9. Assessment of the Flathead Sole-Bering flounder Stock in the Bering Sea and Aleutian Islands

By

Carey R. McGilliard[1], Dan Nichol[2], and Wayne Palsson[2]

[1]Resource Ecology and Fisheries Management Division
[2]Resource Assessment and Conservation Engineering Division
Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE, Seattle, WA 98115-6349

Executive Summary

Summary of Changes in Assessment Inputs

(1) 2018 catch biomass through October 6, 2018 and 1964-1976 catch biomass were added to the model
(2) 2017 catch biomass was updated to reflect October – December 2017 catches
(3) Historical catch prior to 1964 was set equal to the average catch from 1964-1977 (11,659 t).
(4) 2015-2017 fishery age composition data were added
(5) 2016-2018 fishery length composition data were added to the model.
(6) 2017-2018 Eastern Bering Sea (EBS) shelf survey biomass and 2018 Aleutian Islands (AI) survey biomass were added to the linear regression used to determine estimates of AI survey biomass in years when no AI survey occurred; a new survey biomass index was added to the assessment model for 1982-2018 based on updated linear regression results.
(7) 2017-2018 survey bottom temperatures were added to Model 16.0; all survey bottom temperatures were removed from new 2018 models
(8) 2016-2017 survey age composition data were added to the model.
(9) 2017-2018 survey length composition data were added to the model
(10) Data for age within each length bin were added to all versions of Models 18.1 and 18.2 to estimate growth. Growth estimates therefore include data from 1985, 1992-1995, and 2000-2017.
(11) Fishery and survey length compositions for lengths less than 6cm were added to the model.
(12) Fishery and survey age compositions for ages 0-2 were added to the model.

Summary of Changes in Assessment Methodology

(1) Models 18.0, 18.0b, 18.1, 18.1b, 18.2, 18.2b, and 18.2c were done using the Stock Synthesis assessment framework (see Appendix B for full details)
(2) The age-length transition matrix was calculated within the assessment model using model estimates of the CV of length-at-age for ages 3 and 21, as well as the parameters of the von-Bertalanffy growth curve
(3) Models 18.1, 18.1b, 18.2, 18.2b, and 18.2c estimated growth within the assessment model based on age data collected within each length bin (a "conditional age-at-length" approach).
(4) Male and female fishery selectivity were estimated as separate curves (as for the most recent accepted model, the fishery selectivity was modeled as length-based and logistic).
(5) Model 18.1b, 18.2b, and 18.2c model separate fishery selectivity curves for the time period 1964-1988.
(6) Model 18.1b and 18.2b model separate fishery selectivity curves for the time period 1989-2007.

(7) Male and female survey selectivity were estimated as separate curves using an age-based double-normal asymptotic curve to provide for additional flexibility in the curve's shape.
(8) Model 18.2 (all versions) use the number of hauls from which length data originated as input sample sizes for survey and fishery length and age compositions.
(9) Age- and length-composition data were weighted using methods described in Francis (2011) to approximate effective sample size for each year and data type for all models 18.0-18.2 variants.
(10) Recruitment deviations were estimated through 2014 for age 0 recruits.
(11) A sum-to-zero constraint was used in the likelihood component for recruitment deviations.
(12) Historical mean recruitment was set equal to non-historical mean recruitment.
(13) The temperature-catchability relationship that was assumed in the 2012, 2014, and 2016 models was removed from the model.

Summary of Results

The key results of the assessment, based on the author's preferred model (Model 18.2c), are compared to the key results of the accepted 2017 update assessment (McGilliard 2017) in the table below.

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2018	2019	2019*	2020*
M (natural mortality rate)	0.2	0.2	0.2	0.2
Tier	3a	3a	3a	3a
Projected total (3+) biomass (t)	762,513	777,961	673,718	686,431
Projected Female spawning biomass (t)	214,124	205,156	153,203	155,032
$B_{100\%}$	322,938	322,938	212,060	212,060
$B_{40\%}$	129,175	129,175	84,824	84,824
$B_{35\%}$	113,028	113,028	74,221	74,221
F_{OFL}	0.41	0.41	0.47	0.47
$maxF_{ABC}$	0.34	0.34	0.38	0.38
F_{ABC}	0.34	0.34	0.38	0.38
OFL (t)	79,862	78,036	80,918	83,190
maxABC (t)	66,773	65,227	66,625	68,448
ABC (t)	66,773	65,227	66,625	68,448
Status	As determined *last* year for:		As determined *this* year for:	
	2016	2017	2017	2018
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 11,305 t used in place of maximum permissible ABC for 2018 and 12,936 t used in place of maximum permissible ABC for 2019 and 2020. The final catch for 2018 was estimated by taking the average tons caught between October 6 and December 31 over the previous 5 years (2013-2017) and adding this average amount to the catch-to-date as of October 6, 2018. The 2019 and 2020 catch was estimated as the average of the total catch in each of the last 5 years (2013-2017).

Responses to SSC and Plan Team Comments on Assessments in General

The SSC recommends that this approach [the risk matrix approach to reducing ABCs from maxABC] be used qualitatively (not from the example percentages presented in Table 2) in December if any reductions to the ABC are recommended (but please drop the emojis).

No reductions in ABC are recommended for this stock and therefore the risk matrix approach was not necessary.

The SSC recommends that candidates for ensemble modeling should be chosen judiciously where stocks appear to have important structural uncertainty. The SSC looks forward to seeing test cases brought forward for 2018, possibly Pacific cod and/or rock sole.

All of the candidate models attempted for this assessment (with and without fishery selectivity time blocks, estimating natural mortality for males and females, alternative formulations of selectivity curves, estimation of historical mean recruitment, alternative data weighting approaches, internal vs. external estimation of growth, including vs. excluding a relationship between temperature and catchability) showed very similar results and high correlation among models. Therefore, the author decided that an ensemble modeling approach would not be useful at this time.

Responses to SSC and Plan Team Comments on Assessments specific to This Assessment

GOA Plan Team comment 11/2016: The Team recommends examining the use of time blocks in selectivity due to changes in fishing practices.

Author Response: CRM completed a transition of the model to the SS3 framework and SS3 models (Models 18.xb: 18.0b, 18.1b, and 18.2b) were run using time blocks for fishery selectivity from 1964 (the model start year) to 1988, 1989-2007 (when the structure of our current halibut bycatch regulations were implemented), and 2008-present, when the BSAI groundfish trawl fishery was rationalized. Model 18.2c was run using two time blocks for fishery selectivity: 1964-1988, and 1989 to present.

Introduction

"Flathead sole" as currently managed by the North Pacific Fishery Management Council (NPFMC) in the Bering Sea and Aleutian Islands (BSAI) represents a two-species complex consisting of true flathead sole (*Hippoglossoides elassodon*) and its morphologically-similar congener Bering flounder (*H. robustus*). "Flathead sole" was formerly a constituent of the "other flatfish" SAFE chapter. Based on changes in the directed fishing standards to allow increased retention of flatfish, in June 1994 the Council requested the BSAI Plan Team to assign a separate Acceptable Biological Catch (ABC) and Overfishing Limit (OFL) to "flathead sole" in the BSAI, rather than combining them into the "other flatfish" recommendations as in previous assessments. Subsequent to this request, stock assessments for "flathead sole" have been generated annually to provide updated recommendations for ABC and OFL.

Flathead sole are distributed from northern California off Point Reyes northward along the west coast of North America and throughout Alaska (Hart 1973). In the northern part of its range, this species overlaps with its congener, Bering flounder, whose range extends north to the Chukchi Sea and into the western Bering Sea. Bering flounder typically represent less than 3% of the combined biomass of the two species in annual groundfish surveys conducted by the Alaska Fisheries Science Center (AFSC) in the eastern Bering Sea (EBS). The two species are very similar morphologically, but differ in demographic characteristics and spatial distribution. Differences between the two species in the EBS have been described by Walters and Wilderbuer (1997) and Stark (2011). Bering flounder exhibit slower growth and acquire energy more slowly when compared with flathead sole. Individual fish of the same size and sex can be 10 years different in age for the two species, while fish of the same age can differ by almost 10 cm in size. These differences are most pronounced for intermediate-aged fish (5-25 years old) because asymptotic sizes, by sex, are similar for the two species. Thus, whereas age at 50% maturity is similar for both species (8.7 years for Bering flounder, 9.7 years for flathead sole), size at 50% maturity is substantially smaller for Bering flounder than for flathead sole (23.8 cm vs. 32.0 cm, respectively; Stark, 2004 and Stark, 2011). Stark (2011) hypothesized that the difference in growth rates between the two species might be linked to temperature, because Bering flounder generally occupy colder water than flathead sole and growth rates are typically positively correlated with temperature.

Walters and Wilderbuer (1997) illustrated the possible ramifications of combining demographic information from the two species. Although Bering flounder typically represent less than 3% of the combined survey biomass for the two species, lumping the two species increases the uncertainties associated with estimates of life-history and population parameters. Accurate identification of the two species occurs in the annual EBS trawl survey. The fisheries observer program also provides information on Bering flounder in haul and port sampling for fishery catch composition. Biological, fishery, and survey information for Bering flounder was discussed in Appendix C in Stockhausen et al., 2010.

For the purposes of this report, Bering flounder and flathead sole are combined under the heading "*Hippoglossoides* spp." and, where necessary, flathead sole (*H. elassodon*) is used as an indicator species for the complex. Where the fishery is discussed, the term "flathead sole" will generally refer to the two-species complex rather than to the individual species.

Fishery

Catches of flathead sole (*Hippoglossoides* spp.) were reported by foreign fleets beginning in 1964 and were the sole source of the catch time series until 1977, when observers began collecting biological information on some vessels. Bering flounder began to be identified by observers as a separate species in 1978 (however note that geneticists have not concluded that Bering flounder and flathead sole are truly separate species, pers. comm. Spies). Foreign reported catches prior to 1977 fluctuated and were as low as 3,449 t in 1965 and as high as 26,108 t in 1971. Catches during the period of joint venture fisheries from 1978-87 averaged 7,195 t and generally decreased from 1981-1987. From 1988-2007, when the flatfish fishery was a domestic fishery and the BSAI had not yet been rationalized, annual catches averaged 16,179 t (Table 9.2, Figure 9.1). The catch in 2008 (24,539 t) was the highest since 1998. The average catch from 2008-2017 (15,383 t), after the implementation of Amendment 80, was substantially smaller than that from the 1988-2007 period. The catch in 2017 was 9,149 t and the catch-to-date in 2018 (as of October 6, 2018) was 10,320 t. On average, only .5% of the catch in each year was identified as Bering flounder. A maximum in the proportion of the catch that was found to be Bering flounder was 6% occurring in 1980 (Table 9.1).

The majority of the catch was taken by non-pelagic trawl gear (77% on average from 1992-2018) and pelagic trawl gear (20% on average from 1992-2018; Table 9.3). In addition, almost all of the catch was taken from NMFS statistical areas 509, 513, 517, and 521 in each year; 12%, 45%, 14%, and 14% of the catch was taken in each of these four reporting areas, respectively, in 2018 (as of October 23, 2018; Table 9.4).

Although the flathead sole and Bering flounder complex receive a separate ABC and TAC from other flatfish species, until 2008 it was managed in the same Prohibited Species Catch (PSC) classification as rock sole and "other flatfish" and it received the same apportionments and seasonal allowances of incidental catch of prohibited species as these other stocks. In July, 2007, however, the NPFMC adopted Amendment 80 to the BSAI Fishery Management Plan (FMP). The purpose of this amendment was, among other things, to: 1) improve retention and utilization of fishery resources by the non-American Fisheries Act (non-AFA) trawl catcher/processor fleet by extending the AFA's Groundfish Retention

Standards to all vessels and 2) establish a limited access privilege program for the non-AFA trawl catcher/processors and authorize the allocation of groundfish species to cooperatives to encourage lower discard rates and increased value of harvested fish while lowering costs. In addition, Amendment 80 also mandated additional monitoring requirements which include observer coverage on all hauls, motion-compensating scales for weighing samples, flow scales to obtain accurate catch weight estimates for the entire catch, no mixing of hauls and no on-deck sorting. Amendment 80 applies to catcher/processors and creates three designations for flatfish trawlers: Amendment 80 cooperatives, Amendment 80 limited access, and BSAI limited access (i.e., all others not covered by Amendment 80). Under Amendment 80, allocations of target species and PSC are based on individual fishing history. Vessels may form cooperatives, with each cooperative being assigned cooperative-level allocations of target species and PSC. Catcher/processors that do not participate in a cooperative fall under the Amendment 80 limited access designation. Target species and PSC allocations are made to the limited access sub-sector, not to individual vessels within it. Thus, vessels within the Amendment 80 limited access sub-sector function as in a traditional TAC-based fishery (i.e., they compete amongst each other for limited harvests). Additionally, PSC in the Amendment 80 limited access sector is managed in the same manner as it was managed prior to 2008: the Amendment 80 limited access flathead sole fishery is managed in the same PSC classification as Amendment 80 limited access fisheries for rock sole and “other flatfish” and it receives the same apportionments and seasonal allocation as these fisheries. Once TAC and PSC have been allocated to the two Amendment 80 sectors, any remaining allocations of target species and PSC are made to the (non-Amendment 80) BSAI limited access sector.

Prior to the implementation of Amendment 80 in 2008, the flathead sole directed fishery was often suspended or closed seasonally prior to attainment of the TAC for exceeding halibut bycatch limits after the opening of the fishery on January 20th of each year; no such closures have occurred since 2007 (Table 9.5).

Substantial amounts of flathead sole have been discarded in various eastern Bering Sea target fisheries, although retention standards have improved since the implementation of Amendment 80 in 2008 (Table 9.6). Based on data from the NMFS Regional Office Catch Accounting System, about 30% of the *Hippoglossoides spp.* catch was discarded prior to 2008. Subsequent to Amendment 80 implementation, at least 85% of *Hippoglossoides* species caught have been retained in each year since 2008 (Table 9.6).

Data

The following data were used in the assessment:

Source	Data	Species Included	Years
NMFS Aleutian Islands Groundfish Trawl Survey	Survey biomass (linear regression used to combine BS shelf survey estimates with AI survey estimates for a single survey biomass index)	Flathead only; no Bering flounder were caught in the Aleutian Islands	1980, 1983, 1986, 1991-2000 (triennial), 2002-2006 (biennial), 2010-2018 (biennial)
NMFS Bering Sea Shelf Groundfish Survey (standard survey area only[1])	Survey biomass (linear regression used to combine BS shelf survey estimates with AI survey estimates for a single survey biomass index)	Flathead sole and Bering flounder combined	1982-2018
	Age Composition	Flathead sole only	1982, 1985, 1992-1995, 2000-2017
	Length Composition	Flathead sole only	1983, 1984, 1986-1991, 1996-1999, 2018
U.S. trawl fisheries	Catch (Bering Sea and Aleutian Islands; pelagic and non-pelagic trawl[2])	Flathead sole and Bering flounder combined	1977-2018
	Age Composition (Bering Sea only; non-pelagic trawl only)	Flathead sole only	1994, 1995, 1998, 2000, 2001, 2004-2007, 2009-2017
	Length Composition (Bering Sea only; non-pelagic trawl only)	Flathead sole only	1977-1993, 1994, 1996-1997, 1999, 2002-2003, 2008, 2018
Foreign trawl fisheries in the BSAI	Catch (Bering Sea and Aleutian Islands; trawl)	Flathead sole and Bering Flounder combined	1964-1987

1. Excludes survey strata 70, 81, 82, 90, 140, 150, and 160
2. A very small amount of catch is taken with hook and line and is included in the total catch biomass

Fishery:

This assessment used fishery catches for flathead sole and Bering flounder combined (*Hippoglossoides spp.*) from 1964 through October 6, 2018 (Table 9.1, Figure 9.1). Fishery age and length composition data were used for flathead sole caught in the Bering Sea by non-pelagic trawl (and excluding Bering flounder catches, pelagic trawl catches, and Aleutian Islands catches). Fishery age compositions for 2000, 2001, 2004-2007 and 2009-2017 were included in the assessment model (Figure 9.2 and Table 9.7; http://www.afsc.noaa.gov/REFM/docs/2016/BSAIflathead_Age_and_Length_Composition.xlsx). The number of hauls from which age compositions originate were small for years 1994, 1995, and 1998 (Table 9.7 and Table 9.8) and they were excluded from the assessment model. Size compositions were available for 1977-2018 (Table 9.7 and Figure 9.2, http://www.afsc.noaa.gov/REFM/docs/2016/BSAIflathead_Age_and_Length_Composition.xlsx). To avoid double-counting data used to estimate parameters in the assessment model, the size composition data were excluded in the model optimization when the age composition data from the same year were included. Thus, only the flathead sole fishery size compositions for 1977-1999, 2002-2003, 2008 and 2018 were included in the assessment model.

Survey:

Groundfish surveys are conducted annually by the Resource Assessment and Conservation Engineering (RACE) Division of the AFSC on the continental shelf in the EBS using bottom trawl gear. These surveys are conducted using a fixed grid of stations and have used the same standardized research trawl gear since 1982. The "standard" survey area has been sampled annually since 1982, while the "northwest extension" has been sampled since 1987 (Figure 9.3). In 2010, 2017, and 2018, RACE extended the groundfish survey into the northern Bering Sea (Figure 9.3) and conducted standardized bottom trawls at 142 new stations. The data generated by this survey extension are discussed further in the Ecosystem Considerations section of this assessment and may have important implications for the future management of Bering flounder (Stockhausen et al. 2012), but was not included in the current stock assessment models. Unfortunately, only the standard and northwest extension areas were sampled in 2011-2016. RACE also conducts bottom trawl surveys in the Aleutian Islands (AI) on a triennial basis from 1980 to 2000 and on a biennial basis since 2002 (although no survey was conducted in 2008). Bering flounder are caught in small amounts on the EBS shelf (0-6% of *Hippoglossoides spp.* survey biomass; Table 9.9), but have not been recorded in any year of the AI survey.

Survey-based estimates of total biomass use an “area-swept” approach and implicitly assume a catchability of 1. Following Spencer et al. (2004), EBS surveys conducted prior to 1982 were not included in the assessment because the survey gear changed after 1981. To maintain consistent spatial coverage across time, only survey strata that have been consistently sampled since 1982 (i.e., those comprising the "standard" area) are included in the EBS biomass estimates.

This assessment used a single survey index of "total" *Hippoglossoides spp.* biomass that included the EBS “standard” survey areas and AI survey areas for the years 1982-2018 (Table 9.9). Figure 9.4 shows that survey biomass for Hippoglossoides spp in the Aleutian Islands is very small as compared to that from the EBS shelf survey. Figure 9.4 also shows that survey biomass for Bering flounder is very small as compared to that of flathead sole. A linear regression is used to estimate a relationship between EBS shelf *Hippoglossoides spp.* survey biomass estimates and AI survey biomass estimates; this relationship is used to estimate AI survey biomass in years when no AI survey occurred (by using the linear equation to find an AI biomass estimate in a particular year based on the EBS biomass estimate for that year). Based on these surveys, *Hippoglossoides* spp. biomass approximately quadrupled from the early 1980s to a maximum in 1997 (795,463 t). Estimated biomass then declined to 401,723 t in 2000 before increasing to a recent high of 644,948 t in 2006. The 2018 estimate was 495,345 t.

Although survey-based estimates of total biomass assume a catchability (and size-independent selectivity) of 1, previous assessments for flathead sole and other BSAI flatfish have identified a relationship between bottom temperature and survey catchability (e.g., Wilderbuer et al. 2002; Spencer et al., 2004; Stockhausen et al., 2011). A plot of mean bottom temperatures from the EBS shelf survey and the *Hippoglossoides spp* survey biomass index are shown in Figure 9.5. Bottom temperatures are hypothesized to affect survey catchability by affecting the stock distribution and/or the activity level of flatfish. The spatial distribution of flathead sole has been shown to shift location in conjunction with shifts in the location of the cold pool on the EBS shelf. This relationship was investigated in previous assessments for flathead sole (Spencer et al., 2004) by using annual temperature anomalies from data collected at all survey stations as a covariate of survey catchability. Model results from that assessment indicated the utility of this approach and was used in several subsequent assessments (e.g., Stockhausen et al., 2012, McGilliard et al. 2014, and McGilliard et al. 2016). However, in the 2014 and 2016 assessments and in preliminary 2018 model runs the model estimated close to no relationship between temperature and catchability and this relationship was removed from this year's assessment. Figure 9.5 shows that the trend in mean bottom temperature has been different from the trend in the survey biomass index since 2015. It is possible that a relationship exists between the cold pool, other factors, and flathead sole distribution, but that average summer bottom temperature is too coarse a variable to represent the environmental drivers of flathead distribution and catchability. Notably, 2018 was the first year in history of the EBS shelf survey that no temperatures below 2 deg C were observed (no cold pool was observed; the cold pool is defined by the summer EBS trawl survey as a pool of water with temperatures below 2 deg C).

Sex-specific survey age, conditional age-at-length and size composition data for flathead sole only from the EBS shelf survey only ("standard" survey areas) were included in the assessment (http://www.afsc.noaa.gov/REFM/docs/2016/BSAIflathead_Age_and_Length_Composition.xlsx). Survey ages for 1982, 1985, 1992-1995, and 2000-2017 were used. Survey size composition data were available for 1982-2018, but were excluded from the model optimization in years when survey age composition data were available for the same year. Thus, only the survey size compositions for 1984-91, 1996-99, and 2018 were included in the model optimization, using 2 cm size bins, from 6cm to 58cm. Figure 9.6-Figure 9.7 show length-at-age data for flathead sole by sex, cohort, and year from the EBS shelf survey.

Analytical approach

General Model Structure

Age-structured model used in 2016

The assessment for flathead sole was conducted using a split-sex, age-based model with length-based formulations for fishery and survey selectivity. The model structure (see Appendix C for details) was developed following Fournier and Archibald's (1982) methods for separable catch-at-age analysis, with many similarities to Methot (1990). The assessment model simulates the dynamics of the stock and compares expected values of stock characteristics with observed values from survey and fishery sampling programs in a Bayesian framework, based on distributional assumptions regarding the observed data and uniform prior distributions for estimated parameters. Model parameters are estimated by minimizing an associated objective function that describes the error structure between model estimates and observed quantities.

Age classes included in the model were ages 3 to 21. The oldest age class in the model (21 years) served as a plus group; the maximum age of flathead sole in the BSAI, based on otolith age determinations, is 32 years. Survey catchability was fixed at 1.0, but deviated from this value over time as a function of average summer bottom temperature as measured by the EBS shelf survey. Survey and fishery selectivity were logistic, length-based, and not sex-specific. The model estimated historical mean recruitment, mean recruitment over the period for which data were available, and historical fishing mortality. Details of the population dynamics and estimation equations, description of variables and likelihood components are presented in Appendix C of this chapter.

A detailed description of the transition of the previous model to Stock Synthesis (SS3; Methot and Wetzel 2013) and potential benefits of transitioning the assessment to SS3 were presented at the 2018 September Plan Team Meeting and the September SAFE chapter is included in this document as Appendix B. The 2018 results, including an Executive Summary table listing 2018 reference points based on the age-structured model used in 2016 are shown in Appendix B of this document.

Stock Synthesis Framework used in 2018

New models for 2018 were conducted using the SS3 and r4ss frameworks (Method and Wetzel 2013, Taylor et al. 2018, R Core Team 2018); the SS3 framework is coded in AD Model Builder (Fournier et al. 2012). Several updates were made to the best-matching Stock Synthesis version of the 2016 model for the 2018 models. Foreign reported catches were added to the data from 1964-1987 and historical catch (prior to 1964) was set to the average of the catches from 1964-1977. The most recent CIE review feedback listed the initial conditions of the 2016 model as uncertain and in need of investigation. The 2016 model estimated historical recruitment to be 58 million recruits, and main period mean recruitment to be 835 million recruits. Given the data on foreign reported catches that was not considered in the 2016 assessment (and even without that data), it is hard to believe that mean recruitment in the historical period may have been that low. The 2018 models no longer include a separate, historical mean recruitment parameter. Instead, an early period of recruitment deviations for age-0 recruits was estimated for the years 1963-1972 and a main period of age 0 recruitment deviations was estimated for the years 1973-2014, each subject to a sum-to-zero constraint. Recruitment in 2015-2018 was fixed to the mean recruitment for the main period because too few age 0-4 individuals were observed to estimate these recruitment deviations reliably.

Survey selectivity was changed to be age-based and sex-specific, using a double-normal, asymptotic selectivity curve. Appendix B demonstrated that a length- or age-based selectivity curve could be used to represent survey selectivity and the double-normal curve allows greater flexibility in the shape of selectivity because it does not require that the curve be symmetric. Fishery selectivity was changed to be sex-specific because previous assessments showed a persistent pattern in residuals for males. The fishery selectivity curves were estimated using logistic, length-based curves (as for the 2016 model). A data weighting approach developed by Francis (2011) was used as a way to account for the effects on effective sample size of potential time-varying processes that were not explicitly taken into account in the model structure.

The 2018 models estimated the parameters of the von-Bertalanffy growth curve and the CVs in length-at-age defining the age-length transition matrix within the model using data on age within each length bin (a conditional age-at-length approach). Estimating growth within the model using this approach allows for uncertainty in growth estimates to propagate through the model and allows for the effects of selectivity on the length and age samples to be taken into account.

In addition, the 2018 models used the number of hauls from which samples were taken as the input sample size for each year of length and age composition data (rather than setting the input sample size to 200 for each year). Several studies have found that more information on a fish population can be obtained by conducting many small hauls rather than fewer large hauls because fish with similar characteristics (for example, fish of similar ages) tend to be found together within a haul. Therefore, the number of hauls is likely a better indicator of effective sample size each year than assuming equal sample sizes across all years when the number of hauls sometimes varied greatly among years (Pennington and Volstad 1994).

The author's preferred model (Model 18.2c) estimated separate fishery selectivity curves for the period 1964-1987 when management of the BSAI flatfish fishery shifted significantly. Additional model runs are described below.

Description of Alternative Models

Two models were presented at the September 2018 Plan Team Meeting (Appendix B) as candidates for the 2018 assessment model: Model 18.0 and 18.0b, both of which estimated growth outside of the assessment model and used equal input sample sizes of 200 for the length and age composition data each year. Model 18.0 estimated time-invariant (sex-specific) fishery selectivity curves and Model 18.0b estimated separate fishery selectivity curves for the periods 1964-1987, 1988-2007, and 2008-present, which corresponded to three separate eras in the management policies of the BSAI flatfish fishery.

Two improvements were made to both Models 18.0 and 18.0b. First, a conditional age-at-length approach was used to estimate growth and variability in growth within the assessment model. The conditional age-at-length approach was used in Models 18.1 and 18.1b, which are identical to 18.0 and 18.0b, except for the estimation of growth. Second, the input sample sizes for length- and age-composition data were changed to be the number of hauls from which length- or age- samples (respectively) were drawn in each year. Both the conditional age-at-length approach and the change to using number of hauls for input sample sizes were implemented in Model 18.2 and 18.2b, which are identical to Models 18.0 and 18.0b, except for these two changes. For all models that used the conditional age-at-length approach, the sample sizes used for survey age data input within each length bin were the number of age samples within that length bin.

Model 18.2c was developed as a refinement of Models 18.2 and 18.2b, whereby separate fishery selectivity curves were estimated for only two management periods: 1964-1987 and 1988-present. Model 18.2c was developed because model fits were not substantially improved by including a separate selectivity curve for the 2008-present management era, and the extra parameters required for estimating selectivity curves for 3 management eras rather than 2 management eras were not necessary.

Table 9.11 shows the values used for weighting data sources relative to one another in each model.

The sections below describe the parameters estimated outside and inside the assessment models and focus on the alternative Stock Synthesis model runs for 2018. A full description of the parameters estimated outside and inside the assessment model under the 2016 model structure (for which 2018 results are presented in Appendix A) is available in McGilliard et al. (2016).

Parameters estimated outside the assessment model

The survey catchability, natural mortality rates, variability of recruitment (σ_R), the maturity ogive, the ageing error matrix, sex-specific length-at-age transition matrices, and the weight-length relationship were estimated outside the assessment model. The survey catchability parameter was fixed at 1.0. The natural mortality rates were fixed at 0.2 for both sexes, and σ_R was equal to 0.5, consistent with previous assessments. The maturity ogive for flathead sole followed an age-based logistic curve where age at 50% maturity was 9.7 and age at 95% maturity was 12.8. The ageing error matrix was taken directly from the Stock Synthesis model used in assessments prior to 2004 (Spencer et al., 2004).

Sex-specific length-at-age curves were estimated from the survey data using a procedure designed to reduce potential sampling-induced biases (Spencer et al., 2004) for Models 18.0 and 18.0b (all other 2018 models estimated growth parameters within the assessment model). Sex-specific von Bertalanffy growth curves were fit to mean length-at-age data for years 1985, 1992-1995, 2000-2015. The resulting parameters values were:

	L_∞	K	t_0
Females	47.12	0.13	-0.56
Males	38.84	0.17	-0.56

Age was converted to size in the model assuming that size-at-age was normally-distributed with sex-specific mean length-at-age given by the von Bertalanffy equation using the parameters given above and CVs in length-at-age calculated from raw length-at-age data. In Models 18.0 and 18.0b the CVs in length-at-age were estimated outside the model. The CV of the youngest fish (age 3) was 0.15 and the CV of the oldest fish (age 21) was 0.076.

A length–weight relationship of the form $W = a\,L^b$ was fit to survey data from 1982-2016 for males and females combined, with parameter estimates a = 0.00298 and b = 3.327 (weight in g, length in cm).

Parameters estimated inside the assessment model

Parameters estimated within all Stock Synthesis models were the log of unfished recruitment (R_0), log-scale recruitment deviations for an early period (1963-1972) and a main period (1973-2014), yearly fishing mortality (1964-2018), and selectivity parameters for the fishery and survey.

Growth
Sex-specific growth parameters ($L_{amax=21+}$, $L_{amin=3}$, k, CV of length-at-age at age 3, CV of length-at-age at age 21+) were estimated inside the assessment model for all models except for Models 18.0 and 18.0b.

Selectivity
Survey selectivity parameters were estimated using age-based, sex-specific, asymptotic double-normal curves that were time-invariant and are listed in the table below. Alternative model runs were conducted allowing for the descending width, width of plateau, and all male parameters to be estimated, which led to the same selectivity curves estimated using the setup listed in the following table (there was no evidence for dome-shaped survey selectivity).

Double-normal selectivity parameters	**Survey**
Peak: beginning age for the plateau	Estimated
Width: width of plateau	12
Ascending width (log space)	Estimated
Descending width (log space)	3
Initial: selectivity at smallest age bin	0
Final: selectivity at largest age bin	Follows shape of descending limb
Male Peak Offset	Estimated
Male ascending width offset (log space)	Estimated
Male descending width offset (log space)	0
Male "Final" offset (transformation required)	0
Male apical selectivity	1

Fishery selectivity parameters for logistic, length-based, sex-specific curves were estimated (the parameters for each curve were the length at 50% selectivity to the fishery and slope of the selectivity curve). In Models 18.0, 18.1 and 18.2, fishery selectivity was time-invariant. In Models 18.0b, 18.1b, and 18.2b, separate fishery selectivity curves were estimated for 3 distinct time periods (1964-1987, 1988-2007, and 2008-present). In Model 18.2c, separate fishery selectivity curves were estimated for 2 distinct time periods (1964-1987 and 1988-present).

Objective Function
Parameter estimates were obtained by minimizing the overall sum of a weighted set of negative log-likelihood components derived from fits to the model data described above and a set of penalty functions used to improve model convergence and impose various constraints (Methot and Wetzel 2013). Fits to observed annual fishery size and age compositions, as well as survey biomass estimates and size and age compositions were included among the set of likelihood components. A likelihood component based on recruitment deviations from the mean was also included. Penalties were imposed to achieve good fits to annual fishery catches (biomass) and the assumed historical fishery catch. The functions used are described in more detail in Methot and Wetzel (2013) and in Appendix B of this chapter.

Results

Model Evaluation

Model Comparison of updates estimating growth within the assessment model and using number of hauls as relative yearly input sample sizes for length and age composition data
Figure 9.8 shows that Models 18.0 (which estimated growth parameters externally), 18.1 (like 18.0, but with growth parameters estimated within the assessment model), and 18.2 (like 18.1, but with the number of hauls represented in the data used as yearly relative input sample size for length and age composition data) were very similar to one another. The spawning biomass, survey biomass, recruitment and fishing mortality were identical or nearly identical for Models 18.1 and 18.2, indicating that models fits were robust to changes in relative yearly input sample sizes for length and age composition data. Model 18.0 exhibited slightly lower spawning biomass than for the two models where growth was estimated within the model, but spawning biomass in the last few years of the model was nearly identical to the other two models. Likewise, differences in recruitment and fishing mortality between Model 18.0 and the other two models were small.

Figure 9.9 and Figure 9.10 show a comparison of Models 18.0b, 18.1b, and 18.2b. This is the same comparison that was shown in Figure 9.8, except that each of the models estimated a separate set of fishery selectivity curves for the period 1964-1987, 1988-2007, and 2008-present. The results appear to be identical to the comparison between Models 18.0, 18.1, and 18.2, except that Model 18.2b estimated slightly lower values for fishing mortality for the middle fishery selectivity time period (1988-2007), and the uncertainty bounds for fishing mortality during the 1988-2007 time period were much smaller for Model 18.2b than for Model 18.1b or Model 18.0b. The change in Model 18.2b to using the number of hauls represented in the data each year as the relative input sample size for the length and age composition data meant that the fishery length composition data from the early time period (1964-1988) were down-weighted because length data were collected in fewer hauls than for the middle and end time periods. Fishery length data were collected from 79 hauls each year, on average, between 1973 (the first year where lengths were collected) and 1987 (Table 9.7). In contrast, fishery length data were collected from 717 hauls per year on average from 1988-2007 and in 2,727 hauls per year on average from 2008-2018. Few fishery age data were collected before the year 2000 and, similar to the length composition data, more age data exist and were collected from more hauls during the most recent time period (2008-present; Table 9.8). Many otoliths have been collected by observers, but are not yet aged.

Table 9.13 and Figure 9.12 show the external estimates of growth used in Model 18.0 and 18.0b as compared to the growth estimates from the three model configurations that estimated growth internally. Estimating growth within the assessment model led to estimates of length at age 3 for males and females that were lower than the external estimates by 3-4 cm, estimates of length at age 21 were very similar between models, CV in length at age 3 was smaller by 0.03 for females and 0.02 for males, and the CV in length-at-age 21 was larger by 0.01 for both males and females. Estimating growth (including the age-length transition matrix) within the model was a necessary exercise, as one main difference between the old model framework and the best matching Stock Synthesis models presented at the September 2018 Plan Team Meeting (Appendix B) was that the age-length transition matrices from the two models could not be made to match and further verification of growth parameters and variability in growth was required. In addition, estimating growth within the assessment model allows for uncertainty in growth parameters to propagate through the model and allows for the influence of survey selectivity on length and age data that are collected to be taken into account.

Updating the model to estimate growth internally and changing input sample sizes to reflect the number of hauls for which length and age composition data exist are methodological improvements that lead to only very small changes in model dynamics. Therefore, the remainder of the document will focus on model configurations that incorporate these two updates.

Model Comparison: estimating fishery selectivity as time-invariant or with time-blocks
Figure 9.11-Figure 9.21 show a comparison of Models 18.2 (time-invariant fishery selectivity), 18.2b (fishery selectivity curves estimated for three separate time periods), and 18.2c (fishery selectivity curves estimated for two separate time periods). The three models led to almost identical results for spawning biomass, survey biomass, and recruitment (Figure 9.11). Likewise, the three models led to similar fishery selectivity curves in the most recent time period (Figure 9.15) and similar survey selectivity curves (Figure 9.17).

However, Models 18.2b and 18.2c, which both estimated a separate set of fishery selectivity curves for the time period 1964-1988 (when foreign fleets and joint venture operations were permitted in the fishery), estimate fishery selectivity curves that were substantially different during the 1964-1988 time period than for Model 18.2 where fishery selectivity was time-invariant (Figure 9.16). Models 18.2b and 18.2c estimated the length at 50% selectivity to be 23.5cm during the 1964-1987 time period and 38cm during the most recent time period, a 14.5cm difference (Table 9.15). Fishery selectivity slope parameters during the 1964-1987 time period were similar to those estimated for the most recent time period in each model (7-8cm; Table 9.15). This difference in the length at which fishery selectivity occurred in the 1964-1987 time period led to differences in the estimated scale of fishing mortality and overall fishing pressure (as indicated by the plot of 1-SPR) during that period between Model 18.2 and 18.2b-c (Figure 9.11). The period 1964-1987 was the most data poor time period in the assessment with no fishery age data, and fishery length composition data beginning in 1973, but with very few hauls where length data were collected relative to the later time periods (Table 9.7 and Table 9.8). Therefore, the fishery selectivity curves estimated by Model 18.2 were largely informed by data from 1988-2018 and estimates were consistent with those from Models 18.2b and 18.2c for the most recent time period. Given that the 1964-1988 time period was data poor relative to the other time periods and the Francis data weighting approach substantially down-weighted fishery length composition data relative to other sources of data (Table 9.11), the fishery data from the early time period had little overall influence on the likelihood components (Table 9.12), the fits to fishery age composition data aggregated over years (Figure 9.18), the fits to the survey length composition data (Figure 9.19 and Figure 9.21), and only a small noticeable influence on fits to fishery length composition data, aggregated over years (Figure 9.19). However, there was a substantial residual pattern in the model fits to the yearly fishery length composition data from the early time period for Model 18.2 that was largely resolved in Models 18.2b and 18.2c (Figure 9.20). This was an indication that Models 18.2b and 18.2c better represented the selectivity and fishing mortality of the early 1964-1987 time period than did Model 18.2.

Model 18.2c was added to the model set to investigate whether estimating a separate selectivity curve for the most recent time period (2008-present), and therefore adding four additional parameters to the model, improved model fits. The Francis data weighting values were exactly the same for Models 18.2b and 18.2c, allowing for direct comparison of the values of the objective function for each likelihood component and overall (Table 9.11 and Table 9.12). The likelihood component values were nearly identical for the two models. In addition, there were no noticeable differences between the model estimates or fits, aside from the slightly different fishery selectivity curves estimated for the middle time period (1988-2007), which were not big enough to lead to substantial differences in fishing mortality estimates (Table 9.15, Figure 9.11, Figure 9.16-Figure 9.21). Therefore, Model 18.2c was chosen as the author's preferred model because it was able to account for selectivity of smaller fish to the fishery during the 1964-1987 time period and was more parsimonious than Model 18.2b.

Results for the recommended model: Model 18.2c

Figure 9.9b shows that fits to the survey biomass index for Model 18.c (and also all alternative models) fit the data well from 1982-1996. Starting in 1997 there were fluctuations in survey biomass that were not fully captured by the model. Previous assessments modeled a linkage between survey catchability and average bottom temperature (e.g. Stockhausen et al. 2012) and visually the trends look related, but the 2014 and 2016 model estimates of the parameter linking temperature to catchability were close to 0, suggesting that a relationship does not exist (McGilliard et al. 2014, McGilliard et al. 2016), and a model run in 2018 including a linkage between temperature and catchability also showed no meaningful relationship (Figure 9.23). Flathead sole are thought to move in response to the cold pool, avoiding colder water and this was thought to affect catchability. It is possible that the size of the cold pool affects survey catchability, but that a different environmental indicator is needed that more precisely measures the size of the cold pool relative to the range of flathead sole and Bering flounder.

Figure 9.22 shows trends over time in spawning biomass, survey biomass, recruitment, apical fishing mortality, and 1-SPR (1-spawning potential ratio; a measure of fishing intensity over time) for Model 18.2c. Spawning biomass was at a low in 1983 of 87,811 mt, reached a peak in 1999 of 226,535 mt, and decreased to a current spawning biomass of 154,356 mt in 2018 (Table 9.18). A period of high recruitments occurred from 1980-1990, and a period low recruitments occurred from 2004-2010. The age-0 recruitment was fixed to equal mean recruitment for the most recent four years because too few flathead sole are observed at ages 0-3 to estimate recruitment reliably (Table 9.16 and Table 9.19). Historical apical fishing mortality was between 0.007 and 0.07 for the historical period of foreign fleets and the joint venture fishery. The estimates of uncertainty in fishing mortality during this period are artificially small. If future assessments include models with a stock-recruit relationship, the influence of uncertainty in early catches and fishing mortality should be evaluated. Fishing mortality reached a peak in 1990 at 0.11, and remained between 0.6 and 0.9 in the 1990s and early 2000's. Fishing mortality reached another peak of approximately 0.11 in in 2008 year and has generally declined in recent years since 2008 (Table 9.17). In contrast, the plot of 1-SPR shows that overall fishing intensity was highest during the period of foreign fishing, peaking in 1972 of approximately 0.5. 1-SPR fell to between 0.1 and 0.2 in 1987-1989 and stabilized around or just above 0.2 thereafter. The estimated SPRs over the modeled time period were all well below the management target of 1-SPR = 0.6.

Parameter estimates for Model 18.2c are shown in Table 9.13-Table 9.17.

Figure 9.24 shows expected numbers-at-age and expected mean age in each year for Model 18.2c. A similar pattern was estimated for males and females with a period of high recruitment in the early 1980s and again from 2010 onwards (but note that recruitment is set to its mean value from 2014-present).

Selectivity

Figure 9.15 and Figure 9.16 show the estimated length-based fishery selectivity curves and Figure 9.17 shows the estimated age-based survey selectivity curves for Model 18.2c. The fishery selectivity curves suggest that males were caught at smaller lengths than females. Likewise, the survey selectivity curves are age-based and males and females were caught at similar ages, which means that males were caught at smaller lengths than females because males grow more slowly and not as large as females. This could occur if similar ages of flathead sole (male and female) tend to be caught together. Another reason why this could occur is if there was a consistent bias in sexing the fish, such that smaller fish caught within a haul are more likely to be sexed as male. However, conversations with the survey sampling group indicate that flathead sole are relatively easy to sex as compared to other species. Allowing male selectivity to be different from female selectivity is new in the 2018 models and largely resolved a residual pattern in yearly fits to fishery and survey length composition data that occurred across almost every year modeled and in all of the historical BSAI flathead sole assessments that reported yearly fits to fishery and survey length composition data (Stockhausen et al. 2012, McGilliard et al. 2014, McGilliard et al. 2016), in addition to this year's run of the old model with the 2018 data (Appendix A). The survey sampling group reported finding similar ages of flathead sole within hauls, and this could be explored further in the future by looking at the survey and observer age data at the haul level. Model 18.2c estimated male and female fishery selectivity curves for the period 1964-1987 that selected fish at substantially smaller lengths than for the current period beginning in 1988. In the early period there were only catch data from 1964-1976, and only length composition and catch data from 1977-1982. The model could estimate a substantially different fishery selectivity curve if length-at-age were different during this early period. However, survey length-at-age data exist beginning in 1982, during this early period, and show no substantial changes in length-at-age over time (Figure 9.6-Figure 9.7, and Appendix DFigure 9.81-Figure 9.82). Additionally, the model could estimate a different fishery selectivity curve for the early period if length-at-age were different for fishery data than for survey data. If this were occurring it would likely show up in ghost fits to fishery length composition data in years where fishery age composition data were included in the likelihood instead of fishery length composition data. Fishery age composition data were used in many years from 2000 onward (Figure 9.37), and ghost fits to fishery length composition data in those years were quite good (Figure 9.36), suggesting that for these years, length-at-age in the fishery was similar to length-at-age in the survey (only the survey data was used to inform growth parameters and variability in growth in the model). There were no fishery ages available prior to 2000 to further test this hypothesis, but there was also no indication that length-at-age changed meaningfully over time (Appendix D,Figure 9.81-Figure 9.82) or was different between the survey and fishery.

<u>Growth and fits to survey conditional age-at-length data</u>

Figure 9.12 and Table 9.13 show estimated length-at-age from Model 18.2c and external estimates of length-at-age used for the 2018 model with 2016 data, as well as Models 18.0 and 18.0b, overlaid on length-at-age data. When estimated internally, length at young ages was estimated to be smaller than for external estimates for both females and males. Asymptotic length for males was estimated to be slightly smaller when estimated within the assessment model than when estimated externally. Model 18.2c also estimated the CV in length-at-age for age 3 and age 21 individuals, interpolating the CV in length-at-age for intermediate ages (Figure 9.13-Figure 9.14, Table 9.13). This was a slightly different method than was used to obtain estimates of CV in length-at-age externally, whereby the CV in length-at-age was calculated for each age individually. It was important to estimate growth and CV in growth within the assessment model because the estimates of the age-length transition matrix did not match between the 2016 model and the Stock Synthesis framework; this is discussed in detail in Appendix B. Estimating the growth parameters internally both allows for uncertainty in growth parameters to be propagated through the model and reflected in uncertainty in spawning biomass and other quantities, and allows the influence of survey selectivity on the growth data collected to be taken into account in model estimates; the survey is expected to select young individuals that are large for their age. Therefore, it is expected that estimates of length-at-age, particularly at young ages when the fish are not fully selected in the survey, to be different between the internal and external estimates. Figure 9.28-Figure 9.31 show observed and expected mean age-at-length for females and males combined with 90% intervals about observed age-at-length and observed and expected standard deviation in age-at-length for Model 18.2c. Mean age-at-length estimates fit fairly well in 1982-1995. In some years (2001-2003, 2005-2006, 2009-2011, and 2013-2014), the model appears to slightly underestimate mean age-at-length for the oldest ages (ages 15+). This may occur because there were not many observations of ages 15+ relative to younger ages, which was reflected in the plots of expected and observed standard deviations in age-at-length where expected standard deviation at larger lengths is high, while observed standard deviation is very low, or sometimes zero. This difference in standard deviation will occur when sample sizes are low because the

standard deviation calculated from only one sample is zero and the standard deviation calculated from only a few samples is likely to be low and not reflective of the true standard deviation in age-at-length for the population. Figure 9.32-Figure 9.34 shows Pearson residuals in fits to conditional age-at-length data. Many fish that were small at intermediate and older ages were observed in 2007 and 2008, relative to other years and Pearson residuals in these years were larger than in other years. Figure 9.6-Figure 9.7 and Appendix D Figure 9.81-Figure 9.82 show that variability in length-at-age was particularly high in 2007 and 2008, relative to other years.

Fits to survey length-composition data

Fits to survey length composition data are shown in Figure 9.20 and Figure 9.25. Residuals were relatively small, but there was a persistent pattern throughout the time series showing that the model estimated more 20-30cm fish than were observed and fewer 30-40cm fish than were observed. This pattern existed in previous BSAI flathead assessments (McGilliard et al. 2016, McGilliard et al. 2014, and Stockhausen et al. 2012). Several hypotheses were explored through additional model runs about why this residual pattern occurred, as follows.

(1) The shape of the logistic or double-normal asymptotic selectivity curve was too constraining and therefore cannot fully capture the length or age at which selectivity occurs. This was explored with additional models runs using length-based double-normal selectivity or age-based double normal selectivity and allowing for dome-shaped selectivity by allowing the descending width parameter to be estimated, or using a selectivity pattern where selectivity-at-age was determined as a random walk from selectivity at age-1. The residual pattern still occurred in all of these alternative runs;
(2) The shape of the von-Bertalanffy growth curve was too constraining and failed to fully describe mean length-at-age. To explore this hypothesis, the four-parameter Schnute-Richards growth curve was estimated within the model instead of the three-parameter von-Bertalanffy growth curve because it allows more flexibility in the shape of the curve. The growth curves estimated within this model were identical to those in Model 18.2c and the residuals in fits to survey length composition data remained.
(3) Variability in growth was not adequately represented by estimating CV in length-at-age for ages 3 and 21 and interpolating CV in length-at-age for intermediate ages. CV in length-at-age was calculated from data and used to create the age-length transition matrix when growth was estimated outside of the model and the residual pattern in survey length-at-age existed in models where this age-length transition matrix was used as well. This hypothesis was explored by estimating variability in growth by running alternative models that assumed that variability in growth was parameterized as CV as a function of age, standard deviation as a function of length-at-age, standard deviation as a function of age, or the log of standard deviation as a function of age. These model runs either showed the same residual pattern as for Model 18.2c, or failed to converge.
(4) There was a conflict in the data between the survey biomass index and the survey composition data. To explore this hypothesis, the survey biomass likelihood component was given a weighting of 0.0001 in the model and the survey length and age-composition data were given weights of 1. The same residual pattern occurred in this model run.
(5) The data don't fully characterize variability in length-at-age for BSAI flathead sole. A model run was not identified that could easily test this hypothesis, but future data exploration could investigate the distribution of yearly length samples corresponding to the otoliths that have been aged as compared to the whole yearly length sample.

Fits to fishery age- and length-composition data

Overall fits to fishery age composition data were reasonable, but not perfect (Figure 9.18 and Figure 9.37). The yearly distributions of ages varied from year to year, suggesting that perhaps a larger sample of ages from the fishery each year would improve our knowledge of the distribution of ages caught by the fishery. One very large residual occurred in fits to fishery length-composition data in 1983 and in some years the fishery caught more 45-60cm males than were expected (Figure 9.20 and Figure 9.35).

Time series results

Time series of estimated total biomass, spawning biomass, and recruitment are shown in Table 9.18, and Table 9.19, and in Figure 9.22. Estimated numbers-at-age are shown in the following link: http://www.afsc.noaa.gov/REFM/docs/2018/BSAIflathead_Numbers_at_Age.xlsx. Estimated fishing mortality is plotted against spawning stock biomass relative to the harvest control rule in Figure 9.38. The stock was below its estimated $F_{35\%}$ level and above its $B_{35\%}$ level for all years for which data exist. The stock is currently well above its $B_{35\%}$ level and is being fished well below its $F_{35\%}$ level.

Retrospective Analysis

Retrospective analyses were conducted by running this year's assessment model iteratively, each time removing one additional year of data, starting with the most recent year of data.

The retrospective models estimated from the 2016 assessment showed a pattern whereby biomass was estimated to be lower with the addition of each year of data and there was a substantial retrospective pattern for the slope parameter of the survey selectivity curve (McGilliard et al. 2016). This pattern was largely resolved in the current assessment by including data for ages 0-2 and lengths under 6cm in the assessment inputs, as well as using a double-normal asymptotic selectivity curve. With these changes the model estimated a much more realistic survey selectivity curve (see Results section for more details).

The retrospective model estimates for Model 18.2c, including spawning biomass, recruitment, and apical fishing mortality are shown in Figure 9.39. Estimates for the model run excluding 5 years of data were different from all of the other retrospective runs and showed a trajectory of spawning biomass that was lower than for other runs. Otherwise, the estimates of spawning biomass and fishing mortality for the retrospective runs were very similar to one another, with a very small pattern in recent spawning stock biomass showing that newer model estimates estimated slightly higher spawning biomass values. Estimates of recruitment in recent years differed among models, but a consistent retrospective pattern was not clear. A lack of information about young and small flathead sole in the assessment may have contributed to variation in estimates of recruitment in the most recent years of the model. In addition, the model is configured to fix recruitment for the most recent four years to mean recruitment. The Mohn's ρ for Model 18.2c were:

Spawning Biomass	Recruitment	Fishing Mortality
-0.046	-0.232	0.114

Hurtado-Ferro et al. (2015) developed some rules of thumb for ranges of Mohn's ρ values that may arise without the influence of model mis-specification. They found that values between -0.15 and 0.20 for longer lived species and values between -0.22 and 0.30 for shorter-lived species could arise without the influence of model mis-specification based on a simulation-estimation study. The values for Mohn's ρ for this year's BSAI flathead assessment are within these bounds for spawning biomass and fishing mortality, and just outside the bounds for recruitment (however, the Mohn's ρ value for recruitment was not very meaningful, as estimates from the current assessment were being compared to recruitment estimates fixed at the mean value for recruitment in many of the retrospective runs).

Harvest Recommendations

The reference fishing mortality rate for the flathead sole/Bering flounder complex was 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 age-3 recruitment from the

1980-2017 year classes estimated in this assessment represented a reliable estimate of equilibrium recruitment, an estimate of $B_{40\%}$ was calculated as the product of $SPR_{40\%}$ times the equilibrium number of recruits. Since reliable estimates of the current spawning biomass (B), $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and $B>B_{40\%}$, the flathead sole/Bering flounder 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 2019	153,203
$B_{40\%}$	84,824
$F_{40\%}$	0.38
max*Fabc*	0.38
$B_{35\%}$	74,221
$F_{35\%}$	0.47
F_{OFL}	0.47

Because the flathead sole/Bering flounder stock complex has not been overfished in recent years and the stock biomass is relatively high, adjusting F_{ABC} downward from its upper bound is not recommended.

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 current numbers at age estimated in the assessment. This vector is then projected forward to the beginning of next year using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for the current year. 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 estimates used in the projections are 11,305 t and 12,936 t for 2018 and 2019 used in place of maximum permissible ABC. The final catch for 2018 was estimated by taking the average tons caught between October 6 and December 31 over the previous 5 years (2013-2017) and adding this average amount to the catch-to-date as of October 6, 2018. Total catch for all subsequent years was assumed to be equal to the catch associated with the respective harvest scenario. This projections were 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 2019, are as follows ("*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 2019 recommended in the assessment to the *max*F_{ABC} for 2019. (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 2014-2018 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 9.20-Table 9.22.

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 the current year, then the stock is not overfished.)

Scenario 7: In the current year and next year, *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 2031 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 current year of scenario 6 is 154,355 t, which is higher than *B35%* (74,221 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 2031 of scenario 7 (79,574 t) is greater than *B35%*; thus, the stock is not approaching an overfished condition.

Ecosystem Considerations

Ecosystem effects on the stock

Prey availability/abundance trends

Results from an Ecopath-like model (Aydin et al., 2007) based on stomach content data collected in the early 1990's indicate that flathead sole occupy an intermediate trophic level in the eastern Bering Sea ecosystem (Figure 9.40). They feed upon a variety of species, including juvenile walleye pollock and other miscellaneous fish, brittlestars, polychaetes, and crustaceans (Figure 9.41). The proportion of the diet composed of fish appears to increase with flathead sole size (Lang et al., 2003). The 2017 pollock assessment estimated high recruitment in 2014 and 2015 (Ianelli et al. 2017). This year the trend in biomass has declined, but is still above average. Information about the abundance trends of the benthic infauna of the Bering Sea shelf is sparse, although some benthic infauna are caught in the EBS groundfish trawl survey. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not been re-sampled since.

McConnaughy and Smith (2000) compared the diet between areas with high survey CPUE to that in areas with low survey CPUE for a variety of flatfish species. For flathead sole, the diet in high CPUE areas consisted largely of echinoderms (59% by weight; mostly ophiuroids), whereas 60% of the diet in the low CPUE areas consisted of fish, mostly pollock. These areas also differed in sediment types, with the high CPUE areas consisting of relatively more mud than the low CPUE areas. McConnaughy and Smith (2000) hypothesized that the substrate-mediated food habits of flathead sole were influenced by energetic foraging costs.

Predator population trends
The dominant predators of adult flathead sole are Pacific cod and walleye pollock (Figure 9.42). Pacific cod, along with skates, also account for most of the predation upon flathead sole less than 5 cm (Lang et al. 2003). Arrowtooth flounder, Greenland turbot, walleye pollock, and Pacific halibut comprised other predators. Flathead sole contributed a relatively minor portion of the diet of skates from 1993-1996, on average less than 2% by weight, although flatfish in general comprised a more substantial portion of skates greater than 40 cm. A similar pattern was seen with Pacific cod, where flathead sole generally contribute less than 1% of the cod diet by weight, although flatfish in general comprised up to 5% of the diet of cod greater than 60 cm. In 2017 the survey biomass for EBS Pacific cod declined by 46%, the largest decline of Pacific cod in the history of the survey (Thompson et al. 2017). A survey extension to the Northern Bering Sea (NBS) showed a substantial increase in NBS Pacific cod in 2017 from the previous NBS survey in 2010. The NBS survey was completed again in 2018 and showed a high level of Pacific cod in the region. Recent genetics work (pers. comm. Spies) showed that the cod found in the EBS shelf and NBS surveys cannot be distinguished genetically. See the EBS Pacific cod assessment within this SAFE report for more information. Survey biomass of skates in the Bering Sea has been increasing since 2011 (Ormseth 2016, Ormseth 2017). There is a large amount of uncertainty concerning predation on flathead sole; almost 80% of the mortality that flathead sole experience is from unexplained sources (Figure 9.42).

There is some evidence of cannibalism for flathead sole. Stomach content data collected from 1990 indicate that flathead sole were the most dominant predator, and cannibalism was also noted in 1988 (Livingston et al. 1993).

Changes in habitat quality
The habitats occupied by flathead sole are thought to be influenced by temperature or the extent of sea ice, which has shown considerable variation in the eastern Bering Sea in recent years. For example, the timing of spawning and advection to nursery areas are expected to be affected by environmental variation. Flathead sole spawn in deeper waters near the margin of the continental shelf in late winter/early spring and migrate to their summer distribution of the mid and outer shelf in April/May. The distribution of flathead sole, as inferred by summer trawl survey data, has been variable. In 1999, one of the coldest years in the eastern Bering Sea, the distribution was shifted further to the southeast than it was during 1998-2002. Bottom temperatures during the 2006-2010 and 2012-2013 summertime EBS Trawl Surveys were colder than average. 2018 was the warmest year recorded in the EBS shelf trawl survey and the only year in the history of the survey in which no cold pool was observed (i.e. no temperatures below 2 deg C were recorded at any survey station). Further exploration of flathead sole behavior in relation to the cold pool is needed. If flathead sole move to avoid the cold pool, there may be an increase in flathead sole habitat with loss of sea ice.

In the 2010 NBS survey, no flathead sole were found in the northern Bering Sea area, but a substantial abundance of Bering flounder was found. Bering flounder biomass in the northern Bering Sea area was estimated at 12,761 t, larger than that in the standard survey area (12,360 t). This is consistent with the view that Bering flounder in the BSAI fishery are a marginal stock on the edge of their species range in the eastern Bering Sea. Potential management implications of the northern Bering Sea survey for Bering flounder based on the 2010 NBS survey were discussed in more detail in Appendix C of the 2010 SAFE document (Stockhausen et al., 2010).

Survey biomass of flathead sole in the 2017 and 2018 NBS was 83 t and 510 t, respectively, and Bering flounder survey biomass was 20,712 t and 30,025 t. No genetics work has been done to date to determine if the flathead sole in the NBS are genetically the same as the flathead sole in the EBS, or if Bering flounder and flathead sole found in these areas are actually different species. Future assessments may need to incorporate the data from the NBS.

Fishery Effects on the Ecosystem

Table 9.23-Table 9.26 show the contribution of fishing targeting flathead sole on non-target species and prohibited species catch. In 2018, the flathead sole fishery in the BSAI contributed 0-9% of the catch of any nontarget species. Table 9.25 shows the contribution of the directed flathead sole fishery to prohibited species catch estimates as a proportion of all prohibited species catch for each species. The flathead sole fishery caught 18% of *Opilio* tanner (snow) crab and 10% of *Bairdi* tanner crab in 2018.

Table 9.26 shows that the proportion of BSAI halibut mortality as PSC that occurred in the directed flathead sole fishery was at a 10 year high of 6% of the halibut mortality as PSC from all fisheries in the BSAI.

Data Gaps and Research Priorities

The relationship between survey average bottom temperature and catchability that was previously included in this assessment was removed because it was estimated to be almost non-existent. However, flathead sole are thought to move in relation to the cold pool. It may be that average summer bottom temperature was not a sufficient measure of flathead sole behavior with respect to the cold pool. Other variables could be explored, and the data could be explored further to see if the temperature measured at the haul level is correlated with the magnitude of survey catches for flathead sole. In addition, it is thought that some mid-identification of Bering flounder and flathead sole occur, but also Bering flounder are thought to be found in colder, more northern areas. The length-at-age data could be explored with respect to temperature at the time of each survey haul to see if a more effective way to separate the morphologically similar congeners is by area or haul, rather than by species identification. It is not actually known that Bering flounder are a different species than flathead sole (pers. comm. Ingrid Spies).

Estimation of natural mortality and mean catchability, perhaps with development of a prior for each of these two parameters could be explored in future assessments to better represent uncertainty in biomass and management quantities. Uncertainty bounds are small in the current and likely overstate our knowledge of stock status.

The detail with which fishery data are included in the assessment could be explored further. Up to 30% of the catch was taken by pelagic trawls in some years; future assessments could model the pelagic trawl fishery as a separate fleet, which may have different selectivity than non-pelagic trawls. In addition, discards are not modeled separately for this stock and this could be investigated.

EBS slope data, the Northwest region of the EBS shelf survey, and the Northern Bering Sea survey could be investigated for potential incorporation into the assessment. Although flathead sole tend to prefer the shelf, data on flathead sole exist in the slope survey and should be explored further. The upcoming stock structure analysis for BSAI flathead sole will include slope data. Aleutian Islands data could be used as a second survey, although there are relatively few flathead sole found in the Aleutian Islands. Alternatively, a survey averaging approach could be used instead of the linear regression to interpolate AI survey biomass in years without an AI survey. Advantages would be improved estimates of uncertainty about interpolated AI survey biomass estimates, and the assumption that interpolated biomass estimates are more closely related to survey biomass in the AI in surrounding years (rather than related to survey biomass in the EBS in those years). However, the contribution of AI biomass to the survey biomass index is a very small fraction of the total biomass and therefore alternative methods for including AI data may not have a large influence on results.

An exploration of the use of stock-recruitment relationships (Ricker, Beverton-Holt) has been considered in the past and could be considered for this new modeling framework, in response to previous GPT and SSC comments from several years ago. Likewise, a new ageing error matrix could be estimated using updated data and methods described in Punt et al. (2008).

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Tables

Table 9.1. Catch (in tons) of flathead sole and Bering flounder combined (*Hippoglossoides* spp.), flathead sole only, and Bering flounder only in the BSAI as of October 6, 2018. Observer data on species-specific extrapolated weight in each haul was summed over hauls within each year and used to calculate the proportion of the total *Hippoglossoides* spp. catch that was flathead sole or Bering flounder. Proportions were multiplied by the total *Hippoglossoides* spp. (flathead sole and Bering flounder combined) catches reported by AKFIN to obtain total catch of flathead sole separately from that of Bering flounder.

Year	Total (*Hippo. spp*)	Flathead sole	Bering Flounder
1964	12,315		
1965	3,449		
1966	5,086		
1967	11,218		
1968	12,606		
1969	9,610		
1970	21,050		
1971	26,108		
1972	10,380		
1973	17,715		
1974	13,198		
1975	5,011		
1976	7,565		
1977	7,909		
1978	13,864	13,734	130
1979	6,042	6,042	0
1980	8,600	8,026	574
1981	10,609	10,599	10
1982	8,417	8,397	20
1983	5,518	5,509	9
1984	4,458	4,395	63
1985	5,636	5,626	10
1986	5,208	5,146	62
1987	3,595	3,479	116
1988	6,783	6,697	86
1989	3,604	3,594	10
1990	20,245	19,264	981
1991	14,197	14,176	21
1992	14,407	14,347	60
1993	13,574	13,463	111
1994	17,006	16,987	19
1995	14,715	14,710	4
1996	17,346	17,341	5
1997	20,683	20,678	5
1998	24,387	24,381	7
1999	18,573	18,553	20
2000	20,441	20,408	33
2001	17,811	17,795	16
2002	15,575	15,550	25
2003	13,785	13,767	18
2004	17,398	17,374	24
2005	16,108	16,077	31
2006	17,981	17,975	6
2007	18,958	18,952	6
2008	24,540	24,526	14
2009	19,558	19,530	28
2010	20,128	20,102	26
2011	13,559	13,539	20
2012	11,367	11,362	6
2013	17,354	17,274	80
2014	16,512	16,479	33
2015	11,308	11,274	33
2016	10,357	10,345	12
2017	9,149	9,146	3
2018*	10,320	10,316	5

*2018 catches are current as of October 6, 2018

Table 9.2. Combined catch (t) of flathead sole and Bering flounder (*Hippoglossoides* spp.) in the Bering Sea and Aleutian Islands as of October 23, 2018.

Year	Total	non-CDQ	CDQ	Proportion CDQ
1995	14,715	14,603	112	0.01
1996	17,346	17,220	126	0.01
1997	20,683	20,649	34	0.00
1998	24,387	24,387		0.00
1999	18,573	17,844	729	0.04
2000	20,441	19,984	457	0.02
2001	17,811	17,588	223	0.01
2002	15,575	15,111	464	0.03
2003	13,785	13,785		0.00
2004	17,398	16,853	545	0.03
2005	16,108	15,217	891	0.06
2006	17,981	17,576	405	0.02
2007	18,958	17,887	1,071	0.06
2008	24,540	24,040	500	0.02
2009	19,558	19,050	508	0.03
2010	20,128	19,184	943	0.05
2011	13,559	12,885	674	0.05
2012	11,367	10,860	507	0.04
2013	17,354	16,657	697	0.04
2014	16,512	15,786	726	0.04
2015	11,308	10,712	596	0.05
2016	10,357	9,763	594	0.06
2017	9,149	8,567	582	0.06
2018	10,432	9,549	883	0.08

Table 9.3. Proportion of combined catch of flathead sole and Bering flounder (*Hippoglossoides spp.*) by gear type in recent years. Proportions are shown on a scale of white to dark gray, with the lowest proportions in white and the highest proportions in dark grey. Proportions for 2018 are current as of October 25, 2018.

Year	Non-Pelagic Trawl	Pelagic Trawl	Pair Trawl	Shrimp Trawl	Pot or Trap	Longline
1992	0.52	0.45	0.00	0.00	0.00	0.03
1993	0.85	0.14	0.00	0.00	0.00	0.02
1994	0.89	0.09	0.00	0.00	0.00	0.02
1995	0.85	0.13	0.00	0.00	0.00	0.02
1996	0.79	0.19	0.00	0.00	0.00	0.02
1997	0.81	0.16	0.00	0.00	0.00	0.03
1998	0.86	0.12	0.00	0.00	0.00	0.02
1999	0.76	0.21	0.00	0.00	0.00	0.02
2000	0.77	0.21	0.00	0.00	0.00	0.02
2001	0.74	0.23	0.00	0.00	0.00	0.02
2002	0.73	0.24	0.00	0.00	0.00	0.03
2003	0.75	0.21	0.00	0.00	0.00	0.04
2004	0.76	0.20	0.00	0.00	0.00	0.04
2005	0.74	0.22	0.00	0.00	0.00	0.05
2006	0.73	0.24	0.00	0.00	0.00	0.03
2007	0.67	0.31	0.00	0.00	0.00	0.02
2008	0.83	0.16	0.00	0.00	0.00	0.01
2009	0.80	0.19	0.00	0.00	0.00	0.01
2010	0.79	0.20	0.01	0.00	0.00	0.01
2011	0.63	0.35	0.00	0.00	0.00	0.02
2012	0.64	0.34	0.00	0.00	0.00	0.02
2013	0.82	0.17	0.00	0.00	0.00	0.01
2014	0.83	0.14	0.00	0.00	0.00	0.02
2015	0.78	0.20	0.00	0.00	0.00	0.03
2016	0.83	0.15	0.00	0.00	0.00	0.03
2017	0.86	0.10	0.00	0.00	0.00	0.04
2018	0.87	0.10	0.00	0.00	0.00	0.02

Table 9.4. Combined proportions of catch of flathead sole and Bering flounder (*Hippoglossoides spp.*) by NMFS reporting area in recent years. Proportions are shown on a scale of white to dark green, with the lowest proportions in white and the highest proportions in dark green.

