28 | 5.33 |
| 1992 | 7,064 | 90.33 | 65.64 | 115.01 | 3.83 | 2.28 | 5.38 |
| 1993 | 5,573 | 82.93 | 58.95 | 106.91 | 3.32 | 1.97 | 4.67 |
| 1994 | 6,220 | 81.01 | 57.24 | 104.78 | 3.00 | 1.79 | 4.21 |
| 1995 | 7,134 | 86.36 | 61.97 | 110.75 | 3.23 | 1.91 | 4.54 |
| 1996 | 7,525 | 92.48 | 67.42 | 117.54 | 3.56 | 2.10 | 5.02 |
| 1997 | 8,010 | 93.26 | 67.98 | 118.55 | 3.58 | 2.09 | 5.08 |
| 1998 | 4,098 | 62.69 | 41.84 | 83.53 | 2.01 | 1.17 | 2.86 |
| 1999 | 6,387 | 87.32 | 62.62 | 112.02 | 2.99 | 1.75 | 4.24 |
| 2000 | 6,514 | 88.12 | 63.15 | 113.10 | 3.07 | 1.78 | 4.37 |
| 2001 | 5,591 | 82.41 | 57.98 | 106.85 | 3.00 | 1.72 | 4.29 |
| 2002 | 4,110 | 59.43 | 39.24 | 79.62 | 2.08 | 1.19 | 2.97 |
| 2003 | 5,560 | 72.12 | 49.62 | 94.61 | 2.64 | 1.53 | 3.74 |
| 2004 | 6,054 | 73.88 | 51.13 | 96.63 | 2.68 | 1.58 | 3.79 |
| 2005 | 6,844 | 78.41 | 54.89 | 101.93 | 2.85 | 1.68 | 4.01 |
| 2006 | 6,480 | 79.78 | 56.02 | 103.54 | 2.91 | 1.71 | 4.11 |
| 2007 | 4,970 | 74.16 | 51.14 | 97.19 | 2.59 | 1.51 | 3.67 |
| 2008 | 5,461 | 87.02 | 61.94 | 112.09 | 3.03 | 1.75 | 4.31 |
| 2009 | 7,662 | 108.80 | 82.08 | 135.51 | 4.09 | 2.32 | 5.85 |
| 2010 | 7,937 | 112.32 | 85.00 | 139.63 | 4.19 | 2.33 | 6.04 |
| 2011 | 8,206 | 112.51 | 84.54 | 140.47 | 4.23 | 2.30 | 6.15 |
| 2012 | 6,537 | 101.18 | 72.54 | 129.81 | 3.26 | 1.78 | 4.74 |
| 2013 | 4,763 | 85.45 | 57.73 | 113.18 | 2.70 | 1.45 | 3.96 |
| 2014 | 4,960 | 84.41 | 56.49 | 112.34 | 2.71 | 1.46 | 3.97 |
| 2015 | 7,516 | 100.50 | 70.71 | 130.29 | 4.08 | 2.17 | 5.99 |

[1]OFL/ACL values for 2015 and 2016 have already been adopted, and are not based on the results of this assessment.

Table 23: Comparison among sensitivity results to the inclusion of environmental indicies.

| Component | Base case | SSH index | Zoo index |
|---|---|---|---|
| Negative log-likelihoods | | | |
| Total | 5077.15 | 5169.30 | 5169.63 |
| Indices | -35.83 | 14.48 | -10.15 |
| Discard | -78.42 | -78.45 | -78.16 |
| Mean Body Wght | -20.46 | -18.27 | -19.77 |
| Length-frequency data | 1474.49 | 1490.30 | 1502.73 |
| Age-frequency data | 3708.83 | 3723.81 | 3742.57 |
| Recruitment | 25.48 | 34.94 | 29.19 |
| Forecast Recruitment | 0.00 | 0.00 | 0.00 |
| Select parameters | | | |
| Priors | 3.07 | 2.48 | 3.23 |
| Equilibrium recruitment (R0,age-0) | 16831.71 | 13150.90 | 16459.50 |
| Steepness (h) | 0.60 | 0.60 | 0.60 |
| Management quantities | | | |
| Female M | 0.08 | 0.08 | 0.07 |
| Male M | 0.06 | 0.07 | 0.06 |
| Equilibrium spawning biomass (SB0) | 147209.00 | 106353.00 | 147132.00 |
| 2015 Spawning depletion | 0.33 | 0.38 | 0.35 |
| 2014 SPR | 0.84 | 0.96 | 0.81 |
| Recruitment 2012 | 4061.23 | 3067.25 | 7789.38 |
| MSY (mt) | 7639.43 | 5812.38 | 7558.06 |

Table 24: Projection of potential sablefish OFL, ACL, and estimated spawning biomass and depletion for the base-case model based on the 40:10 correction to the $F_{45}$% overfishing limit/target (OFL) and an 8.7% reduction to approximate the P* approach. Catch allocation used for the forecast reflects the average distribution of fishing intensity among fleets (hook-and-line, pot, and trawl) during 2012-2013.

| Year | OFL[1] (mt) | ABC[1] (mt) | ACL[1] (mt) | Spawning biomass (mt) | Relative depletion |
|---|---|---|---|---|---|
| 2015 | 7857 | 7173 | 6512 | 6512 | 33% |
| 2016 | 8526 | 7784 | 7121 | 7121 | 35% |
| 2017 | 7596 | 6935 | 6602 | 51469 | 35% |
| 2018 | 7879 | 7194 | 6902 | 52503 | 36% |
| 2019 | 8050 | 7350 | 7086 | 53162 | 36% |
| 2020 | 8217 | 7502 | 7253 | 53544 | 36% |
| 2021 | 8286 | 7565 | 7323 | 53727 | 36% |
| 2022 | 8185 | 7473 | 7238 | 53812 | 37% |
| 2023 | 8105 | 7400 | 7172 | 53913 | 37% |
| 2024 | 8070 | 7368 | 7148 | 54039 | 37% |
| 2025 | 8043 | 7343 | 7131 | 54182 | 37% |
| 2026 | 8018 | 7320 | 7116 | 54330 | 37% |

Table 25: Decision table of 12-year projections for alternate states of nature (columns) and management options (rows) beginning in 2017. The percentiles of the asymptotic distribution are used to describe the relative probabilities among the states of nature. Values of relative SPR that exceed 100% indicate overfishing; order is reversed to maintain the 'lower-to-higher' pattern consistent with other quantities, i.e., larger values implying greater relative fishing intensity are reported on the left side of the table. The results of this table are conditioned on the already-specified ACLs for 2015 and 2016 being achieved exactly.

| **Management alt** | | | **State of nature** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $12.5^{th}$ pctl | | | Max likelihood est. | | | $87.5^{th}$ pctl | | |
| | Year | Dead catch (mt) | Depl | Rel SPR | Spawning biomass (mt) | Depl | Rel SPR | Spawning biomass (mt) | Depl | Rel SPR | Spawning biomass (mt) |
| $12.5^{th}$ | 2017 | 4053 | 27% | 80% | 36215 | 35% | 64% | 51469 | 43% | 49% | 66724 |
| pctl | 2018 | 4389 | 28% | 81% | 37517 | 36% | 66% | 53472 | 45% | 50% | 69427 |
| 40:10 | 2019 | 4659 | 29% | 83% | 38423 | 37% | 67% | 55174 | 46% | 50% | 71925 |
| catch | 2020 | 4914 | 29% | 85% | 38913 | 38% | 67% | 56605 | 48% | 49% | 74296 |
| | 2021 | 5091 | 29% | 87% | 39061 | 39% | 68% | 57816 | 49% | 49% | 76572 |
| | 2022 | 5143 | 29% | 89% | 38994 | 40% | 68% | 58878 | 51% | 48% | 78761 |
| | 2023 | 5188 | 29% | 91% | 38849 | 41% | 69% | 59869 | 52% | 47% | 80890 |
| | 2024 | 5244 | 29% | 92% | 38682 | 41% | 69% | 60813 | 54% | 47% | 82944 |
| | 2025 | 5293 | 29% | 93% | 38521 | 42% | 70% | 61717 | 55% | 47% | 84913 |
| | 2026 | 5334 | 29% | 94% | 38375 | 43% | 70% | 62583 | 56% | 46% | 86792 |
| | 2017 | 6602 | 27% | 110% | 36215 | 35% | 91% | 51469 | 43% | 73% | 66724 |
| | 2018 | 6902 | 27% | 111% | 36565 | 36% | 92% | 52518 | 44% | 73% | 68470 |
| 40:10 | 2019 | 7086 | 27% | 113% | 36440 | 36% | 92% | 53190 | 45% | 71% | 69939 |
| catch | 2020 | 7253 | 27% | 114% | 35897 | 36% | 92% | 53587 | 46% | 70% | 71277 |
| | 2021 | 7323 | 26% | 116% | 35050 | 37% | 92% | 53796 | 47% | 68% | 72542 |
| | 2022 | 7238 | 26% | 118% | 34052 | 37% | 92% | 53909 | 48% | 67% | 73765 |
| | 2023 | 7172 | 25% | 119% | 33057 | 37% | 92% | 54027 | 49% | 65% | 74997 |
| | 2024 | 7148 | 24% | 120% | 32105 | 37% | 92% | 54162 | 49% | 64% | 76219 |
| | 2025 | 7131 | 24% | 121% | 31210 | 37% | 92% | 54312 | 50% | 63% | 77414 |
| | 2026 | 7116 | 23% | 122% | 30366 | 37% | 92% | 54469 | 51% | 63% | 78572 |
| $87.5^{th}$ | 2017 | 9151 | 27% | 130% | 36215 | 35% | 111% | 51469 | 43% | 92% | 66724 |
| pctl | 2018 | 9415 | 27% | 132% | 35614 | 35% | 112% | 51564 | 43% | 92% | 67513 |
| 40:10 | 2019 | 9514 | 26% | 134% | 34466 | 35% | 112% | 51213 | 44% | 90% | 67959 |
| catch | 2020 | 9592 | 25% | 137% | 32913 | 34% | 113% | 50593 | 44% | 89% | 68274 |
| | 2021 | 9556 | 24% | 139% | 31101 | 34% | 113% | 49821 | 44% | 87% | 68541 |
| | 2022 | 9334 | 22% | 141% | 29207 | 33% | 113% | 49009 | 44% | 85% | 68811 |
| | 2023 | 9157 | 21% | 143% | 27394 | 33% | 113% | 48276 | 45% | 83% | 69157 |
| | 2024 | 9051 | 20% | 145% | 25685 | 32% | 113% | 47619 | 45% | 82% | 69553 |
| | 2025 | 8968 | 19% | 146% | 24071 | 32% | 114% | 47023 | 45% | 81% | 69975 |
| | 2026 | 8897 | 17% | 148% | 22535 | 32% | 114% | 46471 | 46% | 80% | 70407 |

# 10 Figures

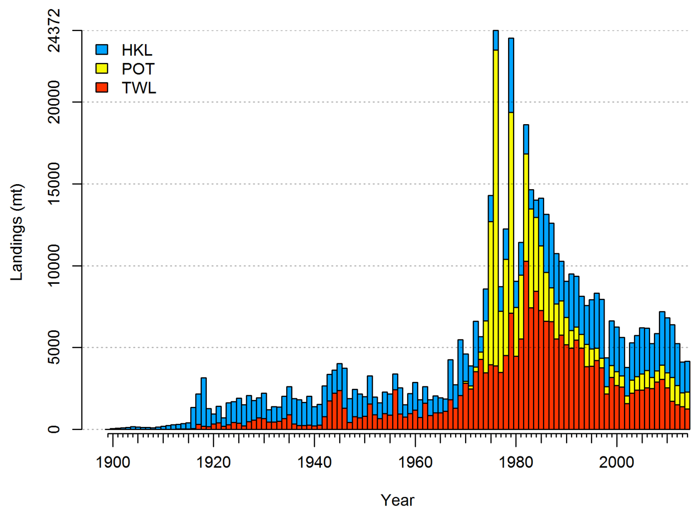



Figure 9: Sablefish landings history, 1900-2014. Fleet names indicate gear type (HKL = Hook-and-line, POT = Pot, and TWL = Trawl). Foreign fleets are included and are largely responsible for the peak landings in 1976 and 1979.

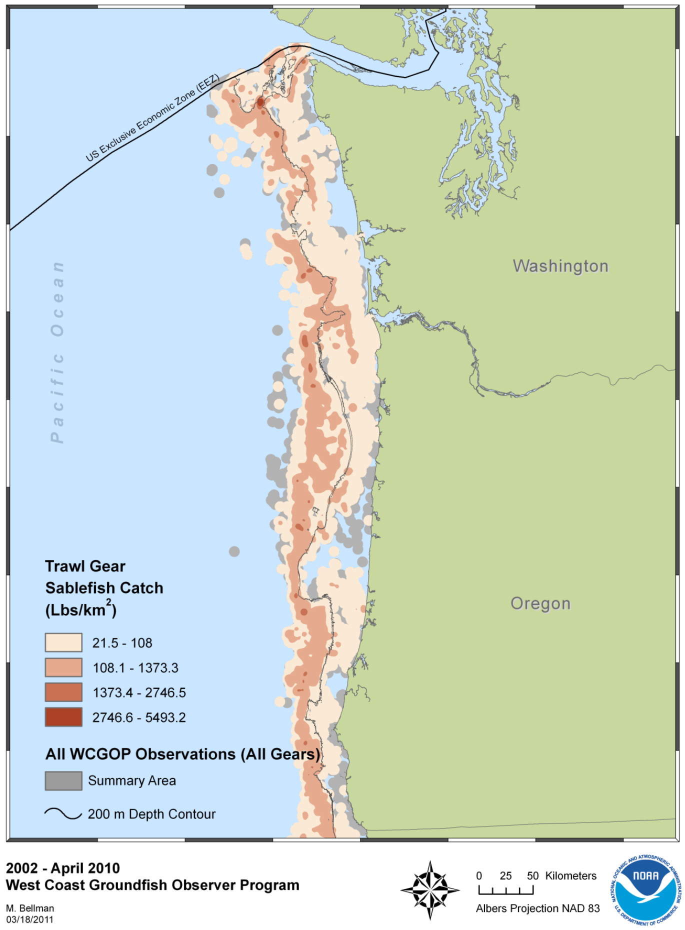



Figure 10: Spatial distribution of sablefish catch by all trawl fisheries (lbs/$km^2$) observed by the West Coast Groundfish Observer Program from 2002 April 2010 in Oregon and Washington.

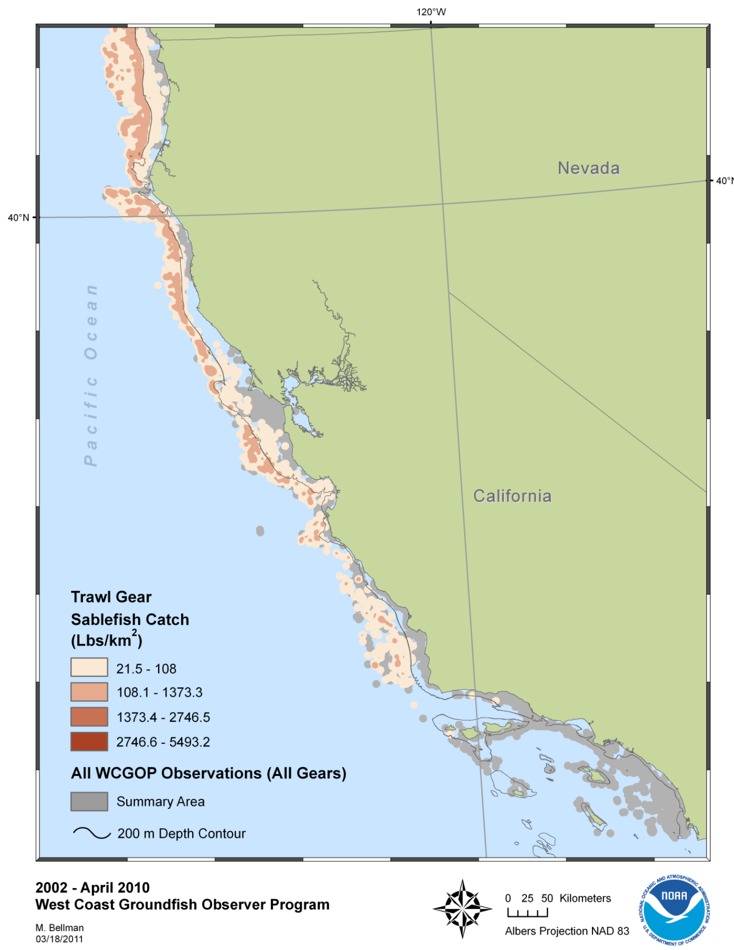



Figure 11: Spatial distribution of sablefish catch by all trawl fisheries (lbs/$km^2$) observed by the West Coast Groundfish Observer Program from 2002 April 2010 in California.

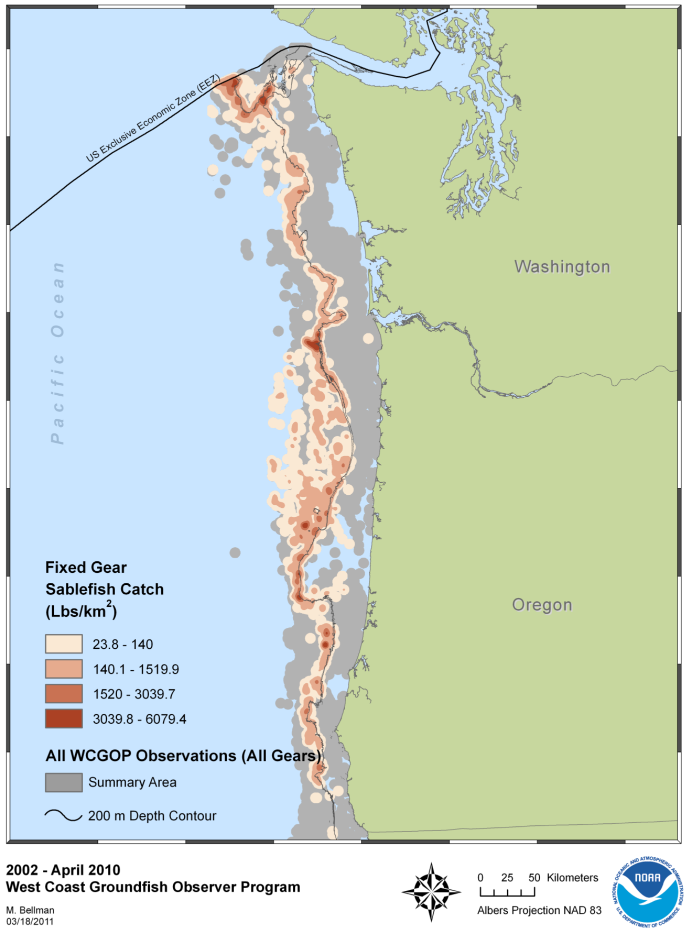



Figure 12: Spatial distribution of sablefish catch by all fixed-gear fisheries (lbs/$km^2$) observed by the West Coast Groundfish Observer Program from 2002 April 2010 in Oregon and Washington.

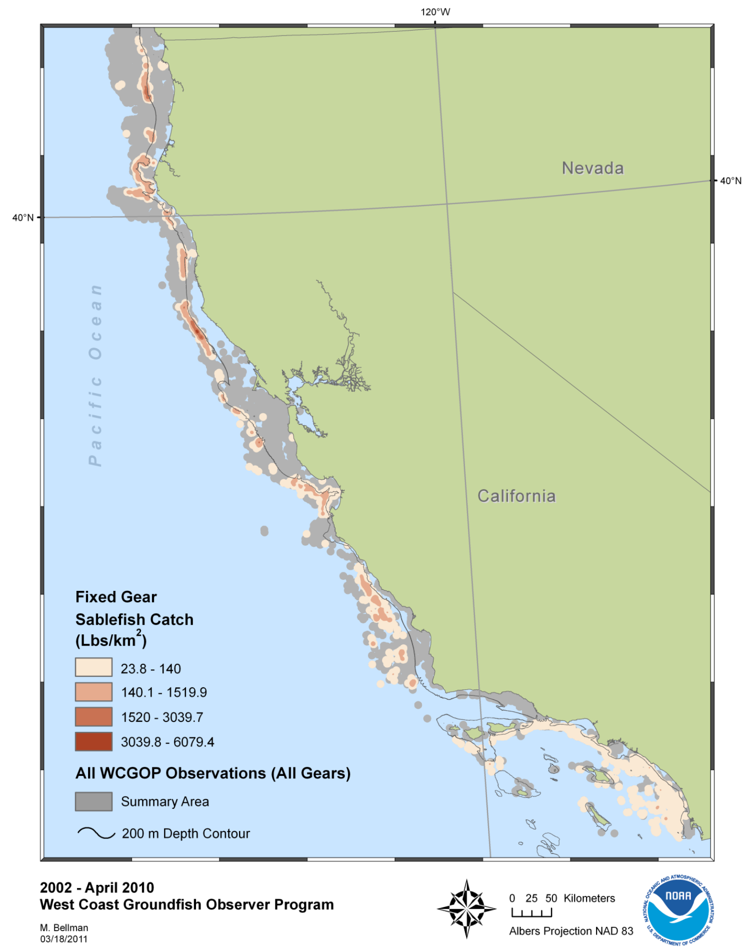



Figure 13: Spatial distribution of sablefish catch by all fixed-gear fisheries (lbs/$km^2$) observed by the West Coast Groundfish Observer Program from 2002 April 2010 in California.

