Chapter 8:
Assessment of the Flathead Sole Stock in the Bering Sea and Aleutian Islands

by
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Executive Summary

The following changes have been made to this assessment relative to the November 2009 SAFE:

Changes to the Input Data

1) The 2009 fishery catch data was updated and the 2010 catch through September 25, 2010 was added to the assessment.
2) Sex-specific size compositions from the 2010 fishery, based on observer data, were added to the assessment. Fishery size compositions from 2009 were updated.
3) The estimated survey biomass and standard error from the 2010 EBS Trawl Survey were added to the assessment.
4) Sex-specific size compositions from the 2010 EBS Trawl Survey were added to the assessment.
5) Sex-specific age compositions from the 2009 EBS Trawl Survey were added to the assessment.
6) The mean bottom temperature from the 2010 EBS trawl survey was added to the assessment.

Changes in the Assessment Model

The preferred model is identical to that selected in last year's assessment.

Changes in Assessment Results

1) The recommended ABC, based on an $F_{40\%}$ (0.280) harvest level, is 69,348 t for 2011 and 68,334 t for 2012.
2) The OFL, based on an $F_{35\%}$ (0.342) harvest level, is 83,321 t for 2011 and 82,089 t for 2012.
3) Projected female spawning biomass is 240,796 t for 2011 and 237,489 t for 2012.
4) Projected total biomass (age 3+) is 791,018 t for 2011 and 785,891 t in 2012.

The recommendations for 2011 and 2012 from this assessment (2010) are summarized and compared with the recommendations from the 2009 assessment in the following table:

Quantity/Status	Last year (2009 Assessment)		This year (2010 Assessment)	
	2010	2011	**2011**	**2012**
M (natural mortality)	0.2	0.2	**0.2**	**0.2**
Specified/recommended tier	3a	3a	**3a**	**3a**
Total biomass (Age 3+; t)	784,911	773,431	**791,018**	785,891
Female Spawning Biomass (t)	238,070	232,059	**240,796**	237,489
$B_{100\%}$	342,942	342,942	**336,027**	336,027
$B_{40\%}$	137,177	137,177	**134,411**	134,411
$B_{35\%}$	120,030	120,030	**117,609**	117,609
$F_{OFL} = F_{35\%}$	0.344	0.344	**0.342**	0.342
$max\ F_{ABC} = F_{40\%}$	0.282	0.282	**0.280**	0.280
recommended F_{ABC}	0.282	0.282	**0.280**	0.280
Specified/recommended OFL (t)	83,132	81,809	**83,321**	82,089
Specified/recommended ABC (t)	69,200	68,098	**69,348**	68,334
Is the stock being subjected to overfishing?	no	no	**no**	no
Is the stock currently overfished?	no	no	**no**	no
Is the stock approaching a condition of being overfished?	no	no	**no**	no

SSC Comments Specific to the Flathead Sole Assessment

SSC Comment (Dec. 2006): *The mixed stock fishery for* Hippoglossoides *is a good candidate for a management strategy evaluation to determine whether the current management approach, which focuses on the dynamics of the much larger stock of flathead sole, provides adequate protection of Bering flounder.*

Author response: The principal author continues to work on this issue. However, basic biological information (e.g., age/size-at-maturity) has been lacking to parameterize the Bering flounder model. Maturity samples for Bering flounder collected during the 2006 and 2007 EBS shelf groundfish surveys have been processed by J. Stark (RACE, AFSC) and a manuscript based on this work is undergoing peer review. Samples were also collected this year (2010) in the northern Bering Sea; these should provide a latitudinal contrast with results from the previous sampling. Recent biological, fishery, and survey information for Bering flounder is discussed in Appendix C of this chapter.

SSC Comments on Assessments in General

SSC Comment (Dec., 2009): "*The SSC also recommends a research topic to flatfish assessment scientists. A meta-analysis of stock-recruit relationships for flatfish stocks may be very useful to evaluate productivity of these stocks, similar to one previously conducted for rockfish. This could help inform decisions about when a flatfish assessment using Tier 3 may qualify for Tier 1.* "

Author response: No progress to report on this research recommendation; however, flatfish assessment authors plan to examine the research previously conducted for rockfish and perform a similar analysis for flatfish.

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 past 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 Bering flounder, whose range extends north to the Chukchi Sea and into the western Bering Sea. The two species are very similar morphologically, but differ in demographic characteristics and spatial distribution. Differences between the two species were described by Walters and Wilderbuer (1997), who illustrated the possible ramifications of combining demographic information from the two species. Bering flounder exhibit slower growth and smaller maximum size when compared with flathead sole, and fish of the same size could possibly be 3 years different in age for the two species. Although Bering flounder typically represent less than 3% of the combined survey biomass for the two species, combining them increases the uncertainty in 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, although the accuracy of species identification by observers is unknown. In addition, more information concerning the biology of Bering flounder is becoming available. Maturity samples collected during the 2006 and 2007 EBS shelf groundfish surveys have been processed and a manuscript based on the results is under peer review (J. Stark, pers. comm.). This work includes determination of the maturity schedule for Bering flounder in the EBS--a critical component in development of an age-structured model for Bering flounder. Thus, it may be possible in the near future to consider developing species-specific components for ABC and OFL for this complex. Recent biological, fishery, and survey information for Bering flounder is discussed in Appendix C of this chapter.

For the purposes of this report, however, 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.

Catch History

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 17,882 t (Table 8.1, Figure 8.1). The catch in 2008 (24,539 t) was the highest since 1998. The 2010 catch (18,544 as of Sept. 25) was similar to catches in 2006, 2007, and 2009. The majority of the catch was taken by non-pelagic trawl gear (77% in 2010; Figure 8.2), with a substantial fraction also taken by pelagic trawl gear (22% in 2010). Other gear types (hook and line, pot) account for a very small fraction of the total catch (<2% in 2010). The majority of the catch in 2009 and 2010 was taken in NMFS Statistical Area 521 (32% and 39%, respectively; Figure 8.2). Substantial fractions (> 10%) of the total catch are also taken in areas 509, 513, and 517. Using observed species-specific catches within each statistical area and extrapolating to the total *Hippoglossoides* spp. catch within each area yields disaggregated estimates of total catch of flathead sole and Bering flounder in 2009 and 2010 (Figure 8.3). The majority of catches of both species occurred in area 521 in both 2009 and 2010. In 2010, area 521 accounted for 33% of the total catch of flathead sole (*H. elassodon*) while it accounted for 91% of the catch of Bering flounder. However, Bering flounder constituted only 3.4% of the total catch in area 521 in 2010 while flathead sole constituted 96.6% of the catch. Overall, Bering flounder accounted for only 1.2% of the total *Hippoglossoides* spp. catch in 2010. Similar results occurred in 2009, as well.

Although flathead sole receives a separate ABC and TAC, 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 (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 (Table 8.2). Since the implementation of Amendment 80, the Amendment 80 Cooperative sector has never reached its in-season halibut bycatch limits. The Amendment 80 Limited Access sector reached its halibut bycatch limit in November in 2008 and in May in 2010.

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 (Table 8.3). Based on data from the NMFS Regional Office Catch Accounting System, about 30% of flathead sole catch was discarded prior to 2008, while only 10% has been discarded since 2008. In 2008, the flathead sole directed fishery caught almost 12,000 t and discarded only 2% while in 2007 it caught a little over 7,000 t and discarded 17%. In 2009, the directed fishery caught more than 8,500 t and discarded only 1%. In 2008, the yellowfin sole and pollock directed fisheries also caught substantial amounts of flathead sole

(5,597 and 4,209 t, respectively). Retention was high in the yellowfin sole fishery (93%), while the pollock fishery retained only 74% of flathead sole caught. In 2009, these fisheries caught 3,525 t and 4,652 t of flathead sole as incidental catch and retained 90% and 78%, respectively.

The annual spatial distribution of observed catches of flathead sole and Bering flounder by trawl (non-pelagic and pelagic) gear in the Bering Sea is shown in Figure 8.4a for 2008-2010 and for flathead sole (only) by quarter for 2009 and 2010 in Figure 8.4b. Note that the plots for 2008-2009 differ somewhat from those in previous assessments because catches from individual hauls are now summed over a grid cell, rather than averaged over a grid cell, in the gridding procedure prior to interpolation. The new approach results in maps that conform closer to expectation in that disaggregated maps (e.g., catch by quarter) appear to sum as expected to the aggregated map (e.g., the annual catch). Catches of flathead sole occurred consistently in three principal areas on the continental shelf: a band starting northwest of Unimak Island and extending northwestward across the shelf toward the Pribilof Islands, an area west of the Pribilof Islands to the shelf edge, and an area ~200 km southeast of St. Matthew Island. Bering flounder were also identified as being caught in this latter area in 2009, as well as in the vicinity of St. Paul in the Pribilof Islands in 2009 and 2010. Although still quite small (< 300 t), observer-extrapolated catches of Bering flounder were greater than 10 times larger than extrapolated annual catches during 1995-2008 (~10 t). The extent to which this increase is a consequence of increased precision due to changes in observer coverage and sampling procedures or to changes in fishing patterns, both of which occurred under Amendment 80, is unclear.

Data

Fishery Catch, Catch-at-Length and Catch-at-Age Data

This assessment used fishery catches from 1977 through September 25, 2010 (Table 8.1, Figure 8.1), estimates of the fraction of animals caught annually by age class and sex (i.e., age compositions) for several years, and estimates of the fraction of animals caught annually by size class and sex (i.e., size compositions). Fishery age compositions for 2000, 2001, 2004-2007 were included in the assessment model (Table 8.4, Figure 8.5). Although age compositions were available for 1994, 1995, and 1998, the sample sizes for these age compositions are small and they have been excluded. Size compositions were available for 1977-2010 (Table 8.5, Figure 8.6). However, to avoid over-weighting data used to estimate the parameters for the assessment model, fishery size compositions from the same year that age composition data was used were not included in the model optimization. Thus, only the fishery size compositions for 19877-1999, 2002-2003, and 2008-2010 were included in the assessment model. Associated sample sizes are given in Table 8.6.

Survey Data

Because *Hippoglossoides* spp. are often taken incidentally in target fisheries for other species, CPUE from commercial fisheries seldom reflects trends in abundance for flathead sole and Bering flounder. It is therefore necessary to use fishery-independent survey data to assess the condition of these stocks. Bottom trawl surveys are conducted annually by the Resource Assessment and Conservation Engineering (RACE) Division of the Alaska Fisheries Science Center on the continental shelf in the Eastern Bering Sea (EBS). 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 8.7). In 2010, RACE extended the groundfish survey into the northern Bering Sea (Figure 8.7) and conducted standardized bottom trawls at 142 new stations. The data generated by this new survey may have important implications for the future management of Bering flounder, in particular. RACE also conducts bottom trawl surveys in the Aleutian Islands (AI) on a triennial basis from 1980 to 2000 (1980, 1983, 1986, 1991, 1994, 1997, 2000) and on a biennial basis (2002, 2004, 2006, 2010) since, although no survey was conducted in 2008.

This assessment used survey estimates of "total" *Hippoglossoides* spp. biomass for the years 1982-2010 (Table 8.7, Figure 8.8) as inputs to the assessment model. Survey-based estimates of total biomass use an “area-swept” approach and implicitly assume a catchability of 1. Following Spencer et al. (2004), surveys conducted prior to 1982 were not included in the assessment because the survey gear changed after 1981. In order 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. A linear regression between EBS and AI survey biomass in years when both surveys were conducted is used to predict the Aleutian Islands biomass in years in which an AI survey was not conducted. Based on the surveys, *Hippoglossoides* spp. biomass approximately quadrupled from the early 1980s to a maximum in 1997 (807,825 t). Estimated biomass then declined to 398,095 t in 2000 before increasing to a recent high of 635,755 t in 2006. The 2010 survey estimate was 495,215 t, a 19% increase from the 2009 survey estimate of 418,812 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 (Wilderbuer et al. 2002; Spencer et al., 2004; Stockhausen et al., 2009). Bottom temperatures are hypothesized to affect survey catchability by affecting either stock distributions 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 a previous assessment 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., 2009). Compared with previous years, mean bottom temperatures have been particularly cold since 2006 (Table 8.8, Figure 8.9) and the cold pool has extended well to the south along the so-called “middle domain” of the continental shelf (Figure 8.10). This 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.

Areas of high survey abundance appear to be remarkably similar over this time period (Figure 8.11). For the most part, the survey results indicate little spatial overlap between flathead sole and Bering flounder (Figure 8.11), although some occurs in the area west of St. Matthew Island. Interestingly, survey abundance patterns for flathead sole appear to correspond fairly closely with the spatial distribution of observer-reported fishery catches for this species (Figure 8.4a), whereas this does not appear to be the case for Bering flounder. For example, the majority of the Bering flounder catch occurred to the west of the Pribilof Islands in 2009 and 2010, but there is little indication in the survey results of a substantial abundance there. Given the high abundance of flathead sole found in this area by the surveys and the fishery, the mismatch for Bering flounder could possibly result from misidentification by observers of some flathead sole as Bering flounder in this area. However, the mismatch may also reflect differences in timing between the survey and the fishery in this area, confounded with seasonal movement of Bering flounder.

In 2010, as noted previously, RACE extended the groundfish survey into the northern Bering Sea (Figure 8.7; also, compare the distribution of survey stations in Figure 8.11 for 2009 and 2010). No flathead sole were found in the northern Bering Sea area, but a substantial abundance of Bering flounder was found. Based on a preliminary analysis, Bering flounder biomass in the northern Bering Sea area was estimated at 12,761 t, larger than that in the standard survey area (12,360 t). This is consistent with the view that Bering flounder in the BSAI fishery are a marginal stock on the edge of their species range in the eastern Bering Sea. Potential management implications of the northern Bering Sea survey for Bering flounder are discussed in more detail in Appendix C.

Survey age compositions, the fraction of animals caught by age class and sex, were included in the assessment for 1982, 1985, 1992-1995, 2000-01 and 2003-09 (Table 8.9, Figure 8.12). Survey size compositions, the fraction of animals by sex caught by 2 cm size bin, were available for 1982-2010 (Table 8.10, Figure 8.13). However, as with the fishery size compositions, survey size compositions from the same year that survey age composition data was available were not included in the model optimization. Thus, only the survey size compositions for 1984-91, 1996-99, 2002 and 2010 were included in the model fitting. Associated sample sizes are given in Table 8.11.

In summary, the data for *Hippoglossoides* spp. used in the assessment model are:

Data source	Temporal coverage
fishery catch	1977-2010
fishery size compositions	1977-2010
fishery age compositions	2000, 2001, 2004-2007
survey biomass and standard error	1982-2010
survey length compositions	1982-2010
survey age compositions	1982, 1985, 1992-95, 2000-01, 2003-09
survey bottom temperatures	1982-2010

Analytical Approach

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 likelihood framework, based on distributional assumptions regarding the observed data. Model parameters are estimated by minimizing an associated objective function (the negative total log-likelihood plus imposed penalty functions) 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 run from age 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. Model parameters that are typically fixed (estimated outside the model) are described in Tables A.2 and A.10 and discussed below. A total of 77 parameters were estimated in the preferred model.

Changes from last year

No changes were made to the model structure. Four alternative models (Table 8.12) were evaluated. The base model was identical to the preferred model from the 2009 assessment and incorporated the standard model options, a stock-recruit function where recruitment was independent of stock size ("no SRF", i.e., no stock-recruit function), and temperature-dependent catchability with no time lag ("TDQ"). The three other models also incorporated the standard model options. As with the base model, the "no TDQ, no SRF" model also assumed recruitment was independent of stock size but it did not include temperature-dependent catchability. In contrast, the "TDQ, Ricker SRF" model included temperature-dependent catchability but also included a stock-recruit function given by a Ricker curve. Finally, the "TDQ, B-H SRF" model included temperature-dependent catchability as well, but incorporated a Beverton-Holt stock-recruit function. After model evaluation, the preferred model was the base model, i.e. identical to that for 2009 (Stockhausen et al., 2009).

The experimental option added to the model in 2008 that incorporated a time-lagged version of bottom temperature in the model for temperature-dependent survey catchability (TDQ) was not re-tested this year.

Parameters Estimated Independently

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 conversion matrices ($\mathbf{\Phi}_{x,l,a}$), weights-at-length ($W_{x,l}$), and individual 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 selectivity 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 was based on Stark (2004), who found a length at 50% maturity of 320.2 mm using a logistic curve. 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 previously estimated from survey data using a procedure designed to reduce potential sampling-induced biases (Spencer et al., 2004). Mean lengths-at-age did not exhibit consistent temporal trends, so sex-specific von Bertalanffy growth curves were fit to mean length-at-age data using all years available at the time (1982, '85, '92, '94, '95 and 2000). The parameters values are given in the following table:

	von Bertalanffy growth parameters		
Sex	t_0	L_∞	K
Male	-0.27	37.03	0.19
Female	-1.24	50.35	0.10

The L_∞ estimates of 37 cm and 50 cm for males and females, respectively, are somewhat lower than those obtained using a potentially biased approach in previous assessments (40 cm and 55 cm, respectively; Spencer et al., 2003). The resulting growth curves are illustrated in Figure 8.14 (top graph). 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 a constant cv of 0.13 (Figure 8.14, bottom graphs).

A length–weight relationship of the form $W = a\ L^b$ was fit to survey data from 1982-2004, with parameter estimates a = 0.00326 and b = 3.3 applying to both sexes (weight in g, length in cm). Application of the length-weight relationship to the predicted size-at-age from the von Bertalanffy relationships yielded weight-at-age relationships for the fishery and survey (Figure 8.15).

Parameters Estimated Conditionally

A total of 77 parameters were estimated in the base model. The majority of parameters were associated with annual estimates of fishing mortality or recruitment. The number of estimable parameters associated with different model components is summarized in the following table:

Parameter type	Number
mean fishing mortality	1
fishing mortality deviations	34
mean recruitment	1
recruitment deviations	34
historic fishing mortality	1
historic mean recruitment	1
fishery length selectivity parameters	2
survey length selectivity parameters	2
survey catchability parameters	1
Total parameters	77

The "no TDQ, no SRF" model had one less parameter than the base model because the temperature-dependent survey catchability parameter was fixed at 0. The other two models had one more parameter than the base model as the stock-recruit functions used in those models required two parameters (ln(R_0) and h) rather than the one parameter ($\overline{\ln(R)}$) required in the base model.

A Markov Chain Monte Carlo (MCMC) algorithm was used to obtain estimates of parameter uncertainty for all the models (Gelman et al. 1995). Twenty million MCMC simulations were conducted for each model, with every 2,000th sample saved, to sample the joint posterior distribution. Marginal posterior densities for several model parameters and other quantities of interest were estimated from the MCMC simulations using the "density" function in R (R Development Core Team, 2010). Ninety-five percent confidence intervals were produced using the values corresponding to the 2.5th and 97.5th percentiles of the MCMC evaluation. For this assessment, MCMC confidence intervals are presented from the preferred model for total biomass, spawning biomass, and recruitment strength.

Model evaluation

In total, four alternative models were evaluated for this assessment (Table 8.12). All models were run using the same input data set, model constants, and likelihood multipliers. Three of the models converged successfully without arriving at the bounds of any of the parameters. However, the model with the Beverton-Holt stock-recruit function converged after hitting the upper bound (1) set on the steepness parameter (h) in the stock-recruit function. With h=1, the Beverton-Holt stock-recruit function is constant for non-zero stock sizes and recruitment essentially independent of stock size. As a consequence, the "TDQ, B-H SRF" model essentially "collapsed" to the base model and the resulting model quantities were identical to those from the base model. As such, this alternative model was eliminated from further consideration, although results from this model are included in the model comparison plots.

The posterior densities, based on MCMC integration, for estimates of the logistic function slope and size at 50%-selectability parameters for the fishery and the survey, as well as the temperature-dependent catchability parameter, are shown for all four models in Figure 8.16. With the exception of the TDQ parameter for the "no TDQ, no SRF" model (which was fixed at zero and not estimated), the posterior distributions for the survey-related parameters are remarkably similar in location and shape for all four models. The posterior distributions for the fishery selectivity are somewhat more variable among the models and the "TDQ, Ricker SRF" posterior density for the β parameter displays distinct bi-modality, but the medians are quite similar for all four models. The resulting survey and fishery selectivity curves are, however, essentially identical across all four models (Figure 8.17).

Posterior densities based on MCMC integration are compared in Figure 8.18 for all models for estimates of $F_{40\%}$, $F_{35\%}$, final (2010) spawning biomass, final (2011) total biomass, and final (2010) recruitment. All four models result in quite similar distributions and median values.

All four models appear to fit the fishery catch data equally well (Figure 8.19). The three models incorporating temperature-dependent catchability result in nearly identical fits to survey biomass trends, whereas the model that did not include it resulted in a slightly worse, but smoother (as one would expect), fit (Figure 8.20). Not adjusting survey catchability for temperature accounts for a decrease of almost four log-likelihood units in the "no TDQ, no SRF" model with respect to the base model.

While the early values in the estimated time series for fully-selected fishing mortality are slightly lower for the "TDQ, Ricker SRF" model when compared with the other models (which are all similar), the estimates are nearly identical for all four models after 1982 (Figure 8.21).

All four models give extremely similar estimates for time series of total (age 3+) biomass, spawning biomass, and recruitment (Figure 8.22). The stock-recruit functions underlying the recruitment estimates are compared in Figure 8.23. Although the Ricker curve appears to fit the stock-recruit time series reasonably well, the base model with constant recruitment fits better (by more than 1 likelihood unit). This result gives qualified support to preferring the base model over the Ricker model in pure model selection terms. However, selection of the Ricker model would allow use of a Tier 1 approach to determine management reference points based on direct estimation of F_{msy} and MSY, rather than the current Tier 3 approach that uses proxies (e.g., $F_{35\%}$) for these quantities. Unfortunately, it is unclear whether the change from low spawning stock/high recruitment prior to 1989 to high spawning stock/low recruitment following 1989 was driven by density-dependent factors or by a change in density-independent, environmental factors which is known to have occurred in 1989 (Rodionov and Overland, 2005). The precautionary approach in this case would be to assume the change was driven by density-independent factors and select the base model as preferable. This results from the observation that, if stock size declined through an intermediate range from the current large size (in the event of sustained overfishing or recruitment failure, for example), the Ricker model would suggest that recruitment would be expected to increase in a compensatory response (the stock becomes more productive at lower stock sizes), thereby reducing the need to possibly reduce or curtail fishing activity. The assumption of constant recruitment, on the other hand, would suggest no change in productivity as stock size declined and would require a more active response on the part of management. The dilemma outlined here is not new: the past solution has been to prefer a model with constant recruitment over one with a Ricker stock-recruit function (e.g., Stockhausen et al., 2009).

Finally, the three models that successfully converged were compared using Akaike's Information Criterion (AIC; Akaike 1973; Table 8.12), which provides a means of ranking models based on overall fit to the data and parameter parsimony. The AIC statistic for each model was calculated as

$$AIC = -2\ln(\mathcal{L}) + 2\mathcal{K}$$

where $\mathscr{L}$ was the model likelihood and $\mathscr{K}$ was the number of fitted model parameters. The model that "best" represents the data is the one with the smallest AIC. Because AIC is an information-based criteria for model selection, it also provides a scaling (the "evidence ratio") for the relative likelihood that one model is the correct choice, vis-à-vis a second model. The evidence ratio for model 1 vis-à-vis model 2 is given by

$$ER = \exp[-0.5 \cdot (AIC_1 - AIC_2)]$$

and represents the odds of model 1 being the "correct" model of the two being compared. Using this approach, the base model is over 10 times more likely to be correct than the "no TDQ, no SRF" or "TDQ, Ricker SRF" models. Given the overall similarity in the results from all the models, together with the more precautionary approach embodied in assuming constant recruitment for this stock, the author's preferred model is the base model with temperature-dependent catchability and constant recruitment. Thus, this year's preferred model is identical to that from last year.

Model Results

Model parameters from the preferred model are listed in Table 8.13. The marginal posterior distributions, fro MCMC sampling, and estimated values for several parameters are shown in Figure 8.24. The fishery and survey selectivity curves corresponding to the estimated parameters are shown in Figure 8.25. The fishery shows relatively little selection of flathead sole less that 30 cm, while those larger than 40 cm are well-selected. Selection in the trawl survey extends to smaller sizes than in the fishery, but it increases with size more gradually than in the fishery.

The model fit to reported catches is shown in Figure 8.26 (see also Table 8.14). The fit is nearly exact because a high relative weight was applied to the catch likelihood in the model optimization. The model generally provides a good fit to the survey size compositions included in the likelihood, as shown in Figure 8.27. Reasonable fits generally resulted for fishery size composition observations (Figure 8.28), with the worst fits occurring early in the time series (1977, 1978 and 1983). The model also provides reasonable fits to the survey age compositions (Figure 8.29) and fishery age compositions (Figure 8.30). The best fit to the size and age composition data was achieved with the survey age compositions, which resulted in an average effective *n* of 311 and 192 for females and males, respectively, corresponding to input weights of 200. The fishery age compositions produced the lowest effective samples sizes: 121 and 84, for females and males respectively. The effective sample sizes for the remaining data types ranged between 98 and 205.

Estimated total biomass (ages 3+) increased from a low of 122,170 t in 1977 to a peak of 987,110 t in 1994 (Table 8.15, Figure 8.31). Total biomass then declined to 800,810 t in 2003, rose briefly to 825,570 in 2006 and subsequently declined again to 772,260 in 2010. This was the lowest total biomass since 1988. Estimated female spawning biomass followed a similar trend, although the peak value (327,760 t) occurred in 1997 (Table 8.15, Figure 8.31). Spawning biomass in 2009 (239,675 t) was the lowest since 1991, but it was slightly higher in 2010 (240,432 t). These results from the accepted model are extremely similar to results from the previous two assessments for both total biomass and spawning biomass (Figure 8.31).

The changes in stock biomass are primarily a function of recruitment, as fishing pressure has been relatively light. The estimated recruitment at age 3 was generally higher during the early portion of the data series, averaging 1.1 billion for the 1974-1989 year classes, but only 0.81 billion for the 1994-2007 year classes (Table 8.15, Figure 8.32). The model suggests that recent age 3 recruitment (2004-2006 year classes) has been particularly weak but that higher-than-average recruitment of age 3 fish occurred this year (2007 year class), although the uncertainty associated with this estimate is large.

The fully-selected fishing mortality estimates were small, and averaged 0.051 from 2001 to 2010 (Figure 8.33). The time series of estimated fishing mortality rates and spawning stock biomass estimates relative to the harvest control rule is shown in Figure 8.34. The flathead sole stock has always been below its estimated $F_{35\%}$ level and has been above its $B_{35\%}$ level since 1987. Marginal posterior distributions for $F_{35\%}$ and $F_{40\%}$ (F_{OFL} and max F_{ABC} for a Tier 3a status determination, see below) are shown in Figure 8.35, as well as 2010 recruitment, 2010 spawning biomass, and 2011 total (age 3+) biomass estimates.

Projections and Harvest Alternatives

The projection model used for this assessment requires "best estimates" of the fishery catch for 2010 and 2011 in order to estimate population numbers-at-age at the beginning of 2011 and 2012. We assumed that the relative within-year progression of the fishery would be similar in 2010 to that in 2009. Since the most recent catch value available in 2010 was from the week of Sept. 25, we calculated an inflation factor based on the ratio of the final catch in 2009 to the weekly catch corresponding to Sept 25 of that year (1.045). We then multiplied the Sept. 25, 2010 catch by this inflation factor to arrive at a "best" estimate for the total catch in 2010 (19,370 t). We further assumed that this would also be a reasonable estimate for the catch taken in 2011.

Tier determination and reference fishing mortality rates

The reference fishing mortality rate for flathead sole is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). In recent years, flathead sole has been assigned a Tier 3 designation. Tier 3 requires reliable point estimates of $B_{40\%}$, $F_{35\%}$ and $F_{40\%}$, derived from a spawner-per-recruit analysis, as well as a reliable point estimate of 2010 spawning biomass B. A Tier 2 designation additionally requires reliable point estimates of F_{MSY} and B_{MSY} while a Tier 1 designation further requires a reliable probability density function for F_{MSY}. In order to derive estimates of F_{MSY} and B_{MSY} for a stock, a valid stock-recruit relationship must be identified for the stock in question. However, recruitment is independent of stock size in the preferred model for this assessment. **Consequently, a valid stock-recruit relationship has not been identified for this assessment, while reliable point estimates of B, $B_{40\%}$, $F_{35\%}$ and $F_{40\%}$ are available.** Thus, the flathead sole stock remains in Tier 3 for computing OFLs and max ABCs, as well as for harvest scenario evaluation and status determination.

Estimates of $F_{40\%}$, $F_{35\%}$, and $SPR_{40\%}$ were obtained using a spawner-per-recruit analysis from the preferred assessment model. Assuming that the average recruitment from the 1977-2007 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 $SPR_{40\%}$ (145.26 g) times the equilibrium number of recruits (925 million); thus $B_{40\%}$ is 134,411 t. The year 2010 spawning stock biomass is estimated as 240,432 t. Because estimated 2010 $B > B_{40\%}$, the flathead sole reference fishing mortality is defined in Tier 3a. For this tier, F_{ABC} is constrained to be $\leq F_{40\%}$, and F_{OFL} is defined to be $F_{35\%}$. The values of these quantities are:

Quantity	Value
2010 SSB (t)	240,432
$B_{40\%}$ (t)	134,411
$F_{40\%}$ =	0.280
F_{ABC} <=	0.280
$F_{35\%}$ =	0.342
F_{OFL} =	0.342

The estimated catch level for 2011 associated with the maximum allowed F_{ABC} of 0.280 is 69,348 t. Even though the rate of change in spawning stock biomass has been slightly negative since 1998, stock biomass is high relative to $B_{40\%}$ and the stock is only lightly fished. Consequently, we do not see a need to adjust F_{ABC} downward from its upper bound. Thus, the recommended ABC for 2011 is 69,348 t with an associated F_{ABC} of 0.280. The OFL for year 2011 is 83,321 t, associated with a fishing mortality of F_{OFL} = 0.342.

Stock projections

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 2010 numbers-at-age estimated in the assessment. This vector is then projected forward to the beginning of 2011 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2010. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2011, 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 2011 recommended in the assessment to the *max* F_{ABC} for 2011. [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 2005-2010 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 results from Scenarios 1 and 2 are identical. Fourteen-year projections of the mean harvest, spawning stock biomass and fishing mortality are shown in Table 8.16 for these five scenarios.

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 $B_{35\%}$):

> *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 1) above its MSY level in 2011 or 2) above 1/2 of its MSY level in 2011 and above its MSY level in 2021 under this scenario, then the stock is not overfished.]
>
> *Scenario 7*: In 2011 and 2012, 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 2023 under this scenario, then the stock is not approaching an overfished condition.]

The results of these two scenarios indicate that the BSAI flathead sole stock is neither overfished nor approaching an overfished condition (Table 8.16). With regard to assessing the current stock level, the expected spawning stock size in 2011 of scenario 6 is 234,084 t, almost two times larger than $B_{35\%}$ (117,609 t), so the stock is not overfished. With regard to whether the stock is approaching an overfished condition, the expected stock size in the year 2023 of scenario 7 is 125,361, somewhat larger than $B_{35\%}$. Thus, the stock is not approaching an overfished condition.

We used our "best" estimate of 2011 year-end catch (see above) to estimate an ABC and OFL for 2012. Using these values and the estimated population size at the start of 2010 from the assessment model, the stock was projected ahead through 2011 to calculate the ABC and OFL for 2012. The ABC for 2012 is 68,334 t while the OFL is 82,089 t. Total biomass for 2012 is predicted to be 785,891 t, while female spawning biomass is predicted to be 237,489 t.

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 8.36). They feed upon a variety of species, including juvenile walleye pollock and other miscellaneous fish, brittlestars, polychaetes, and crustaceans (Figure 8.37). 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 is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. 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.

Comparison of maps of survey biomass for flathead sole and Bering flounder (Figure 8.11) suggest little spatial overlap between the two species, at least within the area covered by the standard EBS trawl survey, although fishery observer data indicates that both species are taken together in an area to the west of the Pribilof Islands (Figure 8.4). The southern spatial extent of Bering flounder appears to expand with the cold pool. In 2005, Bering flounder were concentrated north of St. Matthew Island in the middle of the continental shelf while the nearest concentrations of flathead sole were to the south and west closer to the edge of the continental shelf (Stockhausen et al., 2007). In 2006-2008, Bering flounder were found west and southeast of St. Matthew, perhaps as a result of the extensive cold pools in these years (Fig. 8.7; Stockhausen et al., 2008). In 2006, there appeared to have been substantial overlap of Bering flounder by flathead sole, with a high concentration of flathead sole coincident with that of Bering flounder to the west of St. Matthew. In 2007-2009 there was little overlap between the two species as flathead sole were not found immediately to the west of St. Matthew Island. In 2010, flathead sole were again found in moderate abundance west of St. Matthew Island and appear to have overlapped with the southern extent of Bering flounder. In 2010, the EBS shelf groundfish survey also surveyed the northern Bering Sea for the first time, extending sampling from the US-Russia border and the shelf edge east and north to Norton Sound and the Bering Strait (Figure 8.7). While no flathead sole were found in this area, the abundance of Bering flounder in the northern Bering Sea was estimated to be similar to that in the annually-surveyed area (see Appendix C of this chapter). Thus, these results suggest that the potential for competition between the two morphologically-similar species exists, but that it may be infrequent and involve only small fractions of either population.

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, and McConnaughy and Smith (2000) hypothesized that substrate-mediated food habits of flathead sole are influenced by energetic foraging costs.

Predator population trends

The dominant predators of adult flathead sole are Pacific cod and walleye pollock (Figure 8.38). 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. Based upon recent stock assessments, both Pacific cod and skate abundance have been relatively stable since the early 1990s. 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 summertime EBS Trawl Surveys have also been remarkably cold (Table 8.8, Figures 8.9 and 8.10). Visual inspection of the spatial distributions of flathead sole from the 2008-2010 trawl surveys (Figure 8.11) suggests that, in response to the expanded cold pools, flathead sole may have reduced the extent of their on-shelf summertime feeding migration and remained concentrated along the continental margin. Whether this exclusion has had any impacts beyond spatial distribution, such as reducing summertime foraging success, is unknown.

