8. Assessment of the Flathead Sole Stock in the Gulf of Alaska

By

Carey R. McGilliard[1], Wayne Palsson[3], William Stockhausen[2], and Jim Ianelli[2]

[1]Joint Institute for the Study of the Atmosphere and Ocean
University of Washington
Seattle, WA 98195
[2]Resource Ecology and Fisheries Management Division
[3]Resource Assessment and Conservation Engineering Division
Alaska Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE., Seattle, WA 98115-6349

EXECUTIVE SUMMARY

Summary of Changes in Assessment Inputs

(1) 1978-1983 and 2012-2013 catch data were included in the model

2011 catch was updated to include October – December catch in that year

(2) 2012 and 2013 fishery length composition data were added to the model
(3) 1985-1988, 2000, and 2008 fishery length composition data were excluded from the model due to low sample size
(4) The number of hauls was used as the effective sample size of fishery length-composition data
(5) The range of length bins was expanded such that the lowest length bin included 0-6cm fish and the oldest bin included 70cm+ fish.
(6) The 2013 survey biomass index was added to the model
(7) Survey length composition data for 2013 were added to the model
(8) Survey age composition data within each length bin were used in the model instead of marginal age composition data (combined over lengths); 2011 age composition data (within each length bin) were added to the model.
(9) The "plus" group was increased to age 29.

Summary of Changes in Assessment Methodology

The following substantive structural changes were made to the assessment methodology:

(1) The assessment was conducted in Stock Synthesis version 3.14o (SS3); Attachment 8B includes a full description of the transition from the 2011 flathead sole assessment model to an equivalent model in SS3.
(2) The fishery and survey selectivity curves were estimated using an age-based double-normal function without a descending limb instead of an age-based logistic function.
(3) A conditional age-at-length likelihood approach was used: expected age composition within each length bin was fit to age data conditioned on length in the likelihood function, rather than fitting the expected marginal age-composition to age data that weren't conditioned on length.
(4) Parameters of the von-Bertlanffy growth curve were estimated within the model.
(5) The CVs of length at age 2 and 29 were estimated within the model and used to define the age-length transition matrix.
(6) Initial equilibrium F was estimated within the model

(7) Relative weights of composition data were adjusted according to the data-weighting method described in Francis (2011).
(8) Ageing uncertainty was incorporated into the model using the ageing error matrix used in the most recent accepted BSAI flathead sole assessment.
(9) Recruitment deviations prior to 1984 were estimated as "early-period" recruits separately from main-period recruits (1984-2008) such that the vector of recruits for each period had a sum-to-zero constraint, rather than forcing a sum-to-zero constraint across all recruitment deviations.

Summary of Results

The key results of the assessment, based on the author's preferred model, are compared to the key results of the accepted 2011 assessment model in the table below.

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2013	2014	2014	2015
M (natural mortality rate)	0.2	0.2	0.2	0.2
Tier	3a	3a	3a	3a
Projected total (3+) biomass (t)	288,538	285,128	252,361	253,418
Female spawning biomass (t)				
Projected				
Upper 95% confidence interval	--		84,076	83,287
Point estimate	106,377	107,178	84,058	83,204
Lower 95% confidence interval	--		84,045	83,141
$B_{100\%}$	103,868	103,868	88,829	88,829
$B_{40\%}$	41,547	41,547	35,532	35,532
$B_{35\%}$	36,354	36,354	31,090	31,090
F_{OFL}	0.593	0.593	0.61	0.61
$maxF_{ABC}$	0.45	0.45	0.47	0.47
F_{ABC}	0.45	0.45	0.47	0.47
OFL (t)	61,036	62,296	50,664	50,376
maxABC (t)	48,738	49,771	41,231	41,007
ABC (t)	48,738	49,771	41,231	41,007
Status	As determined in 2012 for:		As determined in 2013 for:	
	2011	2012	2012	2013
Overfishing	no	n/a	no	n/a
Overfished	n/a	no	n/a	no
Approaching overfished	n/a	no	n/a	no

The table below shows apportionment of the 2014 and 2015 ABCs and OFLs among areas, based on the percentage of flathead sole 2013 survey biomass in each area.

Quantity	Western	Central	West Yakutat	Southeast	Total
Area Apportionment	30.88%	60.16%	8.55%	0.41%	100.00%
2014 ABC (t)	12,730	24,805	3,525	171	41,231
2015 ABC (t)	12,661	24,670	3,506	170	41,007

Responses to SSC and Plan Team Comments on Assessments

Due to the October government shutdown, Alaska Fisheries Science Center (AFSC) leadership has determined that responses to Plan Team and SSC comments were optional for this year's stock assessments. The following issues were addressed.

GPT (11/11 minutes): *"The Team noted the model starts in 1984 rather than 1977. Since catches prior to 1984 are presented in the assessment, the Team recommends the author attempt to start the model in 1977 to be consistent with other stock assessments".* Catches from 1978-1983 were included in the model. The 2013 model starts in 1978 and an initial equilibrium catch is estimated to account for fishing prior to 1978.

GPT (11/11 minutes): *"The Team also recommends the author work to incorporate an ageing error matrix for flathead sole for use in the model".* Ageing uncertainty was incorporated into the model using the ageing error matrix calculated from BSAI flathead sole ageing data and used in the most recent accepted BSAI flathead sole assessment. Future assessments should estimate an ageing error matrix using GOA flathead ageing error data.

GPT (11/11 mintues):*"The Team recommends the model be configured to accept fishery ages and that the author evaluate available sample sizes and work with the ageing lab to get additional ages processed".* The SS3 model framework used for the 2013 assessment is configured to accept fishery ages. The author is working with the ageing lab to get additional ages processed so that fishery ages can be used in future assessments.

SSC (12/11 minutes): *The SSC supports the authors' plans to estimate new age-length transition matrices with newly available age data.* Age-length transition matrices with newly available age data were evaluated within the assessment model by estimating the parameters of the von-Bertalanffy growth curve and the CV of length-at-age for the youngest and oldest fish in the population (from which an age-length transition matrix was calculated). All available survey age-at-length data were included in the model to inform the estimation of growth and age-length transition matrices.

SSC (12/11 minutes): *The SSC asks the authors to consider whether an analysis of aging error would be timely either by the AFSC's Age and Growth Program or internal to the model or both.* Ageing uncertainty was incorporated into the model using the ageing error matrix calculated from BSAI flathead sole ageing data and used in the most recent accepted BSAI flathead sole assessment. Future assessments should estimate an ageing error matrix using GOA flathead ageing error data.

GPT (9/13 minutes): *The Team recommended that the author continue to use the stock synthesis framework for both species since it can accommodate past issues that have been raised. Also fits to the survey index data were much better.* The Stock Synthesis framework was used for the current assessment.

SSC (10/13 minutes): *The SSC recommends that the previous stock assessment platforms be updated with the most current data for comparison to the new SS models before transition to the new SS platform.* Attachment 8B of the assessment shows the results of model runs using the previous stock assessment platform, updated with the most current data and compares model results to those of the current assessment using the new SS platform.

INTRODUCTION

General

Flathead sole (*Hippoglossoides elassodon*) are distributed from northern California, off Point Reyes, northward along the west coast of North America and throughout the GOA and the BS, the Kuril Islands, and possibly the Okhotsk Sea (Hart 1973). They occur primarily on mixed mud and sand bottoms (Norcross et al. 1997, McConnaughey and Smith 2000) in depths < 300 m (Stark and Clausen 1995). The flathead sole distribution overlaps with the similar-appearing Bering flounder (*Hippoglossoides robustus*) in the northern half of the Bering Sea and the Sea of Okhotsk (Hart 1973), but not in the Gulf of Alaska.

Review of Life History

Adults exhibit a benthic lifestyle and occupy separate winter spawning and summertime feeding distributions on the EBS shelf and in the GOA. From over-winter grounds near the shelf margins, adults begin a migration onto the mid and outer continental shelf in April or May each year for feeding. The spawning period may range from as early as January but is known to occur in March and April, primarily in deeper waters near the margins of the continental shelf. Eggs are large (2.75 to 3.75 mm) and females have egg counts ranging from about 72,000 (20 cm fish) to almost 600,000 (38 cm fish). Eggs hatch in 9 to 20 days depending on incubation temperatures within the range of 2.4 to 9.8°C and have been found in ichthyoplankton sampling on the southern portion of the BS shelf in April and May (Waldron 1981). Larvae absorb the yolk sac in 6 to 17 days, but the extent of their distribution is unknown. Nearshore sampling indicates that newly settled larvae are in the 40 to 50 mm size range (Norcross et al. 1996). Fifty percent of flathead sole females in the GOA are mature at 8.7 years, or at about 33 cm (Stark 2004). Juveniles less than age 2 have not been found with the adult population and probably remain in shallow nearshore nursery areas.

FISHERY

Description of the Directed Fishery

Flathead sole in the Gulf of Alaska are caught in a directed fishery using bottom trawl gear. Typically 25 or fewer shore-based catcher vessels from 58-125’ participate in this fishery, as do 5 catcher-processor vessels (90-130’). Fishing seasons are driven by seasonal halibut PSC apportionments, with approximately 7 months of fishing occurring between January and November. Catches of flathead sole occur only in the Western and Central management areas in the gulf (statistical areas 610 and 620 + 630, respectively, Figure 8.2-Figure 8.6). Recruitment to the fishery begins at about age 3.

Historically, catches of flathead sole have exhibited decadal-scale trends (Table 8.1, Figure 8.1). From a high of ~2000 t in 1980, annual catches declined steadily to a low of ~150 t in 1986 but thereupon increased steadily, reaching a high of ~3100 t in 1996. Catches subsequently declined over the next three years, reaching a low of ~900 t in 1999, followed by an increasing trend through 2010, when the catch reached its highest level ever (3,842 t).

Based on observer data, the majority of the flathead sole catch in the Gulf of Alaska is taken in the Shelikof Strait and on the Albatross Bank near Kodiak Island, as well as near Unimak Island (Stockhausen 2011). Previously, most of the catch is taken in the first and second quarters of the year (Stockhausen 2011).

Annual catches of flathead sole have been well below TACs in recent years (Table 8.2), although the population appears to be capable of supporting higher exploitation rates. Limits on flathead sole catches are driven by within-season closures of the directed fishery due to restrictions on halibut PSC, not by attainment of the TAC (Stockhausen 2011).

