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) 2016-2017 catch data were added to the model and 2015 catch was updated to include October to December catch in that year.
2) 2016 and 2017 fishery length composition data were added to the model and 2015 fishery length composition data were updated to include October to December length data from that year.
3) The 2017 bottom trawl survey biomass index and standard error was added to the model.
4) Survey length composition data for 2017 were added to the model.
5) Survey conditional age-at-length data for 2015 were added to the model.

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 2016 update assessment in the table below. Biomass has increased and F_{OFL} and F_{ABC} decreased resulting in similar OFL and ABC to last years' assessment.

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2017	2018	2018*	2019*
M (natural mortality rate)	0.2	0.2	0.2	0.2
Tier	3a	3a	3a	3a
Projected total (3+) biomass (t)	269,638	272,323	281,635	283,107
Female spawning biomass (t)	82,819	84,273	85,765	89,118
$B_{100\%}$	92,165	92,165	91,551	91,551
$B_{40\%}$	36,866	36,866	36,620	36,620
$B_{35\%}$	32,258	32,258	32,043	32,043
F_{OFL}	0.40	0.40	0.36	0.36
$maxF_{ABC}$	0.32	0.32	0.28	0.28
F_{ABC}	0.32	0.32	0.28	0.28
OFL (t)	43,128	43,872	43,011	44,822
maxABC (t)	35,243	35,829	35,266	36,746
ABC (t)	35,243	35,829	35,266	36,746
Status	As determined in 2016 for:		As determined in 2017 for:	
	2015	2016	2016	2017
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 2044.2 t, 2,255.7 t, for 2017 and 2018 respectively. The 2017 projected catch was calculated as the current catch as of October 1, 2017 added to the average October 1–December 31 GOA flathead sole catches over the 5 previous years. The 2018 projected catch was calculated as the average catch from 2012-2016.

The table below shows apportionment of the 2018 and 2019 ABCs and OFLs among areas, based on the proportion of survey biomass projected for each area in 2017 estimated using the random effects model developed by the survey averaging working group.

Quantity	Western	Central	West Yakutat	Southeast	Total
Area Apportionment	35.98%	57.39%	5.48%	1.15%	100.00%
2018 ABC (t)	12,690	20,238	1,932	406	35,266
2019 ABC (t)	13,222	21,087	2,013	424	36,746

Responses to SSC and Plan Team Comments on Assessments in General

Dec 2016, SSC: Any new model that diverges substantial from the currently accepted model will be marked with the two-digit year and a "0" version designation (e.g., 16.0 for a model from 2016). Variants that incorporate major changes are then distinguished by incremental increases in the version integer (e.g., 16.1 then 16.2), and minor changes are identified by the addition of a letter designation (e.g., 16.1a). The SSC recommends this method of model naming and notes that it should reduce confusion and simplify issues associated with tracking model development over time.

Authors' response: Two models are presented in this assessment numbered 2015 and 2017.

Responses to SSC and Plan Team Comments Specific to this Assessment

The SSC concurs with the PT and author that 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. In addition, the SSC supports the PT and author's recommendations that 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. Finally, the SSC encourages the author to explore ways to better account for scientific uncertainty, especially uncertainty associated with parameters that are currently fixed in the model.

Authors' response: This assessment includes joint profiles likelihoods for survey Q and natural mortality. Ageing error estimation and scientific uncertainty will be explored in future assessments.

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 middle 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 prohibited species catch (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 then 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 then declined to 2,000 t in 2015 and was 2,421 t in 2016. Closures of the flathead sole fishery in 2015 due to reaching bycatch caps 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 yearsTable 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).

The stock within the GOA is managed as a unit stock but with area-specific ABC and TAC apportionments to avoid the potential for localized depletion. Little is known on the stock structure of this species. See Stockhausen (2011) for a description of the management history of flathead sole.

Non-commercial catch of GOA flathead sole are in shown Appendix 8A.

Data

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

Source	Type	Years
Fishery	Catch biomass	1978-2017 (through October 1, 2017)
Fishery	Catch length composition	1989-1999, 2001-2007, 2009-2017
GOA survey bottom trawl	Survey biomass	Triennial: 1984-1999, Biennial: 2001-2017
GOA survey bottom trawl	Catch length composition	Triennial: 1984-1999, Biennial: 2001-2017
GOA survey bottom trawl	Catch age composition, conditioned on length	Triennial: 1984-1999, Biennial: 2001-2015

Fishery:

Catch Biomass

The assessment included catch data from 1978 to October 1, 2017 (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 2009-2017; 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/2017/GOA_Flathead_Composition_Data_And_SampleSize17.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). Survey biomass increased from 217,763 t in 2015 to 236,588 t in 2017.

Figure 2 shows maps of survey CPUE in the GOA for the 2013, 2015, and 2017 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/2017/GOA_Flathead_Composition_Data_And_SampleSize17.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 2015 assessment and the 2017 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 2015 and 2017 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 (2017), 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 2017 assessment model for GOA flathead sole (2017 Model). The proposed model structure is the same as the most recent (2015) accepted model for flathead sole. The 2015 and 2017 models use the effective sample size for all length composition data 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. The 2015 model is presented with no new updated data (updated 2015, 2016 and 2017 data are not included) for comparison, which is the same as the accepted 2015 model in the 2015 assessment.

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 $O_a = 1/(1 + e^{\gamma(a - a_{50})})$, 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 $\sigma_R = 0.6$ and this value is used in the current assessment.

Catchability

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

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 3-5 and Table 7-Table 10 and Tables 13-14, compare the 2015 model with the 2017 model. Fits to the survey biomass index and resulting estimates of spawning stock biomass over time are very similar between the two models (Figure 3, Figure 4). Spawning biomass is slightly lower in recent years for the 2017 model than the 2015 model. Estimation of age-0 recruitment are very similar among models (Table 14 and Figure 5). Estimates of growth parameters, unfished recruitment, and survey selectivity were very similar among models (Table 8, Table 10 and Figure 7). The fishery selectivity curve was shifted to younger ages with the 2017 model vs the 2015 model for both males and females (Table 9 and Figure 8). The 2017 model estimates peak female selectivity at age 12.42 and the 2015 model at age 13.08 (Table 9).

The 2017 Base Case Model

The estimated fishery and survey selectivity curves for the 2017 base case model are shown in Figure 6. 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 9). 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 length composition data, aggregated over years are shown in Figure 10. 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 11- Figure 13 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 14-Figure 17 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 18-Figure 20 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 of biomass and recruitments are shown in Table 13-Table 14 and Figure 4, Figure 5 and Figure 21. A time series of numbers-at-age is available at http://www.afsc.noaa.gov/REFM/Docs/2017/GOA_Flathead_TimeSeries_of_NumbersAtAge17.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 21 shows spawning stock biomass estimates and corresponding asymptotic 95% confidence intervals. Figure 22 shows that biomass has been above $B_{35\%}$ and F has been low relative to $F_{35\%}$ for each year in the time series.

Retrospective Analyses

Spawning stock biomass, age 0 recruits, and the model fit to the survey for retrospective analyses extending back 10 years are shown in Figure 23 to 25. A retrospective pattern in spawning stock biomass extending back 10 years is evident, whereby each year of added data lowers the most current estimates by a small amount (Figure 23 and Figure 25). The time series of the fit to survey biomass only plots estimates of survey biomass in the years when there was a survey, which was every other year from 2007 to 2017 (Figure 25). This retrospective pattern should be explored further in future analyses where alternative values and approaches for modeling catchability, natural mortality, and selectivity are explored.

Likelihood Profile Analyses

The 2017 base model has Q fixed at 1.0 and M fixed at 0.2. When Q is fixed at 1.0 the minimum total likelihood occurs at M=0.26 (Figure 26). At M fixed at 0.2, the lowest total likelihood occurs at Q greater than 1.5 (Figure 27). Model runs with all combinations of survey Q from 0.6 to 1.5 (by 0.1 intervals) and natural mortality from 0.1 to 0.3 (by 0.02 intervals for males and females) show that the minimum total likelihood occurs at M=0.28 and Q=1.4.

	lowest likelihood for:			
	Total	Survey	Age data	Length data
Total	1483.15	1689.4	1483.24	1495.98
Survey	-17.1193	-20.0377	-17.0739	-10.986
Age data	525.278	554.402	525.117	533.3
Length data	985.251	1159.99	985.444	982.176
Q	1.4	1.3	1.5	1.1
M	0.28	0.16	0.28	0.28

Survey likelihood was minimum at Q=1.3 and M=0.16. Age data fit best at Q=1.1 and M=0.28, While length data was best fit at Q=1.5 and M=0.28. The M where the total likelihood surface is lowest increases with increasing survey Q (Figure 28). Survey likelihood is relatively flat over the range of survey Q with M between about 0.25 and 0.2 (Figure 29). The survey likelihood surface and a small dip at Q=1.3 and M=0.16 where the lowest likelihood occurs. Length data are fit best a higher M and higher Q, however length likelihood also declines as M declines towards 0.1 (Figure 30). Age likelihood is the highest component of the total likelihood and is relatively flat from Q>1.0 and M between about 0.25 and 0.3 (Figure 31). However, the fishery age at 50% selected for males and females shifts up to above 16 when M is below 0.18 (Figures 32 and 33). This indicates instability in the fishery selectivity parameters which needs to be investigated for the interpretation of the likelihood profiles to be meaningful. However, the length data are fit better as M goes below 0.18 (Figure 30). Age at 50% selected for the survey increases from about 3.4 to 6.0 as M increases from 0.1 to 0.3 for both males and females (Figures 34 and 35). Survey Q seems to have little effect on the age at 50% selected.

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 2018 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 2018	85,765
$B_{40\%}$	36,620
$F_{40\%}$	0.28
max*Fabc*	0.28
$B_{35\%}$	32,043
$F_{35\%}$	0.36
F_{OFL}	0.36

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 2017 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2018 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2017. 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 2018 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 2018 recommended in the assessment to the *max*F_{ABC} for 2018. (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 the 2012-2016 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 4: In all future years, F is set equal to $F_{60\%}$. (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. This was requested by public comment for the DSEIS developed in 2006).

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 2018 and 2019, *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 2030 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 2018 of scenario 6 is 85,765, more than 2 times *B35%* (32,043 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 2030 of scenario 7 (33,775 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 2018 and 2019 from the survey averaging random effects model to the 2018 and 2019 ABC's. The area-specific allocations for 2018 and 2019 are:

Quantity	Western	Central	West Yakutat	Southeast	Total
Area Apportionment	35.98%	57.39%	5.48%	1.15%	100.00%
2018 ABC (t)	12,690	20,238	1,932	406	35,266
2019 ABC (t)	13,222	21,087	2,013	424	36,746

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 36, Figure). 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, Figure38), while euphausids and mysids constituted the most important prey items for juvenile flathead sole (Figure , Figure). 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 (Figure40, Figure). 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 2015 and 2017 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. Examination of genetic stock structure of flathead sole throughout its range and within the Gulf of Alaska and the Bering Sea is important for understanding whether spatial management units are properly allocated.

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Tables

Table 1. Total and regional annual catch of GOA flathead sole through October 1, 2017.

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	2,000	199	1,801	0.6
2016	2,421	228	2,190	2.1
2017	1,610	38	1,572	0.1

Table 2. Historical OFLs, ABCs, TACs, total catch, and percent of catch that was retained. Catch through October 1, 2017.

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	50,792	41,349	27,756	2,000	93
2016	42,840	35,020	27,832	2,421	96
2017	43,128	35,243	27,856	1,610	93

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							
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
2017	70,815	44,934	7,338	0	0	0	123,087
EASTERN GOA							
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
2017	3,197	11,030	266	0	0	0	14,493
WESTERN GOA							
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
2017	86,797	12,169	42	0	0	0	99,009

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
2017	236,588	0.11

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 2015 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 2017 model, the base case model with new data removed (data are as for the 2015 model), and the 2015 model. Values for likelihood components for the 2017 base case model cannot be compared directly with the other two models. The likelihoods for the 2015 model and the 2017 model with 2015 data are the same since there is no difference between the 2015 and 2017 model structure.

Likelihood Component	2015 Model	2017 Model w/ 2015 Data	2017 Model
TOTAL	1,425	1,425	1,534.88
Survey	-17.88	-17.88	-19.01
Length_comp	507	507	539.11
Age_comp	941	941	1019.12
Recruitment	-4.694	-4.694	-4.347

Table 8. Final parameter estimates of growth parameters and unfished recruitment with corresponding standard deviations for the 2017 base case model, the 2017 base case model with data up to 2015, and the 2015 model.

	2017 Model		**2017 Model, 2015 Data**		**2015 Model**	
Parameter	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Length at age 2 (f)	9.473	0.254	9.420	0.254	9.420	0.254
Linf (f)	44.398	0.372	44.215	0.395	44.215	0.395
von Bertalanffy k (f)	0.188	0.005	0.189	0.006	0.189	0.006
CV in length at age 2 (f)	0.107	0.008	0.106	0.008	0.106	0.008
CV in length at age 59 (f)	0.095	0.003	0.096	0.003	0.096	0.003
Length at age 2 (m)	9.543	0.309	9.596	0.326	9.596	0.326
Linf (m)	36.860	0.195	36.784	0.203	36.784	0.203
von Bertalanffy k (m)	0.256	0.007	0.256	0.007	0.256	0.007
CV in length at age 2 (m)	0.128	0.009	0.130	0.009	0.130	0.009
CV in length at age 59 (m)	0.081	0.002	0.081	0.003	0.081	0.003
R0 (log space)	12.822	0.033	12.826	0.036	12.826	0.036

Table 9. Final fishery selectivity parameters for the 2017 base case model, the 2017 model with data up to 2015, and the 2015 model. "Est" refers to the estimated value and "Std. Dev" is the standard deviation of the estimate. Parameters with NA for Std. Dev. are not estimated.

	2017 Model		**2017 Model, 2015 Data**		**2015 Model**	
Double-normal selectivity parameters	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Peak: beginning size for the plateau	12.42	0.53	13.08	0.68	13.08	0.68
Width: width of plateau	30	NA	30	NA	30	NA
Ascending width (log space)	2.77	0.15	2.93	0.17	2.93	0.17
Descending width (log space)	8	NA	8	NA	8	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	-0.98	0.43	-0.94	0.49	-0.94	0.49
Male ascending width offset (log space)	-0.12	0.15	-0.10	0.15	-0.10	0.15
Male descending width offset (log space)	0	NA	0	NA	0	NA
Male "Final" offset (transformation required)	1	NA	1	NA	1	NA
Male apical selectivity	1	NA	1	NA	1	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. Parameters with NA for Std. Dev. are not estimated.

	2017 Model		**2017 Model, 2015 Data**		**2015 Model**	
Double-normal selectivity parameters	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Peak: beginning size for the plateau (in cm)	7.25	0.23	7.22	0.24	7.22	0.24
Width: width of plateau	30	NA	30	NA	30	NA
Ascending width (log space)	2.14	0.11	2.13	0.12	2.13	0.12
Descending width (log space)	8	NA	8	NA	8	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	-0.67	0.25	-0.59	0.26	-0.59	0.26
Male ascending width offset (log space)	-0.30	0.14	-0.26	0.15	-0.26	0.15
Male descending width offset (log space)	0	NA	0	NA	0	NA
Male "Final" offset (transformation required)	0	NA	0	NA	0	NA
Male apical selectivity	1	NA	1	NA	1	NA

Table 11. Estimated yearly fishing mortality rates (rates are apical fishing mortality rates across ages) for the proposed 2017 model.

Year	Fishing Mortality	Std. Dev.	Year	Fishing Mortality	Std. Dev.
Initial F	0.0065	0.0003	1998	0.0145	0.0008
1978	0.0050	0.0005	1999	0.0074	0.0004
1979	0.0019	0.0002	2000	0.0127	0.0007
1980	0.0251	0.0026	2001	0.0156	0.0008
1981	0.0135	0.0013	2002	0.0175	0.0009
1982	0.0176	0.0016	2003	0.0202	0.0010
1983	0.0136	0.0012	2004	0.0199	0.0010
1984	0.0065	0.0005	2005	0.0214	0.0011
1985	0.0034	0.0003	2006	0.0263	0.0013
1986	0.0014	0.0001	2007	0.0260	0.0014
1987	0.0013	0.0001	2008	0.0283	0.0015
1988	0.0042	0.0003	2009	0.0298	0.0016
1989	0.0059	0.0004	2010	0.0311	0.0016
1990	0.0114	0.0007	2011	0.0220	0.0012
1991	0.0097	0.0006	2012	0.0172	0.0009
1992	0.0182	0.0010	2013	0.0220	0.0012
1993	0.0226	0.0013	2014	0.0198	0.0011
1994	0.0205	0.0011	2015	0.0146	0.0008
1995	0.0179	0.0010	2016	0.0179	0.0010
1996	0.0256	0.0014	2017	0.0106	0.0006
1997	0.0205	0.0011			

Table 12. Recruitment deviations and standard deviations for the proposed 2017 model.

Year	Recruitment Deviations	Std. Dev.	Year	Recruitment Deviations	Std. Dev.
1955	-0.133	0.563	1985	-0.251	0.373
1956	-0.158	0.557	1986	-0.235	0.328
1957	-0.188	0.550	1987	-0.133	0.296
1958	-0.222	0.542	1988	-0.207	0.317
1959	-0.261	0.534	1989	0.207	0.206
1960	-0.304	0.525	1990	-0.345	0.268
1961	-0.353	0.515	1991	-0.162	0.242
1962	-0.405	0.505	1992	0.320	0.170
1963	-0.460	0.495	1993	-0.166	0.216
1964	-0.516	0.486	1994	-0.085	0.197
1965	-0.568	0.477	1995	-0.279	0.214
1966	-0.619	0.468	1996	-0.503	0.240
1967	-0.672	0.459	1997	0.190	0.151
1968	-0.729	0.451	1998	-0.035	0.184
1969	-0.788	0.443	1999	0.379	0.148
1970	-0.843	0.436	2000	-0.240	0.236
1971	-0.880	0.431	2001	-0.010	0.169
1972	-0.889	0.428	2002	-0.047	0.170
1973	-0.855	0.429	2003	0.300	0.144
1974	-0.760	0.437	2004	-0.004	0.190
1975	-0.564	0.456	2005	0.262	0.153
1976	-0.179	0.515	2006	-0.153	0.202
1977	0.841	0.311	2007	-0.016	0.183
1978	0.103	0.479	2008	-0.233	0.209
1979	-0.271	0.426	2009	0.147	0.182
1980	-0.116	0.354	2010	0.576	0.164
1981	-0.104	0.353	2011	0.488	0.197
1982	-0.090	0.364	2012	0.280	0.228
1983	-0.059	0.371			
1984	-0.047	0.347			

Table 13. Time series of total (age 3+) and spawning biomass and standard deviation of spawning biomass (Std_Dev) for the previous and proposed 2017 assessments.