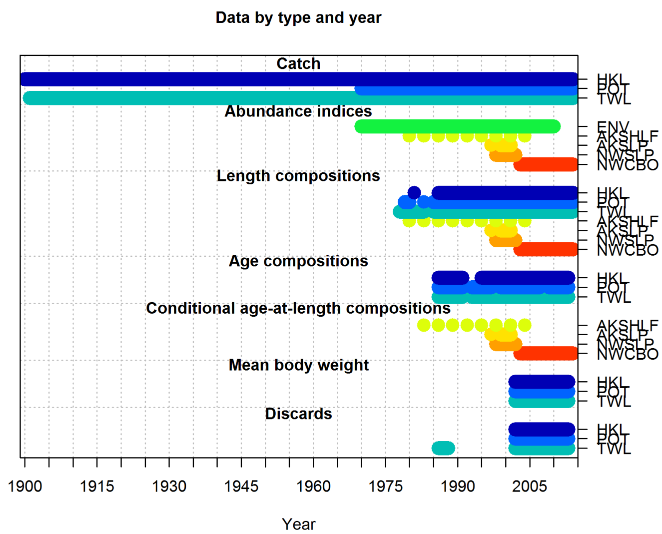



Figure 14: Overview of data sources used in this stock assessment.

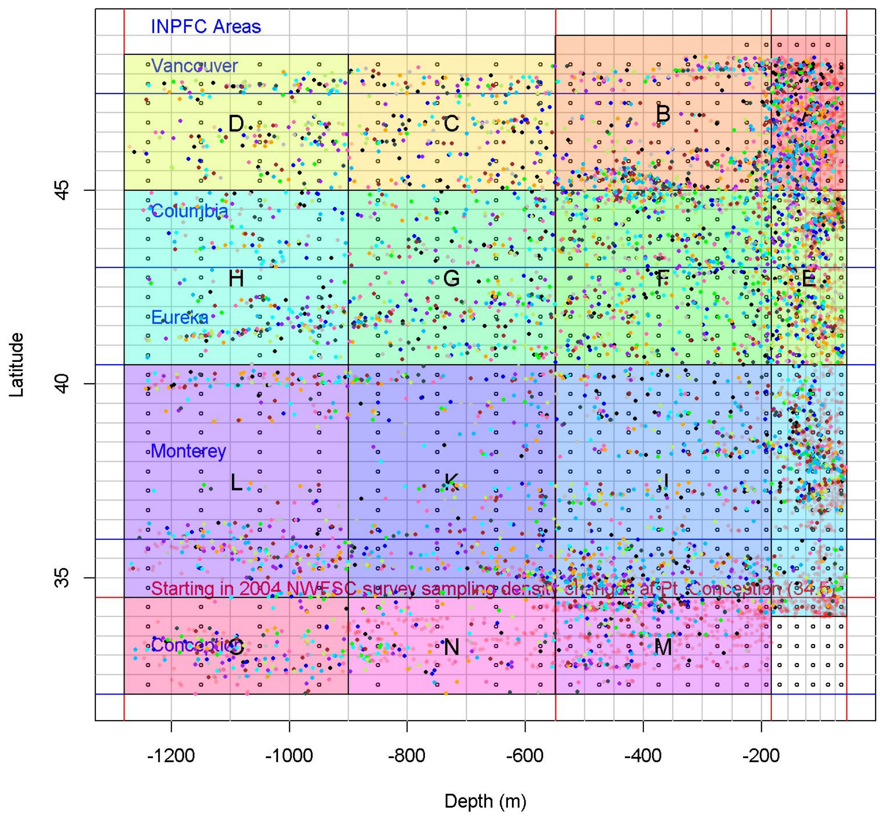



Figure 15: Strata used in the delta-GLMM for the NWFSC Slope-Shelf Survey. Solid circles represent tows with positive values for catches of sablefish in each of the International North Pacific Fisheries Commission areas.

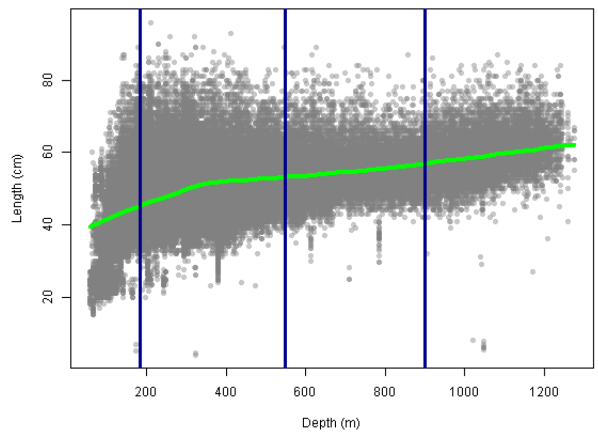



Figure 16: Pattern in size by depth of sablefish captured by the NWFSC Shelf-Slope trawl survey. A loess smoother has been added to aid in visualizing the central tendency of the data. Horizontal vertical lines indicate strata boundaries.

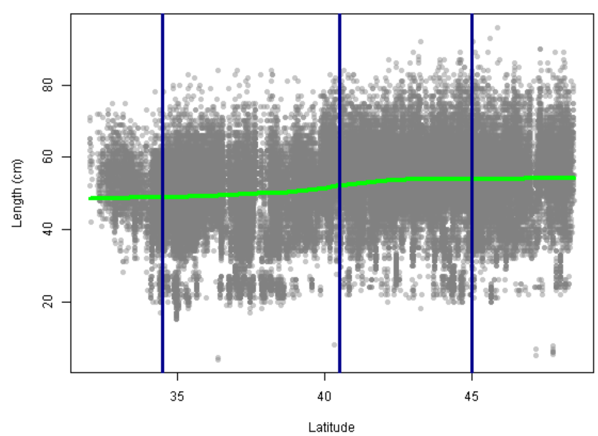



Figure 17: Latitudinal pattern in size of sablefish captured by the NWFSC Shelf-Slope trawl survey. A loess smoother has been added to aid in visualizing the central tendency of the data. Horizontal Vertical lines indicate strata boundaries.

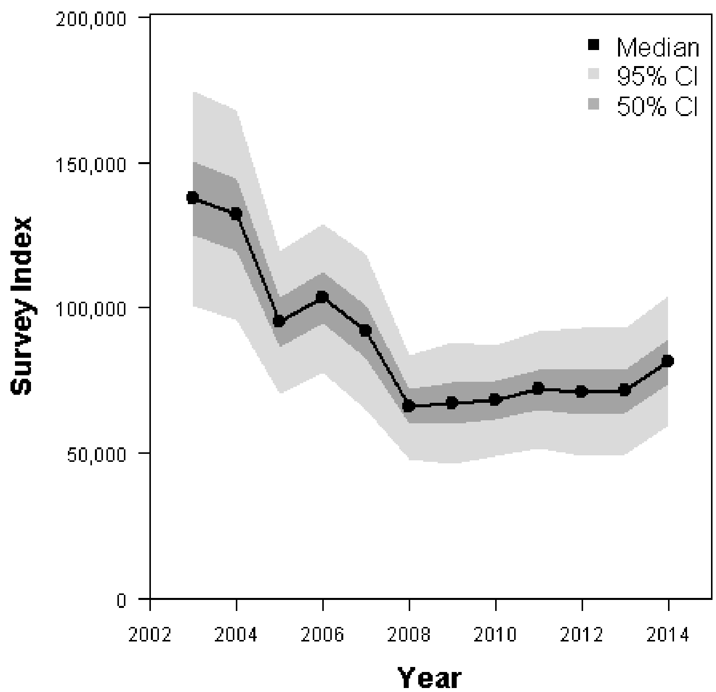



Figure 18: Chosen index of relative abundance for the NWFSC Shelf-Slope survey using data from 2003-2014, with 50 and 95% intervals.

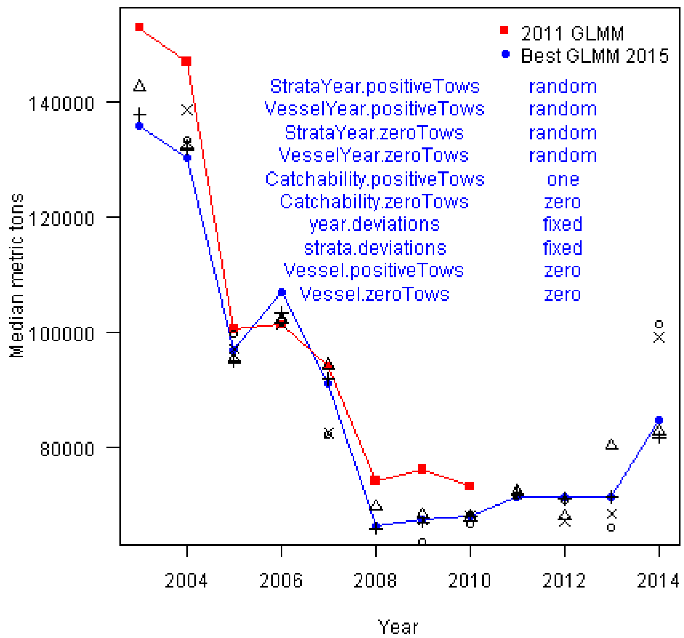



Figure 19: Chosen index of relative abundance for the NWFSC Shelf-Slope survey (blue) compared to the 2011 index of relative abundance (red) and other models tested (open shapes).

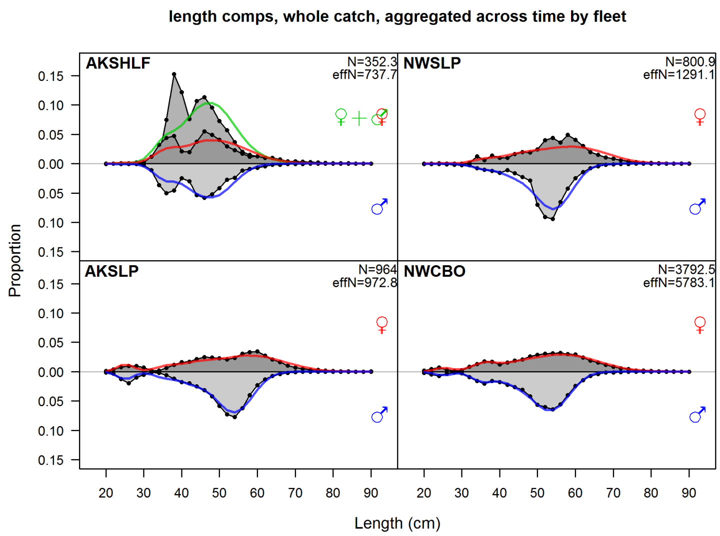



Figure 20: Length-frequency distributions for sablefish aggregated across all years from fishery-independent surveys.

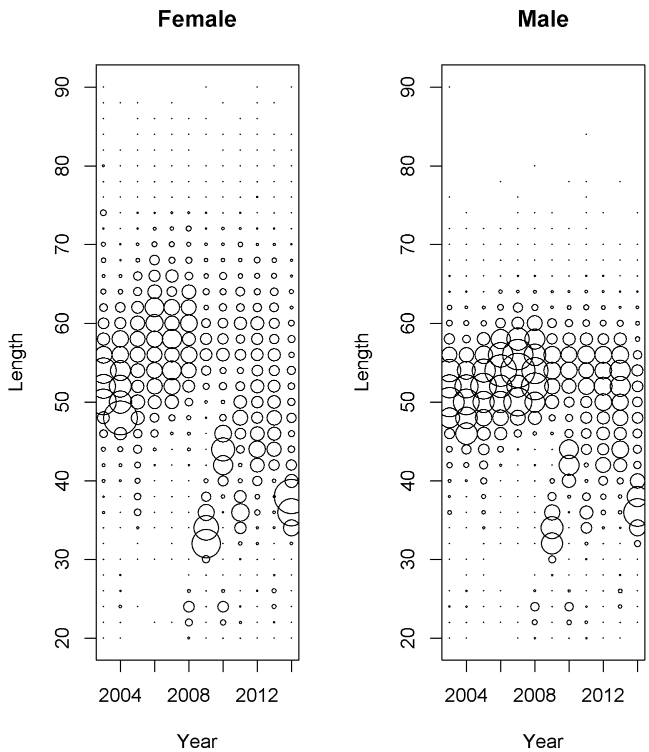



Figure 21: Length-frequency distributions (2 cm size bin) for female (left) and male (right) sablefish from the NWFSC Shelf-Slope survey. Distributions sum to 1.0 in each year; the largest bubble sizes indicate proportions of 0.08 (females) and 0.11 (males).

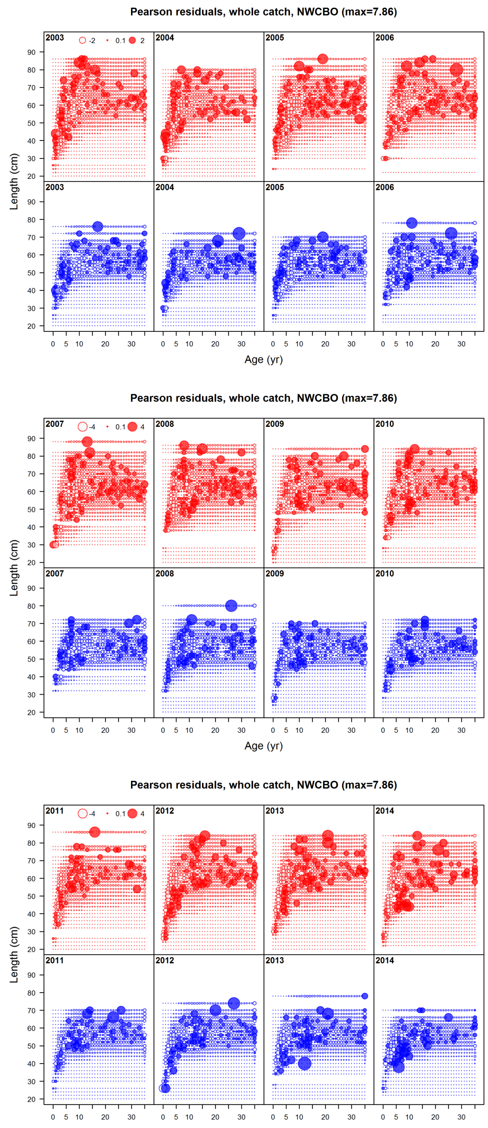



Figure 22: Pearson residuals for the NWFSC Shelf-Slope survey combined-sex retained conditional age-frequency data (maximum = 7.86). Filled circles represent positive residuals (observed  expected).

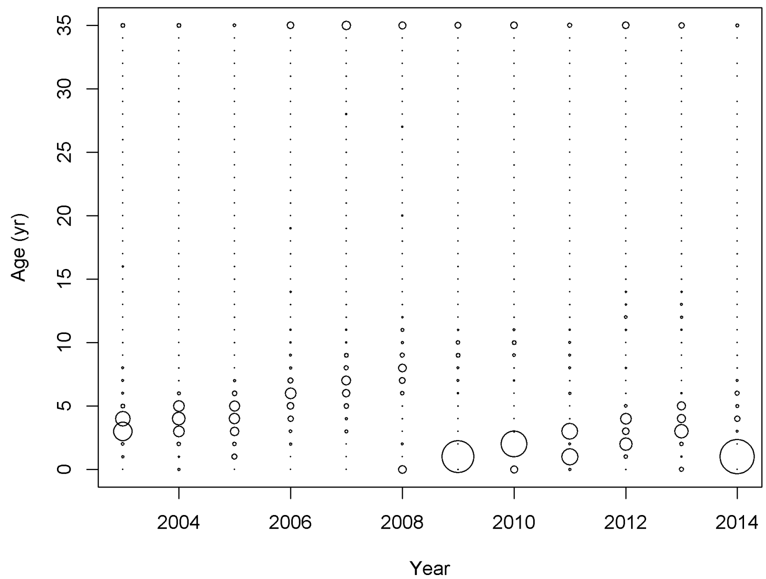



Figure 23: Combined-sex marginal age-frequency distributions for sablefish from the NWFSC Shelf-Slope survey. Maximum bubble size indicates a proportion of 0.51. This summary is for inspection of the data only and is not included in the objective function.

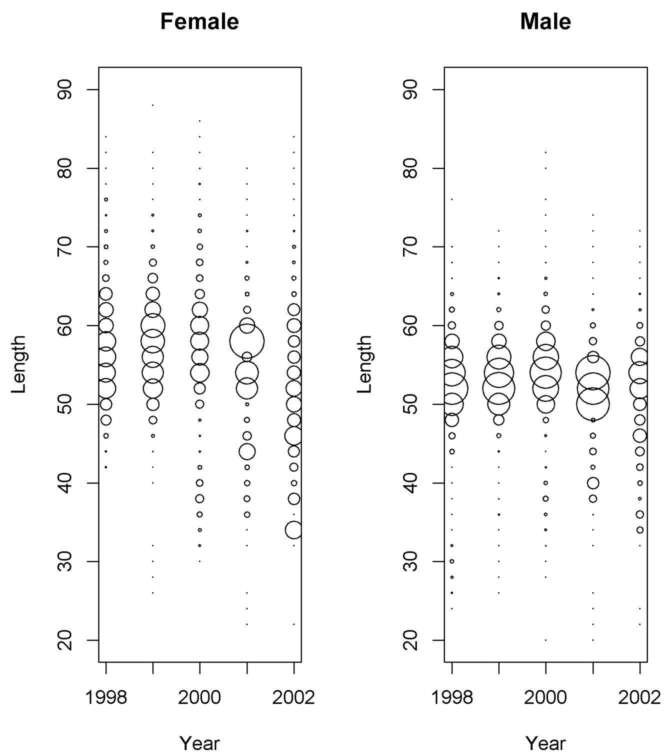
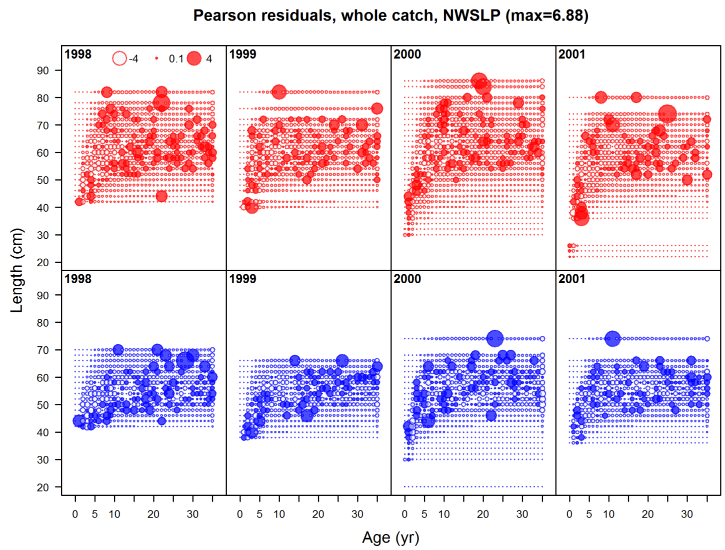



Figure 24: Length-frequency distributions for female (left panel) and male (right panel) sablefish from the NWFSC slope survey. Distributions sum to 1.0 in each year; the largest bubble sizes indicate proportions of 0.06 (females) and 0.11 (males).



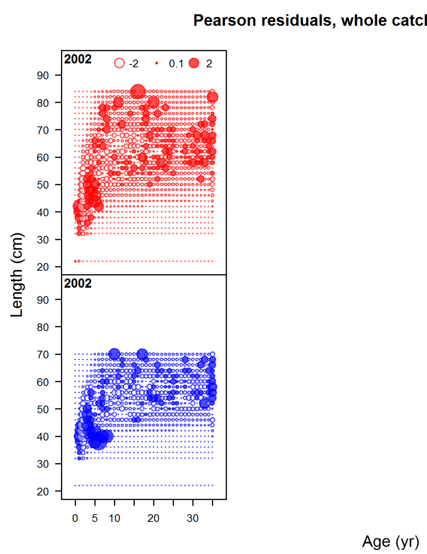




Figure 25: Conditional age-frequency distributions for female and male sablefish from the NWFSC slope survey.

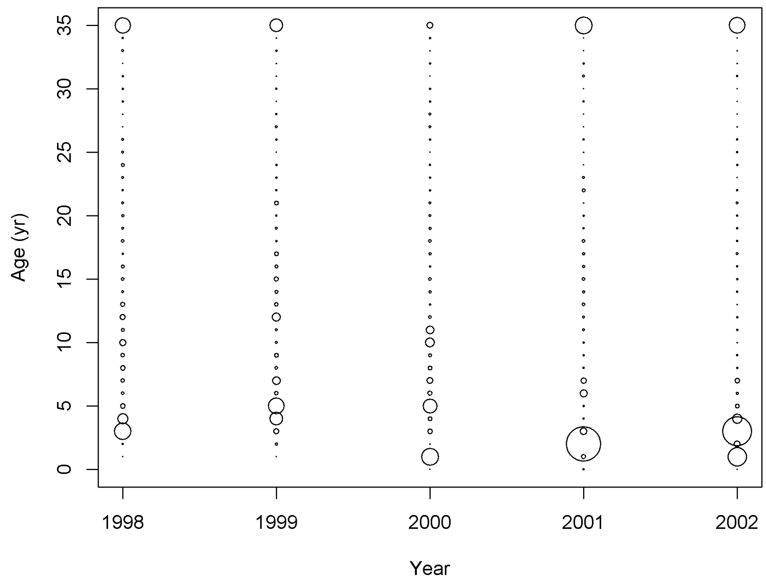



Figure 26: Combined-sex marginal age-frequency distributions for sablefish from the NWFSC Slope survey. Maximum bubble size indicates a proportion of 0.27. This summary is for inspection of the data only and is not included in the objective function.