Fishery effects on the ecosystem

Prohibited species catches (PSC) in the flathead sole target fishery since 2008, the first year of fishing under Amendment 80, have typically been smaller than in years prior to Amendment 80 (Tables 8.17a-c). The "target fishery" comprises those hauls that the NMFS Alaska Region has identified as targeting flathead sole. The annual halibut bycatch in the flathead sole directed fishery was smaller in 2008-2010 than in the four years prior to Amendment 80 (Table 8.17a) and has constituted on about 3% of the total halibut PSC in the Bering Sea groundfish fisheries.

King crab PSC in the target fishery tends to be fairly variable over time (Table 8.17b). In 2009, the target fishery accounted for 7.9% of the blue king crab PSC but only 0.2% in 2010. PSC of golden and king crabs in the target fishery were generally less than 1% of the total PSC for these species. The target fishery takes substantially more tanner crab than king crab, both in absolute numbers and as fractions of the species-specific total PSC. The PSC for Bairdi crab in the target fishery was larger in 2010 than 2009 in both absolute (71,039 vs. 46,532 crabs) and relative (8.7% vs. 4.8%) terms, while the reverse was true for Opilio PSC (96,381 vs. 201,926 crabs; 4.8% vs. 16.5%).

The target fishery accounts for very little salmon PSC, either in absolute or relative terms (Table 8.17c).

Over the last 5 years, pollock has been the largest non-prohibited incidental catch species in the flathead sole-directed fishery, followed variously by yellowfin sole, arrowtooth flounder, Pacific cod and rock sole (Table 8.18). In 2010, 2,904 t of pollock were caught in the directed flathead sole fishery, similar to that in recent years.

The flathead sole fishery is not likely to diminish the amount of flathead sole available as prey due to its low selectivity for fish less than 30 cm. Additionally, the fishery is not suspected of affecting the size-structure of the population due to its relatively light fishing mortality, averaging 0.051 over the last 5 years. It is not known what effects the fishery may have on the maturity-at-age of flathead sole, although these would also be expected to be small.

It seems unlikely that the flathead sole fishery presents a substantial risk to the Bering flounder population in the Bering Sea. The new survey conducted this year in the northern Bering Sea suggests that a substantial fraction (> 50%) of the stock in federally-managed waters in the Bering Sea is outside the current extent of fishing operations (see Appendix C of this chapter). In addition, the NPFMC has formally closed a significant fraction of this area (the Northern Bering Sea Research Area) to bottom trawling pending scientific assessment of the effect of bottom trawling on this region (http://www.fakr.noaa.gov/npfmc/current_issues/ecosystem/NBSRA.htm).

Data gaps and research priorities

A number of data gaps and research priorities have been identified for the flathead sole assessment.

The amount of age data available for the fishery is marginal (6 years: 2000, 2001, 2004-2007), and future assessments would undoubtedly benefit from more fishery age compositions. Several hundred individuals have generally been sampled by fishery observers each year for the past decade, but reading flathead otoliths has not been a high priority task for the age readers at the Alaska Fisheries Science Center. However, progress is being made: ages were read from otoliths collected by observers 2006 and 2007 last year and incorporated as age compositions in this assessment, and otoliths from the 2009 fishery are currently being processed. Although more survey age compositions are available (14 years of data), it is desirable to continue processing survey age data. Additional age data should improve future stock assessments by allowing improved estimates of individual growth and age-length transition matrices, and by filling in missing years with age composition data.

The parameters estimated outside the assessment model (e.g., natural mortality, size-at-age) have not been updated for several years. In particular, newer age data is available to update the size-at-age conversion matrices used in the assessment model. We are developing a new stock assessment model that will have the potential to estimate growth and natural mortality parameters directly within the model and look forward to testing its application.

A concerted effort has been underway to acquire more data on Bering flounder. Current models for Bering flounder length-at-age and weight-at-age are based on data collected in 1985. During the 2006 and 2007 EBS Trawl Surveys, several hundred Bering flounder otoliths were collected to update length-at-age and length-at-weight models for this species. Ages have been read for many of these otoliths and analyses for growth and size-weight relationships are underway, but were not completed at the time of this assessment. Maturity samples were also collected off St. Matthew Island during the 2006 EBS Trawl Survey, in October 2007 during a special RACE cruise aboard the Miller Freeman, and in the northern Bering Sea during the 2010 EBS Trawl Survey (J. Stark, AFSC, pers. comm.). The 2006 and 2007 samples have been processed and a manuscript based on the results has been submitted to a peer-reviewed journal (J. Stark, AFSC, pers. comm.). Sample processing for the 2010 survey awaits a funding source. In conjunction with a two-species population model being developed for flathead sole and Bering flounder, this new data will better allow us to determine the effects of “lumping” Bering flounder together with flathead sole in the current assessment model.

Finally, although Wilderbuer et al. (2002) found that a valid stock-recruit model (a Ricker model) was statistically-significant for flathead sole in the Bering Sea when they fit stock-recruit models that included environmental terms, they also found that wind-driven advection to favorable nursery grounds corresponded to years of above average recruitment, and these years coincided with years of low spawning stock biomass. Thus, potential physical mechanisms influencing recruitment strength were confounded with potential density dependent mechanisms in the time series data they analyzed for flathead sole. As such, we have always recommended against attempts to move flathead sole into Tier 1. However, ten years more data are now available to re-assess this issue. We will re-apply Wilderbuer et al.’s (2002) analysis to flathead sole in the coming year to re-evaluate their conclusions and try to resolve this issue of confounding effects.

Summary

In summary, several quantities pertinent to the management of the BSAI flathead sole are:

Tier 3a		
Reference mortality rates		
M	0.2	
$F_{35\%}$	0.342	
$F_{40\%}$	0.280	
Equilibrium female spawning biomass		
$B_{100\%}$	336,027 t	
$B_{40\%}$	134,411 t	
$B_{35\%}$	117,609 t	
Fishing rates		
F_{OFL}	0.342	
F_{ABC} (maximum allowable)	0.280	
F_{ABC} (recommended)	0.280	
2010 biomass		
Total biomass (age 3+)	772,260 t	
Female spawning biomass	240,432 t	
Projected biomass	**2011**	**2012**
Age 3+ biomass (t)	791,018	785,891
Female spawning biomass (t)	240,796	237,489
Harvest limits	**2011**	**2012**
OFL (t)	83,321	82,089
ABC (maximum allowable; t)	69,348	68,334
ABC (recommended; t)	69,348	68,334

References

Akaike, H. 1973. Information theory as an extension extension of the maximum likelihood principle. In Petrov, B.N. and F. Csaki (ed.s), Second international symposium on information theory. Akadeiai Kiado, pp. 267-281.

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

Fournier, D.A. and C.P. Archibald. 1982. A general theory for analyzing catch-at-age data. Can. J. Fish. Aquat. Sci. 39:1195-1207.

Gelman, A., J.B. Carlin, H.S. Stern, and D.A. Rubin. 1995. Bayesian data analysis. Chapman and Hall, New York. 552 pp.

Greiwank, A. and G.F. Corliss (ed.s). 1991. Automatic differentiation of algorithms: theory, implementation and application. Proceedings of the SIAM Workshop on the Automatic Differentiation of Algorithms, held Jan 6-8, Breckenridge, CO. Soc., Indust. and Applied Mathematics, Philadelphia.

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

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

Lang, G.M., C.W. Derah, and P.A. Livingston. 2003. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1993 to 1996. U.S. Dep. Commer., AFSC Proc. Rep. 2003-04. 351 pp.

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

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

Methot, R.D. 1990. Synthesis model: An adaptable framework for analysis of diverse stock assessment data. Intl. N. Pac. Fish. Comm. Bull. 50:259-277.

Press, W.H., A.A. Teukolsky, W.T. Vetterling and B.P. Flannery. 1992. Numerical Recipes in C. Second Ed. Cambrige Univ. Press. 994 p.

R Development Core Team. 2010. R: A Language and Environment for Statistical Computing. http://www.R-project.org.

Rodionov, S.N., Overland, J.E., 2005. Application of a sequential regime shift detection method to the Bering Sea ecosystem. ICES Journal of Marine Science 62, 328–332.

Quinn, T.J. and R.B. Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press. New York. 542 pp.

Spencer, P.D., Walters, G.E., and T.K. Wilderbuer. 2003. Flathead sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 2004, p.463-510. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

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

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

Stockhausen, W.T., P.D. Spencer and D. Nichol. 2007. Flathead sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 2008, p.687-754. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

Stockhausen, W.T., P.D. Spencer and D. Nichol. 2008. Flathead sole. In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Region, p.777-864. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

Stockhausen, W.T. and D. Nichol. 2009. Assessment of the Flathead sole Stock in the Bering Sea and Aleutian Islands. In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Region. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

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

Walters, G.E. and T.K. Wilderbuer. 2000. Decreasing length at age in a rapidly expanding population of northern rock sole in the eastern Bering Sea and its effect on management advice. J. Sea Res. 44:171-26.

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

Wilderbuer, T.K. and D. Nichol. 2002. Chapter 3: Yellowfin sole. In Stock Assessment and Fishery Evaluation Document for Groundfish Resources in the Bering Sea/Aleutian Islands Region as Projected for 2003, p.207-254. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, Alaska 99510.

Tables

Table 8.1. Harvest (t) of *Hippoglossoides* spp. from 1977-2010 (as of Sept. 25, 2010).

Year	total	non-CDQ	CDQ
1977	7,909	7,909	
1978	6,957	6,957	
1979	4,351	4,351	
1980	5,247	5,247	
1981	5,218	5,218	
1982	4,509	4,509	
1983	5,240	5,240	
1984	4,458	4,458	
1985	5,636	5,636	
1986	5,208	5,208	
1987	3,595	3,595	
1988	6,783	6,783	
1989	3,604	3,604	
1990	20,245	20,245	
1991	14,197	14,197	
1992	14,407	14,407	
1993	13,574	13,574	
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	
2000	20,422	19,983	439
2001	17,809	17,586	223
2002	15,572	15,108	464
2003	14,184	13,792	392
2004	17,394	16,849	545
2005	16,151	15,260	891
2006	17,947	17,545	402
2007	18,744	17,673	1,071
2008	24,539	24,039	500
2009	19,549	19,041	508
2010	18,544	17,774	770

Table 8.2. Restrictions in the BSAI management area on the flathead sole fishery (1994-2010). 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": stock allowed as incidental catch. "Open": directed fishery allowed. "Bycatch": directed fishery closed, only incidental catch allowed.

Year	Dates	Bycatch Closure
1994	2/28 – 12/31	Red King crab cap (Zone 1 closed)
	5/7 – 12/31	Bairdi Tannner crab (Zone 2 closed)
	7/5 – 12/31	Annual halibut allowance
1995	2/21 – 3/30	1st seasonal halibut cap
	4/17 – 7/1	2nd seasonal halibut cap
	8/1 – 12/31	Annual halibut allowance
1996	2/26 – 4/1	1st seasonal halibut cap
	4/13 – 7/1	2nd seasonal halibut cap
	7/31 – 12/31	Annual halibut allowance
1997	2/20 – 4/1	1st seasonal halibut cap
	4/12 – 7/1	2nd seasonal halibut cap
	7/25 – 12/31	Annual halibut allowance
1998	3/5 – 3/30	1st seasonal halibut cap
	4/21 – 7/1	2nd seasonal halibut cap
	8/16 – 12/31	Annual halibut allowance
1999	2/26 – 3/30	1st seasonal halibut cap
	4/27 – 7/04	2nd seasonal halibut cap
	8/31 – 12/31	Annual halibut allowance
2000	3/4 – 3/31	1st seasonal halibut cap
	4/30 – 7/03	2nd seasonal halibut cap
	8/25 – 12/31	Annual halibut allowance
2001	3/20 – 3/31	1st seasonal halibut cap
	4/27 – 7/01	2nd seasonal halibut cap
	8/24 – 12/31	Annual halibut allowance
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

Year	Dates	Bycatch Closure
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

Table 8.3. ABC's, TAC's, OFL's, and total, retained, and discarded *Hippoglossoides* spp. catch (t), 1995-2010 (through Sept. 25, 2010).

Year	ABC	TAC	OFL	Total Catch	Retained	Discarded	Percent Retained
1995	138,000	30,000	167,000	14,713	7,520	7,193	51
1996	116,000	30,000	140,000	17,344	8,964	8,380	52
1997	101,000	43,500	145,000	20,681	10,859	9,822	53
1998	132,000	100,000	190,000	24,597	17,438	7,159	71
1999	77,300	77,300	118,000	18,555	13,757	4,797	74
2000	73,500	52,652	90,000	20,422	14,959	5,481	73
2001	84,000	40,000	102,000	17,809	14,436	3,373	81
2002	82,600	25,000	101,000	15,572	11,311	4,236	73
2003	66,000	20,000	81,000	14,184	9,926	3,866	72
2004	61,900	19,000	75,200	17,394	11,658	5,192	69
2005	58,500	19,500	70,200	16,151	12,263	3,888	76
2006	59,800	19,500	71,800	17,947	12,997	4,255	76
2007	79,200	30,000	95,300	18,744	13,349	5,394	71
2008	71,700	50,000	86,000	24,539	22,209	2,330	91
2009	71,400	60,000	83,800	19,549	17,523	2,026	90
2010	69,200	60,000	83,100	18,544	16,849	1,695	91

Table 8.4a. Fishery age composition for flathead sole females.

Age bin	1994	1995	1998	2000	2001	2004	2005	2006	2007
	year								
3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0030	0.0000	0.0024	0.0017
5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0137	0.0000	0.0029	0.0081
6	0.0000	0.0048	0.0000	0.0108	0.0006	0.0351	0.0051	0.0076	0.0234
7	0.0000	0.0026	0.0000	0.0017	0.0189	0.0215	0.0233	0.0305	0.0156
8	0.0000	0.0228	0.0140	0.0245	0.0117	0.0289	0.0301	0.0235	0.0288
9	0.0188	0.0347	0.0267	0.0290	0.0167	0.0439	0.0430	0.0443	0.0448
10	0.0204	0.0563	0.0190	0.0350	0.0311	0.0342	0.0324	0.0314	0.0304
11	0.0511	0.0362	0.0394	0.0340	0.0544	0.0387	0.0515	0.0342	0.0255
12	0.0614	0.0215	0.0705	0.0382	0.0471	0.0332	0.0260	0.0252	0.0380
13	0.0901	0.0496	0.0214	0.0737	0.0398	0.0445	0.0492	0.0372	0.0273
14	0.0724	0.0819	0.0879	0.0335	0.0538	0.0474	0.0436	0.0372	0.0249
15	0.0561	0.0596	0.0193	0.0491	0.0415	0.0378	0.0500	0.0318	0.0383
16	0.0317	0.0330	0.0089	0.0357	0.0447	0.0301	0.0250	0.0253	0.0157
17	0.0319	0.0147	0.0297	0.0437	0.0417	0.0082	0.0184	0.0331	0.0285
18	0.0207	0.0339	0.0000	0.0384	0.0248	0.0067	0.0249	0.0180	0.0202
19	0.0064	0.0127	0.0652	0.0417	0.0345	0.0129	0.0051	0.0178	0.0213
20	0.0252	0.0173	0.0000	0.0144	0.0202	0.0143	0.0135	0.0105	0.0148
21	0.0109	0.0414	0.0196	0.0297	0.0413	0.0047	0.0406	0.0360	0.0499

Table 8.4b. Fishery age compositions for flathead sole males.

Age bin	1994	1995	1998	2000	2001	2004	2005	2006	2007
	year								
3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.0000	0.0000	0.0000	0.0000	0.0025	0.0000	0.0034	0.0053	0.0000
5	0.0000	0.0000	0.0000	0.0000	0.0036	0.0171	0.0019	0.0141	0.0141
6	0.0000	0.0108	0.0000	0.0022	0.0025	0.0532	0.0132	0.0125	0.0303
7	0.0000	0.0126	0.0000	0.0150	0.0119	0.0389	0.0378	0.0539	0.0169
8	0.0440	0.0144	0.0339	0.0255	0.0401	0.0600	0.0383	0.0567	0.0561
9	0.0456	0.1111	0.0474	0.0332	0.0346	0.0468	0.0583	0.0554	0.0802
10	0.0066	0.0657	0.0260	0.0381	0.0490	0.0449	0.0456	0.0429	0.0399
11	0.0592	0.0382	0.0505	0.0643	0.0365	0.0324	0.0462	0.0369	0.0595
12	0.0853	0.0267	0.0494	0.0310	0.0470	0.0380	0.0192	0.0209	0.0224
13	0.0269	0.0424	0.0795	0.0573	0.0349	0.0420	0.0574	0.0187	0.0091
14	0.0376	0.0745	0.0476	0.0398	0.0631	0.0261	0.0191	0.0260	0.0286
15	0.0457	0.0276	0.0550	0.0389	0.0260	0.0154	0.0251	0.0449	0.0383
16	0.0339	0.0154	0.0174	0.0410	0.0295	0.0280	0.0333	0.0263	0.0387
17	0.0643	0.0143	0.0609	0.0225	0.0136	0.0240	0.0298	0.0271	0.0320
18	0.0167	0.0011	0.0448	0.0130	0.0190	0.0137	0.0184	0.0199	0.0151
19	0.0140	0.0011	0.0281	0.0178	0.0225	0.0093	0.0092	0.0159	0.0205
20	0.0126	0.0071	0.0222	0.0102	0.0071	0.0153	0.0095	0.0189	0.0043
21	0.0102	0.0139	0.0156	0.0171	0.0342	0.0360	0.0523	0.0546	0.0366

Table 8.5a. Fishery size compositions for flathead sole females.

Length cutpoints	year 1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
6	--	--	--	--	--	--	0.0000	0.0000	0.0000	0.0000
8	--	--	--	--	--	--	0.0000	0.0000	0.0000	0.0000
10	--	--	--	--	--	--	0.0004	0.0002	0.0001	0.0000
12	--	--	--	--	--	--	0.0009	0.0003	0.0005	0.0000
14	--	--	--	--	--	--	0.0040	0.0018	0.0043	0.0006
16	--	--	--	--	--	--	0.0093	0.0051	0.0081	0.0033
18	--	--	--	--	--	--	0.0241	0.0120	0.0183	0.0135
20	--	--	--	--	--	--	0.0296	0.0252	0.0369	0.0286
22	--	--	--	--	--	--	0.0240	0.0295	0.0440	0.0512
24	--	--	--	--	--	--	0.0276	0.0314	0.0323	0.0735
26	--	--	--	--	--	--	0.0428	0.0293	0.0288	0.0589
28	--	--	--	--	--	--	0.0501	0.0333	0.0302	0.0546
30	--	--	--	--	--	--	0.0639	0.0485	0.0305	0.0478
32	--	--	--	--	--	--	0.0652	0.0700	0.0311	0.0400
34	--	--	--	--	--	--	0.0551	0.0794	0.0465	0.0362
36	--	--	--	--	--	--	0.0436	0.0658	0.0608	0.0399
38	--	--	--	--	--	--	0.0292	0.0461	0.0629	0.0388
40	--	--	--	--	--	--	0.0151	0.0404	0.0692	0.0332
43	--	--	--	--	--	--	0.0022	0.0109	0.0327	0.0090
46	--	--	--	--	--	--	0.0008	0.0024	0.0108	0.0013
49	--	--	--	--	--	--	0.0002	0.0003	0.0008	0.0003
52	--	--	--	--	--	--	0.0000	0.0002	0.0000	0.0001
55	--	--	--	--	--	--	0.0000	0.0001	0.0000	0.0000
58	--	--	--	--	--	--	0.0037	0.0002	0.0000	0.0000

Length cutpoints	year 1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0007	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.0006	0.0000	0.0000	0.0002	0.0007	0.0000	0.0002	0.0000	0.0000	0.0000
14	0.0009	0.0004	0.0000	0.0028	0.0010	0.0014	0.0000	0.0003	0.0002	0.0000
16	0.0119	0.0000	0.0003	0.0044	0.0035	0.0084	0.0002	0.0011	0.0007	0.0002
18	0.0196	0.0000	0.0007	0.0070	0.0036	0.0294	0.0000	0.0037	0.0021	0.0000
20	0.0082	0.0014	0.0014	0.0201	0.0100	0.0266	0.0017	0.0051	0.0072	0.0010
22	0.0044	0.0040	0.0007	0.0211	0.0174	0.0378	0.0015	0.0070	0.0157	0.0010
24	0.0086	0.0137	0.0038	0.0153	0.0174	0.0266	0.0049	0.0148	0.0158	0.0010
26	0.0273	0.0356	0.0003	0.0202	0.0199	0.0336	0.0101	0.0149	0.0176	0.0023
28	0.0642	0.0727	0.0031	0.0322	0.0229	0.0490	0.0169	0.0293	0.0331	0.0036
30	0.0943	0.1173	0.0072	0.0362	0.0276	0.0518	0.0238	0.0479	0.0464	0.0069
32	0.1067	0.1044	0.0188	0.0463	0.0404	0.0448	0.0385	0.0661	0.0639	0.0163
34	0.0823	0.0734	0.0348	0.0873	0.0544	0.0476	0.0910	0.0713	0.0734	0.0307
36	0.0580	0.0381	0.0519	0.1131	0.0767	0.0602	0.0962	0.0625	0.0878	0.0676
38	0.0517	0.0403	0.0888	0.0915	0.0858	0.0658	0.0667	0.0504	0.0817	0.0900
40	0.0564	0.0529	0.1565	0.0772	0.1125	0.0420	0.0520	0.0431	0.0715	0.1257
43	0.0269	0.0245	0.1086	0.0320	0.0438	0.0182	0.0101	0.0167	0.0390	0.0898
46	0.0063	0.0061	0.0458	0.0102	0.0132	0.0042	0.0020	0.0054	0.0194	0.0394
49	0.0006	0.0000	0.0161	0.0016	0.0060	0.0000	0.0005	0.0009	0.0056	0.0062
52	0.0000	0.0000	0.0048	0.0002	0.0018	0.0000	0.0000	0.0001	0.0001	0.0032
55	0.0000	0.0000	0.0044	0.0000	0.0029	0.0000	0.0000	0.0000	0.0001	0.0000
58	0.0000	0.0000	0.0061	0.0000	0.0053	0.0000	0.0000	0.0000	0.0000	0.0000

Length cutpoints	year 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	0.0001	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0002
18	0.0002	0.0000	0.0000	0.0002	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000
20	0.0005	0.0000	0.0008	0.0003	0.0011	0.0001	0.0002	0.0001	0.0000	0.0005
22	0.0007	0.0000	0.0008	0.0005	0.0032	0.0001	0.0011	0.0005	0.0002	0.0009
24	0.0016	0.0016	0.0037	0.0026	0.0022	0.0010	0.0032	0.0019	0.0011	0.0026
26	0.0044	0.0003	0.0061	0.0060	0.0046	0.0016	0.0047	0.0035	0.0036	0.0044
28	0.0139	0.0064	0.0097	0.0064	0.0099	0.0033	0.0080	0.0071	0.0065	0.0105
30	0.0197	0.0094	0.0260	0.0141	0.0165	0.0070	0.0161	0.0104	0.0164	0.0240
32	0.0267	0.0121	0.0368	0.0273	0.0320	0.0182	0.0265	0.0205	0.0284	0.0373
34	0.0363	0.0307	0.0479	0.0309	0.0343	0.0384	0.0487	0.0358	0.0421	0.0590
36	0.0422	0.0565	0.0618	0.0455	0.0476	0.0567	0.0682	0.0489	0.0520	0.0692
38	0.0640	0.0627	0.0792	0.0672	0.0529	0.0651	0.0803	0.0584	0.0691	0.0678
40	0.0797	0.0869	0.1445	0.0988	0.1132	0.0988	0.1063	0.0936	0.1073	0.0973
43	0.0545	0.0707	0.1141	0.0789	0.1210	0.1093	0.1053	0.0895	0.0865	0.0785
46	0.0171	0.0336	0.0309	0.0431	0.0618	0.0544	0.0542	0.0662	0.0507	0.0526
49	0.0055	0.0165	0.0079	0.0225	0.0141	0.0108	0.0135	0.0243	0.0189	0.0197
52	0.0006	0.0000	0.0011	0.0048	0.0028	0.0020	0.0017	0.0029	0.0023	0.0033
55	0.0004	0.0020	0.0000	0.0007	0.0002	0.0002	0.0000	0.0000	0.0006	0.0004
58	0.0000	0.0000	0.0000	0.0009	0.0000	0.0000	0.0000	0.0000	0.0005	0.0004

Table 8.5 a (cont.). Fishery size compositions for flathead sole females.

Length cutpoints	year									
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000
12	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	0.0000	0.0001	0.0002	0.0000	0.0001	0.0000	0.0000	0.0001	0.0000	0.0000
16	0.0000	0.0000	0.0001	0.0002	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000
18	0.0005	0.0005	0.0001	0.0003	0.0001	0.0002	0.0003	0.0000	0.0001	0.0000
20	0.0009	0.0006	0.0006	0.0004	0.0004	0.0009	0.0007	0.0002	0.0000	0.0000
22	0.0012	0.0014	0.0008	0.0024	0.0002	0.0014	0.0018	0.0006	0.0005	0.0001
24	0.0021	0.0006	0.0027	0.0045	0.0023	0.0020	0.0047	0.0020	0.0014	0.0005
26	0.0061	0.0021	0.0065	0.0098	0.0056	0.0041	0.0067	0.0057	0.0038	0.0023
28	0.0186	0.0064	0.0084	0.0160	0.0158	0.0078	0.0128	0.0088	0.0093	0.0058
30	0.0180	0.0101	0.0158	0.0232	0.0220	0.0188	0.0151	0.0189	0.0208	0.0200
32	0.0344	0.0182	0.0232	0.0312	0.0328	0.0304	0.0242	0.0332	0.0338	0.0418
34	0.0497	0.0396	0.0407	0.0459	0.0467	0.0485	0.0394	0.0546	0.0513	0.0547
36	0.0710	0.0618	0.0615	0.0491	0.0699	0.0534	0.0494	0.0685	0.0741	0.0755
38	0.0693	0.0751	0.0758	0.0553	0.0633	0.0499	0.0542	0.0609	0.0756	0.0832
40	0.0989	0.1179	0.1335	0.0885	0.0861	0.0783	0.0922	0.0788	0.0902	0.0950
43	0.0798	0.0805	0.0914	0.0844	0.0777	0.0788	0.0806	0.0714	0.0695	0.0609
46	0.0472	0.0458	0.0384	0.0371	0.0428	0.0560	0.0518	0.0535	0.0492	0.0367
49	0.0185	0.0157	0.0096	0.0071	0.0108	0.0122	0.0170	0.0191	0.0166	0.0139
52	0.0034	0.0037	0.0022	0.0018	0.0011	0.0013	0.0013	0.0023	0.0018	0.0022
55	0.0008	0.0012	0.0000	0.0004	0.0000	0.0002	0.0002	0.0002	0.0007	0.0001
58	0.0003	0.0009	0.0003	0.0000	0.0001	0.0001	0.0000	0.0000	0.0000	0.0000

Table 8.5b. Fishery size composition for flathead sole males.

Length					year					
cutpoints	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
6	--	--	--	--	--	--	0.0000	0.0000	0.0000	0.0000
8	--	--	--	--	--	--	0.0001	0.0000	0.0000	0.0000
10	--	--	--	--	--	--	0.0006	0.0000	0.0003	0.0001
12	--	--	--	--	--	--	0.0006	0.0006	0.0008	0.0000
14	--	--	--	--	--	--	0.0034	0.0034	0.0070	0.0002
16	--	--	--	--	--	--	0.0085	0.0058	0.0121	0.0021
18	--	--	--	--	--	--	0.0238	0.0155	0.0174	0.0078
20	--	--	--	--	--	--	0.0232	0.0229	0.0335	0.0203
22	--	--	--	--	--	--	0.0221	0.0329	0.0380	0.0431
24	--	--	--	--	--	--	0.0453	0.0360	0.0240	0.0532
26	--	--	--	--	--	--	0.0849	0.0387	0.0246	0.0403
28	--	--	--	--	--	--	0.1115	0.0712	0.0359	0.0457
30	--	--	--	--	--	--	0.1001	0.1039	0.0643	0.0889
32	--	--	--	--	--	--	0.0563	0.0784	0.0909	0.1051
34	--	--	--	--	--	--	0.0196	0.0400	0.0622	0.0508
36	--	--	--	--	--	--	0.0035	0.0133	0.0278	0.0095
38	--	--	--	--	--	--	0.0009	0.0032	0.0093	0.0014
40	--	--	--	--	--	--	0.0015	0.0003	0.0027	0.0005
43	--	--	--	--	--	--	0.0010	0.0000	0.0003	0.0000
46	--	--	--	--	--	--	0.0000	0.0000	0.0001	0.0000
49	--	--	--	--	--	--	0.0000	0.0004	0.0001	0.0000
52	--	--	--	--	--	--	0.0000	0.0003	0.0000	0.0000
55	--	--	--	--	--	--	0.0000	0.0001	0.0000	0.0000
58	--	--	--	--	--	--	0.0013	0.0005	0.0000	0.0000

Length					year					
cutpoints	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	0.0005	0.0000	0.0000	0.0000
12	0.0002	0.0000	0.0000	0.0005	0.0003	0.0000	0.0007	0.0000	0.0002	0.0000
14	0.0027	0.0000	0.0000	0.0011	0.0007	0.0014	0.0005	0.0003	0.0000	0.0002
16	0.0127	0.0022	0.0000	0.0014	0.0022	0.0028	0.0000	0.0020	0.0002	0.0006
18	0.0156	0.0007	0.0000	0.0039	0.0031	0.0098	0.0010	0.0064	0.0028	0.0000
20	0.0040	0.0036	0.0000	0.0150	0.0125	0.0140	0.0017	0.0093	0.0097	0.0014
22	0.0064	0.0047	0.0014	0.0176	0.0194	0.0266	0.0047	0.0141	0.0161	0.0024
24	0.0125	0.0122	0.0058	0.0151	0.0248	0.0574	0.0123	0.0303	0.0170	0.0043
26	0.0368	0.0237	0.0092	0.0262	0.0323	0.0728	0.0194	0.0468	0.0334	0.0064
28	0.0822	0.0633	0.0294	0.0398	0.0369	0.0546	0.0373	0.0728	0.0504	0.0115
30	0.0927	0.1119	0.0680	0.0442	0.0494	0.0616	0.0601	0.1182	0.0667	0.0209
32	0.0648	0.1000	0.1008	0.0760	0.0567	0.0518	0.1384	0.1326	0.0779	0.0493
34	0.0297	0.0612	0.1042	0.0772	0.0683	0.0560	0.1764	0.0857	0.0743	0.0897
36	0.0067	0.0202	0.0762	0.0398	0.0651	0.0224	0.1013	0.0307	0.0437	0.1259
38	0.0010	0.0068	0.0328	0.0171	0.0332	0.0182	0.0265	0.0073	0.0161	0.1091
40	0.0017	0.0022	0.0092	0.0035	0.0139	0.0028	0.0022	0.0028	0.0080	0.0626
43	0.0010	0.0025	0.0027	0.0007	0.0024	0.0000	0.0005	0.0004	0.0017	0.0167
46	0.0000	0.0000	0.0010	0.0002	0.0014	0.0000	0.0000	0.0000	0.0001	0.0092
49	0.0000	0.0000	0.0007	0.0000	0.0020	0.0000	0.0000	0.0000	0.0002	0.0040
52	0.0000	0.0000	0.0007	0.0002	0.0020	0.0000	0.0000	0.0000	0.0000	0.0006
55	0.0000	0.0000	0.0003	0.0002	0.0022	0.0000	0.0000	0.0000	0.0000	0.0000
58	0.0000	0.0000	0.0034	0.0009	0.0040	0.0000	0.0000	0.0000	0.0000	0.0000

Length					year					
cutpoints	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	0.0000	0.0000	0.0004	0.0001	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000
16	0.0003	0.0048	0.0009	0.0001	0.0000	0.0000	0.0002	0.0000	0.0000	0.0001
18	0.0009	0.0022	0.0009	0.0007	0.0003	0.0001	0.0004	0.0003	0.0001	0.0006
20	0.0017	0.0239	0.0001	0.0009	0.0012	0.0006	0.0012	0.0007	0.0006	0.0006
22	0.0030	0.0182	0.0017	0.0037	0.0030	0.0014	0.0028	0.0023	0.0022	0.0019
24	0.0063	0.0170	0.0035	0.0079	0.0052	0.0029	0.0083	0.0041	0.0044	0.0039
26	0.0132	0.0297	0.0128	0.0206	0.0105	0.0083	0.0219	0.0128	0.0110	0.0125
28	0.0342	0.0455	0.0259	0.0408	0.0271	0.0147	0.0348	0.0223	0.0266	0.0233
30	0.0531	0.0572	0.0324	0.0673	0.0414	0.0458	0.0568	0.0461	0.0487	0.0565
32	0.0790	0.0753	0.0644	0.0894	0.0705	0.0929	0.0903	0.0790	0.0753	0.0832
34	0.1286	0.0928	0.0995	0.1048	0.0984	0.1304	0.0911	0.1158	0.1085	0.0995
36	0.1623	0.1023	0.1007	0.0969	0.0997	0.1239	0.0798	0.1179	0.1035	0.0866
38	0.1044	0.0747	0.0551	0.0558	0.0704	0.0724	0.0506	0.0832	0.0755	0.0558
40	0.0398	0.0663	0.0230	0.0303	0.0335	0.0293	0.0215	0.0427	0.0450	0.0297
43	0.0030	0.0004	0.0062	0.0117	0.0142	0.0053	0.0019	0.0068	0.0086	0.0094
46	0.0012	0.0000	0.0011	0.0072	0.0064	0.0026	0.0001	0.0020	0.0029	0.0046
49	0.0007	0.0000	0.0000	0.0060	0.0010	0.0013	0.0000	0.0003	0.0005	0.0018
52	0.0001	0.0000	0.0000	0.0039	0.0000	0.0006	0.0000	0.0001	0.0001	0.0006
55	0.0000	0.0000	0.0000	0.0006	0.0000	0.0001	0.0000	0.0000	0.0001	0.0006
58	0.0000	0.0000	0.0000	0.0006	0.0000	0.0003	0.0000	0.0000	0.0000	0.0004

Table 8.5b (cont.). Fishery size composition for flathead sole males.