	2017 Assessment			*2015 Assessment*		
Year	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**
1978	141,306	57,963	6,107	141,975	58,089	6,159
1979	139,662	55,329	5,639	140,348	55,470	5,688
1980	149,819	53,164	5,189	150,713	53,318	5,234
1981	161,741	50,591	4,764	162,748	50,751	4,807
1982	174,983	49,601	4,384	176,027	49,778	4,424
1983	186,746	50,043	4,062	187,764	50,243	4,100
1984	196,594	52,752	3,826	197,571	52,985	3,864
1985	204,709	57,864	3,712	205,660	58,136	3,750
1986	211,193	64,246	3,730	212,188	64,542	3,771
1987	216,404	70,210	3,799	217,348	70,501	3,843
1988	219,488	74,582	3,814	220,399	74,843	3,856
1989	220,474	77,204	3,752	221,360	77,433	3,792
1990	220,309	78,661	3,648	221,208	78,873	3,685
1991	218,596	79,153	3,534	219,546	79,357	3,570
1992	218,955	79,341	3,427	220,077	79,543	3,462
1993	217,313	78,632	3,325	218,587	78,828	3,361
1994	215,182	77,422	3,223	216,623	77,623	3,260
1995	216,101	76,343	3,119	217,713	76,576	3,157
1996	217,055	75,654	3,018	218,763	75,944	3,059
1997	217,148	74,888	2,928	218,974	75,244	2,970
1998	216,620	74,787	2,850	218,544	75,216	2,894
1999	214,597	75,239	2,782	216,628	75,734	2,829
2000	214,649	76,223	2,724	216,872	76,770	2,773
2001	214,248	76,843	2,675	216,677	77,424	2,727
2002	216,787	76,961	2,629	219,537	77,572	2,683
2003	218,435	76,495	2,575	221,399	77,148	2,632
2004	219,965	75,654	2,514	223,115	76,372	2,575
2005	221,062	75,132	2,460	224,310	75,936	2,528
2006	223,681	75,223	2,436	226,919	76,121	2,513
2007	225,446	75,678	2,449	228,563	76,661	2,539
2008	228,635	76,430	2,490	231,727	77,474	2,595
2009	230,173	76,955	2,546	233,324	78,025	2,667
2010	230,780	77,306	2,614	233,972	78,367	2,754
2011	229,336	77,712	2,702	232,367	78,739	2,866
2012	229,344	78,839	2,815	231,266	79,826	3,006
2013	233,835	80,171	2,942	233,760	81,114	3,166
2014	241,014	80,854	3,072	238,766	81,718	3,334
2015	249,797	81,321	3,208	265,088	82,006	3,510
2016	258,531	82,110	3,369			
2017	265,264	83,296	3,600			

Table 14. Time series of recruitment at ages 3 and 0 and standard deviation of age 0 recruits for the previous and proposed 2017 assessments.

	2017 Assessment			*2015 Assessment*		
Year	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. dev**	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. dev**
1978	105,486	370,720	177,067	106,393	368,484	177,506
1979	154,476	254,217	108,203	155,476	253,772	108,446
1980	427,023	295,871	104,607	433,871	297,149	105,949
1981	203,448	298,640	105,063	202,218	301,679	106,894
1982	139,513	301,837	109,935	139,268	305,519	112,206
1983	162,372	310,388	113,553	163,073	316,566	116,231
1984	163,893	312,914	109,924	165,559	309,669	111,617
1985	165,649	254,293	95,021	167,669	257,747	97,245
1986	170,343	257,547	84,653	173,734	260,632	86,860
1987	171,731	284,249	83,858	169,949	288,331	86,107
1988	139,559	263,313	84,409	141,454	267,445	87,185
1989	141,344	396,687	80,399	143,037	405,666	82,826
1990	155,997	227,652	61,534	158,238	229,639	62,810
1991	144,507	272,732	66,731	146,773	277,449	68,434
1992	217,703	439,867	73,399	222,629	445,008	74,920
1993	124,934	269,811	58,947	126,024	271,093	59,833
1994	149,673	291,525	57,569	152,259	298,176	59,033
1995	241,394	239,369	51,515	244,213	243,695	53,035
1996	148,070	190,681	46,582	148,772	196,069	48,182
1997	159,985	380,569	56,823	163,633	390,474	58,701
1998	131,364	303,875	56,718	133,736	310,045	58,382
1999	104,645	459,538	67,704	107,601	471,911	69,994
2000	208,857	247,556	59,278	214,291	249,058	60,890
2001	166,766	311,548	53,037	170,152	317,992	54,702
2002	252,193	300,180	52,046	258,981	304,039	53,283
2003	135,857	424,688	61,899	136,681	426,427	63,497
2004	170,975	313,186	60,690	174,510	314,108	62,031
2005	164,736	408,867	63,402	166,852	420,247	66,478
2006	233,064	270,004	55,695	234,017	279,669	58,466
2007	171,872	309,512	57,506	172,376	312,754	60,275
2008	224,380	249,208	53,433	230,623	242,828	53,751
2009	148,174	364,575	68,319	153,476	315,972	65,533
2010	169,854	559,803	94,755	171,631	511,681	98,931
2011	136,760	519,302	105,101	133,257	504,307	126,418
2012	200,074	427,776	101,288	173,400	445,553	137,487
2013	307,215	370,248	12,278	280,805	371,808	13,501
2014	284,987	370,248	12,278	276,755	371,808	13,501
2015	234,760	370,248	12,278	244,513	371,808	
2016	203,190	370,248	12,278			
2017	203,190	370,248	12,278			
Average	180,815	330,844		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
2017	83,298	83,298	83,298	83,298	83,298	83,298	83,298
2018	85,765	85,765	85,765	85,765	85,765	85,765	85,765
2019	89,118	89,118	89,118	89,118	89,118	70,420	73,924
2020	76,813	76,813	92,548	89,672	93,674	60,587	65,945
2021	67,320	67,320	95,158	89,630	97,378	53,396	57,045
2022	59,493	59,493	96,506	88,583	99,763	47,588	50,002
2023	53,104	53,104	96,677	86,690	100,878	42,917	44,467
2024	48,126	48,126	96,006	84,335	101,023	39,358	40,328
2025	44,437	44,437	94,853	81,878	100,548	36,805	37,396
2026	41,824	41,824	93,509	79,566	99,749	35,224	35,532
2027	40,043	40,043	92,156	77,523	98,824	34,387	34,528
2028	38,874	38,874	90,891	75,786	97,887	33,989	34,044
2029	38,137	38,137	89,758	74,346	97,001	33,822	33,839
2030	37,694	37,694	88,775	73,176	96,202	33,774	33,775

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
2017	0.015	0.015	0.015	0.015	0.015	0.015	0.015
2018	0.016	0.016	0.016	0.016	0.016	0.356	0.284
2019	0.284	0.284	0.017	0.061	0.000	0.356	0.284
2020	0.284	0.284	0.017	0.061	0.000	0.356	0.356
2021	0.284	0.284	0.017	0.061	0.000	0.356	0.356
2022	0.284	0.284	0.017	0.061	0.000	0.356	0.356
2023	0.284	0.284	0.017	0.061	0.000	0.356	0.356
2024	0.284	0.284	0.017	0.061	0.000	0.355	0.356
2025	0.284	0.284	0.017	0.061	0.000	0.347	0.350
2026	0.284	0.284	0.017	0.061	0.000	0.337	0.339
2027	0.283	0.283	0.017	0.061	0.000	0.330	0.331
2028	0.281	0.281	0.017	0.061	0.000	0.327	0.328
2029	0.280	0.280	0.017	0.061	0.000	0.326	0.326
2030	0.279	0.279	0.017	0.061	0.000	0.325	0.325

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
2017	2,044	2,044	2,044	2,044	2,044	2,044	2,044
2018	2,256	2,256	2,256	2,256	2,256	43,011	35,266
2019	36,746	36,746	2,428	8,645	0	35,479	30,500
2020	31,697	31,697	2,530	8,720	0	30,555	33,255
2021	27,726	27,726	2,607	8,727	0	26,870	28,701
2022	24,409	24,409	2,639	8,606	0	23,868	25,066
2023	21,715	21,715	2,632	8,381	0	21,485	22,243
2024	19,664	19,664	2,600	8,117	0	19,711	20,187
2025	18,188	18,188	2,560	7,857	0	18,131	18,522
2026	17,165	17,165	2,518	7,624	0	16,968	17,196
2027	16,441	16,441	2,478	7,426	0	16,343	16,450
2028	15,936	15,936	2,443	7,263	0	16,056	16,096
2029	15,609	15,609	2,414	7,132	0	15,949	15,958
2030	15,410	15,410	2,388	7,027	0	15,928	15,927

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**	**2016**
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		
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		
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		
Dark Rockfish						0.00	0.01	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	0.12	
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	7.17	0.19
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		
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		
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		
Gunnels	0.00			1.00		0.24				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	0.06	
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		
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		
Great Sculpin						0.00	0.01	0.01	0.02	0.00	0.00	0.00		
Plain Sculpin						0.00	0.00	0.00	0.00	0.00	0.00	0.00		
Warty Sculpin						0.41	0.00	0.00				0.00		
Yellow Irish Lord						0.01	0.00	0.01	0.00	0.01	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	0.07	0.35
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		0.01
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		
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	2.81	0.48
Polychaete unidentified	0.00		0.03		0.00	0.00	0.00	0.00	0.78		0.00		0.01	
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		0.91
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		0.05
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		0.01
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	1.41	0.20
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	0.20	0.08
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		
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	0.13	0.04
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	0.01	0.01

Table 19. Prohibited species catch caught in the GOA flathead sole fishery in 2015, 2016 and 2017.

	2017	2017	2016	2016	2015	2015
Species Group Name	PSCNQ Estimate (numbers)	Halibut Mortality (t)	PSCNQ Estimate (numbers)	Halibut Mortality (t)	PSCNQ Estimate (numbers)	Halibut Mortality (t)
Bairdi Tanner Crab	0.000		293.025		3,224.718	
Blue King Crab	0.000		0.000		0.000	
Chinook Salmon	0.000		1.179		0.000	
Golden (Brown) King Crab	0.000		0.261		0.000	
Halibut	0.664	0.564	17.363	11.633	3.528	2.293
Herring	0.000		0.000		0.000	
Non-Chinook Salmon	0.000		0.687		0.000	
Opilio Tanner (Snow) Crab	0.000		0.045		0.000	
Red King Crab	0.000		0.000		0.000	

Figures

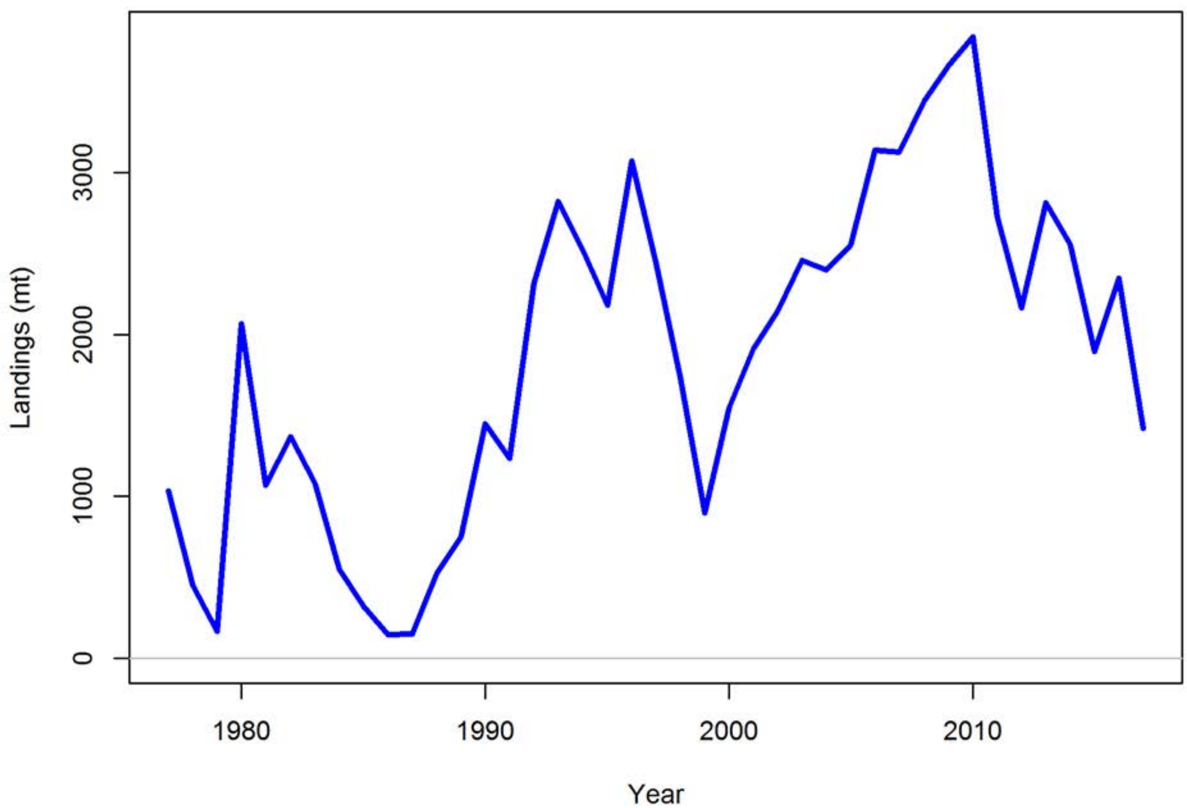

Figure 1. Catch biomass in metric tons 1978-2017 (as of October 1, 2017).

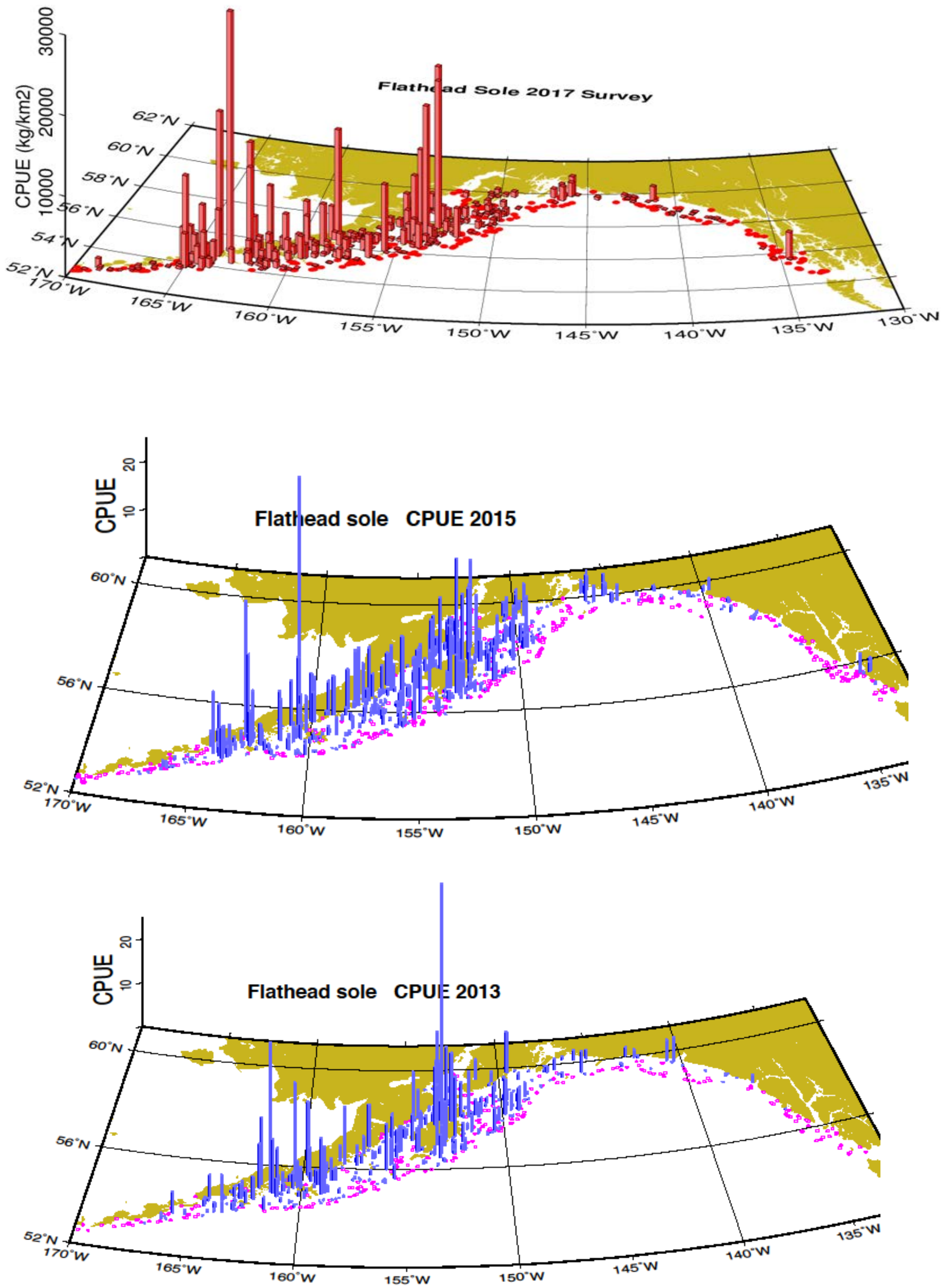

Figure 2. GOA trawl survey catch per unit effort (CPUE kg/km2 2017 and tons/km2 2011-2015) for flathead sole for the 2013-2017 surveys. Bars denote CPUE values and pink (or red) dots denote hauls were no flathead sole were caught.

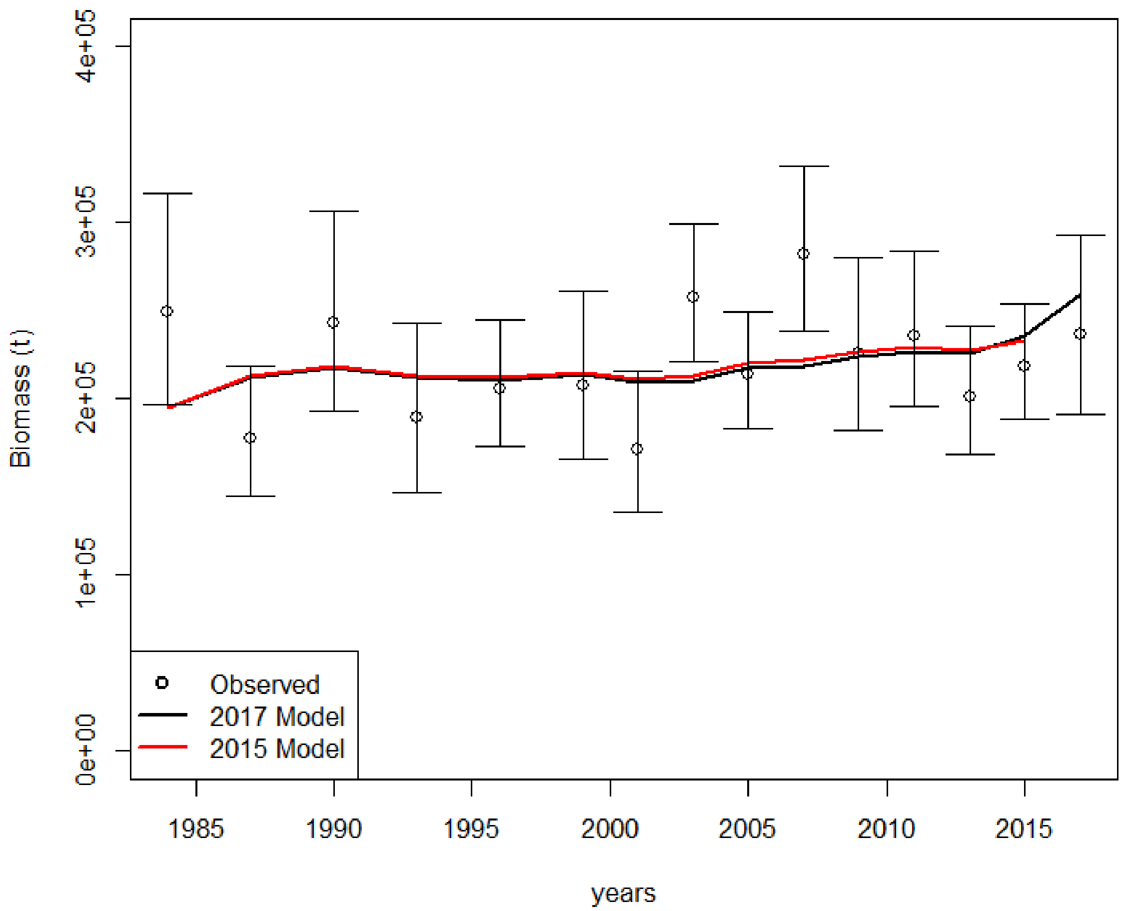

Figure 3. Survey biomass index (circles), asymptotic 95% confidence intervals (vertical black lines), and estimated survey biomass for the proposed 2017 model and the accepted 2015 model (the same as the 2017 Model without 2016-2017 data).

