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

By

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Executive Summary

Summary of Changes in Assessment Inputs

(1) 2016 catch biomass was added to the model
(2) 2015 catch biomass was updated to reflect October – December 2015 catches
(3) 2013-2015 fishery age composition data were added
(4) 2015-2016 fishery length composition data were added to the model.
(5) 2015-2016 Eastern Bering Sea (EBS) shelf survey biomass and 2016 Aleutian Islands (AI) survey biomass were added to the linear regression used to determine estimates of AI survey biomass in years when no AI survey occurred; a new survey biomass index was added to the assessment model for 1982-2016 based on updated linear regression results.
(6) 2015-2016 survey bottom temperatures were added to the model.
(7) 2014-2015 survey age composition data were added to the model.
(8) 2015-2016 survey length composition data were added to the model
(9) Estimates of the length-at-age, length-weight, and weight-at-age relationships, and the length-at-age transition matrices were updated by adding data from 2001 to 2015. Growth estimates therefore include data from 1985, 1992-1995, and 2000-2015.

Summary of Changes in Assessment Methodology

All age- and length-composition data were weighted using methods described in McAllister and Ianelli (1997) to approximate effective sample size for each year and data type. The harmonic mean over years was used to approximate the effective sample size for each data type and the assessment model was iteratively tuned such that input and effective sample sizes were approximately equal.

Summary of Results

The key results of the assessment, based on the author's preferred model, are compared to the key results of the accepted 2015 update assessment in the table below.

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2016	2017	2017*	2018*
M (natural mortality rate)	0.2	0.2	0.2	0.2
Tier	3a	3a	3a	3a
Projected total (3+) biomass (t)	737,777	747,389	747,557	758,543
Projected Female spawning biomass (t)	240,427	231,139	223,469	206,029
$B_{100\%}$	319,206	319,206	322,938	322,938
$B_{40\%}$	127,682	127,682	129,175	129,175
$B_{35\%}$	111,722	111,722	113,028	113,028
F_{OFL}	0.35	0.35	0.41	0.41
$maxF_{ABC}$	0.28	0.28	0.34	0.34
F_{ABC}	0.28	0.28	0.34	0.34
OFL (t)	79,562	77,544	81,654	79,136
maxABC (t)	66,250	64,580	68,278	66,164
ABC (t)	66,250	64,580	68,278	66,164
Status	As determined in 2015 for:		As determined in 2016 for:	
	2014	2015	2015	2016
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 10,013 t and 14,020 t for 2016 and 2017 used in place of maximum permissible ABC. The final catch for 2016 was estimated by taking the average tons caught between October 22 and December 31 over the previous 5 years (2011-2015) and adding this average amount to the catch-to-date as of October 22, 2016. The 2017 catch was estimated as the average of the total catch in each of the last 5 years (2011-2015). The 2018 catch was calculated as the projected maxABC for 2018.

Responses to SSC and Plan Team Comments on Assessments in General

SSC, December 2015: The SSC reminds the authors and PTs to follow the model numbering scheme adopted at the December 2014 meeting.

The author will follow the new numbering scheme in the next full assessment.

Many assessments are currently exploring ways to improve model performance by re-weighting historic survey data. The SSC encourages the authors and PTs to refer to the forthcoming CAPAM data-weighting workshop report.

The current assessment includes data weighting according to methods detailed in McAllister and Ianelli (1997).

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

SSC December 2015 comments for BSAI flathead sole: The SSC supports the future research and model improvement work identified by the authors to assess residual patterns in the survey length composition including examining growth estimates, assumptions about selectivity, and the estimation of an ageing error matrix.

Length-at-age, the length-age transition matrix, and the weight-length relationship were re-evaluated in this year's assessment using all years of data that were available (up to 2015). Residual patterns in survey length compositions were lessened by including the updated estimates of growth, but not eliminated. A Stock Synthesis model was developed for BSAI flathead sole and will be presented to the BSAI Plan Team before the next full assessment. The Stock Synthesis model is flexible and will allow for exploration of alternative assumptions about selectivity. An updated ageing error matrix will be estimated for the next full assessment.

Introduction

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

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

Walters and Wilderbuer (1997) illustrated the possible ramifications of combining demographic information from the two species. Although Bering flounder typically represent less than 3% of the combined survey biomass for the two species, lumping the two species increases the uncertainties associated with estimates of life-history and population parameters. Accurate identification of the two species occurs in the annual EBS trawl survey. The fisheries observer program also provides information on Bering flounder in haul and port sampling for fishery catch composition. It may be possible in the near future to consider developing species-specific components for ABC and OFL for this complex. Current 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

Prior to 1977, catches of flathead sole (*Hippoglossoides* spp.) were combined with several other flatfish species in an "other flatfish" management category. These catches increased from around 25,000 t in the 1960s to a peak of 52,000 t in 1971. At least part of this apparent increase was due to better species identification and reporting of catches in the 1970s. After 1971, catches declined to less than 20,000 t in 1975. Catches during 1977-89 averaged 5,286 t. Since 1990, annual catches have averaged approximately 17,000 t (Table 9.1, Figure 9.1). The catch in 2008 (24,539 t) was the highest since 1998. The average catch from 2011-2015 (14,020 t) was smaller than that from the previous time period (2006-2010; 20,181 t). The catch in 2015 was 11,308 t and the catch-to-date in 2016 (as of October 22, 2016) was 9,353 t.

The majority of the catch is taken by non-pelagic trawl gear (77-82% for the period 2013-2016 and 63-64% in 2011 and 2012) and pelagic trawl gear (14%-17% in 2013-2016; 35% and 33% in 2011 and 2012; Table 9.2). In addition, almost all of the catch is taken from NMFS statistical areas 509, 513, 517, and 521 in each year; 14%, 55%, 9%, and 11% of the catch was taken in each of these four reporting areas, respectively, in 2016 (as of October 22, 2016; Table 9.3 and Figure 9.2).

Using observer-reported species-specific catches and extrapolating to the total *Hippoglossoides* spp. catch within each area yields disaggregated estimates of total catch of flathead sole and Bering flounder (Table 9.4, Figure 9.2). Bering flounder constitutes only a small percentage of the total Hippoglossoides species catch each year (0.2% and 0.07% in 2015 and 2016, respectively, Figure 9.2).

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. At present, flathead sole is 100% allocated to the Amendment 80 cooperative and limited access sectors, so directed fishing for flathead sole is prohibited in the BSAI limited access sector.

Prior to the implementation of Amendment 80 in 2008, the flathead sole directed fishery was often suspended or closed prior to attainment of the TAC for exceeding halibut bycatch limits; 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 flathead sole catch was discarded prior to 2008. Subsequent to Amendment 80 implementation, the average discard rate has been less than 15% (Table 9.6).

Data

The following data were used in the assessment:

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

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 1977 through October 22, 2016 (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 2009-2015 were included in the assessment model (Figure 9.3; http://www.afsc.noaa.gov/REFM/docs/2016/BSAIflathead_Age_and_Length_Composition.xlsx). The sample sizes for age compositions are small for years 1994, 1995, and 1998 (Table 9.7) and they were excluded from the assessment model. Size compositions were available for 1977-2016 (Figure 9.4, http://www.afsc.noaa.gov/REFM/docs/2016/BSAIflathead_Age_and_Length_Composition.xlsx). To avoid double-counting data used to estimate parameters in the assessment model, the size composition data were excluded in the model optimization when the age composition data from the same year were included. Thus, only the flathead sole fishery size compositions for 1977-1999, 2002-2003, 2008 and 2016 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 9.5). In 2010, RACE extended the groundfish survey into the northern Bering Sea (Figure 9.5) and conducted standardized bottom trawls at 142 new stations. The data generated by this survey extension may have important implications for the future management of Bering flounder (Stockhausen et al. 2012). Unfortunately, only the standard and northwest extension areas were sampled in 2011-2016. RACE also conducts bottom trawl surveys in the Aleutian Islands (AI) on a triennial basis from 1980 to 2000 and on a biennial basis since 2002 (although no survey was conducted in 2008). Bering flounder are caught in small amounts on the EBS shelf (0-6% of *Hippoglossoides spp.* catch; (Table 9.8, Figure 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 1982-2016 (Table 9.8, Figure 9.7). A single 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 401,767 t in 2000 before increasing to a recent high of 644,948 t in 2006. The 2016 estimate was 453,060 t.

Although survey-based estimates of total biomass assume a catchability (and size-independent selectivity) of 1, previous assessments for flathead sole and other BSAI flatfish have identified a relationship between bottom temperature and survey catchability (e.g., Wilderbuer et al. 2002; Spencer et al., 2004; McGilliard et al. 2014). 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 so-called “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 it has been used subsequently (e.g., Stockhausen et al., 2011). EBS shelf mean bottom temperatures were warm from 2002-2005 and cold from 2006-2009 (Table 9.8, Figure 9.8). Bottom temperatures were colder than average and survey biomass lower than average in 2012 (1.9 deg. C and 387,043 t, respectively); bottom temperatures were warmer than average and survey biomass higher than average in 2014 (3.2 deg C and 532,886 t, respectively; Figure 9.7, Figure 9.9, Table 9.8). During the cold period from 2006-2009, the cold pool extended well to the south along the so-called “middle domain” of the continental shelf, which would be expected to have a substantial effect on survey catchability for these years. Flathead sole appear to have been constrained to the outer domain of the shelf in response to the extended cold pools in 2006-2010 and 2012 (Stockhausen et al. 2012). Spatial distribution of flathead sole and Bering flounder biomass and mean bottom temperatures from the EBS shelf survey in 2015 and 2016 are shown in Figure 9.9 for flathead sole and Bering flounder. Summer bottom temperatures in the EBS were warmer 2016 than in any other year of the EBS shelf survey (4.46 deg C). The survey biomass in 2016 was 13% higher than for 2015, while the mean bottom temperature was 33% higher than in 2015.

Sex-specific survey age and size composition data for flathead sole only from the EBS shelf survey only (“standard” survey areas) were included in the assessment (http://www.afsc.noaa.gov/REFM/docs/2016/BSAIflathead_Age_and_Length_Composition.xlsx). Survey age composition data for 1982, 1985, 1992-1995, 2000-2015 were used. Survey size composition data were available for 1982-2016, but were excluded from the model optimization in years when survey age composition data were available for the same year. Thus, only the survey size compositions for 1984-91, 1996-99, and 2016 were included in the model optimization, using 2 cm size bins.

Analytical approach

General Model Structure

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

The model was implemented AD Model Builder, automatic differentiation software developed as a set of C++ libraries. AD Model Builder can estimate a large number of parameters in a non-linear model using automatic differentiation software extended from Greiwank and Corliss (1991). This software provides the derivative calculations needed for finding the minimum of an objective function via a quasi-Newton function minimization routine (e.g., Press et al. 1992). It also gives simple and rapid access to these routines and provides the ability to estimate the variance-covariance matrix for all parameters of interest, as well as to perform Markov Chain Monte Carlo (MCMC) analysis.

Age classes included in the model are ages 3 to 21. Age at recruitment was set at 3 years in the model because few fish are caught at younger ages in either the survey or the fishery. The oldest age class in the model (21 years) serves as a plus group in the model; the maximum age of flathead sole in the BSAI, based on otolith age determinations, is 32 years. Details of the population dynamics and estimation equations, description of variables and likelihood components are presented in Appendix A of this chapter.

Description of Alternative Models

The model structure from the accepted 2014 assessment was used to conduct the 2016 assessment with two adjustments: (1) data were weighted according to methods presented in McAllister and Ianelli (1997) and (2) updated estimates for the parameters of the von-Bertalanffy growth curve and the weight-length relationship were used and a new length-at-age transition matrix was calculated based on the updated growth relationships and additional data. A comparison of the following models is presented to show the effects of the two adjustments described above and the influence of newly added data:

(1) last year’s accepted model with data up to 2014
(2) Model 14.1: last year’s accepted model with new data up to 2016

(3) Model 14.1a: this is Model 14.1, but with updated data weighting methods (as for McAllister and Ianelli 1997, but with effective sample size for a series calculated as the harmonic mean of yearly effective sample sizes),
(4) Model 14.1b: this is Model 14.1, but with updated growth parameters
(5) Model 14.1c: this is the recommended model with both updated data weighting methods and updated growth parameters

The following table shows the values used for data weighting in each model:

Objective Function Component	**Model 14.1c (recommended) and 14.1a**	**Model 14.1 and 14.1b**
Survey	1.00	1.00
Fishery Length Comp	0.42	0.30
Fishery Age Comp	0.52	0.30
Survey Length Comp	2.20	1.00
Survey Age Comp	0.93	1.00

Parameters estimated outside the assessment model

Parameters estimated independently include the log-scale mean survey catchability α_q, natural mortality rates (M_x), the age-based maturity ogive, the ageing error matrix, sex-specific length-at-age transition matrices ($\mathbf{\Phi}_{x,l,a}$), weights-at-length ($W_{x,l}$), and weights-at-age for the survey ($W^S_{x,a}$) and the fishery ($W^F_{x,a}$; see Appendix A for definitions of coefficients). The log-scale mean survey catchability parameter α_q was fixed at 0.0, producing a mean survey catchability of 1.0. The natural mortality rates M_x were fixed at 0.2 for both sexes, consistent with previous assessments. The maturity ogive for flathead sole follows a logistic curve where age at 50% maturity is 9.7 and age at 95% maturity is 12.8 (Figure 9.10, bottom right panel). The ageing error matrix was taken directly from the Stock Synthesis model used in assessments prior to 2004 (Spencer et al., 2004).

Sex-specific length-at-age curves were newly estimated from survey data using a procedure designed to reduce potential sampling-induced biases (Spencer et al., 2004). Sex-specific von Bertalanffy growth curves were fit to mean length-at-age data for all available years (1985, 1992-1995, 2000-2015). The new and previously used parameters values are as follows:

	2016 Assessment (Models 14.1c and 14.1b)			2004-2014 Assessments (Models 14.1 and 14.1a)		
	L_∞	K	t_0	L_∞	K	t_0
Females	47.12	0.13	-0.56	50.35	0.10	-1.24
Males	38.84	0.17	-0.56	37.03	0.19	-0.27

The resulting old and new growth curves, along with mean length-at-age data are shown in Figure 9.10 (top panels). Age is converted to size in the model assuming that size-at-age is normally-distributed with sex-specific mean size-at-age given by the von Bertalanffy equation using the parameters given above and CVs in length-at-age calculated from raw length-at-age data. The CV of the youngest fish (age 3) is 0.15

and the CV of the oldest fish (age 21) is 0.076. In Models 14.1, 14.1a, and in previous assessments, a CV of 0.13 was applied to all ages to compute the length-age transition matrix.

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; Figure 9.10, bottom left). In Models 14.1, 14.1a, and in previous assessments the weight-length parameters were estimated based on data available up to 2004 and the parameter values were similar: a = 0.00326 and b = 3.3.

Parameters estimated inside the assessment model

The majority of parameters estimated inside the model are associated with annual estimates of fishing mortality and recruitment. The other parameters estimated inside the model include historical fishing mortality, historical mean recruitment, fishery and survey length selectivity parameters, and survey temperature-dependent catchability. Details are described in Appendix A. The number of estimable parameters associated with different model components is summarized for the model in the following table:

Parameter type	**Number of Parameters**
Mean fishing mortality	1
Fishing mortality deviations	40
Mean recruitment	1
Recruitment deviations	35
Historical fishing mortality	1
Historical mean recruitment	1
Logistic fishery selectivity-at-length	2
Logistic survey selectivity-at-length	2
Temperature-dependent catchability coefficient	1
Total parameters	**84**

Parameter estimates are 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 (Appendix A, this chapter). Fits to observed annual fishery size and age compositions, as well as survey biomass estimates and size and age compositions are included among the set of likelihood components. A likelihood component based on recruitment deviations from the mean is also included. Penalties are 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 Appendix A of this chapter.

Results

Model Evaluation

The survey biomass component of the objective function and the trajectory of estimated survey biomass over time were nearly identical for the recommended model (Model 14.1c) and the 2014 accepted model (Model 14.1; Table 9.10 and Figure 9.11). Model fits to the survey biomass time series are within the 95% asymptotic confidence intervals of the data in most years. Exceptions are predicted survey biomass in 2012 and 1999-2000, where observed survey biomass was particularly low, and in 1988 when survey biomass was higher than in the surrounding years. Corresponding EBS mean bottom temperatures in 2012 and 1999-2000 were particularly low relative to the mean (especially in 1999 and 2012), but the relationship in the model between temperature and catchability only partially explains the extremely low survey biomass observations those years.

Figure 9.12 shows the posterior distributions for key parameters and derived quantities for each of the 4 models included in the analysis and for the 2014 accepted model with data up to 2014 only. These plots are shown to tease apart the influence of new data, data weighting, and new growth estimates on the assessment model. The inclusion of new growth estimates influences the estimated fishery selectivity. The length at which 50% of fish are selected (L_{50}) and the slope of the fishery selectivity curve were 35 cm and 0.33 cm^{-1}, respectively, when old growth estimates were used and 37.5 cm and 0.33 cm^{-1}, respectively, when new growth estimates were used. These results suggest that new growth estimates influenced fishery selectivity. However, the differences in fishery selectivity estimates are relatively small. This can be seen when comparing the selectivity curves for Models 14.1c and 14.1 directly (Figure 9.13).

Differences among models in the posterior distributions for survey selectivity parameters, as well as the width of the posterior distribution for L_{50} show that there is uncertainty about survey selectivity for flathead sole. The resulting selectivity curves for Model 14.1c and 14.1 (this year's recommended model and the 2014 accepted model with new data) show that the survey and fishery selectivity curves are similar and that the slope of the survey selectivity curve is very low. The slope of the survey selectivity curve is shallow for all models and this is not a new phenomenon (Figure 9.13).

There is no distinguishing influence on the posterior distributions of derived parameters (Figure 9.12). Distributions of 2014 spawning stock biomass and 2015 total biomass were similar among models (and were compared because these years are estimated in both the 2014 and 2016 models). Likewise, posterior distributions for temperature dependent catchability were similar among models (just at or below 0.05 per degree Celcius, a small effect of temperature on survey biomass, a very small positive influence of temperature on catchability, as for previous models; Figure 9.12).

Model 14.c was chosen as the recommended model because it utilizes data on length-at-age and weight-at-length from the previous 15 years that were not used in previous assessments. In addition, Model 14.1c applies modern data weighting methods. It is more up-to-date than Model 14.1 and is otherwise structurally unchanged. The results below focus on Model 14.1c.

Fits to age- and length-compositions for the Recommended Model (Model 14.1c)

Fits to survey age composition data for flathead sole in the EBS shelf survey are reasonable in most years (Figure 9.14, Figure 9.15). The model predicted a smaller proportion of older (age 10-15) males and females than were observed in 1993 (Figure 9.14). Figure 9.16 and Figure 9.17 show fits to survey length composition data of EBS flathead sole. A greater concentration of males in the 30-35cm size range are observed than are predicted in many years; however, note that the model fits to length composition data in a small number of years when no age composition data are available. Future assessments should explore whether availability/selectivity can be better represented by a different functional form, such as age-based or dome-shaped selectivity and whether selectivity is different for males and females. Estimating an ageing error matrix with updated methods (i.e. Punt et al. 2008) may improve fits to age and length composition data as well. These hypotheses should be explored in future assessments.

Figure 9.18 and Figure 9.19 show model fits to fishery age composition data. In many years, the fishery caught a greater proportion of male fish of ages 5-10 than predicted by the model. Likewise, fits to fishery length composition data show that a greater concentration of male fish in the 30-40 cm length category were observed than were predicted by the model (Figure 9.20 and Figure 9.21); this is a similar pattern as observed in the survey length composition data (however, as for the survey data, the model fits to length composition data only in years where no fishery age composition data are available). As mentioned above, mis-specification of selectivity curves and/or ageing error may contribute to systematic mismatches between observed and predicted age and length compositions (especially mis-matches that occur in fits to both the survey and fishery length composition data). The model fits to female fishery age and length composition data are reasonable in most years. Exceptions are 1983, 1993, and 1995, when a greater concentration of larger fish (35-45 cm) were observed than were predicted by the model, the opposite problem as is seen for fits to male length composition data. This may be a consequence of modeling selectivity curves that are not sex-specific or there may be variation over time in fishery selectivity.

Time series results

Time series of estimated total biomass, spawning biomass, and recruitment are shown in Figure 9.23, Table 9.14, and Table 9.15. Estimated numbers-at-age are shown in the following link: http://www.afsc.noaa.gov/REFM/docs/2016/BSAIflathead_Numbers_at_Age.xlsx. Estimated fishing mortality is plotted against spawning stock biomass relative to the harvest control rule in Figure 9.24. The stock has been below its estimated $F_{35\%}$ level and above its $B_{35\%}$ level since 1987. 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. Retrospective model estimates for recent spawning biomass and total biomass are show a pattern whereby biomass is estimated to be lower the addition of each year of data (Figure 9.25 and Figure 9.26). Estimates of recruitment deviations show a positive retrospective pattern in early years. Estimates of fishing mortality show a negative retrospective pattern (Figure 9.27 and Figure 9.28); Table 9.13 shows estimates of the time-invariant model parameters for each retrospective model, with conditional formatting to highlight any systematic changes in estimates. Small, systematic changes in estimates occur among most model parameters from 2007 to 2016, but notably, the largest pattern is seen in the slope of the survey selectivity curve. This corroborates results discussed above that the survey selectivity curve is particularly uncertain and may mis-specified in the model. Mohn's ρ for spawning biomass was 0.119. Hurtado-Ferro et al. (2015) used simulation analysis to investigate what conditions give rise to retrospective patterns and developed a rule of thumb that a Mohn's ρ value of greater than 0.2 and less than -0.15 may be an indication of model misspecification, such as ignoring a major time-varying effect; a Mohn's ρ of 0.119 does not fall within this problematic range.

Harvest Recommendations

The reference fishing mortality rate for the flathead sole/Bering flounder complex is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{40\%}$, $F_{35\%}$, and $SPR_{40\%}$ were obtained from a spawner-per recruit analysis. Assuming that the average recruitment from the 1980-2014 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{40\%}$ is calculated as the product of $SPR_{40\%}$ times the equilibrium number of recruits. Since reliable estimates of the 2017 spawning biomass (B), $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and $B>B_{40\%}$, the flathead sole/Bering flounder reference fishing mortality is defined in Tier 3a. For this tier, F_{ABC} is constrained to be $\leq F_{40\%}$, and F_{OFL} is defined to be $F_{35\%}$. The values of these quantities are:

SSB 2017	223,469
$B_{40\%}$	129,175
$F_{40\%}$	0.34
max*Fabc*	0.34
$B_{35\%}$	113,028
$F_{35\%}$	0.41
F_{OFL}	0.41

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

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). For each scenario, the projections begin with the vector of 2016 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2017 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2016. 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 10,013 t and 14,020 t for 2016 and 2017 used in place of maximum permissible ABC. The final catch for 2016 is estimated by taking the average tons caught between October 22 and December 31 over the previous 5 years (2011-2015) and adding this average amount to the catch-to-date as of October 22, 2016. The 2017 catch is estimated as the average of the total catch in each of the last 5 years (2011-2015). The 2018 catch is calculated as the projected maxABC for 2018. Total catch for all subsequent years is assumed to equal the catch associated with the respective harvest scenario. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2017, 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 2017 recommended in the assessment to the *max*F_{ABC} for 2017. (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 2010-2015 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

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

The 12-year projections of the mean spawning stock biomass, fishing mortality, and catches for the five scenarios are shown in Table 9.16-Table 9.18.

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

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

Scenario 7: In 2016 and 2017, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2029 under this scenario, then the stock is not approaching an overfished condition.)

The results of these two scenarios indicate that the stock is not overfished and is not approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2016 of scenario 6 is 233,997 t, more than 2 times *B35%* (113,028). Thus the stock is not currently overfished. With regard to whether the stock is approaching an overfished condition, the expected spawning stock size in the year 2029 of scenario 7 (121,687) is greater than *B35%*; thus, the stock is not approaching an overfished condition.

Ecosystem Considerations

Ecosystem effects on the stock

Prey availability/abundance trends

Results from an Ecopath-like model (Aydin et al., 2007) based on stomach content data collected in the early 1990's indicate that flathead sole occupy an intermediate trophic level in the eastern Bering Sea ecosystem (Figure 9.29). They feed upon a variety of species, including juvenile walleye pollock and other miscellaneous fish, brittlestars, polychaetes, and crustaceans (Figure 9.30). The proportion of the diet composed of fish appears to increase with flathead sole size (Lang et al., 2003). The population of walleye pollock has fluctuated but has remained relatively stable over the past twenty years. 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.

Over the past 20 years, many of the flatfish populations that occupy the middle shelf of the eastern Bering Sea have increased substantially in abundance, leading to concern regarding the action of potential density-dependent factors. Walters and Wilderbuer (2000) found density-dependent changes in mean length for age-3 northern rock sole during part of that stock's period of expansion, but similar trends in size have not been observed for flathead sole (Spencer et al., 2004). These populations have fluctuated primarily due to variability in recruitment success, in which climatic factors or pre-recruitment density dependence may play important roles (Wilderbuer et al., 2002). Evidence for post-recruitment density dependent effects on flathead sole is lacking, which suggests that food limitation has not occurred and thus the primary infaunal food source has been at an adequate level to sustain the flathead sole resource.

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 9.31). 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. The 2015 stock assessment for BSAI Pacific cod indicates that cod biomass has increased from in 2008 667,841 t to 1,831,620 t in 2015 (Thompson et al. 2015). Biomass of skates appears to have remained stable since the 1980s (Ormseth 2015). However, there is a good deal of uncertainty concerning predation on flathead sole given that, according to the model, almost 80% of the mortality that flathead sole experience is from unexplained sources.

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 influenced by temperature, 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, and 2016 was particularly warm.

In 2010, as noted previously, RACE extended the groundfish survey into the northern Bering Sea (Figure 9.5). 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. Unfortunately, this area has not been surveyed since 2010. Potential management implications of the northern Bering Sea survey for Bering flounder were discussed in more detail in Appendix C of the 2010 SAFE document (Stockhausen et al., 2010).