See Stockhausen (2011) for a description of the management history of flathead sole.

DATA

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

Source	Type	Years
Fishery	Catch biomass	1978-2013
Fishery	Catch length composition	1989-1999, 2001-2007, 2009-2013
GOA survey bottom trawl	Catch per unit effort	Triennial: 1984-1999, Biennial: 2001-2013
GOA survey bottom trawl	Catch length composition	Triennial: 1984-1999, Biennial: 2001-2013
GOA survey bottom trawl	Catch age composition, conditioned on length	Triennial: 1984-1999, Biennial: 2001-2013

Fishery Data

Catch Biomass

The assessment included catch data from 1978 to October 19, 2013 (Table 8.1, Figure 8.1). Fishery catch per unit effort (CPUE) data are excluded because flathead sole are often taken as incidental catch and it is thought that the fishery CPUE data may not reflect abundance. The spatial distribution of fishery CPUE for 2009-2013 is shown in Figure 8.2-Figure 8.6.

Catch Size Composition

Fishery length composition data were included in 2cm bins from 6-56cm in 1989-1999, 2001-2007, and 2009-2013; data were omitted in years where there were less than 15 hauls that included measured flathead sole (1982-1988 2000, 2008). The number of hauls were used as the relative effective sample size. Fishery length composition data were voluminous and can be accessed at http://www.afsc.noaa.gov/REFM/docs/2013/GOA_Flathead_Composition_Data_And_SampleSize_2013.xlsx.

GOA Survey Bottom Trawl Data

Biomass and Numerical Abundance

Survey biomass estimates originate from a cooperative bottom trawl survey between the U.S. and Japan in 1984 and 1987 and a U.S. bottom trawl survey conducted by the Alaska Fisheries Science Center Resource Assessment and Conservation Engineering (RACE) Division thereafter. Calculations for final survey biomass and variance estimates are fully described in Wakabayashi et al. (1985). Depths 0-500 meters were fully covered in each survey and occurrence of flathead at depths greater than 500 meters is rare. The survey excluded the eastern part of the Gulf of Alaska (the Yakutat and Southeastern areas) in 2001 (Table 8.3). As for previous assessments, the availability of the survey biomass in 2001 was assumed to be 0.9 to account for the biomass in the eastern section of the Gulf. The total survey biomass estimates and CVs that were used in the assessment are listed in Table 8.4.

Figure 8.7-Figure 8.9 show maps of survey CPUE in the GOA for the 2009, 2011, and 2013 surveys; survey CPUE in all three years was highest in the Central and Western GOA.

Survey Size and Age Composition

Sex-specific survey length composition data as well as age frequencies of fish by length (conditional age-at-length) were used in the assessment and can be found at http://www.afsc.noaa.gov/REFM/docs/2013/GOA_Flathead_Composition_Data_And_SampleSize_2013.xlsx, along with corresponding sample sizes used in the assessment. There are several advantages to using conditional age-at-length data. The approach preserves information on the relationship between length and age and provides information on variability in length-at-age such that growth parameters and variability in growth can be estimated within the model. In addition, the approach resolves the issue of double-counting individual fish when using both length- and age-composition data (as length-composition data are used to calculate the marginal age compositions). See Stewart (2005) for an additional example of the use of conditional age-at-length data in fishery stock assessments.

ANALYTICAL APPROACH

Model Structure

Tier 3 Model

The assessment was a split sex, age-structured statistical catch-at-age model implemented in Stock Synthesis version 3.24o (SS3) using a maximum likelihood approach. SS3 equations can be found in Methot and Wetzel (2013) and further technical documentation is outlined in Methot (2009). Previous assessments were conducted using an ADMB-based, split-sex, age-structured population dynamics model (Stockhausen 2011). Briefly, the current assessment model covers 1955-2013. Age classes included in the model run from age 0 to 29. Age at recruitment was set at 0 years in the model. The oldest age class in the model, age 29, serves as a plus group. Survey catchability was fixed at 1.0. **A detailed description of the transition of the previous model to SS3 and potential benefits of transitioning the assessment to SS3 were presented at the 2013 September Plan Team Meeting and the September SAFE chapter is included in this document as Attachment 8A.**

Fishery and Survey Selectivity

The fishery and survey selectivity curves were estimated using sex-specific, age-based double-normal functions without a descending limb (instead of a logistic function). The SS3 modeling framework does not currently include the option of estimating sex-specific, age-based logistic selectivity where both male and female selectivity maintain a logistic shape (as was used in the previous assessment model). Therefore, the double-normal curve without a descending limb was the closest match to the selectivity formulation used in the 2011 model (Attachment 8A). Length-based, sex-specific, logistic fishery and survey selectivity were implemented as sensitivity analyses in 2013 assessment model runs (Attachment 8A). Length-based formulations for fishery and survey selectivity were not used in final model runs because the age-based selectivity curves derived from using length-based curves showed that the oldest fish were not selected, effectively lowering survey catchability and suggesting that the fishery fails to catch the oldest, largest fish. Fits to data were similar for length- and age-based asymptotic survey selectivity curves. Sensitivity analyses assuming dome-shaped fishery or survey selectivity failed to improve model fits to the data.

Conditional Age-at-Length

A conditional age-at-length approach was used: expected age composition within each length bin was fit to age data conditioned on length (conditional age-at-length) in the objective function, rather than fitting the expected marginal age-composition to age data (which are typically calculated as a function of the conditional age-at-length data and the length-composition data). This approach provides the information necessary to estimate growth curves and variability about mean growth within the assessment model. In addition, the approach allows for all of the length and age-composition information to be used in the assessment without double-counting each sample. The von-Bertalanffy growth curve and variability in the length-at-age relationship were evaluated within the model using the conditional age-at-length approach.

Data Weighting

In the 2011 assessment, data components within the model were weighted as follows:

Fishery Catch	Fishery Length	Survey Biomass	Survey Length	Survey Age
30	1	1	1	1

The GOA Plan Team expressed concerns about effective sample sizes and data weighting used in the previous assessment. Therefore, in the current assessment, effective sample sizes for fishery length-composition data each year were set to the number of hauls measured to account for non-independence within hauls (Pennington and Volstad 1994). The effective sample sizes for survey length-composition data were the same in each survey year (as for previous assessments). Future assessments should explore intra-haul correlation and the possibility of using number of hauls for effective sample size of survey length-composition data (Pennington and Volstad 1994). To account for process error (e.g. variance in selectivities among years), relative weights measured for length or age composition data (lambdas) were adjusted according to the method described in Francis (2011), which accounts for correlations in length- and age-composition data (data-weighting method number T3.4 was used). The weights used were $\lambda = 0.081$ for the fishery length composition data, $\lambda = 2.191$ for the survey length-composition data, $\lambda = 0.653$ for the survey age composition data, and $\lambda = 1$ for the survey biomass index. The philosophy of this data-weighting method is to avoid allowing age- and length-composition data to prevent the model from fitting the survey biomass data well and to account for correlations in the residuals about the fits to the length- and age-composition data (Francis 2011). Previous studies show that solely using composition data to determine trends in biomass can lead to widely varying conclusions about current biomass and biomass reference points (Horn and Francis 2010).

Ageing Error Matrix

Ageing uncertainty was incorporated into the model using the ageing error matrix calculated from BSAI flathead sole ageing data and used in the most recent accepted BSAI flathead sole assessment (Stockhausen et al. 2012). SS3 accommodates the specification of ageing error bias and imprecision, while the previous assessment model framework did not. Future assessments should estimate ageing error matrices for GOA flathead sole using GOA age-read data. BSAI and GOA flathead sole are aged by the same individuals using the same techniques and ageing error is expected to be very similar. Assuming perfect age-reading of GOA flathead sole otoliths is thought to be an inferior assumption to using estimates of ageing error from the BSAI flathead sole population. The BSAI data was used due to insufficient time to properly analyze GOA ageing error data.

Recruitment Deviations

Recruitment deviations for the period 1955-1983 were estimated as “early-period” recruits separately from “main-period” recruits (1984-2008) such that the vector of recruits for each period had a sum-to-zero constraint, rather than forcing a sum-to-zero constraint across all recruitment deviations.

A bias adjustment factor was specified using the Methot and Taylor (2011) bias adjustment method. Recruitment deviations prior to the start of composition data and in the most recent years in the time-series are less informed than in the middle of the time-series. This creates a bias in the estimation of recruitment deviations and mean recruitment that is corrected using methods described in Methot and Taylor (2011).

Model structures considered in this year’s assessment

Many proposed model changes were presented at the 2013 September Plan Team meeting (Attachment 8A) and were explored using 2012-2013 data. The four models described below are included in the final assessment; all use the SS3 model framework and include nearly all of the changes that were proposed and reviewed at the September Plan Team meeting (Attachment 8A). Survey catchability is fixed and equal to 1 for all models.

Model 0 (the author’s recommended model) implemented the changes described above, fixing natural mortality at 0.2 for males and females, the value specified in the previous assessment. When natural mortality is fixed and equal to 0.2, a constraint is placed on the fishery selectivity curves such that selectivity reaches 1 by age 16. Growth curves for flathead sole indicate that flathead have reached maximum length by age 16. Recruitment deviations for an “early” time period from 1955-1983 (prior to the availability of composition data) were estimated, as described above. Estimating early-period recruitment deviations allows the model to fit to the initial age-composition data.

Model 1 is as for Model 0, but with male and female natural mortality (*M*) estimated. Model fits and the ability to estimate reasonable fishery selectivity curves improved substantially when natural mortality was estimated. Like Model 0, Model 1 recruitment deviations for the “early” time period from 1955-1983 were estimated.

Model 2 is as for Model 0, but a different R_0 value was estimated prior to 1984, and recruitment deviations were estimated starting in 1984. Excluding the early-period recruitment deviations prevents the model from estimating extreme values for early-period recruitment deviations when data to support these estimates are sparse. As for Model 0, fishery selectivity was constrained such that selectivity reached 1 by age 16 and natural mortality was fixed and equal to 0.2 for males and females.

Model 3 is as for Model 1, where male and female natural mortality are estimated, but excluded the estimation of early-period recruits and instead estimated a different R_0 value during the early period. Recruitment deviations were estimated beginning in 1984.

Parameters Estimated Outside the Assessment Model

Natural mortality

Male and female natural mortality were fixed and equal to 0.2 in Models 0 and 2.