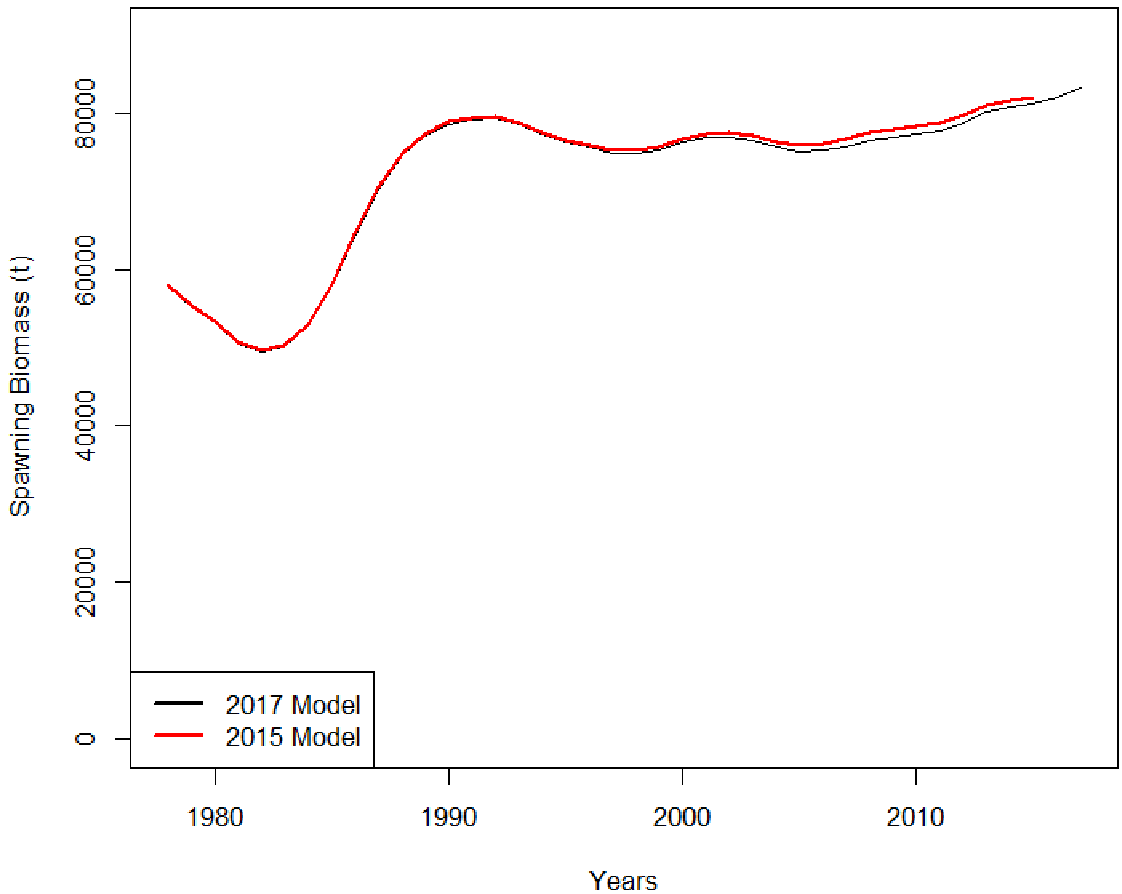

Figure 4. Time series of spawning biomass for the proposed 2017 model and the accepted 2015 model (the same as the 2017 Model without 2016-2017 data).

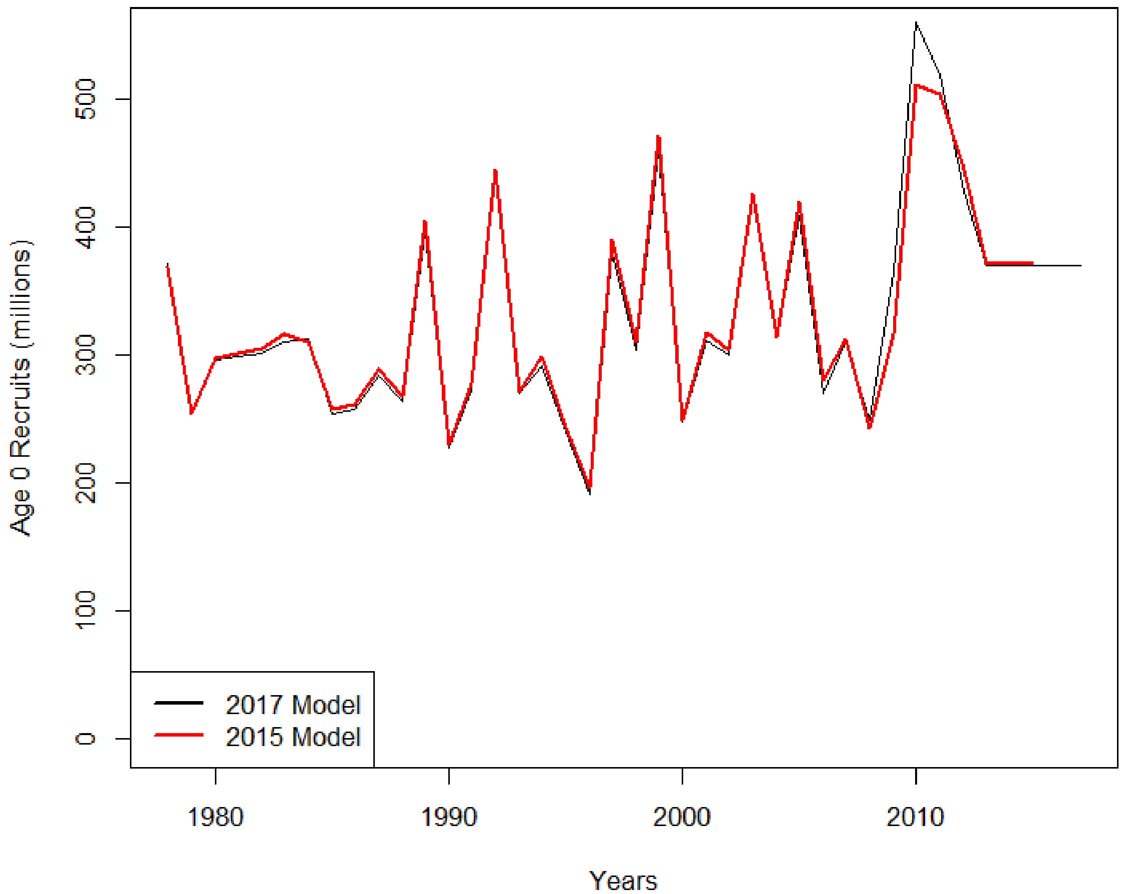

Figure 5. Time series of age-0 recruits for the proposed 2017 model and the accepted 2015 model (the same as the 2017 Model without 2016-2017 data).

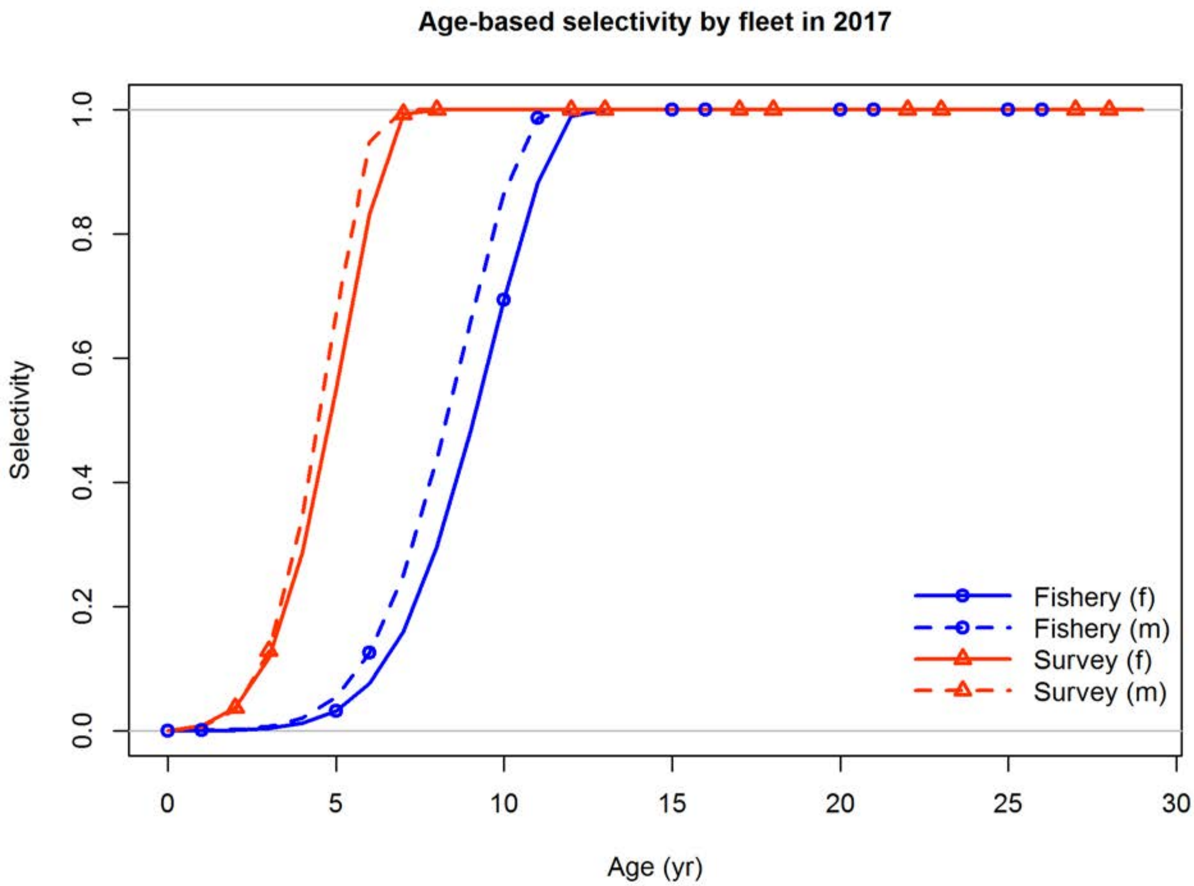

Figure 6. Selectivity curves for the fishery (blue lines) and the survey (red lines), and for females (solid lines) and males (dashed lines) for the proposed 2017 model.

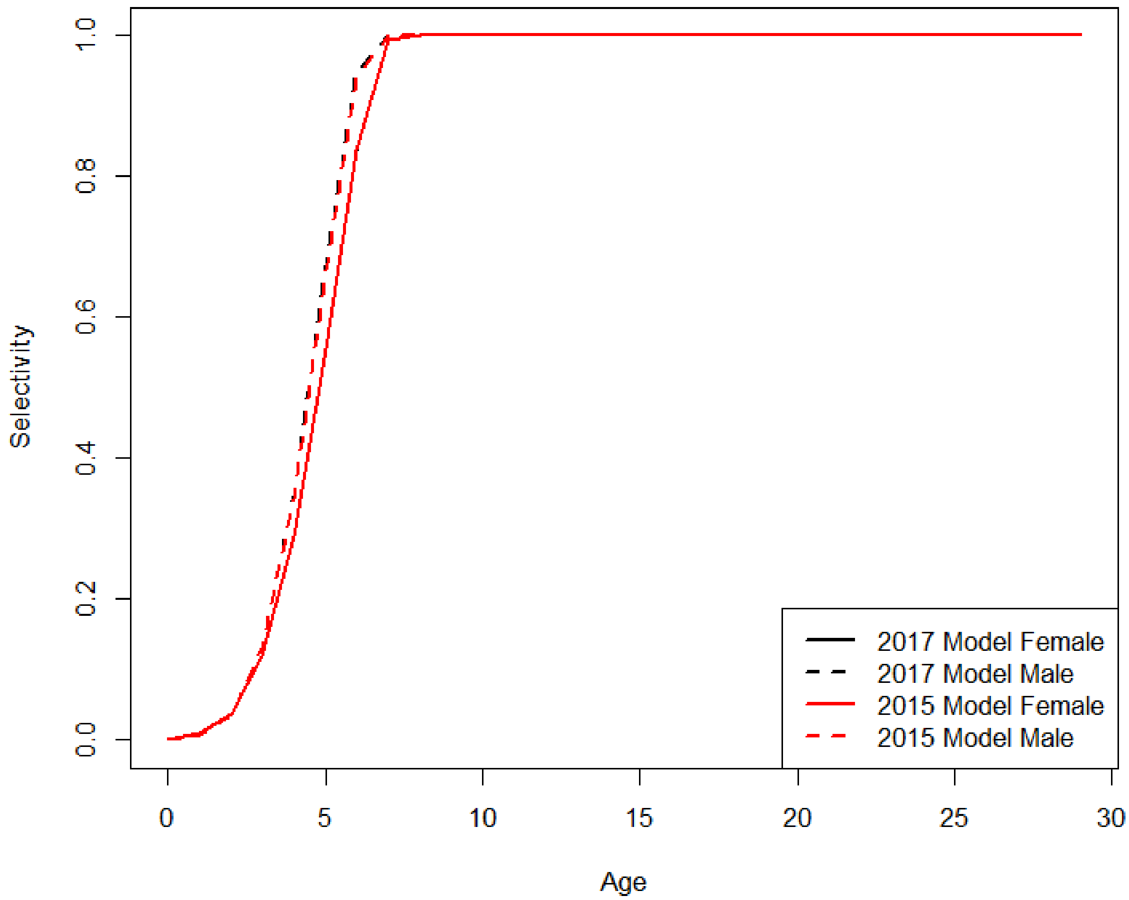

Figure 7. Survey selectivities for males and females for Model 2015 and Model 2017.

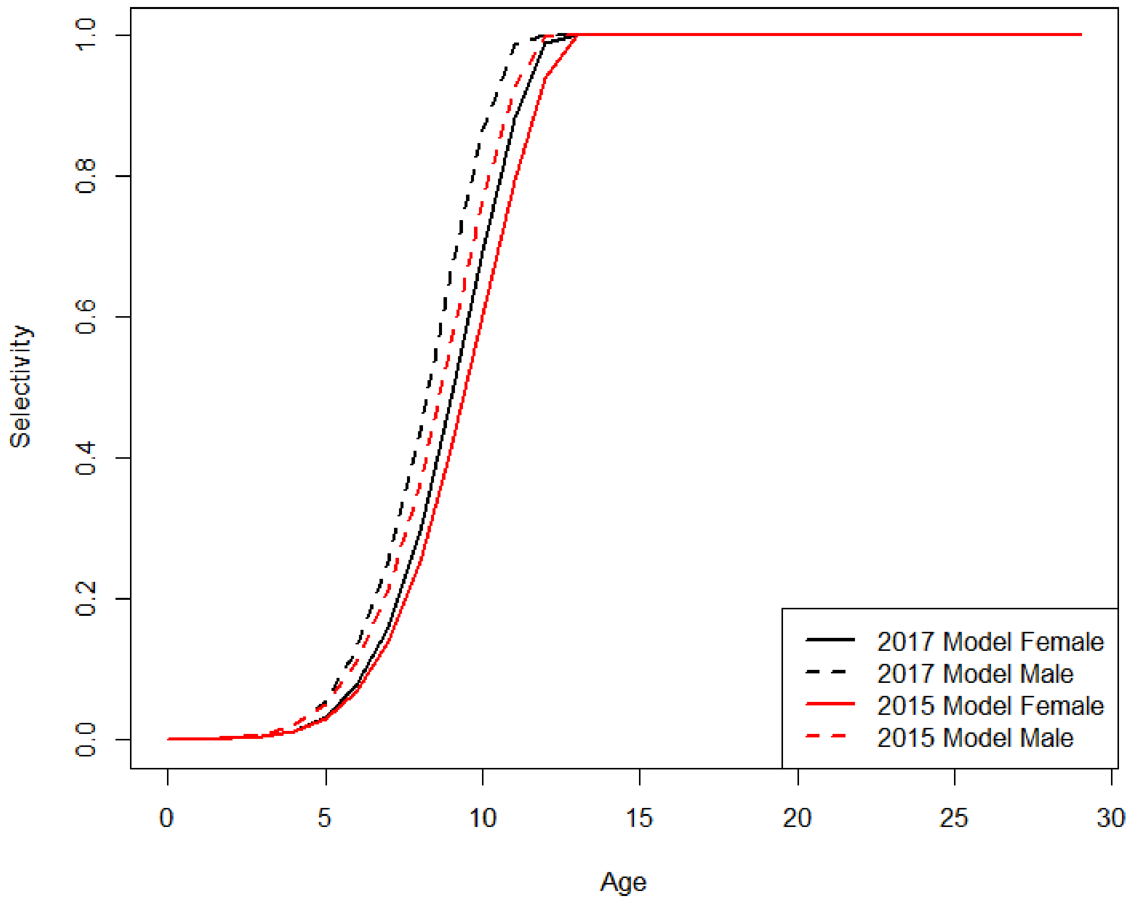

Figure 8. Fishery selectivities for males and females for Model 2015 and Model 2017.

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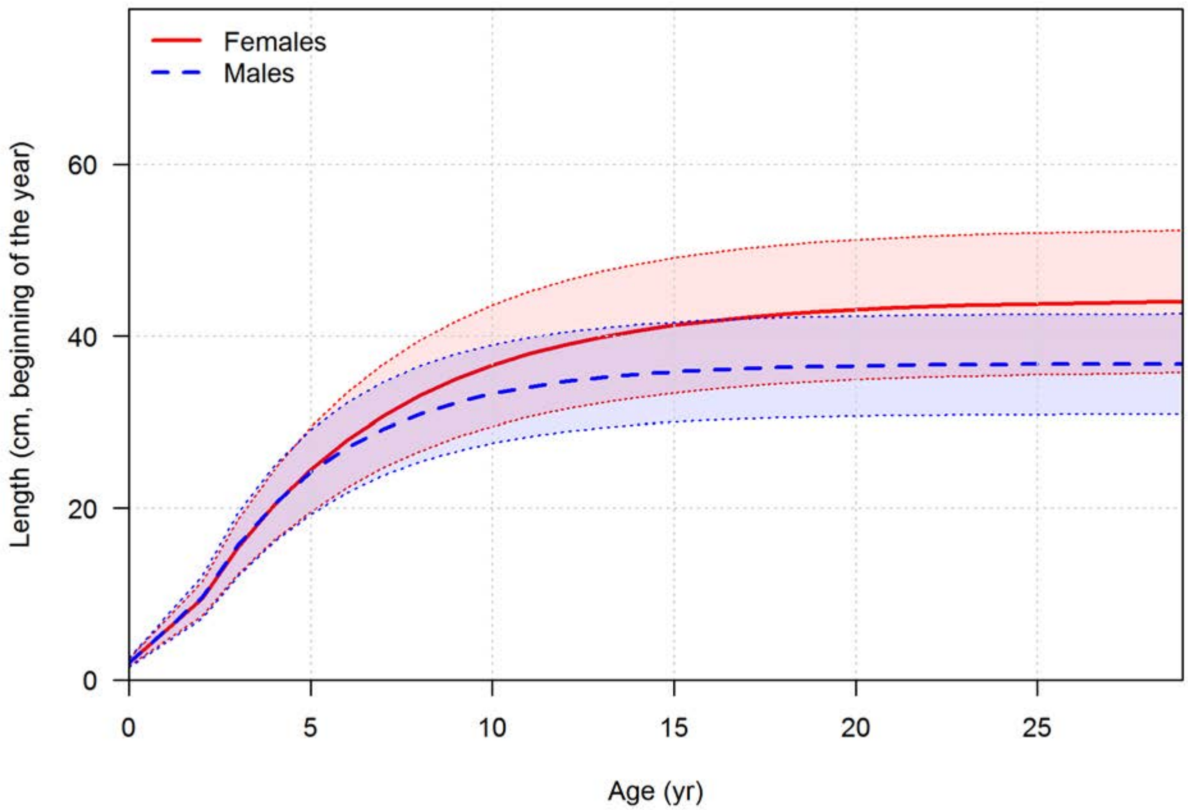


Figure 9. Estimated length-at-age relationship with 95% asymptotic confidence intervals for males (blue) and females (red). The blue dashed line and red solid line show the mean relationship and dotted lines show confidence intervals.

