9. Assessment of the flathead sole-Bering flounder stock complex in the Bering Sea and Aleutian Islands

Cole C. Monnahan[1] and Rebecca Haehn[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. Final 2018 and 2019 catch biomasses and 2020 catch biomass through October 26, 2020 were added to the model
2. 2018-2019 fishery age composition data were added
3. 2020 fishery length composition data were added to the model.
4. 2019 Eastern Bering Sea shelf survey biomass was added to the linear regression used to determine estimates of AI survey biomass in years when no AI survey occurred; this updated survey biomass index was added to the assessment model for 1982-2019.
5. 1999 and 2018-2019 survey age composition data were added to the model.
6. 2019 survey length composition data were added to the model
7. Survey ages 1-2 were added to the model, and survey ages for Bering flounder were removed, both of which were mistakes in the previous assessment.

Summary of Changes in Assessment Methodology

No new models were considered this year. The previously accepted model 18.2c was updated with new data and is referred to as 18.2c (2020).

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 2019 update assessment (McGilliard et al. 2019) in the table below.

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2020	2021	2021*	2022*
M (natural mortality rate)	0.2	0.2	0.2	0.2
Tier	3a	3a	3a	3a
Projected total (3+) biomass (t)	684,768	692,915	602,497	608,576
Projected Female spawning biomass (t)	154,195	160,864	150,433	154,906
$B_{100\%}$	212,060	212,060	203,658	203,658
$B_{40\%}$	84,824	84,824	81,463	81,463
$B_{35\%}$	74,221	74,221	71,280	71,280
F_{OFL}	0.47	0.47	0.46	0.46
$maxF_{ABC}$	0.38	0.38	0.37	0.37
F_{ABC}	0.38	0.38	0.37	0.37
OFL (t)	82,810	86,432	75,863	77,763
maxABC (t)	68,134	71,079	62,567	64,119
ABC (t)	68,134	71,079	62,567	64,119
Status	As determined *last* year for:		As determined *this* year for:	
	2018	2019	2019	2020
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 8,669 t used in place of maximum permissible ABC for 2020 and 11,519 t used in place of maximum permissible ABC for 2021 and 2022. The final catch for 2020 was estimated by taking the average tons caught between October 26 and December 31 over the previous 5 years (2015-2019) and adding this average amount to the catch-to-date as of October 26, 2020. The 2021 and 2022 catch was estimated as the average of the total catch in each of the last 5 years (2015-2019).

Responses to SSC and Plan Team Comments on Assessments in General

From the October 2019 SSC minutes: ***"****The SSC recommends the authors complete the risk table and note important concerns or issues associated with completing the table".*

The risk table was added to this assessment for the first time this year, as 2019 was a partial assessment. No important concerns or issues were identified, so no reduction from maxABC is recommended.

From the September 2019 Joint and BSAI Plan Team minutes: *"The Teams recommend that each author have discretion to use the proposed systematization presented here as a tool to assist them in filling out the risk table."*

The authors filled out the required risk table, but did not use the proposed systematization.

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

From the December 2018 SSC minutes: *The author notes that average summer bottom temperature may not be adequate to describe the relationship among the environmental drivers of flathead sole stock distribution and behavior. The SSC recommends that this continue to be explored.*

No exploration of environmental drivers were done this year.

The SSC recommends the author investigate Northern Bering Sea survey data for Bering flounder, in particular.

Use of the Northern Bering Sea survey data was not investigated this year.

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 apart 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 2010-2019 (13,652 t), after the implementation of Amendment 80, was substantially smaller than that from the 1988-2007 period. The catch in 2019 was 15,858 t and the catch-to-date in 2020 (as of October 26, 2020) was 8,556 t. On average, approximately 0.60% of the catch in each year (1992-2020) was identified as Bering flounder. A maximum in the proportion of the catch that was found to be Bering flounder was 6.7% occurring in 1980 (Table 9.1).

The majority of the catch was taken by non-pelagic trawl gear (78% on average from 1992-2020) and pelagic trawl gear (20% on average from 1992-2020; Table 9.3). In addition, almost all of the catch was taken from NMFS statistical areas 509, 513, 517, and 521 in each year; 13%, 23%, 9%, and 45% of the catch was taken in each of these four reporting areas, respectively, in 2020 (as of October 26, 2020; 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	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	1982-2019
	Age composition, included as conditional age at length	Flathead sole only	1982, 1985, 1992-1995, 1999-2019
	Length composition	Flathead sole only	1982-2019
U.S. trawl fisheries	Catch (Bering Sea and Aleutian Islands; pelagic and non-pelagic trawl[2])	Flathead sole and Bering flounder combined	1977-2020
	Age composition (Bering Sea only; non-pelagic trawl only)	Flathead sole only	2000, 2001, 2004-2007, 2009-2019
	Length composition (Bering Sea only; non-pelagic trawl only)	Flathead sole only	1977-1999, 2002-2003, 2008, 2020
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 26, 2020 (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 2009-2019 were included in the assessment model (Figure 9.2 and Table 9.7). 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). 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 2020 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 2019, 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. 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, and 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 2019 estimate was 604,445 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 had 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 the 2018 assessment, and is not included here either. 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℃ 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℃).

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. Survey ages for 1982, 1985, 1992-1995, and 2000-2019 were used. Survey size composition data were available for 1982-2018, and used in all years because the conditional age-at-length approach prevents double counting the data. A maximum age (plus group) of 20, and lengths were binned using 2 cm size bins, from 6 cm to 58 cm. Figures 9.6 and 9.7 show length-at-age data for flathead sole by sex, cohort, and year from the EBS shelf survey.

The input model data file containing processed fishery and survey data is available at https://archive.fisheries.noaa.gov/afsc/refm/stocks/plan_team/2020/BSAIflathead.dat.

Analytical approach

General Model Structure

Beginning in 2018 models were conducted using the SS3 and r4ss frameworks (Methot and Wetzel 2013, Taylor et al. 2018, R Core Team 2020); the SS3 framework is coded in AD Model Builder (Fournier et al. 2012). SS3 is a flexible, sex- and age-structured integrated modeling platform that allows for rapid exploration of alternative model structures. A detailed control input file is available at https://archive.fisheries.noaa.gov/afsc/refm/stocks/plan_team/2020/BSAIflathead.ctl.

Extensive model exploration and new data sources were added in the 2018 assessment, and we refer the reader to that SAFE for more details (McGilliard *et al*. 2018). Briefly, foreign reported catches (1964-1987) were added and catch prior to 1964 was set to the average of the catches from 1964-1977. Based on CIE review feedback about uncertainty in initial age structure, an early period of recruitment deviations for age-0 recruits was estimated separately for the years 1963-1972, in addition to the main period of age 0 recruitment deviations from 1973 onward, each subject to a sum-to-zero constraint. Recruitment in 2017-2020 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 is age-based and sex-specific, using a double-normal selectivity curve configured to approximate a logistic curve. Fishery selectivity is logistic, length-based and sex-specific because previous assessments showed a persistent pattern in residuals for males. A separate fishery selectivity curves is estimated for the period 1964-1987 when management of the BSAI flatfish fishery shifted significantly.

Sex-specific growth is estimated internally via the von-Bertalanffy growth curve and the CVs in length-at-age defining the age-length transition matrix using data on age within each length bin (a conditional age-at-length approach; e.g., Lee et al. 2019). 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. It also allows the use of the survey marginal length compositions in years with ages.

The number of hauls were used as the initial 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 correlated 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 composition data were then weighted with the Francis (2011) method, 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.

Description of Alternative Models

There were no alternative models considered in 2020. The 2018 accepted model, 18.2c, was run with updated data through 2020 and labeled 18.2c (2020).

Parameters estimated outside the assessment model

The survey catchability, time- and age-invariant natural mortality for females and males, 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). 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

Recruitment

The log of unfished recruitment (R_0), log-scale recruitment deviations for an early period (1963-1972) and a main period (1973-2016) were estimated. A 1:1 sex ratio is assumed.

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.

Selectivity and fishing mortality

Survey selectivity parameters were estimated using age-based, sex-specific, asymptotic curves that were time-invariant and are listed in the table below. The double-normal curve was used to easily allow previous and future explorations of alternative survey selectivity forms. Here the double-normal curve is constrained to mimic a logistic shape because 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). Separate fishery selectivity curves were estimated for 2 distinct time periods (1964-1987 and 1988-present). Finally, annual fishing mortality rates were estimated (1964-2020).

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 McGilliard et al. (2018).

Results

Model Evaluation

Model Comparison of updates from 2018

Figures 9.8-9.12 shows that Models 18.2c and 18.2c (2020) have very similar spawning biomass, survey biomass, recruitment, fishing mortality, and stock status. Estimated growth curves were also very similar (Table 9.13; Figure 9.13, 9.14). The results are similar in expectation and uncertainty, corroborating the stable nature of the model to data and configurations found previously (McGilliard et al. 2018).

Results for the recommended model: Model 18.2c (2020)

Individual parameter estimates for Models 18.2c and 18.2c (2020) are shown in Table 9.13-Table 9.17.

Biomass trend
Figure 9.9b shows that fits to the survey biomass index for Model 18.c (2020) 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.

Spawning biomass was at a low in 1983 of 81,882 t, reached a peak in 1998 of 225,332 t, and decreased to a current spawning biomass of 148,077 t in 2020 (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).

Fishing mortality and SPR

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 0.115, and remained between 0.06 and 0.09 in the 1990s and early 2000's. Fishing mortality reached another peak of approximately 0.121 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.

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 was new in the 2018 model 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).

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 (2020) 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). 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.

Growth
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, which show no concerning patterns.

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 (McGilliard et al. 2018). Briefly, the previous authors tested more flexible selectivity patterns, a four-parameter growth curve, more complexity in CV in length at age, alternative and data weighting schemes, but none of these tests improved the residual patterns found here.

One last, untested hypothesis is that the data do not fully characterize the variability in length at age for this stock. That is, the distribution of lengths for the fish with otoliths collected does not match the length distribution of all fish sampled. This hypothesis was not explored here but could be in future assessments.

We note that in the 2018 assessment some compositions for Bering flounder were included by accident. We removed them here but this did not improve this particular issue fitting to the length compositions.

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 Figures 9.22 and 9.23. 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. Previous assessments had moderate retrospective patterns, but they were largely eliminated in the 2018 assessment (McGilliard et al. 2018).

The retrospective model estimates for Model 18.2c (2020), including spawning biomass, recruitment, and apical fishing mortality are shown in Figure 9.39. Estimates of spawning biomass and fishing mortality for the retrospective runs were very similar to one another, while 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, complicating the interpretation of the retrospective pattern for recruitment. The Mohn's ρ for Model 18.2c (2020) were:

Spawning Biomass	Recruitment	Fishing Mortality
-0.046	-0.283	0.068

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, but outside them 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

Amendment 56 Reference Points

This stock complex is managed as a Tier 3a stock. The following table shows the reference points calculated for the 2020 assessment.

SSB 2021	150,433
$B_{40\%}$	81,463
$F_{40\%}$	0.37
max$Fabc$	0.37
$B_{35\%}$	71,280
$F_{35\%}$	0.46
F_{OFL}	0.46

Specification of OFL and Maximum Permissible ABC

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 1980-2019 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 $F_{35\%}$.

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 8,669 t in 2020 and 11,519 t for 2021 and 2022 used in place of maximum permissible ABC. The final catch for 2020 was estimated by taking the average tons caught between October 26 and December 31 over the previous 5 years (2015-2019) and adding this average amount to the catch-to-date as of October 26, 2020, and the catch for 2021 and 2022 was taken as the average catch over the last 5 years (2015-2019). Total catch for all subsequent years was assumed equal to the catch associated with the respective harvest scenario. The projection was 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 2021, 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 2021 recommended in the assessment to the *max*F_{ABC} for 2021. (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 2016-2020 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 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 2033 under this scenario, then the stock is not approaching an overfished condition.)

Results of these projections are given in Tables 9.20-9.22.

Risk Table and ABC Recommendation

Overview

The following template is used to complete the risk table:

	Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
Level 1: Normal	Typical to moderately increased uncertainty/minor unresolved issues in assessment.	Stock trends are typical for the stock; recent recruitment is within normal range.	No apparent environmental/ecosystem concerns	No apparent fishery/resource-use performance and/or behavior concerns
Level 2: Substantially increased concerns	Substantially increased assessment uncertainty/ unresolved issues.	Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.	Some indicators showing adverse signals relevant to the stock but the pattern is not consistent across all indicators.	Some indicators showing adverse signals but the pattern is not consistent across all indicators
Level 3: Major Concern	Major problems with the stock assessment; very poor fits to data; high level of uncertainty; strong retrospective bias.	Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns.	Multiple indicators showing consistent adverse signals a) across the same trophic level as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock)	Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types
Level 4: Extreme concern	Severe problems with the stock assessment; severe	Stock trends are unprecedented; More rapid changes	Extreme anomalies in multiple ecosystem indicators that are highly	Extreme anomalies in multiple

	retrospective bias. Assessment considered unreliable.	in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	likely to impact the stock; Potential for cascading effects on other ecosystem components	performance indicators that are highly likely to impact the stock

The table is applied by evaluating the severity of four types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. These considerations are stock assessment considerations, population dynamics considerations, environmental/ecosystem considerations, and fishery performance. Examples of the types of concerns that might be relevant include the following:

1. Assessment considerations—data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data; model fits: poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs; model performance: poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds; estimation uncertainty: poorly-estimated but influential year classes; retrospective bias in biomass estimates.

2. Population dynamics considerations—decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.

3. Environmental/ecosystem considerations—adverse trends in environmental/ecosystem indicators, ecosystem model results, decreases in ecosystem productivity, decreases in prey abundance or availability, increases or increases in predator abundance or productivity.

4. Fishery performance—fishery CPUE is showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in the duration of fishery openings.

Assessment considerations
Overall, the model fits all the data sets very well. Both the survey index, and survey and fishery composition data show no concerning patterns. All parameters were well estimated, without any convergence issues. Adding the new data had a minimal impact on estimated parameters and management quantities, corroborating the general stability of the model found in previous assessments. There was also no meaningful retrospective pattern. We therefore conclude there are no increased concerns and set this consideration at level 1.

Population dynamics considerations
The spawning stock biomass has been above target for the entire time period for which there are data. It is projected to increase into the near future (based on Scenario 4 projection above) as there have been larger than average cohorts over the past 5 years that will mature. This is already born out in the estimated age 3+ biomass and index, both of which show a general increase since 2015. Since we have no increased concerns we set the concern level to 1.

Environmental/Ecosystem considerations
Environmental processes: Following two years of physical oceanographic perturbations, the eastern Bering Sea experienced a return to near-normal climatic conditions in 2020. Summer bottom temperatures and spatial extent of the cold pool were average based on the ROMS hindcast model and observations

from the 2020 Dyson cruise. However, summer sea surface temperatures through August were above average in the southern and northern Bering Sea, similar to those observed in 2019 (Siddon, 2020).

Based on the OSCURS model, the 2020 springtime drift pattern was mixed, with an early period of favorable winds consistent with eastward drift followed by a period of unfavorable winds consistent with westward drift (Cooper and Wilderbuer, 2020). This drift pattern appears consistent with years when below-average recruitment occurred for flathead sole (FHS).

Prey: The 2020 springtime drift pattern likely retained FHS larvae over the southern middle domain (Cooper and Widerbuer, 2020). In that region, the 2020 spring bloom timing occurred about a week earlier than the long-term mean while production was below the long-term mean (Nielsen et al., 2020). Depending on the spatial and temporal overlap between larvae and available primary production, this can result in a match or mismatch with favorable feeding conditions. Prey resources for adult FHS and Bering flounder include brittle stars (echinoderms), polychaetes, and crustaceans as well as juvenile walleye pollock. Trends in the abundance of motile epifauna remained above the long-term mean in 2019, although decreased 10% from 2018 (Whitehouse, 2019). This indicates sufficient prey availability for adult FHS over the southern Bering Sea shelf. Recent years of pollock recruitment were low, but the 2018 year class appears strong (as age-1 in 2019 assessment; Ianelli et al., 2019), therefore juvenile pollock may have been an available prey resource for FHS and Bering flounder.

In 2019, FHS condition (as measured by weighted length-weight residuals) was near the historical average over the SEBS shelf with positive residuals over the southern portion of the bottom trawl survey area (strata 10, 30, and 50) and negative residuals over the northwest region (strata 40 and 40) (Rohan and Laman, 2020).

Predators: Predators of FHS include Pacific Cod, pollock, arrowtooth flounder, Greenland turbot, and halibut. In terms of predation pressure on FHS, we focus on biomass trends over the southern Bering Sea shelf. The biomass within the apex predator guild (including Pacific cod, arrowtooth flounder, Greenland turbot, and halibut) increased slightly (2%) from 2018 to 2019 and remains at the long term mean (Whitehouse, 2019). Pacific cod and arrowtooth flounder are the biomass-dominant components of the guild. Pacific cod biomass has decreased since 2015 and is below its long term mean. In 2019, the biomass of Pacific cod in the standard bottom trawl survey area increased slightly (2%) while the abundance increased dramatically (112%) from 2018. This indicates strong recruitment of age-1 fish. Depending on the eventual year class strength of the 2018 Pacific cod cohort, this could present increased predation risk to FHS in the future. arrowtooth flounder biomass increased 13% from 2018 to 2019.

The biomass of pelagic foragers, dominated by pollock, increased from 2018 to 2019, but remains below the long term mean (Whitehouse, 2019). However, the biomass of pollock increased 75% from 2018 and indicates movement of adult pollock into the region that could present predation risk to FHS (Ianelli et al., 2019).

Competitors for FHS prey resources include other benthic foragers, like northern rock sole and yellowfin sole. The trend in biomass of the benthic foragers guild has been declining since approximately 2010 and remained below the long term mean in 2019 (Whitehouse, 2019), suggesting a reduction in prey competition that is supported by the positive length-weight residuals over the southern shelf (strata 10, 30, and 50).

Together, the most recent data available suggest there are no apparent ecosystem concerns, although predation pressure may be rising – level 1.

Fishery performance

There is no ESP for this stock complex, but we note that the fishery has consistently caught only a small fraction of the ABC (average 16% over last 5 years). We did not examine CPUE trends nor spatial patterns of fishing. There are no changes in the duration of fishing openings. Altogether, we see no cause for concern and give this consideration a level 1 as well.

Summary and ABC recommendation

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ ecosystem considerations*	*Fishery Performance considerations*
Level 1: no increased concerns	Level 1: no increased concerns	Level 1: no increased concerns	Level 1: no increased concerns

Since we rated all four considerations at level 1, we do not believe a reduction from maxABC is warranted.

Status Determination

The stock is not being subjected to overfishing, because the catch in 2019 (15,858 t) is less than the 2019 OFL (80,918 t). The results of scenarios 6 and 7 above 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 146,307 t, which is higher than *B35%* (71,280 t), so the stock is not currently overfished. The expected spawning stock size in the year 2033 of scenario 7 (76,046 t) is greater than *B35%*; thus, the stock is not approaching an overfished condition. The *F* that would have produced a catch for last year equal to last year's OFL was *F*=0.495.

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). 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 2020, the flathead sole fishery in the BSAI contributed 0-12% 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 21% of *Opilio* tanner (snow) crab and 24% of *Bairdi* tanner crab in 2020.

Table 9.26 shows that the proportion of BSAI halibut mortality as PSC that occurred in the directed flathead sole fishery was at 8% in 2019 and 2.5% in 2020 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. The VAST software package (Thorson and Barnett 2017) is a promising avenue because it provides sophisticated capabilities to explore such relationships, and has already been used to explore the effect of the cold pool on the distribution of EBS species (Thorson 2019).

In addition, it is thought that some mis-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).

Literature Cited

Aydin, K., S. Gaichas, I. Ortiz, D. Kinzey, and N. Friday. 2007. A comparison of the Bering Sea, Gulf of Alaska, and Aleutian Islands large marine ecosystems through food web modeling. NOAA Tech. Memo. NMFS-AFSC-178. 298 p.

Cooper, D. and Wilderbuer, T. (2020). Update on Eastern Bering Sea Winter Spawning Flatfish Recruitment and Wind Forcing. In: E.C. Siddon, 2020. Ecosystem Status Report 2020: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501

Fournier, D.A., Skaug, H.J., Ancheta, J., Ianelli, J., Magnusson, A., Maunder, M.N., Nielsen, A., and Sibert, J. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

Francis, R. I. C. C. (2011). Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Sciences, 68, 1124-1138.

Haflinger, K. 1981. A survey of benthic infaunal communities of the southeastern Bering Sea shelf. In D.W Hood and J.A. Calder (eds), The eastern Bering Sea shelf: oceanography and resources. Univ. of Wash. Press, Seattle, pp 1091-1104.

Hart, J.L. 1973. Pacific fishes of Canada. Canadian Government Publishing Centre, Supply and Services Canada, Ottawa, Canada KIA OS9.

Ianelli, J., Kotwicki, S., Honkalehto, T., Holsman, K., and Fissel, B. 2017. 1. Assessment of the Walleye Pollock Stock in the Eastern Bering Sea. In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Region, p. 55-184. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

Ianelli, J., B. Fissel, K. Holsman, T. Honkalehto, S. Kotwicki, C. Monnahan, E. Siddon, S. Stienessen, and J. Thorson (2019). Assessment of the Walleye Pollock Stock in the Eastern Bering Sea. In: Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions. Report, North Pacific Fishery Management Council.

Lee, H., K.R. Piner, I.G. Taylor, T. Kitakado (2019). On the use of conditional age at length data as a likelihood component in integrated population dynamics models. Fisheries Research. 216: 204-211. https://doi.org/10.1016/j.fishres.2019.04.007

Livingston, P.A., A. Ward, G.M. Lang, and M-S. Yang. 1993. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1987 to 1989. U.S. Dep. Commer. NOAA Tech. Memo. NMFS-AFSC-11. 192 pp.

McConnaughy, R.A. and K.R. Smith. 2000. Associations between flatfish abundance and surficial sediments in the eastern Bering Sea. Can J. Fish. Aquat. Sci. 2410-2419.

McGilliard, C.R., D. Nichol, and L. Britt. 2019. 9. Assessment of the Flathead Sole-Bering flounder Stock in the Bering Sea and Aleutian Islands. In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Region, p. 855-860. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

McGilliard, C.R., Nichol, D., and Palsson, W. 2018. 9. Assessment of the Flathead Sole-Bering flounder Stock in the Bering Sea and Aleutian Islands. In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Region, p. 1229-1318. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

McGilliard, C.R., Stockhausen, W., Nichol, D., and Palsson, W. 2016. 9. Assessment of the Flathead Sole-Bering flounder Stock in the Bering Sea and Aleutian Islands. In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Region, p. 1229-1318. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

McGilliard, C.R., Nichol, D., and Palsson, W., Stockhausen, W. 2014. 9. Assessment of the Flathead Sole-Bering flounder Stock in the Bering Sea and Aleutian Islands. In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Region, p. 1151-1258. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

Methot. R.D. and Wetzel, C. 2013. Stock Synthesis: a biological and statistical framework for fish stock assessment. Fisheries Research. 142: 86-99.

Nielsen, J.M., Eisner, L., Watson, J., Gann, J.C., Mordy, C.W., Bell, S.W., Harpold, C., Crouser, D., and Stabeno, P. (2020). Spring satellite chlorophyll-a concentrations in the Eastern Bering Sea. In: E.C. Siddon, 2020. Ecosystem Status Report 2020: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501

Ormseth, O.A. 2017. Assessment of the skate stock complex in the Eastern Bering Sea and Aleutian Islands Area. In Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 1045-1054. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Ormseth, O.A. 2016. Assessment of the skate stock complex in the Eastern Bering Sea and Aleutian Islands Area. In Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 1769-1868. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Pennington, M., and Volstad, J.H. 1994. Assessing the effect of intra-haul correlation and variable density on estimates of population characteristics from marine surveys. Biometrics. 50: 725-732.

Punt, A.E., Smith, D.C., Krusic-Golub, K., Robertson, S. 2008. Quantifying age-reading error for use in fisheries stock assessments, with application to species in Australia's southern and eastern scalefish and shark fishery. Can. J. Fish. Aquat. Sci. 65(9): 1991-2005.

R Core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Rohan, S., and Laman, N., 2020. Eastern and Northern Bering Sea Groundfish Condition. In Siddon, E.C., 2020. Ecosystem Status Report 2020: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501

Siddon, E.C., 2020. Ecosystem Status Report 2020: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501

Spencer, P.D., Walters, G. E., and T. K. Wilderbuer. 2004. Flathead sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 2005, p.515-616. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

Stark, J.W. 2004. A comparison of the maturation and growth of female flathead sole in the central Gulf of Alaska and south-eastern Bering Sea. J. Fish. Biol. 64:876-889.

Stark, J. W. 2011. Contrasting the maturation, growth, spatial distribution and vulnerability to environmental warming of Hippoglossoides robustus (Bering flounder) with H. elassodon (flathead sole) in the eastern Bering Sea. Marine Biology Research. 7:778-785.

Stockhausen, W.T., D. Nichol, R. Lauth and M. Wilkins. 2010. Assessment of the Flathead sole Stock in the Bering Sea and Aleutian Islands. In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Region. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

Stockhausen, W.T., and D. Nichol. 2011. Assessment of the Flathead sole Stock in the Bering Sea and Aleutian Islands. In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Region. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

Stockhausen, W.T., and D. Nichol. 2012. Assessment of the Flathead sole Stock in the Bering Sea and Aleutian Islands. In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Region. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

Taylor, I.G., Ian J. Stewart, Allan C. Hicks, Tommy M. Garrison, Andre E. Punt, John R. Wallace, Chantel R. Wetzel, James T. Thorson,Yukio Takeuchi, Kotaro Ono, Cole C. Monnahan, Christine C. Stawitz, Z. Teresa A'mar, Athol R. Whitten, Kelli F. Johnson, Robbie L. Emmet, Sean C. Anderson, Gwladys I. Lambert, Megan M. Stachura, Andrew B. Cooper, Andi Stephens, Neil L. Klaer and Carey R. McGilliard (2018). r4ss: R Code for Stock Synthesis. R package version 1.32.1. https://github.com/r4ss

Thompson, G. G., and R. R. Lauth. 2017. Assessment of the Pacific cod stock in the Eastern Bering Sea and Aleutian Islands Area. In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Region. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

Thorson, J.T. 2019. Measuring the impact of oceanographic indices on species distribution shifts: The spatially varying effect of cold-pool extent in the eastern Bering Sea. Limnology and Oceanography, 64(6), pp.2632-2645.

Thorson, J.T. and Barnett, L.A., 2017. Comparing estimates of abundance trends and distribution shifts using single-and multispecies models of fishes and biogenic habitat. ICES Journal of Marine Science, 74(5), pp.1311-1321.

Walters, G.E., and T.K. Wilderbuer. 1997. Flathead sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 1998, p.271-295. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

Wilderbuer, T.K., A.B. Hollowed, W.J. Ingraham, Jr., P.D. Spencer, M.E. Conners, N.A. Bond and G.E. Walters. 2002. Flatfish recruitment response to decadal climatic variability and ocean conditions in the eastern Bering Sea. Progress in Oceanography. 55:235-247.

Whitehouse, G.A. (2019). 2019 Report Card. In Siddon, E., and Zador, S., 2019. Ecosystem Status Report 2019: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

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 26, 2020. 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	20,127	20,101	26
2011	13,558	13,538	20
2012	11,368	11,362	6
2013	17,355	17,275	80
2014	16,512	16,479	33
2015	11,308	11,274	33
2016	10,313	10,301	12
2017	9,111	9,108	3
2018	11,007	11,001	5
2019	15,858	15,857	1
2020*	8,556	8,554	2

*2020 catches are current as of October 26, 2020

Table 9.2. Combined catch (t) of flathead sole and Bering flounder (Hippoglossoides spp.) in the Bering Sea and Aleutian Islands as of October 26 2020.