Data Gaps and Research Priorities

A main research priority is to investigate the potential causes of systematic mismatches between observed and estimated male survey and fishery length composition. These systematic mismatches may be the result of mis-specification of selectivity or ageing error. The paragraphs below describe future work that would improve the current assessment model. Stock Synthesis (SS) is a flexible assessment framework that would allow for many of the topics below to be explored without the need for an extensive expansion of the current model code. An SS model has been developed for BSAI flathead sole for the purpose of exploring model assumptions.

Alternative methods for estimating selectivity should be explored. The current assessment uses logistic, length-based selectivity curves that are not sex-specific and are time-invariant. Age-based, sex-specific, or dome-shaped selectivity could be considered. In addition, halibut bycatch rates fell after changes to fisheries management in 2008, indicating fishing behavior (and thus potentially selectivity) may have changed. 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. Time-varying selectivity could be explored to investigate whether changes to management and fishing fleet behavior resulted in changes to fishery selectivity in 2008 and beyond. A new ageing error matrix should be estimated using updated data and methods described in Punt et al. (2008).

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

Further future research priorities include the following ideas. Estimating growth within the assessment model using raw age data within each length bin (conditional age-at-length) could be considered in future assessments, such that uncertainty in growth is propagated through the model and represented in uncertainty bounds for quantities such as spawning biomass and reference points. Use of conditional age-at-length data provides allows for use of both length and age data in the assessment without “double counting.” Early recruitment deviations could be estimated to inform initial estimates of age composition. An exploration of the use of stock-recruitment relationships (Ricker, Beverton-Holt) could be considered, in response to previous GPT and SSC comments. Lastly, an exploration of alternative ways to incorporate Aleutian Islands data into the assessment could be conducted. Aleutian Islands data could be used as a second survey, and AI length- and age-composition data could be incorporated. 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.

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Tables

Table 9.1. Combined catch (in tons) of flathead sole and Bering flounder (*Hippoglossoides spp.*) in the Bering Sea and Aleutian Islands as of October 22, 2016.

Year	total	non-CDQ	CDQ	Year	total	non-CDQ	CDQ
1977	7,909	7,909		2000	20,422	19,983	439
1978	6,957	6,957		2001	17,809	17,586	223
1979	4,351	4,351		2002	15,572	15,108	464
1980	5,247	5,247		2003	14,184	13,792	392
1981	5,218	5,218		2004	17,394	16,849	545
1982	4,509	4,509		2005	16,151	15,260	891
1983	5,240	5,240		2006	17,947	17,545	402
1984	4,458	4,458		2007	18,744	17,673	1,071
1985	5,636	5,636		2008	24,539	24,039	500
1986	5,208	5,208		2009	19,549	19,041	508
1987	3,595	3,595		2010	20,125	19,182	943
1988	6,783	6,783		2011	13,556	12,882	674
1989	3,604	3,604		2012	11,366	10,859	507
1990	20,245	20,245		2013	17,358	16,661	697
1991	14,197	14,197		2014	16,513	15,787	726
1992	14,407	14,407		2015	11,308	10,712	596
1993	13,574	13,574		2016	9,353	8,822	531
1994	17,006	17,006					
1995	14,713	14,713					
1996	17,344	17,344					
1997	20,681	20,681					
1998	24,597	24,597					
1999	18,555	18,555					

Table 9.2. Proportion of combined catch of flathead sole and Bering flounder (*Hippoglossoides spp.*) by gear type in recent years. Proportions are shown on a scale of white to dark gray, with the lowest proportions in white and the highest proportions in dark grey.

Year	Non-pelagic Trawl	Pelagic Trawl	Hook and Line
1998	0.92	0.06	0.02
1999	0.88	0.1	0.02
2000	0.86	0.12	0.02
2001	0.86	0.12	0.02
2002	0.86	0.12	0.02
2003	0.86	0.11	0.03
2004	0.84	0.12	0.03
2005	0.82	0.14	0.04
2006	0.81	0.16	0.03
2007	0.76	0.22	0.02
2008	0.81	0.17	0.01
2009	0.76	0.23	0.01
2010	0.77	0.2	0.01
2011	0.63	0.35	0.03
2012	0.64	0.33	0.03
2013	0.81	0.17	0.02
2014	0.82	0.14	0.03
2015	0.77	0.19	0.04
2016	0.79	0.16	0.05

Table 9.3. Combined proportions of catch of flathead sole and Bering flounder (*Hippoglossoides spp.*) by NMFS reporting area in recent years. Only NMFS reporting areas with greater than 1% of the catch in one or more years are included in the table. Proportions are shown on a scale of white to dark green, with the lowest proportions in white and the highest proportions in dark green.

Year	509	513	514	516	517	519	521	523	524	540	541
1995	0.19	0.39	0.01	0.01	0.28	0.01	0.11	0.00	0.00	0.00	0.00
1996	0.36	0.30	0.00	0.01	0.25	0.01	0.06	0.00	0.00	0.00	0.00
1997	0.17	0.38	0.00	0.00	0.35	0.01	0.08	0.00	0.00	0.00	0.00
1998	0.20	0.24	0.00	0.00	0.31	0.00	0.24	0.00	0.00	0.00	0.00
1999	0.12	0.36	0.00	0.02	0.26	0.01	0.24	0.00	0.00	0.00	0.00
2000	0.21	0.34	0.00	0.00	0.18	0.00	0.25	0.00	0.01	0.00	0.00
2001	0.13	0.25	0.00	0.02	0.13	0.01	0.41	0.01	0.04	0.00	0.00
2002	0.09	0.23	0.00	0.01	0.12	0.01	0.50	0.00	0.04	0.00	0.01
2003	0.11	0.33	0.01	0.02	0.07	0.01	0.40	0.00	0.04	0.00	0.00
2004	0.11	0.19	0.00	0.02	0.11	0.03	0.53	0.00	0.01	0.00	0.00
2005	0.13	0.27	0.00	0.01	0.13	0.02	0.29	0.00	0.15	0.00	0.00
2006	0.18	0.18	0.00	0.01	0.13	0.01	0.44	0.00	0.04	0.00	0.00
2007	0.15	0.20	0.00	0.01	0.20	0.01	0.39	0.00	0.03	0.00	0.00
2008	0.27	0.23	0.00	0.01	0.16	0.00	0.27	0.00	0.06	0.00	0.00
2009	0.28	0.21	0.00	0.01	0.16	0.00	0.30	0.00	0.03	0.00	0.00
2010	0.23	0.25	0.00	0.03	0.11	0.00	0.37	0.00	0.00	0.00	0.00
2011	0.26	0.27	0.00	0.01	0.17	0.01	0.27	0.00	0.01	0.00	0.00
2012	0.17	0.18	0.02	0.01	0.19	0.01	0.41	0.00	0.02	0.00	0.00
2013	0.19	0.16	0.00	0.01	0.29	0.00	0.34	0.00	0.00	0.00	0.00
2014	0.20	0.18	0.01	0.01	0.24	0.00	0.35	0.00	0.00	0.00	0.00
2015	0.15	0.34	0.05	0.01	0.07	0.01	0.36	0.00	0.00	0.00	0.00
2016	0.14	0.55	0.05	0.02	0.09	0.03	0.11	0.00	0.01	0.00	0.00

Table 9.4. Catch (in tons) of combined flathead sole and Bering flounder (*Hippoglossoides spp.*), flathead sole only, and Bering flounder only in the Bering Sea and Aleutian Islands as of October 22, 2016. 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**
1977	7,909	7,909.00	0.00
1978	6,957	6,891.61	65.39
1979	4,351	4,350.69	0.31
1980	5,247	4,897.00	350.00
1981	5,218	5,213.00	5.00
1982	4,509	4,498.40	10.60
1983	5,240	5,231.69	8.31
1984	4,458	4,394.75	63.25
1985	5,636	5,626.04	9.96
1986	5,208	5,145.85	62.15
1987	3,595	3,478.97	116.03
1988	6,783	6,697.08	85.92
1989	3,604	3,593.61	10.39
1990	20,245	19,263.85	981.15
1991	14,197	14,175.93	21.07
1992	14,407	14,346.72	60.28
1993	13,574	13,462.77	111.23
1994	17,006	16,987.43	18.57
1995	14,713	14,708.58	4.42
1996	17,344	17,339.24	4.76
1997	20,681	20,675.87	5.13
1998	24,597	24,590.40	6.60
1999	18,555	18,534.64	20.36

Year	**Total *(Hippo. spp)***	**Flathead sole**	**Bering Flounder**
2000	20,422	20,389.10	32.90
2001	17,809	17,792.62	16.38
2002	15,572	15,546.78	25.22
2003	14,184	14,165.74	18.26
2004	17,394	17,369.90	24.10
2005	16,151	16,120.18	30.82
2006	17,947	17,941.22	5.78
2007	18,744	18,738.18	5.82
2008	24,539	24,524.78	14.22
2009	19,549	19,360.02	188.98
2010	20,125	19,898.93	226.07
2011	13,556	13,474.99	81.01
2012	11,366	11,360.28	5.72
2013	17,358	17,277.76	80.24
2014	16,513	16,479.90	33.10
2015	11,308	11,274.59	33.41
2016	9,353	9,346.59	6.41

Table 9.5. BSAI flathead sole fishery status from 2002-2016. Unless otherwise indicated, the closures were applied to the entire BSAI management area. Zone 1 consists of areas 508, 509, 512, and 516; zone 2 consists of areas 513, 517, and 521. "Incidental catch allowance" means stock allowed as incidental catch. "Open" means the directed fishery is allowed. "Bycatch" means that the directed fishery is closed, and only incidental catch allowed.

Year	Dates	Fishery Status
2002	2/22 – 12/31	Red King crab cap (Zone 1 closed)
	3/1 – 3/31	1st seasonal halibut cap
	4/20 – 6/29	2nd seasonal halibut cap
	7/29 – 12/31	Annual halibut allowance
2003	2/18 – 3/31	1st seasonal halibut cap
	4/1 – 6/21	2nd seasonal halibut cap
	7/31 – 12/31	Annual halibut allowance
2004	2/24 – 3/31	1st seasonal halibut cap
	4/16 – 6/30	2nd seasonal halibut cap
	7/31 – 9/3	Bycatch status
	9/4 – 12/31	Prohibited species status
2005	3/1 – 3/31	1st seasonal halibut cap
	4/22 – 6/4	2nd seasonal halibut cap
	8/18 – 12/31	Annual halibut allowance
2006	2/21 – 3/31	1st seasonal halibut cap
	4/13 – 6/30	2nd seasonal halibut cap
	8/8 – 12/31	Annual halibut allowance
2007	2/17-3/31	1st seasonal halibut cap
	4/9-6/30	2nd seasonal halibut cap
	8/6-	Annual halibut allowance
2008	1/1-	Incidental catch allowance
	1/20-	Open: Amend. 80 cooperatives
	1/20-11/22	Open: Amend. 80 limited access
	1/20-	Bycatch: BSAI trawl limited access
	11/22-	Bycatch: Amend. 80 limited access
2009	1/1-	Incidental catch allowance
	1/20-	Open: Amend. 80 cooperatives
	1/20-	Open: Amend. 80 limited access
	1/20-	Bycatch: BSAI trawl limited access
2010	1/1-	Incidental catch allowance

	1/20-	Open: Amend. 80 cooperatives
	1/20-5/28	Open: Amend. 80 limited access
	1/20-	Bycatch: BSAI trawl limited access
	5/28-	Bycatch: Amend. 80 limited access
2011	1/1-	Incidental catch allowance
	1/20-	Open: Amend. 80 cooperatives
	1/20-	Bycatch: BSAI trawl limited access
2012	1/1-	Incidental catch allowance
	1/20-	Open: Amend. 80 cooperatives
	1/20-	Bycatch: BSAI trawl limited access
2013	1/1-	Bycatch (Directed fishery closed): All
	1/20-	Open: Amendment 80
2014	1/1-	Bycatch (Directed Fishery Closed): All
	1/20-	Open: Amendment 80
2015	1/1-	Bycatch (Directed Fishery Closed): All
	1/20-	Open: Amendment 80
2016	1/1-	Bycatch (Directed Fishery Closed): All
	1/20-	Open: Amendment 80

Table 9.6. Retained and discarded catch biomass and catch limits (ABC, TAC, and OFL) as of October 22, 2016.

Year	ABC	TAC	OFL	Total	Retained	Discarded	Percent Retained
1995	138,000	30,000	167,000	14,713	7,519	7,194	51%
1996	116,000	30,000	140,000	17,344	8,963	8,381	52%
1997	101,000	43,500	145,000	20,681	10,859	9,822	53%
1998	132,000	100,000	190,000	24,597	17,406	7,191	71%
1999	77,300	77,300	118,000	18,555	13,754	4,801	74%
2000	73,500	52,652	90,000	20,422	14,945	5,477	73%
2001	84,000	40,000	102,000	17,809	14,435	3,374	81%
2002	82,600	25,000	101,000	15,572	11,310	4,262	73%
2003	66,000	20,000	81,000	14,184	10,231	3,953	72%
2004	61,900	19,000	75,200	17,394	11,976	5,418	69%
2005	58,500	19,500	70,200	16,151	12,255	3,896	76%
2006	59,800	19,500	71,800	17,947	13,575	4,372	76%
2007	79,200	30,000	95,300	18,744	13,565	5,179	72%
2008	71,700	50,000	86,000	24,539	22,207	2,332	90%
2009	71,400	60,000	83,800	19,549	17,515	2,034	90%
2010	69,200	60,000	83,100	20,125	18,315	1,810	91%
2011	69,300	41,548	83,300	13,556	11,738	1,818	87%
2012	70,400	34,134	84,500	11,366	9,622	1,744	85%
2013	67,900	22,699	81,500	17,358	15,792	1,566	91%
2014	66,293	24,500	79,633	16,513	15,128	1,385	92%
2015	66,130	24,250	79,419	11,308	10,077	1,231	89%
2016	66,250	21,000	79,562	9,353	8,084	1,269	86%

Table 9.7. Sample sizes of fishery lengths and ages measured for flathead sole only from the Bering Sea-Aleutian Islands.

	Size compositions				Age compositions				
Year	**Hauls with Lengths**	**Number Individual Lengths**	**Females**	**Males**	**Hauls with Ages**	**Number Individual Ages**	**Females**	**Males**	**Otoliths collected**
1990	141	10,113	4,499	3,975					843
1991	169	12,207	3,509	4,976					154
1992	62	4,750	381	529					0
1993	136	11,478	2,646	2,183					0
1994	136	10,878	4,729	4,641	15	138	90	48	143
1995	148	11,963	5,464	4,763	13	186	112	74	195
1996	260	14,921	7,075	7,054					0
1997	208	16,374	6,388	5,388					0
1998	454	35,738	14,573	15,098	10	99	48	51	99
1999	846	18,743	9,325	9,318					622
2000	2,449	20,160	11,293	8,824	241	564	349	215	856
2001	1,684	12,921	7,021	5,815	333	620	353	267	642
2002	1,214	10,928	5,562	5,341					558
2003	1,129	11,170	5,964	5,076					531
2004	1,540	17,860	8,515	9,239	241	496	248	248	814
2005	1,159	13,742	6,872	6,773	187	389	195	194	628
2006	1,251	14,008	6,594	7,390	210	538	275	263	546
2007	1,041	10,944	5,113	5,769	174	434	224	210	441
2008	4,172	39,551	19,728	19,738					1,884
2009	3,110	28,972	14,833	14,078	387	594	288	305	1,423
2010	2,768	22,728	11,635	11,078	357	598	298	300	1,081
2011	2,580	16,192	8,987	7,181	482	835	494	339	877
2012	2,387	15,462	9,148	6,295	425	872	559	313	877
2013	3,164	24,279	13,550	10,711	418	680	343	337	1,294
2014	2,671	22,887	12,154	10,705	347	582	316	266	1,168
2015	2,636	17,847	9,843	7,995	310	460	261	199	940
2016	1,522	11,656	6,668	4,982					552

Table 9.8. 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**	**Bio.**	**CV**	**Bio.**	**CV**	**Bio.**	**CV**	**Bio.**	**CV**	
1982	195,201	0.09			192,037	0.09	192,037	0.09	0		2.27
1983	272,185	0.10	1,213	0.20	270,972	0.10	252,612	0.11	18,359	0.20	3.02
1984	290,651	0.08			285,849	0.08	270,794	0.09	15,054	0.22	2.33
1985	269,874	0.07			265,428	0.07	252,046	0.08	13,382	0.12	2.37
1986	363,208	0.09	5,245	0.16	357,963	0.09	344,002	0.09	13,962	0.17	1.86
1987	400,272	0.09			393,588	0.09	379,394	0.10	14,194	0.14	3.22
1988	571,489	0.09			561,868	0.09	538,770	0.09	23,098	0.22	2.36
1989	530,050	0.08			521,140	0.08	502,310	0.09	18,830	0.20	2.97
1990	603,678	0.09			593,504	0.09	574,174	0.09	19,331	0.15	2.45
1991	552,949	0.08	6,939	0.20	546,010	0.08	518,380	0.08	27,630	0.22	2.70
1992	628,945	0.11			618,338	0.11	603,140	0.11	15,198	0.21	2.01
1993	618,146	0.07			607,724	0.07	585,400	0.07	22,324	0.21	3.06
1994	700,088	0.07	9,935	0.23	690,153	0.07	664,396	0.07	25,757	0.19	1.57
1995	604,611	0.09			594,421	0.09	578,945	0.09	15,476	0.18	1.74
1996	627,035	0.09			616,460	0.09	604,427	0.09	12,034	0.20	3.42
1997	795,463	0.21	11,554	0.24	783,909	0.21	769,783	0.22	14,126	0.19	2.74
1998	695,374	0.20			683,627	0.20	675,766	0.21	7,861	0.21	3.27
1999	408,010	0.09			401,194	0.09	387,995	0.09	13,199	0.18	0.83
2000	401,767	0.09	8,950	0.23	392,817	0.09	384,592	0.09	8,225	0.19	2.16
2001	524,171	0.10			515,362	0.10	503,943	0.11	11,419	0.21	2.58
2002	563,230	0.18	9,898	0.24	553,333	0.18	548,401	0.18	4,932	0.19	3.25
2003	523,669	0.10			514,868	0.10	509,156	0.11	5,712	0.21	3.81
2004	625,587	0.09	13,298	0.14	612,289	0.09	604,186	0.09	8,103	0.31	3.39
2005	622,971	0.09			612,467	0.09	605,350	0.09	7,116	0.28	3.47
2006	644,948	0.09	9,665	0.18	635,283	0.09	621,390	0.09	13,893	0.32	1.87
2007	572,201	0.09			562,568	0.09	552,114	0.09	10,453	0.22	1.79
2008	554,805	0.14			545,470	0.14	535,359	0.15	10,111	0.19	1.29
2009	425,936	0.12			418,812	0.12	412,163	0.12	6,649	0.17	1.38
2010	507,047	0.15	11,812	0.31	495,235	0.15	488,626	0.15	6,610	0.16	1.53
2011	593,296	0.19			583,300	0.19	576,498	0.19	6,802	0.15	2.47
2012	387,043	0.12	5,566	0.15	381,477	0.12	374,842	0.12	6,635	0.14	1.01
2013	499,579	0.17			491,191	0.17	485,486	0.17	5,705	0.14	1.87
2014	532,886	0.14	13,436	0.14	519,450	0.14	509,801	0.14	9,649	0.18	3.22
2015	399,870	0.11			393,194	0.11	382,173	0.12	11,021	0.17	3.36
2016	453,060	0.07	6,759	0.15	446,300	0.07	433,469	0.07	12,831	0.24	4.46

Table 9.9. EBS survey summary information for flathead sole only on sample sizes of length and age measurements and the number of hauls for which lengths and ages were collected.

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

Table 9.10. Components of the objective function for Model 14.1c (the recommended model) and for Model 14.1 (last year's accepted model with new data). Grey highlights the rows where values can be compared directly for the two models. The length and age composition components cannot be compared because the data are weighted differently in each model. Likewise, the total objective function value cannot be compared across models.

Objective Function Component	Model 14.1c (recommended)	Model 14.1
TOTAL	1,257	1,003
Survey	37.04	37.34
Fishery Length Comp	412	313
Fishery Age Comp	170	84
Survey Length Comp	272	212
Survey Age Comp	384	379
Recruitment	-20.460	-22.946

Table 9.11. Parameter estimates for parameters estimated within the assessment model and corresponding standard deviations from the hessian for Model 14.1c, the recommended model.

Parameter	Estimate	Std_dev
Fishery selectivity (L_{50})	37.029	0.474
Fishery selectivity (slope)	0.285	0.008
Survey Selectivity (L_{50})	32.473	2.120
SurveySelectivity (slope)	0.083	0.006
Log Mean Recruitment	6.728	0.100
Log Mean Fishing Mortality	-2.810	0.088
Survey Temperature-Dependent Catchability	0.050	0.016
Historical Fishing Mortality	0.107	0.017
Log Historical Mean Recruitment	4.000	0.100

Table 9.12. Estimated recruitment deviations and fishing mortality deviations with corresponding standard deviations.

Year	Recruitment Deviations	Std. Dev.	Fishing mortality Deviations	Std. Dev.
1977	0.669	0.142	2.139	0.154
1978	-2.864	5.400	2.009	0.154
1979	0.796	0.172	1.349	0.142
1980	-0.735	0.359	1.186	0.124
1981	-0.084	0.218	0.782	0.113
1982	-0.580	0.246	0.289	0.108
1983	0.638	0.132	0.086	0.105
1984	0.856	0.128	-0.322	0.104
1985	-0.737	0.302	-0.330	0.103
1986	-0.154	0.191	-0.607	0.102
1987	0.133	0.171	-1.138	0.101
1988	0.789	0.136	-0.652	0.101
1989	0.559	0.162	-1.397	0.101
1990	0.656	0.153	0.218	0.101
1991	-0.276	0.259	-0.201	0.101
1992	-0.027	0.212	-0.258	0.101
1993	-0.432	0.299	-0.382	0.101
1994	0.273	0.206	-0.206	0.102
1995	-0.324	0.299	-0.388	0.102
1996	0.145	0.173	-0.248	0.102
1997	-0.904	0.267	-0.075	0.102
1998	-0.049	0.165	0.108	0.102
1999	-0.014	0.173	-0.153	0.102
2000	-0.433	0.265	-0.038	0.102
2001	0.326	0.179	-0.147	0.102
2002	0.004	0.201	-0.251	0.102
2003	-0.994	0.296	-0.344	0.102
2004	0.353	0.153	-0.087	0.102
2005	0.069	0.210	-0.140	0.102
2006	0.525	0.151	-0.001	0.102
2007	-0.861	0.305	0.073	0.103
2008	-0.452	0.232	0.354	0.103
2009	-0.249	0.207	0.142	0.103
2010	-0.727	0.250	0.170	0.104
2011	-0.618	0.222	-0.224	0.104
2012	-0.357	0.193	-0.404	0.104
2013	-1.112	0.288	0.035	0.105
2014	0.421	0.156	0.016	0.106
2015	-2.032	1.247	-0.341	0.106
2016	0.493	0.175	-0.624	0.107

Table 9.13. Parameter estimates for retrospective analyses using Model 14.1c. Conditional formatting shows smaller values in white and larger values in dark grey, compared across retrospective peels.

Year	Fishery selectivity slope	Fishery selectivity L50	Survey selectivity slope	Survey selectivity L50	Log of Avg F	Log of Avg Rec.	Historical F	Historical R	Temp-dependent catchability parameter
2007	0.273	37.226	0.069	40.120	-2.943	6.923	0.084	4.183	0.058
2008	0.275	37.151	0.070	39.547	-2.933	6.903	0.085	4.167	0.052
2009	0.276	37.115	0.073	37.990	-2.901	6.848	0.088	4.140	0.055
2010	0.278	37.036	0.075	36.785	-2.882	6.826	0.090	4.119	0.053
2011	0.279	36.999	0.075	36.639	-2.894	6.831	0.090	4.113	0.054
2012	0.280	37.089	0.078	35.282	-2.860	6.792	0.096	4.079	0.058
2013	0.281	37.109	0.079	34.677	-2.842	6.769	0.099	4.055	0.059
2014	0.283	37.103	0.080	34.275	-2.833	6.770	0.102	4.036	0.063
2015	0.284	36.992	0.081	33.358	-2.828	6.749	0.103	4.023	0.058
2016	0.285	37.029	0.083	32.473	-2.810	6.728	0.107	4.000	0.050

Table 9.14 Time series of predicted total biomass, spawning biomass, and associated standard deviations. Std_B and Std_spb are the standard deviation of total biomass and spawning biomass, respectively.