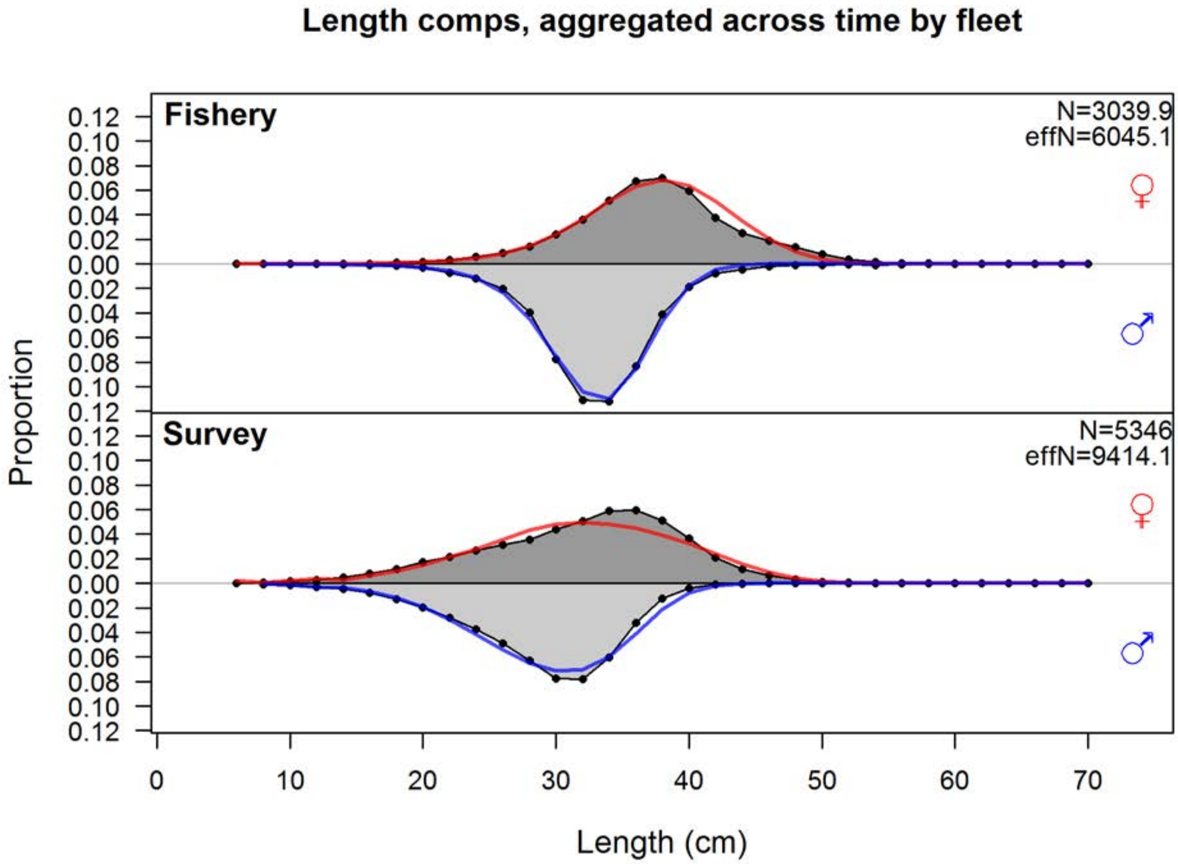


Figure 10. Observed (grey shaded area, black lines) and expected (red lines) proportions-at-length, aggregated over years for the fishery and survey and for females (upper half of plots) and males (lower half of plots) for the proposed 2017 model.

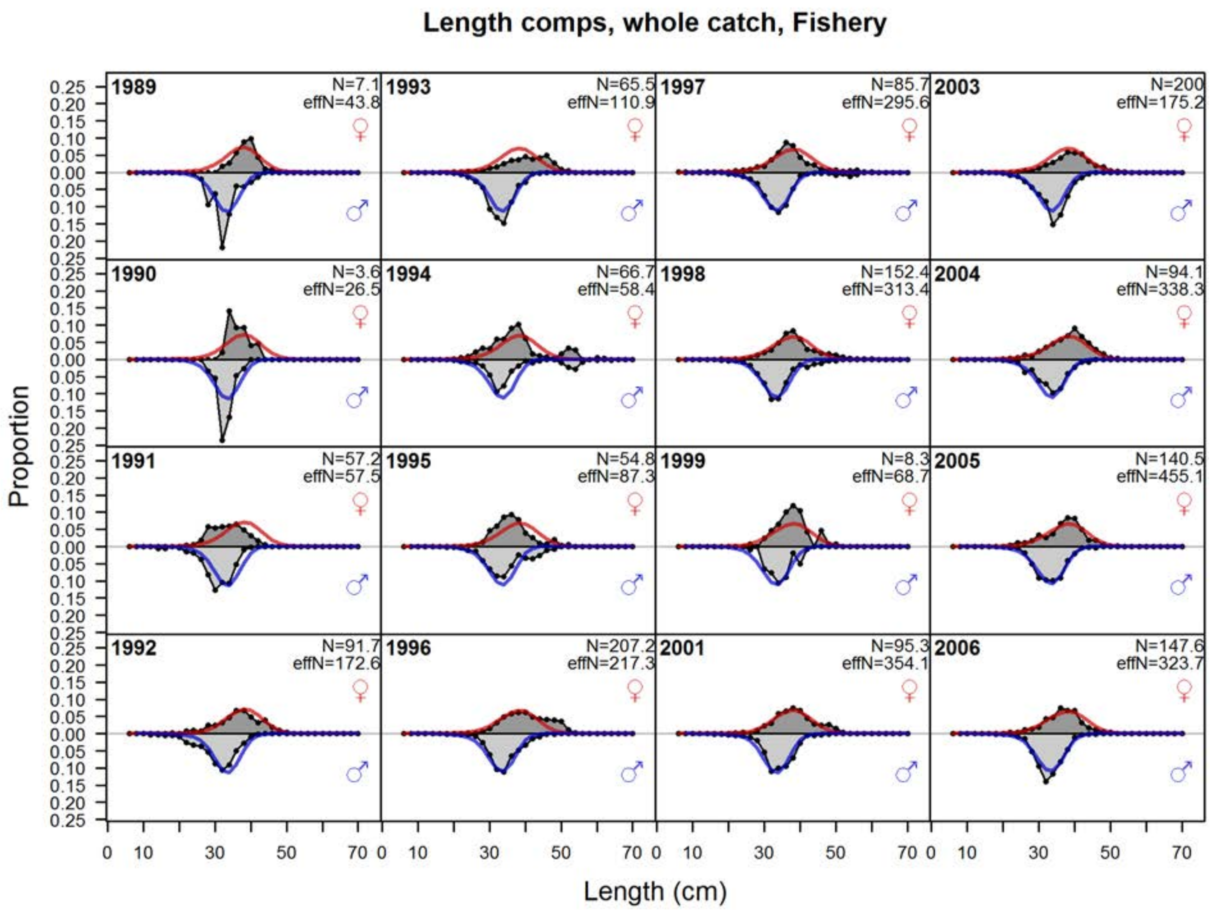


Figure 11. Observed (grey filled area and black line) and expected (lines) fishery length compositions for the proposed 2017 model (1 of 2).

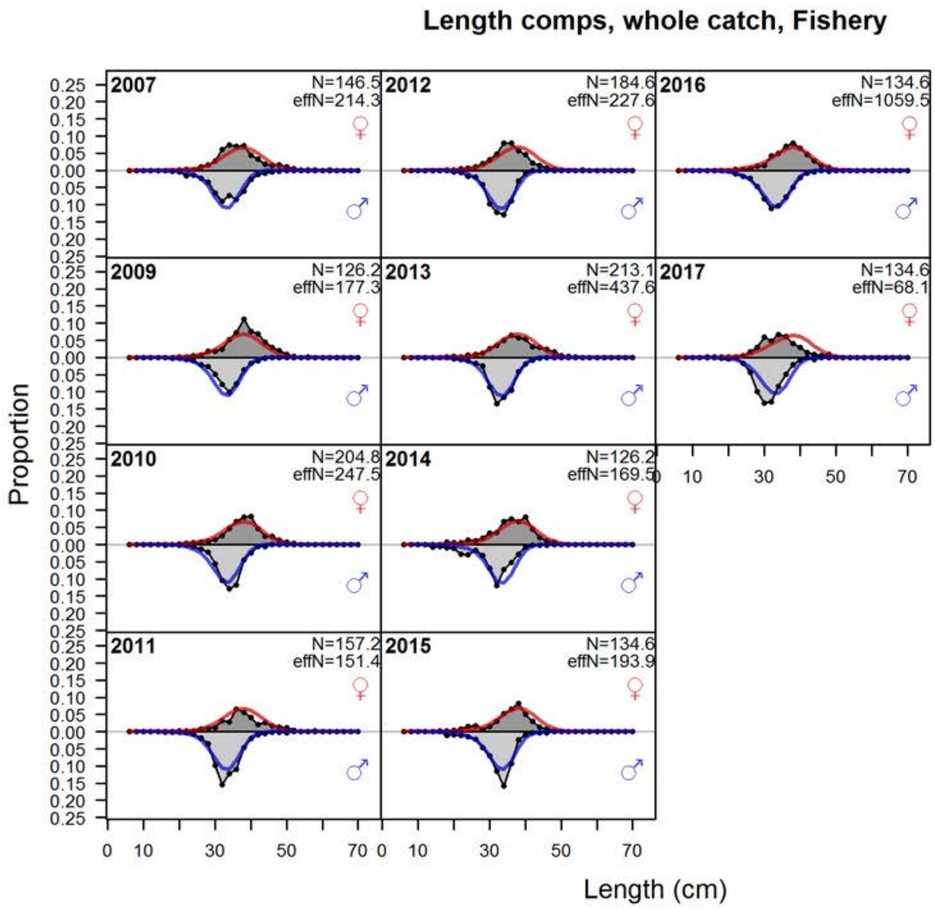


Figure 12. As for Figure , but for years 2007 to 2017 (2 of 2).

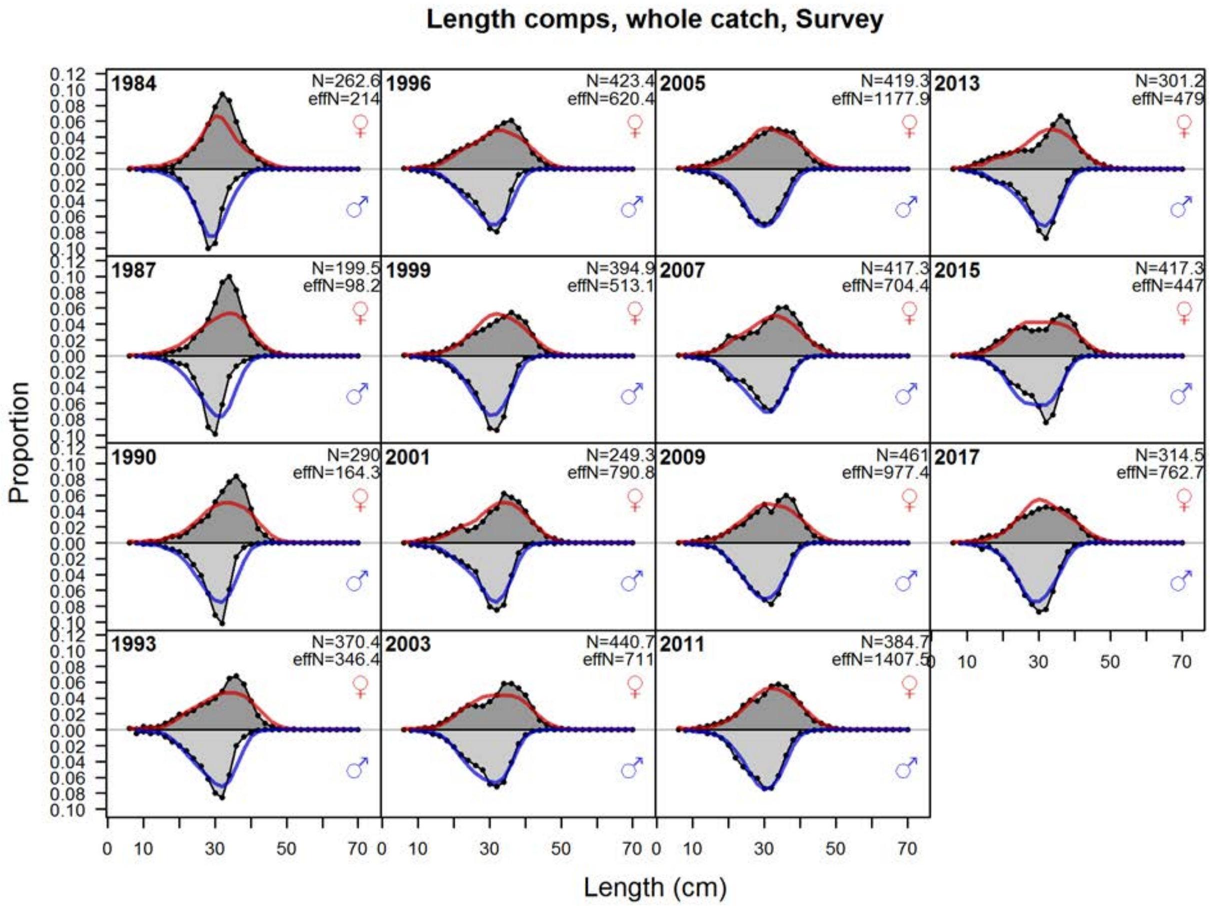


Figure 13. Observed (grey filled area and black line) and expected (lines) survey length compositions for the proposed 2017 model.

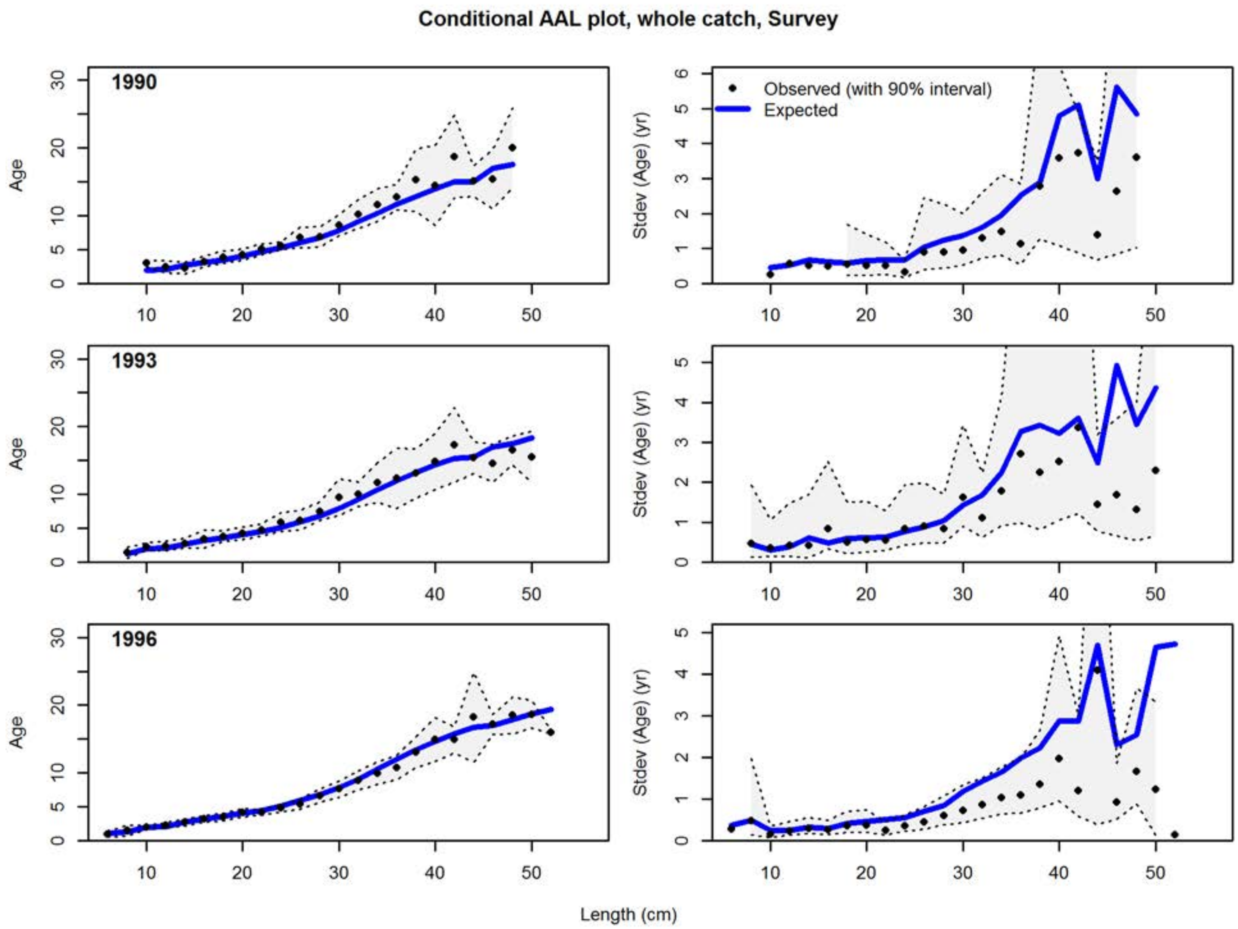


Figure 14. Observed and expected mean age-at-length for both females and males with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the proposed 2017 model for years 1990-1996 (1 of 4).

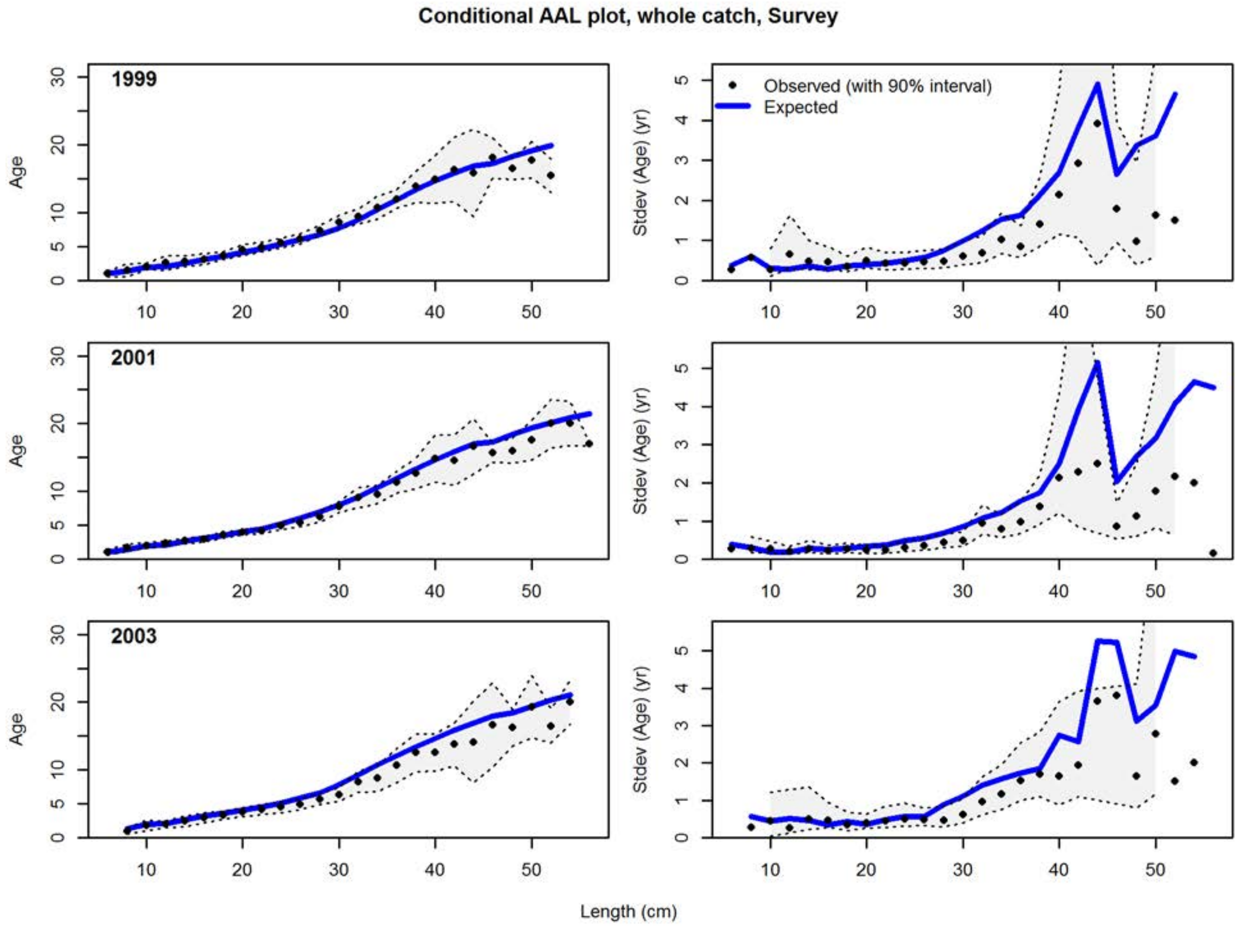


Figure 15. Observed and expected mean age-at-length for both females and males with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the proposed 2017 model for years 1999-2003 (2 of 4).