Year	Total	non-CDQ	CDQ	Proportion CDQ
1995	14,715	112	14,603	0.01
1996	17,346	126	17,220	0.01
1997	20,683	34	20,649	0.00
1998	24,387	0	24,387	0.00
1999	18,573	729	17,844	0.04
2000	20,441	457	19,984	0.02
2001	17,811	223	17,588	0.01
2002	15,575	464	15,111	0.03
2003	13,785	0	13,785	0.00
2004	17,398	545	16,853	0.03
2005	16,108	891	15,217	0.06
2006	17,981	405	17,576	0.02
2007	18,958	1,071	17,887	0.06
2008	24,540	500	24,040	0.02
2009	19,558	508	19,050	0.03
2010	20,127	943	19,184	0.05
2011	13,558	674	12,884	0.05
2012	11,368	507	10,861	0.04
2013	17,355	697	16,657	0.04
2014	16,512	726	15,786	0.04
2015	11,308	596	10,712	0.05
2016	10,313	594	9,719	0.06
2017	9,111	582	8,529	0.06
2018	11,007	999	10,007	0.09
2019	15,858	680	15,178	0.04
2020	8,556	438	8,117	0.05

Table 9.3. Proportion of combined catch of flathead sole and Bering flounder (Hippoglossoides spp.) by gear type in recent years, as calculated from observer data. 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 2020 are current as of October 26, 2020.

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	0.89	0.08	0.00	0.00	0.00	0.02
2019	0.92	0.06	0.00	0.00	0.00	0.02
2020	0.74	0.22	0.00	0.00	0.00	0.04

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. Catches in 2020 are through 10/26/2020.

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	0.11	0.00	0.45	0.03	0.01	0.12	0.00	0.01	0.14	0.00	0.14	0.00	0.00	0.00
2019	0.00	0.09	0.00	0.50	0.02	0.01	0.07	0.00	0.00	0.20	0.01	0.10	0.00	0.00	0.00
2020	0.00	0.13	0.00	0.23	0.01	0.02	0.09	0.00	0.00	0.45	0.02	0.05	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
Pot Gear	All	Bycatch	1-Jan-15
Trawl 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
Hook and Line Gear	All	Bycatch	1-Jan-17
Jig Gear	All	Bycatch	1-Jan-17
Pot Gear	All	Bycatch	1-Jan-17
Trawl Gear	All	Bycatch	1-Jan-17
Trawl Gear	AM 80	Bycatch	1-Jan-17
Hook and Line Gear	CDQ	Open	1-Jan-17
Jig Gear	CDQ	Open	1-Jan-17
Pot 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
Hook and Line Gear	All	Bycatch	1-Jan-18
Jig Gear	All	Bycatch	1-Jan-18
Pot Gear	All	Bycatch	1-Jan-18
Trawl Gear	All	Bycatch	1-Jan-18
Trawl Gear	AM 80	Bycatch	1-Jan-18
Hook and Line Gear	CDQ	Open	1-Jan-18
Jig Gear	CDQ	Open	1-Jan-18
Pot 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
Hook and Line Gear	All	Bycatch	1-Jan-19
Jig Gear	All	Bycatch	1-Jan-19
Pot Gear	All	Bycatch	1-Jan-19
Trawl Gear	All	Bycatch	1-Jan-19
Trawl Gear	AM 80	Bycatch	1-Jan-19
Hook and Line Gear	CDQ	Open	1-Jan-19
Jig Gear	CDQ	Open	1-Jan-19
Pot Gear	CDQ	Open	1-Jan-19
Trawl Gear	CDQ	Bycatch	1-Jan-19
Trawl Gear	AM 80	Open	20-Jan-19
Trawl Gear	CDQ	Open	20-Jan-19
Hook and Line Gear	All	Bycatch	1-Jan-20
Jig Gear	All	Bycatch	1-Jan-20
Pot Gear	All	Bycatch	1-Jan-20
Trawl Gear	All	Bycatch	1-Jan-20
Trawl Gear	AM 80	Bycatch	1-Jan-20
Hook and Line Gear	CDQ	Open	1-Jan-20
Jig Gear	CDQ	Open	1-Jan-20
Pot Gear	CDQ	Open	1-Jan-20
Trawl Gear	CDQ	Bycatch	1-Jan-20
Trawl Gear	AM 80	Open	20-Jan-20
Trawl Gear	CDQ	Open	20-Jan-20

Table 9.6. Retained and discarded catch biomass and catch limits (OFL, ABC, TAC, and OFL) as of October 26, 2020.

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	13,785	9,943	3,842	72%
2004	75,200	61,900	19,000	17,398	11,979	5,420	69%
2005	70,200	58,500	19,500	16,108	12,222	3,886	76%
2006	71,800	59,800	19,500	17,981	13,601	4,380	76%
2007	95,300	79,200	30,000	18,958	13,720	5,238	72%
2008	86,000	71,700	50,000	24,540	22,207	2,332	90%
2009	83,800	71,400	60,000	19,558	17,523	2,034	90%
2010	83,100	69,200	60,000	20,127	18,319	1,808	91%
2011	83,300	69,300	41,548	13,558	11,742	1,816	87%
2012	84,500	70,400	34,134	11,368	9,623	1,744	85%
2013	81,500	67,900	22,699	17,355	15,797	1,558	91%
2014	79,633	66,293	24,500	16,512	15,130	1,382	92%
2015	79,419	66,130	24,250	11,308	10,080	1,228	89%
2016	79,562	66,250	21,000	10,313	9,022	1,291	87%
2017	81,654	68,278	14,500	9,111	8,113	998	89%
2018	79,862	66,773	14,500	11,007	10,217	790	93%
2019	80,918	66,625	14,500	15,858	14,886	972	94%
2020	82,810	68,134	19,500	8,556	7,567	988	88%

*2020 total catch is current as of October 26, 2020

Table 9.7. Sample sizes of fishery lengths measured for flathead sole only from the Bering Sea-Aleutian Islands, excluding 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	1	14	1	8	1	6
1975	34	2,112	33	1,494	34	618
1976	4	124	4	64	4	60
1977	138	8,948	132	4,401	134	4,547
1978	145	10,479	135	5,583	136	4,896
1979	218	17,756	218	9,745	206	8,011
1980	90	9,656	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	2,928	42	1,622	43	1,306
1984	56	5,684	55	3,522	56	2,162
1985	152	7,172	144	4,067	140	3,105
1986	55	714	48	391	43	323
1987	40	4,075	40	1,697	40	2,378
1988	166	15,083	160	6,612	160	8,471
1989	140	10,216	140	5,754	137	4,462
1990	72	4,870	72	2,434	70	2,436
1991	69	7,676	69	2,962	69	4,714
1992	10	910	10	381	10	529
1993	59	4,829	59	2,646	59	2,183
1994	98	7,728	97	3,392	98	4,336
1995	127	10,227	127	5,464	127	4,763
1996	241	14,129	240	7,075	241	7,054
1997	151	11,776	150	6,388	150	5,388
1998	392	29,671	391	14,573	392	15,098
1999	845	18,643	841	9,325	838	9,318
2000	2,437	20,077	2,305	11,254	2,139	8,823
2001	1,671	12,800	1,589	6,998	1,391	5,802
2002	1,124	10,574	1,052	5,270	982	5,304
2003	1,002	10,369	973	5,509	922	4,860
2004	1,499	17,595	1,449	8,380	1,383	9,215
2005	1,065	13,304	1,031	6,645	986	6,659
2006	1,216	13,784	1,163	6,447	1,132	7,337
2007	1,022	10,713	987	5,019	930	5,694
2008	4,164	39,394	3,973	19,685	3,717	19,709
2009	3,102	28,899	2,905	14,824	2,782	14,075
2010	2,658	21,971	2,481	11,150	2,368	10,821
2011	2,473	15,732	2,276	8,646	1,996	7,086
2012	2,262	14,993	2,032	8,764	1,743	6,229

2013	3,090	23,960	2,870	13,363	2,517	10,597
2014	2,631	22,687	2,436	12,035	2,204	10,652
2015	2,605	17,720	2,363	9,782	2,127	7,938
2016	3,110	20,341	2,892	11,451	2,676	8,890
2017	2,037	13,850	1,824	7,040	1,748	6,810
2018	2,407	16,093	2,252	8,647	2,113	7,446
2019	3,547	27,558	3,338	14,196	3,110	13,362
2020	1,002	8,763	947	5,159	829	3,604

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	539	546
2007	170	437	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	433	731	755
2019	531	835	1178

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	1213.1	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	5244.9	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	0.08			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	6938.8	0.20	546,010	0.08	518,380	0.08	27,630	0.22	2.70
1992	628,857	0.10			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	9934.9	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	11554.4	0.24	783,909	0.21	769,783	0.22	14,126	0.19	2.74
1998	695,296	0.20			683,627	0.21	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	8906.3	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	0.17	9897.6	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	0.08	13297.8	0.14	612,289	0.09	604,186	0.09	8,103	0.31	3.39
2005	622,883	0.08			612,467	0.09	605,350	0.09	7,116	0.28	3.47
2006	644,948	0.09	9664.5	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	11811.6	0.31	495,235	0.15	488,626	0.15	6,610	0.16	1.53
2011	593,203	0.18			583,300	0.19	576,498	0.19	6,802	0.15	2.47
2012	387,043	0.11	5565.8	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	0.13	13435.9	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	6759.1	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	6930	0.12	488,415	0.08	484,890	0.08	3,524	0.16	4.26
2019	604,445	0.14			594,348	0.14	592,257	0.14	2,092	0.33	4.53

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**	**Total Lengths**	**Males**	**Females**	**Hauls with Otoliths**	**Hauls with Ages**	**Otoliths Collected**	**Total Ages**	**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	18	420	413	187	226
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	256	766	757	352	397
2019	356	312	19,779	9,144	9,626	254	254	759	753	365	386

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
18.2c	0.06	0.33	0.14	0.15
18.2c (2020)	0.06	0.34	0.12	0.28

Table 9.12. 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 18.2c		**Model 18.2c (2020)**	
Parameter	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Length at age 3 (f)	14.24	0.30	14.26	0.19
Length at age 21 (f)	44.56	0.38	44.88	0.38
von Bertalanffy k (f)	0.14	0.01	0.14	0.01
CV in length at age 3 (f)	0.12	0.01	0.11	0.01
CV in length at age 21 (f)	0.09	0.01	0.08	0.01
Length at age 3 (m)	13.93	0.34	14.09	0.34
Length at age 21 (m)	37.06	0.26	37.57	0.26
von Bertalanffy k (m)	0.22	0.01	0.22	0.01
CV in length at age 3 (m)	0.14	0.01	0.12	0.01
CV in length at age 21 (m)	0.08	0.00	0.07	0.00

Table 9.13. Comparison of estimates of the log of R0 and initial fishing mortality.

	Model 18.2c		**Model 18.2c (2020)**	
Parameter	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
ln(R0)	13.786	0.028	13.773	0.025
Initial F	0.024	0.002	0.024	0.001

Table 9.14. Parameter estimates for parameters estimated within the assessment model and corresponding standard deviations from the inverse Hessian for Models 18.2c and 18.c (2020).

		Current Selectivity (1988-present)				**Past Selectivity (1964-1987)**			
		Model 18.2c		Model 18.2c (2020)		Model 18.2c		Model 18.2c (2020)	
		Est	Std	Est	Std	Est	Std	Est	Std
Fishery	Logistic length at 50% selectivity (f)	38.09	0.79	38.29	0.82	23.59	2.19	23.33	2.10
	Logistic slope (f)	7.91	0.67	8.33	0.67	6.93	2.38	6.71	2.30
	Male offset length at 50% selectivity	-2.96	0.51	-2.76	0.50	0.72	2.50	0.93	2.41
	Male offset slope (m)	-0.46	0.71	-0.34	0.70	0.71	3.18	0.86	3.07
Survey	Peak: beginning size for the plateau (f)	7.53	0.34	6.70	0.25				
	Ascending width (f; ln)	2.34	0.14	2.03	2.34	As for current survey selectivity			
	Male peak offset	-0.9	0.36	-0.77	0.28				
	Male ascending width offset (ln)	-0.32	0.18	-0.31	0.16				

Table 9.15. Estimated recruitment deviations with corresponding standard deviations. Recruitment deviations were fixed to 0 after 2016.

Year	Recruitment Deviations	Std	Year	Recruitment Deviations	Std
1964	-0.799	0.371	1993	-0.168	0.286
1965	-0.848	0.365	1994	-0.247	0.274
1966	-0.883	0.361	1995	-0.177	0.233
1967	-0.890	0.358	1996	0.154	0.185
1968	-0.857	0.356	1997	0.153	0.196
1969	-0.783	0.354	1998	0.153	0.191
1970	-0.715	0.348	1999	-0.106	0.200
1971	-0.731	0.342	2000	-0.189	0.211
1972	-0.780	0.337	2001	0.146	0.174
1973	-0.908	0.353	2002	0.299	0.154
1974	-0.669	0.350	2003	0.603	0.117
1975	-0.429	0.338	2004	-0.940	0.287
1976	-0.395	0.332	2005	0.033	0.151
1977	-0.463	0.331	2006	-0.174	0.169
1978	-0.093	0.249	2007	-0.537	0.193
1979	0.044	0.224	2008	-0.299	0.168
1980	0.158	0.239	2009	-0.297	0.162
1981	0.944	0.152	2010	-0.673	0.213
1982	0.090	0.267	2011	0.647	0.111
1983	-0.063	0.326	2012	-0.482	0.260
1984	0.299	0.308	2013	0.364	0.170
1985	0.835	0.209	2014	0.166	0.234
1986	-0.020	0.388	2015	1.047	0.181
1987	0.945	0.155	2016	0.055	0.337
1988	-0.436	0.346	2017	0	_
1989	0.134	0.225	2018	0	_
1990	0.231	0.212	2019	0	_
1991	0.083	0.227	2020	0	_
1992	0.183	0.221			

Table 9.16. Estimated yearly fishing mortality with corresponding standard deviations.

Year	Estimate	StdDev	Year	Estimate	StdDev
1964	0.025	0.001	**1993**	0.061	0.006
1965	0.007	0.000	**1994**	0.072	0.007
1966	0.010	0.001	**1995**	0.059	0.006
1967	0.022	0.001	**1996**	0.067	0.007
1968	0.026	0.001	**1997**	0.079	0.008
1969	0.021	0.001	**1998**	0.094	0.009
1970	0.049	0.002	**1999**	0.073	0.007
1971	0.067	0.004	**2000**	0.082	0.008
1972	0.029	0.002	**2001**	0.073	0.007
1973	0.054	0.003	**2002**	0.066	0.006
1974	0.044	0.003	**2003**	0.060	0.006
1975	0.018	0.001	**2004**	0.078	0.007
1976	0.028	0.002	**2005**	0.074	0.007
1977	0.031	0.002	**2006**	0.085	0.008
1978	0.057	0.004	**2007**	0.091	0.009
1979	0.026	0.002	**2008**	0.121	0.011
1980	0.037	0.003	**2009**	0.098	0.009
1981	0.046	0.004	**2010**	0.102	0.010
1982	0.035	0.003	**2011**	0.068	0.007
1983	0.022	0.002	**2012**	0.057	0.005
1984	0.016	0.001	**2013**	0.087	0.008
1985	0.018	0.002	**2014**	0.084	0.008
1986	0.015	0.001	**2015**	0.059	0.005
1987	0.009	0.001	**2016**	0.055	0.005
1988	0.048	0.005	**2017**	0.049	0.004
1989	0.023	0.002	**2018**	0.060	0.005
1990	0.115	0.012	**2019**	0.087	0.008
1991	0.074	0.008	**2020**	0.046	0.004
1992	0.070	0.007			

Table 9.17. 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.

	Model 18.2c			*Model 18.2c (2020)*		
Year	**Tot B (age 3+)**	**SSB**	**Std**	**Tot B (age 3+)**	**SSB**	**Std**
1964	651,988	179,275	6,668	567,611	182,885	6,164
1965	651,304	179,032	6,664	566,991	182,643	6,159
1966	650,106	182,084	6,676	568,636	185,674	6,166
1967	638,118	184,527	6,679	561,439	188,105	6,165
1968	611,695	184,544	6,657	541,017	188,122	6,146
1969	578,674	183,616	6,622	513,481	187,163	6,113
1970	546,346	183,007	6,575	485,062	186,430	6,067
1971	501,898	175,985	6,506	444,072	179,080	6,002
1972	455,021	164,019	6,549	399,600	166,451	6,034
1973	428,754	156,028	6,820	373,321	157,543	6,261
1974	398,350	142,710	7,236	342,861	143,056	6,620
1975	376,572	130,891	7,577	320,030	130,076	6,908
1976	365,420	123,088	7,749	307,181	121,239	7,040
1977	354,396	115,078	7,737	294,365	112,324	7,015
1978	347,612	108,157	7,584	285,114	104,669	6,875
1979	338,832	100,165	7,307	274,327	96,077	6,637
1980	340,850	96,535	7,014	274,653	91,945	6,391
1981	346,418	92,908	6,663	277,954	87,808	6,093
1982	359,732	89,445	6,273	285,545	83,862	5,752
1983	386,416	87,811	5,876	302,118	81,882	5,395
1984	445,123	88,447	5,476	341,555	82,420	5,036
1985	500,781	91,110	5,089	385,794	85,272	4,690
1986	544,934	95,341	4,765	428,215	89,908	4,384
1987	589,290	102,249	4,580	469,907	97,207	4,178
1988	648,407	113,239	4,615	519,889	108,285	4,140
1989	692,187	127,029	4,889	560,836	121,724	4,289
1990	758,547	146,257	5,371	613,711	140,791	4,645
1991	785,288	160,073	5,882	640,512	154,970	5,116
1992	808,936	173,827	6,272	665,585	169,637	5,530
1993	824,075	185,185	6,412	682,676	181,764	5,726
1994	830,605	197,595	6,504	692,067	194,308	5,843
1995	827,244	209,942	6,685	692,954	206,166	6,012
1996	817,014	222,404	6,879	688,332	217,915	6,197
1997	797,315	230,255	7,031	674,550	224,983	6,357
1998	768,311	231,344	7,131	653,009	225,332	6,459
1999	742,954	226,535	7,131	628,751	219,832	6,460
2000	728,855	222,459	7,099	611,951	215,281	6,417
2001	717,147	216,009	7,037	596,844	208,643	6,352
2002	705,420	209,453	6,917	585,170	202,217	6,246
2003	693,261	202,399	6,714	574,538	195,259	6,069
2004	686,551	196,182	6,482	567,554	188,888	5,850
2005	685,652	190,036	6,283	561,636	182,115	5,649
2006	692,570	187,206	6,174	566,685	178,385	5,519
2007	683,865	184,701	6,102	564,788	175,103	5,437
2008	672,741	181,989	6,061	562,454	172,095	5,395
2009	651,436	175,849	5,982	551,522	166,128	5,341
2010	629,427	173,293	5,949	539,934	163,890	5,317
2011	607,548	172,469	6,009	524,374	163,655	5,361
2012	591,691	175,380	6,159	511,792	168,082	5,495
2013	573,880	177,142	6,304	496,934	172,401	5,661
2014	574,977	172,372	6,345	487,928	170,257	5,748
2015	574,589	165,698	6,295	479,621	165,368	5,730
2016	593,120	160,864	6,218	484,226	161,167	5,649
2017	624,424	156,768	6,160	493,537	156,481	5,537
2018	652,804	154,356	6,153	523,788	152,668	5,432
2019				553,805	149,776	5409
2020				579,131	148,077	5601

Table 9.18. Recruitment (in thousands) and standard deviations about the estimates. Age 0 recruits in 1964 in the table will appear under age 3 recruits in 1967.

Year	Recruits (Age 3)	Recruits (Age 0)	Std. Dev (Age 0)
1964	525,715	407,345	150,781
1965	525,705	387,289	141,212
1966	237,175	373,779	134,678
1967	223,512	370,386	132,338
1968	212,474	382,502	135,914
1969	205,042	411,435	145,084
1970	203,189	439,799	152,420
1971	209,761	432,138	146,765
1972	225,550	411,076	137,259
1973	241,193	361,254	128,909
1974	236,943	458,182	161,213
1975	225,413	582,151	196,057
1976	198,165	601,095	199,260
1977	251,329	561,003	186,091
1978	319,317	811,416	201,087
1979	329,586	929,246	207,563
1980	307,697	1,040,710	250,211
1981	445,018	2,279,570	334,441
1982	509,580	970,035	260,272
1983	570,750	830,960	271,787
1984	1,250,437	1,192,620	369,301
1985	532,179	2,034,650	414,597
1986	455,887	864,019	340,812
1987	654,334	2,265,770	333,243
1988	1,116,413	569,001	199,587
1989	474,153	1,004,990	224,704
1990	1,243,458	1,105,780	233,643
1991	312,266	952,305	216,200
1992	551,538	1,051,680	230,349
1993	606,848	739,007	211,793
1994	522,625	681,879	186,919
1995	577,164	731,088	170,843
1996	405,568	1,015,860	186,677
1997	374,216	1,014,230	198,743
1998	401,221	1,012,890	191,926
1999	557,503	780,752	156,020
2000	556,606	717,481	152,250
2001	555,871	1,002,010	173,633
2002	428,475	1,167,740	179,895
2003	393,753	1,583,420	180,069
2004	549,903	338,190	98,552
2005	640,856	894,896	134,811
2006	868,981	727,532	122,964
2007	185,598	506,160	98,829
2008	491,116	642,228	108,492
2009	399,264	643,181	104,883
2010	277,777	441,825	95,920
2011	352,451	1,653,060	184,231
2012	352,977	534,923	141,673
2013	242,474	1,245,920	216,055
2014	907,198	1,022,210	244,672
2015	293,564	2,467,780	460,404
2016	683,762	952,525	329,099
2017	560,989	958,335	23,911
2018	1,354,324	958,335	23,911
2019	522,747	958,335	23,911
2020	1,354,324	958,335	23,911
Average	494,946	884,777	

Table 9.19. 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
2020	146,307	146,307	146,307	146,307	146,307	146,307	146,307
2021	150,433	150,433	150,433	150,433	150,433	150,433	150,433
2022	154,906	154,906	154,906	154,906	154,906	126,440	132,188
2023	160,138	160,138	160,138	160,138	160,138	111,184	120,168
2024	141,369	141,369	165,473	163,740	170,785	101,378	107,715
2025	126,904	126,904	169,518	166,203	179,926	94,343	98,708
2026	115,617	115,617	172,274	167,545	187,468	88,925	91,857
2027	106,673	106,673	173,601	167,649	193,147	84,545	86,457
2028	99,680	99,680	173,793	166,817	197,185	81,081	82,227
2029	94,379	94,379	173,304	165,489	200,037	78,827	79,426
2030	90,509	90,509	172,424	163,941	201,996	77,495	77,780
2031	87,871	87,871	171,328	162,329	203,259	76,725	76,844
2032	86,184	86,184	170,395	160,978	204,371	76,283	76,323
2033	85,099	85,099	169,198	159,503	204,708	76,041	76,046

Table 9.20 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
2020	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2021	0.06	0.06	0.06	0.06	0.06	0.46	0.37
2022	0.06	0.06	0.06	0.06	0.06	0.46	0.37
2023	0.37	0.37	0.06	0.08	0.00	0.46	0.46
2024	0.37	0.37	0.06	0.08	0.00	0.46	0.46
2025	0.37	0.37	0.06	0.08	0.00	0.46	0.46
2026	0.37	0.37	0.06	0.08	0.00	0.46	0.46
2027	0.37	0.37	0.06	0.08	0.00	0.45	0.46
2028	0.37	0.37	0.06	0.08	0.00	0.44	0.44
2029	0.37	0.37	0.06	0.08	0.00	0.43	0.43
2030	0.36	0.36	0.06	0.08	0.00	0.42	0.42
2031	0.36	0.36	0.06	0.08	0.00	0.41	0.41
2032	0.35	0.35	0.06	0.08	0.00	0.41	0.41
2033	0.35	0.35	0.06	0.08	0.00	0.41	0.41

Table 9.21. 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
2020	8,669	8,669	8,669	8,669	8,669	8,669	8,669
2021	11,519	11,519	11,519	11,519	11,519	75,863	62,567
2022	11,519	11,519	11,519	11,519	11,519	65,335	55,918
2023	65,775	65,775	11,647	15,467	0	58,290	62,296
2024	58,629	58,629	11,916	15,677	0	53,371	56,233
2025	53,016	53,016	12,108	15,798	0	49,703	51,705
2026	48,650	48,650	12,248	15,861	0	46,906	48,279
2027	45,212	45,212	12,319	15,850	0	44,493	45,579
2028	42,542	42,542	12,335	15,782	0	41,622	42,463
2029	40,457	40,457	12,316	15,680	0	39,596	40,062
2030	38,578	38,578	12,270	15,559	0	38,423	38,654
2031	37,159	37,159	12,208	15,430	0	37,819	37,924
2032	36,264	36,264	12,158	15,324	0	37,488	37,530
2033	35,698	35,698	12,087	15,203	0	37,347	37,360

Table 9.22. 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	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Benthic urochordata	0.064	0.010	0.007	0.001	0.014	0.010	0.149	0.046	0.024	0.130	0.042
Bivalves	0.022	0.002	0.005	0.004	0.073	0.000	0.010	0.016	0.007	0.046	0.023
Bristlemouths	NA	NA	NA	NA	NA	NA	NA	NA	0.000	0.000	0.000
Brittle star unidentified	0.081	0.003	0.002	0.034	0.025	0.007	0.002	0.041	0.020	0.229	0.092
Capelin	0.000	0.006	0.000	0.044	0.000	0.000	0.000	0.000	0.000	0.003	0.000
Corals Bryozoans - Corals Bryozoans Unidentified	0.037	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.002	0.005	0.001
Corals Bryozoans - Red Tree Coral	0.000	0.000	0.000	0.000	0.000	NA	NA	0.000	0.000	0.000	NA
Eelpouts	0.096	0.083	0.161	0.272	0.171	0.079	0.014	0.034	0.043	0.123	0.053
Eulachon	0.015	0.005	0.001	0.174	0.018	0.000	0.006	0.002	0.011	0.178	0.000
Giant Grenadier	0.000	0.000	0.002	0.000	0.000	0.001	0.002	0.008	0.000	0.028	0.001
Greenlings	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.008	0.123	0.002
Grenadier - Pacific Grenadier	0.000	0.000	NA	NA	NA	NA	NA	NA	NA	NA	NA
Grenadier - Rattail Grenadier Unidentified	0.000	0.000	0.000	0.002	0.000	0.024	0.000	0.003	0.000	0.023	0.000
Gunnels	NA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	NA	0.000	0.000
Hermit crab unidentified	0.062	0.005	0.032	0.048	0.020	0.074	0.082	0.065	0.082	0.090	0.118
Invertebrate unidentified	0.086	0.009	0.001	0.001	0.002	0.030	0.000	0.004	0.000	0.060	0.006
Lanternfishes (myctophidae)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Misc crabs	0.011	0.007	0.004	0.020	0.013	0.012	0.052	0.031	0.022	0.096	0.014
Misc crustaceans	0.080	0.017	0.008	0.163	0.041	0.047	0.002	0.284	0.043	0.128	0.104
Misc deep fish	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Misc fish	0.006	0.002	0.001	0.004	0.005	0.004	0.006	0.003	0.002	0.012	0.006
Misc inverts (worms etc)	0.030	0.059	0.093	0.077	0.020	0.071	0.516	0.227	0.058	0.184	0.041
NP Shrimp	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.000
Other osmerids	0.001	0.017	0.000	0.009	0.001	0.000	0.000	0.000	0.000	0.005	0.001
Pacific Hake	NA	0.000	NA	NA	NA	NA	0.000	0.000	0.000	NA	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	0.000
Pacific Sandfish	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pandalid shrimp	0.040	0.008	0.056	0.069	0.064	0.030	0.012	0.073	0.048	0.135	0.070
Polychaete unidentified	0.006	0.007	0.001	0.004	0.002	0.013	0.032	0.772	0.005	0.107	0.021
Scypho jellies	0.007	0.001	0.000	0.002	0.005	0.005	0.003	0.001	0.001	0.029	0.002
Sea anemone unidentified	0.133	0.020	0.017	0.068	0.040	0.022	0.012	0.020	0.003	0.063	0.074
Sea pens whips	0.001	0.001	0.000	0.001	0.000	0.000	0.001	0.006	0.001	0.007	0.004
Sea star	0.037	0.023	0.005	0.016	0.036	0.028	0.036	0.053	0.034	0.088	0.039
Snails	0.061	0.034	0.022	0.045	0.096	0.057	0.024	0.025	0.030	0.068	0.105
Sponge unidentified	0.013	0.001	0.000	0.013	0.006	0.000	0.005	0.002	0.001	0.005	0.042
Squid	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.002	0.002
State-managed Rockfish	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Stichaeidae	0.047	0.002	0.000	0.009	0.006	0.002	0.000	0.000	0.008	0.146	0.019
Surf smelt	NA	NA	NA	NA	NA	NA	0.000	0.000	NA	0.000	NA
urchins dollars cucumbers	0.023	0.034	0.006	0.025	0.006	0.014	0.019	0.070	0.010	0.120	0.024

Table 9.23. 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. Over this time period there were no seabirds caught in targeted flathead sole trips.