	2014 Assessment				*2016 Assessment*			
Year	**Total Biomass (age 3+)**	**Stdev B**	**Spawning Biomass**	**Stdev SPB**	**Total Biomass (age 3+)**	**Stdev B**	**Spawning Biomass**	**Stdev SPB**
1977	118,840	10,823	20,978	3,102	97,055	8,716	13,907	2,079
1978	145,440	11,590	18,695	3,051	121,412	10,391	11,653	2,000
1979	197,670	12,548	17,654	2,991	195,054	12,765	10,846	1,922
1980	247,790	14,133	18,602	2,946	257,694	15,696	12,121	1,905
1981	303,630	15,974	21,852	2,914	325,867	18,912	15,890	1,981
1982	353,070	17,841	29,908	3,054	383,807	21,850	24,738	2,365
1983	420,790	20,136	45,188	3,622	463,502	25,550	41,599	3,320
1984	510,430	22,877	66,906	4,572	563,776	29,958	66,294	4,718
1985	576,490	25,174	90,448	5,477	637,089	33,360	95,350	6,183
1986	635,340	27,142	112,910	6,276	701,659	36,295	124,573	7,628
1987	690,120	28,926	134,520	7,049	759,732	38,862	151,062	8,958
1988	761,280	30,995	156,600	7,794	835,027	41,980	175,232	10,095
1989	823,870	32,812	180,280	8,570	906,248	44,912	200,133	11,221
1990	893,430	34,680	207,170	9,460	985,770	47,981	228,511	12,482
1991	925,030	35,863	228,670	10,373	1,027,570	49,994	250,502	13,713
1992	951,640	36,764	246,690	11,069	1,061,950	51,551	267,939	14,633
1993	958,170	37,075	261,040	11,540	1,074,000	52,199	281,455	15,284
1994	962,580	37,279	276,530	12,001	1,084,360	52,830	297,537	15,986
1995	952,930	37,191	295,610	12,671	1,073,700	52,732	316,634	16,870
1996	939,870	36,854	310,460	13,172	1,064,100	52,533	335,393	17,725
1997	912,820	36,207	319,440	13,564	1,033,650	51,536	345,872	18,289
1998	882,780	35,529	317,100	13,614	1,002,060	50,547	344,269	18,402
1999	855,100	35,044	307,620	13,461	968,445	49,524	333,946	18,198
2000	825,890	34,394	297,000	13,173	934,981	48,292	322,715	17,860
2001	811,620	34,374	286,500	12,932	915,712	47,711	310,620	17,510
2002	802,590	34,537	277,410	12,711	900,231	47,220	299,510	17,119
2003	782,550	34,315	266,710	12,369	875,971	46,322	288,665	16,642
2004	785,240	35,138	257,230	12,069	871,370	46,359	278,250	16,135
2005	788,120	36,257	248,690	11,866	865,304	46,575	268,106	15,693
2006	810,970	38,547	244,070	11,844	879,082	47,876	261,006	15,390
2007	812,650	40,035	240,070	11,902	874,294	48,407	255,621	15,235
2008	809,820	41,449	237,900	12,116	864,997	48,812	251,589	15,224
2009	795,050	42,570	234,130	12,384	847,996	49,091	246,634	15,282
2010	776,210	43,236	234,700	12,809	825,461	48,835	244,872	15,418
2011	752,210	43,674	238,390	13,449	797,203	48,296	246,240	15,738
2012	738,030	44,478	246,830	14,305	773,924	47,776	252,116	16,221
2013	709,700	44,344	252,320	15,074	743,299	46,729	255,884	16,628
2014	709,710	47,342	249,980	15,572	730,918	47,385	251,576	16,744
2015	712,530	50,078	239,357	--	702,393	47,037	242,963	16,564
2016					707,420	48,850	234,293	16,241
2017					747,557	50,724	223,469	--

Table 9.15. Age 3 recruitment (millions) estimated in the 2014 and 2016 assessments and standard deviations about the estimates.

	2014 Assessment		*2016 Assessment*	
Year	**Recruits (Age 3)**	**Std. dev**	**Recruits (Age 3)**	**Std. dev**
1977	1,890.70	248.58	1,631.10	192.54
1978	119.16	353.88	47.63	257.29
1979	1,179.80	322.81	1,852.20	277.78
1980	564.59	202.20	400.30	144.12
1981	869.86	184.94	768.03	156.31
1982	589.62	137.11	467.64	111.42
1983	1,486.70	206.71	1,580.50	167.93
1984	2,015.50	239.44	1,966.70	196.61
1985	497.03	148.92	399.67	119.64
1986	779.67	169.81	715.68	124.88
1987	1,009.90	203.10	953.65	146.80
1988	1,844.70	260.86	1,839.30	204.92
1989	1,323.70	254.59	1,460.30	210.53
1990	1,579.00	233.68	1,609.80	209.25
1991	545.90	159.47	633.77	158.65
1992	832.46	156.79	813.23	160.80
1993	520.57	148.37	542.31	159.21
1994	990.79	190.21	1,097.30	207.22
1995	613.42	173.02	603.91	177.85
1996	877.00	162.36	965.37	147.36
1997	396.67	110.81	338.06	88.71
1998	726.74	136.03	795.25	116.67
1999	912.92	150.57	823.67	128.67
2000	504.87	135.72	541.62	140.07
2001	1,147.70	181.11	1,156.80	186.33
2002	891.73	162.72	838.91	158.29
2003	334.59	98.03	309.20	90.67
2004	1,361.60	176.83	1,189.30	158.20
2005	1,002.90	201.03	895.17	180.21
2006	1,513.10	206.10	1,411.80	186.00
2007	354.96	109.71	353.24	107.17
2008	565.82	126.02	531.48	118.61
2009	587.80	131.66	651.31	127.88
2010	443.66	111.11	403.59	98.96
2011	521.04	123.28	450.34	96.87
2012	800.91	163.64	584.22	107.41
2013	118.33	115.28	274.60	79.06
2014	1,674.00	353.03	1,272.00	184.72
2015			109.43	136.27
2016			1,367.60	223.55
Average	894.46		866.15	

Table 9.16. 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
2016	233,997	233,997	233,997	233,997	233,997	233,997	233,997
2017	223,469	223,469	223,469	223,469	223,469	215,857	217,444
2018	206,029	206,029	211,757	211,449	213,146	169,094	177,246
2019	170,129	170,129	202,952	201,039	211,787	137,634	148,049
2020	146,866	146,866	198,369	195,142	213,638	119,116	126,219
2021	133,758	133,758	198,436	194,116	219,337	111,629	115,547
2022	128,065	128,065	202,517	197,262	228,467	111,098	113,243
2023	127,811	127,811	209,870	203,792	240,442	114,359	115,428
2024	129,885	129,885	218,611	211,772	253,552	118,255	118,686
2025	131,737	131,737	226,387	218,855	265,397	120,754	120,844
2026	132,873	132,873	232,737	224,572	275,544	121,892	121,829
2027	133,413	133,413	237,728	228,995	284,028	122,170	122,058
2028	133,585	133,585	241,574	232,343	291,030	122,014	121,906
2029	133,630	133,630	244,641	234,972	296,948	121,772	121,687

Table 9.17 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
2016	0.05	0.05	0.05	0.05	0.05	0.05	0.05
2017	0.07	0.07	0.07	0.07	0.07	0.41	0.34
2018	0.34	0.34	0.07	0.08	0.00	0.41	0.34
2019	0.34	0.34	0.07	0.08	0.00	0.41	0.41
2020	0.34	0.34	0.07	0.08	0.00	0.38	0.40
2021	0.34	0.34	0.07	0.08	0.00	0.35	0.37
2022	0.33	0.33	0.07	0.08	0.00	0.35	0.36
2023	0.33	0.33	0.07	0.08	0.00	0.36	0.37
2024	0.33	0.33	0.07	0.08	0.00	0.37	0.37
2025	0.33	0.33	0.07	0.08	0.00	0.38	0.38
2026	0.32	0.32	0.07	0.08	0.00	0.38	0.38
2027	0.32	0.32	0.07	0.08	0.00	0.38	0.38
2028	0.32	0.32	0.07	0.08	0.00	0.37	0.37
2029	0.32	0.32	0.07	0.08	0.00	0.37	0.37

Table 9.18. 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
2016	10,013	10,013	10,013	10,013	10,013	10,013	10,013
2017	14,020	14,020	14,020	14,020	14,020	81,655	68,278
2018	66,164	66,164	13,584	16,554	0	67,591	58,370
2019	57,160	57,160	13,258	16,050	0	57,960	61,465
2020	51,418	51,418	13,154	15,834	0	48,359	53,649
2021	47,752	47,752	13,162	15,769	0	43,047	45,822
2022	45,327	45,327	13,373	15,965	0	42,634	44,161
2023	44,216	44,216	13,663	16,264	0	44,306	45,090
2024	43,988	43,988	13,980	16,602	0	46,013	46,351
2025	44,012	44,012	14,309	16,961	0	46,965	47,078
2026	44,127	44,127	14,628	17,309	0	47,393	47,404
2027	44,254	44,254	14,913	17,619	0	47,585	47,557
2028	44,370	44,370	15,166	17,893	0	47,608	47,570
2029	44,429	44,429	15,375	18,116	0	47,562	47,529

Table 9.19. Non-target catch in the directed flathead sole fishery as a proportion of total bycatch of each species. Conditional highlighting from white (lowest numbers) to green (highest numbers) is applied.

Non-Target Species	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Benthic urochordata	0.00	0.01	0.04	0.10	0.05	0.00	0.06	0.01	0.01	0.00	0.01	0.01	0.16
Bivalves	0.04	0.00	0.01	0.03	0.01	0.00	0.02	0.00	0.00	0.00	0.07	0.00	0.01
Brittle star unidentified	0.11	0.02	0.17	0.03	0.02	0.25	0.08	0.00	0.00	0.03	0.02	0.01	0.02
Capelin	0.01	0.00	0.00	0.00	0.05	0.03	0.00	0.01	0.00	0.04	0.00	0.00	0.00
Corals Bryozoans	0.01	0.01	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Eelpouts	0.20	0.13	0.12	0.04	0.03	0.02	0.10	0.08	0.16	0.27	0.17	0.08	0.02
Eulachon	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.14	0.01	0.00	0.00
Giant Grenadier	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Greenlings	0.02	0.00	0.00	0.01	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grenadier	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
Hermit crab unidentified	0.13	0.07	0.03	0.12	0.06	0.02	0.06	0.01	0.03	0.05	0.02	0.08	0.08
Invertebrate unidentified	0.05	0.03	0.03	0.00	0.18	0.08	0.09	0.01	0.00	0.00	0.00	0.03	0.00
Lanternfishes (myctophidae)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large Sculpins	0.10	0.08	0.10	0.05	0.09	0.06	0.05	0.02	0.01	0.01	0.03	0.03	0.02
Misc crabs	0.03	0.05	0.03	0.02	0.03	0.01	0.01	0.01	0.00	0.02	0.01	0.01	0.05
Misc crustaceans	0.32	0.11	0.03	0.09	0.22	0.03	0.08	0.02	0.01	0.16	0.04	0.05	0.01
Misc fish	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01
Misc inverts (worms etc)	0.85	0.89	0.13	0.00	0.57	0.11	0.03	0.06	0.09	0.08	0.02	0.07	0.56
Other osmerids	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.00	0.00	0.00
Other Sculpins	0.02	0.13	0.01	0.14	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01
Pacific Sand lance	0.00	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pandalid shrimp	0.07	0.33	0.03	0.05	0.11	0.04	0.04	0.01	0.06	0.07	0.06	0.03	0.01
Polychaete unidentified	0.54	0.04	0.00	0.03	0.07	0.11	0.01	0.01	0.00	0.00	0.00	0.01	0.04
Scypho jellies	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00
Sea anemone unidentified	0.24	0.03	0.06	0.47	0.11	0.03	0.13	0.02	0.02	0.07	0.04	0.02	0.01
Sea pens whips	0.02	0.01	0.01	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sea star	0.09	0.05	0.09	0.05	0.10	0.08	0.04	0.02	0.01	0.02	0.04	0.03	0.03
Snails	0.20	0.11	0.05	0.10	0.09	0.03	0.06	0.03	0.02	0.05	0.09	0.06	0.03
Sponge unidentified	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00
Stichaeidae	0.02	0.18	0.73	0.00	0.03	0.10	0.05	0.00	0.00	0.01	0.00	0.00	0.00
urchins dollars cucumbers	0.07	0.01	0.02	0.02	0.06	0.03	0.02	0.03	0.01	0.02	0.01	0.01	0.01

Table 9.20. Prohibited species catch in the flathead sole directed fishery as a proportion of all prohibited species catch in the BSAI.

Species Group Name	2016 PSCNQ Estimate (*)	2016 Halibut Mortality (mt)	2015 PSCNQ Estimate (*)	2015 Halibut Mortality (mt)
Bairdi Tanner Crab	14,524	14,524	54,230	54,230
Blue King Crab	0		58	58
Chinook Salmon	0		93	
Golden (Brown) King Crab	273	273	0	
Halibut	45	33	64	47
Herring	0	0	0	0
Non-Chinook Salmon	723		561	
Opilio Tanner (Snow) Crab	7,764	7,764	21,114	21,114
Red King Crab	430	430	51	51

*Note: PSCNQ Estimate reported in metric tons for halibut and herring, counts of fish for crab and salmon

Figures

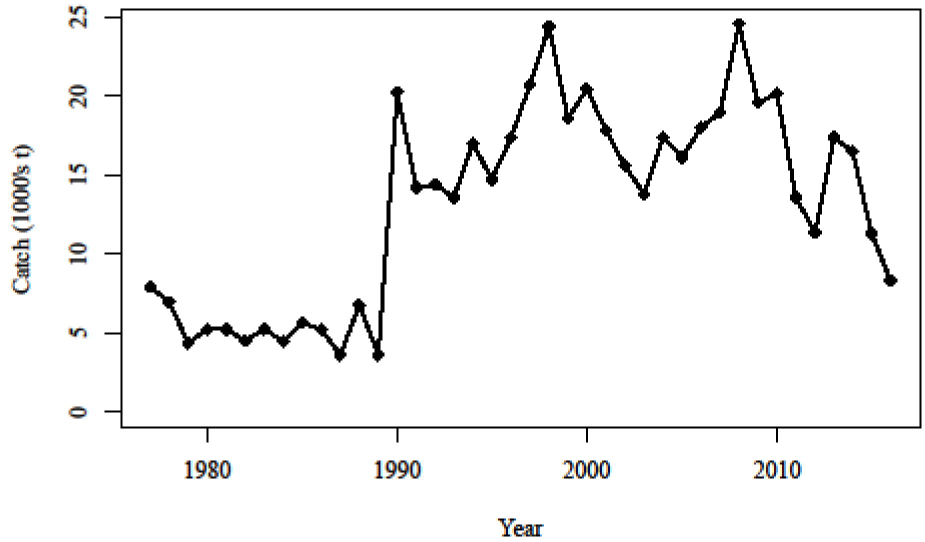
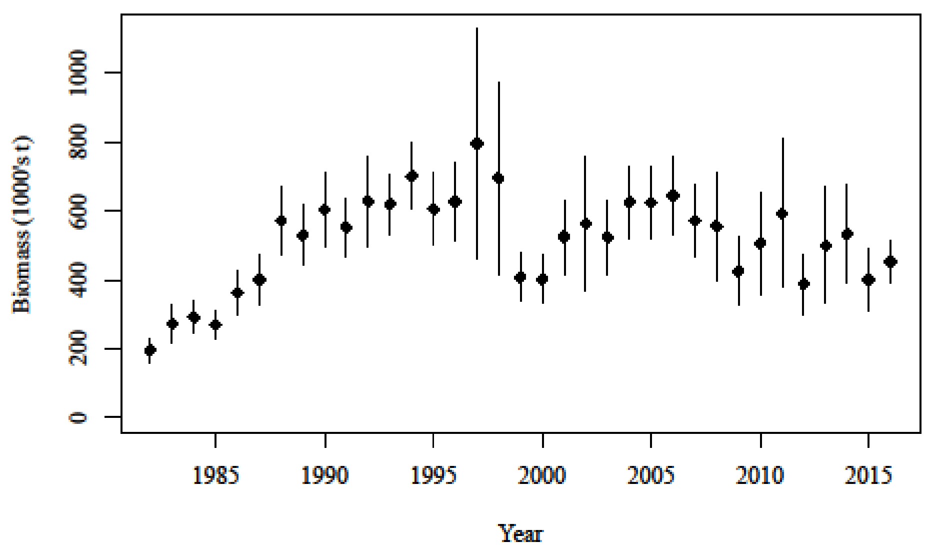


Figure 9.1. Combined catch (in metric tons) of flathead sole and Bering flounder (Hippoglossoides spp.) by year in total and for CDQ and non-CDQ fisheries combined



Observed fishery catches and survey biomass.

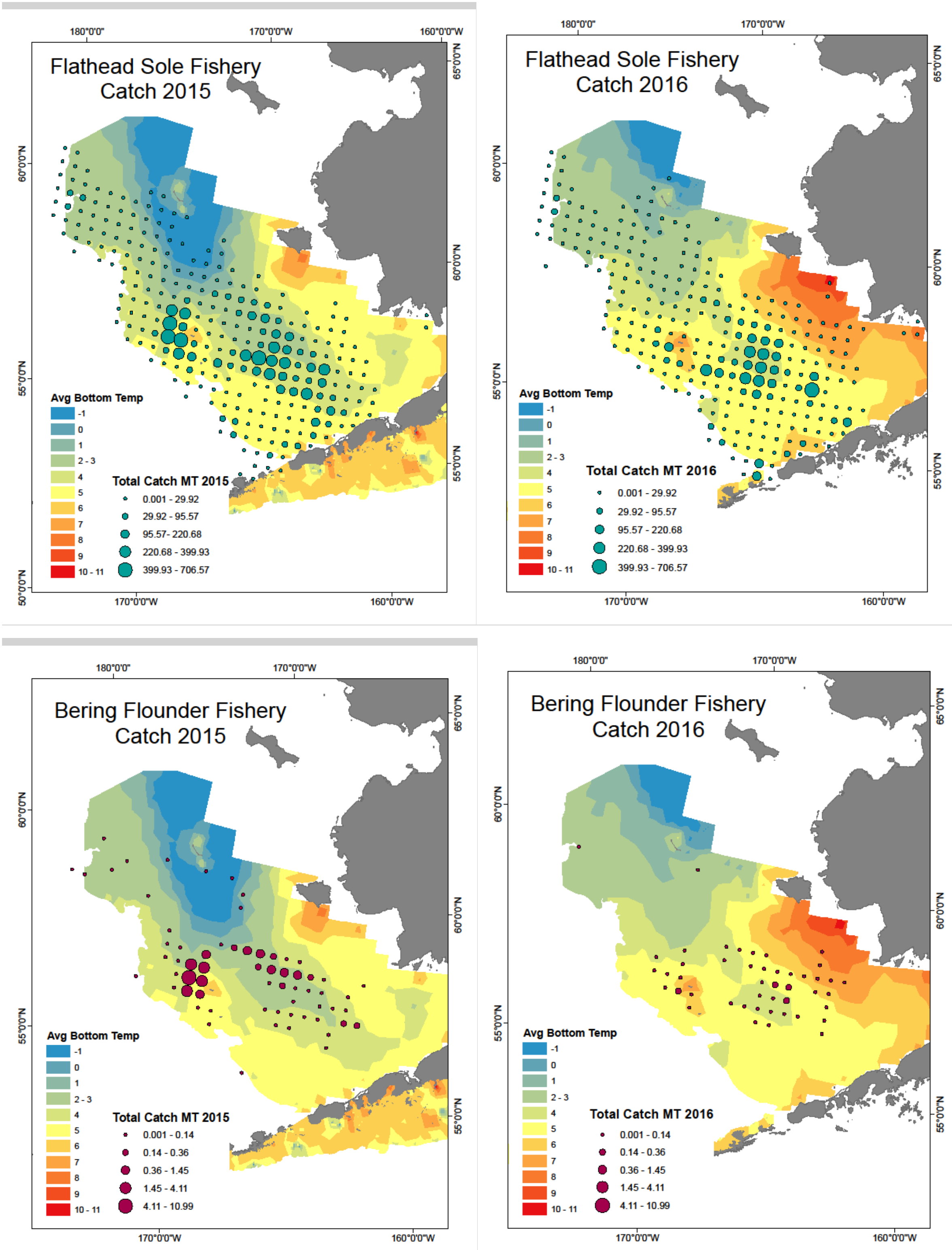


Figure 9.2. Spatial distribution of fishery catches, aggregated by EBS shelf survey stations for flathead sole (top; blue circles) and Bering flounder (bottom; purple circles) in 2015 and 2016. Scale for Bering flounder maps is different from that for flathead sole maps. Catches are overlaid on EBS summer mean bottom temperatures from the EBS shelf survey, while fishery occurs year-round.

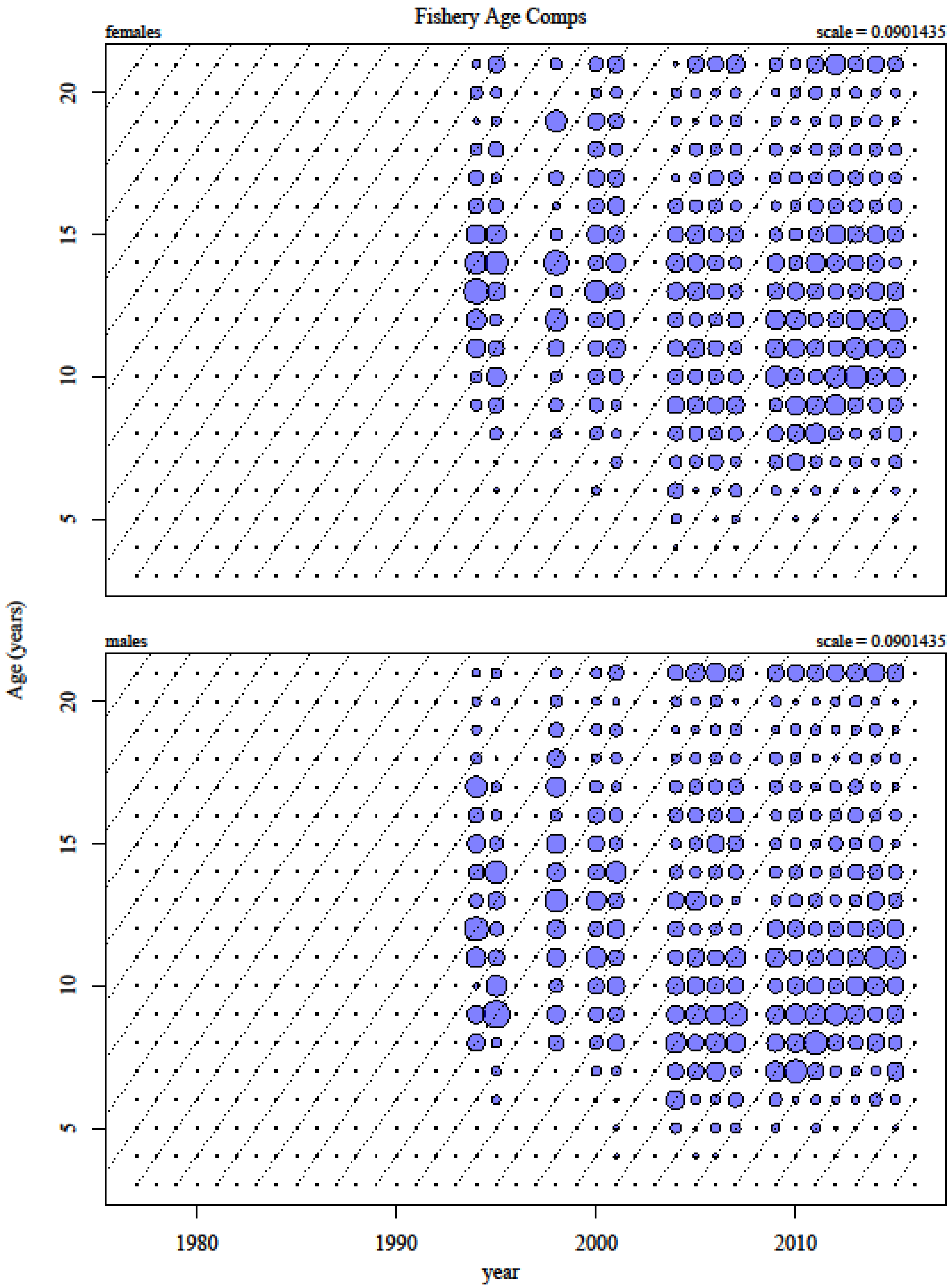


Figure 9.3. Annual age compositions for flathead sole from fishery observer data. Circle area reflects relative numbers-at-age within each year across both sexes. Dotted lines indicate cohort progression. Ages 21+ are grouped together. Age compositions from 1994, 1995 and 1998 were not used in the model due to small sample sizes but are included here for completeness. “Scale” is the maximum observed proportion-at-age.

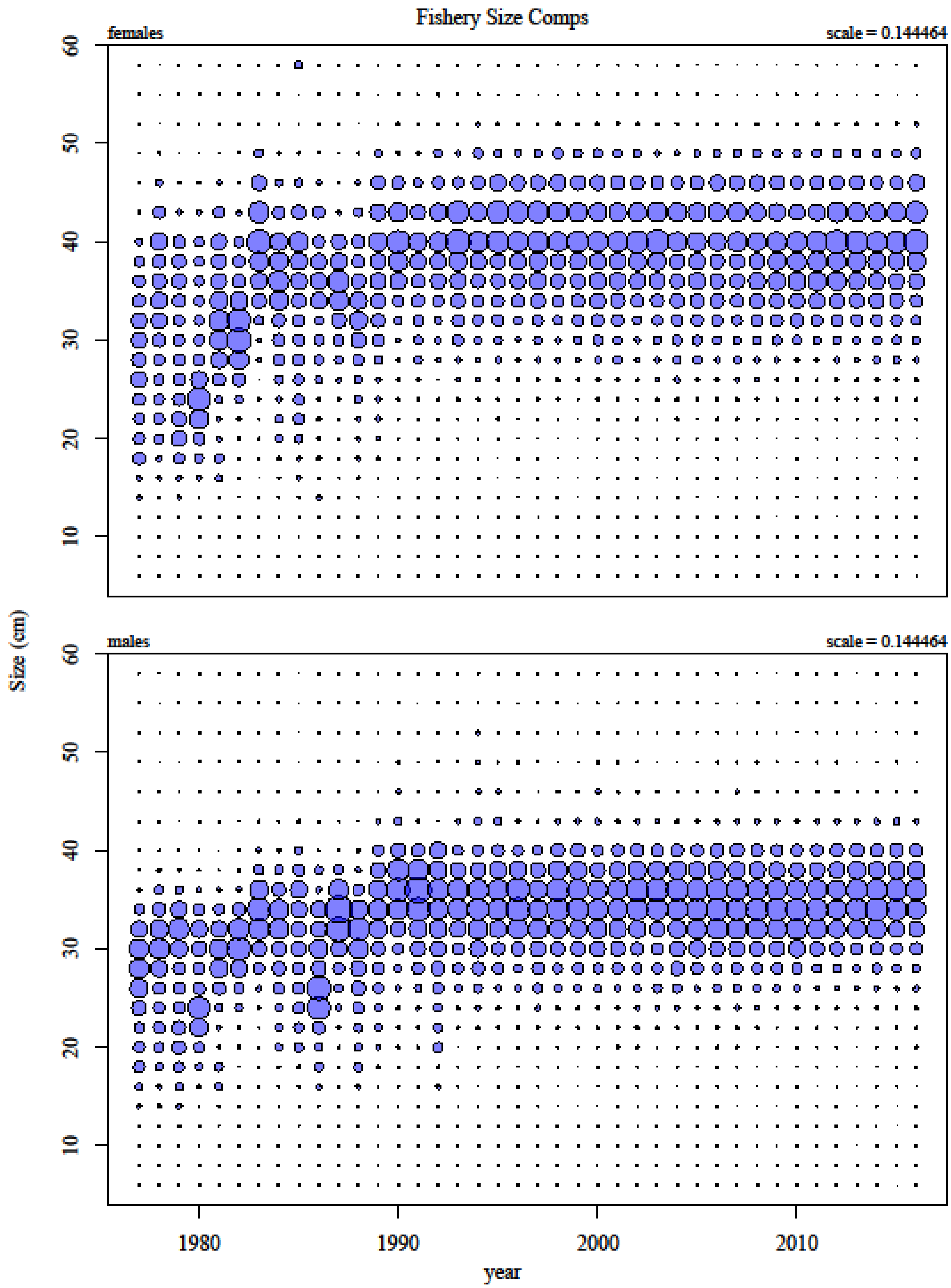


Figure 9.4. Annual size compositions for BSAI *Hippoglossoides* spp. (flathead sole and Bering flounder) from fishery observer data. Circle area reflects relative numbers-at-size within each year, across both sexes. 2 cm size bins are used for sizes 6-40 cm and 3 cm bins are used for sizes > 40 cm. All sizes >= 58cm were grouped into one size bin. The "scale" is the maximum proportion observed.