Length cutpoints	year 2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
12	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000
14	0.0003	0.0001	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16	0.0003	0.0005	0.0003	0.0000	0.0000	0.0001	0.0005	0.0000	0.0000	0.0000
18	0.0004	0.0005	0.0001	0.0005	0.0002	0.0013	0.0007	0.0001	0.0000	0.0000
20	0.0033	0.0017	0.0007	0.0007	0.0006	0.0020	0.0016	0.0008	0.0002	0.0004
22	0.0030	0.0054	0.0030	0.0021	0.0019	0.0029	0.0038	0.0020	0.0010	0.0010
24	0.0046	0.0074	0.0071	0.0063	0.0045	0.0060	0.0089	0.0057	0.0027	0.0036
26	0.0094	0.0113	0.0209	0.0196	0.0084	0.0147	0.0145	0.0128	0.0116	0.0095
28	0.0310	0.0236	0.0261	0.0437	0.0335	0.0211	0.0285	0.0267	0.0288	0.0268
30	0.0520	0.0408	0.0359	0.0609	0.0677	0.0553	0.0608	0.0551	0.0552	0.0720
32	0.0786	0.0710	0.0551	0.0775	0.0881	0.0991	0.0901	0.0985	0.0903	0.0993
34	0.0951	0.1074	0.1053	0.1004	0.1009	0.1168	0.1027	0.1097	0.1129	0.1114
36	0.0919	0.1194	0.1136	0.1078	0.1067	0.1028	0.1074	0.0954	0.0955	0.0890
38	0.0645	0.0762	0.0763	0.0794	0.0679	0.0777	0.0667	0.0654	0.0606	0.0558
40	0.0335	0.0406	0.0356	0.0379	0.0353	0.0472	0.0463	0.0381	0.0330	0.0327
43	0.0057	0.0081	0.0055	0.0043	0.0049	0.0062	0.0081	0.0069	0.0068	0.0052
46	0.0029	0.0030	0.0019	0.0011	0.0013	0.0009	0.0057	0.0026	0.0016	0.0005
49	0.0012	0.0007	0.0006	0.0003	0.0003	0.0009	0.0010	0.0012	0.0009	0.0002
52	0.0005	0.0001	0.0002	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000
55	0.0003	0.0000	0.0000	0.0000	0.0000	0.0003	0.0001	0.0000	0.0000	0.0000
58	0.0008	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000	0.0001	0.0000

Table 8.6. Sample sizes from the BSAI domestic fishery for flathead sole size and age compositions. The "hauls" column under each data type refers to the number of hauls in which individuals were collected.

year	Size compositions				Age compositions				
	hauls	total indiv.s	females	males	hauls	total indiv.s	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	845	18,721	9,319	9,302					622
2000	2,448	32,983	17,465	15,465	241	564	349	215	856
2001	1,680	19,710	10,282	9,258	333	620	353	267	642
2002	1,178	16,156	8,411	7,643					558
2003	1,123	20,441	10,681	9,608					531
2004	1,518	23,426	10,879	12,397	241	496	248	248	814
2005	1,148	15,750	7,829	7,810	187	389	195	194	628
2006	1,242	19,164	8,757	10,384	210	538	275	263	546
2007	1,025	11,675	5,461	6,150	174	434	224	210	441
2008	4,163	39,471	19,680	19,708					1,884
2009	3,095	28,920	14,800	14,059					1,423
2010	1,831	16,682	8,379	8,293					870

Table 8.7. Estimated biomass (t) of *Hippoglossoides* spp. from the EBS and AI trawl surveys. A linear regression between AI and EBS biomass was used to estimate AI biomass in years for which an AI survey was not conducted. The disaggregated biomass estimates for flathead sole and Bering flounder in the EBS (standard survey area) are also given. The "Fraction flathead" column gives the fraction of total EBS *Hippoglossoides* spp. biomass that is accounted for by flathead sole.

	Hippoglossoides spp.					Bering flounder		Flathead sole		
Year	EBS Biomass	CV	AI Biomass	CV	Total	EBS Biomass	CV	EBS Biomass	CV	fraction Flathead
1982	191,988	0.09			195,327	--	--	191,988	0.09	--
1983	269,808	0.10	1,214	0.20	271,022	18,359	0.20	251,449	0.11	0.93
1984	341,697	0.08			347,385	17,820	0.22	323,877	0.09	0.95
1985	276,350	0.07			281,014	14,241	0.12	262,110	0.08	0.95
1986	357,951	0.09	5,273	0.16	363,224	13,962	0.17	343,989	0.09	0.96
1987	394,758	0.09			401,280	14,194	0.14	380,564	0.10	0.96
1988	572,805	0.09			582,120	23,521	0.22	549,284	0.09	0.96
1989	536,433	0.08			545,177	18,794	0.20	517,639	0.09	0.96
1990	628,266	0.09			638,452	21,217	0.15	607,049	0.09	0.97
1991	544,893	0.08	6,939	0.20	551,832	27,412	0.22	517,480	0.08	0.95
1992	651,384	0.10			661,933	15,927	0.21	635,458	0.10	0.98
1993	610,259	0.07			620,162	22,323	0.21	587,936	0.07	0.96
1994	726,212	0.07	9,929	0.23	736,140	26,837	0.19	699,375	0.07	0.96
1995	594,814	0.09			604,474	15,476	0.18	579,337	0.09	0.97
1996	616,373	0.09			626,372	12,034	0.20	604,339	0.09	0.98
1997	807,825	0.22	11,540	0.24	819,365	14,641	0.19	793,184	0.22	0.98
1998	692,234	0.21			703,424	7,911	0.21	684,324	0.21	0.99
1999	402,173	0.09			408,811	13,229	0.18	388,944	0.09	0.97
2000	398,095	0.09	8,906	0.23	407,001	8,311	0.19	389,784	0.09	0.98
2001	515,362	0.10			523,776	11,419	0.21	503,943	0.11	0.98
2002	579,176	0.18	9,897	0.24	589,073	5,223	0.20	573,953	0.18	0.99
2003	517,445	0.10			525,891	5,712	0.21	511,732	0.11	0.99
2004	614,769	0.09	13,299	0.14	628,068	8,103	0.31	606,666	0.09	0.99
2005	612,535	0.09			622,474	7,116	0.28	605,418	0.09	0.99
2006	635,755	0.09	9,664	0.18	645,419	13,891	0.32	621,864	0.09	0.98
2007	562,396	0.09			571,548	10,453	0.217	551,942	0.09	0.98
2008	545,467	0.14			554,353	10,111	0.188	535,356	0.15	0.98
2009	418,812	0.12			425,711	6,649	0.166	412,163	0.12	0.98
2010	495,215	0.15	11,812	0.31	507,027	6,610	0.155	488,605	0.15	0.99

Table 8.8. Mean bottom temperature from the Eastern Bering Sea shelf surveys using standard stations (1982-2010) in less than 200m depth.

Year	Bottom Temperature (deg C)
1982	2.118
1983	2.928
1984	2.153
1985	2.217
1986	1.679
1987	3.124
1988	2.220
1989	2.906
1990	2.337
1991	2.613
1992	1.897
1993	2.973
1994	1.397
1995	1.617
1996	3.353
1997	2.646
1998	3.214
1999	0.611
2000	2.042
2001	2.446
2002	3.189
2003	3.739
2004	3.316
2005	3.401
2006	1.692
2007	1.626
2008	1.112
2009	1.213
2010	1.331

Table 8.9a. Survey age composition for flathead sole females. Age 21 is a plus group.

Age bin	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
3	--	66,181	–	--	58,702	--	--	--	--	--
4	--	95,337	–	--	137,933	--	--	--	--	--
5	--	56,061	–	--	90,562	--	--	--	--	--
6	--	85,292	–	--	55,030	--	--	--	--	--
7	--	58,603	–	--	74,828	--	--	--	--	--
8	--	48,159	–	--	31,147	--	--	--	--	--
9	--	46,723	–	--	38,024	--	--	--	--	--
10	--	15,071	–	--	35,626	--	--	--	--	--
11	--	9,314	–	--	24,252	--	--	--	--	--
12	--	23,602	–	--	32,394	--	--	--	--	--
13	--	12,322	–	--	6,565	--	--	--	--	--
14	--	3,279	–	--	1,723	--	--	--	--	--
15	--	4,654	–	--	6,236	--	--	--	--	--
16	--	0	–	--	9,831	--	--	--	--	--
17	--	0	–	--	786	--	--	--	--	--
18	--	0	–	--	395	--	--	--	--	--
19	--	0	–	--	1,202	--	--	--	--	--
20	--	0	–	--	0	--	--	--	--	--
21	--	0	–	--	756	--	--	--	--	--

Age bin	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
3	--	105,598	0	66,285	47,925	--	--	--	--	18,934
4	--	35,496	41,723	93,933	59,236	--	--	--	--	53,449
5	--	159,704	67,897	82,012	85,661	--	--	--	--	30,041
6	--	153,454	112,285	77,949	52,380	--	--	--	--	41,682
7	--	149,287	60,563	157,919	94,825	--	--	--	--	24,936
8	--	63,181	81,965	102,928	153,079	--	--	--	--	38,607
9	--	133,432	81,374	131,469	66,567	--	--	--	--	61,425
10	--	73,427	56,446	113,465	71,912	--	--	--	--	54,114
11	--	70,422	101,668	63,732	62,935	--	--	--	--	39,971
12	--	121,265	167,633	94,043	48,720	--	--	--	--	30,772
13	--	62,793	19,692	68,020	42,016	--	--	--	--	46,454
14	--	26,253	34,041	48,660	30,952	--	--	--	--	30,714
15	--	11,305	19,884	28,432	25,636	--	--	--	--	18,717
16	--	11,259	2,502	10,131	16,942	--	--	--	--	18,186
17	--	7,529	0	6,270	12,210	--	--	--	--	25,230
18	--	3,796	0	2,242	6,778	--	--	--	--	10,013
19	--	0	0	0	814	--	--	--	--	8,919
20	--	0	0	0	0	--	--	--	--	4,384
21	--	1,511	0	0	2,714	--	--	--	--	10,309

Age bin	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
3	54,228	--	32,810	112,683	79,171	119,137	20,261	26,457	17,791	--
4	58,888	--	47,551	43,666	150,760	103,248	147,668	63,147	42,781	--
5	78,728	--	97,712	108,215	27,759	134,989	98,397	110,169	22,317	--
6	65,882	--	86,951	97,211	83,923	73,725	90,244	73,920	114,443	--
7	54,770	--	86,361	56,091	113,324	80,317	47,077	99,193	74,812	--
8	68,825	--	27,069	55,020	87,368	67,384	82,445	80,612	92,591	--
9	81,260	--	27,283	21,996	19,711	85,712	61,296	70,285	46,635	--
10	47,684	--	51,951	68,491	46,537	71,694	53,482	60,889	39,050	--
11	27,500	--	12,546	53,277	40,632	25,296	36,920	52,698	15,473	--
12	34,608	--	35,630	42,992	47,080	34,429	30,907	16,459	27,229	--
13	30,891	--	8,972	46,817	40,136	34,218	49,241	30,897	37,265	--
14	33,910	--	34,068	20,432	56,309	21,800	32,700	11,824	27,548	--
15	28,952	--	24,457	16,244	17,112	11,916	24,644	15,227	12,832	--
16	12,597	--	45,206	31,940	4,747	5,964	21,878	13,065	6,570	--
17	31,967	--	16,508	7,646	11,665	22,617	15,973	12,255	8,336	--
18	12,969	--	40,509	11,825	23,821	9,249	24,024	18,255	9,827	--
19	8,792	--	11,970	13,184	9,094	5,334	12,559	6,576	9,008	--
20	8,488	--	4,618	3,422	4,747	11,024	4,339	1,394	6,456	--
21	17,652	--	22,195	18,510	40,082	40,504	31,801	26,397	13,343	--

Table 8.9b. Survey age composition for flathead sole males, in 1000's of individuals.

Age bin	1981	1982	1983	1984	year 1985	1986	1987	1988	1989	1990
3	--	70,877	–	--	62,664	--	--	--	--	--
4	--	79,924	–	--	149,763	--	--	--	--	--
5	--	103,935	–	--	75,402	--	--	--	--	--
6	--	97,136	–	--	78,249	--	--	--	--	--
7	--	59,125	–	--	56,783	--	--	--	--	--
8	--	44,013	–	--	52,419	--	--	--	--	--
9	--	12,471	–	--	55,900	--	--	--	--	--
10	--	15,544	–	--	32,926	--	--	--	--	--
11	--	23,507	–	--	42,002	--	--	--	--	--
12	--	6,472	–	--	19,807	--	--	--	--	--
13	--	13,324	–	--	16,107	--	--	--	--	--
14	--	12,861	–	--	10,696	--	--	--	--	--
15	--	1,264	–	--	8,440	--	--	--	--	--
16	--	0	–	--	3,906	--	--	--	--	--
17	--	737	–	--	0	--	--	--	--	--
18	--	1,424	–	--	0	--	--	--	--	--
19	--	0	–	--	0	--	--	--	--	--
20	--	2,520	–	--	0	--	--	--	--	--
21	--	0	–	--	0	--	--	--	--	--

Age bin	1991	1992	1993	1994	year 1995	1996	1997	1998	1999	2000
3	--	137,340	29,048	64,567	38,982	--	--	--	--	21,999
4	--	54,452	29,844	100,663	119,340	--	--	--	--	70,837
5	--	239,031	105,619	147,670	80,072	--	--	--	--	59,928
6	--	131,375	93,817	62,607	105,802	--	--	--	--	21,675
7	--	232,703	130,954	220,441	54,013	--	--	--	--	36,010
8	--	123,578	191,643	106,766	129,308	--	--	--	--	77,593
9	--	113,438	126,623	129,480	115,161	--	--	--	--	90,390
10	--	129,113	41,961	140,613	134,493	--	--	--	--	35,508
11	--	54,764	72,489	61,230	87,084	--	--	--	--	24,750
12	--	45,028	91,516	65,011	53,040	--	--	--	--	16,259
13	--	55,310	26,115	69,074	7,998	--	--	--	--	41,623
14	--	8,330	6,337	38,769	63,789	--	--	--	--	10,025
15	--	0	0	8,707	41,097	--	--	--	--	24,069
16	--	0	20,107	32,723	18,005	--	--	--	--	13,562
17	--	9,482	0	2,040	2,896	--	--	--	--	7,109
18	--	0	0	0	2,701	--	--	--	--	19,823
19	--	0	4,959	0	0	--	--	--	--	4,774
20	--	0	0	16,590	3,999	--	--	--	--	8,344
21	--	0	0	9,952	0	--	--	--	--	13,867

Age bin	2001	2002	2003	2004	year 2005	2006	2007	2008	2009	2010
3	67,744	--	45,956	128,534	121,116	125,857	43,952	36,140	32,635	--
4	98,884	--	96,078	38,563	143,922	117,786	153,803	82,222	48,817	--
5	114,870	--	83,200	146,542	16,575	146,229	110,528	115,876	25,667	--
6	73,202	--	79,539	147,241	126,905	99,512	124,856	130,498	121,638	--
7	84,302	--	68,152	57,809	106,030	129,511	60,391	92,801	97,712	--
8	74,316	--	87,282	65,017	37,732	95,369	81,937	71,487	86,127	--
9	57,731	--	49,100	26,320	75,258	54,103	26,590	51,637	40,633	--
10	48,358	--	74,096	23,810	16,707	62,251	51,290	46,879	57,047	--
11	39,032	--	10,442	23,930	38,062	24,812	29,933	46,215	30,117	--
12	19,052	--	37,990	23,574	66,607	7,043	32,283	20,006	34,945	--
13	32,247	--	9,060	51,692	40,161	19,105	3,840	14,065	17,325	--
14	20,399	--	87,399	29,078	29,700	30,543	56,288	20,969	3,465	--
15	20,472	--	9,060	30,969	18,877	10,548	19,382	18,456	7,132	--
16	26,967	--	17,027	4,438	8,324	21,043	3,640	7,310	6,946	--
17	25,972	--	2,038	35,307	21,711	9,429	14,780	56,713	8,731	--
18	17,562	--	5,475	25,647	17,229	2,386	17,092	2,725	8,291	--
19	5,687	--	4,661	10,618	2,661	21,244	10,773	29,255	6,683	--
20	6,605	--	1,224	0	12,959	13,301	8,832	15,047	2,792	--
21	17,179	--	29,138	52,776	53,608	35,265	33,827	28,941	20,854	--

Table 8.10a. Survey size composition for flathead sole females.

Length cutpoints (cm)	year 1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
6	--	0	0	0	0	0	0	0	0	0
8	--	0	499	609	1,178	474	0	0	142	196
10	--	1,228	12,003	6,067	1,241	3,439	4,258	2,503	15,549	1,946
12	--	16,766	37,341	33,446	7,937	12,091	18,415	19,331	43,406	13,165
14	--	24,103	24,660	58,494	21,577	13,379	26,985	72,656	28,119	58,995
16	--	19,745	43,528	80,385	33,109	17,437	39,894	98,745	39,994	70,066
18	--	29,374	55,918	62,883	52,706	30,883	40,571	92,229	104,402	48,568
20	--	46,820	53,281	56,567	78,316	46,880	48,677	114,631	103,797	67,851
22	--	48,315	45,111	71,798	67,720	64,653	45,238	80,627	109,914	91,460
24	--	48,180	50,443	71,369	50,080	75,024	56,276	74,643	77,047	93,559
26	--	53,370	55,043	72,414	48,994	66,409	66,520	78,177	62,324	82,057
28	--	66,872	61,234	83,441	53,248	60,581	70,321	78,816	67,972	74,652
30	--	70,421	76,519	83,217	54,635	68,367	71,671	79,198	78,141	66,360
32	--	55,205	78,812	84,653	56,393	70,617	70,273	101,099	68,045	77,542
34	--	32,850	70,227	84,327	52,323	74,523	78,824	104,472	85,363	72,180
36	--	13,477	32,309	56,007	34,397	55,192	60,342	97,848	91,007	83,777
38	--	6,745	15,573	26,953	23,531	40,456	46,751	69,773	67,119	80,801
40	--	8,708	9,124	12,299	14,451	30,456	35,048	63,722	65,475	91,997
43	--	1,670	1,582	1,256	4,177	6,975	13,747	26,021	26,583	39,876
46	--	397	468	924	1,014	1,995	2,756	3,473	7,973	11,284
49	--	0	0	26	0	181	104	1,333	806	2,424
52	--	0	0	0	0	0	0	0	0	0
55	--	0	0	0	0	0	0	0	0	0
58	--	0	0	0	0	0	0	0	0	0

Length cutpoints (cm)	year 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
6	0	0	43	0	0	0	0	0	0	249
8	845	0	534	414	0	183	485	579	142	401
10	5,000	3,993	4,803	2,306	1,184	3,038	1,601	12,841	2,129	1,702
12	4,753	30,724	9,927	13,288	5,240	18,724	6,559	23,993	5,818	4,975
14	6,972	54,861	19,370	31,959	15,944	28,209	14,262	11,426	14,643	9,364
16	31,829	42,634	50,290	47,097	30,573	43,057	21,927	20,989	15,786	17,925
18	69,334	48,506	59,062	66,616	38,951	47,929	29,263	28,256	15,047	18,440
20	95,628	75,783	46,114	56,174	54,493	61,574	36,170	41,443	20,443	21,487
22	94,662	102,927	70,870	47,417	50,606	61,114	40,984	45,340	29,157	20,535
24	104,163	123,144	95,049	74,661	49,624	66,251	47,342	47,685	36,063	29,591
26	99,363	115,064	97,495	97,274	62,117	65,118	59,172	66,997	42,592	37,912
28	89,166	114,328	109,177	118,081	80,465	64,305	63,353	72,369	41,851	40,821
30	68,349	83,729	106,749	125,572	97,867	75,826	80,376	61,316	45,534	53,474
32	77,350	79,041	85,765	112,860	92,096	88,045	94,284	76,214	50,877	58,695
34	86,470	84,573	73,980	96,708	80,953	93,106	111,971	94,184	65,311	63,910
36	76,829	85,107	67,036	77,868	67,390	81,046	108,648	89,050	60,728	69,016
38	107,868	81,450	58,948	78,927	59,931	52,624	97,669	80,662	46,454	50,016
40	124,831	94,724	95,198	103,178	69,656	72,781	129,297	87,741	42,994	51,288
43	44,334	51,907	49,323	70,917	50,893	51,341	107,964	57,871	28,128	28,968
46	14,632	16,495	15,798	25,650	16,665	23,325	32,829	24,883	15,217	12,774
49	961	2,481	2,879	3,586	5,559	3,154	7,874	11,339	7,704	4,371
52	0	133	91	318	252	276	612	1,390	953	525
55	0	0	0	0	0	0	0	0	0	0
58	0	0	0	155	0	0	0	0	174	0

Length cutpoints (cm)	year 2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
6	163	196	393	67	0	458	106	61	0	0
8	412	619	26	600	630	632	1,659	261	565	305
10	3,274	2,105	2,075	2,621	5,793	1,522	4,050	3,102	2,030	3,627
12	5,049	4,990	9,223	6,157	19,408	8,824	6,814	7,731	5,269	23,407
14	8,565	11,314	11,382	18,002	22,984	25,248	7,763	9,225	12,778	24,478
16	15,429	14,440	14,759	33,497	34,108	43,963	19,020	14,319	12,087	25,951
18	29,037	18,041	19,055	36,825	45,297	53,718	39,221	16,494	18,068	26,826
20	46,052	26,209	25,036	37,561	48,995	58,970	68,881	27,468	19,024	25,481
22	48,401	37,728	29,842	39,347	49,693	46,791	65,595	48,900	25,260	27,846
24	39,541	41,681	44,319	43,661	52,782	60,782	57,747	65,253	33,998	34,944
26	39,660	42,593	61,377	53,003	62,665	86,063	64,912	72,647	53,766	38,590
28	59,651	49,710	71,464	71,088	68,552	90,178	66,269	72,782	78,124	66,258
30	66,547	52,791	66,160	81,685	78,570	100,714	76,337	86,816	71,212	90,389
32	78,510	74,045	71,411	82,229	86,847	91,650	81,894	87,470	71,321	80,983
34	88,444	83,709	75,997	71,823	89,003	91,998	89,396	90,771	69,822	70,358
36	83,107	67,586	58,647	75,719	74,670	74,462	76,932	81,741	57,275	63,062
38	59,990	60,699	62,237	53,644	52,631	58,028	56,025	51,864	47,060	46,259
40	62,255	66,363	75,047	77,294	66,753	69,048	68,009	54,226	39,513	44,622
43	39,035	52,885	41,568	57,665	59,369	46,772	51,912	27,625	26,964	22,470
46	18,871	44,374	10,895	30,658	33,738	26,489	26,402	16,099	11,345	10,481
49	4,318	24,636	2,390	7,050	11,472	5,090	5,595	4,668	3,557	2,967
52	867	5,264	164	198	1,096	817	657	310	414	220
55	71	967	0	0	0	0	0	0	0	0
58	0	0	52	0	0	0	0	0	0	0

Table 8.10b. Survey size composition for flathead sole males.

Length cutpoints (cm)	1981	1982	1983	1984	year 1985	1986	1987	1988	1989	1990
6	--	270	472	719	34	466	57	537	0	0
8	--	296	1,359	1,504	2,702	831	207	1,633	1,542	1,300
10	--	1,423	16,949	10,405	4,272	7,254	7,513	5,230	17,375	4,751
12	--	19,372	48,266	31,200	8,827	23,709	23,995	30,885	70,043	17,315
14	--	30,558	27,901	57,558	23,652	17,415	27,067	77,092	40,335	74,021
16	--	27,807	49,502	94,504	39,868	22,825	44,089	101,891	43,436	78,166
18	--	33,607	65,942	72,641	61,002	38,524	43,976	73,960	127,715	64,404
20	--	46,438	56,130	68,822	86,019	65,068	53,560	76,373	102,697	94,976
22	--	54,947	50,271	79,823	75,191	74,075	63,006	64,687	102,989	114,383
24	--	63,582	57,082	79,918	57,149	82,941	79,701	70,875	72,955	99,884
26	--	84,479	71,398	87,228	70,290	84,310	78,040	75,182	74,827	96,768
28	--	90,192	85,472	96,036	74,926	69,949	90,860	86,131	76,267	97,843
30	--	72,522	81,972	92,244	80,923	87,559	99,297	115,638	76,468	109,661
32	--	31,547	58,870	70,882	60,959	88,824	97,642	137,931	128,410	136,167
34	--	10,411	23,816	34,055	38,857	49,434	55,065	120,561	127,731	132,391
36	--	3,084	6,723	7,580	14,297	20,699	28,648	51,741	58,911	69,937
38	--	591	1,372	3,571	3,332	6,896	14,990	17,666	18,021	27,546
40	--	416	124	115	784	1,659	3,819	5,158	3,020	5,463
43	--	0	0	0	0	112	0	259	0	499
46	--	0	0	136	0	0	0	0	0	0
49	--	0	0	0	0	0	0	0	0	0
52	--	0	0	0	0	0	0	0	0	0
55	--	0	0	0	0	0	0	0	0	0
58	--	0	0	0	0	0	0	0	0	0

Length cutpoints (cm)	1991	1992	1993	1994	year 1995	1996	1997	1998	1999	2000
6	104	0	0	0	0	65	62	63	0	63
8	704	19	911	888	116	627	473	1,263	462	359
10	12,034	3,458	6,946	4,968	1,971	3,147	3,003	17,181	2,612	5,332
12	8,805	44,852	13,504	20,094	7,676	19,702	10,380	34,491	7,341	7,613
14	10,320	74,833	19,313	43,444	19,001	38,017	12,432	18,227	20,402	11,397
16	47,573	45,930	58,282	65,764	34,430	35,646	24,205	26,354	16,443	24,138
18	91,910	49,481	64,410	87,742	44,097	55,729	30,196	29,318	18,296	22,029
20	125,851	91,687	61,036	75,729	60,255	69,113	40,225	37,447	30,029	25,510
22	119,070	128,805	72,453	68,493	70,084	74,663	53,243	46,656	32,087	28,109
24	112,653	160,500	109,604	92,896	65,626	77,901	66,194	69,562	49,353	43,037
26	111,827	144,343	139,127	126,882	106,692	89,210	73,602	77,228	61,089	63,628
28	92,098	119,009	138,738	142,646	133,120	116,174	91,153	94,432	67,466	64,670
30	101,782	124,420	121,887	157,124	152,698	139,289	142,540	135,438	80,740	87,320
32	95,911	135,703	128,755	153,685	139,029	145,854	151,214	161,070	99,152	87,424
34	107,636	138,556	117,834	144,324	120,434	135,787	144,887	157,738	83,524	73,411
36	72,527	88,969	68,837	95,407	73,474	84,999	101,655	106,858	46,103	49,001
38	21,392	32,185	26,737	31,708	32,089	33,756	53,182	59,743	21,418	19,299
40	4,766	6,546	7,095	8,362	10,573	12,379	23,771	14,973	11,042	7,638
43	447	325	237	389	497	1,009	2,371	2,642	1,044	588
46	57	24	0	0	141	0	1,854	436	102	240
49	0	180	0	0	0	0	0	0	0	33
52	0	0	0	0	0	31	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0	0	0	0

Length cutpoints (cm)	2001	2002	2003	2004	year 2005	2006	2007	2008	2009	2010
6	0	72	0	81	0	638	0	31	265	191
8	742	501	635	444	1,200	379	2,490	966	2,476	212
10	5,056	1,942	4,379	3,012	8,545	2,230	3,541	4,745	2,741	3,481
12	6,574	6,513	10,622	10,372	23,852	12,541	5,582	12,664	7,265	23,133
14	17,029	13,392	12,613	21,710	27,815	32,505	8,758	14,063	13,034	20,281
16	20,786	17,985	23,170	32,872	36,736	50,465	21,199	16,233	15,440	28,454
18	37,297	21,845	28,478	46,472	49,358	58,073	47,793	18,397	19,456	39,393
20	63,484	35,926	31,023	40,504	57,370	63,491	72,609	30,877	26,224	25,428
22	59,990	57,205	42,634	48,182	59,440	61,223	71,653	52,040	27,088	29,646
24	46,244	59,348	69,681	58,450	59,889	65,365	72,140	81,613	44,272	44,548
26	59,537	59,477	85,251	79,146	85,080	79,000	78,834	91,583	76,770	55,573
28	97,817	74,859	103,423	117,149	113,368	108,798	86,818	95,052	92,104	99,533
30	120,340	108,751	113,692	133,542	137,621	126,039	111,318	121,469	89,740	130,340
32	123,229	116,123	99,195	122,533	128,307	141,467	112,440	145,654	95,521	116,970
34	105,454	107,589	87,687	114,557	100,952	112,683	94,141	118,550	77,539	107,474
36	59,994	63,228	65,020	71,398	61,070	73,291	60,010	57,581	45,779	71,976
38	30,875	25,992	32,534	44,616	33,434	37,638	33,159	39,755	25,367	42,742
40	9,795	12,491	8,622	15,805	14,867	15,919	15,938	12,320	12,135	17,306
43	1,885	2,022	2,167	1,650	1,546	1,971	1,422	915	981	252
46	561	3,015	89	0	877	202	92	250	444	29
49	18	16	0	68	797	0	0	235	0	257
52	18	0	0	0	0	0	0	0	0	81
55	0	0	0	0	0	0	0	0	0	0
58	0	0	29	0	0	90	0	0	0	0

Table 8.11a. Sample sizes for flathead sole from the EBS shelf survey standard stations.

year	Size compositions				Age compositions				
	hauls	total indiv.s	females	males	hauls	total indiv.s	females	males	otoliths collected
1982	108	11,029	4,942	5,094	15	390	207	181	390
1983	170	15,727	7,480	7,671					
1984	152	14,043	6,792	6,639					569
1985	189	13,560	6,769	6,789	23	496	268	227	496
1986	259	13,561	6,844	6,692					
1987	191	13,878	6,502	7,003					
1988	202	14,049	7,068	6,729					
1989	253	15,509	7,682	7,261					
1990	256	15,437	7,504	7,922					
1991	266	16,102	7,731	8,057					
1992	273	15,813	8,037	7,357	11	419	228	191	419
1993	288	17,057	8,438	8,227	5	136	78	58	140
1994	277	16,366	8,078	8,149	7	371	204	166	371
1995	263	14,946	7,326	7,298	10	395	216	179	396
1996	290	19,244	9,606	9,485					420
1997	281	16,339	8,006	7,932					301
1998	315	21,611	10,634	10,352					87
1999	243	14,172	6,966	7,080					420
2000	277	15,905	8,054	7,536	18	437	243	193	439
2001	286	16,399	8,234	8,146	21	536	282	254	537
2002	281	16,705	8,332	8,196	19	465	265	200	471
2003	276	17,652	8,396	8,854	34	246	135	111	576
2004	274	18,737	8,864	9,026	16	473	265	208	477
2005	284	16,875	8,181	8,224	17	450	222	227	465
2006	255	17,618	8,798	8,755	27	508	277	229	515
2007	262	14,855	7,494	7,120	38	560	314	242	583
2008	255	16,367	8,269	7,805	45	581	328	244	588
2009	236	13,866	6,864	6,619	51	666	369	292	673
2010	244	12,568	6,253	6,131					

Table 8.11b. Sample sizes for Bering flounder from the EBS shelf survey standard stations.

year	Size compositions				Age compositions				
	hauls	total indiv.s	females	males	hauls	total indiv.s	females	males	otoliths collected
1982									
1983	23	1,427	989	438					
1984	31	1,331	882	435					
1985	54	2,062	1,368	686	14	237	128	107	237
1986	95	1,846	1,222	566					
1987	32	1,550	1,034	516					
1988	42	2,094	1,445	649					
1989	52	1,999	1,449	549					
1990	58	1,674	1,222	452					
1991	68	2,284	1,913	369					
1992	63	2,094	1,678	415					
1993	76	2,042	1,502	540					
1994	80	2,358	1,949	392					
1995	86	1,278	1,053	225					
1996	60	1,272	975	286					
1997	49	1,518	1,313	198					
1998	56	944	782	162					
1999	78	1,087	805	282					
2000	63	954	715	239					
2001	62	805	660	145					
2002	41	385	306	79					
2003	56	585	412	143					
2004	50	681	410	182					
2005	41	650	507	132					
2006	70	1,042	847	195	9	87	56	31	263
2007	72	1,131	893	231	28	185	121	64	285
2008	74	1,509	1,237	235	30	216	138	70	269
2009	86	1,153	791	181					
2010	96	1,597	693	293					

Table 8.12. Comparison of base and alternative model results for various combinations of stock-recruit and time-dependent catchability (TDQ) options. The evidence ratio for each model is evaluated against the model with the lowest AIC (the base model, in this case).

Alternative model	Options					Results				
	historical recruitment option	stock-recruit deviations option	initial n-at-age option	stock-recruit function	temperature-dependent catchability (TDQ)	Convergence/ Bounds OK?	No. of parameters	-lnL	AIC	Evidence Raio
base (TDQ, no SRF)	standard	standard	standard	constant	0-lag	ok	77	871.39	1896.77	1.00
no TDQ, no SRF	standard	standard	standard	constant	none	ok	76	875.04	1902.08	0.07
TDQ, Ricker SRF	standard	standard	standard	Ricker	0-lag	ok	79	872.73	1903.46	0.04
TDQ, B-H SRF	standard	standard	standard	Beverton-Holt	0-lag	bounds	79	--	--	--

Table 8.13. Parameter estimates corresponding to the selected (base) model.

