8. Assessment of the Flathead Sole Stock in the Gulf of Alaska

By

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Executive Summary

Summary of Changes in Assessment Inputs

(1) 2014-2015 catch data were added to the model and 2013 catch was updated to include October to December catch in that year.
(2) 2014 and 2015 fishery length composition data were added to the model and 2013 fishery length composition data were updated to include October to December length data from that year.
(3) The 2015 bottom trawl survey biomass index was added to the model
(4) Survey length composition data for 2015 were added to the model
(5) Survey conditional age-at-length data for 2015 were added to the model
(6) Effective sample sizes for survey length composition data were changed to the number of hauls for which lengths were collected.
(7) The data sources were weighted using the harmonic mean of effective sample sizes, calculating effective sample sizes following the methods described in McAllister-Ianelli (1997), Appendix 2. Data weighting according to methods in Francis (2011) were used in the 2013 assessment.

Summary of Changes in Assessment Methodology

No changes were made to the assessment methodology.

Summary of Results

The key results of the assessment, based on the author's preferred model, are compared to the key results of the accepted 2014 update assessment in the table below.

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2015	2016	2016*	2017*
M (natural mortality rate)	0.2	0.2	0.2	0.2
Tier	3a	3a	3a	3a
Projected total (3+) biomass (t)	254,602	256,029	265,088	269,388
Female spawning biomass (t)	83,818	83,342	82,375	82,690
$B_{100\%}$	88,829	88,829	92,165	92,165
$B_{40\%}$	35,532	35,532	36,866	36,866
$B_{35\%}$	31,090	31,090	32,258	32,258
F_{OFL}	0.61	0.61	0.40	0.40
$maxF_{ABC}$	0.47	0.47	0.32	0.32
F_{ABC}	0.47	0.47	0.32	0.32
OFL (t)	50,792	50,818	42,840	43,060
maxABC (t)	41,349	41,378	35,020	35,187
ABC (t)	41,349	41,378	35,020	35,187
Status	As determined in 2014 for:		As determined in 2015 for:	
	2013	2014	2014	2015
Overfishing	no	n/a	no	n/a
Overfished	n/a	no	n/a	no
Approaching overfished	n/a	no	n/a	no

*Projections are based on estimated catches of 1,981.8 t, 2,825 t, and 35,187 t used in place of maximum permissible ABC for 2015, 2016, and 2017 respectively. The 2015 projected catch was calculated as the current catch as of October 10, 2015 added to the average October 10 – December 31 GOA catches over the 5 previous years. The 2016 projected catch was calculated as the average catch from 2010-2014. The 2017 projected catch was calculated as the projected maxABC for 2017.

The table below shows apportionment of the 2016 and 2017 ABCs and OFLs among areas, based on the proportion of survey biomass projected for each area in 2016 and 2017 estimated using the survey averaging random effects model developed by survey averaging working group.

Quantity	Western	Central	West Yakutat	Southeast	Total
Area Apportionment	31.49%	57.71%	8.37%	2.43%	100.00%
2016 ABC (t)	11,027	20,211	2,930	852	35,020
2017 ABC (t)	11,080	20,307	2,944	856	35,187

Responses to SSC and Plan Team Comments on Assessments in General

GPT comment: *The Teams recommend that the random effects survey smoothing model be used as a default for determining current survey biomass and apportionment among areas.*

The random effects model was used in the current assessment to estimate 2016 and 2017 survey biomass, proportion of survey biomass expected in each management area in 2016 and 2017, and apportionment of ABCs according to these estimates of survey biomass in each area.

SSC comment: *Of the options presented in the Joint Plan Teams minutes <for model numbering>, the SSC agrees that that Option 4 has several advantages and recommends that this Option be advanced next year. Under Option 4, analysts would number their models as follows: "Alpha-numeric model identifiers incorporating two-digit year labels of the form "yy.jx," where the digit after the decimal ("j") represents a major accepted model change and the alphabetic character ("x") represents a proposed model change (e.g., "12.1c" and "13.4a" might describe two models introduced in 2012 and 2013, respectively)". Differences between major and minor changes would be calculated based on "average difference in spawning biomass" (ADSB: see equation in Team Procedures) or as noted in sub-option c below, some other improvement to the model.*

The above system for numbering models will be adopted for the next assessment, as recommended by the SSC.

Responses to SSC and Plan Team Comments Specific to this Assessment

GPT, November 2013: The Team agreed with the author and recommends that the next assessment should include exploration of natural mortality and survey catchability. This effort might also include how selectivity is treated, and potentially place a prior on natural mortality based on maximum observed age. Additional model development should include estimation of a stock-specific ageing error matrix and exploration of strong patterns exhibited in early recruitment deviations.

Preliminary analyses were explored for the 2015 assessment and will be more fully explored in the future.

SSC, Dec. 2013: The SSC encourages development of a stock-specific aging error matrix and encourages exploration of the extreme patterns in early recruitment deviations.

The extreme patterns in early recruitment deviations were not evident in the 2015 assessment.

Introduction

Flathead sole (*Hippoglossoides elassodon*) are distributed from northern California, off Point Reyes, northward along the west coast of North America and throughout the Gulf of Alaska (GOA) and the Eastern Bering Sea (EBS), the Kuril Islands, and possibly the Okhotsk Sea (Hart 1973). They occur primarily on mixed mud and sand bottoms (Norcross et al. 1997, McConnaughey and Smith 2000) in depths < 300 m (Stark and Clausen 1995). The flathead sole distribution overlaps with the similar-appearing Bering flounder (*Hippoglossoides robustus*) in the northern half of the Bering Sea and the Sea of Okhotsk (Hart 1973), but not in the Gulf of Alaska.

Adults exhibit a benthic lifestyle and occupy separate winter spawning and summertime feeding distributions on the EBS shelf and in the GOA. From over-winter grounds near the shelf margins, adults begin a migration onto the mid and outer continental shelf in April or May each year for feeding. The spawning period may range from as early as January but is known to occur in March and April, primarily in deeper waters near the margins of the continental shelf. Eggs are large (2.75 to 3.75 mm) and females have egg counts ranging from about 72,000 (20 cm fish) to almost 600,000 (38 cm fish). Eggs hatch in 9 to 20 days depending on incubation temperatures within the range of 2.4 to 9.8°C and have been found in ichthyoplankton sampling on the southern portion of the BS shelf in April and May (Waldron 1981). Larvae absorb the yolk sac in 6 to 17 days, but the extent of their distribution is unknown. Nearshore sampling indicates that newly settled larvae are in the 40 to 50 mm size range (Norcross et al. 1996). Fifty percent of flathead sole females in the GOA are mature at 8.7 years, or at about 33 cm (Stark 2004). Juveniles less than age 2 have not been found with the adult population and probably remain in shallow nearshore nursery areas.

Fishery

Flathead sole in the Gulf of Alaska are caught in a directed fishery using bottom trawl gear. Typically 25 or fewer shore-based catcher vessels from 58-125’ participate in this fishery, as do 5 catcher-processor vessels (90-130’). Fishing seasons are driven by seasonal halibut PSC apportionments, with approximately 7 months of fishing occurring between January and November. Catches of flathead sole occur almost entirely in the Western and Central management areas in the gulf (statistical areas 610 and 620 + 630, respectively,Table 1). Recruitment to the fishery begins at about age 3.

Historically, catches of flathead sole have exhibited decadal-scale trends (Table 1, Figure 1). From a high of ~2000 t in 1980, annual catches declined steadily to a low of ~150 t in 1986 but thereupon increased steadily, reaching a high of ~3100 t in 1996. Catches subsequently declined over the next three years, reaching a low of ~900 t in 1999, followed by an increasing trend through 2010, when the catch reached its highest level ever (3,854 t). Catch in 2014 was 2,556 t. 2015 closures of the flathead sole fishery are shown in Table 3.

Based on observer data, the majority of the flathead sole catch in the Gulf of Alaska is taken in the Shelikof Strait and on the Albatross Bank near Kodiak Island, as well as near Unimak Island (Stockhausen 2011). Previously, most of the catch is taken in the first and second quarters of the year (Stockhausen 2011).

Annual catches of flathead sole have been well below TACs in recent years (

Table 2), although the population appears to be capable of supporting higher exploitation rates. Limits on flathead sole catches are driven by restrictions on halibut PSC, not by attainment of the TAC (Stockhausen 2011).

See Stockhausen (2011) for a description of the management history of flathead sole.

Data

The following table specifies the source, type, and years of all data included in the assessment models.

Source	Type	Years
Fishery	Catch biomass	1978-2015 (through October 10, 2015)
Fishery	Catch length composition	1989-1999, 2001-2007, 2009-2015
GOA survey bottom trawl	Survey biomass	Triennial: 1984-1999, Biennial: 2001-2015
GOA survey bottom trawl	Catch length composition	Triennial: 1984-1999, Biennial: 2001-2015
GOA survey bottom trawl	Catch age composition, conditioned on length	Triennial: 1984-1999, Biennial: 2001-2013

Fishery:

Catch Biomass

The assessment included catch data from 1978 to October 10, 2015 (Figure 1, Table 1). Catches of flathead sole occur almost entirely in the Western and Central management areas in the GOA (statistical areas 610 and 620 + 630, respectively, Table 1).

Catch Size Composition

Fishery length composition data were included in 2cm bins from 6-56cm in 1989-1999, 2001-2007, and 2009-2015; data were omitted in years where there were less than 15 hauls that included measured flathead sole (1982-1988 2000, 2008). The number of hauls were used as the relative effective sample size. Fishery length composition data were voluminous and can be accessed at http://www.afsc.noaa.gov/REFM/Docs/2015/GOA_Flathead_Composition_Data_And_SampleSize.xlsx.

Survey:

Biomass and Numerical Abundance

Survey biomass estimates originate from a cooperative bottom trawl survey conducted by the U.S. and Japan in 1984 and 1987 and a U.S. bottom trawl survey conducted by the Alaska Fisheries Science Center Resource Assessment and Conservation Engineering (RACE) Division thereafter. Calculations for final survey biomass and variance estimates are fully described in Wakabayashi et al. (1985). Depths 0-500 meters were fully covered in each survey and occurrence of flathead at depths greater than 500 meters is rare. The survey excluded the eastern region of the Gulf of Alaska (the Yakutat and Southeastern areas) in 2001 (

Table 4 and Table 5). As for previous assessments, the availability of the survey biomass in 2001 was assumed to be 0.9 to account for the biomass in the eastern region of the Gulf. The total survey biomass estimates and CVs that were used in the assessment are listed in (Table 5).

Figure 2 shows maps of survey CPUE in the GOA for the 2011, 2013, and 2015 surveys; survey CPUE in all three years was highest in the Central and Western GOA.

Survey Size and Age Composition

Sex-specific survey length composition data as well as age frequencies of fish by length (conditional age-at-length) were used in the assessment and can be found at http://www.afsc.noaa.gov/REFM/Docs/2015/GOA_Flathead_Composition_Data_And_SampleSize.xlsx, along with corresponding sample sizes used in the assessment. There are several advantages to using conditional age-at-length data. The approach preserves information on the relationship between length and age and provides information on variability in length-at-age such that growth parameters and variability in growth can be estimated within the model. In addition, the approach resolves the issue of double-counting individual fish when using both length- and age-composition data (as length-composition data are used to calculate the marginal age compositions). See Stewart (2005) for an additional example of the use of conditional age-at-length data in fishery stock assessments.

Analytic Approach

Model Structure

Tier 3 Model

The assessment was a split sex, age-structured statistical catch-at-age model implemented in Stock Synthesis version 3.24u (SS3) using a maximum likelihood approach. SS3 equations can be found in Methot and Wetzel (2013) and further technical documentation is outlined in Methot (2009). Before 2013 assessments were conducted using an ADMB-based, split-sex, age-structured population dynamics model (Stockhausen 2011). A benchmark assessment was conducted in 2013 in SS3 (McGilliard et al. 2013). Briefly, the current assessment model covers 1955-2015. Age classes included in the model run from age 0 to 29. Age at recruitment was set at 0 years in the model. The oldest age class in the model, age 29, serves as a plus group. Survey catchability was fixed at 1.0.

Fishery and Survey Selectivity

The fishery and survey selectivity curves were estimated using sex-specific, age-based double-normal functions without a descending limb (instead of a logistic function as previously used). The SS3 modeling framework does not currently include the option of estimating sex-specific, age-based logistic selectivity where both male and female selectivity maintain a logistic shape (as was used in the previous assessment model). Therefore, the double-normal curve without a descending limb was the closest match to the selectivity formulation used in the 2011 model (McGilliard et al. 2013). Length-based, sex-specific, logistic fishery and survey selectivity were implemented as sensitivity analyses in the 2013 assessment model runs (McGilliard et al. 2013). Length-based formulations for fishery and survey selectivity were not used in final model runs because the age-based selectivity curves derived from using length-based curves showed that the oldest fish were not selected, effectively lowering survey catchability and suggesting that the fishery fails to catch the oldest, largest fish. Fits to data were similar for length- and age-based asymptotic survey selectivity curves. Sensitivity analyses assuming dome-shaped fishery or survey selectivity failed to improve model fits to the data.

Conditional Age-at-Length

A conditional age-at-length approach was used: expected age composition within each length bin was fit to age data conditioned on length (conditional age-at-length) in the objective function, rather than fitting the expected marginal age-composition to age data (which are typically calculated as a function of the conditional age-at-length data and the length-composition data). This approach provides the information necessary to estimate growth curves and variability about mean growth within the assessment model. In addition, the approach allows for all of the length and age-composition information to be used in the assessment without double-counting each sample. The von-Bertalanffy growth curve and variability in the length-at-age relationship were evaluated within the model using the conditional age-at-length approach.

Data Weighting

In the 2013 assessment, the assumptions about data-weighting were re-evaluated using a more formal approach for assessing variability in mean proportions-at-age and proportions-at-length (Francis, 2011). To account for process error (e.g. variance in selectivities among years), the relative weights for length or age composition data (lambdas) were adjusted according to the method described in Francis (2011), which accounts for correlations in length- and age-composition data (data-weighting method number T3.4 was used). The 2013 assessment used weights calculated using the Francis (2011) method, but the weights for the fishery length-composition data were increased slightly to improve model stability.

In the current assessment, the method described in Francis (2011) was not used because of concerns raised about its use when using conditional age-at-length data. The effective sample size for length composition data was changed to the number of hauls (Volstad and Pennington 1994). The McAllister-Ianelli method for weighting among data sources was used in the current assessment (McAllister and Ianelli 1997).

Ageing Error Matrix

Ageing uncertainty was incorporated into the model using the ageing error matrix calculated from Bering Sea/Aleutian Islands (BSAI) flathead sole ageing data and used in the most recent accepted BSAI flathead sole assessment (McGilliard et al. 2014). SS3 accommodates the specification of ageing error bias and imprecision, while the previous assessment model framework did not. Future assessments should estimate ageing error matrices for GOA flathead sole using GOA age-read data. BSAI and GOA flathead sole are aged by the same individuals using the same techniques and ageing error is expected to be very similar. Assuming perfect age-reading of GOA flathead sole otoliths is thought to be an inferior assumption to using estimates of ageing error from the BSAI flathead sole population. The BSAI data was used in the current assessment, and will be replaced with GOA data when fully analyzed GOA ageing error data are available.

Recruitment Deviations

Recruitment deviations for the period 1955-1983 were estimated as “early-period” recruits separately from “main-period” recruits (1984-2012) such that the vector of recruits for each period had a sum-to-zero constraint, rather than forcing a sum-to-zero constraint across all recruitment deviations.

A bias adjustment factor was specified using the Methot and Taylor (2011) bias adjustment method. Recruitment deviations prior to the start of composition data and in the most recent years in the time-series are less informed than in the middle of the time-series. This creates a bias in the estimation of recruitment deviations and mean recruitment that is corrected using methods described in Methot and Taylor (2011).

Model structures considered in this year's assessment

One model is presented as the current, base case 2015 assessment model for GOA flathead sole (2015 Model). The proposed model structure is very similar to the most recent (2013) accepted model for flathead sole except that the effective sample size for all length composition data is now equal to the number of hauls for which lengths were collected for each data source due to correlations within hauls, which was analyzed in Volstad and Pennington (1994). In addition, data were weighted using the McAllister-Ianelli data weighting method, as described above. In addition, the 2013 model is presented with no new updated data (2014 and 2015 data are not included), and the 2015 model with 2013 data (2014 and 2015 data are excluded) are presented for the purpose of comparison.

Parameters Estimated Outside the Assessment Model

Natural mortality

Male and female natural mortality were fixed and equal to 0.2.

Weight-Length Relationship

The following weight-length relationship used in the previous assessment (McGilliard et al. 2013) is used in the current assessment: $w_L = \alpha L^{\beta}$, where $\alpha = 4.28E-06$ and $\beta = 3.2298$, length (*L*) was measured in centimeters and weight (*w*) was measured in kilograms.

Maturity-at-Age

Maturity-at-age (O_a) in the assessment was defined as $O_a = 1/(1+\gamma e^{(a-a_{50})})$, where the slope of the curve was $\gamma = -0.773$ and the age-at-50%-maturity was $a_{50} = 8.74$. These values were used in the previous assessment and were estimated from a histological analysis of 180 samples of GOA flathead sole ovaries collected in the central Gulf of Alaska from January 1999 (Stark, 2004).

Standard deviation of the Log of Recruitment (σ_R)

The standard deviation of the log of recruitment was not defined in previous assessments. Variability of the recruitment deviations that were estimated in previous flathead sole assessments was approximately σ_R =0.6 and this value is used in the current assessment.

Catchability

Catchability was assumed equal to 1, as for previous flathead sole assessments.