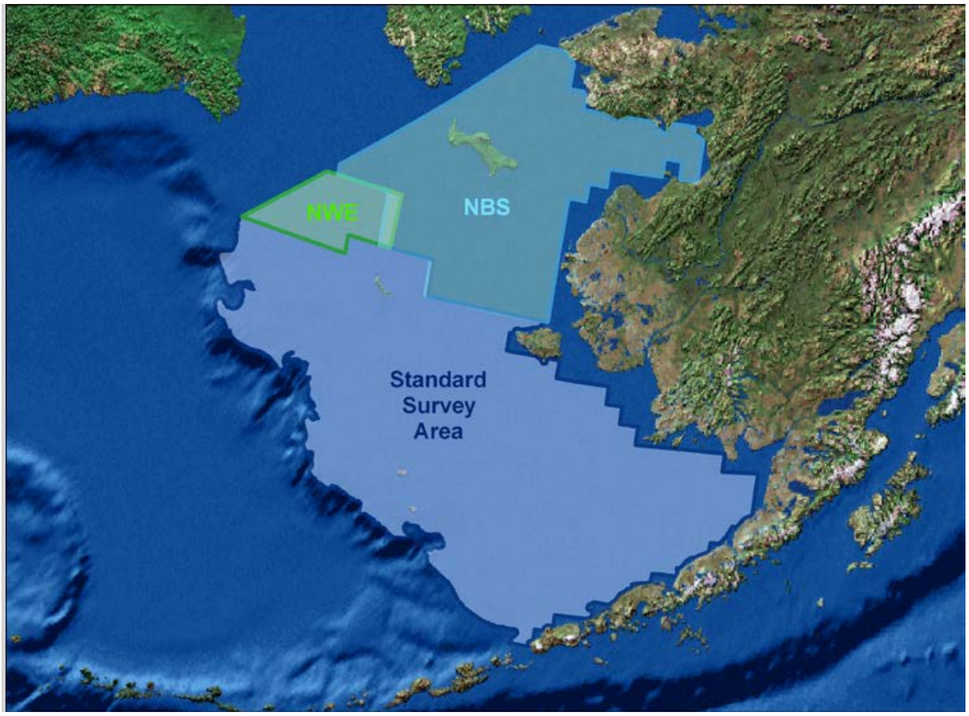
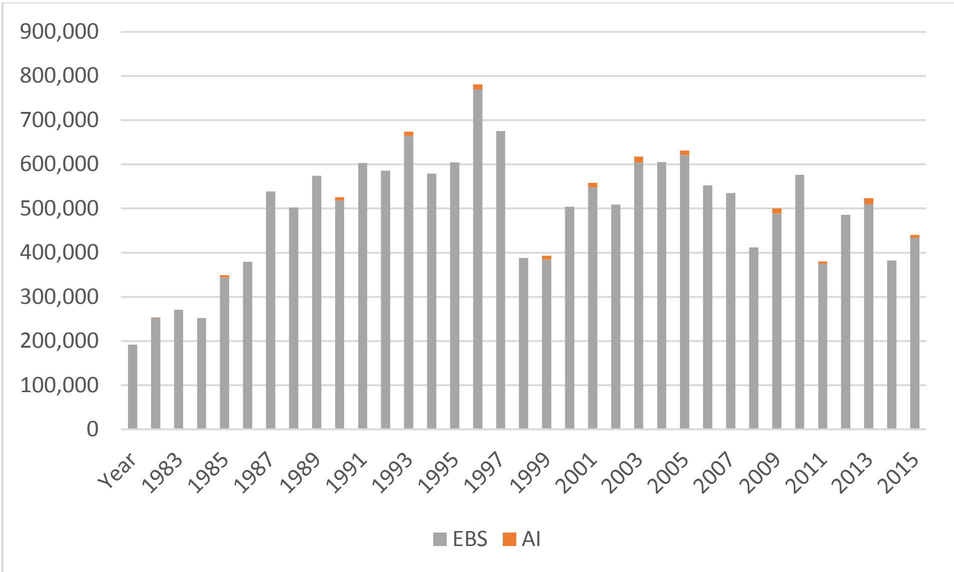


Figure 9.5. Eastern Bering Sea shelf survey areas. Only data from the standard survey area are used in the assessment model; data from the Northwest Extension (NWE) and Northern Bering Sea (NBS) are excluded.



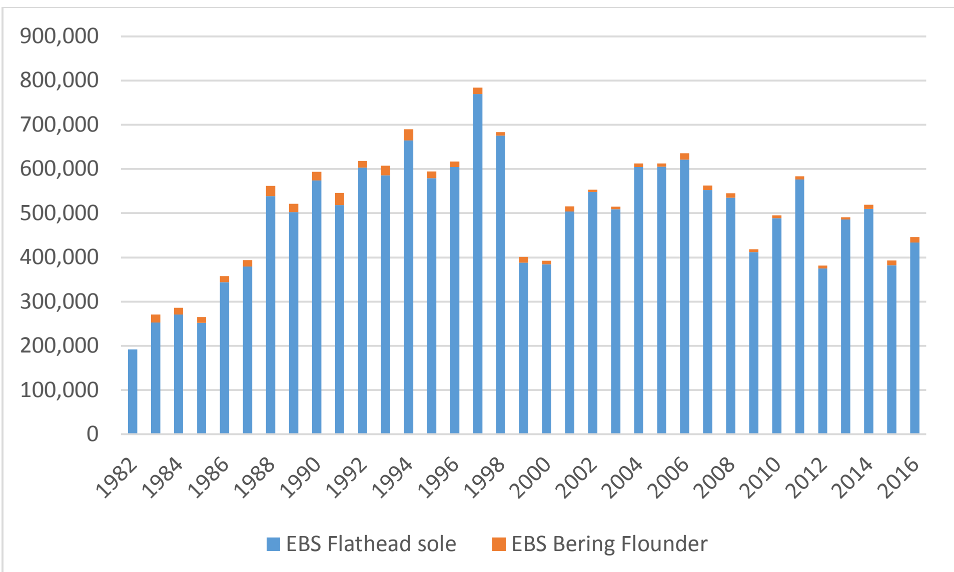


Figure 9.6. Flathead sole (only) survey biomass from the EBS shelf survey and the Aleutian Islands survey (top). Flathead sole and Bering flounder biomass in the EBS shelf survey (bottom).

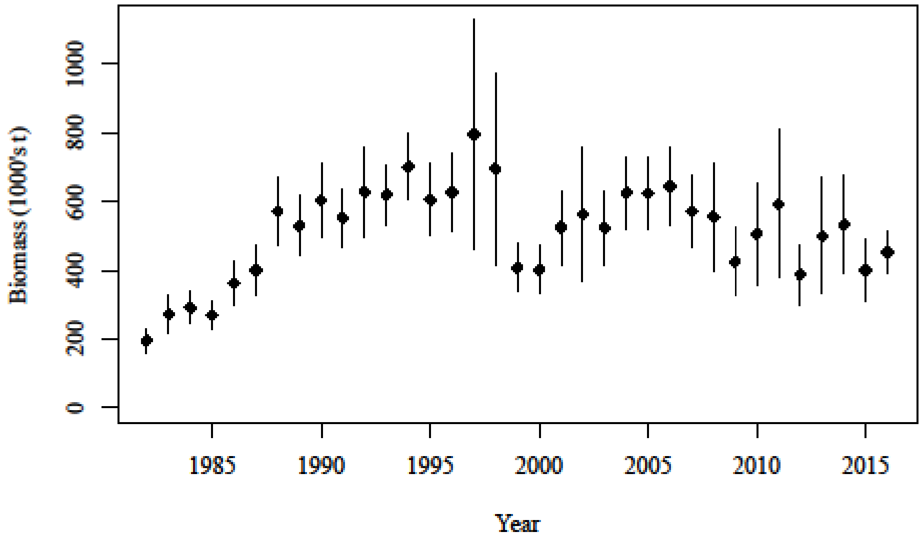


Figure 9.7. Survey biomass estimates (dots) and 95% asymptotic confidence intervals (vertical lines) used in the assessment. The biomass estimates include the Aleutian Islands and EBS shelf survey areas and represent both flathead sole and Bering flounder. A linear regression is used to estimate a relationship between EBS shelf survey biomass and Aleutian Islands survey biomass; the linear relationship is used to estimate Aleutian Islands survey biomass in years without an Aleutian Islands survey.

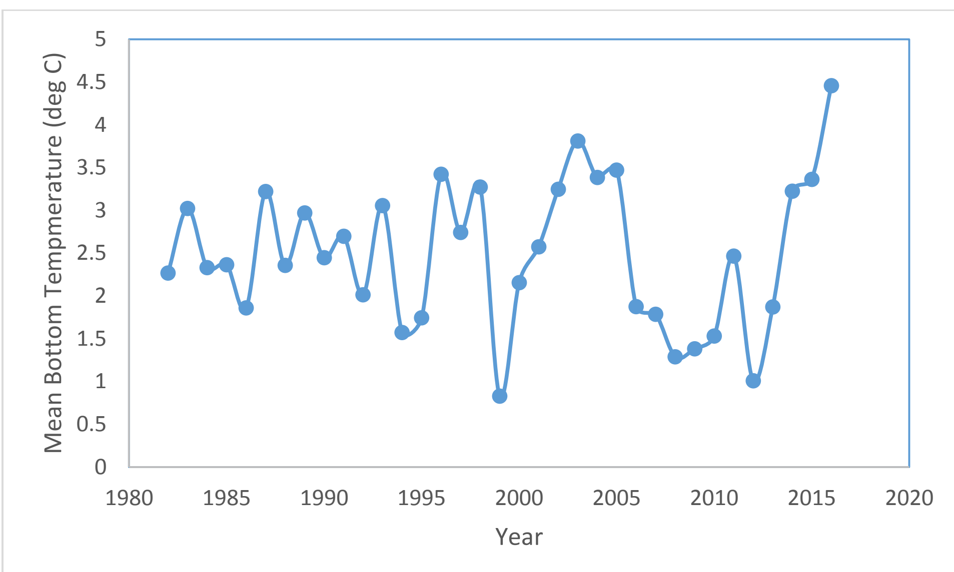


Figure 9.8. Mean bottom temperatures (deg C) from the EBS shelf survey for station depths less than or equal to 200 meters.

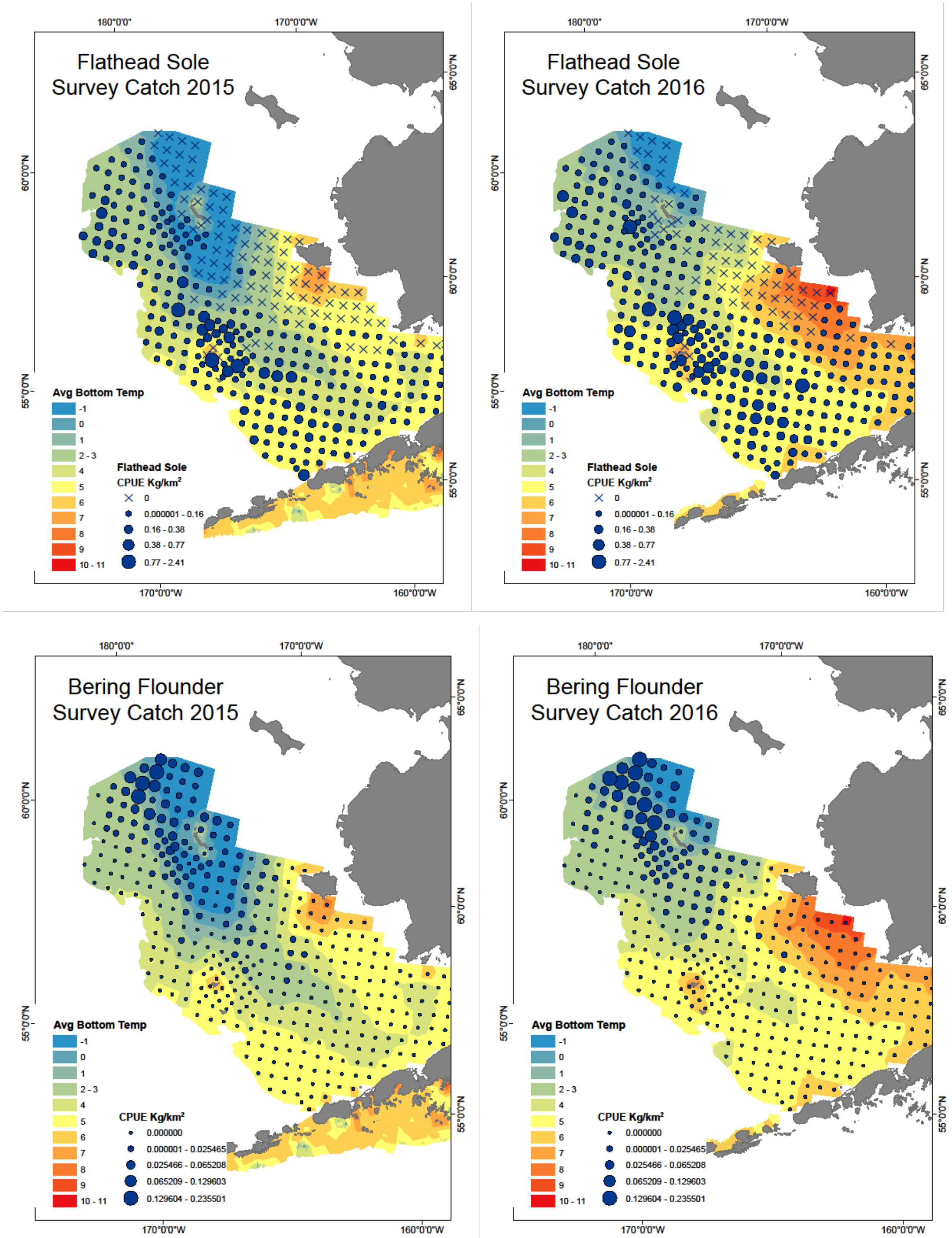


Figure 9.9. Spatial distribution flathead sole (top) Bering flounder (bottom) catch per unit effort (CPUE) for 2015 and 2016 from the Eastern Bering Sea shelf survey overlaid on a map of mean bottom temperatures measured by the survey.

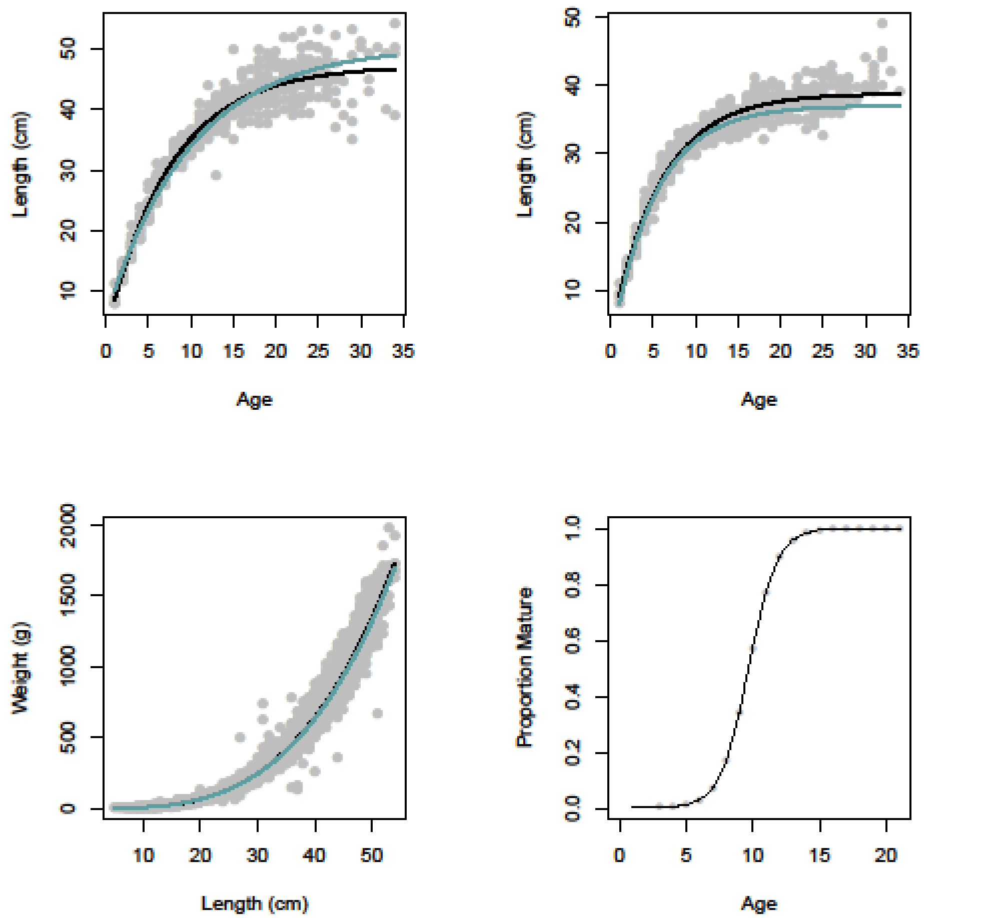


Figure 9.10. Top: length-at-age relationships used in the assessment model for females (top left) and males (top right). Bottom left: weight-length relationship estimated outside the model for males and females combined. Bottom right: maturity curve used in the assessment. Data are shown using grey dots, black lines are the relationships estimated with all available data up to 2016, and blue lines show relationships estimated using data up to 2004 and used in previous assessments.

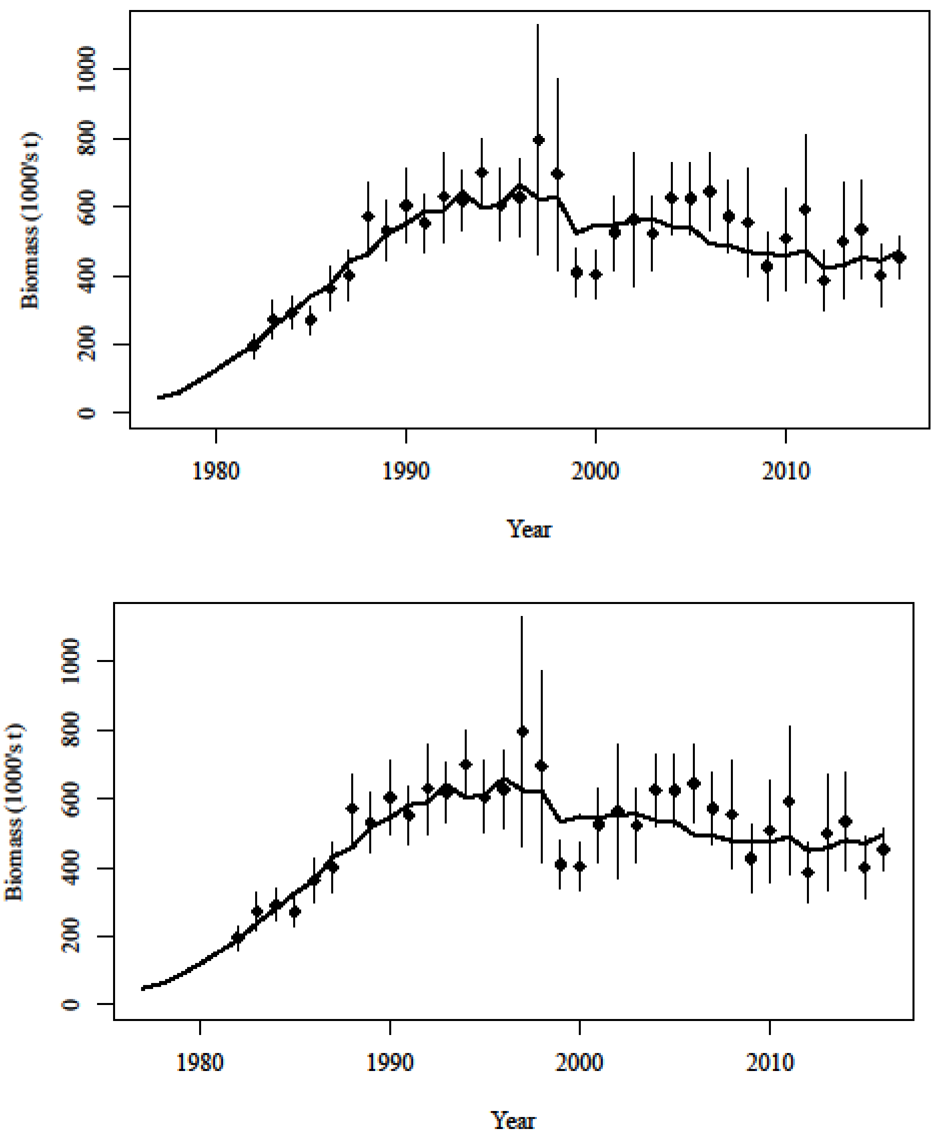


Figure 9.11. Observed (dots) and predicted (solid line) survey biomass (in tons) over time. Vertical lines represent the 95% asymptotic confidence intervals around the survey biomass data. Top panel shows this year's recommended model (Model 14.c) and the bottom panel shows last year's accepted model (Model 14.1).

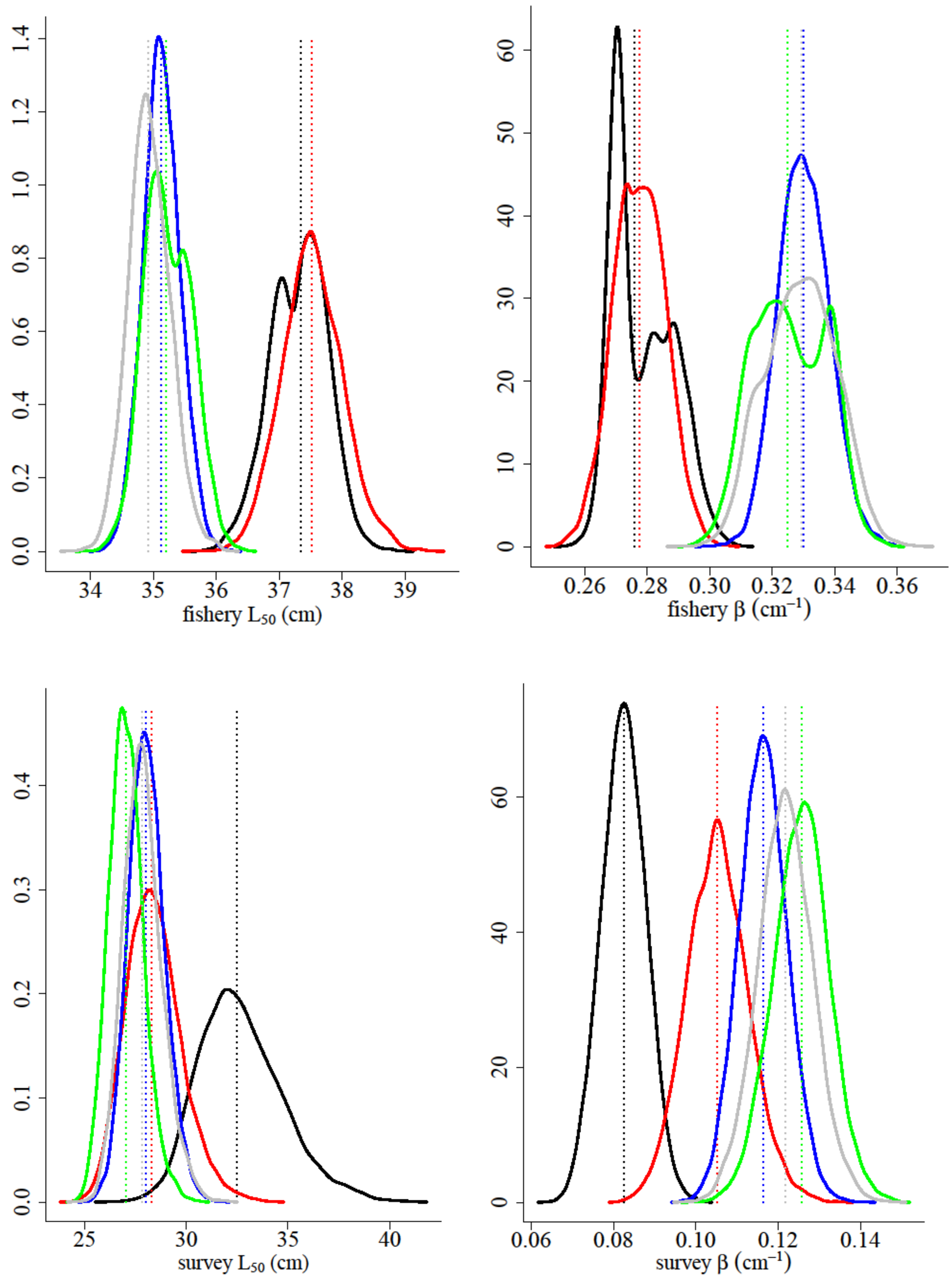


Figure 9.12. Posterior distributions for parameter estimates and derived quantities based on MCMC. Vertical lines indicate the median of the posterior. Grey lines indicate last year's accepted model with data up to 2014, Model 14.1 (new data) is shown in green, Model 14.1 with new data and new data weighting is shown is blue, Model 14.1b (updated growth parameters) in red, and Model 14.1c (the recommended model) is shown in black (part 1 of 2).