	NMFS Area														
Year	**508**	**509**	**512**	**513**	**514**	**516**	**517**	**518**	**519**	**521**	**523**	**524**	**541**	**542**	**543**
1992	0.00	0.14	0.00	0.19	0.05	0.01	0.16	0.00	0.02	0.40	0.02	0.01	0.00	0.00	0.00
1993	0.00	0.19	0.00	0.39	0.02	0.01	0.12	0.00	0.00	0.24	0.01	0.01	0.00	0.00	0.00
1994	0.00	0.14	0.00	0.37	0.00	0.03	0.25	0.00	0.01	0.18	0.00	0.01	0.00	0.00	0.00
1995	0.00	0.19	0.00	0.40	0.01	0.01	0.27	0.00	0.01	0.12	0.00	0.00	0.00	0.00	0.00
1996	0.00	0.32	0.00	0.34	0.00	0.01	0.25	0.00	0.01	0.06	0.00	0.01	0.00	0.00	0.00
1997	0.00	0.18	0.00	0.36	0.01	0.00	0.34	0.00	0.01	0.09	0.00	0.01	0.00	0.00	0.00
1998	0.00	0.22	0.00	0.25	0.00	0.00	0.33	0.00	0.01	0.18	0.00	0.00	0.00	0.00	0.00
1999	0.00	0.12	0.00	0.40	0.00	0.02	0.31	0.00	0.01	0.14	0.00	0.00	0.00	0.00	0.00
2000	0.00	0.18	0.00	0.40	0.00	0.00	0.23	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00
2001	0.00	0.13	0.00	0.32	0.00	0.02	0.14	0.00	0.01	0.30	0.01	0.05	0.00	0.00	0.00
2002	0.00	0.11	0.00	0.28	0.00	0.01	0.16	0.00	0.01	0.42	0.00	0.01	0.00	0.00	0.00
2003	0.00	0.13	0.00	0.34	0.01	0.02	0.08	0.00	0.00	0.36	0.00	0.05	0.00	0.00	0.00
2004	0.00	0.13	0.00	0.23	0.00	0.02	0.11	0.00	0.01	0.48	0.00	0.01	0.00	0.00	0.00
2005	0.00	0.14	0.00	0.25	0.00	0.01	0.13	0.00	0.00	0.27	0.00	0.18	0.00	0.00	0.00
2006	0.00	0.21	0.00	0.17	0.00	0.01	0.13	0.00	0.00	0.41	0.00	0.06	0.00	0.00	0.00
2007	0.00	0.15	0.00	0.19	0.00	0.01	0.23	0.00	0.01	0.35	0.00	0.05	0.00	0.00	0.00
2008	0.00	0.26	0.00	0.24	0.00	0.01	0.15	0.00	0.00	0.27	0.00	0.06	0.00	0.00	0.00
2009	0.00	0.25	0.00	0.23	0.00	0.01	0.15	0.00	0.00	0.32	0.00	0.03	0.00	0.00	0.00
2010	0.00	0.23	0.00	0.26	0.00	0.03	0.11	0.00	0.00	0.37	0.00	0.00	0.00	0.00	0.00
2011	0.00	0.25	0.00	0.28	0.00	0.01	0.17	0.00	0.00	0.27	0.00	0.01	0.00	0.00	0.00
2012	0.00	0.17	0.00	0.18	0.02	0.01	0.18	0.00	0.01	0.41	0.00	0.02	0.00	0.00	0.00
2013	0.00	0.19	0.00	0.16	0.00	0.01	0.28	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00
2014	0.00	0.20	0.00	0.18	0.01	0.01	0.24	0.00	0.00	0.35	0.00	0.00	0.00	0.00	0.00
2015	0.00	0.15	0.00	0.35	0.05	0.01	0.07	0.00	0.00	0.37	0.00	0.00	0.00	0.00	0.00
2016	0.00	0.17	0.00	0.54	0.05	0.02	0.09	0.00	0.02	0.09	0.00	0.01	0.00	0.00	0.00
2017	0.00	0.20	0.00	0.51	0.02	0.01	0.11	0.00	0.01	0.12	0.00	0.01	0.00	0.00	0.00
2018	0.00	0.12	0.00	0.45	0.02	0.01	0.14	0.00	0.01	0.14	0.00	0.11	0.00	0.00	0.00

Table 9.5. BSAI flathead sole fishery status from 2013-2018. "Open" indicates that the directed fishery is allowed. "Bycatch" indicates that the directed fishery is closed, and only incidental catch allowed.

Status Type	Program	Status	Effective Date
Pot Gear	All	Bycatch	1-Jan-13
Trawl Gear	All	Bycatch	1-Jan-13
Hook and Line Gear	ICA	Bycatch	1-Jan-13
Trawl Gear	AM 80	Open	20-Jan-13
Pot Gear	All	Bycatch	1-Jan-14
Trawl Gear	All	Bycatch	1-Jan-14
Hook and Line Gear	ICA	Bycatch	1-Jan-14
Trawl Gear	AM 80	Open	20-Jan-14
Trawl Gear	All	Bycatch	1-Jan-15
Pot Gear	All	Bycatch	1-Jan-15
Hook and Line Gear	ICA	Bycatch	1-Jan-15
Trawl Gear	AM 80	Open	20-Jan-15
Pot Gear	All	Bycatch	1-Jan-16
Trawl Gear	All	Bycatch	1-Jan-16
Hook and Line Gear	ICA	Bycatch	1-Jan-16
Trawl Gear	AM 80	Open	20-Jan-16
Trawl Gear	All	Bycatch	1-Jan-17
Pot Gear	All	Bycatch	1-Jan-17
Hook and Line Gear	All	Bycatch	1-Jan-17
Jig Gear	All	Bycatch	1-Jan-17
Trawl Gear	AM 80	Bycatch	1-Jan-17
Pot Gear	CDQ	Open	1-Jan-17
Hook and Line Gear	CDQ	Open	1-Jan-17
Jig Gear	CDQ	Open	1-Jan-17
Trawl Gear	CDQ	Bycatch	1-Jan-17
Trawl Gear	AM 80	Open	20-Jan-17
Trawl Gear	CDQ	Open	20-Jan-17
Trawl Gear	All	Bycatch	1-Jan-18
Pot Gear	All	Bycatch	1-Jan-18
Hook and Line Gear	All	Bycatch	1-Jan-18
Jig Gear	All	Bycatch	1-Jan-18
Trawl Gear	AM 80	Bycatch	1-Jan-18
Pot Gear	CDQ	Open	1-Jan-18
Hook and Line Gear	CDQ	Open	1-Jan-18
Jig Gear	CDQ	Open	1-Jan-18
Trawl Gear	CDQ	Bycatch	1-Jan-18
Trawl Gear	AM 80	Open	20-Jan-18
Trawl Gear	CDQ	Open	20-Jan-18

Table 9.6. Retained and discarded catch biomass and catch limits (OFL, ABC, TAC, and OFL) as of October 23, 2018.

Year	OFL	ABC	TAC	Total	Retained	Discarded	Percent Retained
1995	167,000	138,000	30,000	14,715	7,520	7,195	51%
1996	140,000	116,000	30,000	17,346	8,964	8,382	52%
1997	145,000	101,000	43,500	20,683	10,860	9,823	53%
1998	190,000	132,000	100,000	24,387	17,258	7,129	71%
1999	118,000	77,300	77,300	18,573	13,768	4,806	74%
2000	90,000	73,500	52,652	20,441	14,959	5,482	73%
2001	102,000	84,000	40,000	17,811	14,437	3,374	81%
2002	101,000	82,600	25,000	15,575	11,312	4,263	73%
2003	81,000	66,000	20,000	13,798	10,335	3,463	75%
2004	75,200	61,900	19,000	17,063	11,979	5,085	70%
2005	70,200	58,500	19,500	15,775	12,222	3,553	77%
2006	71,800	59,800	19,500	17,709	13,601	4,109	77%
2007	95,300	79,200	30,000	18,583	13,720	4,863	74%
2008	86,000	71,700	50,000	24,269	22,207	2,062	92%
2009	83,800	71,400	60,000	19,359	17,523	1,835	91%
2010	83,100	69,200	60,000	20,128	18,319	1,809	91%
2011	83,300	69,300	41,548	13,559	11,740	1,818	87%
2012	84,500	70,400	34,134	11,367	9,623	1,744	85%
2013	81,500	67,900	22,699	17,354	15,789	1,565	91%
2014	79,633	66,293	24,500	16,512	15,127	1,385	92%
2015	79,419	66,130	24,250	11,308	10,077	1,231	89%
2016	79,562	66,250	21,000	10,357	9,011	1,347	87%
2017	81,654	68,278	14,500	9,149	8,112	1,037	89%
2018*	79,862	66,773	14,500	10,432	9,662	769	93%

*2018 total catch is current as of October 23, 2018

Table 9.7. Sample sizes of fishery lengths measured for flathead sole only from the Bering Sea-Aleutian Islands, including unsexed individuals and for all gears.

Year	Hauls with Lengths	Number Individual Lengths	Hauls with Lengths (Female)	Number Individual Lengths (Female)	Hauls with Lengths (Male)	Number Individual Lengths (Male)
1973	8	32	1	8	1	6
1975	34	2,112	33	1,494	34	618
1976	4	124	4	64	4	60
1977	138	9,117	132	4,401	134	4,547
1978	145	10,485	135	5,583	136	4,896
1979	219	17,791	218	9,745	206	8,011
1980	90	9,657	88	5,127	87	4,529
1981	62	8,930	62	5,615	62	3,315
1982	46	2,779	44	1,625	43	1,154
1983	48	2,930	42	1,622	43	1,306
1984	57	5,687	55	3,522	56	2,162
1985	152	7,258	144	4,067	140	3,105
1986	55	714	48	391	43	323
1987	42	4,343	40	1,697	40	2,378
1988	168	15,252	160	6,612	160	8,471
1989	140	10,233	140	5,754	137	4,462
1990	144	10,319	123	4,551	120	4,129
1991	169	12,207	123	3,509	114	4,976
1992	62	4,750	10	381	10	529
1993	136	11,478	59	2,646	59	2,183
1994	136	10,878	119	4,729	120	4,641
1995	148	11,963	127	5,464	127	4,763
1996	260	14,921	240	7,075	241	7,054
1997	208	16,374	150	6,388	150	5,388
1998	454	35,738	391	14,573	392	15,098
1999	846	18,743	841	9,325	838	9,318
2000	2,449	20,160	2,315	11,293	2,140	8,824
2001	1,684	12,921	1,598	7,021	1,400	5,815
2002	1,214	10,928	1,141	5,562	1,009	5,341
2003	1,129	11,170	1,096	5,964	1,007	5,076
2004	1,540	17,860	1,489	8,515	1,398	9,239
2005	1,159	13,742	1,115	6,872	1,035	6,773
2006	1,251	14,008	1,197	6,594	1,154	7,390
2007	1,041	10,944	1,006	5,113	947	5,769
2008	4,172	39,551	3,978	19,728	3,721	19,738
2009	3,110	28,972	2,911	14,833	2,784	14,078
2010	2,768	22,728	2,581	11,635	2,444	11,078
2011	2,580	16,192	2,377	8,987	2,039	7,181
2012	2,387	15,462	2,149	9,148	1,782	6,295
2013	3,164	24,279	2,937	13,550	2,554	10,711
2014	2,671	22,887	2,470	12,154	2,233	10,705
2015	2,636	17,847	2,390	9,843	2,150	7,995
2016	3,140	20,481	2,921	11,557	2,684	8,911
2017	2,053	13,915	1,838	7,080	1,758	6,828
2018	1,317	10,204	1,239	5,437	1,160	4,766

Table 9.8. Sample sizes of fishery ages measured for flathead sole only from the Bering Sea-Aleutian Islands. Data presented is from non-pelagic trawl gear only, and flathead sole only.

Year	Hauls with Ages	Number Individual Ages	Otoliths collected
1990			843
1991			154
1992			0
1993			0
1994	5	138	143
1995	13	186	195
1996			0
1997			0
1998	10	99	99
1999			622
2000	241	564	856
2001	333	620	642
2002			558
2003			531
2004	234	496	814
2005	179	389	628
2006	189	538	546
2007	170	434	441
2008			1,884
2009	387	594	1,423
2010	347	598	1,081
2011	474	835	877
2012	404	872	877
2013	406	680	1,294
2014	344	582	1,168
2015	307	460	940
2016	580	969	552
2017	375	648	663
2018			489

Table 9.9. Survey biomass ("Bio."; in tons) of *Hippoglossoides* spp. combined (flathead sole and Bering flounder) in the Eastern Bering Sea (EBS) shelf survey, flathead sole only in the Aleutian Islands and EBS shelf survey, and Bering flounder only in the EBS shelf survey.

	***Hippoglossoides* spp. EBS-AI Combined (used in assessment)**		**Aleutian Islands**		***Hippoglossoides* spp. EBS Only**		**EBS Flathead Sole Only**		**EBS Bering Flounder Only**		**EBS Bottom Temp (deg c)**
Year	**Bio.**	**CV**	**AI**	**CV**	**Bio.**	**CV**	**EBS**	**CV**	**Bio.**	**CV**	
1982	195,048	0.09			192,037	0.09	192,037	0.09	0		2.27
1983	272,185	0.10	1,213	0.20	270,972	0.10	252,612	0.11	18,359	0.20	3.02
1984	290,513	0.08			285,849	0.08	270,794	0.09	15,054	0.22	2.33
1985	269,732	0.07			265,428	0.07	252,046	0.08	13,382	0.12	2.37
1986	363,208	0.09	5,245	0.16	357,963	0.09	344,002	0.09	13,962	0.17	1.86
1987	400,150	0.09			393,588	0.09	379,394	0.10	14,194	0.14	3.22
1988	571,393	0.09			561,868	0.09	538,770	0.09	23,098	0.22	2.36
1989	529,948	0.08			521,140	0.08	502,310	0.09	18,830	0.20	2.97
1990	603,587	0.09			593,504	0.09	574,174	0.09	19,331	0.15	2.45
1991	552,949	0.08	6,939	0.20	546,010	0.08	518,380	0.08	27,630	0.22	2.70
1992	628,857	0.11			618,338	0.11	603,140	0.11	15,198	0.21	2.01
1993	618,057	0.07			607,724	0.07	585,400	0.07	22,324	0.21	3.06
1994	700,088	0.07	9,935	0.23	690,153	0.07	664,396	0.07	25,757	0.19	1.57
1995	604,520	0.09			594,421	0.09	578,945	0.09	15,476	0.18	1.74
1996	626,947	0.09			616,460	0.09	604,427	0.09	12,034	0.20	3.42
1997	795,463	0.21	11,554	0.24	783,909	0.21	769,783	0.22	14,126	0.19	2.74
1998	695,296	0.20			683,627	0.20	675,766	0.21	7,861	0.21	3.27
1999	407,889	0.09			401,194	0.09	387,995	0.09	13,199	0.18	0.83
2000	401,723	0.09	8,906	0.23	392,817	0.09	384,592	0.09	8,225	0.19	2.16
2001	524,068	0.10			515,362	0.10	503,943	0.11	11,419	0.21	2.58
2002	563,230	0.18	9,898	0.24	553,333	0.18	548,401	0.18	4,932	0.19	3.25
2003	523,566	0.10			514,868	0.10	509,156	0.11	5,712	0.21	3.81
2004	625,587	0.09	13,298	0.14	612,289	0.09	604,186	0.09	8,103	0.31	3.39
2005	622,883	0.09			612,467	0.09	605,350	0.09	7,116	0.28	3.47
2006	644,948	0.09	9,665	0.18	635,283	0.09	621,390	0.09	13,893	0.32	1.87
2007	572,105	0.09			562,568	0.09	552,114	0.09	10,453	0.22	1.79
2008	554,706	0.14			545,470	0.14	535,359	0.15	10,111	0.19	1.29
2009	425,818	0.12			418,812	0.12	412,163	0.12	6,649	0.17	1.38
2010	507,047	0.15	11,812	0.31	495,235	0.15	488,626	0.15	6,610	0.16	1.53
2011	593,203	0.19			583,300	0.19	576,498	0.19	6,802	0.15	2.47
2012	387,043	0.12	5,566	0.15	381,477	0.12	374,842	0.12	6,635	0.14	1.01
2013	499,472	0.17			491,191	0.17	485,486	0.17	5,705	0.14	1.87
2014	532,886	0.14	13,436	0.14	519,450	0.14	509,801	0.14	9,649	0.18	3.22
2015	399,748	0.11			393,194	0.11	382,173	0.12	11,021	0.17	3.36
2016	453,060	0.07	6,759	0.15	446,300	0.07	433,469	0.07	12,831	0.24	4.46
2017	549,717	0.08			540,567	0.08	531,291	0.08	9,275	0.23	2.83
2018	495,345	0.08	6,930	0.12	488,415	0.08	484,890	0.08	3,524	0.16	4.26

Table 9.10. EBS survey summary information for flathead sole only on sample sizes of length and age measurements and the number of hauls for which lengths and ages were collected.

	Size compositions					Age compositions					
Year	Total Hauls	Hauls with Lengths	Lengths Measured	Males	Females	Hauls with Otoliths	Hauls with Ages Measured	Otoliths Collected	Ages Measured	Males	Females
1982	329	108	11,029	5,094	4,942	15	15	390	390	181	207
1983	353	170	15,727	7,671	7,480						
1984	355	152	14,043	6,639	6,792	34		569			
1985	353	189	13,560	6,789	6,769	23	23	496	496	227	268
1986	354	259	13,561	6,692	6,844						
1987	343	192	13,924	7,017	6,534						
1988	353	202	14,049	6,729	7,068						
1989	354	253	15,509	7,261	7,682						
1990	351	256	15,437	7,922	7,504						
1991	352	267	16,151	8,063	7,774						
1992	336	273	15,813	7,357	8,037	11	11	419	419	191	228
1993	355	288	17,057	8,227	8,438	5	5	140	136	58	78
1994	355	277	16,366	8,149	8,078	7	7	371	371	166	204
1995	356	263	14,946	7,298	7,326	10	10	396	395	179	216
1996	355	290	19,244	9,485	9,606	10		420			
1997	356	281	16,339	7,932	8,006	6		301			
1998	355	315	21,611	10,352	10,634	2		87			
1999	353	243	14,172	7,080	6,966	18		420			
2000	352	277	15,905	7,536	8,054	18	18	439	437	193	243
2001	355	286	16,399	8,146	8,234	21	21	537	536	254	282
2002	355	281	16,705	8,196	8,332	19	19	471	465	200	265
2003	356	276	17,652	8,854	8,396	38	34	576	246	111	135
2004	355	274	18,737	9,026	8,864	16	16	477	473	208	265
2005	353	284	16,875	8,224	8,181	17	17	465	450	227	222
2006	356	255	17,618	8,755	8,798	27	27	515	508	229	277
2007	356	262	14,855	7,120	7,494	39	38	583	560	242	314
2008	355	255	16,367	7,805	8,269	46	45	588	581	244	328
2009	356	236	13,866	6,619	6,864	51	51	673	666	292	369
2010	356	244	12,568	6,131	6,253	62	62	684	668	285	382
2011	356	257	14,039	6,642	7,044	53	53	743	733	318	403
2012	356	234	11,376	5,405	5,538	51	51	587	576	257	311
2013	356	258	14,257	6,566	6,377	66	66	669	657	285	347
2014	356	260	13,249	5,849	5,669	57	57	679	667	308	348
2015	356	258	14,140	6,728	6,730	231	231	718	708	306	382
2016	356	287	17,234	8,301	8,725	237	237	696	688	282	397
2017	356	269	18,307	8,622	9,108	229	229	688	676	282	381
2018	356	320	25,820	11,230	11,826	256		766			

Table 9.11. Data weighting applied in each model, using the Francis (2011) approach. A weight of 1 was applied to the likelihood components for survey biomass and catch.

Model	Fishery Length	Survey Length	Fishery Age	Survey Age
18.0	0.01	0.18	0.33	0.34
18.0b	0.03	0.12	0.20	0.20
18.1	0.01	0.28	0.23	0.16
18.1b	0.03	0.29	0.22	0.16
18.2	0.02	0.30	0.14	0.15
18.2b	0.06	0.33	0.14	0.15
18.2c	0.06	0.33	0.14	0.15

Table 9.12. Components of the objective function for Models 18.2, 18.2b, and 18.2c. Grey highlights the rows where values can be compared directly for the two models. The length composition component (and therefore the total likelihood) from Model 18.2 cannot be compared directly to the other two models because of differences in data weighting (Table 9.11).

Likelihood Component	Model 18.2 (time-invariant selectivity)	Model 18.2b (3 fishery selectivity periods)	Model 18.2c (2 fishery selectivity periods)
TOTAL	1,015	1,037	1,039
Survey	-37.48	-36.79	-37.17
Length_comp	173	198	199
Age_comp	866	865	867
Recruitment	12.766	10.315	10.203

Table 9.13. Parameters defining growth estimated within the assessment model and corresponding standard deviations from the hessian for the three alternative models: Model 18.2, 18.2b, and 18.2c, and for the old model updated with 2018 data.

	Model 18.2		**Model 18.2b**		**Model 18.2c**		**2016 Model with 2018 Data***	
Parameter	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Length at age 3 (f)	14.26	0.30	14.25	0.30	14.24	0.30	17.46	NA
Length at age 21 (f)	44.49	0.40	44.58	0.38	44.56	0.38	44.26	NA
von Bertalanffy k (f)	0.14	0.01	0.14	0.01	0.14	0.01	0.13	NA
CV in length at age 3 (f)	0.12	0.01	0.12	0.01	0.12	0.01	0.15	NA
CV in length at age 21 (f)	0.09	0.01	0.09	0.01	0.09	0.01	0.08	NA
Length at age 3 (m)	13.94	0.34	13.93	0.34	13.93	0.34	17.67	NA
Length at age 21 (m)	37.05	0.27	37.07	0.26	37.06	0.26	37.85	NA
von Bertalanffy k (m)	0.22	0.01	0.22	0.01	0.22	0.01	0.17	NA
CV in length at age 3 (m)	0.14	0.01	0.14	0.01	0.14	0.01	0.16	NA
CV in length at age 21 (m)	0.08	0.00	0.08	0.00	0.08	0.00	0.07	NA

* The 2016 model with 2018 data used growth parameter values estimated outside of the assessment model with CV in length-at-age calculated for each age. The SS models interpolated CVs for intermediate ages based on the CV in length-at-age of age 3 and age 21 fish.

Table 9.14. Estimates of the log of R0 and initial fishing mortality for Models 18.2, 18.2b, and 18.2c.

	Model 18.2		**Model 18.2b**		**Model 18.2c**	
Parameter	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
ln(R0)	13.7780	0.0289	13.7867	0.0281	13.7860	0.0281
Initial F	0.0537	0.006	0.0244	0.002	0.0244	0.002

Table 9.15. Parameter estimates for parameters estimated within the assessment model and corresponding standard deviations from the hessian for the three alternative models: Model 18.2, 18.2b, and 18.2c.

		Current Selectivity						**Past Selectivity**					
		Model 18.2		Model 18.2b 2008-present		Model 18.2c 1988-present		Model 18.2b 1988-2007		Model 18.2b 1964-1987		Model 18.2c 1964-1987	
		Est	Std	Est	Std	Est	Std	Est	Std	Est	Std	Est	Std
Fishery	Logistic length at 50% selectivity (f)	38.09	0.99	37.22	0.92	38.09	0.79	39.18	1.26	23.61	2.19	23.59	2.19
	Logistic slope (f)	8.34	0.82	7.24	0.84	7.91	0.67	8.72	1.06	6.93	2.38	6.93	2.38
	Male offset length at 50% selectivity	-2.78	0.61	-2.72	0.60	-2.96	0.51	-3.31	0.80	0.72	2.50	0.72	2.50
	Male offset slope (m)	-0.49	0.89	-0.38	0.88	-0.46	0.71	-0.54	1.15	0.71	3.18	0.71	3.18
Survey	Peak: beginning size for the plateau (f)	7.56	0.35	7.54	0.33	7.53	0.34						
	Ascending width (f; ln)	2.36	0.14	2.35	0.14	2.34	0.14	As for current survey selectivity					
	Male peak offset	-0.93	0.38	-0.90	0.36	-0.90	0.36						
	Male ascending width offset (ln)	-0.33	0.18	-0.32	0.18	-0.32	0.18						

Table 9.16. Estimated recruitment deviations with corresponding standard deviations. Recruitment deviations were fixed to 0 after 2014.

Year	Recruitment Deviations	Std	Year	Recruitment Deviations	Std
1963	-0.662	0.386	1992	-0.134	0.340
1964	-0.716	0.379	1993	-0.165	0.327
1965	-0.760	0.374	1994	-0.271	0.338
1966	-0.791	0.370	1995	0.285	0.235
1967	-0.799	0.367	1996	0.241	0.254
1968	-0.777	0.365	1997	0.147	0.250
1969	-0.728	0.362	1998	-0.186	0.273
1970	-0.679	0.359	1999	-0.138	0.270
1971	-0.665	0.354	2000	0.192	0.229
1972	-0.665	0.350	2001	0.411	0.192
1973	-0.773	0.361	2002	0.346	0.173
1974	-0.611	0.361	2003	-0.994	0.320
1975	-0.417	0.351	2004	-0.095	0.198
1976	-0.397	0.346	2005	-0.199	0.218
1977	-0.501	0.360	2006	-0.482	0.247
1978	-0.136	0.296	2007	-0.160	0.211
1979	0.145	0.277	2008	-0.219	0.220
1980	0.285	0.305	2009	-0.605	0.289
1981	0.900	0.191	2010	0.713	0.150
1982	0.062	0.300	2011	-0.267	0.329
1983	-0.268	0.388	2012	0.387	0.256
1984	0.388	0.339	2013	0.508	0.297
1985	0.840	0.256	2014	0.000	NA
1986	0.004	0.453	2015	0.000	NA
1987	0.969	0.180	2016	0.000	NA
1988	-0.455	0.390	2017	0.000	NA
1989	0.152	0.280	2018	0.000	NA
1990	0.276	0.273			
1991	0.125	0.284			
1992	0.097	0.289			

Table 9.17. Estimated yearly fishing mortality with corresponding standard deviations.

Year	Estimate	StdDev	Year	Estimate	StdDev
1964	0.026	0.002	**2001**	0.071	0.006
1965	0.007	0.000	**2002**	0.064	0.006
1966	0.010	0.001	**2003**	0.058	0.005
1967	0.023	0.001	**2004**	0.075	0.007
1968	0.027	0.002	**2005**	0.070	0.006
1969	0.021	0.001	**2006**	0.080	0.007
1970	0.050	0.003	**2007**	0.086	0.008
1971	0.068	0.004	**2008**	0.114	0.010
1972	0.029	0.002	**2009**	0.093	0.009
1973	0.054	0.004	**2010**	0.096	0.009
1974	0.044	0.003	**2011**	0.065	0.006
1975	0.017	0.001	**2012**	0.055	0.005
1976	0.027	0.002	**2013**	0.084	0.008
1977	0.030	0.003	**2014**	0.083	0.007
1978	0.055	0.005	**2015**	0.058	0.005
1979	0.025	0.002	**2016**	0.055	0.005
1980	0.035	0.003	**2017**	0.049	0.004
1981	0.043	0.004	**2018**	0.055	0.005
1982	0.034	0.003			
1983	0.021	0.002			
1984	0.016	0.001			
1985	0.018	0.002			
1986	0.014	0.001			
1987	0.009	0.001			
1988	0.045	0.005			
1989	0.021	0.002			
1990	0.110	0.011			
1991	0.072	0.007			
1992	0.068	0.007			
1993	0.059	0.006			
1994	0.070	0.007			
1995	0.058	0.006			
1996	0.065	0.006			
1997	0.077	0.007			
1998	0.091	0.009			
1999	0.070	0.007			
2000	0.079	0.007			

Table 9.18. Time series of predicted total biomass, spawning biomass, and associated standard deviations. "Tot B (age 3+)" is total biomass for ages 3+, SSB is the spawning biomass, and Std is the standard deviation of spawning biomass.

	2016 Assessment			2018 Assessment		
Year	Tot B (age 3+)	SSB	Std	Tot B (age 3+)	SSB	Std
1964				651,988	179,275	6,668
1965				651,304	179,032	6,664
1966				650,106	182,084	6,676
1967				638,118	184,527	6,679
1968				611,695	184,544	6,657
1969				578,674	183,616	6,622
1970				546,346	183,007	6,575
1971				501,898	175,985	6,506
1972				455,021	164,019	6,549
1973				428,754	156,028	6,820
1974				398,350	142,710	7,236
1975				376,572	130,891	7,577
1976				365,420	123,088	7,749
1977	97,055	13,907	2,079	354,396	115,078	7,737
1978	121,412	11,653	2,000	347,612	108,157	7,584
1979	195,054	10,846	1,922	338,832	100,165	7,307
1980	257,694	12,121	1,905	340,850	96,535	7,014
1981	325,867	15,890	1,981	346,418	92,908	6,663
1982	383,807	24,738	2,365	359,732	89,445	6,273
1983	463,502	41,599	3,320	386,416	87,811	5,876
1984	563,776	66,294	4,718	445,123	88,447	5,476
1985	637,089	95,350	6,183	500,781	91,110	5,089
1986	701,659	124,573	7,628	544,934	95,341	4,765
1987	759,732	151,062	8,958	589,290	102,249	4,580
1988	835,027	175,232	10,095	648,407	113,239	4,615
1989	906,248	200,133	11,221	692,187	127,029	4,889
1990	985,770	228,511	12,482	758,547	146,257	5,371
1991	1,027,570	250,502	13,713	785,288	160,073	5,882
1992	1,061,950	267,939	14,633	808,936	173,827	6,272
1993	1,074,000	281,455	15,284	824,075	185,185	6,412
1994	1,084,360	297,537	15,986	830,605	197,595	6,504
1995	1,073,700	316,634	16,870	827,244	209,942	6,685
1996	1,064,100	335,393	17,725	817,014	222,404	6,879
1997	1,033,650	345,872	18,289	797,315	230,255	7,031
1998	1,002,060	344,269	18,402	768,311	231,344	7,131
1999	968,445	333,946	18,198	742,954	226,535	7,131
2000	934,981	322,715	17,860	728,855	222,459	7,099
2001	915,712	310,620	17,510	717,147	216,009	7,037
2002	900,231	299,510	17,119	705,420	209,453	6,917
2003	875,971	288,665	16,642	693,261	202,399	6,714
2004	871,370	278,250	16,135	686,551	196,182	6,482
2005	865,304	268,106	15,693	685,652	190,036	6,283
2006	879,082	261,006	15,390	692,570	187,206	6,174
2007	874,294	255,621	15,235	683,865	184,701	6,102
2008	864,997	251,589	15,224	672,741	181,989	6,061
2009	847,996	246,634	15,282	651,436	175,849	5,982
2010	825,461	244,872	15,418	629,427	173,293	5,949
2011	797,203	246,240	15,738	607,548	172,469	6,009
2012	773,924	252,116	16,221	591,691	175,380	6,159
2013	743,299	255,884	16,628	573,880	177,142	6,304
2014	730,918	251,576	16,744	574,977	172,372	6,345
2015	702,393	242,963	16,564	574,589	165,698	6,295
2016	707,420	234,293	16,241	593,120	160,864	6,218
2017	747,557	223,469	--	624,424	156,768	6,160
2018	747,557	223,469	--	652,804	154,356	6,153
2019				673,718	153,203	--
2020				686,431	155,032	--

Table 9.19. Recruitment (in thousands) estimated in the 2016 and 2018 assessments and standard deviations about the estimates. Age 0 recruits in 1964 in the table will appear under age 3 recruits in 1967.

	2016 Assessment		*2018 Assessment*		
Year	**Recruits (Age 3)**	**Std. Dev**	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. Dev (age 0)**
1964			532,613	455,615	172,553
1965			532,603	435,985	162,791
1966			264,059	422,282	155,861
1967			249,995	418,335	153,036
1968			239,185	427,371	155,281
1969			231,643	448,528	161,835
1970			229,487	470,738	168,065
1971			234,357	476,659	167,531
1972			245,872	476,513	164,846
1973			258,151	427,138	156,069
1974			261,346	501,793	182,230
1975			261,290	609,171	213,463
1976			234,301	621,030	215,005
1977	1,631,100	192,540	275,249	558,901	202,236
1978	47,633	257,290	334,137	804,832	237,951
1979	1,852,200	277,780	340,518	1,065,140	294,830
1980	400,300	144,120	306,545	1,223,000	376,223
1981	768,030	156,310	441,410	2,262,170	421,507
1982	467,640	111,420	584,106	976,982	294,041
1983	1,580,500	167,930	670,727	702,171	274,589
1984	1,966,700	196,610	1,240,885	1,352,310	459,656
1985	399,670	119,640	535,989	2,121,820	531,982
1986	715,680	124,880	385,229	919,482	423,372
1987	953,650	146,800	741,947	2,409,590	412,364
1988	1,839,300	204,920	1,164,238	579,668	229,915
1989	1,460,300	210,530	504,590	1,063,110	296,951
1990	1,609,800	209,250	1,322,387	1,202,660	327,278
1991	633,770	158,650	318,123	1,032,960	293,068
1992	813,230	160,800	583,436	1,003,370	289,105
1993	542,310	159,210	660,025	795,886	270,679
1994	1,097,300	207,220	566,892	771,220	251,876
1995	603,910	177,850	550,654	693,230	235,681
1996	965,370	147,360	436,786	1,207,050	281,840
1997	338,060	88,707	423,249	1,154,200	293,600
1998	795,250	116,670	380,447	1,049,860	260,787
1999	823,670	128,670	662,431	751,622	205,868
2000	541,620	140,070	633,428	788,530	213,267
2001	1,156,800	186,330	576,167	1,095,690	250,948
2002	838,910	158,290	412,493	1,362,720	261,831
2003	309,200	90,667	432,748	1,275,090	217,596
2004	1,189,300	158,200	601,320	333,892	108,694
2005	895,170	180,210	747,864	819,649	162,279
2006	1,411,800	186,000	699,772	737,612	161,073
2007	353,240	107,170	183,241	555,717	138,800
2008	531,480	118,610	449,826	766,015	162,817
2009	651,310	127,880	404,802	721,013	160,055
2010	403,590	98,956	304,978	489,730	144,452
2011	450,340	96,869	420,390	1,828,830	273,697
2012	584,220	107,410	395,694	714,452	239,586
2013	274,600	79,055	268,767	1,429,300	369,424
2014	1,272,000	184,720	1,003,667	1,613,410	489,040
2015	109,430	136,270	392,093	970,941	27,324
2016	1,367,600	223,550	784,405	970,941	27,324
2017			885,449	970,941	27,324
2018			532,858	970,941	
Average	866,149		496,998	914,687	

Table 9.20. 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
2018	154,355	154,355	154,355	154,355	154,355	154,355	154,355
2019	153,203	153,203	153,203	153,203	153,203	153,203	153,203
2020	131,658	131,658	155,734	153,870	160,825	125,631	131,658
2021	120,838	120,838	162,261	158,774	172,032	111,667	120,838
2022	116,417	116,417	171,170	166,223	185,357	105,497	111,883
2023	115,186	115,186	180,793	174,508	199,203	103,167	107,554
2024	114,318	114,318	189,155	181,631	211,609	101,501	104,446
2025	111,465	111,465	193,949	185,312	220,166	98,099	100,018
2026	106,764	106,764	195,257	185,635	224,941	93,156	94,374
2027	101,600	101,600	194,129	183,700	226,822	88,128	88,859
2028	97,043	97,043	191,841	180,784	227,044	84,313	84,701
2029	93,535	93,535	189,220	177,690	226,499	81,833	82,021
2030	91,066	91,066	186,547	174,685	225,463	80,347	80,427
2031	89,447	89,447	184,012	171,941	224,162	79,546	79,574

Table 9.21 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
2018	0.06	0.06	0.06	0.06	0.06	0.06	0.06
2019	0.38	0.38	0.06	0.08	0.00	0.47	0.38
2020	0.38	0.38	0.06	0.08	0.00	0.47	0.38
2021	0.38	0.38	0.06	0.08	0.00	0.47	0.47
2022	0.38	0.38	0.06	0.08	0.00	0.47	0.47
2023	0.38	0.38	0.06	0.08	0.00	0.47	0.47
2024	0.38	0.38	0.06	0.08	0.00	0.47	0.47
2025	0.38	0.38	0.06	0.08	0.00	0.47	0.47
2026	0.38	0.38	0.06	0.08	0.00	0.47	0.47
2027	0.38	0.38	0.06	0.08	0.00	0.46	0.46
2028	0.38	0.38	0.06	0.08	0.00	0.44	0.45
2029	0.37	0.37	0.06	0.08	0.00	0.44	0.44
2030	0.37	0.37	0.06	0.08	0.00	0.43	0.43
2031	0.37	0.37	0.06	0.08	0.00	0.43	0.43

Table 9.22. 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
2018	11,305	11,305	11,305	11,305	11,305	11,305	11,305
2019	66,625	66,625	11,363	15,547	0	80,918	66,625
2020	59,622	59,622	11,690	15,832	0	69,740	59,622
2021	55,783	55,783	12,161	16,332	0	63,609	67,942
2022	53,687	53,687	12,682	16,916	0	60,206	63,270
2023	52,156	52,156	13,149	17,433	0	57,787	59,926
2024	50,517	50,517	13,484	17,781	0	55,405	56,870
2025	48,600	48,600	13,659	17,921	0	52,835	53,814
2026	46,588	46,588	13,717	17,910	0	50,183	50,877
2027	44,660	44,660	13,674	17,776	0	46,877	47,412
2028	42,749	42,749	13,565	17,567	0	44,125	44,439
2029	41,057	41,057	13,427	17,332	0	42,335	42,498
2030	39,821	39,821	13,276	17,092	0	41,283	41,360
2031	39,007	39,007	13,125	16,865	0	40,750	40,783

Table 9.23. Non-target catch in the directed flathead sole fishery as a proportion of total non-target catch of each species in the BSAI by weight. Conditional highlighting from white (lowest numbers) to green (highest numbers) is applied. “NA” indicates that no catch of the species occurred in that year.

Nontarget Species	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Benthic urochordata	0.002	0.064	0.010	0.007	0.001	0.014	0.009	0.149	0.046	0.025
Bivalves	0.005	0.022	0.002	0.005	0.004	0.073	0.000	0.010	0.016	0.009
Bristlemouths	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.000
Brittle star unidentified	0.253	0.081	0.003	0.002	0.034	0.025	0.007	0.002	0.040	0.027
Capelin	0.026	0.000	0.006	0.000	0.040	0.000	0.000	0.000	0.000	0.000
Corals Bryozoans - Corals Bryozoans Unidentified	0.001	0.038	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.001
Corals Bryozoans - Red Tree Coral	0.000	0.000	0.000	0.000	0.000	0.000	NA	NA	0.000	0.000
Dark Rockfish	0.000	NA	NA	NA	NA	NA	NA	NA	NA	NA
Deep sea smelts (bathylagidae)	NA	NA	NA	NA	0.000	NA	0.000	0.000	0.000	0.000
Eelpouts	0.017	0.097	0.083	0.161	0.272	0.171	0.079	0.017	0.034	0.043
Eulachon	0.001	0.007	0.004	0.001	0.141	0.015	0.000	0.004	0.001	0.011
Giant Grenadier	0.000	0.000	0.000	0.003	0.001	0.000	0.001	0.002	0.008	0.000
Greenlings	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.010
Grenadier - Pacific Grenadier	0.000	0.000	0.000	NA	NA	NA	NA	NA	NA	NA
Grenadier - Ratail Grenadier Unidentified	0.000	NA	NA	NA	NA	NA	NA	NA	NA	NA
Grenadier - Rattail Grenadier Unidentified	NA	0.000	0.000	0.000	0.003	0.000	0.027	0.000	0.003	0.000
Gunnels	NA	NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	NA
Hermit crab unidentified	0.017	0.062	0.005	0.032	0.048	0.020	0.076	0.082	0.065	0.093
Invertebrate unidentified	0.080	0.086	0.009	0.001	0.001	0.002	0.030	0.000	0.004	0.000
Lanternfishes (myctophidae)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Large Sculpins - Bigmouth Sculpin	0.143	NA	NA	NA	NA	NA	NA	NA	NA	NA
Large Sculpins - Brown Irish Lord	0.000	NA	NA	NA	NA	NA	NA	NA	NA	NA
Large Sculpins - Great Sculpin	0.061	NA	NA	NA	NA	NA	NA	NA	NA	NA
Large Sculpins - Hemilepidotus Unidentified	0.000	NA	NA	NA	NA	NA	NA	NA	NA	NA
Large Sculpins - Myoxocephalus Unidentified	0.005	NA	NA	NA	NA	NA	NA	NA	NA	NA
Large Sculpins - Plain Sculpin	0.009	NA	NA	NA	NA	NA	NA	NA	NA	NA
Large Sculpins - Red Irish Lord	0.000	NA	NA	NA	NA	NA	NA	NA	NA	NA
Large Sculpins - Warty Sculpin	0.042	NA	NA	NA	NA	NA	NA	NA	NA	NA
Large Sculpins - Yellow Irish Lord	0.106	NA	NA	NA	NA	NA	NA	NA	NA	NA
Misc crabs	0.006	0.010	0.007	0.004	0.020	0.013	0.012	0.053	0.031	0.018
Misc crustaceans	0.034	0.080	0.017	0.008	0.163	0.041	0.047	0.002	0.284	0.054
Misc deep fish	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Misc fish	0.014	0.006	0.002	0.001	0.004	0.005	0.004	0.006	0.003	0.001
Misc inverts (worms etc)	0.112	0.030	0.059	0.093	0.077	0.020	0.071	0.516	0.227	0.080
Other osmerids	0.001	0.001	0.017	0.000	0.009	0.001	0.000	0.000	0.000	0.000
Other Sculpins	0.012	NA	NA	NA	NA	NA	NA	NA	NA	NA
Pacific Hake	NA	NA	0.000	NA	NA	NA	NA	0.000	0.000	0.000
Pacific Sand lance	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pacific Sandfish	NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pandalid shrimp	0.042	0.040	0.008	0.056	0.069	0.064	0.030	0.012	0.073	0.063
Polychaete unidentified	0.110	0.006	0.007	0.001	0.004	0.002	0.013	0.032	0.772	0.005
Scypho jellies	0.002	0.007	0.001	0.000	0.002	0.005	0.005	0.003	0.001	0.001
Sea anemone unidentified	0.030	0.133	0.020	0.017	0.068	0.040	0.022	0.012	0.020	0.002
Sea pens whips	0.003	0.001	0.001	0.000	0.001	0.000	0.000	0.001	0.006	0.000
Sea star	0.078	0.037	0.023	0.005	0.016	0.036	0.029	0.036	0.053	0.039
Snails	0.028	0.061	0.035	0.022	0.045	0.097	0.057	0.024	0.025	0.034
Sponge unidentified	0.001	0.013	0.001	0.000	0.013	0.006	0.000	0.005	0.002	0.001
State-managed Rockfish	NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stichaeidae	0.099	0.047	0.002	0.000	0.008	0.005	0.002	0.000	0.000	0.030
urchins dollars cucumbers	0.027	0.023	0.035	0.006	0.025	0.006	0.014	0.019	0.070	0.007

Table 9.24. Non-target seabird catch in the directed flathead sole fishery as a proportion of total non-target catch of each species in the BSAI by counts. Conditional highlighting from white (lowest numbers) to green (highest numbers) is applied. “NA” indicates that no catch of the species occurred in that year.

Bycatch Species	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Birds - Auklets	NA	NA	NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Birds - Black-footed Albatross	0.000	0.000	0.000	NA	0.000	0.000	0.000	NA	NA	NA
Birds - Cormorant	NA	NA	NA	NA	NA	NA	0.000	NA	NA	NA
Birds - Gull	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Birds - Kittiwake	0.000	NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Birds - Laysan Albatross	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Birds - Murre	0.000	0.000	0.000	0.000	0.000	0.000	NA	0.000	0.000	NA
Birds - Northern Fulmar	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Birds - Other	0.000	NA	NA	NA	NA	NA	NA	NA	0.000	NA
Birds - Other Alcid	0.000	NA	NA	NA	NA	NA	NA	NA	NA	0.000
Birds - Puffin	NA	0.000	NA	NA	NA	NA	NA	0.000	NA	NA
Birds - Shearwaters	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Birds - Short-tailed Albatross	NA	0.000	0.000	NA	NA	0.000	NA	NA	NA	NA
Birds - Storm Petrels	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.000
Birds - Unidentified	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Birds - Unidentified Albatross	NA	NA	NA	NA	NA	0.000	NA	NA	NA	NA

Table 9.25. Proportion of BSAI prohibited species catch that comes from the BSAI flathead sole directed fishery. PSCNQ estimate is reported in metric tons for halibut and herring and in counts of fish for crab and salmon.

PSC Species	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Bairdi Tanner Crab	0.04	0.09	0.03	0.05	0.08	0.07	0.05	0.03	0.03	0.10
Blue King Crab	0.08	0.00	0.00	0.00	0.05	0.00	0.02	0.00	0.00	0.00
Chinook Salmon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Golden (Brown) King Crab	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00
Halibut	0.03	0.03	0.01	0.01	0.02	0.02	0.01	0.01	0.00	0.02
Herring	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-Chinook Salmon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Opilio Tanner (Snow) Crab	0.13	0.04	0.06	0.04	0.11	0.17	0.03	0.05	0.09	0.18
Red King Crab	0.01	0.01	0.03	0.01	0.01	0.00	0.00	0.01	0.00	0.00

Table 9.26. Proportion of BSAI halibut mortality as prohibited species catch that comes from the BSAI flathead sole directed fishery

Year	Proportion of Halibut Mortality
2009	0.0493
2010	0.0536
2011	0.0217
2012	0.0229
2013	0.0361
2014	0.0343
2015	0.0204
2016	0.0247
2017	0.0324
2018	0.0680

Figures

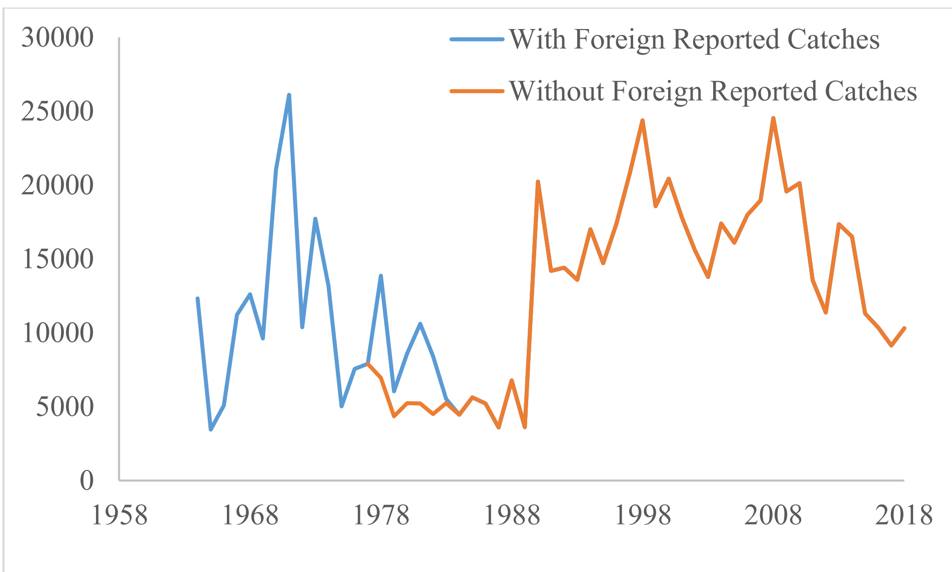


Figure 9.1. Combined catch (in metric tons) of flathead sole and Bering flounder (*Hippoglossoides* spp.) by year in total and for CDQ and non-CDQ fisheries combined. The 2018 assessment data included foreign reported catches for the first time. 1983 was the last year of foreign reported catches.

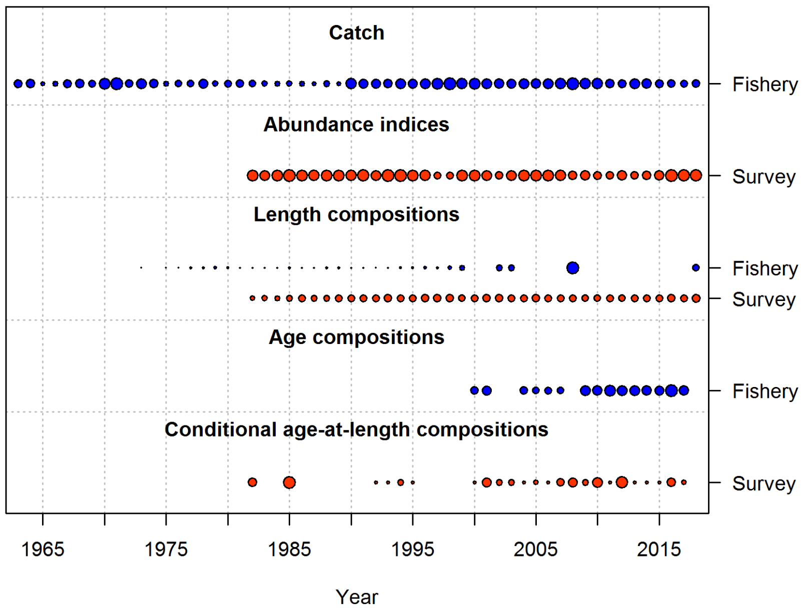


Figure 9.2. Data used in the assessment model, with sizes of circles indicating the relative catches or biomass for fishery catch or survey biomass (listed as "Abundance indices"), respectively, and indicating precision for the length and age composition data included. Circles are relative to the maximum value within each data source.

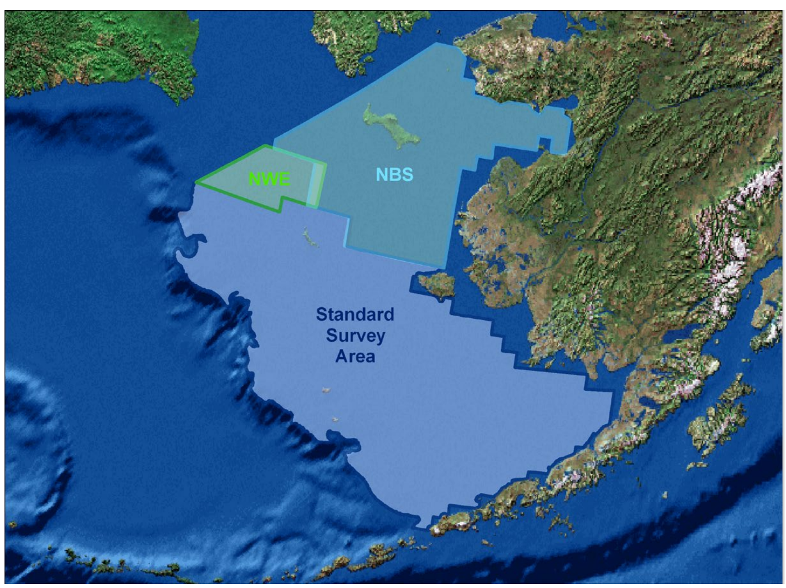
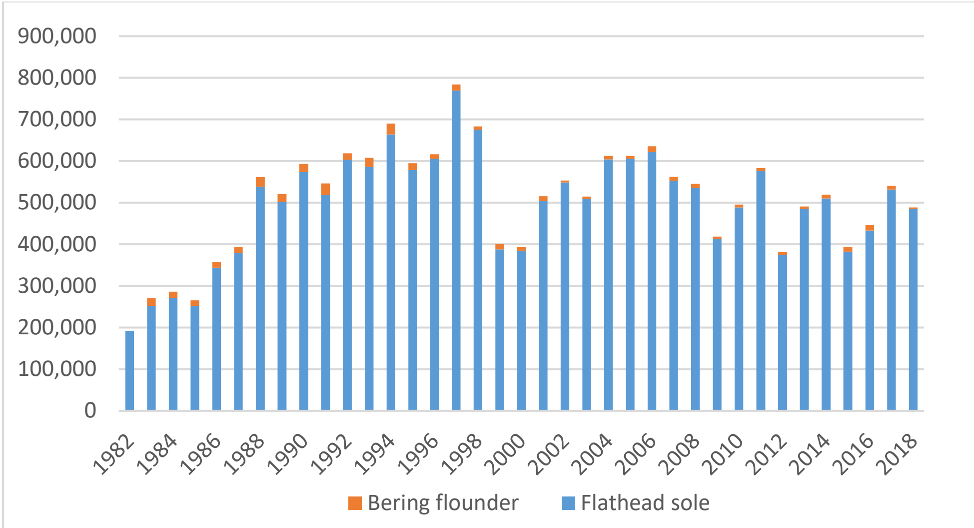


Figure 9.3. Eastern Bering Sea shelf survey areas. Only data from the standard survey area are used in the assessment model; data from the Northwest Extension (NWE) and Northern Bering Sea (NBS) are excluded.



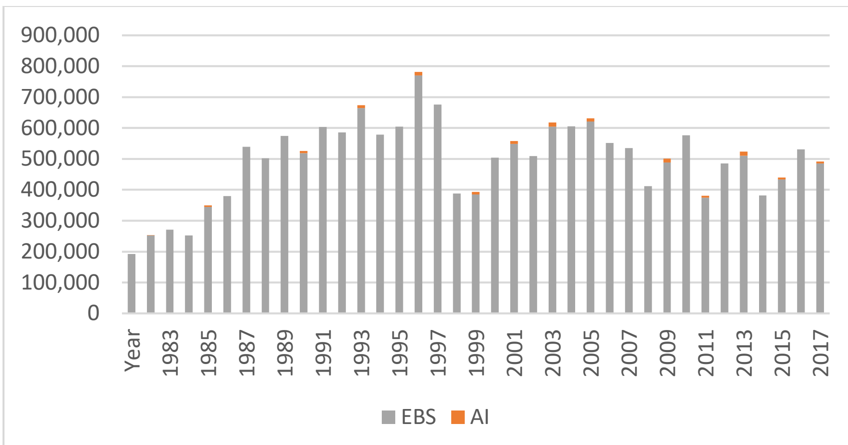


Figure 9.4. Flathead sole and Bering flounder biomass in the EBS shelf survey (top panel). Flathead sole (only) survey biomass from the EBS shelf survey and the Aleutian Islands survey (bottom panel).

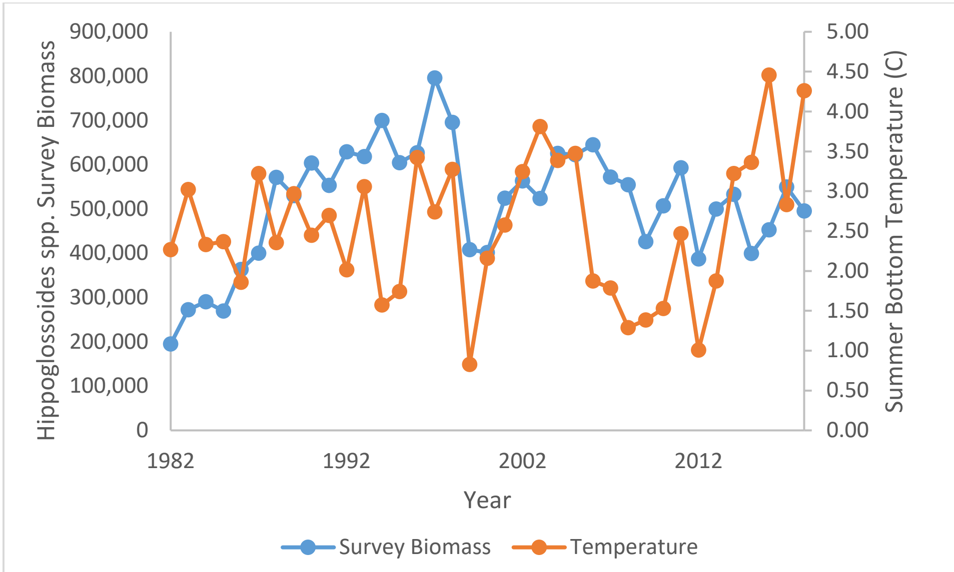


Figure 9.5. *Hippoglossoides* spp. survey biomass index and mean bottom temperatures (deg C) from the EBS shelf survey for station depths less than or equal to 200 meters.

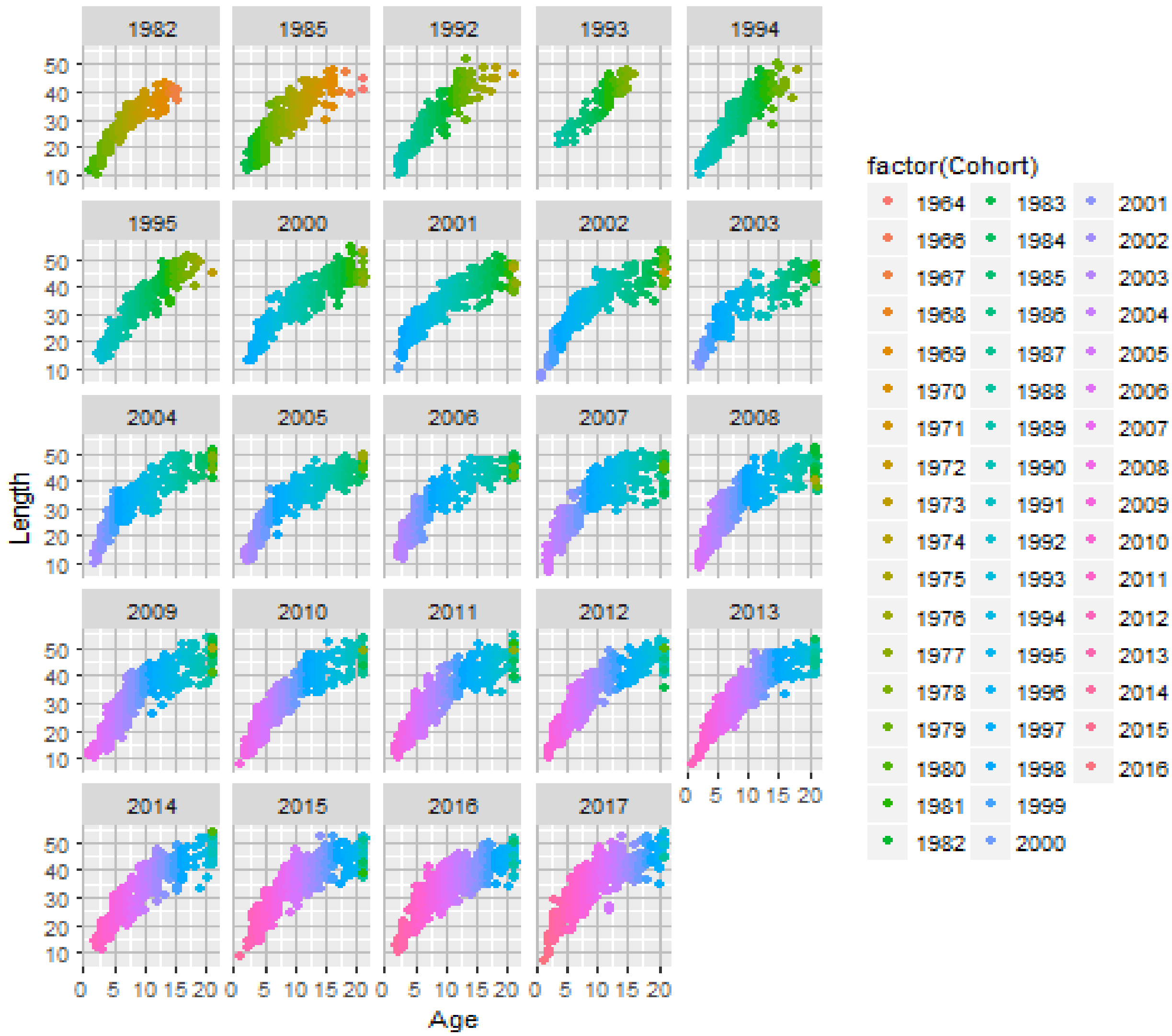


Figure 9.6. EBS shelf survey length-at-age data by cohort and year for females and for flathead sole only.

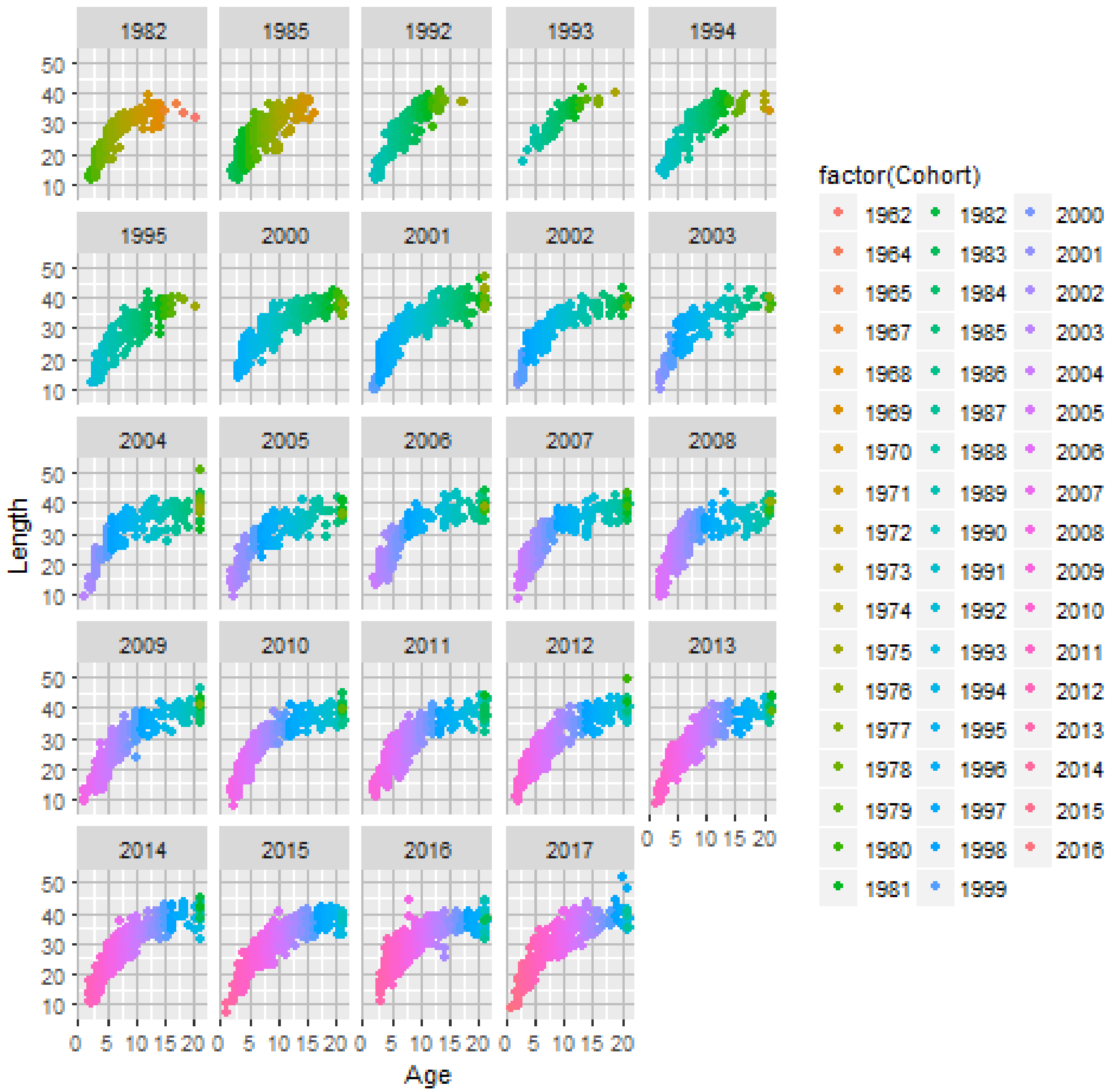


Figure 9.7. EBS shelf survey length-at-age data by cohort and year for males and for flathead sole only.

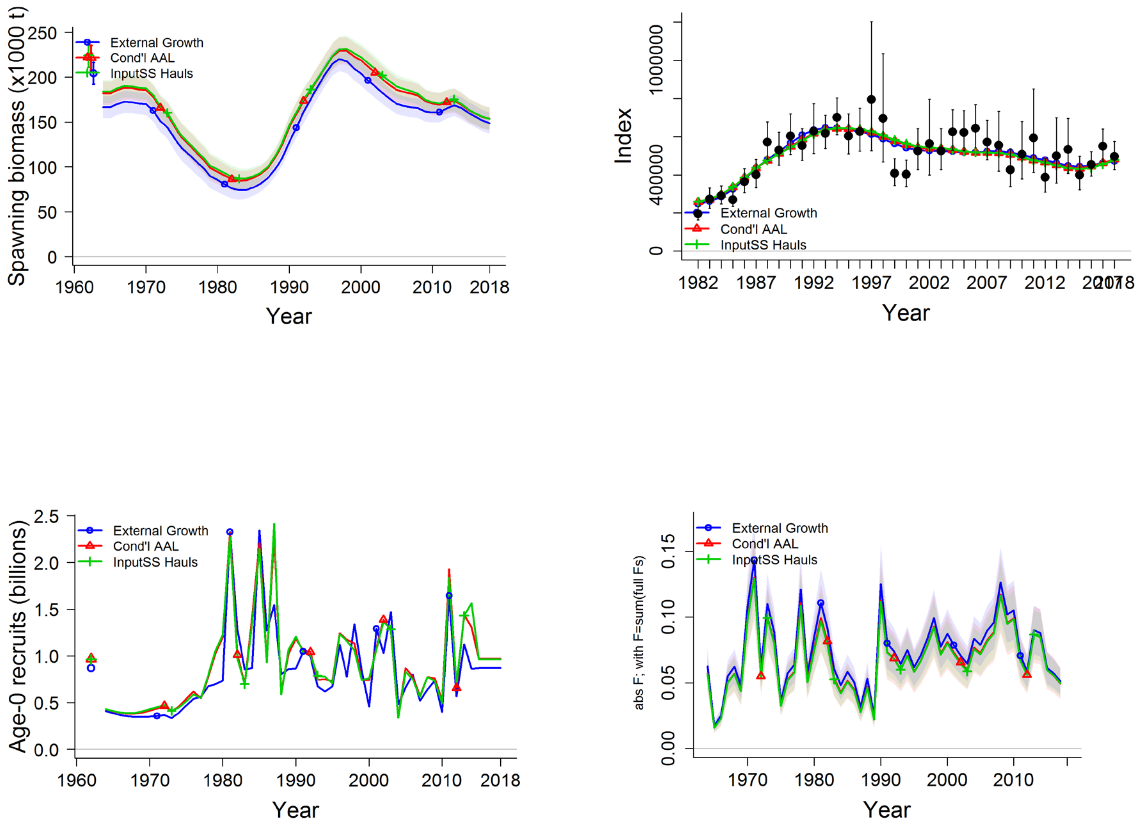


Figure 9.8. A comparison of spawning biomass (top left), fits to survey biomass (top right), recruitment (bottom left), and fishing mortality (bottom right) for Models 18.0 (growth estimated outside the assessment model), 18.1 (growth estimated within the assessment model), and 18.2 (growth estimated within the assessment model, input sample size for comp data equal to the number of hauls represented in the data each year). All three models estimate time-invariant fishery selectivity.