Bycatch Species	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Birds - Auklets	NA	NA	0	0	0	0	0	0	0	NA	NA
Birds - Black-footed Albatross	0	0	NA	0	0	0	NA	NA	NA	NA	NA
Birds - Cormorant	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA
Birds - Gull	0	0	0	0	0	0	0	0	0	0	0
Birds - Kittiwake	NA	0	0	0	0	0	0	0	0	0	0
Birds - Laysan Albatross	0	0	0	0	0	0	0	0	0	0	0
Birds - Murre	0	0	0	0	0	NA	0	0	NA	NA	0
Birds - Northern Fulmar	0	0	0	0	0	0	0	0	0	0	0
Birds - Other	NA	NA	NA	NA	NA	NA	NA	0	NA	NA	NA
Birds - Other Alcid	NA	NA	NA	NA	NA	NA	NA	NA	0	0	NA
Birds - Puffin	0	NA	NA	NA	NA	NA	0	NA	NA	NA	NA
Birds - Shearwaters	0	0	0	0	0	0	0	0	0	0	0
Birds - Short-tailed Albatross	0	0	NA	NA	0	NA	NA	NA	NA	NA	0
Birds - Storm Petrels	NA	NA	NA	NA	NA	NA	NA	NA	0	NA	NA
Birds - Unidentified	0	0	0	0	0	0	0	0	0	0	0
Birds - Unidentified Albatross	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA

Table 9.24. 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	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Bairdi Tanner Crab	0.093	0.030	0.047	0.075	0.070	0.051	0.032	0.026	0.085	0.235
Blue King Crab	0.001	0.000	0.000	0.046	0.000	0.018	0.000	0.003	0.000	0.020
Chinook Salmon	0.000	0.000	0.000	0.000	0.000	0.004	0.002	0.000	0.004	0.009
Golden (Brown) King Crab	0.000	0.000	0.000	0.001	0.000	0.000	0.010	0.009	0.000	0.016
Halibut	0.027	0.011	0.011	0.018	0.019	0.011	0.018	0.029	0.053	0.082
Herring	0.001	0.001	0.000	0.002	0.001	0.000	0.000	0.002	0.000	0.003
Non-Chinook Salmon	0.001	0.001	0.002	0.000	0.003	0.002	0.002	0.001	0.010	0.007
Opilio Tanner (Snow) Crab	0.043	0.059	0.038	0.106	0.170	0.034	0.054	0.093	0.170	0.213
Red King Crab	0.012	0.028	0.010	0.007	0.001	0.000	0.009	0.003	0.003	0.025

Table 9.25. Proportion of BSAI halibut mortality as prohibited species catch that comes from the BSAI flathead sole directed fishery

Year	Proportion of Halibut Mortality
2010	0.054
2011	0.022
2012	0.023
2013	0.036
2014	0.034
2015	0.020
2016	0.025
2017	0.032
2018	0.062
2019	0.079
2020	0.025

Figures

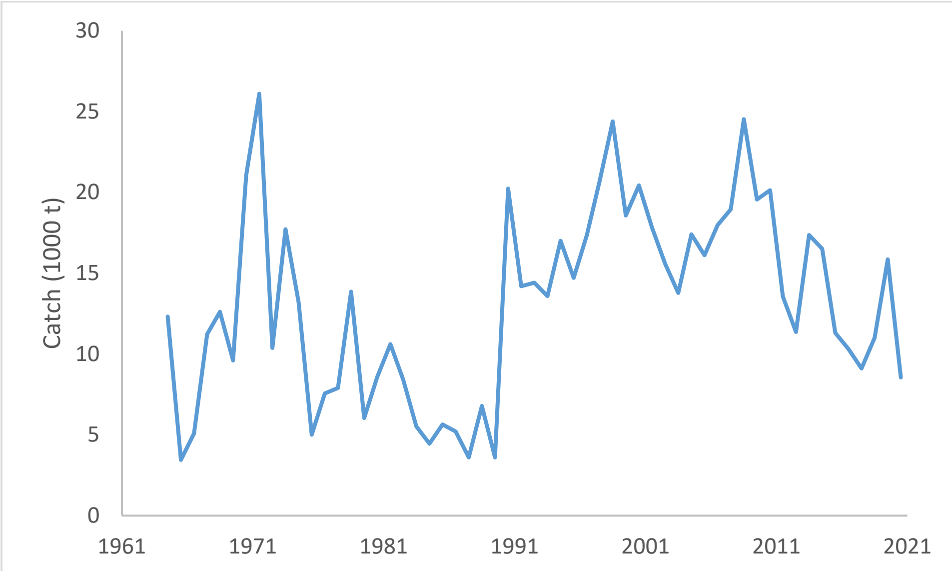


Figure 9.1. Combined catch (in metric tons) of flathead sole and Bering flounder (*Hippoglossoides* spp.) by year in total, and for CDQ and non-CDQ fisheries combined, and foreign and domestic catches combined.

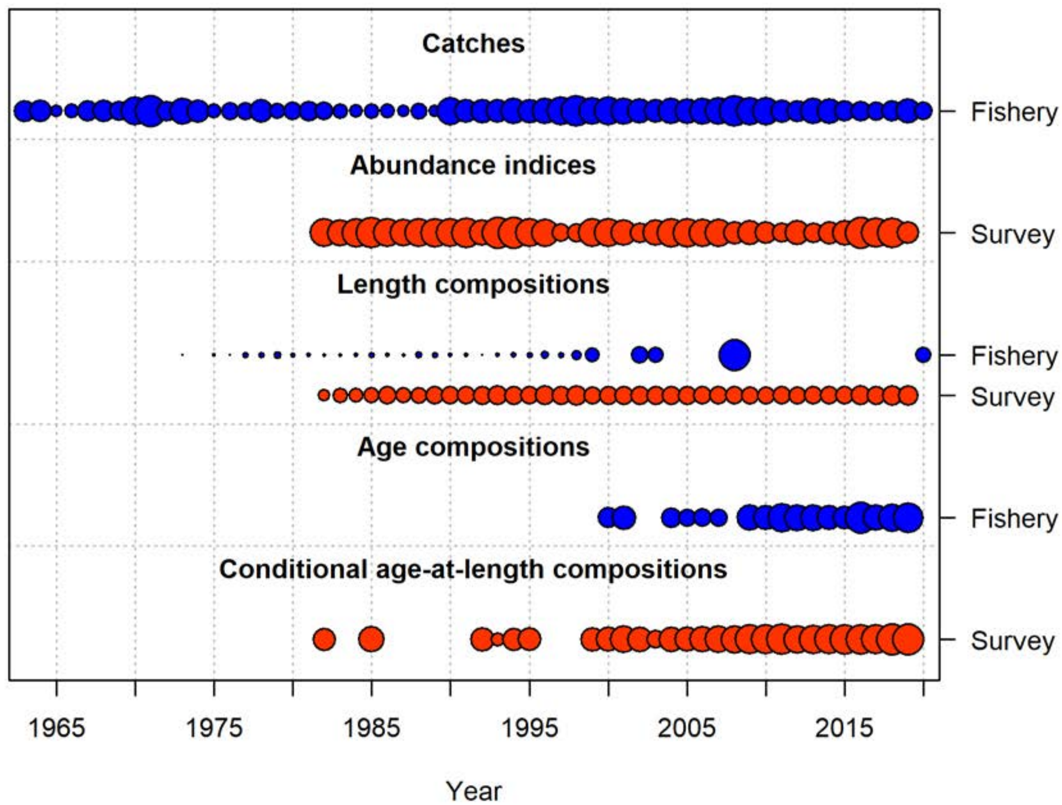


Figure 9.2. Data used in the assessment model, with sizes of circles indicating the relative catches or biomass for fishery catch or survey biomass (listed as "Abundance indices"), respectively, and indicating precision for the length and age composition data included. Circles are relative to the maximum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

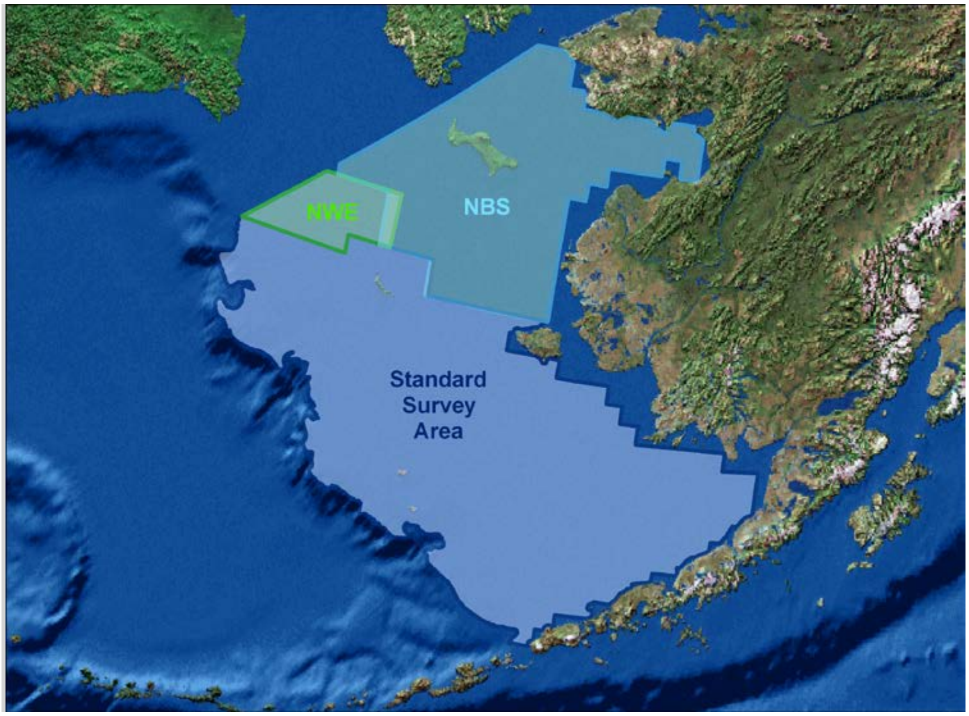


Figure 9.3. Eastern Bering Sea shelf survey areas. Only data from the standard survey area are used in the assessment model; data from the Northwest Extension (NWE) and Northern Bering Sea (NBS) are excluded.

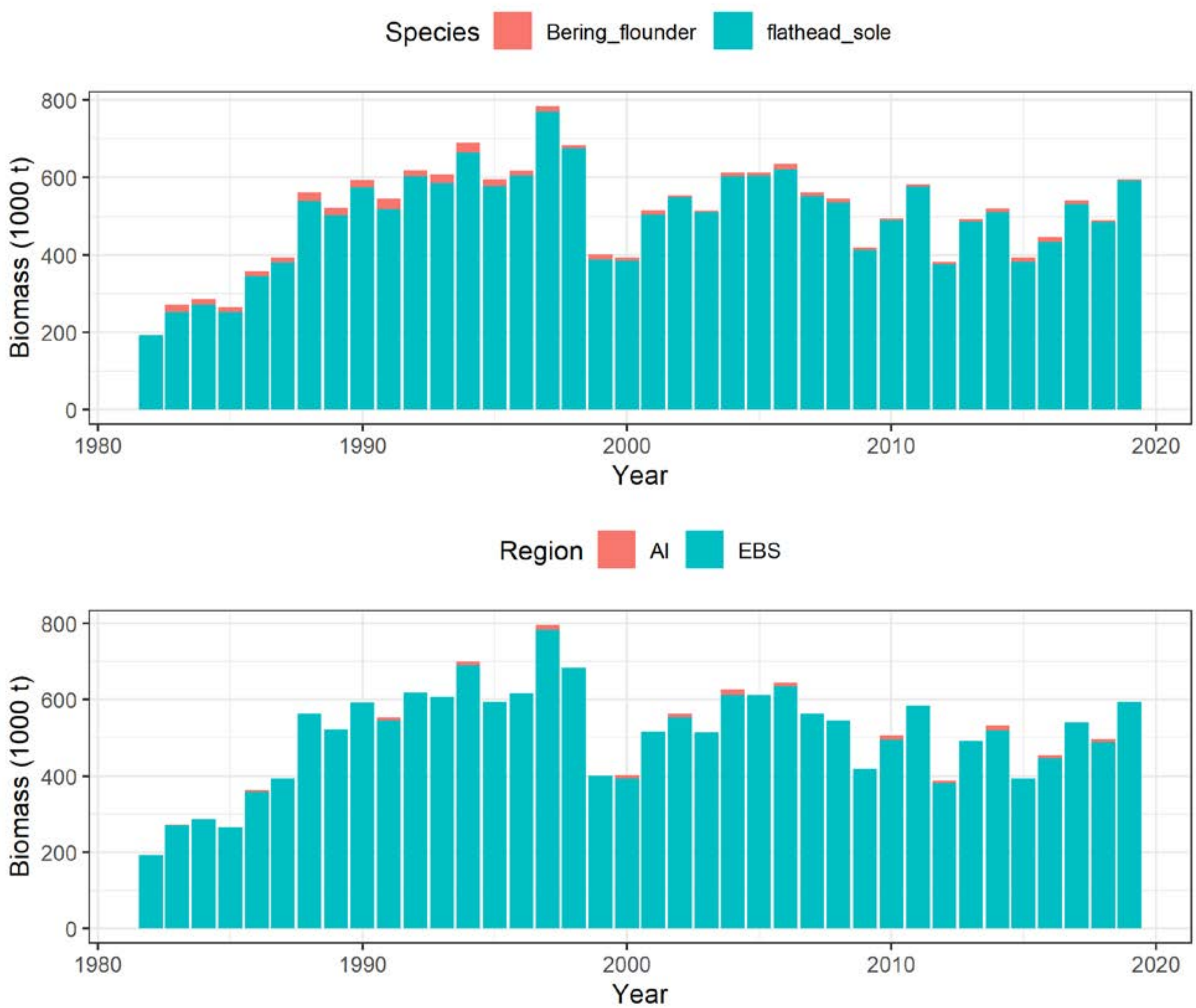


Figure 9.4. Flathead sole and Bering flounder biomass in the EBS shelf survey (top panel). Flathead sole (only) survey biomass from the EBS shelf survey and the Aleutian Islands survey (bottom panel).

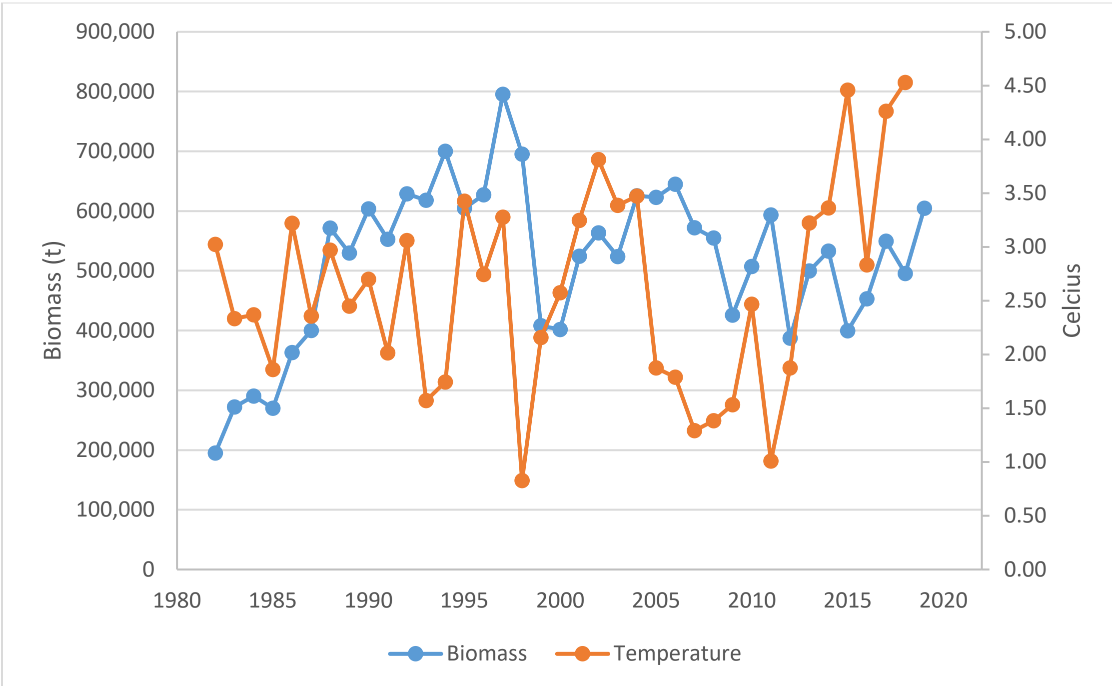


Figure 9.5. Survey biomass and mean bottom temperatures from the EBS shelf survey for station depths less than or equal to 200 meters.

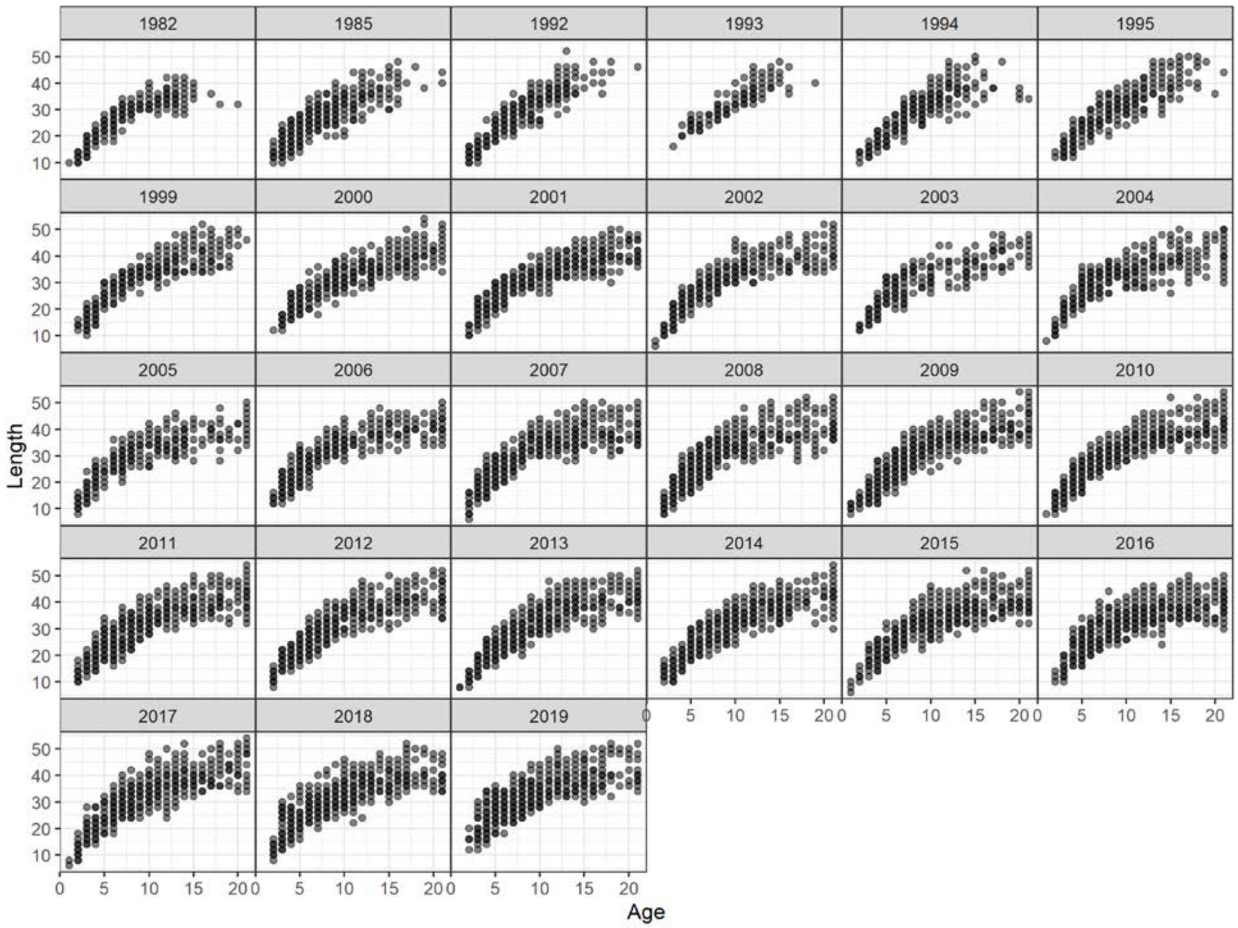


Figure 9.6. EBS shelf survey length-at-age data by cohort and year for females and for flathead sole only.

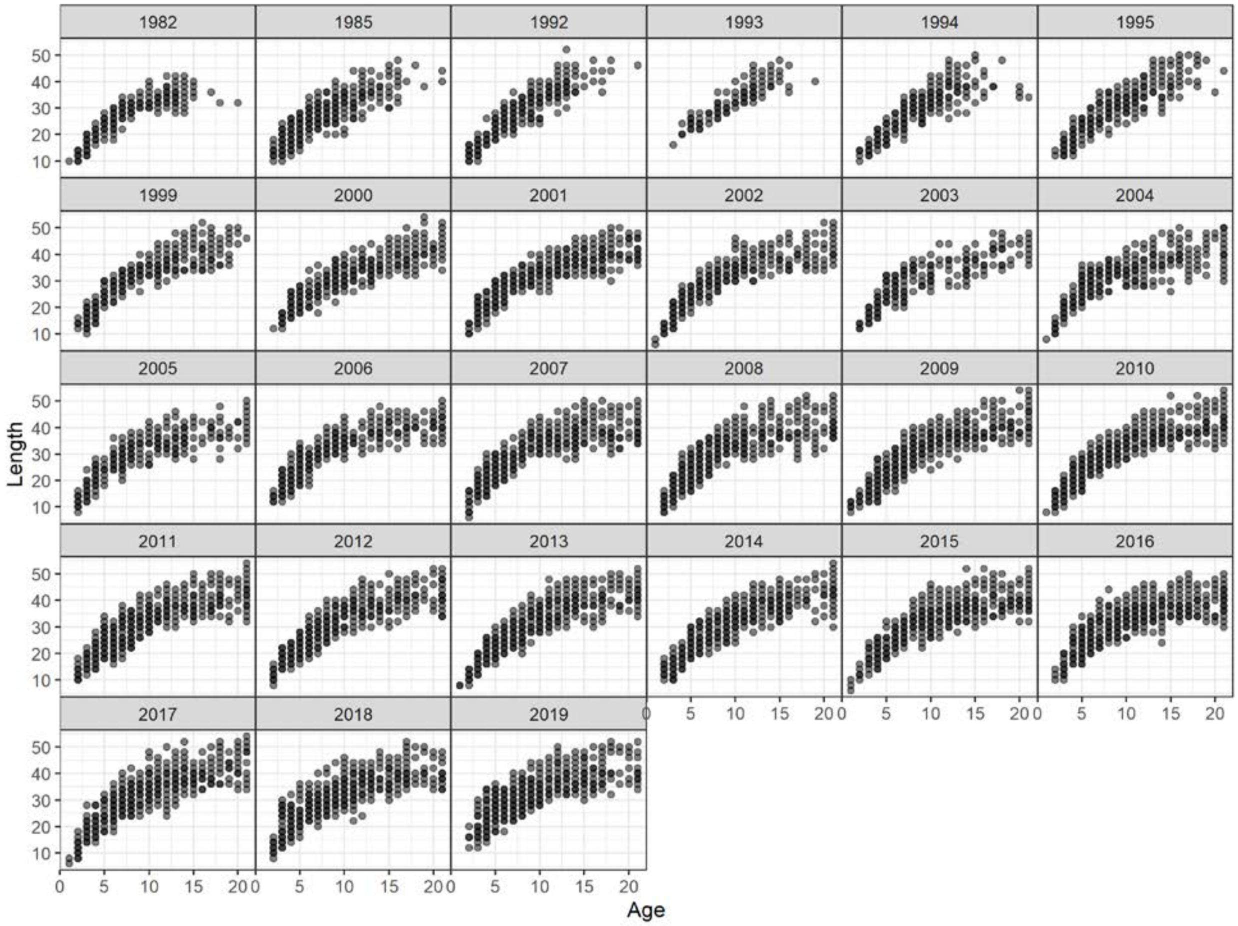


Figure 9.7. EBS shelf survey length-at-age data by cohort and year for males and for flathead sole only.

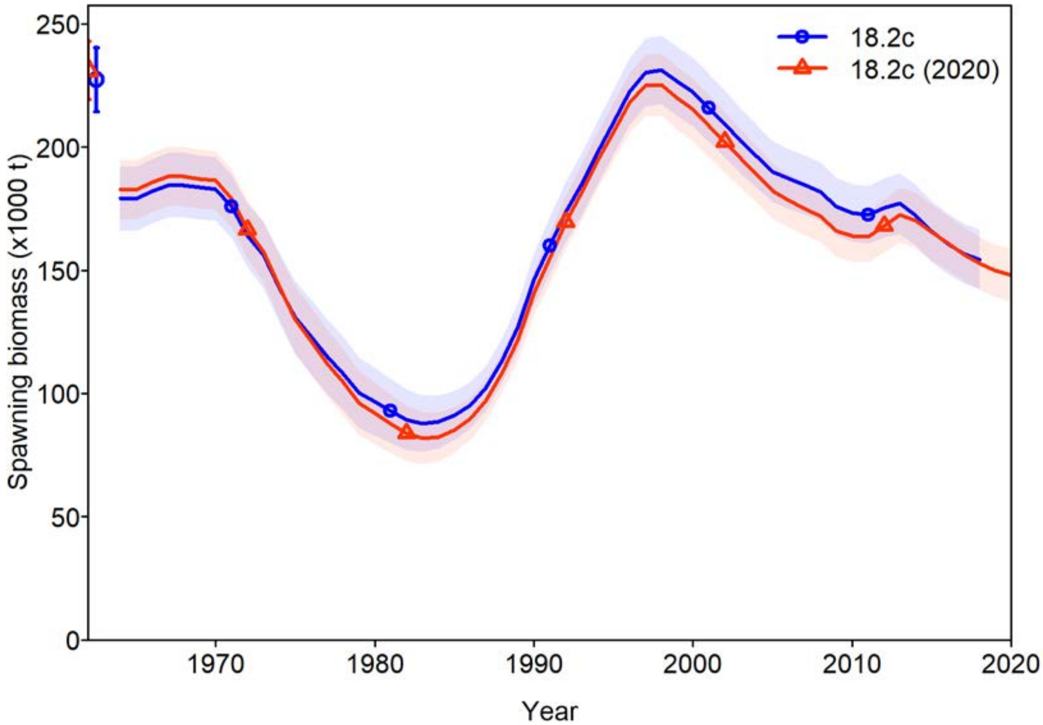


Figure 9.8. A comparison of spawning biomass for models 18.2c and 18.2c (2020).