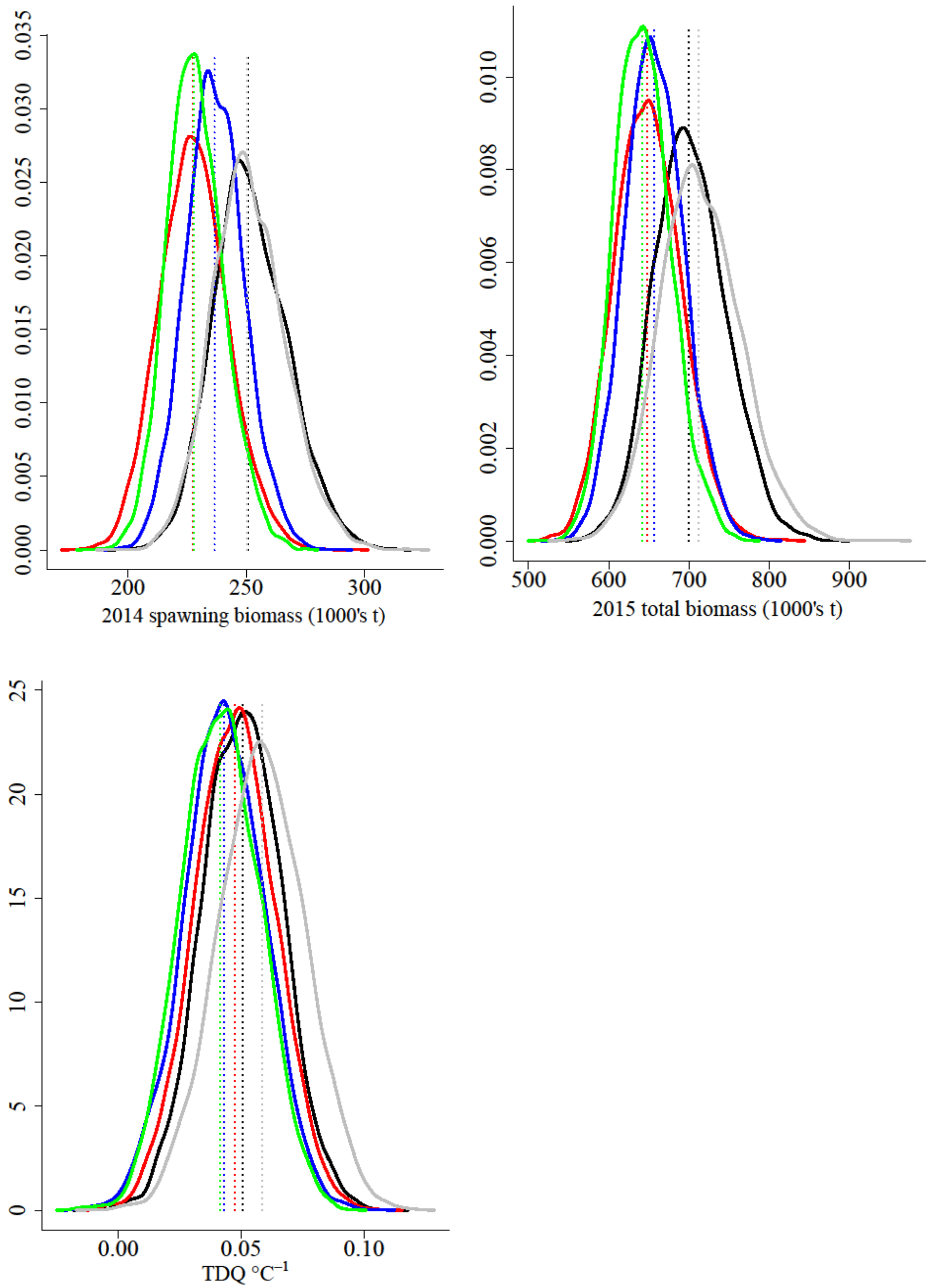


Figure 9.12, continued (part 2 of 2).

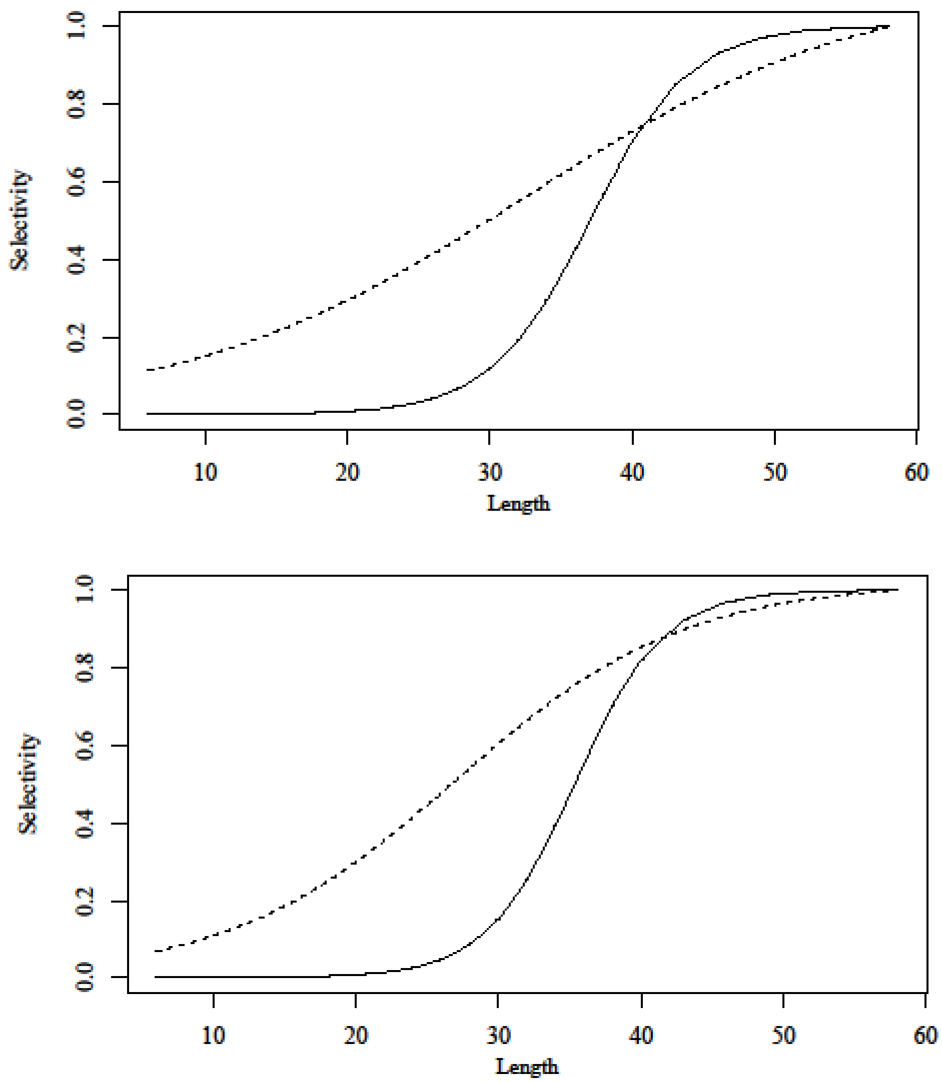


Figure 9.13. Length-based survey (dotted line) and fishery (solid line) selectivity estimated by the assessment model for the recommended model (Model 14.1c; top panel) and for Model 14.1 (bottom panel).

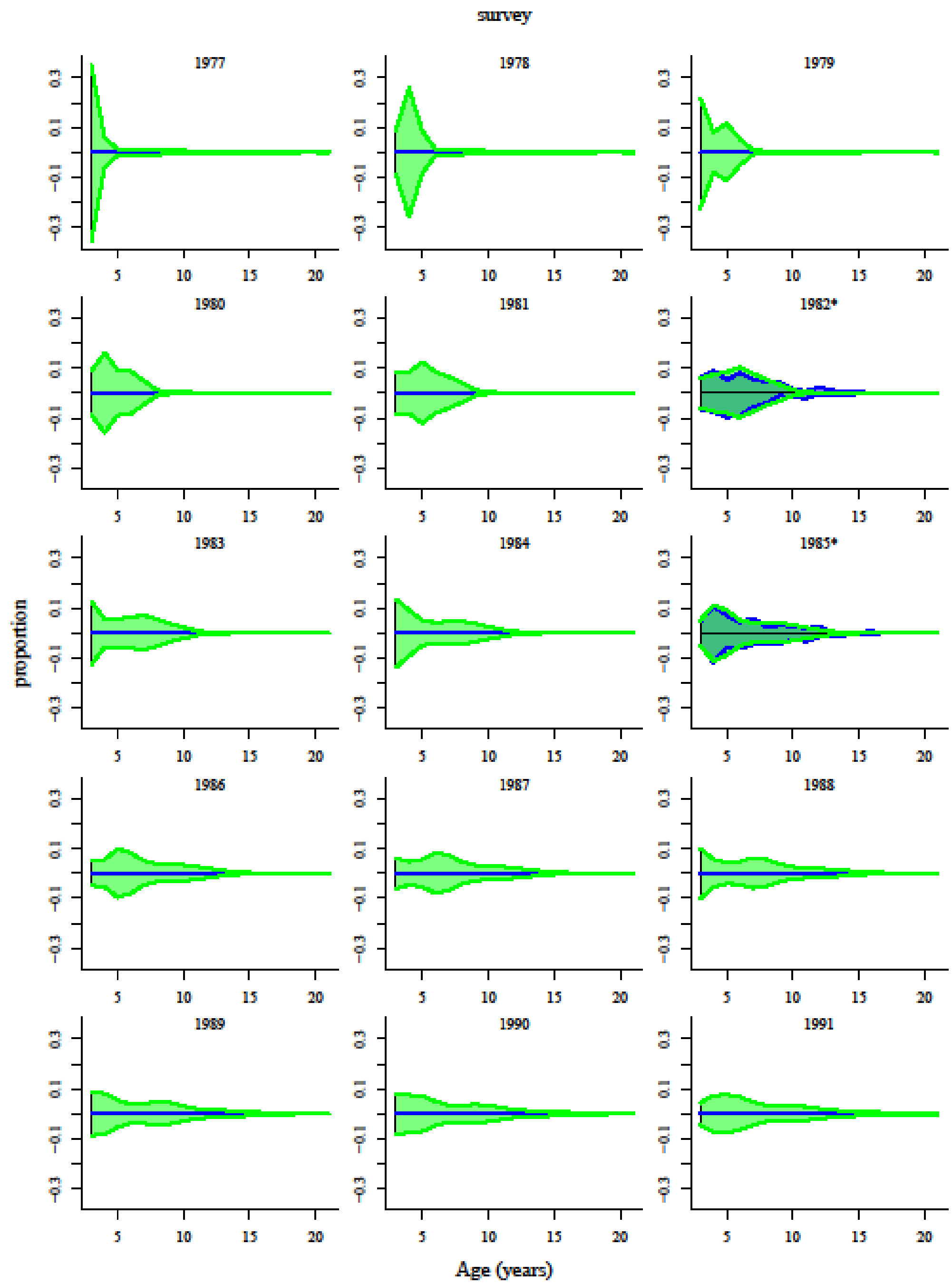


Figure 9.14. Observed (blue) and predicted (green) EBS survey age compositions for flathead sole only (part 1 of 3). Females are shown as positive values, males are shown as negative values. Years with no data are indicated by a horizontal blue line at proportion = 0. Asterisks indicate years included in the model fit.

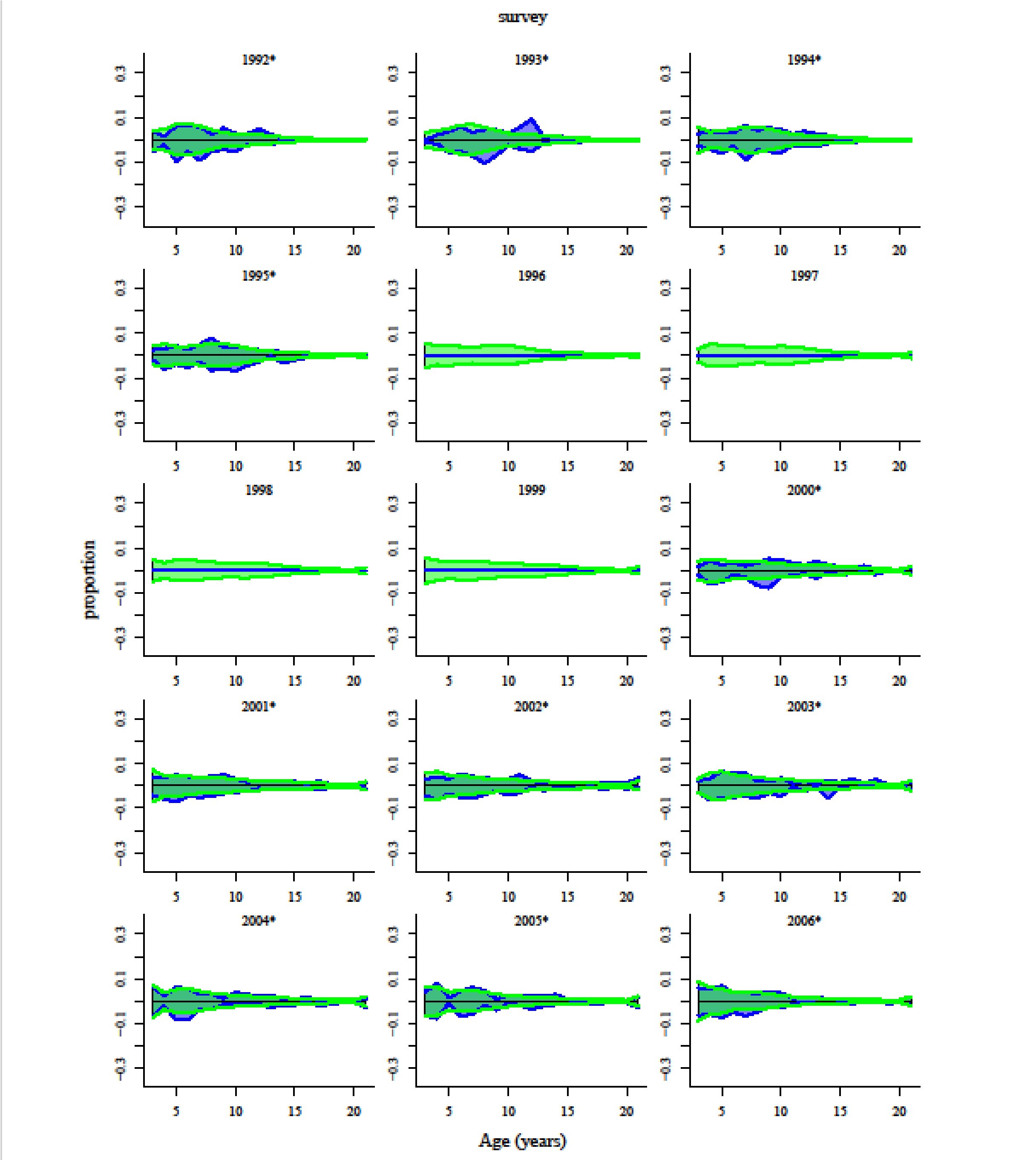
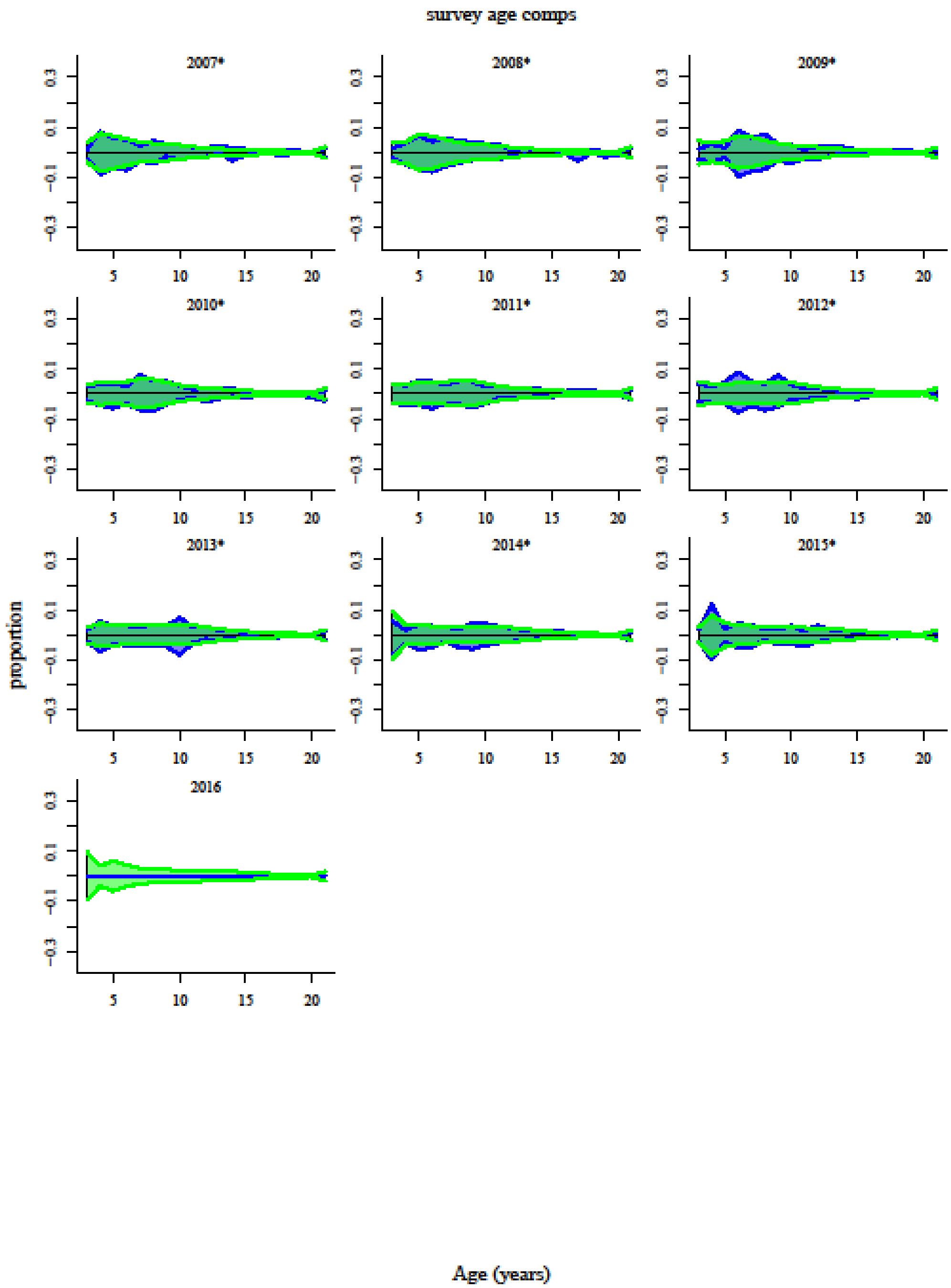


Figure 9.14, continued (part 2 of 3).


survey age comps
2007*
2008*
2009*
2010*
2011*
2012*
2013*
2014*
2015*
2016
proportion
Age (years)

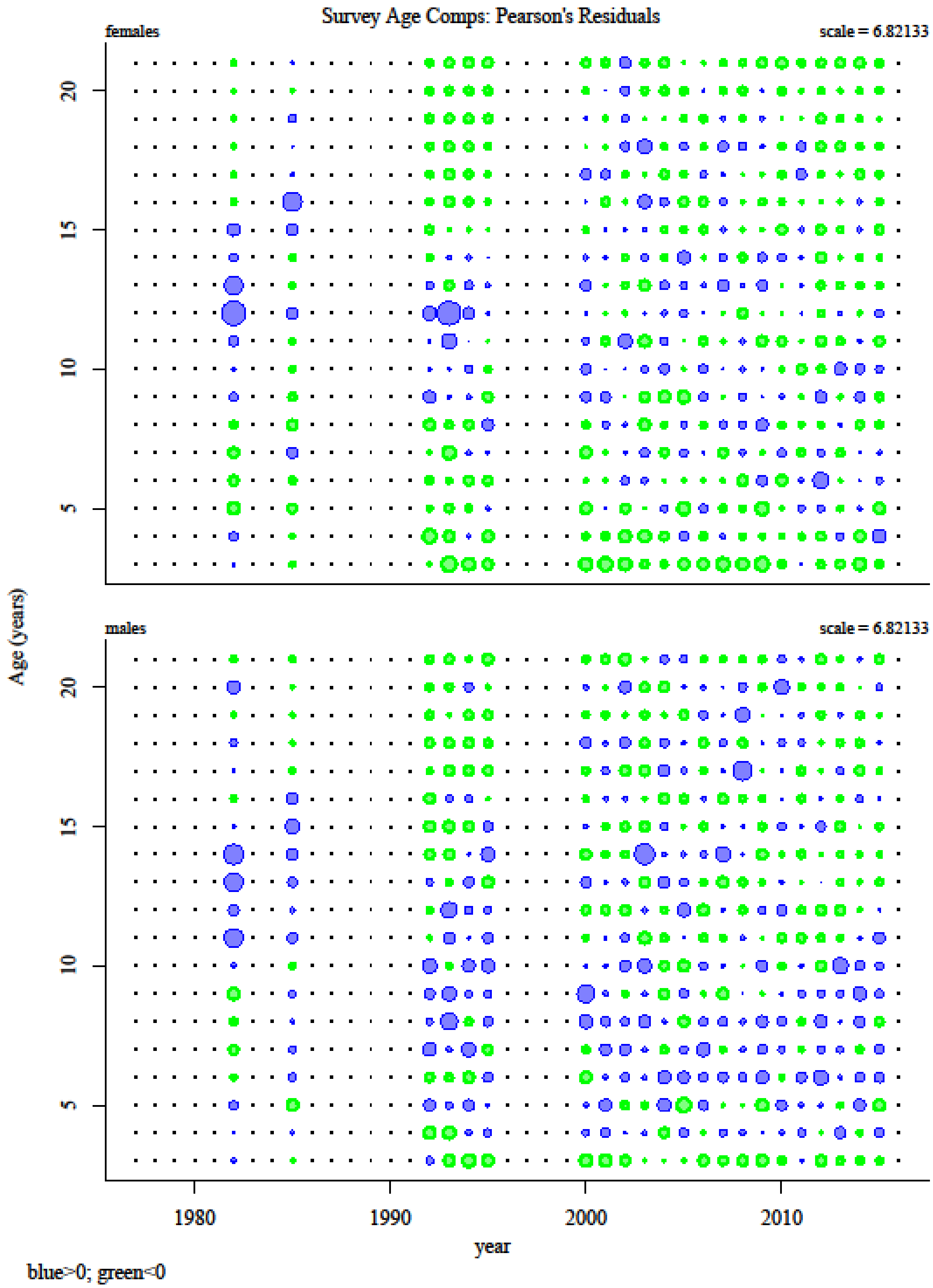


Figure 9.15. Pearson's residuals plots for the EBS flathead sole survey age compositions. Blue circles represent positive residuals, green circles represent negative residuals. Circle area scales with size of the residual.

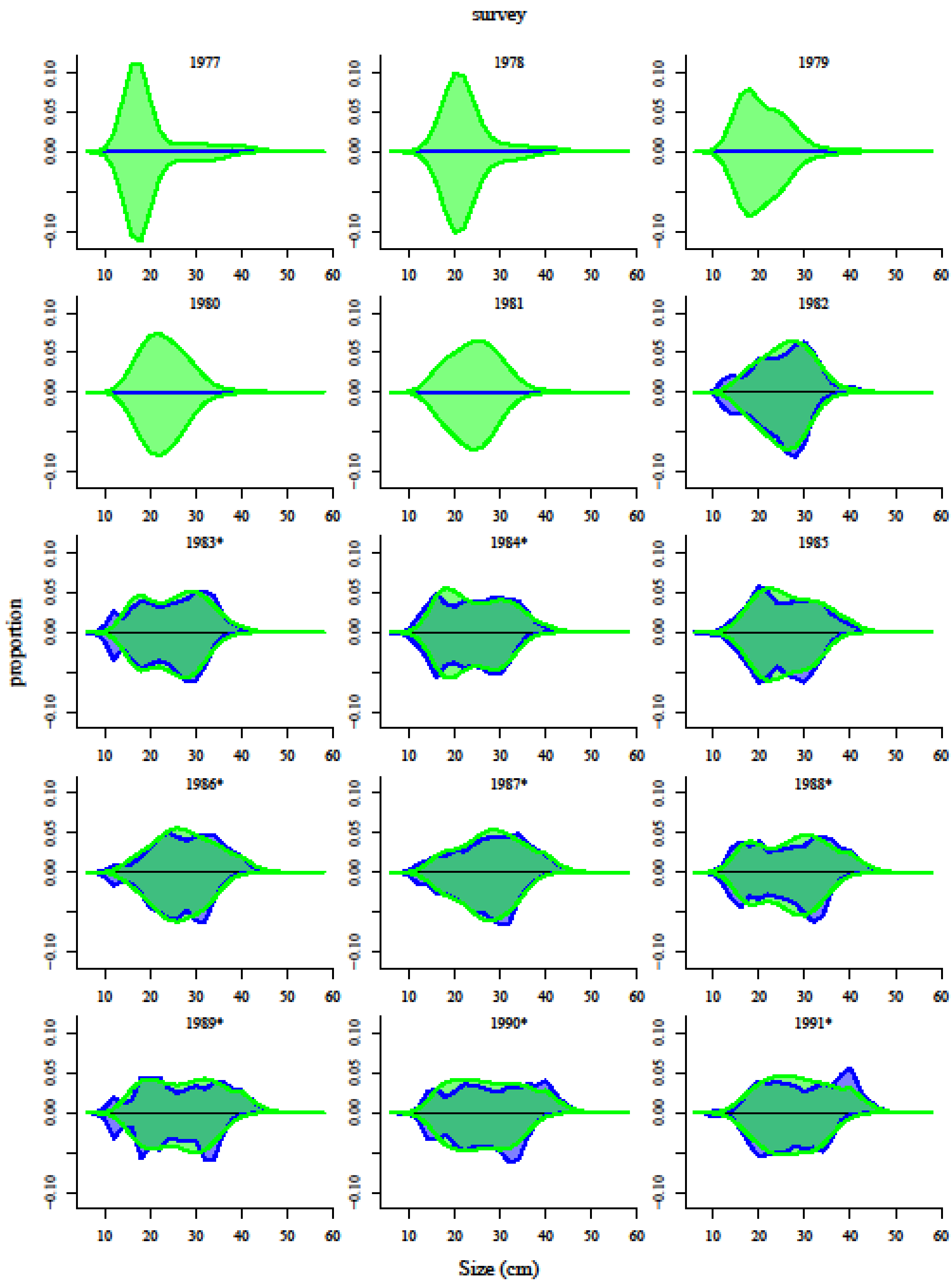


Figure 9.16. Observed (blue) and predicted (green) EBS survey length compositions for flathead sole only (part 1 of 3). Females are shown as positive values, males are shown as negative values. Years with no data are indicated by a horizontal blue line at proportion = 0. Asterisks indicate years included in the model fit.