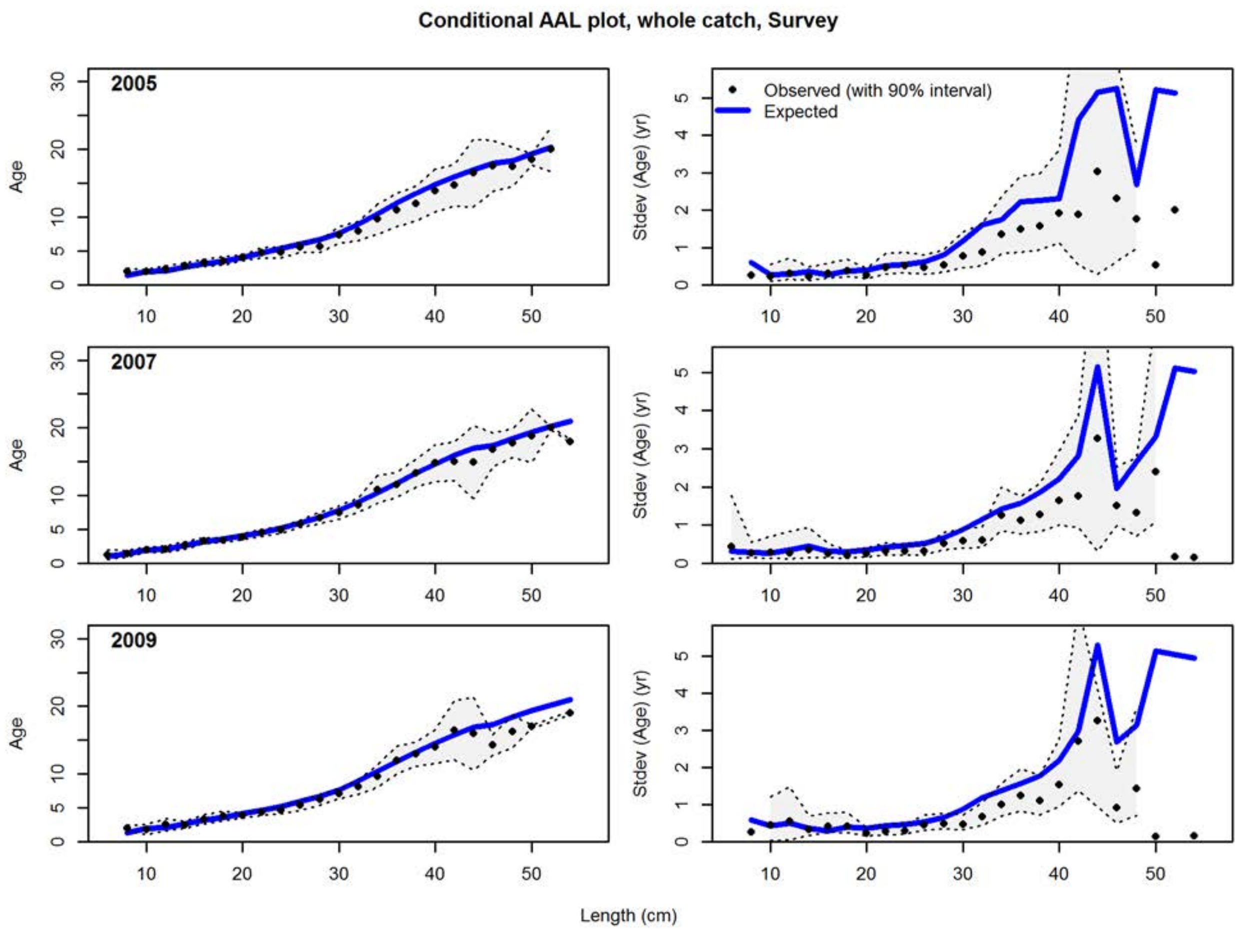
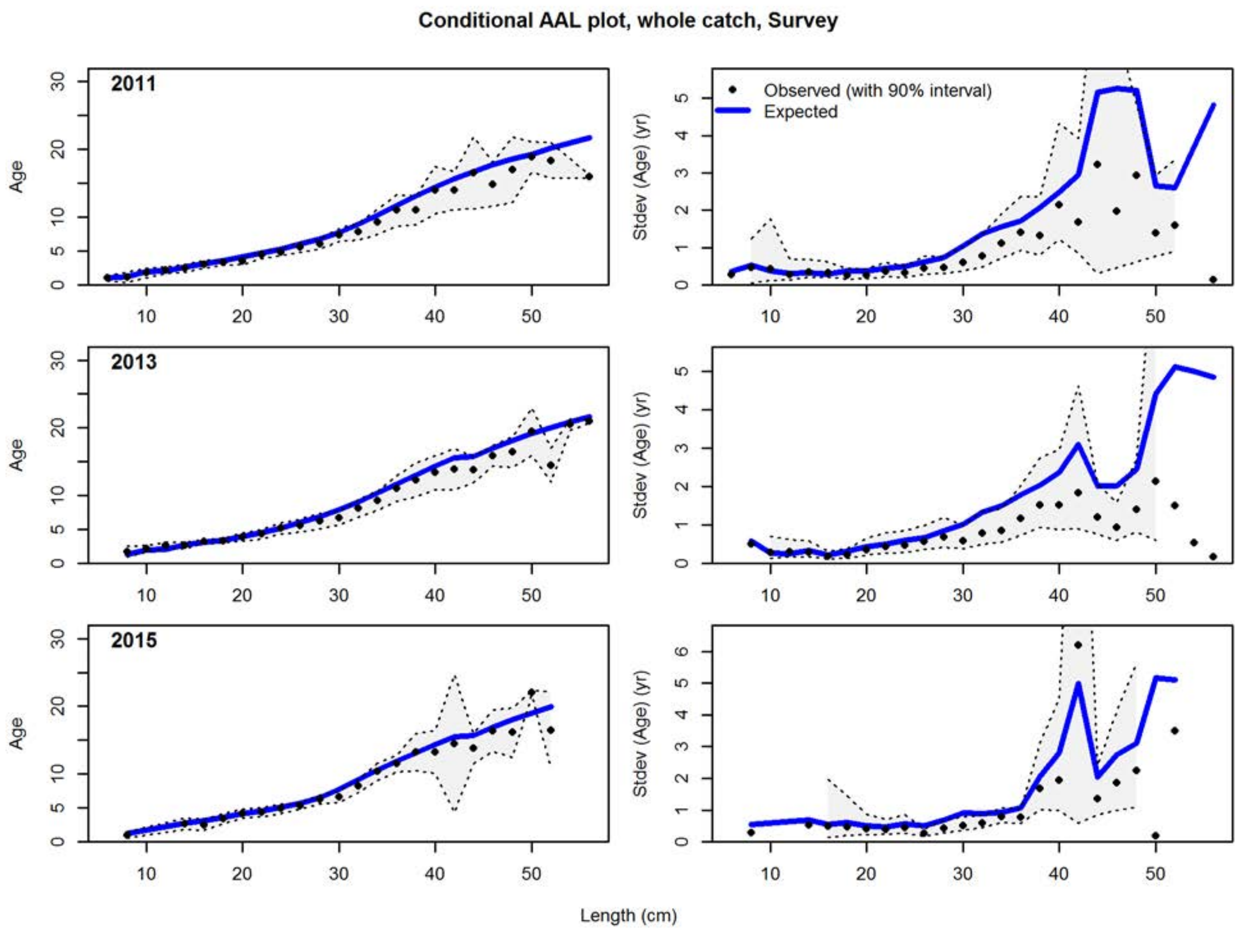


Figure 16. Observed and expected mean age-at-length for both females and males with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the proposed 2017 model for years 2005-2009 (3 of 4).



Length (cm)

Figure 17. 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 2017 model for years 2011-2015 (4 of 4).

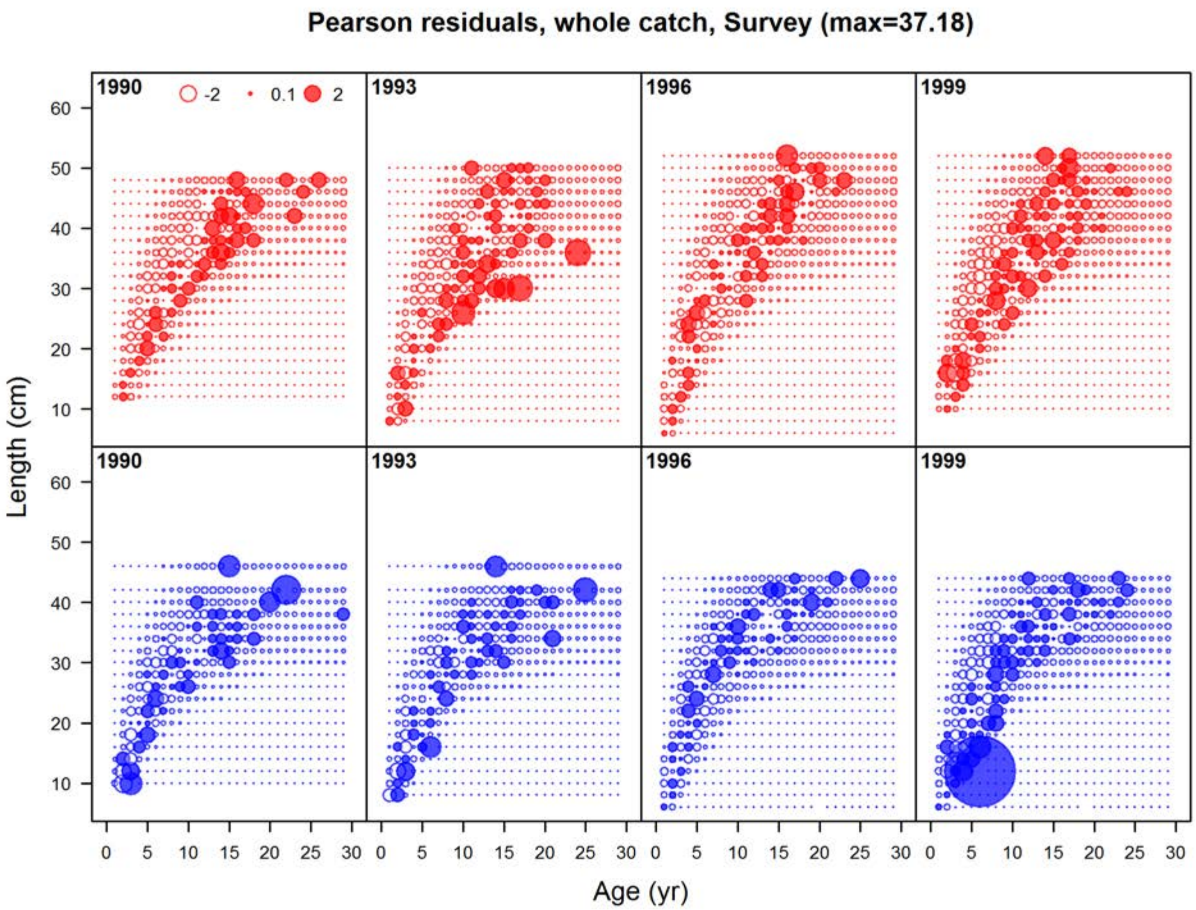


Figure 18. Pearson residuals associated with fits to the length-at-age relationship within the model for females (red, top panel) and males (blue, bottom panel) for the survey (1 of 3).

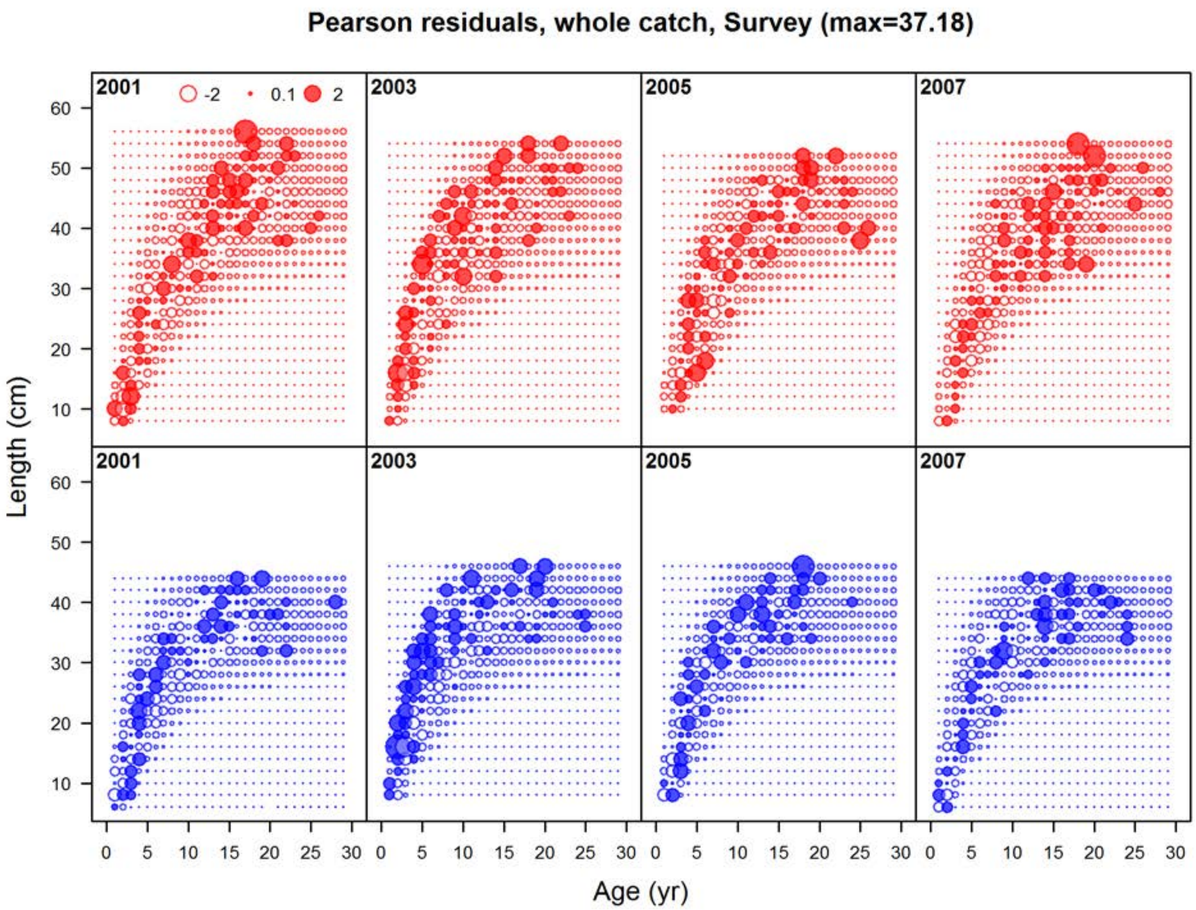


Figure 19. Pearson residuals associated with fits to the length-at-age relationship within the model for females (red, top panel) and males (blue, bottom panel) for the survey (2 of 3).

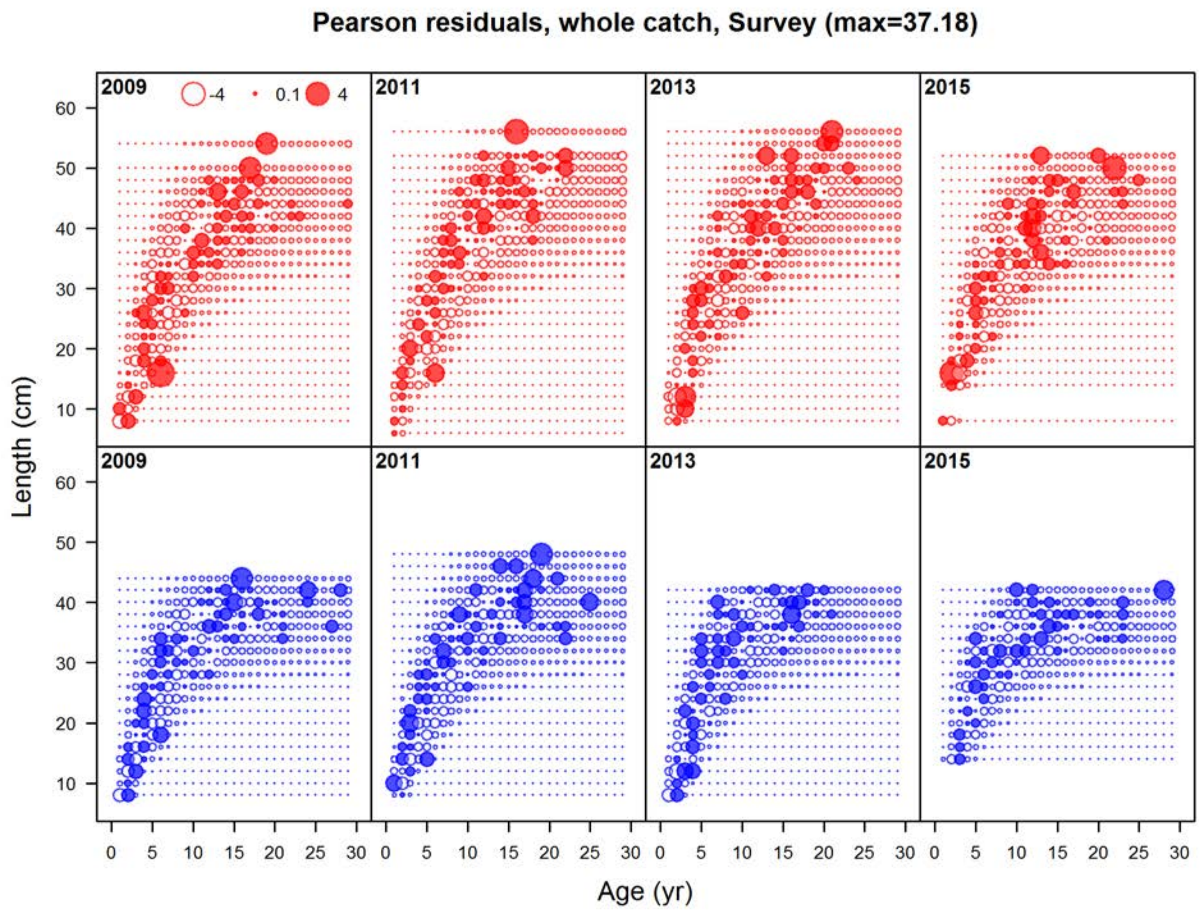


Figure 20. Pearson residuals associated with fits to the length-at-age relationship within the model for females (red, top panel) and males (blue, bottom panel) for the survey (3 of 3).