Select selectivity parameters

Selectivity parameter definitions and values for fixed parameters are shown in Table 6.

Parameters Estimated Inside the Assessment Model

Parameters estimated within the assessment model were the log of unfished recruitment (R_0), log-scale recruitment deviations, yearly fishing mortality, sex-specific parameters of the von-Bertalanffy growth curve, CV of length-at-age for ages 2 and 29, and selectivity parameters for the fishery and survey. The selectivity parameters are described in greater detail in Table 6.

Results

Model Evaluation

Comparison among models

Figure 3-Figure 4 and Table 7-Table 10 compare the 2015 base case model with (1) a model with the same structure of the base case model, but only including that data that were included in the 2013 model, and (2) the 2013 model. Fits to the survey biomass index and resulting estimates of spawning stock biomass over time are similar among the three model runs in recent years (after 2000; Figure 3, Figure 4). Before 2000, the fits to survey biomass index and estimates of spawning stock biomass for 2015 model with and without new data were higher, indicating that differences in the fits can be attributed to changes to the effective sample sizes and methods for data weighting among data sources. The negative log likelihood component for the survey index improved slightly for the 2015 model run with data only up to 2013 (-lnL = -16.23) as compared to the 2013 model (-lnL = -15.77; Table 7). Estimations of recruitment deviations and resulting age-0 recruitment are very similar among models, with the exception of the two most recent years, where there is little information to inform estimates (Figure 5, Figure 6). Estimates of growth parameters, unfished recruitment, and survey selectivity were very similar among models (Table 8, Table 10). Estimates of the age at which peak fishery selectivity was reached and the width of the ascending limb of the fishery selectivity curve were smaller for both models run with the 2015 model structure, indicating that changes in estimates of selectivity were due to changes in effective sample size and data weighting methods (Table 9). The 2013 model imposed a constraint on fishery selectivity such that peak female selectivity was reached by age 16. Without the constraint on peak female selectivity, the model estimated an asymptotic fishery selectivity curve that did not reach a selectivity of 1 (McGilliard et al. 2013). The base case 2015 model and the 2015 model with data up to 2013 estimate peak female selectivity at age 13.08 and 13.25, respectively, without a constraint (Table 9). The 2015 model was chosen because the approach to specifying effective sample sizes and methods for the relative weighting of data has a scientific basis and avoids issues that have been encountered (and are still being researched) about using the Francis (2011) data weighting methods with a conditional age-at-length approach. In addition, the 2015 model without new data fit the survey biomass index slightly better than the 2013 model and the 2015 model does not require a constraint peak female fishery selectivity.

The 2015 Base Case Model

The estimated fishery and survey selectivity curves for the 2015 base case model are shown in Figure 7. Although selectivity curves for males and females are similar, it is puzzling that males would be selected at slightly younger ages than females, given that they grow more slowly than females (Figure 8). Future work will explore potential causes for this result. One constraint in the current assessment is that natural mortality is fixed at the same value for both males and females. Furthermore, natural mortality and catchability are both fixed in the assessment.

Fits to fishery and survey selectivity, aggregated over years are shown in Figure 9. These aggregated fits show that the model predicted slightly more females length 40-45cm in the fishery than were observed. In addition, the model predicted that more 25-30cm females in the survey than were observed and fewer females in the 32-40cm range than were observed in the survey. Similarly, the model predicted slightly fewer 30-32cm males and in the survey and slightly more 34-40cm males in the survey than were observed. Overall, however, model fits to the length composition data, aggregated over years were fairly reasonable. Figure 10-Figure 12 show fits to yearly fishery and survey length composition data. Fits to fishery length composition data were particularly poor in 1990; fishery selectivity appears to have been quite different in that year. Fits to survey length composition data were poor in 1984, 1987, and 1990. Survey methods in 1984 and 1987 differed from the current protocol and we would expect differences in fits in these years (McGilliard 2013).

Figure 13-Figure 16 show model fits to the mean age at each length and corresponding estimated and observed standard deviations about mean age-at-length and show that the model fits growth data reasonably well. Observed standard deviations are expected to differ from estimated standard deviations about the age-at-length for older ages and larger size bins due to low sample size. Figure 17-Figure 19 show pearson residuals in age-at-length model fits. One very large residual occurs in 1999, but otherwise, the pearson residuals are relatively small.

Time Series Results

Time series results are shown in Table 13-Table 14 and Figure 20-Figure 21. A time series of number-at-age is available at http://www.afsc.noaa.gov/REFM/Docs/2015/GOA_Flathead_TimeSeries_of_NumbersAtAge.xlsx. Age 3 recruitment, age 0 recruitment, and standard deviations of age 0 recruitment are presented in Table 14 for the current and previous assessments. Total biomass for ages 3+, spawning stock biomass, and standard deviations of spawning stock biomass estimates for the previous and current assessments are presented in Table 13. Figure 20 shows spawning stock biomass estimates and corresponding asymptotic 95% confidence intervals. Figure 21 is a plot of biomass relative to $B_{35\%}$ and F relative to $F_{35\%}$ for each year in the time series, along with the OFL and ABC control rules.

Retrospective Analyses

Spawning stock biomass, age 0 recruits, and recruitment deviations for retrospective analyses extending back 10 years are shown in Figure 22 and Figure 23. A retrospective pattern in spawning stock biomass extending back 8 years is evident, whereby each year of added data lowers the most current estimates by a small amount; runs removing 9 and 10 years of data do not follow this pattern (Figure 22). This retrospective pattern should be explored further in future analyses where alternative values and approaches for modeling catchability, natural mortality, and selectivity are explored.

Harvest Recommendations

The reference fishing mortality rate for flathead sole is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{40\%}$, $F_{35\%}$, and $SPR_{40\%}$ were obtained from a spawner-per recruit analysis. Assuming that the average recruitment from the 1983-2012 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{40\%}$ is calculated as the product of $SPR_{40\%}$ times the equilibrium number of recruits. Since reliable estimates of the 2013 spawning biomass (B), $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and $B > B_{40\%}$, the flathead sole reference fishing mortality is defined in Tier 3a. For this tier, F_{ABC} is constrained to be $\leq F_{40\%}$, and F_{OFL} is defined to be $F_{35\%}$. The values of these quantities are:

SSB 2016	82,375
$B_{40\%}$	36,866
$F_{40\%}$	0.32
max*Fabc*	0.32
$B_{35\%}$	32,258
$F_{35\%}$	0.40
F_{OFL}	0.40

Because the flathead sole stock has not been overfished in recent years and the stock biomass is relatively high, it is not recommended to adjust F_{ABC} downward from its upper bound.

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). For each scenario, the projections begin with the vector of 2015 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2016 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2015. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2016 are as follow ("max F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2016 recommended in the assessment to the *max*F_{ABC} for 2016. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 2011-2015 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.) The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, so scenarios 1 and 2 yield identical results.

The 12-year projections of the mean spawning stock biomass, fishing mortality, and catches for the five scenarios are shown in Table 15-Table 17.

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the flathead sole stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as *B35%*):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above its MSY level in 2016, then the stock is not overfished.)

Scenario 7: In 2016 and 2017, *F* is set equal to *max* F_{ABC}, and in all subsequent years, *F* is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2028 under this scenario, then the stock is not approaching an overfished condition.)

The results of these two scenarios indicate that the stock is not overfished and is not approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2016 of scenario 6 is 82,375, more than 2 times *B35%* (32,258 t). Thus the stock is not currently overfished. With regard to whether the stock is approaching an overfished condition, the expected spawning stock size in the year 2028 of scenario 7 (34,031 t) is greater than *B35%*; thus, the stock is not approaching an overfished condition.

Area Allocation of Harvests

TAC's for flathead sole in the Gulf of Alaska are divided among four smaller management areas (Western, Central, West Yakutat and Southeast Outside). The area-specific ABC's for flathead sole in the GOA are divided up over the four management areas by applying the fraction of the survey biomass estimated for each area (relative to the total over all areas) in 2016 and 2017 from the survey averaging random effects model to the 2016 and 2017 ABC's. The area-specific allocations for 2016 and 2017 are:

Quantity	**Western**	**Central**	**West Yakutat**	**Southeast**	**Total**
Area Apportionment	31.49%	57.71%	8.37%	2.43%	100.00%
2016 ABC (t)	11,027	20,211	2,930	852	35,020
2017 ABC (t)	11,080	20,307	2,944	856	35,187

Ecosystem Considerations

Ecosystem Effects on the Stock

Prey availability/abundance trends

Based on results from an ecosystem model for the Gulf of Alaska (Aydin et al., 2007), flathead sole in the Gulf of Alaska occupy an intermediate trophic level as both juvenile and adults (Figure 24, Figure 25). Pandalid shrimp and brittle stars were the most important prey for adult flathead sole in the Gulf of Alaska (64% by weight in sampled stomachs; Yang and Nelson, 2000; Figure 24, Figure 26), while euphausids and mysids constituted the most important prey items for juvenile flathead sole (Figure 25, Figure 27). Other major prey items included polychaetes, mollusks, bivalves and hermit crabs for both juveniles and adults. Commercially important species that were consumed included age-0 Tanner crab (3%) and age-0 walleye pollock (< 0.5% by weight). Little to no information is available to assess trends in abundance for the major benthic prey species of flathead sole.

Predator population trends

Important predators on flathead sole include arrowtooth flounder, walleye pollock, Pacific cod, and other groundfish (Figure 24, Figure 25). Pacific cod and Pacific halibut are the major predators on adults, while arrowtooth flounder, sculpins, walleye pollock and Pacific cod are the major predators on juveniles. The flatfish-directed fishery constitutes the third-largest known source of mortality on flathead sole adults. However, the largest component of mortality on adults is unexplained.

Fishery Effects on the Ecosystem

Non-target catch in the directed GOA flathead sole fishery are shown in Table 18. Prohibited species catch in the directed GOA flathead sole fishery are shown in Table 19. Historically, the flathead sole fishery has caught a high proportion of the brittlestar, eelpouts, gunnels, polychaetes, and Stichaeidae in some years. In 2014 and 2015, proportion of non-target species caught in the flathead sole fishery ranged from 0 to 32% (32% of Pandalid shrimp were caught in the flathead sole fishery in 2015). Prohibited species catch in the flathead sole fishery were 0-2% of the prohibited species catch of each of these species in 2014 and 2015.

Data Gaps and Research Priorities

The 2013 and 2015 stock assessments incorporated ageing error by using an existing ageing error matrix for BSAI flathead sole. A priority for future assessments is to analyze ageing error data for GOA flathead sole using methods described in Punt et al. (2008) and to incorporate a resulting ageing error matrix into the assessment. Future analyses should explore the relationship between natural mortality and catchability in the model, alternative parameter values, and the effects of these parameters on estimation of selectivity and other parameters. The assessment would benefit from an exploration of ways to better account for scientific uncertainty, especially uncertainty associated with parameters that are currently fixed in the model.

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Tables

Table 1. Total and regional annual catch of GOA flathead sole through October 10, 2015.

Year	Total Catch	Western Gulf	Central Gulf	Eastern Gulf
1978	452			
1979	165			
1980	2,068			
1981	1,070			
1982	1,368			
1983	1,080			
1984	549			
1985	320			
1986	147			
1987	151			
1988	520			
1989	747			
1990	1,447			
1991	1,237	199	1,036	2.1
1992	2,315	355	1,947	12.7
1993	2,824	581	2,242	0.0
1994	2,525	499	2,013	0.0
1995	2,180	589	1,563	28.0
1996	3,073	807	2,166	100.3
1997	2,441	449	1,934	0.0
1998	1,731	556	1,168	0.0
1999	897	186	687	24.6
2000	1,548	259	1,274	0.0
2001	1,912	600	1,311	0.0
2002	2,146	420	1,725	0.0
2003	2,459	525	1,934	0.1
2004	2,398	828	1,571	0.0
2005	2,552	611	1,941	
2006	3,142	462	2,679	0.9
2007	3,130	666	2,462	2.2
2008	3,446	297	3,149	0.0
2009	3,663	303	3,359	1.0
2010	3,854	462	3,392	0.5
2011	2,729	393	2,336	0.3
2012	2,166	277	1,890	0.2
2013	2,817	588	2,228	0.2
2014	2,556	219	2,336	0.9
2015	1,765	188	1,577	0.6

Table 2. Historical OFLs, ABCs, TACs, total catch, and percent of catch that was retained.

Year	OFL	ABC	TAC	Total Catch	% Retained
1995	31,557	28,790	9,740	2,180	
1996	31,557	52,270	9,740	3,073	
1997	34,010	26,110	9,040	2,441	
1998	34,010	26,110	9,040	1,731	
1999	34,010	26,010	9,040	897.32	
2000	34,210	26,270	9,060	1,548	
2001	34,210	26,270	9,060	1,912	
2002	29,530	22,690	9,280	2,146	
2003	51,560	41,390	11,150	2,459	88
2004	64,750	51,270	10,880	2,398	80
2005	56,500	45,100	10,390	2,552	87
2006	47,003	37,820	9,077	3,142	89
2007	48,658	39,110	9,148	3,130	89
2008	55,787	44,735	11,054	3,446	90
2009	57,911	46,464	11,181	3,663	96
2010	59,295	47,422	10,411	3,854	95
2011	61,412	49,133	10,587	2,729	97
2012	59,380	47,407	30,319	2,166	92
2013	61,036	48,738	30,496	2,817	87
2014	50,664	41,231	27,746	2,556	98
2015	50792	41349	27756	1,765	98

Table 3. GOA flathead sole fishery closures in 2015

Sub-Area	Program	Status	Reason	Effective Date
GOA - Central 620/630	All	Bycatch	Regulations	01-Jan
GOA - Western 610	All	Bycatch	Regulations	01-Jan
GOA - Central 620/630	All	Open	Regulations	20-Jan
GOA - Western 610	All	Open	Regulations	20-Jan
West Yakutat - 640	All	Open	Regulations	20-Jan
West Yakutat - 640	All	Bycatch	Regulations	01-Jan
GOA - Central 620/630	Catcher Vessel	Bycatch	Chinook Salmon	03-May
GOA - Western 610	Catcher Vessel	Bycatch	Chinook Salmon	03-May
GOA - Central 620/630	Catcher Vessel	Open	Regulations	10-Aug
GOA - Western 610	Catcher Vessel	Open	Regulations	10-Aug

Table 4. Survey biomass by area and depth

		Depth (meters)						
		1-100	**101-200**	**201-300**	**301-500**	**501-700**	**701-1000**	**Total**
CENTRAL GOA		960,073	826,531	102,448	69	0	0	1,889,121
	1984	64,191	85,916	8,431	0	0	0	158,539
	1987	64,607	38,880	9,962	36	0	0	113,483
	1990	100,061	52,600	8,591	5			161,257
	1993	64,289	40,912	8,775	0			113,976
	1996	56,342	59,964	6,422	3			122,730
	1999	95,624	40,352	3,366	14	0	0	139,356
	2001	44,046	37,467	3,906	11			85,430
	2003	84,916	76,161	9,775	0	0		170,852
	2005	61,294	75,699	5,050	0	0	0	142,043
	2007	72,109	95,906	9,627	0	0	0	177,641
	2009	60,575	62,431	5,904	0	0	0	128,910
	2011	66,969	50,067	11,391	0	0		128,428
	2013	72,923	42,847	5,293	0	0		121,063
	2015	52,128	67,331	5,955	0	0	0	125,414
EASTERN GOA		131,961	159,546	5,580	370	0	0	297,456
	1984	21,029	24,596	74	4	0	0	45,703
	1987	6,060	23,835	564	0	0		30,459
	1990	11,041	11,010	991	17			23,059
	1993	4,839	10,377	1,434	193			16,843
	1996	10,773	4,607	674	6			16,059
	1999	5,145	13,271	182	0	0	0	18,598
	2003	7,790	11,542	56	0	0		19,388
	2005	2,060	9,365	135	151	0	0	11,712
	2007	9,050	16,196	154	0	0	0	25,400
	2009	10,111	6,150	90	0	0	0	16,351
	2011	19,801	10,785	577	0	0		31,162
	2013	11,007	6,887	146	0	0		18,039
	2015	13,257	10,924	503	0	0	0	24,684
WESTERN GOA		690,651	178,842	1,122	58	8	0	870,680
	1984	33,754	11,279	66	1	0	0	45,100
	1987	20,815	12,761	27	0	0	0	33,603
	1990	45,913	12,696	131	0			58,740
	1993	43,944	13,854	68	5			57,871
	1996	52,543	13,974	174	41			66,732
	1999	44,578	5,018	33	0	8	0	49,636
	2001	49,387	18,667	100	11			68,164
	2003	53,313	13,718	24	0	0		67,055
	2005	51,541	7,805	112	0	0	0	59,458
	2007	59,759	18,560	42	0	0	0	78,361
	2009	68,139	11,814	163	0	0	0	80,115
	2011	63,066	12,866	117	0	0		76,049
	2013	52,263	9,841	28	0	0		62,131
	2015	51,636	15,991	37	0	0	0	67,665

Table 5. Survey biomass estimates and CVs used in the assessment as an absolute index of abundance

Year	Biomass Estimate	CV
1984	249,341	0.12
1987	177,546	0.11
1990	243,055	0.12
1993	188,690	0.13
1996	205,521	0.09
1999	207,590	0.12
2001	170,660	0.12
2003	257,294	0.08
2005	213,213	0.08
2007	281,402	0.08
2009	225,377	0.11
2011	235,639	0.09
2013	201,233	0.09
2015	217,763	0.08

Table 6. Configuration of fishery and survey age-based, sex-specific double-normal selectivity curves used in the assessment. A numeric value indicates the fixed value of a parameter. The asterisk denotes that the parameter was estimated, but constrained to be below age 16 (as for the accepted 2013 model). A "+" denotes that initial selectivity was fixed at zero for ages 0-2.