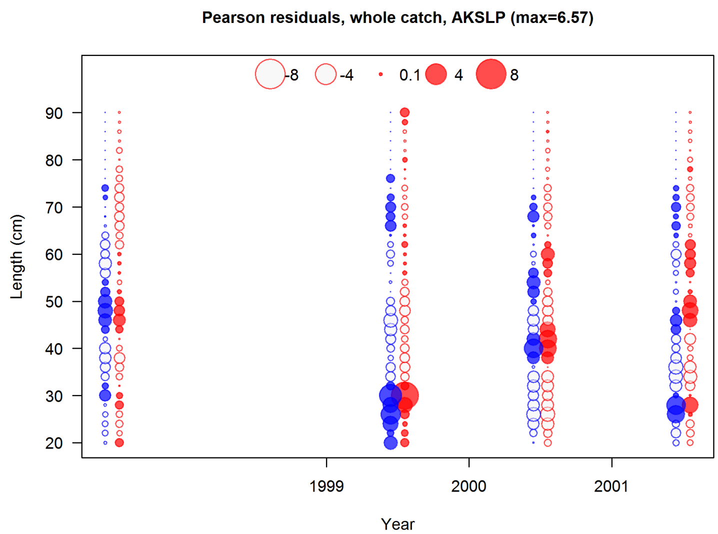



Figure 27: Length-frequency distributions for female sablefish from the AFSC slope survey.

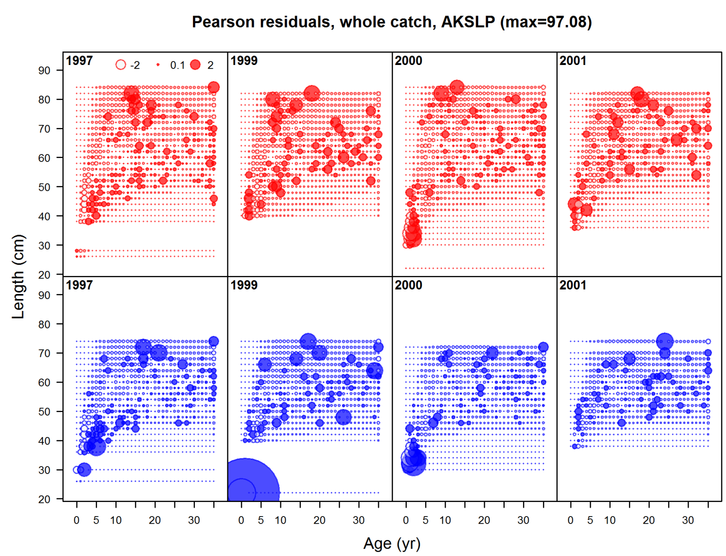



Figure 28: Pearson residuals for the AKFSC slope survey combined-sex retained conditional age-frequency data (maximum = 97.08). Filled circles represent positive residuals (observed expected).

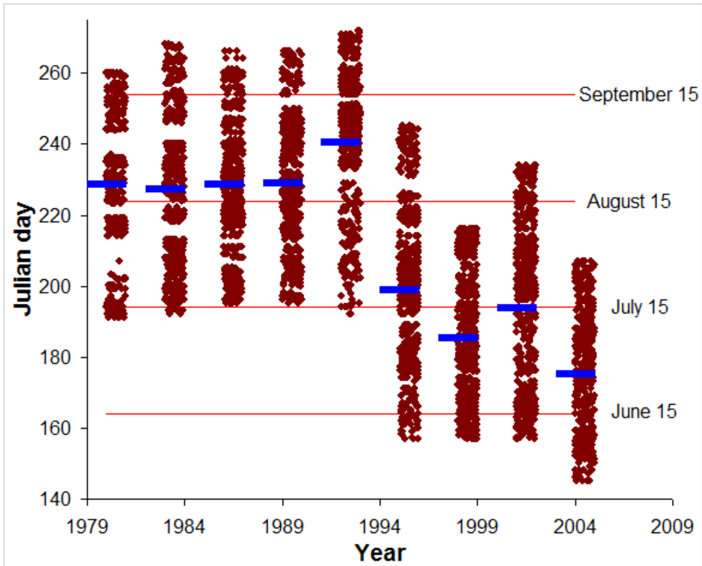



Figure 29: Distribution of dates of operation for the AFSC triennial bottom trawl survey (1980-2004). Solid bars show the mean date for each survey year, points represent individual hauls dates, but are jittered to allow better delineation of the distribution of individual points.

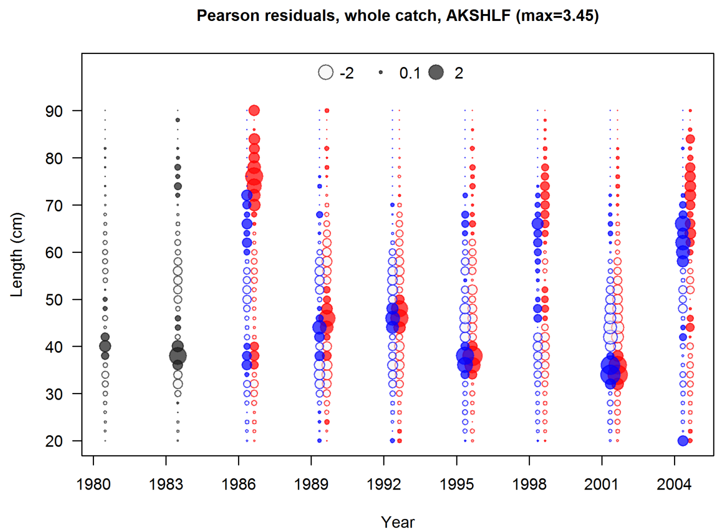
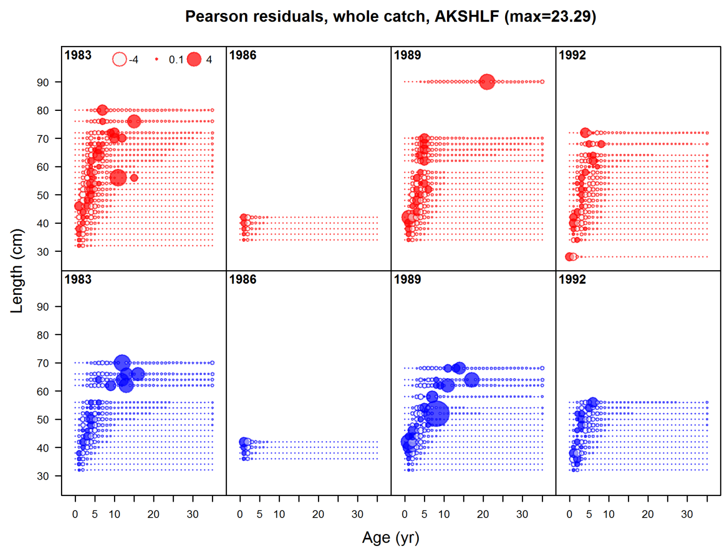



Figure 30: Length-frequency distributions for female and male sablefish from the AFSC triennial shelf survey. Black circles represent combined sexes from the early years where samples were unsexed.



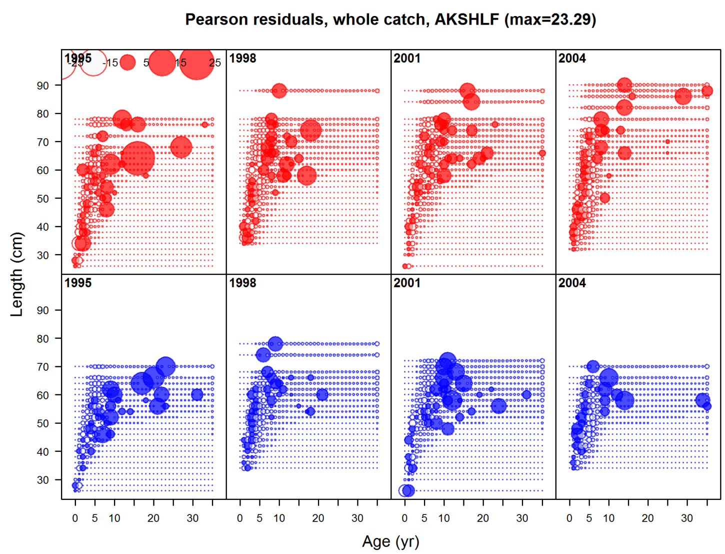




Figure 31: Pearson residuals for the AKFSC shelf survey combined-sex retained conditional age-frequency data (maximum = 23.29). Filled circles represent positive residuals (observed  expected).

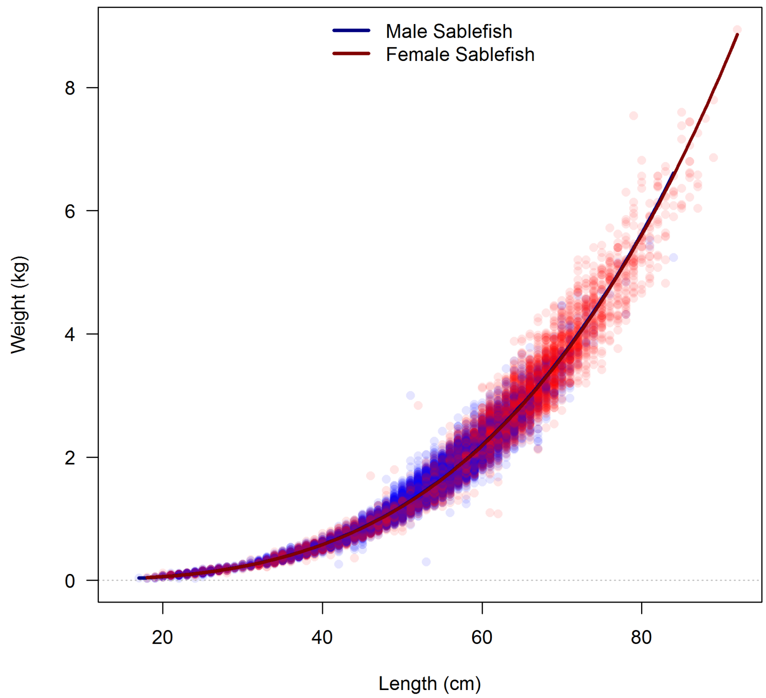



Figure 32: W-L relationship for male and female sablefish estimated. Data represent all available commercial and survey length-individual weight observations.

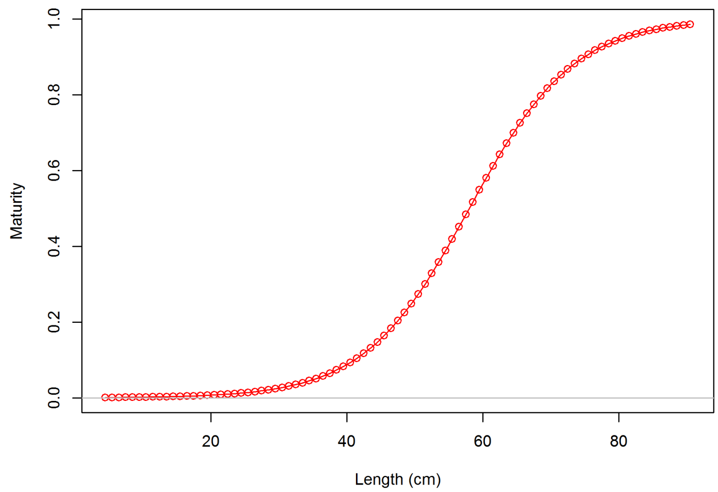



Figure 33: Female maturity curve derived from published studies.

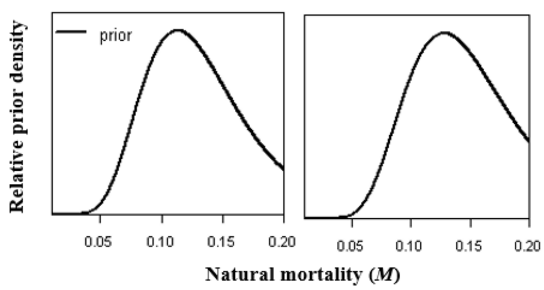



Figure 34: Prior for female (left panel) and male (right panel) natural mortality ($M$).

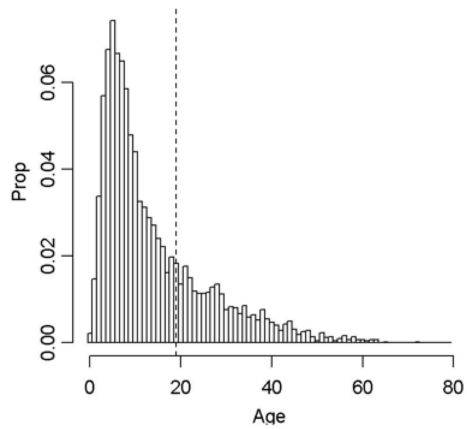



Figure 35: Summary of all age reads included in the analysis of within- and among-aging lab bias and imprecision. Vertical line indicates the AIC-selected maximum age for estimated proportions in the underlying sample.

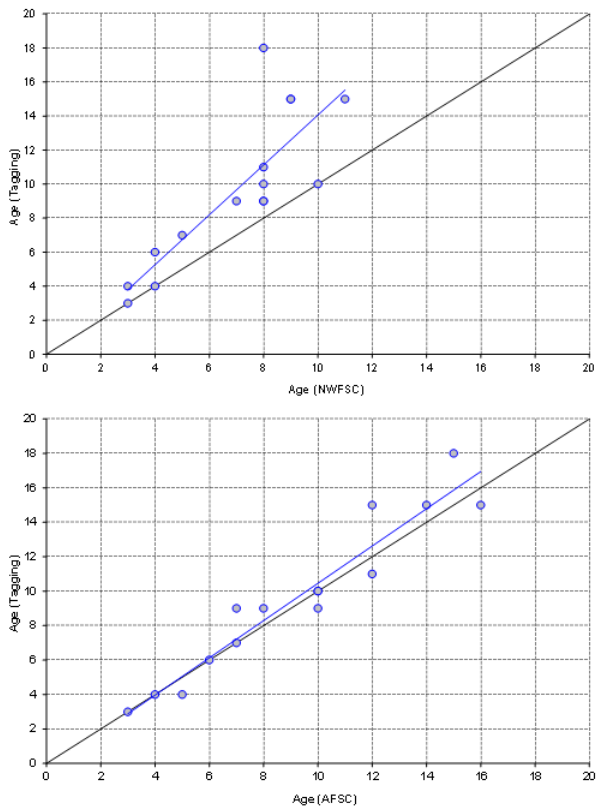



Figure 36: Summary of age reads from tagged sablefish. Full diagonal line indicates the one-one relationship, shorter line a linear fit to age estimates.

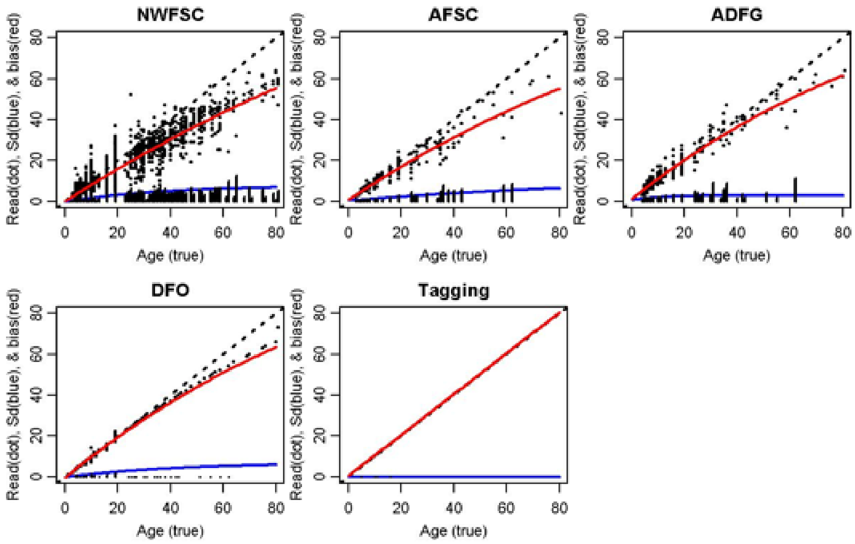



Figure 37: Summary of ageing bias, and imprecision, for various ageing labs used in preliminary modeling. Black points represent observed ages, black bars the observed standard deviation of observed age at estimated true age. Dashed line indicates a 1:1 relationship. Solid lines indicate the predicted observed age at estimated true age (upper line in each panel) and the predicted standard deviation of observed age at estimated true age (lower line in each panel).

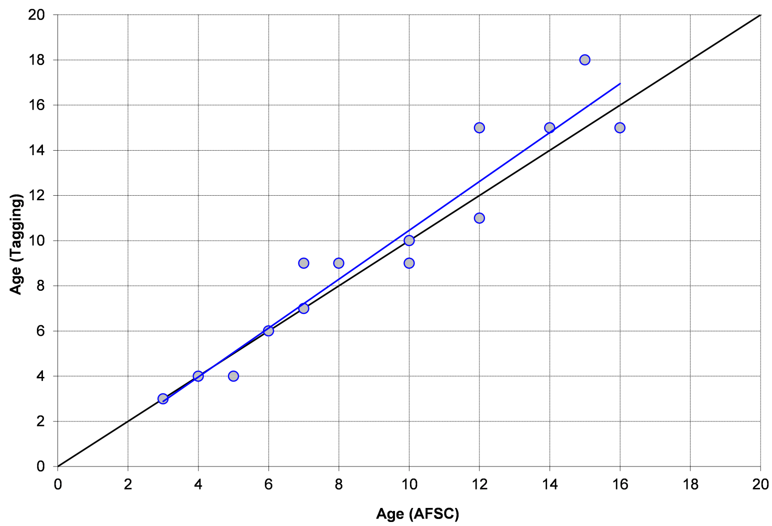



Figure 38: Summary of age reads from west coast sablefish. Diagonal lines for both the one-one relationship and a linear fit to age estimates are plotted.

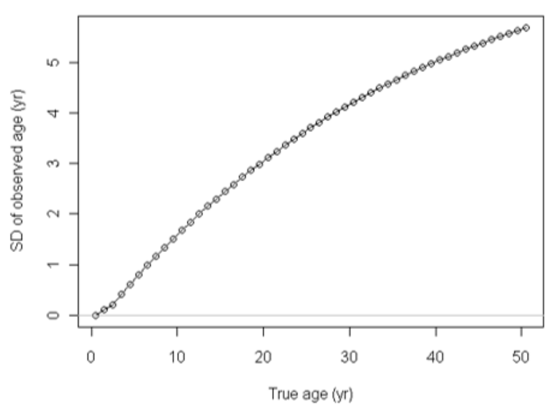



Figure 39: Externally estimated relationship describing the variability of observed age conditioned on true age.

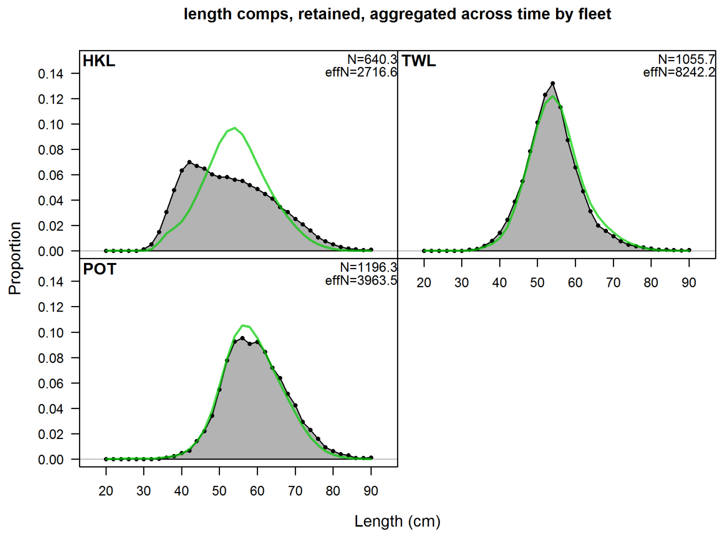
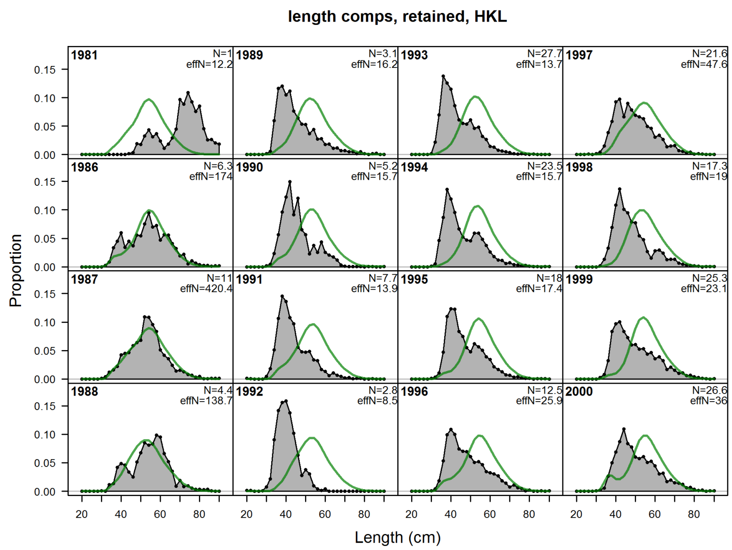



Figure 40: Aggregate length-frequency distributions for sexes-combined sablefish from retained catch sampling of commercial fisheries in all years.