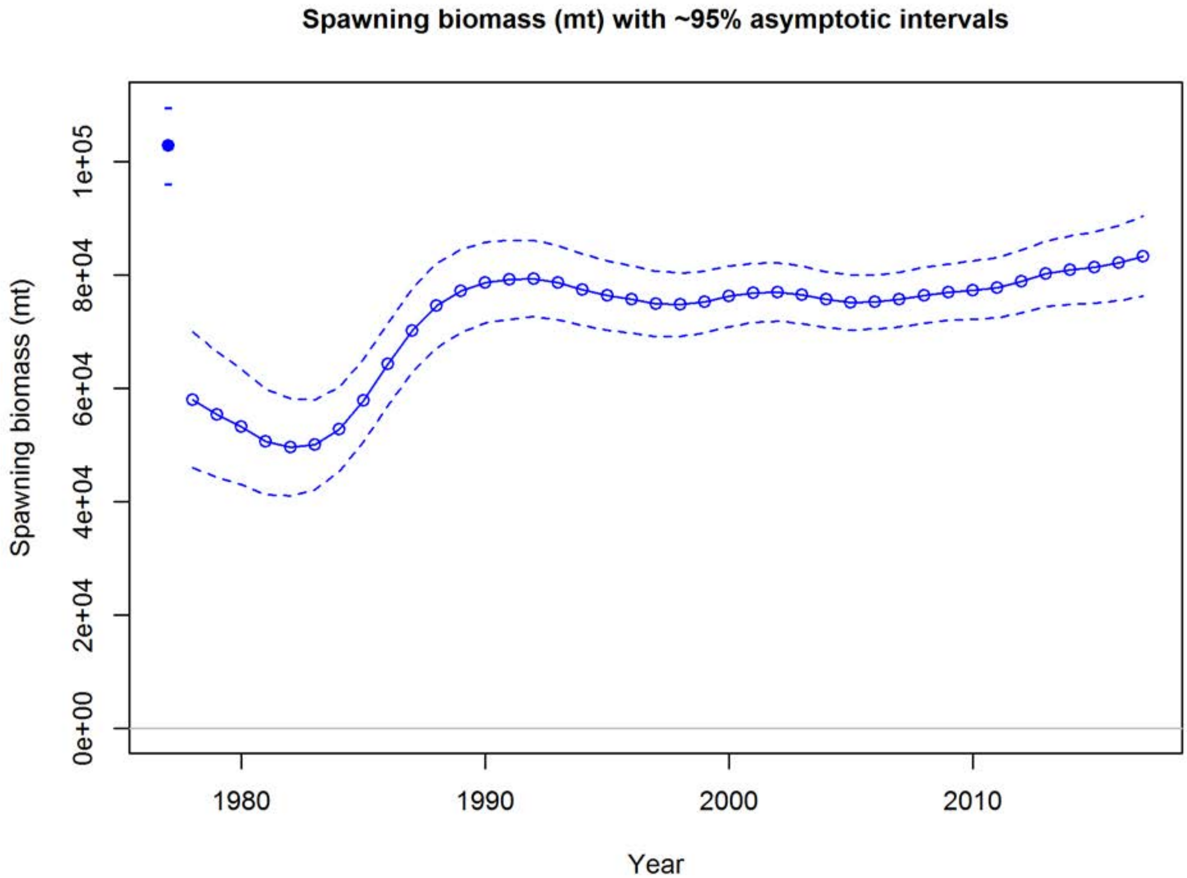


Figure 21. Time series of estimated spawning stock biomass (t) over time (solid blue line and circles) and asymptotic 95% confidence intervals (blue dashed lines) for the current base case model. Point at 1977 is virgin biomass.

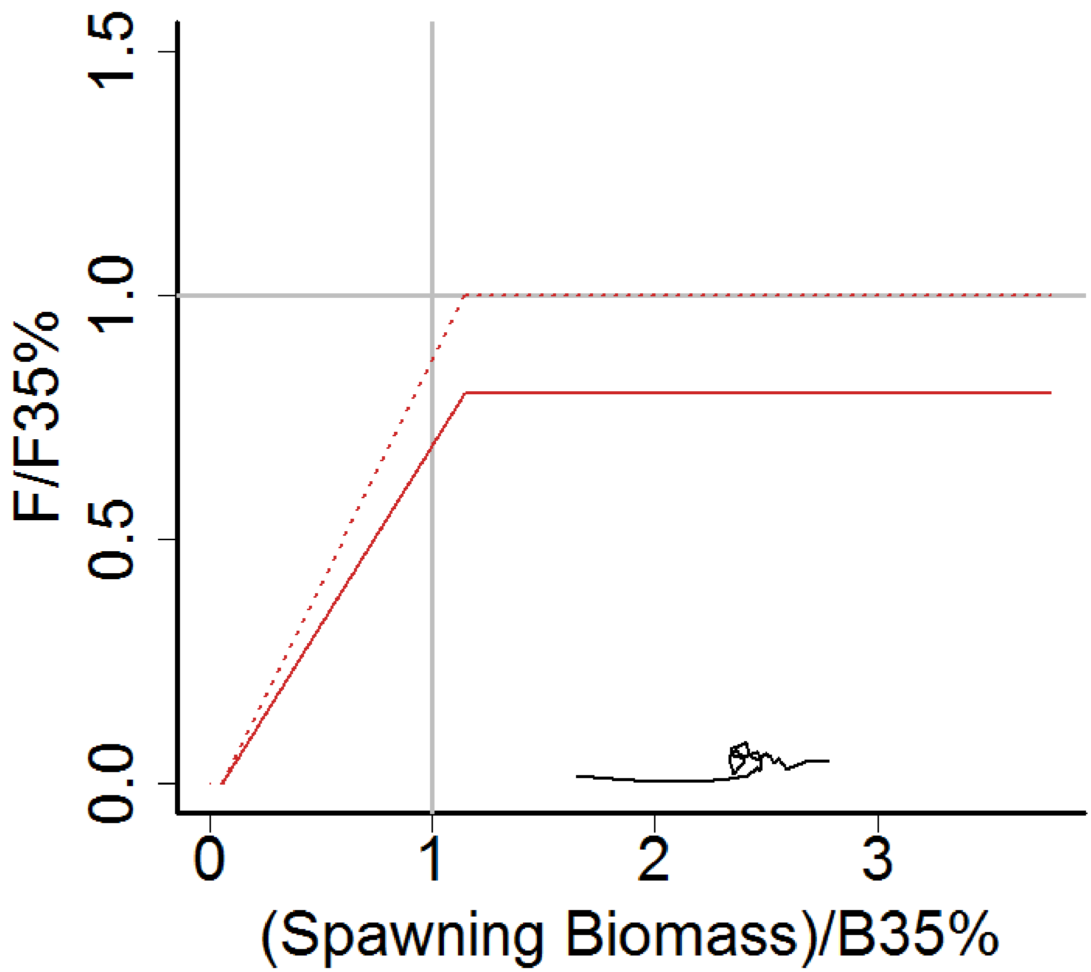


Figure 22. Spawning stock biomass relative to $B_{35\%}$ and fishing mortality (F) relative to $F_{35\%}$ from 1978-2019 (solid black line), the OFL control rule (dotted red line), the maxABC control rule (solid red line), $B_{35\%}$ (vertical grey line), and $F_{35\%}$ (horizontal grey line). The 2018 and 2019 spawning biomass and fishing mortality rates are as predicted by Alternatives 1 and 2 in the harvest projections.

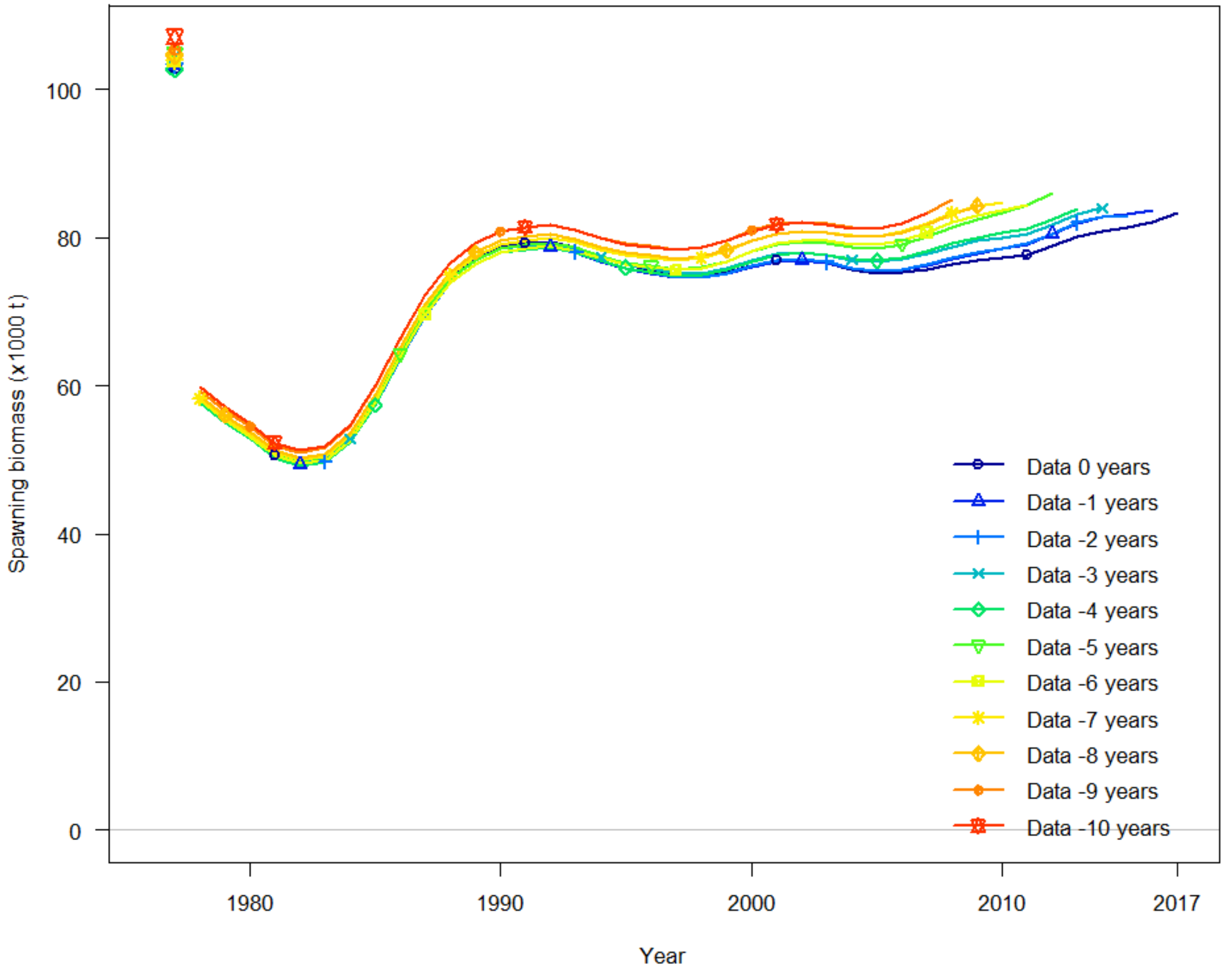


Figure 23. Spawning stock biomass for base case model runs with 0 to 10 years of the most recent data removed. Points at first year are virgin biomass.

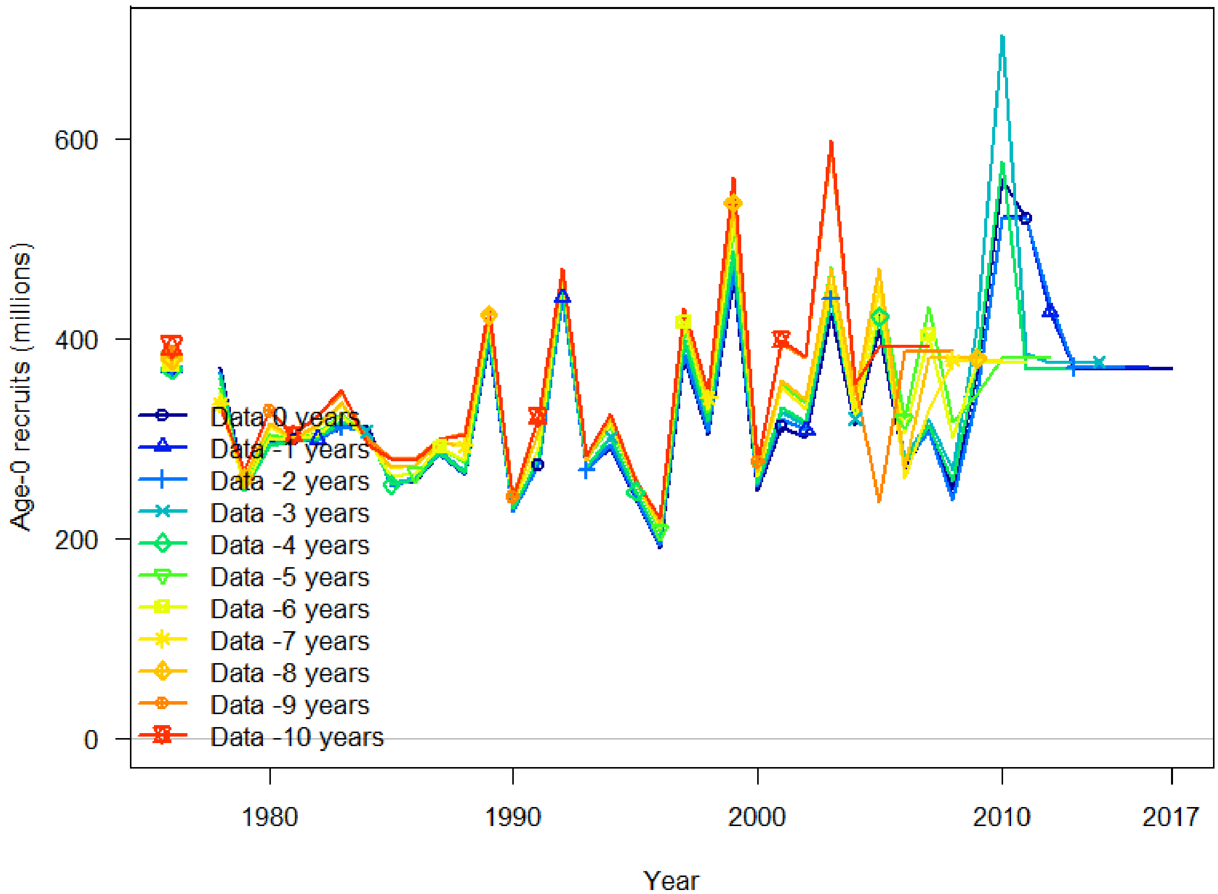


Figure 24. Age-0 recruitment for base case model runs with 0 to 10 years of the most recent data removed. The last three years of recruitments for each run were fixed at the mean.

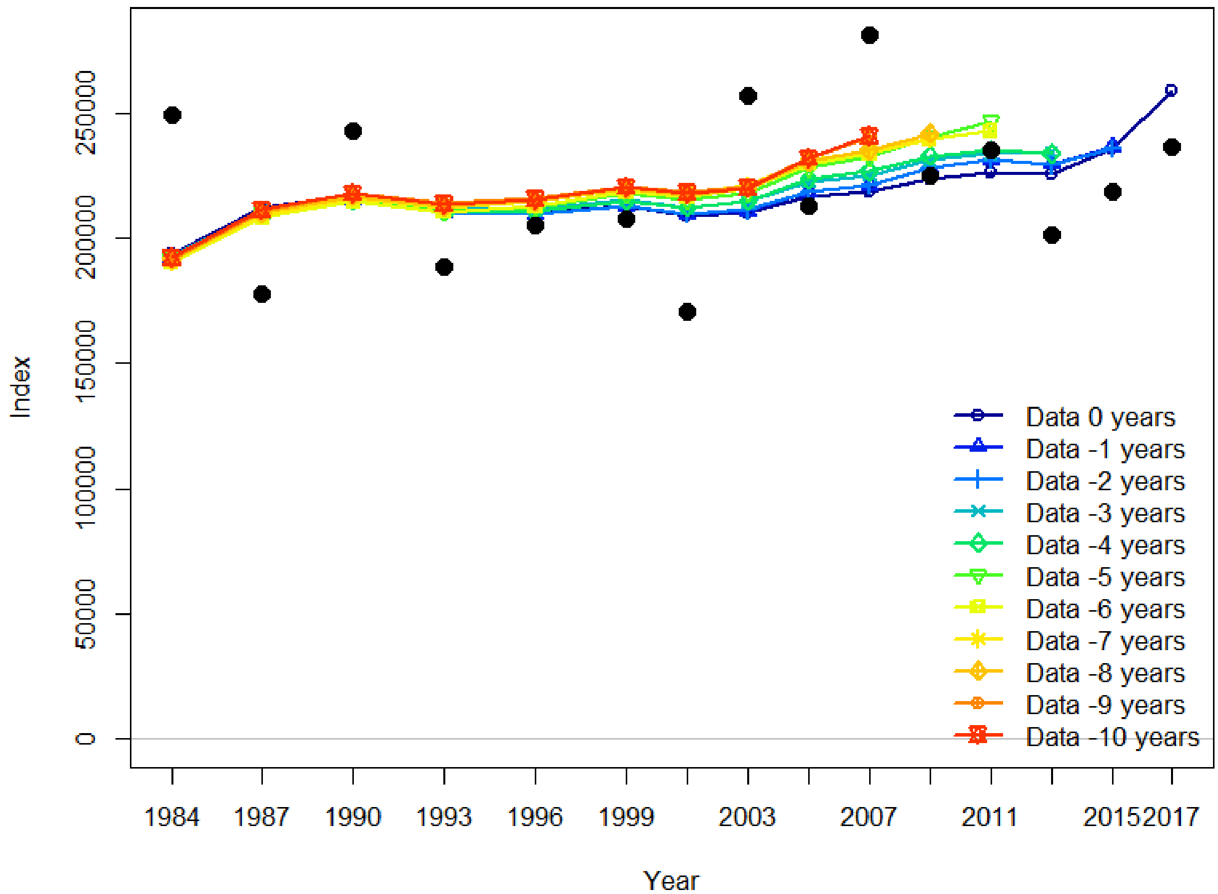


Figure 25. Model fit to survey biomass for the base case model with 0 to 10 years of the most recent data removed. Biomass in years where no survey occurred are not plotted.

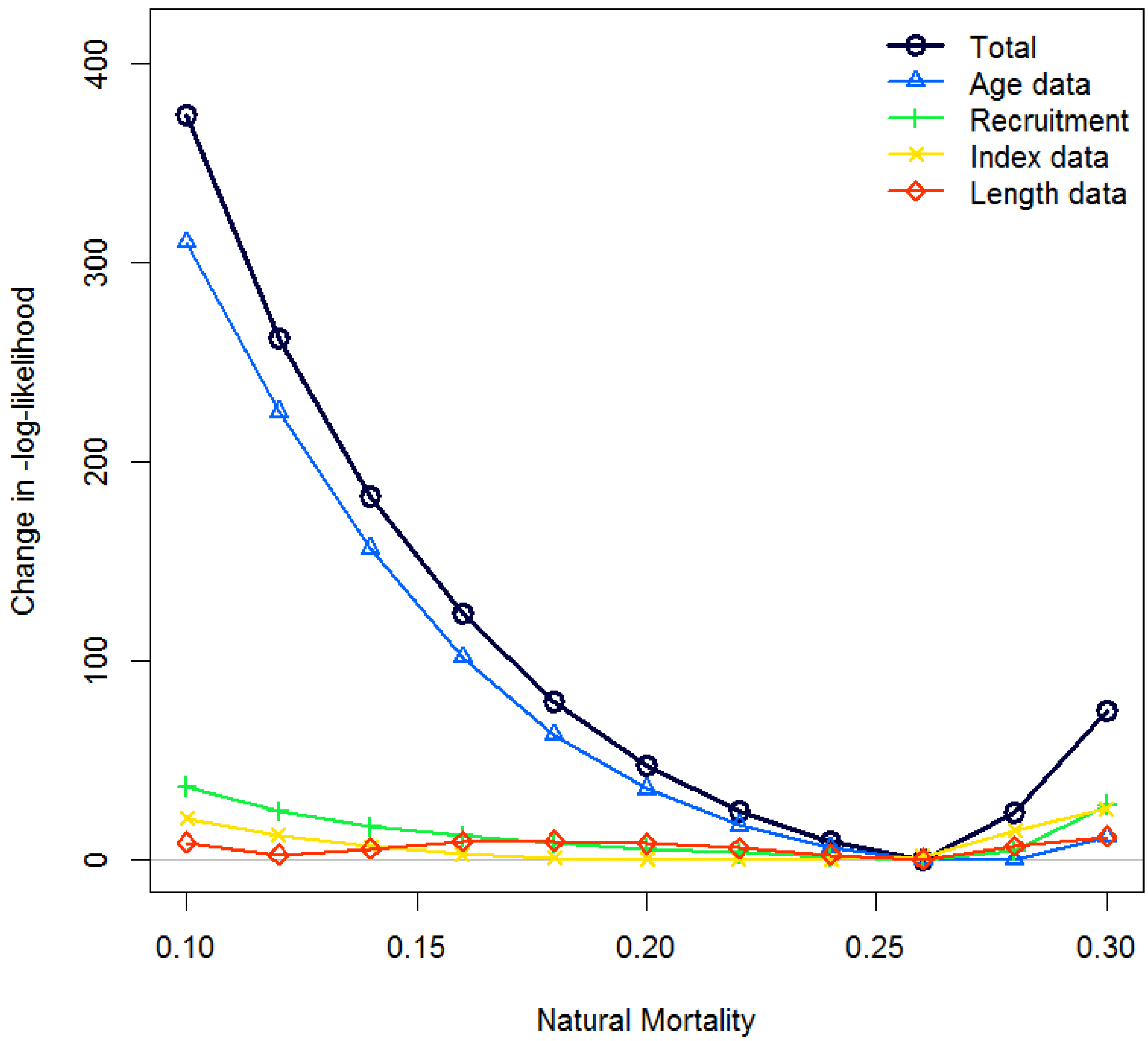


Figure 26. Likelihood profile on Male and Female M 2017 model.