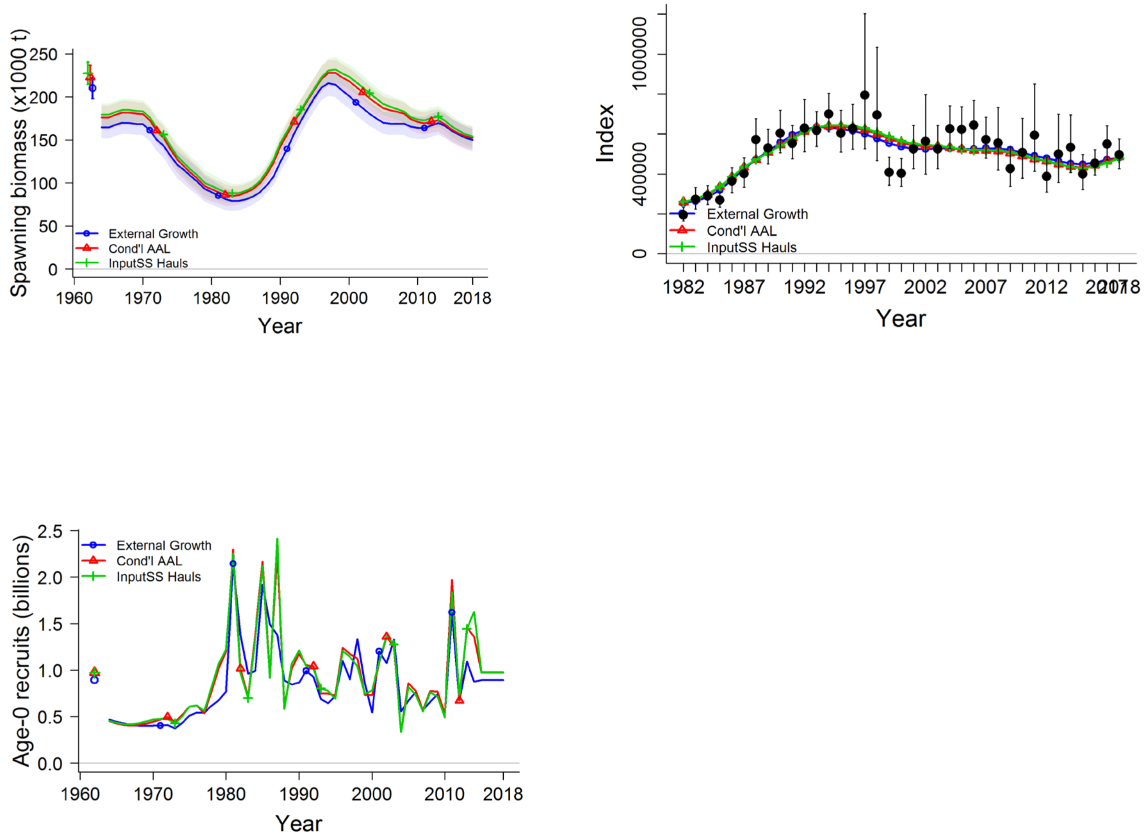


Figure 9.9. A comparison of spawning biomass (top left), fits to survey biomass (top right), and recruitment (bottom left) for Models 18.0b (blue lines; growth estimated outside the assessment model), 18.1b (red lines; growth estimated within the assessment model), and 18.2b (green lines; growth estimated within the assessment model, input sample size for comp data equal to the number of hauls represented in the data each year). All three models estimate separate selectivity curves for the time periods 1964-1987, 1987-2007, and 2008-present.

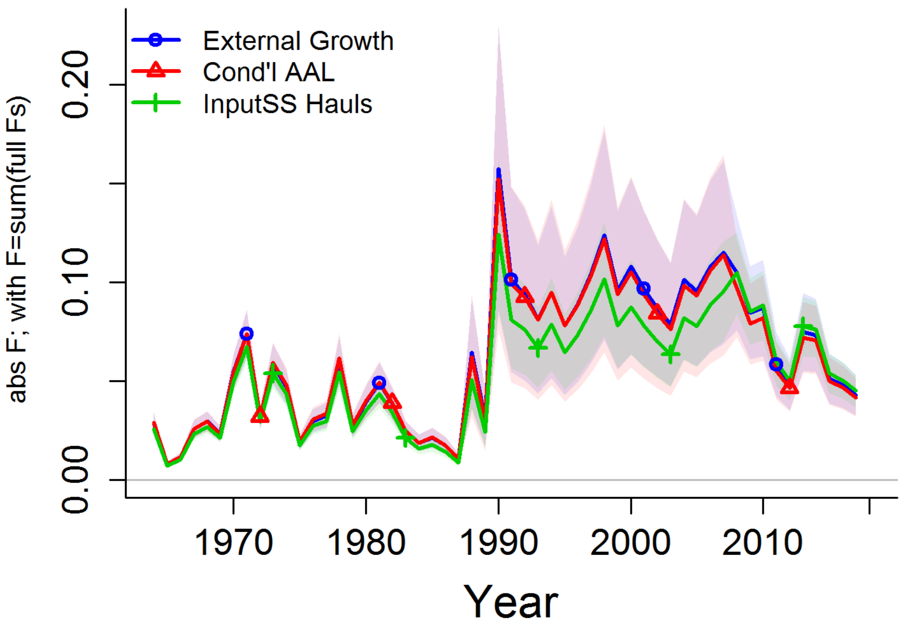


Figure 9.10. A comparison of fishing mortality for Models 18.0b (growth estimated outside the assessment model), 18.1b (growth estimated within the assessment model), and 18.2b (growth estimated within the assessment model, input sample size for comp data equal to the number of hauls represented in the data each year). All three models estimate separate selectivity curves for the time periods 1964-1987, 1987-2007, and 2008-present. The uncertainty bounds for fishing mortality in the middle time period was reduced substantially when the number of hauls represented in the data was used as the relative input sample size for length and age compositions (green line and shading).

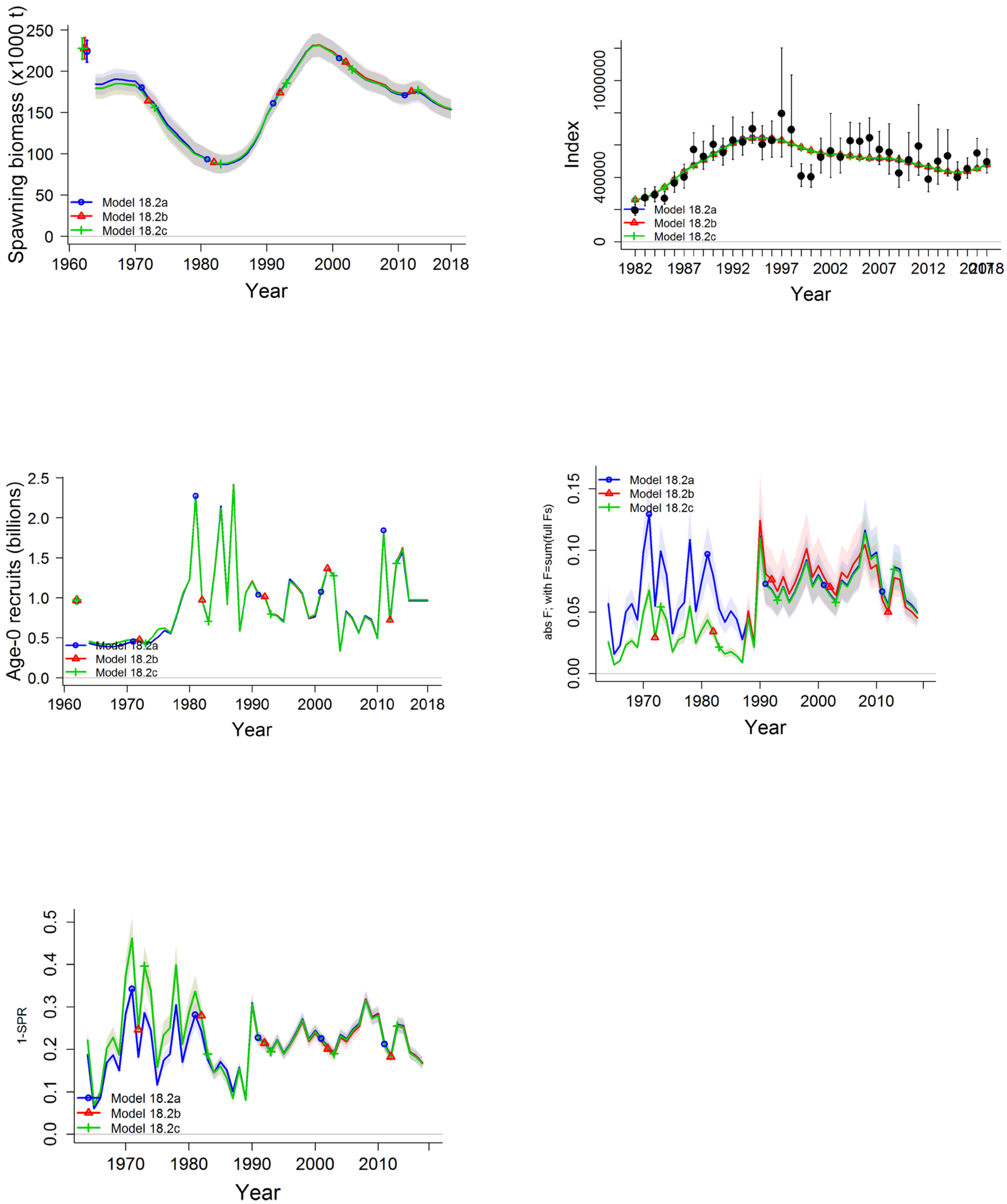


Figure 9.11. A comparison of spawning biomass (top left), survey biomass (top right), recruitment (second row left), fishing mortality (second row right), and 1-SPR (1-spawning potential ratio; bottom left) for Models 18.2 (time-invariant fishery selectivity), 18.2b (fishery selectivity estimated for 3 time periods), and 18.2c (fishery selectivity estimated for 2 time periods).

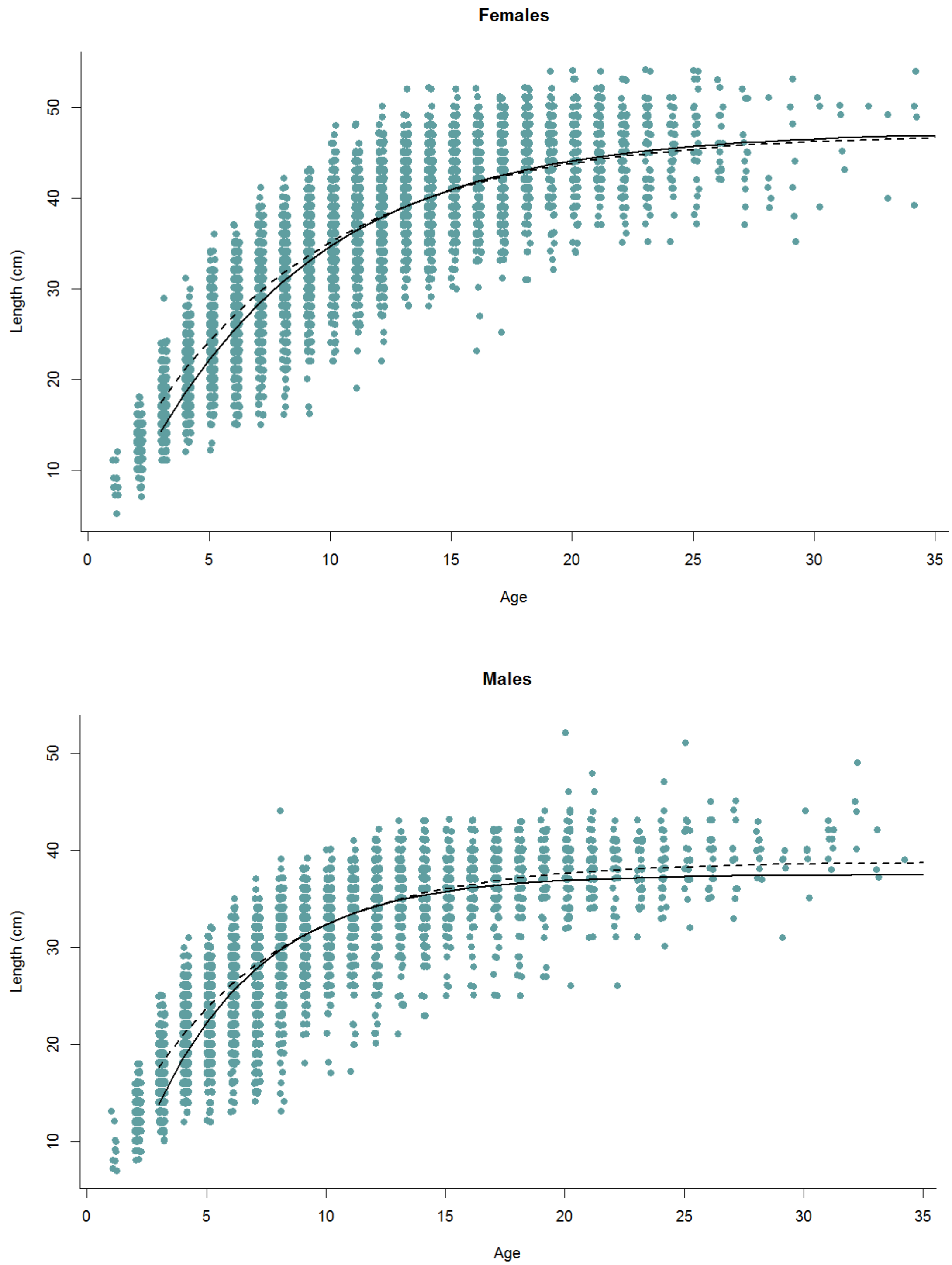


Figure 9.12. Length-at-age data aggregated over all years (blue dots), fits to the data as estimated externally and used in the 2018 version of the old model and in Models 18.0 and 18.0b (dotted lines), and fits to the data as estimated within the assessment model (solid lines; results for Model 18.2c are shown, but estimates are nearly identical for Models 18.1, 18.1b, 18.2, and 18.2b).

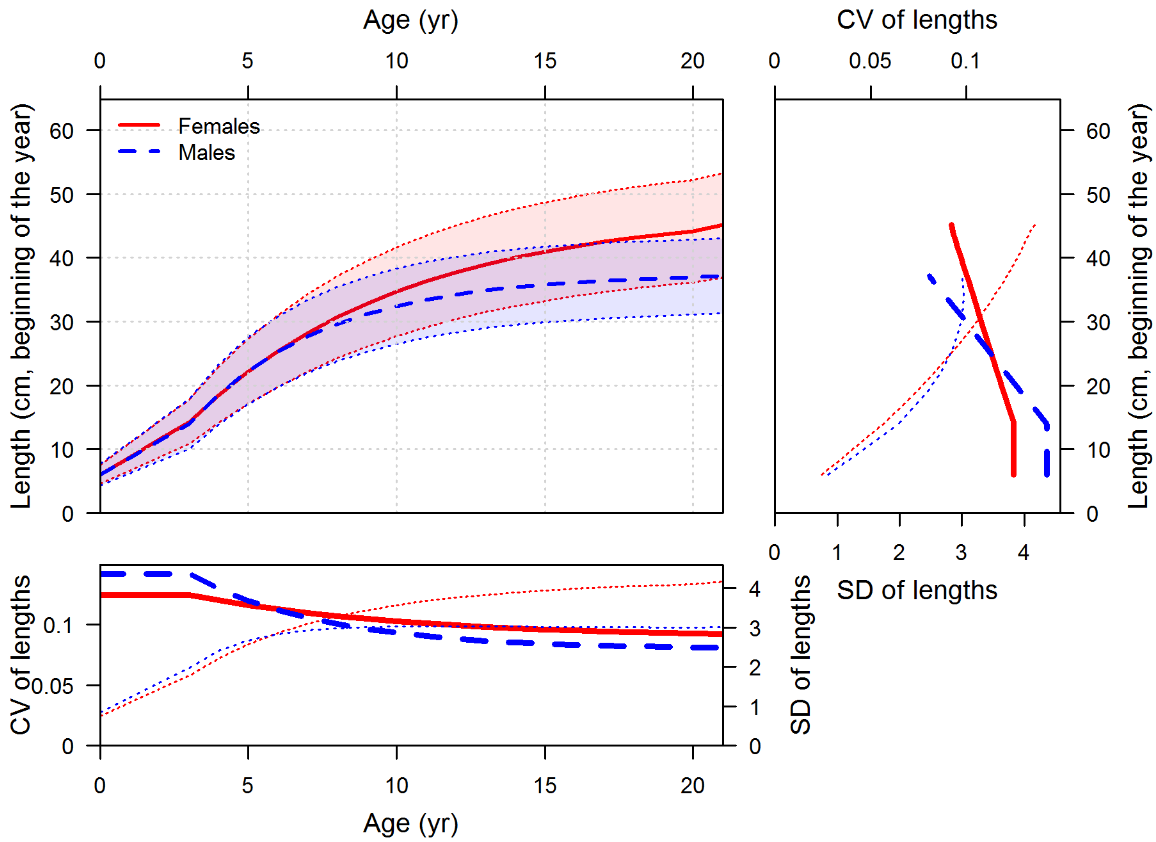


Figure 9.13. Estimated length-at-age and variability in length-at-age for Model 18.2c, as well as estimates of CV in length-at-age over ages (bottom plot) and lengths (right plot) and translation into standard deviations of lengths. Thick lines are CVs and thin dotted lines are standard devations. Red indicates females and blue indicates males.

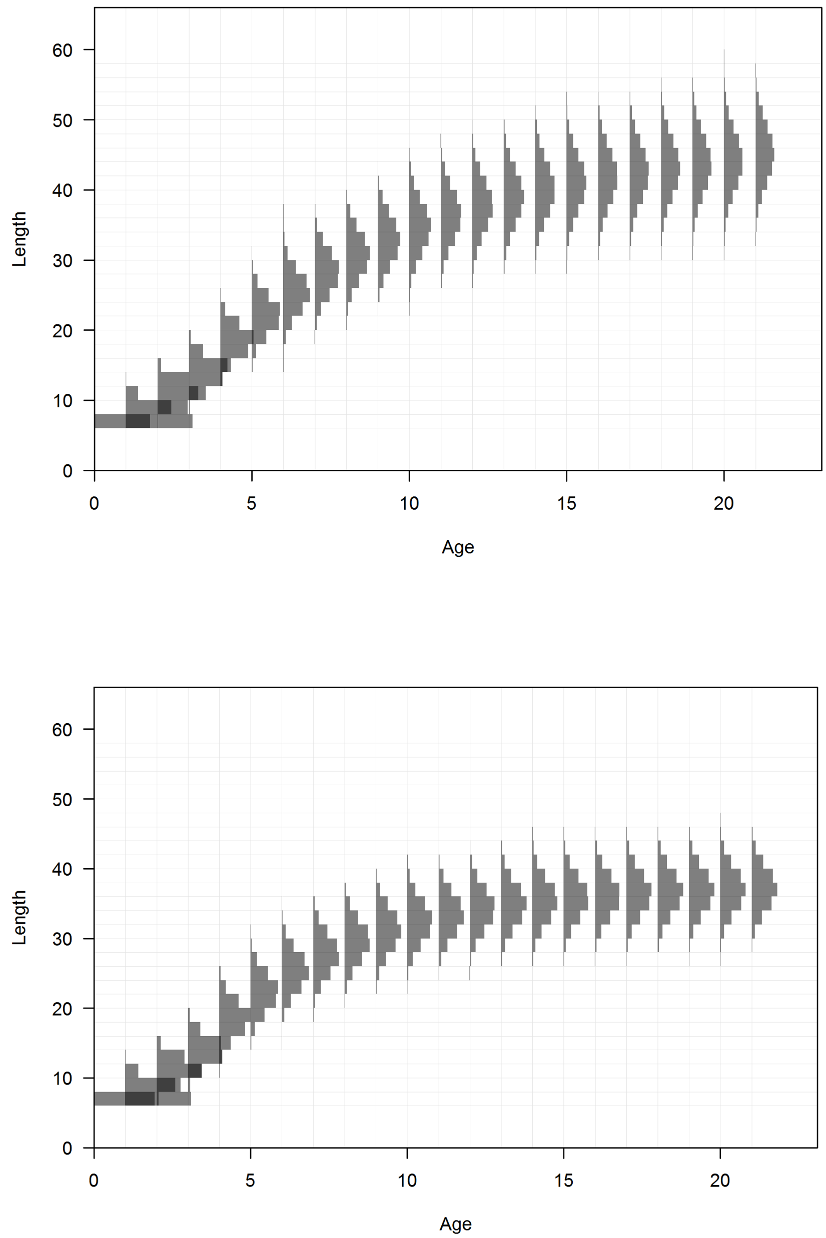


Figure 9.14. Estimated distribution of lengths at each age for females (upper panel) and males (lower panel) for Model 18.2c.

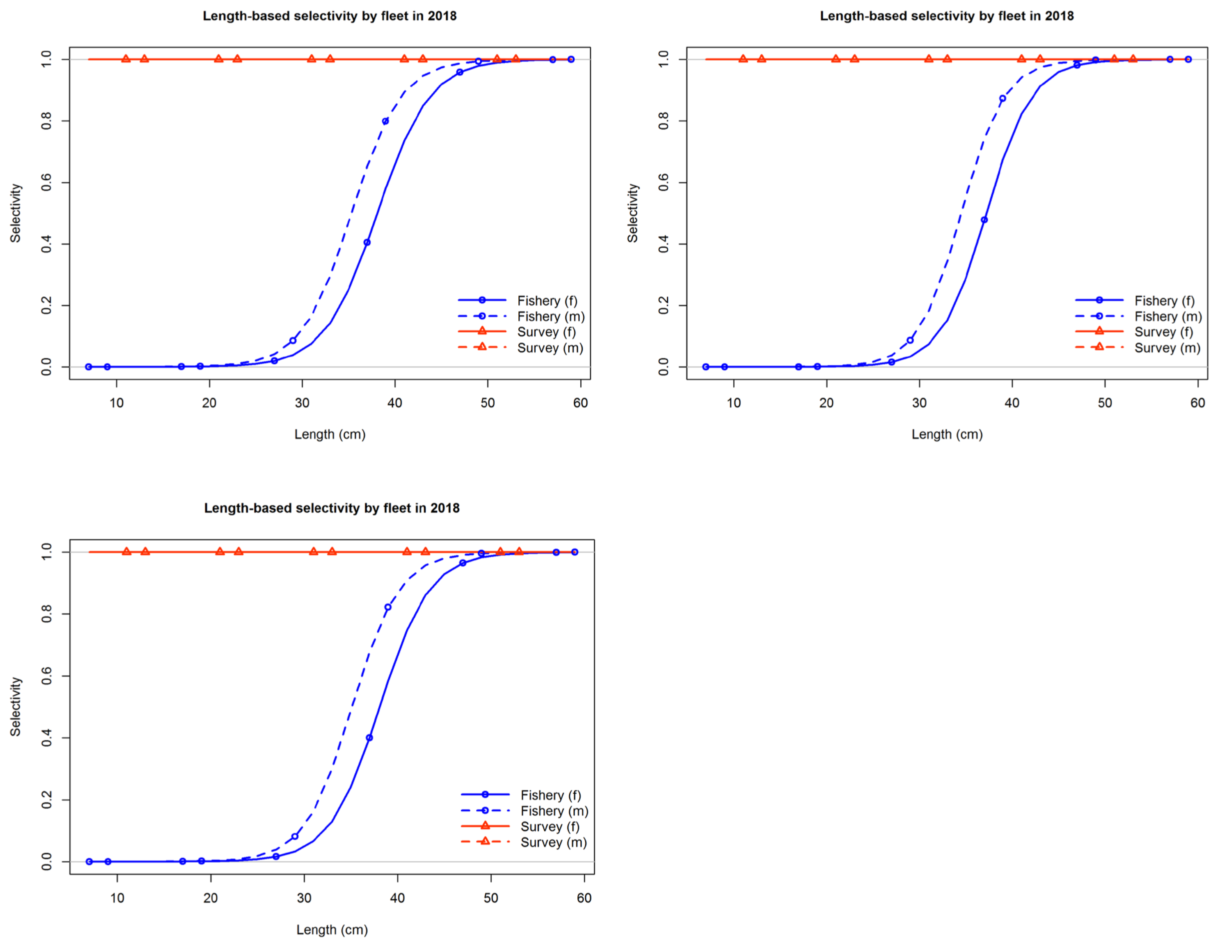


Figure 9.15. A comparison of fishery selectivity curves in the end year of the model (2018) for Models 18.2 (time-invariant fishery selectivity; top left), 18.2b (fishery selectivity estimated for 3 time periods; top right), and 18.2c (fishery selectivity estimated for 2 time periods; bottom left).

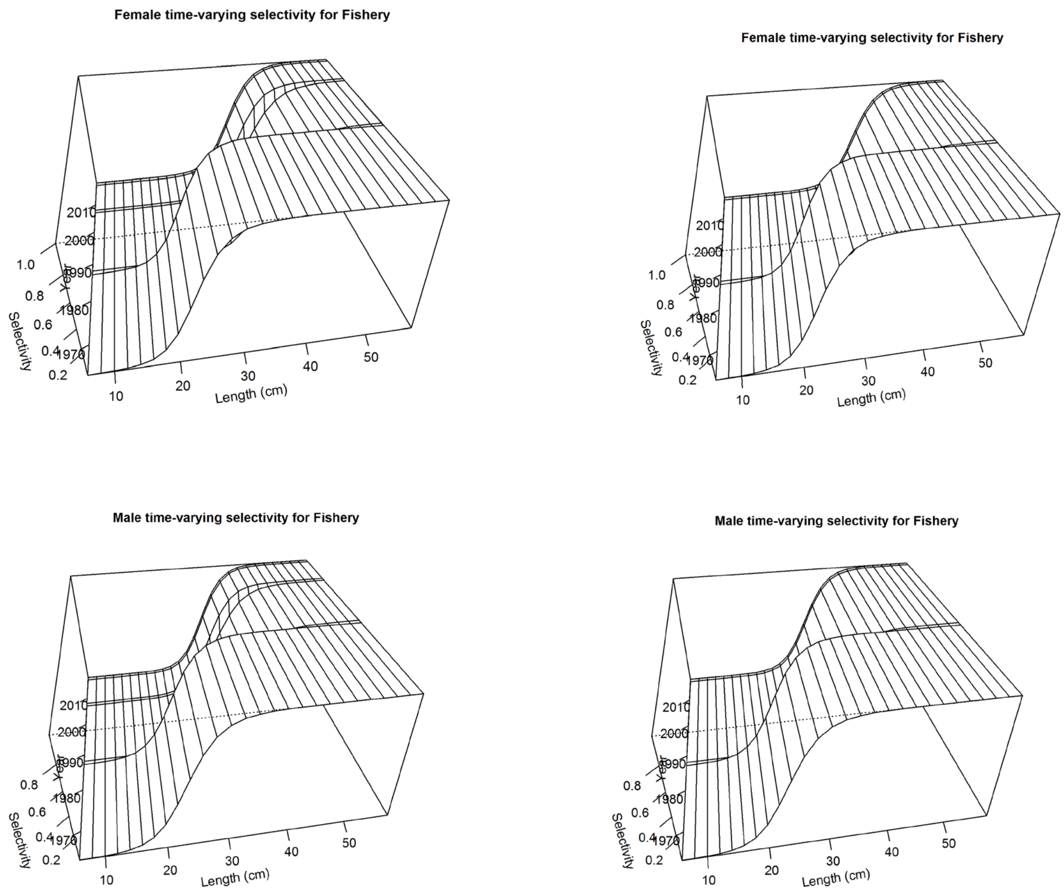


Figure 9.16. A comparison of fishery selectivity curves in the end year of the model (2018) for Models 18.2b (fishery selectivity estimated for 3 time periods; left panels), and 18.2c (fishery selectivity estimated for 2 time periods; right panels) for females (top panels) and males (bottom panels).

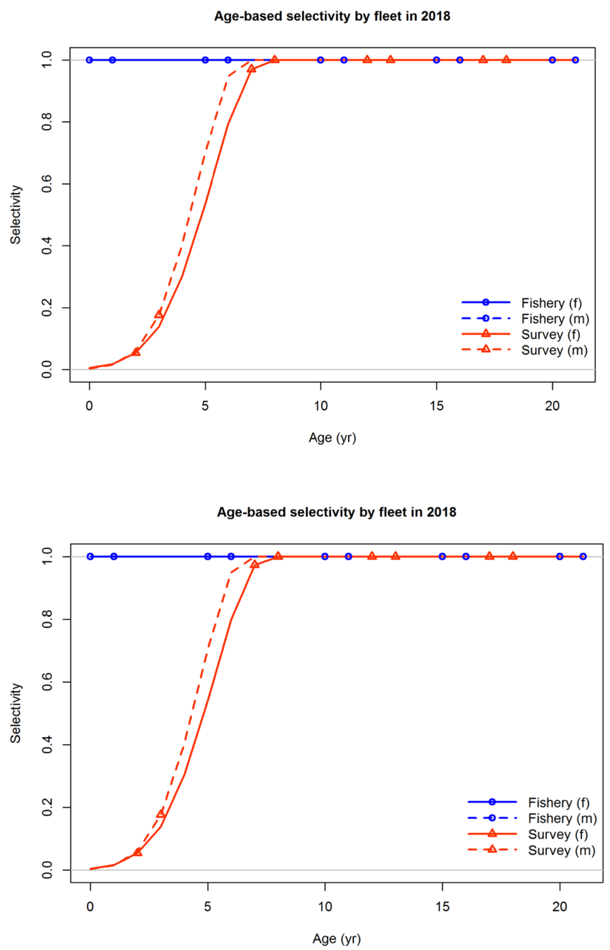
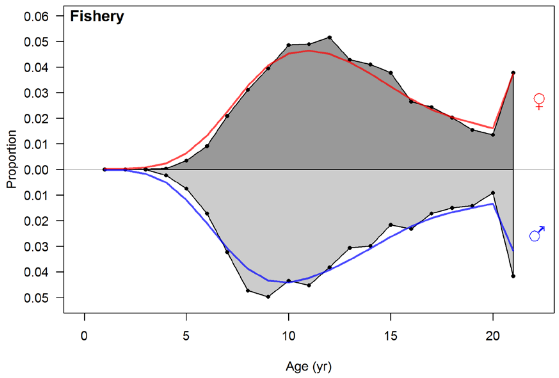
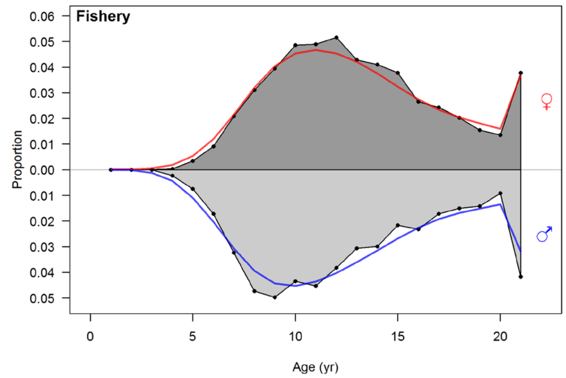


Figure 9.17. A comparison of survey selectivity curves for Models 18.0 (time-invariant fishery selectivity; top left), 18.2b (fishery selectivity estimated for 3 time periods; top right), and 18.2c (fishery selectivity estimated for 2 time periods; bottom left).





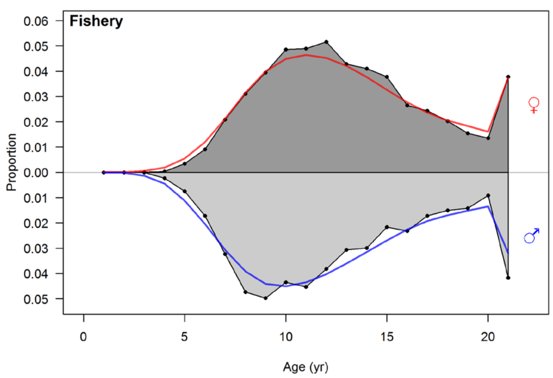


Figure 9.18. A comparison of fits to fishery age data, aggregated across time, for Models 18.2 (time-invariant fishery selectivity; top left), 18.2b (fishery selectivity estimated for 3 time periods; top right), and 18.2c (fishery selectivity estimated for 2 time periods; bottom left).

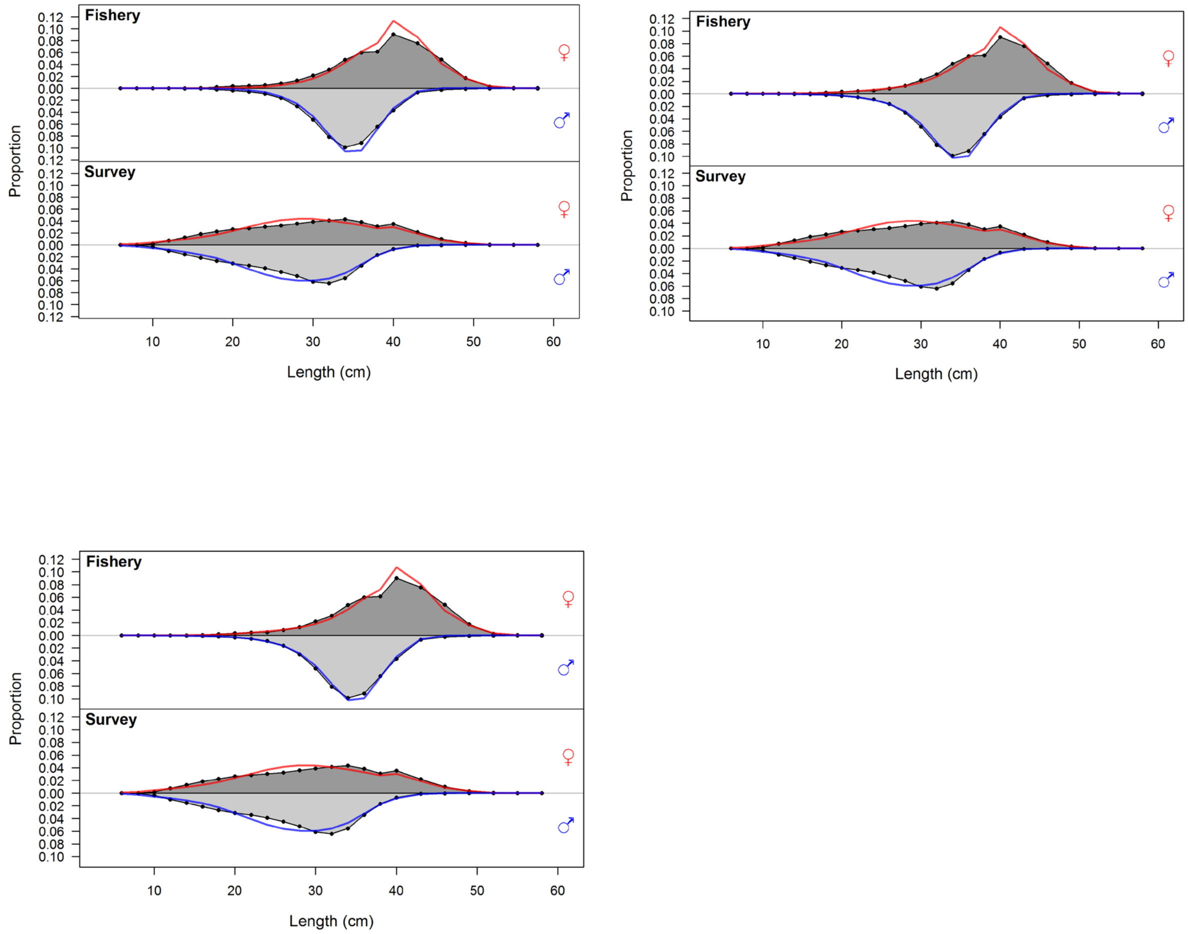
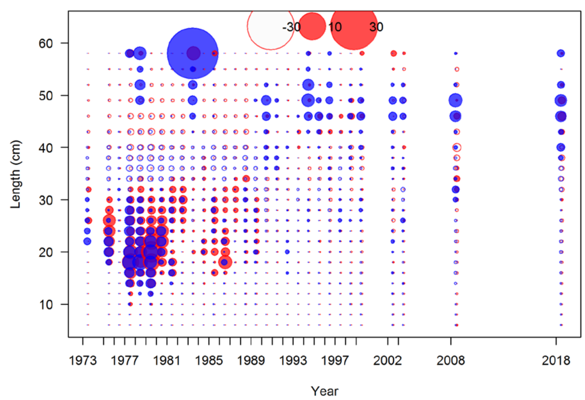
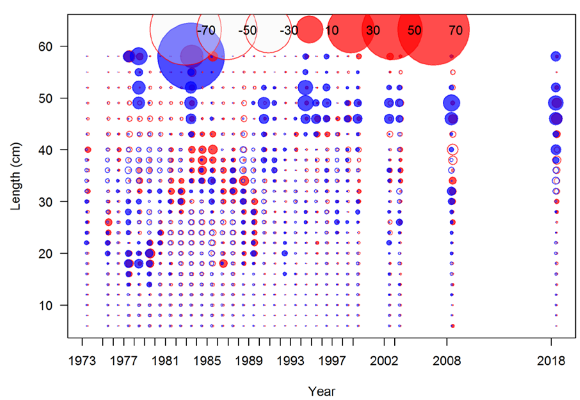


Figure 9.19. A comparison of fits to fishery and survey length composition data, aggregated across time, for Models 18.2 (time-invariant fishery selectivity; top left), 18.2b (fishery selectivity estimated for 3 time periods; top right), and 18.2c (fishery selectivity estimated for 2 time periods; bottom left).





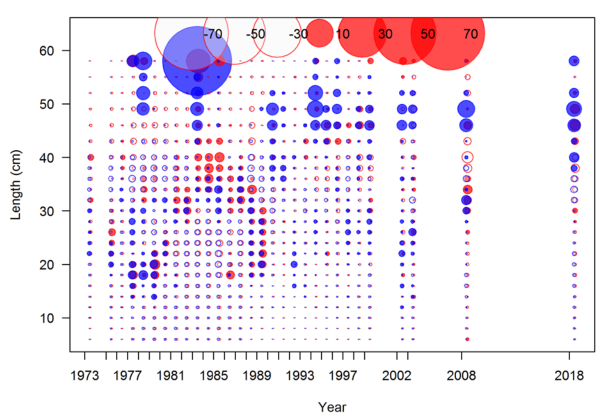
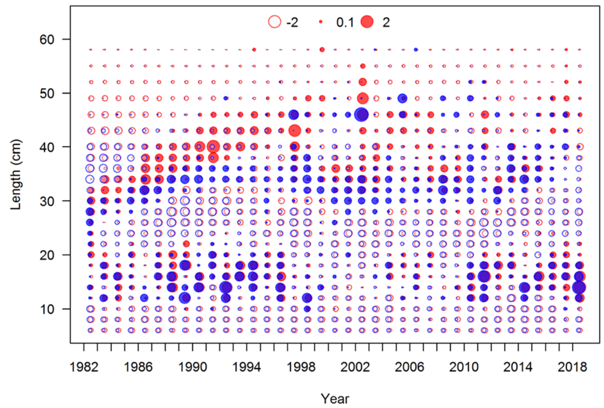
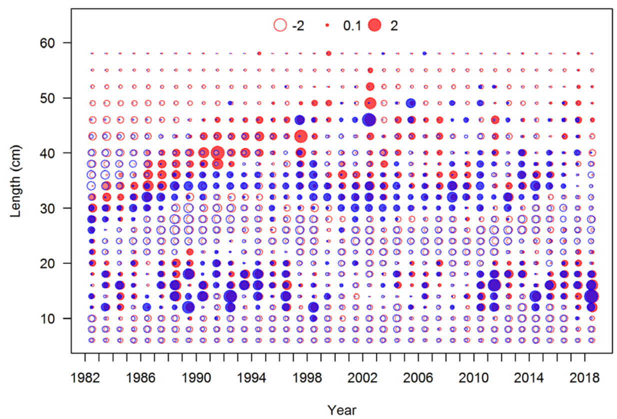


Figure 9.20. A comparison of Pearson residuals showing fits to fishery length composition data for Models 18.2 (time-invariant fishery selectivity; top left), 18.2b (fishery selectivity estimated for 3 time periods; top right), and 18.2c (fishery selectivity estimated for 2 time periods; bottom left). Red bubbles along the top of the plots show the scale. Filled circles are positive residuals (observed > expected) and open circles are negative residuals (observed < expected), blue indicates males and red indicates females. Circles across the top of the plots are a legend.





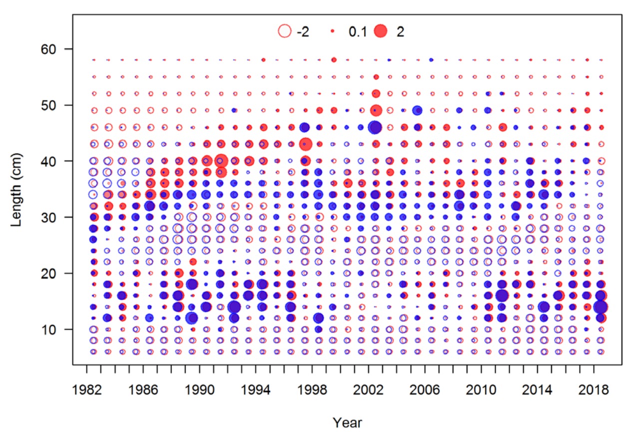


Figure 9.21. A comparison of Pearson residuals showing fits to the survey length composition data for Models 18.2 (time-invariant fishery selectivity; top left), 18.2b (fishery selectivity estimated for 3 time periods; top right), and 18.2c (fishery selectivity estimated for 2 time periods; bottom left). Filled circles are positive residuals (observed > expected) and open circles are negative residuals (observed < expected), blue indicates males and red indicates females. Circles across the top of the plots are a legend.

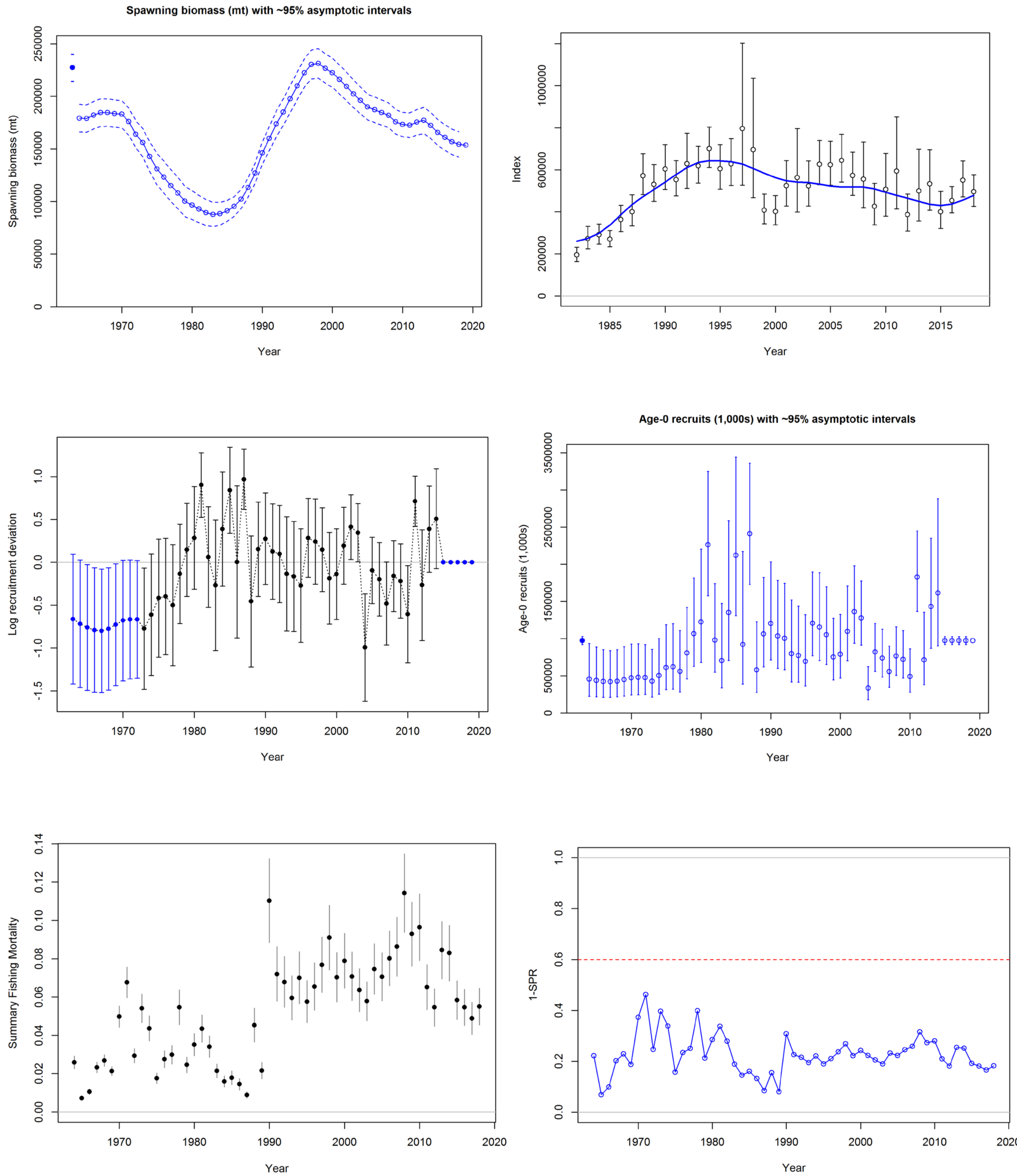


Figure 9.22. Model 18.2c estimated trends over time for spawning biomass (top left), survey biomass (dots) with 95% asymptotic intervals (vertical lines) and model fit to survey biomass (blue line; top right), recruitment deviations in log-space (middle left), age-0 recruits with 95% asymptotic intervals (middle right), apical fishing mortality with 95% asymptotic intervals (bottom left), and 1-spawning potential ratio (bottom right).

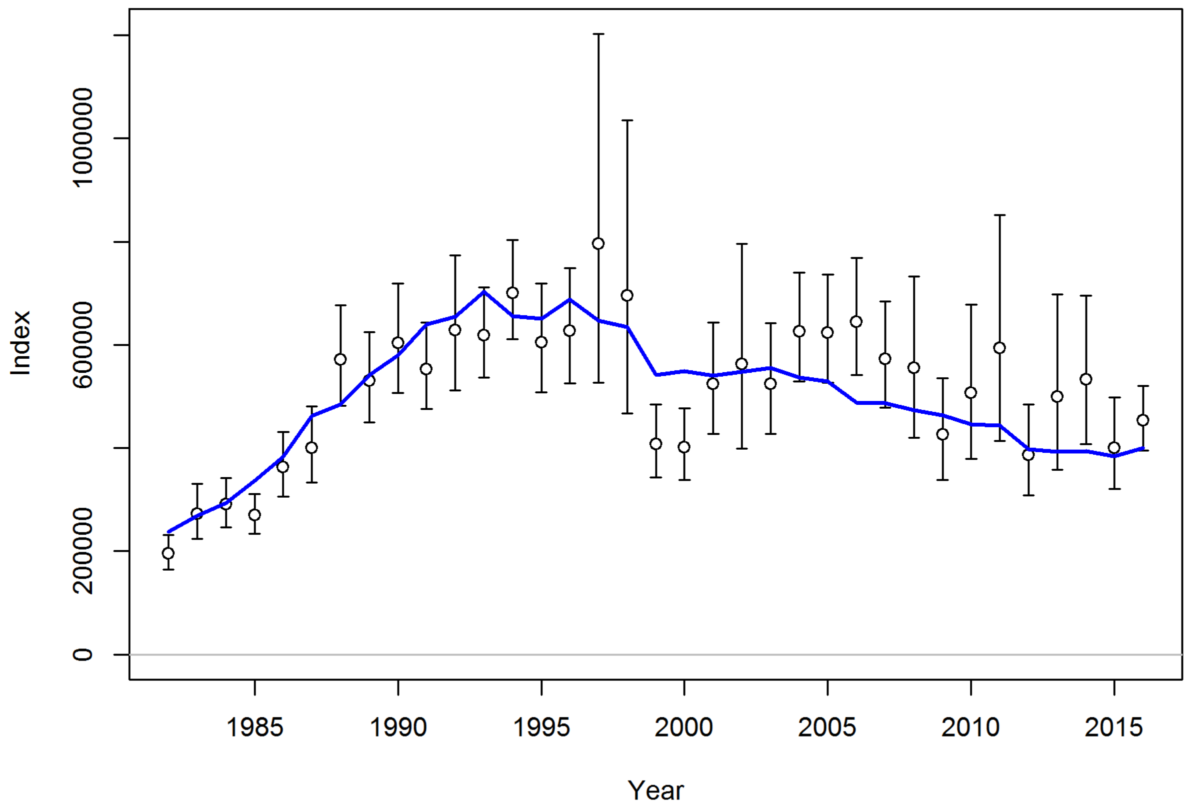
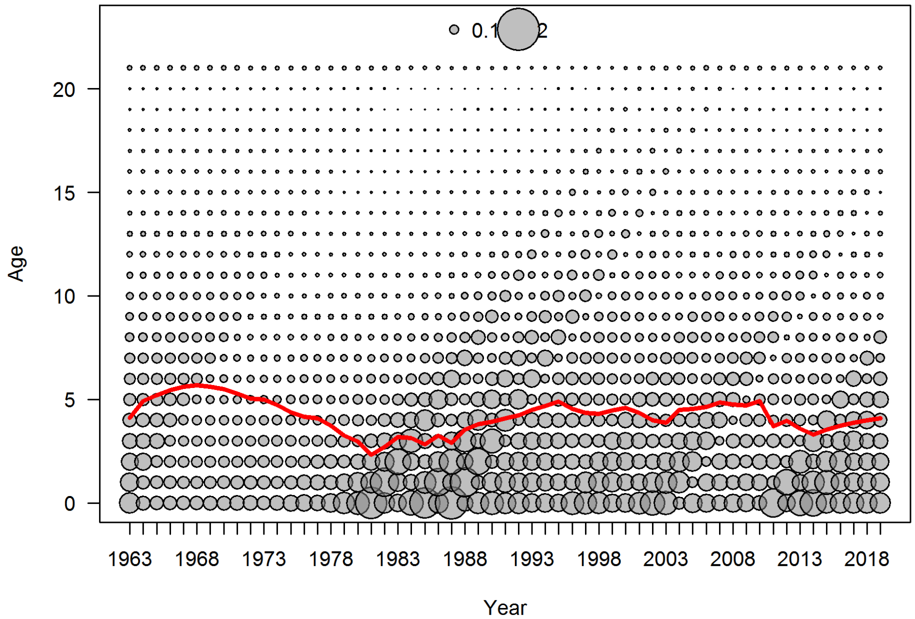


Figure 9.23. Survey biomass index (dots) and model fit to the survey biomass index (blue line) for a preliminary model run including a relationship between temperature and catchability with an estimated parameter determining the magnitude of the linkage. Vertical lines indicate 95% uncertainty interval around index values. Model run was as for Model 18.0, but with a temperature-catchability relationship added.



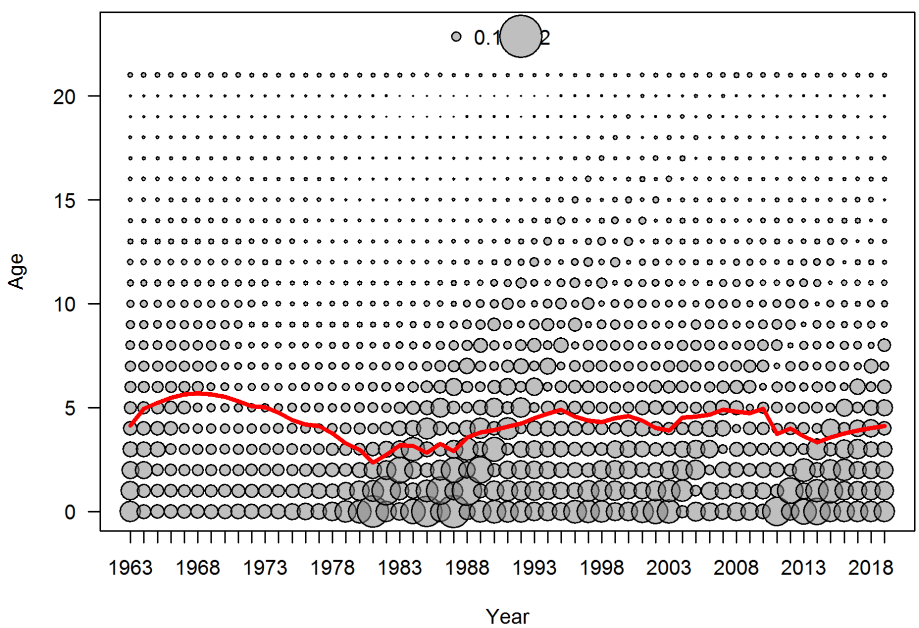


Figure 9.24. Expected numbers-at-age at the beginning of the year for females (top panel) and males (bottom panel) for Model 18.2c. Red lines show expected mean numbers-at-age.

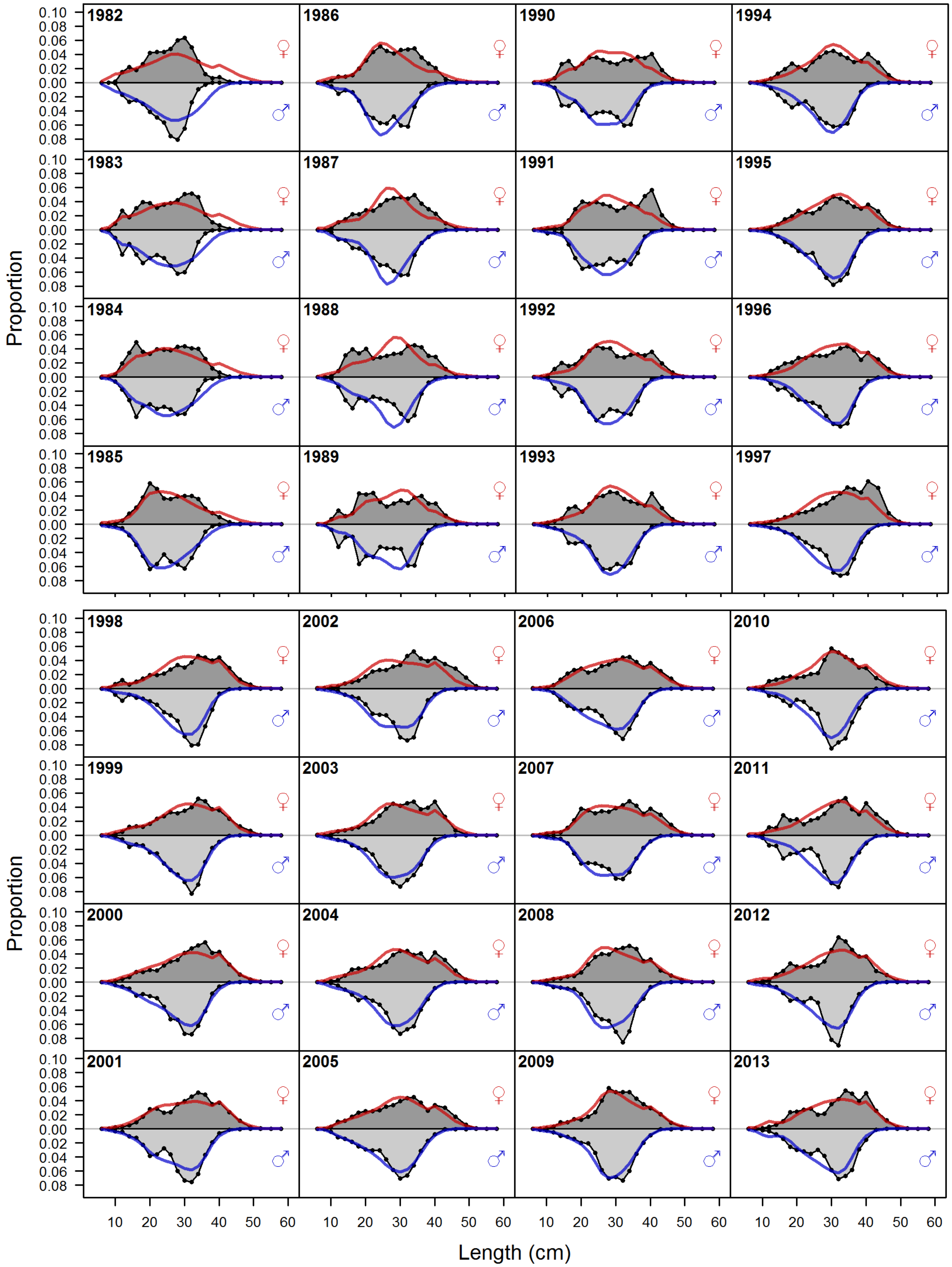


Figure 9.25. Observed (grey filled area and black line) and expected (red and blue lines) survey length compositions for males (blue lines) and females (red lines) for 1982-2013 for Model 18.2c.

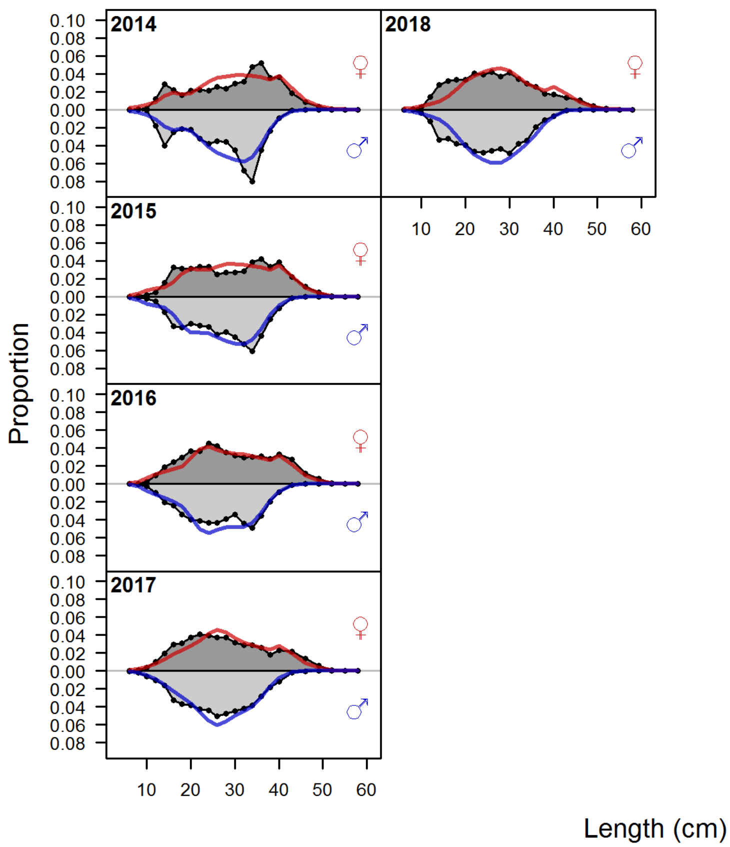


Figure 9.26. As for Figure 9.25, but for 2014-2018.

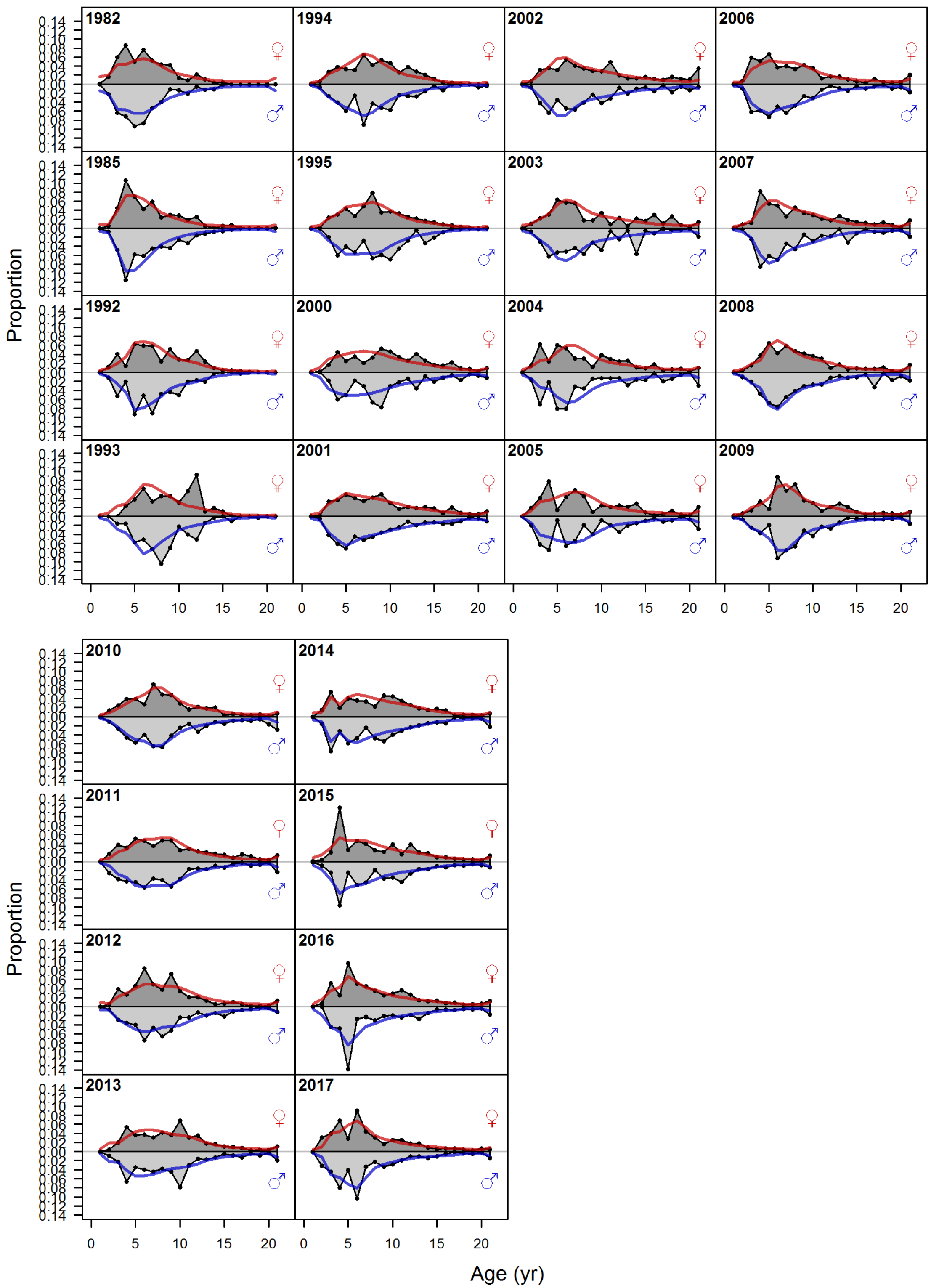


Figure 9.27. Observed (grey filled area and black line) and expected (red and blue lines) ghost survey age compositions for males (blue lines) and females (red lines) for all years of age composition data for Model 18.2c. A conditional age-at-length approach was used for Model 18.2c and age composition aggregated over length bins was not fit in the objective function.