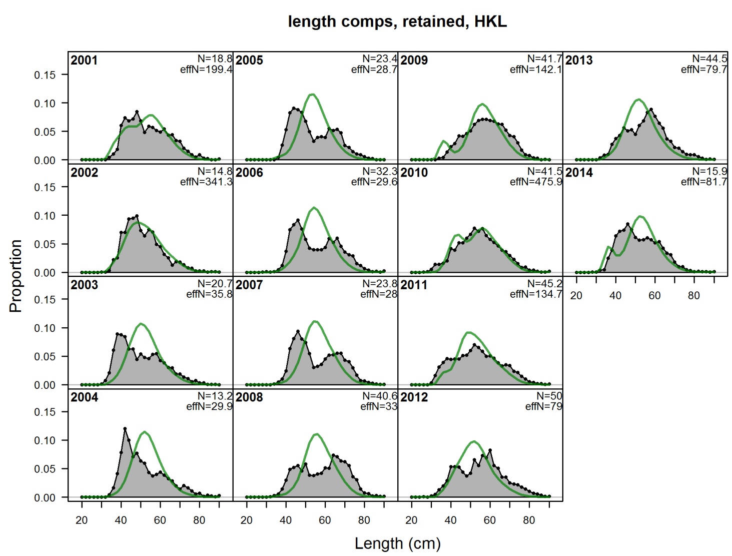




Figure 41: Length-frequency distributions for sexes-combined sablefish from the retained catch in the hook-and-line fishery.

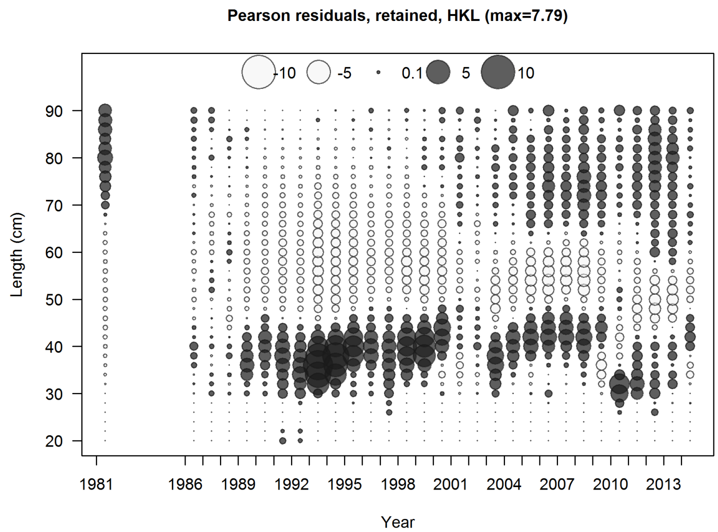



Figure 42: Pearson residuals for the fit to the hook-and-line combined-sex retained length-frequency data (maximum = 7.79). Filled circles represent positive residuals (observed  expected).

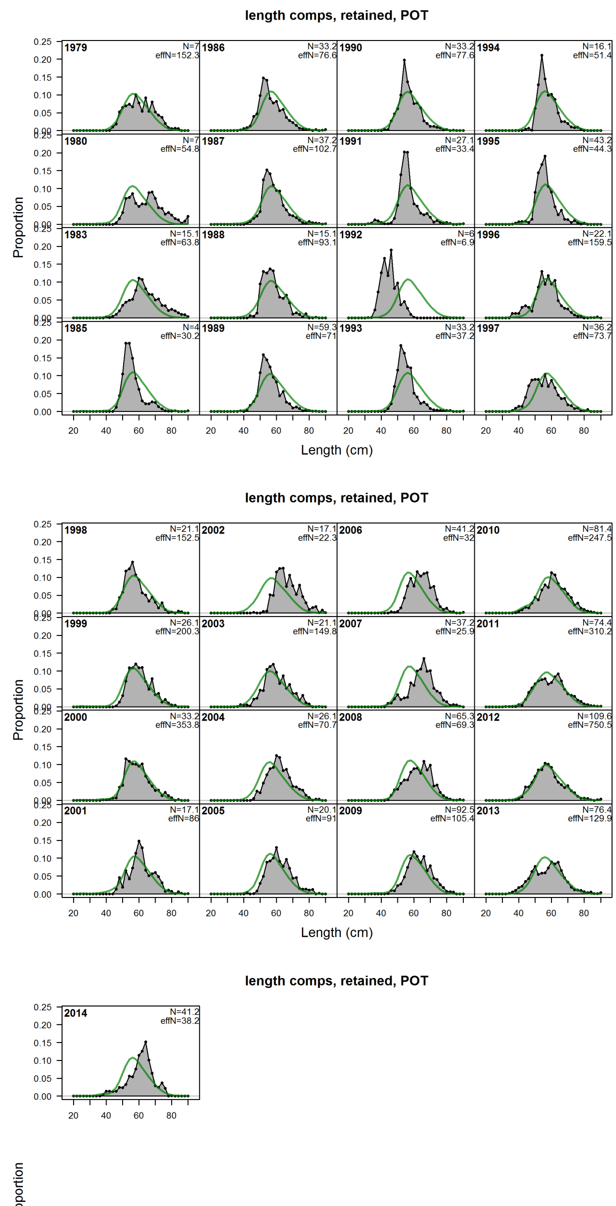



Figure 43: Length-frequency distributions for sexes-combined sablefish from the retained catch in the pot fishery.

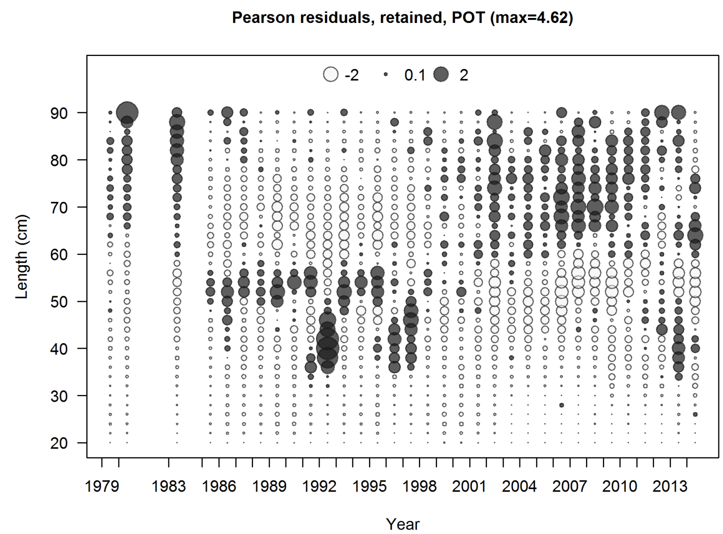
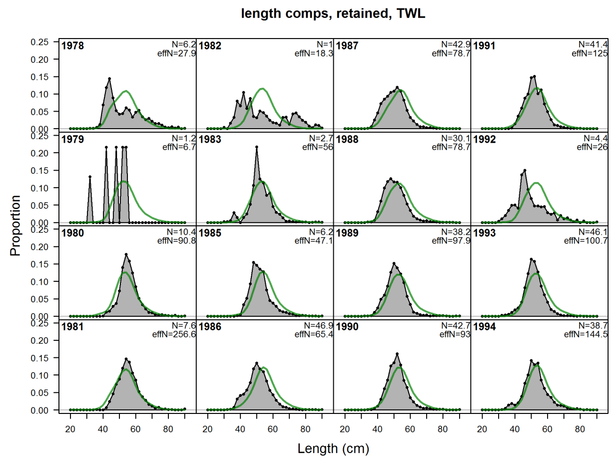
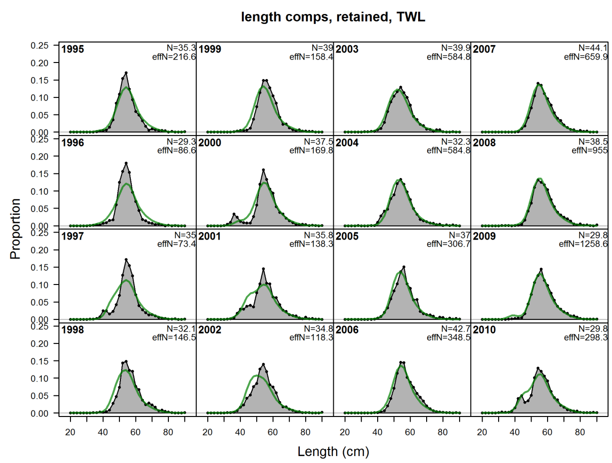



Figure 44: Pearson residuals for the fit to the pot combined-sex retained length-frequency data (maximum = 4.62). Filled circles represent positive residuals (observed expected).



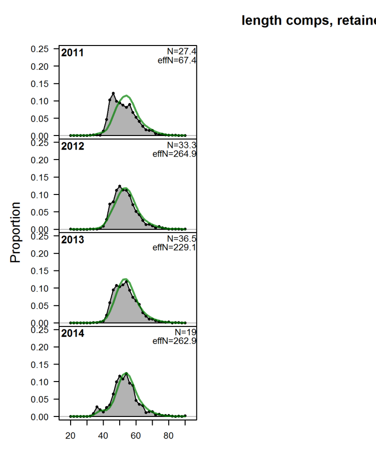




Figure 45: Length-frequency distributions for sexes-combined sablefish from the retained catch in the trawl fishery.

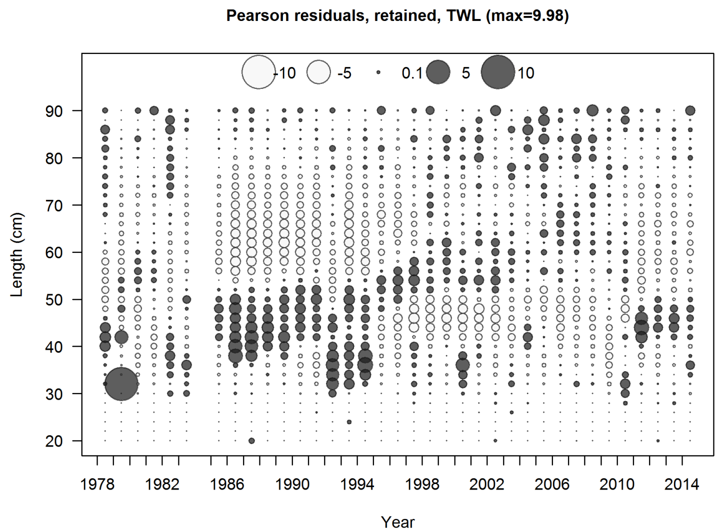



Figure 46: Pearson residuals for the fit to the trawl combined-sex retained length-frequency data (maximum = 9.98). Filled circles represent positive residuals (observed  expected).

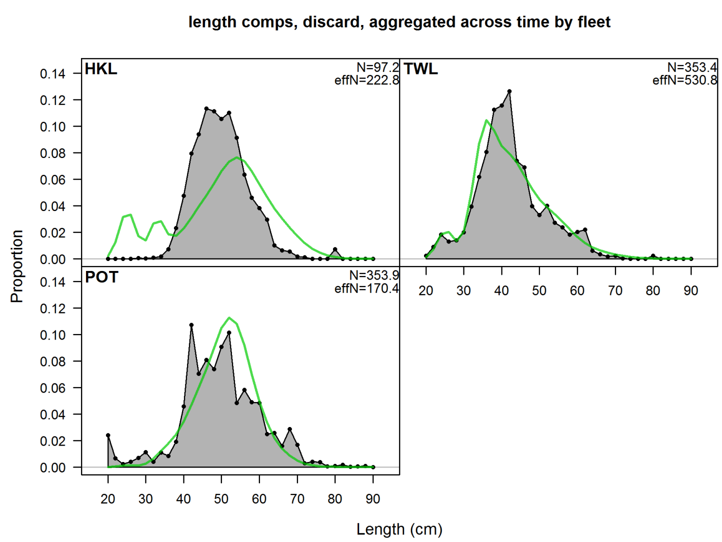



Figure 47: Aggregate length-frequency distributions for sexes-combined sablefish from discarded catch sampling of commercial fisheries in all years.

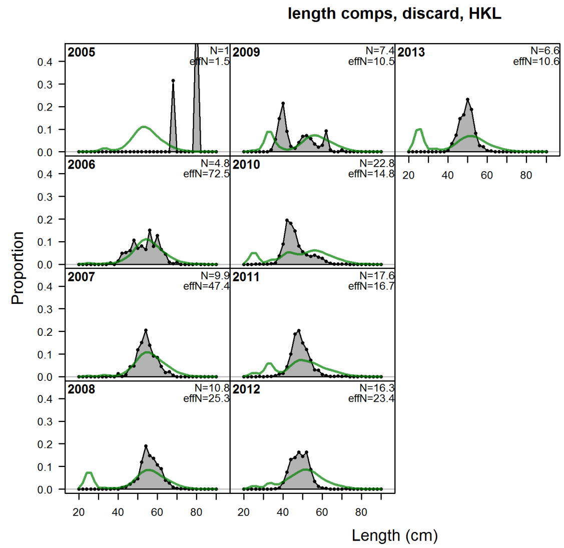



Figure 48: Length-frequency distributions for sexes-combined sablefish from the discarded catch in the hook-and-line fishery.

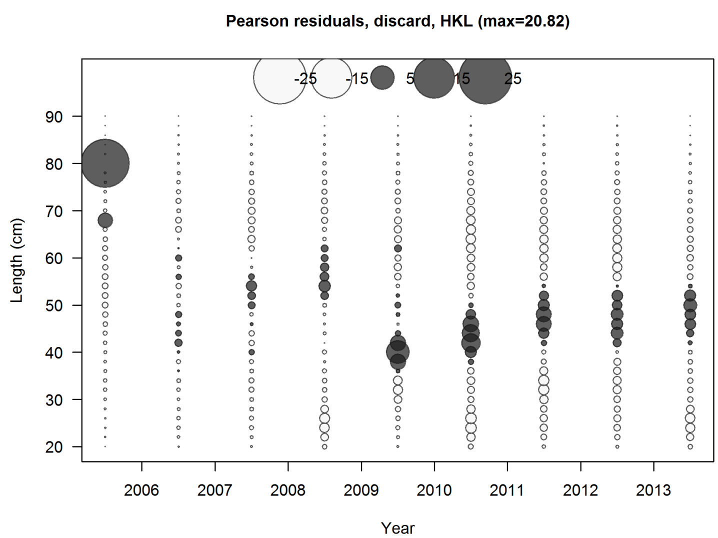



Figure 49: Pearson residuals for the fit to the hook-and-line combined-sex discard length-frequency data (maximum = 20.82). Filled circles represent positive residuals (observed  expected).

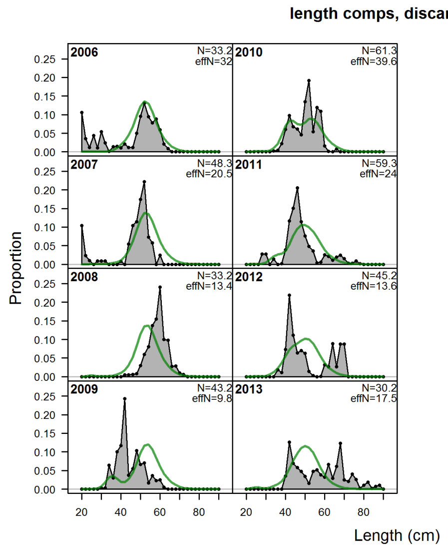



Figure 50: Length-frequency distributions for sexes-combined sablefish from the discarded catch in the pot fishery.

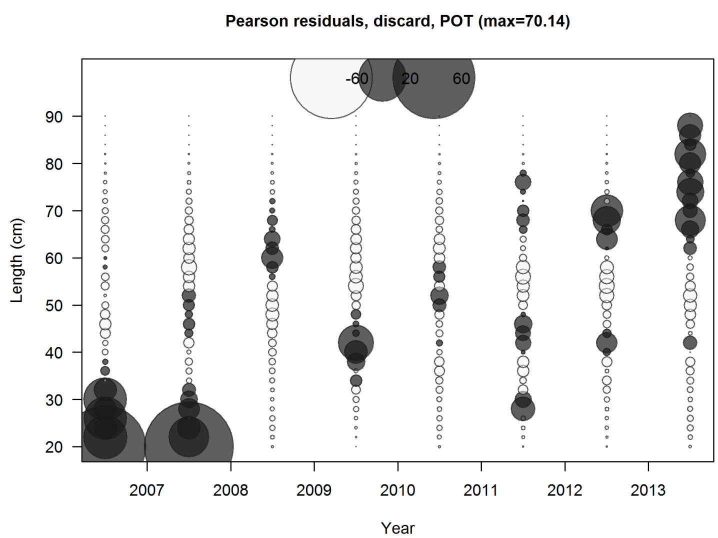



Figure 51: Pearson residuals for the fit to the pot combined-sex discard length-frequency data (maximum = 70.14). Filled circles represent positive residuals (observed  expected).

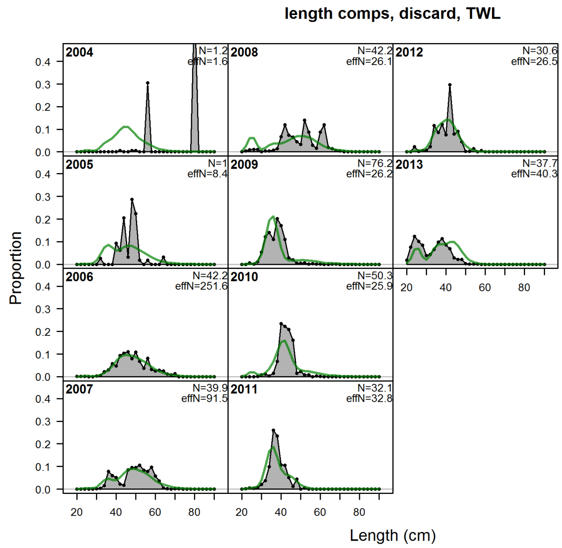



Figure 52: Length-frequency distributions for sexes-combined sablefish from the discarded catch in the trawl fishery.

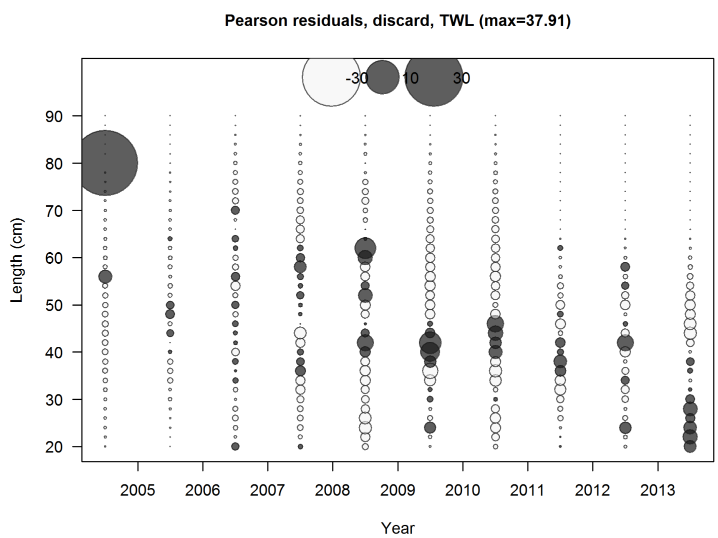



Figure 53: Pearson residuals for the fit to the trawl combined-sex discard length-frequency data (maximum = 37.91). Filled circles represent positive residuals (observed expected).

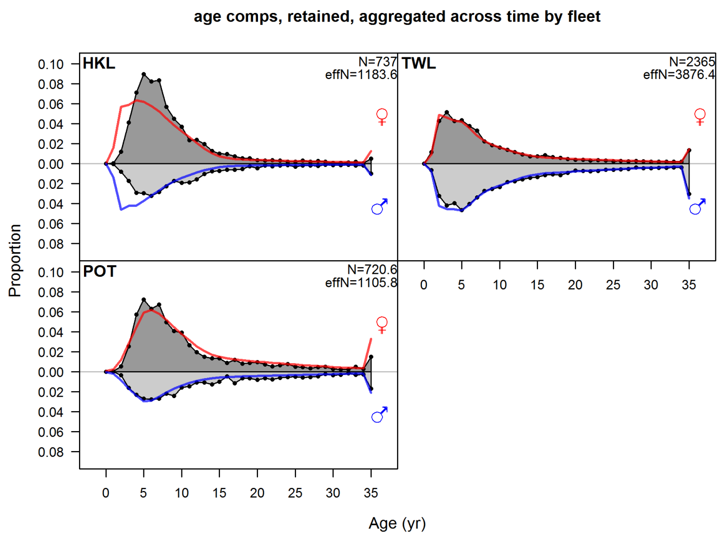



Figure 54: Aggregate age-frequency distributions for female and male sablefish from retained catch sampling of commercial fisheries in all years.