Weight-Length Relationship

The weight-length relationship was that used in the previous assessment (Stockhausen 2011). The relationship was $w_L = \alpha L^{\beta}$, where $\alpha = 4.28E-06$ and $\beta = 3.2298$, length (L) was measured in centimeters and weight (w) was measured in kilograms.

Maturity-at-Age

Maturity-at-age (O_a) in the assessment was defined as $O_a = 1/(1+\gamma e^{(a-a_{50})})$, where the slope of the curve was $\gamma = -0.773$ and the age-at-50%-maturity was $a_{50} = 8.74$. These values were used in the previous assessment and were estimated from a histological analysis of GOA flathead sole ovaries collected in January 1999 based on 180 samples (Stark, 2004).

Standard deviation of the Log of Recruitment (σ_R)

The standard deviation of the log of recruitment was not defined in previous assessments. Variability of the recruitment deviations that were estimated in previous flathead sole assessments was approximately σ_R=0.6 and this value was used in the current assessment.

Catchability

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

Select selectivity parameters

Selectivity parameter definitions and values are shown in Table 8.5.

Parameters Estimated Inside the Assessment Model

Parameters estimated within the assessment model were natural mortality (Models 1 and 3 only), the log of unfished recruitment (R_0), log-scale recruitment deviations, yearly fishing mortality, sex-specific parameters of the von-Bertalanffy growth curve, CV of length-at-age for ages 2 and 29, and selectivity parameters for the fishery and survey. The selectivity parameters are described in greater detail in Table 8.5.

RESULTS

Model Evaluation

Comparison among models

Models with estimated *M* (Models 1 and 3) led to reasonable estimates of selectivity parameters without constraining parameters (Figure 8.16, Figure 8.18), while models with fixed *M* (Models 0 and 2) required a constraint such that selectivity would reach 1 before the age of the plus group. Specifically, the constraint imposed for models with fixed *M* was that selectivity must reach 1 by age 16 (when most fish were fully grown; Figure 8.15, Figure 8.17). Without this constraint, models with *M* = 0.2 led to estimated selectivity curves with very shallow slopes, reaching maximum selectivity at age 37; the plus group age is 29 (Figure 8.19).

Models where *M* was estimated (Models 1 and 3) produced the best total negative log likelihood values due to improvements in fits to length- and age-composition data (Table 8.6). Figure 8.20-Figure 8.23 show observed and predicted proportions-at-length, aggregated over years. Models 1 and 3, where *M* was estimated, led to better fits of both the fishery and survey female proportions-at-length. Predicted male proportions-at-length fit the data closely and fits were similar across the four alternative models. Fits to the survey biomass index were similar among models, but slightly worse for models where *M* was estimated (Table 8.6, Figure 8.11). Models with estimated *M* predicted higher survey biomass and spawning stock biomass in early years of the time series and very similar, but slightly lower survey biomass in later years than models with fixed *M* (Figure 8.11-Figure 8.12).

Estimates of male and female *M* were higher than 0.2, the values used in previous assessments (Model 1 *M*= 0.287 (females) and 0.217 (males) and Model 3 *M*= 0.291 (females) and 0.321 (males); Table 8.7). Higher estimates of *M* led to substantially higher estimates of age-0 recruitment (Figure 8.14) and unfished recruitment (Table 8.7). The models with estimated *M* led to broader uncertainty intervals in estimates of spawning biomass, as expected (Figure 8.12). Estimates of spawning biomass were similar among models (Figure 8.12).

Models 0 and 1 include estimates of early recruitment deviations from 1955 to 1983, prior to the start of the length- and age-composition data. A pattern of negative recruitment deviations occurred from 1955 until the mid-1970s, when a spike in positive recruitment deviations occurred (Figure 8.13). This pattern occurred for every exploratory model run that included early-period recruitment deviations. When comparing between models that differed only in estimation of early recruitment deviations (i.e. comparing Model 0 to Model 2 and Model 1 to Model 3), length- and age-composition likelihood components and total negative log likelihood values were slightly better for models with early-period recruitment deviations than for models without early-period deviations (Table 8.6). It is expected that estimating early recruitment deviations would improve the total negative log likelihood and specifically the fits to composition data because the sole purpose is to allow the model more freedom to specify an initial age composition.

The Author's Recommended Model (Model 0)

The model recommended by the author is Model 0 where natural mortality was fixed to the value used in previous assessments (0.2) and early period recruitment deviations were estimated. Model 0 was selected for two reasons.

(1) Excluding initial recruitment deviations forces an assumption that the age-structure of the population is at a fished equilibrium in 1984. This assumption seems less realistic than the possibility of a large

recruitment pulse in the 1970s, as fish recruitment is known to fluctuate. The magnitude of recruitment deviations in the early period is similar to that of the main-period recruitment deviations in models with estimated *M*. The smoothness of the pattern in early recruitment deviations can largely be attributed to the inclusion of ageing error in the model, such that the model may be able to identify that a large recruitment pulse occurred, but can't identify the exact year or years of the recruitment pulse.

(2) While the models with estimated natural mortality (Models 1 and 3) were a better fit to the data than the models where natural mortality was set equal to 0.2, natural mortality and catchability may be confounded. Future assessments should explore both the possibility that GOA flathead sole natural mortality is higher than is being assumed and whether catchability may be lower than 1. The substantial improvement in fits to the data and the ability of the model to estimate reasonable fishery selectivity curves when natural mortality is estimated is notable and should be considered in future assessments.

Figure 8.20 and Figure 8.24-Figure 8.29 show fits to the aggregated and yearly proportions-at-age data for the fishery and the survey. Fits to male fishery and survey proportion-at-length data were reasonable. Fits to female fishery proportion-at-length data were generally shifted slightly towards smaller lengths and estimated survey proportions-at-length predicted a smaller proportion of females in the 30-40 cm length bins. Figure 8.30 and Table 8.12 shows the length-at-age relationship estimated by Model 0 and Figure 8.31 shows growth relationships for Model 0 in comparison to those used in previous assessments. Estimates of growth were very similar to those obtained in previous assessments from estimating growth outside of the assessment model. Figure 8.32-Figure 8.37 show that fits to age-at-length data are reasonable, as most expected ages-at-length match the mean of the observed values in most years. An exception is expected female age-at-length in 2011, where expected mean age at older lengths is greater than the observed mean age. The expected standard deviation of age-at-length (right column, Figure 8.32-Figure 8.37) is sometimes very different from the observed standard deviation at large lengths. This is a result of low sample sizes in the largest length bins: the observed standard deviation in a length bin will be 0 if only 1 fish in that bin was aged; the expected standard deviation in age-at-length is calculated based on the entire expected number of fish at a given length in the estimated population.

Yearly estimates of fishing mortality rates are reported in Table 8.11.

Additional plots of Model 1 were provided to show the improved fits to length-composition and conditional age-at-length data when natural mortality was estimated (Figure 8.40-Figure 8.54). In addition, Figure 8.54 shows a phase plot based on Model 1 to show implications of the higher values estimated for natural mortality on the model's interpretation of stock status and fishing mortality over time, relative to key reference points.

Time Series Results

Time series results are shown in Table 8.13-Table 8.14 and Figure 8.38-Figure 8.39. A time series of numbers at age is available at http://www.afsc.noaa.gov/REFM/docs/2013/GOA_Flathead_TimeSeries_of_NumbersAtAge_2013.xlsx. Age 3 recruitment, age 0 recruitment, and standard deviations of age 0 recruitment are presented in Table 8.13 for the previous and current assessments. Total biomass for ages 3+, spawning stock biomass, and standard deviations of spawning stock biomass estimates for the previous and current assessments are presented in Table 8.14. Figure 8.38 shows spawning stock biomass estimates and corresponding asymptotic 95% confidence intervals. Figure 8.39 is a plot of biomass relative to $B_{35\%}$ and F relative to $F_{35\%}$ for each year in the time series, along with the OFL and ABC control rules.

HARVEST RECOMMENDATIONS

The reference fishing mortality rate for flathead sole is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{40\%}$, $F_{35\%}$, and $SPR_{40\%}$ were obtained from a spawner-per recruit analysis. Assuming that the average recruitment from the 1983-2010 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{40\%}$ is calculated as the product of $SPR_{40\%}$ times the equilibrium number of recruits. Since reliable estimates of the 2013 spawning biomass (B), $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and $B>B_{40\%}$, the flathead sole reference fishing mortality is defined in Tier 3a. For this tier, F_{ABC} is constrained to be $\leq F_{40\%}$, and F_{OFL} is defined to be $F_{35\%}$. The values of these quantities are:

SSB 2013	84,058
$B_{40\%}$	35,532
$F_{40\%}$	0.47
max$Fabc$	0.47
$B_{35\%}$	31,090
$F_{35\%}$	0.61
F_{OFL}	0.61

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

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). For each scenario, the projections begin with the vector of 2013 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2014 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2013. 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 2014, are as follow ("max F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2014 recommended in the assessment to the *max*F_{ABC} for 2014. (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 2008-2013 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.) The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, so scenarios 1 and 2 yield identical results. The 12-year projections of the mean spawning stock biomass, fishing mortality, and catches for the five scenarios are shown in Table 8.15Table 8.17.

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

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above its MSY level in 2014, then the stock is not overfished.)

Scenario 7: In 2014 and 2015, 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 2026 under this scenario, then the stock is not approaching an overfished condition.)

The results of these two scenarios indicate that the stock is not overfished and is not approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2014 of scenario 6 is 84,059 t, more than 2 times *B35%* (31,090 t). Thus the stock is not currently overfished. With regard to whether the stock is approaching an overfished condition, the expected spawning stock size in the year 2026 of scenario 7 (32,701 t) is greater than *B35%*; thus, the stock is not approaching an overfished condition.

Area Allocation of Harvests

TAC's for flathead sole in the Gulf of Alaska are divided among four smaller management areas (Western, Central, West Yakutat and Southeast Outside). As for previous assessments, the area-specific ABC's for flathead sole in the GOA are divided up over the four management areas by applying the fraction of the most recent survey biomass estimated for each area (relative to the total over all areas) to the 2014 and 2015 ABC's. The area-specific allocations for 2014 and 2015 are:

Quantity	Western	Central	West Yakutat	Southeast	Total
Area Apportionment	30.88%	60.16%	8.55%	0.41%	100.00%
2014 ABC (t)	12,730	24,805	3,525	171	41,231
2015 ABC (t)	12,661	24,670	3,506	170	41,007

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TABLES

Table 8.1. Total and regional annual catch of GOA flathead sole through October 19, 2013.