Double-normal selectivity parameters	**Fishery**	**Survey**
Peak: beginning size for the plateau	Estimated*	Estimated
Width: width of plateau	30	30
Ascending width (log space)	Estimated	Estimated
Descending width (log space)	8	8
Initial: selectivity at smallest length or age bin	0^{+}	0^{+}
Final: selectivity at largest length or age bin	999	999
Male Peak Offset	Estimated	Estimated
Male ascending width offset (log space)	Estimated	Estimated
Male descending width offset (log space)	0	0
Male "Final" offset (transformation required)	0	0
Male apical selectivity	1	1

Table 7. Likelihood components for the base case 2015 model, the base case model with new data removed (data are as for the 2013 model), and the 2013 model. Values for likelihood components for the 2015 base case model cannot be compared directly with the other two models. Only the value for the survey index likelihood component can be compared between the two models using data up to 2013 because effective sample sizes, data weights, and the estimation of the most recent recruitment deviations differ between models.

Likelihood Component	2015 Model	2015 Model w/ 2013 Data	2013 Model
TOTAL	1,425	1,293	1,663
Survey	-17.88	-16.23	-15.77
Length_comp	507	457	182
Age_comp	941	857	1,498
Recruitment	-4.694	-5.062	-0.996

Table 8. Final parameter estimates of growth parameters and unfished recruitment with corresponding standard deviations for the 2015 base case model, the 2015 base case model with data up to 2013, and the 2013 model.

	2015 Model		**2015 Model, 2013 Data**		**2013 Model**	
Parameter	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Length at age 2 (f)	9.420	0.254	9.463	0.271	9.306	0.221
Linf (f)	44.215	0.395	44.241	0.425	44.209	0.419
von Bertalanffy k (f)	0.189	0.006	0.188	0.006	0.190	0.006
CV in length at age 2 (f)	0.106	0.008	0.102	0.008	0.110	0.008
CV in length at age 59 (f)	0.096	0.003	0.098	0.004	0.082	0.003
Length at age 2 (m)	9.596	0.326	9.740	0.369	9.778	0.297
Linf (m)	36.784	0.203	36.818	0.223	36.846	0.241
von Bertalanffy k (m)	0.256	0.007	0.252	0.008	0.256	0.007
CV in length at age 2 (m)	0.130	0.009	0.127	0.010	0.147	0.008
CV in length at age 59 (m)	0.081	0.003	0.083	0.003	0.065	0.003
R0 (log space)	12.826	0.036	12.804	0.046	12.801	0.044

Table 9. Final fishery selectivity parameters for the 2015 base case model, the 2015 model with data up to 2013, and the 2013 model. “Est” refers to the estimated value and “Std. Dev” is the standard deviation of the estimate.

	2015 Model		**2015 Model, 2013 Data**		**2013 Model**	
Double-normal selectivity parameters	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Peak: beginning size for the plateau	13.08	0.68	13.25	0.72	16.00	0.13
Width: width of plateau	30.00	NA	30.00	NA	30.00	NA
Ascending width (log space)	2.93	0.17	2.92	0.18	3.53	0.11
Descending width (log space)	8.00	NA	8.00	NA	8.00	NA
Initial: selectivity at smallest length or age bin	-10	NA	-10	NA	-10	NA
Final: selectivity at largest length or age bin	999	NA	999	NA	999	NA
Male Peak Offset	-0.94	0.49	-1.05	0.51	-1.68	1.77
Male ascending width offset (log space)	-0.10	0.15	-0.15	0.17	-0.23	0.46
Male descending width offset (log space)	0.00	NA	0.00	NA	0.00	NA
Male "Final" offset (transformation required)	1.00	NA	1.00	NA	1.00	NA
Male apical selectivity	1.00	NA	1.00	NA	1.00	NA

Table 10. Final survey selectivity parameters for the 2015 base case model, the 2015 model with data up to 2013, and the 2013 model. "Est" refers to the estimated value and "Std. Dev" is the standard deviation of the estimate.

	2015 Model		**2015 Model, 2013 Data**		**2013 Model**	
Double-normal selectivity parameters	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Peak: beginning size for the plateau (in cm)	7.22	0.24	7.31	0.25	7.12	0.28
Width: width of plateau	30.00	NA	30.00	NA	30.00	NA
Ascending width (log space)	2.13	0.12	2.16	0.12	2.06	0.14
Descending width (log space)	8.00	NA	8.00	NA	8.00	NA
Initial: selectivity at smallest length or age bin	-10	NA	-10	NA	-10	NA
Final: selectivity at largest length or age bin	999	NA	999	NA	999	NA
Male Peak Offset	-0.59	0.26	-0.59	0.28	-0.74	0.32
Male ascending width offset (log space)	-0.26	0.15	-0.24	0.16	-0.32	0.18
Male descending width offset (log space)	0.00	NA	0.00	NA	0.00	NA
Male "Final" offset (transformation required)	0.00	NA	0.00	NA	0.00	NA
Male apical selectivity	1.00	NA	1.00	NA	1.00	NA

Table 11. Estimated yearly fishing mortality rates (rates are apical fishing mortality rates across ages) for the proposed 2015 model.

Year	Fishing Mortality	Std. Dev.	Year	Fishing Mortality	Std. Dev.
Initial F	0.0069	0.0004	1998	0.0153	0.0010
1978	0.0052	0.0006	1999	0.0078	0.0005
1979	0.0020	0.0002	2000	0.0133	0.0008
1980	0.0260	0.0027	2001	0.0164	0.0010
1981	0.0141	0.0014	2002	0.0183	0.0011
1982	0.0183	0.0018	2003	0.0211	0.0013
1983	0.0143	0.0013	2004	0.0208	0.0012
1984	0.0069	0.0006	2005	0.0223	0.0013
1985	0.0037	0.0003	2006	0.0275	0.0016
1986	0.0015	0.0001	2007	0.0273	0.0017
1987	0.0014	0.0001	2008	0.0297	0.0019
1988	0.0045	0.0004	2009	0.0313	0.0020
1989	0.0062	0.0005	2010	0.0326	0.0021
1990	0.0119	0.0008	2011	0.0230	0.0015
1991	0.0102	0.0007	2012	0.0180	0.0011
1992	0.0192	0.0012	2013	0.0231	0.0015
1993	0.0237	0.0015	2014	0.0208	0.0014
1994	0.0215	0.0014	2015	0.0130	0.0009
1995	0.0188	0.0012			
1996	0.0269	0.0017			
1997	0.0216	0.0014			

Table 12. Recruitment deviations and standard deviations for the proposed 2015 model.

Year	Recruitment Deviations	Std. Dev.	Year	Recruitment Deviations	Std. Dev.
1955	-0.131	0.564	1985	-0.242	0.377
1956	-0.156	0.558	1986	-0.228	0.332
1957	-0.185	0.551	1987	-0.123	0.300
1958	-0.219	0.543	1988	-0.195	0.322
1959	-0.257	0.535	1989	0.225	0.209
1960	-0.300	0.526	1990	-0.341	0.271
1961	-0.348	0.516	1991	-0.149	0.244
1962	-0.400	0.506	1992	0.327	0.172
1963	-0.454	0.496	1993	-0.165	0.219
1964	-0.510	0.487	1994	-0.067	0.198
1965	-0.562	0.478	1995	-0.265	0.217
1966	-0.613	0.469	1996	-0.479	0.242
1967	-0.666	0.460	1997	0.212	0.152
1968	-0.722	0.452	1998	-0.019	0.185
1969	-0.780	0.444	1999	0.401	0.149
1970	-0.835	0.437	2000	-0.238	0.241
1971	-0.873	0.432	2001	0.007	0.171
1972	-0.882	0.429	2002	-0.038	0.171
1973	-0.848	0.431	2003	0.300	0.147
1974	-0.754	0.438	2004	-0.006	0.193
1975	-0.560	0.458	2005	0.285	0.156
1976	-0.177	0.517	2006	-0.122	0.205
1977	0.852	0.311	2007	-0.010	0.188
1978	0.092	0.483	2008	-0.263	0.215
1979	-0.277	0.427	2009	0.000	0.200
1980	-0.116	0.357	2010	0.482	0.186
1981	-0.098	0.356	2011	0.455	0.243
1982	-0.082	0.367	2012	0.316	0.298
1983	-0.043	0.373			
1984	-0.062	0.357			

Table 13. Time series of total and spawning biomass and standard deviation of spawning biomass (Std_Dev) for the previous and proposed 2015 assessments.

	2013 Assessment			*2015 Assessment*		
Year	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**
1978	269,959	51,926	5,349	277,139	58,089	6,159
1979	126,738	49,361	4,913	141,975	55,470	5,688
1980	125,801	47,308	4,504	140,348	53,318	5,234
1981	135,017	44,867	4,131	150,713	50,751	4,807
1982	145,957	44,019	3,806	162,748	49,778	4,424
1983	158,409	44,516	3,545	176,027	50,243	4,100
1984	169,804	47,103	3,370	187,764	52,985	3,864
1985	180,069	51,879	3,304	197,571	58,136	3,750
1986	188,930	57,830	3,347	205,660	64,542	3,771
1987	195,676	63,517	3,432	212,188	70,501	3,843
1988	200,541	67,904	3,477	217,348	74,843	3,856
1989	203,678	70,756	3,467	220,399	77,433	3,792
1990	204,544	72,470	3,422	221,360	78,873	3,685
1991	204,089	73,083	3,361	221,208	79,357	3,570
1992	202,641	72,992	3,293	219,546	79,543	3,462
1993	203,362	72,348	3,221	220,077	78,828	3,361
1994	202,816	71,365	3,147	218,587	77,623	3,260
1995	202,782	70,378	3,072	216,623	76,576	3,157
1996	206,051	69,971	3,000	217,713	75,944	3,059
1997	209,034	69,659	2,945	218,763	75,244	2,970
1998	211,821	70,224	2,907	218,974	75,216	2,894
1999	213,612	71,498	2,884	218,544	75,734	2,829
2000	213,109	73,417	2,873	216,628	76,770	2,773
2001	215,414	74,985	2,877	216,872	77,424	2,727
2002	217,217	75,985	2,880	216,677	77,572	2,683
2003	222,411	76,306	2,868	219,537	77,148	2,632
2004	225,341	76,200	2,839	221,399	76,372	2,575
2005	228,763	76,389	2,813	223,115	75,936	2,528
2006	231,545	77,226	2,818	224,310	76,121	2,513
2007	235,092	78,381	2,871	226,919	76,661	2,539
2008	237,259	79,679	2,959	228,563	77,474	2,595
2009	240,735	80,631	3,067	231,727	78,025	2,667
2010	241,844	81,282	3,197	233,324	78,367	2,754
2011	241,226	81,824	3,365	233,972	78,739	2,866
2012	238,297	82,867	3,570	232,367	79,826	3,006
2013	236,745	83,899	3,812	231,266	81,114	3,166
2014	252,361	84,058	0	233,760	81,718	3,334
2015				238,766	82,006	3,510
2016				265,088	82,375	0

Table 14. Time series of recruitment at ages 3 and 0 and standard deviation of age 0 recruits for the previous and proposed 2015 assessments.

	2013 Assessment			*2015 Assessment*		
Year	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. dev**	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. dev**
1978	100,774	358,535	165,729	106,393	368,484	177,506
1979	150,505	251,699	105,587	155,476	253,772	108,446
1980	365,437	289,323	103,307	433,871	297,149	105,949
1981	196,748	309,033	106,072	202,218	301,679	106,894
1982	138,123	292,494	102,141	139,268	305,519	112,206
1983	158,769	263,263	92,987	163,073	316,566	116,231
1984	169,587	265,842	91,170	165,559	309,669	111,617
1985	160,516	265,419	85,684	167,669	257,747	97,245
1986	144,479	231,152	71,352	173,734	260,632	86,860
1987	145,895	251,384	73,740	169,949	288,331	86,107
1988	145,664	272,819	82,111	141,454	267,445	87,185
1989	126,856	404,447	78,027	143,037	405,666	82,826
1990	137,958	208,573	57,071	158,238	229,639	62,810
1991	149,718	308,667	71,517	146,773	277,449	68,434
1992	221,949	477,306	75,450	222,629	445,008	74,920
1993	114,458	252,968	53,346	126,024	271,093	59,833
1994	169,384	343,279	56,150	152,259	298,176	59,033
1995	261,922	240,966	46,048	244,213	243,695	53,035
1996	138,818	172,439	39,645	148,772	196,069	48,182
1997	188,371	447,516	56,870	163,633	390,474	58,701
1998	132,230	330,472	53,743	133,736	310,045	58,382
1999	94,628	509,094	68,171	107,601	471,911	69,994
2000	245,590	208,070	54,735	214,291	249,058	60,890
2001	181,356	380,791	56,138	170,152	317,992	54,702
2002	279,375	330,704	53,962	258,981	304,039	53,283
2003	114,181	413,028	62,922	136,681	426,427	63,497
2004	208,962	320,105	59,460	174,510	314,108	62,031
2005	181,476	436,627	67,398	166,852	420,247	66,478
2006	226,652	254,330	52,683	234,017	279,669	58,466
2007	175,656	284,855	60,856	172,376	312,754	60,275
2008	239,595	248,675	59,976	230,623	242,828	53,751
2009	139,560	362,494	97,638	153,476	315,972	65,533
2010	156,309	536,437	178,348	171,631	511,681	98,931
2011	136,455	355,967	176,865	133,257	504,307	126,418
2012	198,917	362,445	15,778	173,400	445,553	137,487
2013	294,376	362,445		280,805	371,808	13,501
2014				276,755	371,808	13,501
2015				244,513	371,808	
Average	177,535	322,324		183,103	329,639	

Table 15. Projected spawning biomass for the seven harvest scenarios listed in the “Harvest Recommendations” section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2015	82,007	82,007	82,007	82,007	82,007	82,007	82,007
2016	82,375	82,375	82,375	82,375	82,375	82,375	82,375
2017	82,690	82,690	82,690	82,690	82,690	63,484	67,189
2018	68,562	68,562	84,160	81,445	85,342	52,732	58,027
2019	60,299	60,299	86,617	81,584	88,867	47,401	50,806
2020	55,403	55,403	89,388	82,353	92,613	44,726	46,895
2021	51,753	51,753	91,564	82,761	95,691	42,625	43,986
2022	48,341	48,341	92,640	82,277	97,599	40,292	41,128
2023	45,159	45,159	92,694	80,998	98,401	37,927	38,425
2024	42,527	42,527	92,097	79,324	98,446	36,078	36,337
2025	40,596	40,596	91,198	77,611	98,075	34,951	35,070
2026	39,311	39,311	90,220	76,048	97,514	34,371	34,418
2027	38,512	38,512	89,277	74,705	96,892	34,114	34,129
2028	38,043	38,043	88,427	73,594	96,288	34,029	34,031

Table 16. Projected fishing mortality rates for the seven harvest scenarios listed in the “Harvest Recommendations” section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2015	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2016	0.02	0.02	0.02	0.02	0.02	0.40	0.32
2017	0.32	0.32	0.02	0.07	0.00	0.40	0.32
2018	0.32	0.32	0.02	0.07	0.00	0.40	0.40
2019	0.32	0.32	0.02	0.07	0.00	0.40	0.40
2020	0.32	0.32	0.02	0.07	0.00	0.40	0.40
2021	0.32	0.32	0.02	0.07	0.00	0.40	0.40
2022	0.32	0.32	0.02	0.07	0.00	0.40	0.40
2023	0.32	0.32	0.02	0.07	0.00	0.39	0.39
2024	0.32	0.32	0.02	0.07	0.00	0.38	0.38
2025	0.31	0.31	0.02	0.07	0.00	0.37	0.37
2026	0.31	0.31	0.02	0.07	0.00	0.37	0.37
2027	0.31	0.31	0.02	0.07	0.00	0.36	0.36
2028	0.31	0.31	0.02	0.07	0.00	0.36	0.36

Table 17. Projected catches for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2015	1,982	1,982	1,982	1,982	1,982	1,982	1,982
2016	2,825	2,825	2,825	2,825	2,825	42,840	35,020
2017	35,187	35,187	2,447	8,088	0	32,951	28,489
2018	29,050	29,050	2,483	7,937	0	27,306	30,086
2019	25,392	25,392	2,547	7,915	0	24,417	26,203
2020	23,197	23,197	2,627	7,978	0	22,895	24,031
2021	21,606	21,606	2,702	8,040	0	21,735	22,447
2022	20,161	20,161	2,747	8,024	0	20,507	20,949
2023	18,809	18,809	2,752	7,906	0	19,021	19,354
2024	17,677	17,677	2,729	7,725	0	17,645	17,838
2025	16,797	16,797	2,695	7,536	0	16,775	16,867
2026	16,183	16,183	2,661	7,372	0	16,339	16,376
2027	15,800	15,800	2,630	7,237	0	16,155	16,165
2028	15,570	15,570	2,604	7,128	0	16,105	16,105

Table 18. Non-target catch in the directed GOA flathead sole fishery as a proportion of total weight of bycatch of each species. Conditional highlighting from white (lowest numbers) to green (highest numbers) is applied. No seabird bycatch was recorded in the GOA flathead sole fishery.