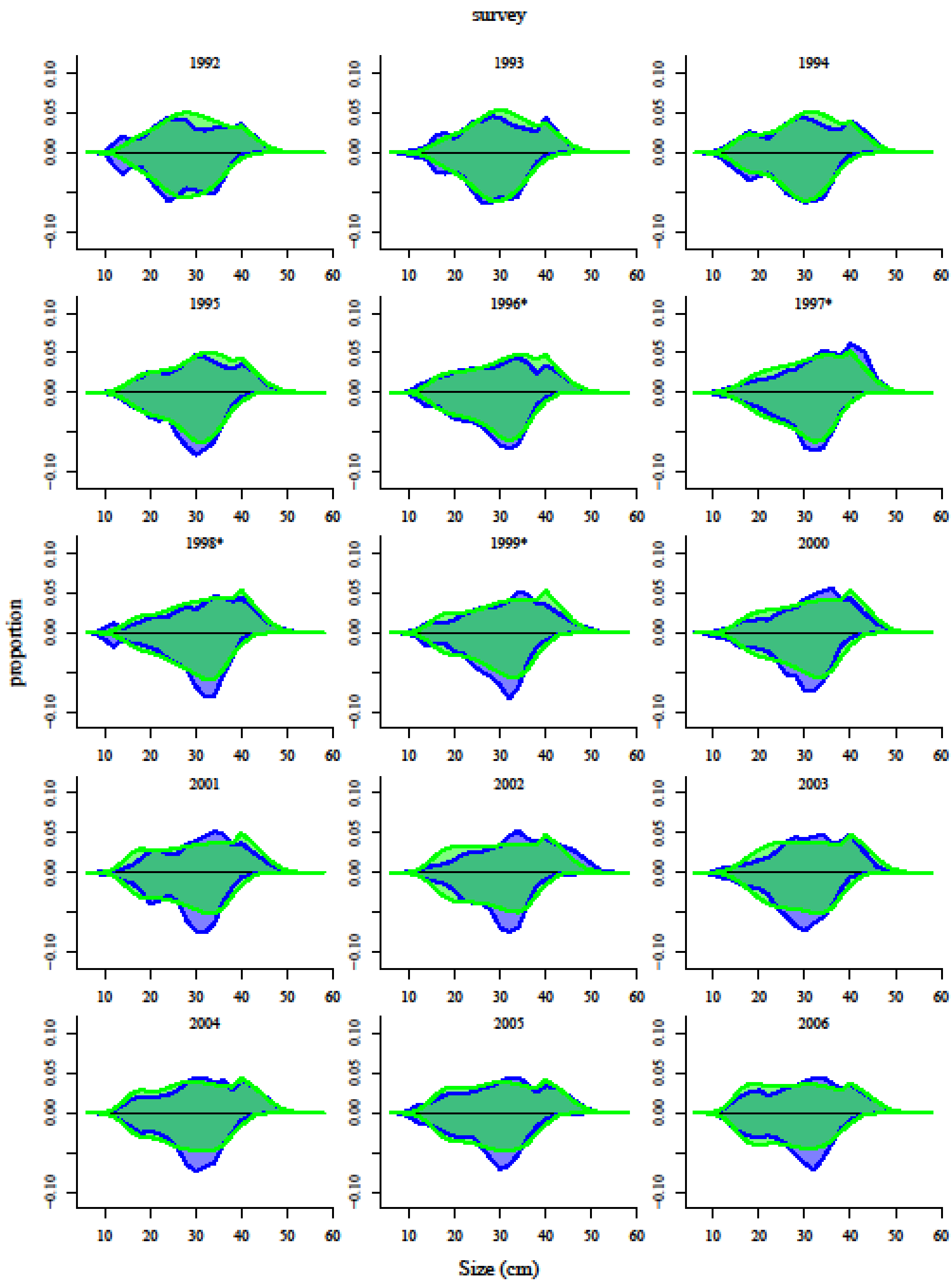
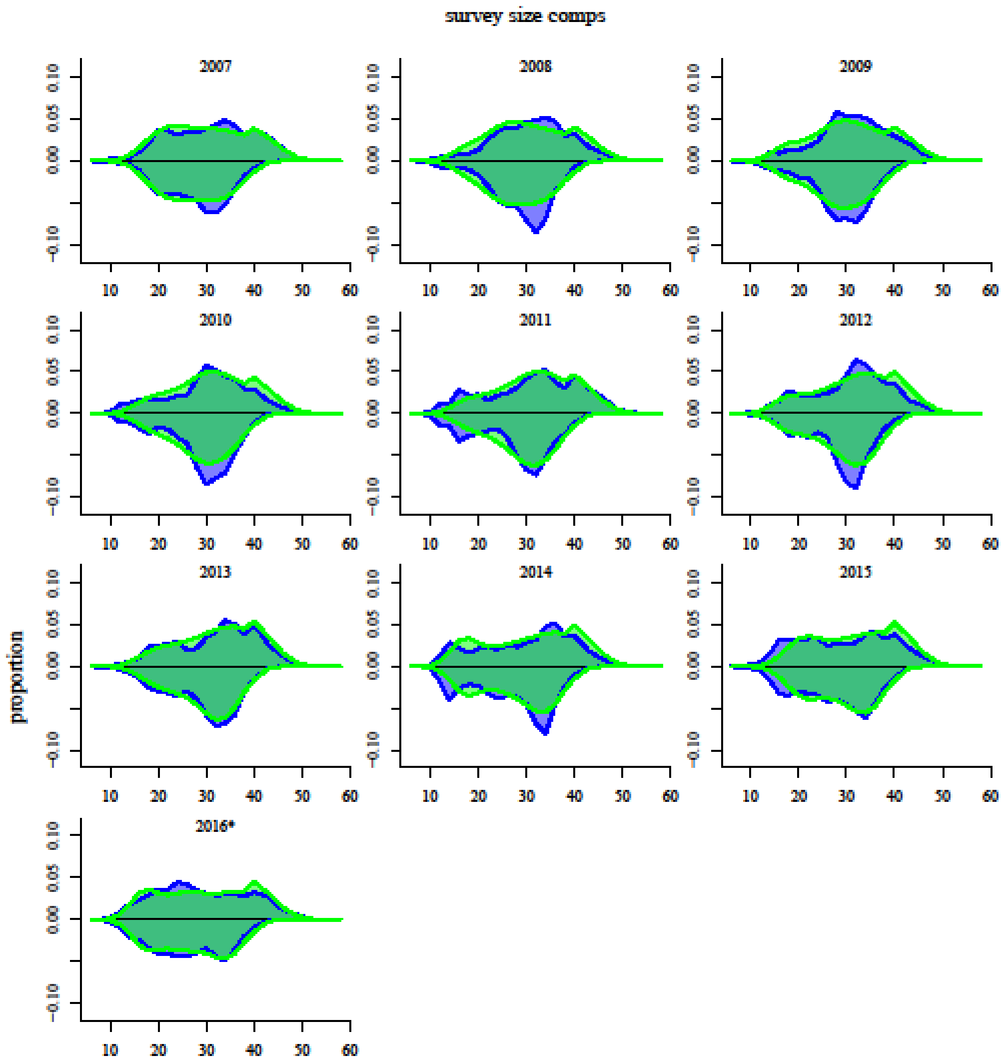


Figure 9.16, continued (part 2 of 3).



Size (cm)

Figure 9.16, continued (part 3 of 3).

Size (cm)

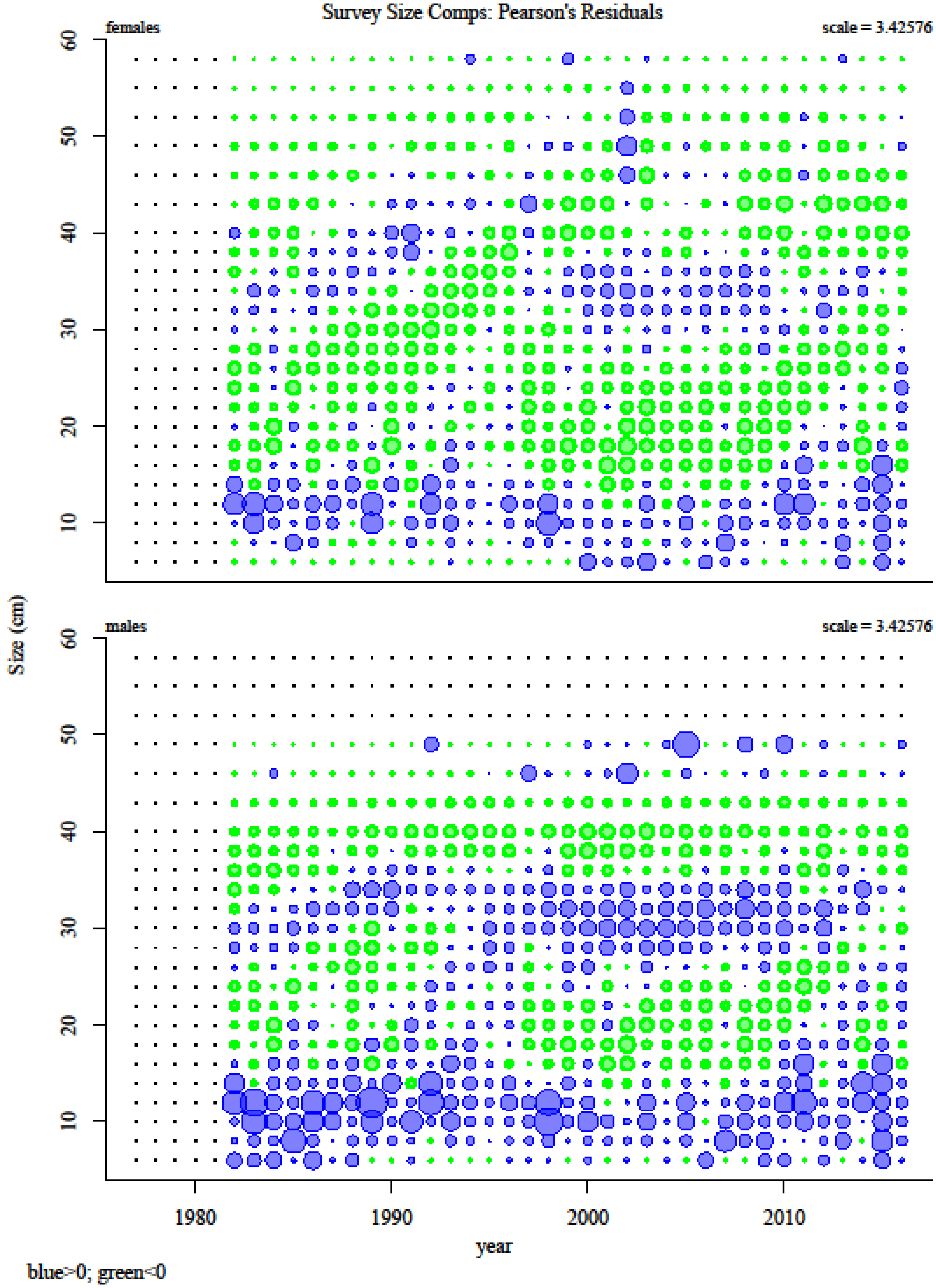


Figure 9.17. Pearson's residuals plots for the EBS flathead sole survey length compositions. Blue circles represent positive residuals, green circles represent negative residuals. Circle area scales with size of the residual.

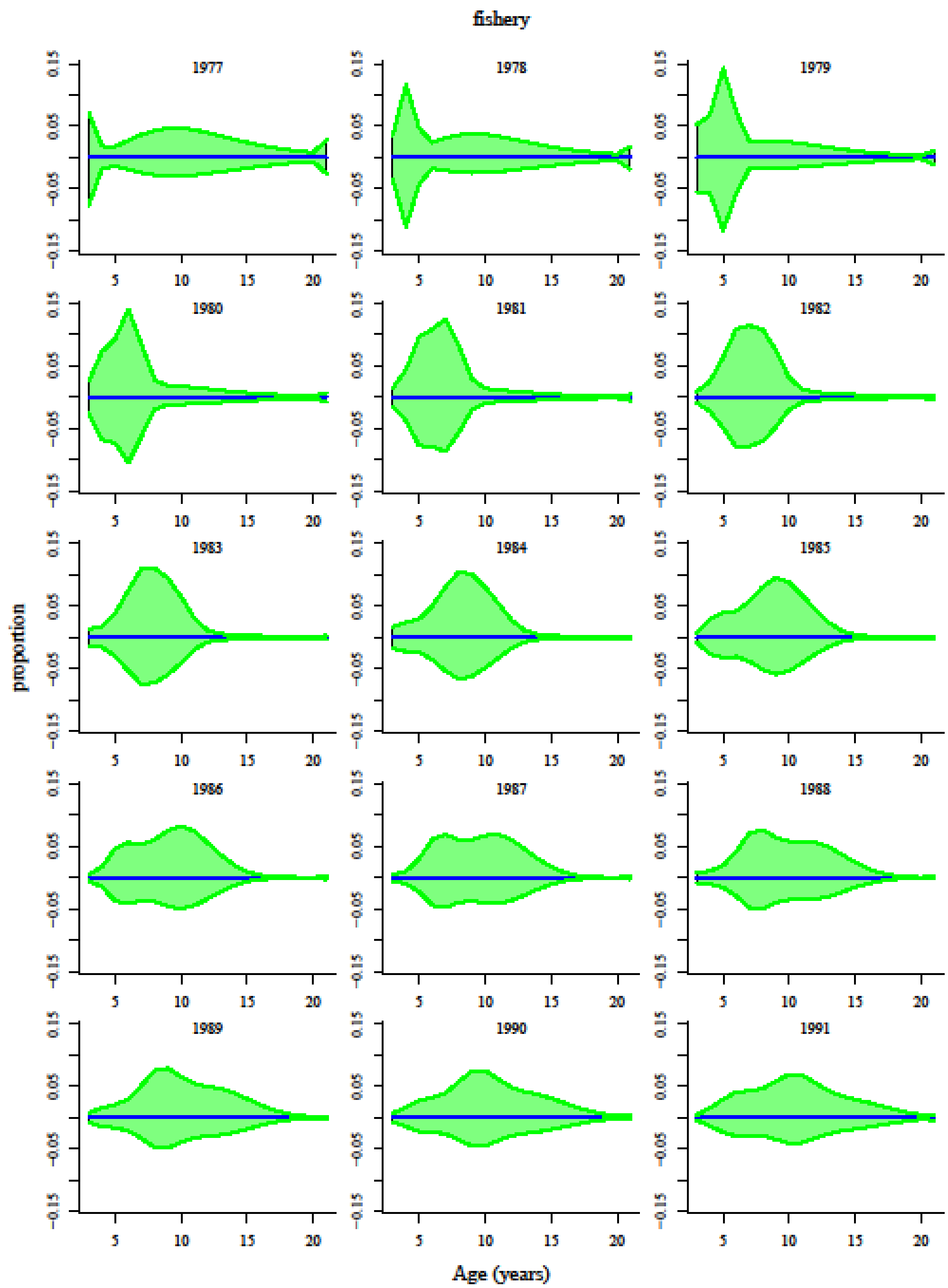


Figure 9.18. Observed (blue) and predicted (green) Bering Sea fishery age compositions for flathead sole only (part 1 of 3). Females are shown as positive values, males are shown as negative values. Years with no data are indicated by a horizontal blue line at proportion = 0. Asterisks indicate years included in the model fit.

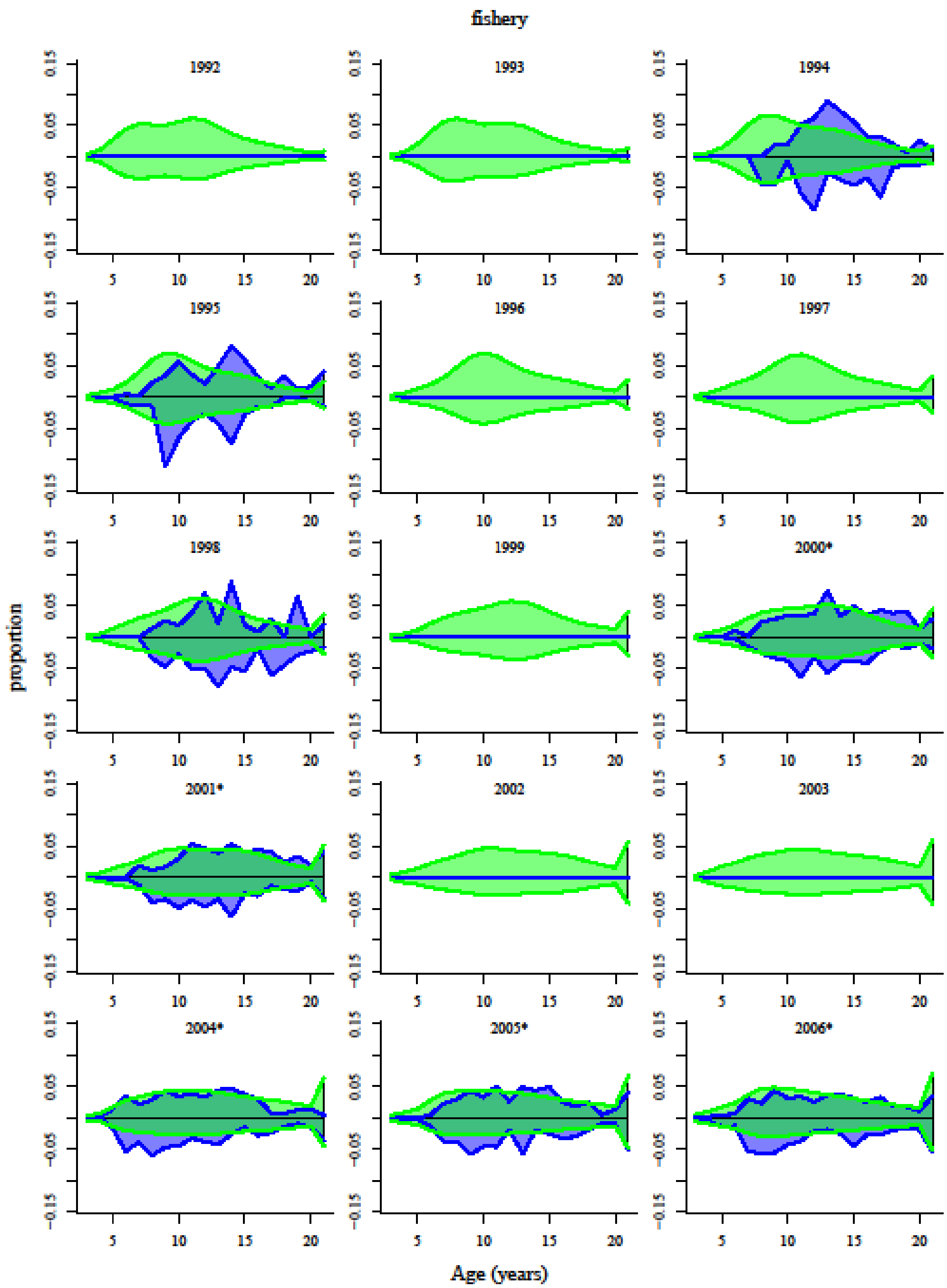
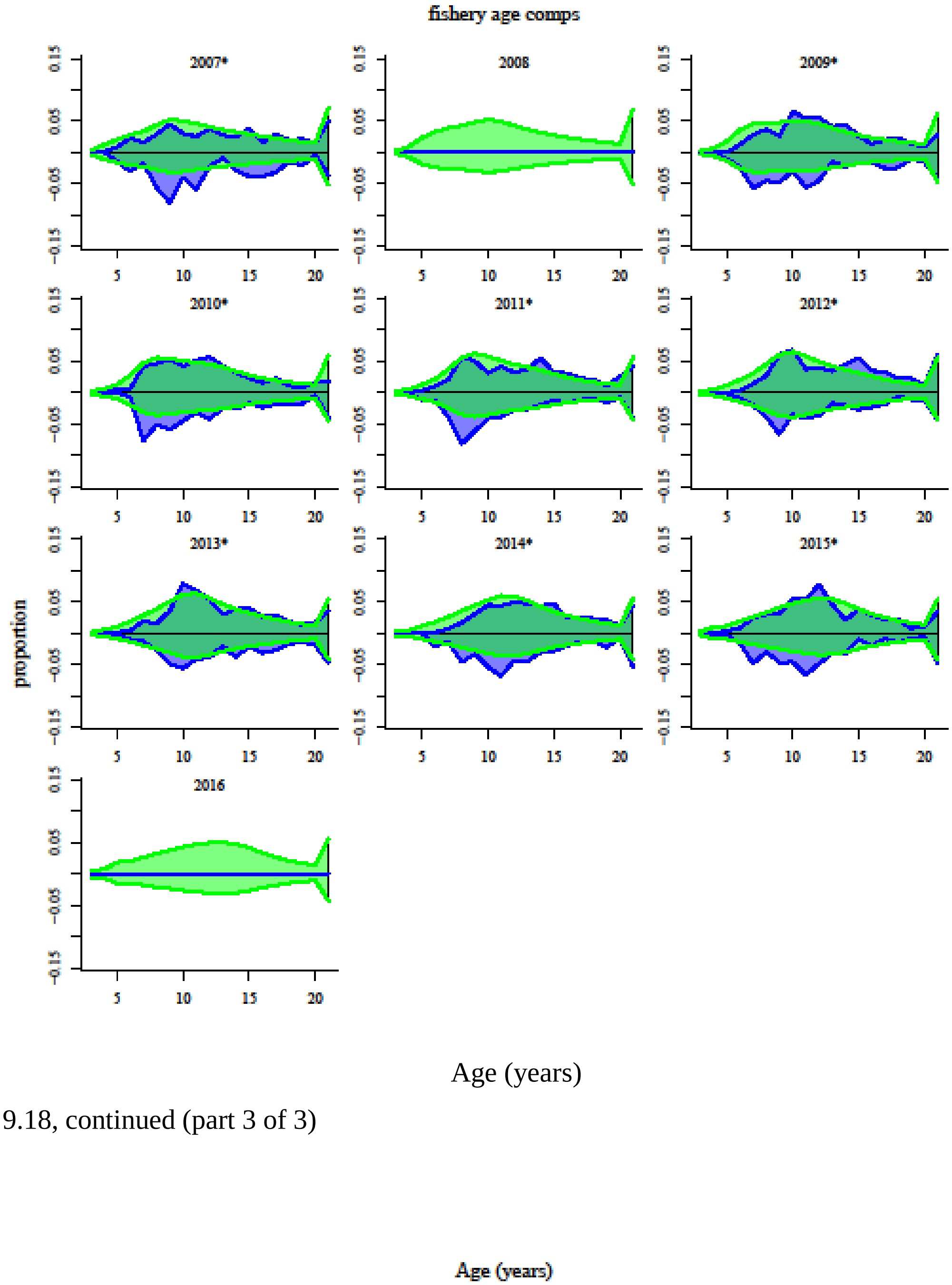


Figure 9.18, continued (part 2 of 3).