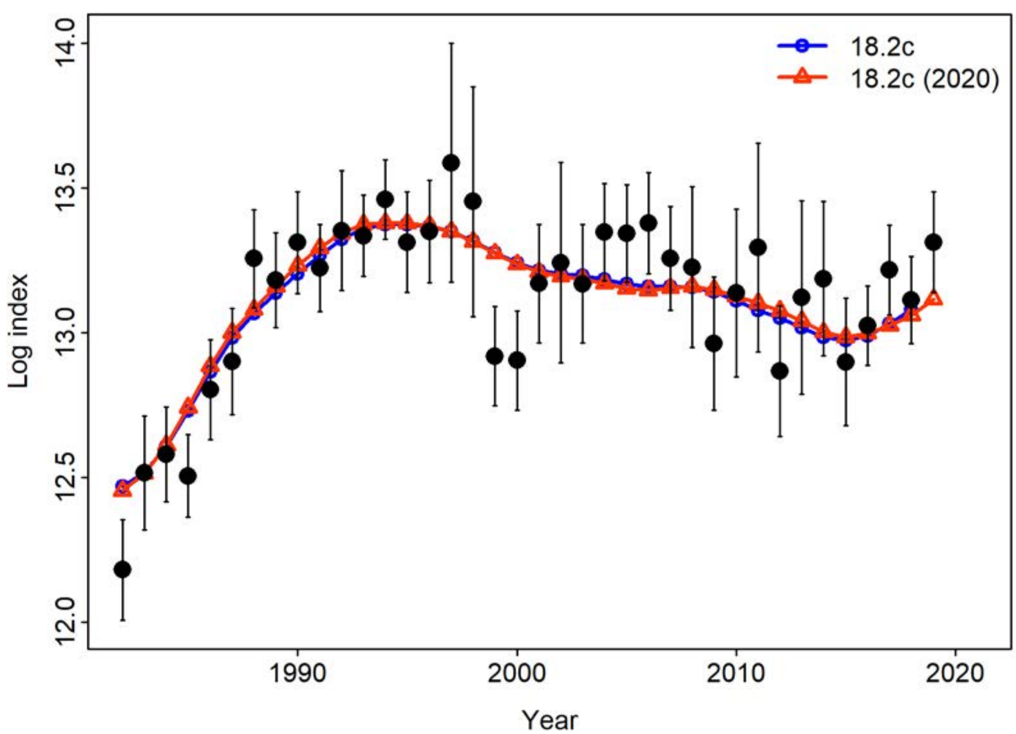


Figure 9.9. A comparison of fit to the survey biomass index for models 18.2c and 18.2c (2020).

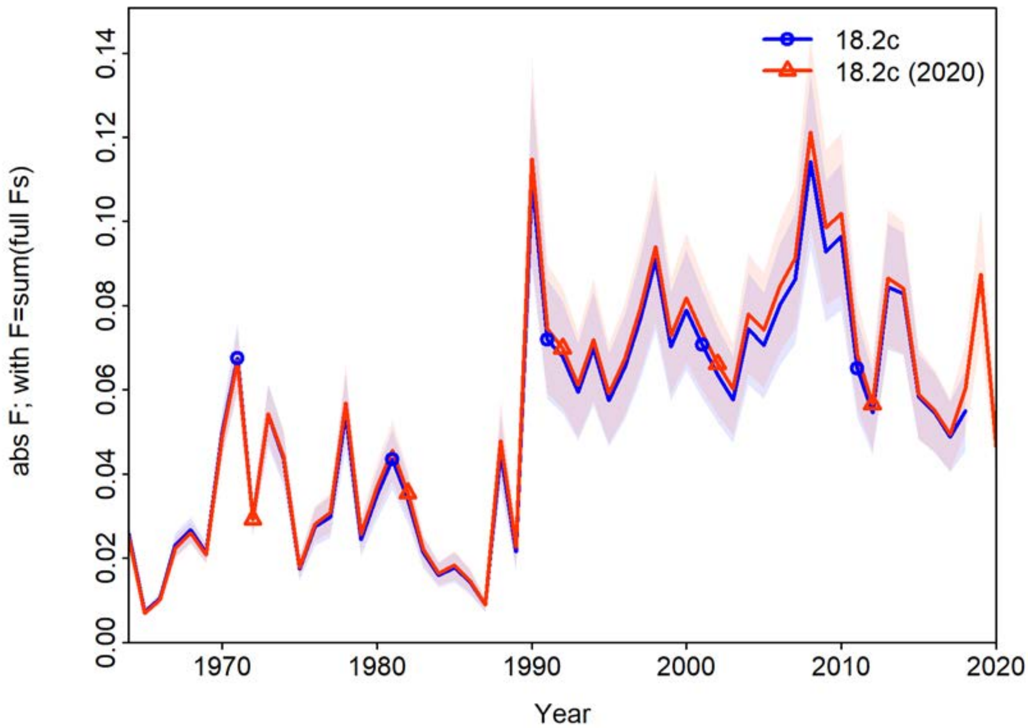


Figure 9.10. A comparison of estimated F values for models 18.2c and 18.2c (2020).

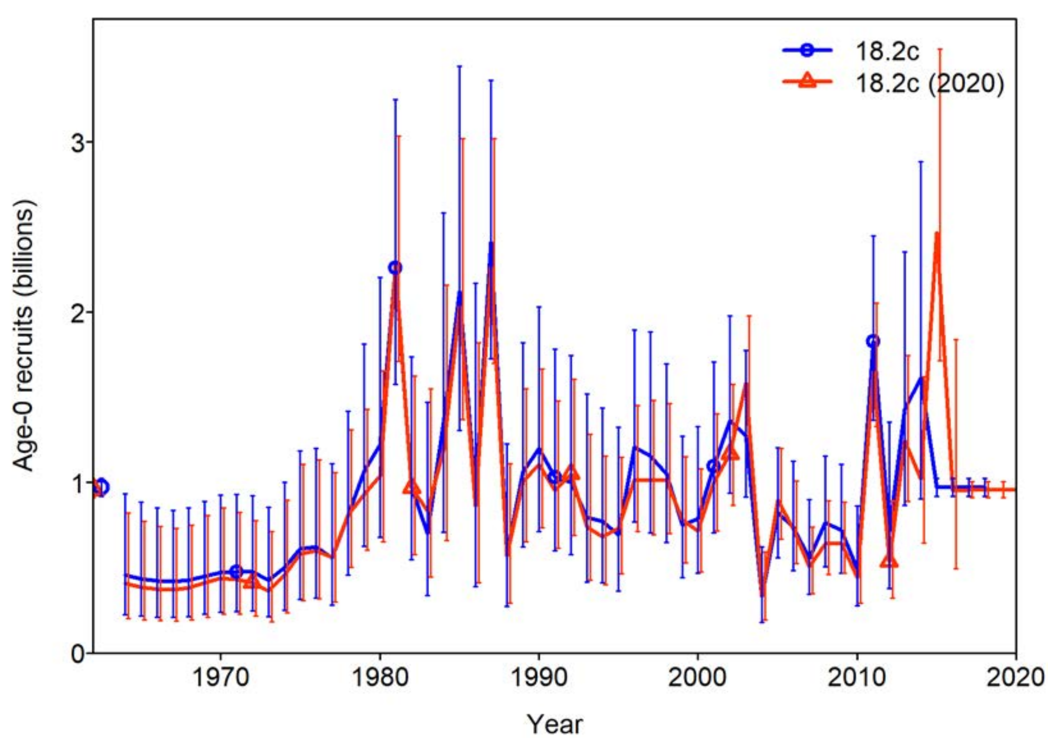


Figure 9.11. A comparison of estimated recruits for models 18.2c and 18.2c (2020).

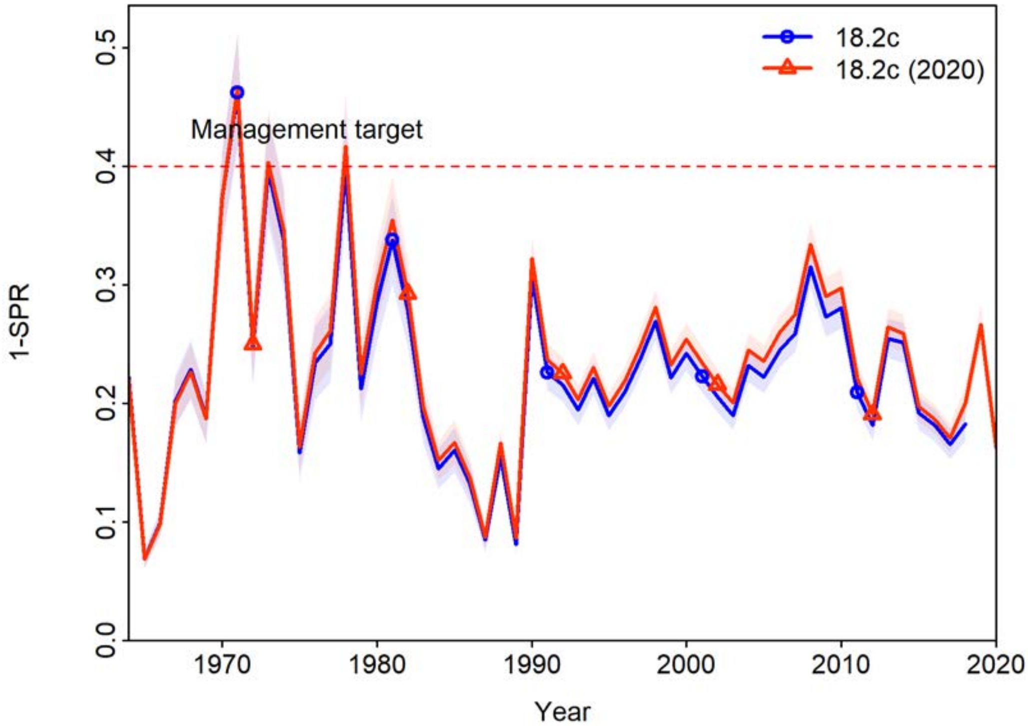


Figure 9.12. A comparison of estimated stock status, represented as one minus the spawning potential ratio, for models 18.2c and 18.2c (2020).

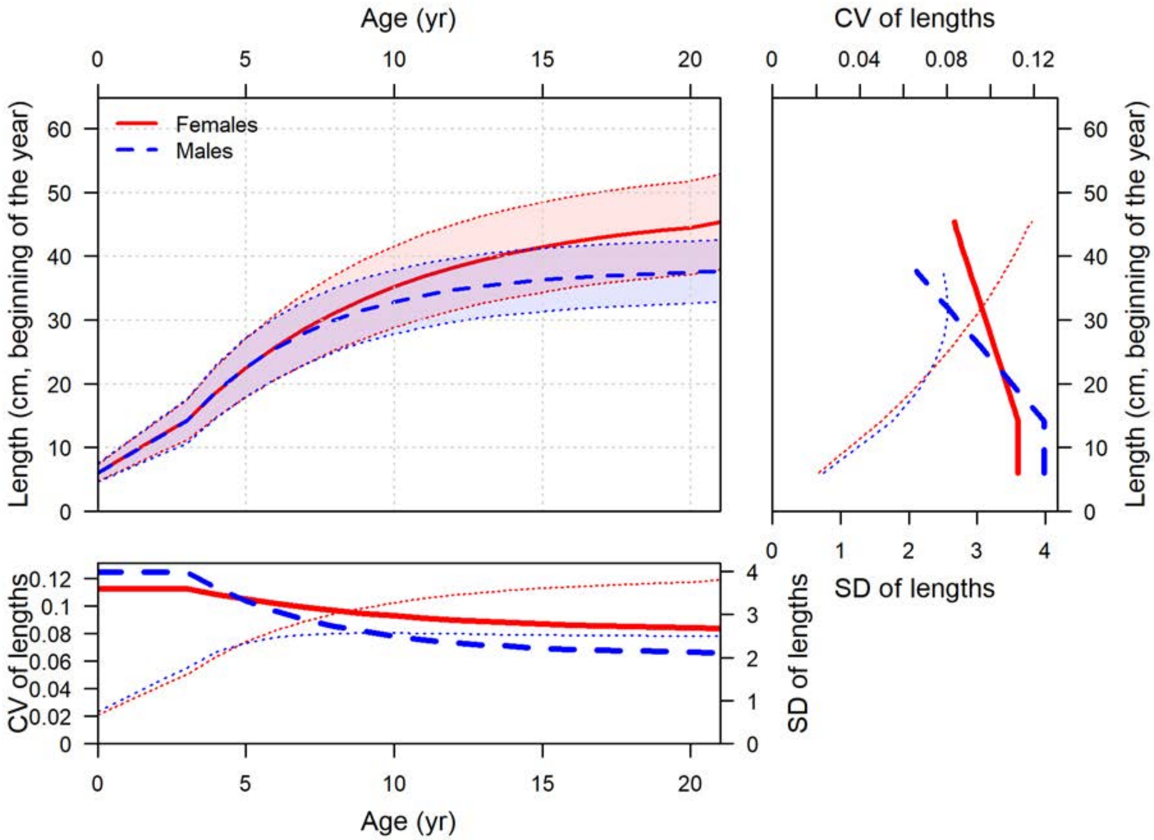
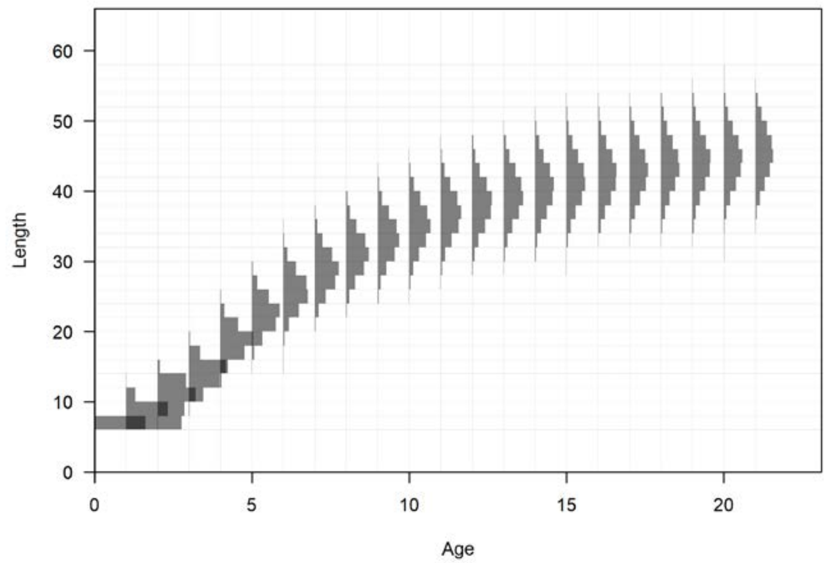


Figure 9.13. Estimated length-at-age and variability in length-at-age for Model 18.2c (2020), as well as estimates of CV in length-at-age over ages (bottom plot) and lengths (right plot) and translation into standard deviations of lengths. Thick lines are CVs and thin dotted lines are standard devations. Red indicates females and blue indicates males.



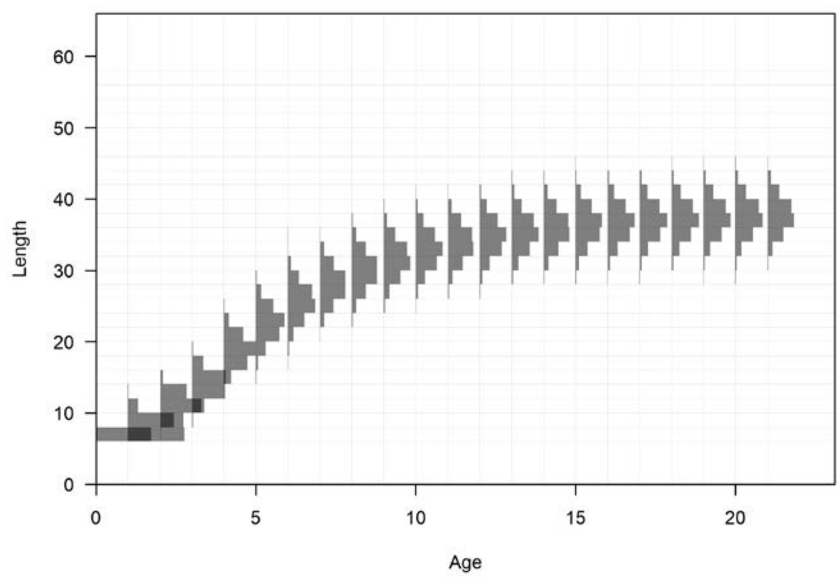


Figure 9.14. Estimated distribution of lengths at each age for females (upper panel) and males (lower panel) for Model 18.2c (2020).

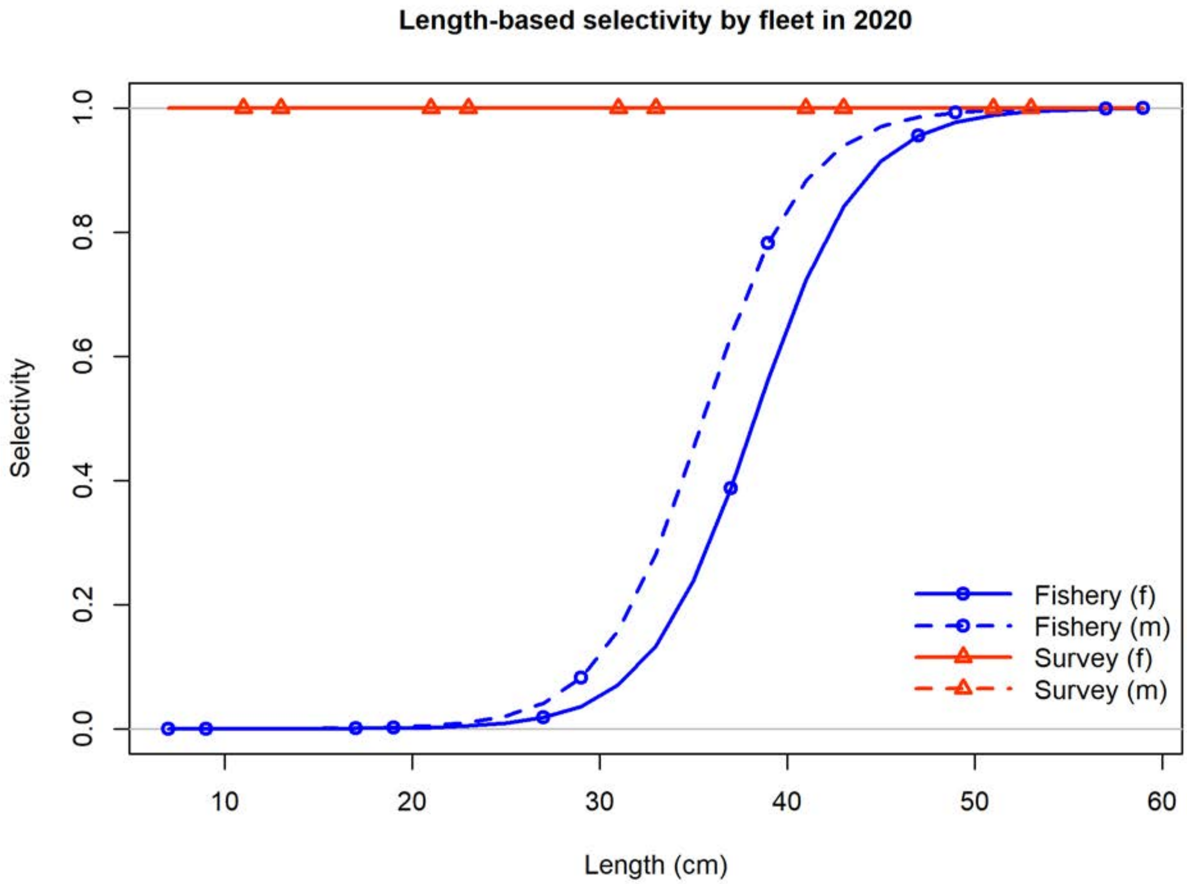


Figure 9.15. Fishery selectivity curves in the end year of the model (2020) for Model 18.2c (2020).

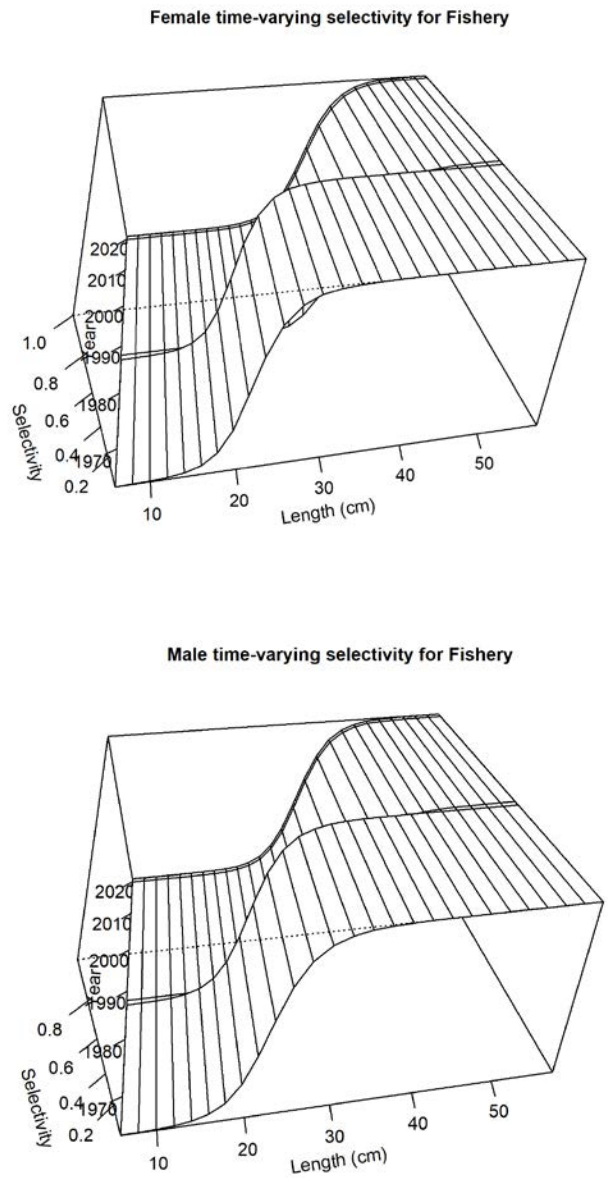


Figure 9.16. Annual fishery selectivity for model 18.2c (2020) which is estimated for 2 time periods,) for females (top panel) and males (bottom panel).

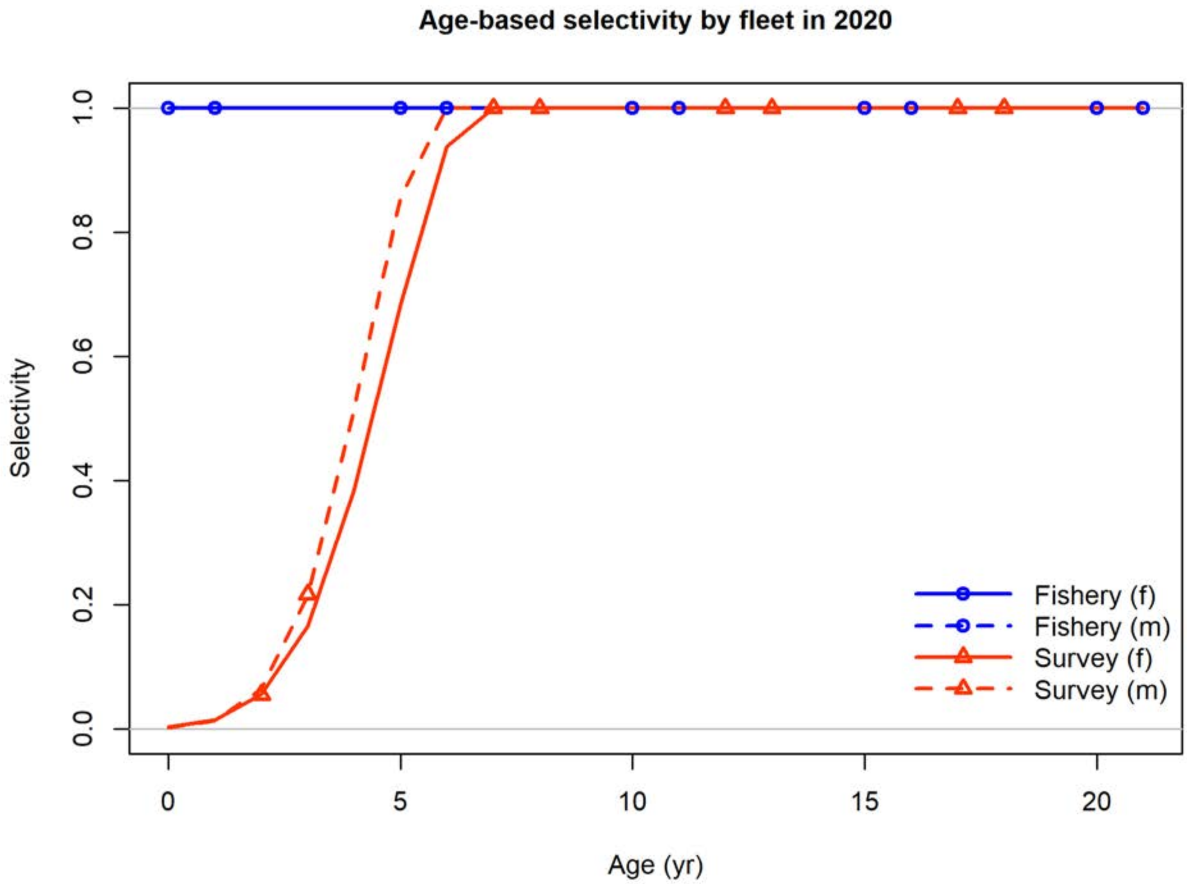


Figure 9.17. Survey selectivity curves for model 18.2c (2020) as a function of age.

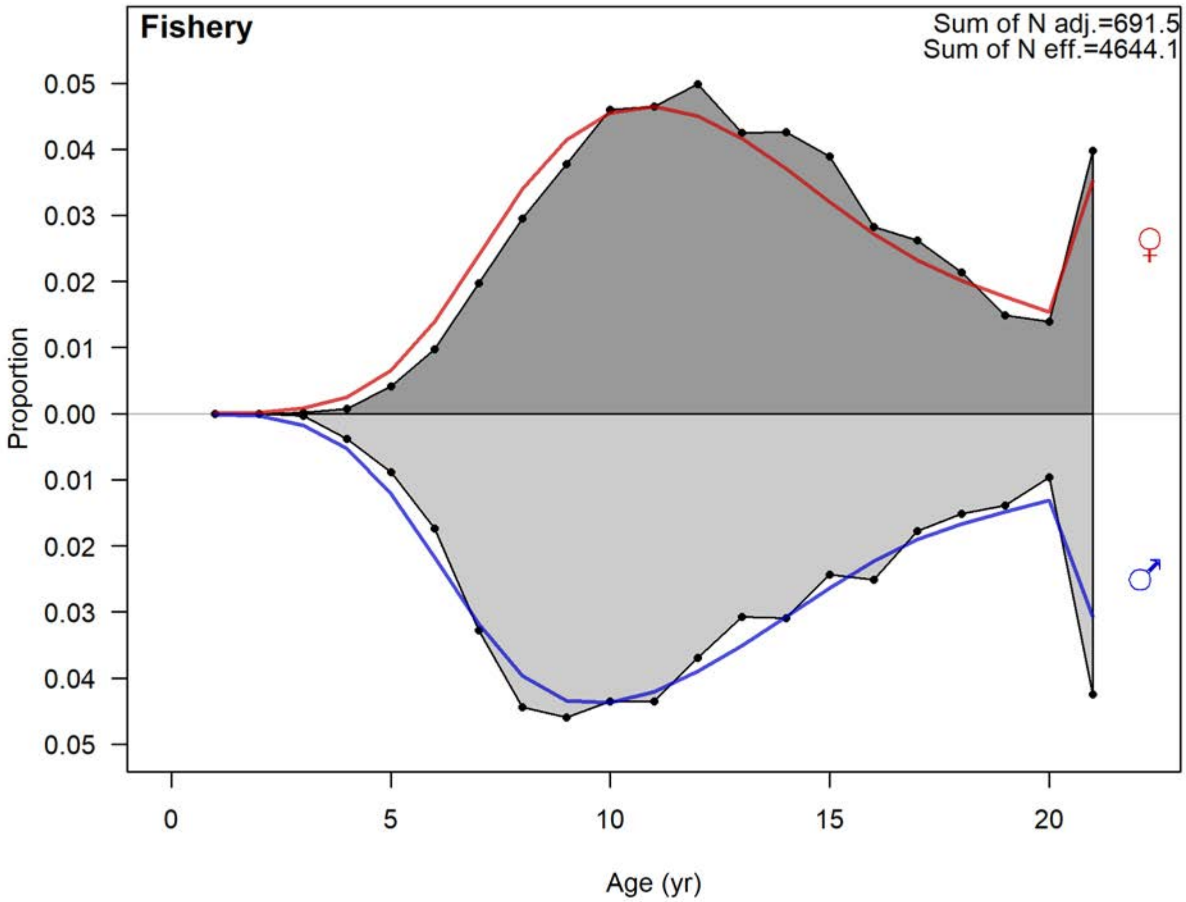


Figure 9.18. Fit to fishery age data, aggregated across time, for Model 18.2c (2020).