Non-Target Species	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Benthic urochordata	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.07	0.06	0.00	0.00
Bivalves	0.03	0.34	0.15	0.09	0.00	0.11	0.00	0.01	0.05	0.00	0.03	0.00	0.00
Brittle star unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.84	0.01	0.00	0.00	0.11	0.00
Capelin	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00
Corals Bryozoans Unidentified	0.02	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Dark Rockfish						0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Eelpouts	0.52	0.07	0.04	0.18	0.12	0.02	0.00	0.94	0.24	0.06	0.00	0.00	0.10
Eulachon	0.07	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.08
Giant Grenadier	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Greenlings	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00
Ratail Grenadier Unidentified	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
Gunnels	0.00			1.00		0.24				0.00	0.00		0.00
Hermit crab unidentified	0.02	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.05	0.00	0.00	0.00	0.02
Invertebrate unidentified	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Large Sculpins	0.00	0.02	0.00	0.00	0.00								
Bigmouth Sculpin						0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00
Great Sculpin						0.00	0.01	0.01	0.02	0.00	0.00	0.00	0.00
Plain Sculpin						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Warty Sculpin						0.41	0.00	0.00				0.00	0.00
Yellow Irish Lord						0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.00
Misc crabs	0.08	0.17	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.00	0.00
Misc fish	0.03	0.00	0.00	0.00	0.00	0.01	0.01	0.05	0.00	0.01	0.00	0.00	0.00
Other osmerids	0.01	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Sculpins	0.01	0.00	0.01	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01
Pandalid shrimp	0.38	0.01	0.08	0.10	0.00	0.02	0.01	0.17	0.02	0.07	0.02	0.00	0.32
Polychaete unidentified	0.00		0.03		0.00	0.00	0.00	0.00	0.78		0.00		0.17
Scypho jellies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sea anemone unidentified	0.04	0.02	0.00	0.00	0.00	0.02	0.00	0.04	0.02	0.00	0.00	0.00	0.00
Sea pens whips	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00
Sea star	0.01	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Snails	0.14	0.02	0.07	0.02	0.00	0.05	0.01	0.03	0.07	0.03	0.02	0.00	0.01
Sponge unidentified	0.12	0.21	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Stichaeidae	0.51	0.02	0.75	0.55	0.00	0.08	0.01	0.20	0.01	0.00	0.03	0.00	0.20
urchins dollars cucumbers	0.05	0.01	0.04	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.01	0.00	0.00

Table 19. Proportion of prohibited species catch caught in the GOA flathead sole fishery in 2015

	2015		2014	
Species Group Name	**PSCNQ Estimate**	**Halibut Mortality**	**PSCNQ Estimate**	**Halibut Mortality**
Bairdi Tanner Crab	0.017	--	0.000	--
Blue King Crab		--		--
Chinook Salmon	0.000	--	0.075	--
Golden (Brown) King Crab	0.000	--	0.000	--
Halibut	0.001	0.002	0.001	0.001
Herring	0.000	--	0.000	--
Non-Chinook Salmon	0.000	--	0.000	--
Opilio Tanner (Snow) Crab	0.000	--	0.000	--
Red King Crab	0.000	--	0.000	--

Figures

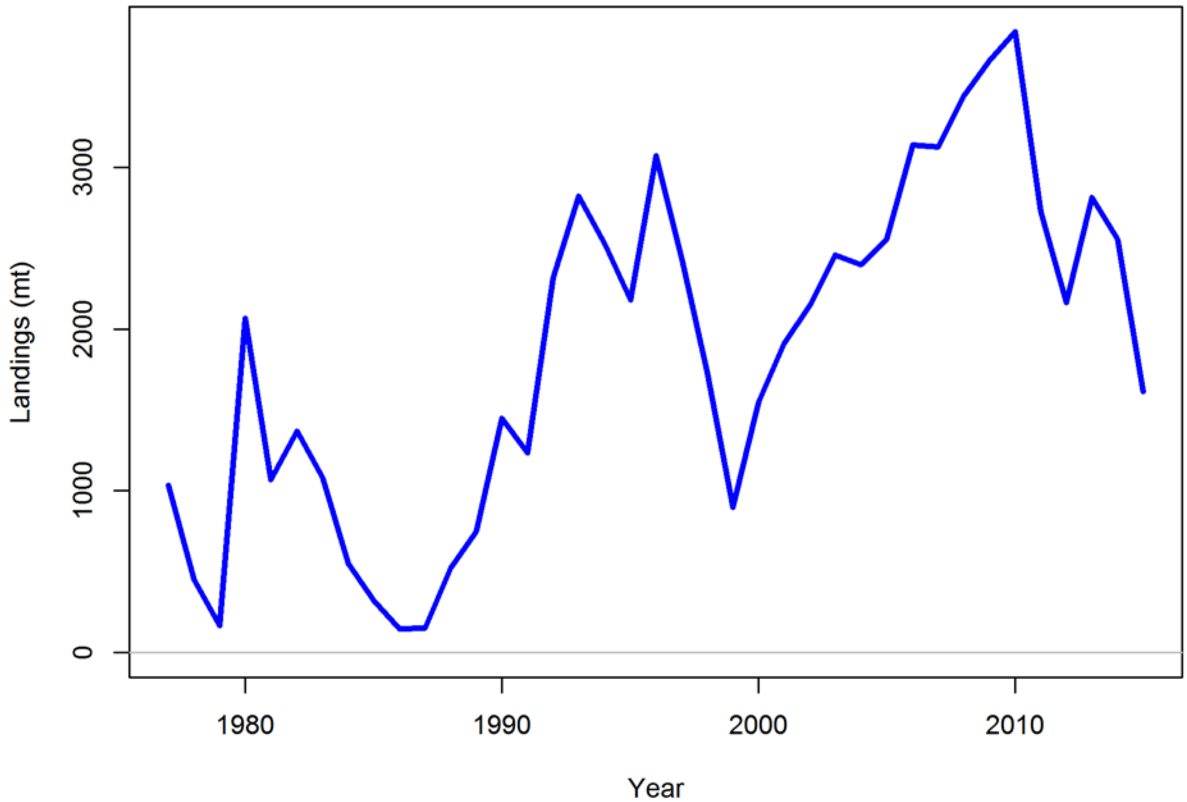

Figure 1. Catch biomass in metric tons 1978-2015 (as of October 10, 2015).

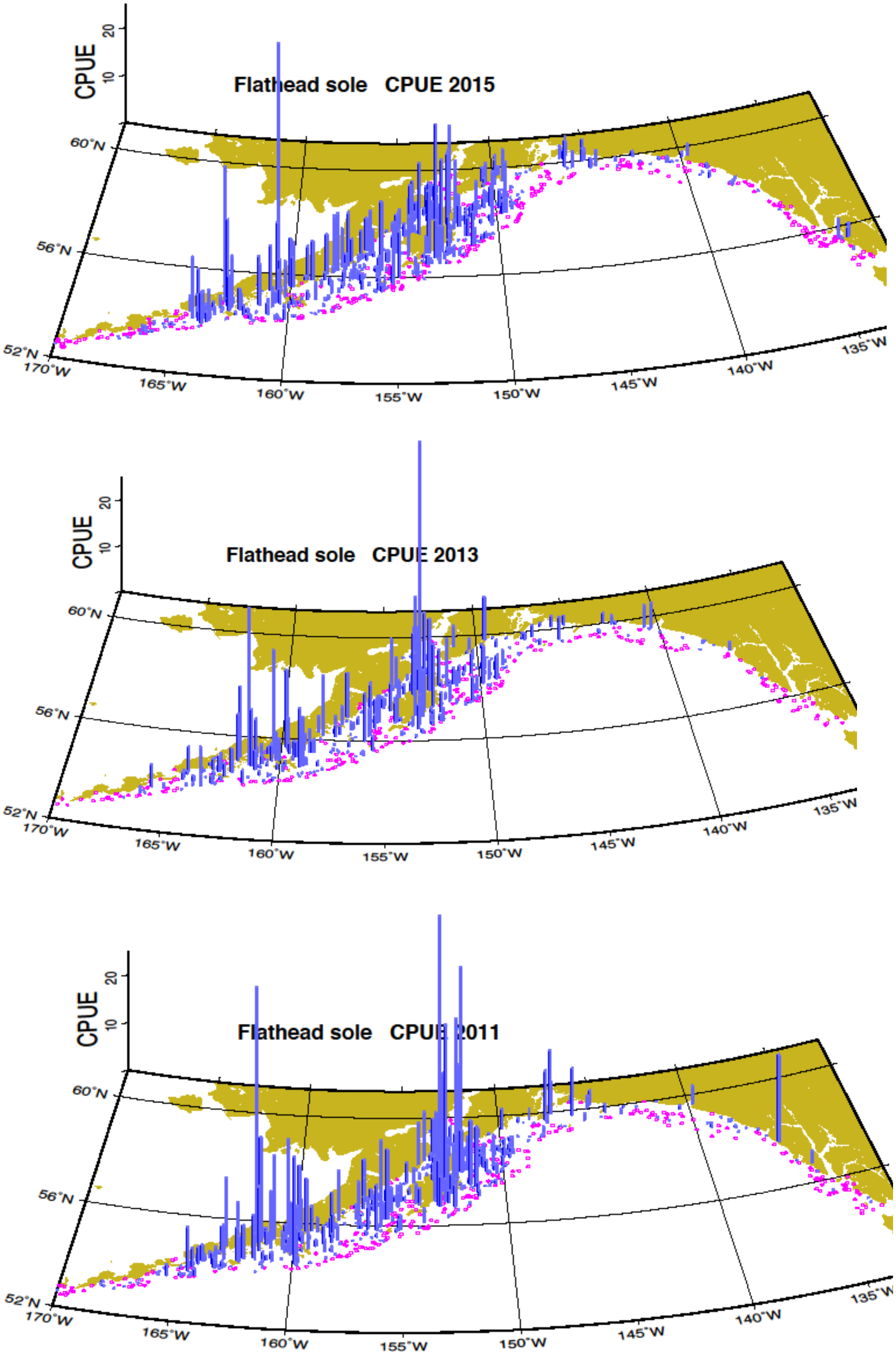

Figure 2. GOA trawl survey catch per unit effort (CPUE) for flathead sole for the 2011-2015 surveys. Purple lines denote CPUE values and pink dots denote hauls were no flathead sole were caught.

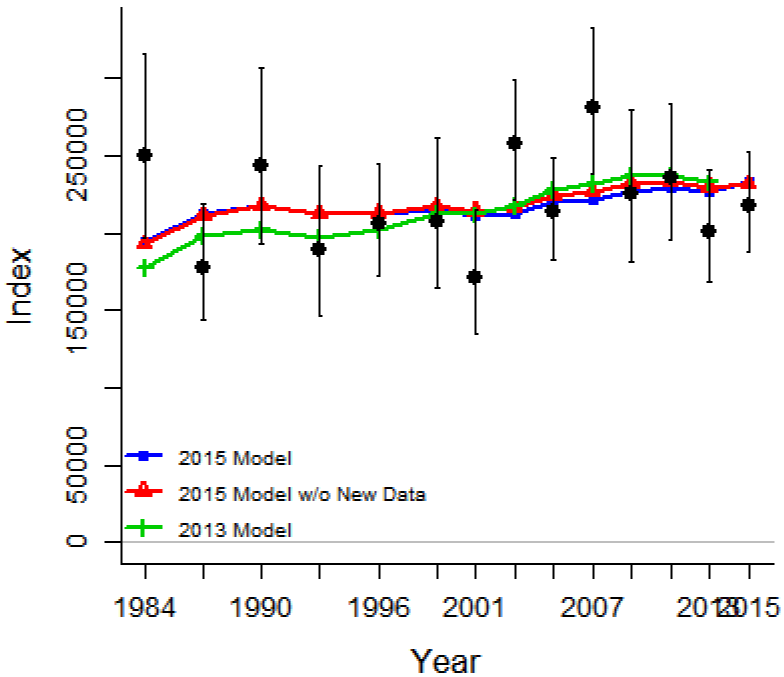

Figure 3. Survey biomass index (black dots), asymptotic 95% confidence intervals (vertical black lines), and estimated survey biomass for the proposed 2015 model, the 2015 model without 2014-2015 data, and the 2013 accepted model (solid lines).

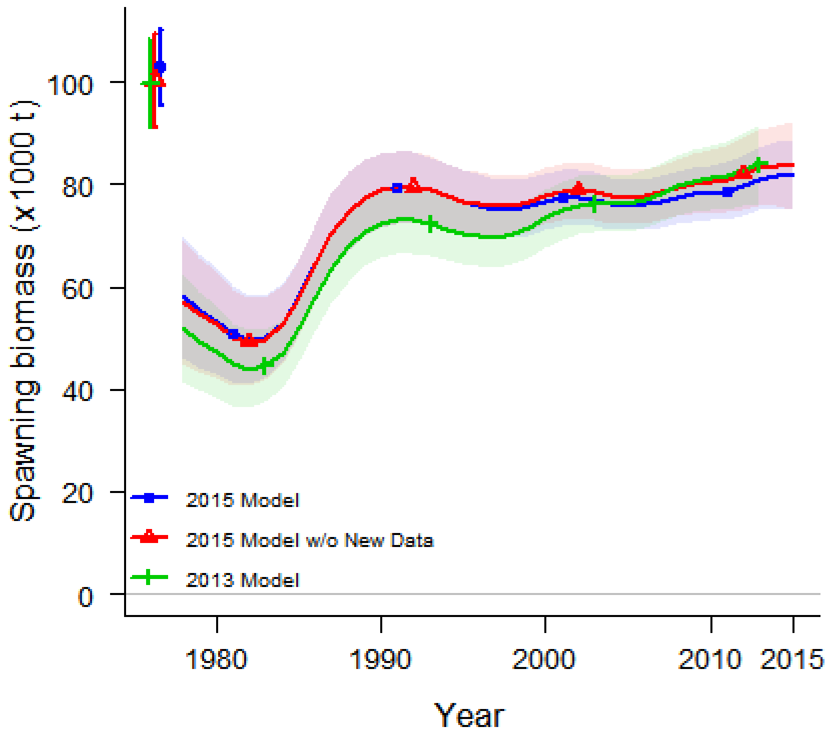

Figure 4. Time series of spawning biomass and 95% asymptotic confidence intervals for the proposed 2015 model, the 2015 model without 2014-2015 data, and the 2013 accepted model.

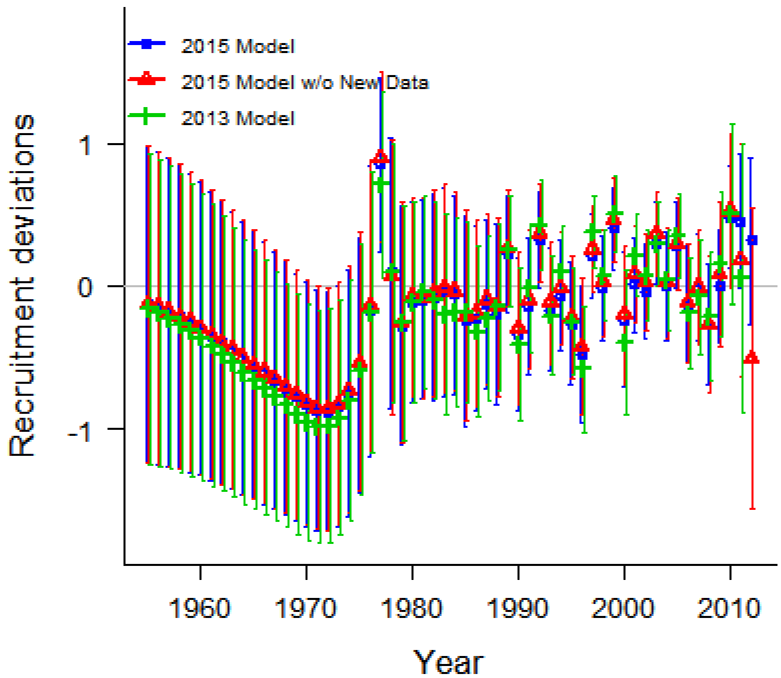

Figure 5. Recruitment deviations for years 1978-2012 and 95% asymptotic confidence intervals for the proposed 2015 model, the 2015 model without 2014-2015 data, and the 2013 accepted model.

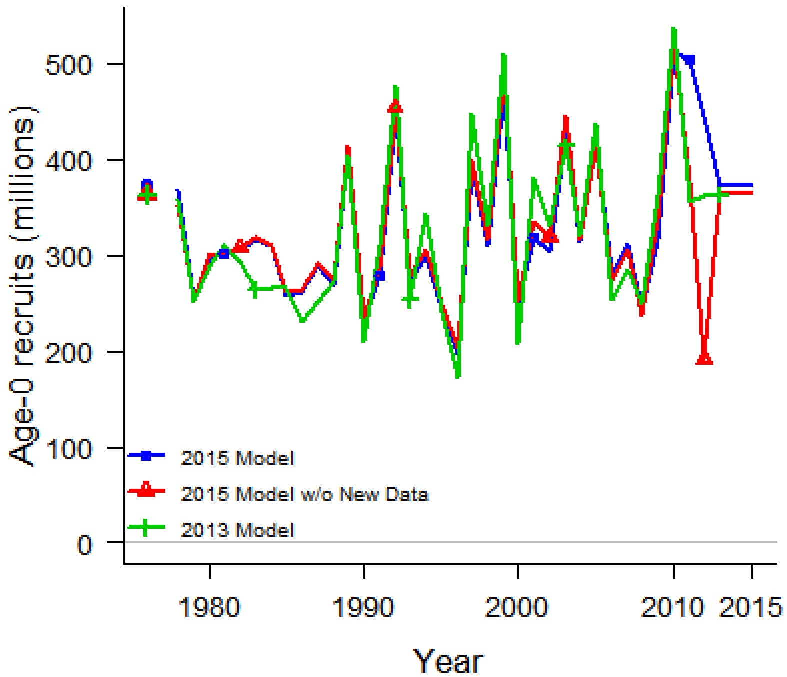

Figure 6. Time series of age-0 recruits for the proposed 2015 model, the 2015 model without 2014-2015 data, and the 2013 accepted model.