Year	Total Catch	Western Gulf	Central Gulf	West Yakutat	Southeast
1978	452				
1979	165				
1980	2,068				
1981	1,070				
1982	1,368				
1983	1,080				
1984	549				
1985	320				
1986	147				
1987	151				
1988	520				
1989	747				
1990	1,447				
1991	1,717	42	729	1	
1992	2,034	291	1,735	8	
1993	2,366	581	2,238	2	
1994	2,580	499	2,067	14	
1995	2,181	589	1,563	29	
1996	3,107	807	2,166	103	
1997	2,446	449	1,938	59	
1998	1,742	556	1,156	8	
1999	900	186	687	16	11
2000	1,547	258	1,274	15	0
2001	1,911	600	1,311	0	0
2002	2,145	421	1,724	0	0
2003	2,425	515	1,910	0	0
2004	2,390	831	1,559	0	0
2005	2,530	611	1,919	0	0
2006	3,134	462	2,671	1	0
2007	3,163	694	2,467	2	0
2008	3,419	288	3,131	0	0
2009	3,658	303	3,355	0	0
2010	3,842	462	3,380	0	0
2011	2,339	341	1,998	0	0
2012	2,166	277	1,889	0	0
2013	2,491	582	1,909	0	0

Table 8.2. Time series of ABC, TAC, OFL, and total catch (in tons), and percent of catch retained. The 2013 ABCs, TAC, and OFL are based on the author's recommended model.

Year	Author ABC	ABC	TAC	OFL	Total Catch	% Retained
1995	--	28,790	9,740	31,557	2,181	
1996	--	52,270	9,740	31,557	3,107	
1997	--	26,110	9,040	34,010	2,446	
1998	--	26,110	9,040	34,010	1,742	
1999	--	26,010	9,040	34,010	900	
2000	--	26,270	9,060	34,210	1,547	
2001	--	26,270	9,060	34,210	1,911	
2002	22,684	22,690	9,280	29,530	2,145	
2003	41,402	41,390	11,150	51,560	2,425	88
2004	51,721	51,270	10,880	64,750	2,390	80
2005	36,247	45,100	10,390	56,500	2,530	87
2006	37,820	37,820	9,077	47,003	3,134	89
2007	39,110	39,110	9,148	48,658	3,163	89
2008	44,735	44,735	11,054	55,787	3,419	90
2009	46,464	46,464	11,181	57,911	3,658	96
2010	47,422	47,422	10,411	59,295	3,842	95
2011	49,133	49,133	10,587	61,412	2,339	97
2012	47,407	47,407	30,319	59,380	2,166	92
2013	62,185	62,185		79,059	2,491	87

Table 8.3. Survey biomass by year and area

Year	Central	Western	Yakutat	Southeastern	Total	Total CV
1984	158,539	45,100	45,694	9	249,341	0.12
1987	113,483	33,603	30,455	5	177,546	0.11
1990	161,257	58,740	23,019	40	243,055	0.06
1993	113,976	57,871	16,720	124	188,690	0.13
1996	122,730	66,732	12,751	3,308	205,521	0.09
1999	139,356	49,636	15,115	3,482	207,590	0.12
2001	85,430	68,164			153,594	0.12
2003	170,852	67,055	17,154	2,234	257,294	0.08
2005	142,043	59,458	11,400	312	213,213	0.08
2007	176,529	78,361	21,430	3,970	280,290	0.08
2009	128,910	80,115	9,458	6,894	225,377	0.11
2011	128,428	76,049	22,656	8,506	235,639	0.09
2013	121,063	62,131	17,205	833	201,233	0.09

Table 8.4. Survey biomass estimates and CVs used in the assessment as an absolute index of abundance.

Year	Biomass Estimate	CV
1984	249,341	0.12
1987	177,546	0.11
1990	243,055	0.12
1993	188,690	0.13
1996	205,521	0.09
1999	207,590	0.12
2001	170,660	0.12
2003	257,294	0.08
2005	213,213	0.08
2007	280,290	0.08
2009	225,377	0.11
2011	235,639	0.09
2013	201,233	0.09

Table 8.5. Configuration of fishery and survey age-based, sex-specific double-normal selectivity curves used in the assessment. A numeric value indicates the fixed value of a parameter. The asterisk denotes that the parameter was estimated, but constrained to be below age 16 for Models 0 and 2. A constraint was not needed for Models 1 and 3 where natural mortality was estimated.

Double-normal selectivity parameters	**Fishery**	**Survey**
Peak: beginning size for the plateau (in cm)	Estimated*	Estimated
Width: width of plateau	30	30
Ascending width (log space)	Estimated	Estimated
Descending width (log space)	8	8
Initial: selectivity at smallest length or age bin	-10	-10
Final: selectivity at largest length or age bin	999	999
Male Peak Offset	Estimated	Estimated
Male ascending width offset (log space)	Estimated	Estimated
Male descending width offset (log space)	0	0
Male "Final" offset (transformation required)	0	0
Male apical selectivity	1	1

Table 8.6. Negative log likelihood components for all four models. All models include the same data.

Likelihood Component	Model 0	Model 1	Model 2	Model 3
TOTAL	1,663	1,589	1,690	1,605
Survey	-15.77	-13.79	-14.89	-14.54
Length_comp	182	166	198	178
Age_comp	1,498	1,446	1,508	1,451
Recruitment	-0.996	-9.284	-0.920	-8.531

Table 8.7. Final parameter estimates of growth, natural mortality, and unfished recruitment parameters with corresponding standard deviations for all four alternative models.

	Model 0		Model 1		Model 2		Model 3	
Parameter	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Female natural mortality	0.2	NA	0.2873	0.01	0.2	NA	0.291	0.01
Length at age 2 (f)	9.306	0.221	9.506	0.235	9.282	0.221	9.505	0.235
Linf (f)	44.209	0.419	45.395	0.485	44.033	0.412	45.317	0.481
von Bertalanffy k (f)	0.190	0.006	0.174	0.006	0.193	0.006	0.175	0.006
CV in length at age 2 (f)	0.110	0.008	0.109	0.008	0.110	0.008	0.108	0.008
CV in length at age 59 (f)	0.082	0.003	0.075	0.003	0.083	0.003	0.075	0.003
Male natural mortality	0.200	NA	0.317	0.012	0.200	NA	0.321	0.012
Length at age 2 (m)	9.778	0.297	9.980	0.279	9.751	0.297	9.982	0.280
Linf (m)	36.846	0.241	38.022	0.275	36.782	0.237	38.027	0.274
von Bertalanffy k (m)	0.256	0.007	0.230	0.007	0.259	0.007	0.230	0.007
CV in length at age 2 (m)	0.147	0.008	0.146	0.007	0.147	0.008	0.146	0.007
CV in length at age 59 (m)	0.065	0.003	0.054	0.003	0.065	0.003	0.054	0.003
R0 (log space)	12.801	0.044	14.011	0.142	12.776	0.036	14.069	0.141
R0 offset (log space)	Fixed	NA	0	NA	Fixed	0.07	-0.281	0.085

Table 8.8. Final fishery selectivity parameters for the four alternative models. “Est” refers to the estimated value and “Std. Dev” is the standard deviation of the estimate.

	Model 0		Model 1		Model 2		Model 3	
Double-normal selectivity parameters	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Peak: beginning size for the plateau (in cm)	16.00	0.13	14.02	1.65	16.00	0.10	14.18	1.60
Width: width of plateau	30.00	NA	30.00	NA	30.00	NA	30.00	NA
Ascending width (log space)	3.53	0.11	2.95	0.40	3.52	0.11	2.97	0.38
Descending width (log space)	8.00	NA	8.00	NA	8.00	NA	8.00	NA
Initial: selectivity at smallest length or age bin	-10	NA	-10	NA	-10	NA	-10	NA
Final: selectivity at largest length or age bin	999	NA	999	NA	999	NA	999	NA
Male Peak Offset	-1.68	1.77	-2.78	1.26	-1.58	1.74	-2.79	1.22
Male ascending width offset (log space)	-0.23	0.46	-0.60	0.40	-0.20	0.45	-0.58	0.38
Male descending width offset (log space)	0.00	NA	0.00	NA	0.00	NA	0.00	NA
Male "Final" offset (transformation required)	1.00	NA	1.00	NA	1.00	NA	1.00	NA
Male apical selectivity	1.00	NA	1.00	NA	1.00	NA	1.00	NA

Table 8.9. As for Table 8.8, but for survey selectivity final parameters values.

	Model 0		Model 1		Model 2		Model 3	
Double-normal selectivity parameters	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Peak: beginning size for the plateau (in cm)	7.12	0.28	9.94	0.41	7.08	0.28	9.99	0.40
Width: width of plateau	30.00	NA	30.00	NA	30.00	NA	30.00	NA
Ascending width (log space)	2.06	0.14	2.77	0.11	2.04	0.14	2.76	0.11
Descending width (log space)	8.00	NA	8.00	NA	8.00	NA	8.00	NA
Initial: selectivity at smallest length or age bin	-10	NA	-10	NA	-10	NA	-10	NA
Final: selectivity at largest length or age bin	999	NA	999	NA	999	NA	999	NA
Male Peak Offset	-0.74	0.32	-1.72	0.37	-0.70	0.31	-1.73	0.36
Male ascending width offset (log space)	-0.32	0.18	-0.52	0.14	-0.30	0.18	-0.52	0.14
Male descending width offset (log space)	0.00	NA	0.00	NA	0.00	NA	0.00	NA
Male "Final" offset (transformation required)	0.00	NA	0.00	NA	0.00	NA	0.00	NA
Male apical selectivity	1.00	NA	1.00	NA	1.00	NA	1.00	NA

Table 8.10. Recruitment deviations and standard deviations for Model 0.