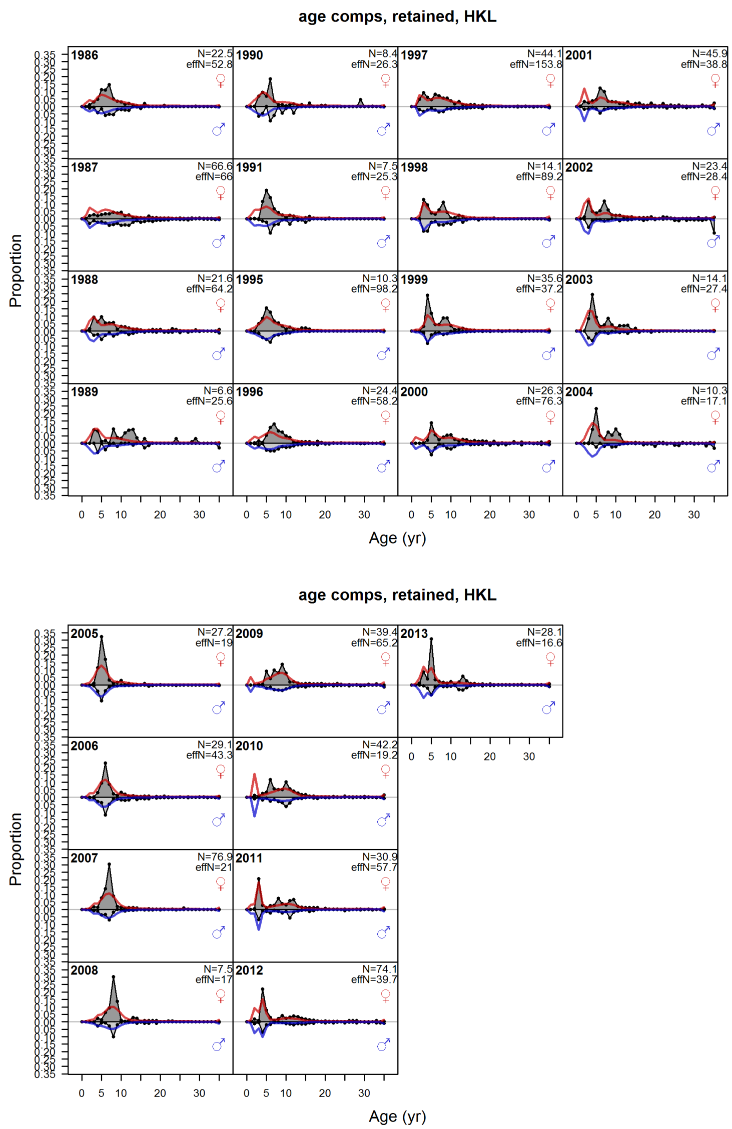



Figure 55: Age-frequency distributions for female and male sablefish from the retained catch in the hook-and-line fishery.

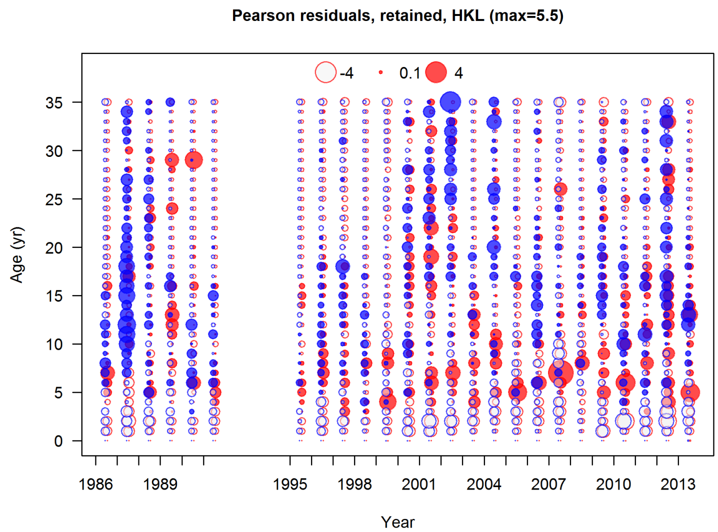
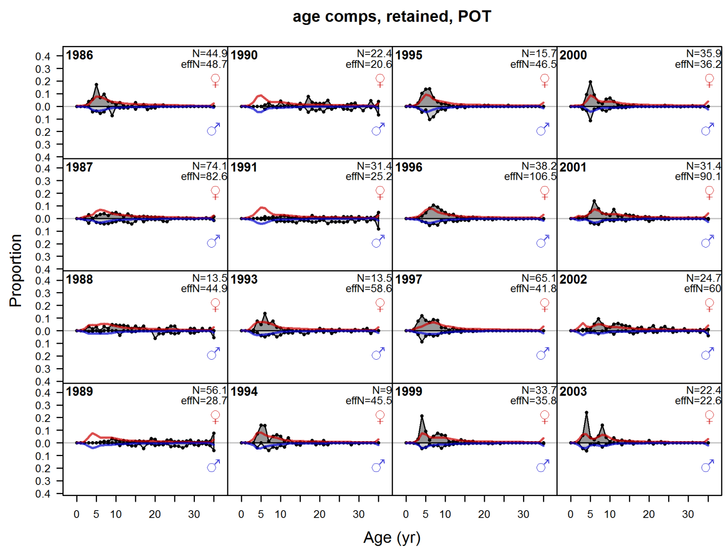



Figure 56: Pearson residuals for the fit to the hook-and-line female retained age-frequency data (maximum = 5.55). Filled circles represent positive residuals (observed  expected).



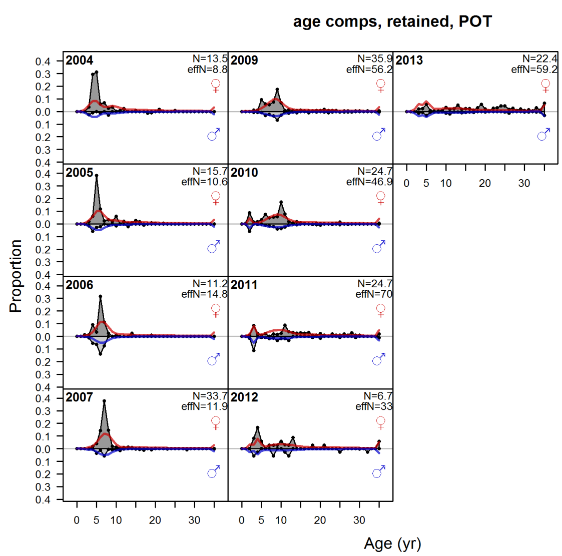




Figure 57: Age-frequency distributions for female and male sablefish from the retained catch in the pot fishery.

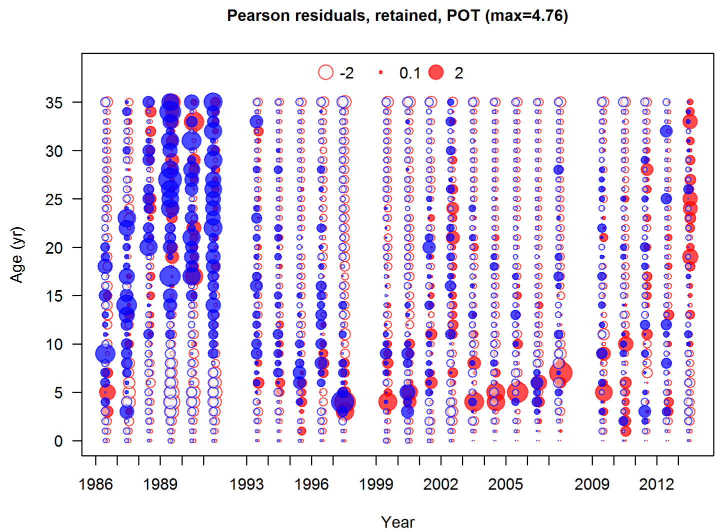



Figure 58: Pearson residuals for the fit to the pot female retained age-frequency data (maximum = 4.76). Filled circles represent positive residuals (observed expected).

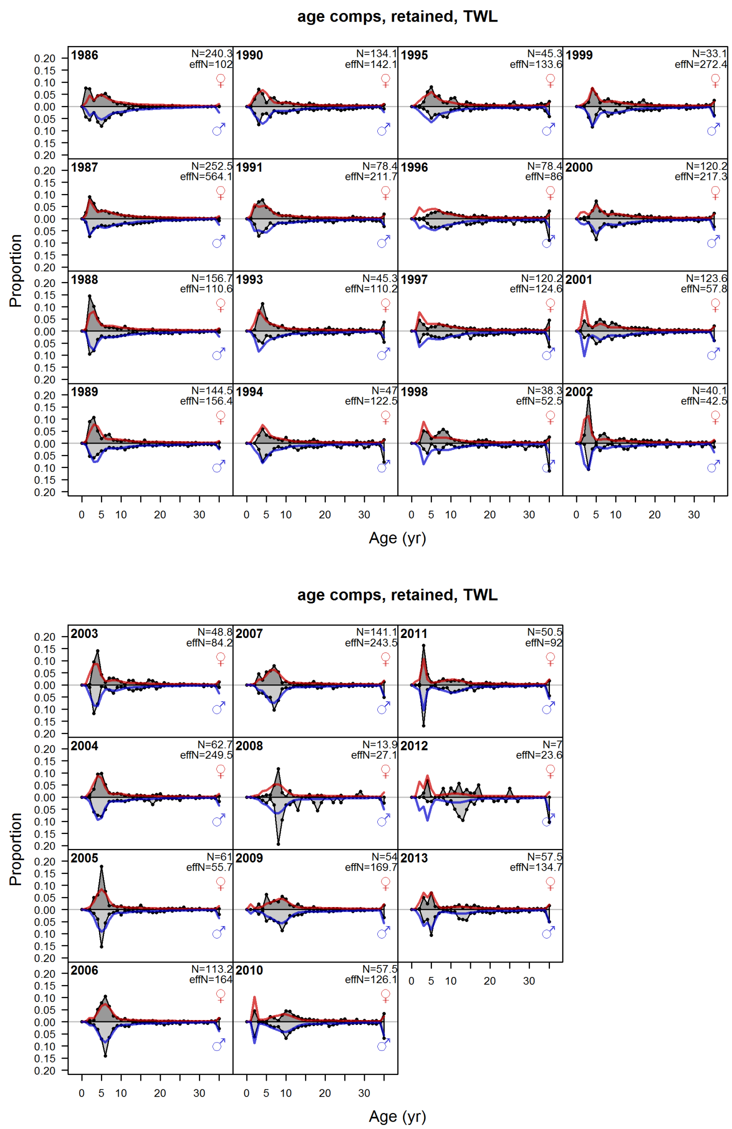



Figure 59: Age-frequency distributions for female and male sablefish from the retained catch in the trawl fishery.

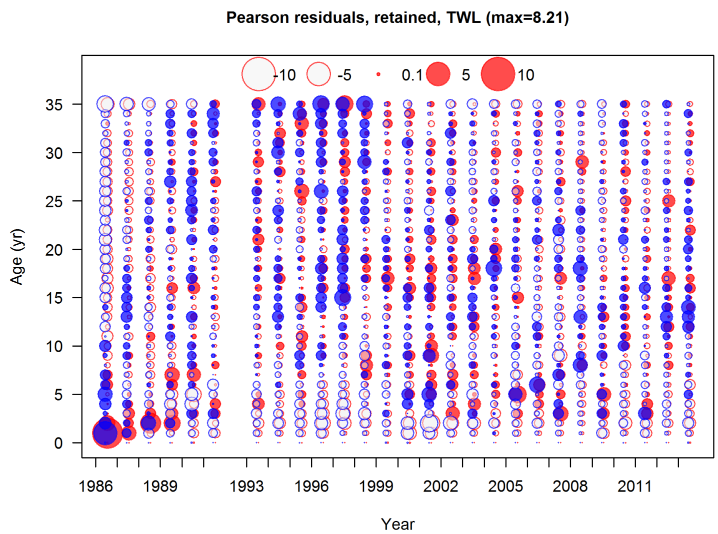



Figure 60: Pearson residuals for the fit to the trawl female retained age-frequency data (maximum = 8.21). Filled circles represent positive residuals (observed  expected).

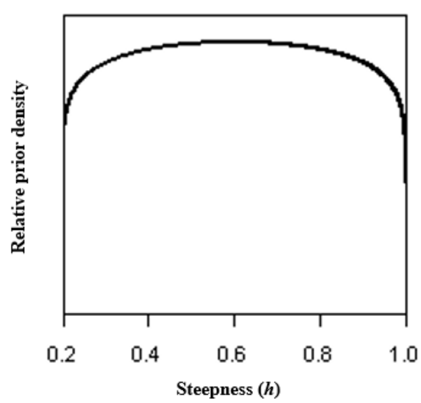



Figure 61: Prior for steepness (h) of the stock-recruitment relationship consistent with the analysis of He et al. (2006).

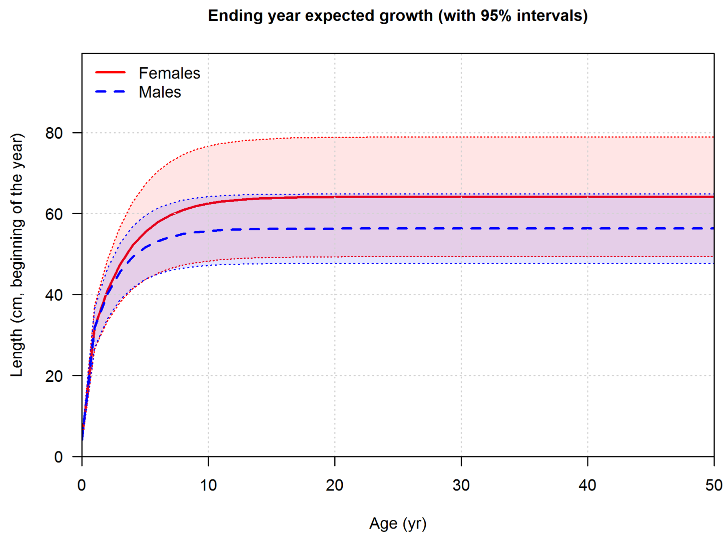



Figure 62: Growth curve for females and males with $sim95\%$ intervals (dashed lines) indicating the expectation and individual variability of length-at-age for the base-case model.

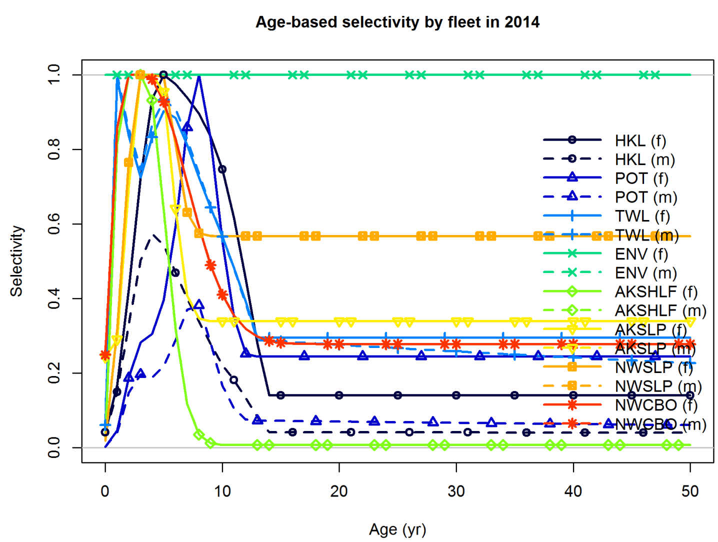



Figure 63: Selectivity at age for multiple fleets.

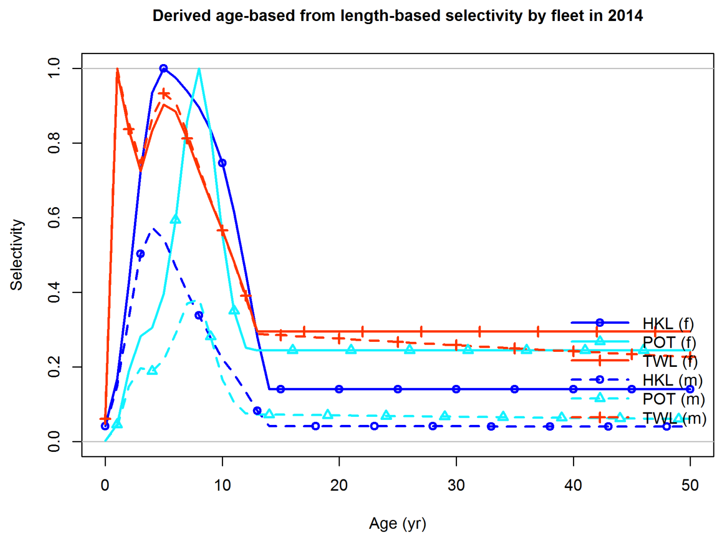
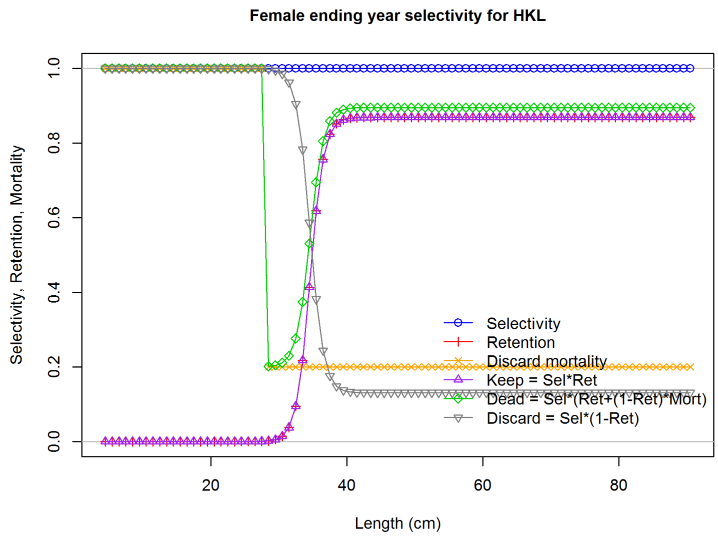



Figure 64: Selectivity at age derived from selectivity at length for multiple fleets.



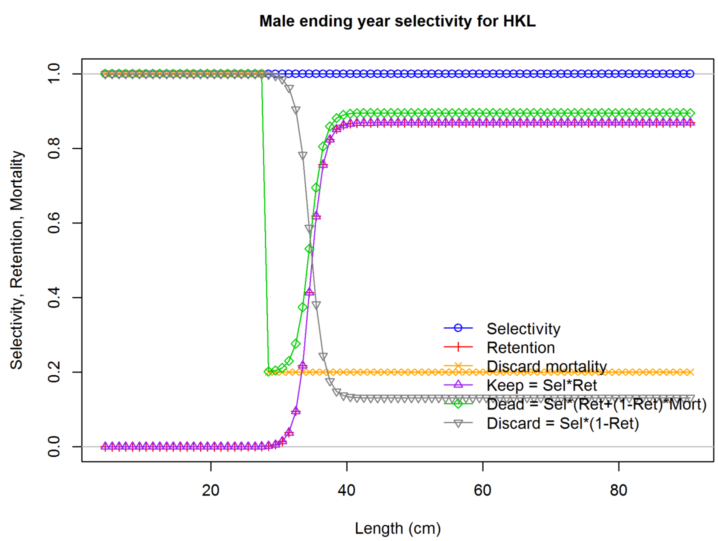




Figure 65: Estimated retention and discard mortality for females (upper panel) and males (lower panel) for the hook-and-line fishery.