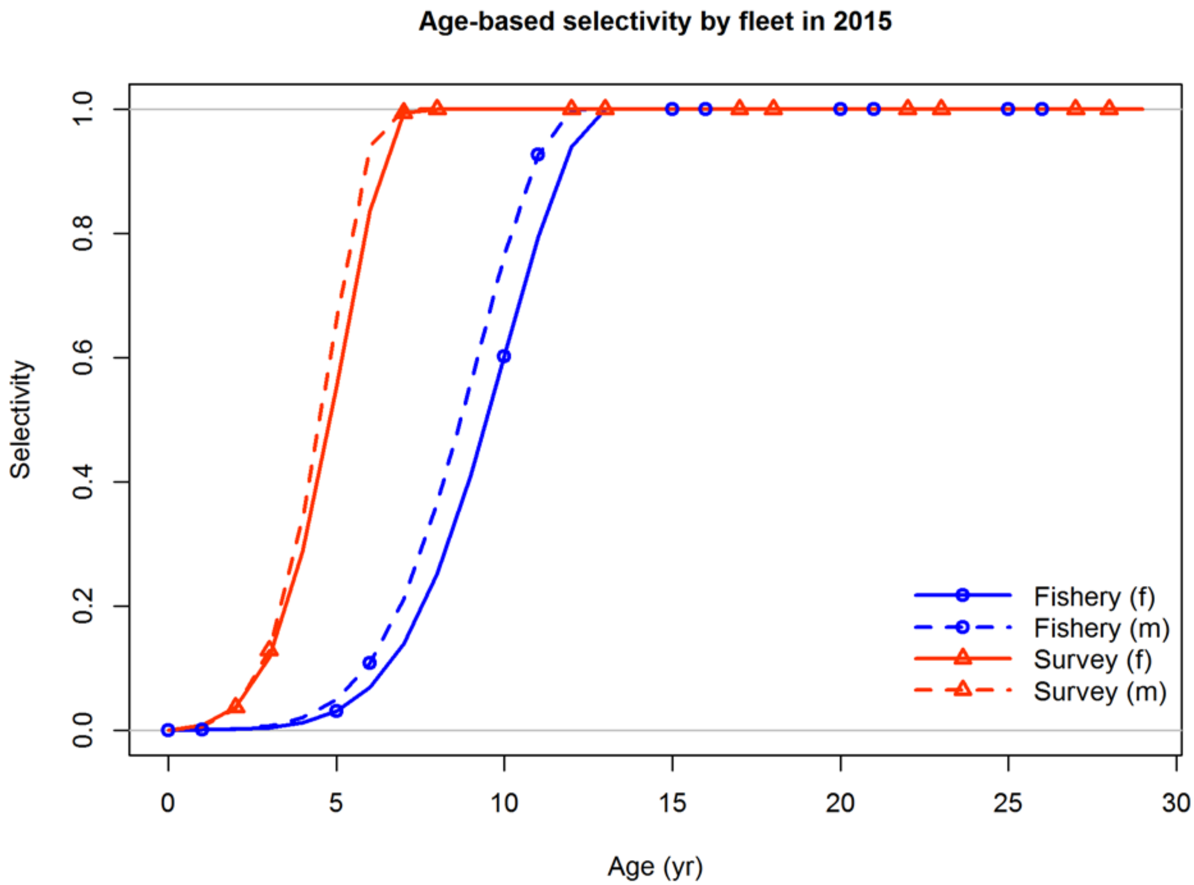

Figure 7. Selectivity curves for the fishery (blue lines) and the survey (red lines), and for females (solid lines) and males (dashed lines) for the proposed 2015 model.

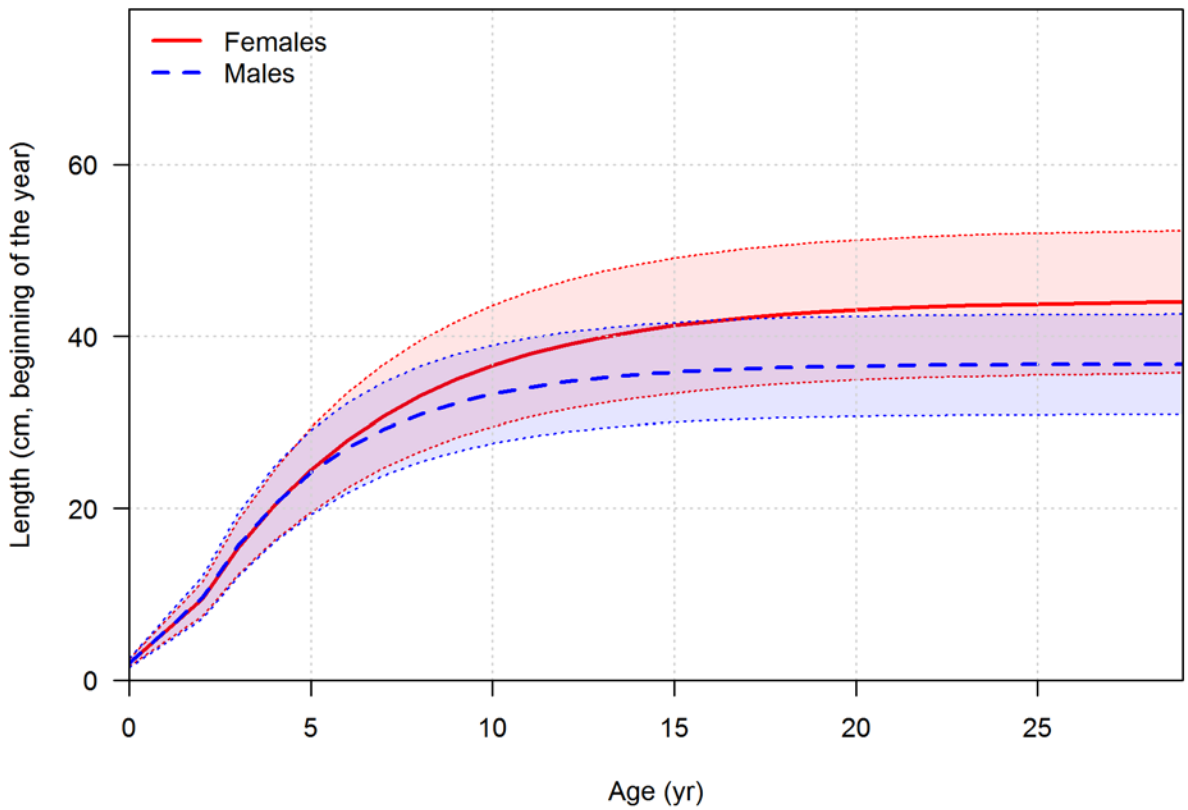

Figure 8. Estimated length-at-age relationship with 95% asymptotic confidence intervals for males (blue) and females (red). The blue dashed line and red solid line show the mean relationship and dotted lines show confidence intervals.

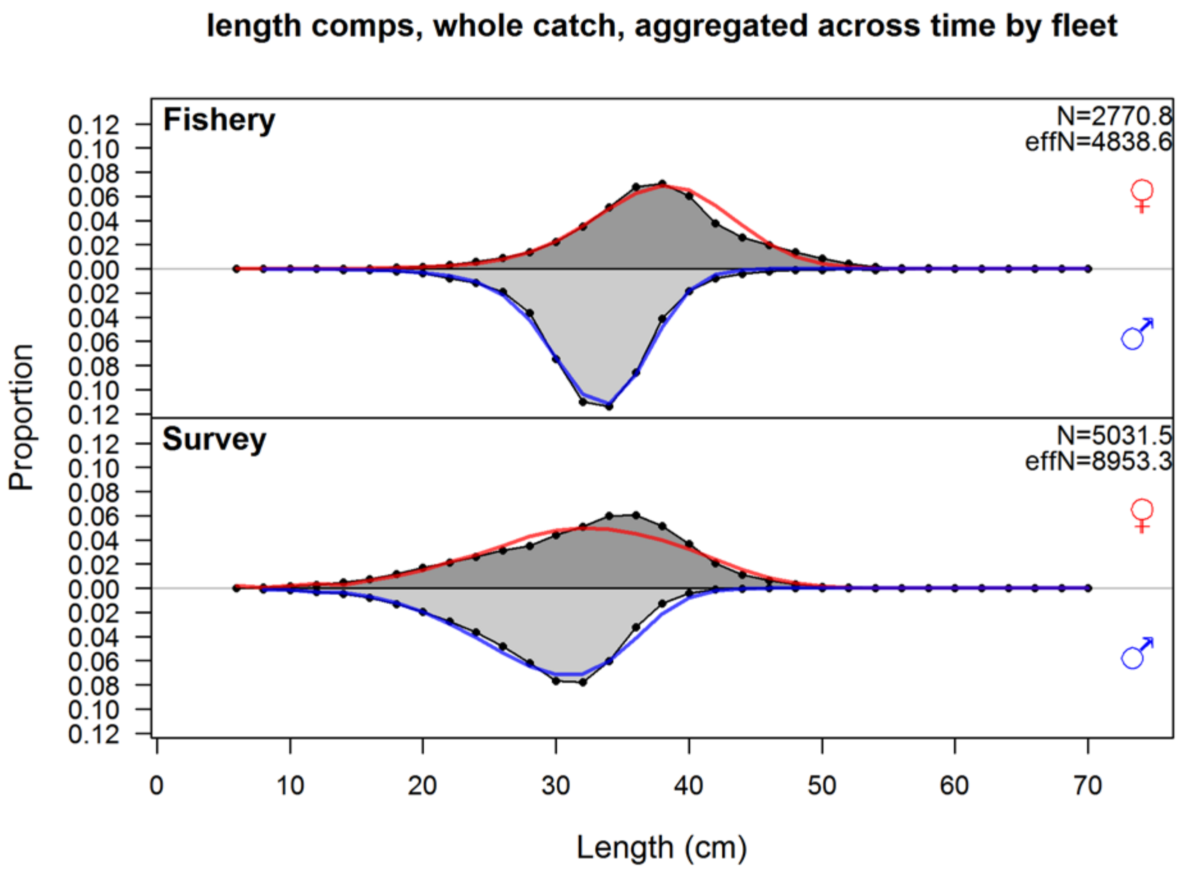

Figure 9. Observed (grey shaded area, black lines) and expected (red lines) proportions-at-length, aggregated over years for the fishery and survey and for females (upper half of plots) and males (lower half of plots) for the proposed 2015 model.

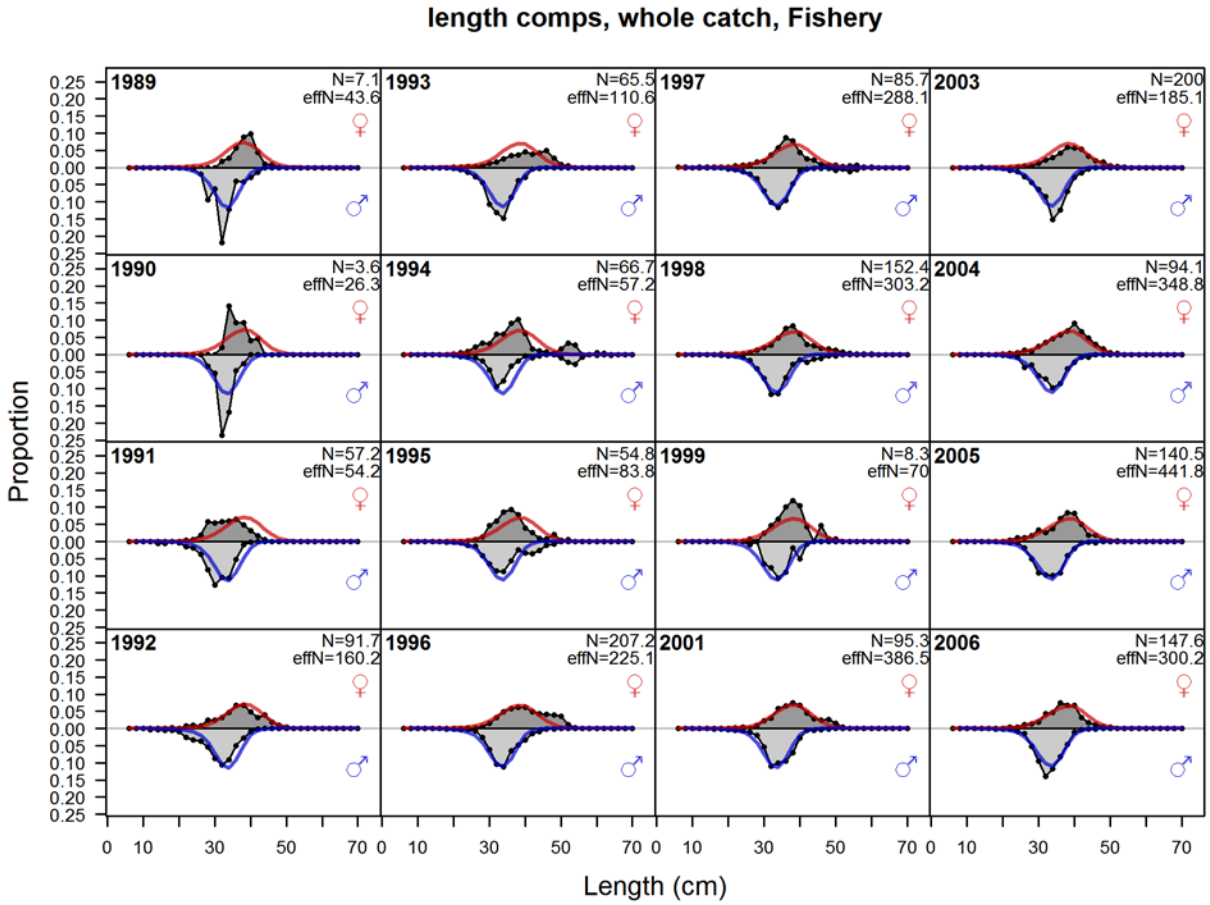

Figure 10. Observed (grey filled area and black line) and expected (lines) fishery length compositions for the proposed 2015 model (1 of 2).

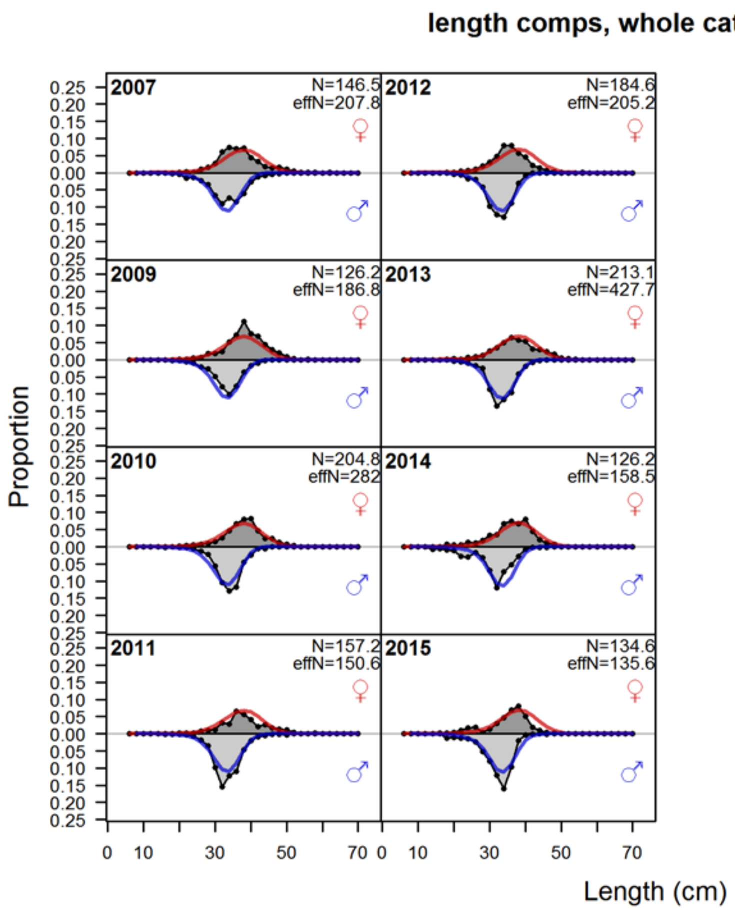

Figure 11. As for Figure 10, but for years (2 of 2).