Year	Recruitment Deviations	Std. Dev.	Year	Recruitment Deviations	Std. Dev.
1955	-0.160	0.557	1985	-0.185	0.325
1956	-0.190	0.550	1986	-0.320	0.307
1957	-0.225	0.542	1987	-0.233	0.295
1958	-0.265	0.533	1988	-0.148	0.299
1959	-0.310	0.524	1989	0.249	0.198
1960	-0.361	0.513	1990	-0.410	0.271
1961	-0.417	0.503	1991	-0.014	0.231
1962	-0.477	0.493	1992	0.425	0.163
1963	-0.539	0.482	1993	-0.207	0.209
1964	-0.603	0.472	1994	0.102	0.166
1965	-0.660	0.463	1995	-0.249	0.191
1966	-0.716	0.454	1996	-0.580	0.226
1967	-0.776	0.445	1997	0.374	0.130
1968	-0.838	0.437	1998	0.071	0.162
1969	-0.901	0.429	1999	0.503	0.137
1970	-0.956	0.423	2000	-0.391	0.259
1971	-0.986	0.419	2001	0.213	0.147
1972	-0.980	0.418	2002	0.072	0.160
1973	-0.924	0.420	2003	0.294	0.149
1974	-0.806	0.428	2004	0.039	0.180
1975	-0.586	0.448	2005	0.350	0.149
1976	-0.182	0.504	2006	-0.191	0.199
1977	0.709	0.333	2007	-0.077	0.205
1978	0.093	0.464	2008	-0.213	0.230
1979	-0.258	0.420	2009	0.155	0.258
1980	-0.115	0.358	2010	0.504	0.322
1981	-0.046	0.346	2011	0.052	0.480
1982	-0.098	0.350			
1983	-0.200	0.359			
1984	-0.187	0.339			

Table 8.11. Estimated yearly fishing mortality rates (rates are apical fishing mortality rates across ages) for Model 0.

Year	Fishing Mortality	Std. Dev.	Year	Fishing Mortality	Std. Dev.
Initial F	0.0086	0.0008	1995	0.0249	0.0022
1978	0.0067	0.0008	1996	0.0360	0.0032
1979	0.0026	0.0003	1997	0.0286	0.0026
1980	0.0341	0.0039	1998	0.0203	0.0019
1981	0.0186	0.0021	1999	0.0103	0.0010
1982	0.0244	0.0027	2000	0.0174	0.0017
1983	0.0194	0.0022	2001	0.0211	0.0020
1984	0.0095	0.0011	2002	0.0234	0.0022
1985	0.0052	0.0006	2003	0.0261	0.0024
1986	0.0022	0.0003	2004	0.0256	0.0024
1987	0.0021	0.0003	2005	0.0269	0.0024
1988	0.0066	0.0008	2006	0.0332	0.0030
1989	0.0089	0.0010	2007	0.0334	0.0031
1990	0.0165	0.0017	2008	0.0358	0.0034
1991	0.0191	0.0018	2009	0.0380	0.0037
1992	0.0225	0.0021	2010	0.0395	0.0039
1993	0.0263	0.0024	2011	0.0277	0.0027
1994	0.0291	0.0026	2012	0.0216	0.0021

Table 8.12. Estimated Length-at-age and weight-at-age for Model 0.

	Length		Weight	
Age	Female	Male	Female	Male
0	2.00	2.00	0.00	0.00
1	5.65	5.89	0.00	0.00
2	9.31	9.78	0.01	0.01
3	15.36	15.90	0.03	0.03
4	20.36	20.64	0.08	0.08
5	24.49	24.31	0.14	0.13
6	27.91	27.14	0.21	0.19
7	30.74	29.34	0.28	0.24
8	33.07	31.04	0.36	0.29
9	35.00	32.35	0.43	0.33
10	36.60	33.37	0.49	0.36
11	37.92	34.15	0.55	0.39
12	39.01	34.76	0.61	0.41
13	39.91	35.23	0.65	0.43
14	40.65	35.60	0.69	0.45
15	41.27	35.88	0.73	0.46
16	41.78	36.10	0.76	0.47
17	42.20	36.27	0.78	0.47
18	42.55	36.40	0.80	0.48
19	42.84	36.50	0.82	0.48
20	43.07	36.58	0.83	0.49
21	43.27	36.64	0.85	0.49
22	43.43	36.69	0.86	0.49
23	43.57	36.72	0.86	0.49
24	43.68	36.75	0.87	0.49
25	43.77	36.77	0.88	0.50
26	43.85	36.79	0.88	0.50
27	43.91	36.80	0.89	0.50
28	43.96	36.81	0.89	0.50
29	44.04	36.82	0.89	0.50

Table 8.13. Time series of recruitment at ages 3 and 0 and standard deviation of age 0 recruits for the previous and current assessments.

	2011 Assessment			*2013 Assessment*		
Year	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. dev**	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. dev**
1978				100,774	358,535	165,729
1979				150,505	251,699	105,587
1980				365,437	289,323	103,307
1981		369,890	39,146	196,748	309,033	106,072
1982		375,356	36,446	138,123	292,494	102,141
1983		322,515	32,397	158,769	263,263	92,987
1984	203,000	349,847	33,746	169,587	265,842	91,170
1985	206,000	437,309	39,146	160,516	265,419	85,684
1986	177,000	335,270	33,746	144,479	231,152	71,352
1987	192,000	371,712	33,746	145,895	251,384	73,740
1988	240,000	393,578	35,096	145,664	272,819	82,111
1989	184,000	473,751	36,446	126,856	404,447	78,027
1990	204,000	377,179	32,397	137,958	208,573	57,071
1991	216,000	442,775	35,096	149,718	308,667	71,517
1992	260,000	366,246	31,047	221,949	477,306	75,450
1993	207,000	408,155	32,397	114,458	252,968	53,346
1994	243,000	419,087	33,746	169,384	343,279	56,150
1995	201,000	326,159	29,697	261,922	240,966	46,048
1996	224,000	317,049	29,697	138,818	172,439	39,645
1997	230,000	479,217	37,796	188,371	447,516	56,870
1998	179,000	544,814	41,846	132,230	330,472	53,743
1999	174,000	581,256	45,895	94,628	509,094	68,171
2000	263,000	424,554	39,146	245,590	208,070	54,735
2001	299,000	444,597	44,545	181,356	380,791	56,138
2002	319,000	486,506	49,945	279,375	330,704	53,962
2003	233,000	608,588	66,143	114,181	413,028	62,922
2004	244,000	440,953	60,744	208,962	320,105	59,460
2005	267,000	659,607	93,140	181,476	436,627	67,398
2006	334,000	371,712	86,391	226,652	254,330	52,683
2007	242,000	249,630	116,088	175,656	284,855	60,856
2008	362,000	253,275	103,939	239,595	248,675	59,976
2009	204,000			139,560	362,494	97,638
2010	137,000			156,309	536,437	178,348
2011	139,000			136,455	355,967	176,865
2012				198,917	362,445	15,778
2013				294,376	362,445	
Average	227,964	422,513	0	177,535	322,324	

Table 8.14. Time series of total and spawning biomass and standard deviation of spawning biomass (Std_Dev) for the previous and current assessments.

	2011 Assessment			*2013 Assessment*		
Year	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**
1978				269,959	51,926	5,349
1979				126,738	49,361	4,913
1980				125,801	47,308	4,504
1981				135,017	44,867	4,131
1982				145,957	44,019	3,806
1983				158,409	44,516	3,545
1984	210,000	49,000	3,000	169,804	47,103	3,370
1985	221,000	59,000	4,000	180,069	51,879	3,304
1986	229,000	68,000	4,000	188,930	57,830	3,347
1987	234,000	76,000	4,000	195,676	63,517	3,432
1988	240,000	81,000	4,000	200,541	67,904	3,477
1989	243,000	84,000	4,000	203,678	70,756	3,467
1990	245,000	86,000	4,000	204,544	72,470	3,422
1991	247,000	86,000	4,000	204,089	73,083	3,361
1992	249,000	86,000	4,000	202,641	72,992	3,293
1993	251,000	86,000	4,000	203,362	72,348	3,221
1994	253,000	86,000	4,000	202,816	71,365	3,147
1995	255,000	86,000	4,000	202,782	70,378	3,072
1996	256,000	87,000	4,000	206,051	69,971	3,000
1997	257,000	87,000	3,000	209,034	69,659	2,945
1998	257,000	88,000	3,000	211,821	70,224	2,907
1999	256,000	89,000	3,000	213,612	71,498	2,884
2000	258,000	90,000	3,000	213,109	73,417	2,873
2001	262,000	91,000	3,000	215,414	74,985	2,877
2002	268,000	91,000	3,000	217,217	75,985	2,880
2003	273,000	91,000	3,000	222,411	76,306	2,868
2004	278,000	91,000	3,000	225,341	76,200	2,839
2005	282,000	92,000	3,000	228,763	76,389	2,813
2006	290,000	93,000	4,000	231,545	77,226	2,818
2007	294,000	95,000	4,000	235,092	78,381	2,871
2008	302,000	97,000	4,000	237,259	79,679	2,959
2009	305,000	99,000	4,000	240,735	80,631	3,067
2010	303,000	101,000	5,000	241,844	81,282	3,197
2011	297,000	102,000	5,000	241,226	81,824	3,365
2012				238,297	82,867	3,570
2013				236,745	83,899	3,812
2014				252,361	84,058	0

Table 8.15. Projected spawning biomass for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2013	83,899	83,899	83,899	83,899	83,899	83,899	83,899
2014	84,059	84,059	84,059	84,059	84,059	84,059	84,059
2015	65,264	65,264	83,575	80,846	85,071	60,818	65,264
2016	53,319	53,319	82,903	77,912	85,730	47,456	53,319
2017	46,318	46,318	82,616	75,798	86,601	40,315	43,688
2018	42,896	42,896	83,067	74,800	88,041	37,186	39,122
2019	41,547	41,547	84,003	74,595	89,822	36,152	37,263
2020	40,827	40,827	84,802	74,486	91,343	35,673	36,260
2021	39,968	39,968	85,077	74,031	92,234	35,017	35,298
2022	38,919	38,919	84,856	73,227	92,538	34,203	34,323
2023	37,918	37,918	84,341	72,251	92,468	33,486	33,527
2024	37,145	37,145	83,705	71,261	92,203	33,010	33,018
2025	36,642	36,642	83,060	70,359	91,862	32,775	32,771
2026	36,366	36,366	82,470	69,597	91,513	32,706	32,701