Fishery selectivity						
k	L_{50}					
0.328	34.83					
Survey selectivity						
k	L_{50}					
0.120	28.16					
Survey catchability						
β_q	0.049					
Historic parameters						
F^H	0.062					
$\ln(R^H)$	4.393					
Fishing mortality						
μ_f	-2.961					
ε_t	1976-1980:		1.654	1.552	1.010	0.976
	1981-1985	0.663	0.198	0.063	-0.341	-0.310
	1986-1990	-0.571	-1.105	-0.617	-1.375	0.257
	1991-1995	-0.176	-0.238	-0.368	-0.195	-0.387
	1996-2000	-0.244	-0.073	0.122	-0.147	-0.030
	2001-2005	-0.144	-0.249	-0.310	-0.079	-0.128
	2006-2010	-0.004	0.056	0.337	0.111	0.095
Recruitment						
$\overline{\ln(R)}$	6.841					
τ_t	1976-1980:		0.717	-1.927	0.231	-0.483
	1981-1985	-0.069	-0.449	0.450	0.755	-0.599
	1986-1990	-0.133	0.196	0.682	0.382	0.535
	1991-1995	-0.483	-0.073	-0.539	0.086	-0.397
	1996-2000	-0.004	-0.821	-0.268	-0.065	-0.526
	2001-2005	0.133	0.016	-0.933	0.447	0.058
	2006-2010	0.343	-1.069	-0.796	-1.506	0.279

Table 8.14. Observed and predicted (from the preferred model) fishery catches.

year	Catch (t)	
	reported	predicted
1977	7,909	8,086
1978	6,957	6,928
1979	4,351	4,315
1980	5,247	5,184
1981	5,218	5,161
1982	4,509	4,483
1983	5,240	5,230
1984	4,458	4,469
1985	5,636	5,657
1986	5,208	5,222
1987	3,595	3,605
1988	6,783	6,799
1989	3,604	3,617
1990	20,245	20,404
1991	14,197	14,316
1992	14,407	14,520
1993	13,574	13,681
1994	17,006	17,223
1995	14,713	14,914
1996	17,344	17,585
1997	20,681	21,030
1998	24,597	25,180
1999	18,555	18,829
2000	20,422	20,568
2001	17,809	17,815
2002	15,572	15,576
2003	14,184	14,187
2004	17,394	17,340
2005	16,151	16,114
2006	17,947	17,943
2007	18,744	18,803
2008	24,539	24,695
2009	19,549	19,609
2010	19,370	19,372

Table 8.15. Assessment model estimates of female spawning biomass, total biomass (ages 3+), and recruitment (age 3), with comparison to the 2009 SAFE estimates.

Year	Spawning stock biomass (t)		Total biomass (t)		Recruitment (thousands)	
	Assessment 2010	Assessment 2009	Assessment 2010	Assessment 2009	Assessment 2010	Assessment 2009
1977	21,926	22,720	122,170	124,850	1,916,640	1,933,070
1978	19,637	20,423	149,520	152,620	136,205	145,946
1979	18,590	19,370	202,220	205,680	1,178,580	1,182,160
1980	19,549	20,335	252,980	256,970	577,339	588,830
1981	22,838	23,644	309,270	313,780	873,512	882,238
1982	31,000	31,870	359,130	364,040	597,358	602,093
1983	46,499	47,510	426,490	431,960	1,467,490	1,481,190
1984	68,532	69,758	515,140	521,290	1,991,270	2,007,210
1985	92,378	93,841	580,770	587,460	514,145	521,185
1986	115,030	116,710	640,040	647,260	819,089	829,723
1987	136,718	138,597	698,230	705,980	1,138,030	1,149,420
1988	158,745	160,813	771,720	780,040	1,849,960	1,864,710
1989	182,239	184,496	837,470	846,510	1,370,690	1,390,370
1990	208,892	211,359	909,650	919,290	1,597,310	1,608,960
1991	230,398	233,080	943,740	954,000	577,532	591,872
1992	249,011	251,892	972,730	983,470	870,209	880,977
1993	264,615	267,681	981,130	992,130	546,105	551,982
1994	281,706	284,971	987,110	998,260	1,020,050	1,028,900
1995	302,225	305,740	978,430	989,620	629,444	636,347
1996	318,082	321,819	966,820	977,910	931,626	939,813
1997	327,760	331,673	940,400	951,290	411,553	418,124
1998	325,944	329,971	909,920	920,680	715,954	726,580
1999	316,870	320,924	880,330	890,780	876,967	880,182
2000	306,534	310,533	850,320	860,310	552,954	554,534
2001	296,198	300,115	832,470	841,870	1,069,120	1,068,190
2002	287,161	290,977	821,950	830,760	950,998	954,500
2003	276,353	280,035	800,810	808,910	368,081	367,773
2004	266,430	269,977	804,860	811,110	1,463,210	1,420,450
2005	257,143	260,527	808,010	810,630	991,980	908,164
2006	251,404	254,567	825,750	822,600	1,319,090	1,201,550
2007	246,459	249,315	823,010	817,270	321,327	386,515
2008	243,607	246,012	812,370	797,990	422,133	183,670
2009	239,675	241,522	781,750	773,510	207,644	655,596
2010	240,432		772,260		1,237,040	

Table 8.16. Projections of catch (t), spawning biomass (t), and fishing mortality rate for the seven standard projection scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 134,411 t and 117,609 t, respectively.

	Catch (t)						
year	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5	scenario 6	scenario 7
2010	19,370	19,370	19,370	19,370	19,370	19,370	19,370
2011	69,348	69,348	35,935	17,242	NA	83,321	69,348
2012	61,777	61,777	34,281	17,070	NA	72,069	61,777
2013	55,131	55,131	32,524	16,759	NA	62,691	66,257
2014	49,746	49,746	30,939	16,442	NA	55,392	58,093
2015	45,719	45,719	29,614	16,149	NA	48,132	52,079
2016	42,145	42,145	28,772	16,011	NA	41,117	43,428
2017	39,521	39,521	28,375	16,022	NA	39,648	40,917
2018	39,270	39,270	28,254	16,110	NA	40,611	41,269
2019	39,868	39,868	28,414	16,319	NA	42,177	42,480
2020	40,527	40,527	28,640	16,534	NA	43,414	43,528
2021	41,087	41,087	28,854	16,714	NA	44,243	44,263
2022	41,681	41,681	29,182	16,979	NA	44,894	44,878
2023	42,038	42,038	29,414	17,170	NA	45,228	45,200

	Female spawning biomass (t)						
year	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5	scenario 6	scenario 7
2010	240,004	240,004	240,004	240,004	240,004	240,004	240,004
2011	235,613	235,613	239,125	241,008	242,695	234,084	235,613
2012	211,186	211,186	232,071	244,083	255,364	202,679	211,186
2013	188,370	188,370	222,216	242,990	263,375	175,407	187,170
2014	165,672	165,672	208,612	236,649	265,355	150,160	158,966
2015	145,025	145,025	193,205	226,602	262,256	128,776	134,973
2016	131,353	131,353	181,960	219,181	260,583	116,317	119,878
2017	126,380	126,380	177,452	217,460	263,705	113,617	115,592
2018	127,054	127,054	177,615	219,731	270,077	115,766	116,773
2019	129,754	129,754	180,256	224,403	278,736	119,148	119,588
2020	132,384	132,384	183,129	229,026	286,913	121,906	122,035
2021	134,339	134,339	185,393	232,599	293,335	123,679	123,655
2022	135,985	135,985	188,013	236,934	301,040	124,903	124,829
2023	136,927	136,927	189,728	239,887	306,615	125,442	125,361

	Fishing mortality						
year	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5	scenario 6	scenario 7
2010	0.074	0.074	0.074	0.074	0.074	0.074	0.074
2011	0.280	0.280	0.140	0.066	NA	0.342	0.280
2012	0.280	0.280	0.140	0.066	NA	0.342	0.280
2013	0.280	0.280	0.140	0.066	NA	0.342	0.342
2014	0.280	0.280	0.140	0.066	NA	0.342	0.342
2015	0.280	0.280	0.140	0.066	NA	0.327	0.342
2016	0.273	0.273	0.140	0.066	NA	0.294	0.303
2017	0.262	0.262	0.140	0.066	NA	0.286	0.292
2018	0.260	0.260	0.140	0.066	NA	0.291	0.294
2019	0.262	0.262	0.140	0.066	NA	0.298	0.299
2020	0.264	0.264	0.140	0.066	NA	0.304	0.304
2021	0.265	0.265	0.140	0.066	NA	0.307	0.307
2022	0.267	0.267	0.140	0.066	NA	0.309	0.309
2023	0.267	0.267	0.140	0.066	NA	0.310	0.310

Table 8.17a. Prohibited species catch for halibut in the flathead sole target fishery (in kg and as % of the total PSC over all fisheries), based on hauls identified as targeting flathead sole.

Year	directed fishery halibut PSC (kg)	% total halibut PSC
2003	223,673	2.5%
2004	632,041	7.3%
2005	357,299	4.9%
2006	485,910	5.7%
2007	426,937	5.0%
2008	337,882	3.1%
2009	262,755	2.6%
2010	223,659	2.9%

Table 8.17b. Prohibited species catch for crab, broken out by species, in the flathead sole target fishery (in numbers and as % of the total PSC over all fisheries) , based on hauls identified as targeting flathead sole.

year	PSC in target fishery (#)					fraction of total PSC				
		King Crab		Tanner Crab			King Crab		Tanner Crab	
	Blue	Golden	Red	Bairdi	Opilio	Blue	Golden	Red	Bairdi	Opilio
2003	154	0	0	320,688	231,653	4.2%	0.0%	0.0%	29.4%	29.5%
2004	0	127	69	163,391	129,063	0.0%	0.2%	0.1%	19.5%	6.8%
2005	15	0	427	266,919	126,167	2.2%	0.0%	0.3%	15.9%	3.7%
2006	0	0	683	230,605	114,907	0.0%	0.0%	0.6%	17.4%	9.1%
2007	41	0	852	137,416	252,348	0.0%	0.0%	0.7%	11.7%	10.3%
2008	613	423	3,192	116,750	117,348	6.0%	0.2%	2.3%	5.2%	7.7%
2009	1,344	57	688	46,532	201,926	7.9%	0.0%	0.8%	4.8%	16.5%
2010	125	56	768	71,039	96,381	0.2%	0.1%	1.2%	8.7%	4.8%

Table 8.17c. Prohibited species catch for salmon, broken out by Chinook/non-Chinook categories, in the flathead sole target fishery (in numbers and as % of the total PSC over all fisheries), based on hauls identified as targeting flathead sole.

Year	Chinook		Non-Chinook	
	PSC (#)	fraction of total	PSC (#)	fraction of total
2003	57	0.1%	173	0.1%
2004	499	0.8%	2,368	0.5%
2005	42	0.1%	441	0.1%
2006	288	0.3%	801	0.2%
2007	0	0.0%	0	0.0%
2008	103	0.4%	145	0.9%
2009	0	0.0%	71	0.1%
2010	0	0.0%	15	0.1%

Table 8.18. Catch of non-prohibited species in the flathead sole target fishery.

	2010		2009		2008		2007		2006	
species	Total (t)	% retained	Total (t)	% retained	Total (t)	% retained	Total (t)	% retained	Total (t)	% retained
flathead sole	8,806	98%	8,561	99%	11,511	99%	7,783	84%	7,662	90%
pollock	2,904	86%	3,166	77%	4,234	74%	3,962	60%	2,640	59%
yellowfinsole	1,418	95%	1,419	98%	3,780	96%	2,448	55%	2,602	86%
pacific cod	1,882	99%	1,970	97%	1,919	97%	1,989	90%	2,002	92%
arrowtooth flounder	2,223	53%	1,211	57%	2,527	56%	1,863	26%	1,599	59%
rock sole spp.	2,372	92%	1,531	95%	1,823	91%	2,303	56%	1,525	84%
all sharks, skates, sculpin, octopus	496	16%	771	14%	1,300	27%	1,301	28%	1,359	29%
alaska plaice	1,255	85%	616	86%	973	74%	687	19%	895	26%
misc flatfish	7	95%	5	78%	18	85%	19	46%	56	77%
atka mackerel	0	--	0	100%	1	39%	138	92%	48	88%
turbot	13	82%	49	86%	98	92%	30	47%	28	95%
POP	98	92%	210	90%	41	75%	104	78%	1	33%
northern rockfish	0	--	1	100%	0	68%	9	1%	1	98%
other rockfish complex	0	67%	0	88%	2	89%	7	16%	1	0%
squid	0	--	0	0%	0	2%	0	--	0	--
sablefish	0	--	0	0%	0	100%	19	100%	0	--
rougheye	0	--	0	0%	0	100%	0	--	0	--
shortraker	0	--	0	100%	0	100%	1	100%	0	--

Table 8.19. Catch of nontarget species in the flathead sole target fishery in recent years as a fraction of the total nontarget species catch over all Bering Sea groundfish fisheries.

Nontarget Species		Year							
Group	subgroup	2003	2004	2005	2006	2007	2008	2009	2010
Benthic urochordata		4.3%	0.0%	0.7%	3.9%	10.2%	4.7%	0.2%	10.5%
Birds	Albatross/Jaeger	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Auklet	0.0%	0.0%	--	--	--	0.0%	--	--
	Cormorant	--	--	--	0.0%	--	--	--	--
	Fulmar	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.5%	0.0%
	Gulls	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Kittiwake	0.0%	0.0%	0.0%	--	0.0%	--	0.0%	--
	Murres	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Other Birds	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Shearwater	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Storm Petrel	0.0%	0.0%	--	0.0%	0.0%	0.0%	--	--
Bivalves		1.6%	4.2%	0.2%	1.0%	2.9%	0.6%	0.6%	3.3%
Brittle star unidentified		30.1%	10.8%	2.3%	1.5%	3.4%	1.6%	25.4%	12.6%
Capelin		0.0%	0.5%	0.0%	0.0%	0.0%	5.2%	3.6%	0.0%
Corals Bryozoans	Corals Bryozoans unidentified	0.2%	1.0%	0.9%	0.4%	0.1%	0.0%	0.1%	4.5%
	Red Tree Coral	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Dark Rockfish		--	--	--	--	--	0.0%	0.0%	0.0%
Deep sea smelts (bathylagidae)		0.0%	0.0%	--	0.0%	0.0%	--	--	--
Eelpouts		10.1%	20.9%	12.9%	9.6%	4.0%	3.4%	1.7%	11.9%
Eulachon		0.0%	0.1%	0.7%	0.0%	0.0%	0.6%	0.1%	0.7%
Giant Grenadier		0.0%	0.5%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%
Greenlings		0.0%	2.1%	0.5%	0.0%	0.6%	0.7%	3.5%	0.0%
Grenadier	Pacific Grenadier	--	0.0%	0.0%	0.0%	0.0%	--	0.0%	0.0%
	Ratail Grenadier Unidentified	1.7%	1.6%	0.2%	0.0%	0.0%	0.2%	0.0%	0.0%
Gunnels		--	0.0%	0.0%	--	0.0%	0.0%	--	--
Hermit crab unidentified		2.1%	13.3%	6.8%	2.7%	12.2%	5.7%	1.8%	7.6%
Invertebrate unidentified		1.0%	5.3%	3.2%	2.7%	1.6%	18.3%	8.3%	11.1%
Lanternfishes (myctophidae)		0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
Large Sculpins		1.8%	10.1%	8.6%	10.3%	5.2%	8.8%	6.2%	5.2%
Misc crabs		21.6%	3.1%	4.2%	2.2%	2.1%	3.1%	0.6%	1.3%
Misc crustaceans		6.7%	32.5%	10.4%	2.6%	9.2%	21.8%	3.4%	8.8%
Misc deep fish		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Misc fish		2.3%	1.9%	1.8%	2.0%	0.7%	1.1%	1.4%	0.6%
Misc inverts (worms etc)		89.9%	87.5%	88.2%	13.3%	0.0%	57.2%	11.3%	2.1%
Octopus		1.2%	2.7%	1.0%	1.2%	0.3%	0.3%	0.6%	0.1%
Other osmerids		1.6%	3.1%	2.4%	1.1%	0.0%	0.0%	0.1%	0.1%
Other Sculpins		8.8%	1.6%	12.9%	0.8%	13.6%	1.2%	1.2%	1.4%
Pacific Sand lance		0.9%	0.0%	1.8%	0.0%	0.0%	2.6%	0.0%	0.0%
Pandalid shrimp		19.1%	7.2%	28.6%	2.7%	4.8%	11.1%	4.2%	4.1%
Polychaete unidentified		37.2%	27.7%	4.4%	0.0%	3.2%	7.2%	11.0%	0.6%
Scypho jellies		0.3%	0.3%	0.1%	0.1%	0.2%	0.1%	0.2%	0.6%
Sea anemone unidentified		7.4%	23.7%	2.1%	6.9%	47.4%	11.4%	3.0%	16.2%
Sea pens whips		3.7%	1.7%	0.8%	1.2%	2.2%	2.0%	0.3%	0.1%
Sea star		4.4%	9.6%	4.7%	9.8%	5.4%	9.7%	7.7%	5.5%
Shark, Other		0.0%	36.9%	0.0%	0.7%	21.1%	0.0%	0.0%	0.0%
Shark, pacific sleeper		9.2%	4.6%	0.3%	2.7%	1.6%	2.0%	0.1%	1.0%
Shark, salmon		0.0%	0.2%	0.5%	40.7%	0.0%	0.3%	0.2%	0.0%
Shark, spiny dogfish		0.0%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Skate, Alaska		--	--	--	--	--	--	--	4.6%
Skate, Big		--	3.1%	12.4%	0.3%	0.0%	5.3%	0.7%	1.7%
Skate, Longnose		0.0%	0.0%	1.5%	0.0%	7.9%	0.8%	3.1%	0.0%
Skate, Other		3.3%	5.3%	3.6%	4.3%	4.2%	3.1%	1.8%	0.0%
Snails		7.0%	19.5%	10.2%	4.8%	9.9%	9.6%	2.9%	7.1%
Sponge unidentified		0.8%	0.4%	0.3%	0.5%	0.0%	0.9%	0.1%	1.5%
Squid		0.0%	0.4%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
Stichaeidae		0.8%	2.5%	21.5%	69.3%	0.1%	2.8%	9.4%	4.9%
Surf smelt		--	--	--	--	0.0%	0.0%	--	--
urchins dollars cucumbers		4.8%	6.8%	0.9%	1.6%	1.6%	6.2%	2.7%	3.1%

Figures

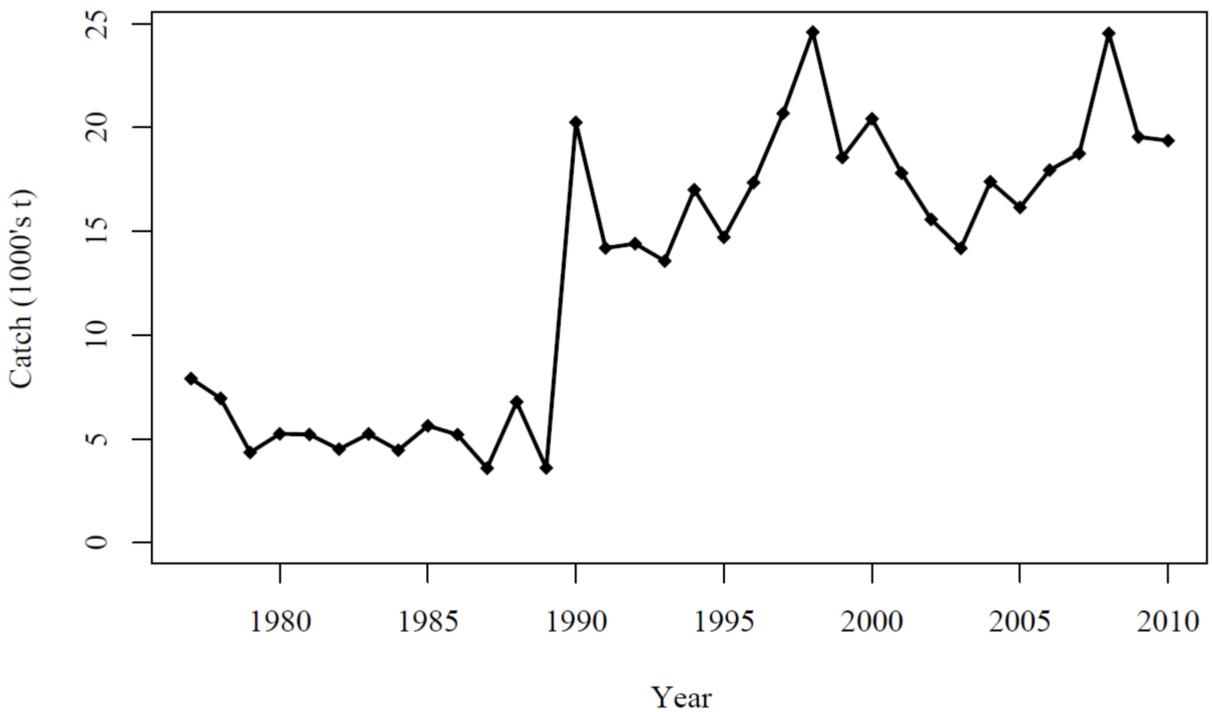


Figure 8.1. Annual fishery catches of flathead sole (*Hippoglossoides* spp.) through Sept. 25, 2010.

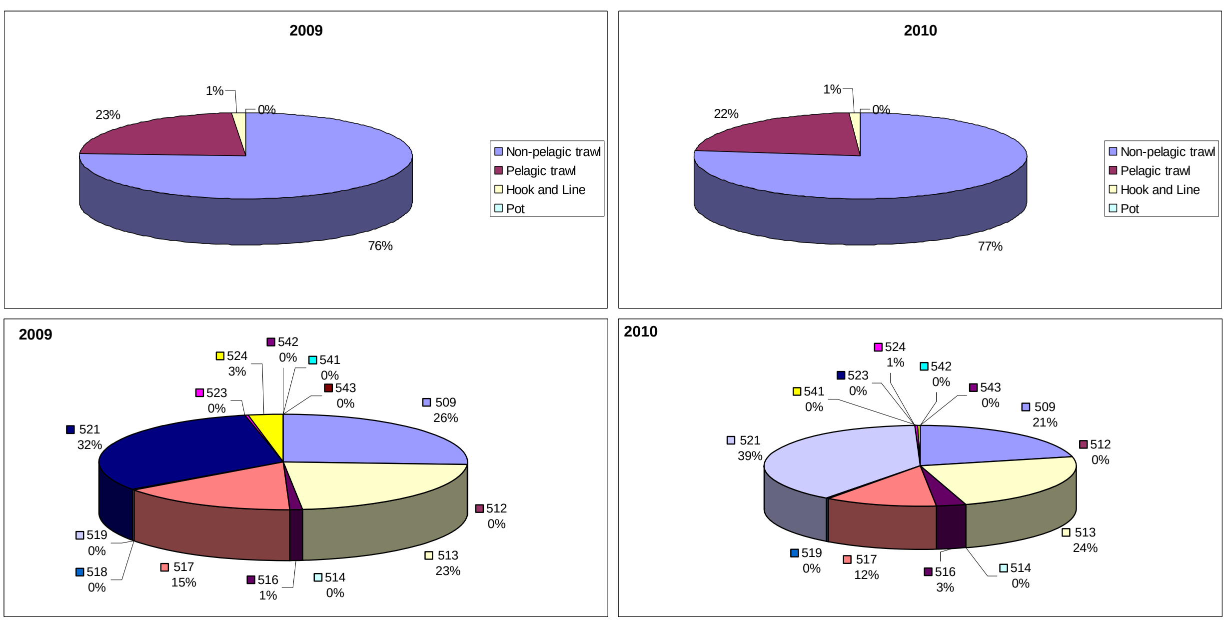


Figure 8.2. Flathead sole (*Hippoglossoides* spp.) fishery catch by gear type (upper row) and NMFS statistical area (lower row) for 2009 and 2010 through Sept. 25.

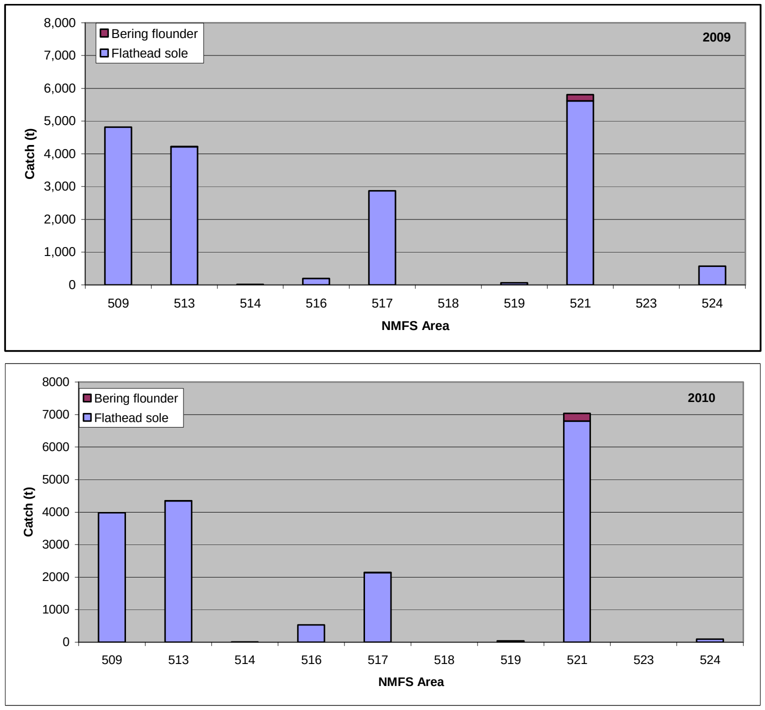


Figure 8.3. Flathead sole (*Hippoglossoides* spp.) fishery catch by species for 2009 (upper plot) and 2010 (lower plot), through Sept. 25.

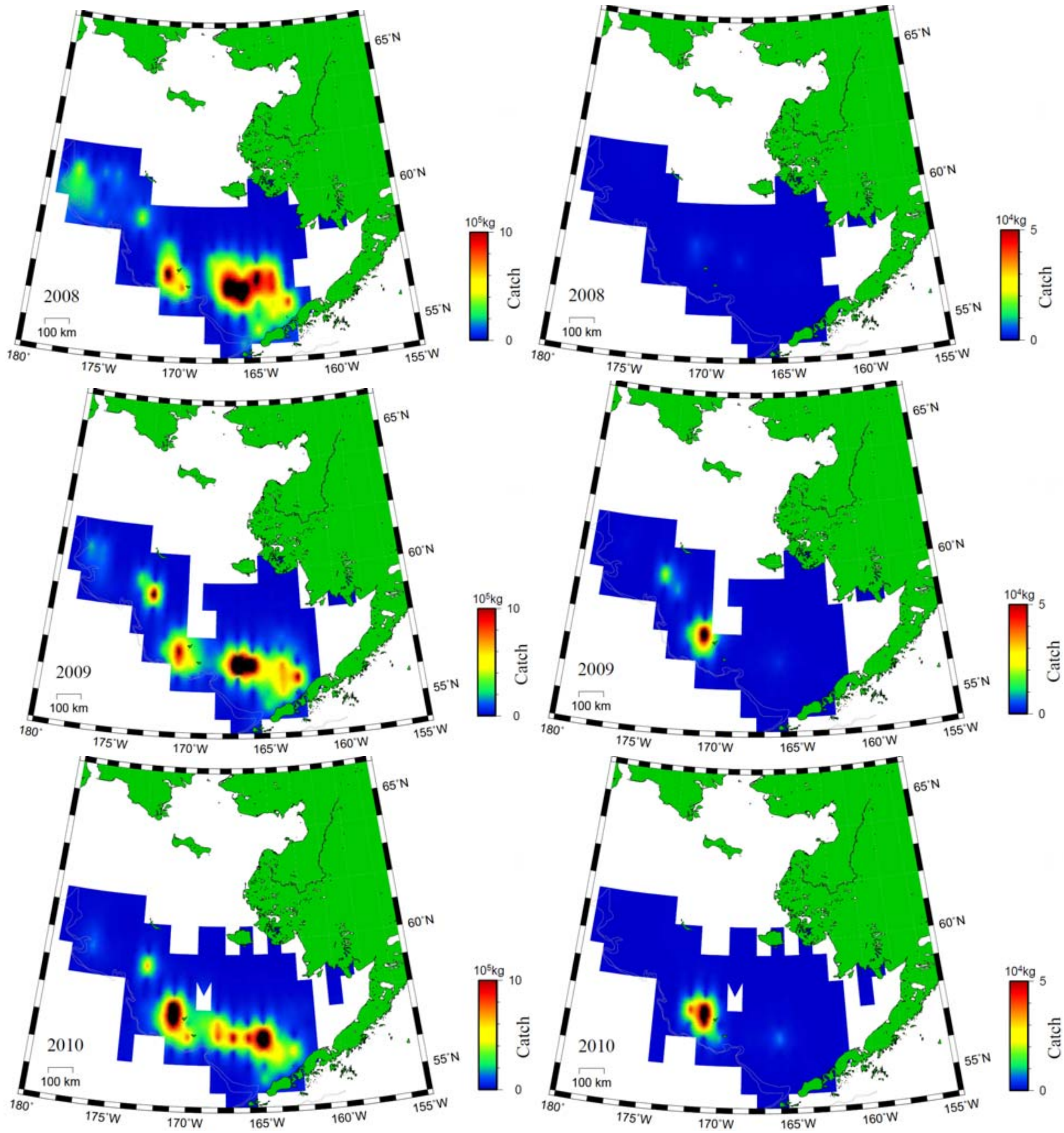


Figure 8.4a. Spatial distributions of total flathead sole (left column) and Bering flounder (right column) catch by trawl (non-pelagic and pelagic) gear for 2008-2010, based on observer data. Note that different scales are used for the two species.

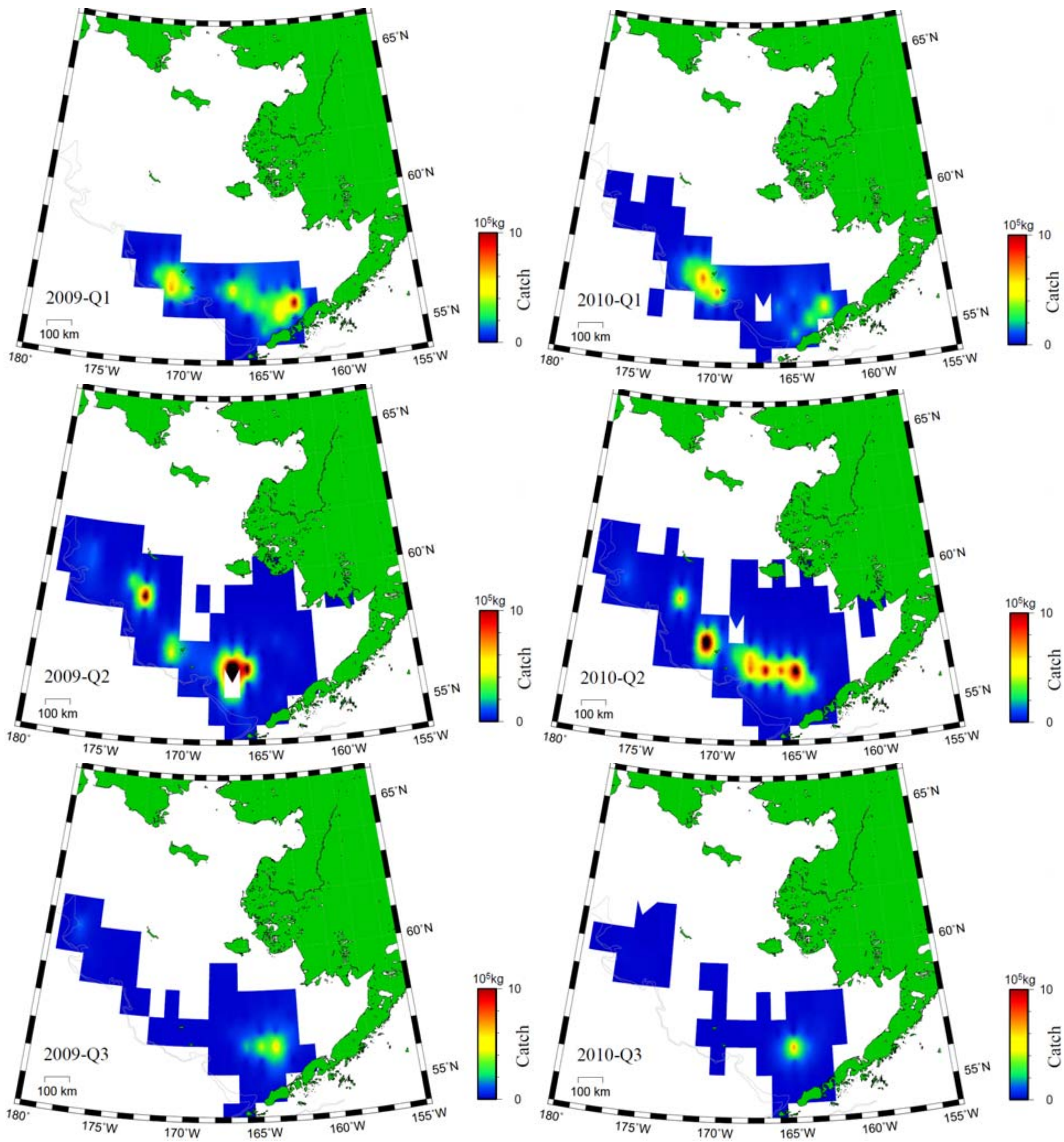


Figure 8.4b. Spatial distributions of total flathead sole catch by trawl (non-pelagic and pelagic) gear in 2009 and 2010 by quarter from observer data. Results for the final quarter of each year are not shown; no catches were observed in 2009 and no data was available for 2010 when these plots was produced.