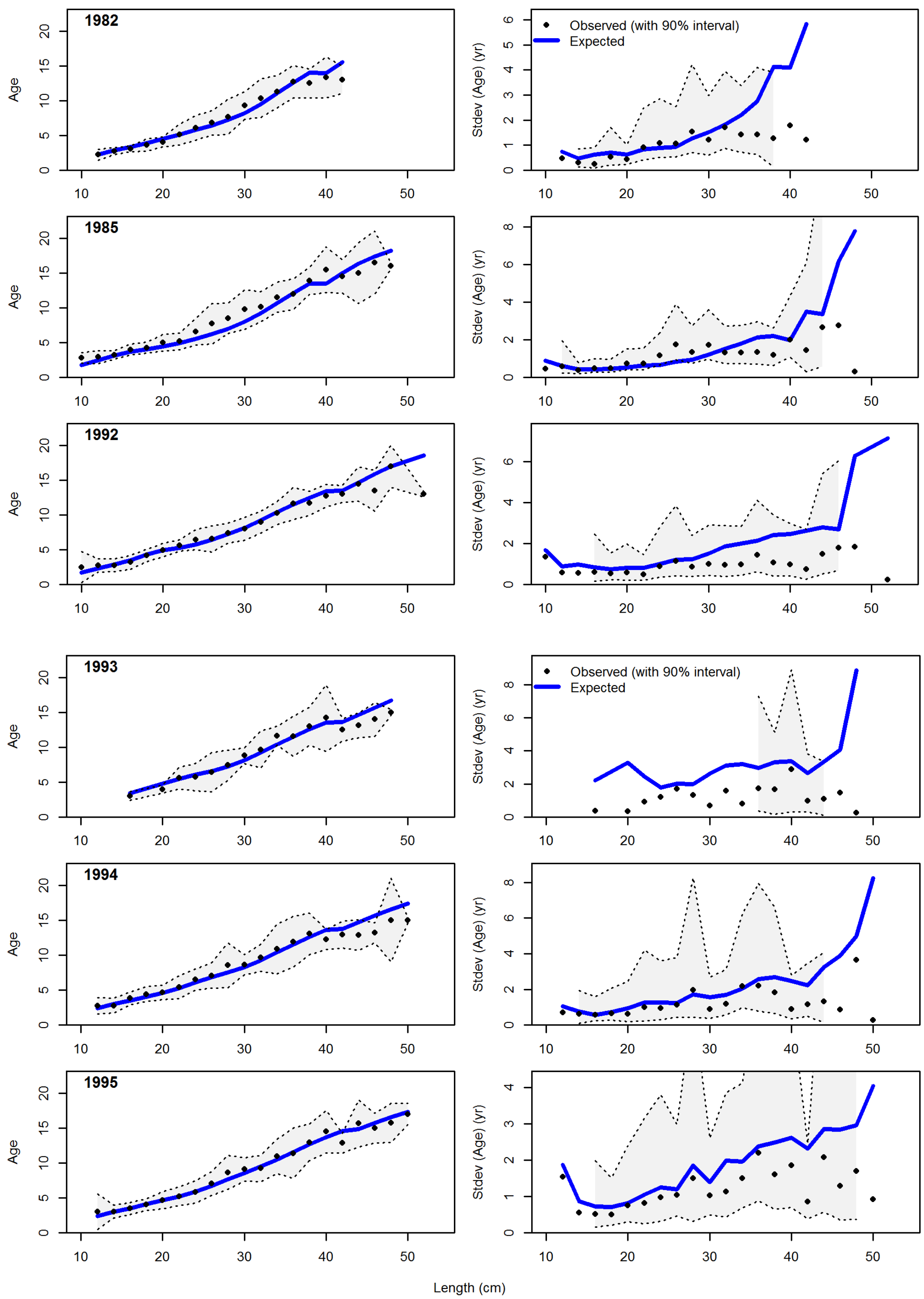


Figure 9.28. Observed and expected mean age-at-length for both females and males with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for Model 18.2c for years 1982-1995.

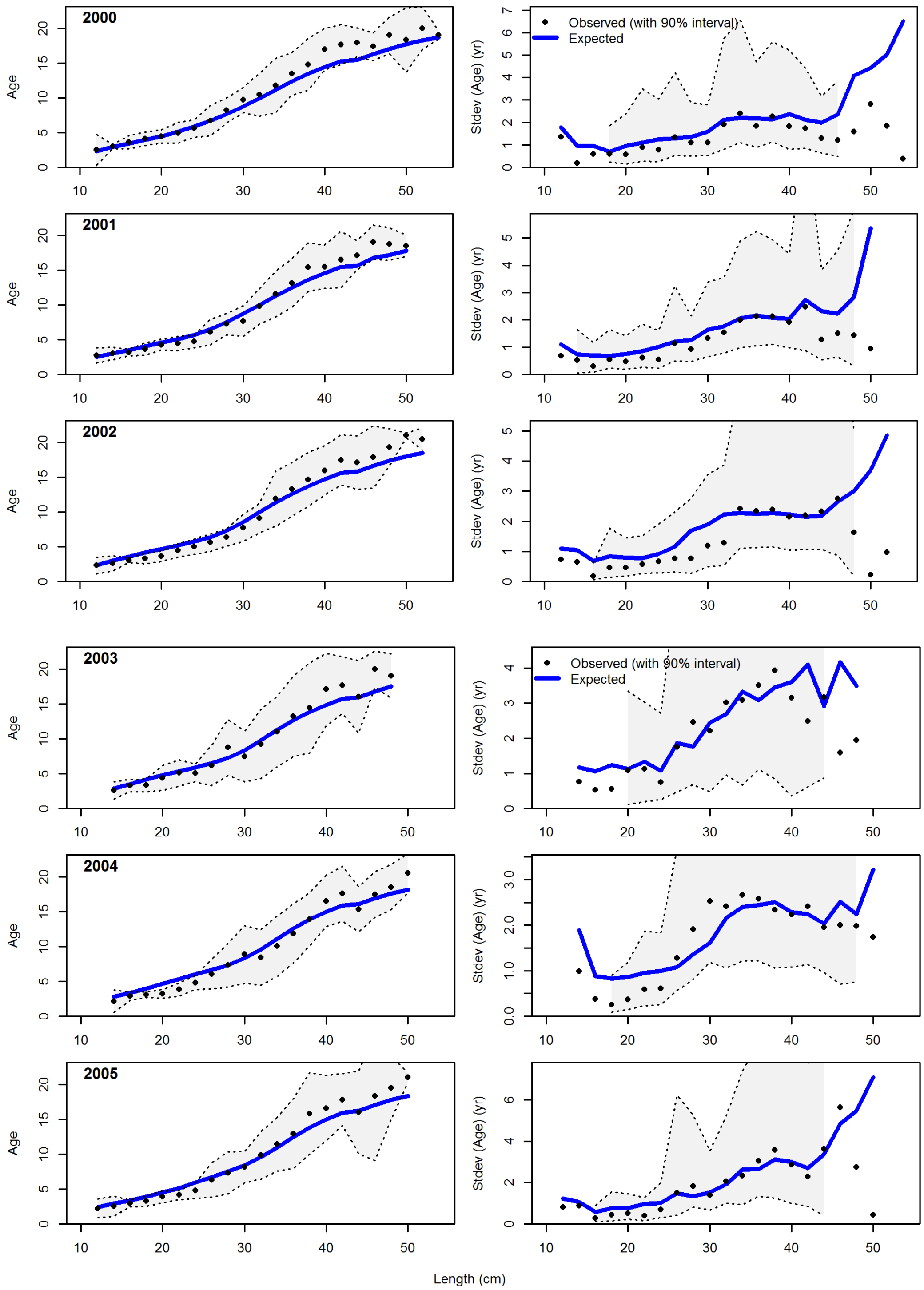


Figure 9.29. As for Figure 9.28, but for years 2000-2005.

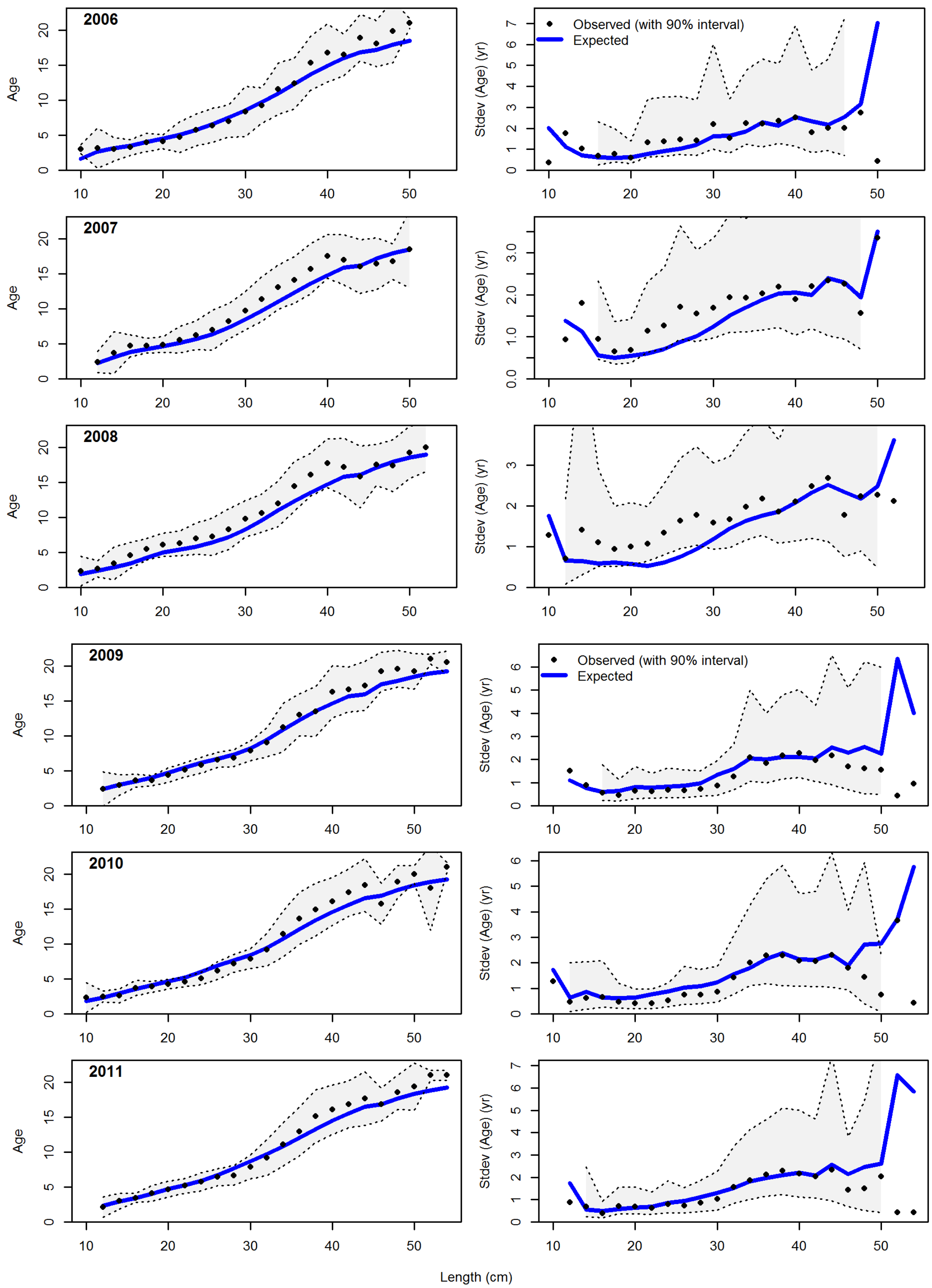


Figure 9.30. As for Figure 9.28, but for years 2006-2011.

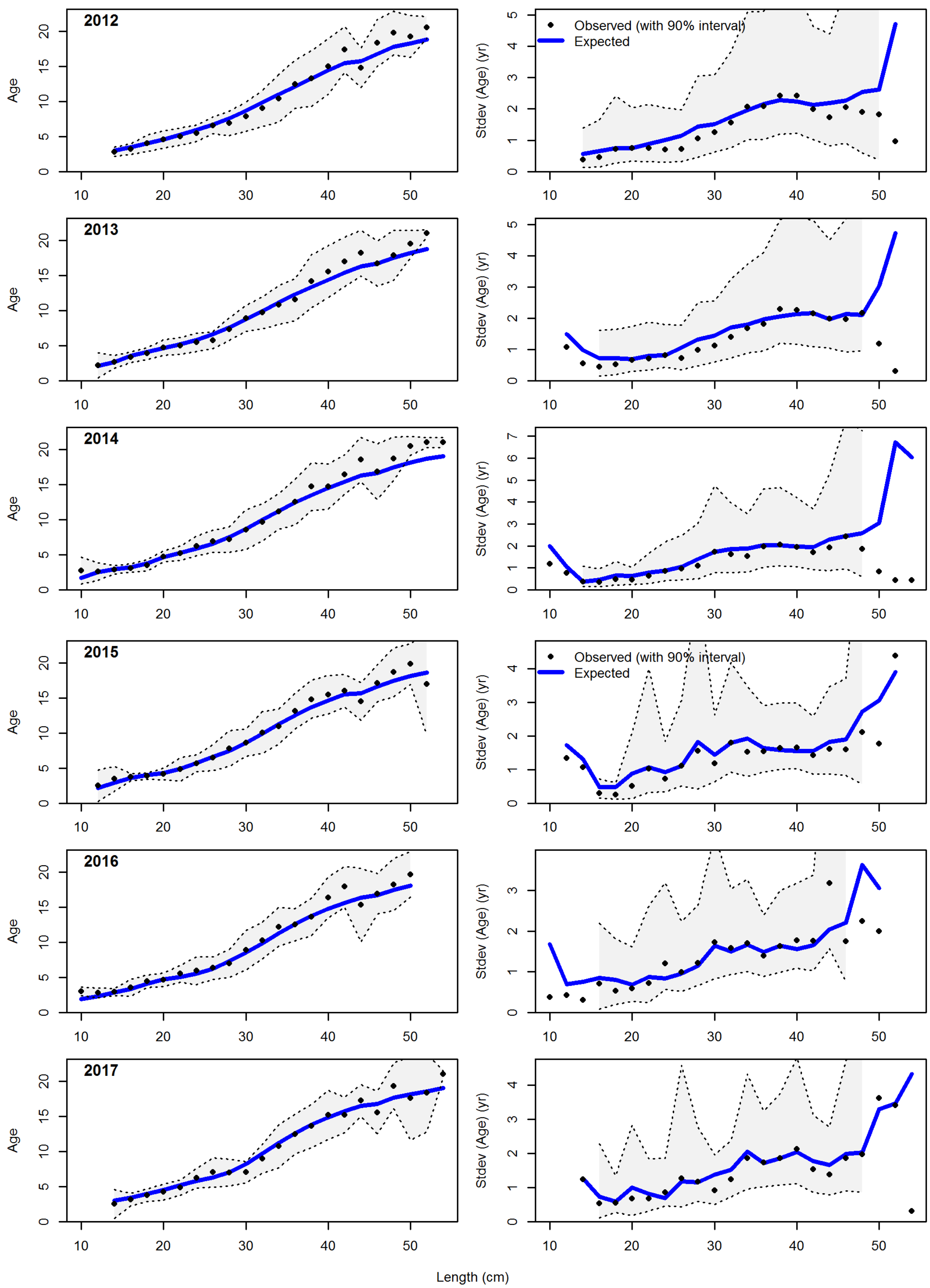
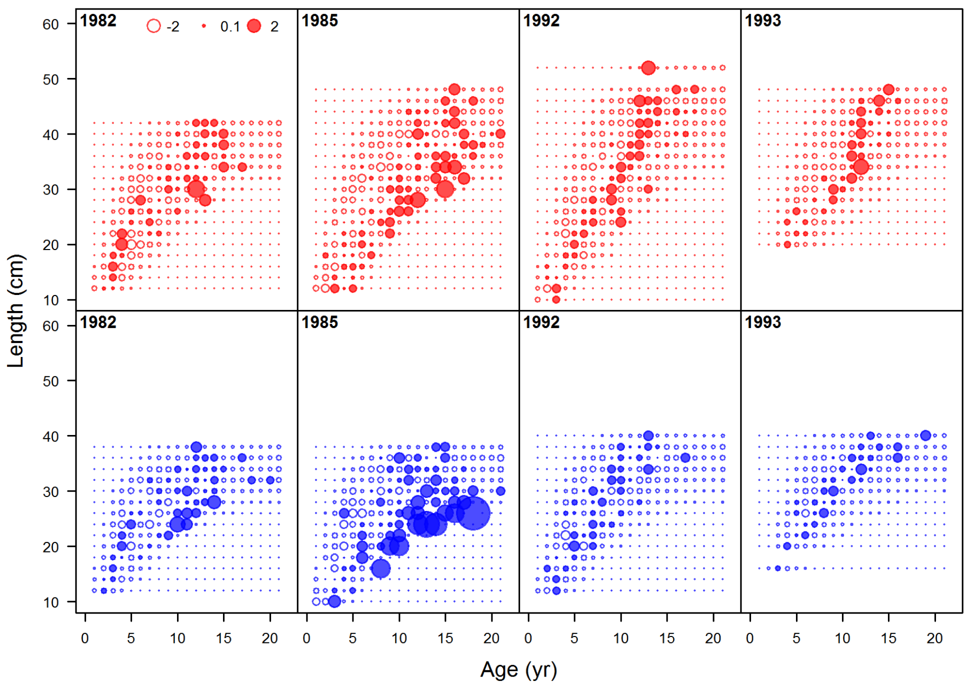


Figure 9.31. As for Figure 9.28, but for years 2012-2017.



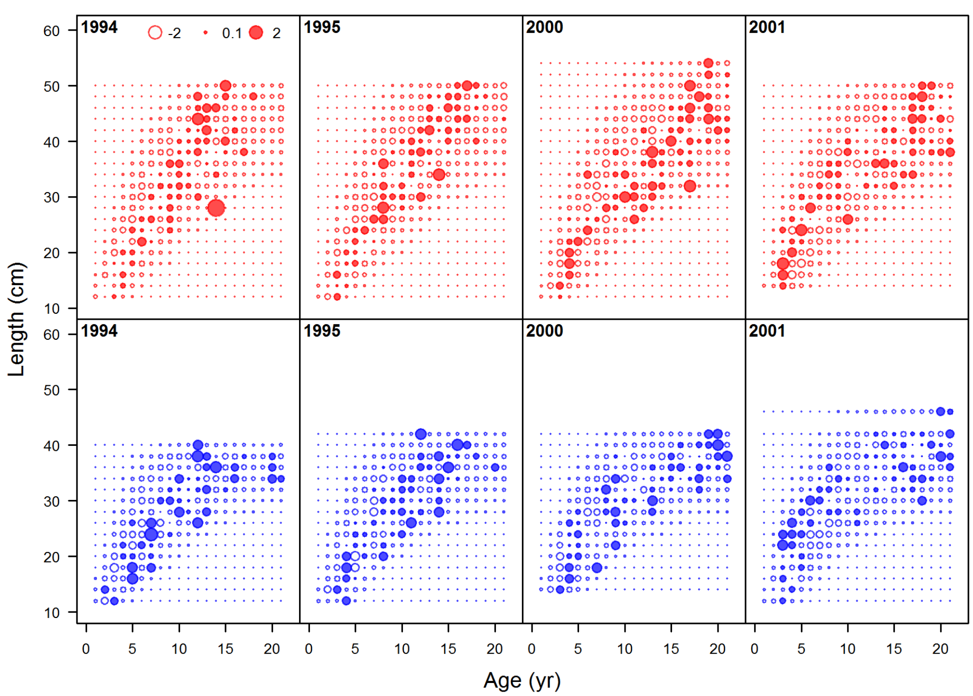


Figure 9.32. Pearson residuals for model fits to conditional age-at-length data for females (red) and males (blue) for years 1982-2001. Filled circles indicate positive residuals (observed>expected) and open circles indicate negative residuals (observed<expected). The maximum value was 21.49.

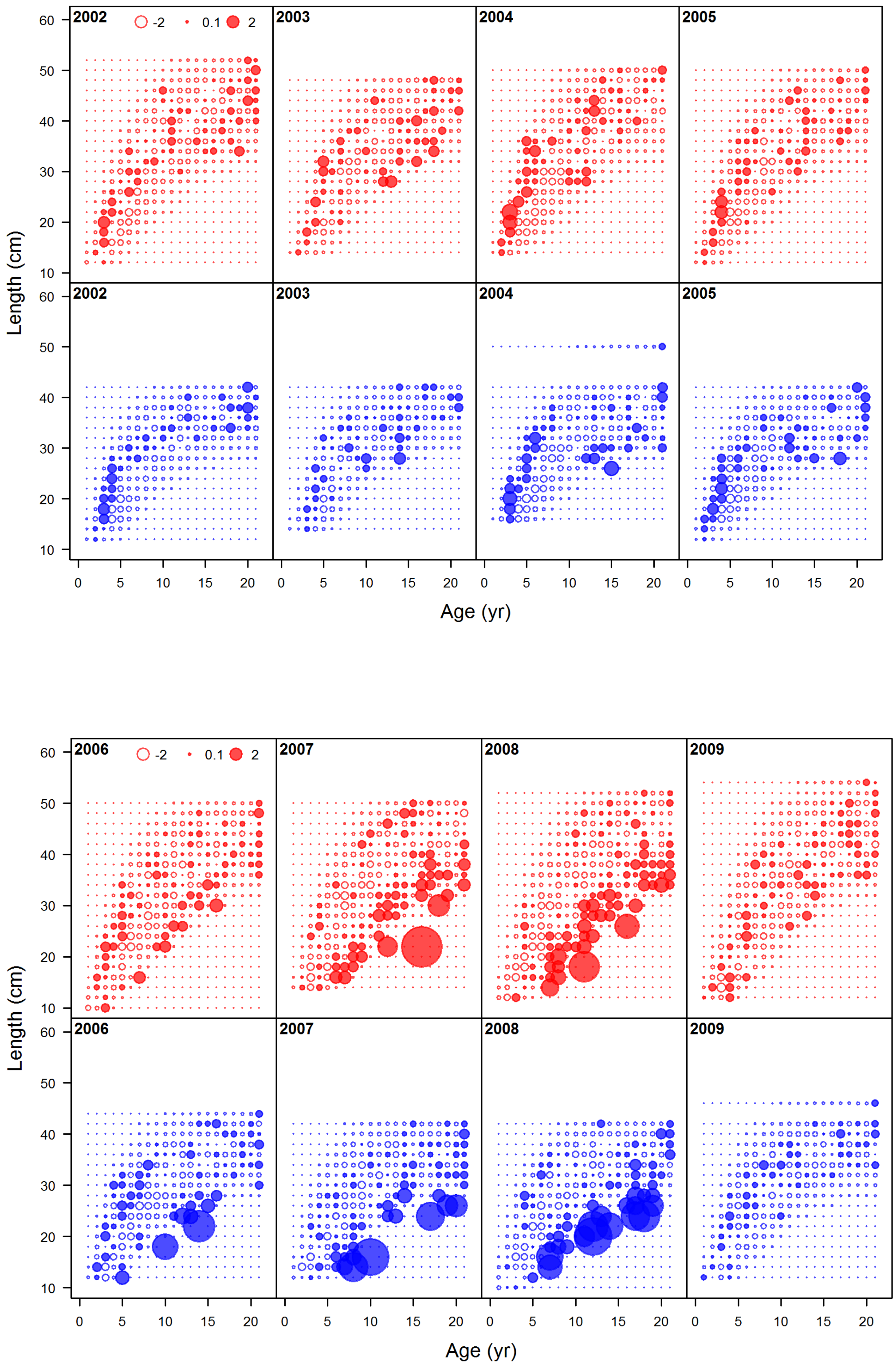
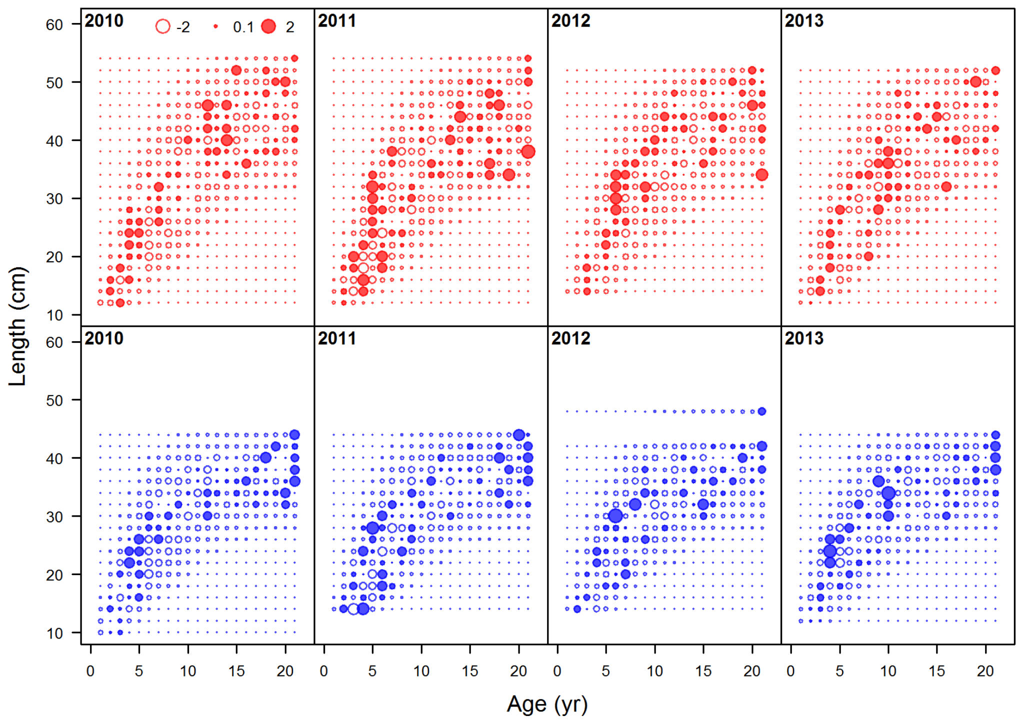


Figure 9.33. As for Figure 9.32, but for years 2002-2009.



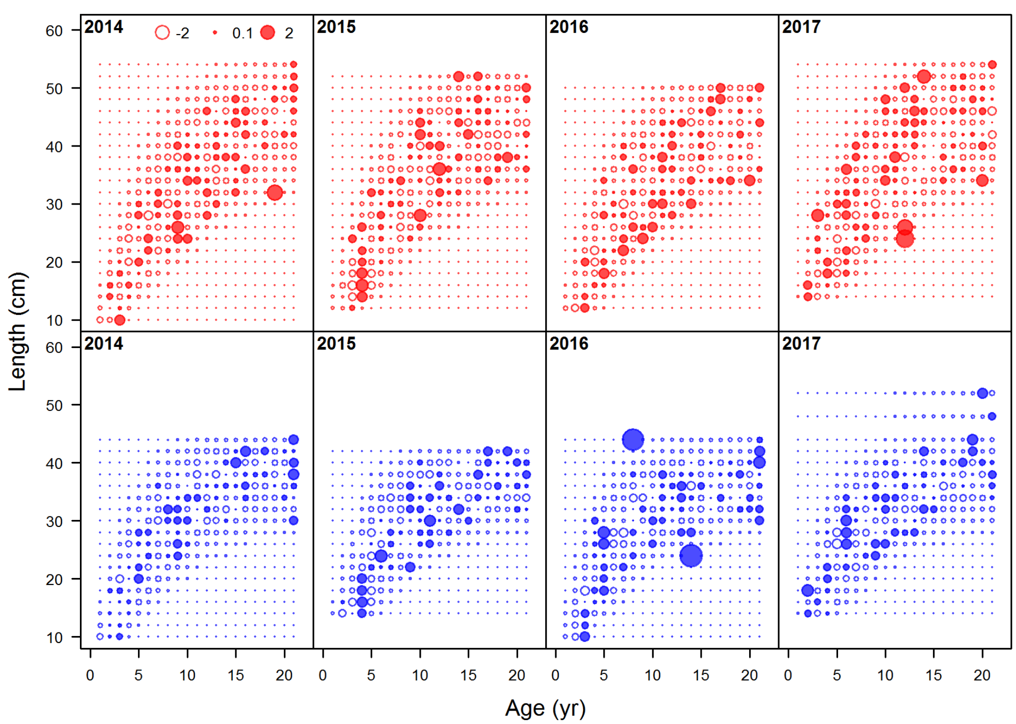


Figure 9.34. As for Figure 9.32, but for years 2010-2017.

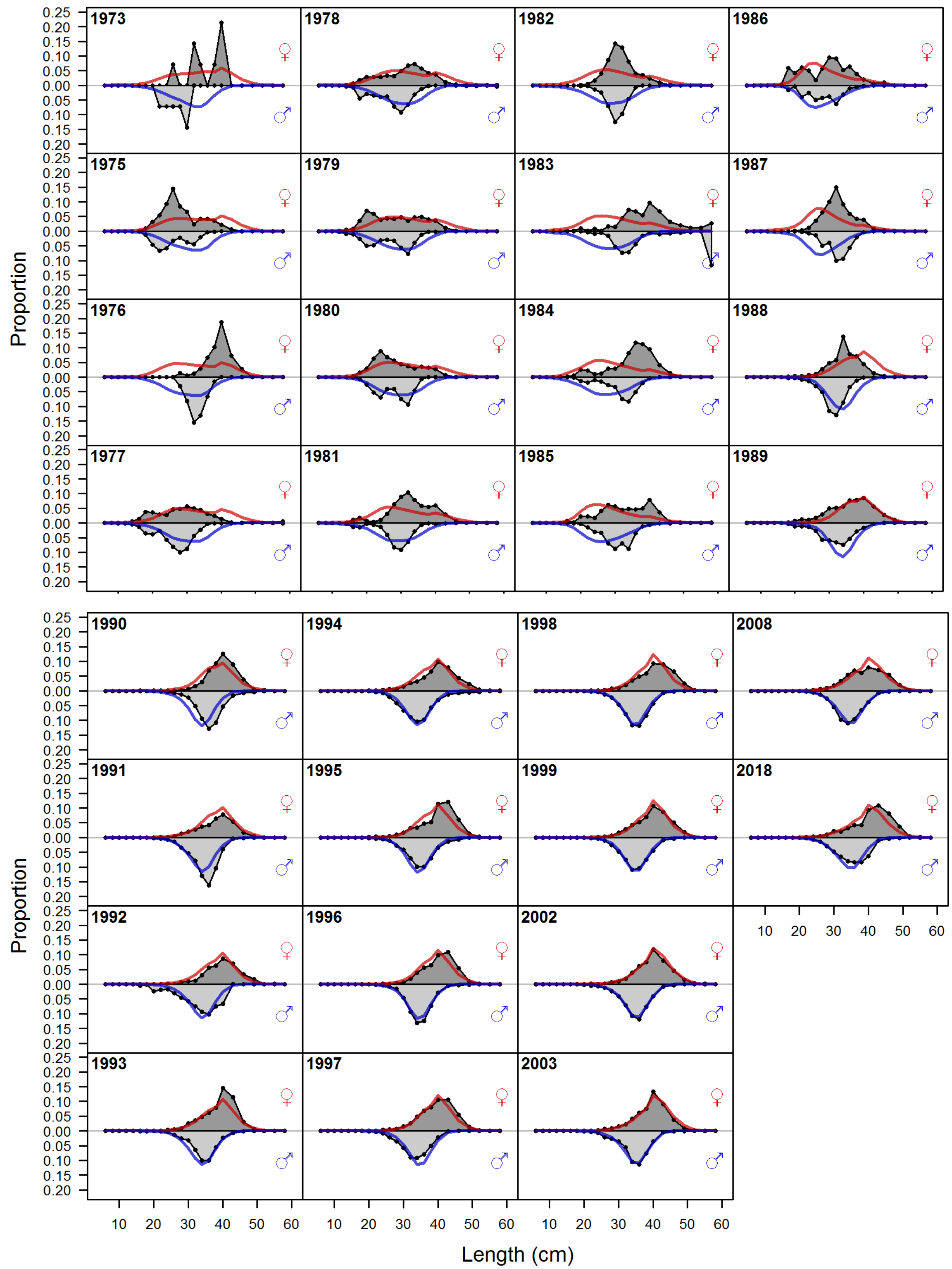


Figure 9.35. Observed (grey filled area and black line) and expected (red and blue lines) fishery length compositions for males (blue lines) and females (red lines) for all years for Model 18.2c.

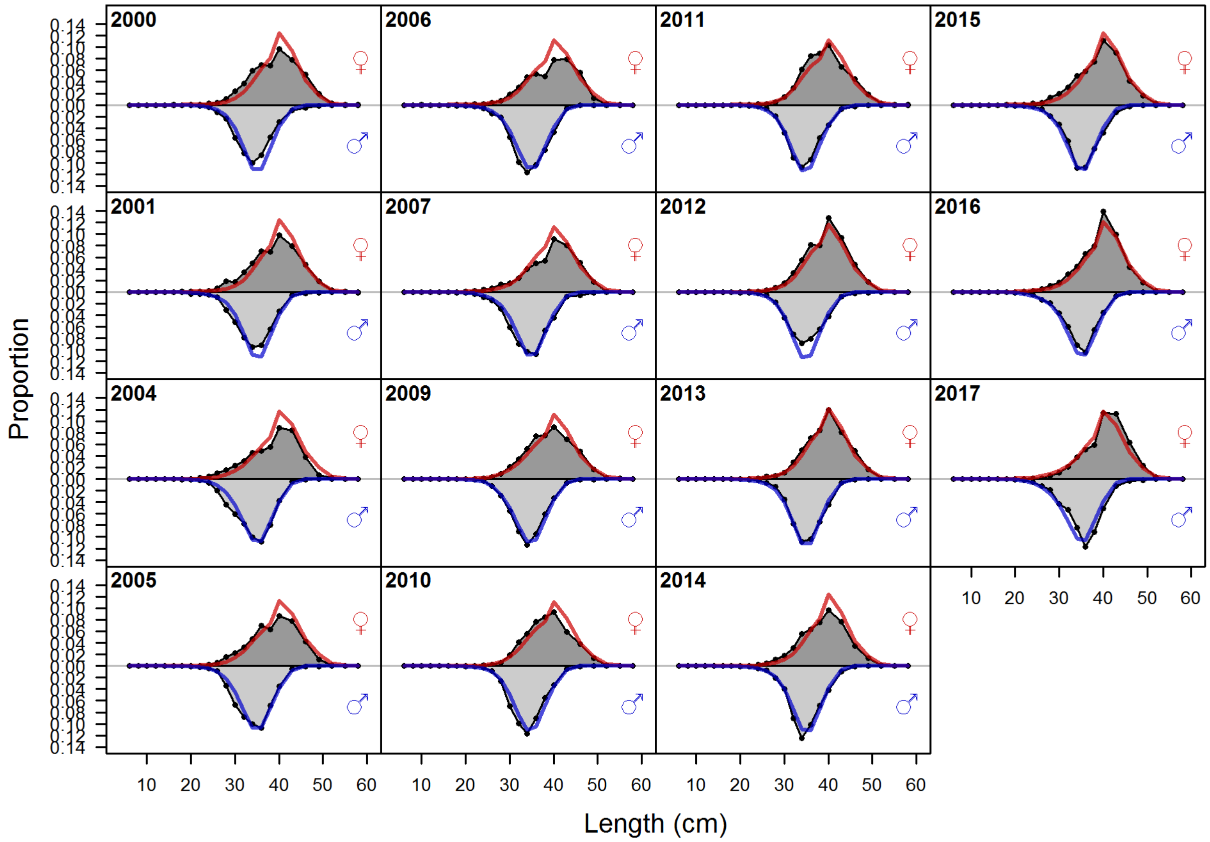


Figure 9.36. Observed (grey filled area and black line) and expected (red and blue lines) ghost fishery length compositions for males (blue lines) and females (red lines) for all years for Model 18.2c. Fishery age composition data exist and the model fit to these data in the years represented in this figure, and therefore the objective function did not fit to length composition data in these years.

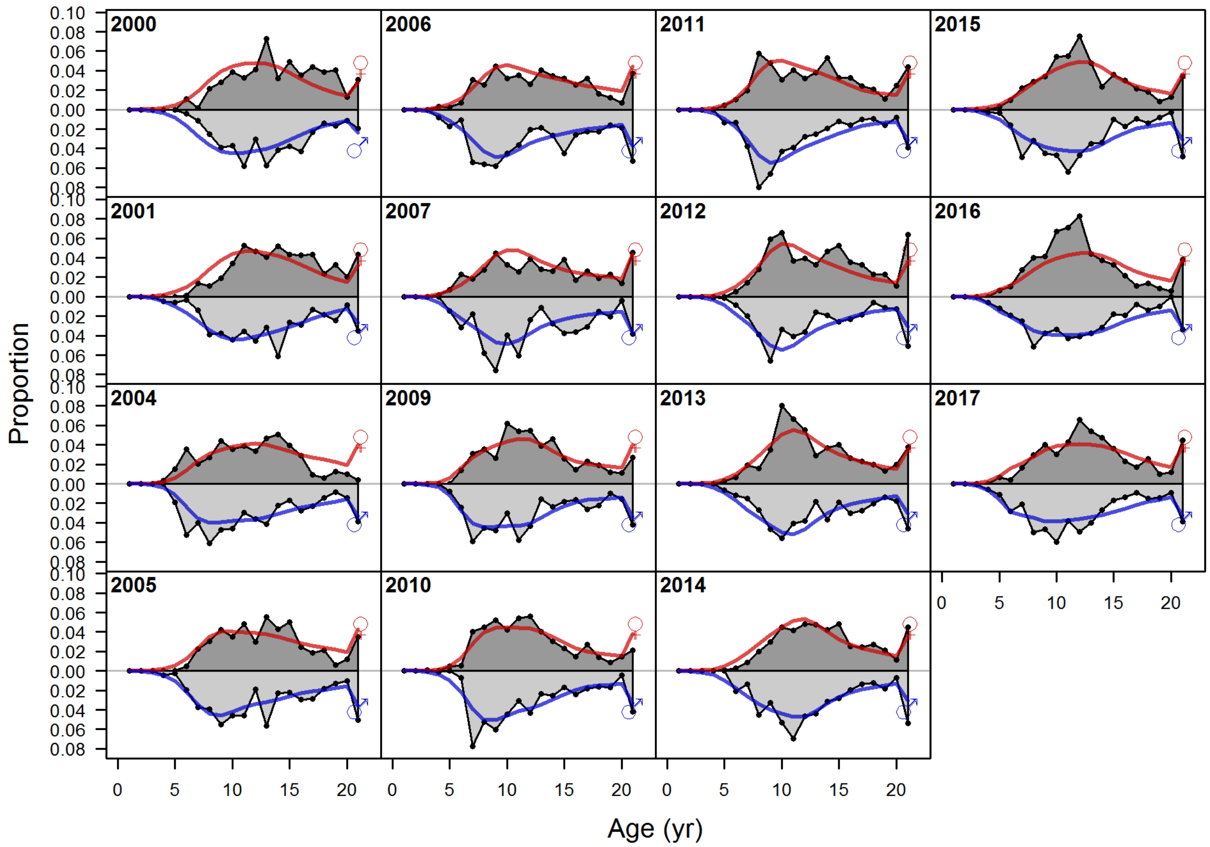


Figure 9.37. Observed (grey filled area and black line) and expected (red and blue lines) fishery age compositions for males (blue lines) and females (red lines) for Model 18.2c.

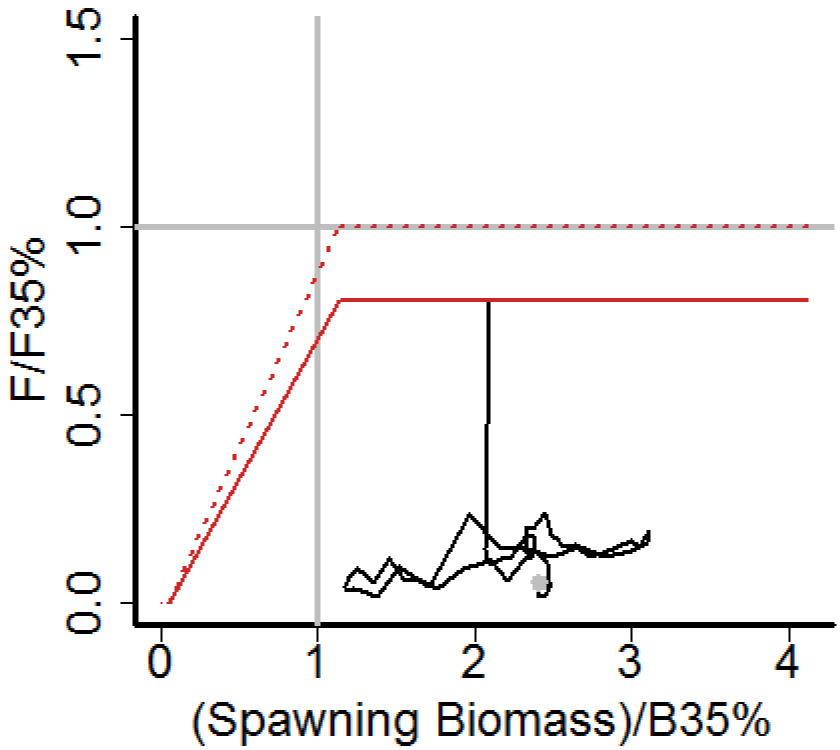


Figure 9.38. Phase plot showing spawning biomass and apical fishing mortality relative to B35% and F35%, respectively for each model year in addition to two projection years (black line). The grey dot shows the first year plotted (1964). The solid red line shows the ABC Tier 3 control rule and the dotted line shows the OFL Tier 3 control rule.

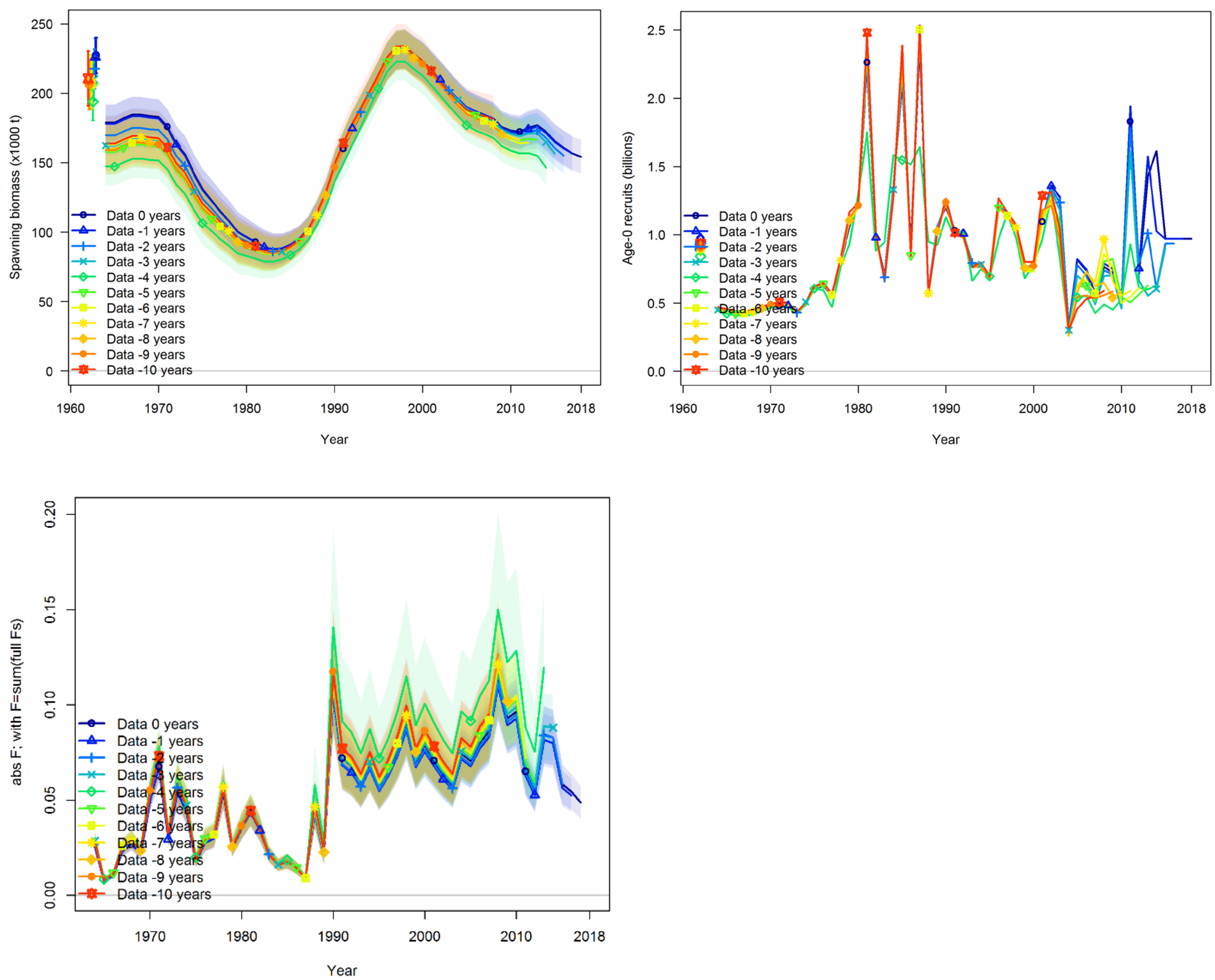


Figure 9.39. Spawning stock biomass (top left), recruitment (top right), and fishing mortality (bottom left) for retrospective model runs leaving out 0 to 10 years of the most recent data for Model 18.2c. Vertical lines show corresponding 95% asymptotic confidence intervals.

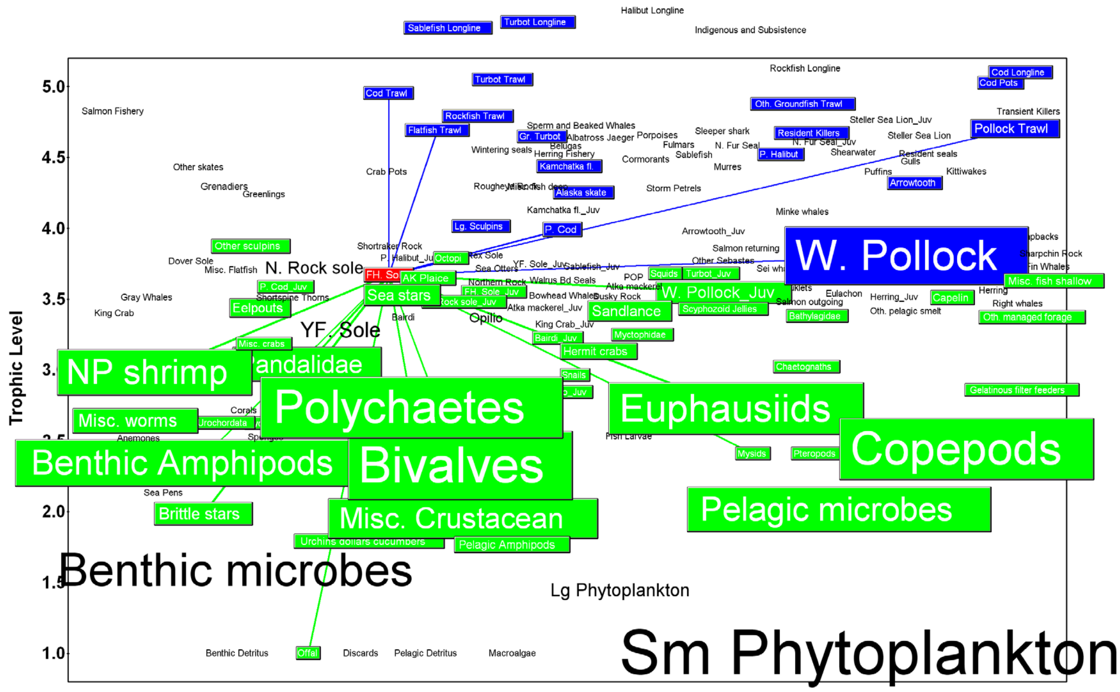


Figure 9.40. Ecosystem links to adult flathead sole in the eastern Bering Sea (based on a balanced ecosystem model for the eastern Bering Sea in the early 1990s; Aydin et al, 2007). Green boxes: prey groups; blue boxes: predator groups. Box size reflects group biomass. Lines indicate significant linkages.

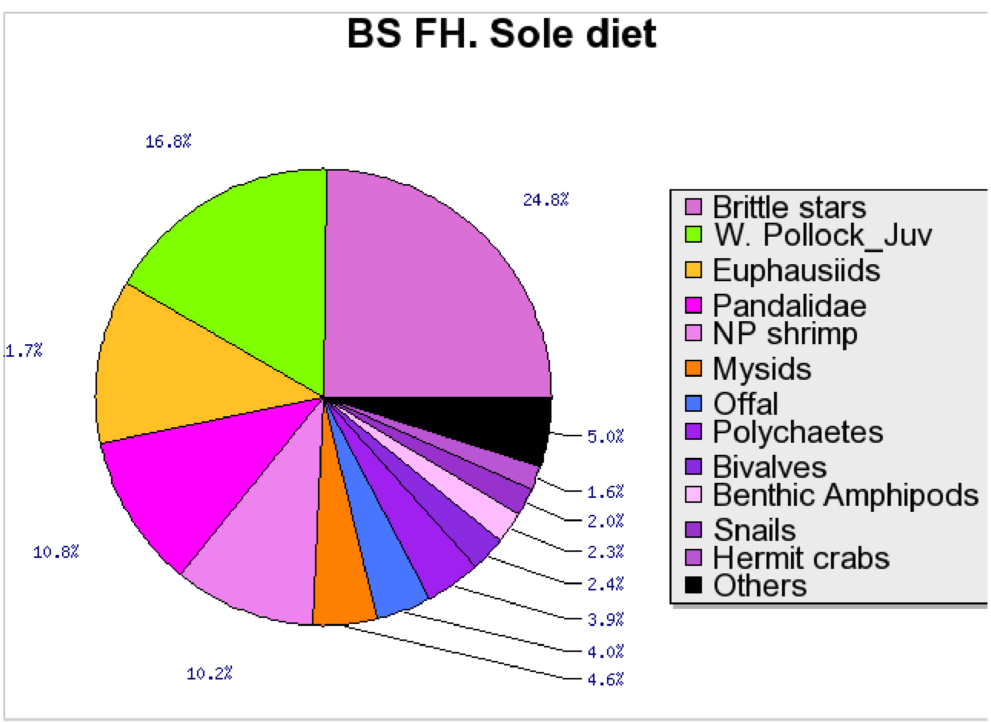


Figure 9.41. Diet composition of adult flathead sole in the eastern Bering Sea (based on a balanced ecosystem model for the eastern Bering Sea in the early 1990s; Aydin et al, 2007).

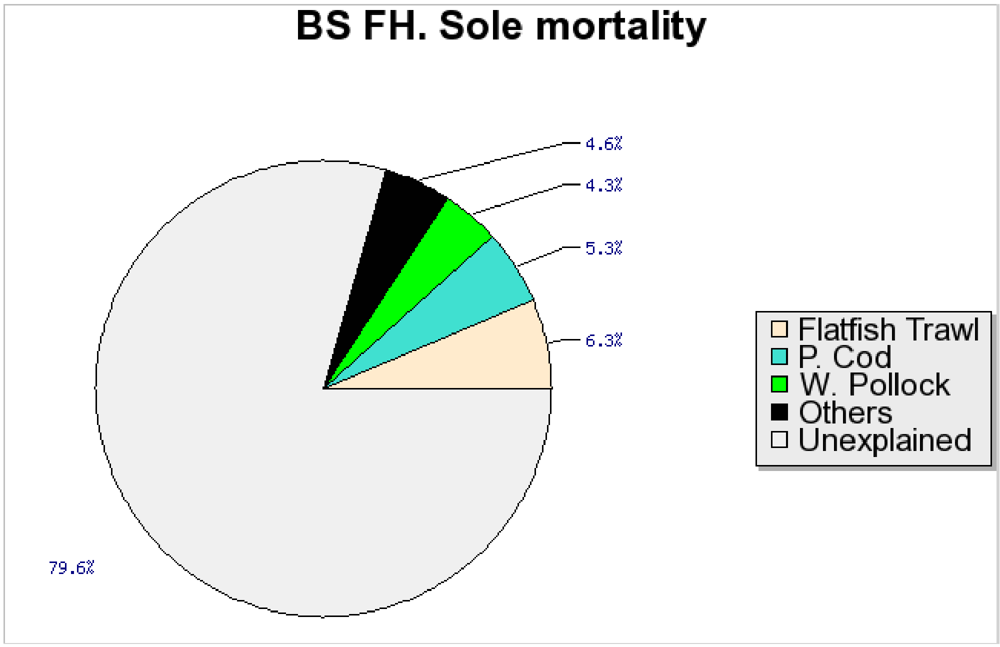


Figure 9.42. Mortality sources for flathead sole in the eastern Bering Sea (based on a balanced ecosystem model for the eastern Bering Sea in the early 1990s; Aydin et al, 2007).

Appendix A

2018 Results for Model 2016.0 (Old Model Framework)

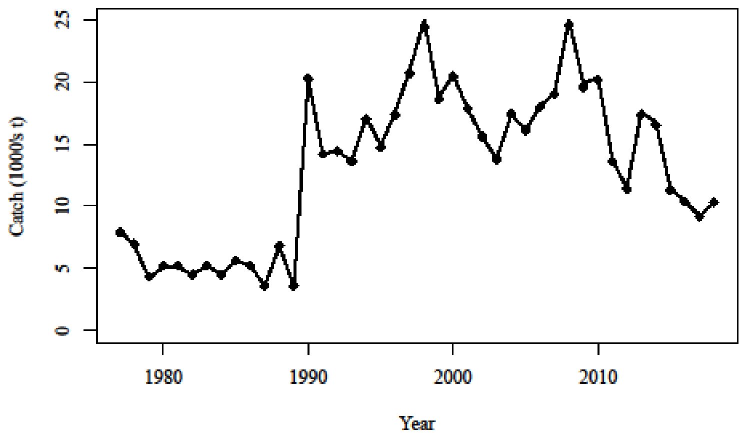
Summary of Results

The key results of the assessment for 2018, based on Model 2016.0, are compared to the key results of the accepted 2017 update assessment in the table below.

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2018	2019	2019*	2020*
M (natural mortality rate)	0.2	0.2	0.2	0.2
Tier	3a	3a	3a	3a
Projected total (3+) biomass (t)	762,513	777,961	870,121	901,496
Projected Female spawning biomass (t)	214,124	205,156	220,319	212,401
$B_{100\%}$	322,938	322,938	325,978	325,978
$B_{40\%}$	129,175	129,175	130,391	130,391
$B_{35\%}$	113,028	113,028	114,092	114,092
F_{OFL}	0.41	0.41	0.39	0.39
$maxF_{ABC}$	0.34	0.34	0.32	0.32
F_{ABC}	0.34	0.34	0.32	0.32
OFL (t)	79,862	78,036	83,239	83,600
maxABC (t)	66,773	65,227	69,612	69,887
ABC (t)	66,773	65,227	69,612	69,887
Status	As determined *last* year for:		As determined *this* year for:	
	2016	2017	2017	2018
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 11,305 t and 12,936 t for 2018 and 2019 used in place of maximum permissible ABC. The final catch for 2018 was estimated by taking the average tons caught between October 6 and December 31 over the previous 5 years (2013-2017) and adding this average amount to the catch-to-date as of October 6, 2018. The 2019 catch was estimated as the average of the total catch in each of the last 5 years (2013-2017). The 2020 catch was calculated as the projected maxABC for 2020.

Selected Plots for Model 16.0 with 2018 data added



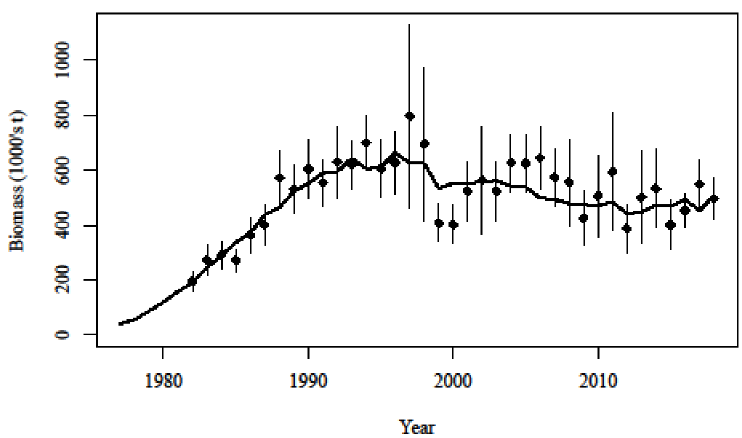


Figure 9.43. Catches (top panel), survey biomass (dots with 95% asymptotic intervals as vertical lines), and fits to survey biomass (black line; bottom panel) for Model 16.0.

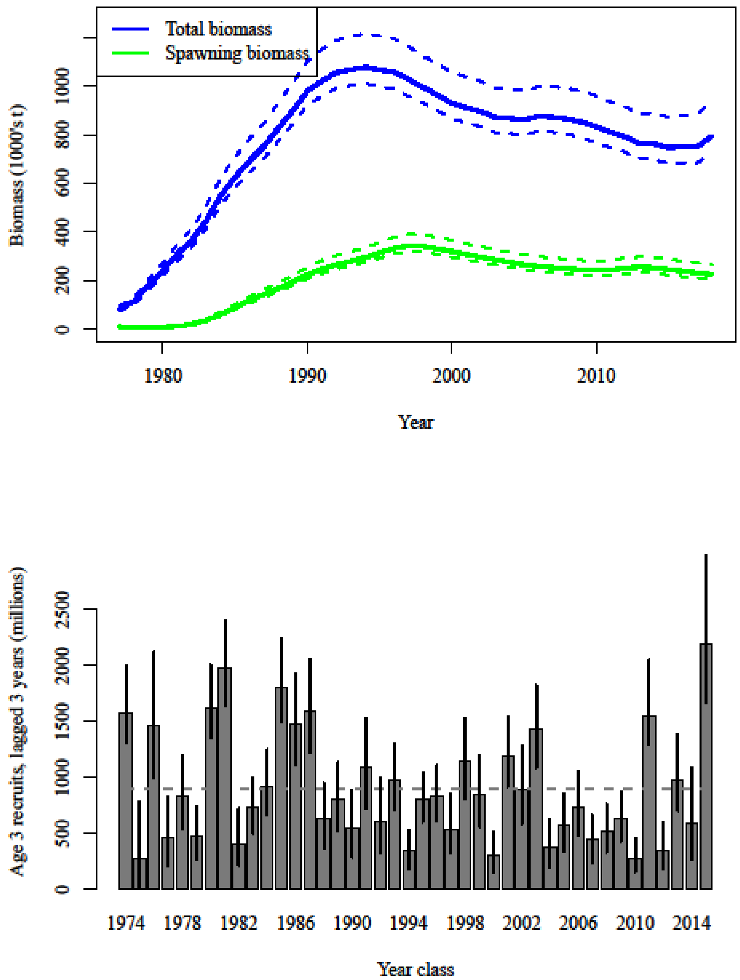


Figure 9.44 Total biomass and spawning biomass (top panel) and age-three recruits, lagged three years (bottom panel)

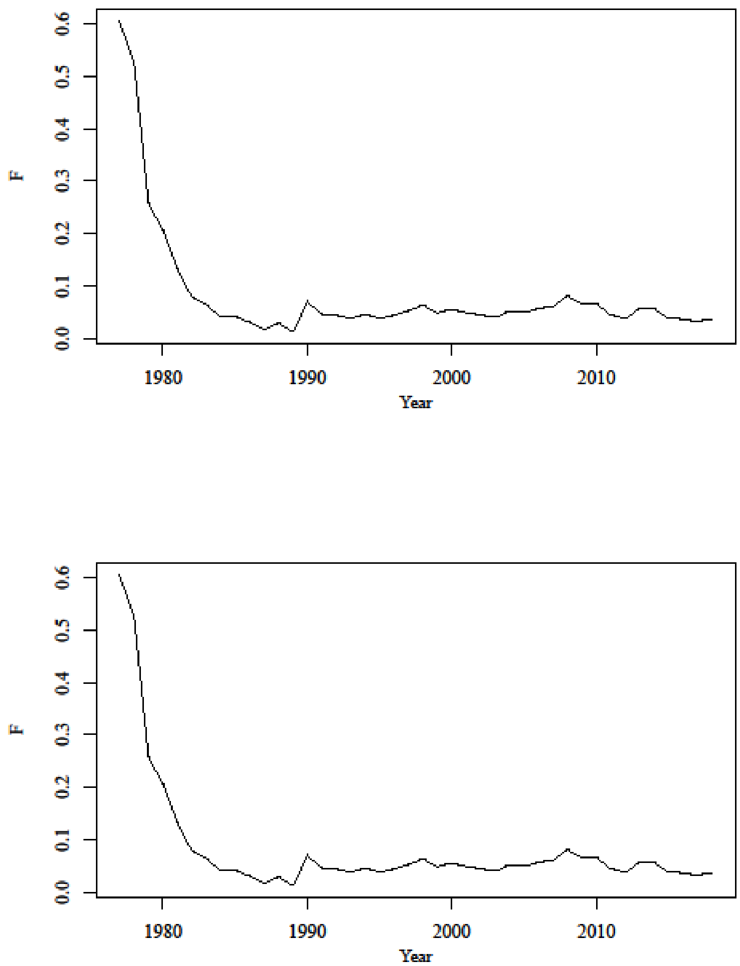


Figure 9.45. Time series of apical F estimates (top panel) and length-based survey selectivity (dotted line) and length-based fishery selectivity (solid line), which was not sex-specific (bottom panel).

Appendix B

A Transition of the Flathead Sole-Bering Flounder Stock Assessment in the Bering Sea and Aleutian Islands to the Stock Synthesis Framework

Introduction

The purpose of this document is to outline a proposed change from conducting assessments using the previous BSAI flathead sole assessment model framework to conducting assessments using Stock Synthesis versions 3.24o and 3.30.12 (SS3; Methot and Wetzel 2013); the two versions of SS3 yield identical results.

Previous assessments were conducted using an ADMB-based age- and sex-structured population dynamics model with length-at-age, weight-at-length, maturity-at-age, and age-length transition matrices estimated outside of the model (referred to as "the 2016 model" or "the 2016 accepted model" in this document). The 2016 model estimated the log of mean recruitment, the log of historical (pre-1977) mean recruitment, the log of mean historical fishing mortality (pre-1977), parameters for logistic length-specific (but not sex-specific) selectivity curves for the fishery and survey, recruitment deviations, and yearly fishing mortality rates. The model included ages 3-21 (age 21 was a plus group) and excluded data for fish younger than age 3 and smaller than 6cm in length. In addition, the 2016 model estimated recruitment deviations beginning in the starting year of the model. The initial conditions assumed that the stock was at a fished equilibrium, based on values estimated within the model for mean historical recruitment and mean historical fishing mortality. A recruitment deviation was estimated for age 3 individuals in the initial year of the model. Additionally, the model assumed that spawning occurred in March of each year (but with spawning biomass calculated based on weight-at-age at the beginning of the year), and that fishing mortality and natural mortality occurred throughout the year. Numbers-at-length were used in equations for predicted catch and biomass and were based on the numbers-at-age and the age-length transition matrix (representative of mid-year lengths).

SS3 is a flexible assessment model framework that extends the capabilities of the old model code to address the concerns expressed by the BSAI Plan Team, the SSC, and previous assessment authors. As an initial effort towards addressing these concerns, this document outlines a framework designed to begin to resolve these issues and transition the assessment to the SS3 framework. SS3 allows for clear specification of alternative models that can easily deal with concerns and issues that have been raised. In particular:

(1) Additional assumptions about the initial conditions, including early recruitment deviations, can be included in the model.

(2) Data on the age distribution within each length bin or mean weight-at-age data can be included and used to estimate growth within the assessment model.

(3) Alternative functional forms of selectivity curves are available and can be used to explore age-based and dome-shaped fishery selectivity, as well as time-varying approaches; the previous model used logistic length-based selectivity.

(4) Multiple survey and fishing fleets can easily be included in the model and hence allow for easy explorations of selectivity and catchability for shelf, slope, and Aleutian Islands survey data, separately, as well as consideration for selectivity of pelagic vs. non-pelagic fishing gear, sector-specific fishery selectivity, or selectivity specific to intended target species.

(5) Alternative equations for including an environmental linkage between temperature and catchability, and for modeling time-varying catchability, can be explored.

(6) The timing of population dynamics and fishing processes is modeled with more attention to detail.

(7) Including ages 0 to 2 in the model, and corresponding data, informs the shape of the survey selectivity curve at its lower bound, and may help to resolve issues with unrealistic survey selectivity estimates.
(8) Area-specific fleet dynamics and/or population dynamics can be modeled if substantial differences are found in stock structure, age-distributions, or fishing characteristics between areas.
(9) Seasons can be modeled if it is found that the characteristics of fishing are substantially different in different parts of the year and that the year-long time step for selectivity cannot represent the dynamics well.

SSC and Plan Team Comments on Previous Assessments

GOA Plan Team comment 11/2016: The Team recommends examining the use of time blocks in selectivity due to changes in fishing practices.

Author Response: CRM completed a transition of the model to the SS3 framework and an SS3 model was run done using time blocks for fishery selectivity from 1964 (the model start year) to 1991, 1992-2007 (when the structure of our current halibut bycatch regulations were implemented), and 2008-present, when the BSAI groundfish trawl fishery was rationalized.

Data used in SS3 and the Old Model

An important difference between the old model code and SS3 is that the youngest age class in the old model code (age 3) represents only age 3 individuals, while SS3 population dynamics begin at age 0 and consider the lowest age and length bins of data to be the proportion of individuals ages 0-3 and lengths 0-the upper limit of the lowest length bin, respectively. Therefore, age- and length-composition data must include ages 0-2 and any lengths no matter how small in SS3, while the old model code omitted data on ages 0-2 (and excluded data on fish smaller than 6 cm). Ignoring this difference between models will result in differences between expected and observed age- and length-compositions for the youngest age and length bins when selectivity at these ages and lengths is estimated to be greater than 0 in SS3. The data on ages 0-2 that are included in SS3 can inform estimates of selectivity at the lowest ages (even, or especially, if they are all zeros). These data may also improve recruitment estimates in the most recent years if age 0-2 fish were captured by the survey or the fishery.

With the exception of age 0-2 individuals, the same data used in the 2016 accepted model (McGilliard et al. 2016) were used in the SS3 model runs, as listed in the table below.

Source	Data	Species Included	Years
NMFS Aleutian Islands Groundfish Trawl Survey	Survey biomass (linear regression used to combine BS shelf survey estimates with AI survey estimates for a single survey biomass index)	Flathead only; no Bering flounder were caught in the Aleutian Islands	1980, 1983, 1986, 1991-2000 (triennial), 2002-2006 (biennial), 2010-2016 (biennial)
NMFS Bering Sea Shelf Groundfish Survey (standard survey area only[1])	Survey biomass (linear regression used to combine BS shelf survey estimates with AI survey estimates for a single survey biomass index)	Flathead sole and Bering flounder combined	1982-2016
	Age Composition	Flathead sole only	1982, 1985, 1992-1995, 2000-2015
	Length Composition	Flathead sole only	1983, 1984, 1986-1991, 1996-1999, 2016
U.S. trawl fisheries	Catch (Bering Sea and Aleutian Islands; pelagic and non-pelagic trawl[2])	Flathead sole and Bering flounder combined	1977-2016
	Age Composition (Bering Sea only; non-pelagic trawl only)	Flathead sole only	1994, 1995, 1998, 2000, 2001, 2004-2007, 2009-2015
	Length Composition (Bering Sea only; non-pelagic trawl only)	Flathead sole only	1977-1993, 1994, 1996-1997, 1999, 2002-2003, 2008, 2016

3. Excludes survey strata 70, 81, 82, 90, 140, 150, and 160
4. A very small amount of catch is taken with hook and line and is included in the total catch biomass

Description of differences between the 2016 model and the SS3 framework

There are fundamental differences between the 2016 accepted model and the SS3 modeling framework and that make it impossible to configure a fully matching model using SS3. The table below lists the differences, whether the way that each of these factors is modeled is effective within the old model code, and whether SS3 offers a more effective way to model each of these factors than does the old model code. While the phrase “the 2016 model” refers to the combination of the old model code and one particular configuration of the input files for running the code that was used to produce the 2016 accepted model, “the old model code” refers to any run configuration of the input files (any model runs) that could be created using the old model’s ADMB code.