Table 8.16. Projected fishing mortality rates for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2013	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2014	0.47	0.47	0.03	0.09	0.00	0.61	0.47
2015	0.47	0.47	0.03	0.09	0.00	0.61	0.47
2016	0.47	0.47	0.03	0.09	0.00	0.61	0.61
2017	0.47	0.47	0.03	0.09	0.00	0.61	0.61
2018	0.47	0.47	0.03	0.09	0.00	0.61	0.61
2019	0.47	0.47	0.03	0.09	0.00	0.60	0.61
2020	0.47	0.47	0.03	0.09	0.00	0.59	0.60
2021	0.47	0.47	0.03	0.09	0.00	0.58	0.58
2022	0.47	0.47	0.03	0.09	0.00	0.57	0.57
2023	0.47	0.47	0.03	0.09	0.00	0.56	0.56
2024	0.46	0.46	0.03	0.09	0.00	0.55	0.55
2025	0.46	0.46	0.03	0.09	0.00	0.55	0.55
2026	0.46	0.46	0.03	0.09	0.00	0.55	0.55

Table 8.17. Projected catches for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2013	2,861	2,861	2,861	2,861	2,861	2,861	2,861
2014	41,231	41,231	3,079	8,706	-	50,664	41,231
2015	31,114	31,114	3,081	8,381	-	35,371	31,114
2016	24,799	24,799	3,076	8,090	-	26,792	30,619
2017	21,001	21,001	3,071	7,844	-	22,148	24,331
2018	18,887	18,887	3,068	7,654	-	19,842	21,083
2019	17,821	17,821	3,072	7,525	-	18,682	19,502
2020	17,282	17,282	3,083	7,447	-	18,011	18,489
2021	16,886	16,886	3,098	7,400	-	17,436	17,671
2022	16,424	16,424	3,110	7,355	-	16,832	16,933
2023	15,932	15,932	3,111	7,294	-	16,298	16,333
2024	15,524	15,524	3,100	7,211	-	15,931	15,937
2025	15,240	15,240	3,078	7,115	-	15,739	15,735
2026	15,076	15,076	3,053	7,024	-	15,684	15,679

Table 8.18. Groundfish bycatch for GOA flathead sole target (in mt; AKFIN, as of November 4th, 2013)

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Arrowtooth Flounder	1477	1756	839	723	801	1337	2650	842	815	1013
Atka Mackerel	8.5	1.8	17.4	35.6	2.7	17.1	10.5	10.3		
Central GOA Skate, Big and Longnose	36.4									
Flathead Sole	909	632	522	423	572	696	1242	371	419	470
GOA Deep Water Flatfish	0.1	2	2.7		4.5	17.9	45.4	18.8	11.6	1.8
GOA Dusky Rockfish									2.5	2.3
GOA Pelagic Shelf Rockfish					1.7	3.8	9.2	1.6		
GOA Rex Sole	242	332	68.1	110	86.3	184	397	103	178	78.7
GOA Rougheye Rockfish		1.3	2.1			2.7	15.3	0.9	18.4	16.4
GOA Shallow Water Flatfish	40.2	2.5	28.7	26.2	41	94.9	122	78.4	150	48.2
GOA Shortraker Rockfish		0.7	7.1			2.6	1.3			1.7
GOA Shortraker/Rougheye Rockfish	2.3									
GOA Skate, Big		21.1	30.3	22.7	65.6	53.2	112	30.8	57.4	14.6
GOA Skate, Longnose		10.9	11.5	13.2	10.8	23.7	30	16.6	59.7	7.9
GOA Skate, Other	52.5	37.8	11.8	19.8	4.7	12.6	18.9	12.5	17	7.9
GOA Thornyhead Rockfish	7.1	1.1	5.7	7.1		7.5	12.6			8.1
Northern Rockfish	4.5	11.4			0.4	1.1	6	7.1	1.6	13.3
Octopus										
Other Rockfish					2.2		1.7			0.3
Other Species	59.5	73.9	16.1	34.7	13.9	9.2	21.5			
Pacific Cod	194	153	38	131	125	279	297	93.7	134	102
Pacific Ocean Perch	16	8.5	4.1	10.8	1.8	1.8	74.3	1.9	2	19.2
Pollock	20.5	10.7	33.4	27	45.4	136	319	101	181	108
Sablefish	6.2	1.5	3.8	4.2	0.7	19	13.7	3.7	6.5	12.5
Sculpin								13.6	4.7	3
Shark								0.3		

Table 8.19. Bycatch of other species in GOA flathead sole target (in mt; AKFIN, as of November 4th, 2013)

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Large Sculpins	10	2	0	0	16	3	4.4	6	5	3
Octopus	0	0	0	0	0	0	0.7	0	0	0
Other Sculpins	0	0	0	0	0	0	0.3	0	0	0
Shark, Other	4	5	0	0	0	0	0	0	0	0
Shark, pacific sleeper	29	48	3	19	0	0	1.3	0	0	0
Shark, salmon	0	0	0	0	0	0	0	0	0	0
Shark, spiny dogfish	0	1	0	0	0	0	13	0	0	0
Skate, Alaska	0	0	0	0	0	0	0	3	0	2
Skate, Aleutian	0	0	0	0	0	0	0	4	7	1
Skate, Big	38	21	30	23	66	53	112	31	57	15
Skate, Longnose	7	11	12	13	11	24	30	17	60	8
Skate, Other	44	38	12	20	5	13	19	6	10	5

Table 8.20. Retained (R) and discarded (D) flathead sole in target fisheries (in mt; AKFIN, as of November 4th, 2013)

	2004		2005		2006		2007		2008		2009		2010		2011		2012		2013	
	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R	D	R
Arrowtooth Flounder	85	702	94	1077	47	1200	114	1370	80	1113	3	1198	18	1080	36	1464	45	811	0	782
Atka Mackerel															0	0				
Deep Water Flatfish	0	10	0	1									0	6	0	6			0	0
Flathead Sole	238	671	110	523	93	429	44	379	48	524	11	685	42	1194	13	358	7	412	10	461
Halibut	0	0			0	0			0	1	0	0	0	0						
No retained catch																				
Other Species	1	11	0	0											0	1	0	0	0	1
Pacific Cod	29	38	5	14	76	104	29	214	9	313	13	95	10	33	5	150	3	158	3	183
Pollock - bottom	9	169	1	111	11	518	13	256	3	320	11	150	1	289	0	170	1	138	2	225
Pollock - midwater	21	60	2	54	0	59	1	56	1	80	0	54	0	61	0	43	2	48	1	72
Rex Sole	23	85	19	107	46	222	20	243	55	229	37	592	16	432	12	167	5	224	6	165
Rockfish	10	24	4	72	2	14	1	15	2	15	4	28	4	20	4	9	3	13	3	20
Sablefish	0	1	0	0			0	1	0	3	0	1	0	0	0	1	0	0	0	0
Shallow Water Flatfish	11	145	21	247	5	260	10	301	24	485	1	745	4	534	1	264	4	199	0	319

Table 8.21. Catch of non-target species in the flathead sole target fishery (in mt; AKFIN, as of November 4th, 2013)

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Benthic urochordata	0.01	0	0	0	0	0	0	0.06	0.18	0
Bivalves	0.61	0.8	0.49	0.02	0.4	0.01	0.04	0.38	0	0.06
Brittle star unidentified	0	0	0	0	0	0	1.19	0.02	0	0
Capelin	0	0	0	0	0	0	0	0	0.01	0
Corals Bryozoans	0	0	0	0	0.15	0	0.02	0	0	0
Dark Rockfish	0	0	0	0	0	0.61	0	0	0	0
Eelpouts	0.12	0.46	0.12	0.11	0.01	0	12	2.09	0.04	0.11
Eulachon	0.05	20.4	1.62	0	0.21	0.07	0.28	0.13	0	0.39
Giant Grenadier	0	0	0	0	0	3.32	36	0	0	0
Greenlings	0.01	0	0	0	0	0	0.06	0.22	0	0
Grenadier	64.2	0.57	42.9	0	0	0	0	0.01	31.5	0
Gunnels	0	0	0.03	0	0.01	0	0	0	0	0
Hermit crab unidentified	0	0	0	0	0.21	0	0.01	0.05	0	0
Invertebrate unidentified	0.15	0	0.04	0	0	0	0	0.33	0	0
Misc crabs	0.18	0	0	0	0	0.01	0.09	0.02	0	0
Misc fish	1.11	0.46	0.41	0.15	5.66	3.91	17.3	2.28	5.05	4.42
Other osmerids	0	0	13.9	0	0	0	0	0.02	0	0
Pandalid shrimp	0.04	0.83	0.42	0	0.03	0.02	0.59	0.09	0.28	0.07
Polychaete unidentified	0	0	0	0	0	0	0	0.01	0	0
Scypho jellies	0.05	0	0.26	0	0	0.04	0.25	0	0	0
Sea anemone unidentified	0.21	0	0.02	0	0	0.06	0.69	0.46	0	0.03
Sea pens whips	0	0	0	0	0	0	0.04	0.03	0	0
Sea star	11.4	26.8	1.63	0.55	1.62	0.7	4.65	6.02	0.53	3.66
Snails	0.03	0.53	0.11	0	0.23	0.11	0.25	0.19	0.22	0.11
Sponge unidentified	0.98	0	0	0	0	0	0.09	0.01	0	0
Stichaeidae	0	1.65	0.5	0	0	0.02	0.16	0	0	0.02
urchins dollars cucumbers	0.01	0.12	0	0	0	0	0.08	0.1	0	0

Table 8.22 Prohibited species catch in the flatfish target fishery (in numbers or mt; AKFIN, as of November 4th, 2013)

	2004	2005	2006	2007	2008	2009	2010	2011	2012
Bairdi Tanner Crab	7,514	43,956	25,884	254	6,515	7,683	6,497	5,240	3,120
Blue King Crab	0	0	0	0	0	0	0	0	0
Chinook Salmon	1,446	16	56	0	0	118	496	36	53
Golden (Brown) King Crab	0	0	0	0	0	0	0	0	0
Halibut	105	70	37	27	95	100	257	92	190
Herring	0	0	0	0	0	0	1	0	0
Non-Chinook Salmon	91	0	0	0	0	0	0	0	0
Opilio Tanner (Snow) Crab	0	0	0	0	273	0	0	0	0
Red King Crab	0	0	0	0	0	0	0	0	0

Prohibited Species Catch estimate reported in kilograms for halibut and herring, counts of fish for crab and salmon, by gear for a given target fishery. Source: NMFS AKRO Blend/Catch Accounting System, PSC Estimates

FIGURES

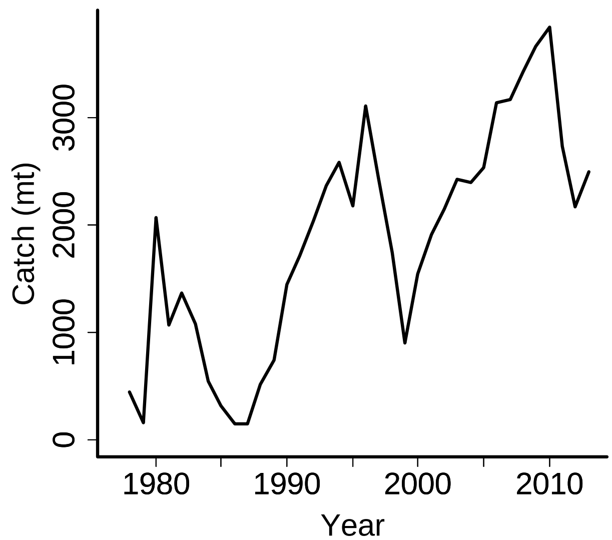


Figure 8.1. Catch biomass in metric tons 1978-2013 (as of October 19, 2013).