Age (years)

Figure 9.18, continued (part 3 of 3)

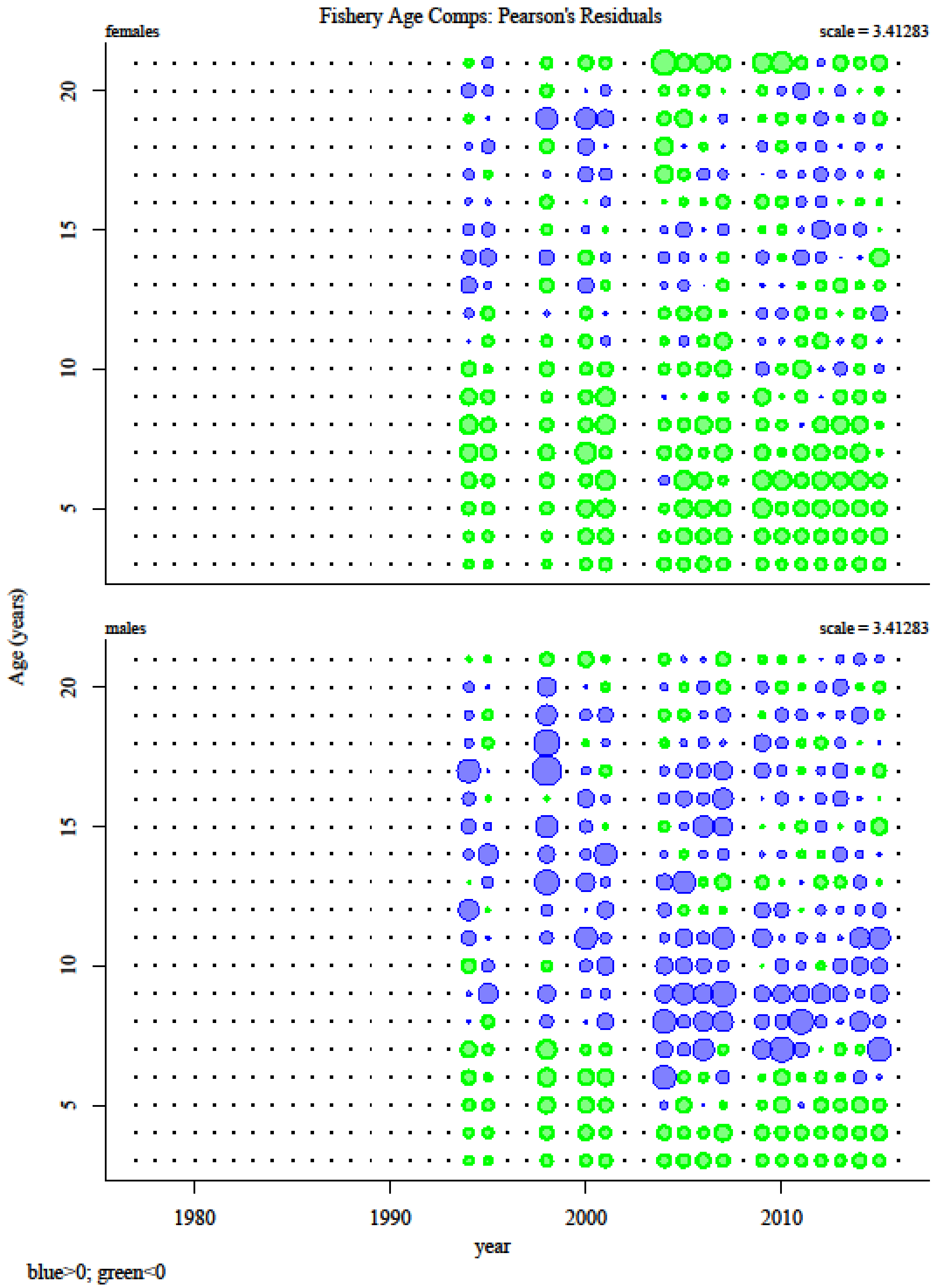


Figure 9.19. Pearson's residuals plots for Bering Sea flathead sole non-pelagic trawl fishery age compositions. Blue circles represent positive residuals, green circles represent negative residuals. Circle area scales with size of the residual.

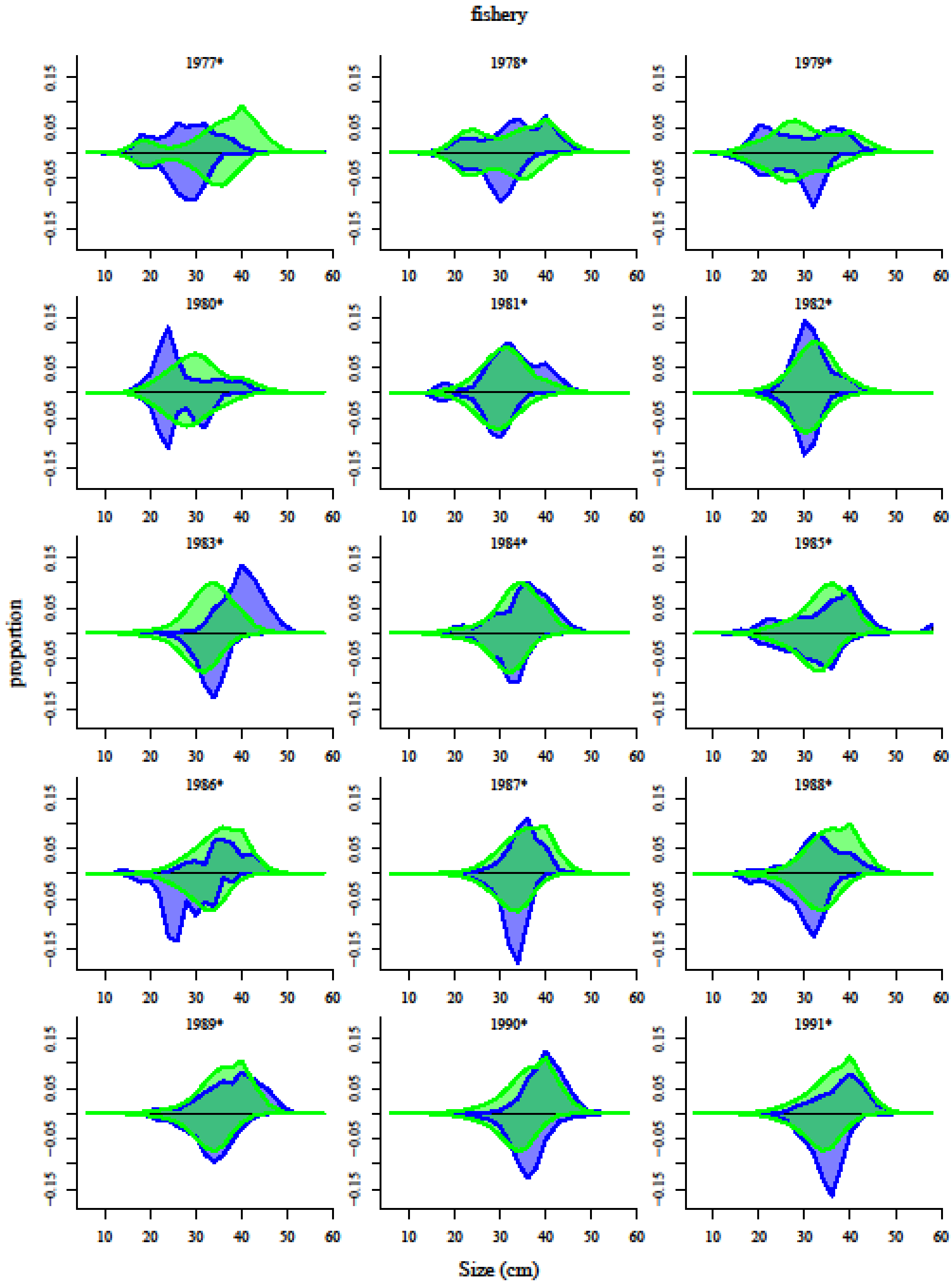


Figure 9.20. Observed (blue) and predicted (green) Bering Sea fishery length compositions for flathead sole only (part 1 of 3). Females are shown as positive values, males are shown as negative values. Years with no data are indicated by a horizontal blue line at proportion = 0. Asterisks indicate years included in the model fit.

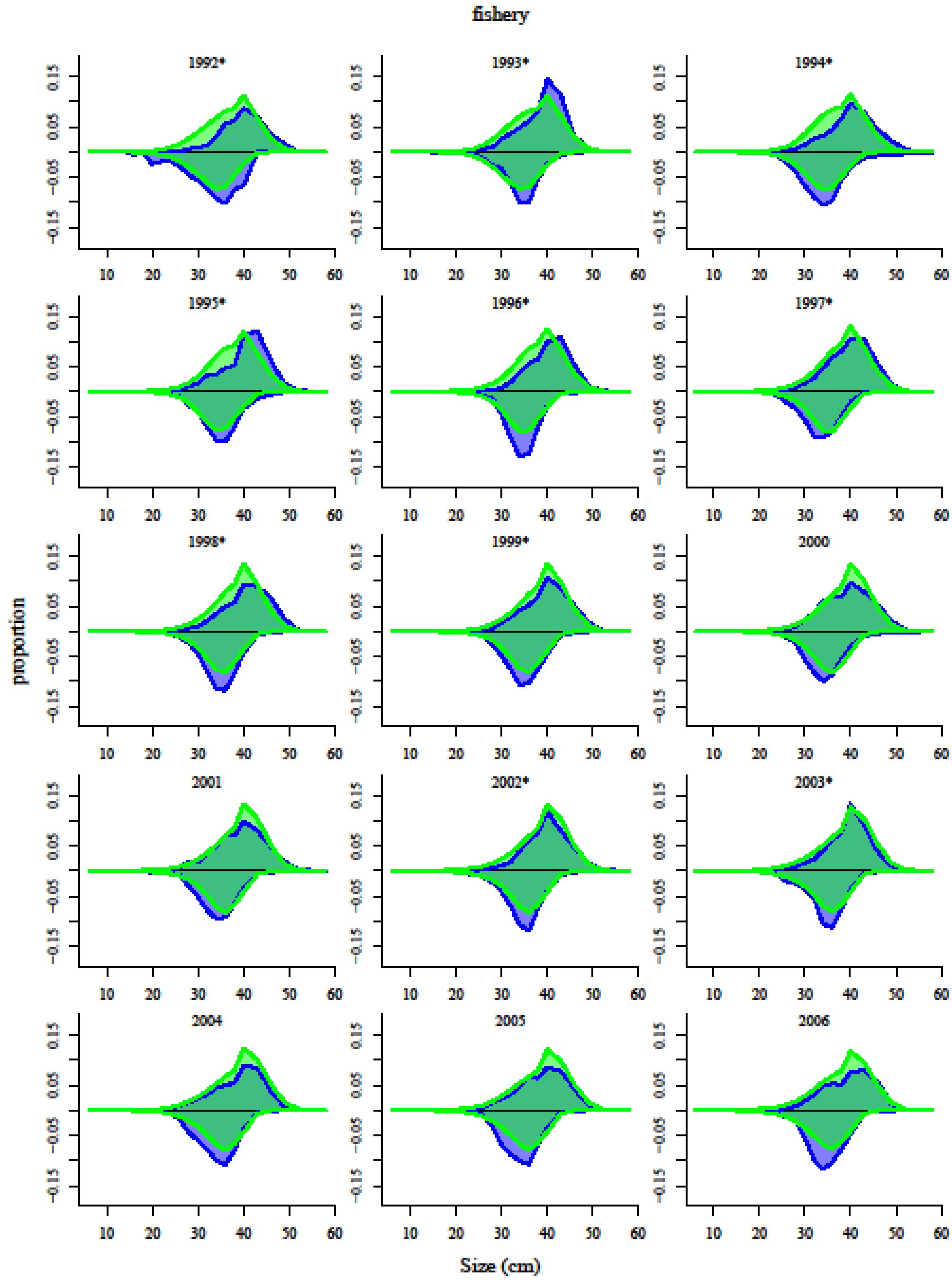


Figure 9.20, continue (part 2 of 3).

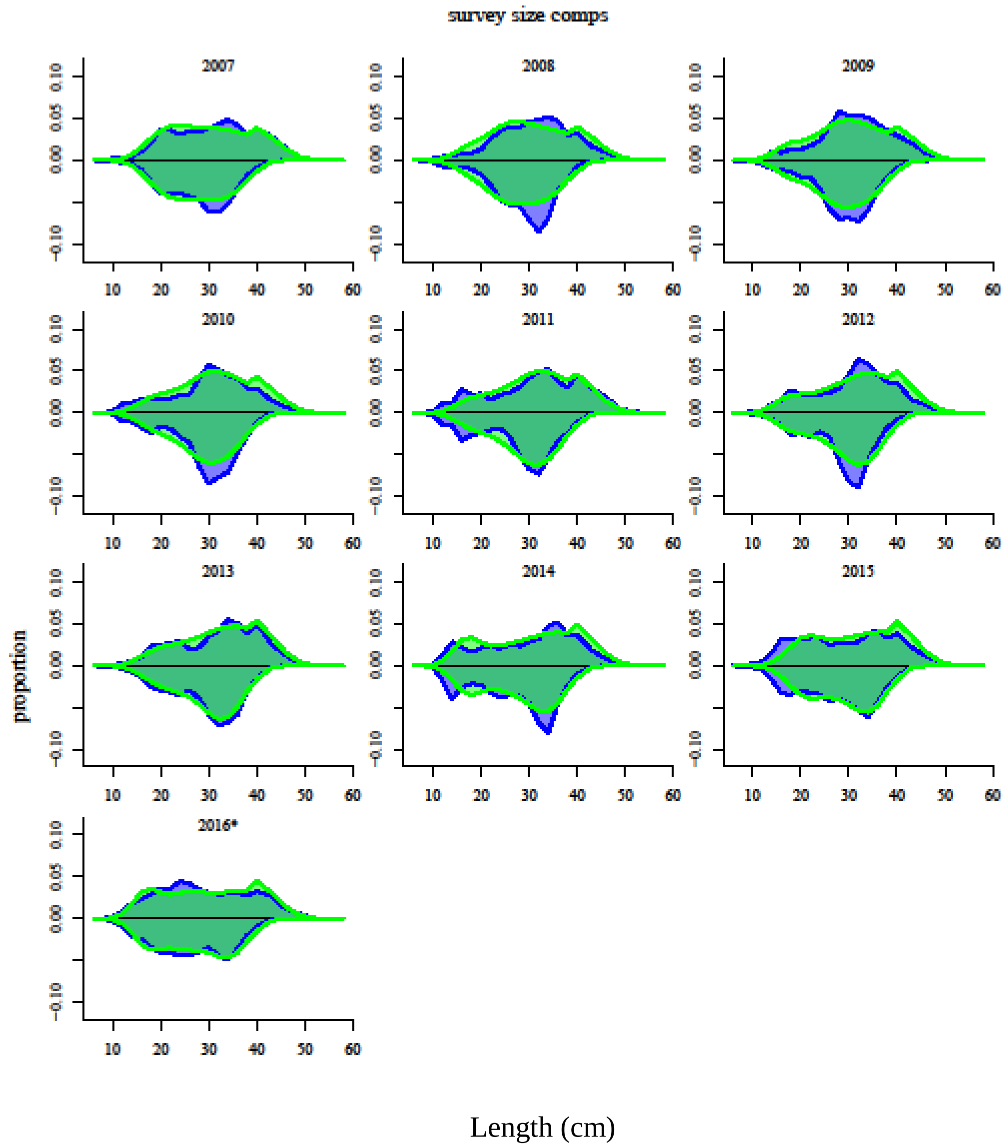


Figure 9.20, continued (part 3 of 3).

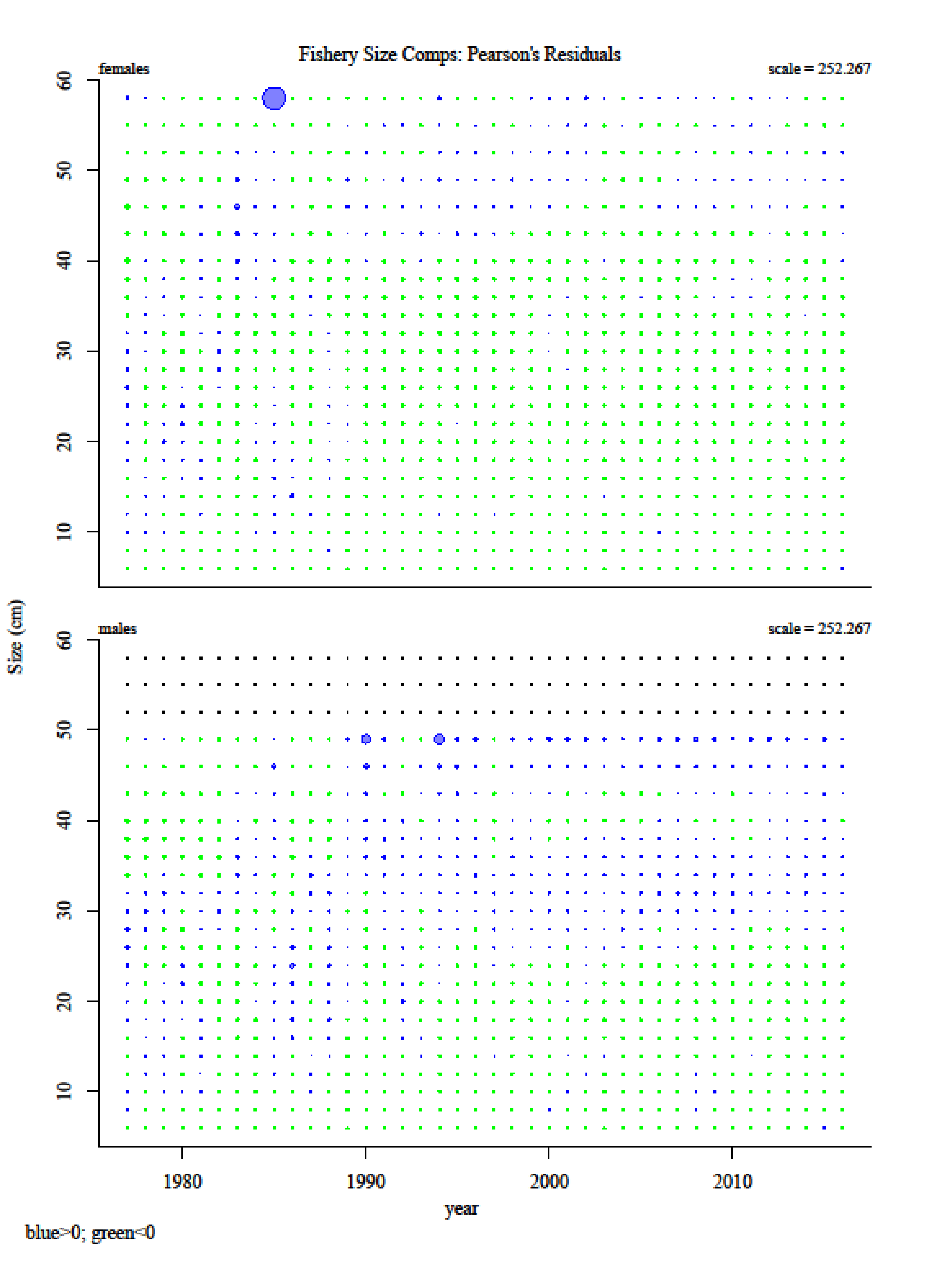


Figure 9.21. Pearson's residuals plots for the Bering Sea flathead sole non-pelagic trawl fishery length compositions. Blue circles represent positive residuals, green circles represent negative residuals. Circle area scales with size of the residual.

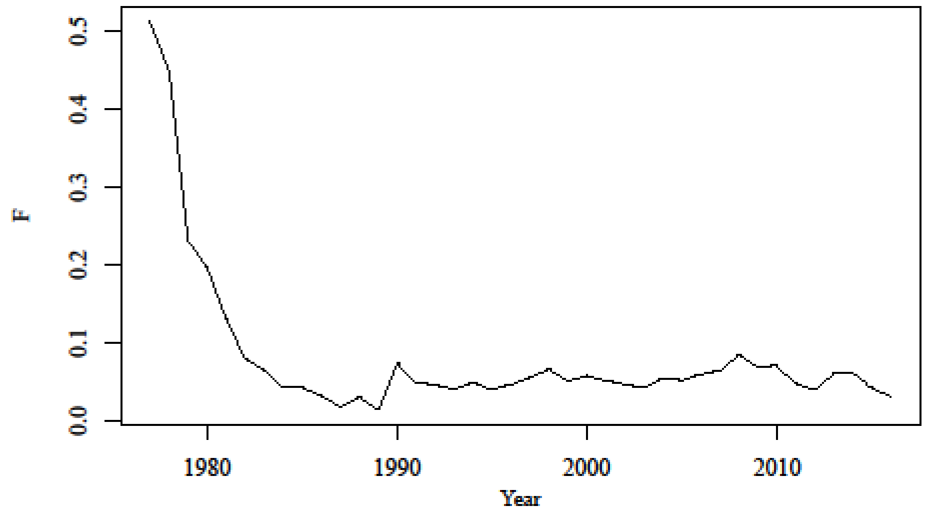


Figure 8.20. Estimated fishing mortality rate of flathead sole

Figure 9.22. Estimates of fishing mortality over time.

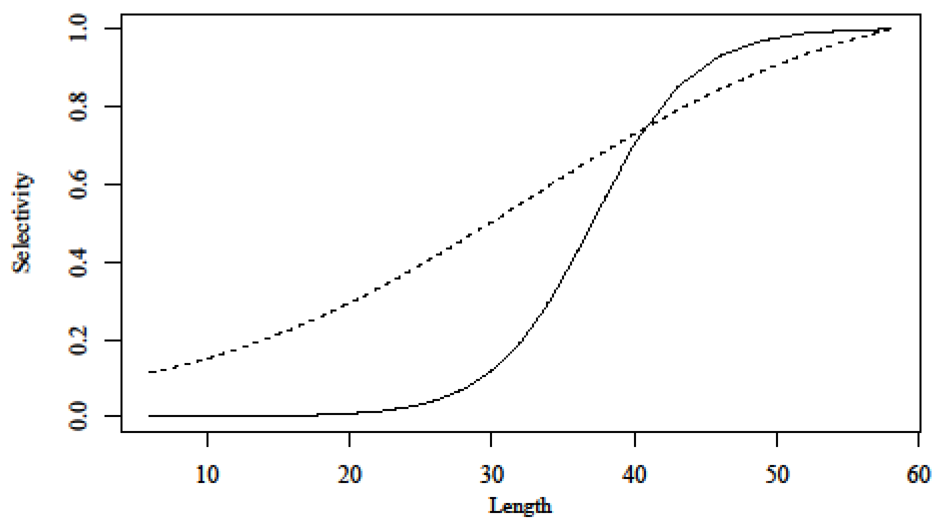


Figure 8.21. Estimated fishery (solid line) and survey (dashed line) selectivity curve by length

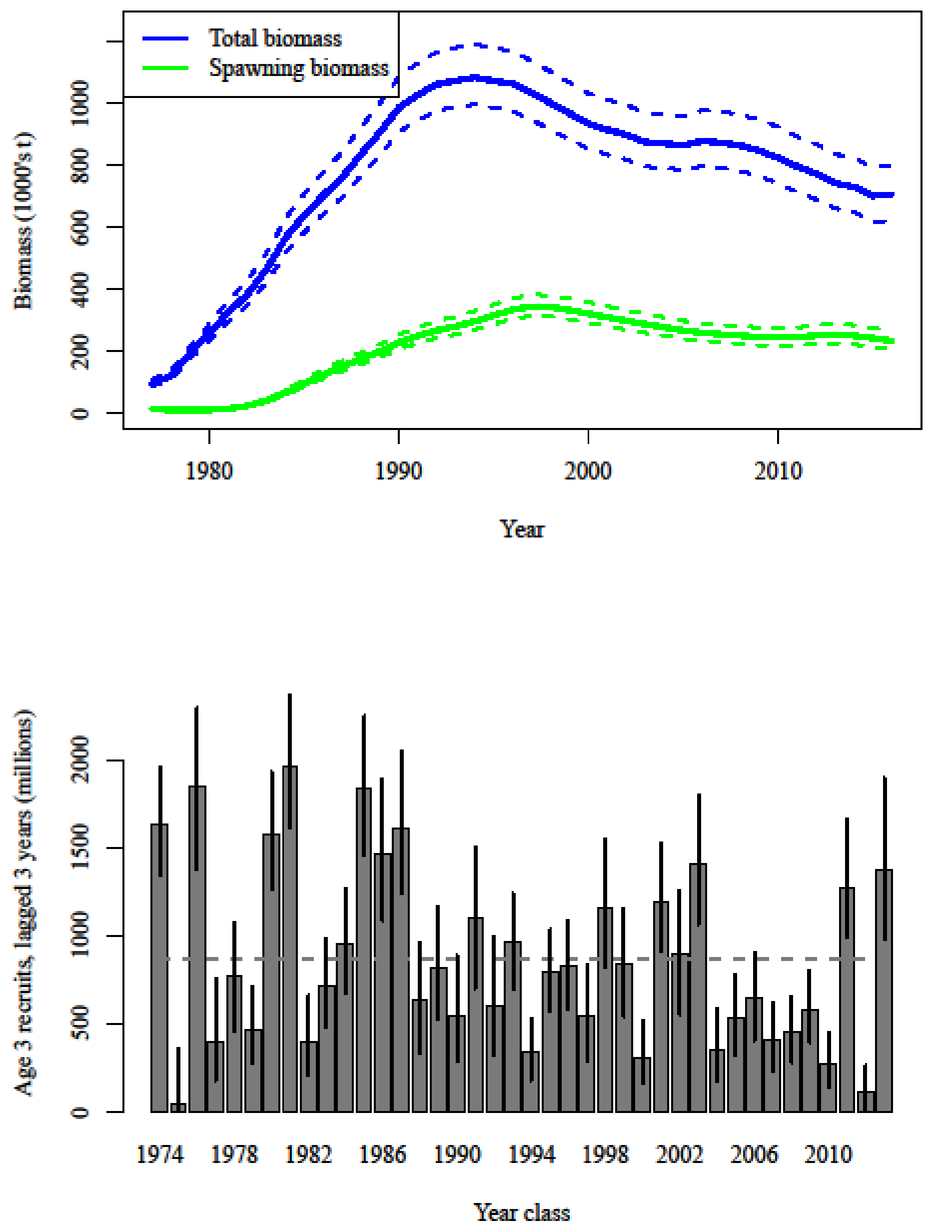


Figure 9.23. (Top) Mean total and spawning biomass (solid lines) and 95% intervals from MCMC integration. (Bottom) Estimated age 3 recruitment, lagged 3 years such that the year shown is the year at which the recruits were age 0 (gray bars) with 95% intervals obtained from MCMC integration (black vertical lines).