Source of Difference between Models	Is this a positive attribute of the 2016 model?	Would SS3 do a better job of modeling this attribute?
2016 model starts at age 3, SS3 model starts at age 0	No. Data from ages 0-2 cannot be used in the 2016 model (or the old model code in general)	Yes, SS3 would allow for data from ages 0-2 to be used, potentially informing selectivity curves at low ages.
Length-based, logistic survey selectivity estimates do not match	No. The survey selectivity in the 2016 model was problematic, as the curve estimated was shallow, never reaching 0, and only reaching 1 at very old ages, which was not believable. In addition, there was a strong retrospective pattern in survey selectivity parameter estimates in the 2016 model.	Yes, SS3 offers a large suite of options for modeling selectivity, including sex-specific, age-based, double-normal, and non-parametric options. In addition, SS3 starts at age 0, and can fit to data for ages 0-2, which would help to define the selectivity curves at low ages.
Growth models, including age-length transition matrices both use the von-Bertalanffy growth curve, but cannot be matched exactly between the 2016 model and an SS3 model. There are small differences in modeling growth, leading to differences in all biomass estimates between the models, even when numbers-at-age match exactly.	Neutral. However, the old model code doesn't include as many options as SS3 to fine-tune the calculations involving growth to be specific to the timing of events in the model.	Yes, SS3 would allow for use of data on the distribution of ages within each length bin, which would, in turn, allow for estimation of growth parameters, including the CV of the youngest and oldest fish, which defines the age-length transition matrix. Likewise, a weight-at-age vector can be input for each year of the model, if desired, to account for time-varying weight-at-age and to avoid defining relationships with length altogether.
Historical mean recruitment can be modeled in both frameworks (the old model code and SS3), but when it is estimated or fixed to a different value than main-period mean recruitment, the model behavior in initial years is different in the old model framework than in SS3. This occurs because a recruit is an age 3 individual in the old model code and an age 0 individual in SS3. Therefore, in the initial model year, age 3s in SS3 were born three years earlier under the assumption of historical mean recruitment, while age 3s in the old model recruited in the initial year of the main period recruitment regime. Also, SS3 models a likelihood penalty for historical mean recruitment values to prevent it from being too high, while the old model code estimates historical mean recruitment without upper or lower bounds or penalty.	There is not a specific problem with the methods for modeling historical recruitment in the old model code, although parameter estimates may be unrealistic because the parameter unbounded. The most recent CIE review identified the estimates of F and recruitment in the initial model years as an area of substantial uncertainty, needing further investigation.	Yes, SS3 would allow for estimation of early recruitment deviations, which would be informed by the length and age composition data on fish that were recruits in this early period. This may allow the model to better distinguish between historical recruitment and historical fishing mortality. Using either modeling framework, foreign reported data on BSAI flathead sole exists back to 1964 and could be investigated for use in better informing initial conditions as well.

Timing of population dynamics is different between the model frameworks. The old model code specifies that the survey occurred mid-year by using mid-year weight-at-length and -age, but applies continuous mortality for the entire year to numbers-at-age when calculating survey biomass and predicted length and age distributions. The spawning month is specified as March in the 2016 model, but spawning biomass is specified using beginning-of-the-year weight-at-age.	No. It would be more accurate if half of the year's natural and fishing mortality were applied when calculating mid-year survey biomass, length, and age distributions.	Yes, the timing of population dynamics in SS3 can be modeled accurately, according to user-specified inputs.
Modeling of the relationship between temperature and catchability cannot follow the exact same equation in SS3 as in the old model code (though it can still be modeled in SS3)	No, the estimate of the temperature-catchability relationship in the 2016 model is close to 0 (no relationship), which leads to a similar fit to survey biomass as for the same model without this relationship estimated, but includes lots of tiny deviations from the trend line that have little meaning.	Possibly. SS3 offers the ability to link an environmental index to catchability (or to any other parameter) through a multiplicative or additive relationship. This is a different equation than the one in the old model code.
Predicted survey and catch biomass are based on mean numbers-at-length and catch-at-length, which means that the numbers-at-age were converted to numbers-at-length by multiplying by the age-length transition matrix (which differs between models). The predicted catch biomass in SS3 is based on numbers-at-age and catch-at-age.	Not clear. The underlying population dynamics in the old model code are age-structured, and numbers-at-age are multiplied by mean weight-at-age to calculate predicted biomass proportions, rather than translating the information through the age-length transition matrix to numbers-at-length, and multiplying by the weight-length relationship. *Note that CRM coded up and used standard predicted survey and catch biomass based on numbers-at-age and catch-at-age for several runs of the old model framework in this exercise to facilitate comparisons with SS3 runs.*	The likelihood components used in SS3 are standard for statistical catch-at-age models. In addition, because the age-length transition matrix is calculated or estimated internally, it can be adjusted to reflect the timing of the calculations for which it is used.

Steps to understanding differences between model frameworks to construct a model in SS3 that best matched the 2016 model

Given that SS3 could not be configured to fully match the 2016 accepted model, an age-based selectivity option and age-based survey biomass and catch biomass prediction options were added to the old model code so that a few variants of the 2016 model could be configured to better match equivalent configurations in SS3. The main goal of adding to the old model code was to start with a configuration of the old model code and SS3 where population dynamics and likelihood equations matched exactly, and from there, to demonstrate the irreconcilable differences in the two model frameworks one piece at a time. Once differences are demonstrated, an SS3 configuration that best matches the 2016 model is shown and compared to the 2016 model. Below is a list of old and SS3 model configurations that are compared to demonstrate where the models match or fail to match, and the corresponding figures. The results section below leads the reader through each of the figures and the reasons for matching or non-matching results in each step.

Old model variant	SS3 configuration	Corresponding Figure(s)
(old_a) As for 2016 model, but with age-based selectivity and all parameters fixed, except for fishing mortality. Also, predicted catch and survey biomass were calculated from numbers-at-age (not numbers-at-length)	(SS3_a) A model with age-based selectivity and all other parameters fixed to the same values as for the old model code variant, with only fishing mortality estimated. Growth schedules (rather than parameters) are specified to match those of old_a	Figure 9.46 and Figure 9.47
(old_b) as for old_a	(SS3_b) As for SS3_a, but with growth specified as parameters (rather than schedules), to match those of old_b as closely as possible.	Figure 9.48 and Figure 9.49
(old_c) as for old_a, but with historical R fixed to its MLE from the 2016 model	(SS3_c) As for SS3_a, but with R1 (historical R in SS3 terms) fixed to an equivalent value to that in old model variant old_c.	Figure 9.50
(old_d) as for old_a, but with mean recruitment and recruitment deviations estimated (in addition to estimating fishing mortality, as was done in old_a)	(SS3_d) As for SS3_b, but with R0 (mean recruitment in SS3 terms) estimated and recruitment deviations estimated (in addition to estimating fishing mortality, as was done in SS3_b)	Figure 9.51
(old_e) as for old_d, but with the age-based selectivity curves estimated, rather than being fixed.	(SS3_e) As for SS3_d, but with the age-based selectivity curves estimated instead of being fixed.	Figure 9.52
(old_f) as for old_d, but with length-based selectivity curves fixed.	(SS3_f) As for SS3_d, but with length-based selectivity curves fixed to match those of old_f (which were chosen such that no fish under age 3 would be selected in SS3)	Figure 9.53
(old_g) as for old_f, but with the length-based selectivity parameters estimated instead of being fixed	(SS3_g) As for SS3_f, but with the length-based selectivity parameters estimated instead of being fixed.	Figure 9.54
(old_h) as for old_g, but with catch and survey biomass calculated from numbers-at-length and length-based selectivity (which requires the age-length transition matrix)	(SS3_h) As for SS3_g	Figure 9.55
(old_i) as for old_g (identical to the 2016 model, except that catch and survey biomass are calculated based on numbers-at-age and selectivity-at-age)	(SS3_i) As for SS3_g and SS3_h, except that survey selectivity (which is estimated) is an age-based, double-normal curve without a descending limb (forced to be asymptotic) and catchability is fixed to be 0.7 (0.7 is the maximum derived age-based survey selectivity from the 2016 model's survey selectivity curve). Therefore, this SS3 configuration acts to mimic the 2016 model.	Figure 9.56
2016 model	(SS3_j) as for SS3_i.	Figure 9.57-Figure 9.65

The following sections offer more details on the population and observation models within both the old model framework and SS3.

Description of population and observation models within both modeling frameworks

Mean recruitment and historical recruitment

Several steps were taken to build an SS3 model with population dynamics that best matched those of the 2016 model using configurations of the old model code and SS3 that were deterministic (Figure 9.46-Figure 9.51). First, the relationship between the log of mean recruitment estimated in the 2016 model

$(\ln(\bar{R}))$ and the log of R_0 (unfished recruitment $(\ln(R_0))$ that is estimated in SS3 was determined (Equation 1), where M is natural mortality. Note that $\ln(R_0)$ in SS3 operates as the log of mean recruitment when no stock-recruitment relationship is assumed.

$$(1)\ln(R_0) = \ln(\bar{R}) + \ln(1000) + 3M$$

The $\ln(\bar{R})$ estimated in the 2016 model refers to total mean recruitment of age 3 individuals (males and females), while $\ln(R_0)$ refers to total recruitment of age 0 individuals in thousands. Both models are able to estimate a separate historical mean recruitment parameter. The 2016 model estimates an $\ln(R_{hist})$ parameter, which translates to the SS3 parameter, $\ln(R_{offset})$, as follows:

$$(2)\ln(R_{offset}) = \ln(R_{hist}) + \ln(1000) + 3M - \ln(R_0)$$

One difference between the two models is that $\ln(R_{hist})$ is an unbounded parameter in the old model, while $\ln(R_{offset})$ is a bounded parameter with user-specified bounds and, in addition, there is a likelihood component associated with $\ln(R_{offset})$ in SS3 to prevent it from becoming too large. In the section below entitled "Initial Conditions," a timing mismatch in the application of historical mean recruitment is explained.

Both models assume a 1:1 sex ratio.

Initial Conditions
Initial conditions are identical between model frameworks when historical mean recruitment is specified to be equal to the main-period mean recruitment ($\ln(\bar{R}) = \ln(R_{hist})$) and historical fishing mortality is set equal to 0 in old model variants and in SS3. When historical fishing mortality is added to the model, the models are identical as long as selectivity below age 3 in SS3 is equal to 0. When historical mean recruitment differs from the main period mean recruitment, numbers-at-age 3 differ for the first three years of the model (1977-1979) because the historical mean recruitment is applied to age 0 fish in 1977-1979 in SS3 and to age 3 fish in the old model. Hence, in 1977-1979, SS numbers-at-age 3 reflect the historical-period's mean recruitment, while the old model's numbers-at-age 3 reflect the main period mean recruitment.

Growth
The old model framework used externally estimated maturity-at-age and weight-at-age schedules. Weight-at-age at the beginning of the year and mid-year were both specified as vector inputs to the model. The maturity and weight-at-age schedules can be input into SS3 to be identical between the old model and SS3 with a setting in SS3 to bypass specifying (or estimating) growth parameters (Figure 9.46). However, the old model code reads in an externally-calculated age-length transition matrix, while SS3 must internally calculate the age-length transition matrix based on the parameters specified for the von-Bertalanffy growth curve, the allometric length-weight relationship, and the CVs in length-at-age of the youngest and oldest age classes modeled. The age-length transition matrix is used in both model frameworks to translate length-based selectivity into age-based selectivity for application in calculating the numbers-at-age, and to calculate predicted survey and fishery length distributions. When growth parameters are specified in SS3 (instead of these schedules being input as vectors), small differences arise between models. Most runs in this matching exercise specify growth parameters (rather than vectors/schedules) in order to match the 2016 model's specification of length-based selectivity (to allow SS3 to calculate the age-length transition matrix required when using length-based selectivity). However, a few comparisons were done where growth schedules were specified (along with age-specific selectivity) to achieve a match between model frameworks in deterministic population dynamics. This approach allowed for some other aspect of the frameworks (such as initial conditions) to be compared without the

confounding influence of slightly different growth curve estimates and age-length transition matrices between the old model framework and SS3.

Selectivity
The 2016 model assumed length-based logistic selectivity curves for fishery and survey selectivity, with the same selectivity curves for males and females. Although selectivity was configured in the same way in SS3, estimates of survey selectivity were different between the two models for several reasons. First, the data used only by SS3 on ages 0-2, and the modeling of ages 0-2 informs SS3's selectivity curves. Second, the length-based selectivity curves were converted into age-based selectivity within the models before use in the numbers-at-age equations by multiplying by the age-length transition matrix, and the age-length transition matrices were a mismatch between models.

In the interest of distinguishing the effects of various differences between the models, some SS3 and old model variant runs were done using age-based, logistic selectivity curves, configured such that selectivity below age 3 was zero. To show the effects of the different age-length transition matrices on the calculation of derived age-based selectivity from length-based selectivity curves, some comparisons were done using length-based selectivity, fixed to the same values in both model frameworks, and set to 0 at lengths that could be associated with fish under the age of 3. In addition, some SS3 runs used double normal, age-based, sex-specific survey selectivity curves with selectivity below age 3 set to 0 and restricting the curves from becoming dome-shaped. The rationale for this approach is described in the results section, and the SS3 model that best matched the dynamics of the 2016 configuration of the old model used this double-normal age-based and sex-specific survey selectivity.

The fishery selectivity curves estimated in SS3 and the old model were similar to each other.

Biomass and Timing
SSB and survey biomass were shown to be very similar in deterministic model variant comparisons when selectivity curves were identical (and equal to 0 below age 3) and the empirical values for beginning and mid-year weight-at-age were used, along with age-based selectivity (which does not require the age-length transition matrix to be used to calculate population dynamics; Figure 9.47). SSB and survey biomass differ slightly between otherwise comparable deterministic model variants when growth parameters are internally specified in SS3 (Figure 9.49). Specifying growth internally in SS3 is a requirement when using length-based selectivity curves because SS3 calculates the age-length transition matrix internally. It is then used to translate length-based selectivity into age-based selectivity to apply selectivity to numbers-at-age and to translate predicted numbers-at-age into predicted proportions-at-length to fit to the length composition data. Therefore, this slight difference in biomass estimates between the 2016 model and SS3 is unavoidable because the 2016 model used length-based selectivity. In addition, in the old model code's spawning biomass was calculated based on numbers-at-age in March, but using January weight-at-age. The survey biomass in the 2016 model was calculated using mid-year weight-at-age and assuming mortality throughout the year. Several model runs were done specifying spawning in old model variants as occurring at the beginning of the year to minimize differences in spawning biomass.

Recruitment Deviations
Recruitment deviations in the old model were estimated from the first to last model year (1977-2016) and applied to age 3 recruits. Recruitment deviations in SS3 were matched to the 2016 model by estimating age 0 recruits beginning in 1974 until 2013.

Yearly and Historical Fishing Mortality
Yearly apical fishing mortality and average historical (pre-1977) fishing mortality were estimated in both model frameworks. The population dynamics associated with fishing mortality were identical in the two models. Estimates of initial numbers-at-age 3 will differ between models when historical F and fishery

selectivity for ages 0-2 are both greater than 0. This occurs because SS3's age 3 fish were subject to fishing mortality in the historical period, whereas the old model's age 3 fish are considered new recruits and were not modeled in the historical period, nor subject to the historical F.

Stock-Recruitment
The 2016 model and SS3 estimated recruits as mean-unbiased recruitment deviations from an estimated mean value with a σ_R set to 0.5. The 2016 model estimated recruitment at age 3 and SS3 estimated recruitment at age 0. Numbers-at-age-3 were compared between the 2016 model and SS3 and were similar for most configurations of the two models.

Temperature-catchability parameter
The old model estimated a parameter relating summer bottom temperature to catchability. This relationship was omitted from model runs comparing the old model variants to equivalent SS3 configurations because it was estimated to have a negligible effect on the population dynamics and fit of the 2016 model. Though visually it appears that there may be a relationship between survey biomass and temperature, the relationship included in the old model was ineffective and should not be a barrier to moving to a different assessment framework. SS3 has the ability to estimate a multiplicative or additive linkage between an environmental index and any model parameter (including catchability). In addition, SS3 can estimate time-varying parameters, such as time-varying catchability.

Likelihood Components

Table 2 lists the equations for each likelihood component used in SS3 and in the 2016 model (and variants).

Catch biomass
The 2016 model translated numbers-at-age into numbers-at-length by multiplying by the age-length transition matrix as an input to the Baranov catch equation in terms of length, multiplied by the weight-length relationship, and summed over length bins to calculate the predicted catch and survey biomass. SS3 uses numbers-at-age in the Baranov catch equation to calculate catch-at-age, multiplies by the weight-at-age relationship, and sums ages to calculate predicted catch biomass. However, the age-length transition matrices used for these processes are mismatched between the 2016 model and SS3, leading to differences in predicted catch biomass for the same fishing mortality estimates.

In the interest of distinguishing the role of the of the mismatched age-length transition matrix between the 2016 model and SS3 from other model differences, an alternative calculation of catch biomass based on numbers-at-age and mid-year weight-at-age was incorporated into the old model code as an option for use (maintaining the original catch biomass equation as an option as well).

Survey biomass

Predicted survey biomass is calculated similarly in both model frameworks, except that SS3 assumes that the survey occurs mid-year (which it does), while the 2016 model uses continuous, year-round mortality (calculated at the end of the year) along with the mid-year weight-length relationship in calculations. As for catch biomass, the 2016 model predicts survey biomass based on numbers-at-length (as calculated from numbers-at-age and the age-length transition matrix), and we know that the age-length transition matrix is a mismatch between the 2016 model and SS3.

As for the predicted catch biomass, in the interest of distinguishing the role of the mismatch in predicted survey biomass between models, an additional option to calculate survey biomass based on numbers-at-age and weight-at-age (leaving the age-length transition matrix out of the calculations) was added to the old model and used in some old model variants to compare to SS3 model configurations.

Age- and length-composition likelihood components
The age- and length-composition likelihood components in SS3 are identical to those in the 2016 model. However, as noted above, the observations of survey proportions-at-age and proportions-at-length differ among models in that the data given to SS3 includes the data given to the old model code in addition to the proportions of age 0-2 fish and lengths below 6 cm.

Recruitment

The 2016 model and SS3 estimate recruitment deviations that are constrained by the σ_R value specified. The likelihood components are slightly different (Table 9.28), but the two model frameworks estimate similar recruitment patterns under a number of alternative model configurations.

Alternative SS3 model configuration to consider for the 2018 assessment

Two alternative models in SS3 are proposed to address some of the shortcomings of the 2016 model and the best matching SS3 model. Changes to the model are:

(1) Foreign reported catches were included in the data from 1964-1987 (Table 9.29). The most recent CIE review feedback listed the initial conditions of the 2016 model as uncertain and in need of investigation. The 2016 model estimated historical recruitment to be 58 million recruits, and main period mean recruitment to be 835 million recruits. Given the data on foreign reported catches that was not considered in the 2016 assessment (and even without that data), it is hard to believe that mean recruitment in the historical period may have been that low.
(2) The recruitment likelihood function used a sum-to-zero constraint
(3) Recruitment was fixed to its mean value for the last 4 model years due to lack of non-zero observations of young fish.
(4) Recruitment deviations were estimated dating back to 1961.
(5) Survey selectivity was changed to be age-based and sex-specific, using a double-normal selectivity curve. Derived age-based selectivity from the length-based curves estimated in the variant SS3_g indicated that age-based selectivity reached 1 – the model estimated that even small, old fish were fully selected by the survey, and therefore survey selectivity can easily be estimated as length- or age-based using a curve with an asymptote at 1. Use of age-based survey selectivity avoids the need to translate selectivity through the age-length transition matrix before being applied to numbers-at-age.
(6) A data weighting scheme developed by Francis, 2011 was used.

The above list describes Model 18.0.

An alternative model, Model 18.0b, is as for Model 18.0, but estimated separate fishery selectivity curves for each of 3 distinct time periods: 1964-1988, 1989-2007, and 2008-2016. These time blocks represent major change-points in the management of the flatfish trawl fishery.

Additional model runs that are not presented
In addition, an SS3 model was configured with an additive (log-based) relationship between summer bottom temperature and catchability (as for the old model), but (as for the 2016 model), the relationship lead to only very small adjustments in the survey biomass estimates. This model was not considered further.

A model was considered to estimate a male offset parameter from female natural mortality in a configuration where fishery length-based selectivity was estimated for males and females together. This was done because it is thought that natural mortality for males is different for that of females for many flatfish populations and the sex-specific selectivity curves in Models 2018.0 and 2018.0b fit the comp data by estimating that males recruit to the fishery at smaller sizes than do females. This seems unlikely unless there is some sex-specific spatial behavior driving this pattern and it was thought to be more likely that male natural mortality is different from female natural mortality, but the model estimates male natural mortality to be almost exactly the same as female natural mortality, so this model is not shown.

Results

Transition of Old Model into an Equivalent SS3 Model

To explore the effects of each of the non-matching factors listed in the table above, a variant of the 2016 accepted model was formulated as described in the section above entitled "Steps to understanding differences between model frameworks" to provide a starting place where the old model variant matched an SS3 model as closely as possible without investing a substantial amount of time in re-coding the old model framework. We start with an old model variant and an SS3 model configuration like the 2016 accepted model, but without historical F or historical catches, and with historical mean recruitment fixed to be equal to mean recruitment, and age-based logistic selectivity curves fixed and equal to zero below age 3. In addition, maturity-at-age and weight-at-age schedules (rather than parameters) were specified in both models, and the models were run deterministically with recruitment deviations fixed to 0, estimating only yearly fishing mortality. Differences in the biomass likelihood components were eliminated by adding an option to the code of the old model to use predicted catch biomass based on catch-at-age, rather than catch-at-length, eliminating the use of the age-length transition matrix from the calculation of the catch biomass from numbers-at-age. This is a standard method for calculating the predicted catch for the catch biomass likelihood component in statistical catch-at-age models. Maturity, weight-at-age, age-based selectivity, mean recruitment, numbers at age 3 (which are new recruits in the old model), and initial numbers-at-age in the absence of historical F and historical mean recruitment can all be matched exactly between the models (Figure 9.46 and Figure 9.47). The 2016 model used length-based survey and fishery selectivity. For the model variants shown in Figure 9.47, it was necessary to add age-based, sex-specific selectivity to the old model code to achieve a close match between model frameworks. This is the case because the age-length transition matrix differed between the 2016 model and SS3 and use of length-based selectivity requires that the age-length transition matrix be used to convert the length-based selectivity into age-based selectivity for calculation of numbers-at-age. Growth parameters (rather than schedules) need to be specified to calculate or estimate an age-length transition matrix within SS3 (SS3 lacks an option to specify an age-length transition matrix that is calculated externally); this leads to small mismatches in the weight-at-age schedules, but maturity-at-age remains exactly the same between models (Figure 9.48: growth as specified in the 2016 model and within SS3 using parameters rather than schedules). In addition, the calculation methods for the age-length transition matrix differ slightly from those input to the 2016 model as well, as described above. Hence, moving from the near-perfect match of models shown in Figure 9.47, incorporating the growth estimates from Figure 9.48 into the SS3 model and specifying identical length-based selectivity curves in both model frameworks leads to small mismatches in biomass quantities from the two model runs, even in a run with only fishing mortality estimated, and using standard catch-at-age likelihood equations (Figure 9.49).

Figure 9.50 shows model configurations identical to that shown in Figure 9.47 (where population dynamics between the two model runs matched almost exactly), except that here, the parameter in each model run determining historical recruitment was fixed to the old model's 2016 estimate (54 million age 3 recruits), which was very low relative to the main period recruitment estimate (834 million age 3 recruits). The numbers-at-age 3 in 1977-1979 are dramatically different between models in Figure 9.50. This occurs because SS3 estimates age 0 recruits and the old model framework estimates age 3 recruits. Therefore, in 1977, the age 3 individuals from SS3 recruited in 1974 under low historical mean recruitment, while the age 3 individuals from the old model variant recruited in 1977 under much higher main-period mean recruitment. The historical period effectively ends three years earlier in the old model framework, which can be seen in the plots of yearly fishing mortality, spawning stock biomass, and survey biomass. This timing mismatch disappears later in the time series after many years in which mean recruitment was high.

A comparison of model variants like those in Figure 9.47, but with growth specified internally, and mean recruitment and recruitment deviations estimated is shown in Figure 9.51. Fishing mortality, spawning stock biomass, and survey biomass match almost exactly between these models, and estimates of numbers-at-age 3 are very similar between models. Both models estimate very large numbers-at-age 3 in the last 2 years, which is likely unrealistic and uninformed by the data. While the old model framework is currently hard-wired to estimate recruitment through the end year that is modeled, SS3 options include specifying the first and last year in which recruitment deviations are estimated, and the user can choose to fix the recruitment in the last years of the model to mean recruitment for the purpose of projections.

Figure 9.52 shows a comparison of model configurations that are like those shown in Figure 9.51, except that the models estimate age-based selectivity (as well as mean recruitment, recruitment deviations, and fishing mortality). Here, fishery selectivity is very similar between the two models, but survey selectivity has a much more shallow slope in the old model than in SS3. SS3 estimates a selectivity of 0 at the lowest ages, which is informed by data indicating zero (or very low) catches of age 0-2 fish in the survey; these data cannot be included in the old model. In the old model, the youngest age modeled is age 3 and it is assumed that the lowest age bin of data (for age 3s) only includes age 3 fish and not age 0-3 fish.

Figure 9.53 shows a model comparison like that in Figure 9.51 where mean recruitment, recruitment deviations, and fishing mortality were estimated and age-based selectivity was fixed, but here the survey and fishery selectivity are length-based (as in the 2016 configuration of the old model) and fixed. As in Figure 9.51, the selectivity parameters were chosen such that selectivity below age 3 would be equal to 0 to minimize differences due to the different age-at-recruitment between models. Given that the selectivity curves match exactly between models, it is the influence of the mismatch between the age-length transition matrices used in the two models that leads to a scale difference in biomass estimates between models (for both spawning and survey biomass) and small mismatches in yearly estimates of fishing mortality. The estimates of numbers-at-age are generally similar in most years.

Adding another layer of the 2016 model configuration back in to the comparison, Figure 9.54 shows the same comparison as for Figure 9.53, but with the length-based selectivity estimated instead of being fixed. As for the model runs where age-based selectivity parameters were estimated (Figure 9.52), the fishery selectivity curves estimated were very similar between the two models. Likewise, the old model estimated a shallow survey selectivity slope that does not reach 0 at small lengths. Again, the old model is informed only by data from age 3+ individuals, while the SS3 model is informed by observations of 0 (or few) individuals of age 0-2. Essentially, the shallow slope estimate in the old model is an estimate of catchability that is below 1, and this shows up as a scale mismatch in spawning biomass, where the spawning biomass of the old model is inflated because the old model estimates that large, mature fish occur in the population that aren't selected by the survey. The SS3 model survey selectivity indicates that the large, mature fish are fully selected.

The scale mismatch in spawning biomass between models becomes larger when, in addition to differences in survey selectivity estimates, and growth, the old model's length-based biomass likelihood equations are used in the objective function (Figure 9.55). The length-based biomass likelihood equations in the old model make use of the mismatching age-length transition matrix to calculate predicted fishery and survey catches in biomass, whereas the SS3 model calculates these quantities using the weight-at-age schedule (which is a better match between models than the age-length transition matrix). To minimize the objective function such that catch biomass matches the data, a different scale of yearly fishing mortalities must be estimated by the old model than by SS3, and other parameter estimates between models must then differ in order to fit predicted proportions-at-age to the age composition data in both models, given the differences in Fs.

The SS3 model that best mimicked the 2016 model

It is possible to configure SS3 into a model that better matches the 2016 configuration of the old model than does the SS3 model shown in Figure 9.55 with historical mean recruitment and historical fishing mortality added. Two main sources of mismatch between the models are (1) the age at recruitment and (2) the age-length transition matrix used to convert length-based selectivity to age-based selectivity for calculation of numbers-at-age. This conversion to age-based selectivity within the model meant that an equivalent model could be configured using sex-specific, age-based selectivity, and this was done using the following approach:

1. Double-normal survey selectivity was specified, fixing the parameter defining the descending limb of the curve to a large value such that selectivity was asymptotic (as selectivity in the old model was asymptotic)
2. Selectivity below age 3 was set to 0 (which is an option that can be specified when specifying the double-normal selectivity curve in SS3).
3. The old model's age-length transition matrix was used to convert the old model's estimated length-based survey selectivity to age-based survey selectivity and the selectivity at which an asymptote (maximum age-based selectivity) occurred was noted. If selectivity is below 1, this means that some old individuals are never subject to being caught by the survey because they never grew large enough to be selected. In function, an age-based selectivity with an asymptote below 1 lowers catchability. In the 2016 model, the asymptote occurs around age 7 and the average age-based selectivity between ages 7 and 21 was 0.7. An assumption of age-based selectivity reaching an asymptote at 1 with a catchability of 0.7 is equivalent to an assumptions of age-based selectivity with an asymptote at 0.7 and a catchability of 1.
4. The SS3 model was configured with catchability fixed at 0.7 (instead of 1) and an age-based, sex-specific, double-normal, asymptotic survey selectivity curve (the descending limb was fixed to a large value).

A model comparison between the SS3 model configured using this approach and the 2016 model configuration was then done, replacing SS3's length-based survey selectivity curve with this age-based curve. Here, estimation of historical fishing mortality and historical mean recruitment were included, and standard catch-at-age likelihood equations in the old model. The comparison is shown in Figure 9.56, using standard catch-at-age likelihood questions in the old model. The estimation of historical recruitment leads to a similar mismatch of fishing mortality and numbers-at-age in the initial years of the model to that seen in Figure 9.50 (a deterministic model with historical recruitment fixed to the value estimated in the 2016 old model configuration). Aside from these initial years, the fishing mortality, numbers-at-age, survey biomass, and fishery selectivity are all similar for the two models. The survey selectivity is somewhat similar when remembering that catchability in the SS3 model is set at 0.7, so one can imagine the SS3 survey selectivity shifted downwards on the y-axis to a maximum value of 0.7. The spawning biomass is a little bit smaller in SS3 than in the old model and this is due to the difference in shape between the estimates of selectivity where the asymptote occurs at an earlier age in SS3 than in the old model.

Finally, Figure 9.57 shows the same comparison as for Figure 9.56, but using the length-based likelihood equations that were used in the 2016 configuration of the old model such that this is a true comparison to the 2016 accepted model. The mismatch between models is more evident when using the length-based likelihood equations in the old model. The yearly fishing mortality rates are similar between models, but the equations for the predicted catch biomass and survey biomass yield different results between models. To match these values to the catch biomass and survey biomass data, the models must adjust a parameter or parameters that have an influence on the scale of the biomass, such as mean recruitment and/or recruitment deviations. The plot of numbers-at-age-3 shows a difference in scale that is then amplified by multiplying by weight-at-age to calculate the spawning biomass. Figure 9.58-Figure 9.65 show a comparison between the SS3 model and the 2016 model of fishery and survey proportions-at-length and proportions-at-age. The difference in the models caused by estimating historical mean recruitment for a model with recruits at age 3 vs age 0 can be seen in fits to age- and length-compositions in the initial model years, but in general, the proportions-at-age/-length are very similar for the two models.

Alternative SS3 models for the 2018 assessment

Differences from the SS3 2016 model match and the two 2018 models

There is a scale difference in spawning biomass between the 2016 best matched model and Models 2018.0 and 2018.0b because the 2016 model match fixed catchability to 0.7 (Figure 9.66-Figure 9.68). This catchability specification was a hack to match SS3 to the 2016 model that is not necessary moving forward because SS3 (making use of data on age 0-2s) estimates a derived age-based selectivity curve that reaches an asymptote at 1 (the 2016 model with the old code estimated this asymptote at 0.7, which prompted this “hack” of setting catchability in SS3 to 0.7 to best mimic the old model). In addition, the old model did not include foreign-reported catch data, and estimated simple deviations, which led to slightly different estimates of recruitment from the 2018.0-series models.

Comparing Models 2018.0 and 2018.0b

Models 2018.0 and 2018.0b estimate nearly identical spawning biomass and survey biomass (Figure 9.66 and Figure 9.67). The estimation of different selectivity curves in different time periods led to differences in the scale of fishing mortality in the early years of the model, with model 2018.0b estimating lower fishing mortality in the 1st and 3rd time blocks (prior to 1988 and after 2007; Figure 9.68-Figure 9.70, Table 9.32). Selectivity during the middle time block is similar between models (Table 9.32, Figure 9.70).

When sex-specific selectivity is estimated (as it is in Models 2018.0 and 2018.0b), the resulting selectivity curves indicate that males recruit to the fishery at smaller sizes than do females. This could occur if smaller females were for some reason less vulnerable to the fishery due to spatial or some other behavior. However, it is likely that some other difference between males and females is not represented by these models. Growth and/or variation in growth may be mis-specified, as it was estimated outside of the model (and therefore unable to account for the effect of selectivity on length-at-age samples, for instance). It may also be the case that growth has varied over time or space in a different way for males than for females. A model run was done with selectivity for males and females estimated together, and where male natural mortality was estimated; this model run estimated male natural mortality to be almost identical to female selectivity. Further research is needed to understand why smaller males are found in the length composition data as compared to females. Although selectivity may not be a full or accurate explanation for these differences in the data between males and females, it leads to substantially improved fits to age-composition data over the best matching model from 2016 (Figure 9.71).

Model 2018.0 and 2018.0b show similar fits to age composition data, in aggregate over years (Figure 9.71). Model 2018.0 showed very poor fits to fishery length composition data during the early years of the model (prior to the mid-80s; Figure 9.75), which was part of the motivation to implement Model 2018.0b, which estimates a separate selectivity curve for this early time period and for the most recent years after the groundfish fishery was rationalized in 2008. Figure 9.71 and Figure 9.79 shows that fits to fishery length data were improved by including these time blocks for selectivity. Detailed plots of yearly fits to survey and fishery age composition data are shown in Figure 9.73-Figure 9.76 for Model 2018.0 and in Figure 9.77-Figure 9.80 for Model 2018.0b.

Table 9.30 shows likelihood components for the three models. Most likelihood components (except for the survey biomass likelihood component) cannot be compared between the 2016 matching model and the other two models because a different data weighting scheme was implemented in Models 2018.0 and 2018.0b. The survey likelihood components for Models 2018.0 and 0b were lower than for the 2016 SS3 matching model. In addition, the overall likelihood and all components were slightly lower (better) for Model 2018.0b than for Model 2018.0 (but were within a similar range of one another).

Table 9.32 shows the survey and fishery selectivity parameter estimates for each model. The parameter estimates for fishery selectivity had higher standard deviations for the earliest time block (1964-1977) when data were more sparse. Only catches were available for 1964-1976, and only catches and length-composition data were available until the year 2000.

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Tables

Table 9.27. Symbols used in this document.

Symbol	Meaning
x	sex
a	age
l	length
f	fleet (fishery or survey)
t	time
$S_{f,x,a}$	Selectivity for fleet f, sex x, and age a
$N_{t,x,a}$, $\boldsymbol{N_{t,x}}$	Numbers at age a, time t, and sex x, and vector of numbers-at-age
$w_{a,x}$, w_l	Mid-year weight at age a for sex x and weight at length l
$Z_{t,x,a}$	Total mortality at age a, sex x, and time t
$I_{t,f}$	Observed survey biomass at time t for fleet f
$SB_{t,f}$	Predicted survey biomass at time t for fleet f
$\sigma_{survey,t,f}$	Standard deviation of observed survey biomass at time t for fleet f
$n_{t,x,f}$	Number of age-composition observations at time t for sex x and fleet f
$p_{t,x,f,a}$	Observed proportion at age a, time t, fleet f, and sex x
$\hat{p}_{t,x,f,a}$	Predicted proportion at age a, time t, fleet f, and sex x
$n_{2,t,x,f}$	Number of length-composition observations at time t for sex x and fleet f
$p_{t,x,f,l}$	Observed proportion at length l, time t, fleet f, and sex x
$\hat{p}_{t,x,f,l}$	Predicted proportion at length l, time t, fleet f, and sex x
$\tilde{R}_t$	Estimated mean recruitment in year t
σ_R	Recruitment CV
b_t	Bias adjustment factor at time t (specified in SS3 only)
C_t^{obs}	Observed catch at time t
$\hat{C}_t$	Predicted catch at time t
$\sigma_{t,f}$	Standard error of catch at time t for fleet f (specified for SS3 only)
$\boldsymbol{\varphi_x}$	Age-length transition matrix (rows are ages, columns are lengths)

Table 9.28. Likelihood components used in the old model and SS3 model. Numbers in the component column are likelihood component weightings for: (SS3, old model).

Component	SS3	Old Model
Survey biomass $(SB_{t,f})$ equation	$\sum_{x,l} w_l \sum_a S_{f,x,l} S_{f,x,a} \varphi_{t,x,a,l} N_{t,x,a} e^{-0.5(Z_{t,x,a})}$	$N_{t,x,l} = \boldsymbol{N_{t,x}\varphi_x}$; $\sum_{x,l} S_{f,x,l} N_{t,x,l} w_l \frac{1-(e^{-(S_{f,x,l}F+M)})}{(S_{f,x,l}F+M)}$ Alt Option: Age-based
Survey biomass likelihood (1,1)	$\sum_{t \in survey} \frac{\left(\ln(I_{t,f}) - \ln(SB_{t,f})\right)^2}{2\sigma^2_{survey}}$	As for SS3
Age composition (0.93, 0.93) survey (0.52, 0.52) fishery	$\sum_t \sum_x \sum_a n_{t,x,f} p_{t,x,f,a} \ln\left(\frac{p_{t,x,f,a}}{\hat{p}_{t,x,f,a}}\right)$	As for SS3
Length Composition (0.42, 0.42)	$\sum_t \sum_x \sum_l n_{2,t,x,f} p_{t,x,f,1} \ln\left(\frac{p_{t,x,f,l}}{\hat{p}_{t,x,f,l}}\right)$	As for SS3
Recruitment (1,1)	$\frac{1}{2}\left(\sum_{t=1977}^{2016} \frac{\tilde{R}_t^2}{\sigma_R^2} + b_t \ln(\sigma_R^2)\right)$ (sum to 0 constraint possible, but not used)	$\frac{1}{2\sigma_R^2}\sum_{t=1977}^{2016}\left(\ln(N_{t,1}) - \ln(\tilde{R}_t) + \frac{\sigma_R^2}{2}\right) + n_t \ln(\sigma_R)$, (sum to 0 constraint possible, but not used)
Catch biomass $(\hat{C}_t)$ equation	$\sum_{a,x}\left(\frac{S_{a,x} F_t}{(S_{a,x} F_t + M)} N_{t,x,a}(1 - e^{-(S_{a,f} F_t)}) w_{x,a}\right)$	$N_{t,x,l} = \boldsymbol{N_{t,x}\varphi_x}$; $\sum_{l,x}\left(\frac{S_{f,l} F_t}{(S_{f,l} F_t + M)} N_{t,x,l}(1 - e^{-(S_{f,l} F_t)}) w_{x,l}\right)$ Alt option: as for SS3
Catch (50,50)	$\sum_t \frac{(\ln(C_t^{obs}) - \ln(\hat{C}_t))^2}{2\sigma_{t,f}^2}$	$\sum_t (\ln(C_t^{obs}) - \ln(\hat{C}_t))^2$

Table 9.29. Catch biomass as used in the 2016 model and in the alternative 2018 SS3 model

Year	Catch in 2018 SS3 Model	Catch in 2016 Model	Year	Catch in 2018 SS3 Model	Catch in 2016 Model
Initial Catch	11659		1993	13574	13574
1964	12315		1994	17006	17006
1965	3449		1995	14715	14715
1966	5086		1996	17346	17346
1967	11218		1997	20683	20683
1968	12606		1998	24387	24387
1969	9610		1999	18573	18573
1970	21050		2000	20441	20441
1971	26108		2001	17811	17811
1972	10380		2002	15575	15575
1973	17715		2003	13785	13785
1974	13198		2004	17398	17398
1975	5011		2005	16108	16108
1976	7565		2006	17981	17981
1977	7909	7909	2007	18958	18958
1978	13864	6957	2008	24540	24540
1979	6042	4351	2009	19558	19558
1980	8600	5247	2010	20128	20128
1981	10609	5218	2011	13559	13559
1982	8417	4509	2012	11367	11367
1983	5518	5240	2013	17355	17354
1984	4458	4458	2014	16512	16512
1985	5636	5636	2015	11307	11307
1986	5208	5208	2016	8321	8321
1987	3595	3595			
1988	6783	6783			
1989	3604	3604			
1990	20245	20245			
1991	14197	14197			
1992	14407	14407			

Table 9.30. Likelihood component values for the 2016 SS best matching model and for Models 2018.0 and 2018.0b. Only the 2016 SS3 best matching model survey biomass likelihood component can be compared to Models 2018.0 and 0b because the data weighting approach was different in 2016 SS3 best matching model than for the other two models.

Likelihood Component	2016 SS3 best match	Model 2018.0	Model 2018.0b
TOTAL	1,748	456	435
Survey	-21.66	-35.62	-36.36
Length_comp	1,020	159	147
Age_comp	605	312	307
Recruitment	128.991	20.694	16.959

Table 9.31. Parameter estimates for key scale-related parameters for the SS3 best model match, and Model 2018.0 and 0b. Historical mean recruitment = exp(log mean recruitment + log historical recruitment offset). Initial fishing mortality and historical recruitment was applied in 1977 for the 2016 best match and in 1964 for Models 2018.0 and 2018.0b.

	2016 SS3 Best Match		**Model 2018.0**		**Model 2018.0b**	
Parameter	**Est**	**sd**	**Est**	**sd**	**Est**	**sd**
log mean recruitment	13.25	0.07	13.63	0.03	13.64	0.03
log catchability	-0.36	fixed	0	fixed	0	fixed
Initial fishing mortality	0.03	0.00	0.07	0.01	0.03	0.00
log historical recruitment offset	-1.08	0.08	0	fixed	0	fixed

Table 9.32. Selectivity parameter estimates for Models 2018.0 and 2018.0b.

	Model 2018.0, 1964-2016		Model 2018.0b, 2008-2016		Model 2018.0b, 1988-2007		Model 2018.0b 1964-1987	
	Est	StDev	Est	StDev	Est	StDev	Est	StDev
Size at 50% selectivity (f)	39.379	1.084	37.196	1.091	39.429	1.522	28.312	3.522
Slope (f)	7.994	0.870	4.339	1.449	7.050	1.346	9.147	3.688
Size at 50% selectivity (m) (offset from f)	-3.608	0.595	-2.833	0.709	-3.985	0.821	-0.952	3.359
Slope (m) (offset from f)	-1.059	0.939	0.547	1.602	-0.873	1.355	-1.231	4.718
Peak: beginning age for the plateau (f)	7.162	0.312	7.208	0.303	7.208	0.303	7.208	0.303
Ascending width (f; ln)	2.324	0.132	2.338	0.127	2.338	0.127	2.338	0.127
Male peak offset	-0.602	0.319	-0.606	0.315	-0.606	0.315	-0.606	0.315
Male ascending width offset (ln)	-0.188	0.152	-0.188	0.149	-0.188	0.149	-0.188	0.149

Figures

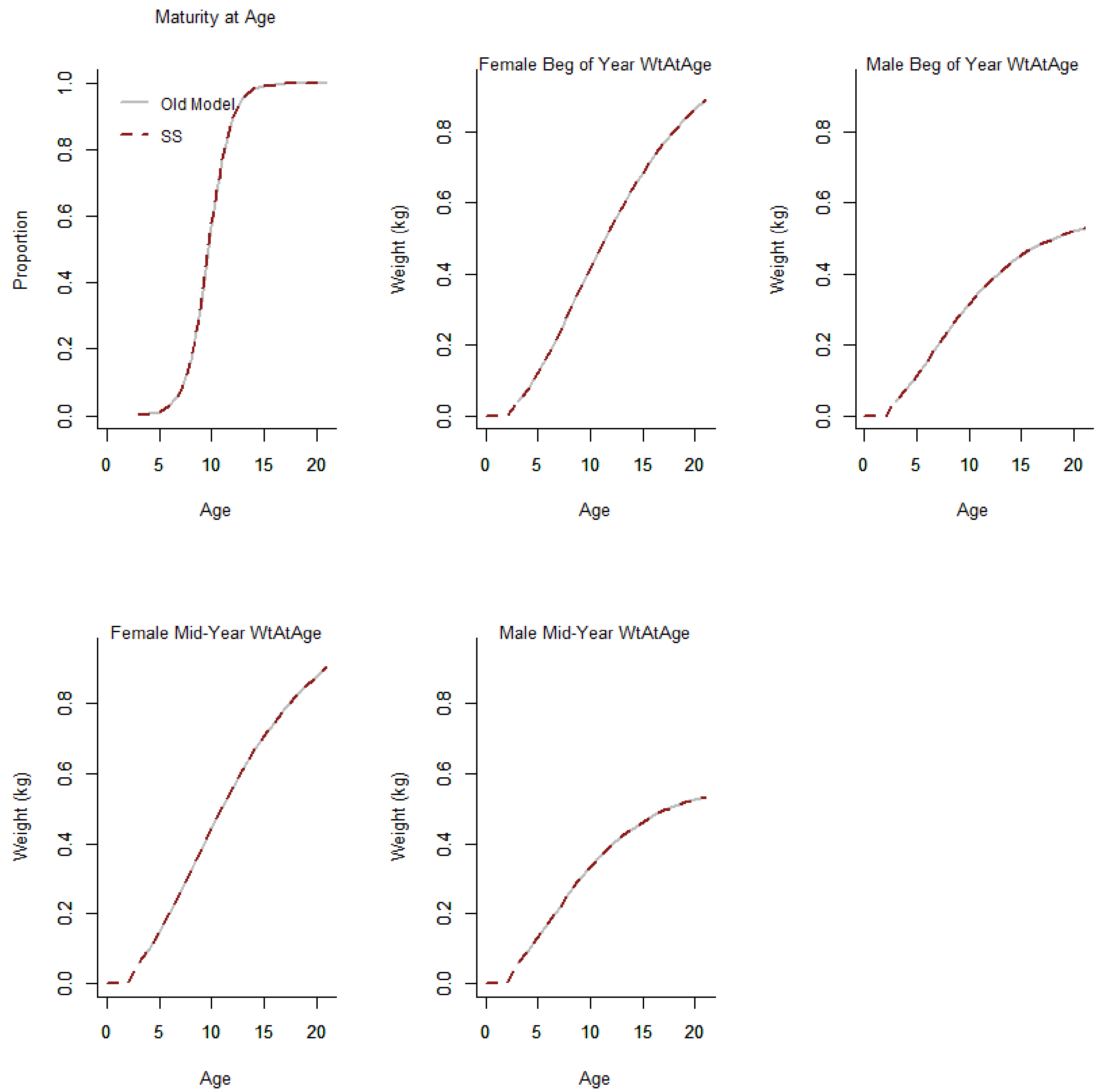


Figure 9.1. Maturity and weight-at-age schedules for the old model (grey lines) and SS3 (dotted red lines) when specified as vectors input to the SS3 model. This method of specifying growth in SS3 cannot be used if length-based selectivity is also used because it does not allow the user to specify an age-length transition matrix.

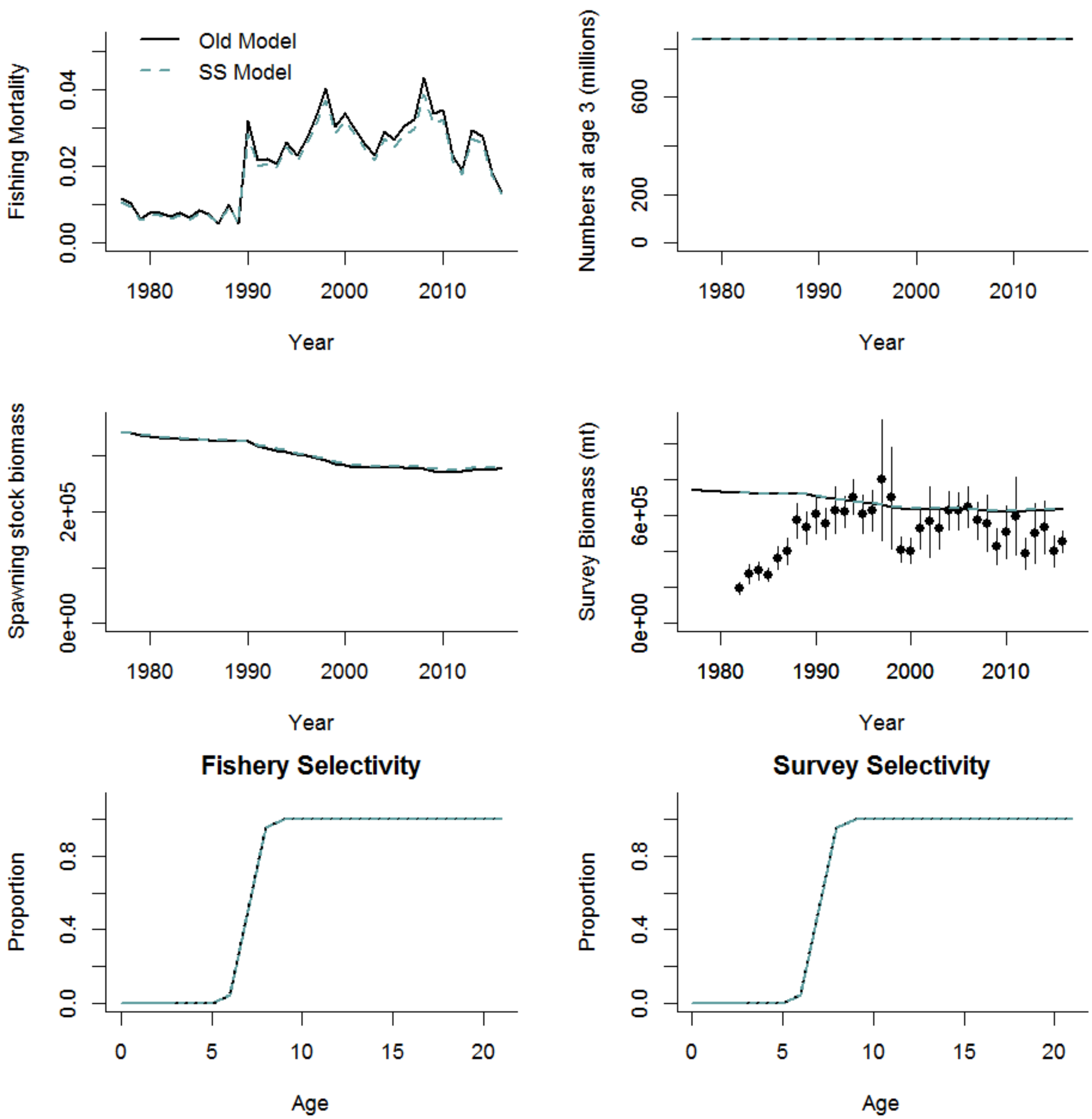


Figure 9.2. Population dynamics of the old model and SS3 in a deterministic run with fishing mortality estimated and all other parameters fixed. Empirical maturity and weight-at-age schedules were input to SS3 and not specified internally. Age-based selectivity was modeled and was chosen such that selectivity at young ages was equal to 0. Biomass likelihood equations were age-based.

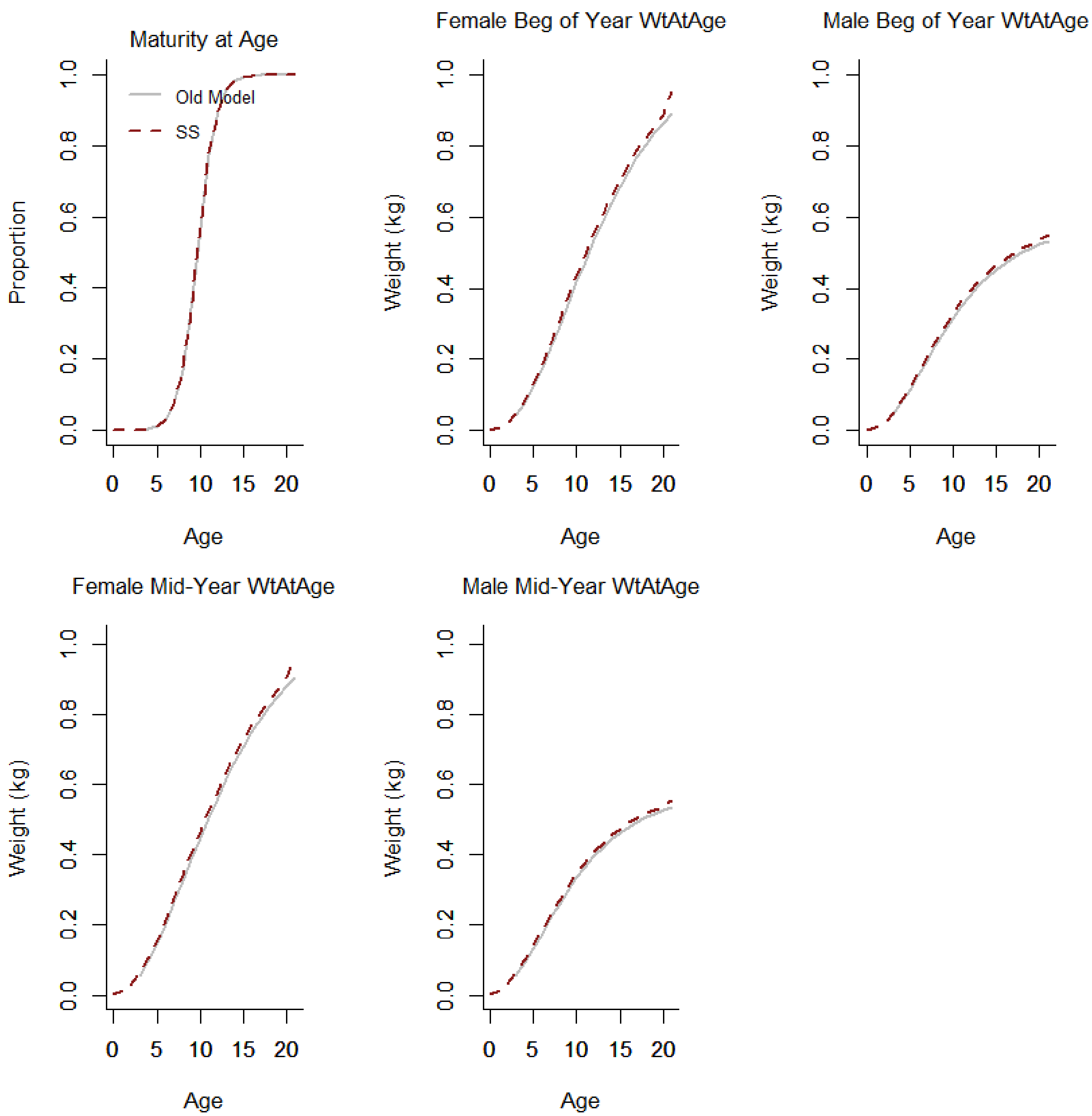


Figure 9.3. Maturity and weight-at-age schedules for the old model (grey lines) and SS3 (dotted red lines) when specified internally in the SS3 model. This method of specifying growth must be used when length-based selectivity is used because it provides SS3 with the information necessary to populate an age-length transition matrix internally, which is needed to apply length-based selectivity to numbers-at-age and to calculate predicted proportions-at-length from predicted numbers-at-age.

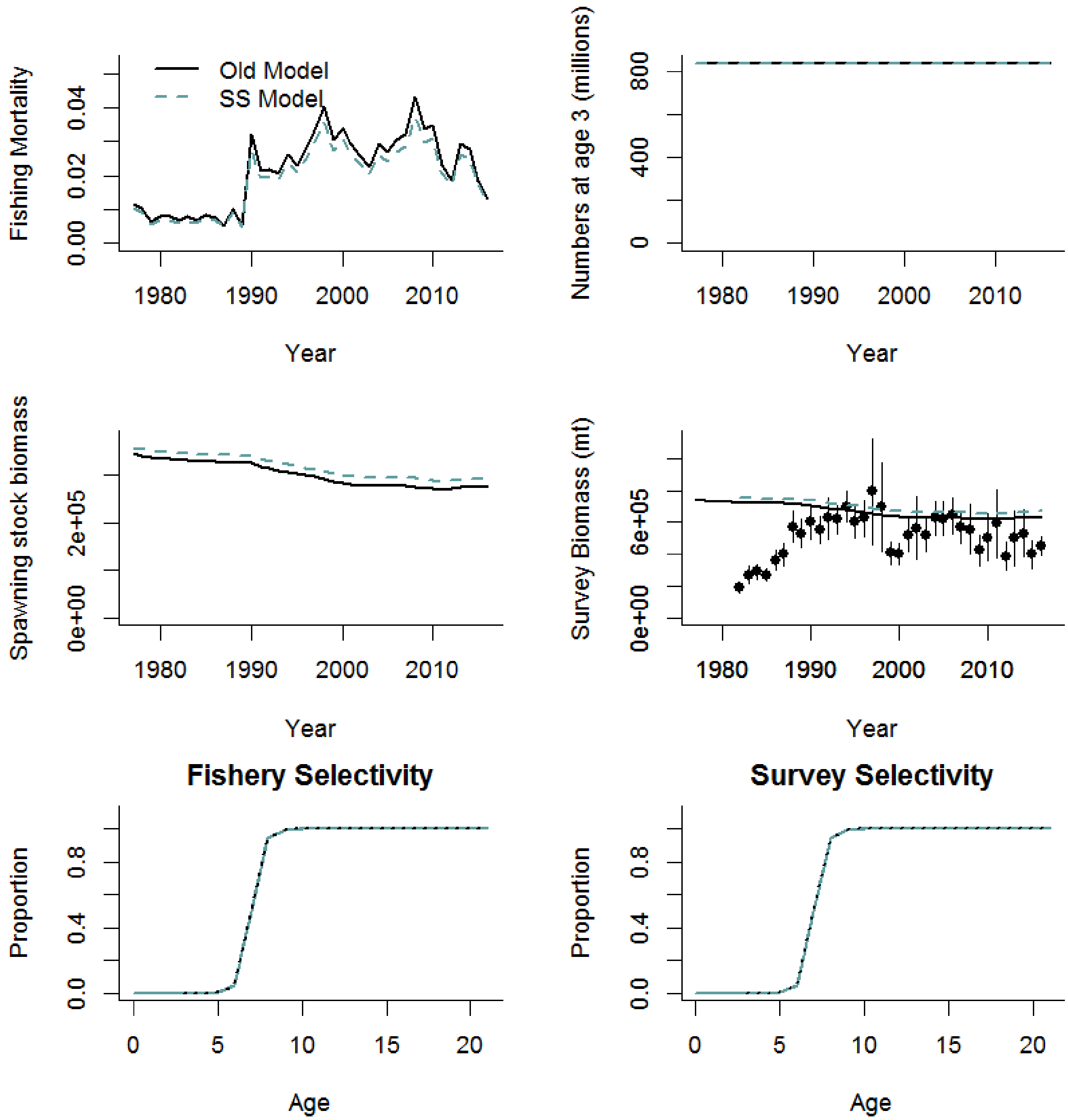


Figure 9.4. Population dynamics of the old model and SS3 in a deterministic run with fishing mortality estimated and all other parameters fixed. Maturity and weight-at-age schedules were specified internally in SS3. Age-based selectivity was modeled and was chosen such that selectivity at young ages was equal to 0. Biomass likelihood equations were age-based.

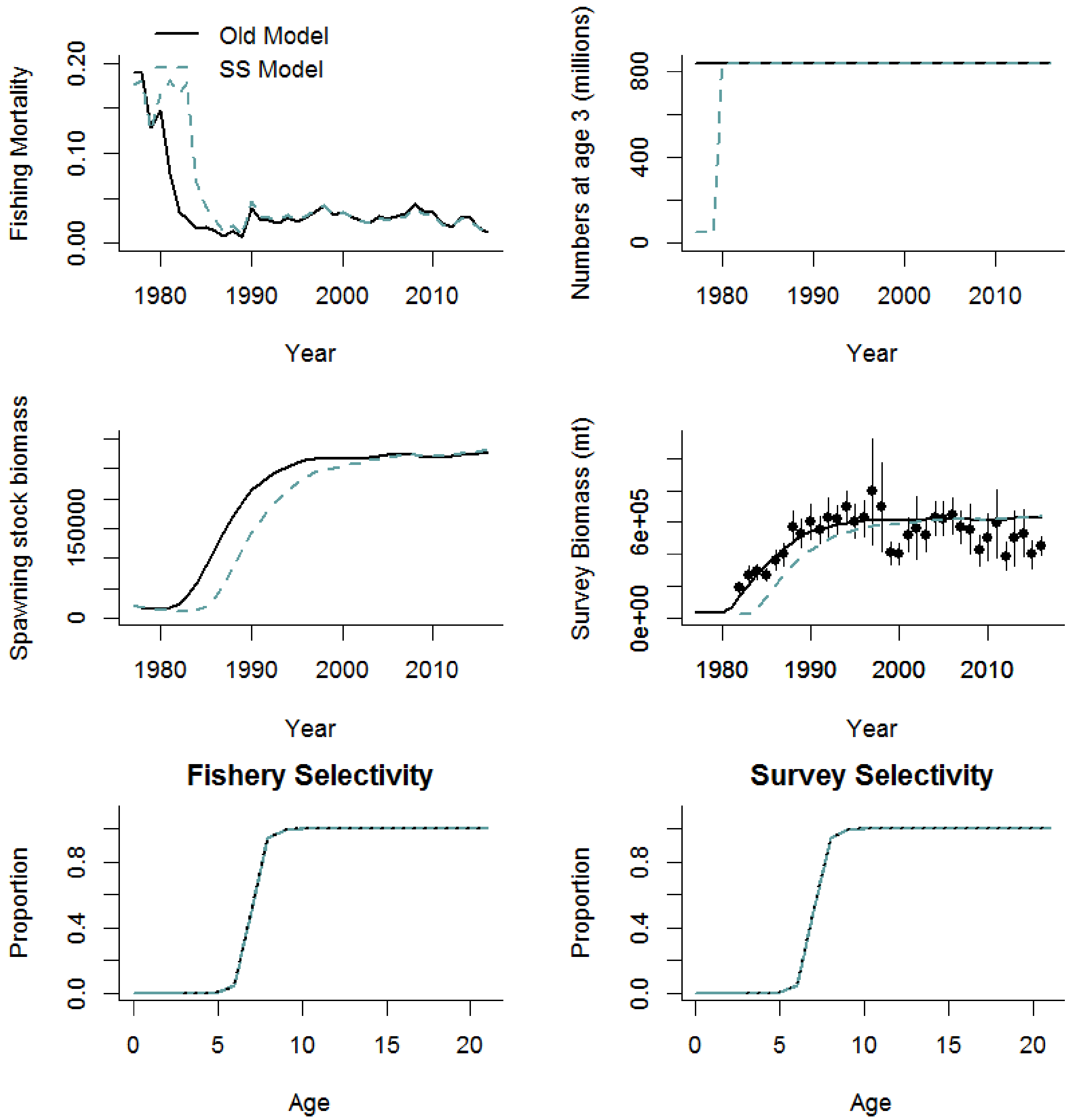


Figure 9.5. Population dynamics of the old model and SS3 in a deterministic run with historical R fixed and equal to 55 million age 3 recruits (mean recruitment from 1977 onwards in the model is equal to 835 million recruits). Fishing mortality was estimated and all other parameters were fixed. Maturity and weight-at-age schedules were specified empirically in SS3 to match exactly between models. Age-based selectivity was modeled and was chosen such that selectivity at young ages was equal to 0. Biomass likelihood equations were age-based.

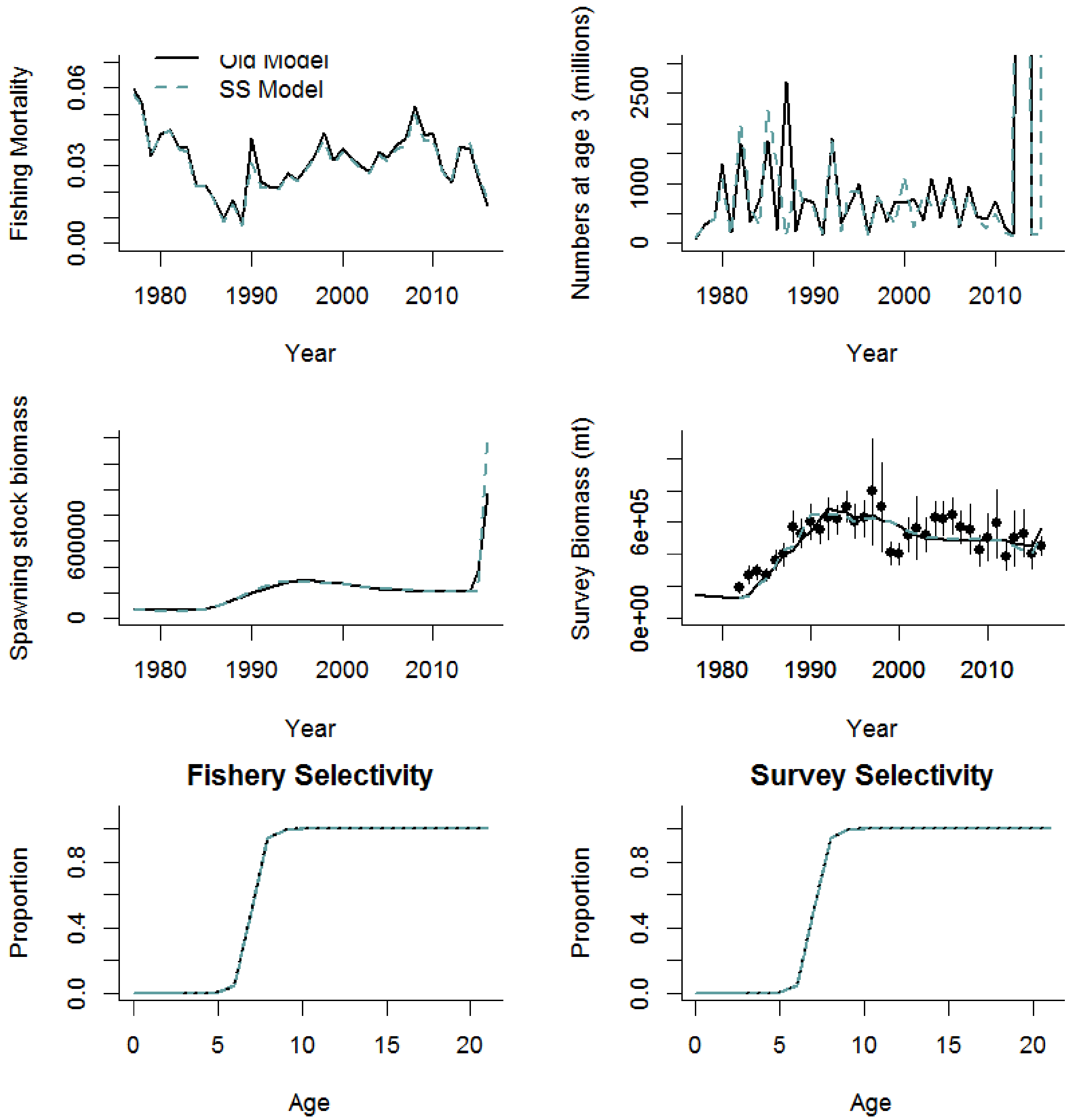


Figure 9.6: Population dynamics of the old model and SS3 in a run with mean log recruitment (R0 in SS3) and recruitment deviations estimated, as well as fishing mortality. Maturity and weight-at-age schedules were specified internally in SS3. Age-based selectivity was modeled and was chosen such that selectivity at young ages was equal to 0. Biomass likelihood equations were age-based.