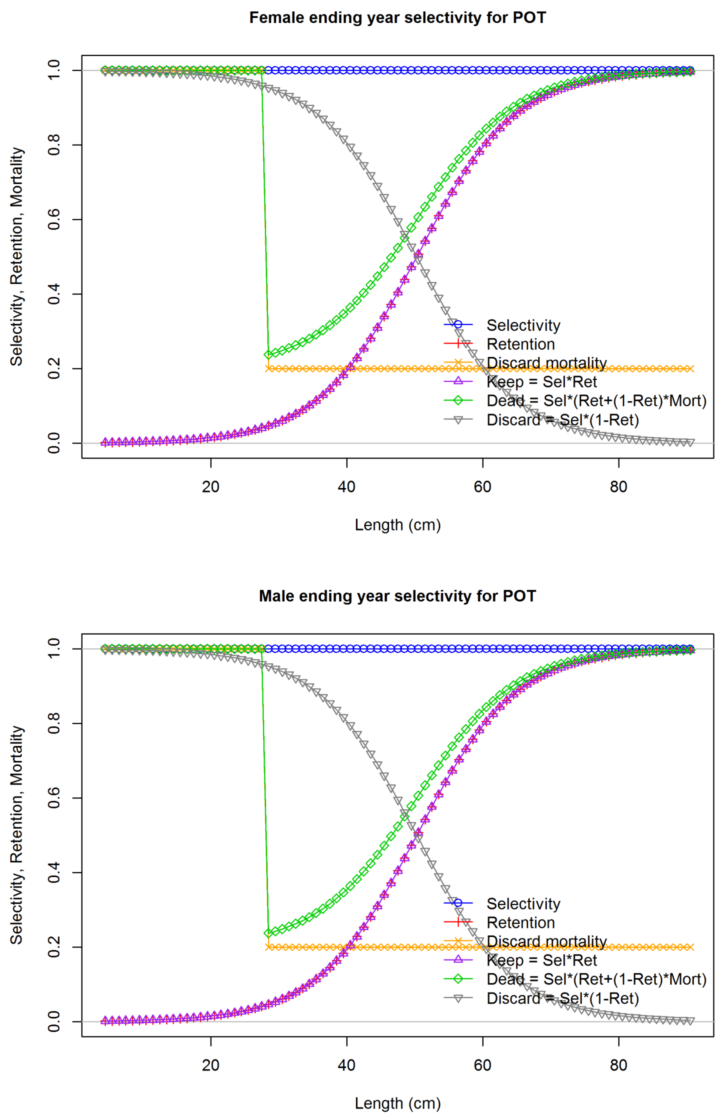
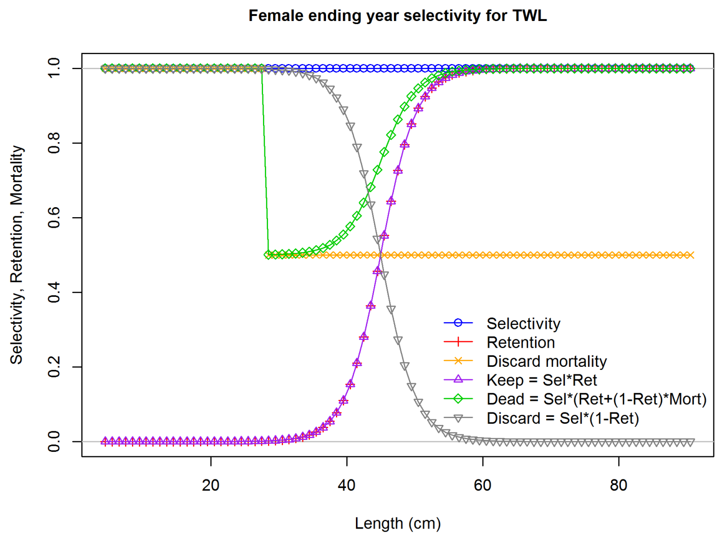



Figure 66: Estimated retention and discard mortality for females (upper panel) and males (lower panel) for the pot fishery.



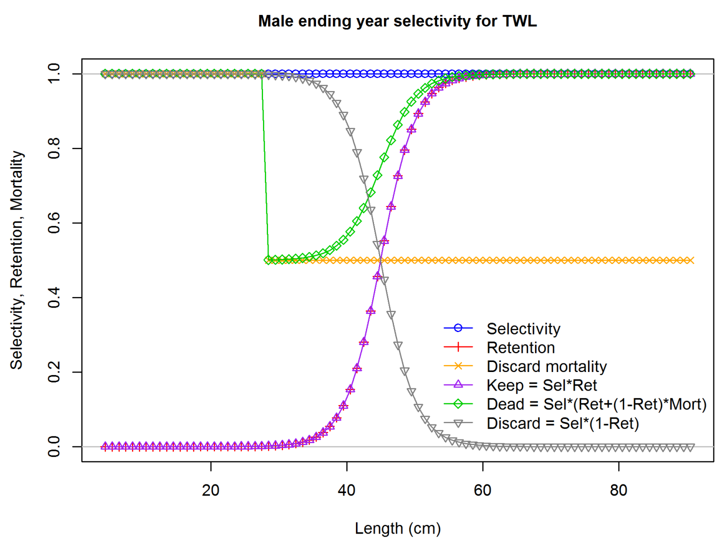




Figure 67: Estimated retention and discard mortality for females (upper panel) and males (lower panel) for the trawl fishery.

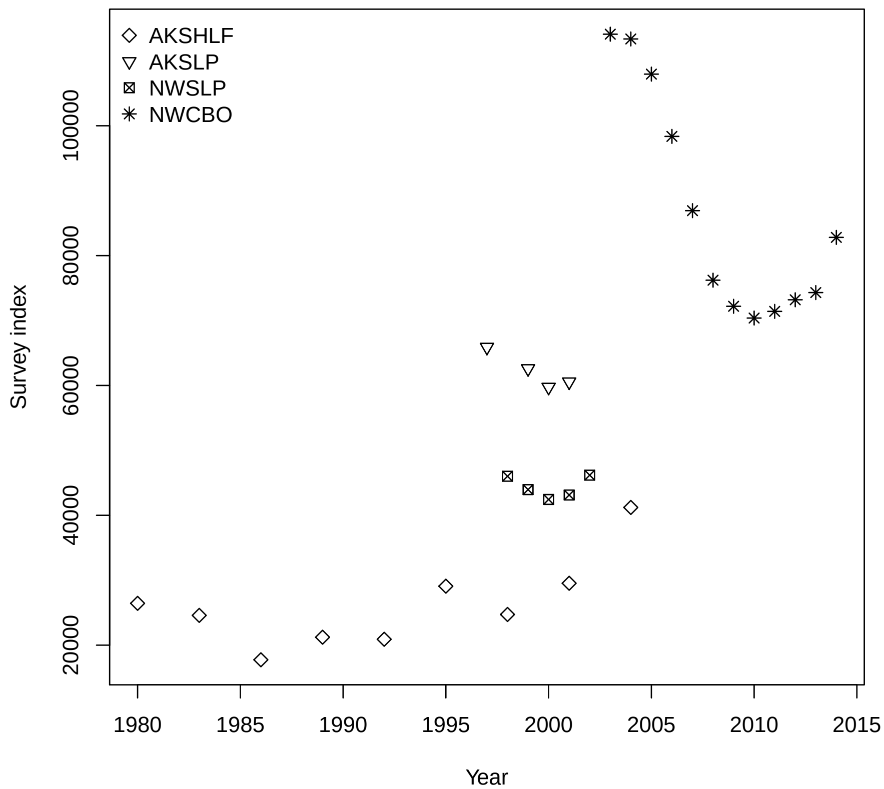



Figure 68: Time series of index of abundance for the NWFSC Shelf-Slope (NWCBO), NWFSC Slope (NWSLP), AKFSC Shelf (AKSHLF), and AKFSC Slope (AKSLP) surveys.

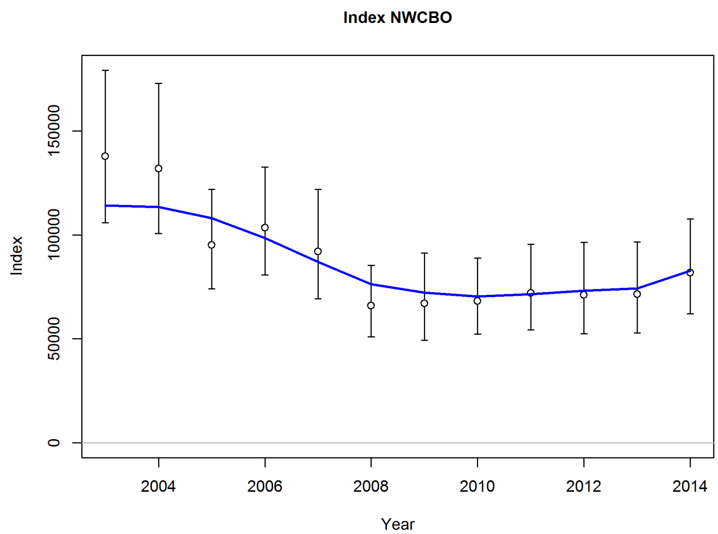



Figure 69: Fit to the NWFSC Shelf-Slope survey.

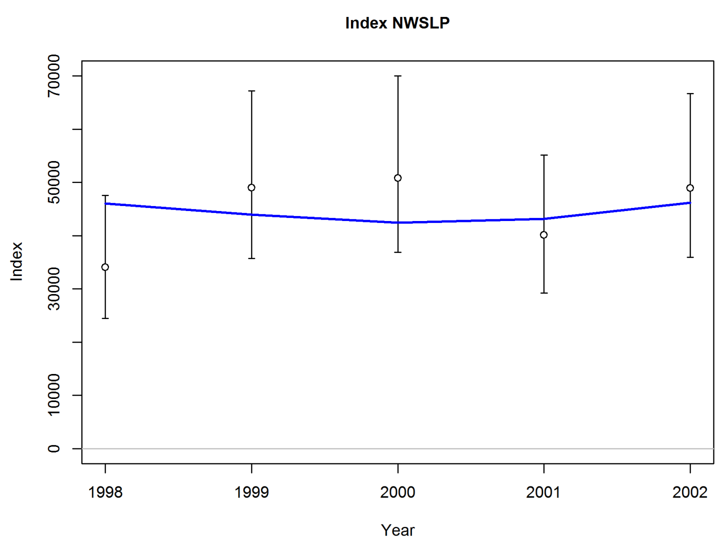



Figure 70: Fit to the NWFSC slope survey.

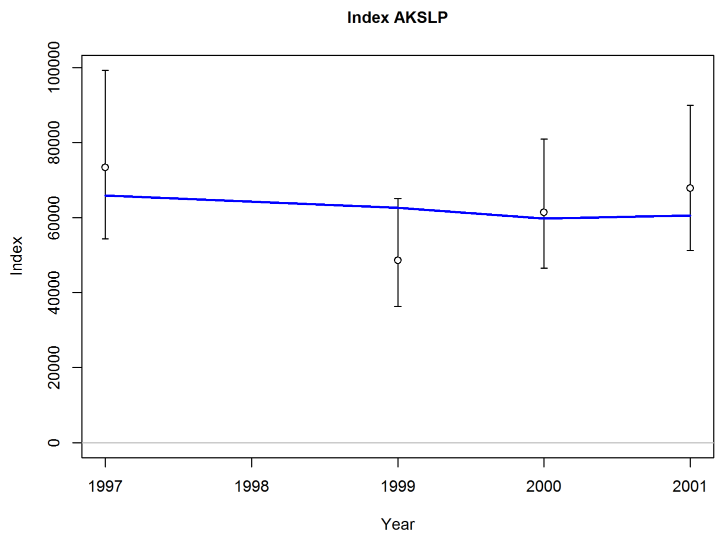



Figure 71: Fit to the AKFSC slope survey.

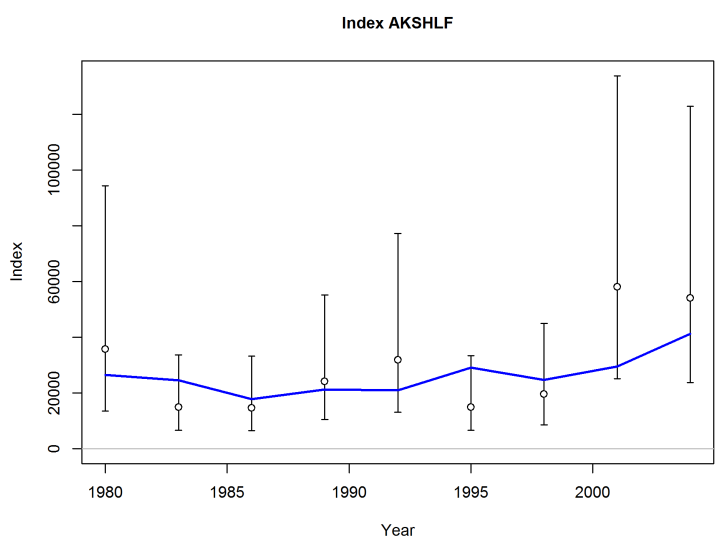



Figure 72: Fit to the AKFSC Triennial shelf survey.

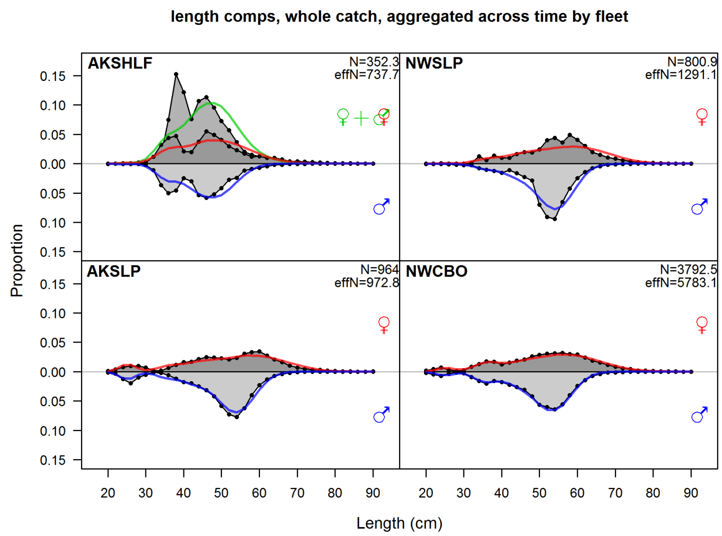



Figure 73: Aggregate fit to the survey length-frequency data for females and males.

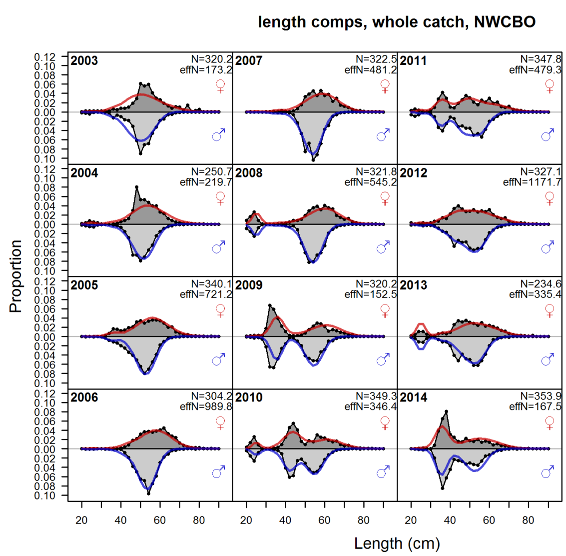



Figure 74: Fit to the NWFSC Shelf-Slope survey female and male length-frequency data.

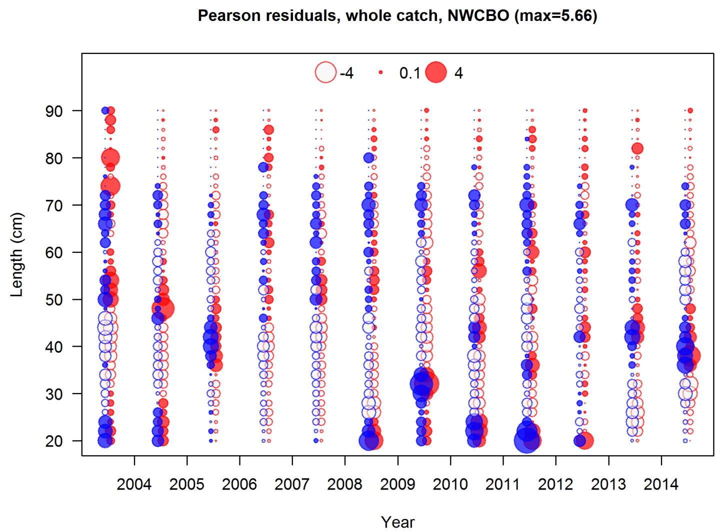



Figure 75: Pearson residuals for the fit to NWFSC Shelf-Slope survey female length-frequencies (max = 5.66). Filled circles represent positive residuals (observed  expected).

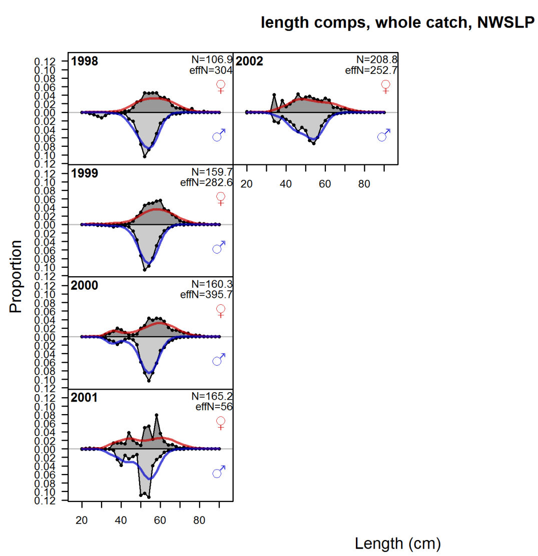



Figure 76: Fit to the NWFSC slope survey female and male length-frequency data.

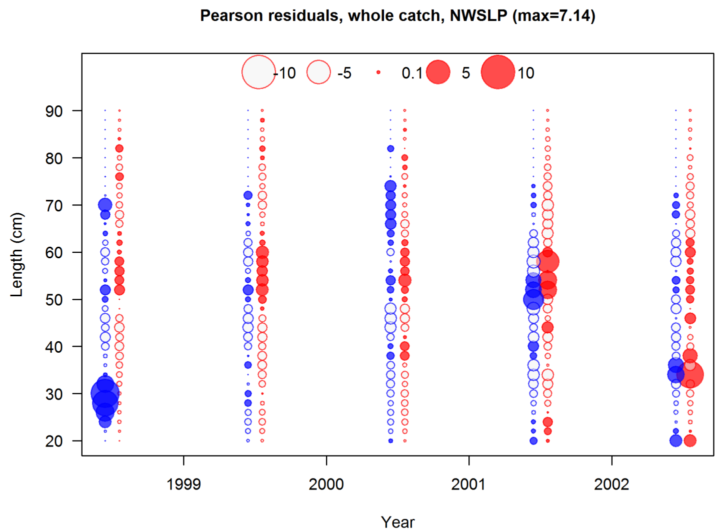



Figure 77: Pearson residuals for the fit to NWFSC slope survey female length-frequencies (max = 7.14). Filled circles represent positive residuals (observed expected).

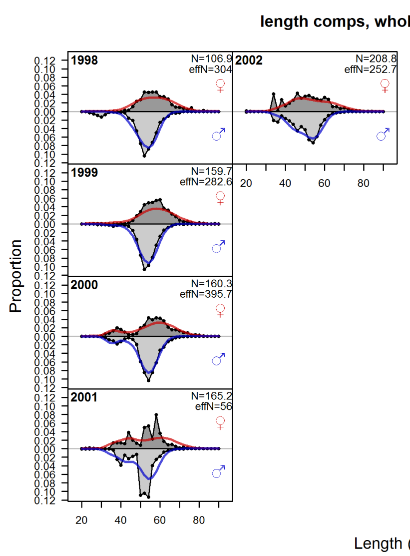



Figure 78: Fit to the AFSC slope survey female and male length-frequency data.

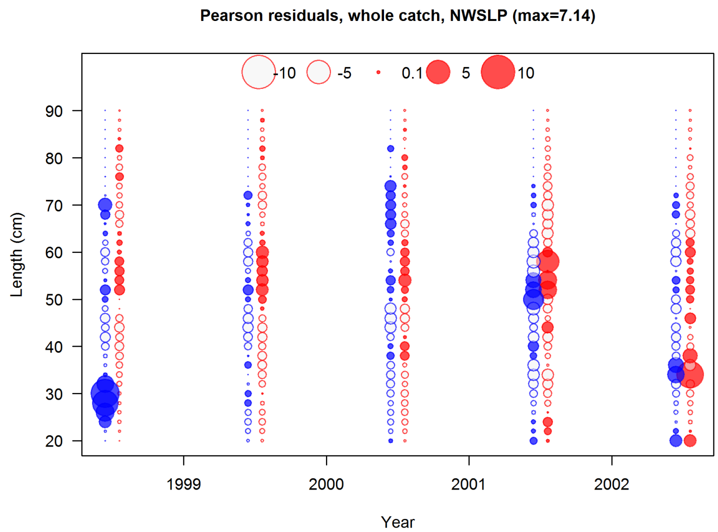



Figure 79: Pearson residuals for the fit to AFSC slope survey female length-frequencies (max = 6.57). Filled circles represent positive residuals (observed expected).

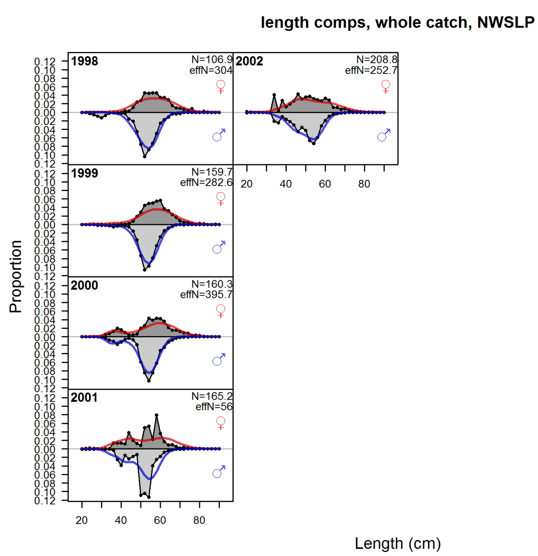



Figure 80: Fit to the AFSC shelf survey female and male length-frequency data.