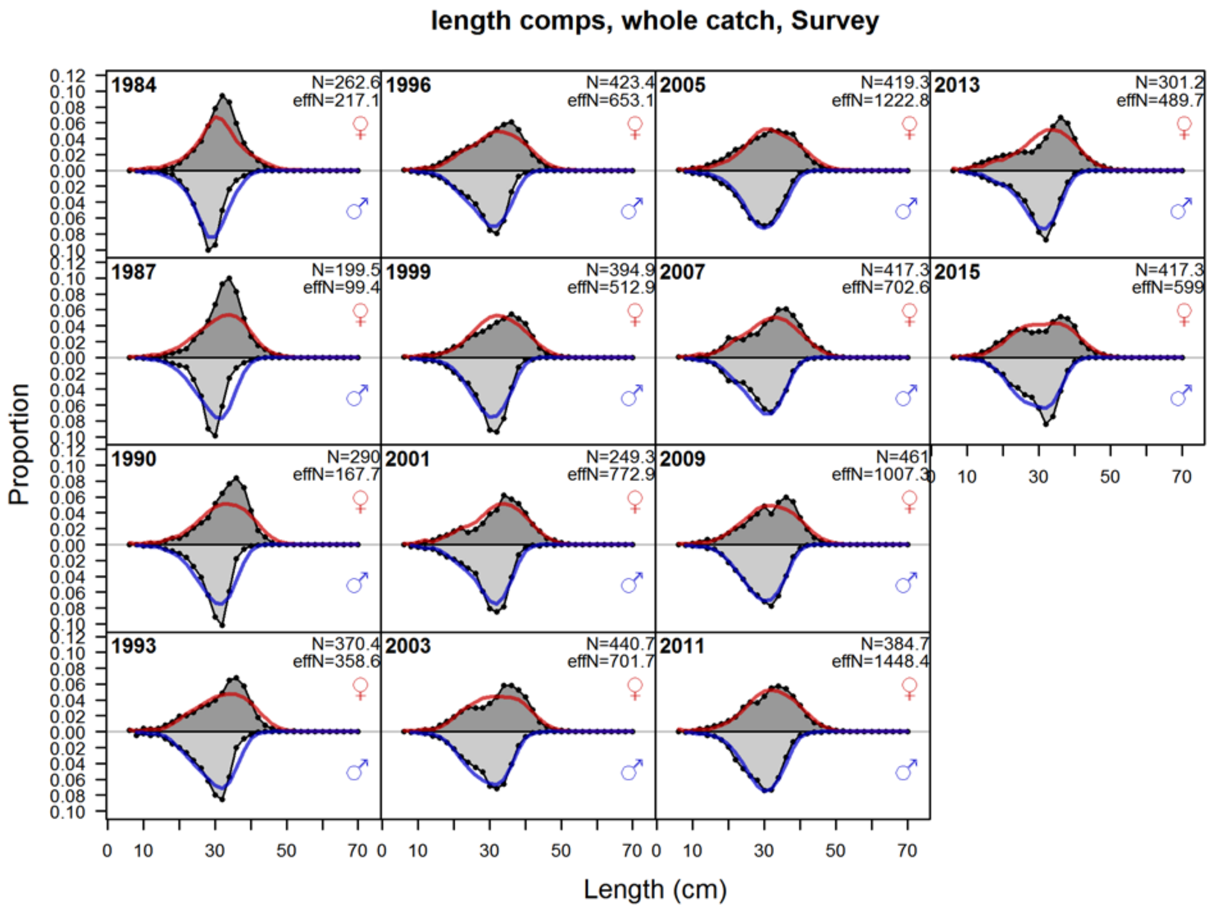

Figure 12. Observed (grey filled area and black line) and expected (lines) survey length compositions for the proposed 2015 model (1 of 2).

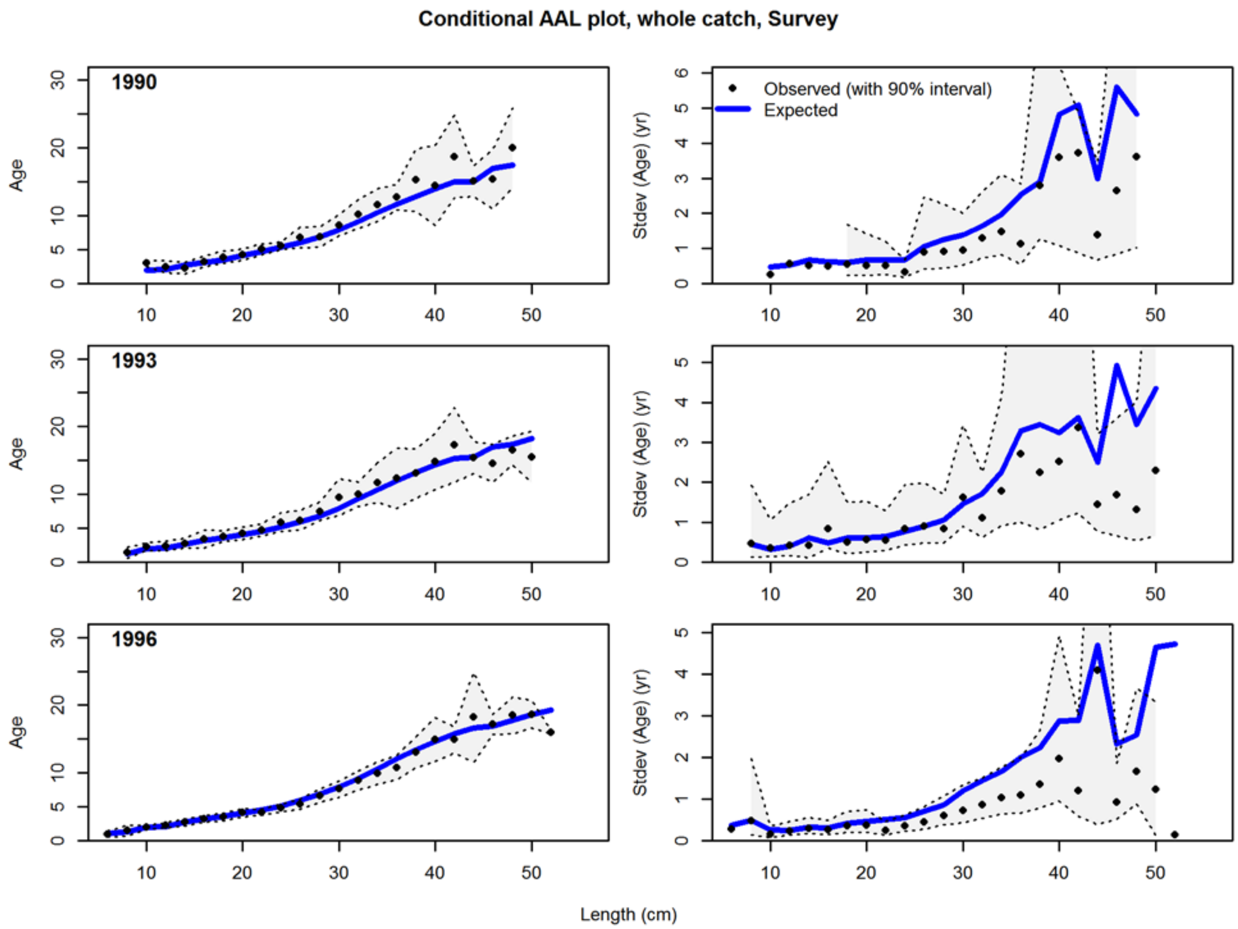

Figure 13. Observed and expected mean age-at-length for both females and males with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the proposed 2015 model for years 1990-1996.

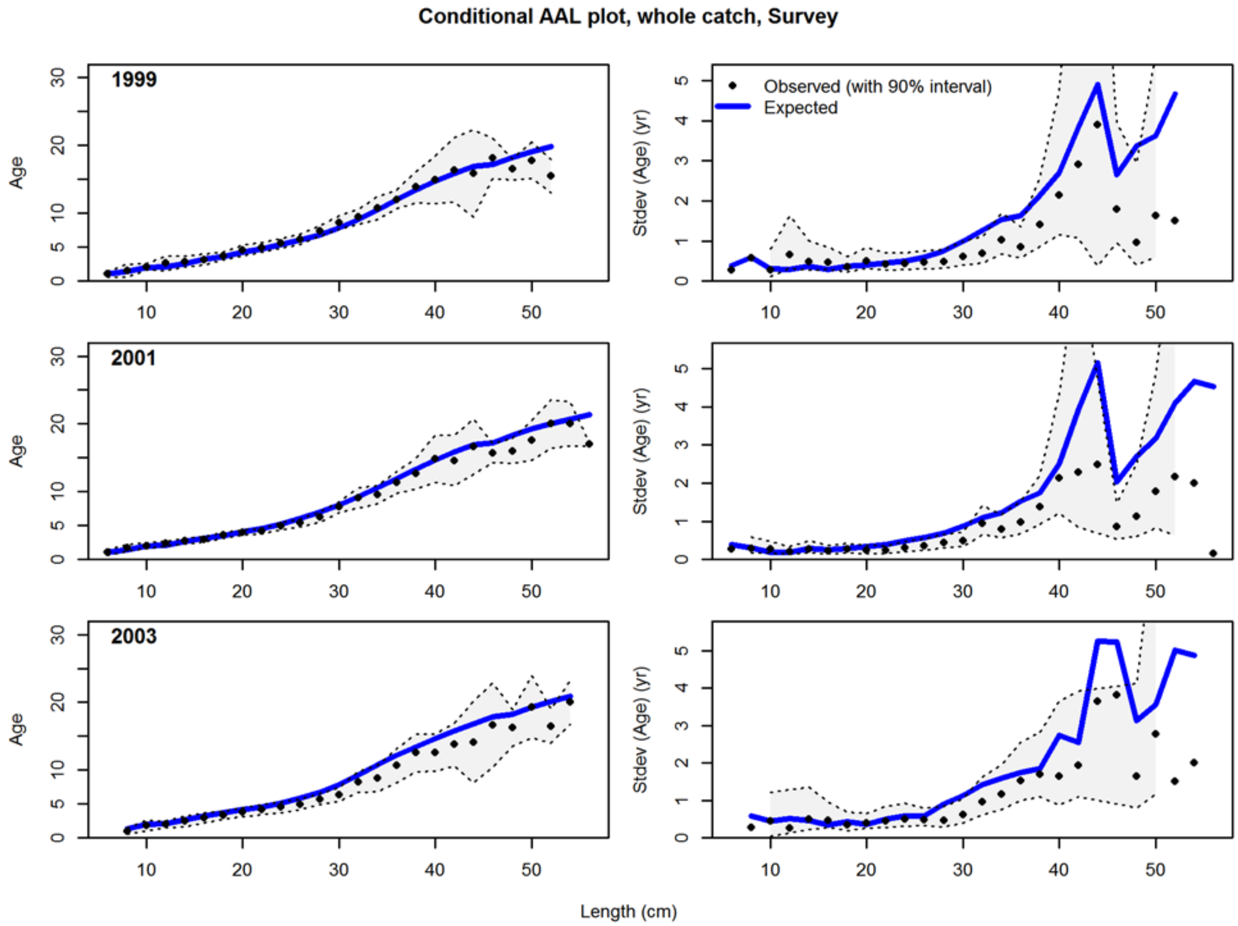

Figure 14. Observed and expected mean age-at-length for both females and males with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the proposed 2015 model for years 1999-2003 (1 of 3).

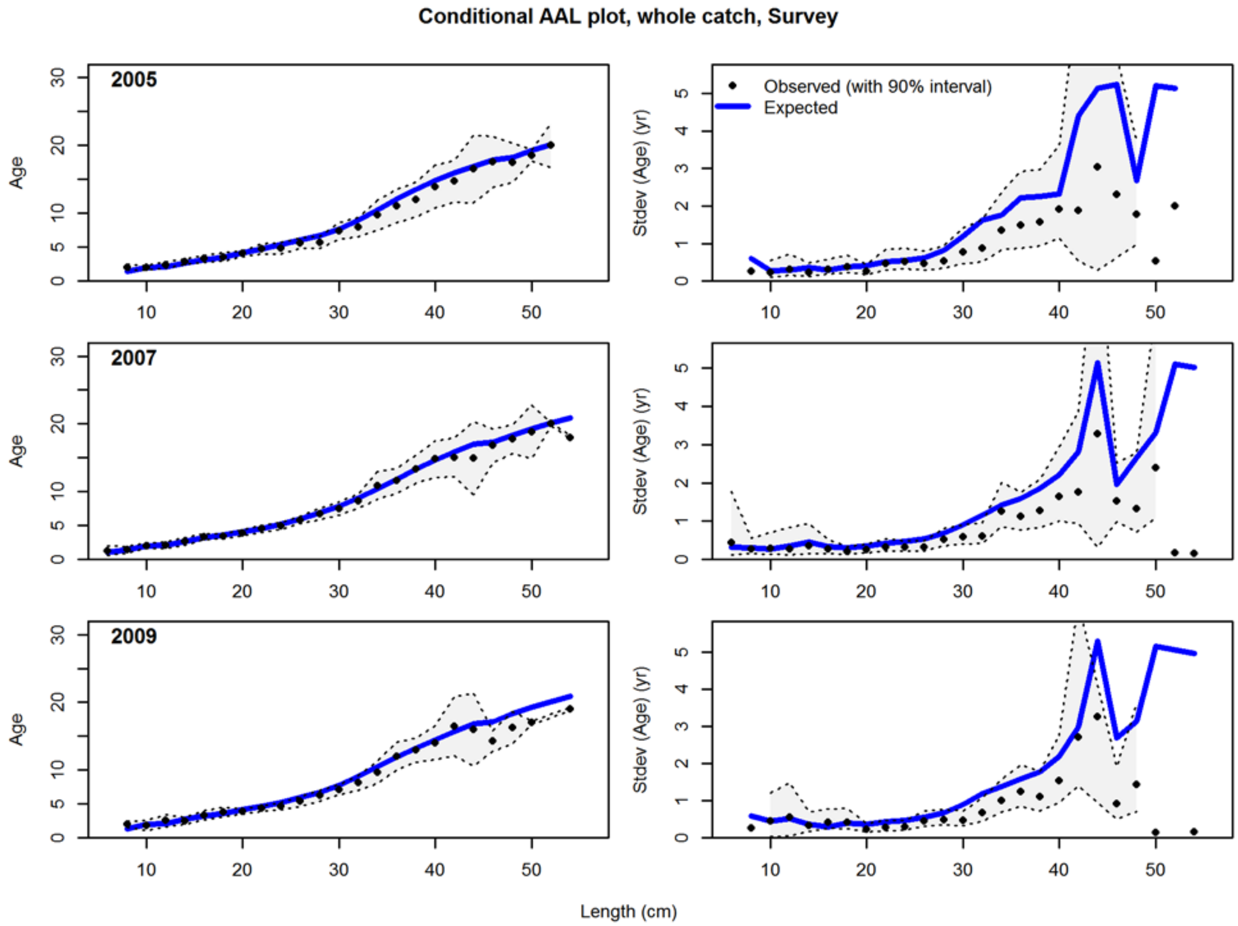

Figure 15. Observed and expected mean age-at-length for both females and males with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the proposed 2015 model for years 2005-2009 (2 of 3).

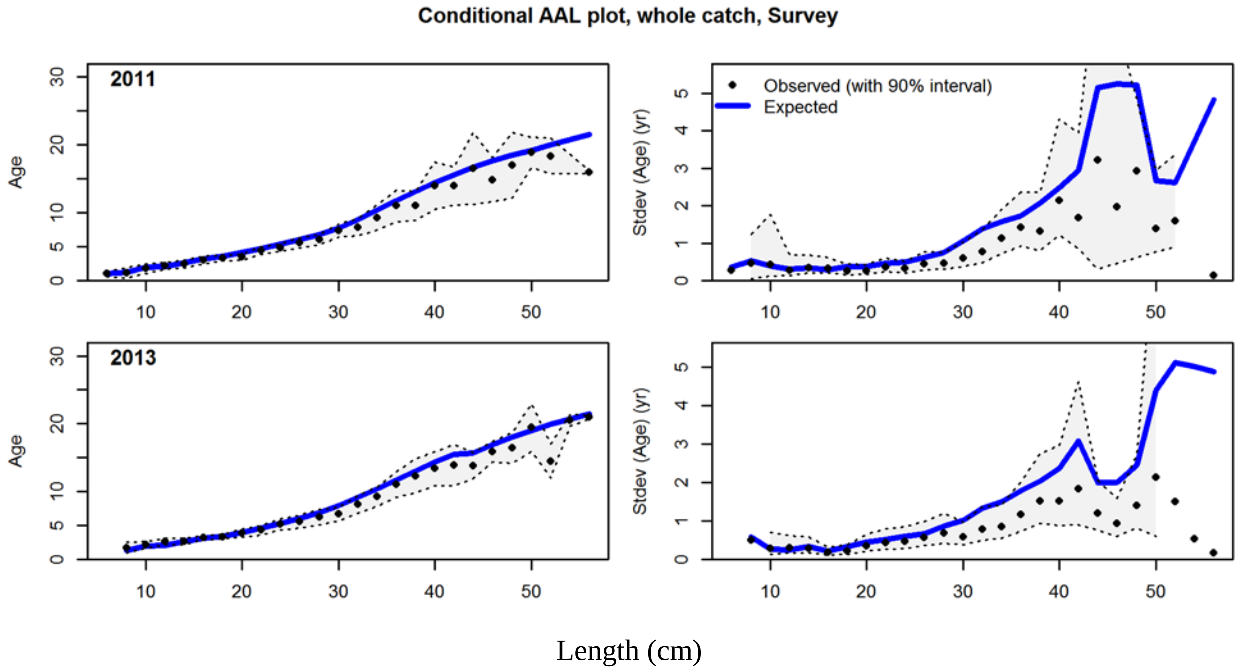

Figure 16. Observed and expected mean age-at-length for both females and males with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the proposed 2015 model for years 2011-2013 (3 of 3).