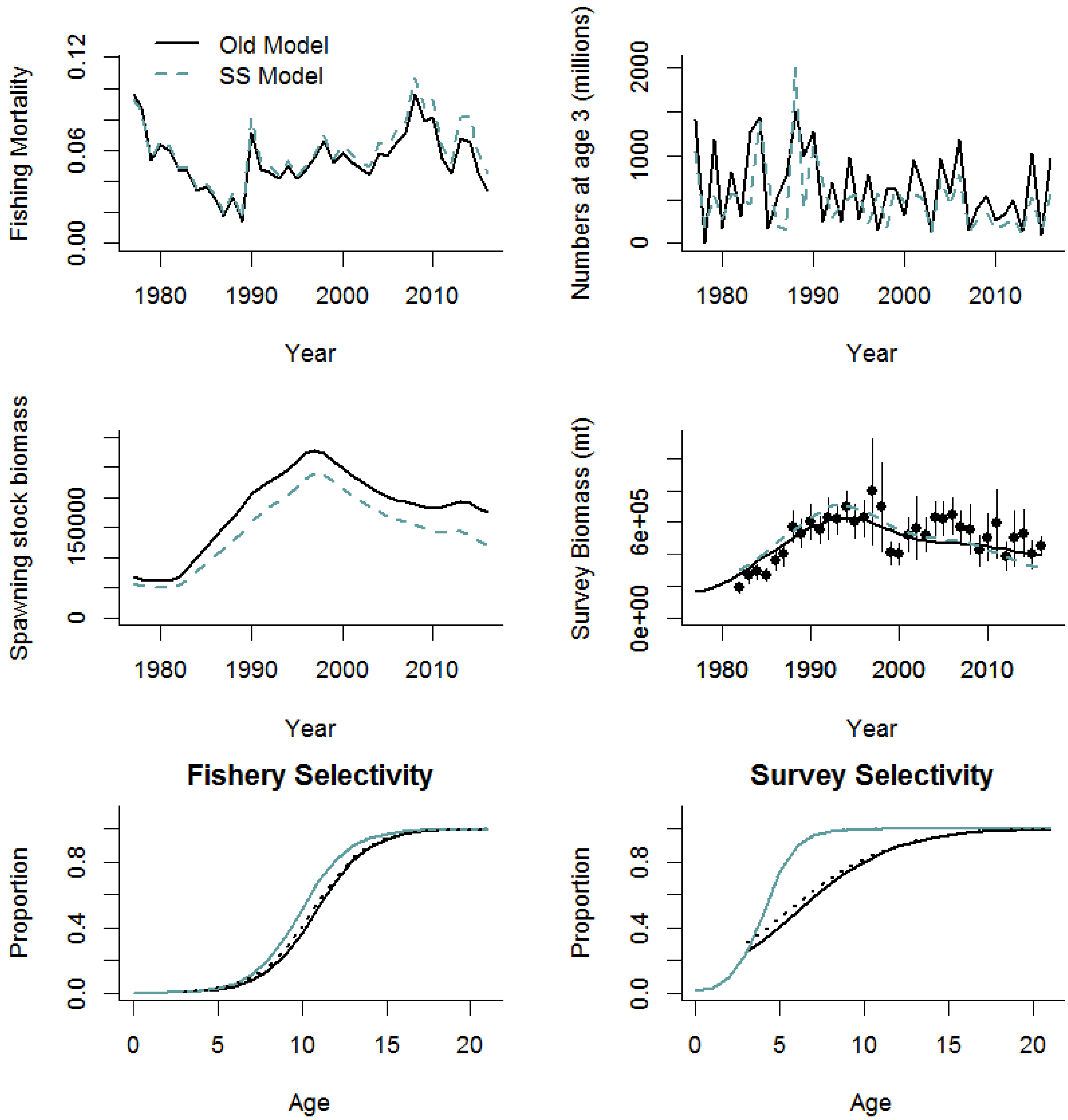


Figure 9.7. As for Figure 9.51, except that age-based selectivity is estimated instead of being fixed.

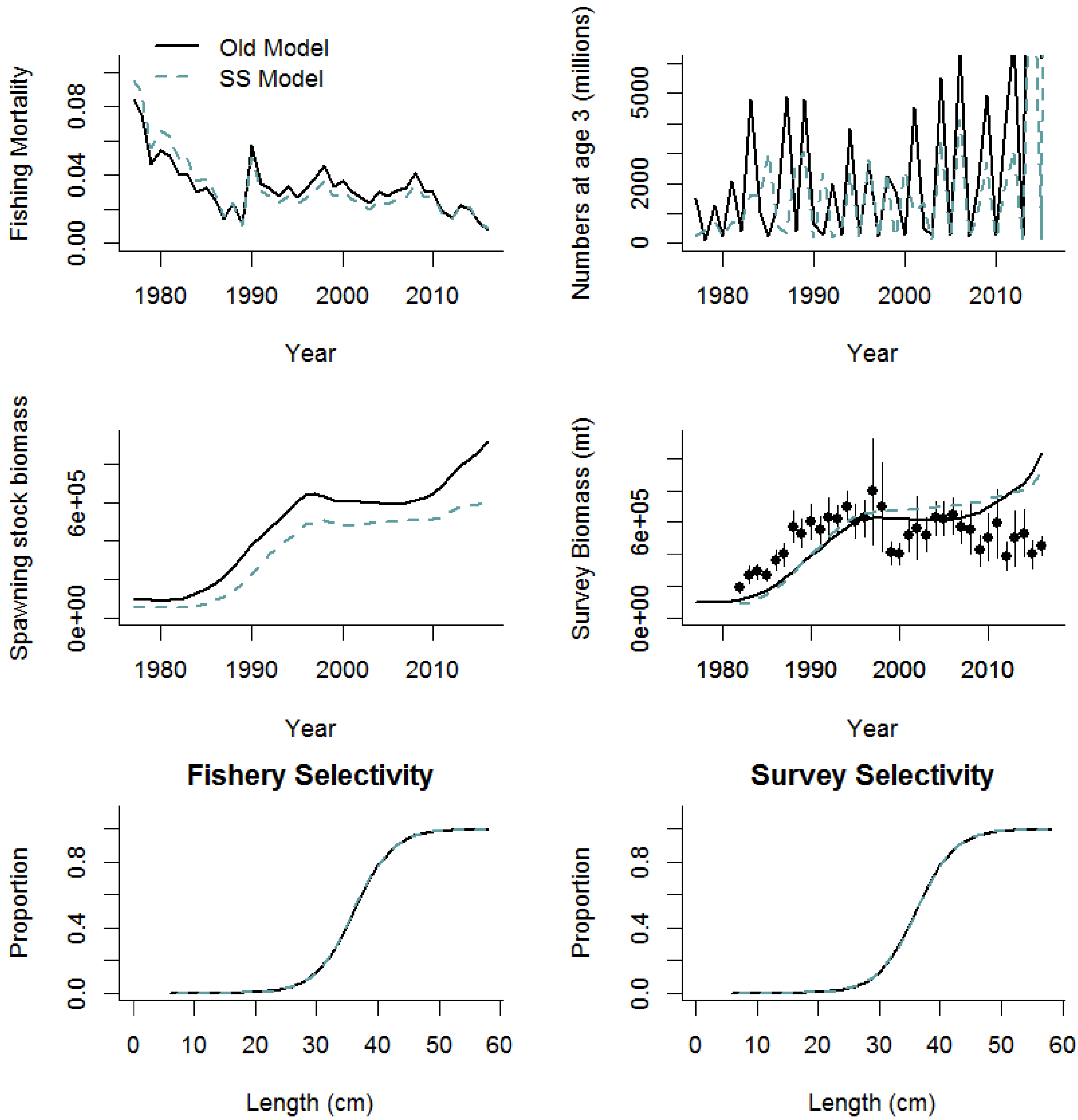


Figure 9.8: As for Figure 6, but length-based selectivity was modeled (and fixed) and was chosen such that selectivity at young ages was equal to 0.

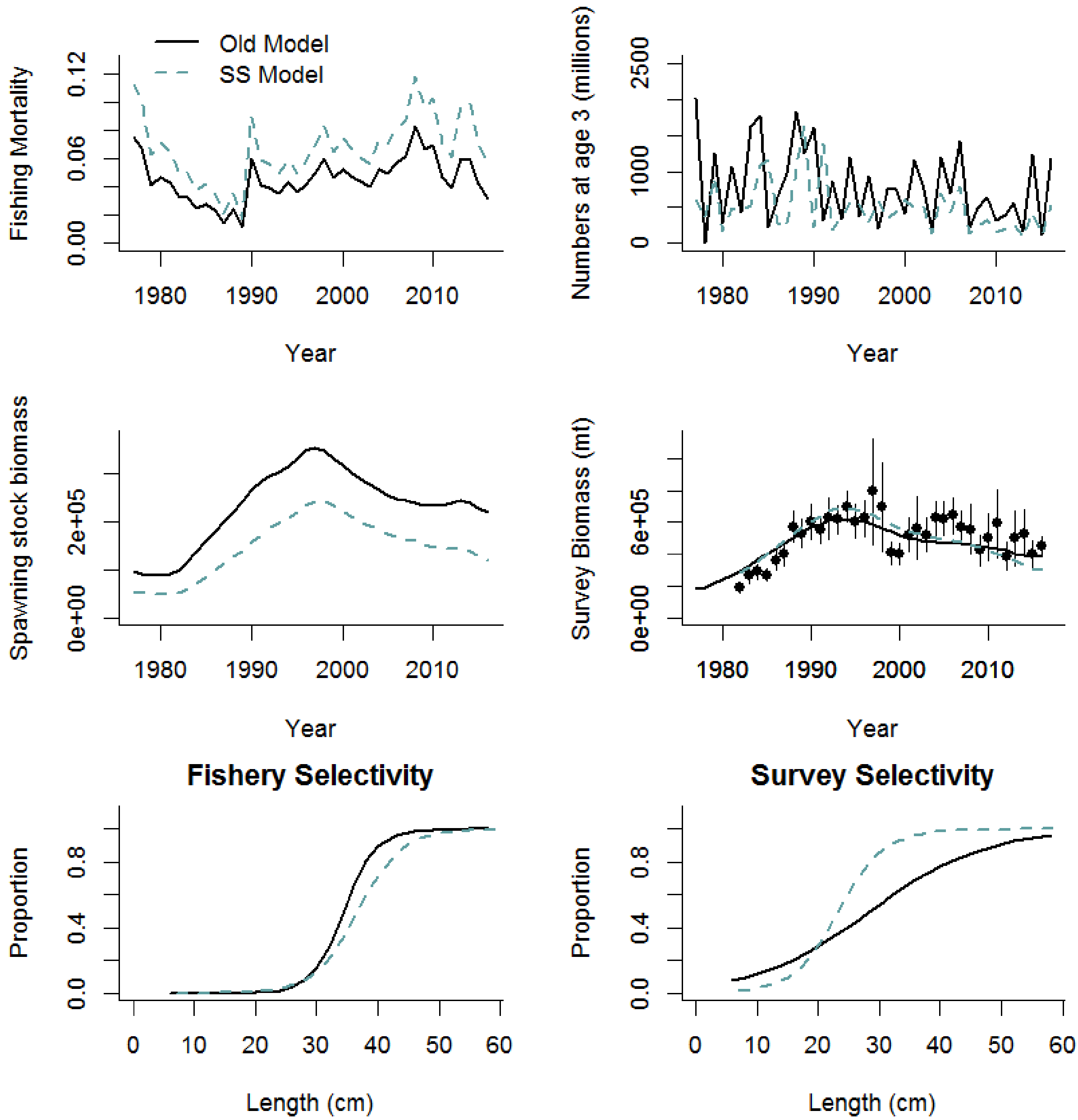


Figure 9.9: As for Figure 9.53, except that the length-based selectivity was estimated and not fixed. The length-based selectivity requires the use the age-length transition matrix to convert length-based selectivity to age-based selectivity, which is required to calculate numbers-at-age. The age-length transition matrix is not an exact match between models, and the result is a difference in the scale of F between models. The survey selectivity in the old model is not informed with data for ages 0-2. This leads to differences in estimates of selectivity, which leads to a bigger mismatch in spawning stock biomass between the two models.

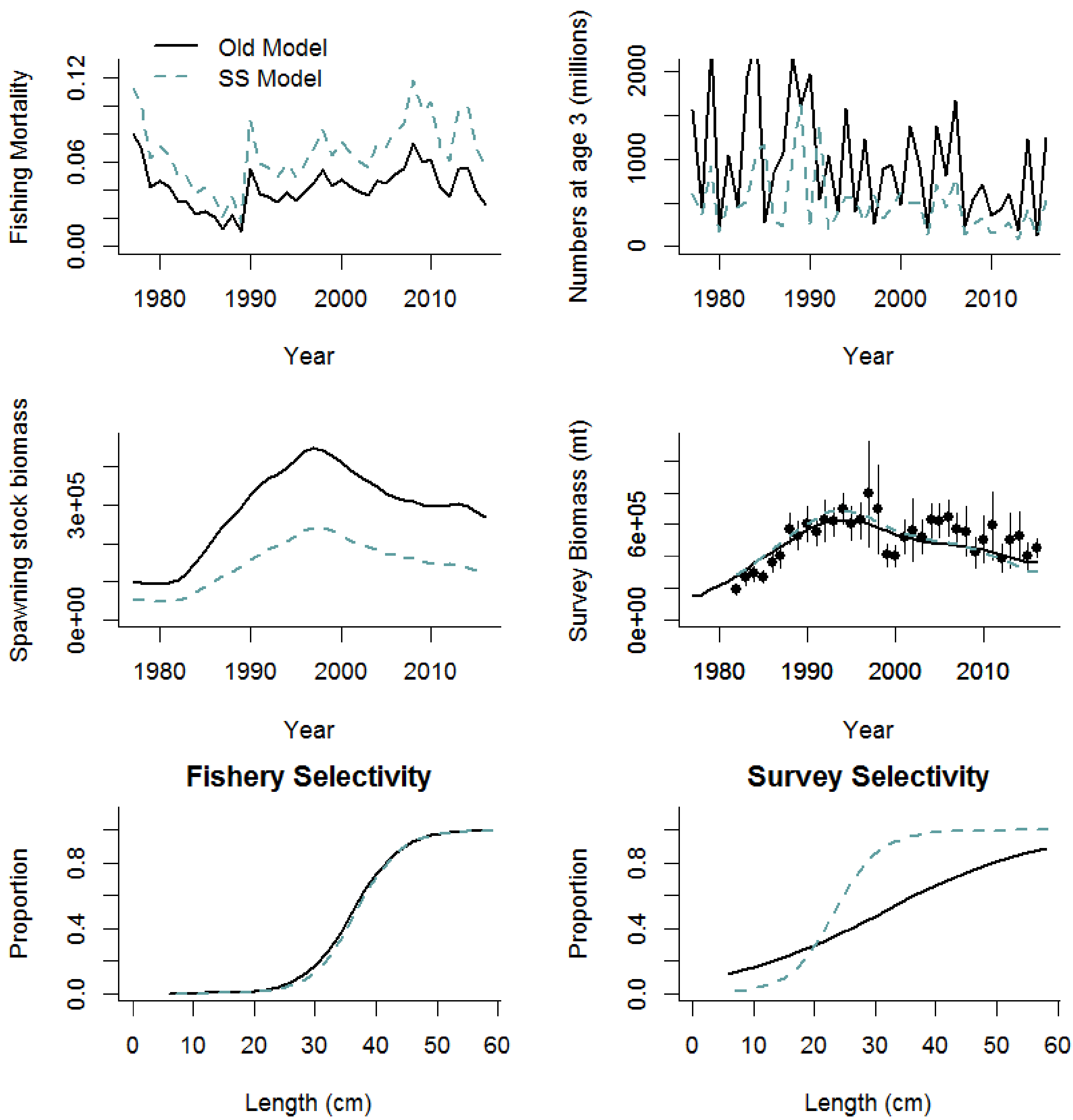


Figure 9.10. As for Figure 9.54, except that the old model uses length-based likelihood formulations, calculating catch and survey biomass from numbers-at-length and length-based selectivity (which requires the age-length transition matrix).

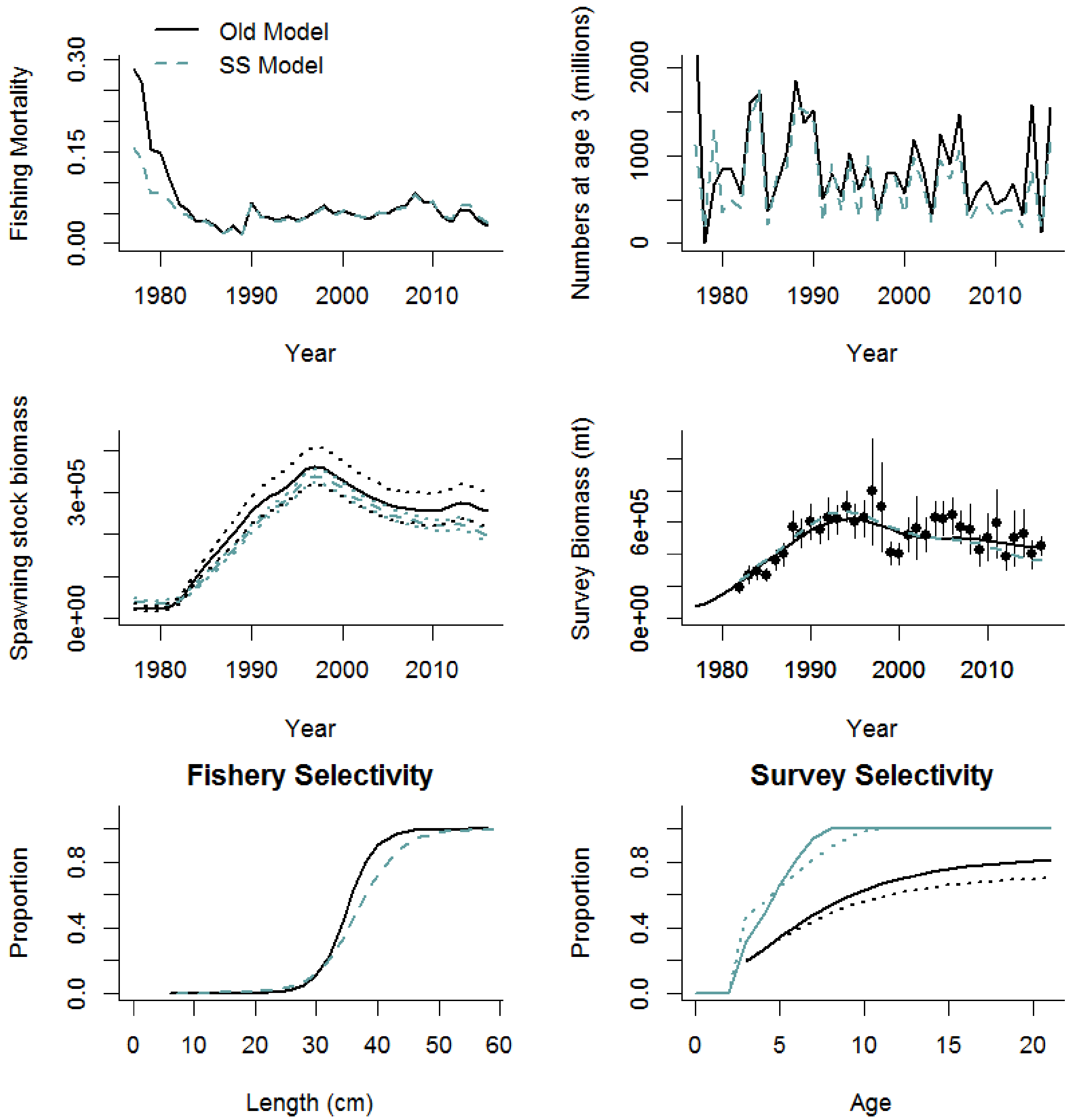


Figure 9.11. An SS3 model that uses double-normal age-based survey selectivity with selectivity below age 3 fixed to 0, and catchability fixed to 0.701 (the mean derived age-based average selectivity in the old model for ages 7-21, when the curve had come to a plateau), compared to the old model, as implemented in 2016, but with standard age-based likelihood formulations.

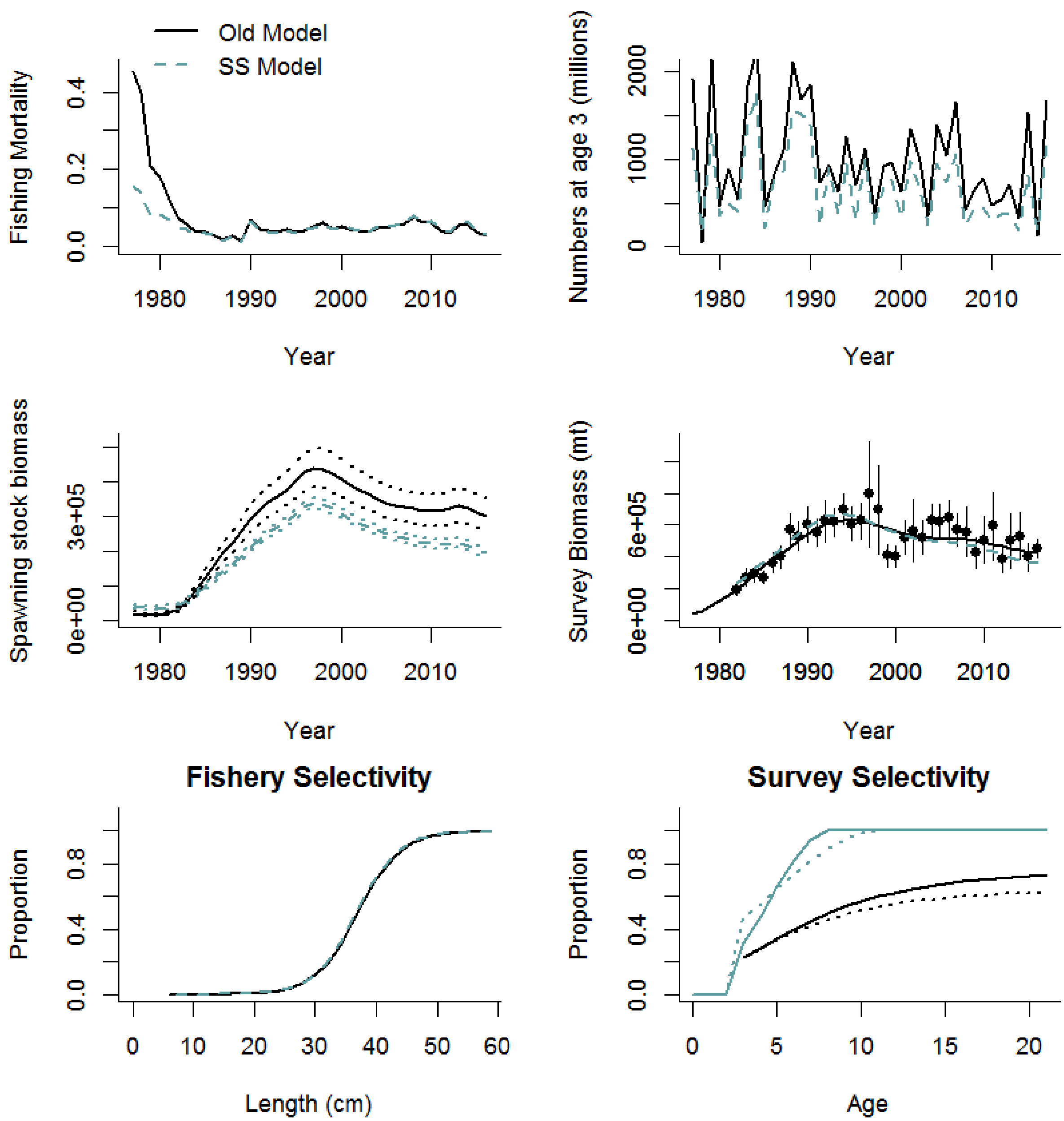
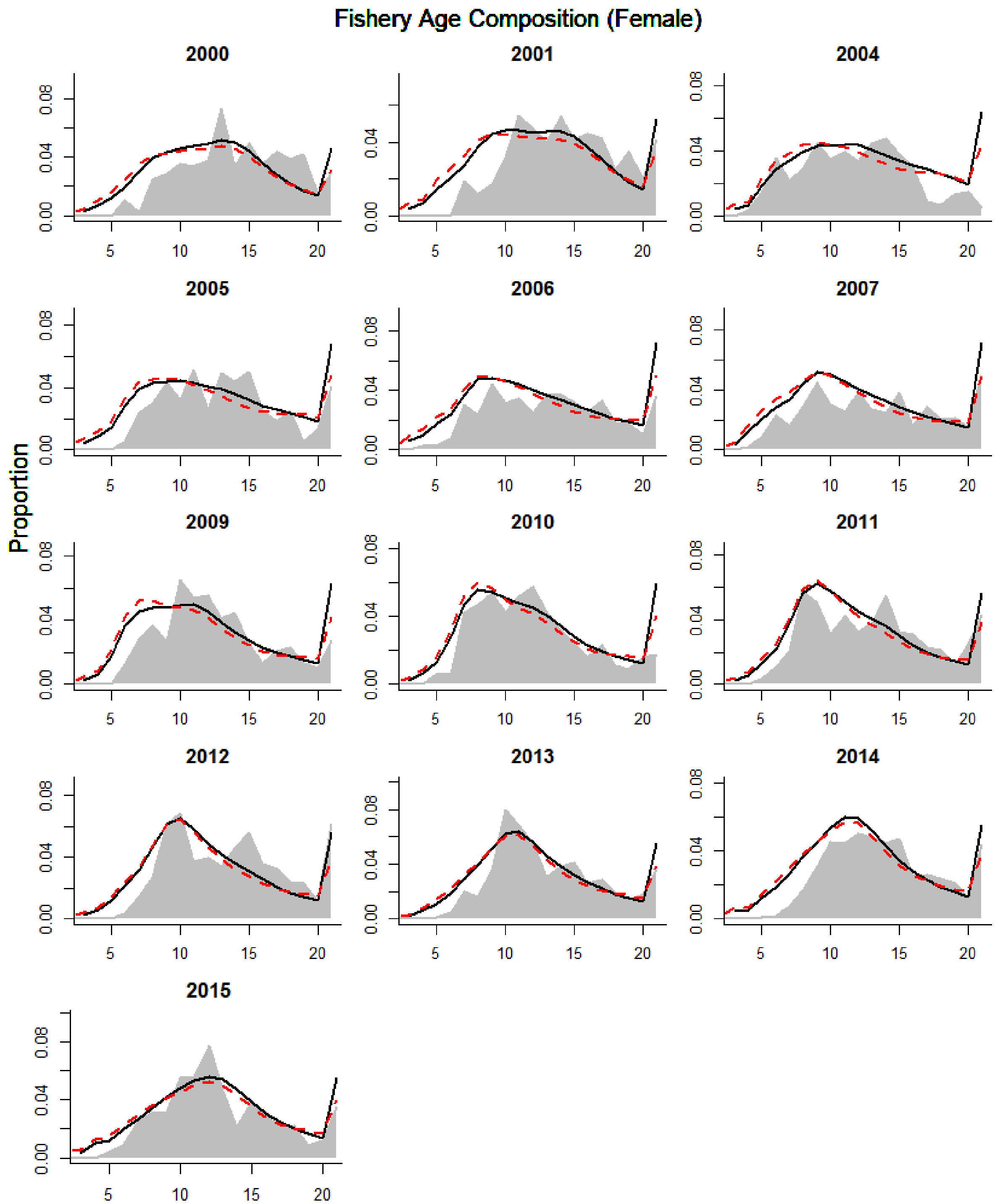
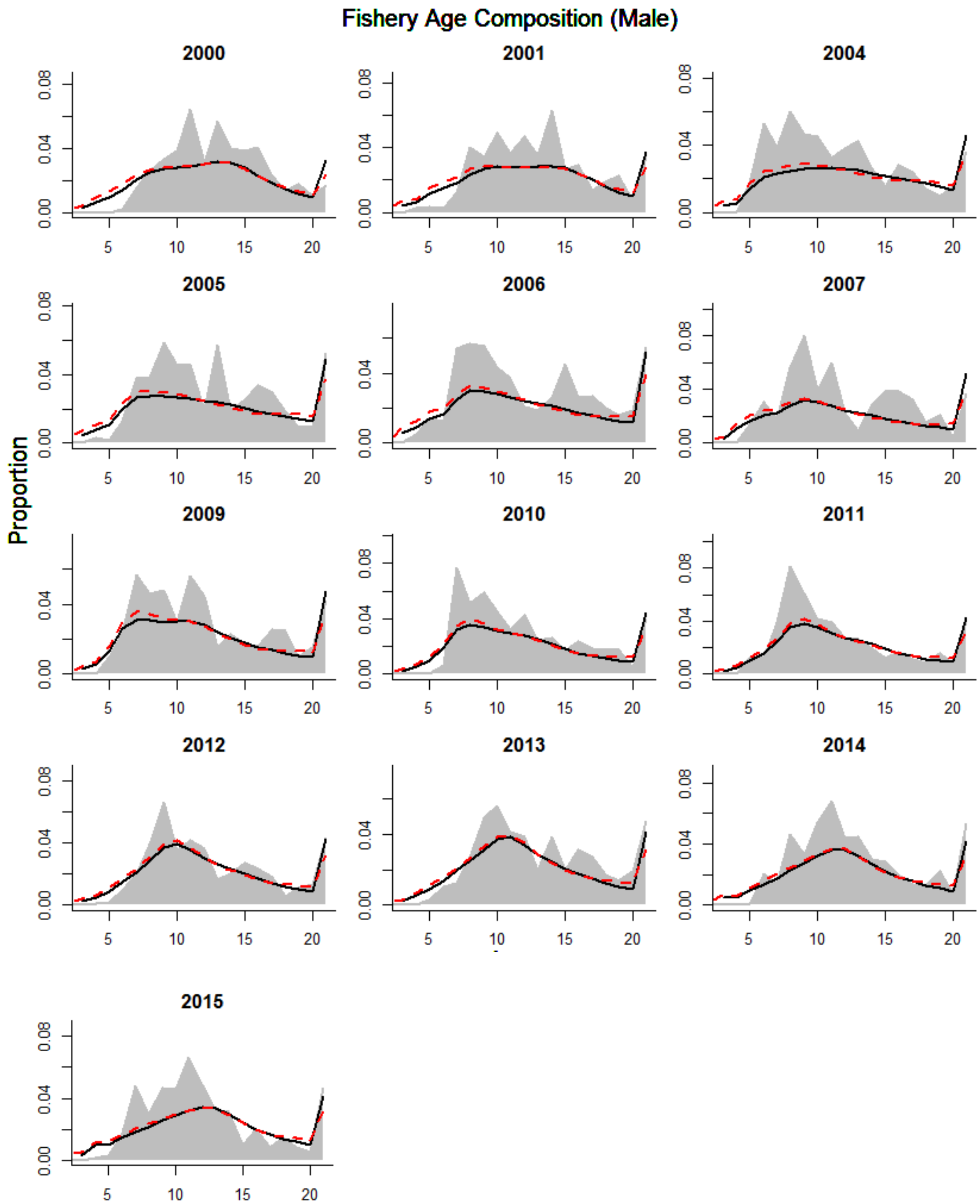


Figure 9.12. As for Figure 9.56, but the old model used is the 2016 model, which calculates predicted catch and survey biomass from numbers-at-length and length-based selectivity.



Age

Figure 9.13. Yearly female fishery age composition for the 2016 model (black lines), the best matching SS3 model (with age-based selectivity and catchability configured to mimic the length-based catchability of the old model) shown in Figure 9.57 (dashed red lines), and the data (grey shaded areas).



Age

Figure 9.14. Yearly male fishery age composition for the 2016 configuration of the old model (black lines), the best matching SS3 model (with age-based selectivity and catchability configured to mimic the length-based catchability of the old model) shown in Figure 9.57 (dashed red lines), and the data (grey shaded areas).

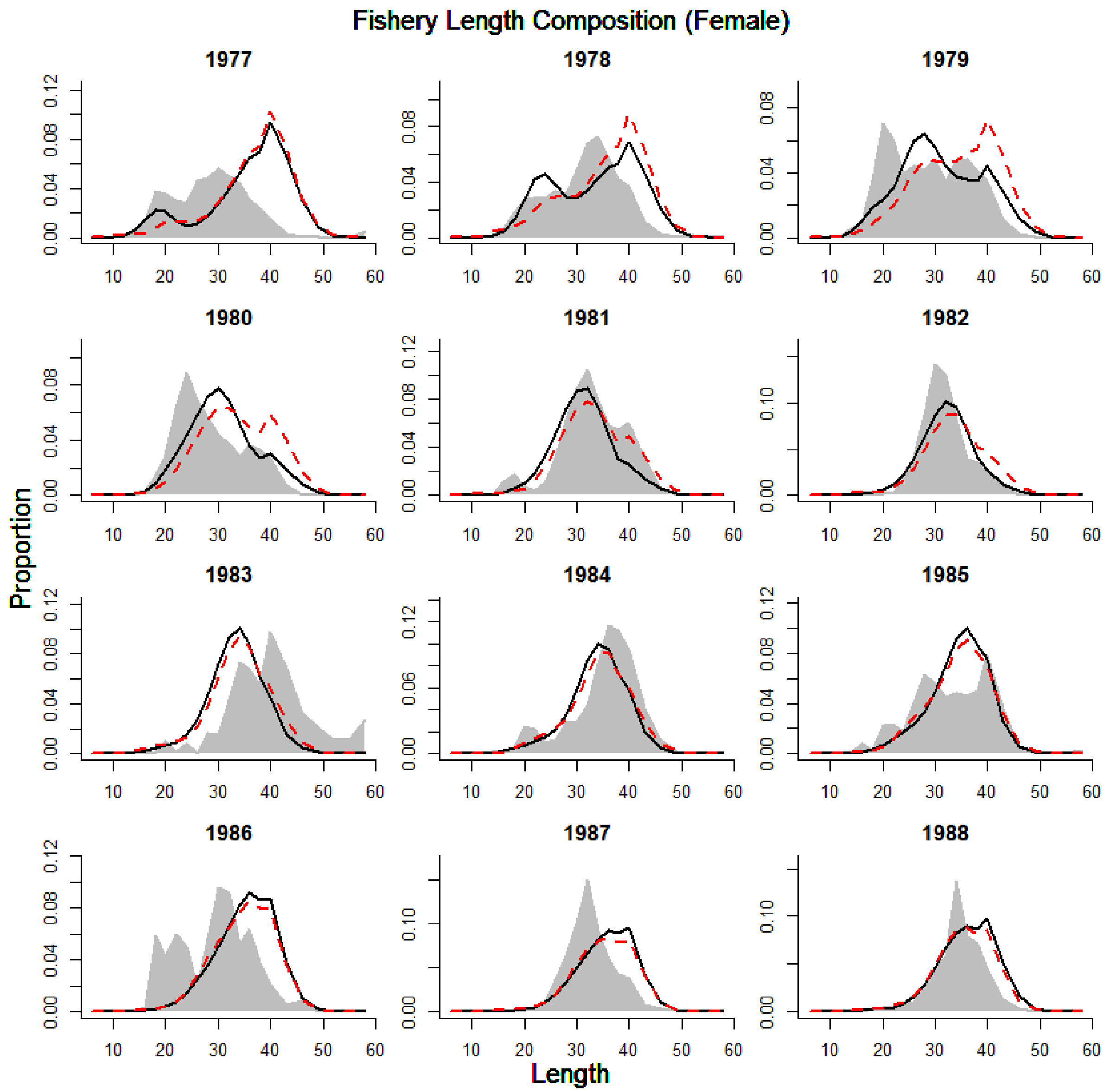


Figure 9.15. Yearly female fishery length composition for the 2016 configuration of the old model (black lines), the best matching SS3 model (with age-based selectivity and catchability configured to mimic the length-based catchability of the old model) shown in Figure 9.57 (dashed red lines), and the data (grey shaded areas).

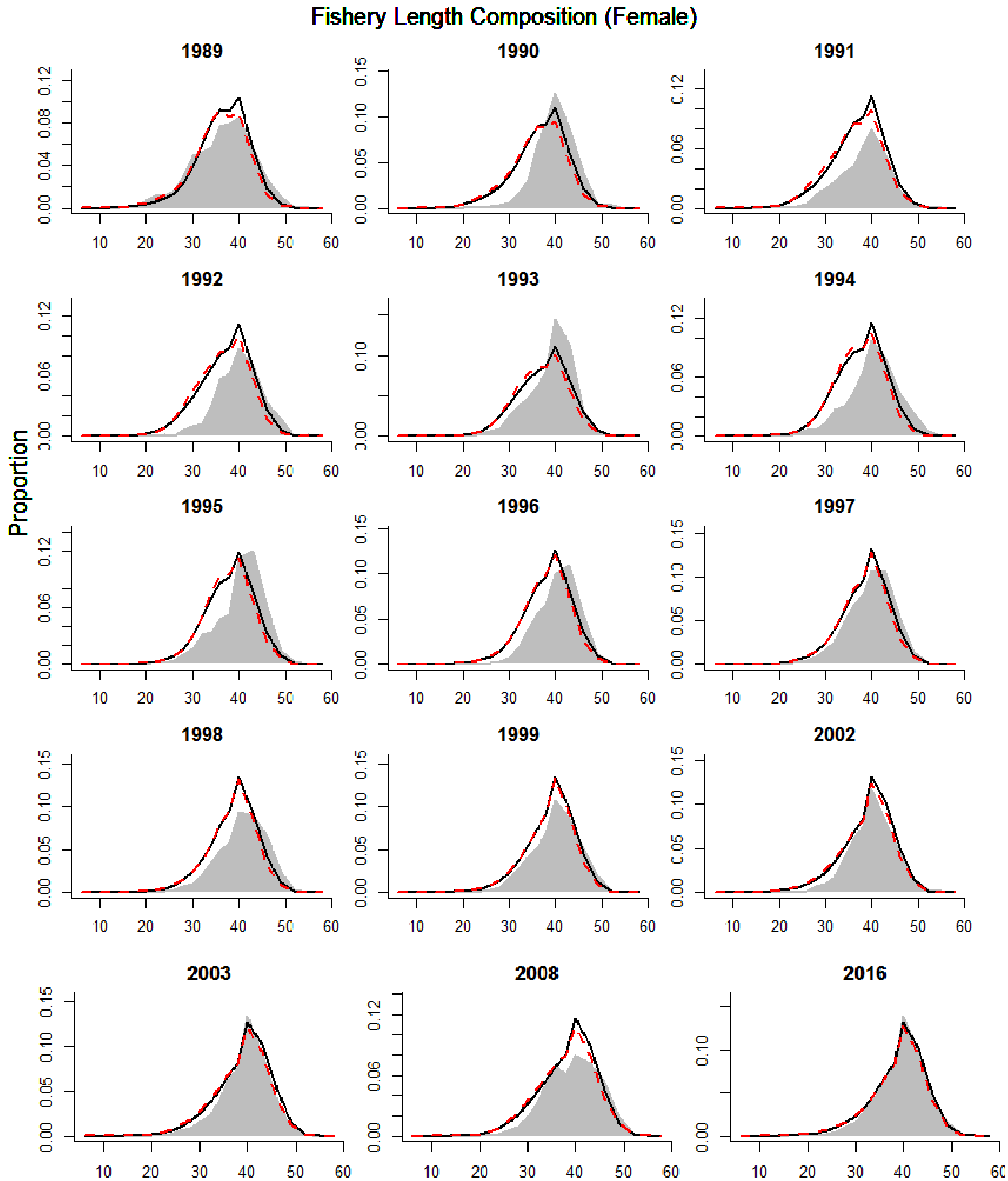


Figure 9.60, continued.

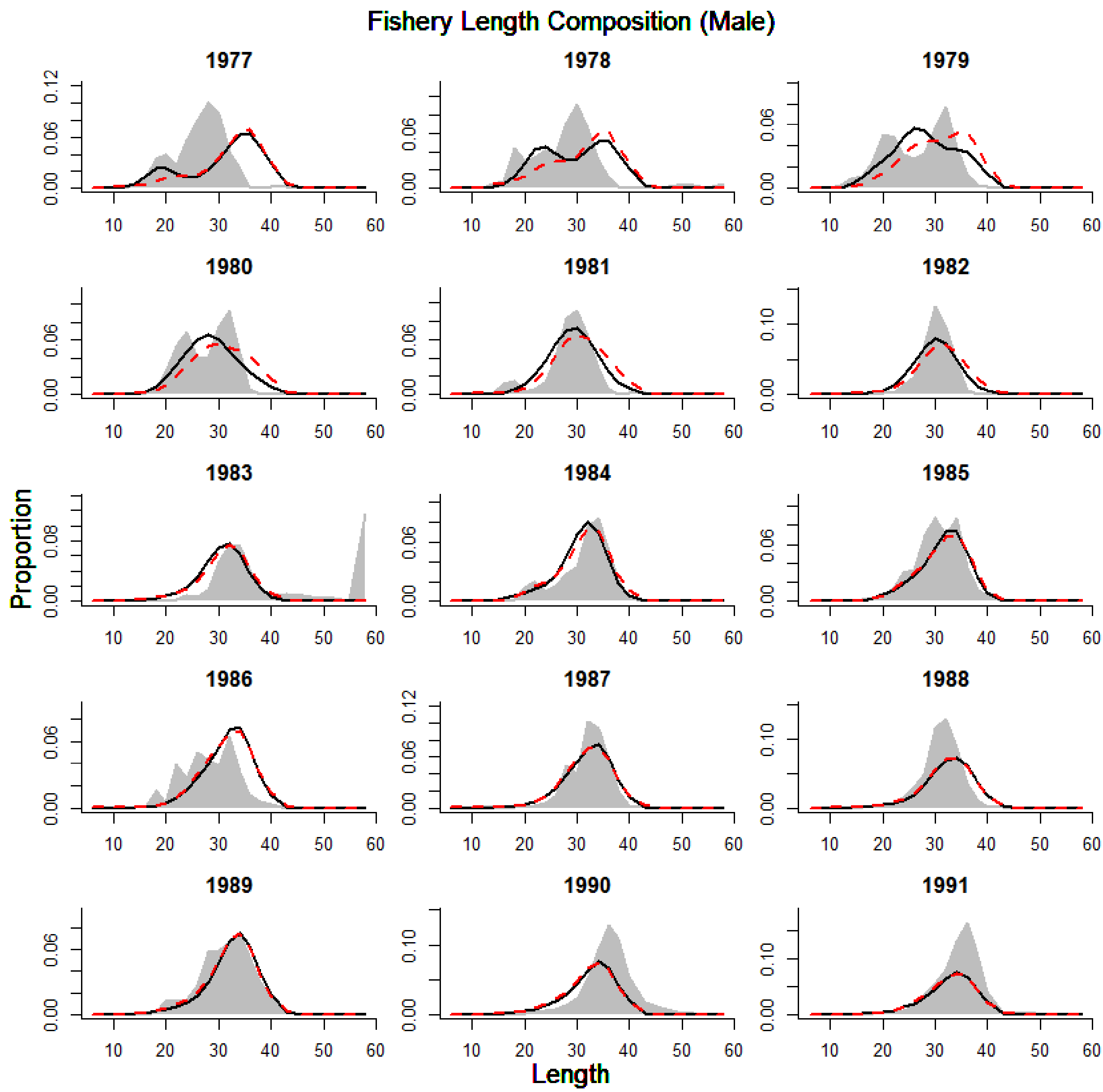


Figure 9.16. Yearly male fishery length composition for the 2016 configuration of the old model (black lines), the best matching SS3 model (with age-based selectivity and catchability configured to mimic the length-based catchability of the old model) shown in Figure 9.57 (dashed red lines), and the data (grey shaded areas).

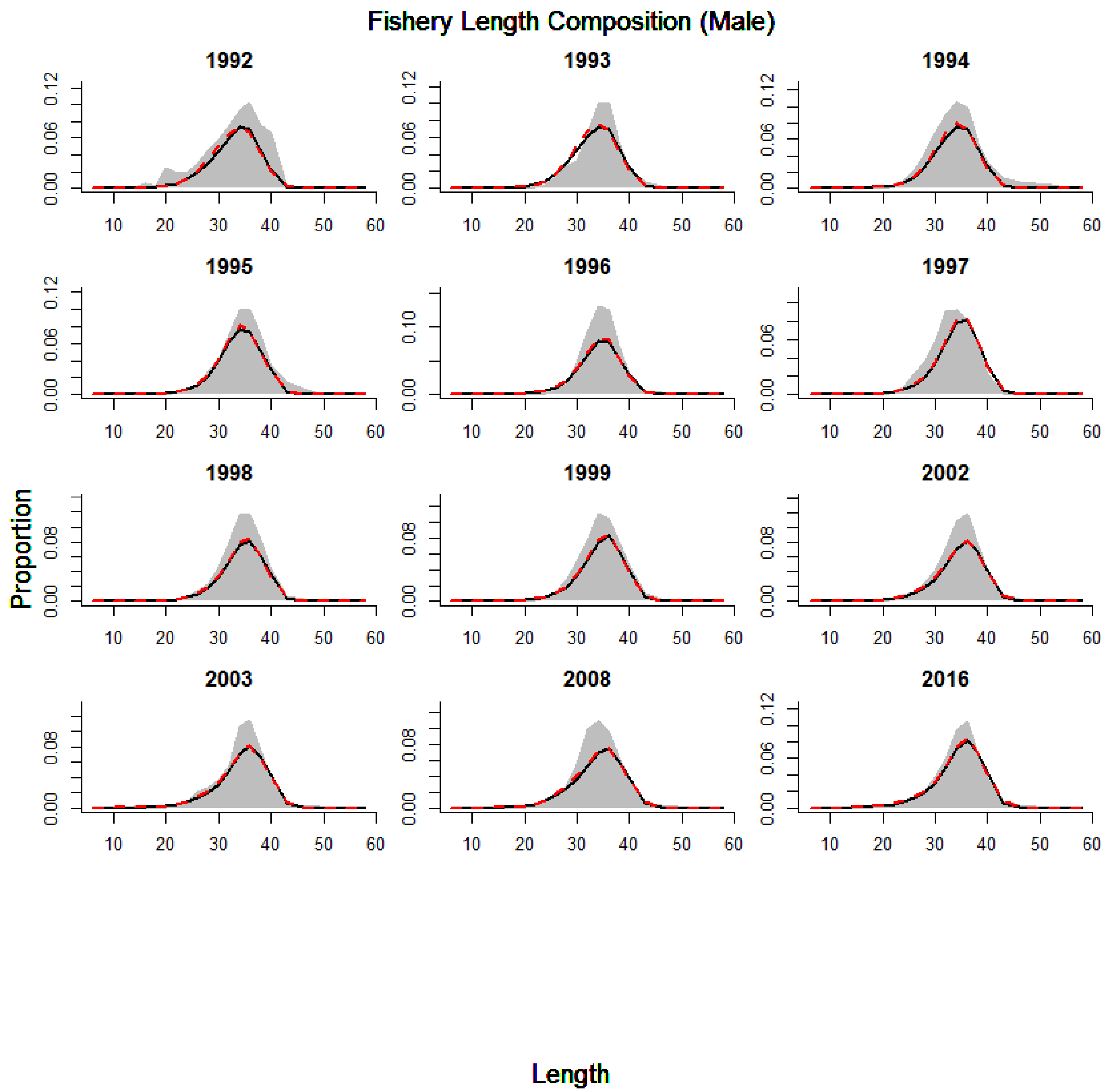


Figure 9.61, continued.

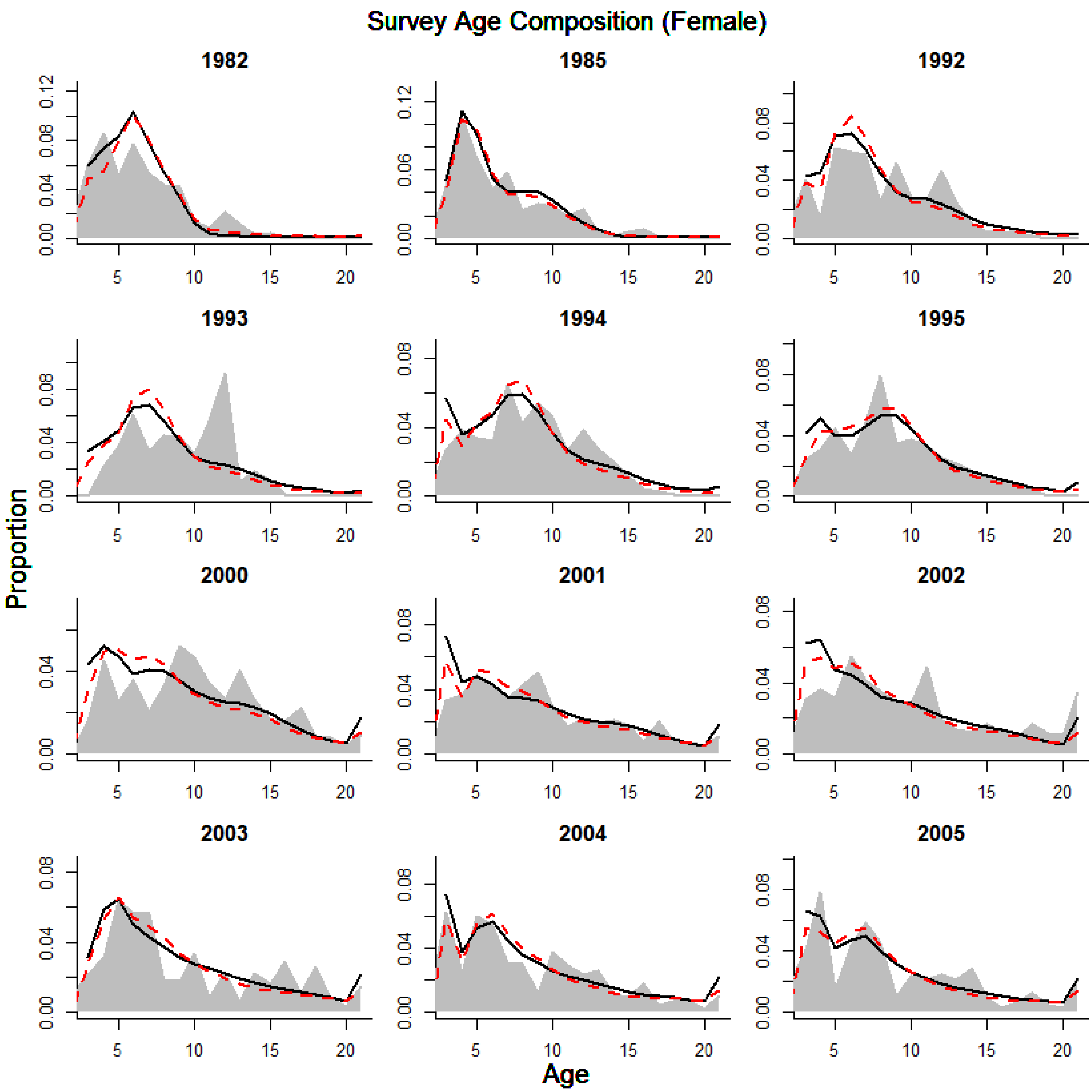


Figure 9.17. Yearly female survey age composition for the 2016 configuration of the old model (black lines), the best matching SS3 model (with age-based selectivity and catchability configured to mimic the length-based catchability of the old model) shown in Figure 9.57 (dashed red lines), and the data (grey shaded areas).

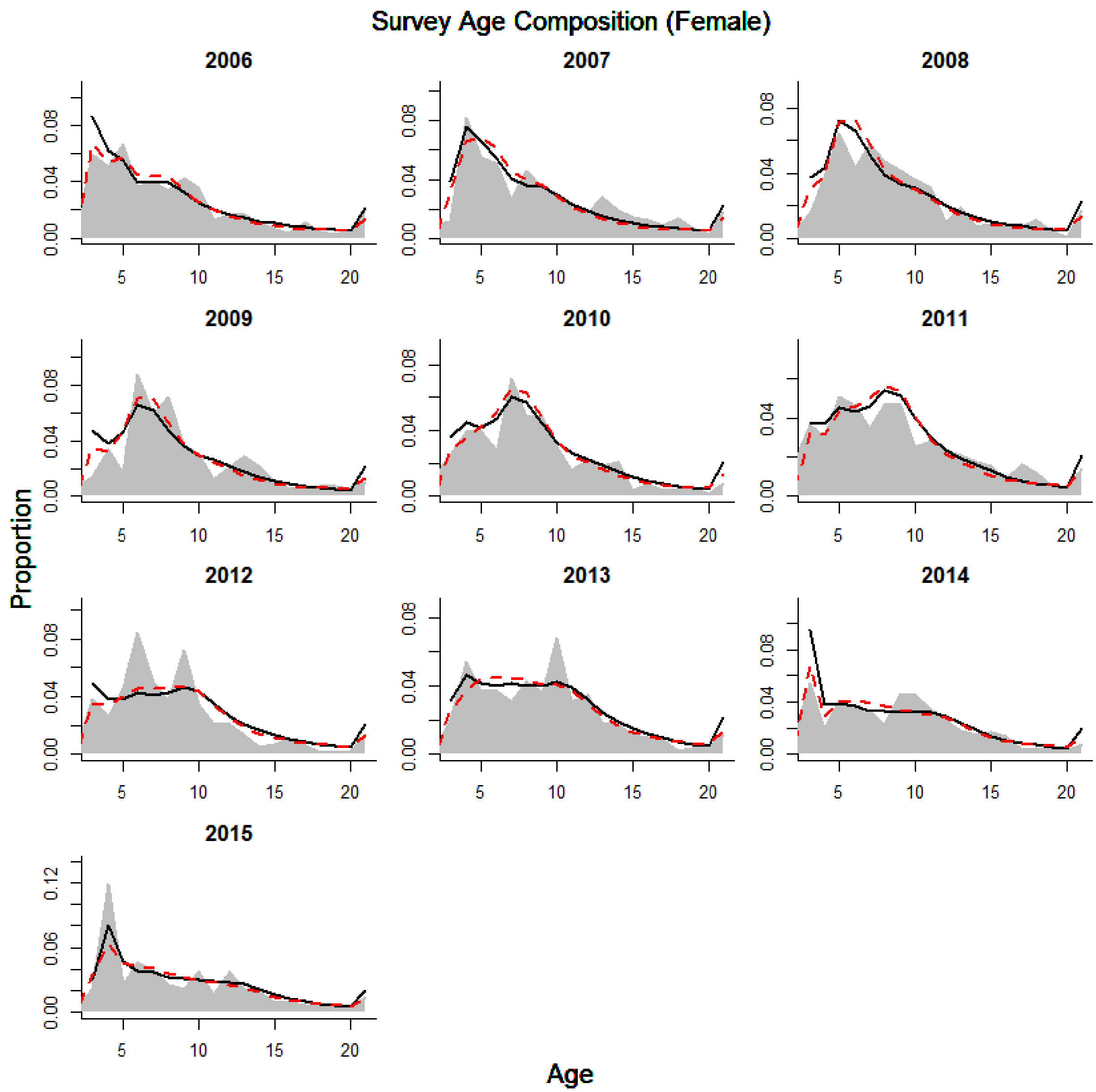


Figure 9.62, continued

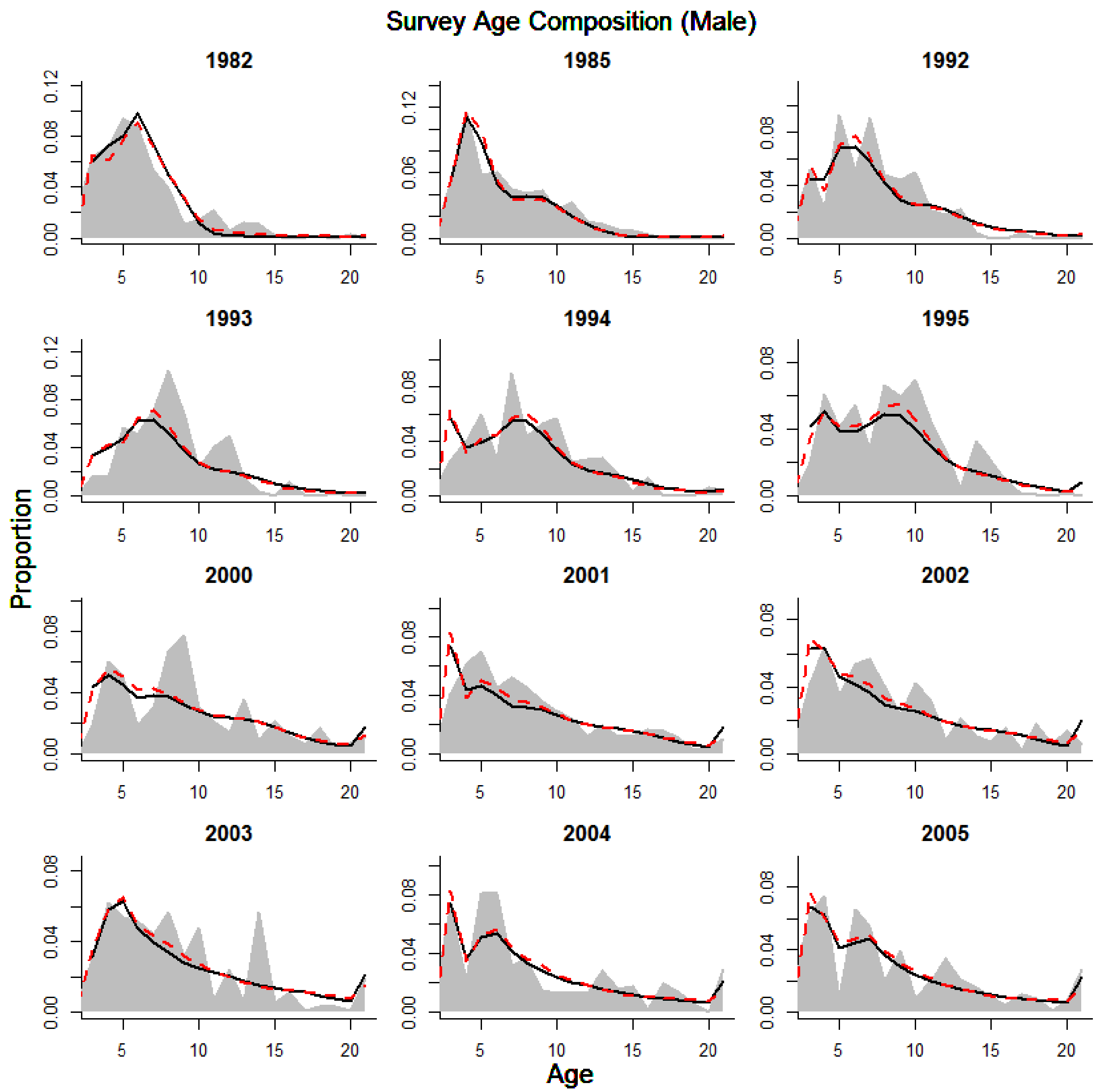


Figure 9.18. Yearly male survey age composition for the 2016 configuration of the old model (black lines), the best matching SS3 model (with age-based selectivity and catchability configured to mimic the length-based catchability of the old model) shown in Figure 9.57 (dashed red lines), and the data (grey shaded areas).

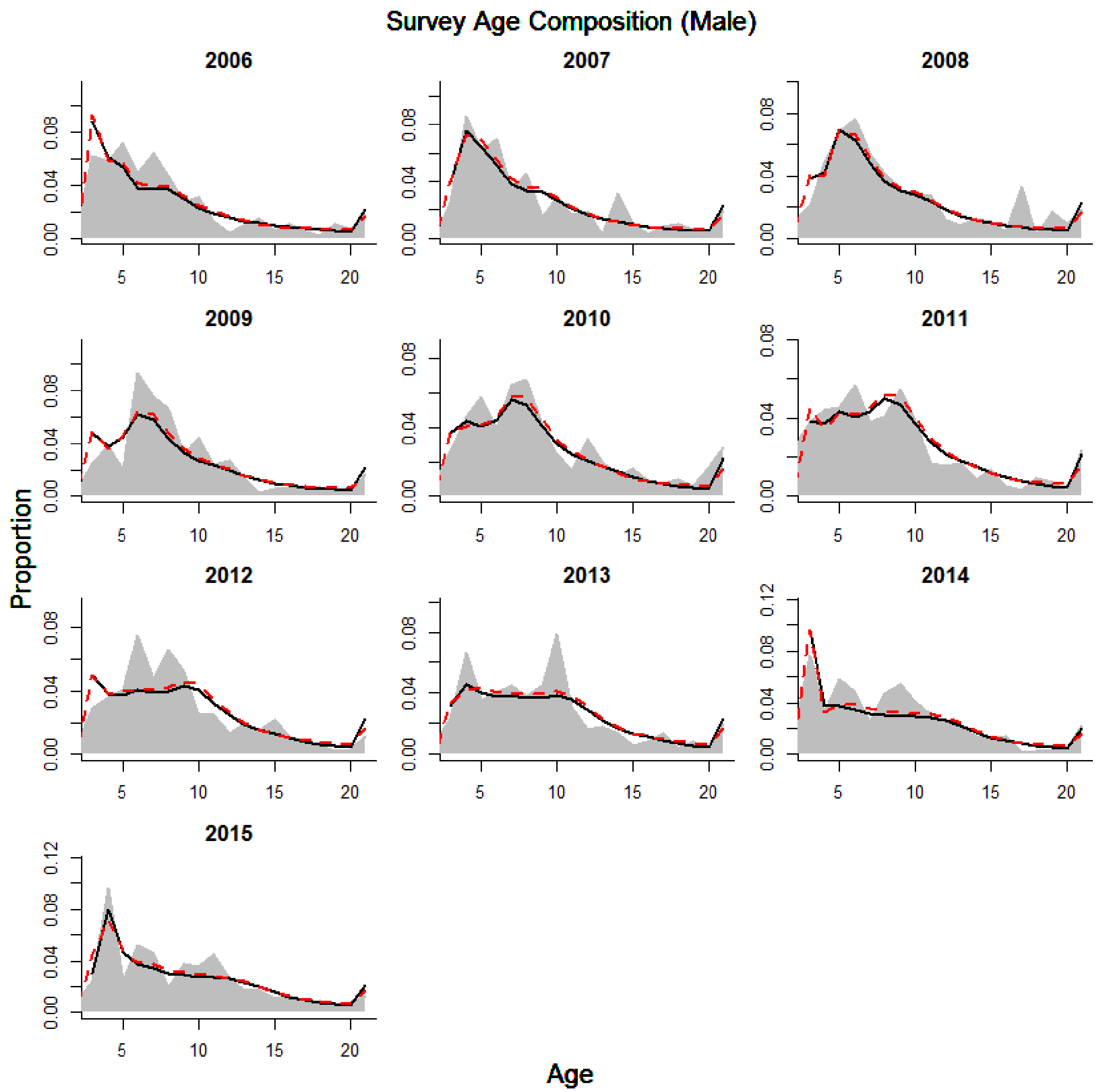


Figure 9.63, continued.

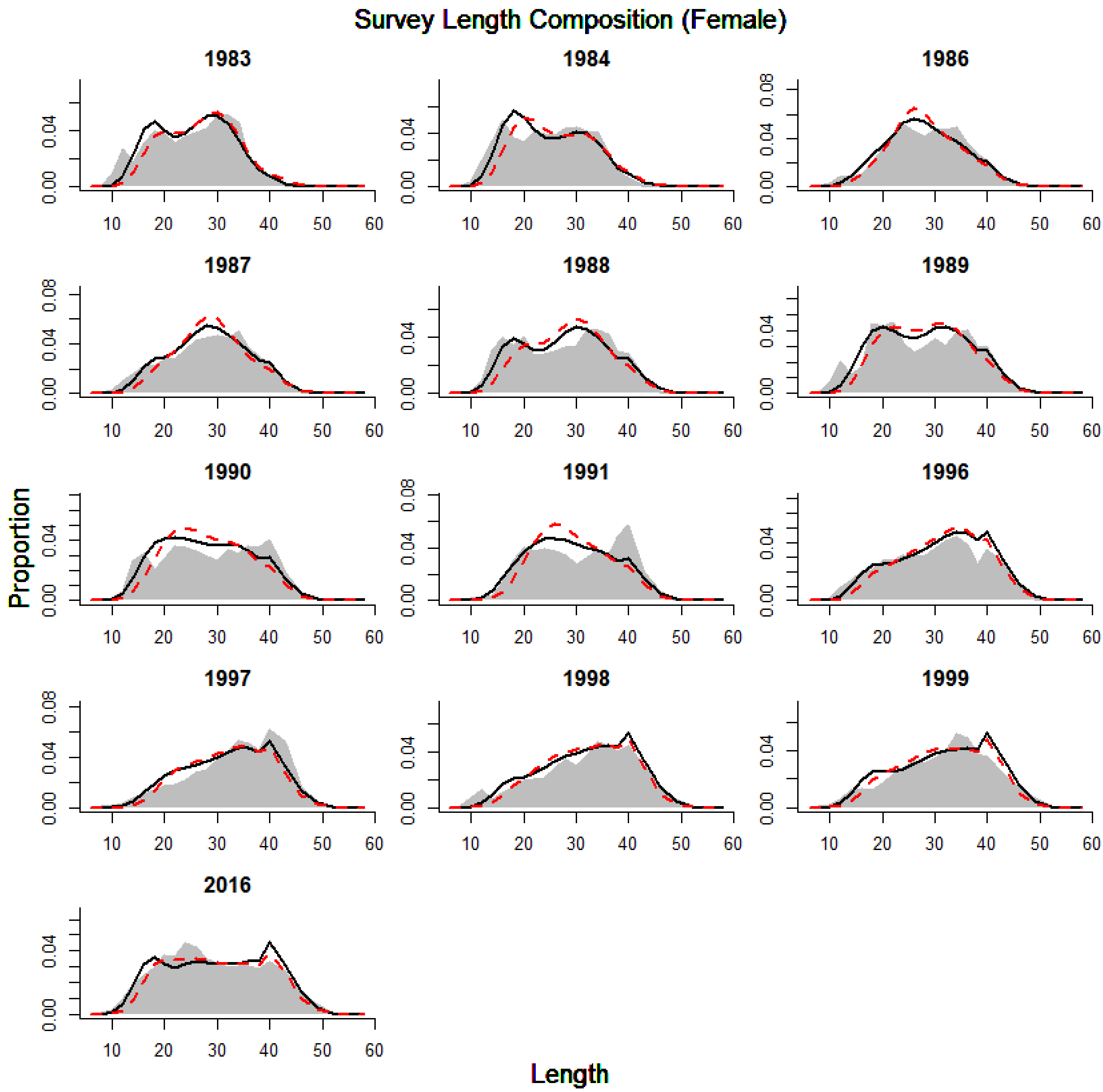


Figure 9.19. Yearly female survey length composition for the 2016 configuration of the old model (black lines), the best matching SS3 model (with age-based selectivity and catchability configured to mimic the length-based catchability of the old model) shown in Figure 9.57 (dashed red lines), and the data (grey shaded areas).