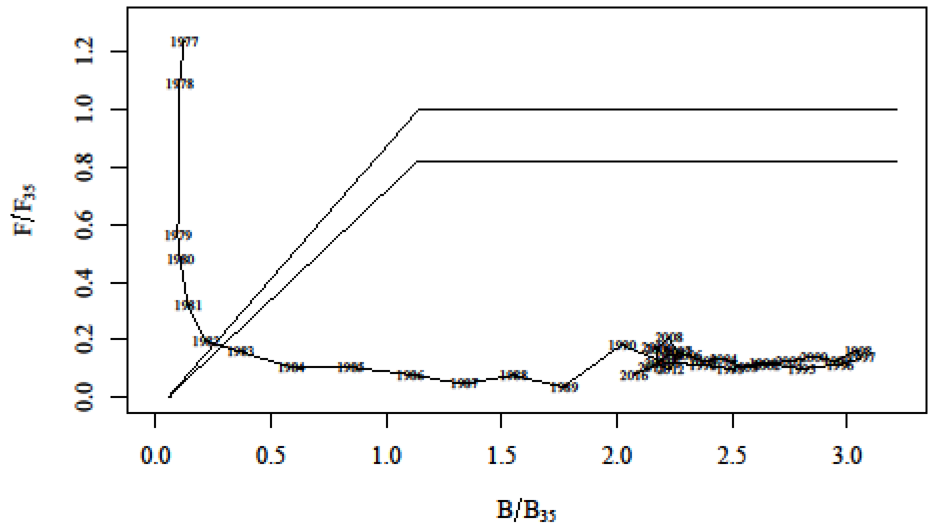


Figure 9.24. Control-rule graph: the ratio of estimated fully-selected fishing mortality (F) to $F_{35\%}$ plotted against the ratio of model spawning stock biomass (B) to $B_{35\%}$. Tier 3 control rules for ABC (lower line) and OFL (upper line) are also shown. Numbers indicate corresponding year.

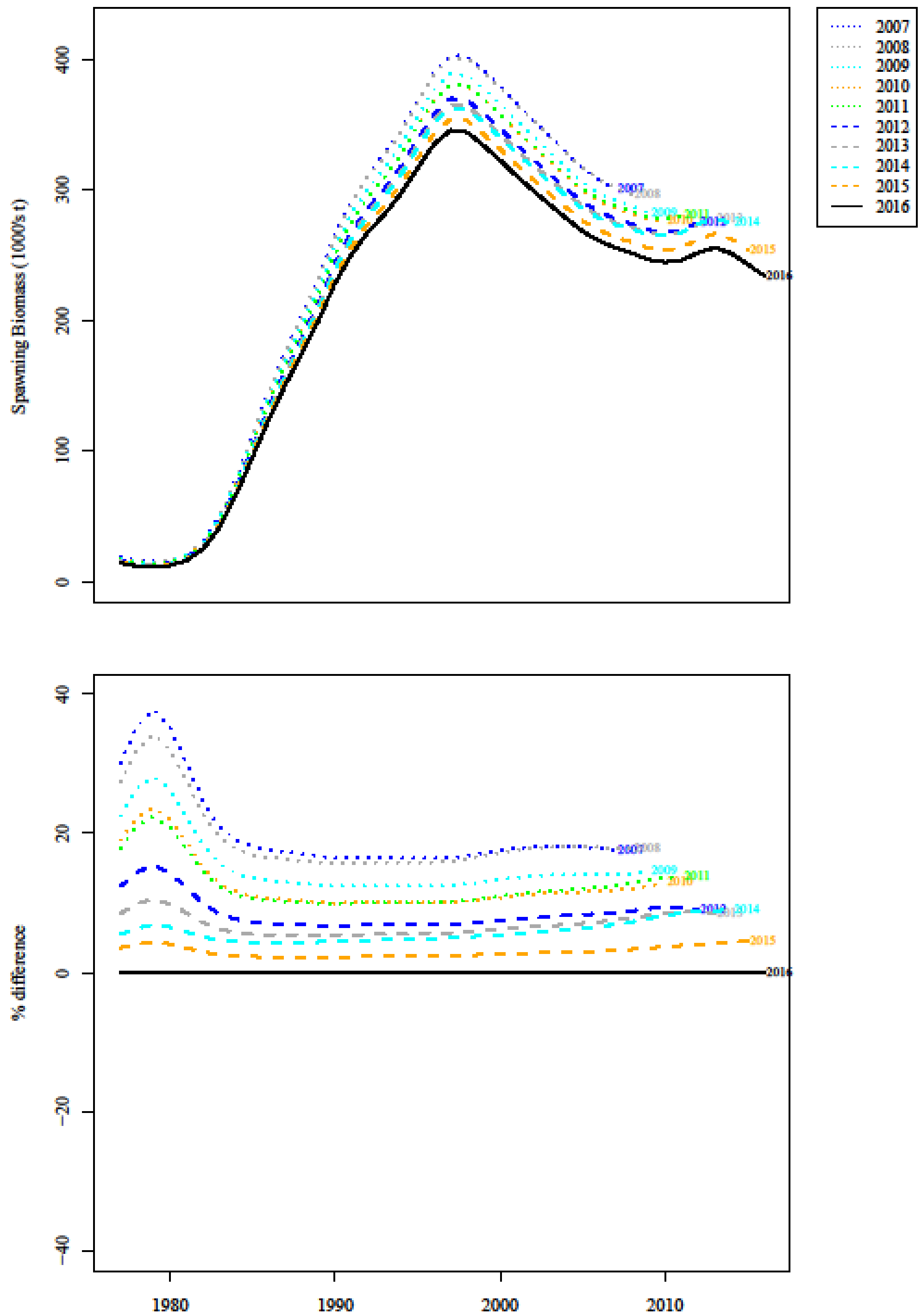


Figure 9.25. Estimated time series of spawning biomass for retrospective analyses for years 2007-2016 conducted using the 2016 assessment model structure (top) and differences in estimates of spawning biomass over time between estimates from each retrospective model and those from the 2016 model (bottom).

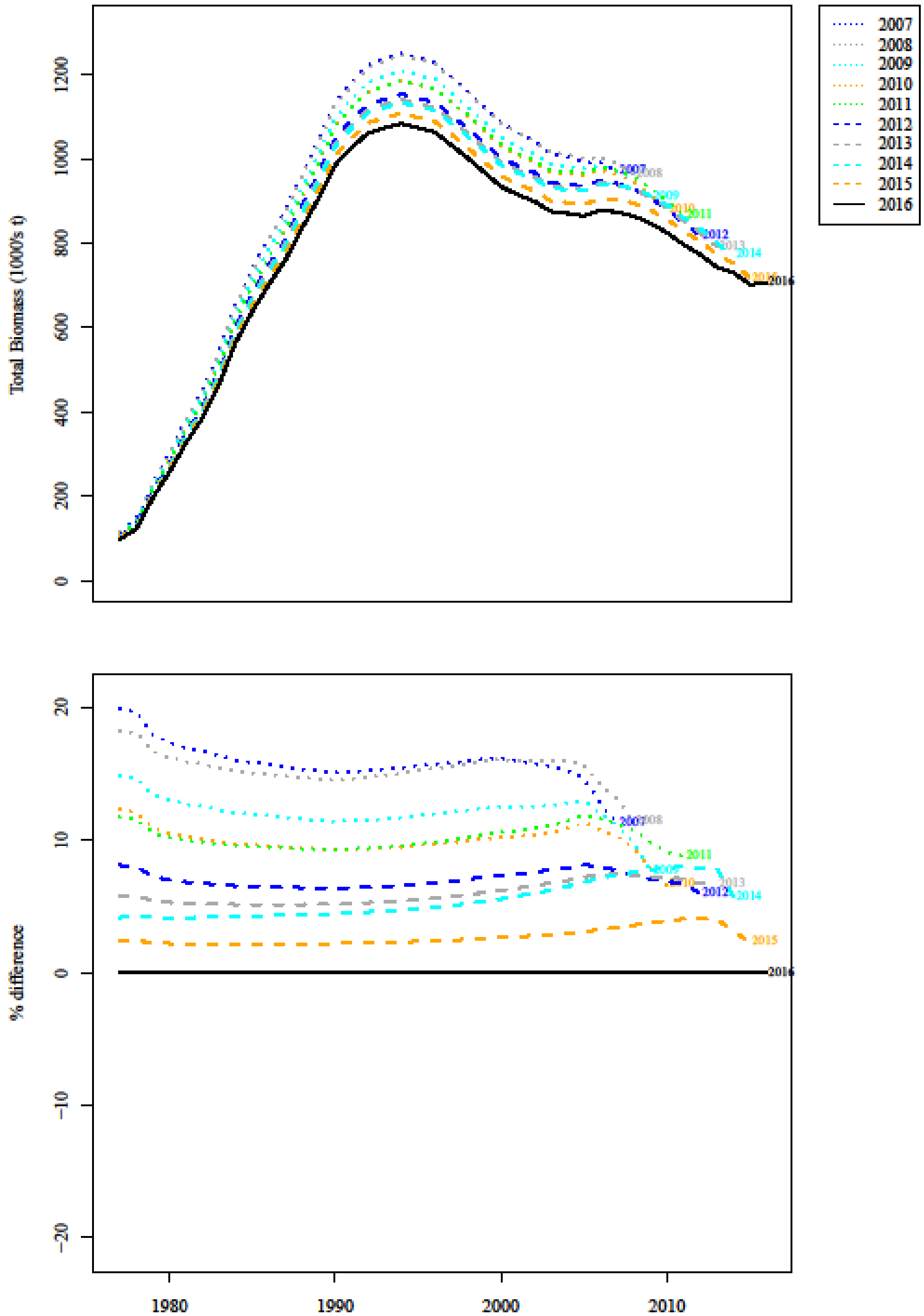


Figure 9.26. As for Figure 9.25, but for total biomass.

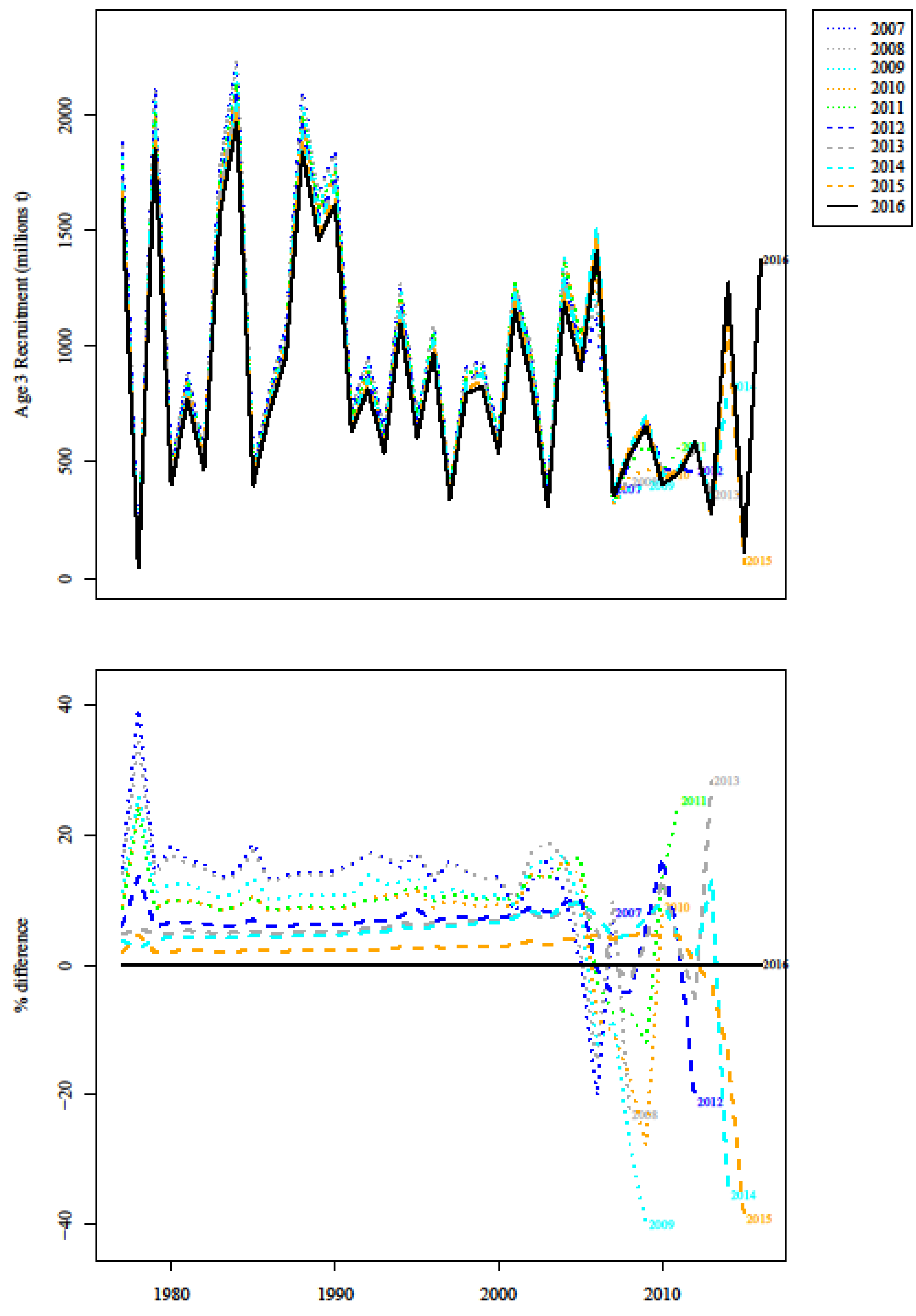


Figure 9.27. As for Figure 9.26, but for age 3 recruitment estimates.

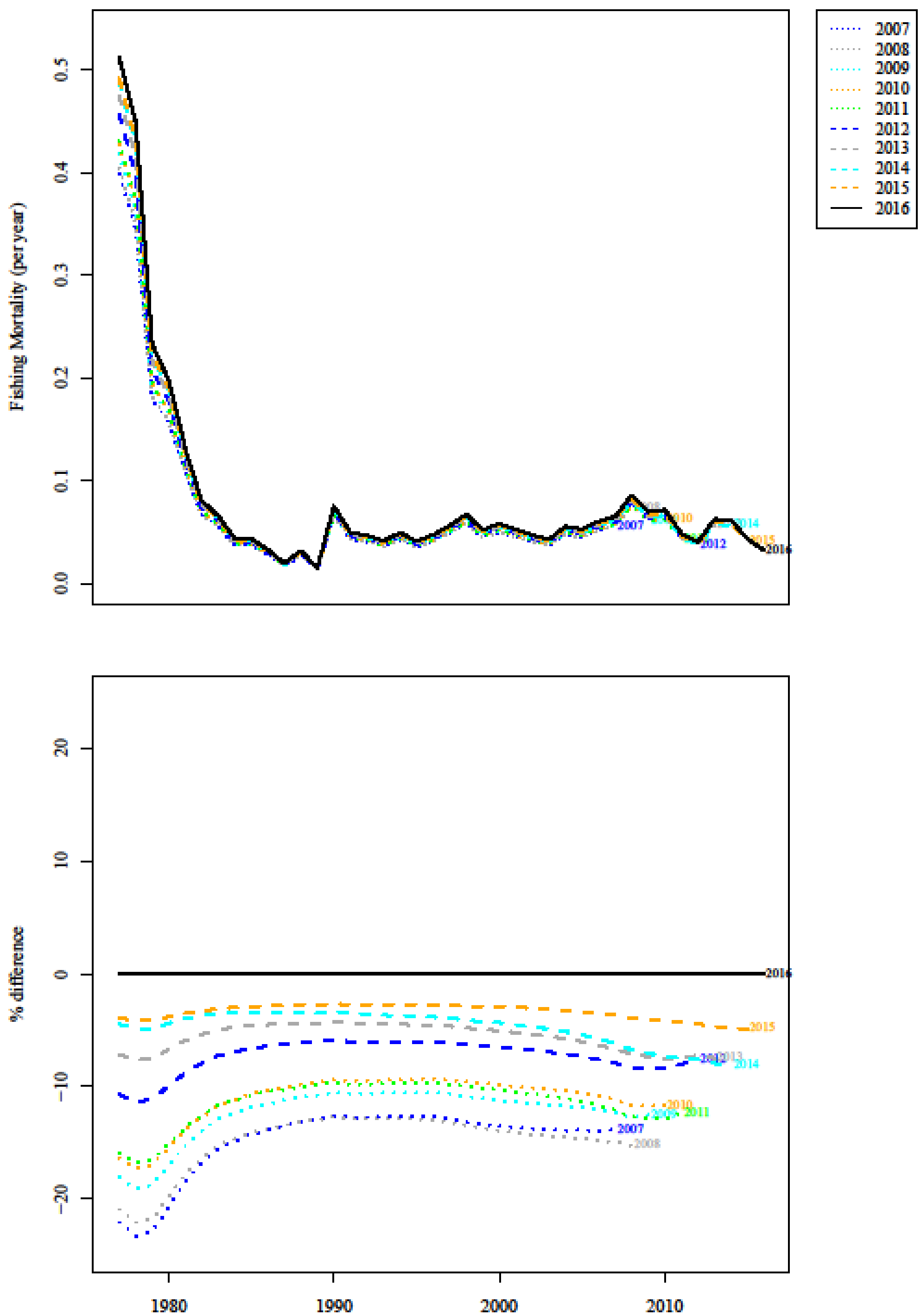


Figure 9.28. As for Figure 9.25, but for fishing mortality estimates.

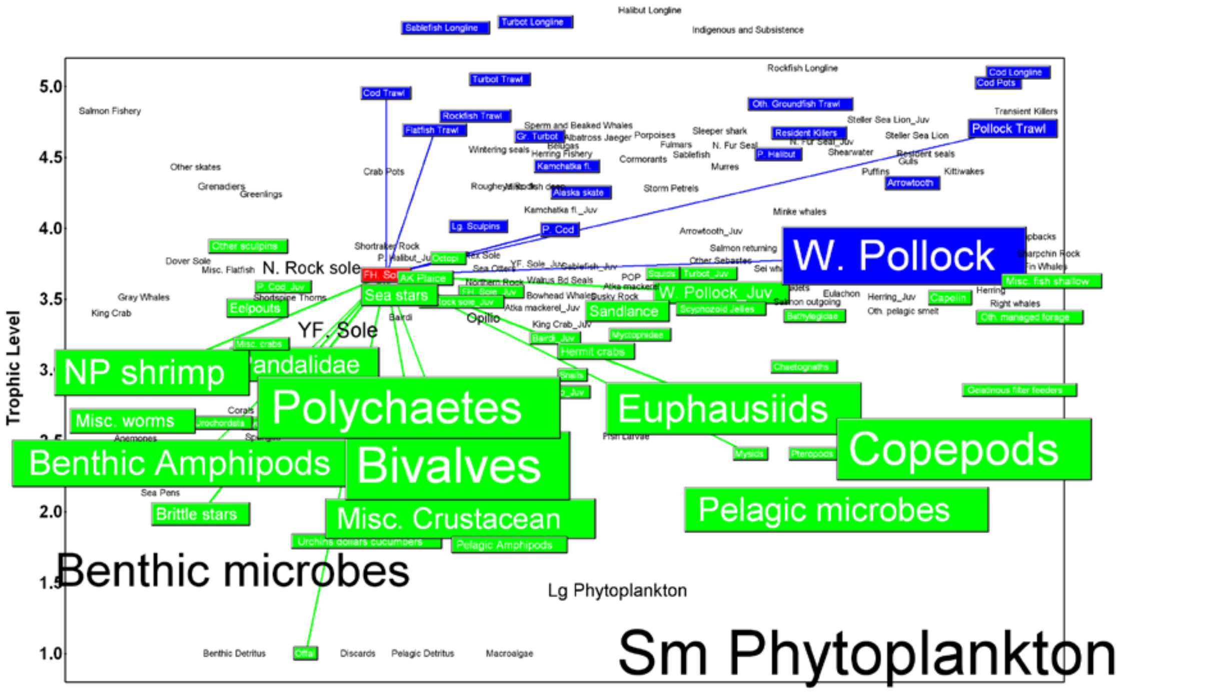


Figure 9.29. Ecosystem links to adult flathead sole in the eastern Bering Sea (based on a balanced ecosystem model for the eastern Bering Sea in the early 1990s; Aydin et al, 2007). Green boxes: prey groups; blue boxes: predator groups. Box size reflects group biomass. Lines indicate significant linkages.

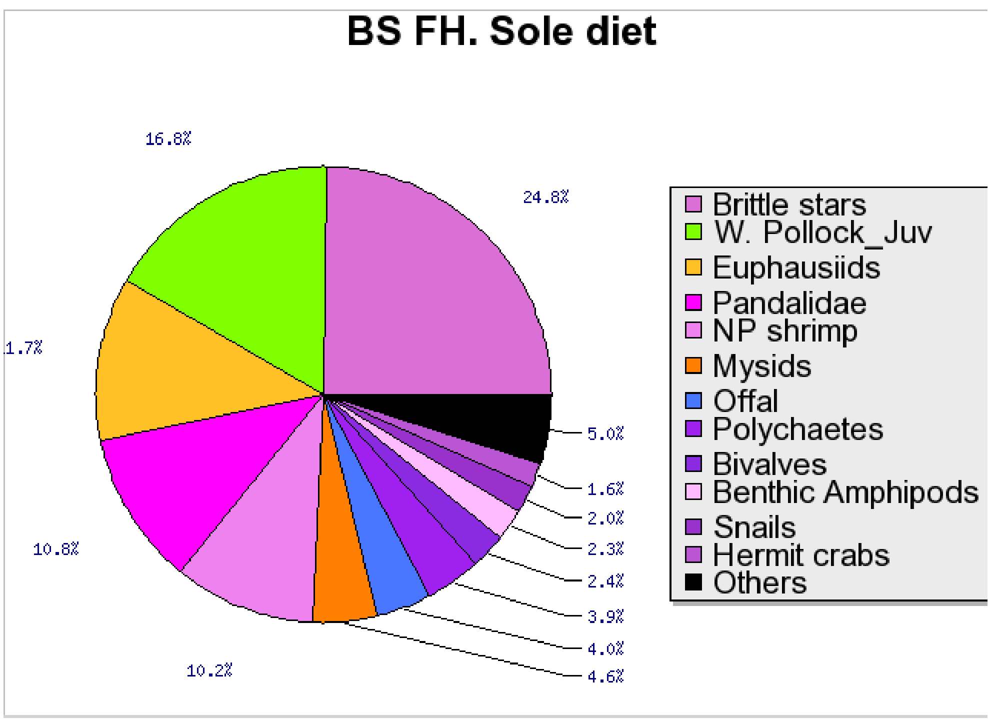


Figure 9.30. Diet composition of adult flathead sole in the eastern Bering Sea (based on a balanced ecosystem model for the eastern Bering Sea in the early 1990s; Aydin et al, 2007).

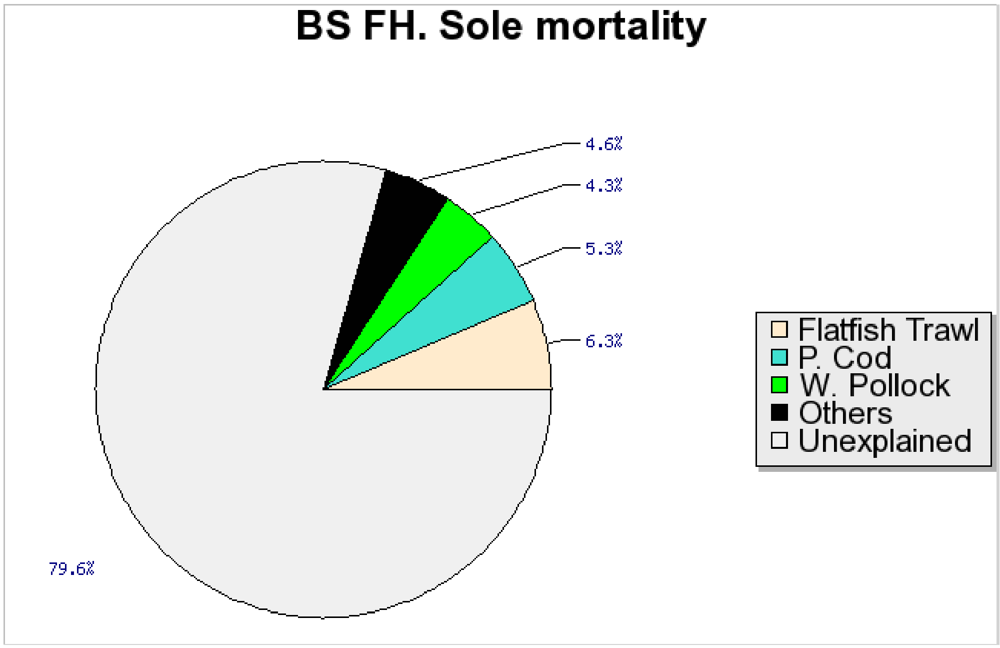


Figure 9.31. Mortality sources for flathead sole in the eastern Bering Sea (based on a balanced ecosystem model for the eastern Bering Sea in the early 1990s; Aydin et al, 2007).

Appendix A: Model Description

The assessment for flathead sole is currently conducted using a split-sex, age-based model with length-based formulations for fishery and survey selectivity. The model structure was developed following Fournier and Archibald's (1982) methods for separable catch-at-age analysis, with many similarities to Methot (1990). The assessment model simulates the dynamics of the stock and compares expected values of stock characteristics with observed values from survey and fishery sampling programs in a likelihood framework, based on distributional assumptions regarding the observed data. Model parameters are estimated by minimizing an associated objective function (basically the negative log-likelihood) that describes the mismatch between model estimates and observed quantities. The model was implemented using AD Model Builder, a software package that facilitates the development of parameter estimation models based on a set of C++ libraries for automatic differentiation.

Basic variables, constants, and indices

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

Table 9A.1. Model constants and indices.

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

Biological data

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

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

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

Fishery data

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

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

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

Survey data

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

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

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

Stock dynamics

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

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

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

Options for spawner-recruit relationships

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

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

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

Options for historical recruitment

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

Options for initial numbers-at-age

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

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

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

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

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

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

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

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

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

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

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

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

Model-predicted survey data

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

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

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

Non-recruitment related likelihood components

Model parameters are estimated by minimizing the objective function

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

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

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

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

Recruitment related likelihood components

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

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

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

Model parameters

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

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

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

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

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

Table 9A.13. Recruitment-related parameters. Superscripts refer to initial n-at-age options: 1-standard option, 2-option 2, 3-option 3. The standard option was used in the 2014 model.

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

Appendix B: Supplemental Catch Data

Table B.1. 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.

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	15,921	18,366

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