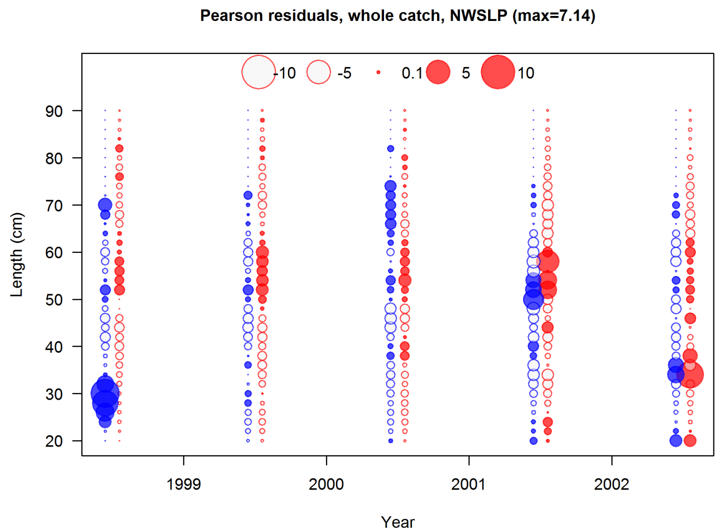



Figure 81: Pearson residuals for the fit to AFSC shelf survey female length-frequencies (max = 3.45). Filled circles represent positive residuals (observed expected).

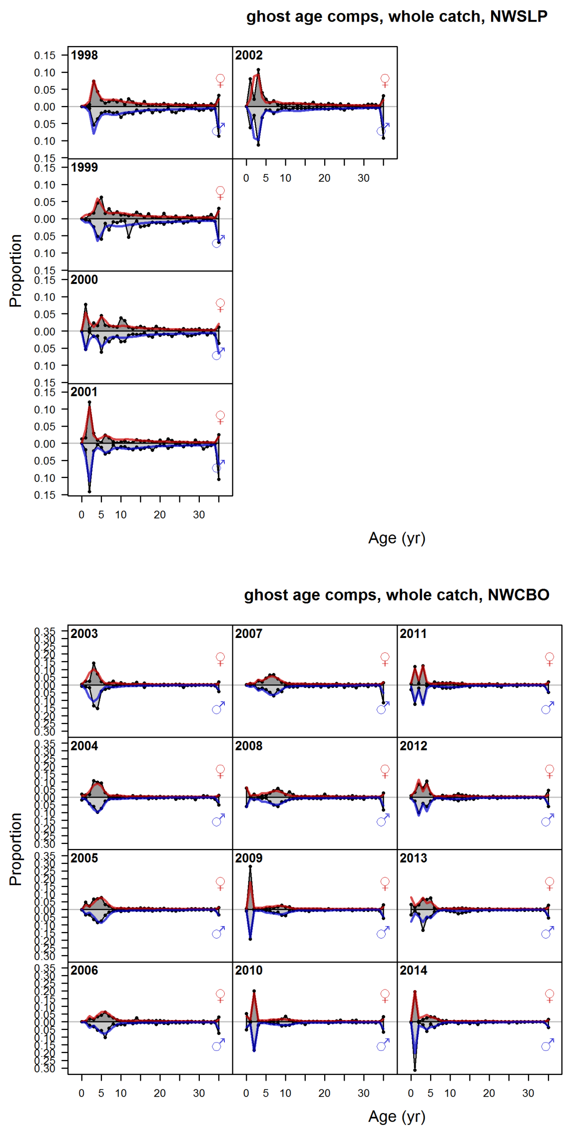



Figure 82: Implied fit to the NWFSC Shelf-Slope (lower) and slope (upper) marginal age-frequencies. Fits are provided for evaluation only, but not included in the model likelihood.

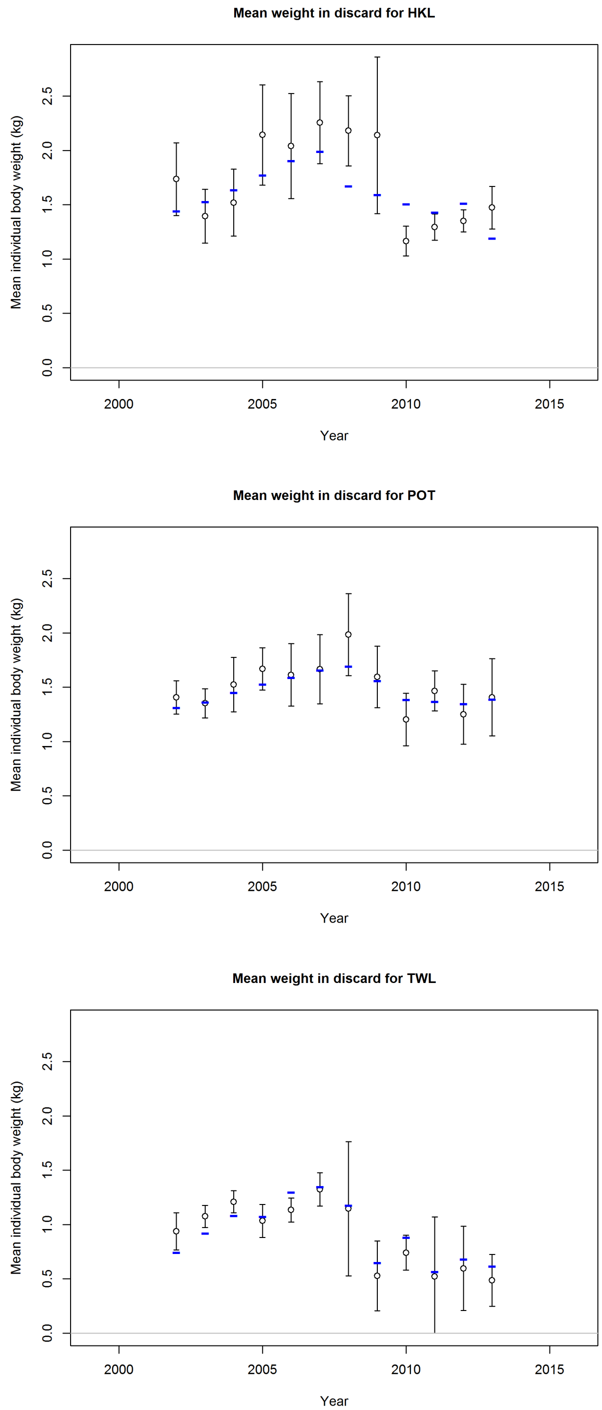



Figure 83: Fit to the fishery discard mean body weight data.

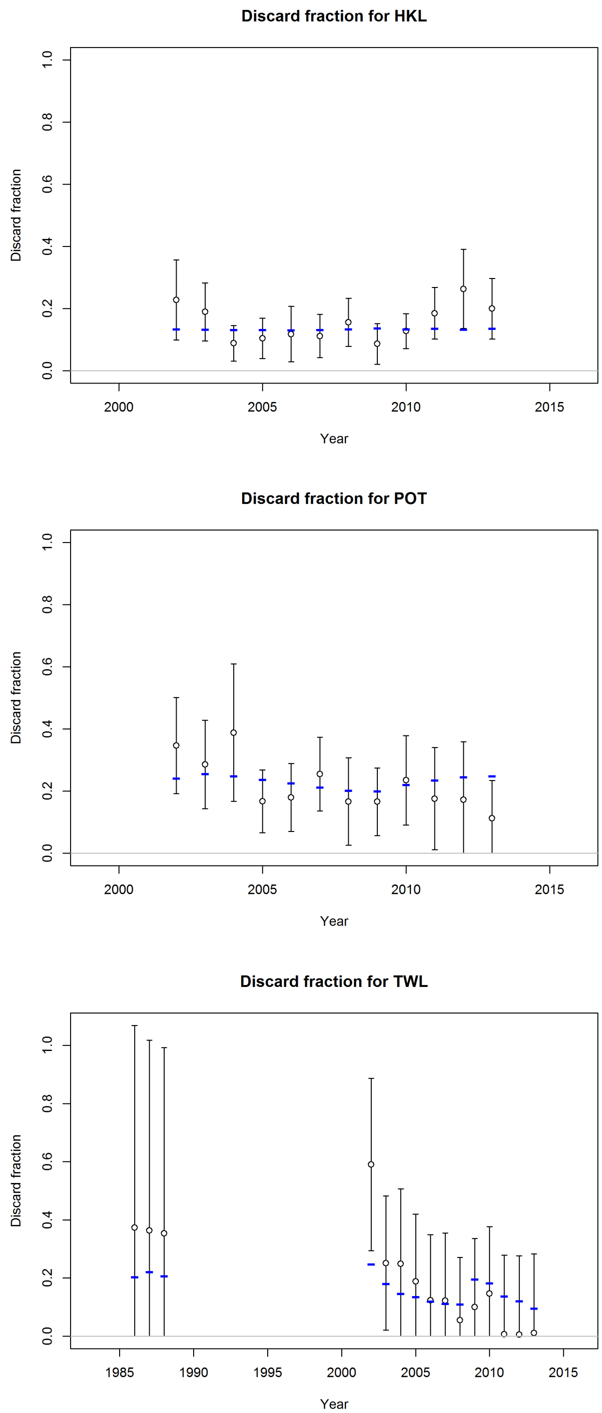



Figure 84: Fit to the fishery fraction data.

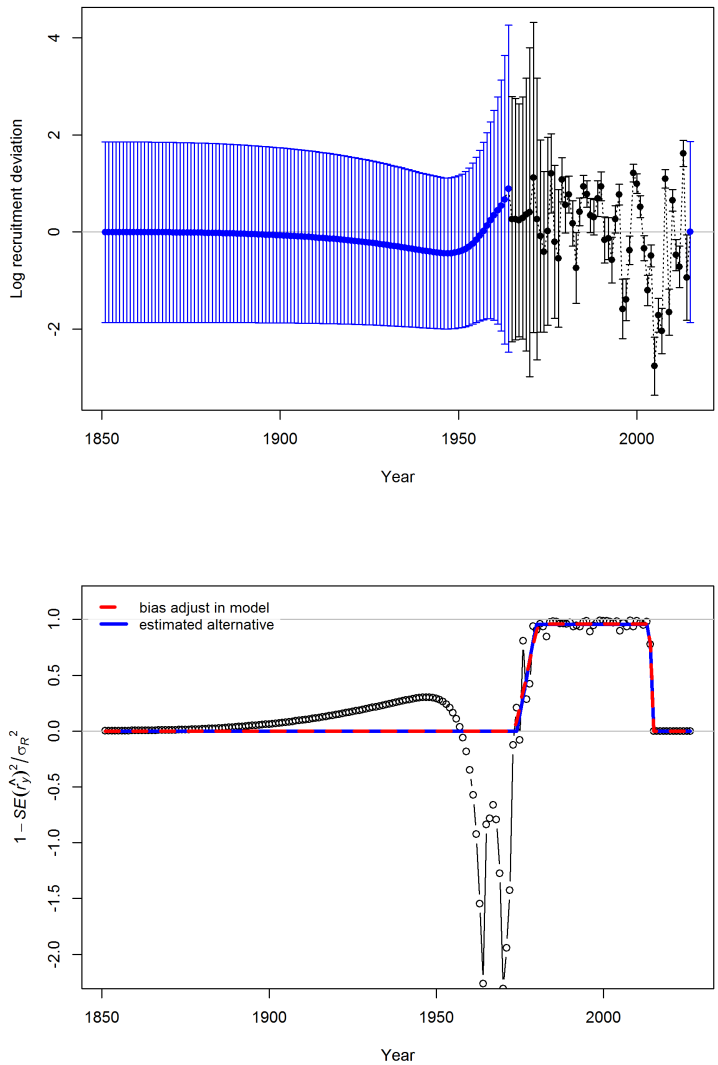
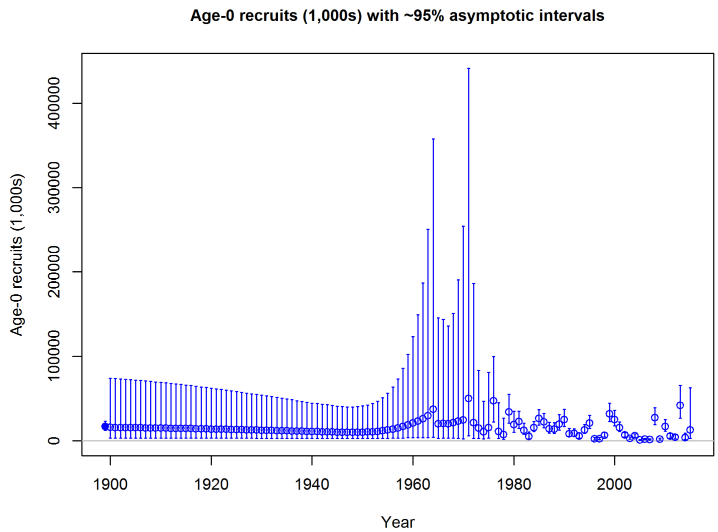



Figure 85: Estimated recruitment deviation time-series (upper panel, horizontal line indicates a value of zero) and bias adjustment relative to the ratio of recruitment estimation uncertainty and $\sigma_r$.



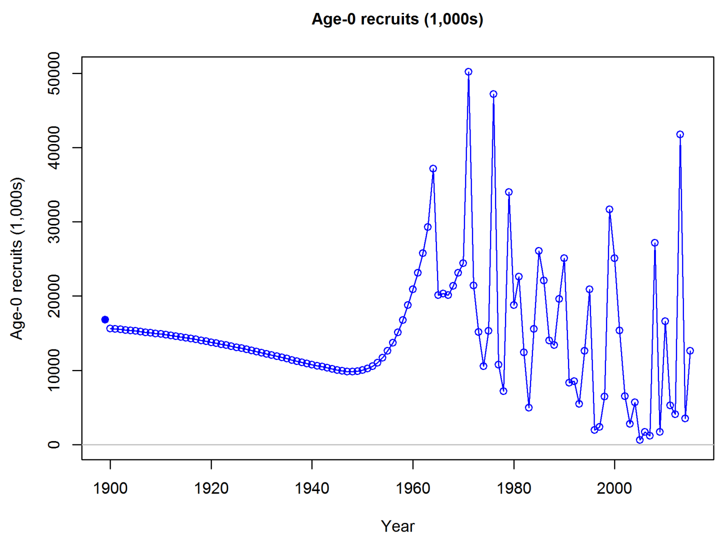




Figure 86: Time series of estimated sablefish recruitments for the base-case model (solid line) with ~95% intervals (vertical lines; upper panel) and without intervals to better visualize recent estimated trends.

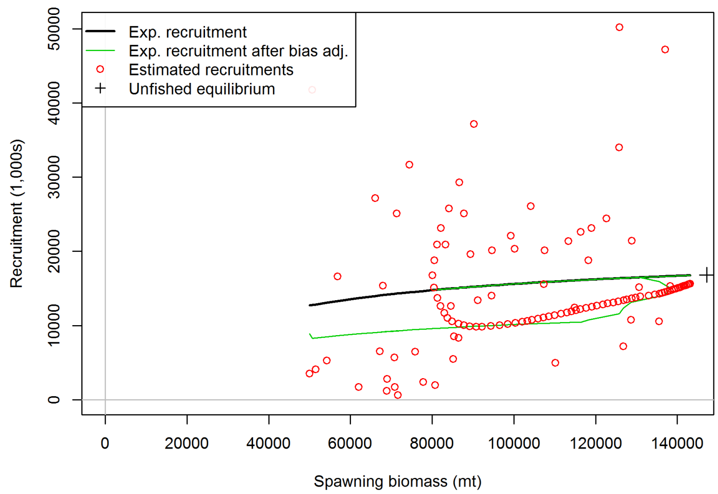



Figure 87: Estimated stock-recruit function for the base-case model.

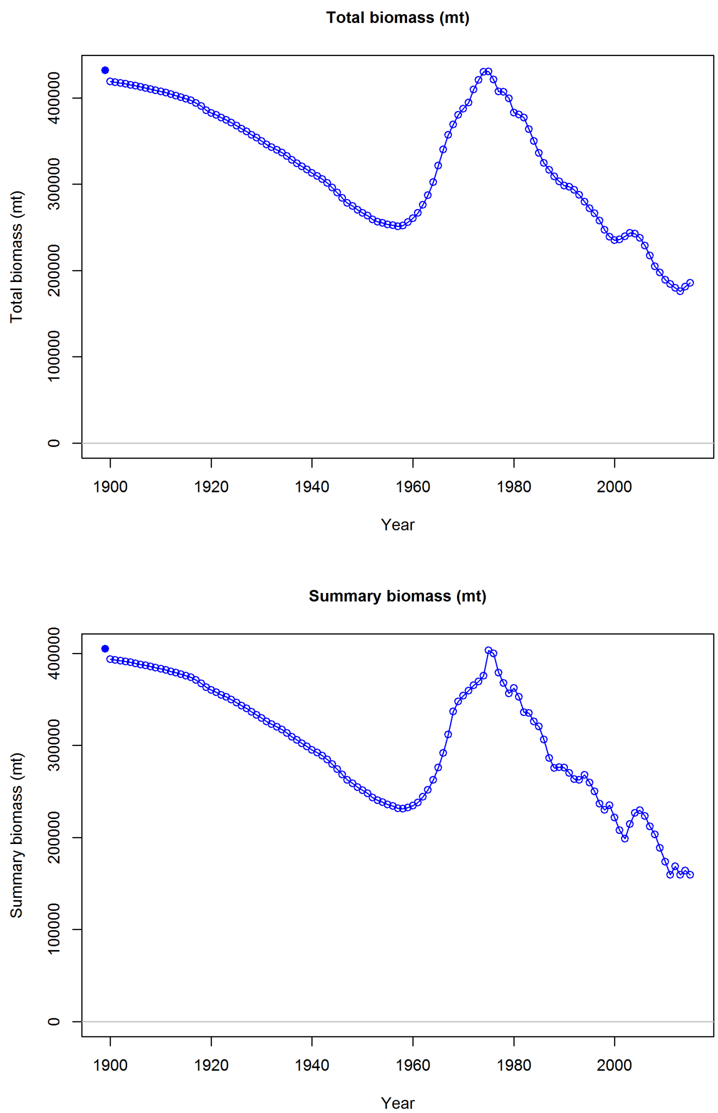
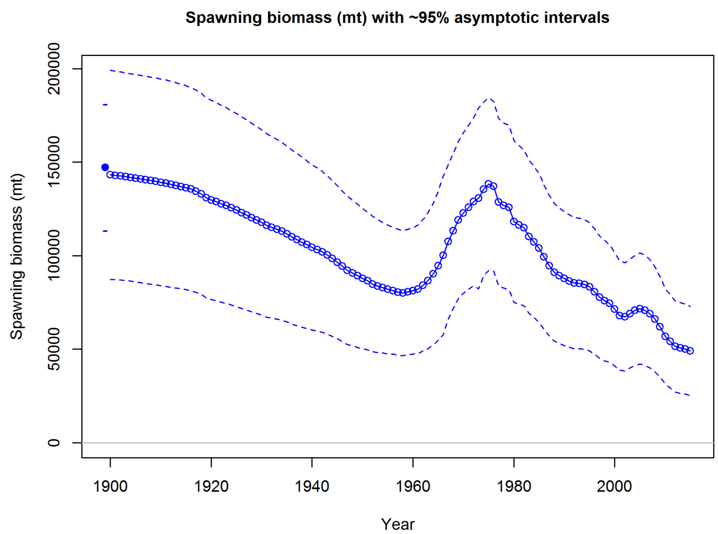



Figure 88: Estimated total (upper panel) and summary (age-4+; lower panel) biomass (age-4+) time-series (1900-2015) for the base-case model.



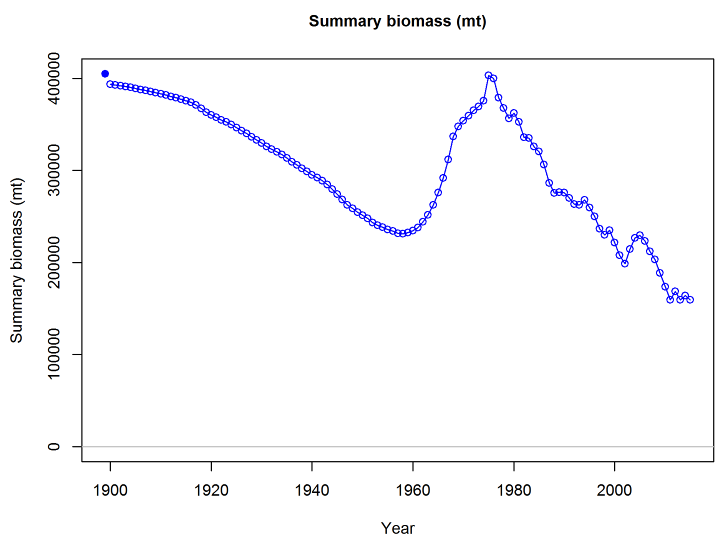




Figure 89: Estimated spawning biomass time-series (1900-2015) for the base-case model (solid line) with ~95% interval (dashed lines).