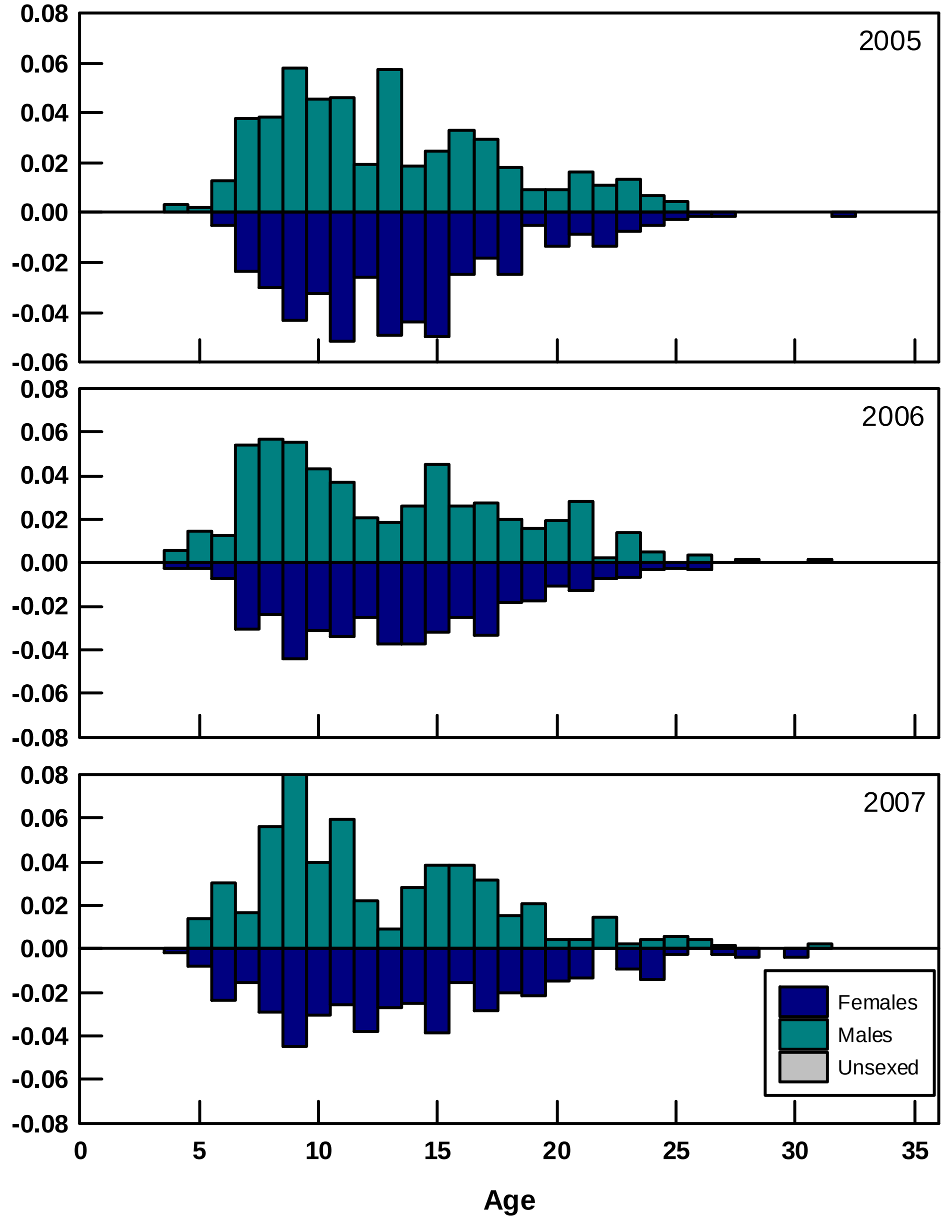


Figure 8.5. Recent flathead sole age compositions for BSAI *Hippoglossoides* spp. (flathead sole and Bering flounder) from fishery observer data. Male age compositions are plotted above each reference line, female age compositions are plotted below the line. These compositions are normalized to 1 over both sexes.

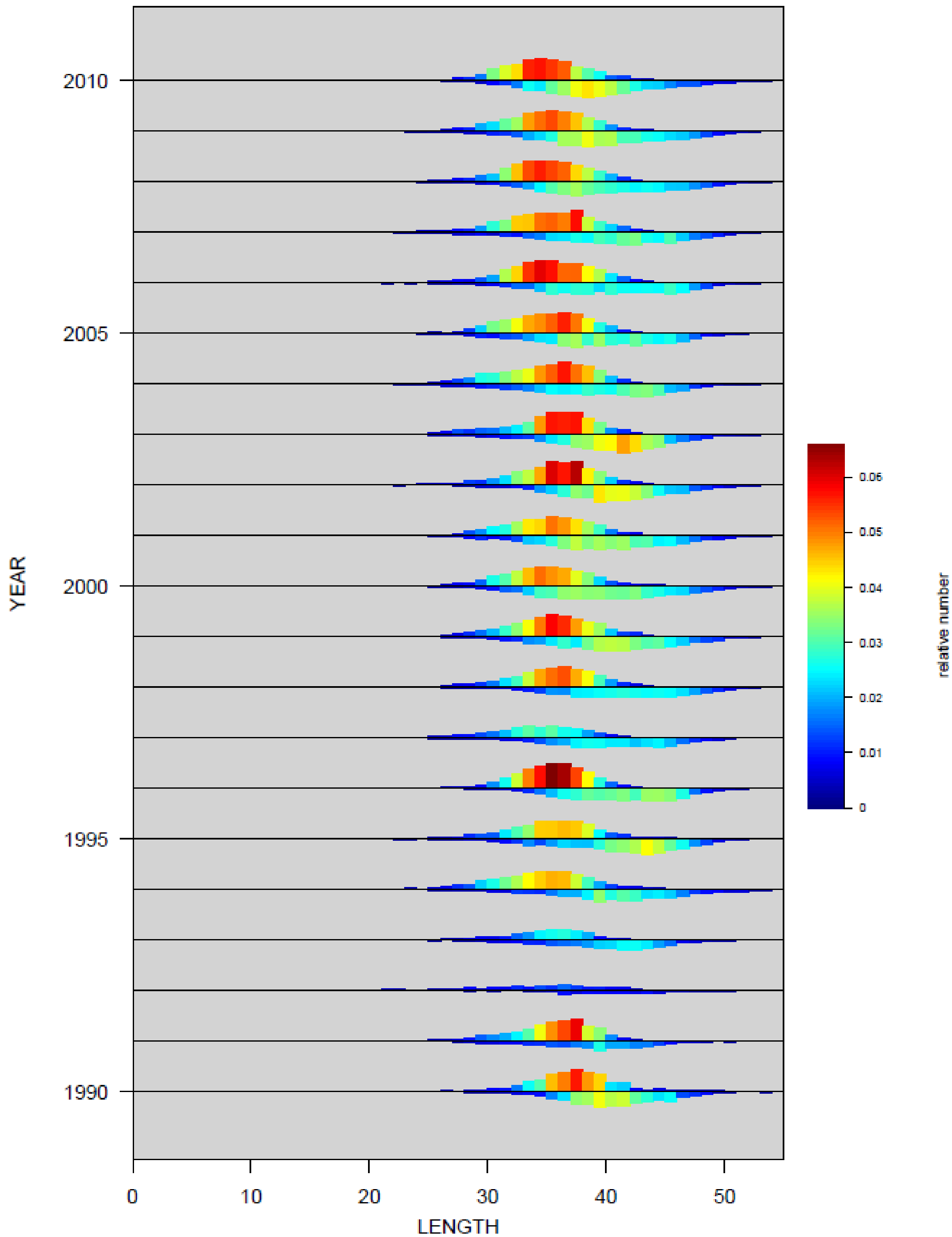


Figure 8.6. Annual size compositions for BSAI *Hippoglossoides* spp. (flathead sole and Bering flounder) from fishery observer data. Male size compositions are plotted above each reference line, female size compositions are plotted below the line. The compositions are normalized to 1 over both sexes by year. Unsexed animals are not included.

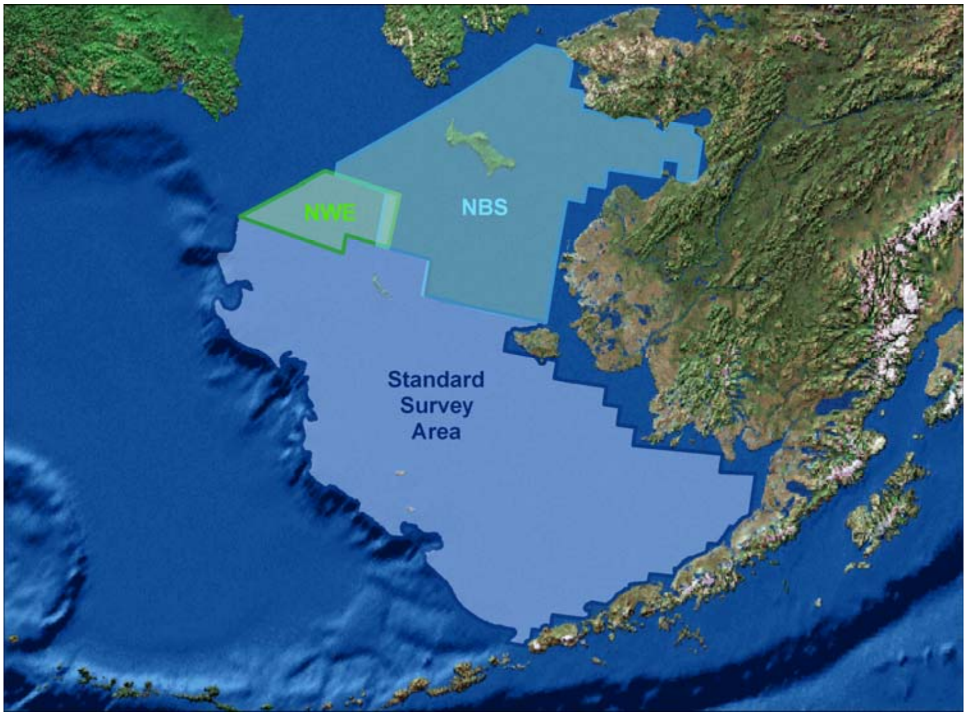


Figure 8.7. Survey areas discussed in text. NWE: Northwest Extension. NBS: Northern Bering Sea.

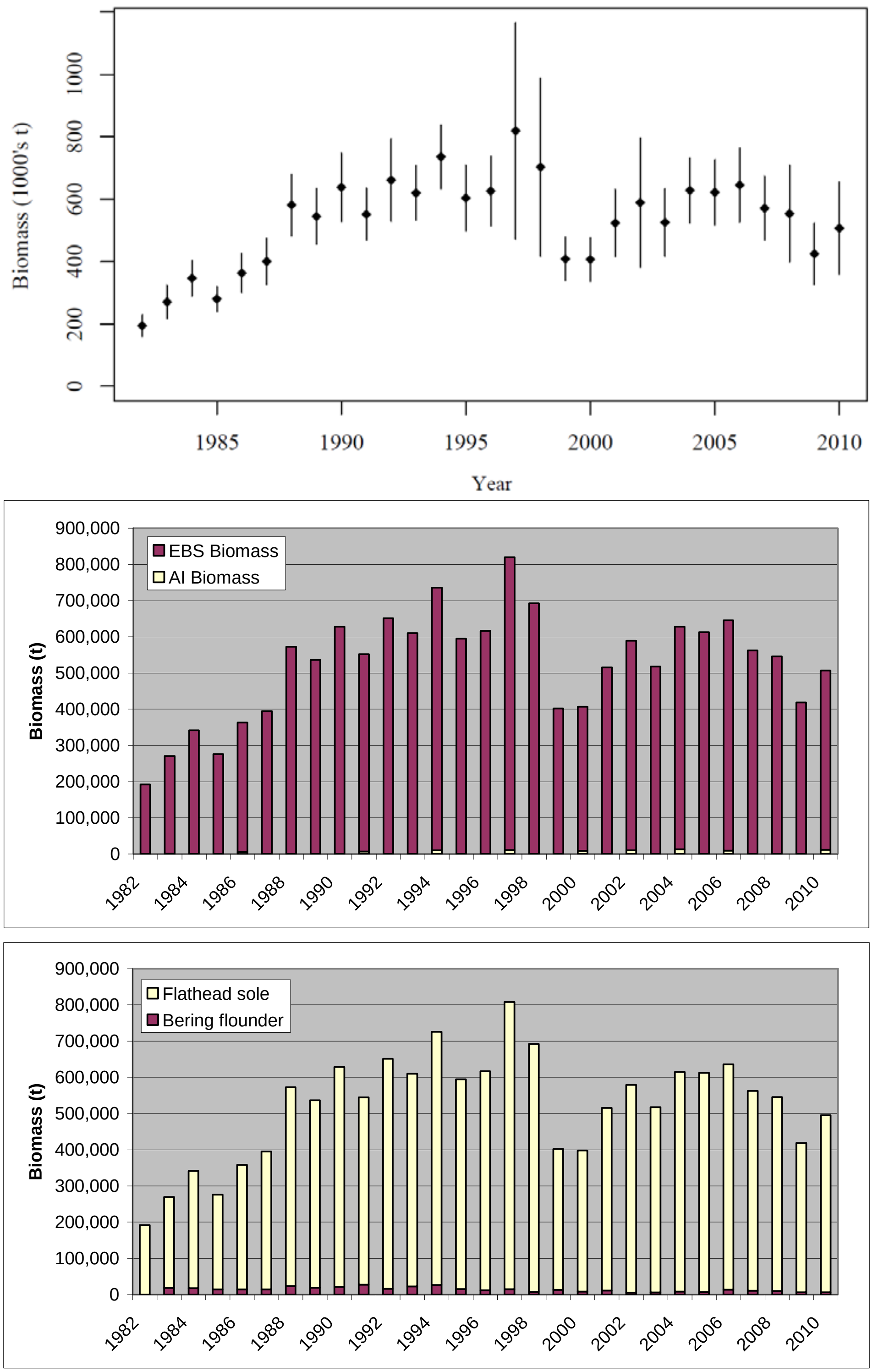


Figure 8.8. Top: estimated biomass for BSAI *Hippoglossoides* spp. (flathead sole and Bering flounder) from EBS and AI surveys. Vertical lines represent 95% confidence intervals. Middle: estimated biomass of flathead sole (only) in the EBS and AI regions. Bottom: estimated biomass for flathead sole and Bering flounder in the EBS (standard survey area).

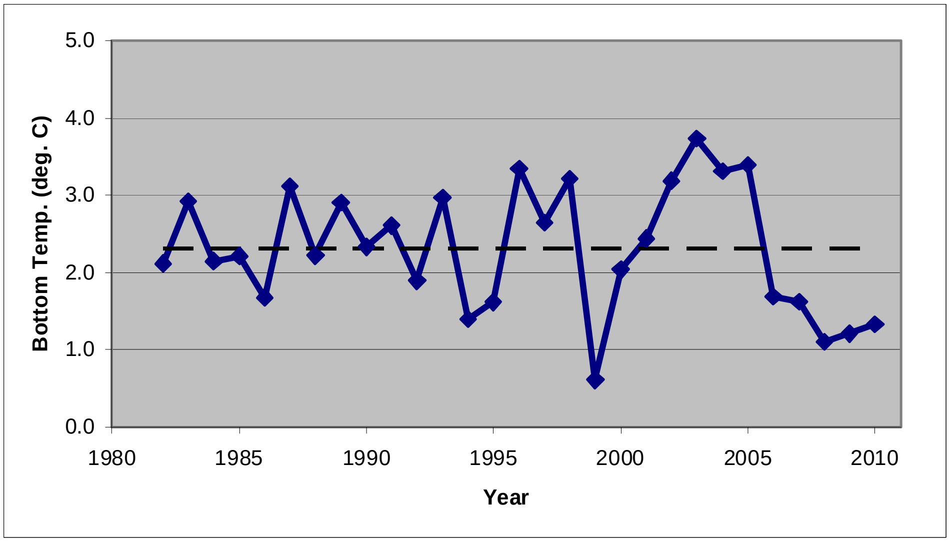


Figure 8.9. Mean bottom temperature from standard EBS shelf survey stations less than 200 m deep. Observed values = solid line, mean value = dashed line.

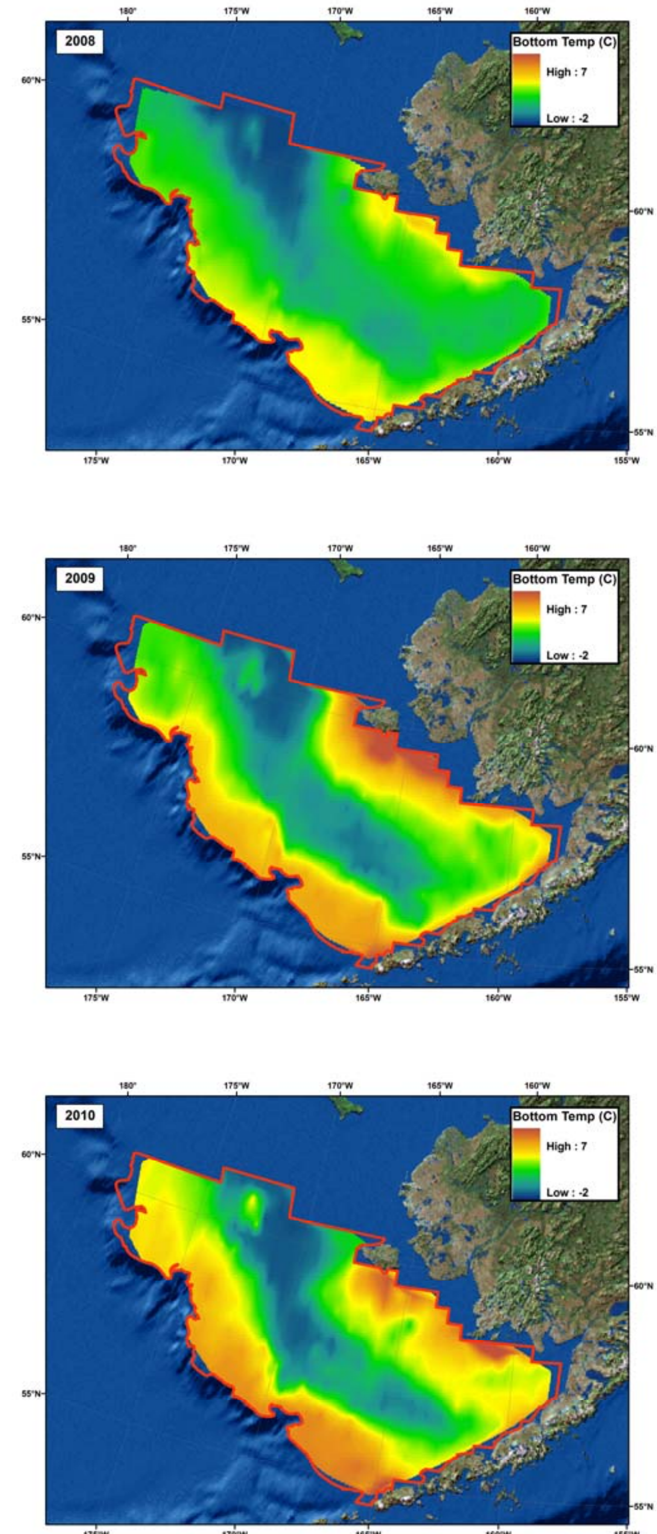


Figure 8.10. Spatial distribution of bottom temperatures from the EBS Groundfish Survey (standard stations) for 2008-2010 (from top to bottom).

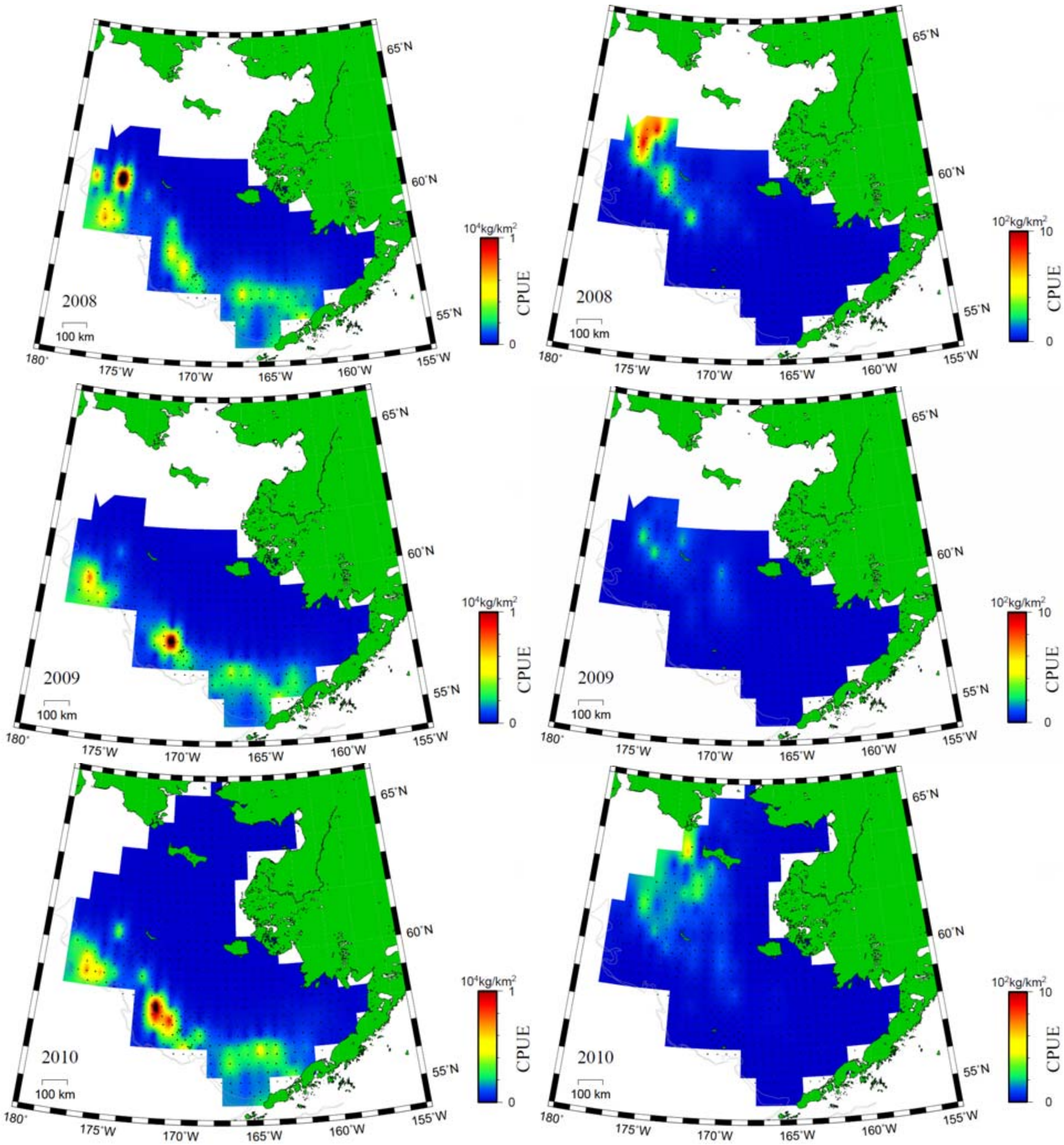


Figure 8.11. Spatial distributions of flathead sole (left column) and Bering flounder (right column) from the 2008-2010 EBS Groundfish Surveys. In 2010, the northern Bering Sea was surveyed in addition to the standard area.

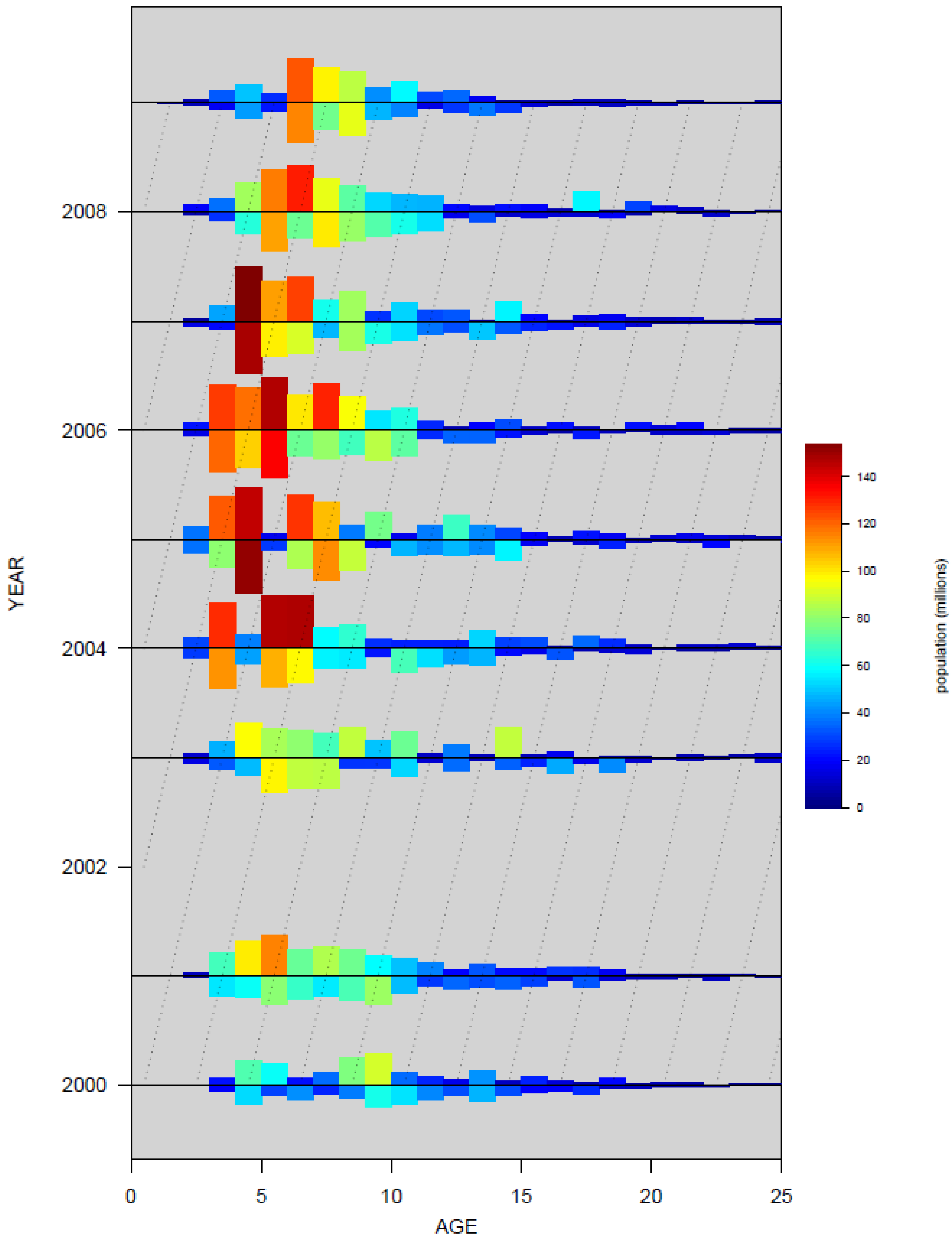


Figure 8.12. Recent flathead sole age compositions from the EBS groundfish surveys. Male age compositions are plotted above each reference line, female age compositions are plotted below the line. Dotted lines indicate cohort progression.

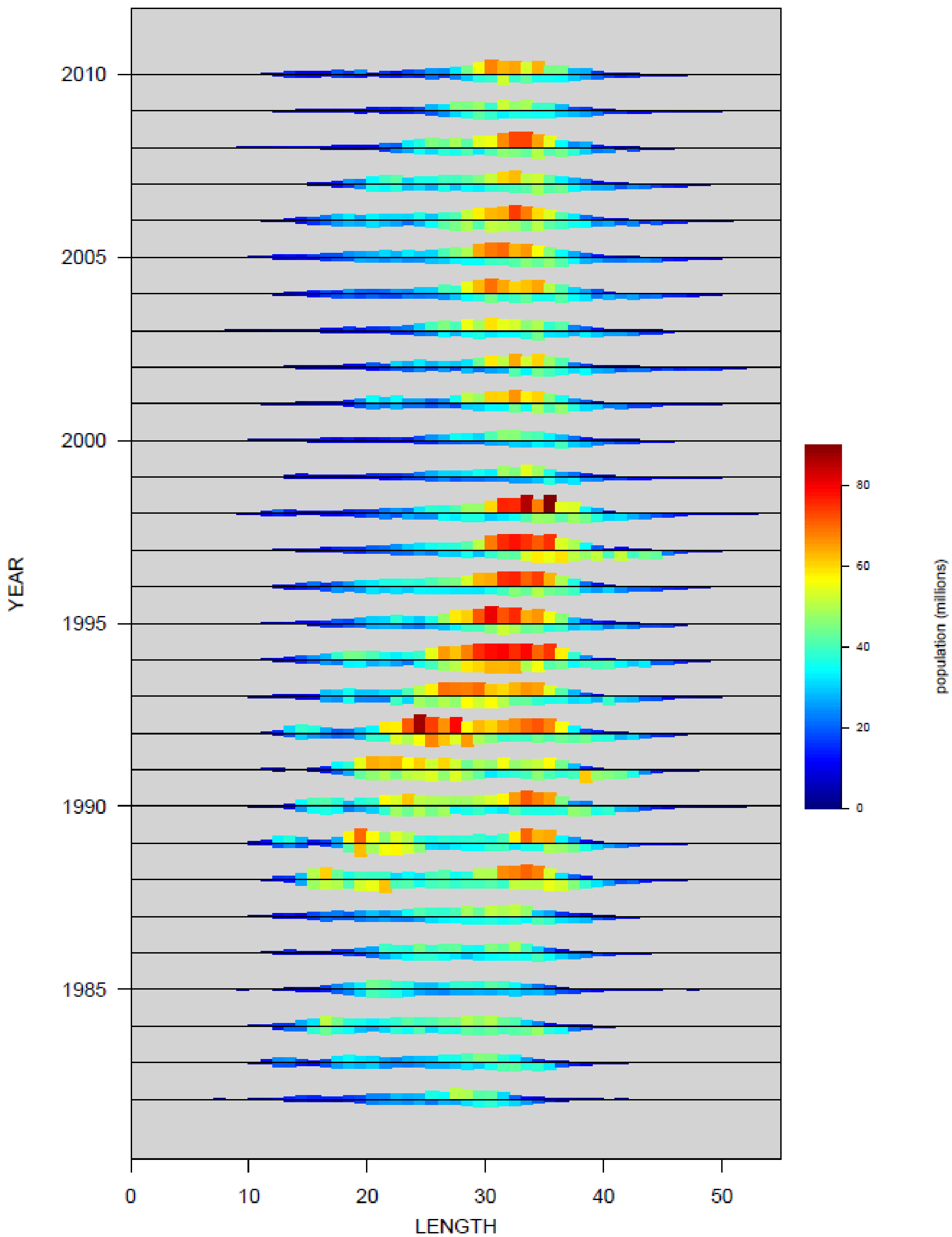


Figure 8.13. Annual size compositions for BSAI *Hippoglossoides* spp. (flathead sole and Bering flounder) from the EBS survey. Male size compositions are plotted above each reference line, female size compositions are plotted below the line. Unsexed animals are not included.

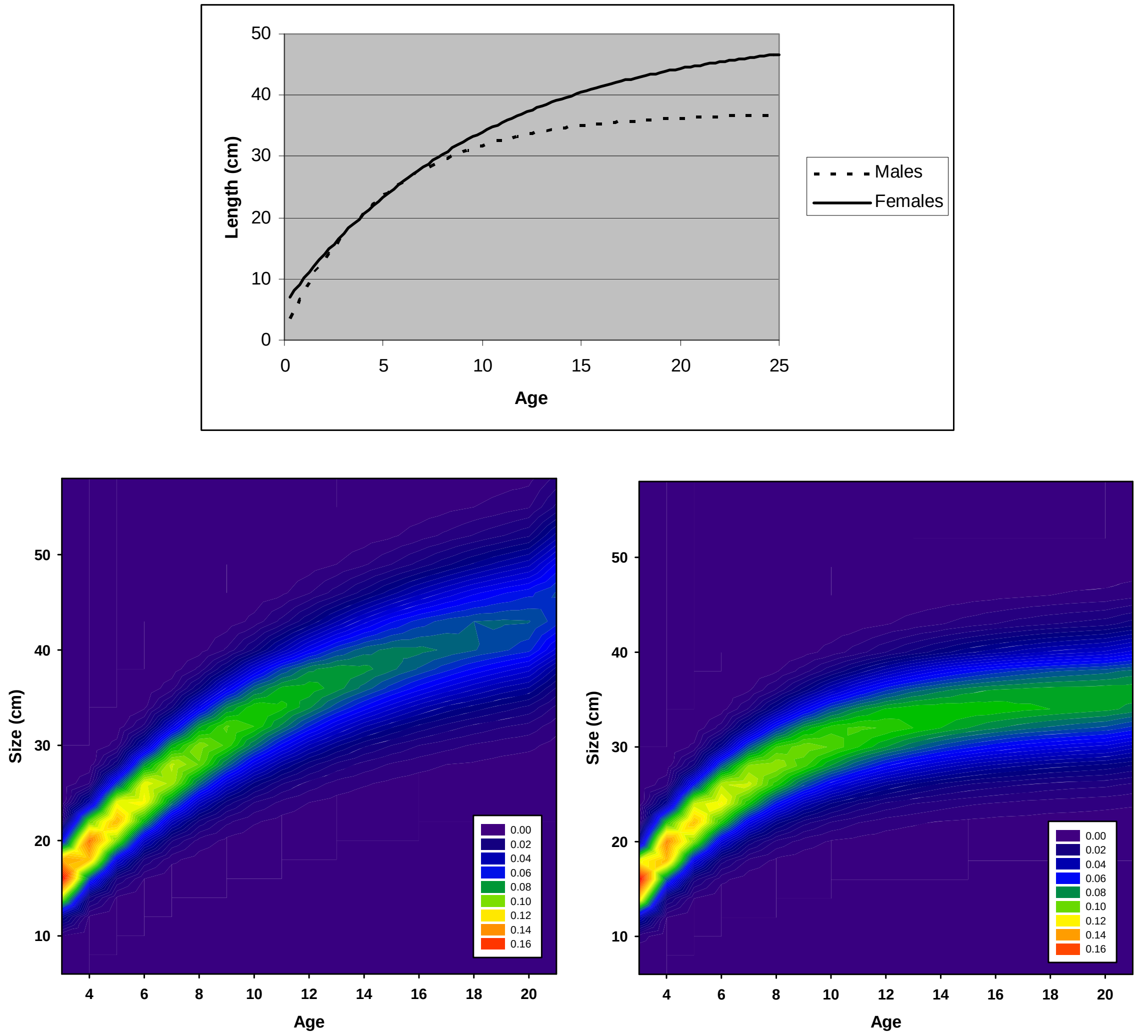


Figure 8.14. Top: sex-specific mean size-at-age used in this assessment (from NMFS summer surveys). Females = solid line, males = dotted line. Bottom left: age-size conversion matrix (plotted as density) for females. Bottom right: age-size conversion matrix (plotted as density) for males.