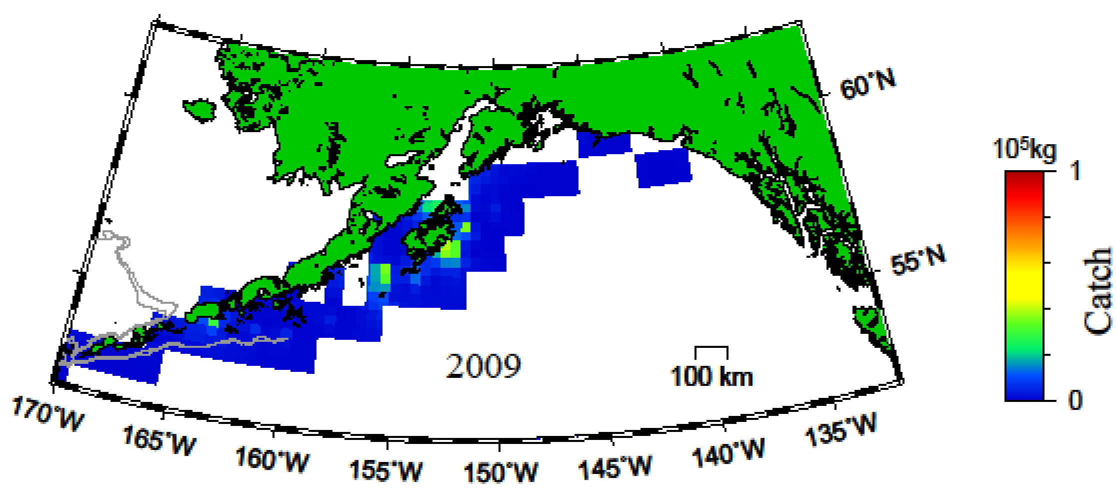


Figure 8.2. Spatial distribution of fishery CPUE in 2009.

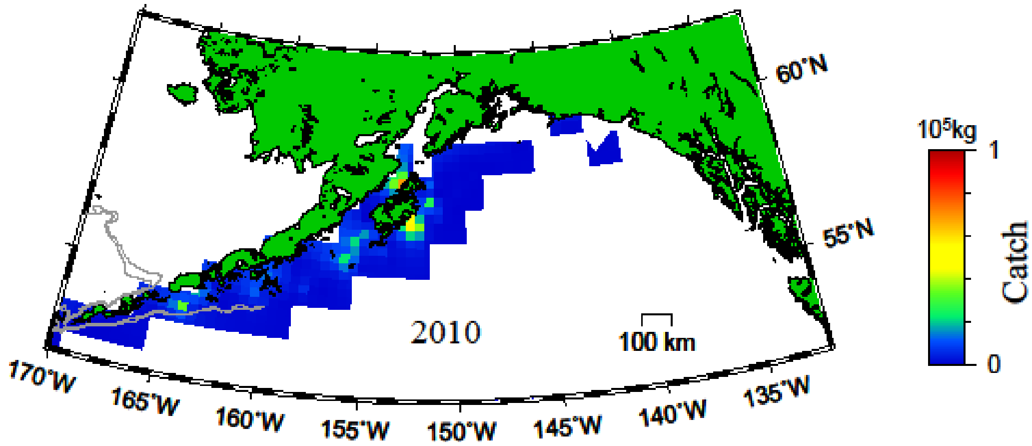


Figure 8.3. Spatial distribution of fishery CPUE in 2010.

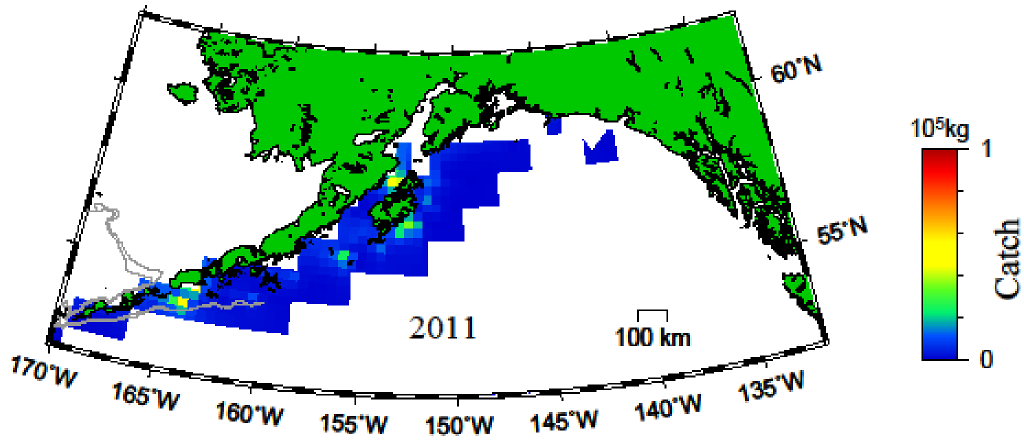


Figure 8.4. Spatial distribution of fishery CPUE in 2011.

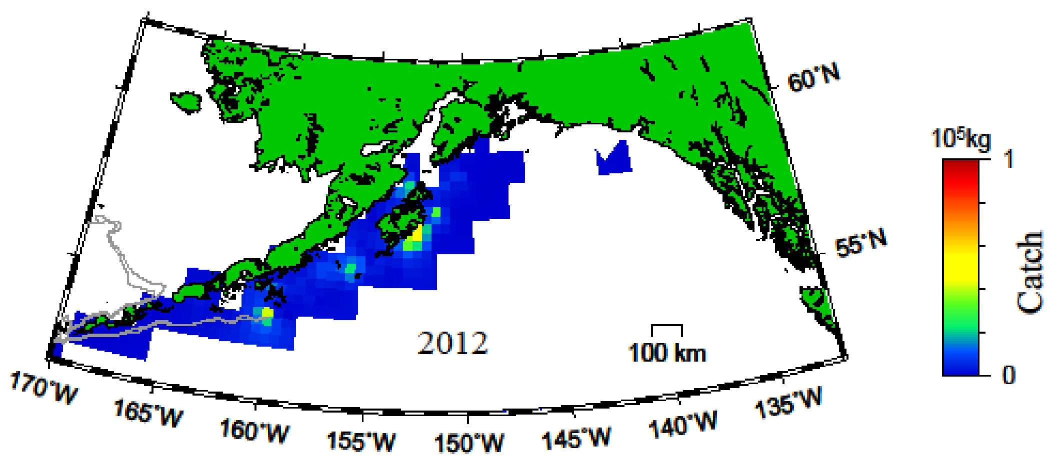


Figure 8.5. Spatial distribution of fishery CPUE in 2012.

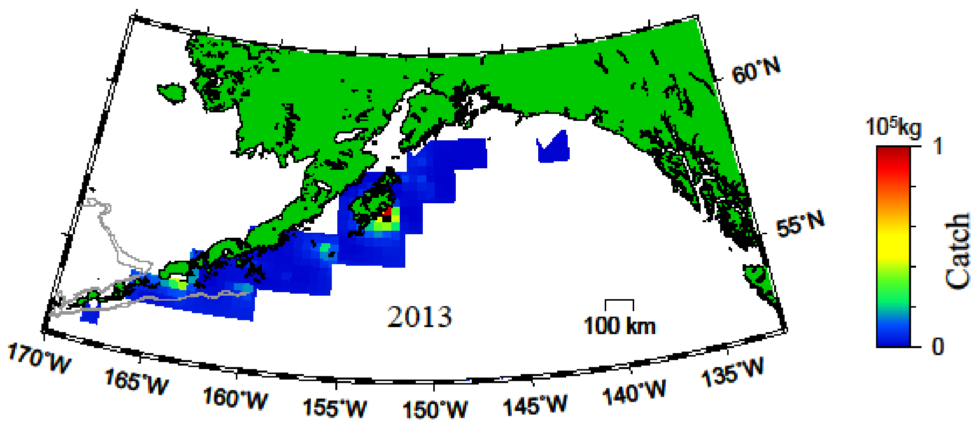


Figure 8.6. Spatial distribution of fishery CPUE in 2013.