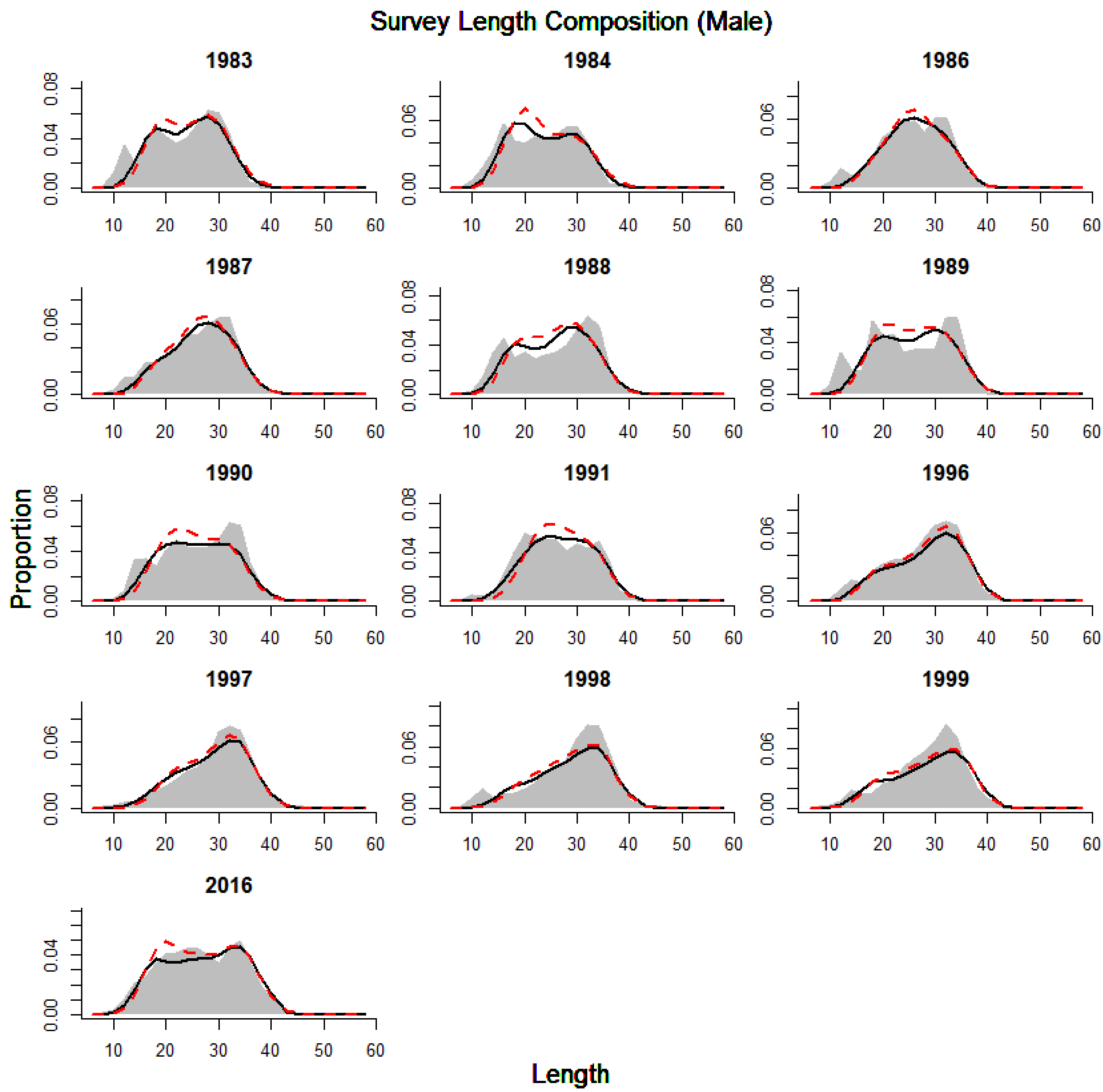


Figure 9.20. Yearly male survey length composition for the 2016 configuration of the old model (black lines), the best matching SS3 model (with age-based selectivity and catchability configured to mimic the length-based catchability of the old model) shown in Figure 9.57 (dashed red lines), and the data (grey shaded areas).

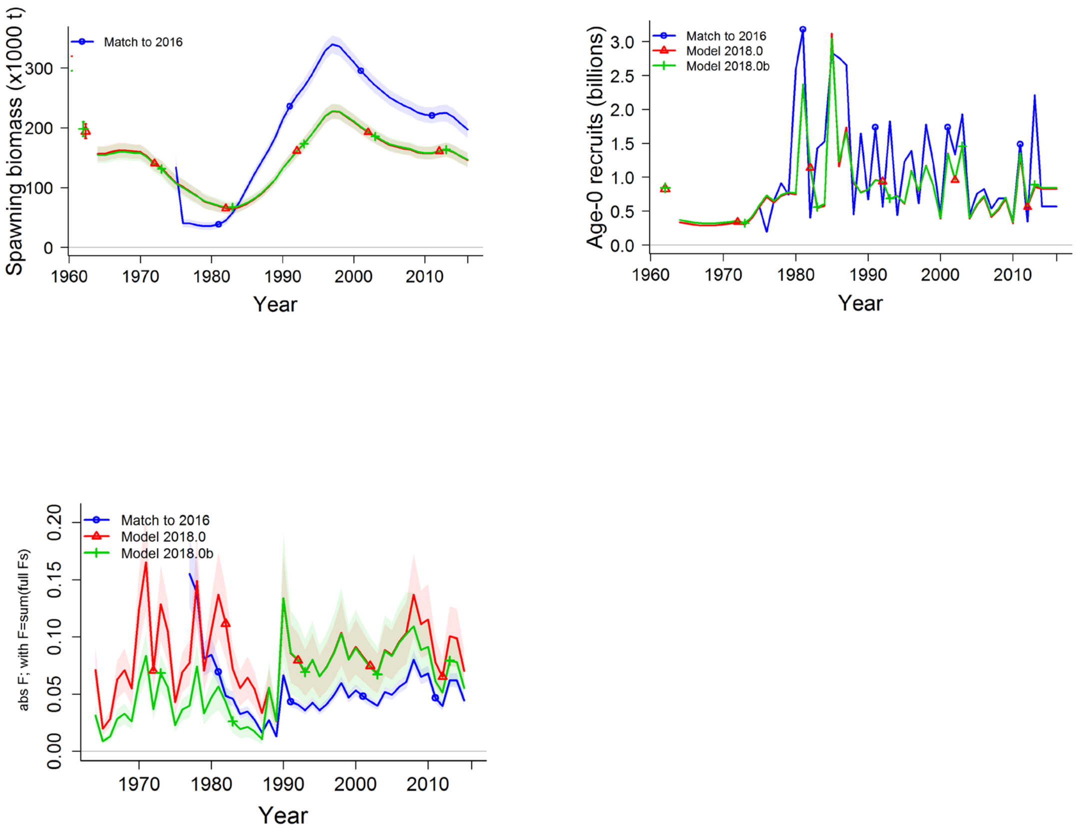


Figure 9.21. A comparison of the best matching SS3 model, and two proposed models for 2018.0 and 2018.0b. Both 2018.0 and 2018.0b. 2018.0 and 2018.0b are identical, except that 2018.0b estimates different selectivity curves for 3 distinct time periods: 1964-1987, 1988-2007, and 2008-2016.

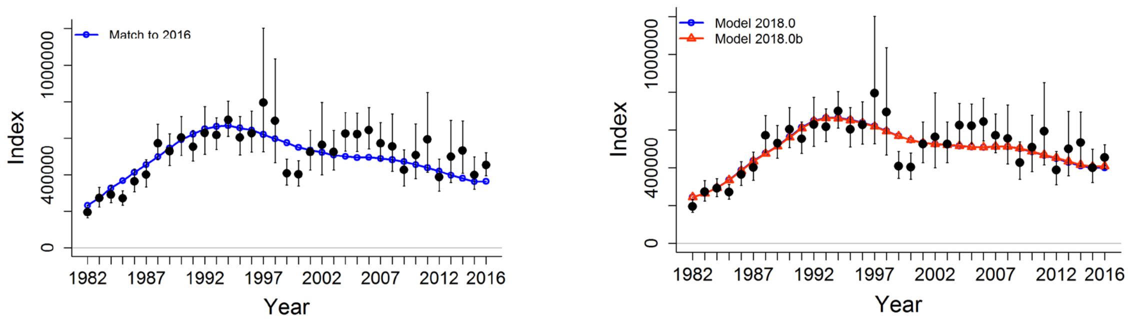


Figure 9.22. Observed (black dots) and predicted index of survey biomass for the best matching SS3 model to the 2016 model (left panel) and for Models 2018.0 and 2018.0b (right panel). Vertical black lines show 95% confidence intervals about the observations.

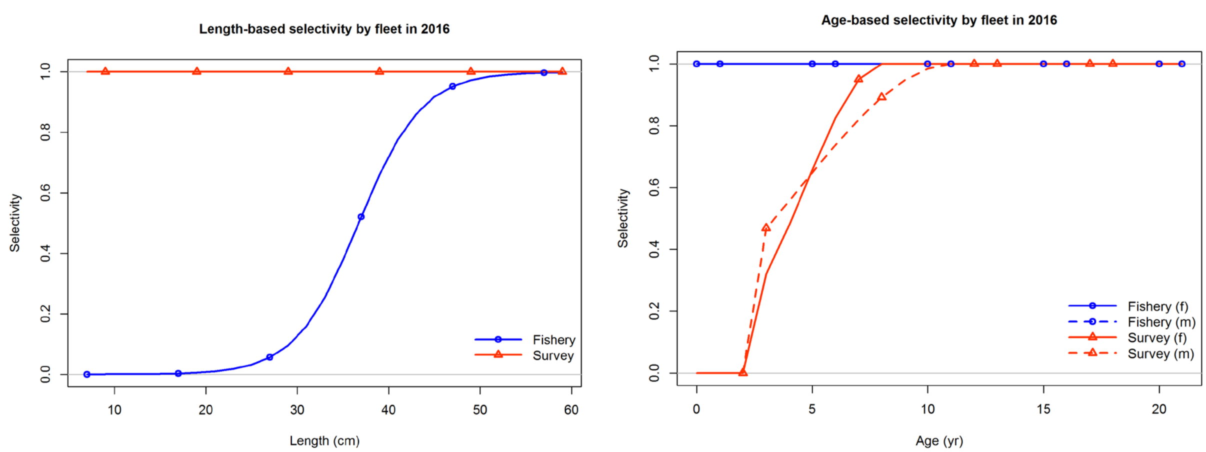


Figure 9.23. Selectivity for the SS3 model that best matched the 2016 model (note that catchability was fixed at 0.7 in this model). Left panel: length-based fishery selectivity (applies to both males and females), right panel: age-based, sex-specific survey selectivity.

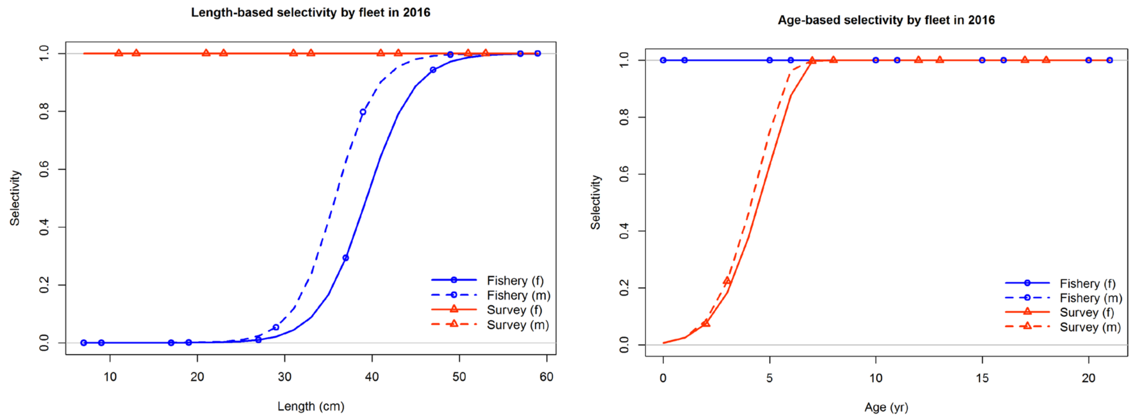


Figure 9.24. Selectivity for Model 2018.0. Left panel: length-based, sex-specific fishery selectivity, right panel: age-based, sex-specific survey selectivity.

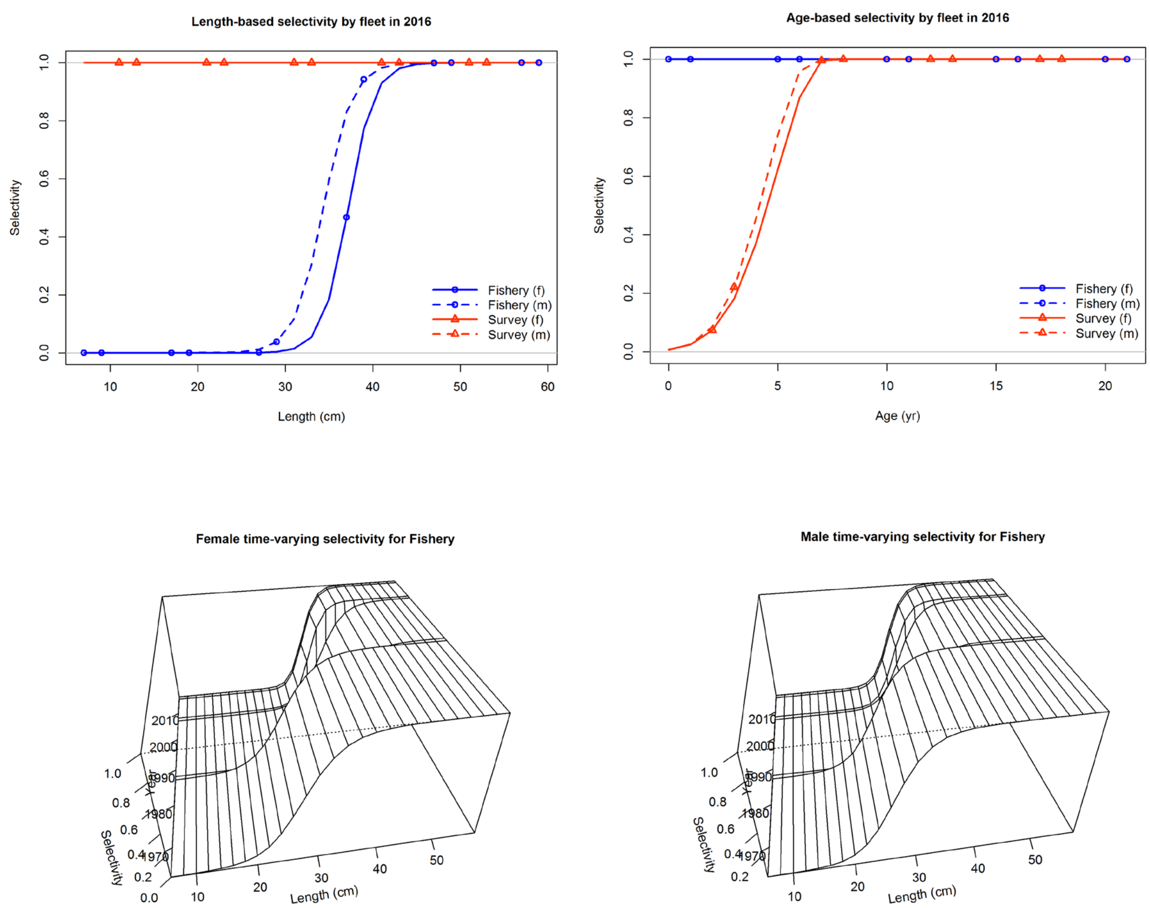


Figure 9.25. Fishery and survey selectivity curves for Model 2018.0b, where separate selectivity cuves were estimated for 3 time periods: 1964-1987, 1988-2007, and 2008-2017.

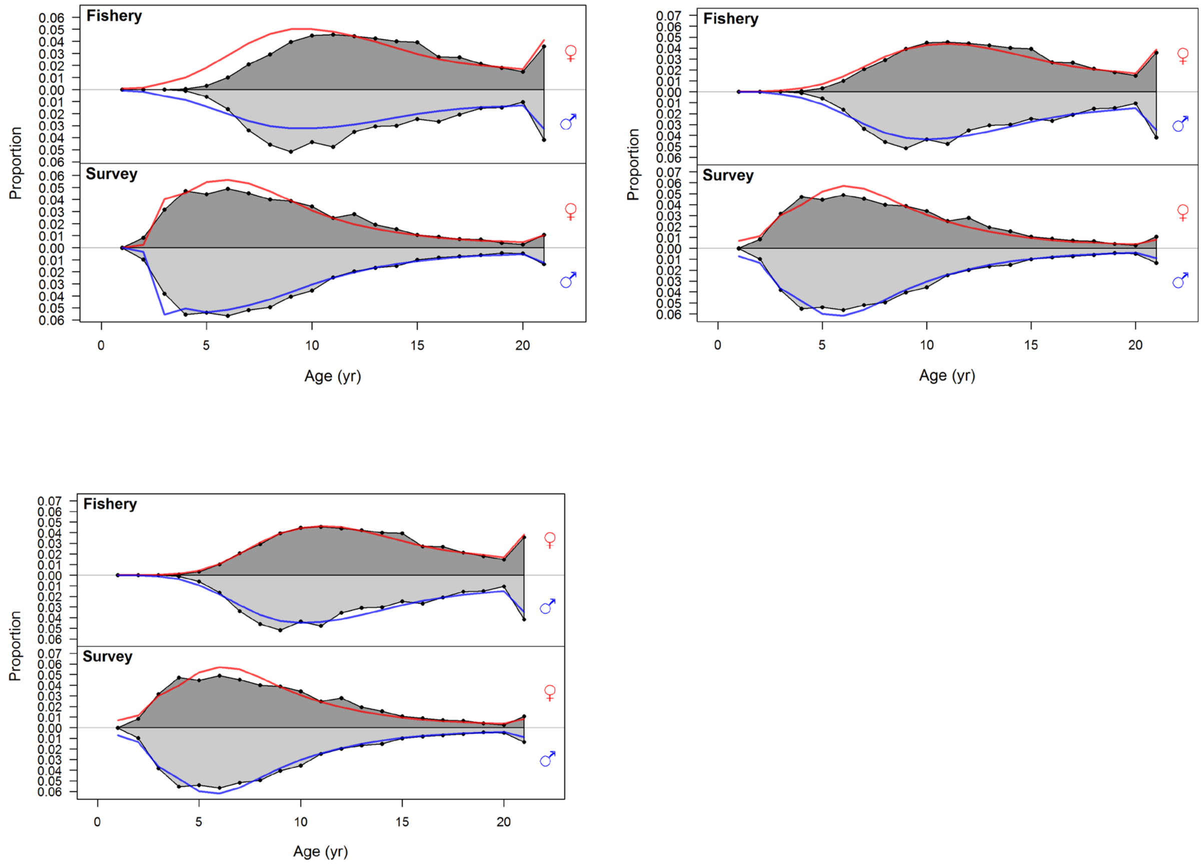


Figure 9.26. A comparison of aggregated fits to age composition data (grey) for the SS3 best model match to the 2016 model (top left), Model 2018.0 (top right), and Model 2018.0b (bottom left).

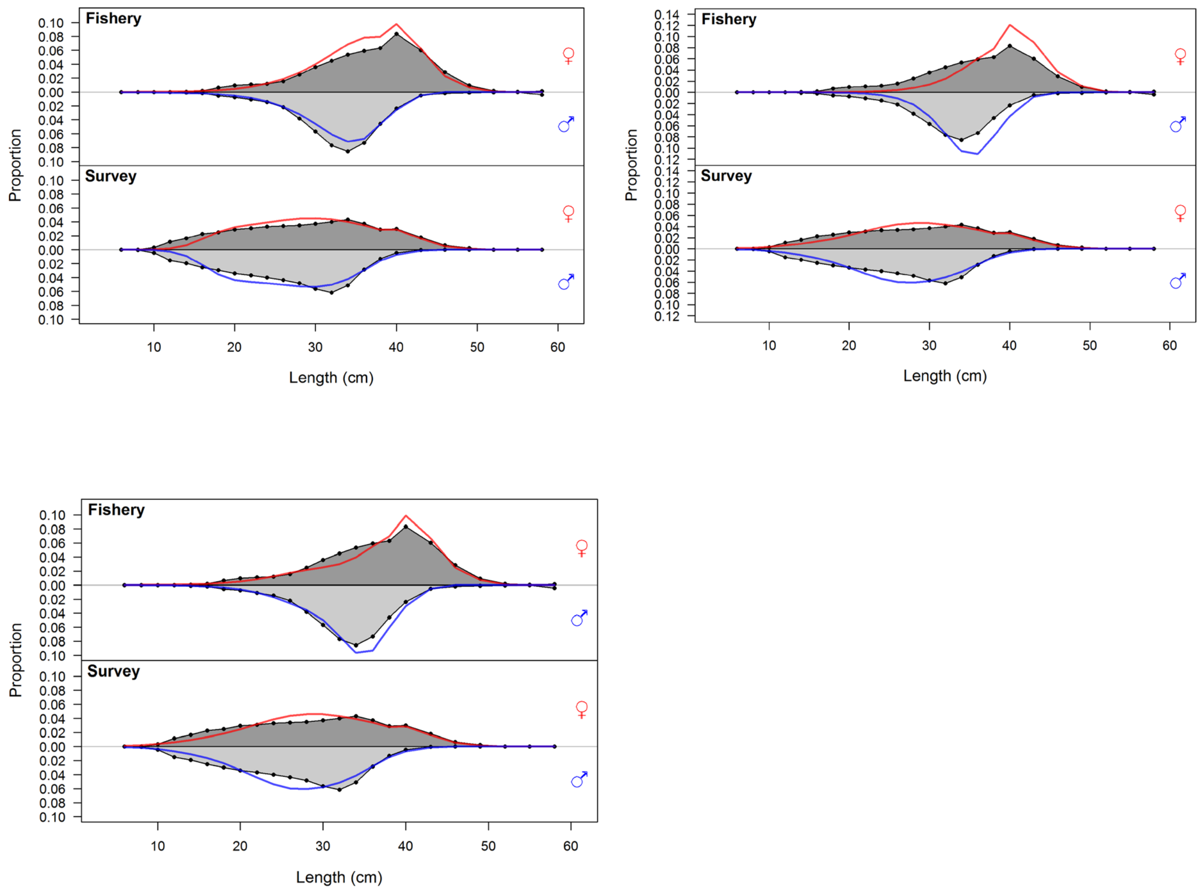


Figure 9.27. A comparison of aggregated fits to length composition data (grey) for the SS3 best model match to the 2016 model (top left), Model 2018.0 (top right), and Model 2018.0b (bottom left).

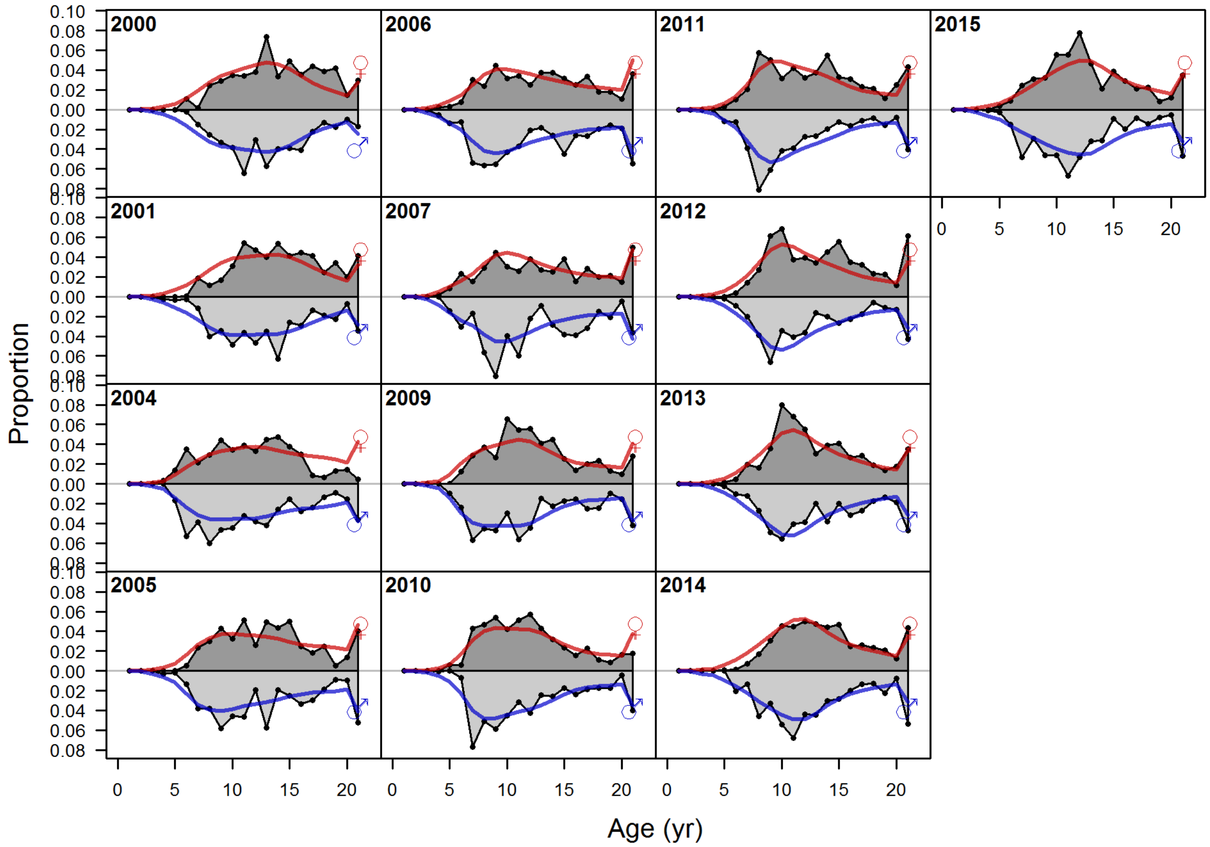


Figure 9.28. Fits to fishery age composition data (grey) by year for Model 2018.0.

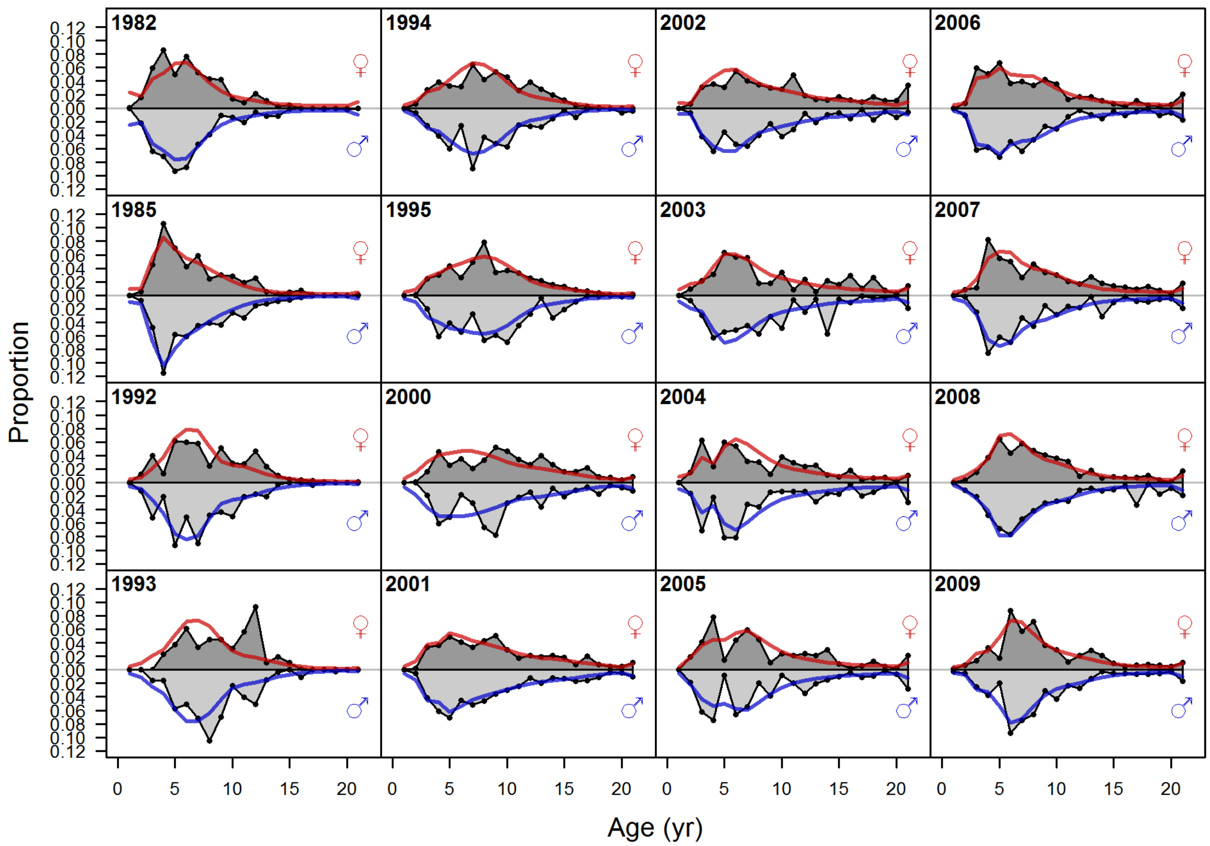


Figure 9.29. Fits to survey age composition data (grey) by year for Model 2018.0 (part 1 of 2).

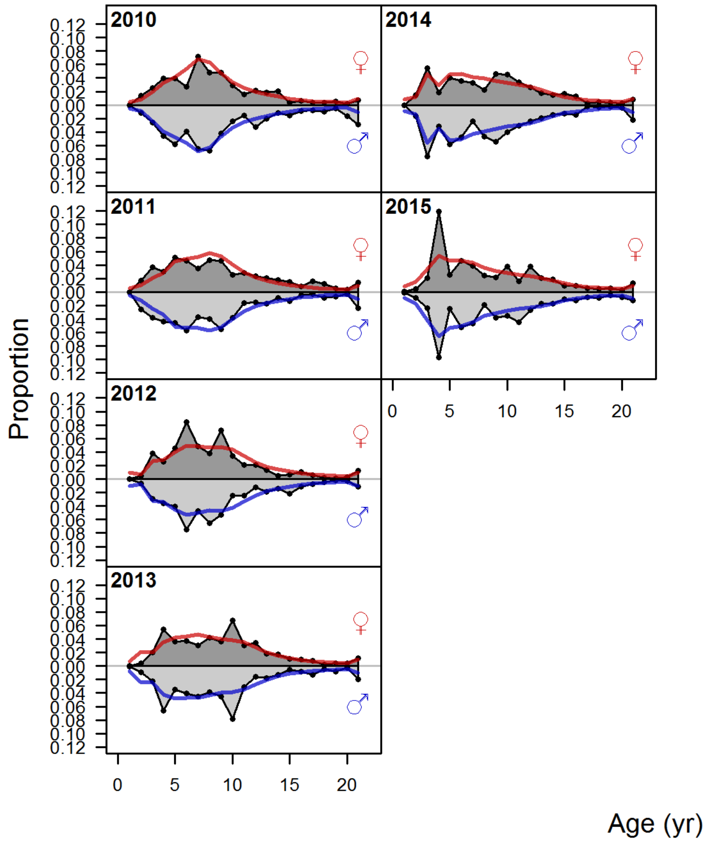


Figure 9.74, continued (part 2 of 2).

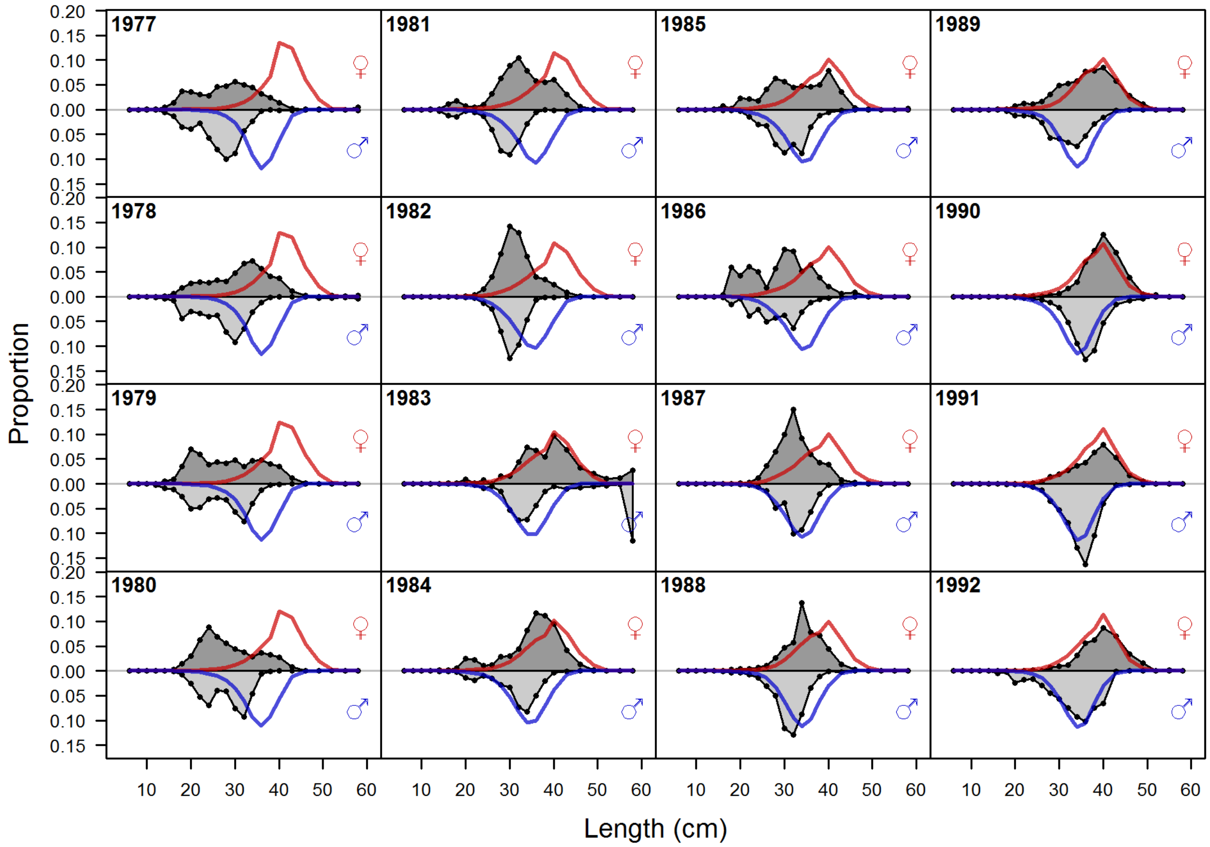


Figure 9.30. Fits to fishery length composition data (grey) by year for Model 2018.0. In years for which age composition data existed, length composition data were given an effective sample size of 1 (part 1 of 2).

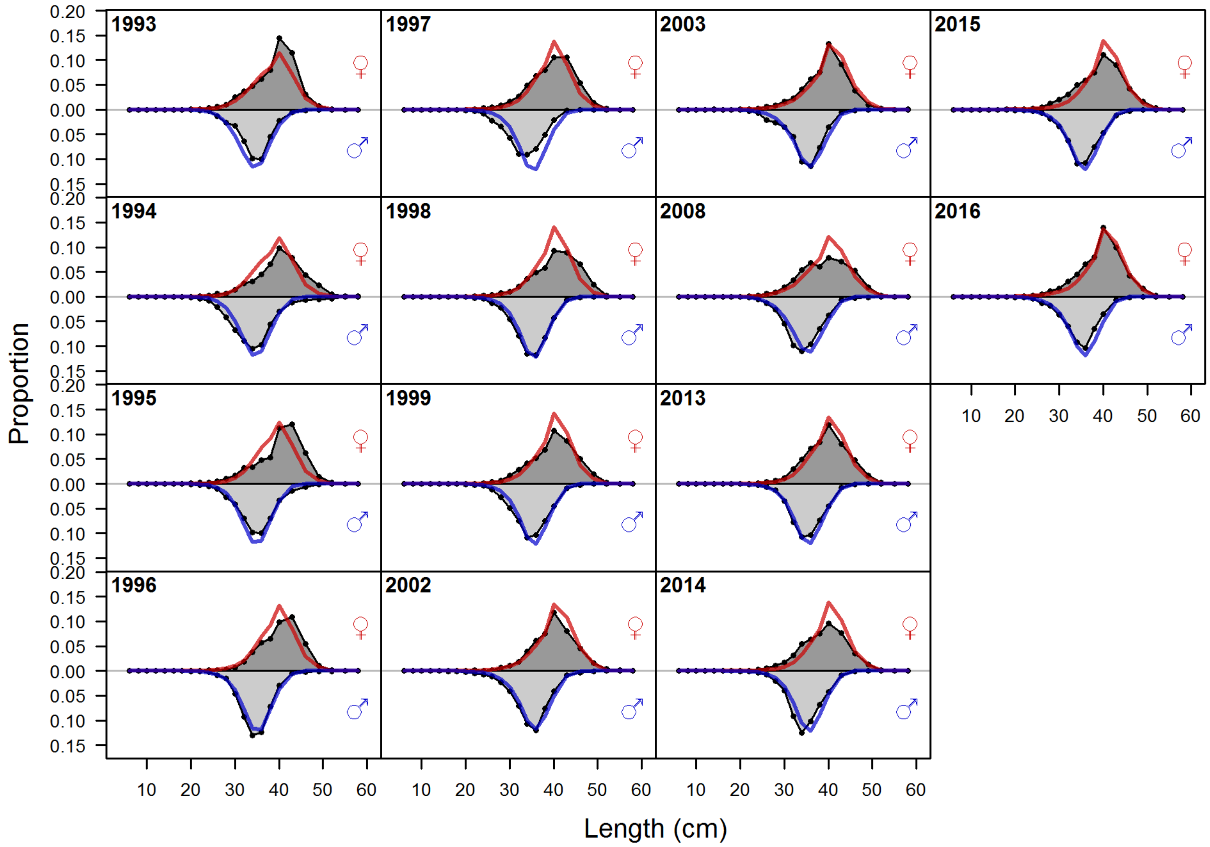


Figure 9.75, continued (part 2 of 2).

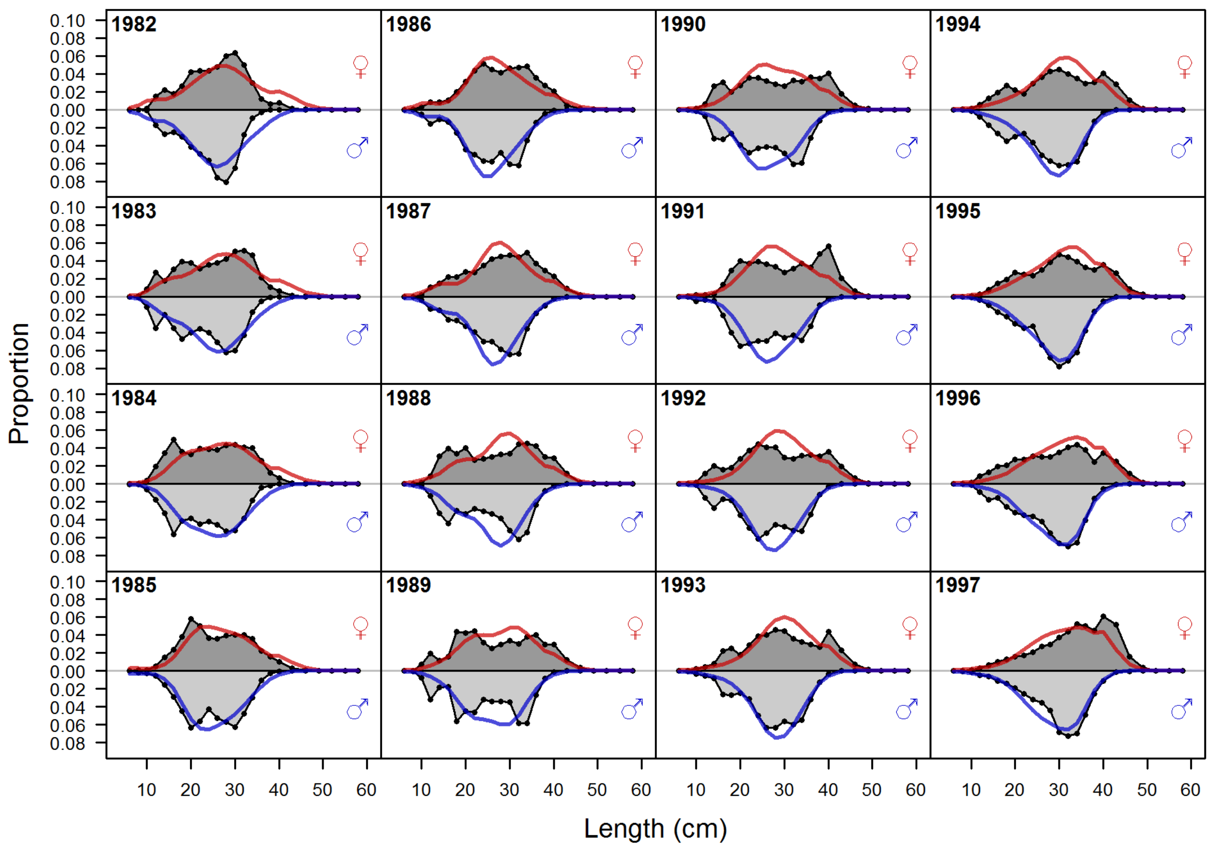


Figure 9.31. Fits to survey length composition data (grey) by year for Model 2018.0. In years for which age composition data existed, length composition data were given an effective sample size of 1 (part 1 of 3).

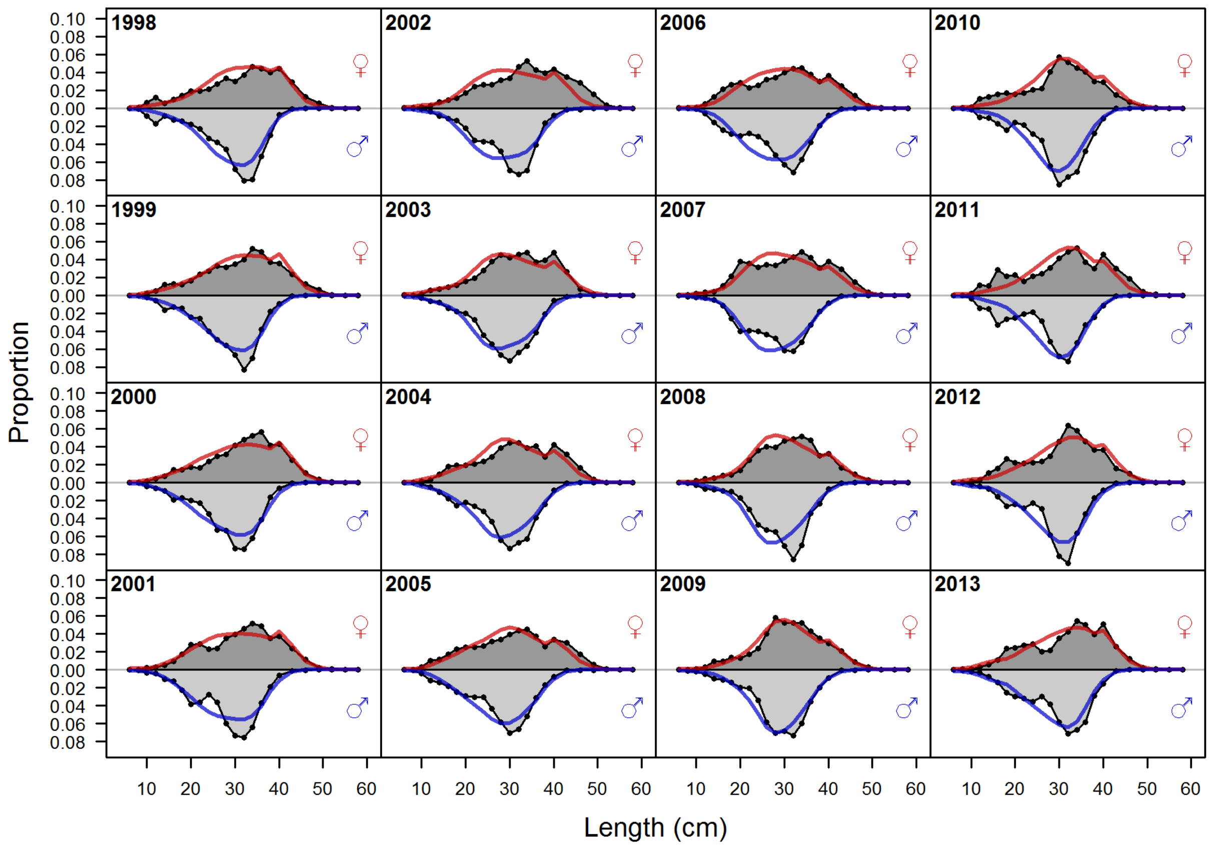


Figure 9.76, continued (part 2 of 3).

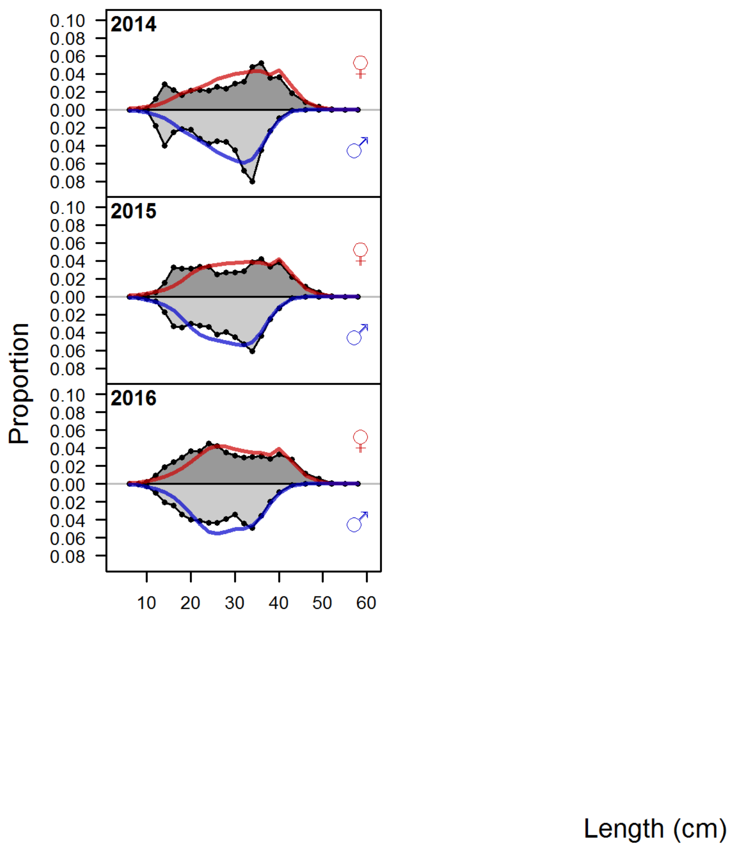


Figure 9.76, continued (part 3 of 3).

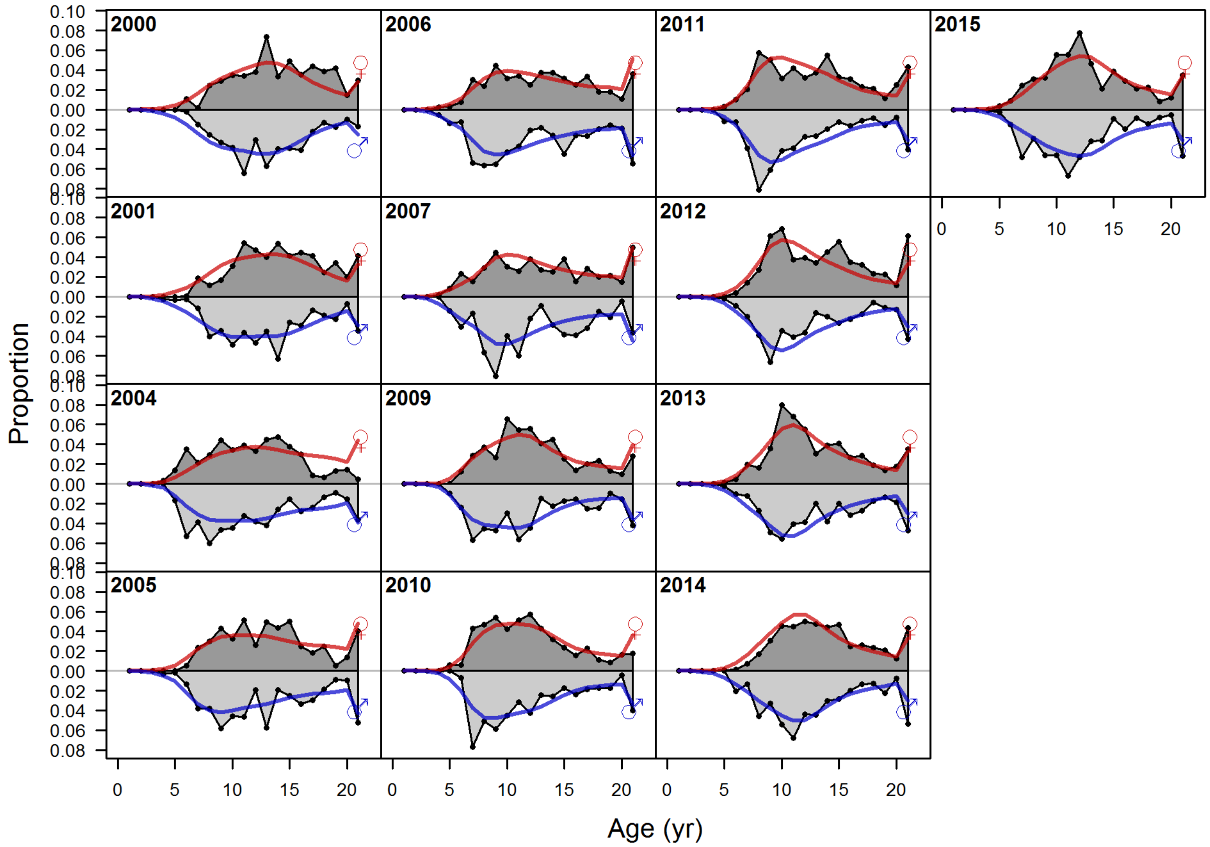


Figure 9.32. Fits to fishery age composition data (grey) by year for Model 2018.0b.

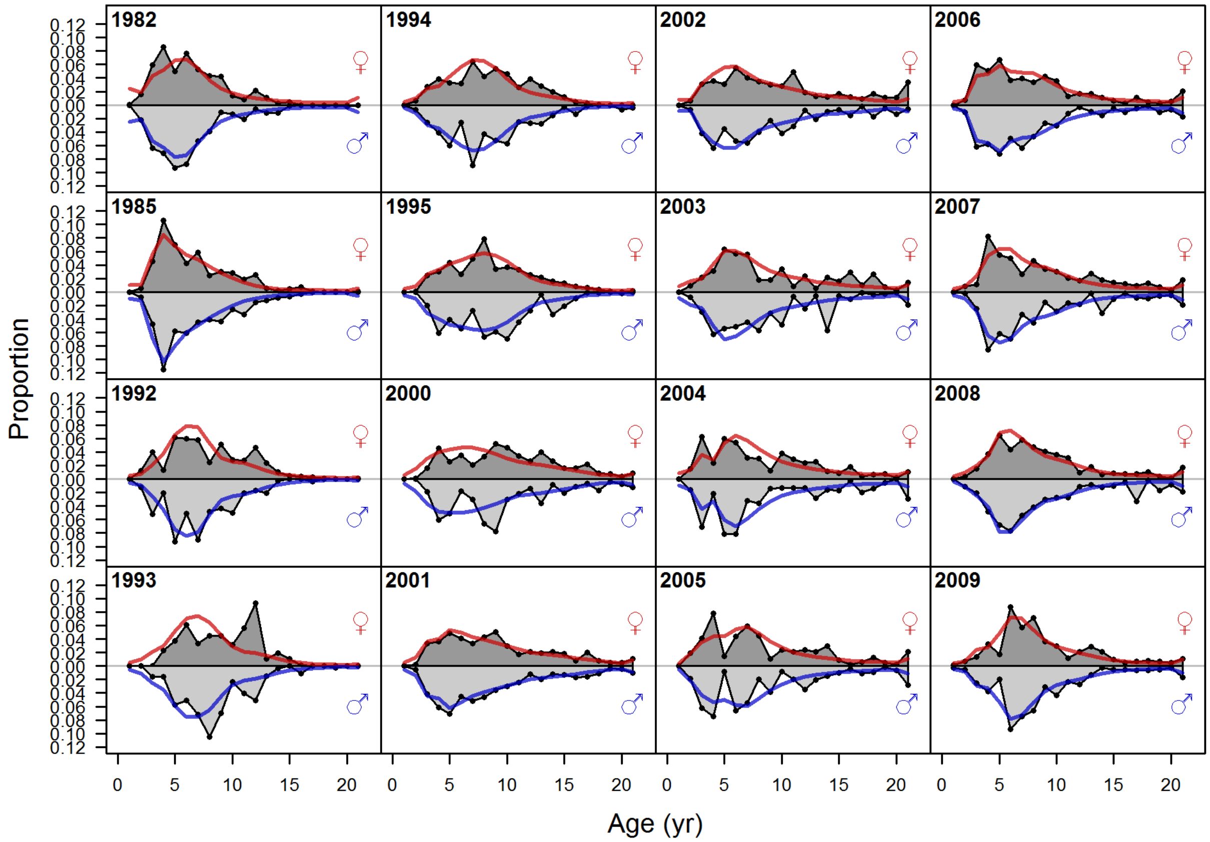


Figure 9.33. Fits to survey age composition data (grey) by year for Model 2018.0b (part 1 of 2).

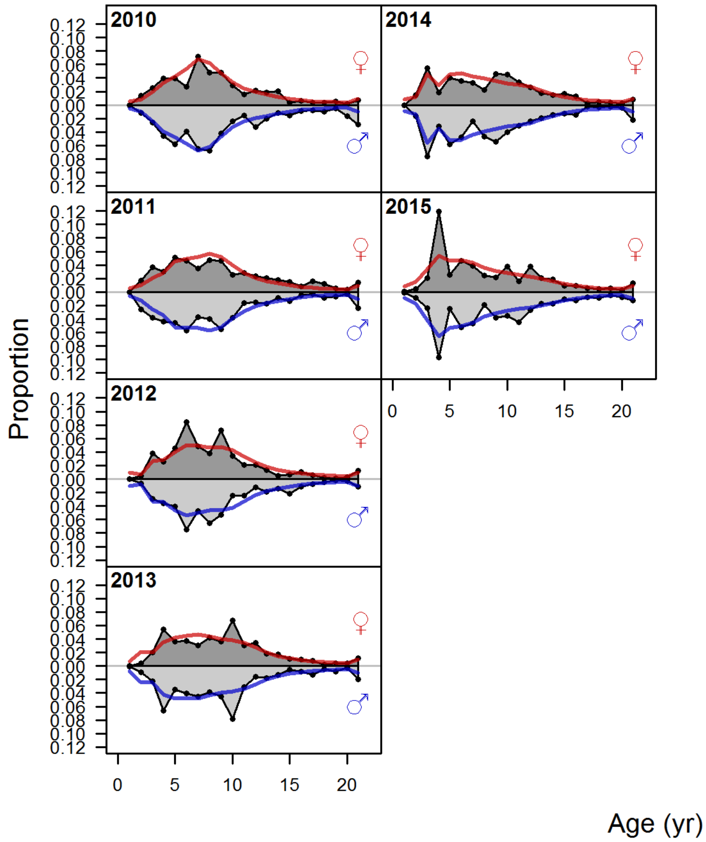


Figure 9.78, continued (part 2 of 2).

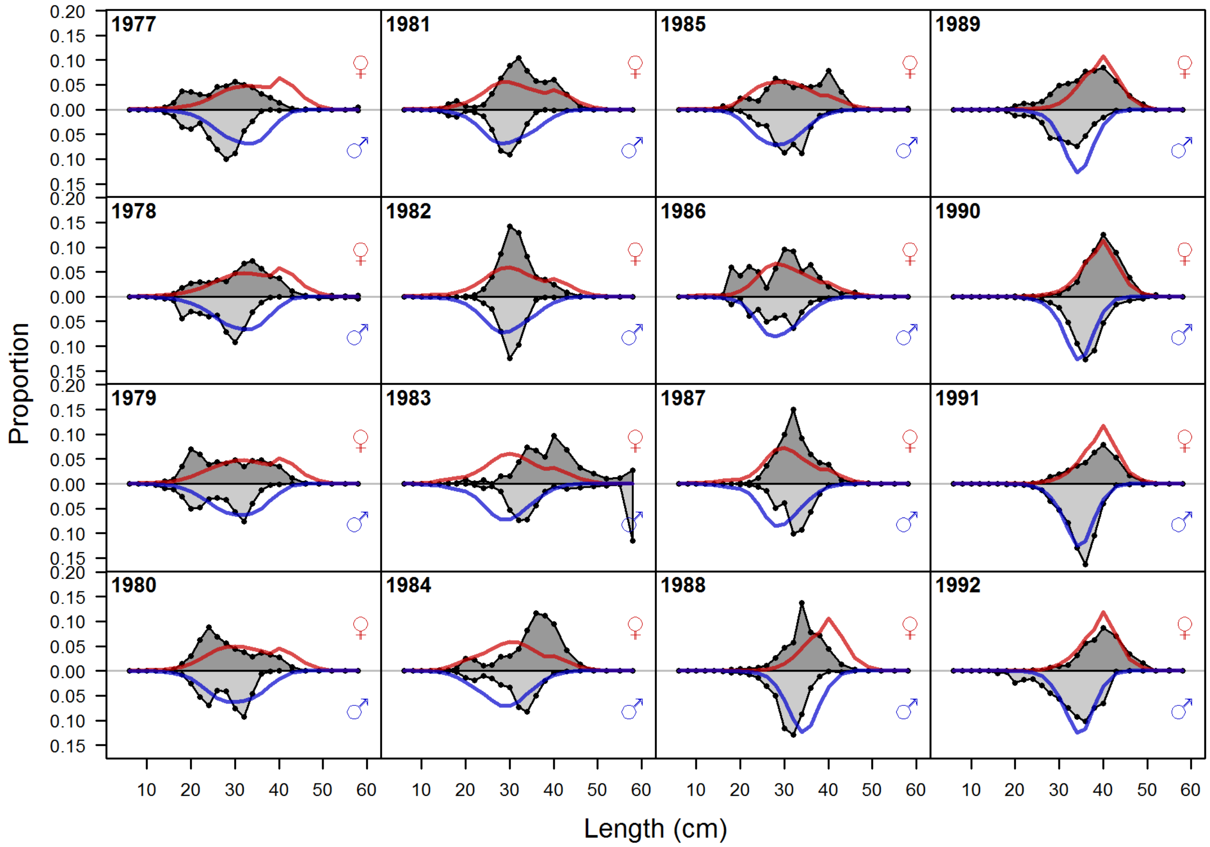


Figure 9.34. Fits to fishery length composition data (grey) by year for Model 2018.0b. In years for which age composition data existed, length composition data were given an effective sample size of 1 (part 1 of 2).

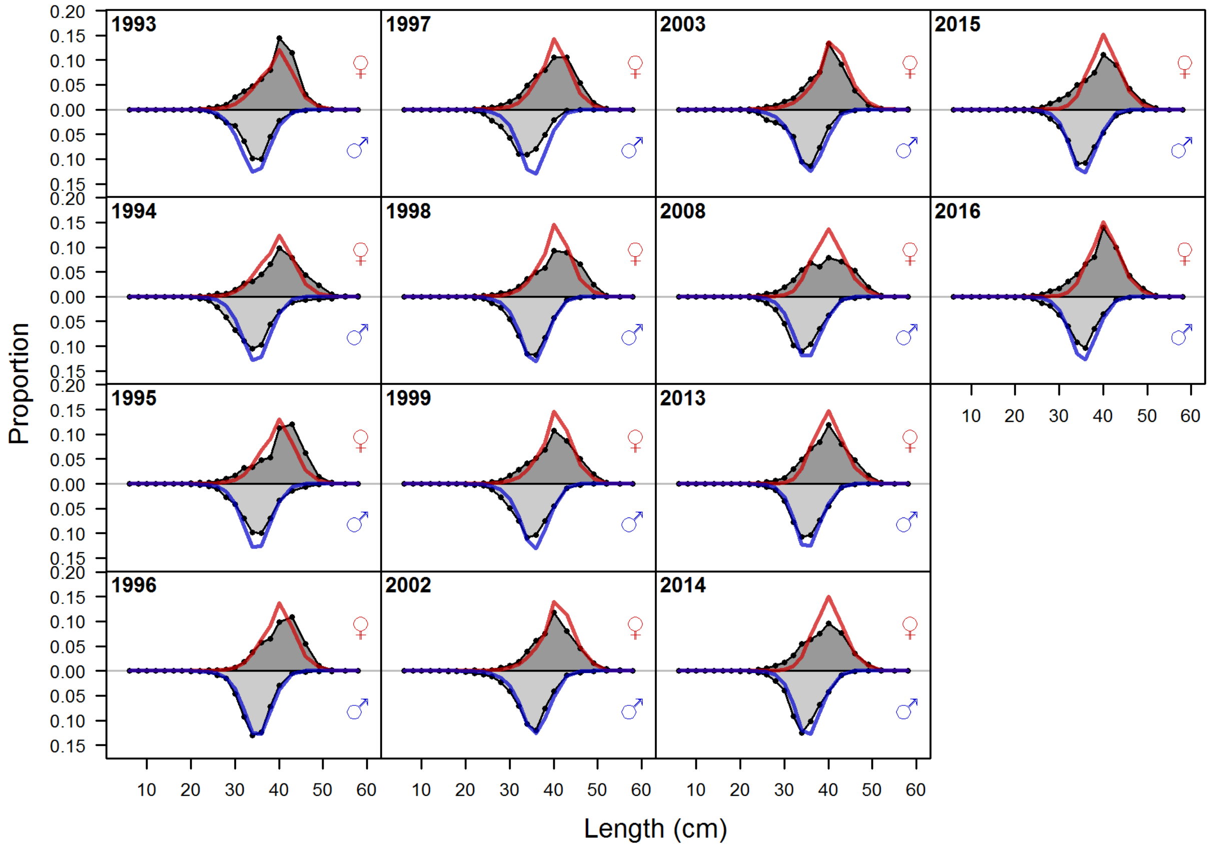


Figure 9.79, continued (page 2 of 2)

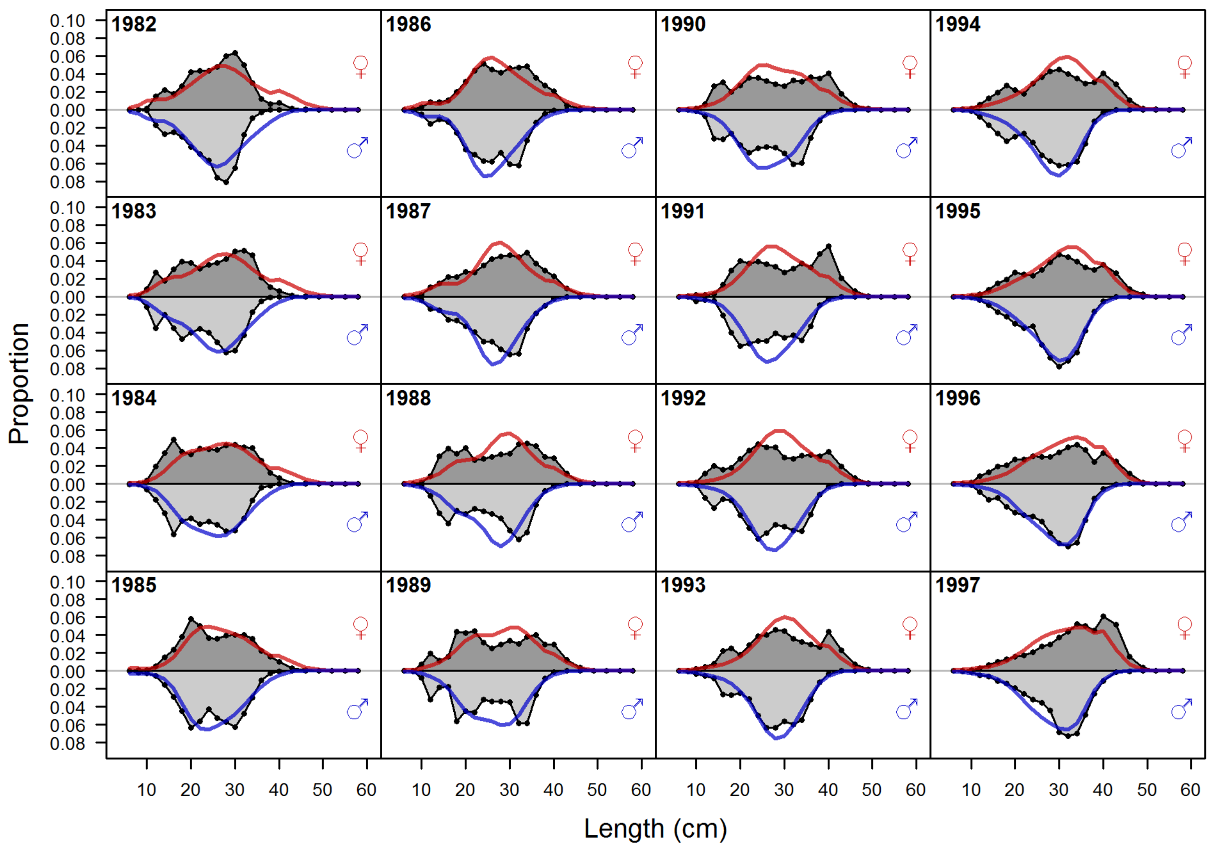


Figure 9.35. Fits to survey length composition data (grey) by year for Model 2018.0b. In years for which age composition data existed, length composition data were given an effective sample size of 1 (part 1 of 3).