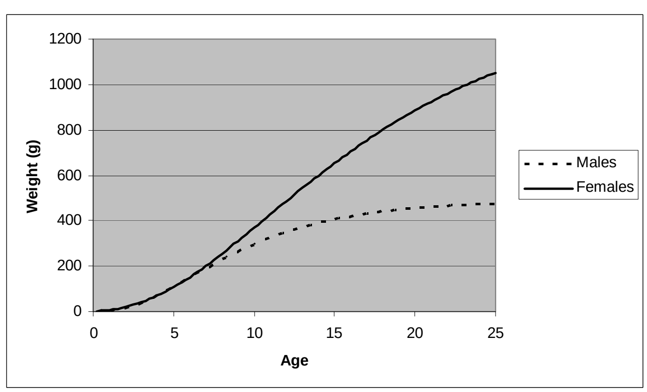


Figure 8.15. Sex-specific weight- at-age used in this assessment (from NMFS summer surveys; same as the 2007 assessment). Females = solid line, males = dotted line.

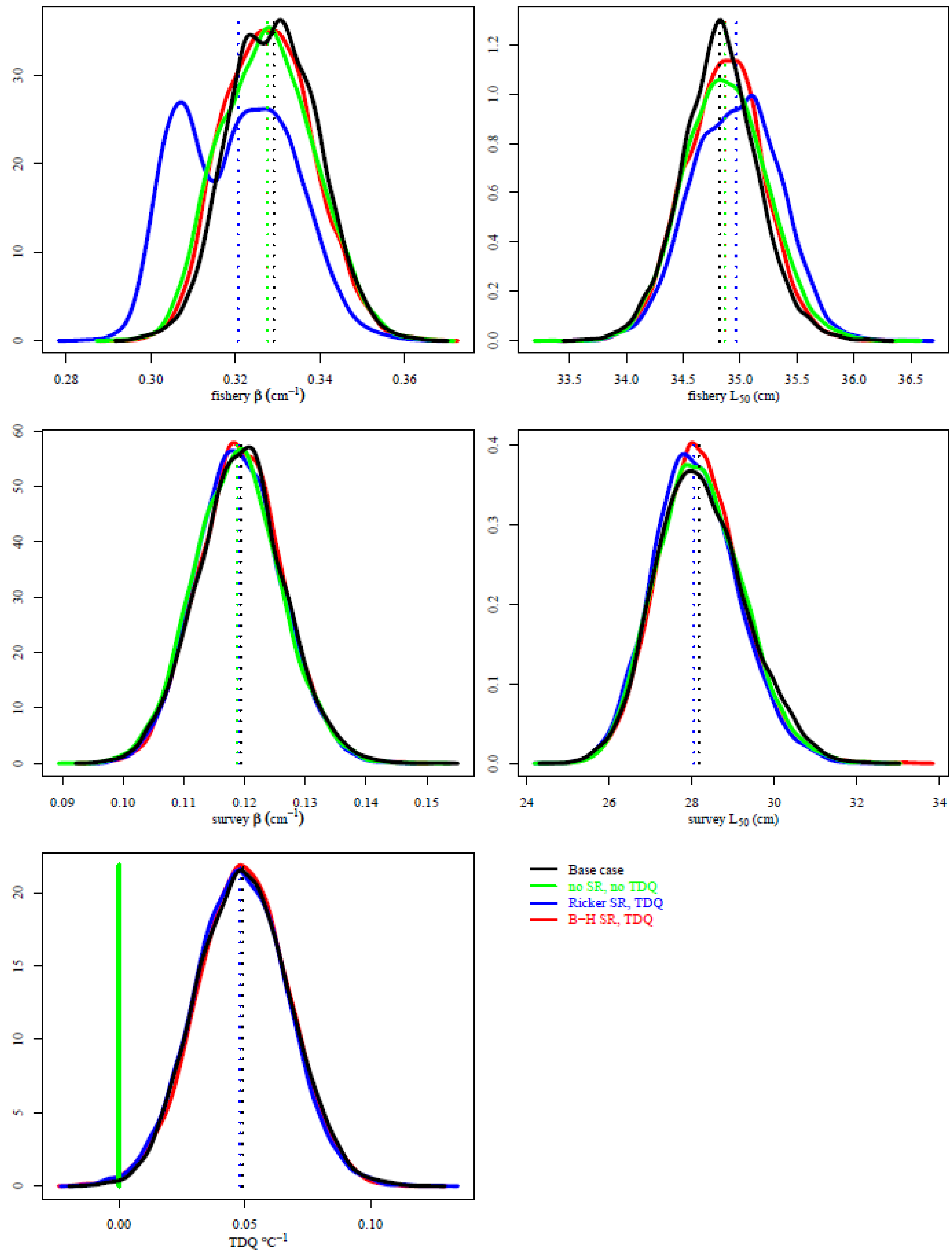
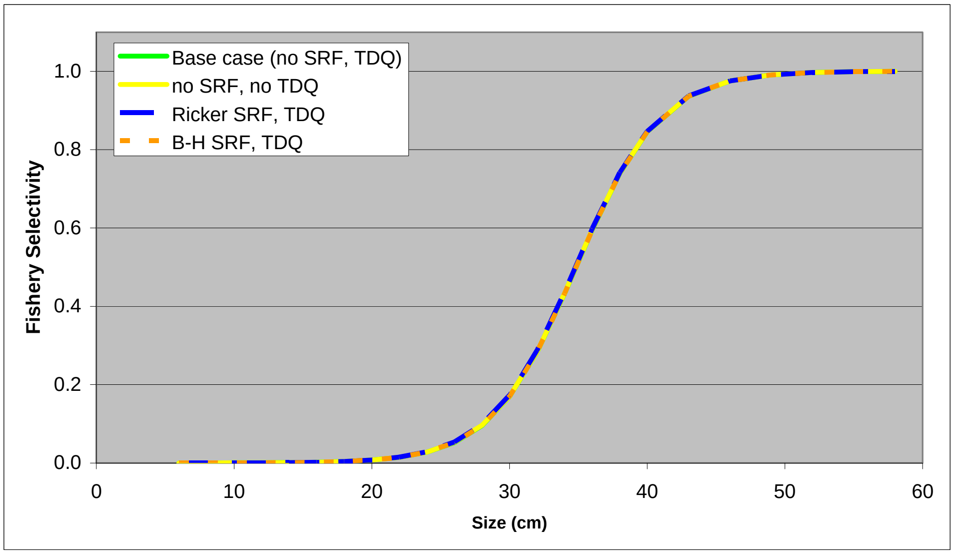


Figure 8.16. Comparisons of the posterior densities (estimated by MCMC integration) from the four alternative models for several model quantities: the fishery selectivity parameters, the survey selectivity parameters, and the survey temperature-dependent catchability (TDQ) parameter. Vertical dotted lines indicate the median for each posterior density.



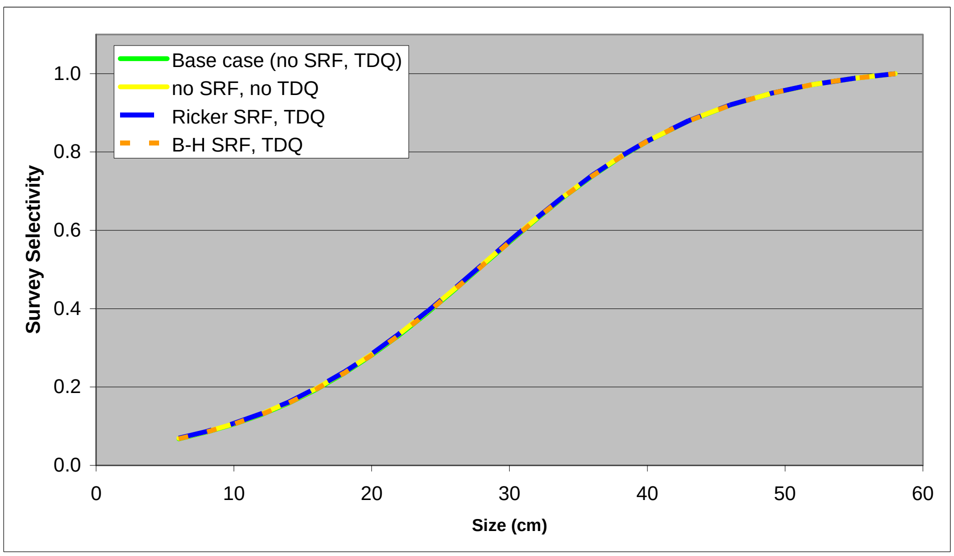


Figure 8.17. Comparison of the estimated fishery (upper) and survey (lower) size selectivity from the four alternative models.

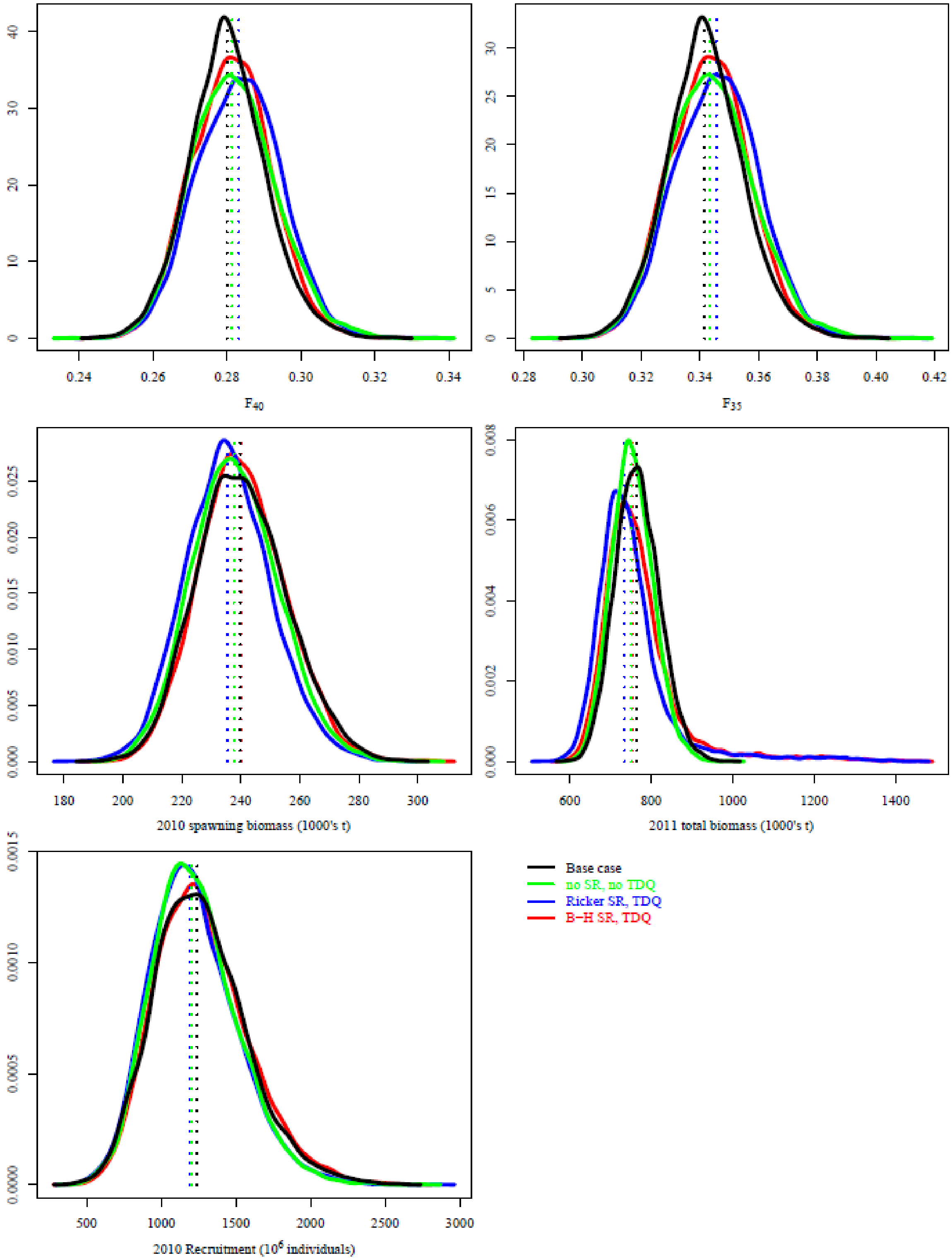


Figure 8.18. Comparisons of the posterior densities (estimated by MCMC integration) from the four alternative models for several model quantities: $F_{40\%}$, $F_{35\%}$, the estimated 2010 spawning biomass, the estimated 2011 total biomass, and the estimated 2010 recruitment. Vertical dotted lines indicate the median for each posterior density.

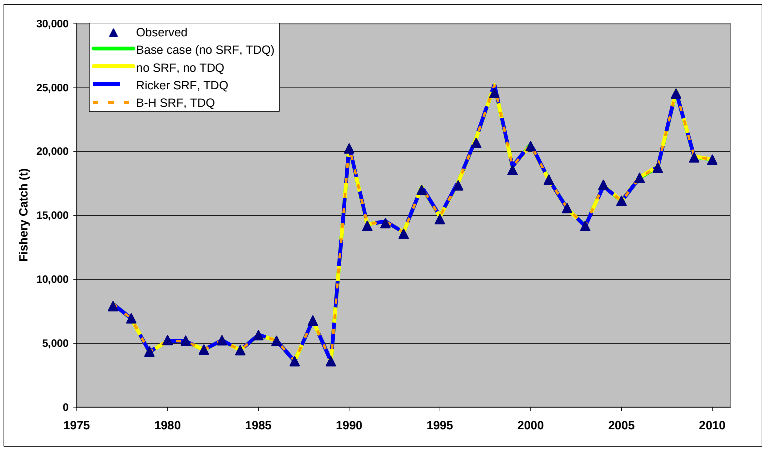


Figure 8.19. Comparison of the fits to fishery catches (triangles) for the four alternative models (lines).

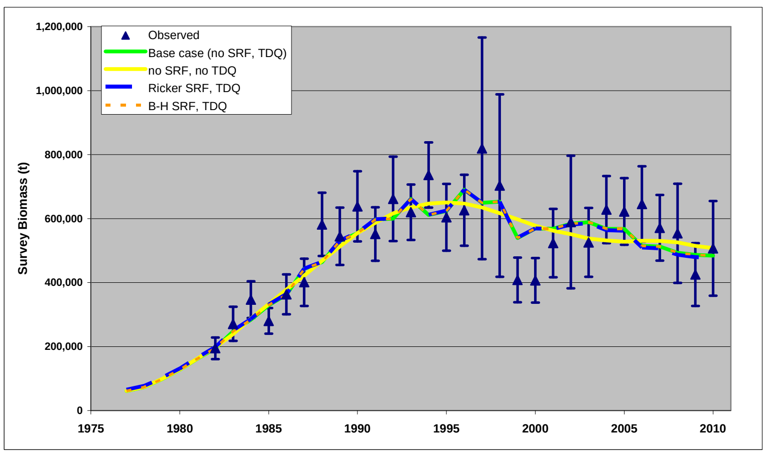


Figure 8.20. Comparison of the fits to survey biomass (triangles) for the four alternative models (lines). 95% confidence intervals are shown for observed survey biomass.

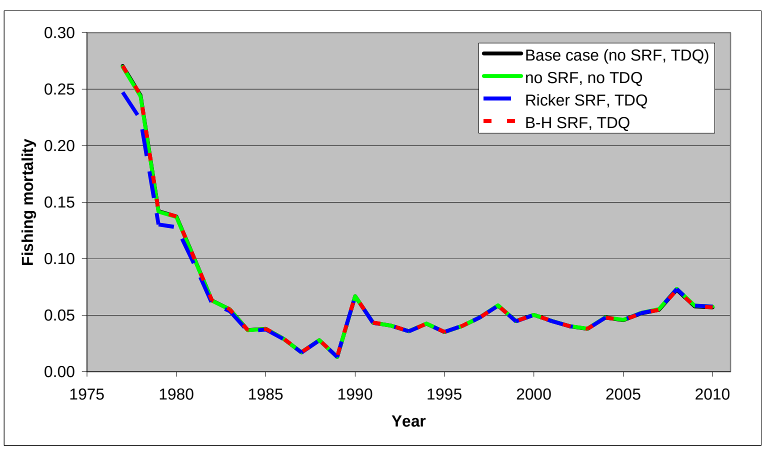


Figure 8.21. Comparison of the estimated fully-selected fishing mortality from the four alternative models.

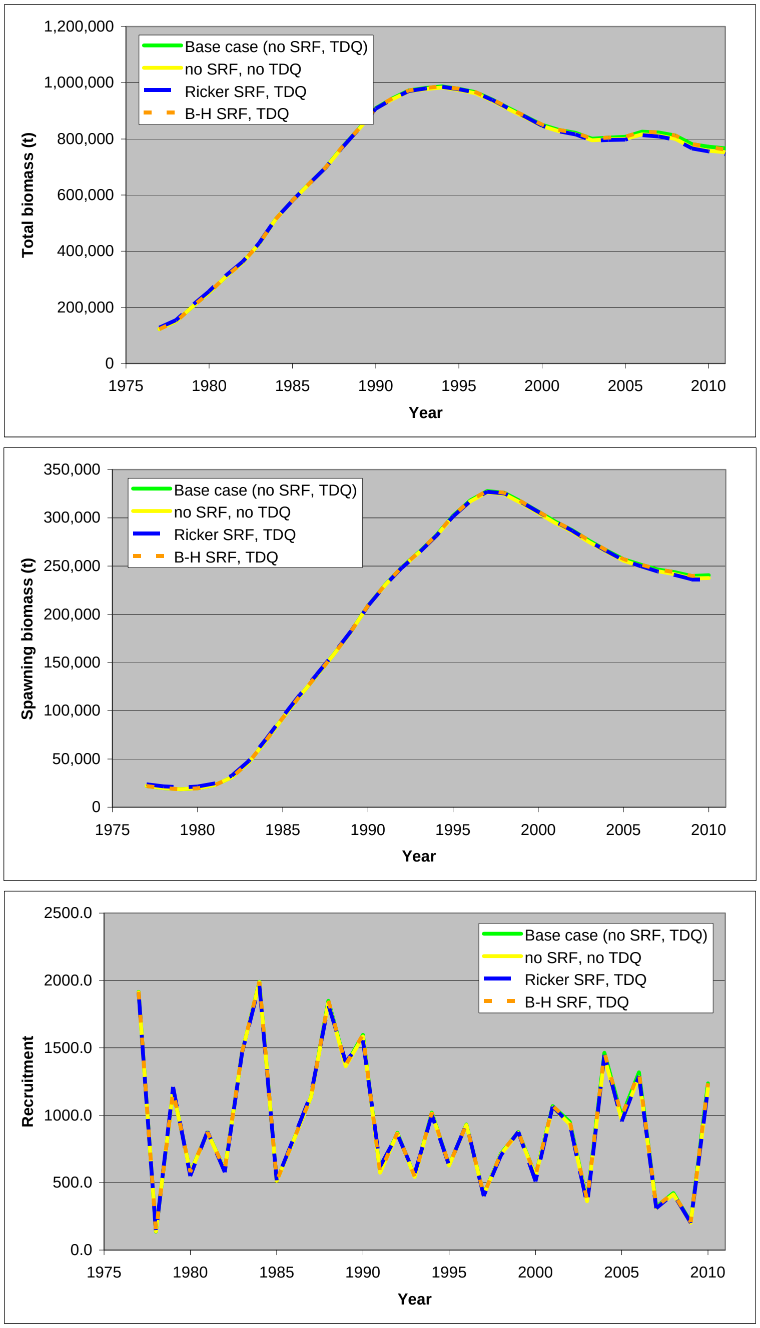


Figure 8.22. Comparison of the estimated total (age 3+) biomass (upper), spawning biomass (middle), and recruitment (lower) time series from the four alternative models.

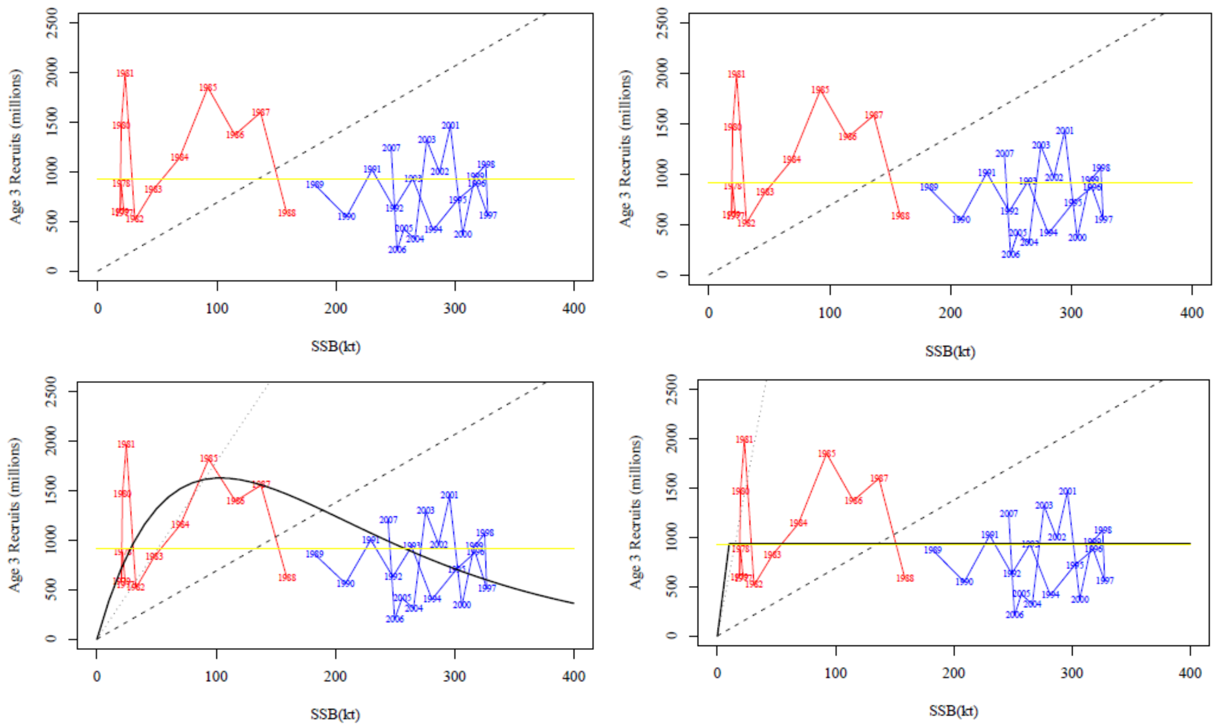


Figure 8.23. Comparison of the stock-recruit curves estimated from the spawning stock and recruitment time series for the four alternative models: base case (upper left); no SR, no TDQ (upper right); Ricker SR, no TDQ (lower left), and Beverton-Holt SR, no TDQ (lower left). Solid black line: stock-recruit model; red line: estimated stock/recruitment time series 1977-1988; blue line: estimated stock/recruitment time series 1989-2007; yellow line: mean recruitment; dashed black line: replacement at $F_{40\%}$; dotted black line: replacement at F_{msy} (undefined in the base case and noSR, no TDQ cases).

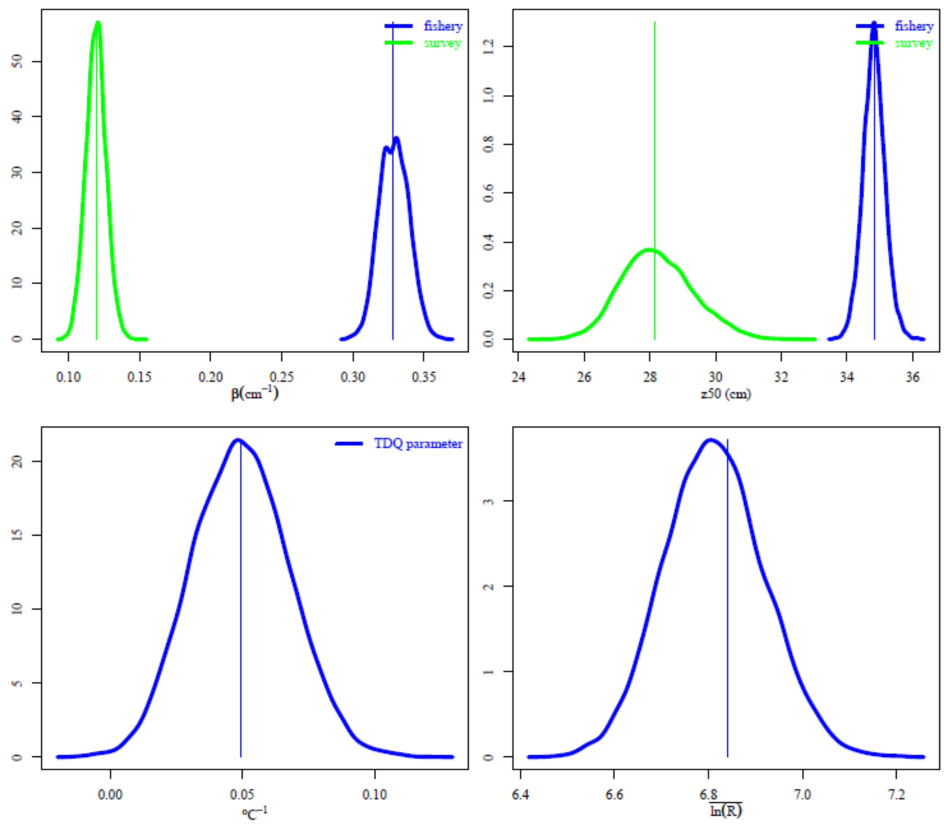


Figure 8.24. Posterior distributions based on MCMC for selected parameters from the preferred model. Upper left: slope parameters for the fishery (blue) and survey (green) size selectivity functions. Upper right: size-at-50% selectivity for the fishery (blue) and survey (green) selectivity functions. Lower right: the temperature-dependent catchability parameter. Lower right: the mean log-scale recruitment parameter.

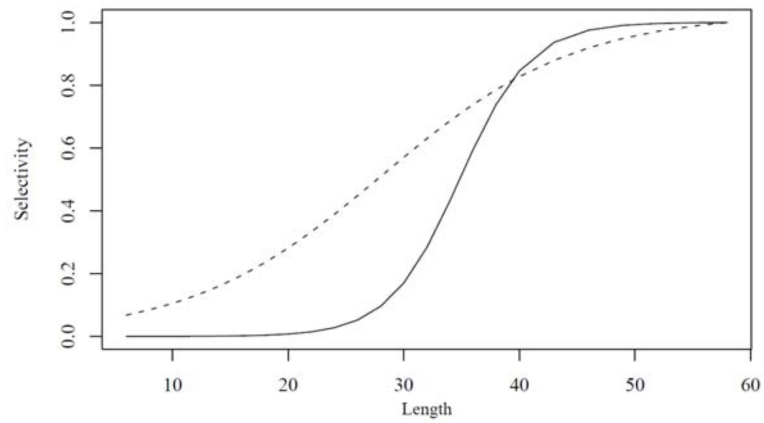


Figure 8.25. The estimated fishery (solid line) and survey (dashed line) size selectivity curves for the preferred model.

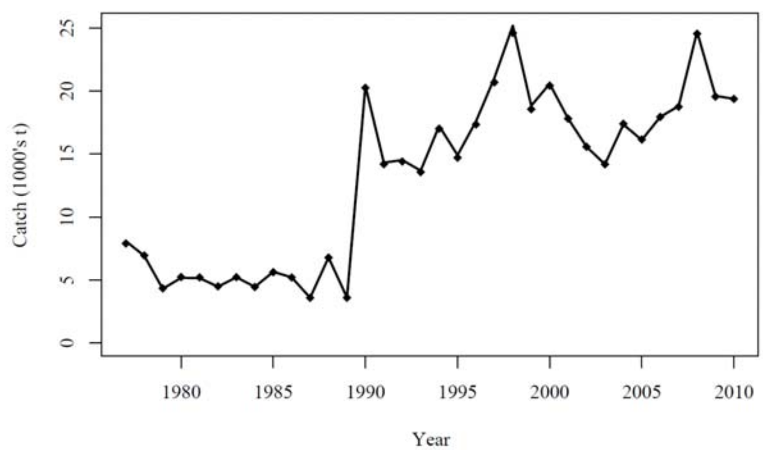


Figure 8.26. Preferred model fit to fishery catches. Predicted catch = solid line, reported catch = diamond symbols.

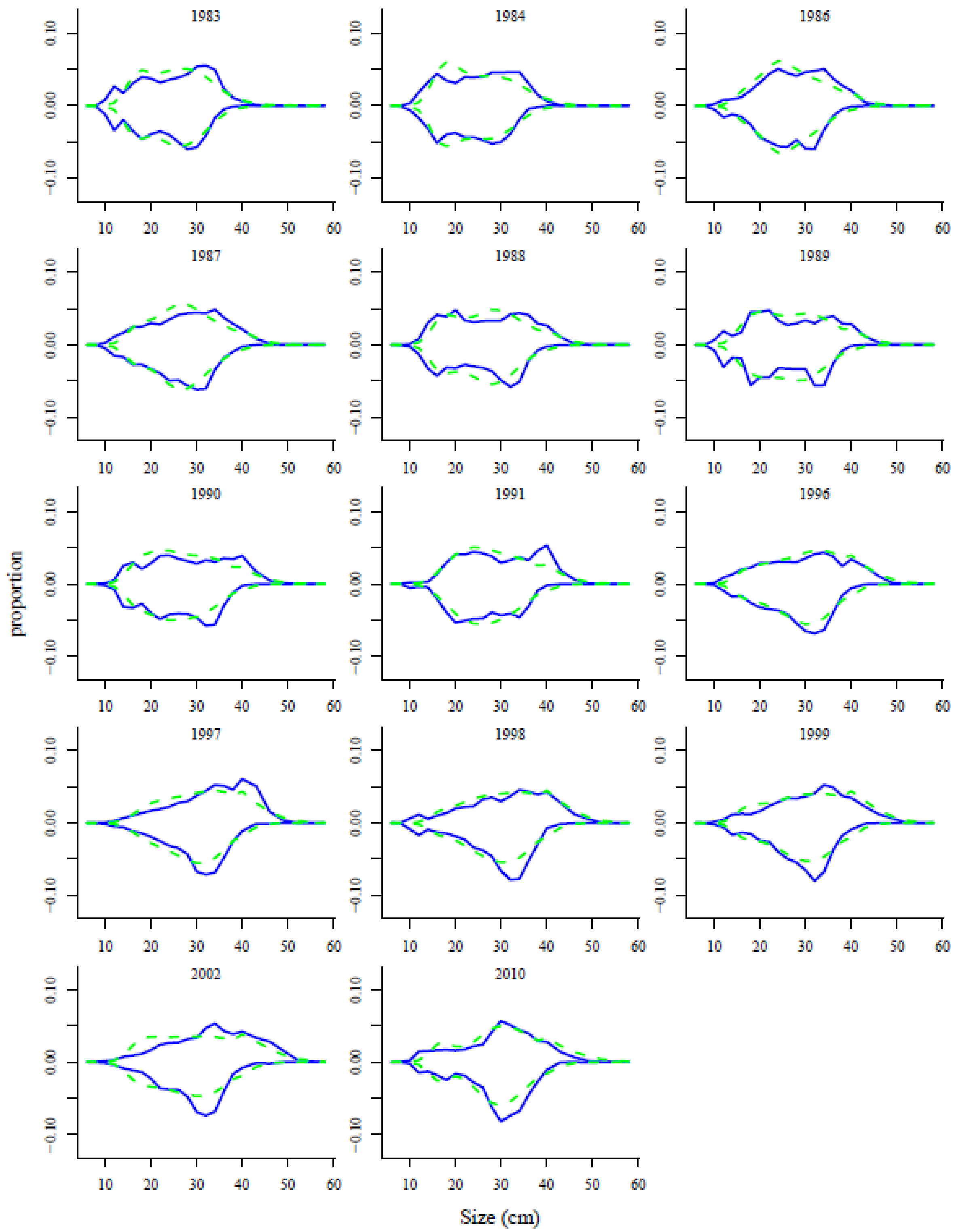


Figure 8.27. Preferred model fits to survey size compositions by year. Solid blue line = observed length composition, dashed green line = model fit. Female proportions are plotted as positive numbers, males as negative numbers.