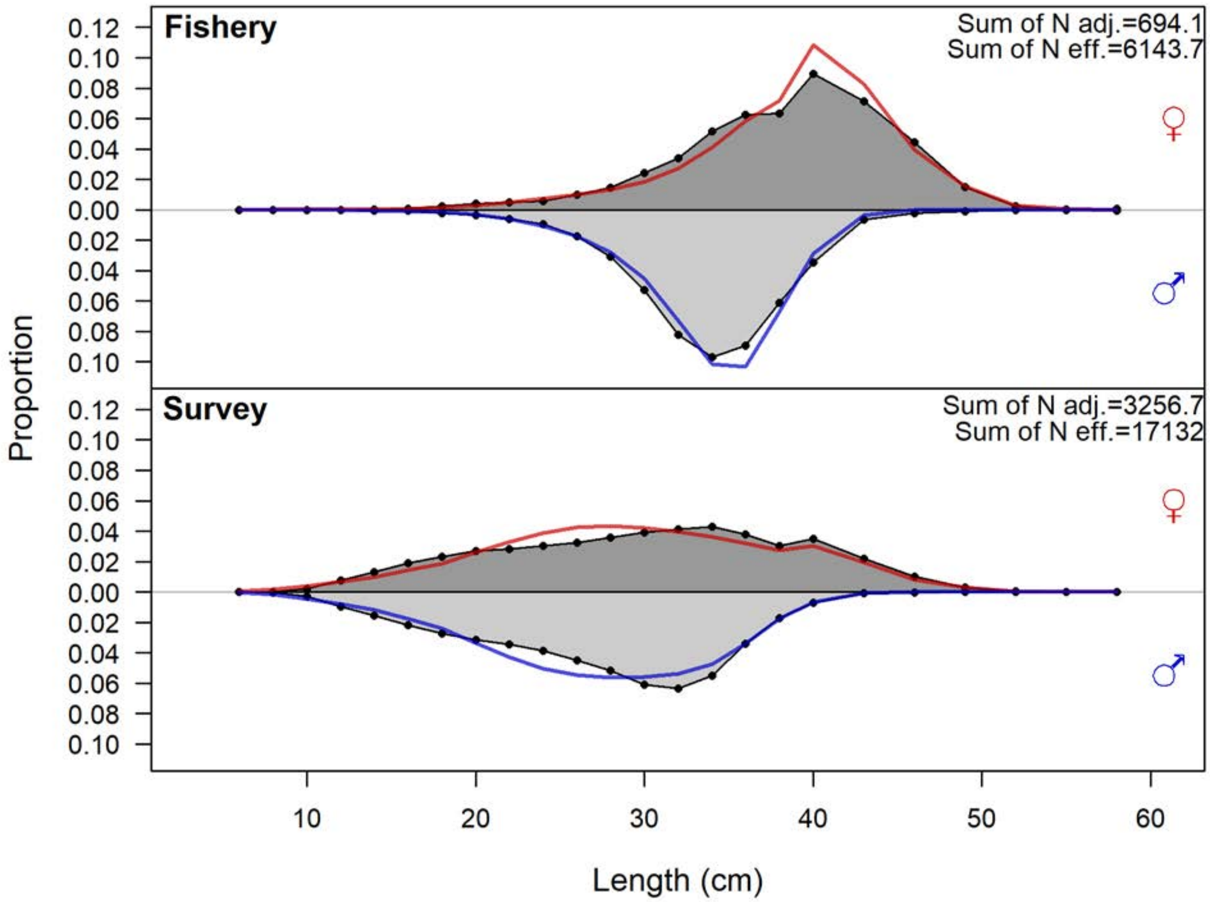


Figure 9.19. Fit to fishery and survey length composition data, aggregated across time, for Model 18.2c (2020).

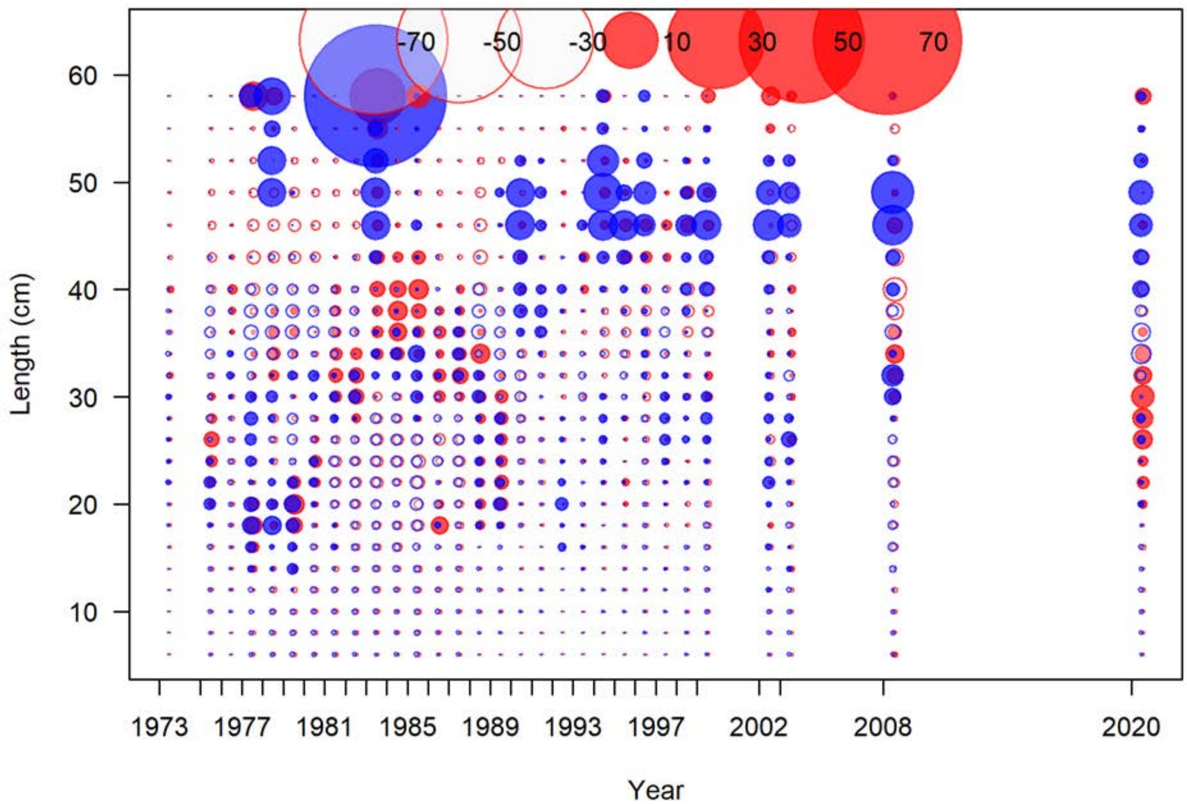


Figure 9.20. Pearson residuals showing fits to fishery length composition data for Model 18.2.c (2020). Red bubbles along the top of the plots show the scale. Filled circles are positive residuals (observed > expected) and open circles are negative residuals (observed < expected), blue indicates males and red indicates females. Circles across the top of the plots are a legend.

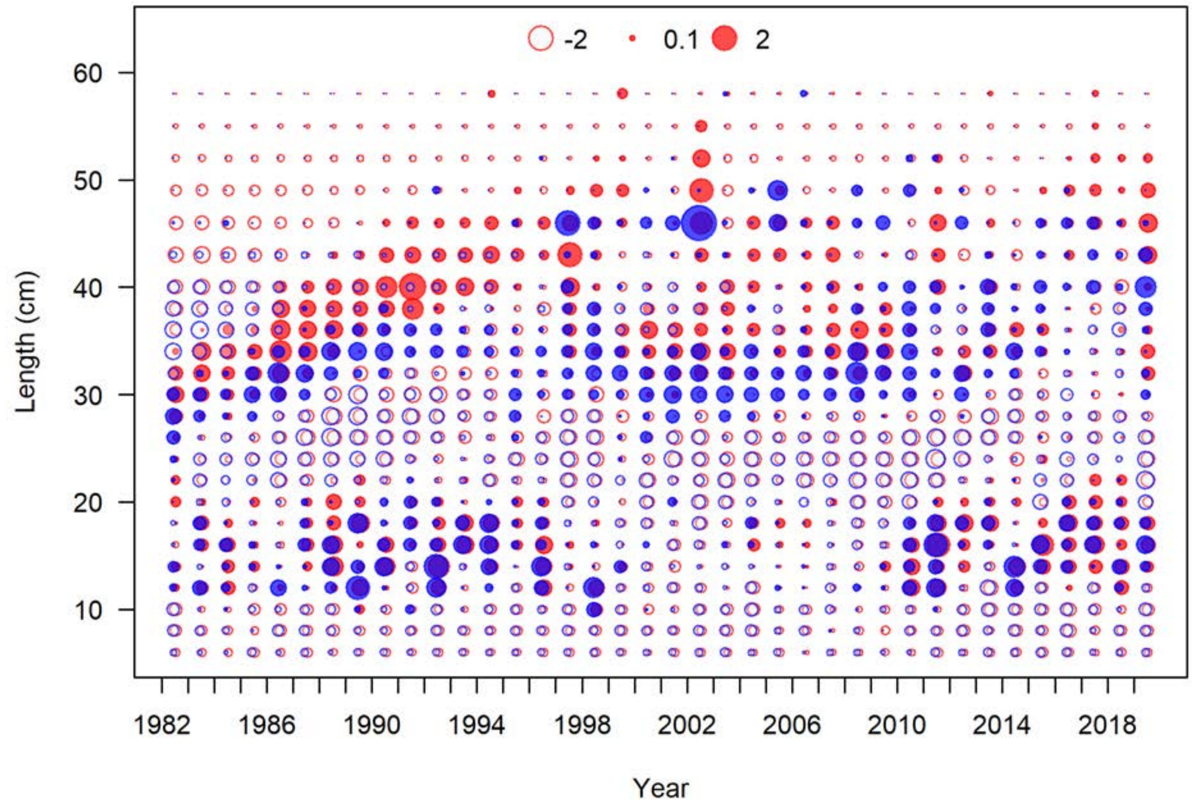
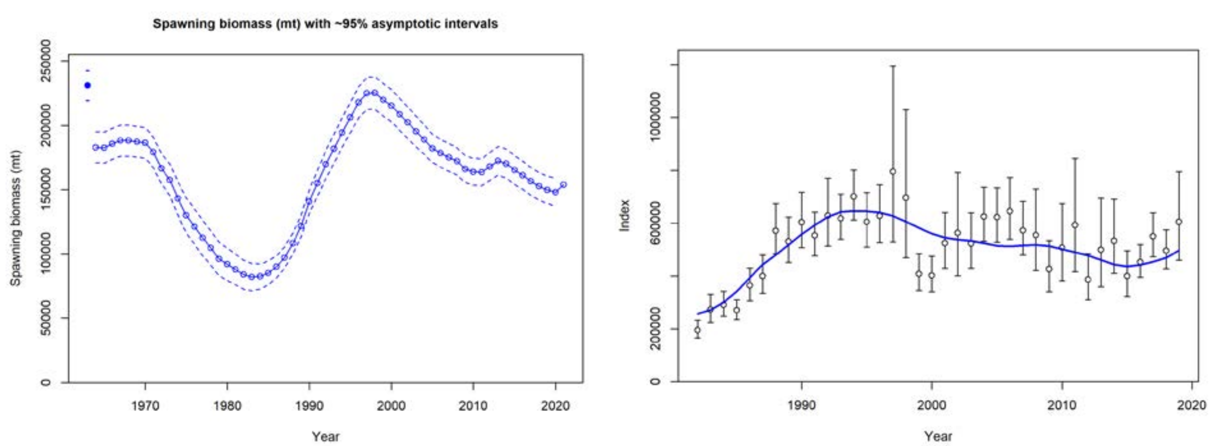


Figure 9.21. Pearson residuals showing fits to the survey length composition data for Model 18.2c (2020). Filled circles are positive residuals (observed > expected) and open circles are negative residuals (observed < expected), blue indicates males and red indicates females. Circles across the top of the plots are a legend.



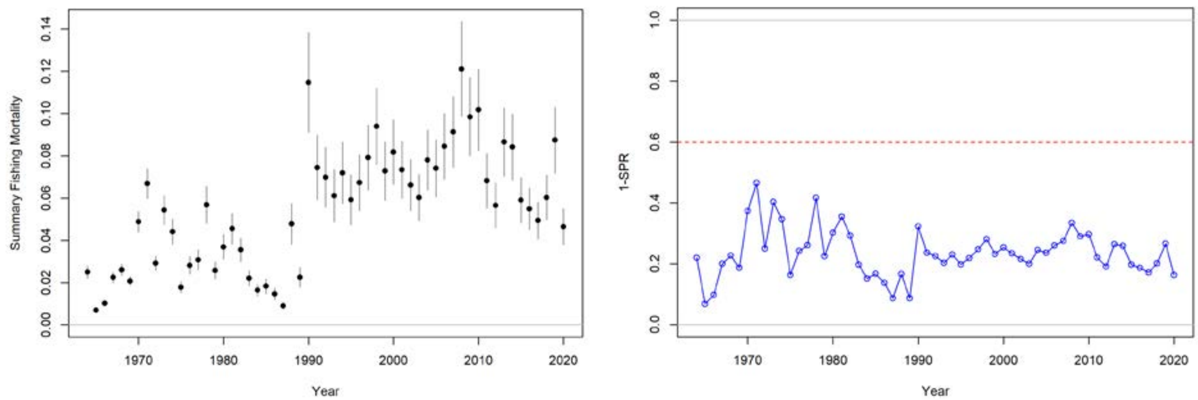


Figure 9.22. Model 18.2c estimated trends over time for spawning biomass (top left), survey biomass (dots) with 95% asymptotic intervals (vertical lines) and model fit to survey biomass (blue line; top right), apical fishing mortality with 95% asymptotic intervals (bottom left), and 1-spawning potential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

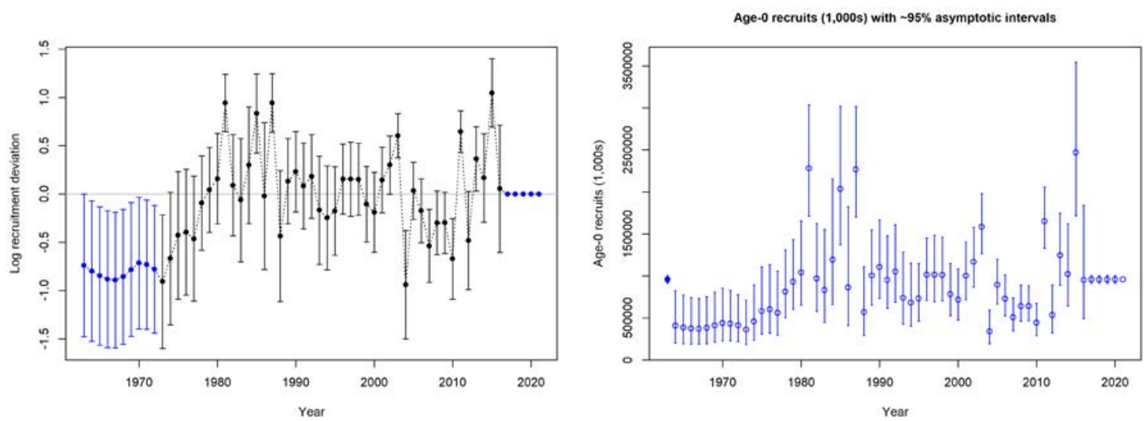


Figure 9.23. Model 18.2 (2020) estimated recruitment. Recruitment deviations in log-space (left), age-0 recruits with 95% asymptotic intervals (right).

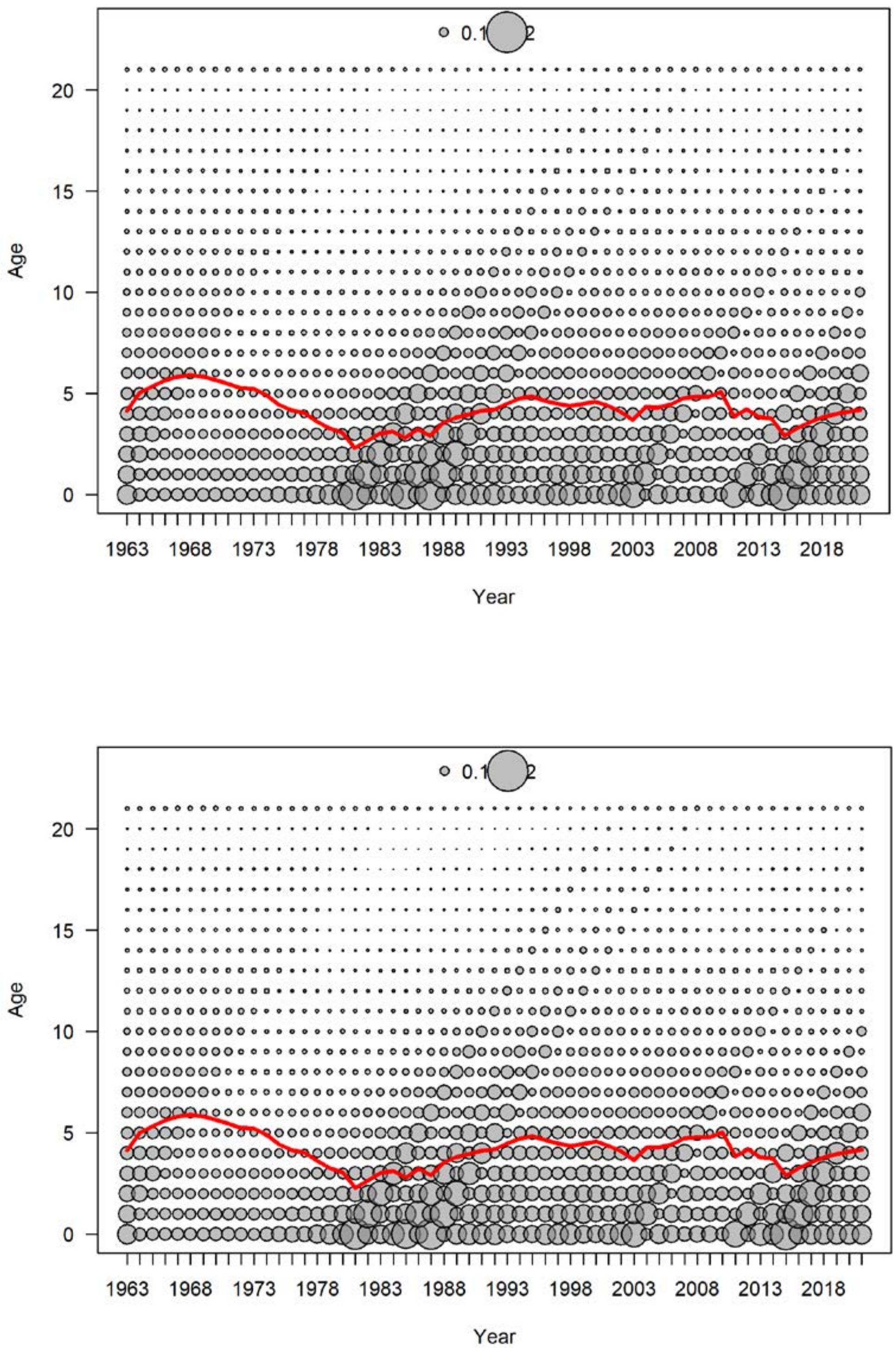
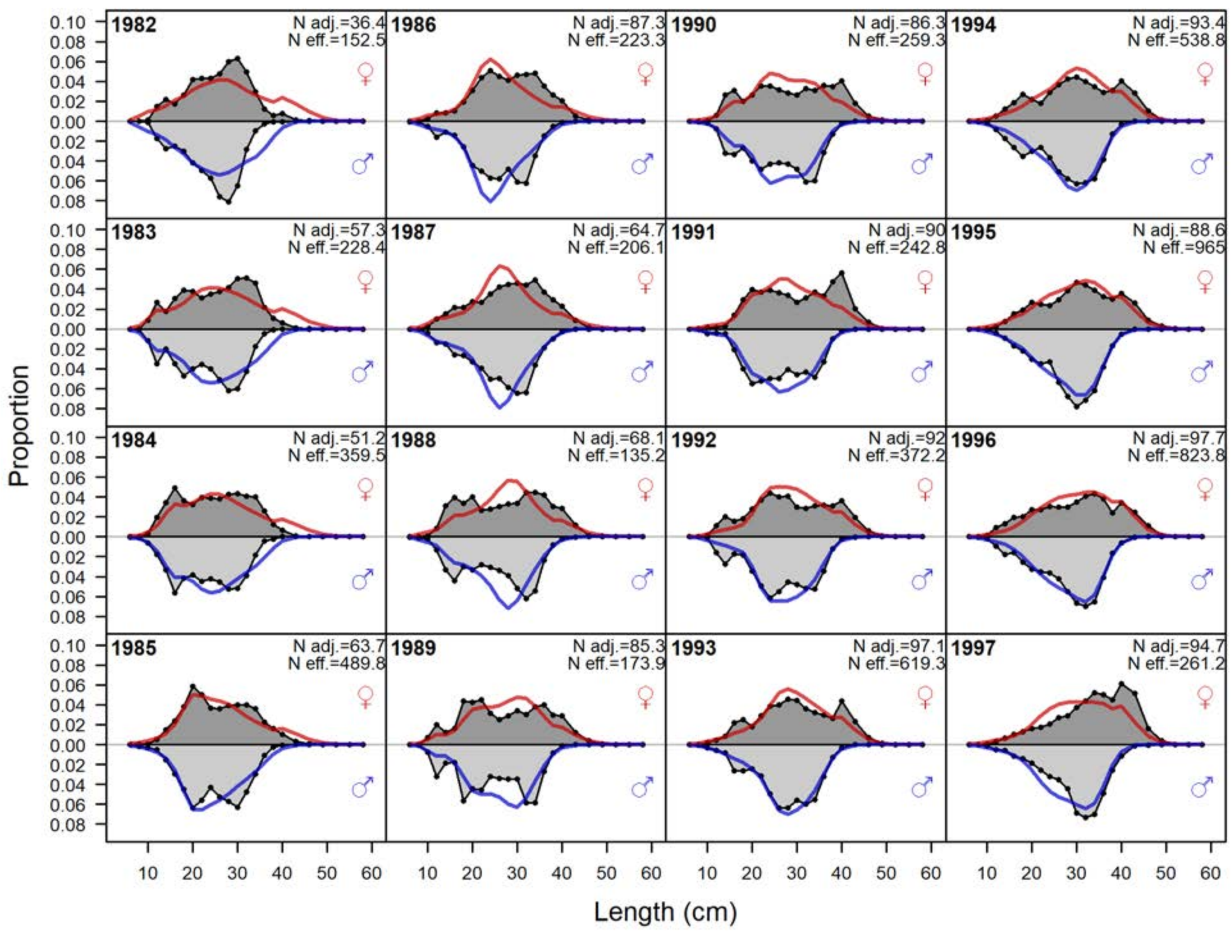


Figure 9.24. Expected numbers-at-age at the beginning of the year for females (top panel) and males (bottom panel) for Model 18.2c (2020). Red lines show expected mean numbers-at-age.


1982
N adj.=36.4
N eff.=152.5
1986
N adj.=87.3
N eff.=223.3
1990
N adj.=86.3
N eff.=259.3
1994
N adj.=93.4
N eff.=538.8
1983
N adj.=57.3
N eff.=228.4
1987
N adj.=64.7
N eff.=206.1
1991
N adj.=90
N eff.=242.8
1995
N adj.=88.6
N eff.=965
1984
N adj.=51.2
N eff.=359.5
1988
N adj.=68.1
N eff.=135.2
1992
N adj.=92
N eff.=372.2
1996
N adj.=97.7
N eff.=823.8
1985
N adj.=63.7
N eff.=489.8
1989
N adj.=85.3
N eff.=173.9
1993
N adj.=97.1
N eff.=619.3
1997
N adj.=94.7
N eff.=261.2
Proportion
Length (cm)

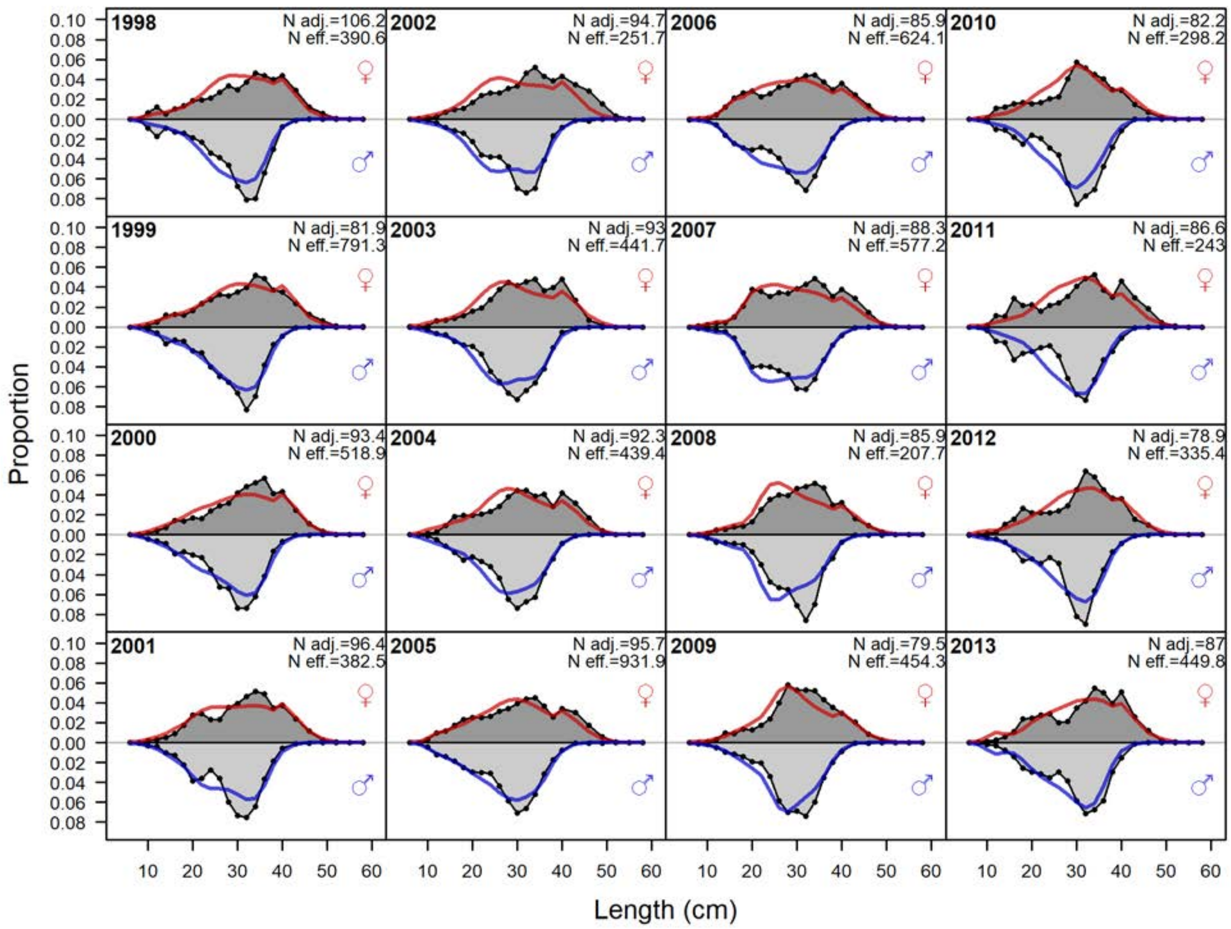


Figure 9.25. Observed (grey filled area and black line) and expected (red and blue lines) survey length compositions for males (blue lines) and females (red lines) for 1982-2013 for Model 18.2c (2020).