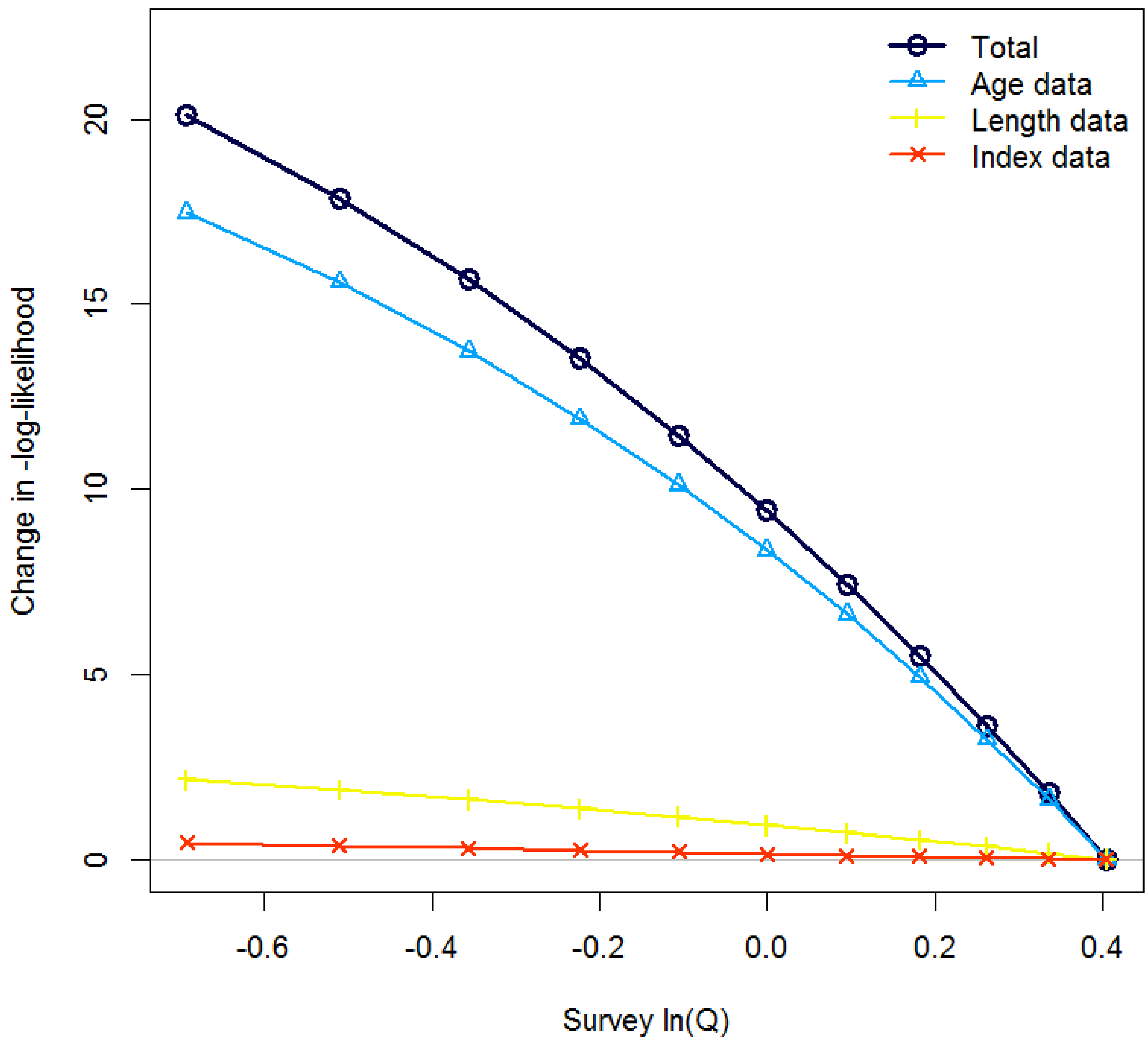


Figure 27. Likelihood profile for ln(Q). Q from 0.5 (ln(Q) = -0.69) to 1.5 (ln(Q) = 0.4).

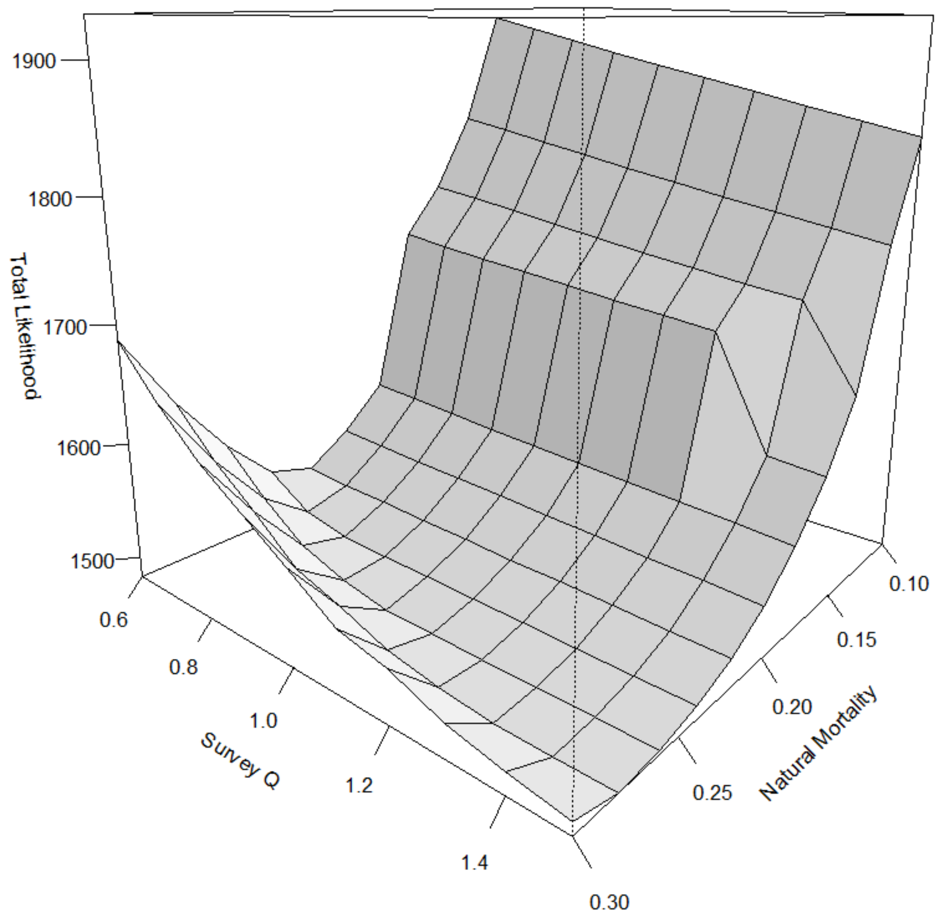


Figure 28. Total Likelihood surface for Natural mortality (0.1 to 0.3) vs Survey Q (0.6 to 1.5).

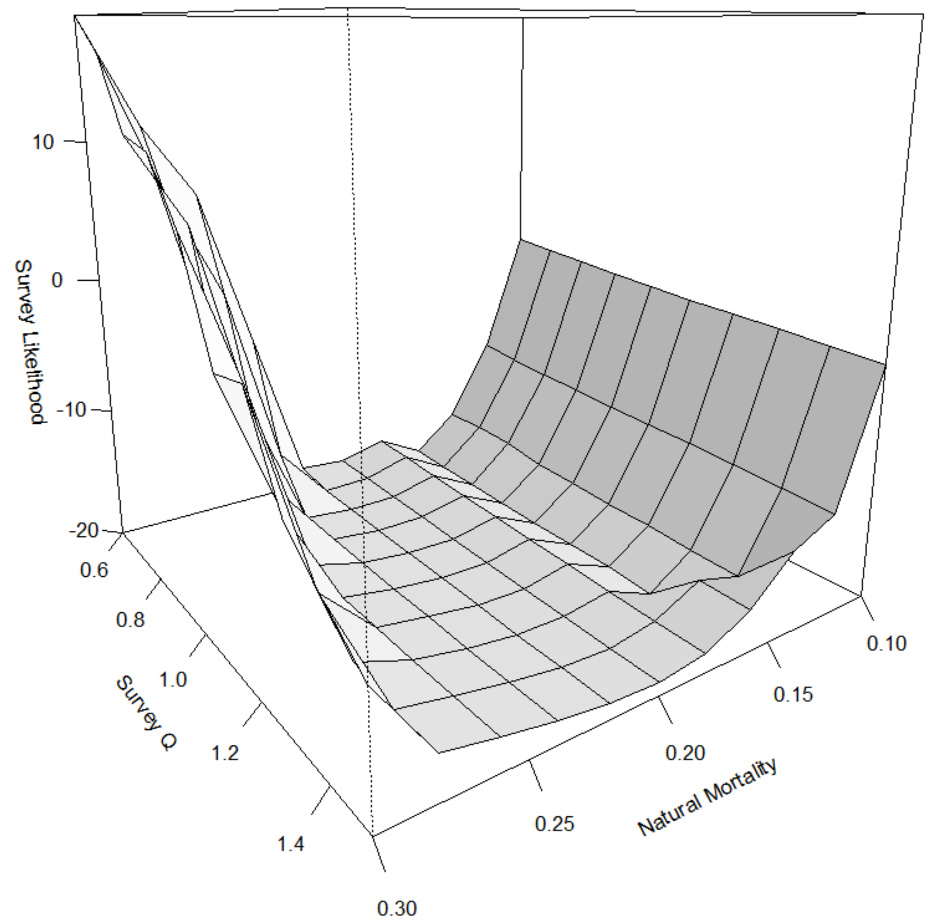


Figure 29. Survey Likelihood surface for Natural mortality (0.1 to 0.3) vs Survey Q (0.6 to 1.5).

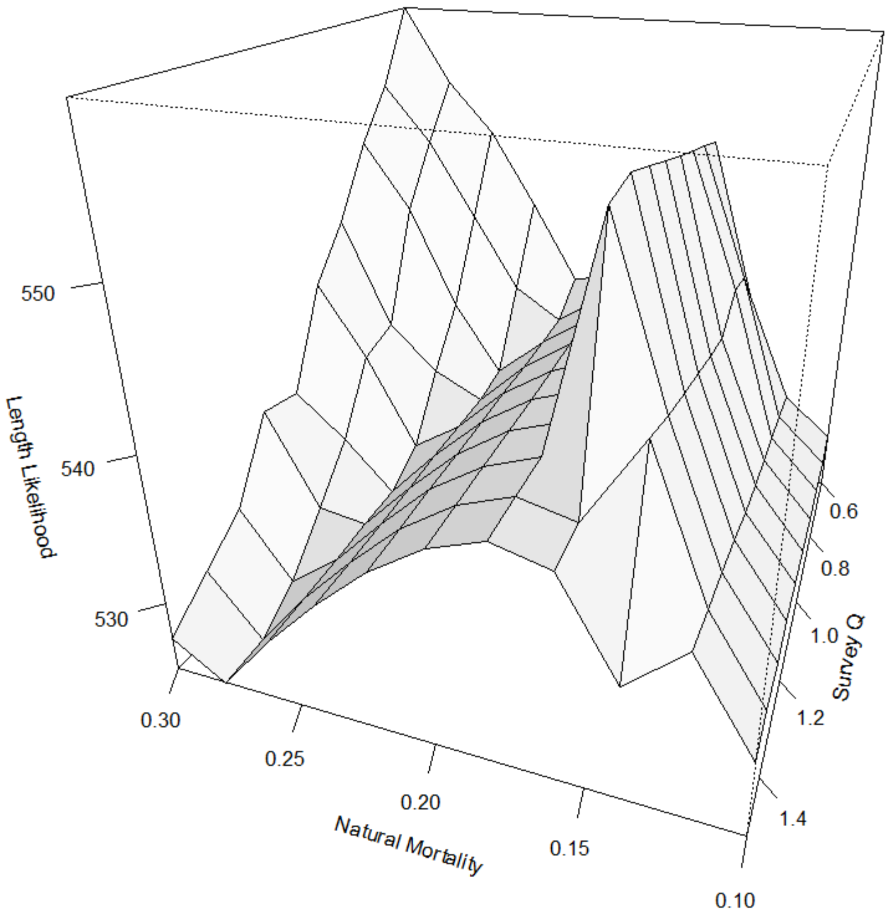


Figure 30. Length Likelihood surface for Natural mortality (0.1 to 0.3) vs Survey Q (0.6 to 1.5).

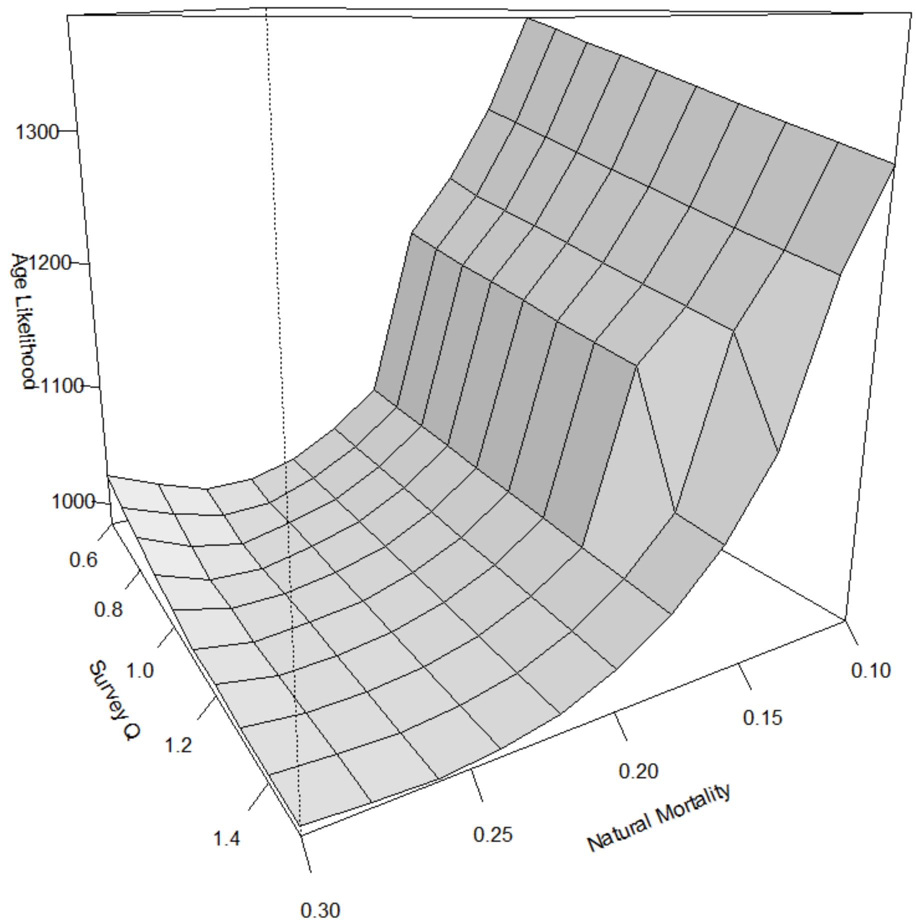


Figure 31. Age Likelihood surface for Natural mortality (0.1 to 0.3) vs Survey Q (0.6 to 1.5).

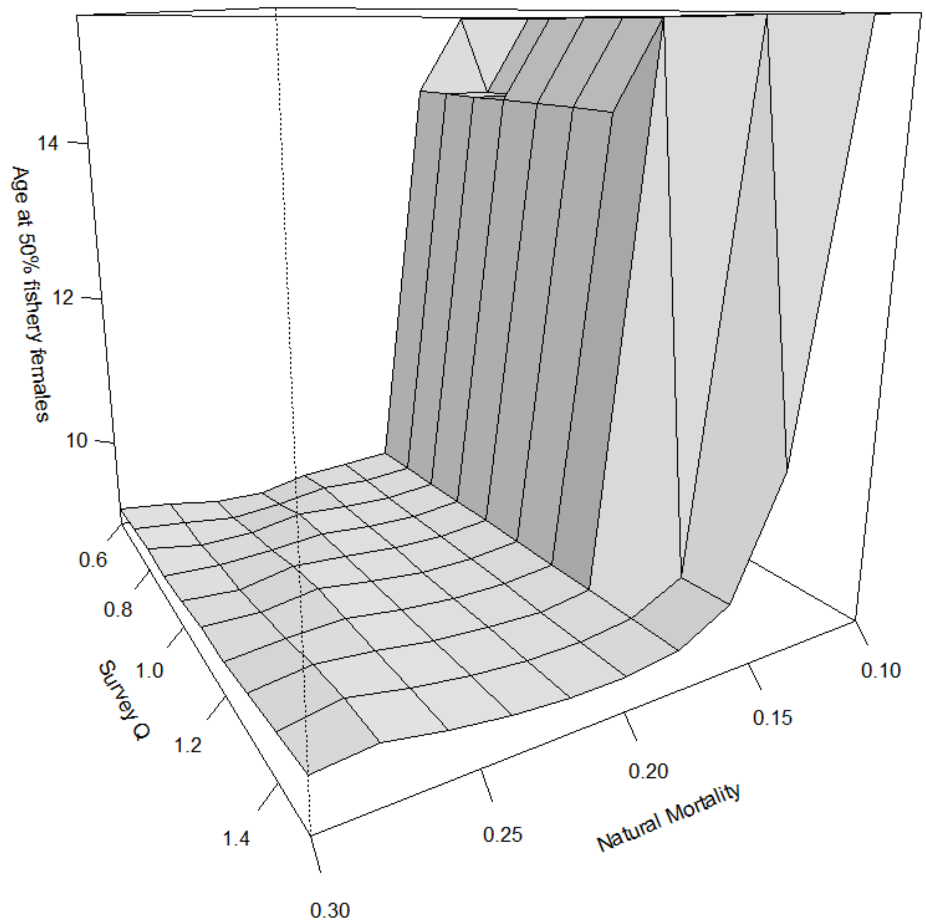


Figure 32. Age at 50% selected for females in the fishery.