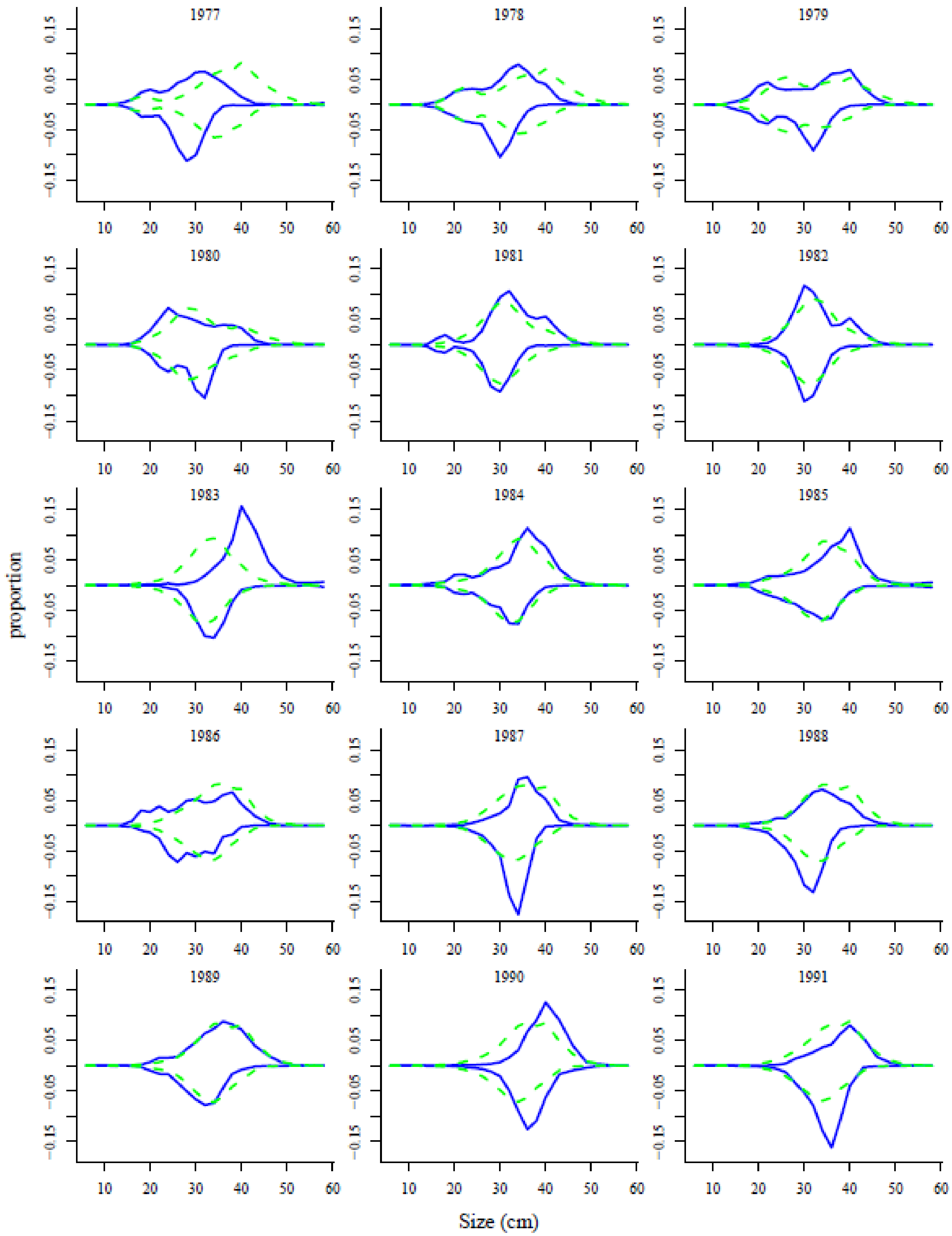


Figure 8.28. Preferred model fits to fishery size compositions by year. Solid blue line = observed length composition, dashed green line = model fit. Female proportions are plotted as positive numbers, males as negative numbers.

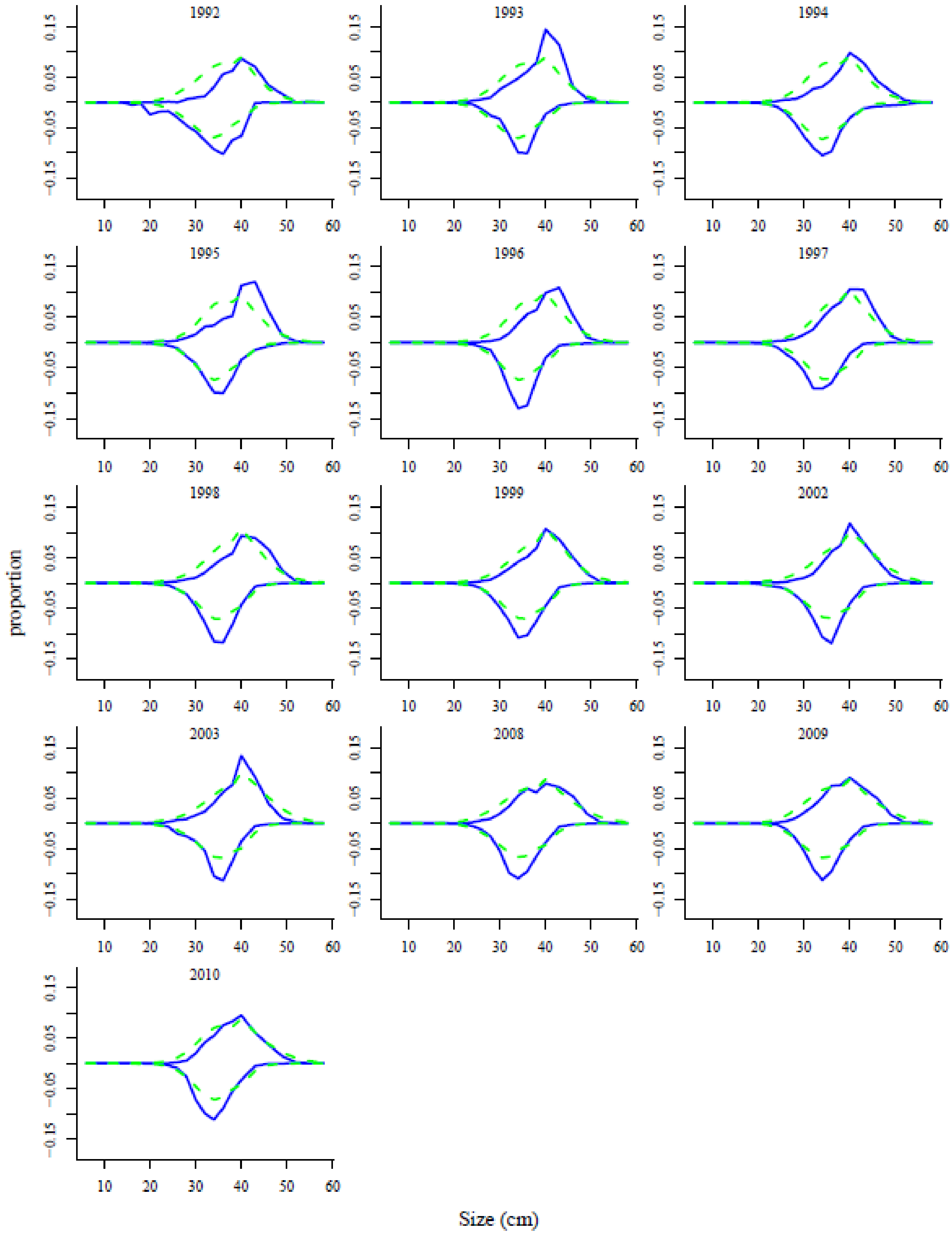


Figure 8.28 (cont.).

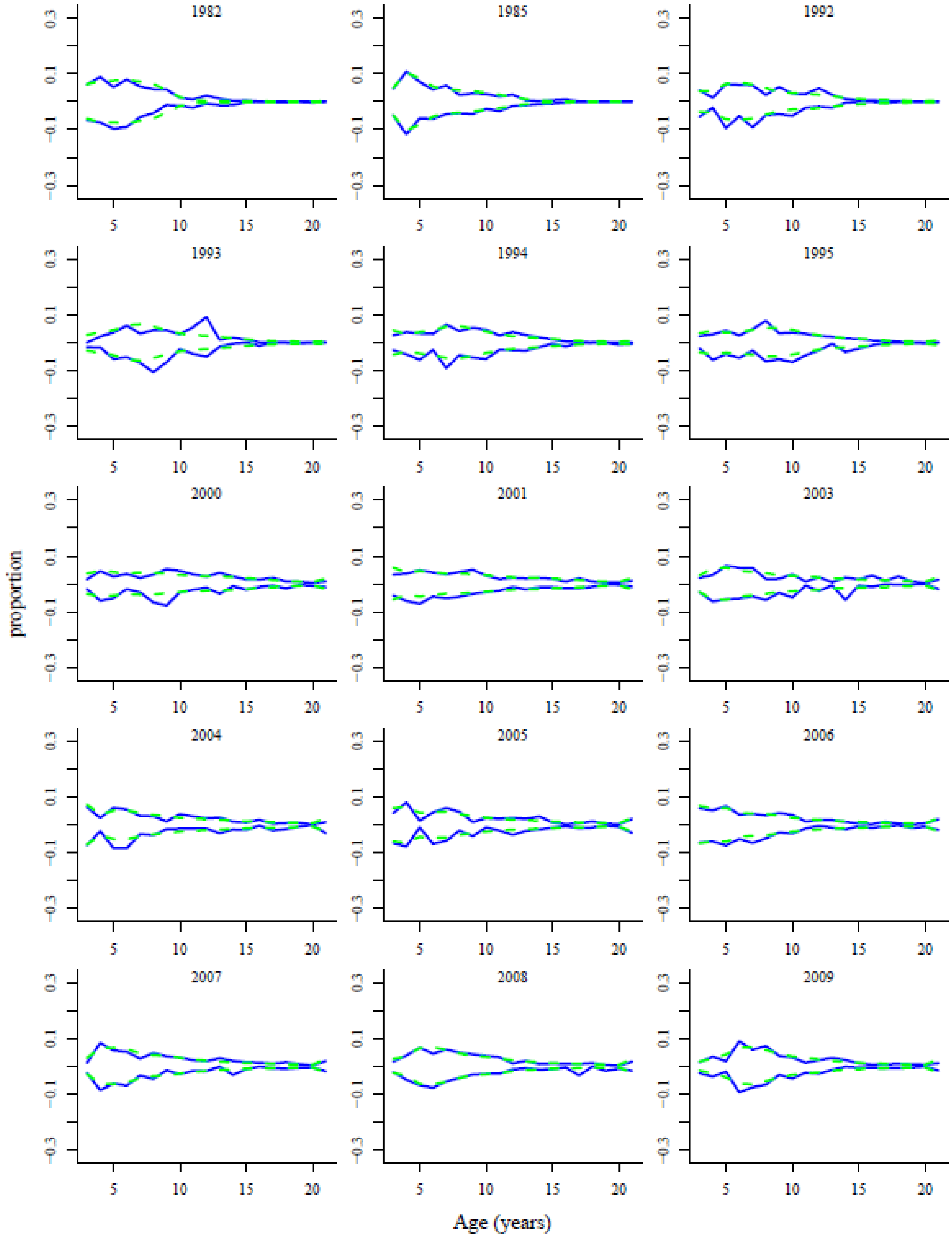


Figure 8.29. Preferred model fits to survey age compositions by year. Solid blue line = observed length composition, dashed green line = model fit. Female proportions are plotted as positive numbers, males as negative numbers.

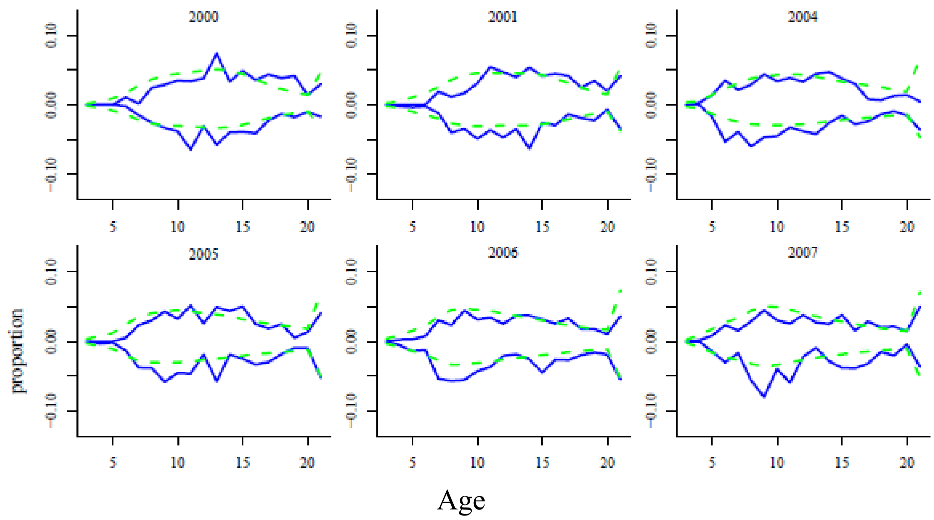
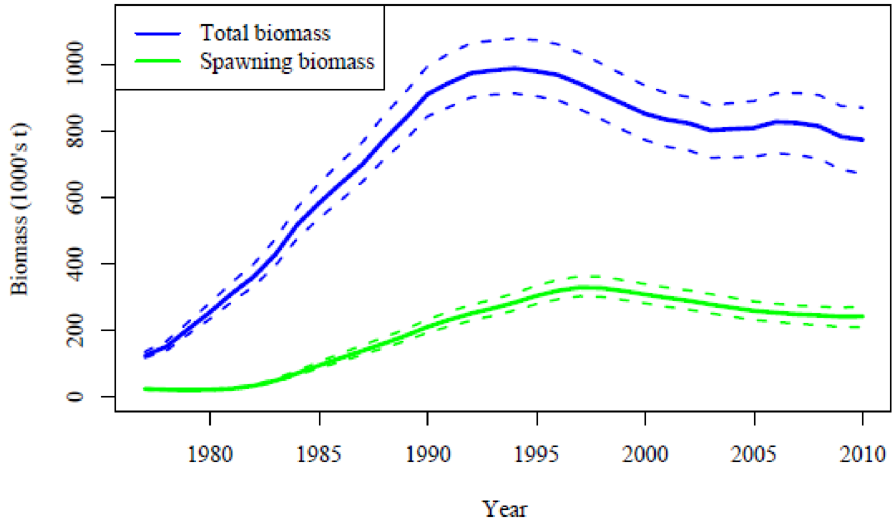


Figure 8.30. Preferred model fits to fishery age compositions by year. Solid blue line = observed length composition, dashed green line = model fit. Female proportions are plotted as positive numbers, males as negative numbers.



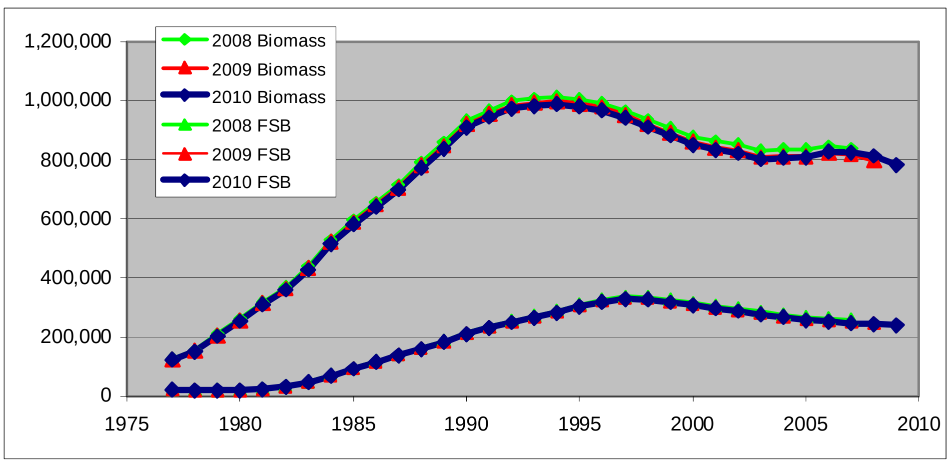


Figure 8.31. Upper graph: Estimates of total and female spawning biomass for BSAI flathead sole, with 95% confidence intervals from MCMC integration, for the preferred model. Lower graph: Comparison of estimated total biomass ("Biomass") and female spawning biomass ("FSB") from the preferred model ("2010") and the previous two assessment models ("2009", "2008").

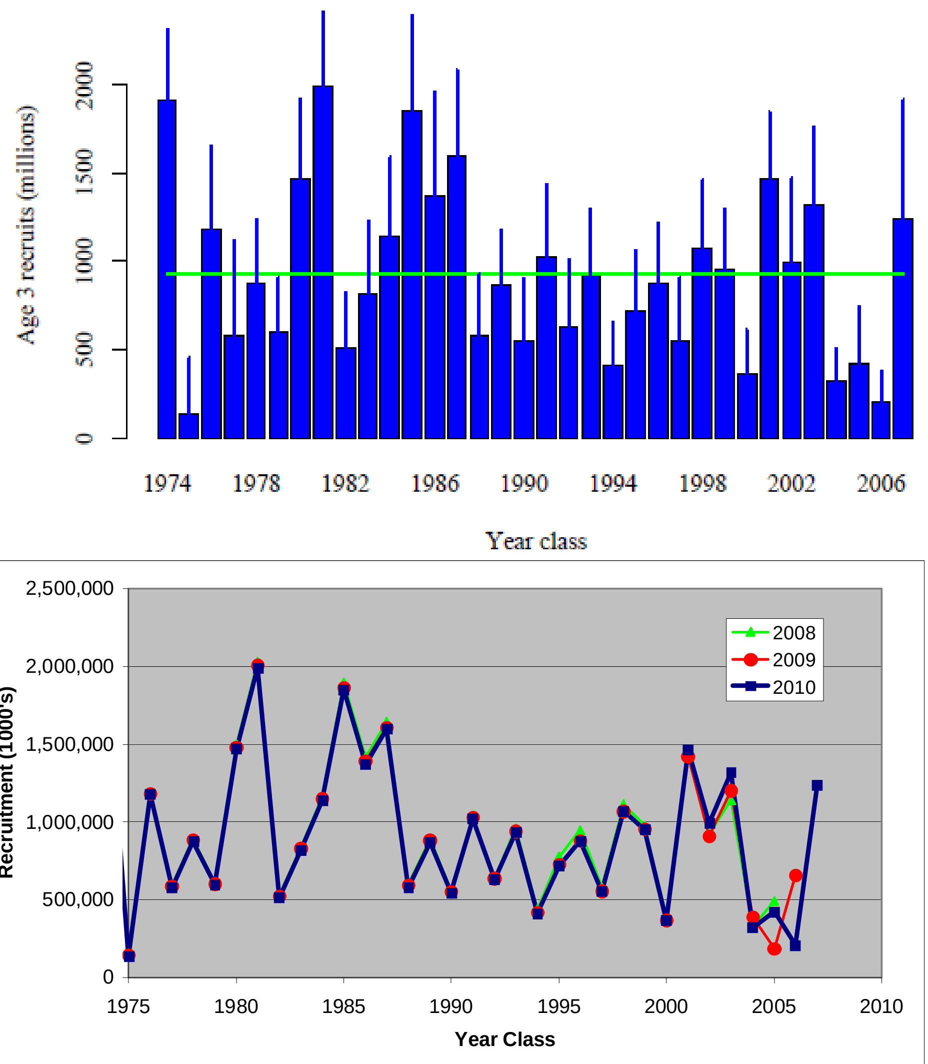


Figure 8.32. Upper graph: Estimated recruitment (age 3) of BSAI flathead sole, with 95% confidence intervals obtained from MCMC integration, for the preferred model. The time series mean recruitment is indicated in green. Lower graph: Comparison of estimated age 3 recruitment from the preferred model ("2010") and the previous two assessment models ("2009", "2008").

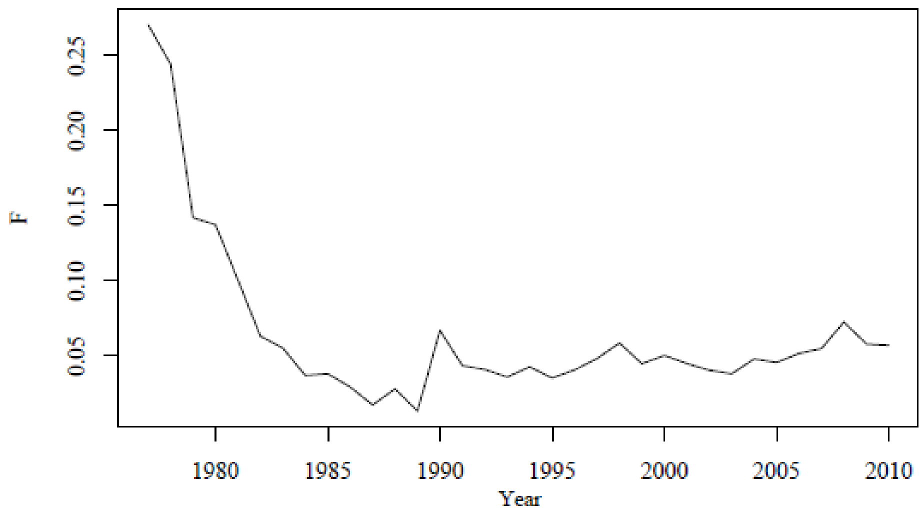


Figure 8.33. Estimated fully-selected fishing mortality rate for BSAI flathead sole from the preferred model.

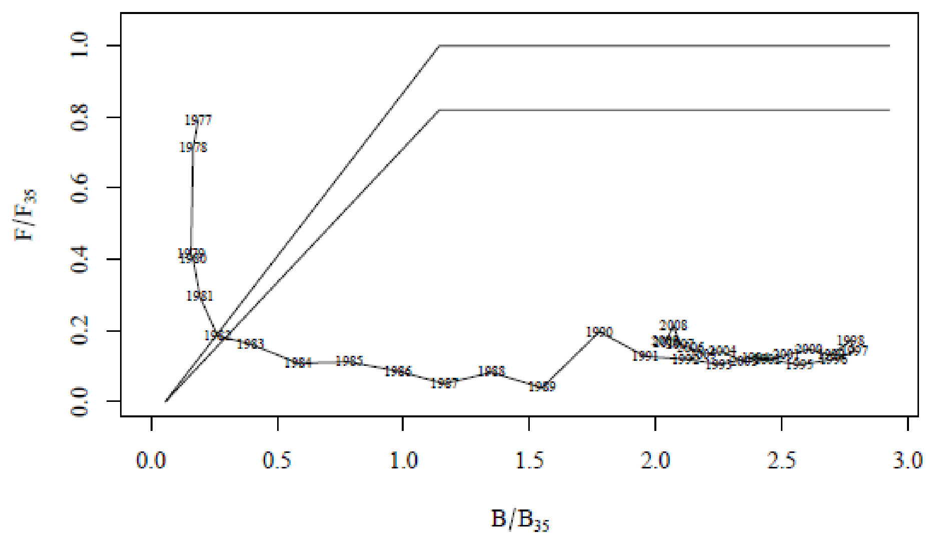


Figure 8.34. The ratio of estimated fully-selected fishing mortality (F) to $F_{35\%}$ plotted against the ratio of model spawning stock biomass (B) to $B_{35\%}$ for each model year. Control rules for ABC (lower line) and OFL (upper line) are also shown.

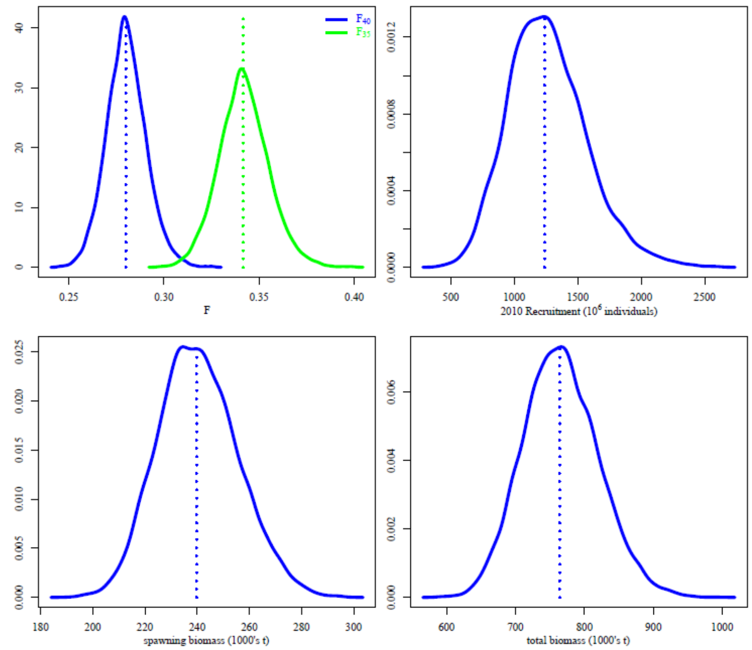


Figure 8.35. Plots of posterior densities (based on MCMC sampling) from the preferred model for several management-related quantities. Upper left: F40% (blue) and F35% (green). Upper right: estimated recruitment in 2010 (2007 year class). Lower left: estimated spawning biomass in 2010. Lower right: estimated total biomass in 2011. Vertical dotted lines indicate the median of the distribution.

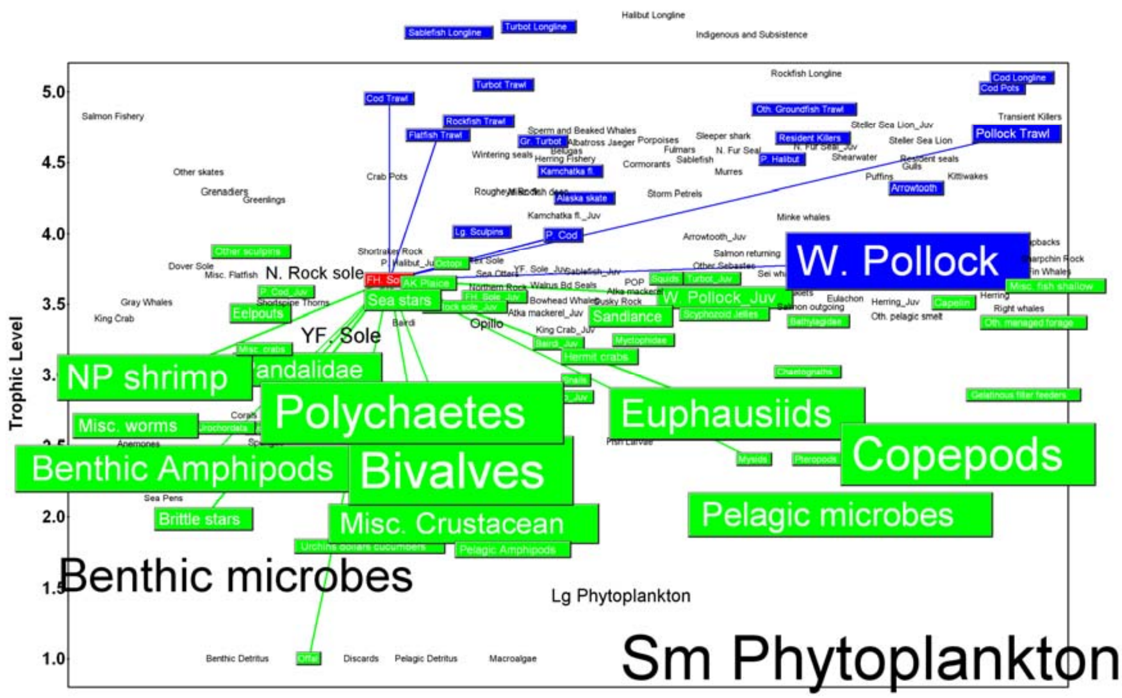


Figure 8.36. Ecosystem links to adult flathead sole in the eastern Bering Sea (based on a balanced ecosystem model for the eastern Bering Sea in the early 1990s; Aydin et al, 2007). Green boxes: prey groups; blue boxes: predator groups. Box size reflects group biomass. Lines indicate significant linkages.

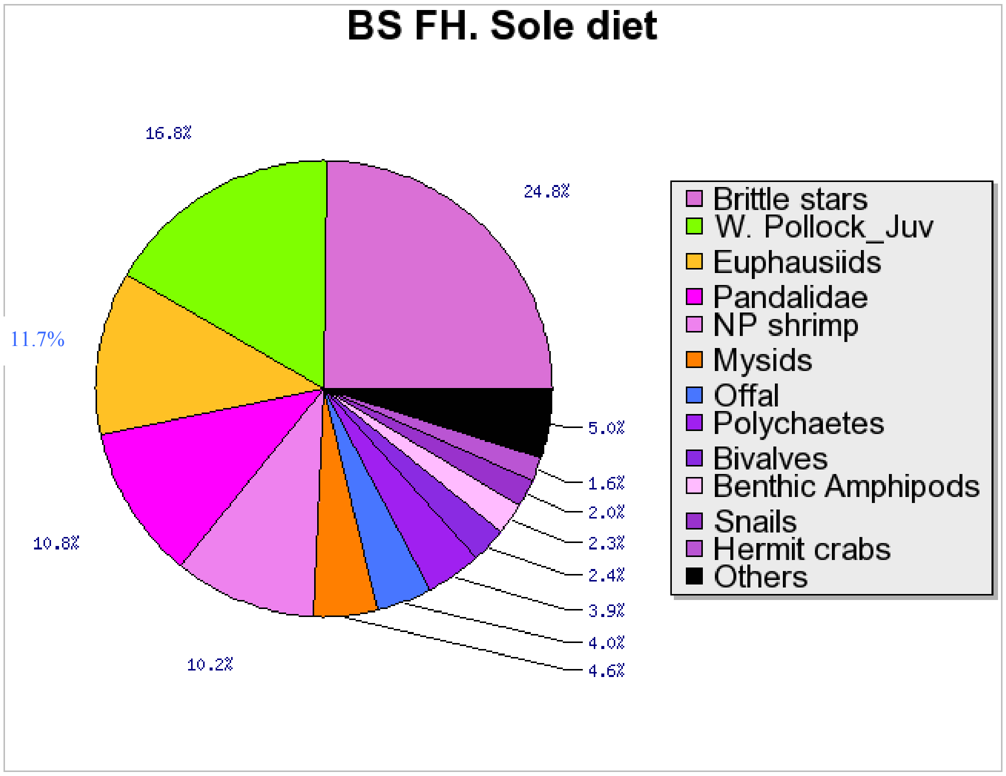


Figure 8.37. Diet composition of adult flathead sole in the eastern Bering Sea (based on a balanced ecosystem model for the eastern Bering Sea in the early 1990s; Aydin et al, 2007).

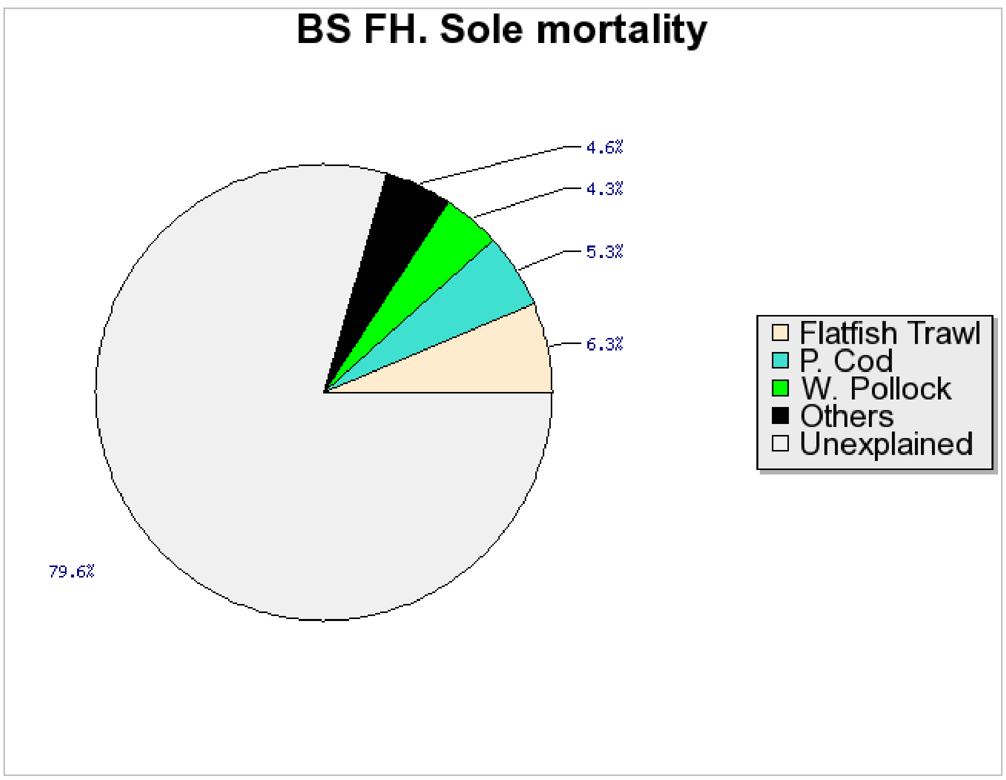


Figure 8.38. Mortality sources for flathead sole in the eastern Bering Sea (based on a balanced ecosystem model for the eastern Bering Sea in the early 1990s; Aydin et al, 2007).

Appendix A. Assessment 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:

Variable	Description
t	year .
t_{start}, t_{end}	start, end years of model period (1977, 2009).
$t^{sr}_{start}, t^{sr}_{end}$	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).

Table 8A.1. Model constants and indices.

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.

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.

Table 8A.2. Input biological data for model.

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.

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

Table 8A.3. Input fishery data for model.

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.

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.
$\widetilde{B}^S_t$, cv^S_t	observed survey biomass and associated coefficient of variation in year t.
$\widetilde{p}^{S,A}_{t,x,a}$	observed proportion of sex x, age a fish from survey during year t.
$\widetilde{p}^{S,L}_{t,x,l}$	observed proportion of sex x fish from survey during year t in length bin l.

Table 8A.4. Input survey data for model.

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.

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*.

Table 8A.5. Equations describing model population dynamics.

Options for spawner-recruit relationships

Three options for incorporating spawner-recruit relationships are included in the 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.

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.

Table 8A.6. Equations describing model spawner-recruit relationships.

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:

$$N_{t_{start},x,a_{rec}} = \tfrac{1}{2} R_{eq}(F^H)$$

$$N_{t_{start},x,a+1} = N_{t_{start},x,a} \cdot \exp(-(F^H \cdot s^F_{x,a} + M_x))$$

$$Y^H = \sum_x \sum_a \frac{F^H \cdot s^F_{x,a}}{F^H \cdot s^F_{x,a} + M_x} \cdot N_{t_{start},x,a} \cdot (1 - \exp(-(F^H \cdot s^F_{x,a} + M_x)))$$

$$\mathscr{P}^H = \lambda^H \cdot \left(\tilde{Y}^H - Y^H\right)^2$$

$$N_{t_{start},x,a_{rec}} = \begin{cases} \tfrac{1}{2}\exp(\overline{\ln R} + \tau_{t_{start}}) & \text{standard deviations option} \\ \tfrac{1}{2} f(B_{t-a_{rec}}) \cdot \exp(\tau_{t_{start}}) & \text{new deviations option} \end{cases}$$

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

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

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

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

$$B_t = B_0 \quad \text{for } t \le t_{start} - a_{\max}$$

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

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}-$a_{max} \le t \le t_{start}$-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}-$a_{max} < t \le t_{end}$, while in "option 2", the τ_t sum to 0 over $t_{start} \le t \le t_{end}$ and the ξ_t sum to 0 over t_{start}-$a_{max} < t \le t_{start}$-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:

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.