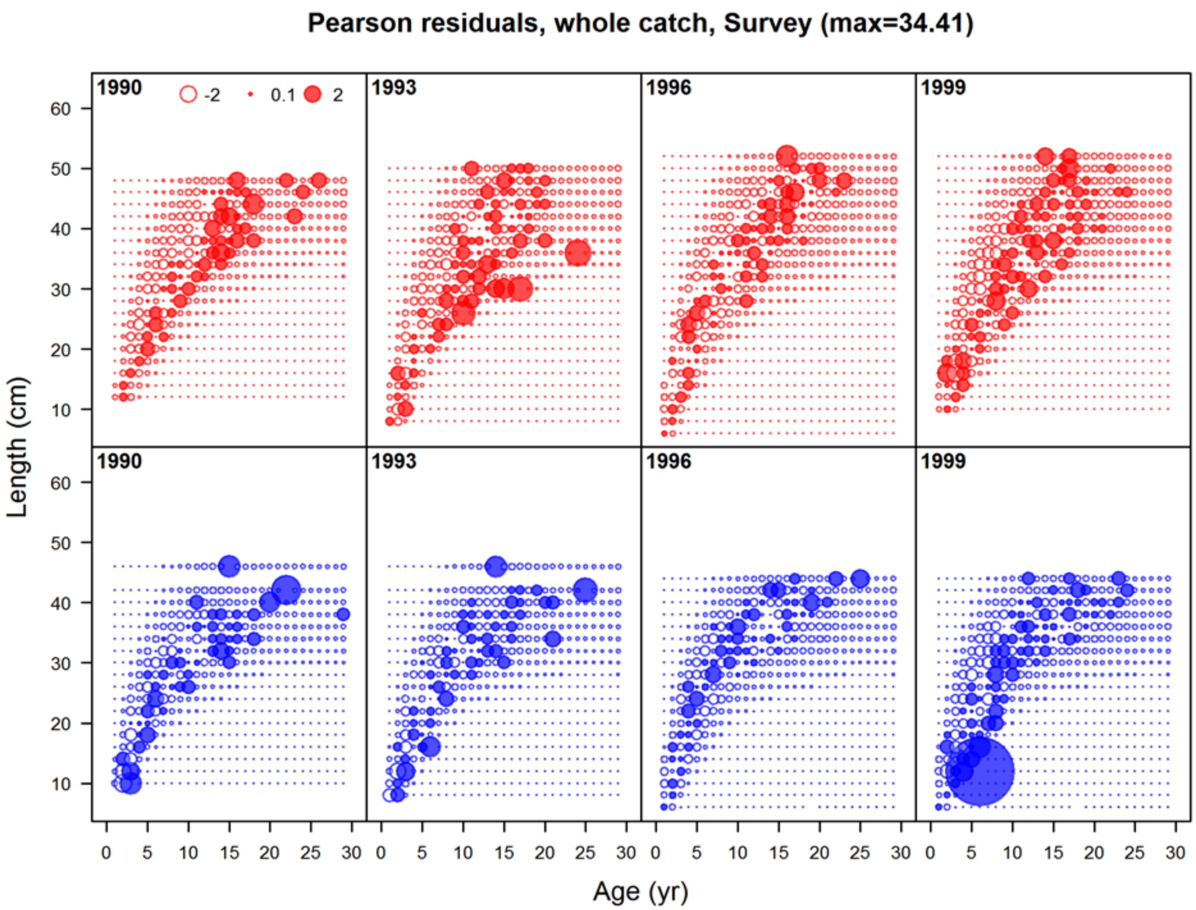

Figure 17. Pearson residuals associated with fits to the length-at-age relationship within the model for females (red, top panel) and males (blue, bottom panel) for the survey (1 of 3).

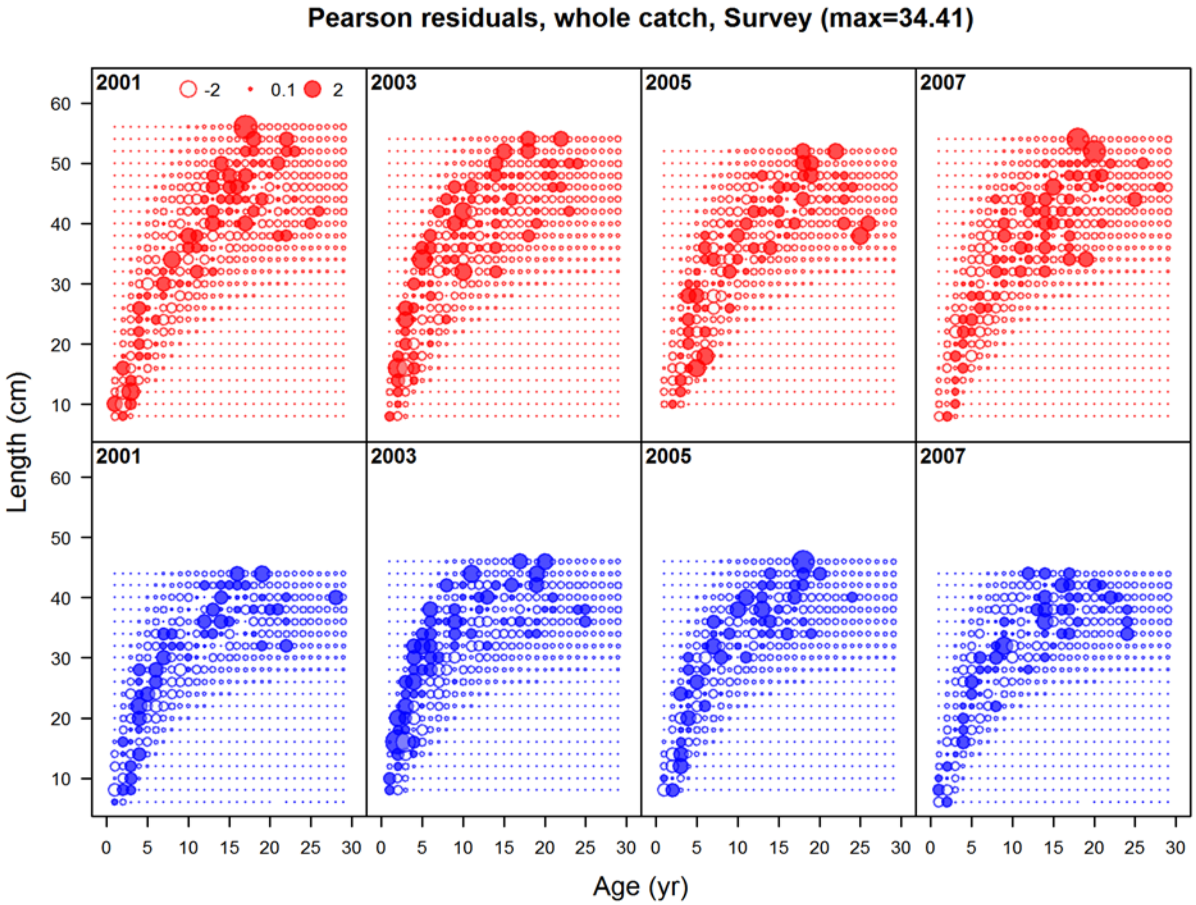

Figure 18. Pearson residuals associated with fits to the length-at-age relationship within the model for females (red, top panel) and males (blue, bottom panel) for the survey (2 of 3).

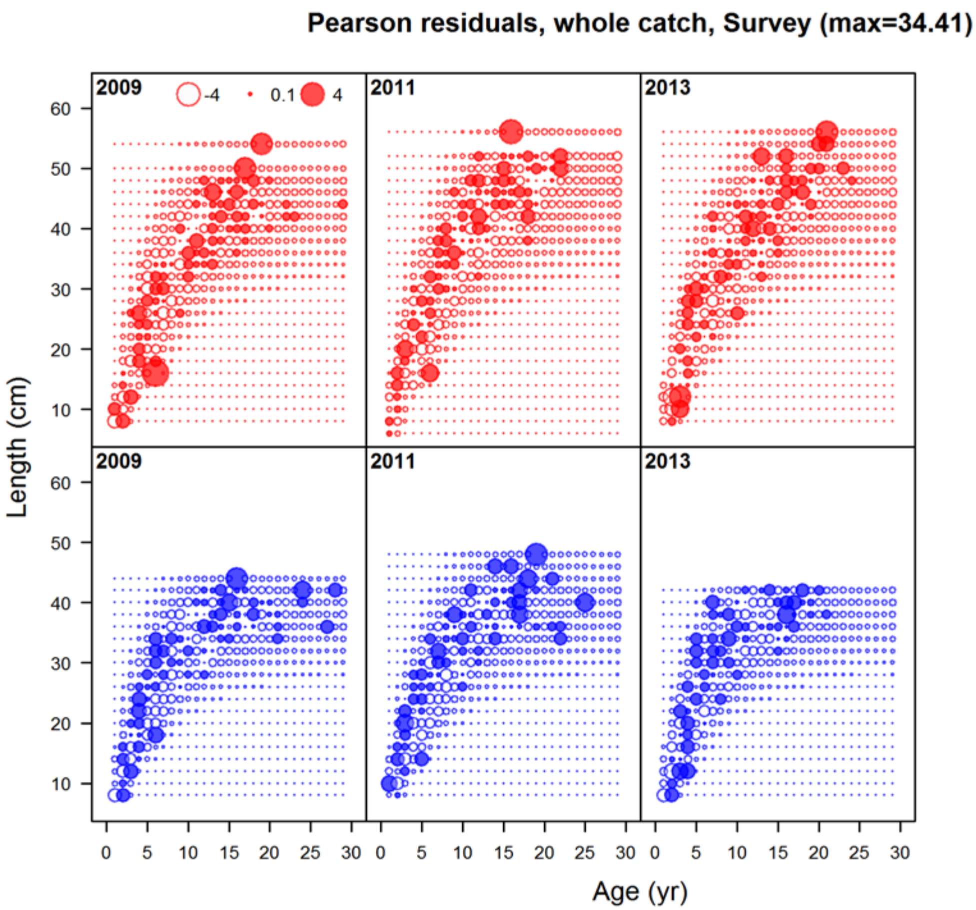

Figure 19. Pearson residuals associated with fits to the length-at-age relationship within the model for females (red, top panel) and males (blue, bottom panel) for the survey (3 of 3).

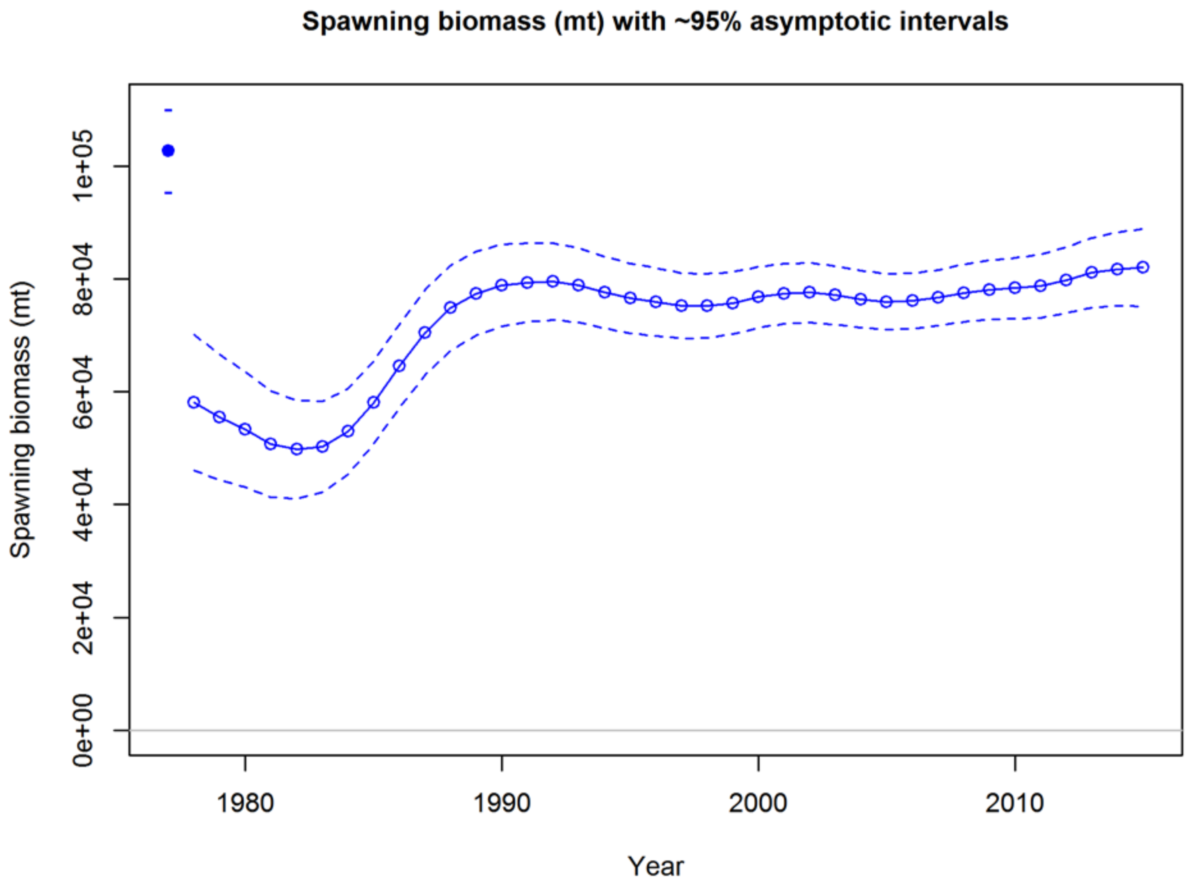

Figure 20. Time series of estimated spawning stock biomass (mt) over time (solid blue line and circles) and asymptotic 95% confidence intervals (blue dashed lines) for the current base case model.

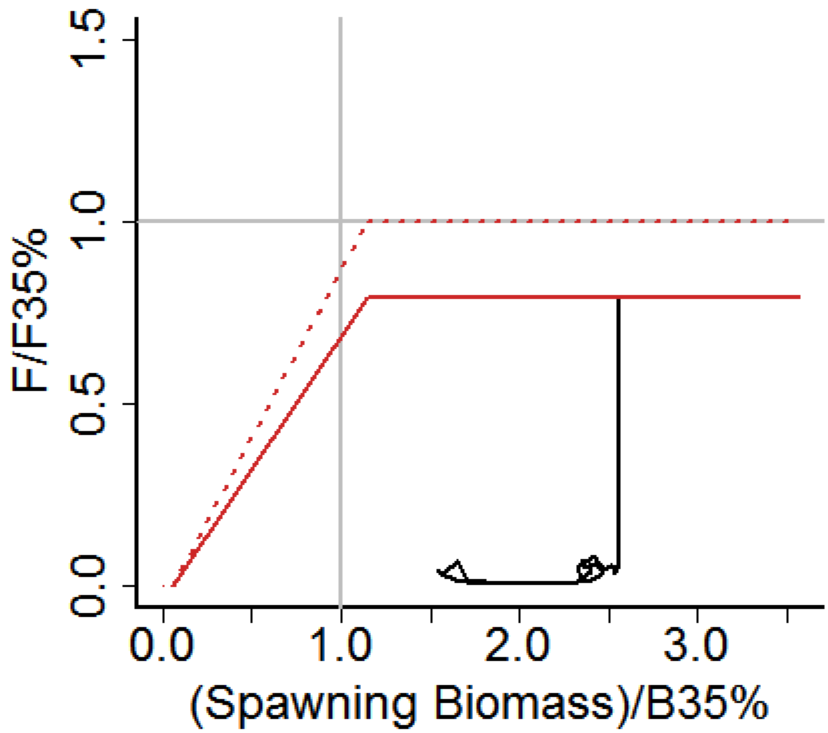

Figure 21. Spawning stock biomass relative to $B_{35\%}$ and fishing mortality (F) relative to $F_{35\%}$ from 1978-2017 (solid black line), the OFL control rule (dotted red line), the maxABC control rule (solid red line), $B_{35\%}$ (vertical grey line), and $F_{35\%}$ (horizontal grey line). The 2016 and 2017 spawning biomass and fishing mortality rates are as predicted by Alternatives 1 and 2 in the harvest projections.

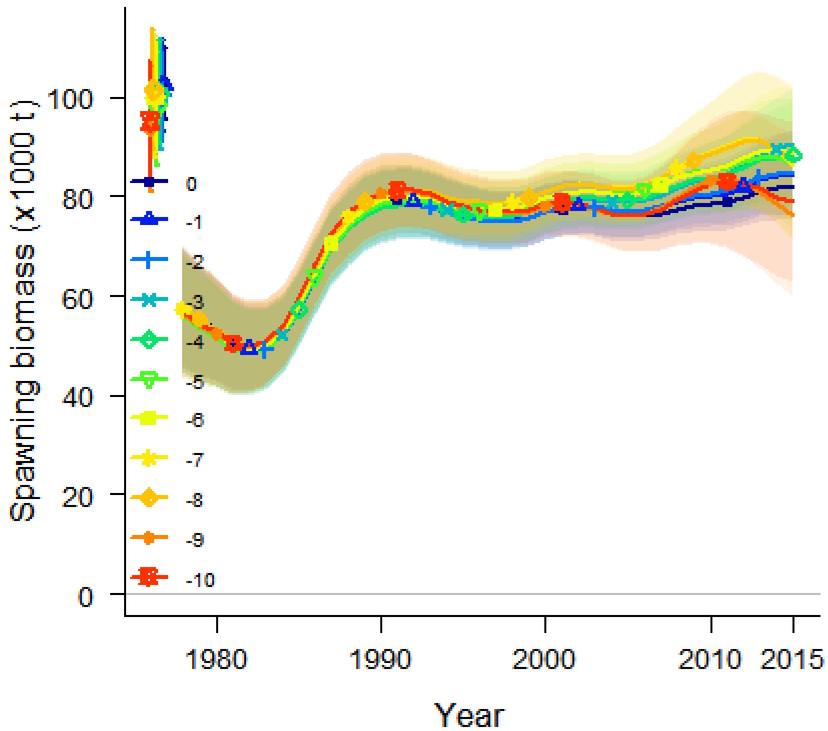

Figure 22. Spawning stock biomass and corresponding 95% asymptotic confidence intervals for base case model runs with 0 to 10 years of the most recent data removed.