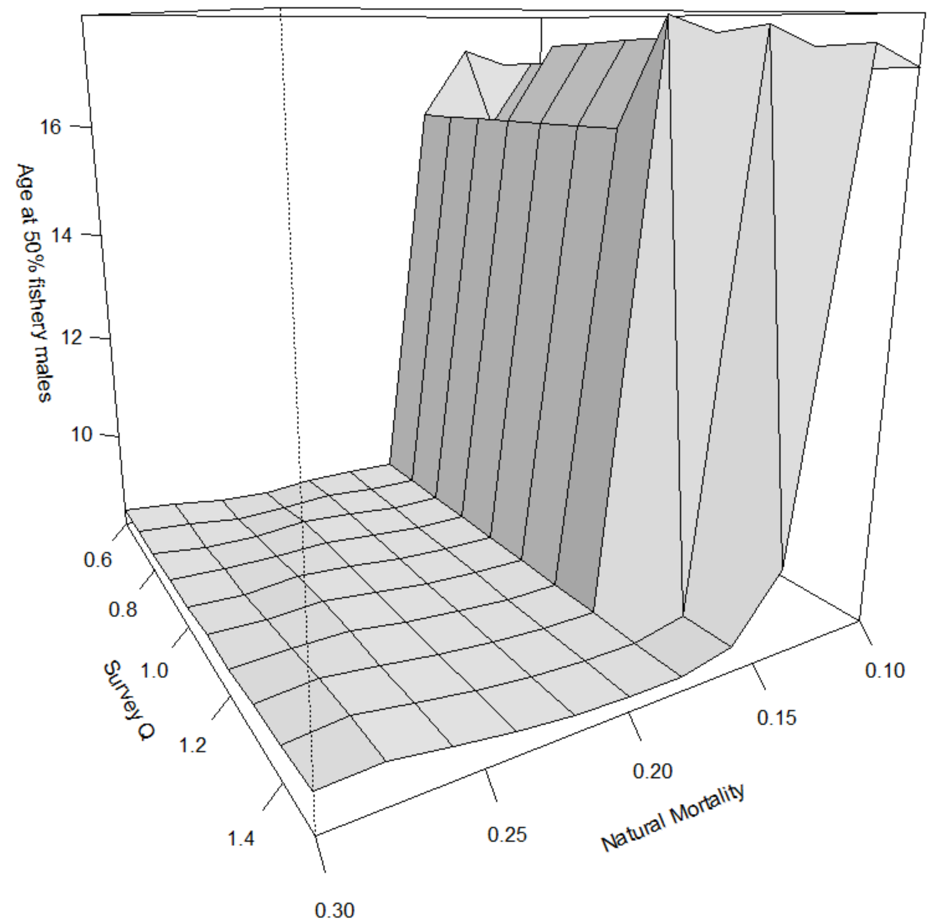


Figure 33. Age at 50% selected for males in the fishery.

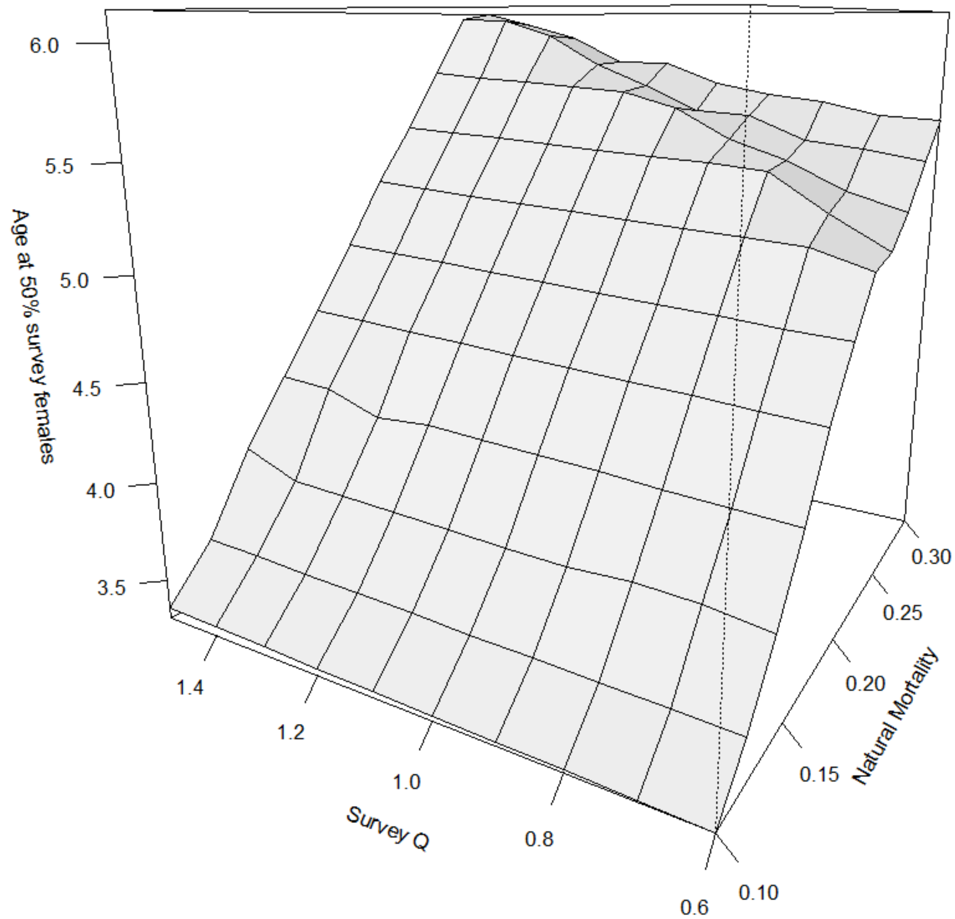


Figure 34. Age at 50% selected for females in the survey.

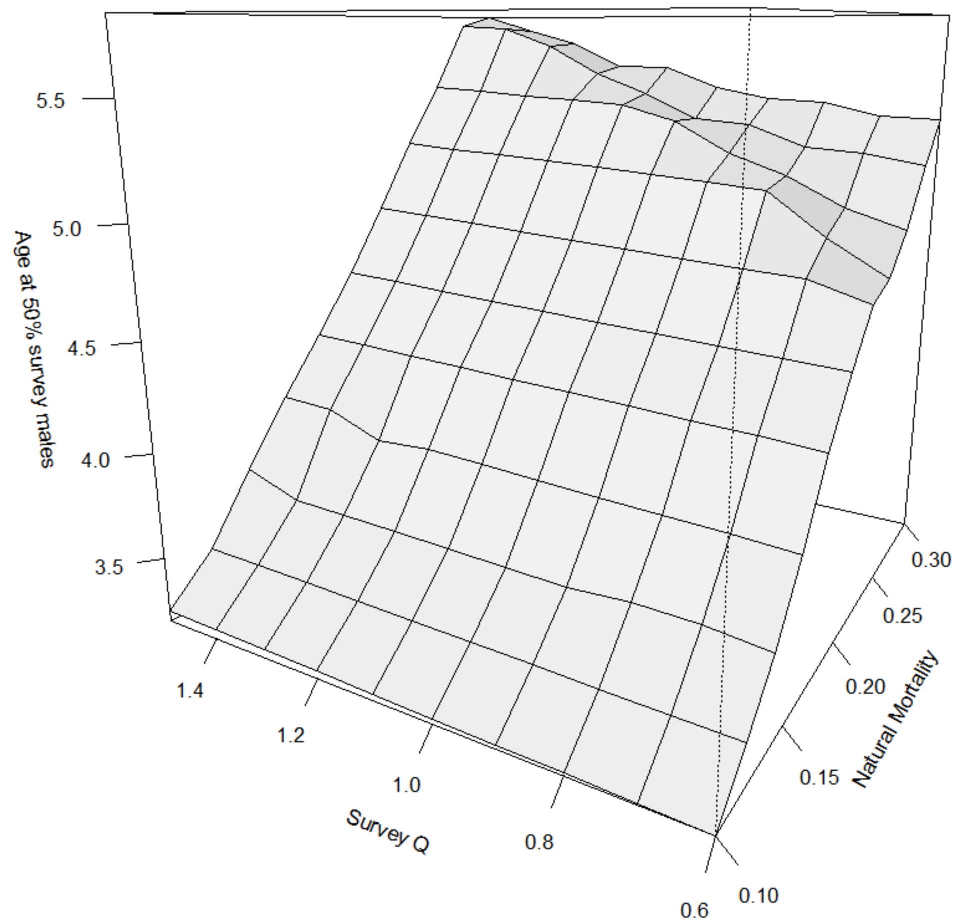


Figure 35. Age at 50% selected for males in the survey.

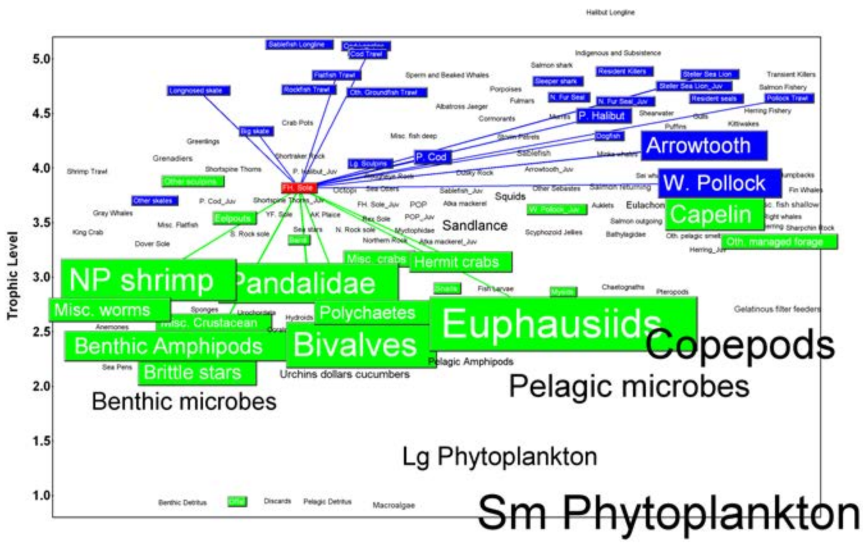


Figure 36. Gulf of Alaska food web from the GOA ecosystem model (Aydin et al., 2007) highlighting adult flathead sole links to predators (blue boxes and lines) and prey (green boxes and lines). Box size reflects relative standing stock biomass.

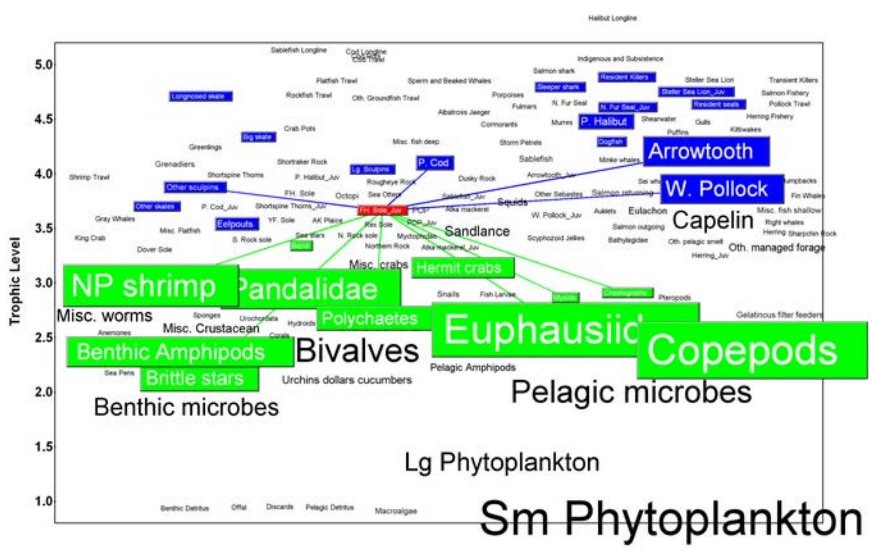


Figure 37. Gulf of Alaska food web from the GOA ecosystem model (Aydin et al., 2007) highlighting juvenile flathead sole links to predators (blue boxes and lines) and prey (green boxes and lines). Box size reflects relative standing stock biomass.

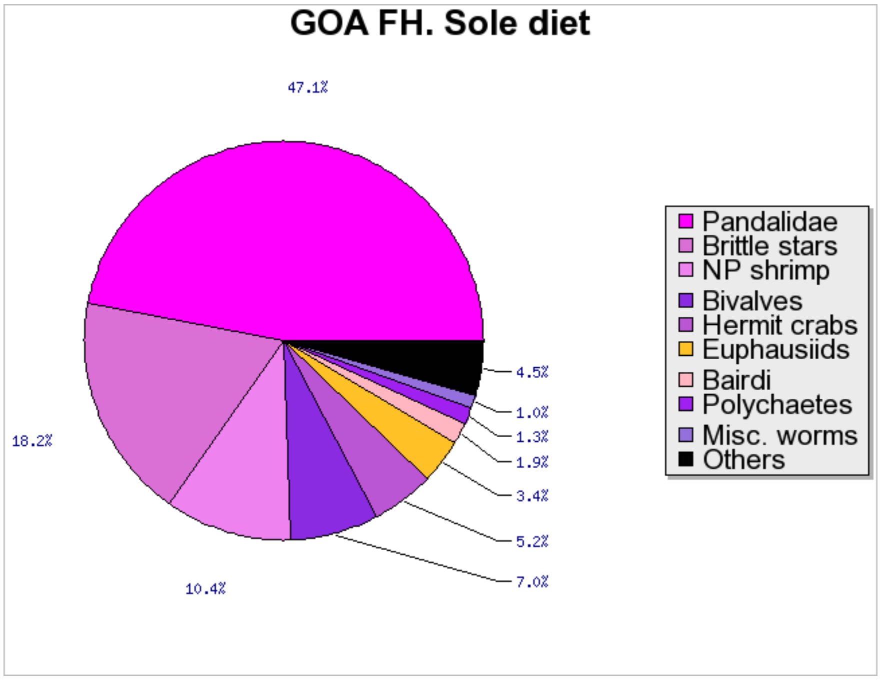


Figure 38. Diet composition for Gulf of Alaska adult flathead sole from the GOA ecosystem model (Aydin et al., 2007).

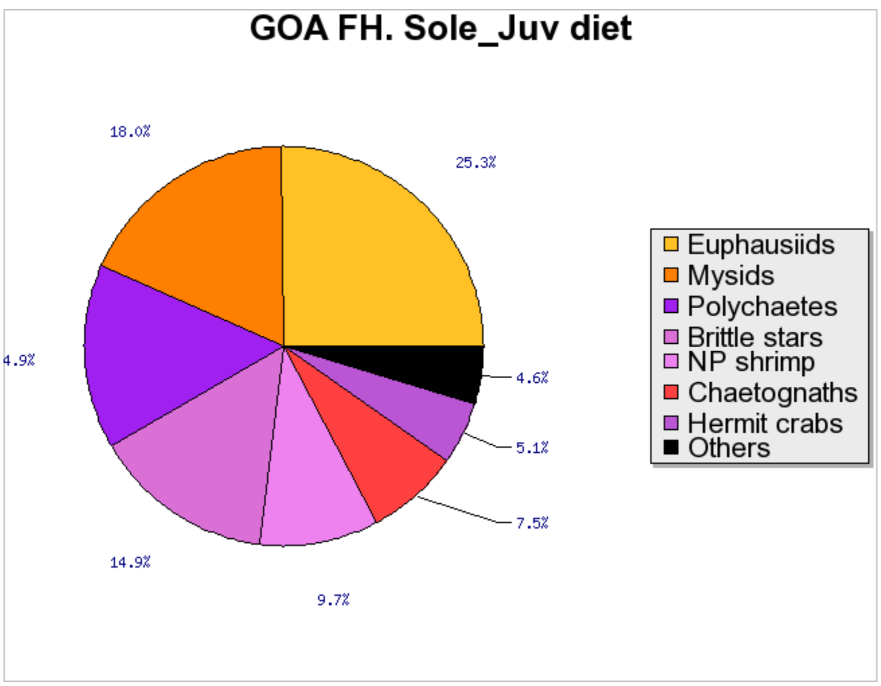


Figure 39. Diet composition for Gulf of Alaska juvenile flathead sole from the GOA ecosystem model (Aydin et al., 2007).

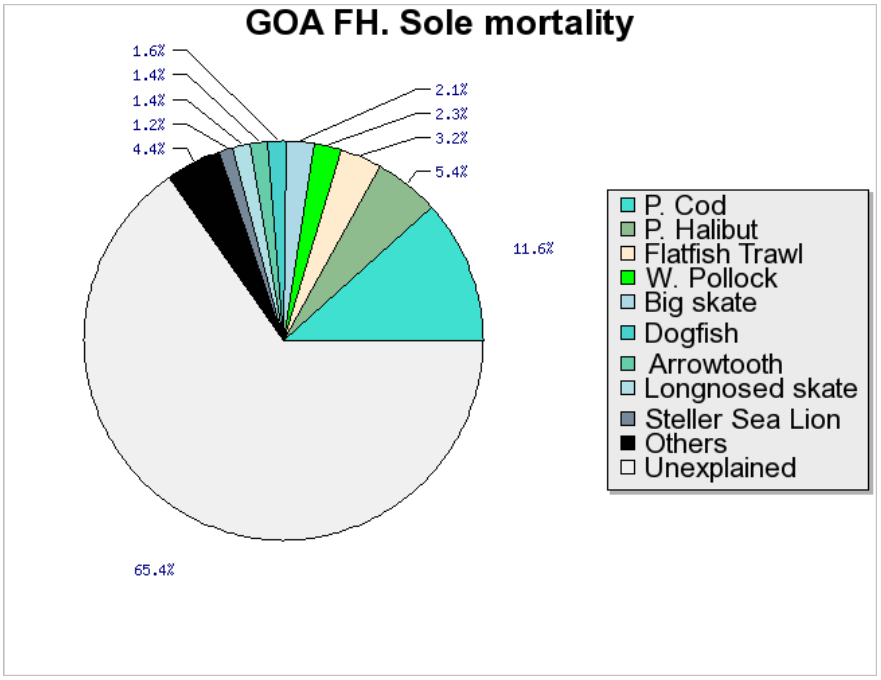


Figure 40. Decomposition of natural mortality for Gulf of Alaska adult flathead sole from the GOA ecosystem model (Aydin et al., 2007).

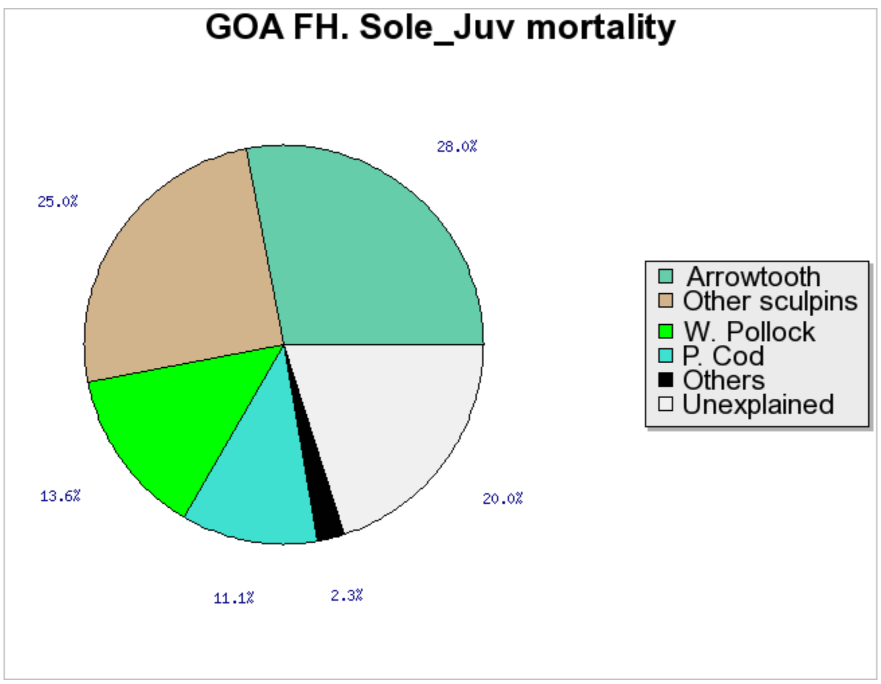


Figure 41. Decomposition of natural mortality for Gulf of Alaska juvenile flathead sole from the GOA ecosystem model (Aydin et al., 2007).

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

Table A4. Flathead sole catch in the NMFS bottom trawl survey in 2011, 2013 and 2015.

Survey Year	Catch (kg)
2011	13,652.9
2013	9,699.2
2015	13,688.6