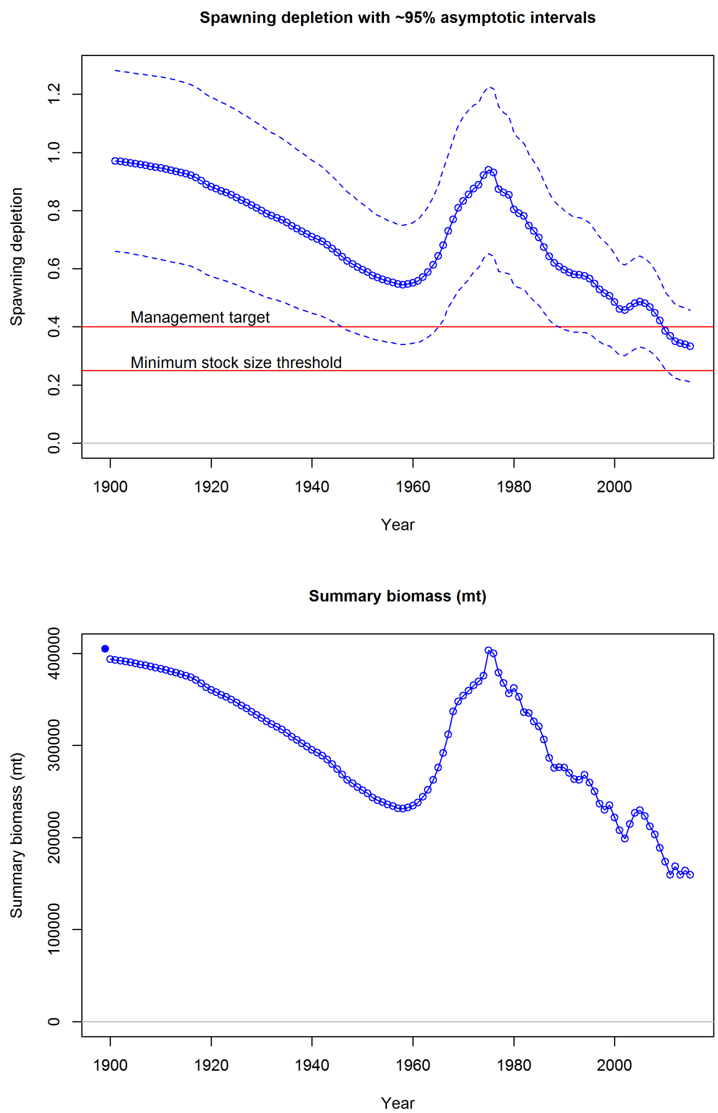



Figure 90: Time series of estimated relative spawning depletion (1900-2015) from the base-case model (solid line) with ~95% interval (dashed lines).

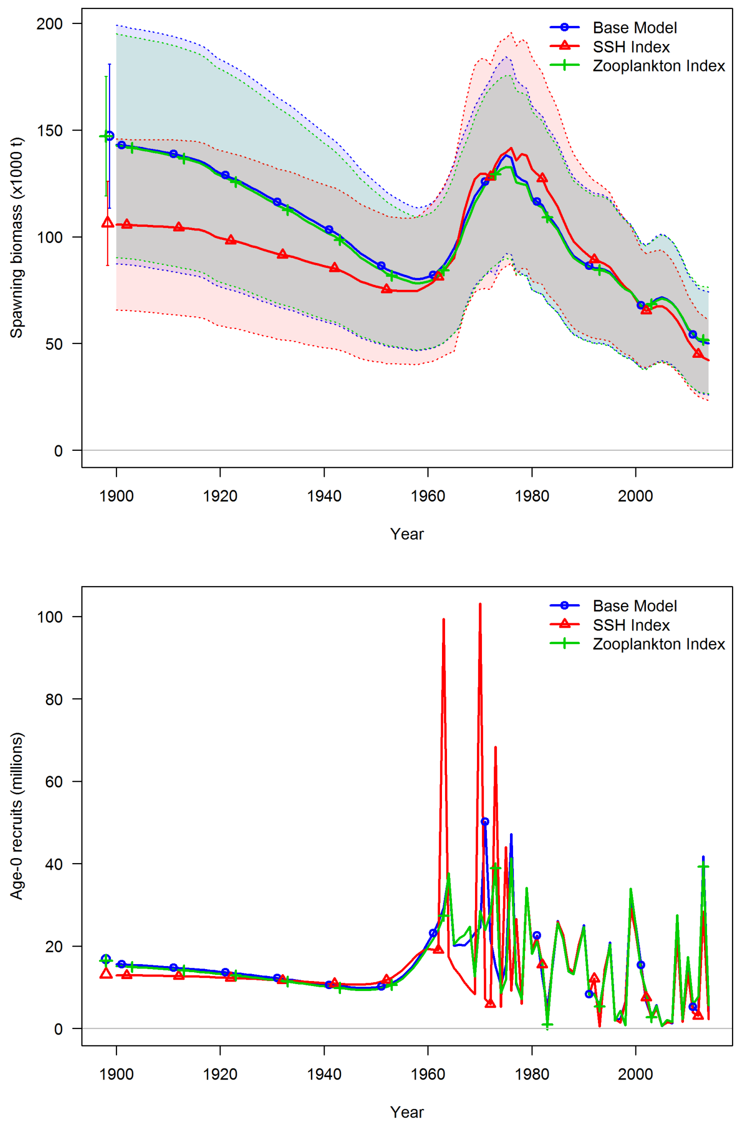



Figure 91: Results of a sensitivity analysis to the inclusion of environmental indices as indices of recruitment deviations.

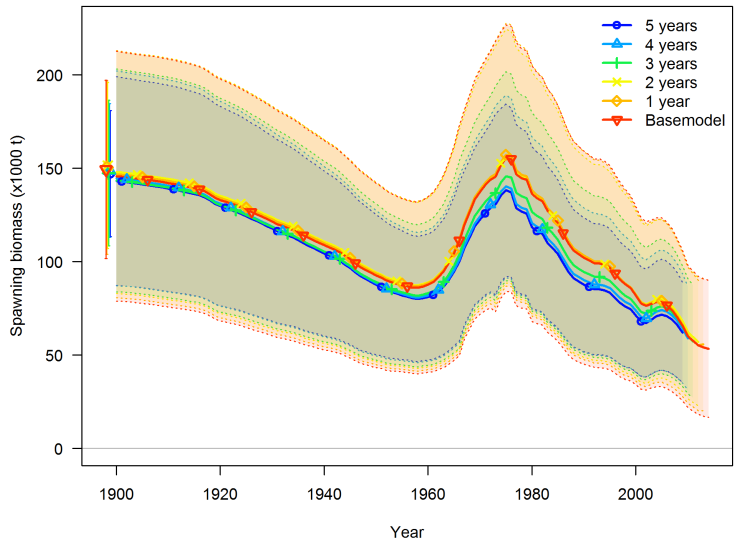



Figure 92: Five year retrospective analysis using the base-case model for comparison.

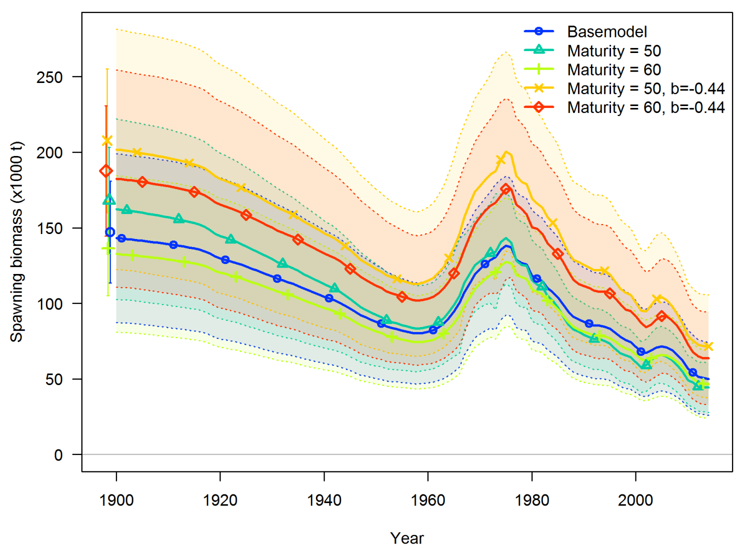



Figure 93: Sensitivity analysis to female maturity.

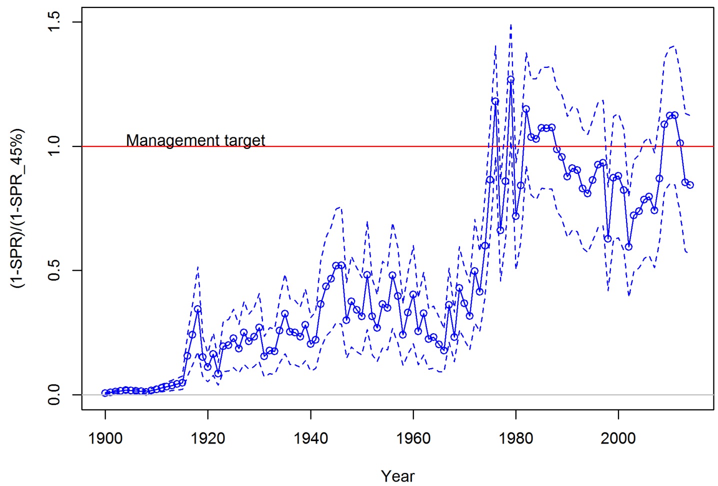



Figure 94: Time series of estimated relative spawning potential ratio ($1 - SPR/1 - SPR_{Target=0.45}$) for the base-case model (round points) with ~95% intervals (dashed lines). Values of relative SPR above 1.0 reflect harvests in excess of the current overfishing proxy.

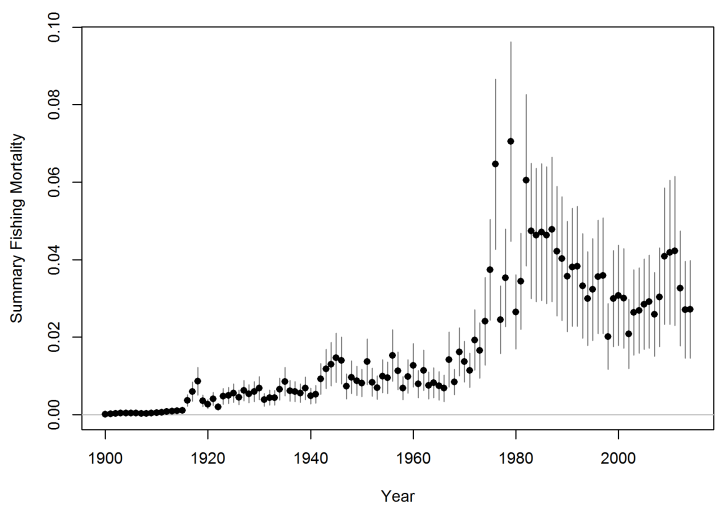



Figure 95: Time series of estimated exploitation fraction (catch/age 4 and older biomass) for the base-case model.

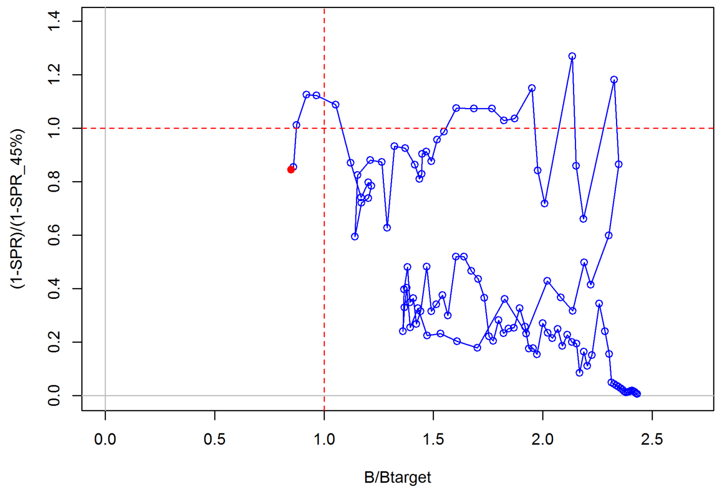



Figure 96: Estimated relative spawning potential ratio relative to the proxy target/limit of 45% vs. estimated spawning biomass relative to the proxy 40% level from the base-case model. Higher spawning output occurs on the right side of the x-axis, higher exploitation rates occur on the upper side of the y-axis. The filled circle indicates 2014. (Plot is based on MLE results).

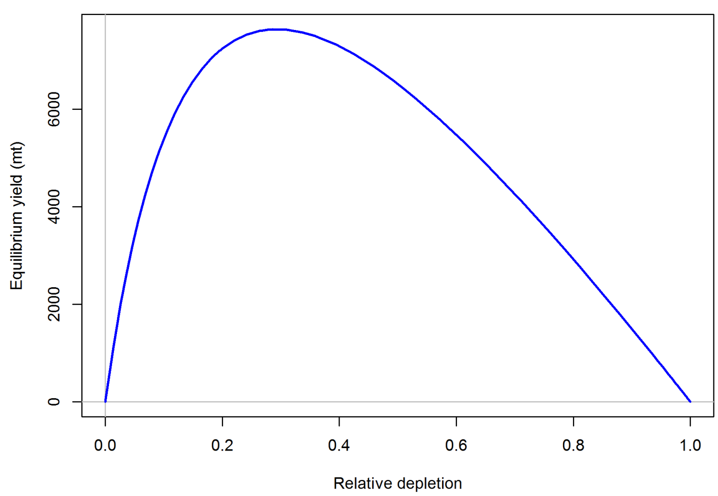



Figure 97: Equilibrium yield curve (total dead catch) for the base-case model.

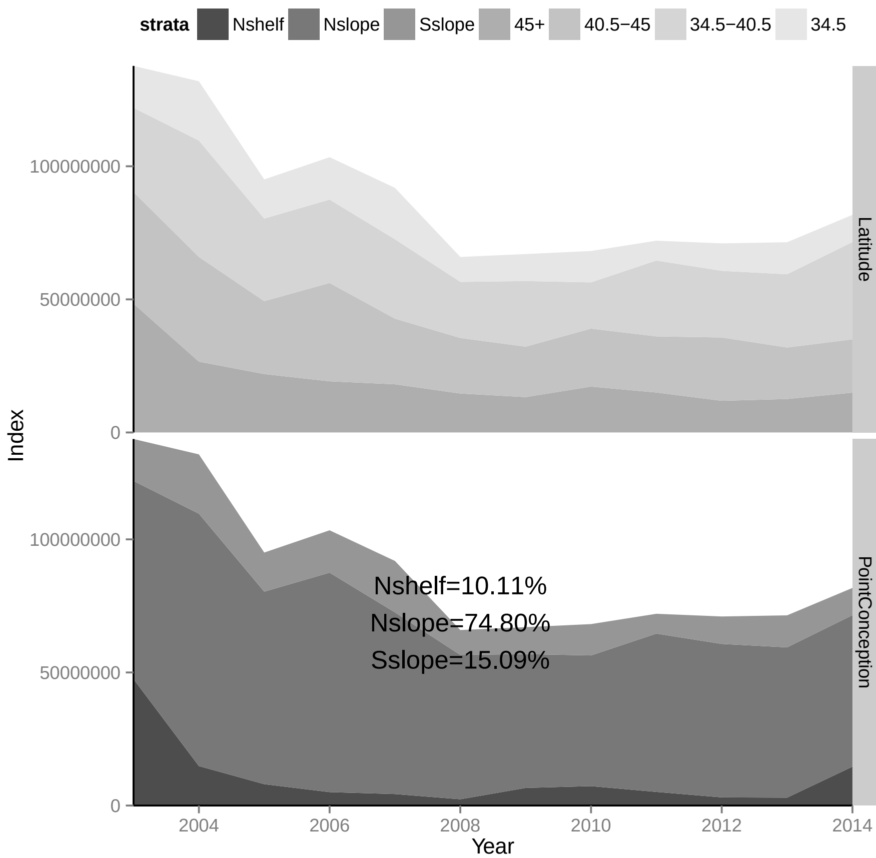



Figure 98: Components of the NWFSC survey trend separated by geography and depth. Percentages are average adult biomass per area over all years shown in the figure.

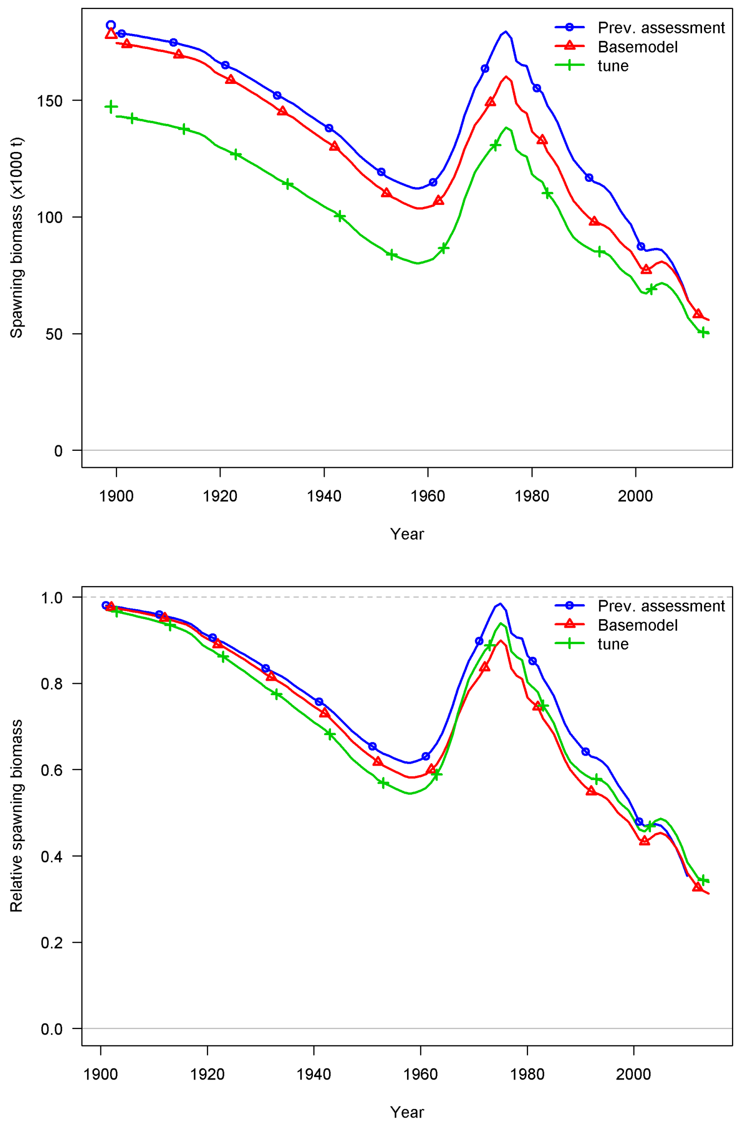



Figure 99: The base-case model and the model used in the 2011 assessment, which forms the basis of this update.

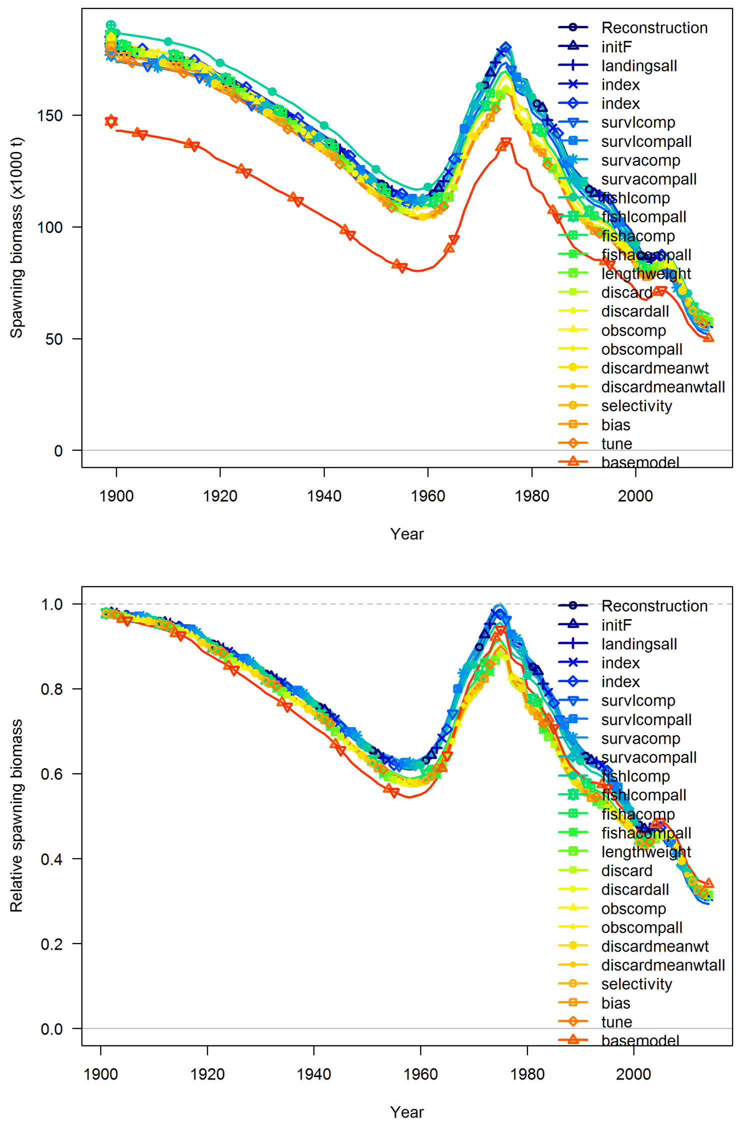



Figure 100: Iterative changes from the 2011 assessment to the base-case model for this assessment update. Prior to each addition of newly available data (2011-2014) the old data was worked up with the newest available methods and added to the assessment prior to adding the new data.