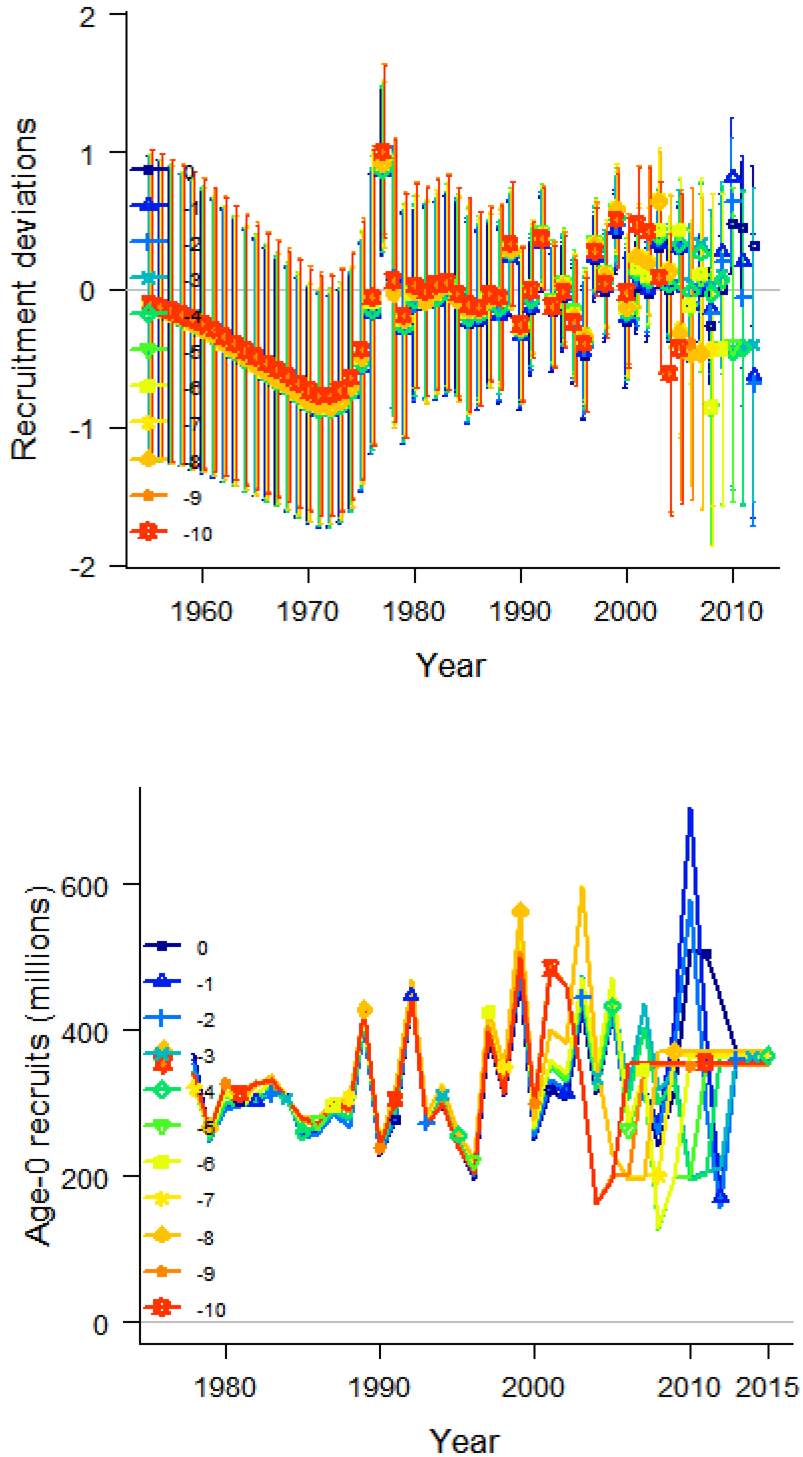

Figure 23. Recruitment deviations (top panel) and age-0 recruits (bottom panel) for base case model runs with 0 to 10 years of the most recent data removed.

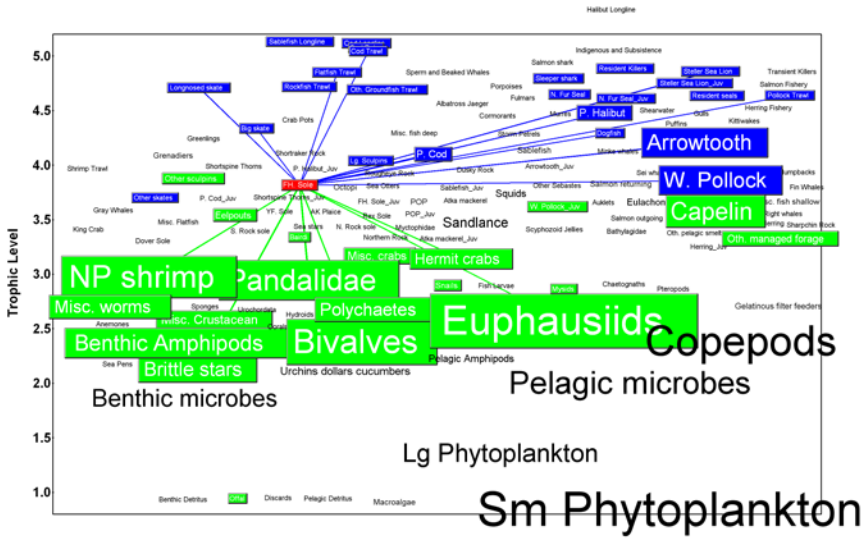

Figure 24. Gulf of Alaska food web from the GOA ecosystem model (Aydin et al., 2007) highlighting adult flathead sole links to predators (blue boxes and lines) and prey (green boxes and lines). Box size reflects relative standing stock biomass.

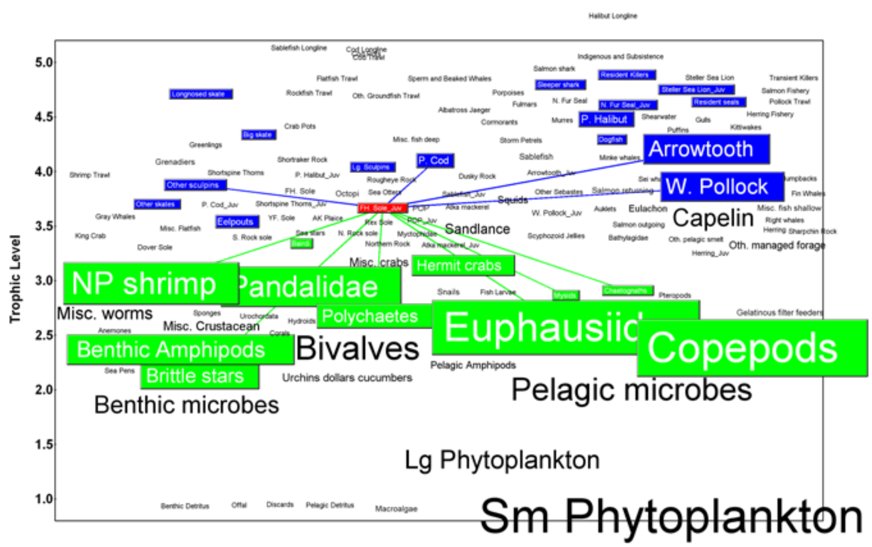

Figure 25. Gulf of Alaska food web from the GOA ecosystem model (Aydin et al., 2007) highlighting juvenile flathead sole links to predators (blue boxes and lines) and prey (green boxes and lines). Box size reflects relative standing stock biomass.

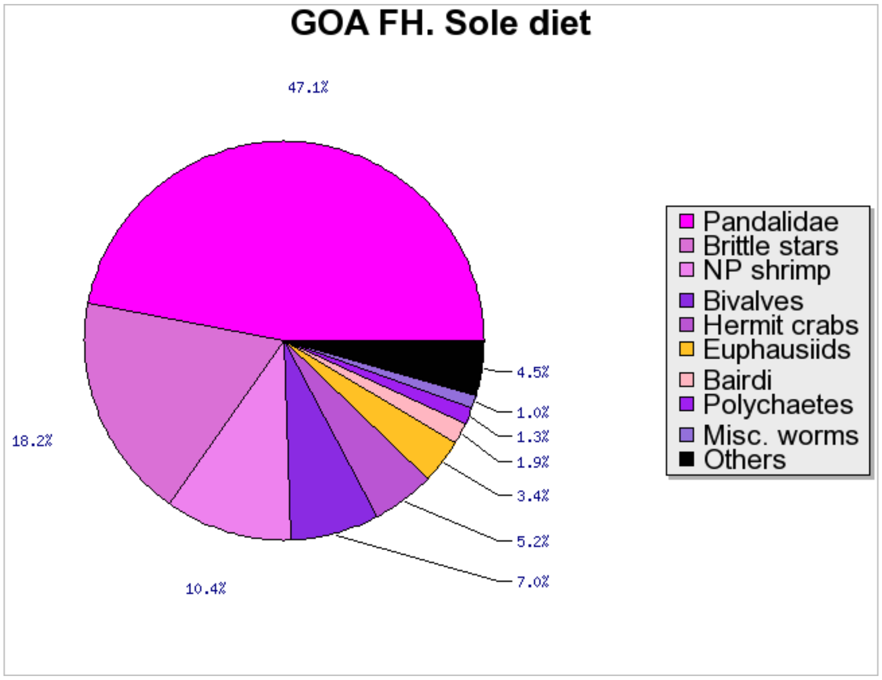

Figure 26. Diet composition for Gulf of Alaska adult flathead sole from the GOA ecosystem model (Aydin et al., 2007).

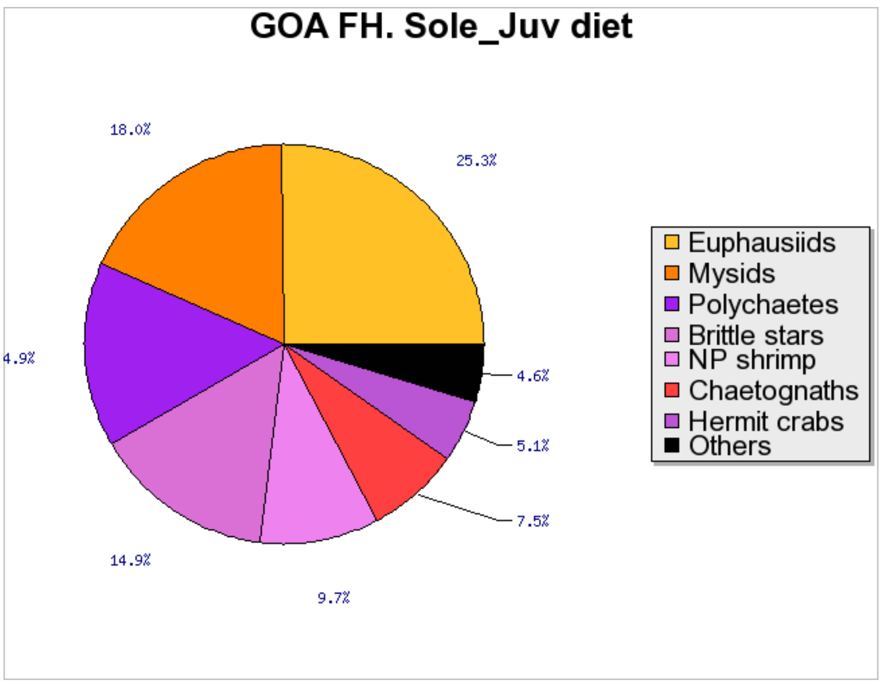

Figure 27. Diet composition for Gulf of Alaska juvenile flathead sole from the GOA ecosystem model (Aydin et al., 2007).

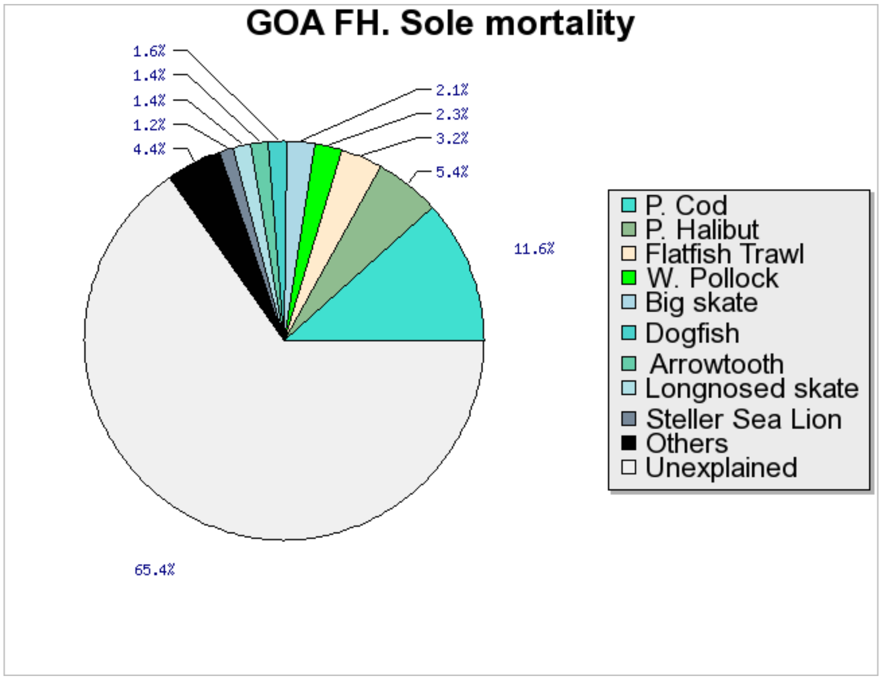

Figure 28. Decomposition of natural mortality for Gulf of Alaska adult flathead sole from the GOA ecosystem model (Aydin et al., 2007).

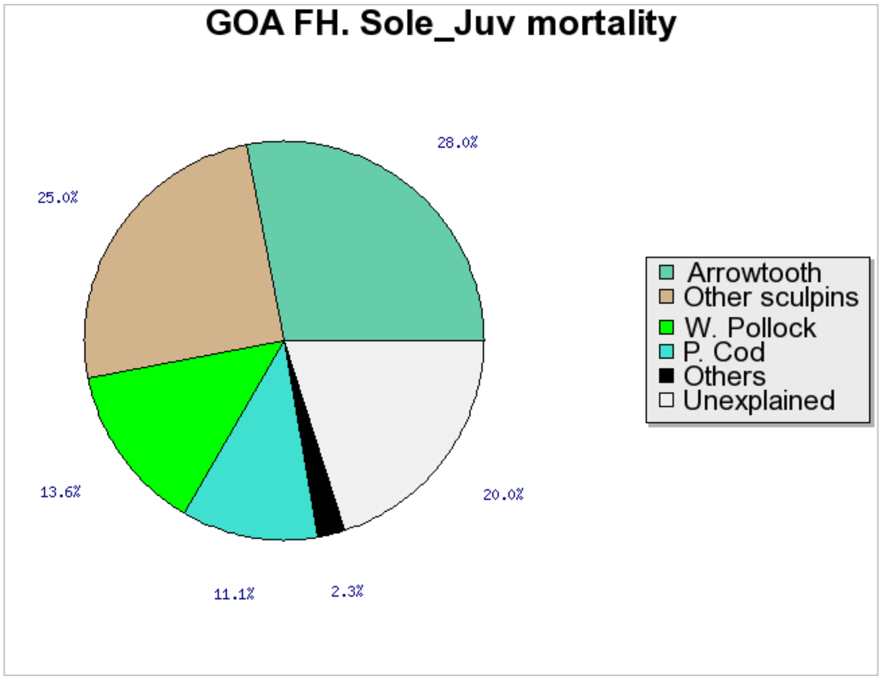

Figure 29. Decomposition of natural mortality for Gulf of Alaska juvenile flathead sole from the GOA ecosystem model (Aydin et al., 2007).

Appendix 8A: Non-Commercial Catches of GOA Flathead Sole

Table A1. NMFS data sources

Year	Annual Longline Survey	Salmon EFP 13-01	Shelikof Acoustic Survey	Shelikof and Chirikof EIT	Shumagin and Sanak EIT	Shumigans Acoustic Survey	Structure of Gulf of Alaska Forage Fish Communities	Western Gulf of Alaska Pollock Acoustic Cooperative Survey
1990	80.785							
1991	53.619							
1992	67.202							
1993	56.48							
1994	40.037							
1995	82.214							
1996	48.615							
1997	46.469							
1998	35.032							
1999	33.602							
2000	12.155							
2001	17.159							
2002	24.309							
2003	15.73							
2004	20.019							
2005	7.15							
2006	40.036							
2007	29.313							
2008	37.891							
2009	54.334							
2010	81.5		4.492			201.01	7.808	15.6
2011	38.606							
2012	18.55			7.22	2.76			
2013	56.478	380						
2014	62.913	180						

Table A2. ADF&G data sources

Year	Large-Mesh Trawl Survey	Sablefish Longline Survey	Scallop Dredge Survey	Small-Mesh Trawl Survey
1998	2465.29	3.8	0.22	
1999	4842.57	5.6	0.45	
2000	2723.03	1		2427.75
2001	6394.27	2.6		
2002	2277.08	1.4	0.09	
2003	5496.63	2.4		2565.67
2004	3864.43	1.1		3299.13
2005	6450.74		7.47	3157.94
2006	2617.47	7.864	7.47	2797.83
2007	3856.18		1.05	385.44
2008	2099.94		0.3	
2009	5154.93		10.41	
2010	84389.475		1.49	12008.01
2011	84023.542		52.078	9154.2
2012	92629.38		5.95	7976.89
2013	78993.8		14.4	4789.321
2014	72746.41			6175.3

Table A3. IPHC data

Year	IPHC Annual Longline Survey
2010	4
2011	1
2012	29
2014	20