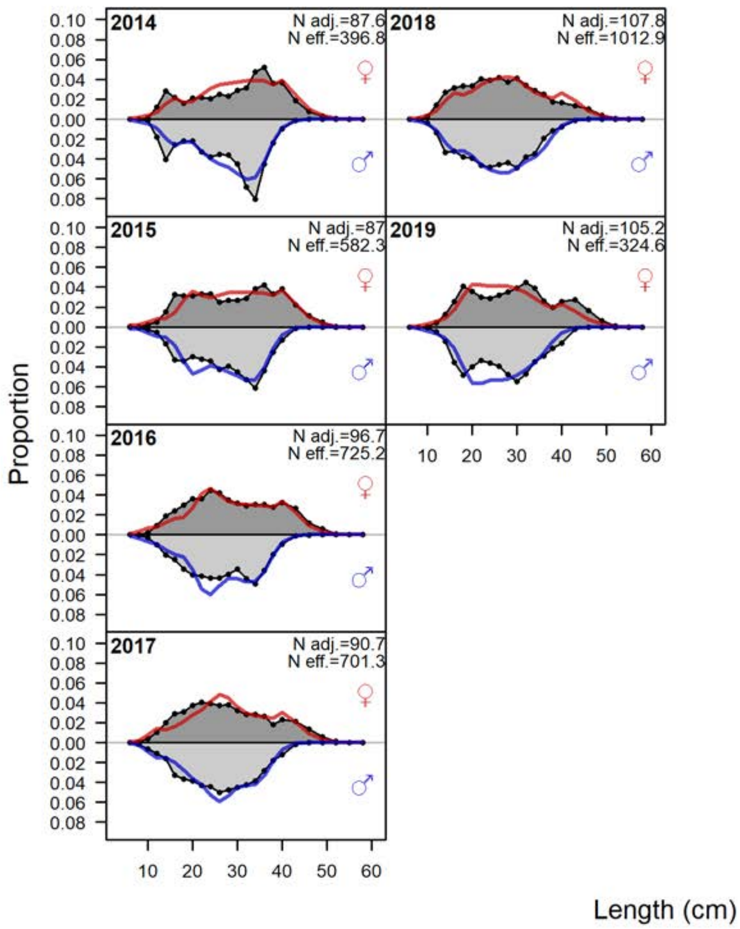
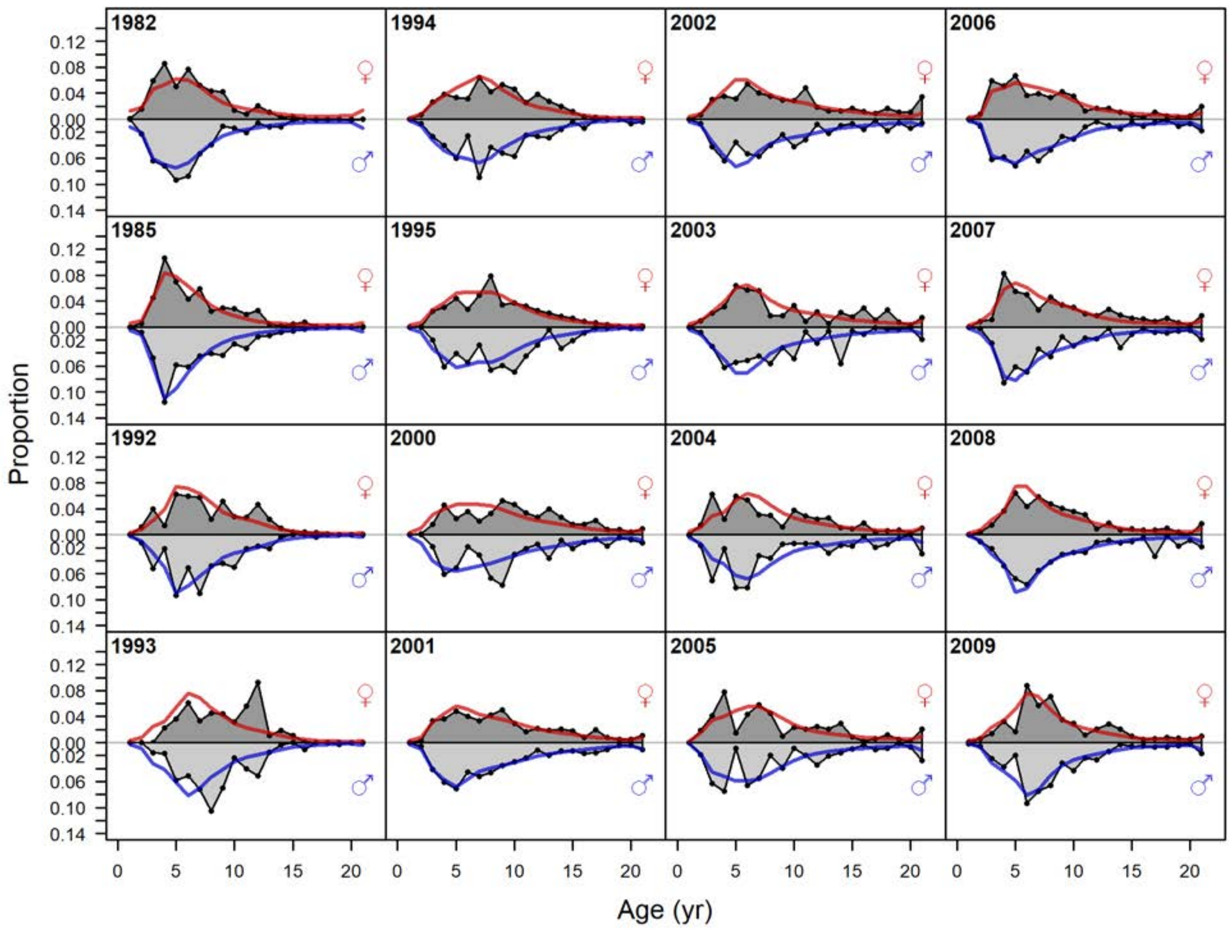


Figure 9.26. As for Figure 9.25, but for 2014-2019.


1982
1994
2002
2006
1985
1995
2003
2007
1992
2000
2004
2008
1993
2001
2005
2009
Proportion
Age (yr)
0.12
0.08
0.04
0.00
0.02
0.06
0.10
0.14
0
5
10
15
20

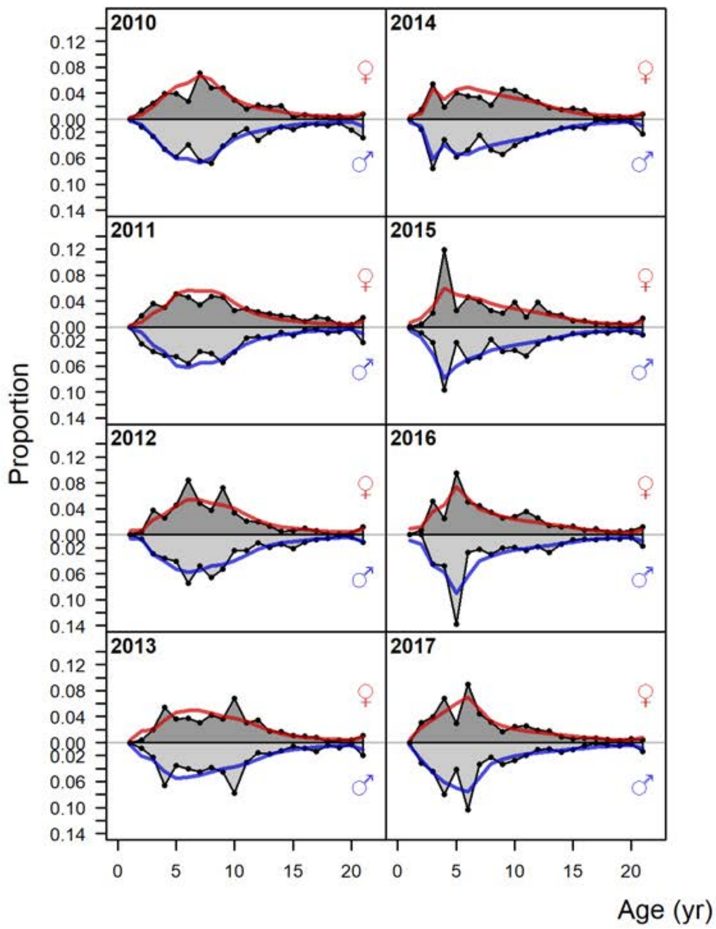
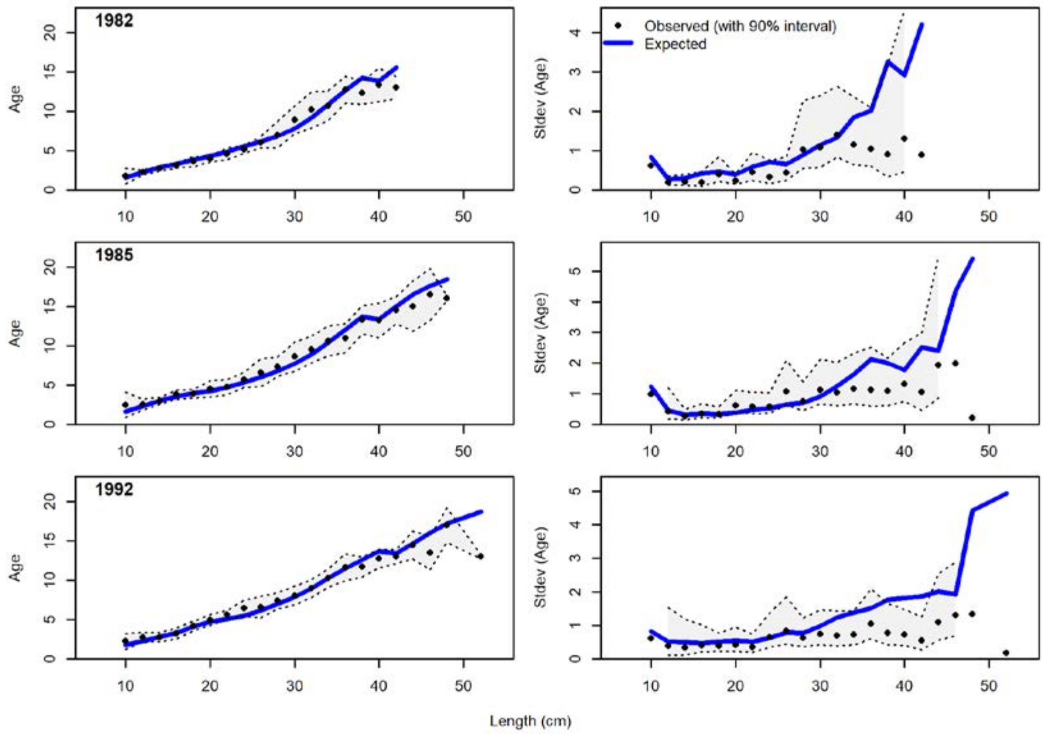


Figure 9.27. Observed (grey filled area and black line) and expected (red and blue lines) ghost survey age compositions for males (blue lines) and females (red lines) for all years of age composition data for Model 18.2c (2020). A conditional age-at-length approach was used and age composition aggregated over length bins was not fit in the objective function.


1982
1985
1992
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

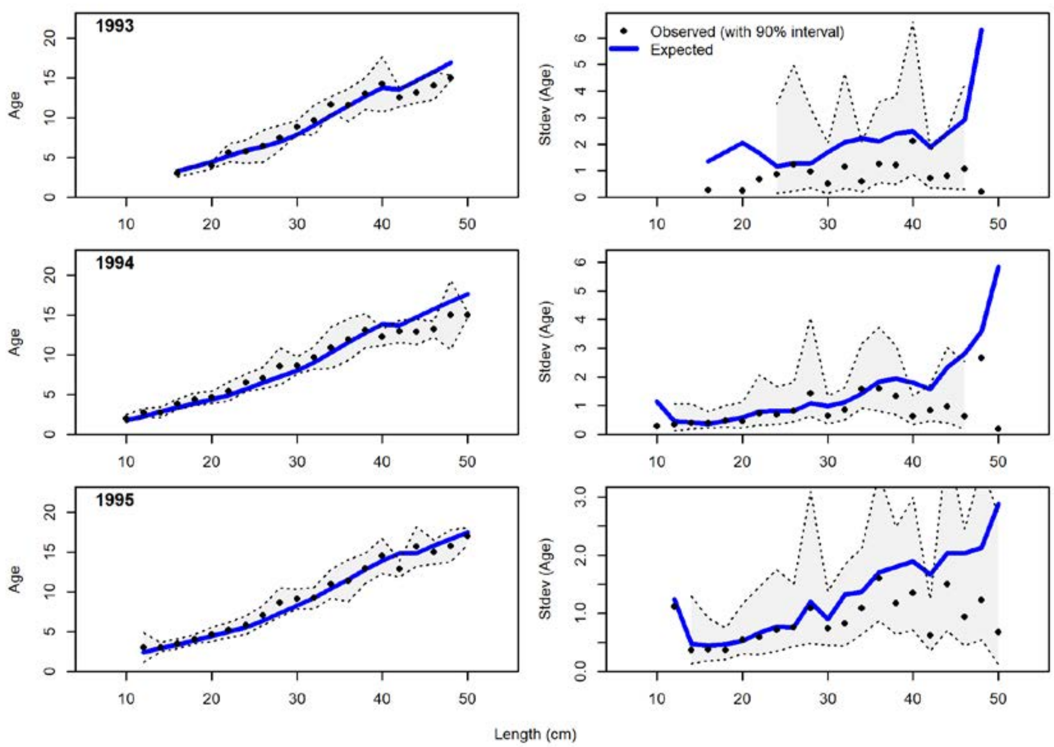
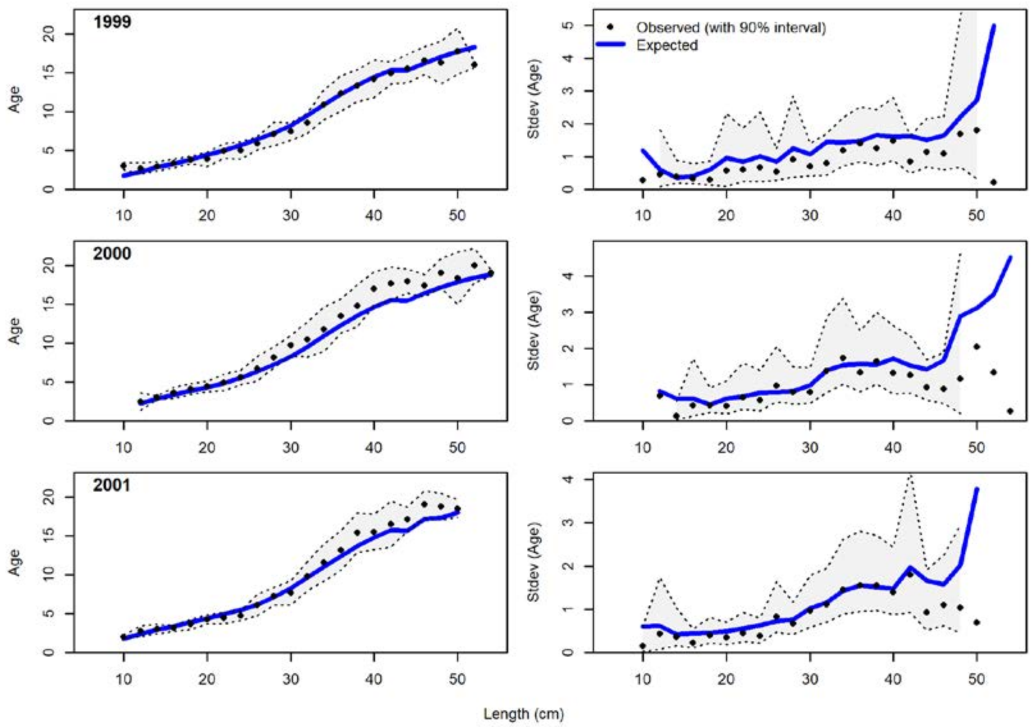

1993
1994
1995
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

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.



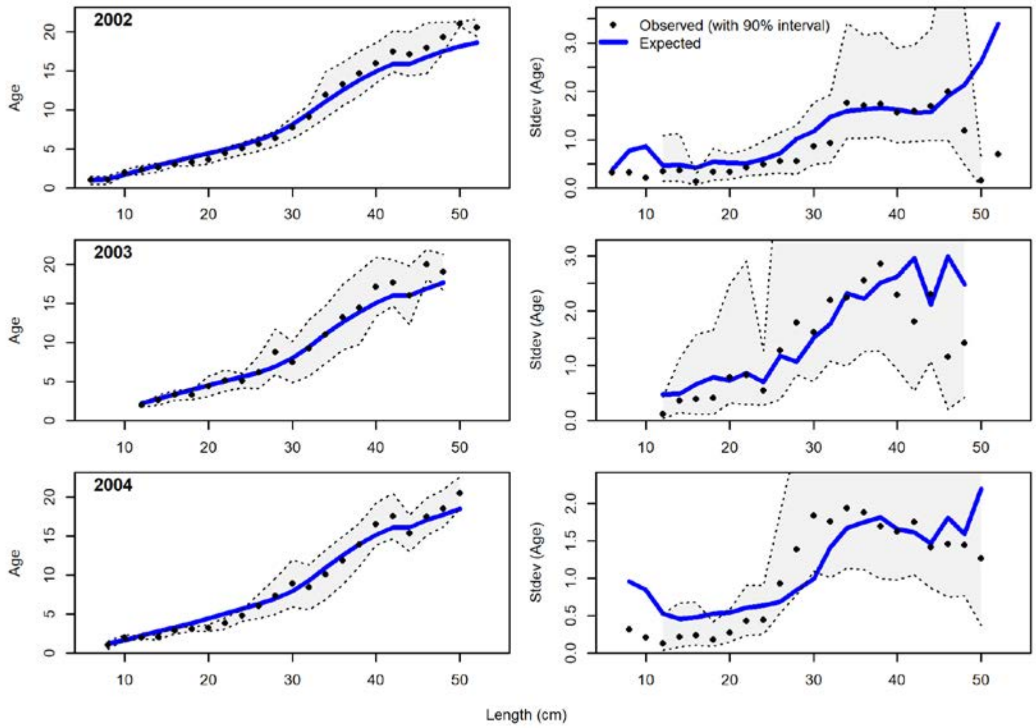
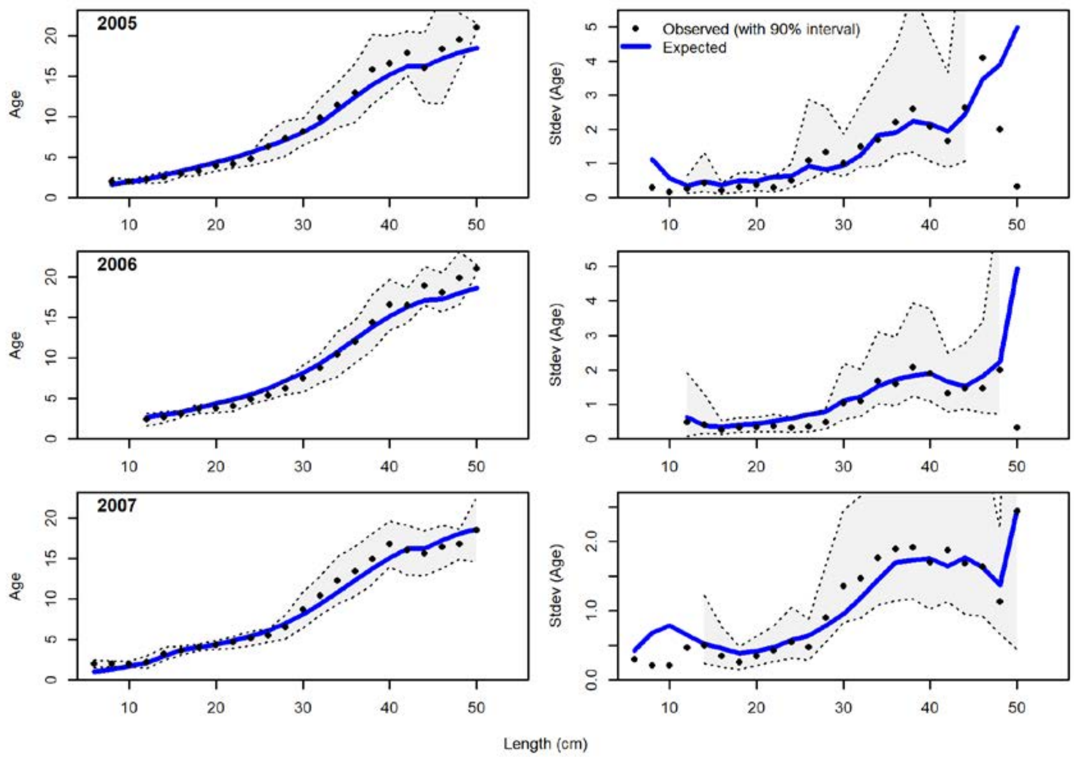


Figure 9.29. As for Figure 9.28, but for years 1999-2004.


2005
2006
2007
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

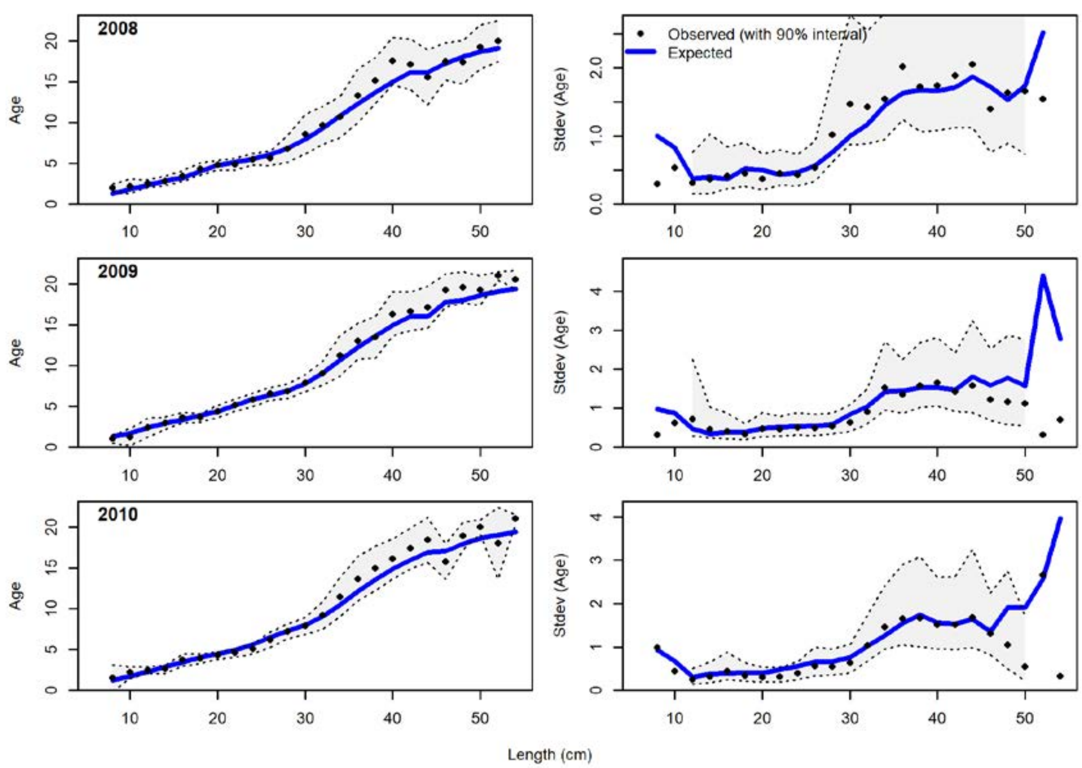
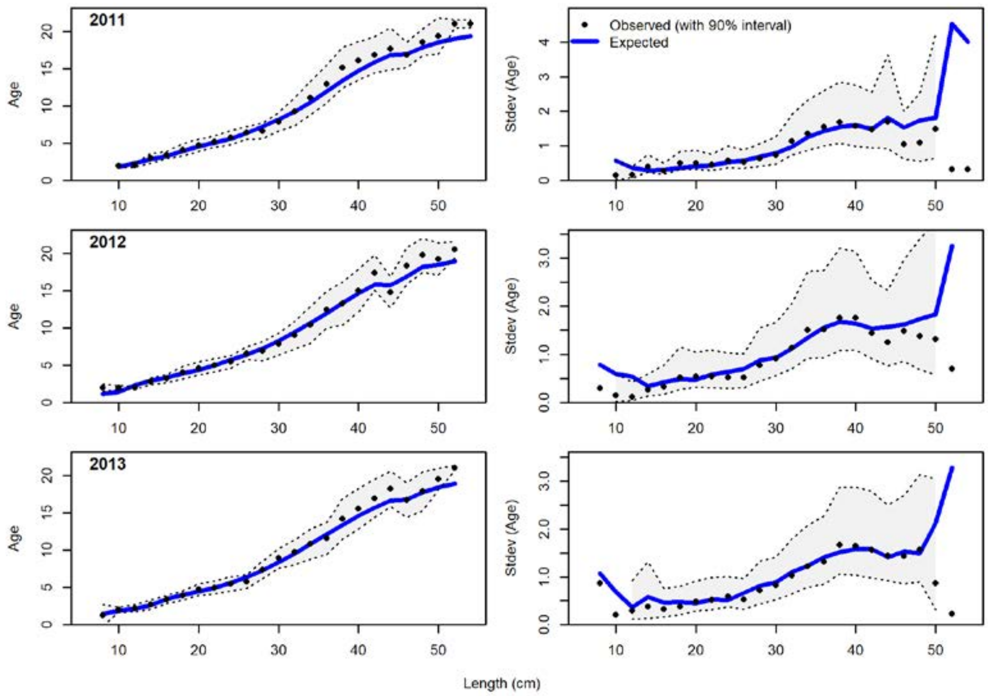
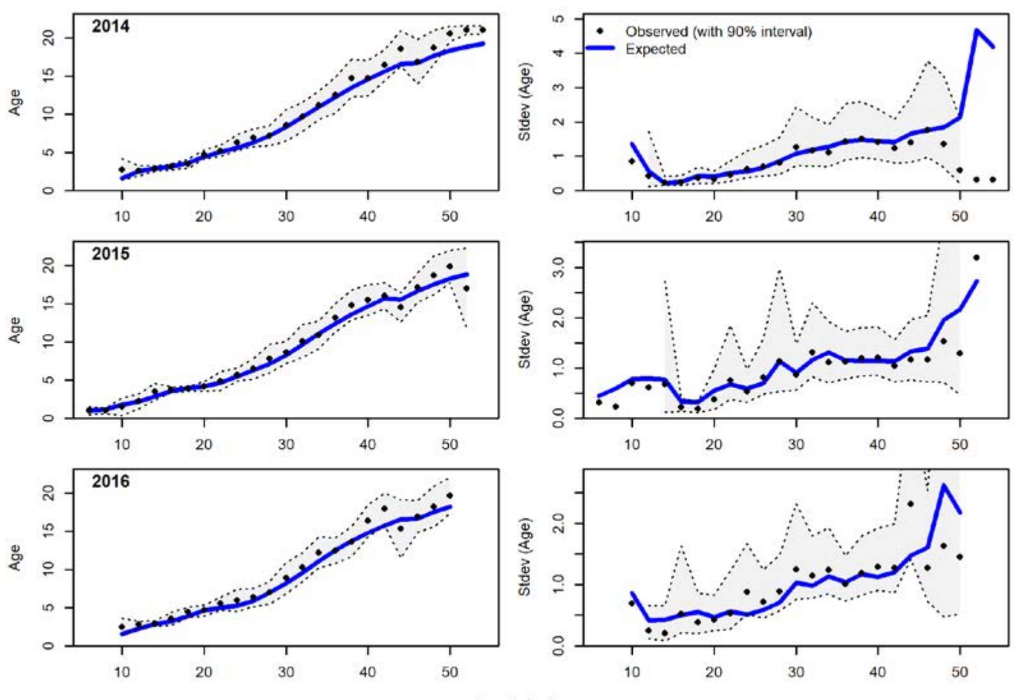

2008
2009
2010
Age
Stdev (Age)
Observed (with 90% interval)
Expected
Length (cm)

Figure 9.30. As for Figure 9.28, but for years 2005-2010.