Table 8A.7. Model equations predicting fishery data.

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:

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 $\exp(\alpha_q)$.
$N^S{}_{t,x,l} = q_t\ s_l^S \cdot \overline{N}_{t,x,l}$	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.

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

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:

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.

Table 8A.9. Non-recruitment related likelihood components (applicable to all model options).

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), $\gamma = 0$ 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, $\gamma = 0$ 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, $\gamma = 1$ and the first sum over t runs from t^{sr}_{start} to t^{sr}_{end} so that recruitment deviation during the historical period and deviations during the model period are not linked.

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

Model parameters

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

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

Table 8A.10. Parameters currently not estimated in the model.

Parameter	Subscript range	Total no. of parameters	Description
β_q	--	1	temperature-dependent catchability "slope" parameter.
$\ln F^H$	--	1	log-scale fishing mortality prior to model period (i.e., historic).
$\overline{\ln F}$	--	1	log-scale mean fishing mortality during model period.
ε_t	$1977 \le t \le 2010$	34	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 8A.11. Non recruitment-related parameters estimated in the 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	$1977 \le t \le 2010^{1,3}$ $1967 \le t \le 2010^{2}$	$34^{1,3}$ 54^{2}	log-scale recruitment deviation in year t.
ξ_t	-- $1967 \le t \le 1976$	$0^{1,3}$ 20^{2}	log-scale recruitment deviation in year t.

Table 8A.12. Recruitment-related parameters. Superscripts refer to initial n-at-age options: 1-standard option, 2-option 2, 3-option 3. Only the standard option was used in 2010.

Appendix B: A comparison of natural mortality estimates for Alaskan flatfish stocks using a variety of methods

A variety of simple relationships have been developed between (more easily measured) life history traits associated with a species or population and its rate of natural mortality, *M*. Consequently, measurement of these associated life history traits allows one to obtain estimates of *M* for a given species or population. Most of the resulting methods for estimating *M* are semi-empirical: based on a combination of life history optimization theory and statistical fitting of free parameters over many species and populations where *M* was known from other means (Pauly, 1979, Hoenig, 1983; Lorenzen, 1996; Gunderson, 1997; Hewitt and Hoenig, 2005). A few methods, however, have no free parameters and are completely based on theoretical "invariants" (Beverton, 1963; Roff, 1984; Charnov and Berrigan, 1990; Jensen, 1996).

Here, I used measured life history characteristics from 9 flatfish species found in the eastern Bering Sea and/or Gulf of Alaska (13 stocks total; Table 8B.1) to calculate sex-specific values of *M* based on 11 different estimation methods: Hoenig's methods based on maximum age (3 varieties; Table 8B.2), Gunderson's method based on the gonadal somatic index (2 varieties; Table 8B.3), emprical relationships based on von Bertalanffy growth parameters and mean environmental temperature (Table 8B.4), Lorenzen's relationship between *M* and weight-at-maturity (Table 8B.5), and the so-called life history invariants (LHI: 3 methods) based on growth rate and age at maturity (Table 8B.6).

Natural mortality estimates for these Alaskan flatfish stocks vary in range from 0.043 yr^{-1} (GOA rex sole, Gunderson's method) to 0.71 yr^{-1} (Bering Sea Alaska plaice, Lorenzen's method), while the range of estimates within a stock is scarcely smaller if results from Lorenzen's method are included (Table 8B.7, Fig. 8B.1). Overall, Lorenzen's method yielded the highest estimates of *M* for all stocks. These estimates were based on female size at 50% maturity and would be expected to decrease if mean size at maturity were used instead (Lorenzen suggests both, but favors the latter). Estimates based on the 2nd Life History Invariant ($M / K = C$) tended to yield the next highest values for M. Estimates based on Hoenig's methods tended to be the lowest. Even if one ignores the estimates based on Lorenzen's method, there is little suggestion of sex-specific differences in natural mortality for any stock except arrowtooth flounder in the Gulf of Alaska.

Note that, while reported, the unweighted means and standard deviations given in Table 8B.7 are likely to be biased because several of the methods used (e.g., the different varieties of Hoenig’s method) are not truly independent. Thus, they cannot be used for conventional statistical inference. It is also unclear how to weight the individual estimates in a meta-analysis because few of the methods give an associated measure of uncertainty.

The results obtained for flathead sole in the BSAI provide no strong evidence against using M = 0.2, the value assumed in this stock assessment, nor for sex-specific differences in natural mortality.

The disparate estimates of natural mortality obtained here, both across species and within species, illustrate that the between-model variation in estimates of *M* can be quite large. This suggests caution in using any single method to estimate *M*, the need to consider the within-model variability associated with each estimate of *M*, and the need to develop meta-analytic methods to combine different estimates of *M* across methods.

References

Beverton, R.J.H. 1963. Maturation, growth and mortality of clupeid and engraulid stocks in relation to fishing. Rapports et Proce's-Verbaux des Re'unions, Conseil International pour l'Exploration de la Mer 154:44-67.

Charnov, E.L. and D. Berrigan, 1990. Dimensionless numbers and life history evolution: age of maturity versus the adult life span. Evol. Ecol. 4:273-275.

Gunderson, D.R. 1997. Trade-off between reproductive effort and adult survival in oviparous and viviparous fishes. Can. J. Fish. Aquat. Sci. 54:990-998.

Hewitt, D.A. and J.M. Hoenig. 2005. Comparison of two approaches for estimating natural mortality based on longevity. Fish. Bull. 103:433-437.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. 81:893-903.

Jensen, A.L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Can. J. Fish. Aquat. Sci. 53:820-822.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. J. Fish. Biol. 49:627-647.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer 39:175-192.

Roff, D.A. 1984. The evolution of life history parameters in teleosts. Can. J. Fish. Aquat. Sci. 41:989-1000.

Tables

Table 8B.1. Data used for estimates of natural mortality by species, region, and sex among 13 Alaskan flatfish stocks. GSI: gonadal somatic index; Linf, K: von Bertalanffy growth parameters; EPT = effective physiological temperature (Pauly, 1980).

Common name	Species	Region	Sex	Max age (years)	Maturity (years)	Size at Maturity (cm)	Weight at Maturity (g)	GSI	Linf (cm)	K	Temp (deg C)	EPT (deg C)
Alaska plaice	*Pleuronectes quadrituberculatus*	EBS	M	36	--	--	--	--	45.6	0.132	1.6	6.6
			F	37	8.5	27	226	--	45.6	0.132	1.6	6.6
Arrowtooth flounder	*Atheresthes stomias*	EBS	M	17	--	--	--	--	57.9	0.170	3.2	4.0
			F	21	5.25	47	11104	0.045	85.0	0.160	3.2	4.0
		GOA	M	20	--	--	--	--	49.7	0.236	5.4	5.4
			F	25	47 cm	47	960	--	81.9	0.102	5.4	5.4
Dover sole	*Microstomus pacificus*	GOA	M	54	--	--	--	--	42.4	0.195	5.0	5.0
			F	53	6.7	44	876	0.046	51.5	0.127	5.0	5.0
Flathead sole	*Hippoglossoides elasodon*	EBS	M	30	--	--	--	--	37.0	0.190	2.6	5.0
			F	31	9.7	32	303	--	50.4	0.100	2.6	5.0
		GOA	M	33	--	--	--	--	37.4	0.204	5.2	5.2
			F	28	8.7	33	354	--	44.4	0.157	5.2	5.2
Greenland turbot	*Reinhardtius hippoglossoides*	EBS	M	33	--	--	--	--	73.8	0.155	1.7	6.3
			F	34	60 cm	60	4200	0.063	92.9	0.117	1.7	6.3
Northern rock sole	*Lepidopsetta polyxystra*	EBS	M	27	--	--	--	--	34.2	0.262	2.9	4.3
			F	27	9.5	32	290	--	34.2	0.262	2.9	4.3
		GOA	M	21	--	--	--	--	38.2	0.261	5.3	5.3
			F	22	6.5	33	409	--	42.9	0.236	5.3	5.3
Southern rock sole	*Lepidopsetta bilineata*	GOA	M	28	--	--	--	--	38.7	0.182	5.6	5.6
			F	25	8.5	35	485	--	52.0	0.120	5.6	5.6
Rex sole	*Glyptocephalus zachirus*	GOA	M	39	--	--	--	--	39.5	0.380	5.2	5.2
			F	28	5.6	35	295	0.024	44.9	0.310	5.2	5.2
Yellowfin sole	*Limanda aspera*	EBS	M	36	--	--	--	--	33.7	0.156	2.8	4.5
			F	37	10.5	30	318	--	37.8	0.141	2.8	4.5
		GOA	M	22	--	--	--	--	32.8	0.190	5.1	5.1
			F	21	9	--	--	--	38.2	0.140	5.1	5.1

Table 8B.2. Hoenig's methods: empirical relationships based on maximum age (t_{max}).

Equation	Parameters	Comments	Reference
$\ln(M) = a + b\ln(t_{\max})$	a=1.46; b=−1.01	arithmetic regression; 84 fish species	Hoenig, 1983
$\ln(M) - \overline{\ln(M)} = \frac{b}{r}[\ln(t_{\max}) - \overline{\ln(t_{\max})}]$	$b = -1.01;\ r = 0.68^{1/2}$ $\overline{\ln(M)} = -0.767$ $\overline{\ln(t_{\max})} = 2.214$	geometric regression	
$\ln(M) = a + b\ln(t_{\max})$	a=1.44; b=−0.982	refit of Hoenig, 1983 (?)	Hewitt and Hoenig, 2005

Table 8B.3. Gunderson's methods: empirical relationships based on gonadal somatic index (GSI).

Equation	Parameters	Comments	Reference
$M = a \cdot GSI + b$	a=1.790; b=0.000 a=1.868; b=0.005	ordinary regression functional regression	Gunderson, 1997

Table 8B.4. Empirical relationships based on growth characteristics: Pauly's temperature-based relationship and Jensen's temperature-independent relationship. L_∞ and K are von Bertalanffy growth parameters.

Equation	Parameters	Comments	Reference
$\log(M) = a + b\log(L_\infty) + c\log(K) + d\log(T)$	a=−0.0066; b=−0.279; c=0.6543; d=0.4634	175 fish stocks	Pauly, 1979
$M / K = C_2$	C_2=1.60	reanalysis of Pauly data	Jensen, 1996

Table 8B.5. Lorenzen's method: an empirical relationship based on weight-at-maturity (W).

Equation	Parameters	Comments	Reference
$M = M_U \cdot W^b$	M_U=3.69; b=-0.305		Lorenzen, 1996

Table 8B.6. Theoretical relationships based on life history invariants. K is the von Bertalanffy growth coefficient and x_m is the age at maturity.

Equation	Parameters	Comments	Reference
$M \cdot x_m = C_1$	1.54 (cod, flatfish) 1.65 (theory) ~2	net reproductive rate maximized wrto age at maturity	Beverton, 1963 Jensen, 1996 Charnov and Berrigan, 1990
$M / K = C_2$	1.5		Jensen, 1966
$M = \frac{3K}{\exp(K \cdot x_m) - 1}$			Roff, 1984

Table 8B.7. Natural mortality estimates by species, region, and sex.

Common name	Species	Region	Sex	Hoenig's M			Pauly's M		GSI M		M based on life history invariants			Lorenzen's M	mean	standard deviation
				ordinary regression	geometric regression	Hewitt & Hoenig, 2005	T	EPT	ordinary regression	functional regression	$M \cdot x_m = C_1$	$M / K = C_2$	$M = \frac{3K}{\exp(K \cdot x_m) - 1}$			
Alaska plaice	*Pleuronectes quadrituberculatus*	EBS	M	0.115	0.087	0.125	0.112	0.216	--	--	--	0.197	--	--	0.142	0.052
			F	0.112	0.084	0.122	0.112	0.216	--	--	0.181	0.197	0.192	0.706	0.214	0.191
Arrowtooth flounder	*Atheresthes stomias*	EBS	M	0.246	0.218	0.261	0.171	0.189	--	--	--	0.255	--	--	0.223	0.037
			F	0.199	0.168	0.212	0.147	0.163	0.081	0.089	0.293	0.240	0.365	0.215	0.198	0.083
		GOA	M	0.209	0.178	0.223	0.281	0.281	--	--	--	0.354	--	--	0.254	0.064
			F	0.167	0.136	0.179	0.141	0.141	--	--	--	0.153	--	0.454	0.196	0.115
Dover sole	*Microstomus pacificus*	GOA	M	0.077	0.053	0.084	0.250	0.250	--	--	--	0.293	--	--	0.168	0.107
			F	0.078	0.054	0.086	0.179	0.179	0.082	0.091	0.230	0.191	0.284	0.467	0.175	0.122
Flathead sole	*Hippoglossoides elasodon*	EBS	M	0.139	0.108	0.150	0.189	0.256	--	--	--	0.285	--	--	0.188	0.070
			F	0.134	0.104	0.145	0.114	0.154	--	--	0.159	0.150	0.183	0.646	0.199	0.169
		GOA	M	0.126	0.097	0.136	0.272	0.272	--	--	--	0.306	--	--	0.202	0.092
			F	0.149	0.118	0.160	0.219	0.219	--	--	0.177	0.236	0.161	0.616	0.228	0.150
Greenland turbot	*Reinhardtius hippoglossoides*	EBS	M	0.126	0.097	0.136	0.112	0.206	--	--	--	0.233	--	--	0.151	0.055
			F	0.122	0.093	0.132	0.087	0.160	0.113	0.123	--	0.176	--	0.290	0.144	0.062
Northern rock sole	*Lepidopsetta polyxystra*	EBS	M	0.154	0.123	0.166	0.251	0.301	--	--	--	0.393	--	--	0.231	0.103
			F	0.154	0.123	0.166	0.251	0.301	--	--	0.162	0.393	0.071	0.655	0.253	0.180
		GOA	M	0.199	0.168	0.212	0.321	0.321	--	--	--	0.392	--	--	0.269	0.088
			F	0.190	0.159	0.203	0.291	0.291	--	--	0.237	0.354	0.195	0.590	0.279	0.132
Southern rock sole	*Lepidopsetta bilineata*	GOA	M	0.149	0.118	0.160	0.259	0.259	--	--	--	0.273	--	--	0.203	0.068
			F	0.167	0.136	0.179	0.181	0.181	--	--	0.181	0.180	0.203	0.559	0.219	0.129
Rex sole	*Glyptocephalus zachirus*	GOA	M	0.106	0.079	0.116	0.403	0.403	--	--	--	0.570	--	--	0.279	0.206
			F	0.149	0.118	0.160	0.340	0.340	0.043	0.049	0.275	0.465	0.199	0.652	0.254	0.186
Yellowfin sole	*Limanda aspera*	EBS	M	0.115	0.087	0.125	0.176	0.219	--	--	--	0.233	--	--	0.159	0.060
			F	0.112	0.084	0.122	0.160	0.200	--	--	0.147	0.212	0.124	0.636	0.200	0.169
		GOA	M	0.190	0.159	0.203	0.267	0.267	--	--	--	0.285	--	--	0.228	0.051
			F	0.199	0.168	0.212	0.210	0.210	--	--	0.171	0.210	0.166	--	0.193	0.021

Figures

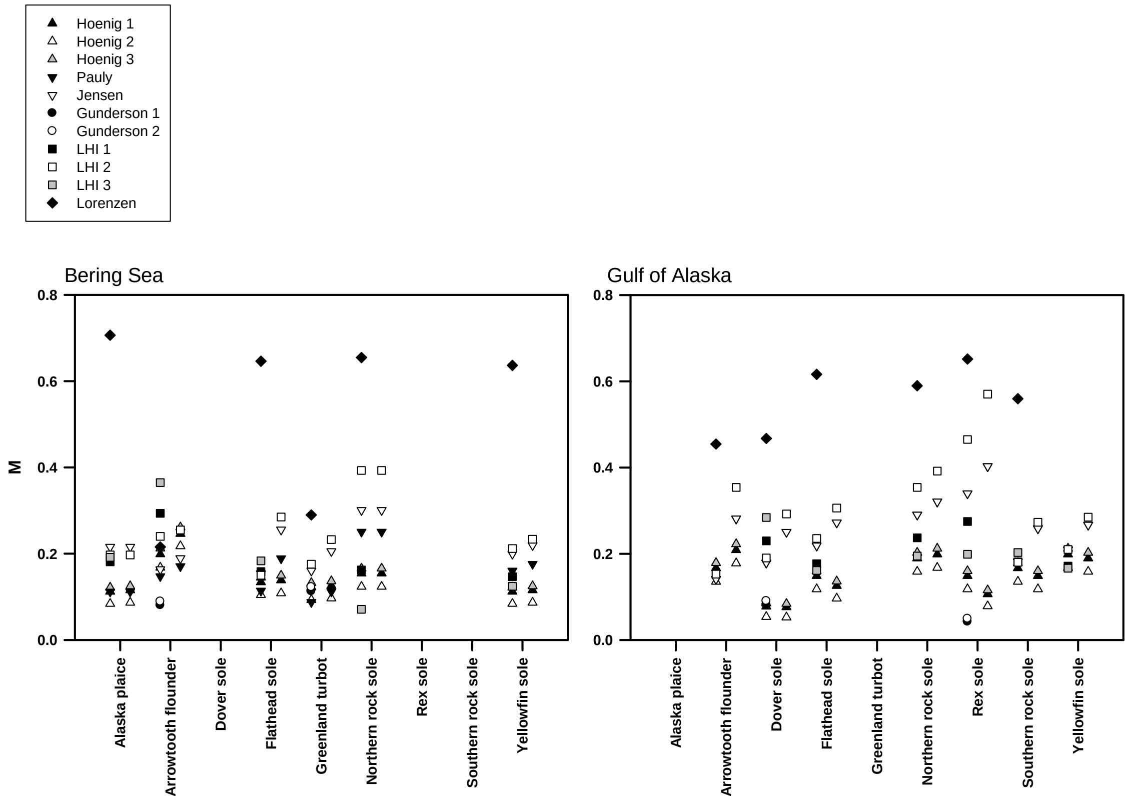


Figure 8B.1. Sex-specific estimates of M for 9 flatfish species (13 stocks) in the eastern Bering Sea and Gulf of Alaska. For each species, estimates for females are in the leftward column and males are in the right. Methods based on GSI and age-at-maturity were not applied to males.

Chapter 8 Appendix C: Bering flounder

Bering flounder (*Hippogolossoides robustus*) is a con-specific of flathead sole (*H. elassodon*) in the Bering Sea, where both species are caught in the BSAI flathead sole target fishery and as bycatch in other BSAI fisheries. It occurs across the northern Pacific from Hokkaido in Japan north into the Sea of Okhotsk, east and south across the eastern Bering Sea shelf to Akutan Island in the Aleutians and east and north across the northern Bering Sea and through the Bering Strait into the Chukchi and Beaufort Seas and the Canadian Arctic. Bering flounder in the eastern Bering Sea (EBS) are considered to here to comprise a single stock.

Annual fishery-independent groundfish surveys have been conducted by the Resource Assessment and Conservation Engineering (RACE) division of the Alaska Fisheries Science Center (AFSC) during the summer on the eastern Bering Sea (EBS) shelf at fixed stations using standardized bottom trawl gear since 1982 (see Figure 8.7). In 1987, the original area covered by the survey (referred to here as the “standard” area) was expanded to include stations further to the northwest (referred to here as the “northwest extension”). This year, in addition to the standard and northwest extension areas, the EBS shelf survey extended its coverage across the US portion of the northern Bering Sea (NBS), as well.

Swept-area biomass trends from the standard and northwest extension areas (Figure. 8C.1) indicate that the distribution of biomass between the two areas has remained fairly stable over time, with an average of ~54% in the northwest extension area and 46% in the standard area. The biomass within the standard area is not evenly distributed across it; rather, is concentrated in the northwest portion of the standard area around St. Matthew Island and extends from there into the northwest extension area (see Figure 8.11). However, although the fraction within each area has remained relatively stable over time, the absolute abundance within each area appears to be decreasing (Figure 8C.1). In both areas, estimated biomass was ~20,000 t in the late 1980’s and is ~7,000 t now, a decline of 65%. The rate of decline appears even more precipitous over the last several years in the northwest area because survey biomass “spiked” in 2005 to a record high of 19,800 t but immediately returned to more normal levels. However, it appears that biomass in the standard area may have stabilized over the past decade, with levels fluctuating around 7,500 t.

Size compositions from the two survey areas display some interesting similarities and contrasts (Figure 8C.2). Three substantial recruitment events are evident in the size compositions for the northwest extension area: in 1987, 1996, and 2010. Only the first and third events are apparent in the standard area, and the 1987 event in the northwest extension doesn’t appear in the standard area until the following year. The size classes in the 2010 event seem to be somewhat smaller (~ 10 cm) than in previous events (~15 cm in 1987 and ~19 cm in 1996). The “spike” in biomass in the northwest area in 2005 was also accompanied by a seemingly-anomalous increase in larger individuals (> 20 cm) in the size composition for that year. No such change was evident in the standard area. Rather than being driven by recruitment of small animals, this phenomenon may have been caused by animals moving south into the northwest extension in 2005 from the heretofore unsurveyed northern Bering Sea area--and subsequently moving north again in 2006 out of the surveyed area.

This year’s survey in the northern Bering Sea suggests that a substantial fraction of the Bering flounder population within US territorial waters resides north of the region typically included in the RACE groundfish trawl surveys (Figure 8C.3). A preliminary estimate of biomass in the NBS was ~12,400 t, equal to the abundance in the standard and northwest survey areas combined. The strong recruitment event evident in the standard and northwest area size compositions was also apparent in the NBS, as well (Figure 8C.4).

Total catch of Bering flounder in the BSAI fisheries for 2008-2010 was estimated by expanding observer sampling of at-sea hauls to total catch of "flathead sole" (i.e., *Hippoglossoides* spp.) for each NMFS Statistical Area in the Bering Sea (Figure 8C.5). Results from 2008 and 2009-2010 were quite different in absolute magnitude, but similar in pattern among statistical areas. Estimated total catches in 2009 (196 t) and 2010 (258 t) were larger than that in 2008 (13 t) by over a factor of 10. In 2009-2010, greater than 90% of the catch was taken in Statistical Area 521; 85% was taken in 2008. It is unclear what accounts for the large change in estimated catch between 2008 and 2009. Using the total survey biomass (standard+northwest+NBS) as an estimate of population size, the fishery exploitation rate for Bering flounder in 2010 was calculated at 1%. The estimated exploitation rate would be twice this, of course, if the biomass in only the standard and northwest extension survey areas had been used.

Using several of the methods outlined in Appendix B, estimates were made for the rate of natural mortality for Bering flounder (Table 8C.1). These ranged from 0.096 yr^{-1} for males based on the second Life History Invariant method to 0.216 yr^{-1} for females based on the third Life History Invariant approach, while the remaining values clustered around 0.15 yr^{-1}. Estimates could not be calculated using Gunderson's formulas based on GSI, Pauly's temperature-based approaches, or Lorenzen's maturity-based estimate because the requisite data is not yet available (maturity and GSI collections were made in the northern Bering Sea during the 2010 survey and the results from this study will be compared with the results from a 2006 and 2007 AFSC study collection made in the central area of the eastern Bering Sea [J. Stark, pers. comm.]).

Using M=0.15 yr^{-1} (as a reasonable value) and survey results from the standard and northwest extension areas for 2009, Tier 5 calculations for Bering flounder would result in a species-specific OFL = 1,376 t and max ABC = 1,032 t for 2010. These are well above the estimated total fishery catch of Bering flounder this year (~250 t). This would also hold true if we had used the highest estimate of M from Table 8C.1

Bering flounder and flathead sole in the Bering Sea are currently managed as a two-species stock complex in the BSAI because species identification by observers in the fishery was not made a priority until recently (2008). As observer identification of Bering flounder is validated, it should become possible to develop species-specific components for OFL and max ABC for both Bering flounder using a Tier 5 approach (at least initially) and flathead sole (*H. elassodon*) using the current Tier 3 approach but with data specific to *H. elassodon* only.

Although the declining trend in survey biomass for Bering flounder in the standard and northwest survey areas is a cause for some concern, it does not appear to be driven by fishing pressure (if exploitation rates are really only 1-2%) and may be due to northward shifts in the species range driven by warming in the EBS. This year's survey in the NBS is encouraging because it indicates that the Bering flounder stock is quite a bit larger than is represented in the regular annual survey. Accurate assessment of the Bering flounder stock will require surveys in the NBS to continue on a regular basis.

Appendix C: Tables

Table 8C.1. Natural mortality estimates for Bering flounder. Estimates of age- and size-at-maturity and von Bertalanffy growth parameters provided by J. Stark (pers. comm.). See references in Appendix B of this chapter for citations for the natural mortality estimators used here.

										Natural Mortality Estimates											Statistics	
Sex	Max age	Maturity	Size at Maturity	Weight at Maturity	GSI	Linf	K	Temp	EPT	Hoenig's M			Pauly's M		GSI M		M based on life history invariants			Lorenzen's M	Mean	Std Deviation
	(years)	(years)	(cm)	(g)		(cm)		(deg C)	(deg C)	ordinary regression	geometric regression	Hewitt & Hoenig, 2005	T	EPT	ordinary regression	functional regression	$M \cdot x_m = C_1$	$M/K = C_2$	$M = \frac{3K}{\exp(K \cdot x_m) - 1}$			
M	29	--	--	--	--	41.3	0.064	-0.9	--	0.144	0.113	0.155	--	--	--	--	--	0.096	--	--	0.127	0.027
F	29	8.7	24	--	--	44.6	0.100	-0.9	--	0.144	0.113	0.155	--	--	--	--	0.177	0.150	0.216	--	0.159	0.035

Appendix C: Figures

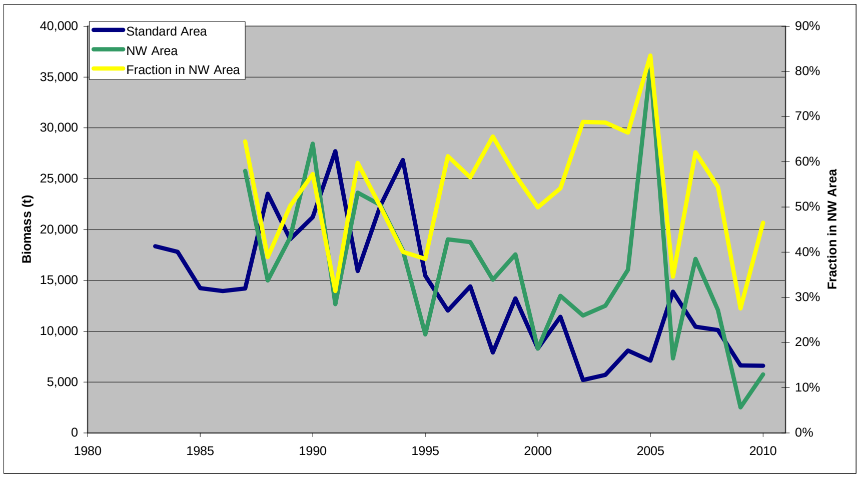


Figure 8C.1. Estimated abundance of Bering flounder by the EBS Groundfish Surveys in the standard area (blue; sampled since 1982) and the northwest extension (green; sampled since 1987). The fraction of biomass in the northwest extension is plotted in yellow.

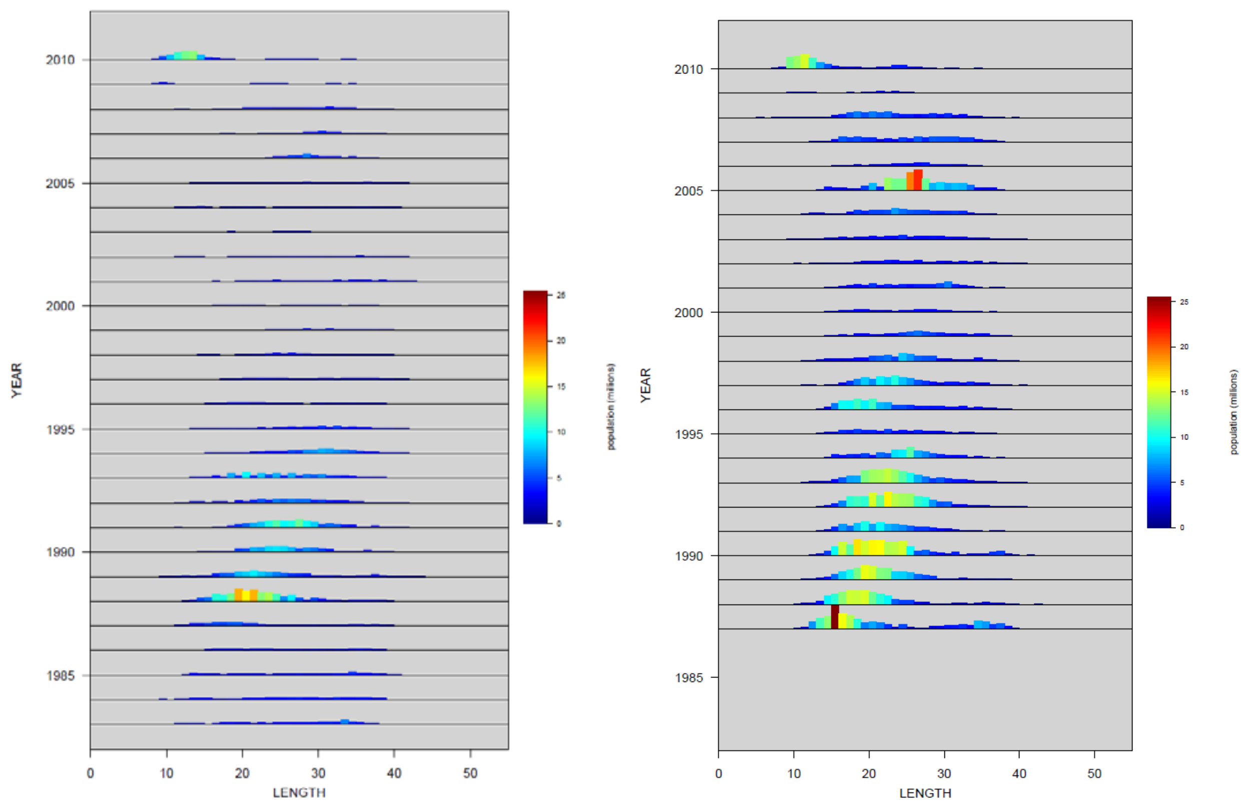


Figure 8C.2. Size compositions (both sexes combined) for Bering flounder in the EBS Groundfish Surveys in the standard area (left plot) and the northwest extension (right plot). The scales are identical in both plots.

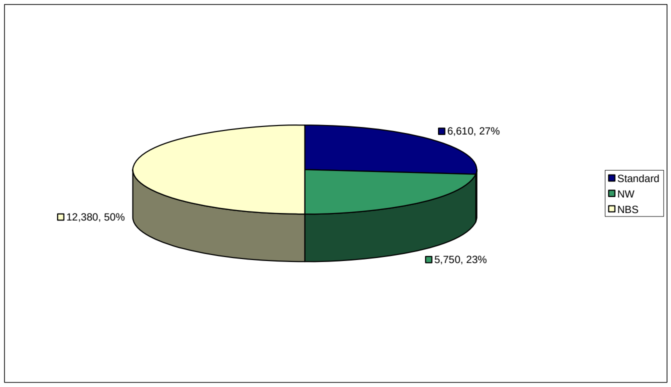


Figure 8C.3. Estimated abundance of Bering flounder in 2010 by the EBS Groundfish Surveys in the standard area (blue), the northwest extension area (green), and in the northern Bering Sea (yellow). The estimated biomass (in t) and the fraction of the total biomass are given for each area.

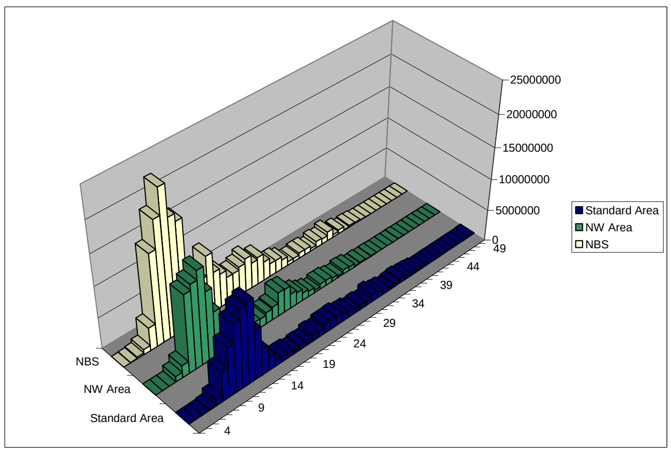


Figure 8C.4. Size compositions (both sexes combined) for Bering flounder from the 2010 EBS Groundfish Survey in the standard area (blue bars), the northwest extension area (green bars), and the northern Bering Sea area (yellow bars).

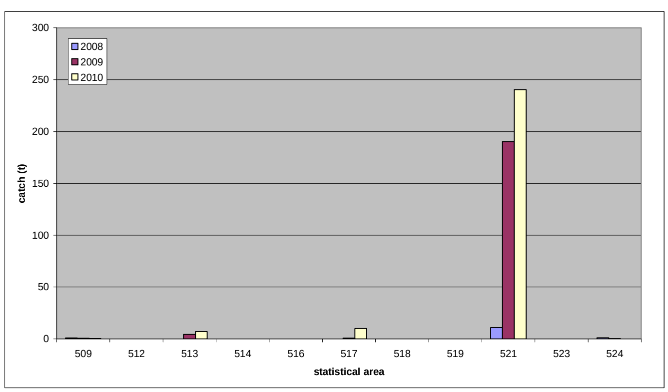


Figure 8C.5. Fishery catch of Bering flounder by NMFS Statistical Area, based on observed hauls, for 2008-2010.

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