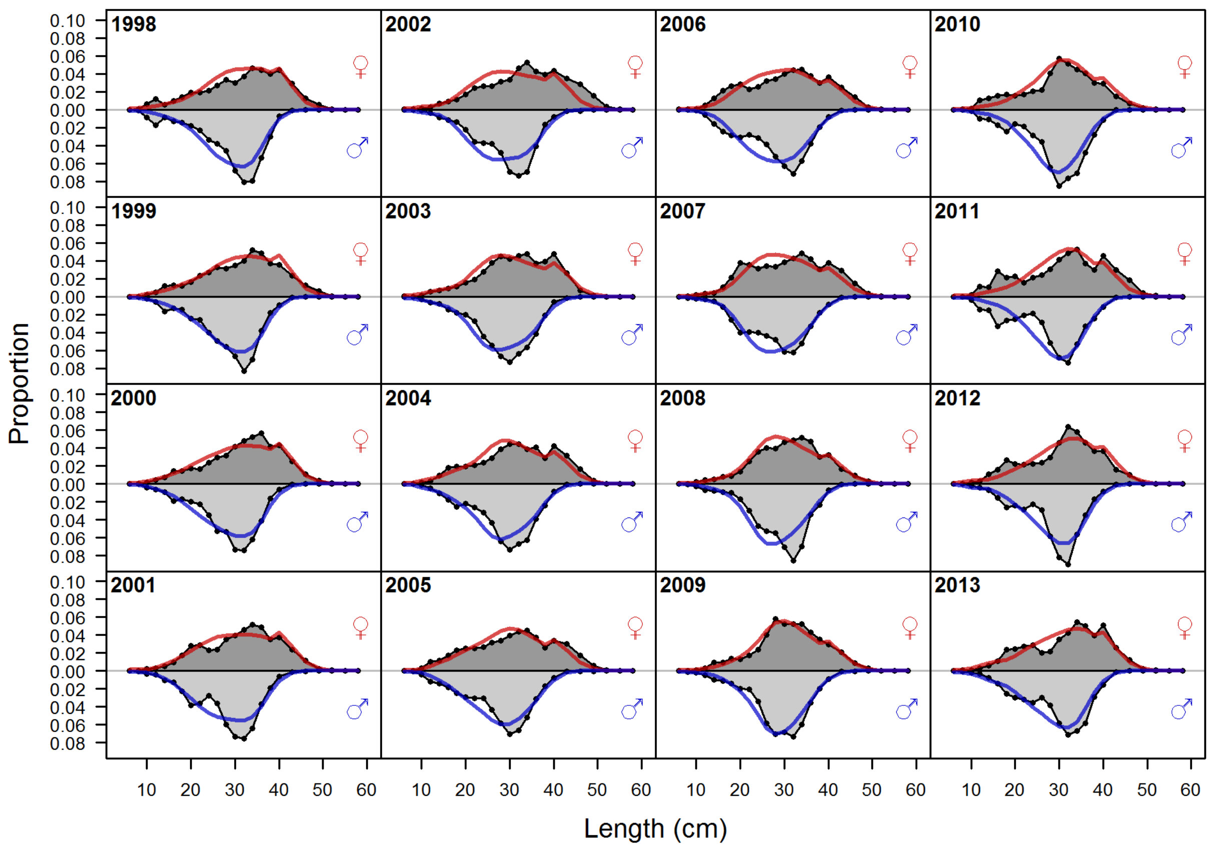


Figure 9.80, continued (part 2 of 3).

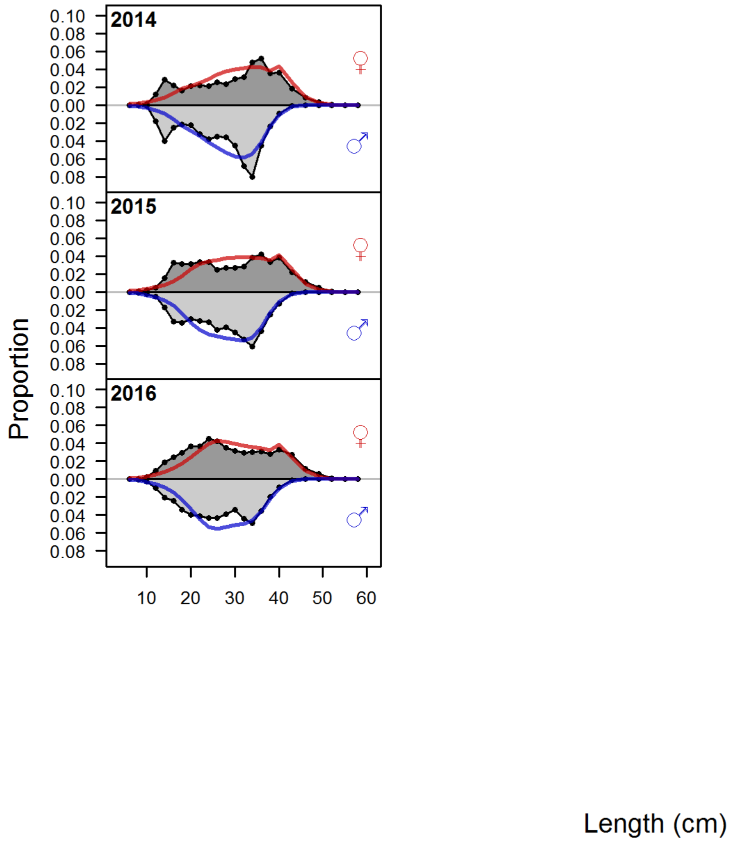


Figure 9.80, continued (part 3 of 3).

Appendix C

Description of Model Framework for Model 2016.0

The assessment for flathead sole is currently conducted using a split-sex, age-based model with length-based formulations for fishery and survey selectivity. The model structure was developed following Fournier and Archibald's (1982) methods for separable catch-at-age analysis, with many similarities to Methot and Wetzel (2013). The assessment model simulates the dynamics of the stock and compares expected values of stock characteristics with observed values from survey and fishery sampling programs in a likelihood framework, based on distributional assumptions regarding the observed data. Model parameters are estimated by minimizing an associated objective function (basically the negative log-likelihood) that describes the mismatch between model estimates and observed quantities. The model was implemented using AD Model Builder, a software package that facilitates the development of parameter estimation models based on a set of C++ libraries for automatic differentiation.

Basic variables, constants, and indices

Basic variables, constants and indices used in the model are described in the following table:

Table 9C.1. Model constants and indices.

Variable	Description
t	year .
t_{start}, t_{end}	start, end years of model period (1977, 2012).
$t^{sr}_{start}, t^{sr}_{end}$	start, end years for estimating a stock-recruit relationship.
a_{rec}	Age at recruitment, in years (3).
a_{max}	maximum age in model, in years (21).
x	sex index ($1 \le x \le 2$; 1=female, 2=male).
l_{max}	number of length bins.
l	length index ($1 \le l \le l_{max}$).
L_l	length associated with length index l (midpoint of length bin).

Biological data

The model uses a number of biologically-related variables that must be estimated outside the model. These are listed in the following table and include weights-at-age and length for individuals caught in the fishery and by the trawl survey, a matrix summarizing the probability of assigning incorrect ages to fish during otolith reading, sex-specific matrices for the probability of length-at-age, the time of the year at which spawning occurs, and the maturity ogive. Sex-specific growth rates are incorporated in the model via the length-at-age matrices.

Table 9C.2. Input biological data for model.

Variable	Description
$w_{x,a}$	mean body weight (kg) of sex *x*, age *a* fish in stock (at beginning of year).
$w^{S}_{x,a}$	mean body weight (kg) of sex *x*, age *a* fish from survey.
$w^{F}_{x,a}$	mean body weight (kg) of sex *x*, age *a* fish from fishery.
w_l	mean body weight (kg) of fish in length bin *l*.
$\Theta_{a,a'}$	ageing error matrix.
$\Phi_{x,a,l}$	sex-specific probability of length-at-age.
t_{sp}	time of spawning (as fraction of year from Jan. 1).
ϕ_a	proportion of mature females at age *a*.

Fishery data

Time series of total yield (catch biomass) from the fishery, as well as length and age compositions from observer sampling of the fishery are inputs to the model and used to evaluate model fit. Under one option for initializing stock numbers-at-age, an historical level of catch (i.e., the catch taken annually prior to the starting year of the model) must also be specified.

Table 9C.3. Input fishery data for model.

Variable	Description
$\{t^F\}$	set of years for which fishery catch data is available.
$\{t^{F,A}\}$	set of years for which fishery age composition data is available.
$\{t^{F,L}\}$	set of years for which fishery length composition data is available.
$\tilde{Y}^H$	assumed historical yield (i.e., prior to t_{start}; catch in metric tons).
$\tilde{Y}_t$	observed total yield (catch in metric tons) in year t.
$\tilde{p}^{F,A}_{t,x,a}$	observed proportion of sex x, age a fish from fishery during year.
$\tilde{p}^{F,L}_{t,x,l}$	observed proportion of sex x fish from fishery during year t in length bin l.

Survey data

The model also uses time series of observed biomass, length compositions, and age compositions from the AFSC's groundfish surveys on the eastern Bering Sea shelf and in the Aleutian Islands to evaluate model fit. Annual values of spatially-averaged bottom temperature from the eastern Bering Sea trawl surveys are also used to estimate temperature effects on survey catchability.

Table 9C.4. Input survey data for model.

Variable	Description
$\{t^S\}$	set of years for which survey biomass data is available.
$\{t^{S,A}\}$	set of years for which survey age composition data is available.
$\{t^{S,L}\}$	set of years for which survey length composition data is available.
δT_t	survey bottom temperature anomaly in year t (difference from mean bottom temperature in year t)
$\tilde{B}^S_t$, cv^S_t	observed survey biomass and associated coefficient of variation in year t.
$\tilde{p}^{S,A}_{t,x,a}$	observed proportion of sex x, age a fish from survey during year t.
$\tilde{p}^{S,L}_{t,x,l}$	observed proportion of sex x fish from survey during year t in length bin l.

Stock dynamics

The equations governing the stock dynamics of the model are given in the following table. These equations describe the effects of recruitment, growth and fishing mortality on numbers-at-age, spawning biomass and total biomass. Note that the form for recruitment depends on the deviations option selected (standard or "new", see below). Under the standard option, recruitment deviations are about a log-scale mean ($\overline{\ln R}$) while under the new option, the deviations are directly about the stock-recruit relationship.

Table 9C.5. Equations describing model population dynamics.

Variable/equation	Description
b^F, ${}_{50}L^F$	parameters for length-specific fishery selectivity (slope and length at 50% selected).
$s_l^F = \dfrac{1}{1+e^{(-b_x^F(L_l - {}_{50}L^F))}}$	length-specific fishery selectivity: 2-parameter ascending logistic.
$s_{x,a}^F = \sum_l \Phi_{x,a,l} \cdot s_l^F$	sex/age-specific fishery selectivity.
$\overline{\ln F}$	log-scale mean fishing mortality.
$\varepsilon_t \sim N(0,\sigma_F^2)$	random log-scale normal deviate associated with fishing mortality.
$F_t = \exp\left(\overline{\ln F} + \varepsilon_t\right)$	fully-selected fishing mortality for year *t*.
$F_{t,l} = F_t \cdot s_l^F$	length-specific fishing mortality for year *t*.
$F_{t,x,a} = F_t \cdot s_{x,a}^F$	sex/age-specific fishing mortality for year *t*.
$Z_{t,x,a} = F_{t,x,a} + M_x$	total sex/age-specific mortality for year *t*.
$\tau_t \sim N(0,\sigma_R^2)$	random log-scale normal deviate associated with recruitment during model time period.
$\overline{\ln R}$	log-scale mean recruitment.
$f(B_t)$	spawner-recruit relationship.
$R_t = \begin{cases} \exp\left(\overline{\ln R} + \tau_t\right) & \text{standard option} \\ f(B_{t-a_{rec}}) \cdot \exp(\tau_t) & \text{new option} \end{cases}$	recruitment during model time period (depends on recruitment deviations option).
$N_{t,x,a_{rec}} = \frac{1}{2} R_t$	recruitment assumed equal for males and females.
$N_{t+1,x,a+1} = N_{t,x,a} \cdot e^{-Z_{t,x,a}}$	numbers at age at beginning of year *t*+1.
$N_{t+1,x,a_{\max}} = N_{t,x,a_{\max}-1} e^{-Z_{t,x,a_{\max}-1}} + N_{t,x,a_{\max}} e^{-Z_{t,x,a_{\max}}}$	numbers in "plus" group at beginning of year *t*+1.
$\overline{N}_{t,x,a} = \dfrac{(1-e^{-Z_{t,x,a}})}{Z_{t,x,a}} N_{t,x,a}$	mean numbers-at-age for year *t*.
$\overline{N}_{t,x,l} = \sum_a \Phi_{x,a,l} \cdot \overline{N}_{t,x,a}$	mean numbers-at-length for year *t*.
$B_t = \sum_a w_{1,a} \cdot \phi_a \cdot N_{t,1,a} \cdot \exp(-Z_{t,x,a} \cdot t_{sp})$	female spawning biomass in year *t*.
$B_t^T = \sum_x \sum_a w_{x,a} \cdot N_{t,x,a}$	total biomass at beginning of year *t*.

Options for spawner-recruit relationships

Three options for incorporating spawner-recruit relationships are included in the model, but were not used in the 2014 model. These are described in the following table and consist of a relationship where recruitment is independent of stock size, a Beverton-Holt-type relationship, and a Ricker-type relationship (Quinn and Deriso, 1999). The latter two have been re-parameterized in terms of R_0, the expected recruitment for a virgin stock, and h, the steepness of the stock-recruit curve at the origin.

Table 9C.6. Equations describing model spawner-recruit relationships.

Variable/equation	Description
$f(B_t) = \exp(\overline{\ln R})$	no stock-recruit relationship: recruitment is independent of stock level.
$\alpha = \frac{4R_0 h}{5h-1}$ $\beta = \frac{\phi_0 R_0 (1-h)}{5h-1}$ $f(B_t) = \frac{\alpha B_t}{\beta + B_t}$	Beverton-Holt stock-recruit relationship parameterized in terms of equilibrium recruitment with no-fishing, R_0, and the steepness parameter, h. ϕ_0 is the spawning biomass-per-recruit in the absence of fishing.
$\alpha = \frac{(5h)^{5/4}}{\phi_0}$ $\beta = \frac{5\ln(5h)}{4\phi_0 R_0}$ $f(B_t) = \alpha B_t \exp(-\beta B_t)$	Ricker stock-recruit relationship parameterized in terms of equilibrium recruitment with no-fishing, R_0, and the steepness parameter, h. ϕ_0 is the spawning biomass-per-recruit in the absence of fishing.

Options for historical recruitment

The standard option for historical recruitment assumes that recruitment prior to the start of the model time period is independent of stock size. Thus, the stock-recruit model relationship to characterize the model period does not apply to historical recruitment, which is parameterized by $\ln R^H$, the log-scale mean historical recruitment. The "new" option for historical recruitment tested in this assessment assumes that the stock-recruit relationship that characterizes the model period is also operative for historical recruitment. As a consequence, the parameter $\ln R^H$ is no longer estimated when the "new" option is used.

Options for initial numbers-at-age

Under the standard option, initial numbers-at-age are deterministic, with historical recruitment in equilibrium historical fishing mortality F^H, a model-estimated parameter. The model algorithm for this option is given by the following pseudo-code:

$$N_{t_{start},x,a_{rec}} = \tfrac{1}{2} R_{eq}(F^H)$$
$$N_{t_{start},x,a+1} = N_{t_{start},x,a} \cdot \exp(-(F^H \cdot s^F_{x,a} + M_x))$$
$$Y^H = \sum_x \sum_a \frac{F^H \cdot s^F_{x,a}}{F^H \cdot s^F_{x,a} + M_x} \cdot N_{t_{start},x,a} \cdot (1 - \exp(-(F^H \cdot s^F_{x,a} + M_x)))$$
$$\mathcal{P}^H = \lambda^H \cdot \left(\tilde{Y}^H - Y^H\right)^2$$
$$N_{t_{start},x,a_{rec}} = \begin{cases} \tfrac{1}{2}\exp(\overline{\ln R} + \tau_{t_{start}}) & \text{standard deviations option} \\ \tfrac{1}{2} f(B_{t-a_{rec}}) \cdot \exp(\tau_{t_{start}}) & \text{new deviations option} \end{cases}$$

where $R_{eq}(F)$ is the equilibrium recruitment at fishing mortality F using the selected historic recruitment option and the assumed stock-recruit mode. $\mathcal{P}^H$ is a penalty added to the objective function with a high weight (λ^H) to ensure that the estimated historical catch equals the observed. Recruitment in the first model year is reset to fluctuate stochastically in the final equation above. If the standard option for historical recruitment is used, then historical recruitment is independent of stock size and $R_{eq}(F)$ is given by $\exp(\ln R^H)$. If the new option is used, then $R_{eq}(F)$ is derived from the operative stock-recruit relationship for the model time period (and $\ln R^H$ is not estimated).

Under "option 1", the initial numbers-at-age are assumed to be in stochastic equilibrium with a virgin stock condition (i.e., no fishing). Lognormal deviations from the mean or median stock-recruit relationship during the historical and modeled time periods are taken to be linked. When the standard option for historical recruitment is also used, the initial numbers-at-age are thus given by:

$$N_{t_{start},x,a} = \tfrac{1}{2}\exp(\ln R^H + \tau_{t_{start}-(a-a_{rec})}) \cdot \exp(-M_x \cdot (a - a_{rec})); \quad a = a_{rec} \ldots a_{\max}$$

When the new option for historical recruitment is used, the algorithm for calculating initial numbers-at-age is identical to the equation above, with $\overline{\ln R}$ replacing $\ln R^H$, when recruitment is assumed independent of stock size. When recruitment is assumed to depend on stock size (through either a Ricker or Beverton-Holt relationship), the algorithm for calculating initial numbers-at-age is somewhat more complicated because historical recruitment now depends on historical spawning biomass, which also fluctuates stochastically. Consequently, an attempt is made to incorporate changes to the historical spawning biomass due to stochastic fluctuations in historical recruitment about the stock-recruit curve when calculating the initial numbers-at-age. The algorithm is described by the following pseudo-code:

$$B_t = B_0 \quad \text{for } t \le t_{start} - a_{\max}$$
$$\begin{cases} \text{for j} = 1 \text{ to } a_{\max} \\ N_{t_{start}-a_{\max}+j,x,a_{rec}} = \tfrac{1}{2} f(B_{t_{start}-a_{\max}+j-a_{rec}}) \cdot \exp(\tau_{t_{start}-a_{\max}+j}) \\ N_{t_{start}-a_{\max}+j,x,a+1} = N_{t_{start}-a_{\max}+j-1,x,a} \cdot \exp(-M_x) \\ B_{t_{start}-a_{\max}+j} = \sum_a w_{1,a} \cdot \phi_a \cdot N_{t_{start}-a_{\max}+j,1,a} \cdot \exp(-M_x\, t_{sp}) \end{cases}$$

where B_0 is the expected biomass for a virgin stock. Conceptually, this option attempts to incorporate the effects of density-dependence implicit in the stock-recruit relationship (if one is being used) when estimating the initial numbers-at-age.

"Option 2" for initial number-at-age represents a subtle variation on "option 1". The equations for "option 2" are identical to those for "option 1" except that the log-scale deviations τ_t over the interval $t_{start}-a_{max} \leq t \leq t_{start}-1$ are replaced by a set of independent log-scale deviations ξ_t. In "option 1", the τ_t are required to sum to 0 over the time interval $t_{start}-a_{max} < t \leq t_{end}$, while in "option 2", the τ_t sum to 0 over $t_{start} \leq t \leq t_{end}$ and the ξ_t sum to 0 over $t_{start}-a_{max} < t \leq t_{start}-1$.

Model-predicted fishery data

In order to estimate the fundamental parameters governing the model, the model predicts annual catch biomass (yield) and sex-specific length and age compositions for the fishery, to compare with the observed input fishery data components. The equations used to predict fishery data are outlined in the following table:

Table 9C.7. Model equations predicting fishery data.

Variable/equation	Description
$C_{t,x,l}=F_{t,l}\ \overline{N}_{t,x,l}$	sex-specific catch-at-length (in numbers) for year *t*.
$C_{t,x,a}=\sum_{a'} \Theta_{a,a'}\ F_{t,x,a'}\ \overline{N}_{t,x,a'}$	sex-specific catch-at-age (in numbers) for year *t* (includes ageing error).
$Y_t = \sum_x \sum_l w_l\, C_{t,x,l}$	total catch in tons (i.e., yield)for year *t*.
$p^{F,L}_{t,x,l} = C_{t,x,l} / \sum_x \sum_l C_{t,x,l}$	proportion at sex/length in the catch.
$p^{F,A}_{t,x,a} = C_{t,x,a} / \sum_x \sum_a C_{t,x,a}$	proportion at sex/age in the catch.

Model-predicted survey data

The model also predicts annual survey biomass and sex-specific length and age compositions from the trawl survey to compare with the observed input survey data components in order to estimate the fundamental parameters governing the model. The equations used to predict survey data are outlined in the following table:

Table 9C.8. Model equations describing survey data.

Variable/equation	Description
b^S, ${}_{50}L^S$	parameters for length-specific survey selectivity (slope and length at 50% selected)
$s_l^S = \dfrac{1}{1+e^{(-b^S(L_l - {}_{50}L^S))}}$	length-specific survey selectivity: 2-parameter ascending logistic.
$s_{x,a}^S = \sum_l \Phi_{x,a,l}\ s_l^S$	sex/age-specific survey selectivity.
$\sigma_T^2 = \dfrac{1}{n_T - 1}\sum_t \delta T_t^2$	variance of bottom temperature anomalies.
$q_t = \exp(\alpha_q + \beta_q\ \delta T_{t-y} - \dfrac{(\beta_q\ \sigma_T)^2}{2})$	temperature-dependent survey catchability in year *t*. *y* is the effect lag (in years). The last term in the exponential implies that the arithmetic mean catchability is exp(α_q).
$N^S{}_{t,x,l} = q_t\ s_l^S \cdot \overline{N}_{t,x,l}$	sex-specific survey numbers-at-length in year *t*.
$N^S{}_{t,x,a} = \sum_{a'} q_t\ \Theta_{a,a'}\ s_{x,a'}^S \overline{N}_{t,x,a'}$	sex-specific survey numbers-at-length in year *t* (includes ageing error).
$B_t^S = \sum_x \sum_a w_l\ N^S{}_{t,x,l}$	total survey biomass in year *t*.
$p_{t,x,l}^{S,L} = N^S{}_{t,x,l} / \sum_x \sum_l N^S{}_{t,x,l}$	proportion at sex/length in the survey.
$p_{t,x,a}^{S,A} = N^S{}_{t,x,a} / \sum_x \sum_a N^S{}_{t,x,a}$	proportion at sex/age in the survey.

Non-recruitment related likelihood components

Model parameters are estimated by minimizing the objective function

$$\mathcal{O} = -\sum_i \lambda_i \cdot \mathbf{ln}\mathcal{L}_i + \sum_j \mathcal{P}^j$$

where the $\mathbf{ln}\mathcal{L}_i$ are log-likelihood components for the model, the λ_i are weights put on the different components, and the $\mathcal{P}^j$ are additional penalties to imposed to improve model convergence and impose various conditions (e.g., $\mathcal{P}^H$ defined above to force estimated historic catch to equal input historic catch). One log-likelihood component is connected with recruitment, while the other components describe how well the model predicts a particular type of observed data. Each component is based on an assumed process or observation error distribution (lognormal or multinomial). The likelihood components that are *not* related to recruitment are described in the following table:

Table 9C.9. Non-recruitment related likelihood components (applicable to all model options).

Component	**Description**
$\mathbf{ln}\mathcal{L}_C = \sum_{t=1}^{T}\left[\ln(\tilde{Y}_t + \eta) - \ln(Y_t + \eta)\right]^2$	catch biomass (yield); assumes a lognormal distribution. η is a small value ($<10^{-5}$).
$\mathbf{ln}\mathcal{L}_{FA} = \sum_{t \in \{t^{F,A}\}} \sum_{x=1}^{2} \sum_{a=1}^{A} \tilde{n}_t^{F,A} \cdot \tilde{p}_{t,x,a}^{F,A} \cdot \ln(p_{t,x,a}^{F,A} + \eta) - \Omega^{F,A}$	fishery age composition; assumes a multinomial distribution. $\tilde{n}_t^{F,A}$ is the observed sample size.
$\mathbf{ln}\mathcal{L}_{FL} = \sum_{t \in \{t^{F,L}\}} \sum_{x=1}^{2} \sum_{l=1}^{L} \tilde{n}_t^{F,L} \cdot \tilde{p}_{t,x,l}^{F,L} \cdot \ln(p_{t,x,l}^{F,L} + \eta) - \Omega^{F,L}$	fishery length composition; assumes a multinomial distribution. $\tilde{n}_t^{F,L}$ is the observed sample size.
$\mathbf{ln}\mathcal{L}_{SA} = \sum_{t \in \{t^{S,A}\}} \sum_{x=1}^{2} \sum_{a=1}^{A} \tilde{n}_t^{S,A} \cdot \tilde{p}_{t,x,a}^{S,A} \cdot \ln(p_{t,x,a}^{S,A} + \eta) - \Omega^{S,A}$	survey age composition; assumes a multinomial distribution. $\tilde{n}_t^{S,A}$ is the observed sample size.
$\mathbf{ln}\mathcal{L}_{SL} = \sum_{t \in \{t^{S,L}\}} \sum_{x=1}^{2} \sum_{l=1}^{L} \tilde{n}_t^{S,L} \cdot \tilde{p}_{t,x,l}^{S,L} \cdot \ln(p_{t,x,l}^{S,L} + \eta) - \Omega^{S,L}$	survey length composition; assumes a multinomial distribution. $\tilde{n}_t^{S,L}$ is the observed sample size.
$\Omega^{\cdot\cdot} = \sum_t \sum_{x=1}^{2} \sum_{a=1}^{A} n_t^{\cdot\cdot} \cdot \tilde{p}_{t,x,a}^{\cdot\cdot} \cdot \ln(\tilde{p}_{t,x,a}^{\cdot\cdot} + \eta))$	the offset constants $\{\Omega^{\cdot\cdot}\}$ for age/length composition components are calculated from the appropriate observed proportions and sample sizes.
$\mathbf{ln}\mathcal{L}_{SB} = \sum_{t \in \{t^S\}} \left[\frac{\ln(\tilde{B}_t^S + \eta) - \ln(B_t^S + \eta)}{\sqrt{2} \cdot \tilde{\sigma}_t^S}\right]^2$	Survey biomass; assumes a lognormal distribution.

Recruitment related likelihood components

The exact details of the recruitment-related likelihood components for a given model run depend on whether or not a stock-recruit relationship has been specified and on which of several combinations of model options have been selected. However, the general equation for the recruitment likelihood is

$$\boldsymbol{ln\mathcal{L}}_R = \sum_t \left\{ \frac{(\ln(R_t+\eta) - \ln(f(B_{t-a_{rec}})+\eta)+b)^2}{2\sigma_R^2} + \ln(\sigma_R) \right\} + \gamma \cdot \sum_{t=t_{start}-a_{\max}}^{t_{start}-1} \left\{ \frac{(\xi_t+b)^2}{2\sigma_R^2} + \ln(\sigma_R) \right\}$$

When the standard stock-recruit deviations option is used, $b = \sigma_R^2/2$ and the recruitment likelihood fits the *mean* stock-recruit relationship; otherwise b = 0 and the *median* (or log-scale mean) stock-recruit relationship is fit. When the standard initial n-at-age option is used (i.e., the initial n-at-age distribution is in equilibrium with an historic catch biomass and deterministic), γ = 0 and the first sum over *t* runs from $t^{sr}{}_{start}$ to $t^{sr}{}_{end}$, the interval selected over which to calculate the stock-recruit relationship. When option 1 for initial n-at-age is used, the initial n-at-age distribution is regarded as in stochastic equilibrium with a virgin stock and the recruitment deviations (τ_t) are indexed from t_{start}-a_{max} to t_{end}. For this option, γ = 0 again and the first sum over *t* runs from t_{start}-a_{max} to t_{end} so that the stock-recruit relationship is fit over both the modeled and the historical periods. Finally, when option 2 is used, γ = 1 and the first sum over *t* runs from $t^{sr}{}_{start}$ to $t^{sr}{}_{end}$ so that recruitment deviation during the historical period and deviations during the model period are not linked.

For the models run in this assessment, the likelihood multipliers are summarized in Table 9C.11. λ_C was assigned a value of 50 to ensure a close fit to the observed catch data while λ_R and λ_B were assigned values of 1. The sample sizes in the age and length composition likelihood components were all set to 200, as in previous assessments. The likelihood components associated with the fishery age and length compositions were de-weighted relative to those from the survey to improve model convergence. Thus, λ_{SA} and λ_{SL} were assigned values of 1 and λ_{FL} and λ_{FA} were assigned values of 0.3.

Table 9C.10. Likelihood multiplier values.

Likelihood Multipliers						
	Fishery		Survey			
catch	age compositions	size compositions	biomass	age compositions	size compositions	Recruitment deviations
λ_C	λ_{FA}	λ_{FL}	λ_B	λ_{SA}	λ_{SL}	λ_R
50	0.3	0.3	1	1	1	1

Model parameters

The following tables describe the potentially estimable parameters for the assessment model.

Table 9C.11. Parameters currently not estimated in the model.

Parameter	Subscript range	Total no. of parameters	Description
M_x	$1 \le x \le 2$	2	sex-specific natural mortality.
σ_R^2	--	1	variance of log-scale deviations in recruitment about spawner-recruit curve.
α_q	--	1	natural log of mean survey catchability.

Table 9A.12. Non recruitment-related parameters estimated in the model.

Parameter	Subscript range	Total no. of parameters	Description
β_q	--	1	temperature-dependent catchability "slope" parameter.
$\ln F^H$	--	1	log-scale fishing mortality prior to model period (i.e., historic).
$\overline{\ln F}$	--	1	log-scale mean fishing mortality during model period.
ε_t	$1977 \le t \le 2012$	36	log-scale deviations in fishing mortality in year t.
b^F, ${}_{50}L^F$	--	2	fishery selectivity parameters (slope and length at 50% selected).
b^S, ${}_{50}L^S$	--	2	survey selectivity parameters (slope and length at 50% selected).

Table 9C.13. Recruitment-related parameters. Superscripts refer to initial n-at-age options: 1-standard option, 2-option 2, 3-option 3. The standard option was used in the 2016 model.

Parameter	Subscript range	Total no. of parameters	Description
$\ln R^H$	--	1	log-scale equilibrium age 3 recruitment prior to model period.
$\overline{\ln R}$	--	1	log-scale mean of age 3 recruitment during the model period.
$\ln R_0$	--	1	natural log of R_0, expected recruitment for an unfished stock (used in Ricker or Beverton-Holt stock-recruit relationships).
h	--	1	steepness of stock-recruit curve (used in Ricker or Beverton-Holt stock-recruit relationships).
τ_t	$1977 \le t \le 2012^{1,3}$ $1957 \le t \le 2012^{2}$	$36^{1,3}$ 56^{2}	log-scale recruitment deviation in year t.
ξ_t	-- $1957 \le t \le 1976$	$0^{1,3}$ 20^{2}	log-scale recruitment deviation in year t.

Appendix D

Plots of length-at-age, mean weight-at-age, and weight-length relationships for flathead sole and Bering flounder from the EBS shelf survey

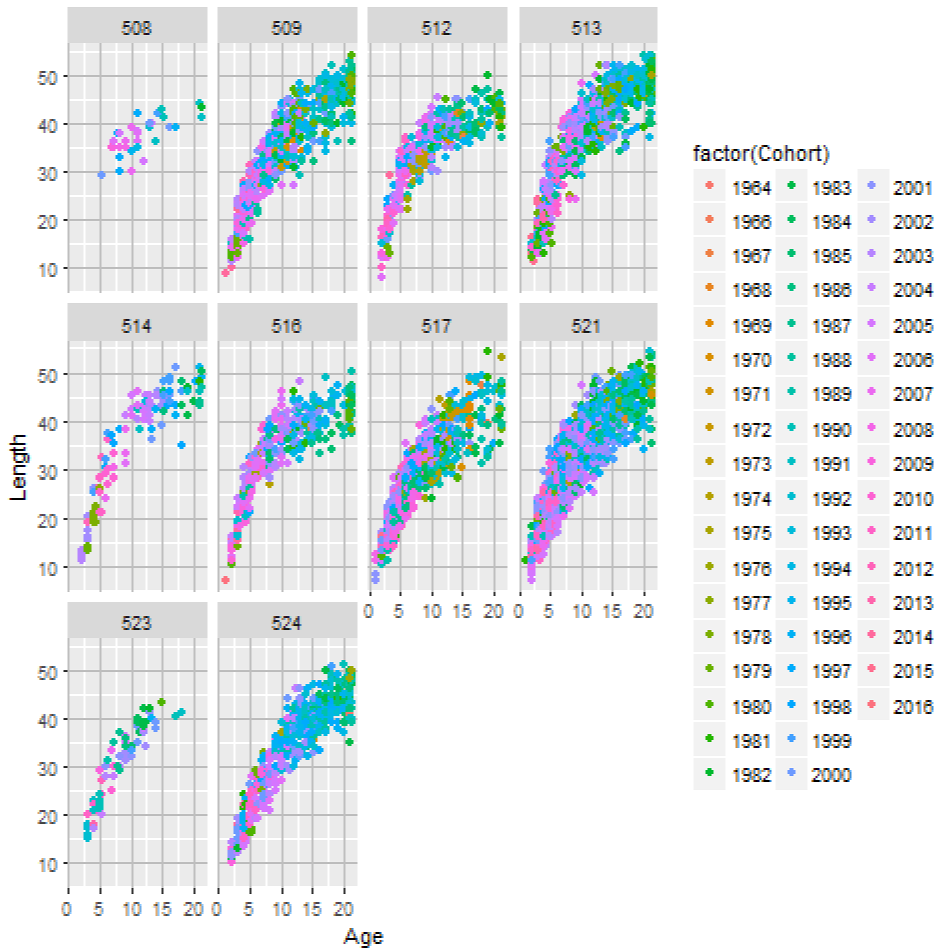


Figure 9.36. Length-at-age of female flathead sole by NMFS area and cohort in the EBS trawl survey. All years for which length-at-age data exist are included. Data points are jittered to better display lengths, ages, and regions where the most and least data exist.

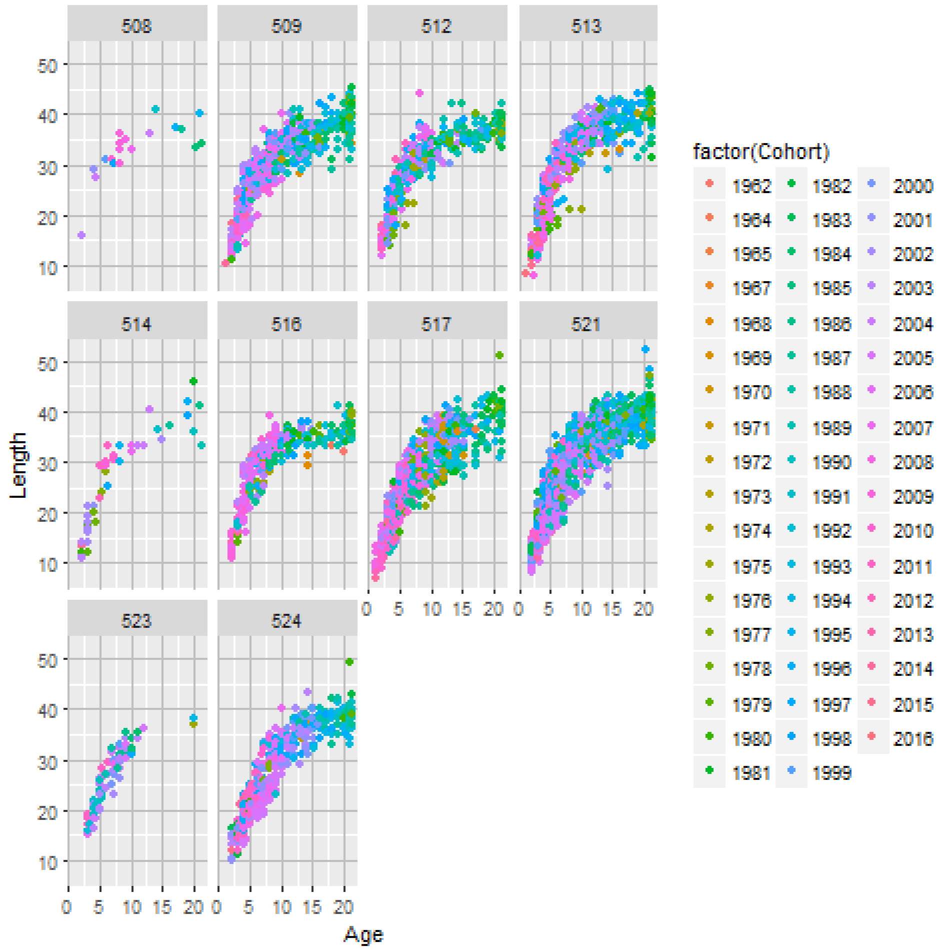


Figure 9.37. Length-at-age of male flathead sole by NMFS area and cohort in the EBS trawl survey. All years for which length-at-age data exist are included. Data points are jittered to better display lengths, ages, and regions where the most and least data exist.

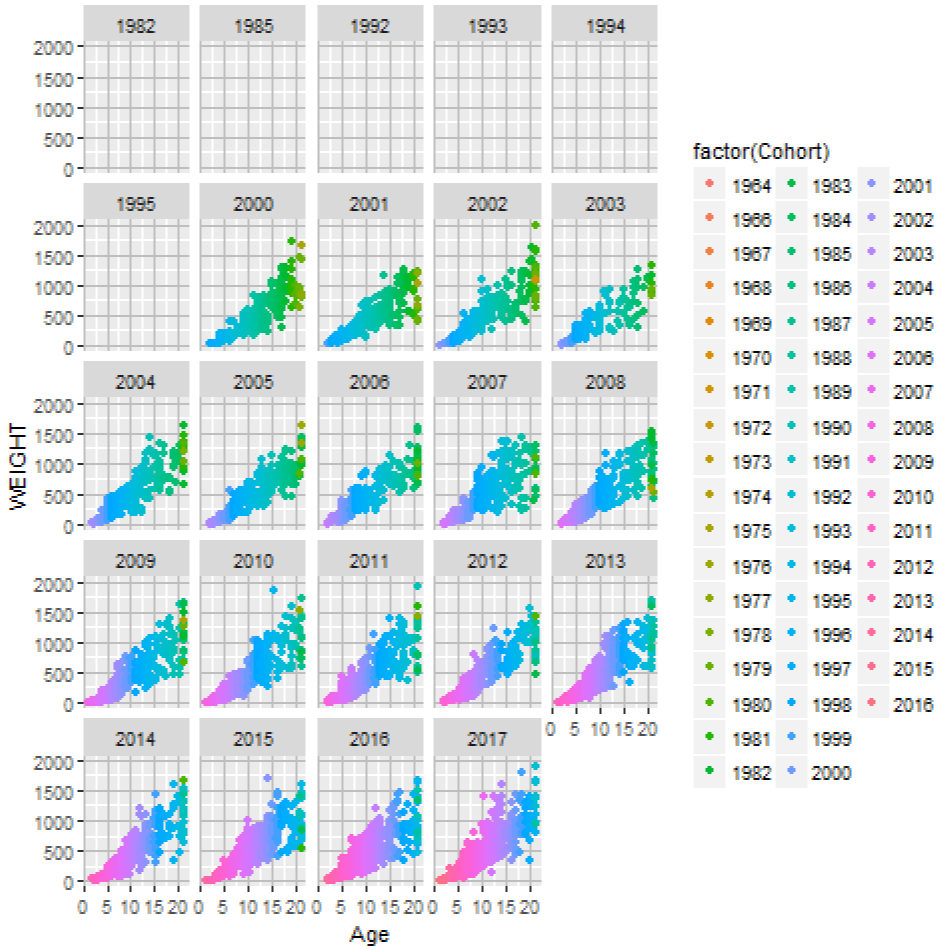


Figure 9.38. Weight-at-age of female flathead sole by year and cohort in the EBS trawl survey. All years for which length-at-age data exist are included. Data points are jittered to better display lengths, ages, and regions where the most and least data exist.

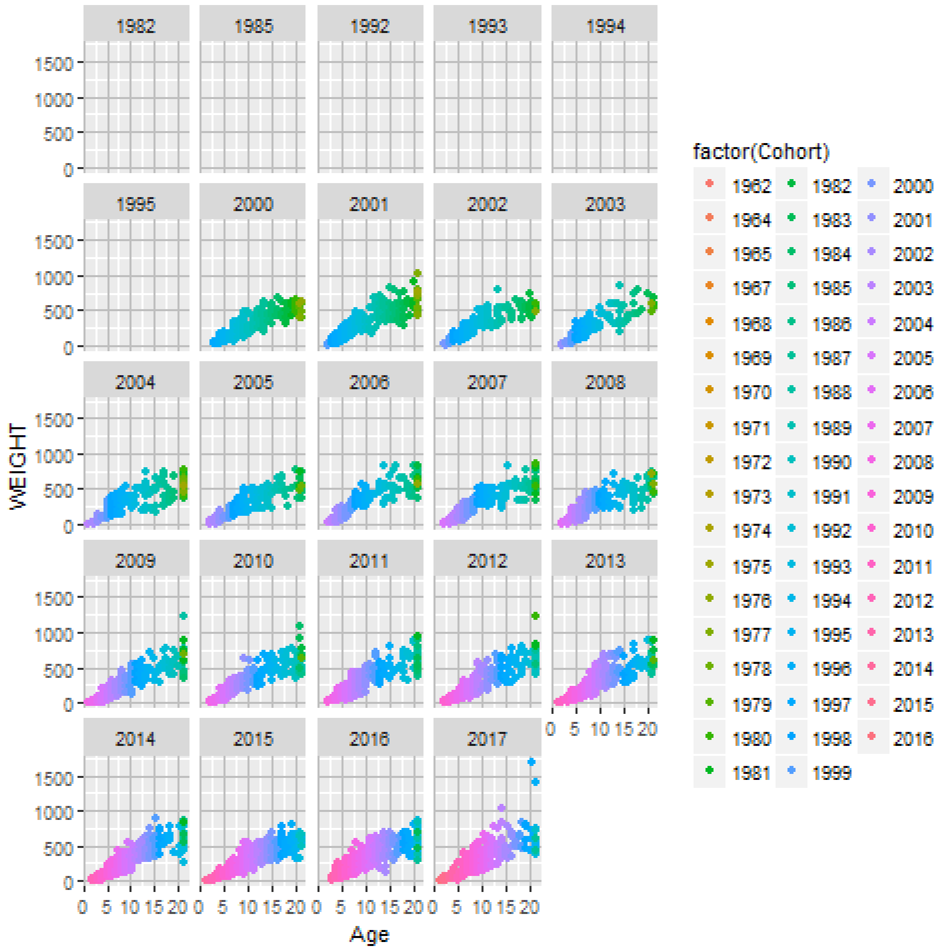


Figure 9.39. Weight-at-age of male flathead sole by year and cohort in the EBS trawl survey. All years for which length-at-age data exist are included. Data points are jittered to better display lengths, ages, and regions where the most and least data exist.

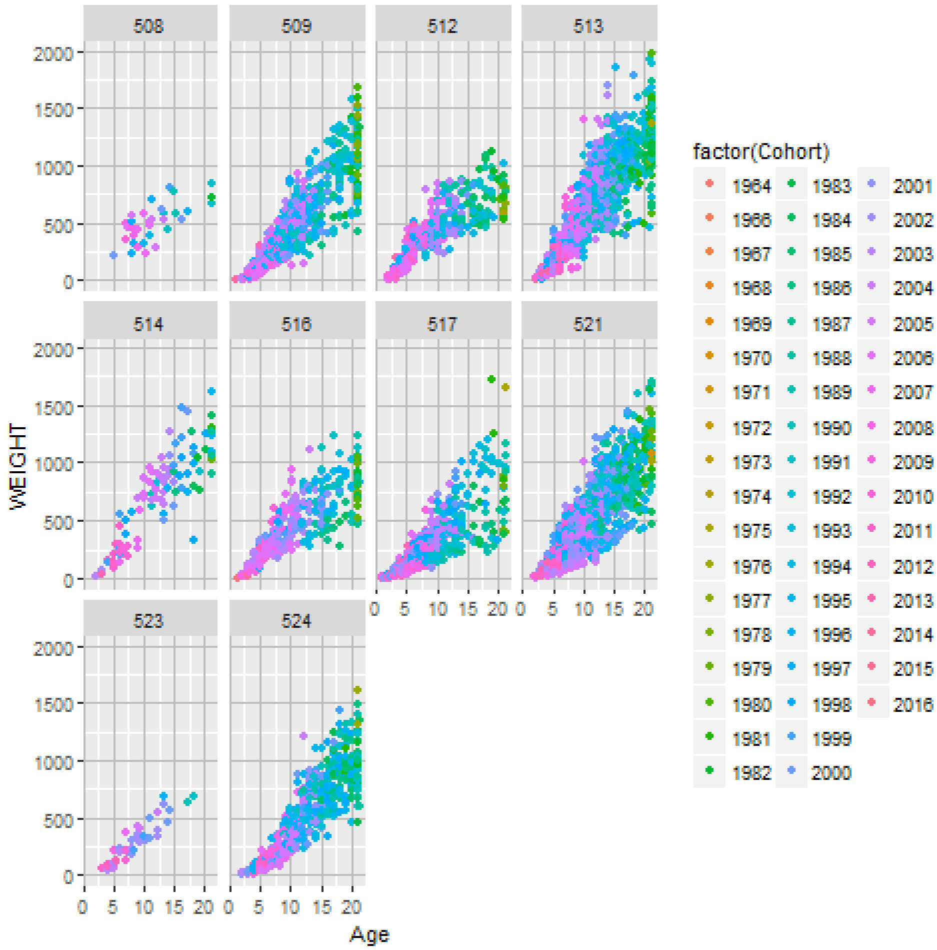


Figure 9.40. Weight-at-age of female flathead sole by NMFS area and cohort in the EBS trawl survey. All years for which weight-at-age data exist are included. Data points are jittered to better display lengths, ages, and regions where the most and least data exist.

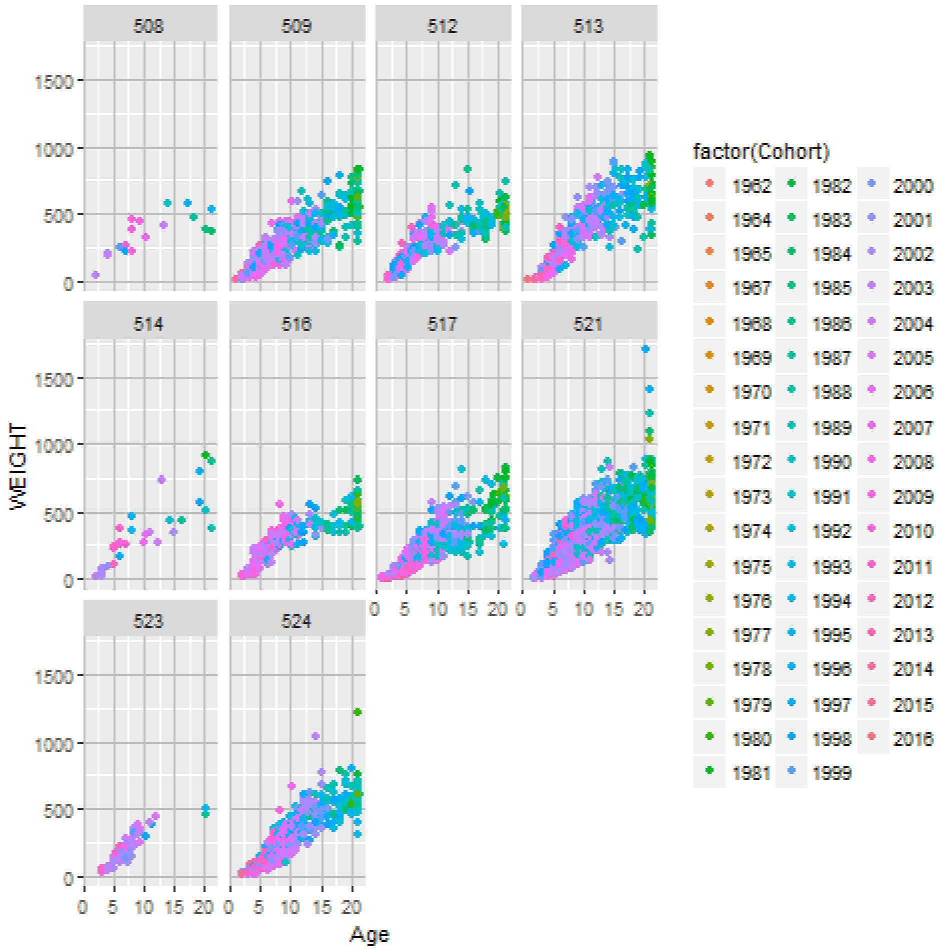


Figure 9.41. Weight-at-age of male flathead sole by NMFS area and cohort in the EBS trawl survey. All years for which weight-at-age data exist are included. Data points are jittered to better display where the most and least data exist.

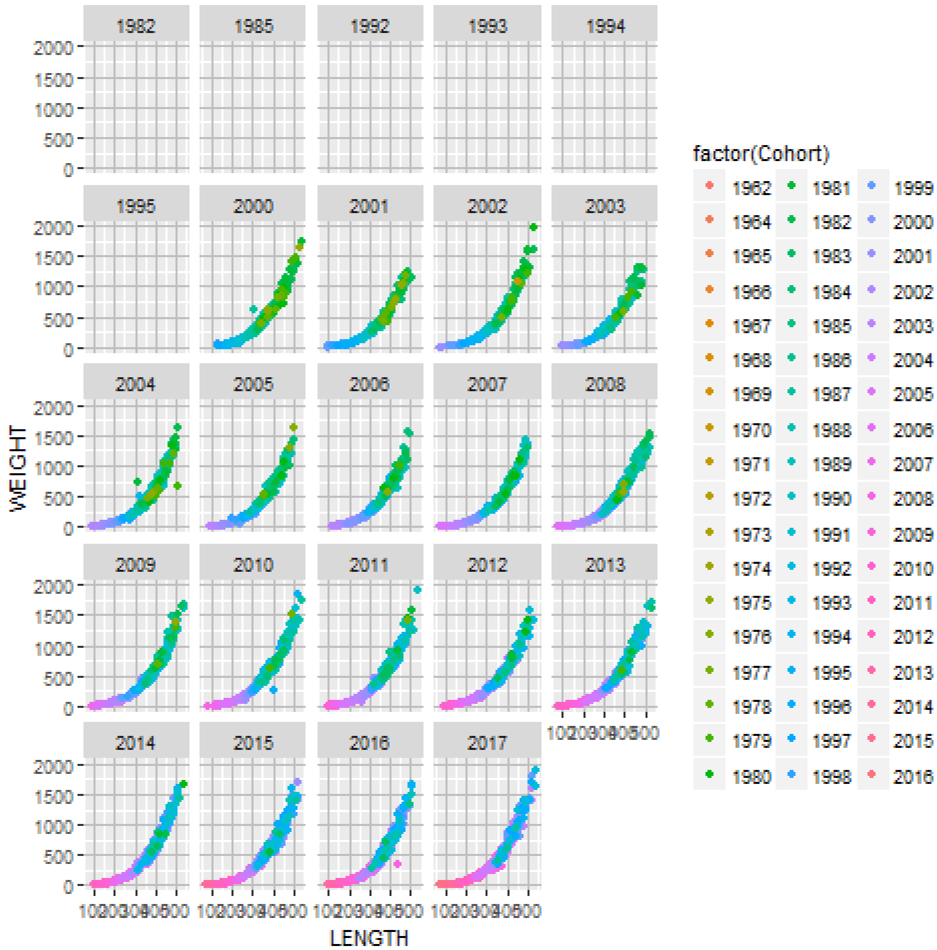


Figure 9.42. Weight-at-length for flathead sole with males and females combined by year and cohort. Data points are jittered to better display where the most and least data exist.

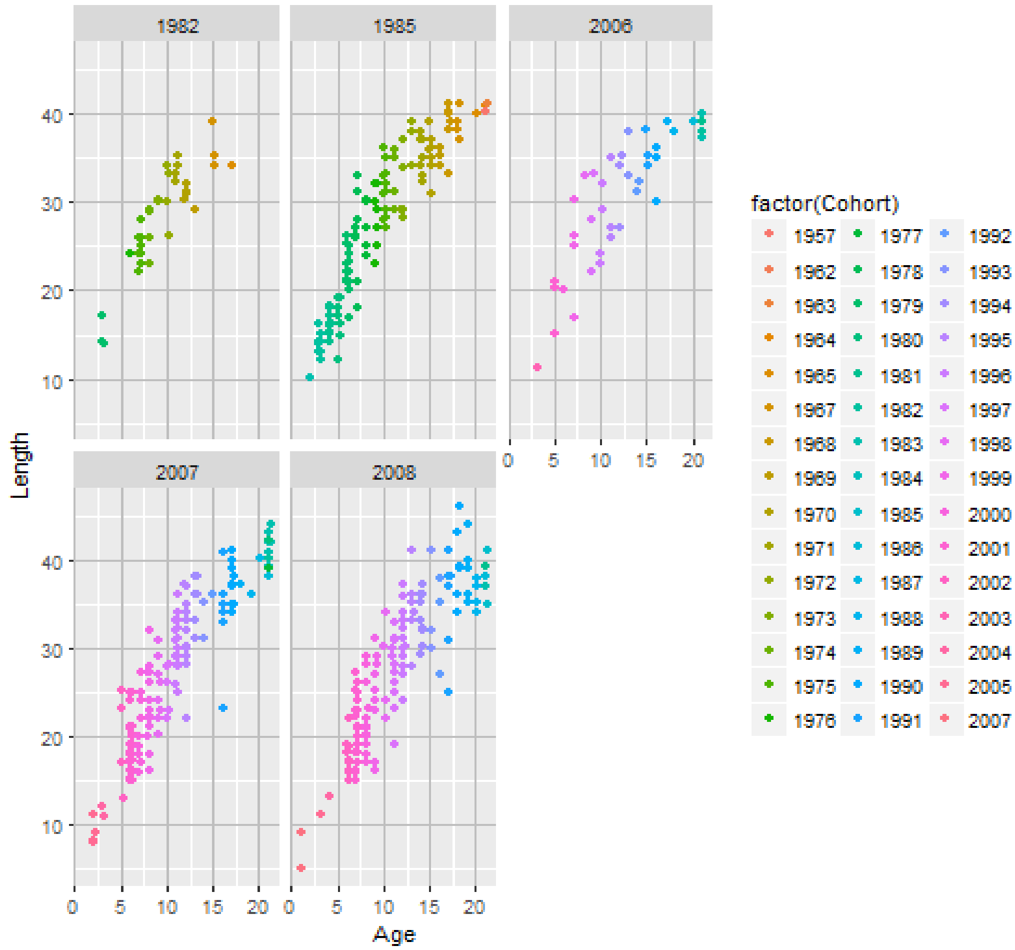


Figure 9.43. Length-at-age of female Bering flounder by year and cohort in the EBS trawl survey. All years for which length-at-age data exist are included. Data points are jittered to better display lengths, ages, and regions where the most and least data exist.

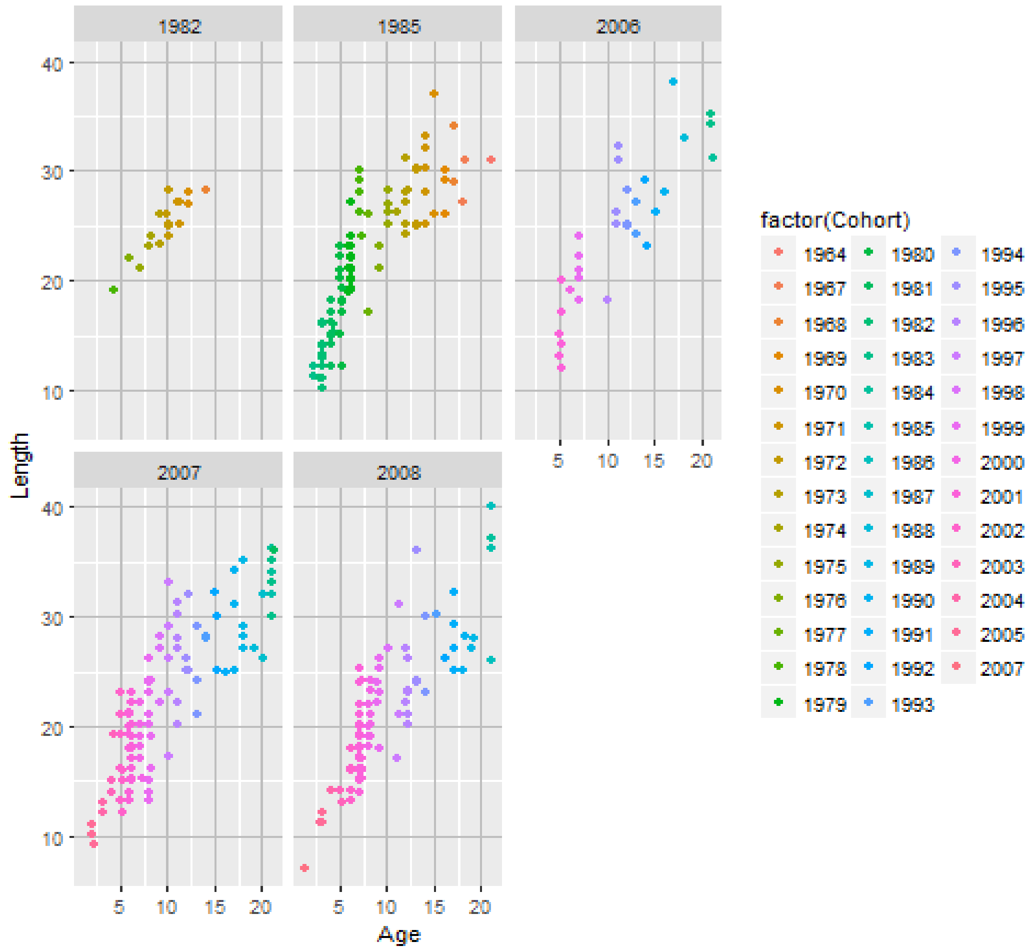


Figure 9.44. Length-at-age of male Bering flounder by year and cohort in the EBS trawl survey. All years for which length-at-age data exist are included. Data points are jittered to better display lengths, ages, and regions where the most and least data exist.

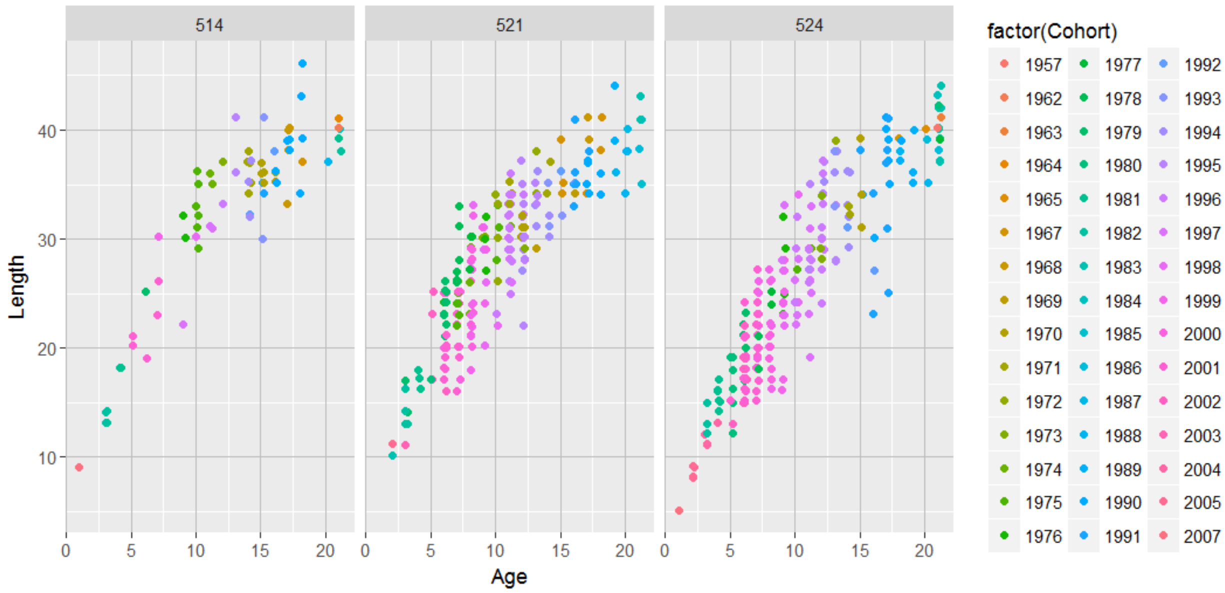


Figure 9.45. Length-at-age of female Bering flounder by NMFS area and cohort in the EBS trawl survey. All years for which length-at-age data exist are included. Data points are jittered to better display lengths, ages, and regions where the most and least data exist.

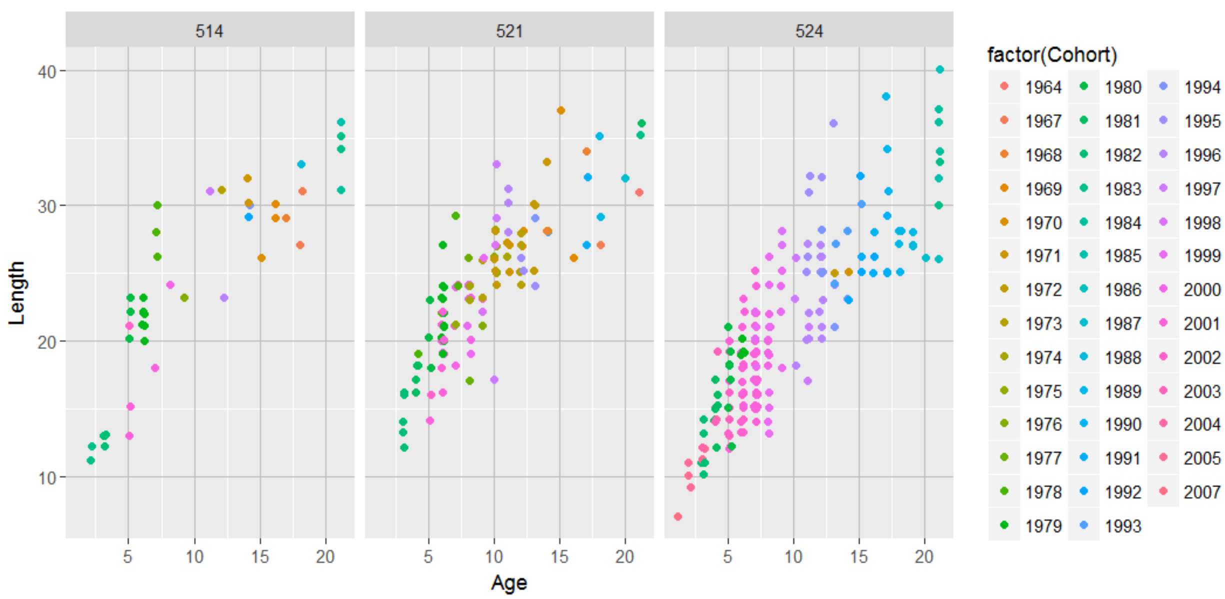


Figure 9.46. Length-at-age of male Bering flounder by NMFS area and cohort in the EBS trawl survey. All years for which length-at-age data exist are included. Data points are jittered to better display lengths, ages, and regions where the most and least data exist.

Appendix E

Supplemental Catch Data

Table D.1-D3. Total non-commercial fishery catches not included in the AKFIN estimates of total catch. Units are not known (not identified on the AKFIN website), but may be kg. Top table is by agency, and bottom two tables are by type of collection and within agency.

Year	ADFG	IPHC	NMFS	Total
2010	3,244	5	27,156	30,406
2011	2,592	13	32,555	35,160
2012	2,814	39	22,284	25,137
2013	2,426		19,647	22,072
2014	1,938	6	23,118	25,062
2015	2,432	13	15,920	18,366
2016	2,699		22,256	24,955
2017	2,584	14	22,548	25,145

	ADFG		IPHC
Year	Large-Mesh Trawl Survey	St. Matthews Crab Survey	IPHC Annual Longline Survey
2011	2,592		13
2012	2,814		39
2013	2,426		
2014	1,938		6
2015	2,432		13
2016	2,699		
2017	2,583	1	14

	NMFS									
Year	Aleutian Island Bottom Trawl Survey	Aleutian Islands Cooperative Acoustic Survey	Annual Longline Survey	Bering Sea Acoustic Survey	Bering Sea Bottom Trawl Survey	Bering Sea Slope Survey	Eastern Bering Sea Bottom Trawl Survey	Northern Bering Sea Bottom Trawl Survey	Pollock EFP 11-01	Summer EBS Survey with Russia
2011			105				26,921		5,529	
2012	1,082		5			4,479	16,122		552	45
2013			107				19,540			
2014	2,518		22				20,578			
2015			180				15,740			
2016	1,444		6			3,182	17,624			
2017			86				21,792	670		