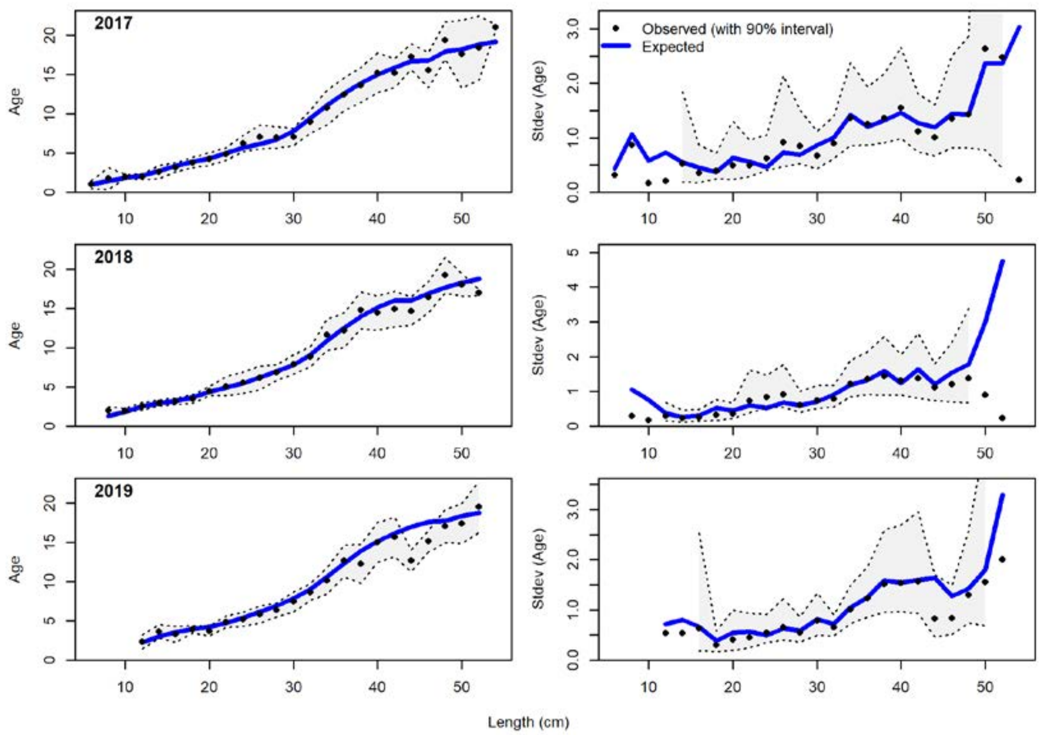


Figure 9.31. As for Figure 9.28, but for years 2011-2019.

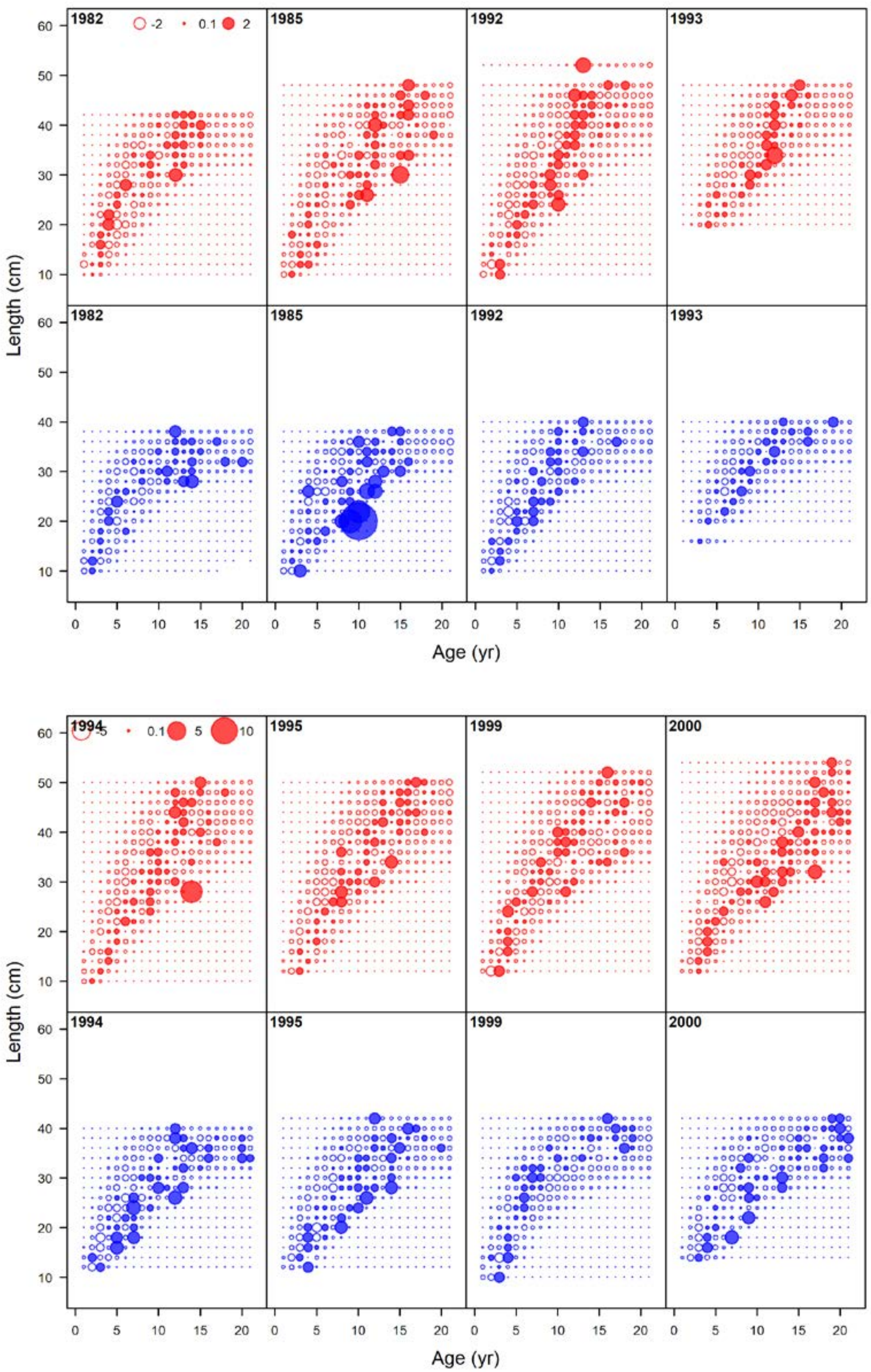
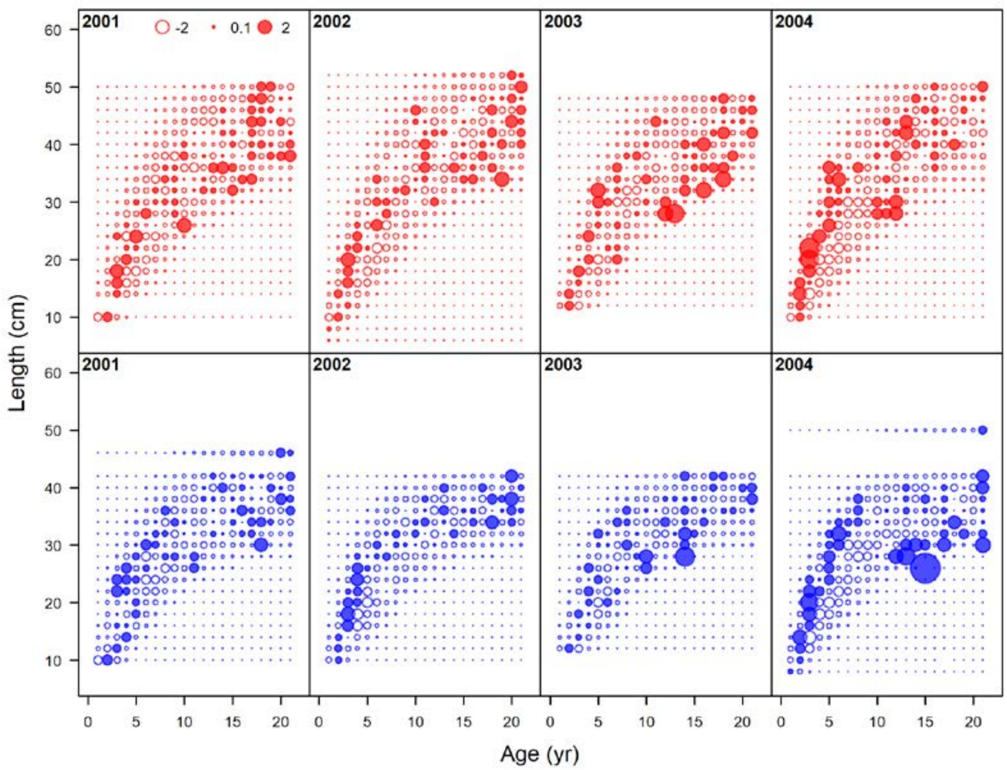


Figure 9.32. Pearson residuals for model fits to conditional age-at-length data for females (red) and males (blue) for years 1982-2001. Filled circles indicate positive residuals (observed>expected) and open circles indicate negative residuals (observed<expected). The maximum value was 20.55.



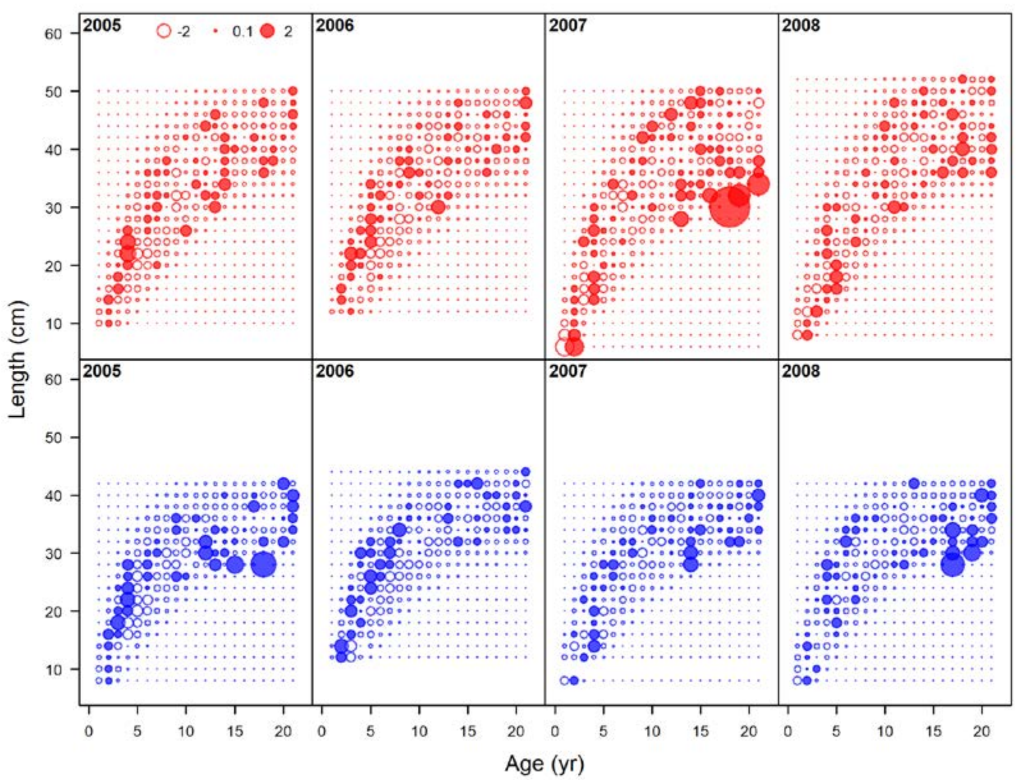
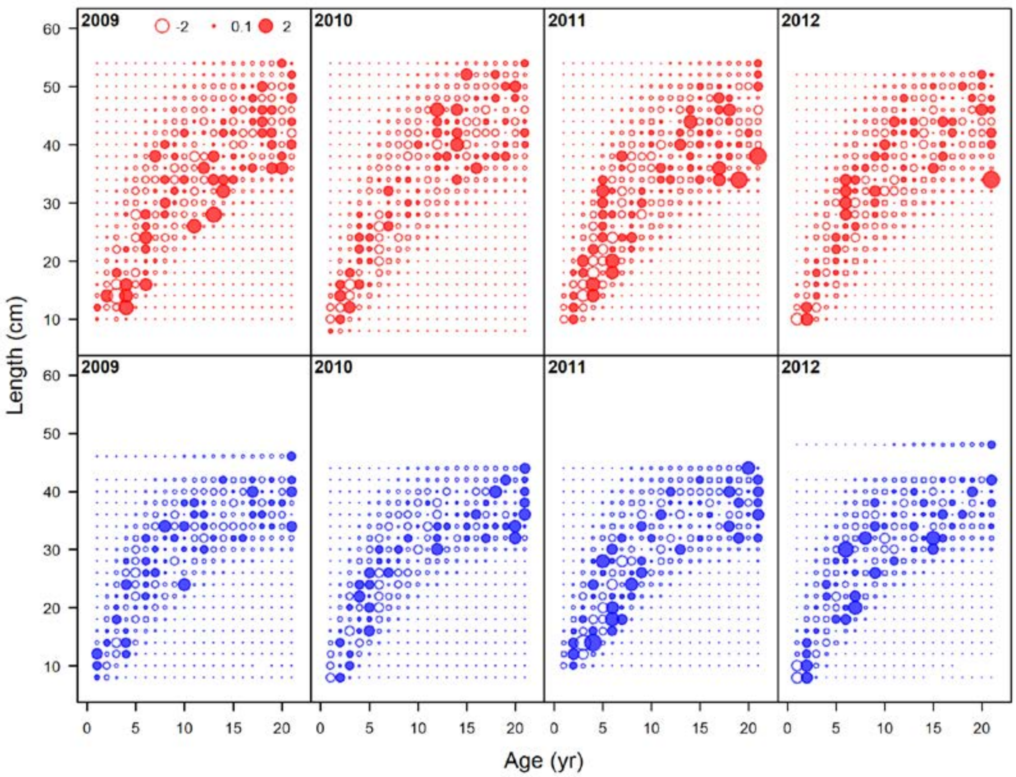
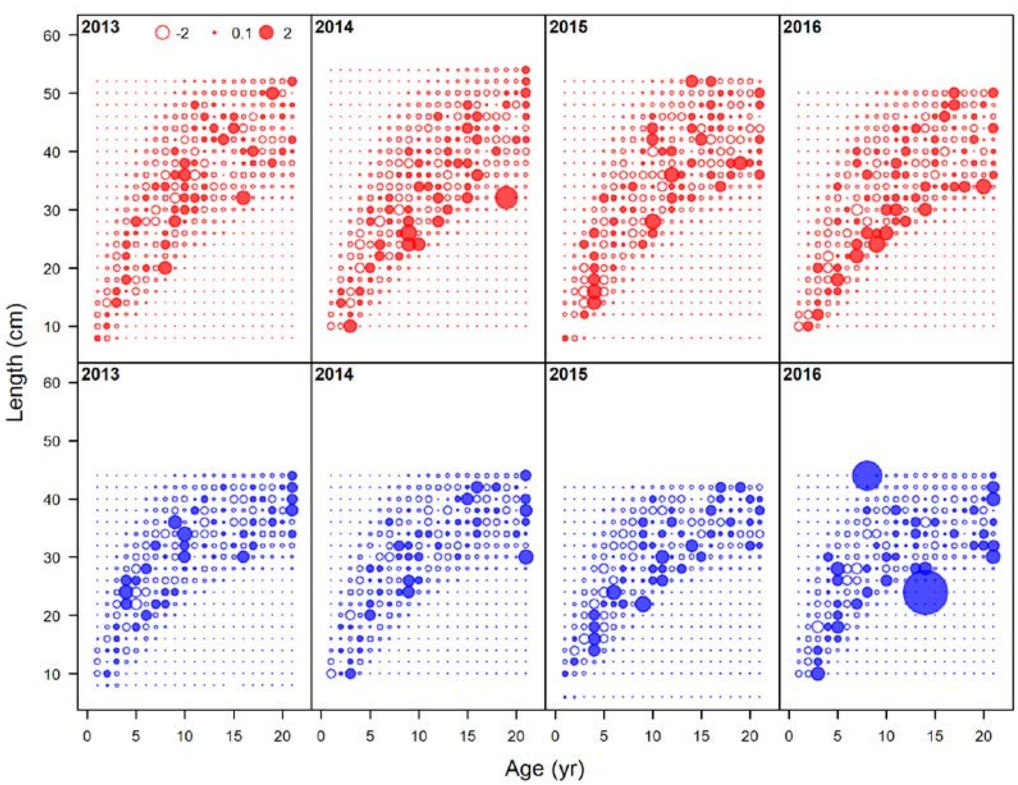


Figure 9.33. As for Figure 9.32, but for years 2002-2009.


2009
-2
0.1
2
2010
2011
2012
Length (cm)
Age (yr)


2013
-2
0.1
2
2014
2015
2016
Length (cm)
Age (yr)

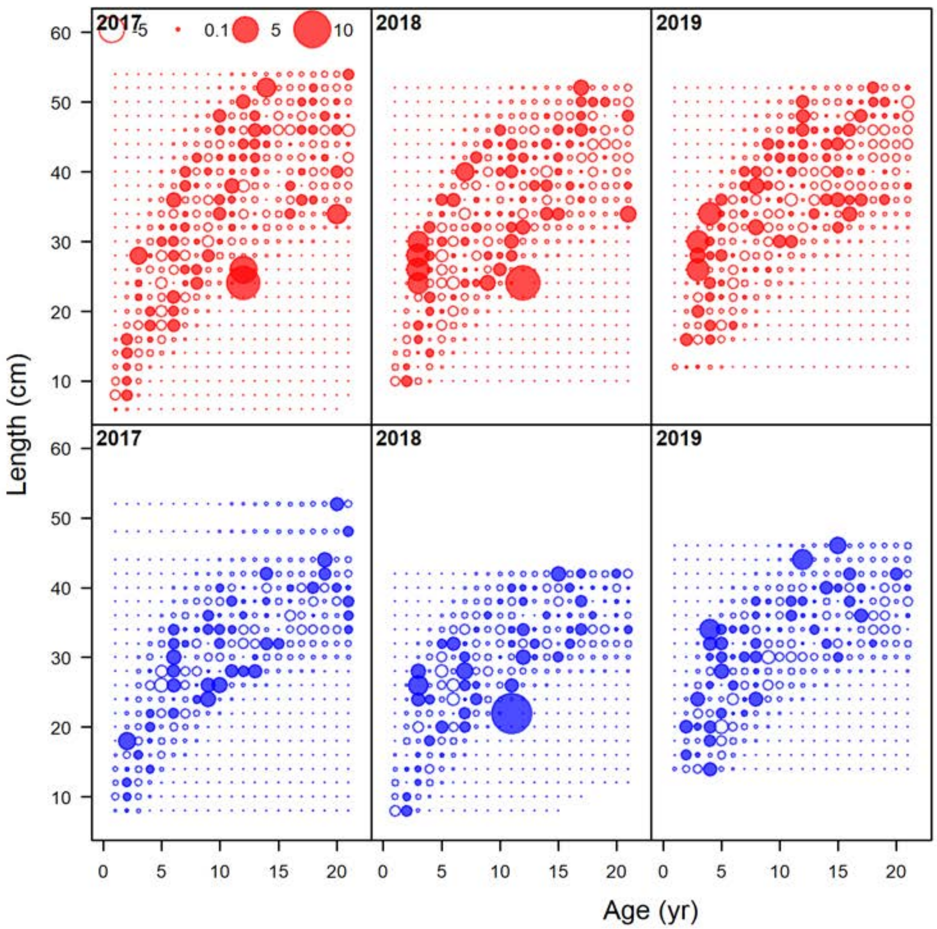
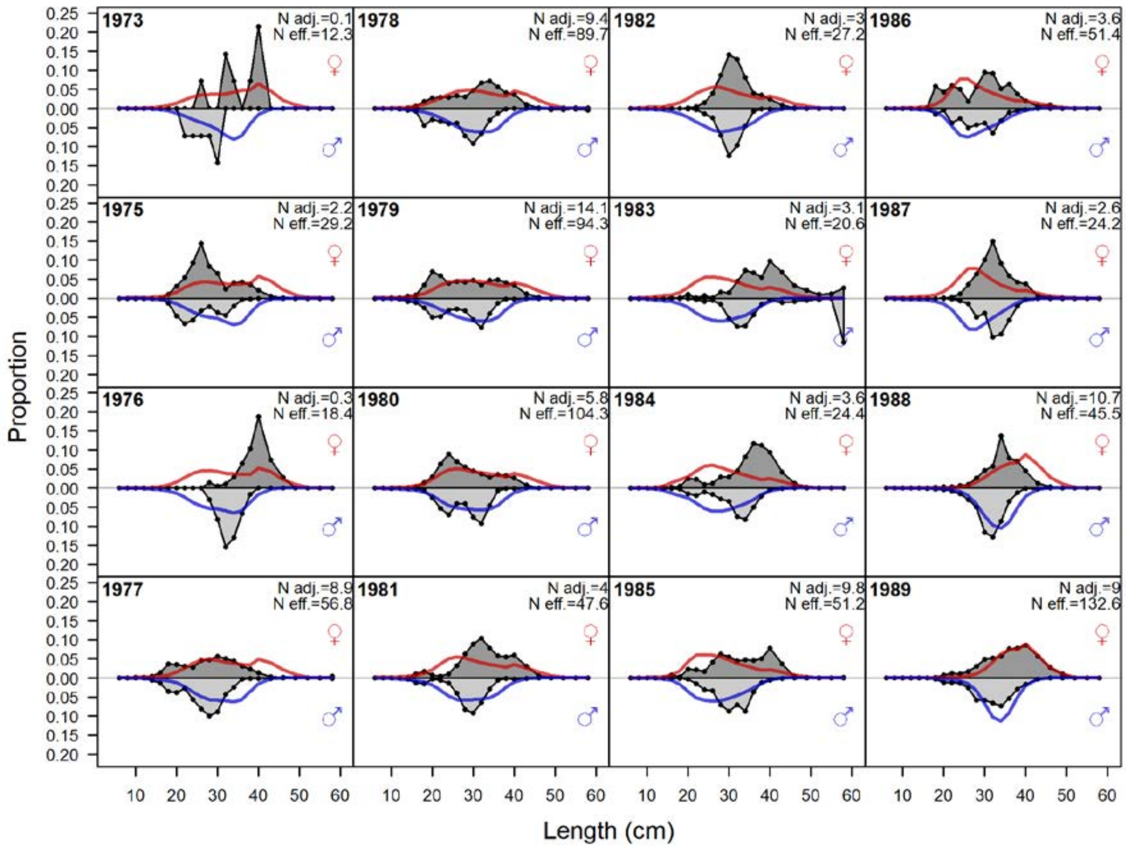


Figure 9.34. As for Figure 9.32, but for years 2010-2019.


1973
N adj.=0.1
N eff.=12.3
1978
N adj.=9.4
N eff.=89.7
1982
N adj.=3
N eff.=27.2
1986
N adj.=3.6
N eff.=51.4
1975
N adj.=2.2
N eff.=29.2
1979
N adj.=14.1
N eff.=94.3
1983
N adj.=3.1
N eff.=20.6
1987
N adj.=2.6
N eff.=24.2
1976
N adj.=0.3
N eff.=18.4
1980
N adj.=5.8
N eff.=104.3
1984
N adj.=3.6
N eff.=24.4
1988
N adj.=10.7
N eff.=45.5
1977
N adj.=8.9
N eff.=56.8
1981
N adj.=4
N eff.=47.6
1985
N adj.=9.8
N eff.=51.2
1989
N adj.=9
N eff.=132.6
Proportion
Length (cm)

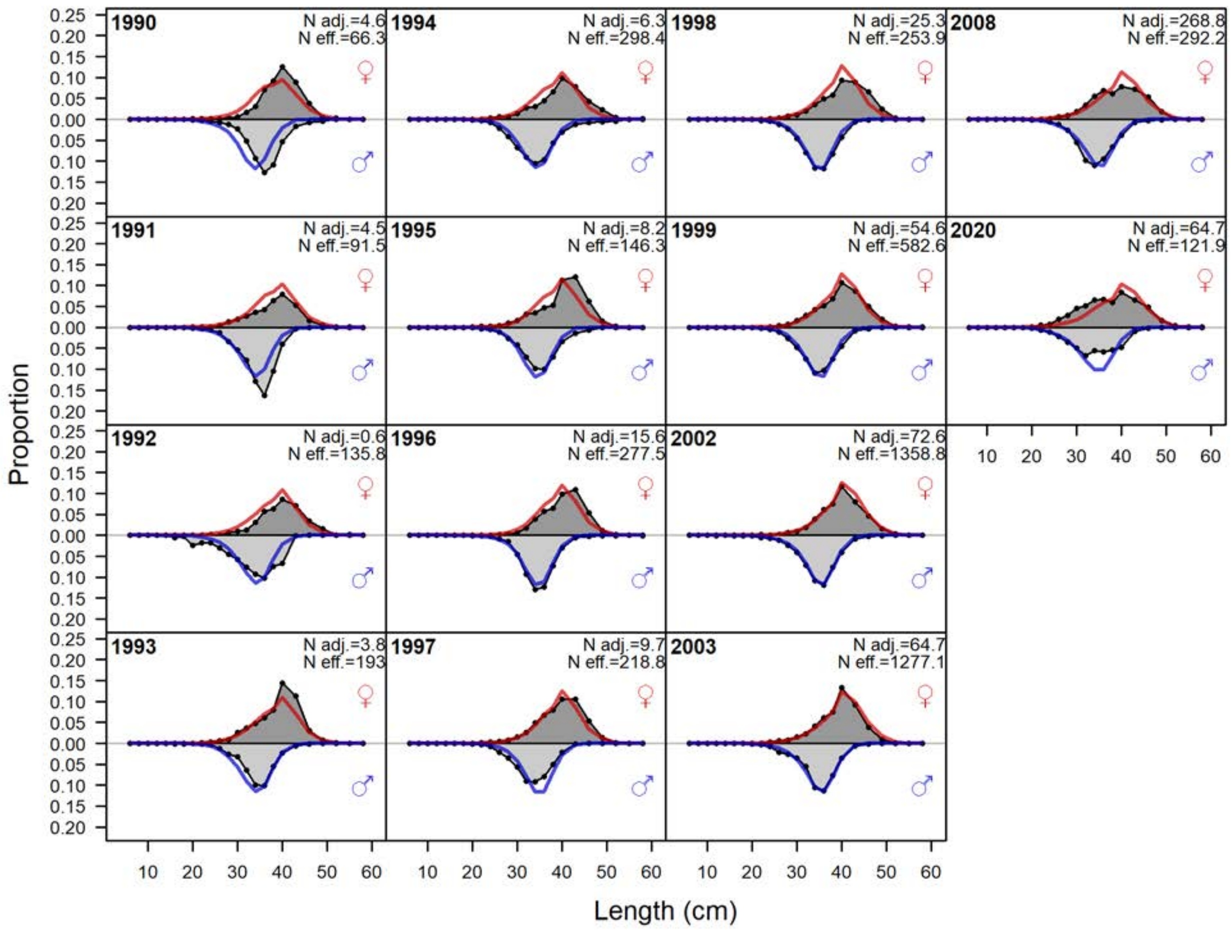


Figure 9.35. Observed (grey filled area and black line) and expected (red and blue lines) fishery length compositions for males (blue lines) and females (red lines) for all years for Model 18.2c (2020). Lengths compositions are only included in the model likelhiood for years when there are not age compositions, otherwise the lengths are included as a ghost fleet (Fig. 9.36).

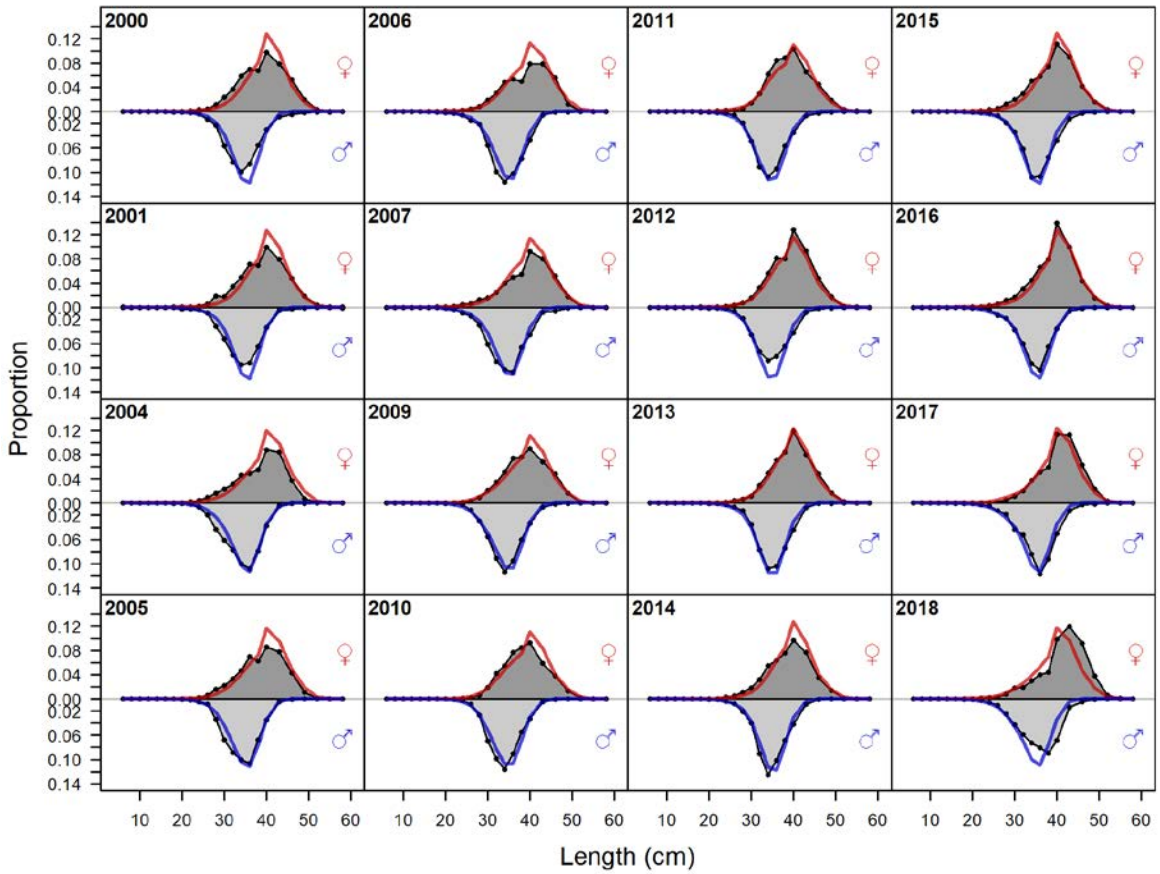
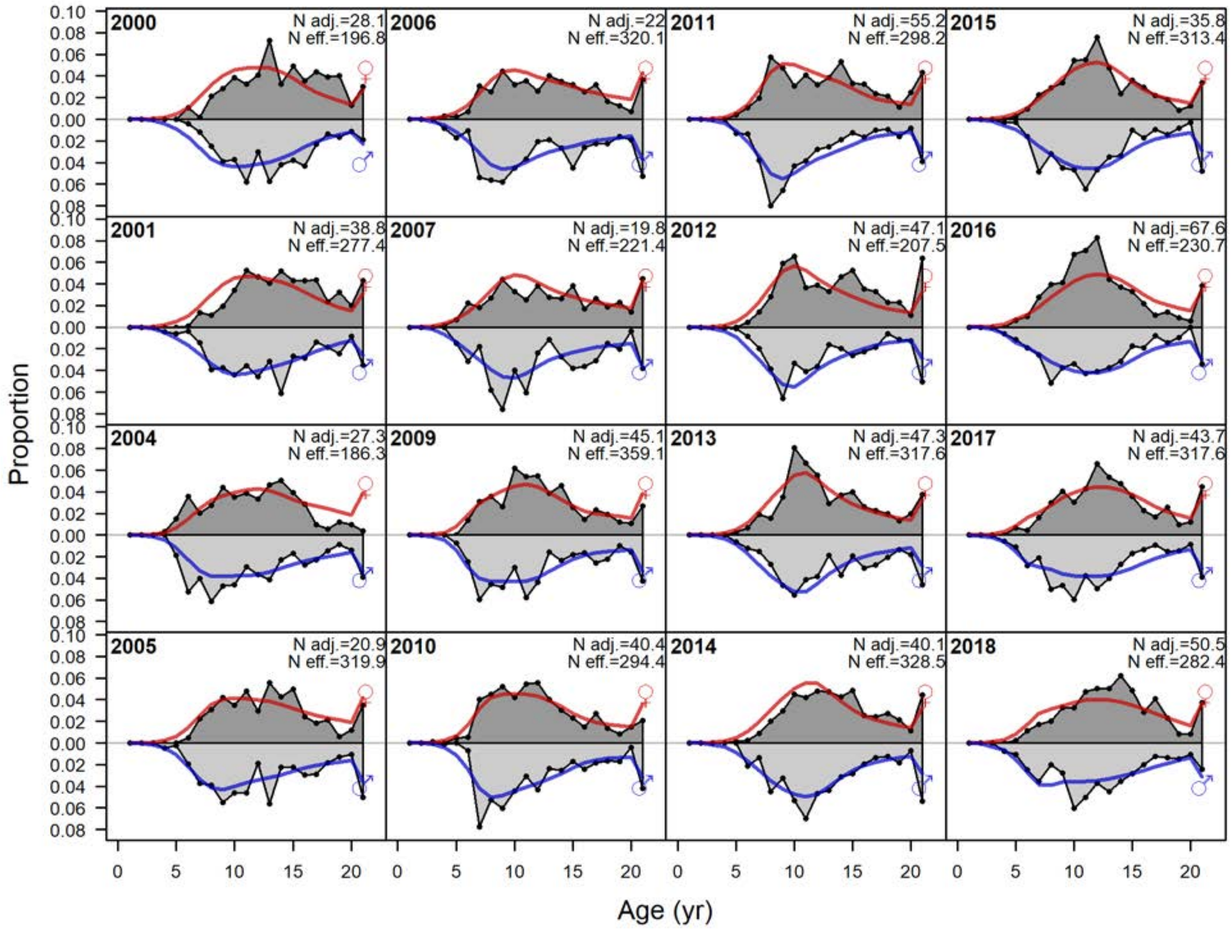


Figure 9.36. Observed (grey filled area and black line) and expected (red and blue lines) ghost fishery length compositions for males (blue lines) and females (red lines) for all years for Model 18.2c (2020). Fishery age composition data exist and the model fit to these data in the years represented in this figure, and therefore the objective function did not fit to length composition data in these years.


2000
N adj.=28.1
N eff.=196.8
2006
N adj.=22
N eff.=320.1
2011
N adj.=55.2
N eff.=298.2
2015
N adj.=35.8
N eff.=313.4
2001
N adj.=38.8
N eff.=277.4
2007
N adj.=19.8
N eff.=221.4
2012
N adj.=47.1
N eff.=207.5
2016
N adj.=67.6
N eff.=230.7
2004
N adj.=27.3
N eff.=186.3
2009
N adj.=45.1
N eff.=359.1
2013
N adj.=47.3
N eff.=317.6
2017
N adj.=43.7
N eff.=317.6
2005
N adj.=20.9
N eff.=319.9
2010
N adj.=40.4
N eff.=294.4
2014
N adj.=40.1
N eff.=328.5
2018
N adj.=50.5
N eff.=282.4
Proportion
Age (yr)

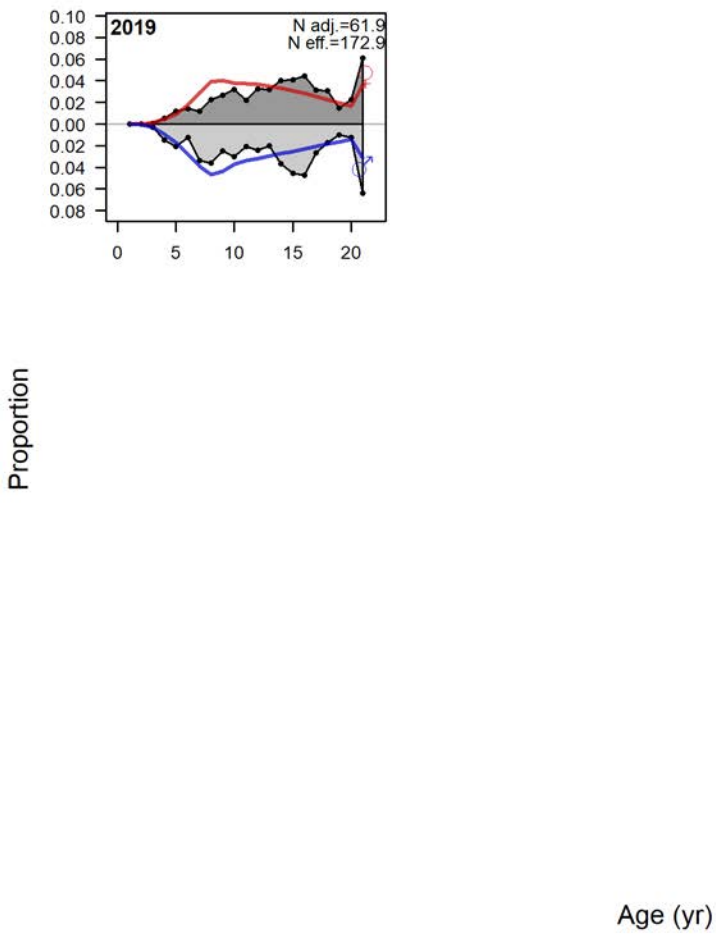


Figure 9.37. Observed (grey filled area and black line) and expected (red and blue lines) fishery age compositions for males (blue lines) and females (red lines) for Model 18.2c (2020).

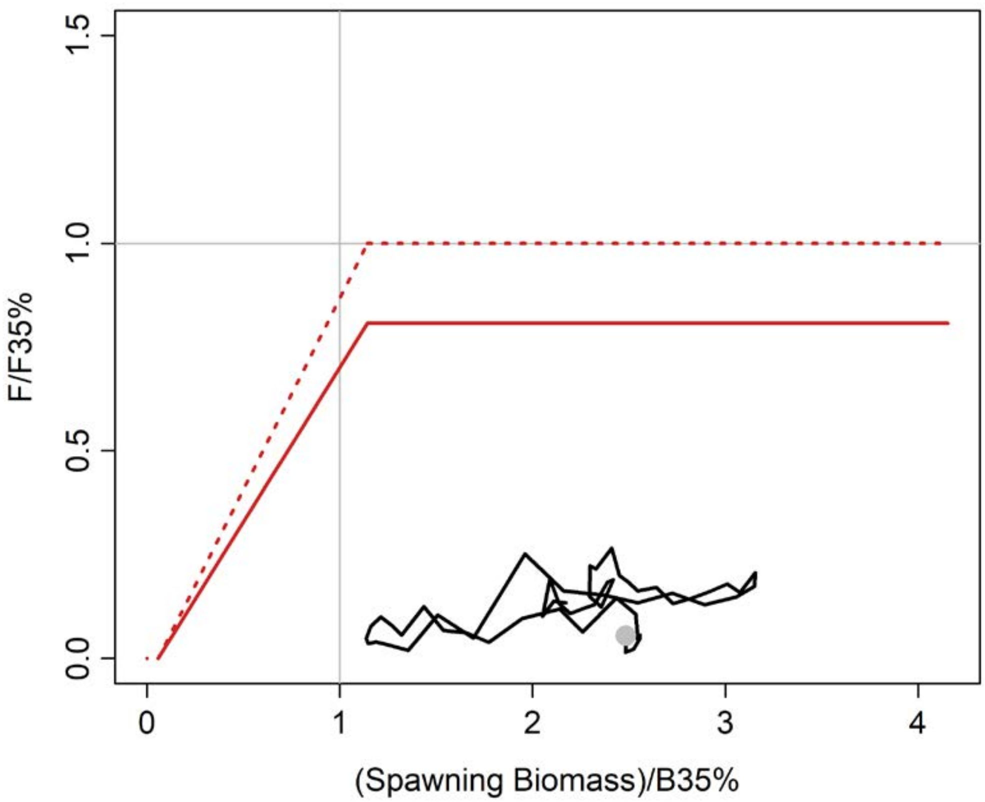
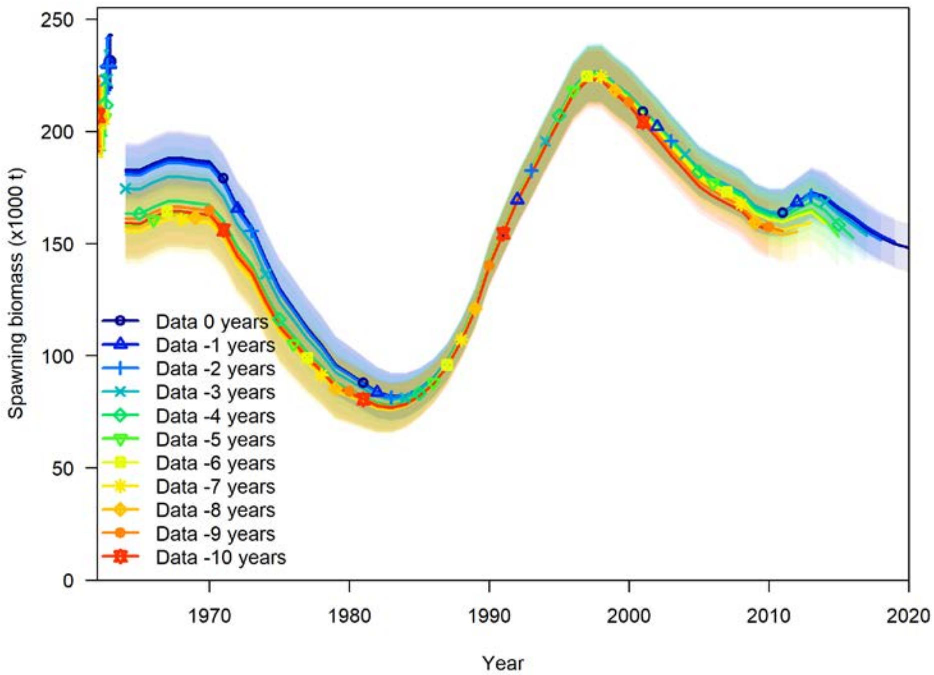
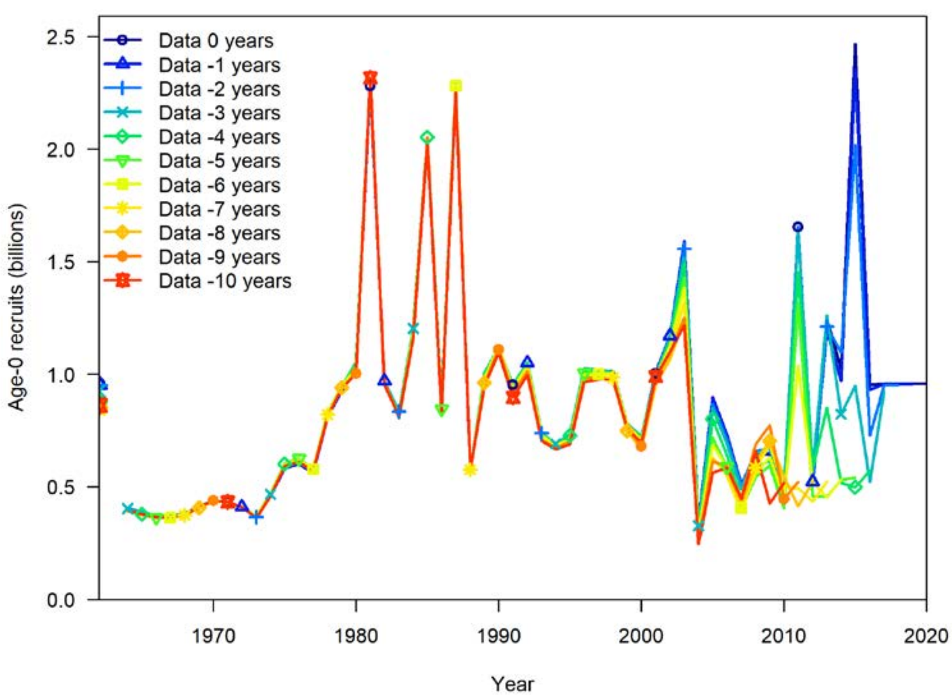


Figure 9.38. Phase plot showing spawning biomass and apical fishing mortality relative to B35% and F35%, respectively for each model year in addition to two projection years (black line). The grey dot shows the first year plotted (1964). The solid red line shows the ABC Tier 3 control rule and the dotted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


Spawning biomass (x1000 t)
Year
Data 0 years
Data -1 years
Data -2 years
Data -3 years
Data -4 years
Data -5 years
Data -6 years
Data -7 years
Data -8 years
Data -9 years
Data -10 years


Age-0 recruits (billions)
Year
Data 0 years
Data -1 years
Data -2 years
Data -3 years
Data -4 years
Data -5 years
Data -6 years
Data -7 years
Data -8 years
Data -9 years
Data -10 years

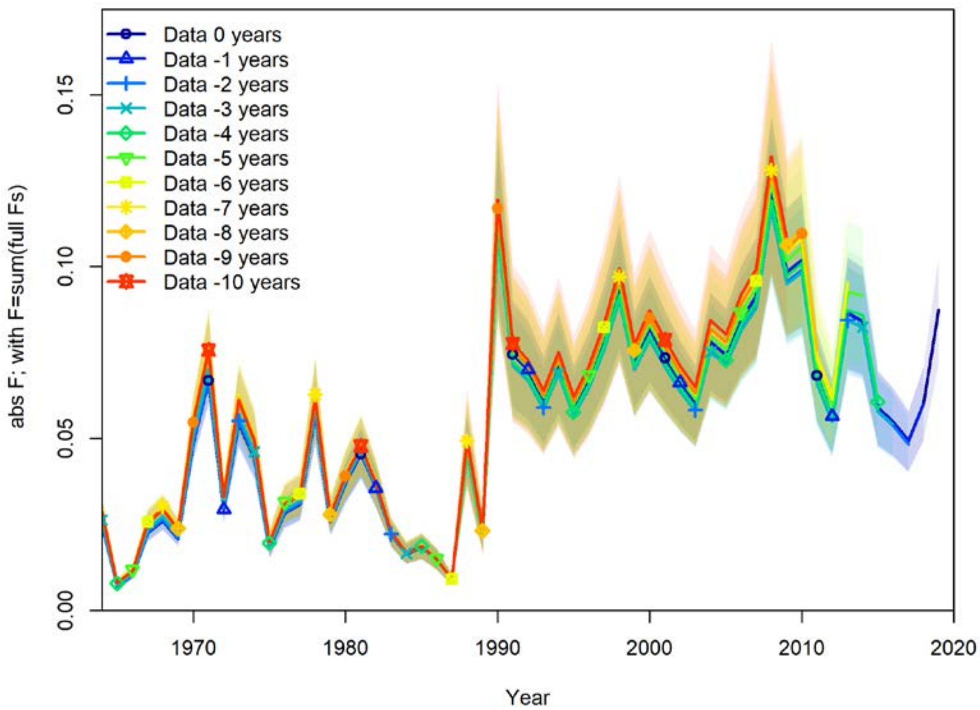


Figure 9.39. Spawning stock biomass (top), recruitment (middle), and fishing mortality (bottom) for retrospective model runs leaving out 0 to 10 years of the most recent data for Model 18.2c. Vertical lines show corresponding 95% asymptotic confidence intervals.

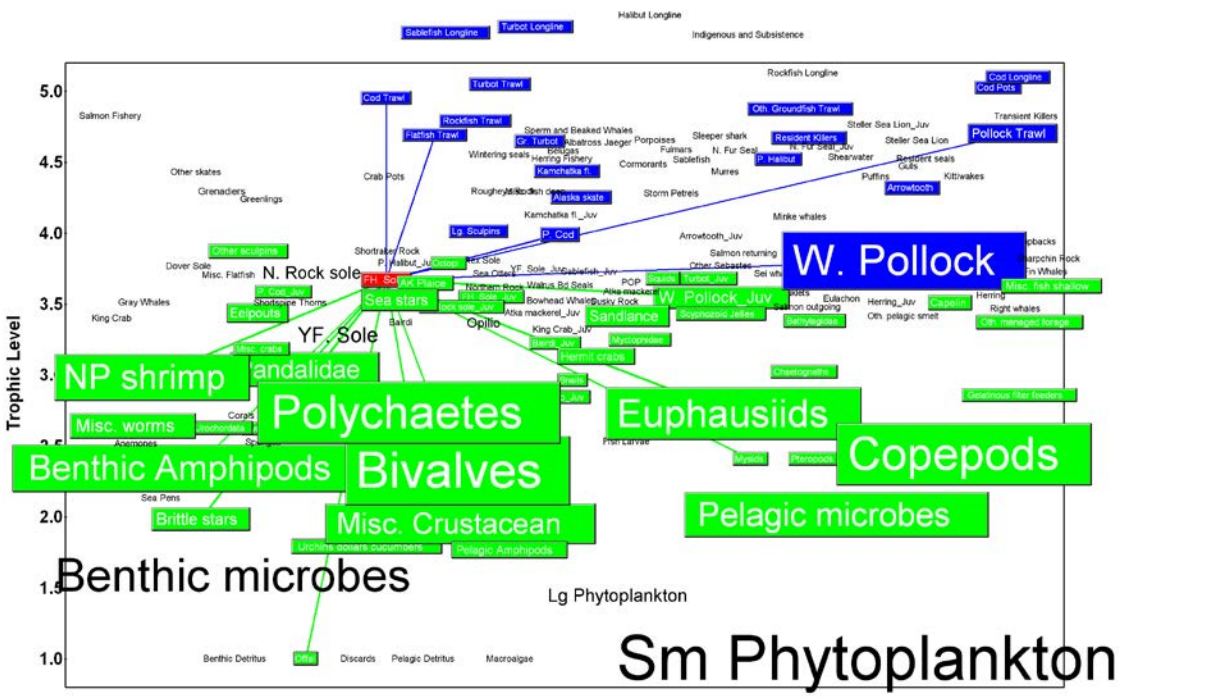


Figure 9.40. Ecosystem links to adult flathead sole in the eastern Bering Sea (based on a balanced ecosystem model for the eastern Bering Sea in the early 1990s; Aydin et al, 2007). Green boxes: prey groups; blue boxes: predator groups. Box size reflects group biomass. Lines indicate significant linkages.

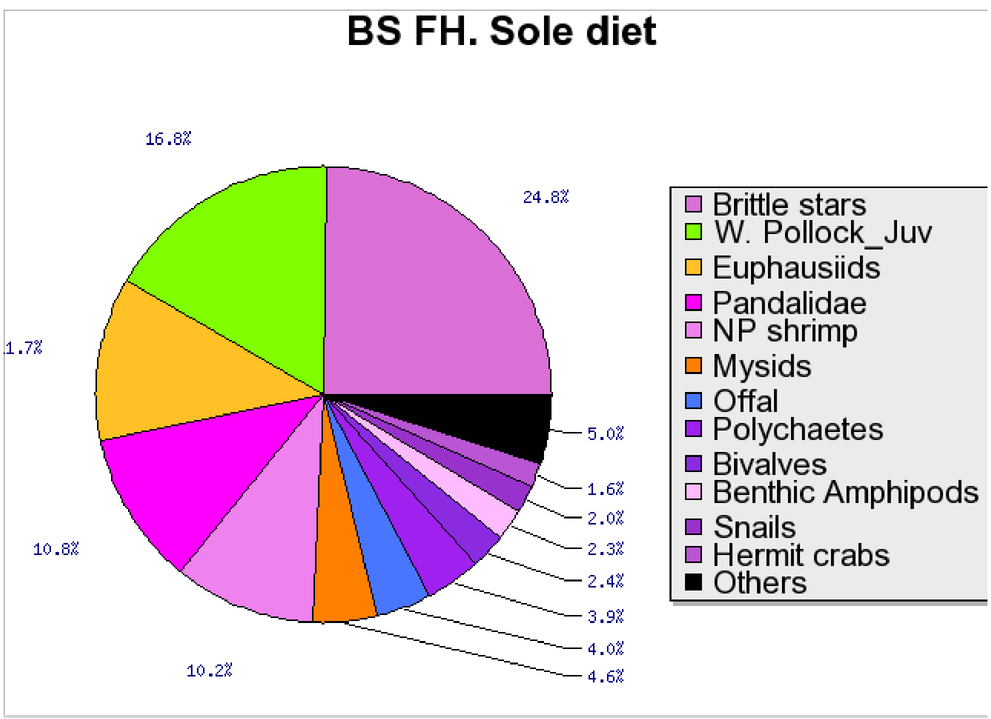


Figure 9.41. Diet composition of adult flathead sole in the eastern Bering Sea (based on a balanced ecosystem model for the eastern Bering Sea in the early 1990s; Aydin et al, 2007).

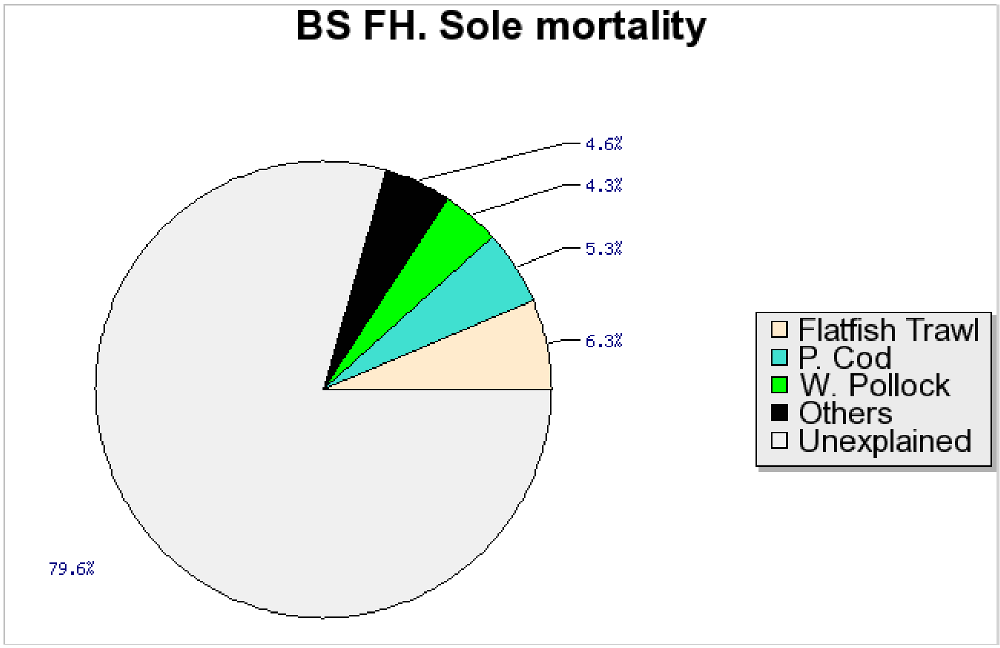


Figure 9.42. Mortality sources for flathead sole in the eastern Bering Sea (based on a balanced ecosystem model for the eastern Bering Sea in the early 1990s; Aydin et al, 2007).

Appendix A

Supplemental Catch Data

Table A.1-A3. 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
2018	2,144	12	20,825	22,981
2019	2,679	2	23,998	26,680

	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
2018	2,144		12
2019	2,679		2

	NMFS									
Year	AFSC Annual Longline Survey	Aleutian Island Bottom Trawl Survey	Bering Sea Acoustic Survey	Bering Sea Bottom Trawl Survey	Bering Sea Slope Survey	Eastern Bering Sea Bottom Trawl Survey	Eastern Bering Sea Walleye Pollock Acoustic-Trawl Survey	Northern Bering Sea Bottom Trawl Survey	Pollock EFP 11-01	Summer EBS Survey with Russia
2011	105					26,921			5,529	
2012	5	1,082			4,479	16,122			552	45
2013	107					19,540				
2014	22	2,518				20,578				

2015	180			15,740		
2016	6	1,444	3,182	17,624		
2017	86			21,792		670
2018	9	1,566		18,781	18	451
2019	112			23,211		675