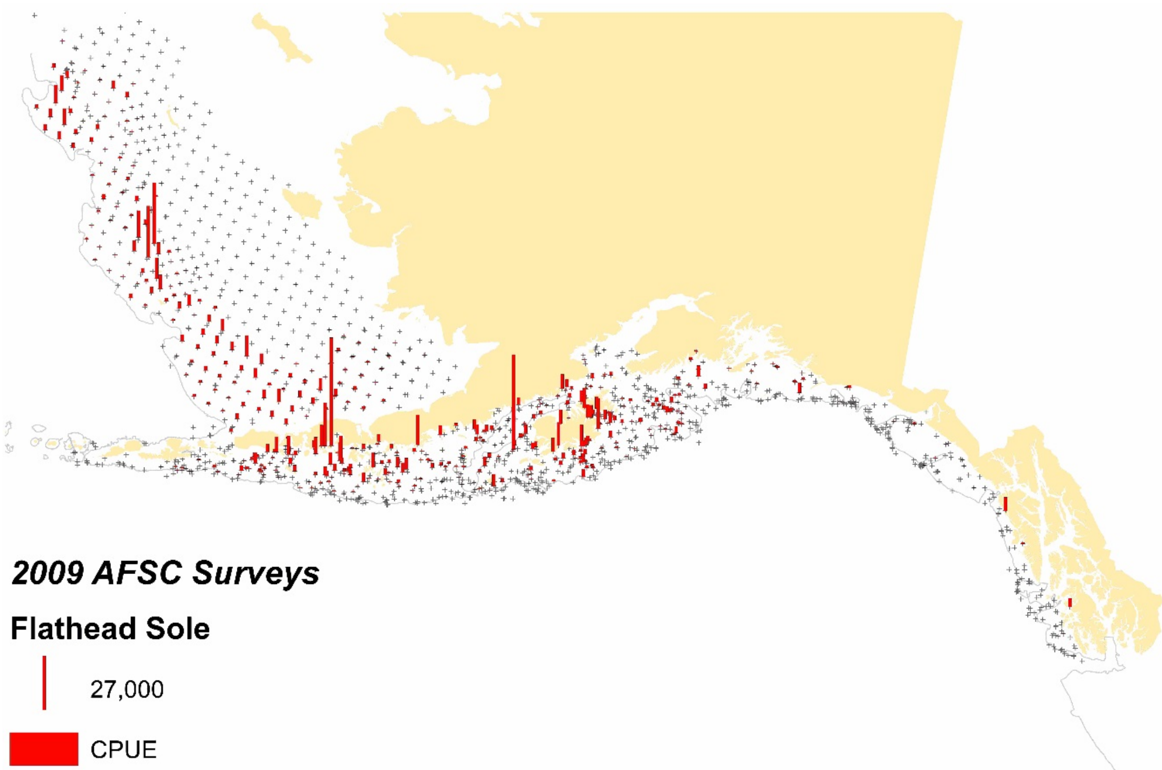


Figure 8.7. Flathead sole CPUE from the survey bottom trawl in 2009.

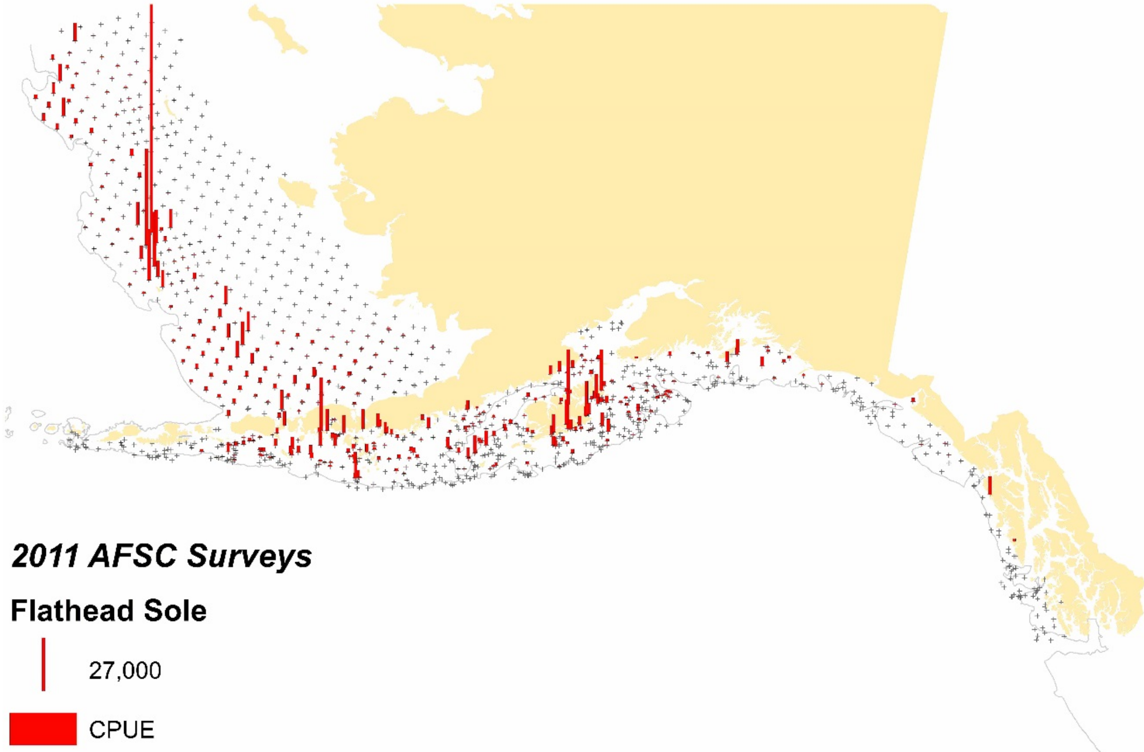


Figure 8.8. Flathead sole CPUE from the survey bottom trawl in 2011.

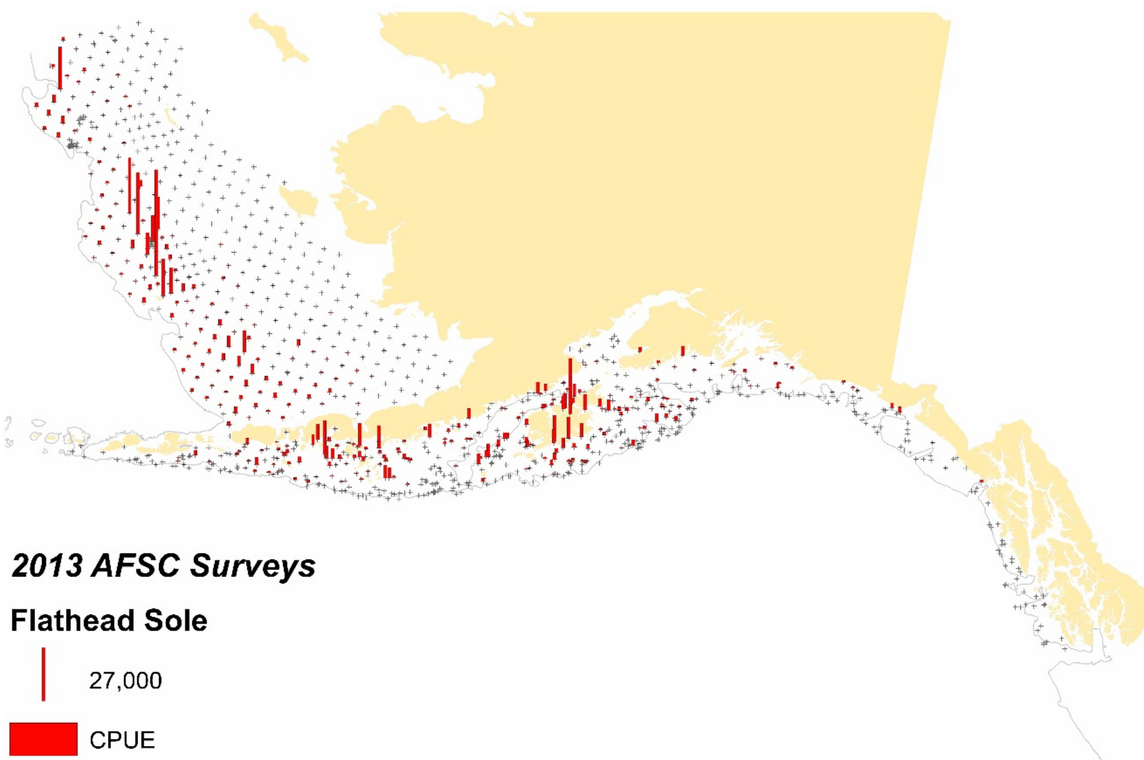


Figure 8.9. Flathead sole CPUE from the survey bottom trawl in 2013.

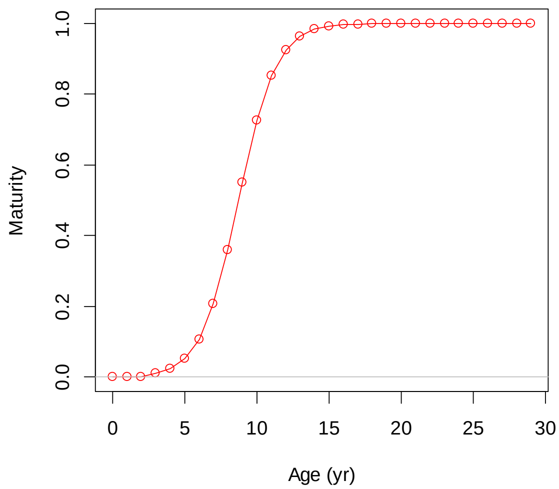


Figure 8.10. Maturity-at-age relationship used for all model runs.

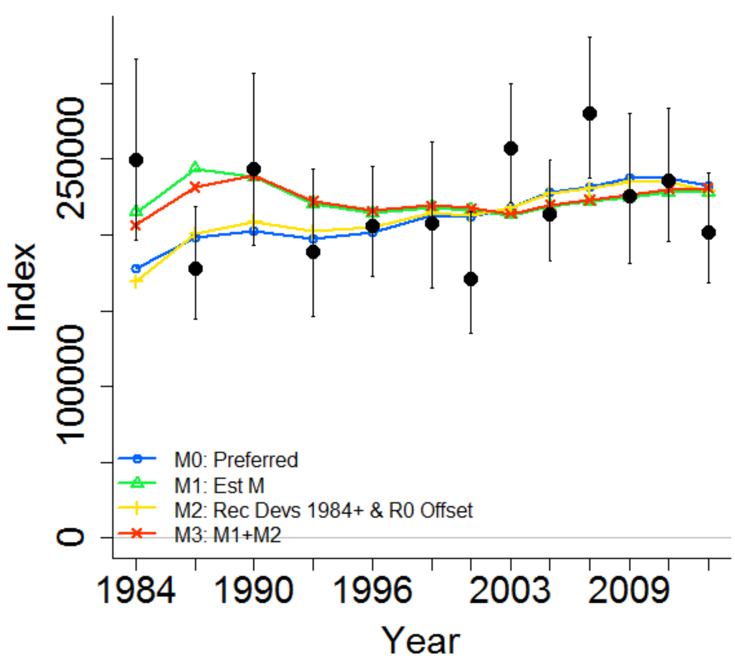


Figure 8.11. Survey biomass index (black dots), asymptotic 95% confidence intervals (vertical black lines), and estimated survey biomass for the four alternative models (solid lines).

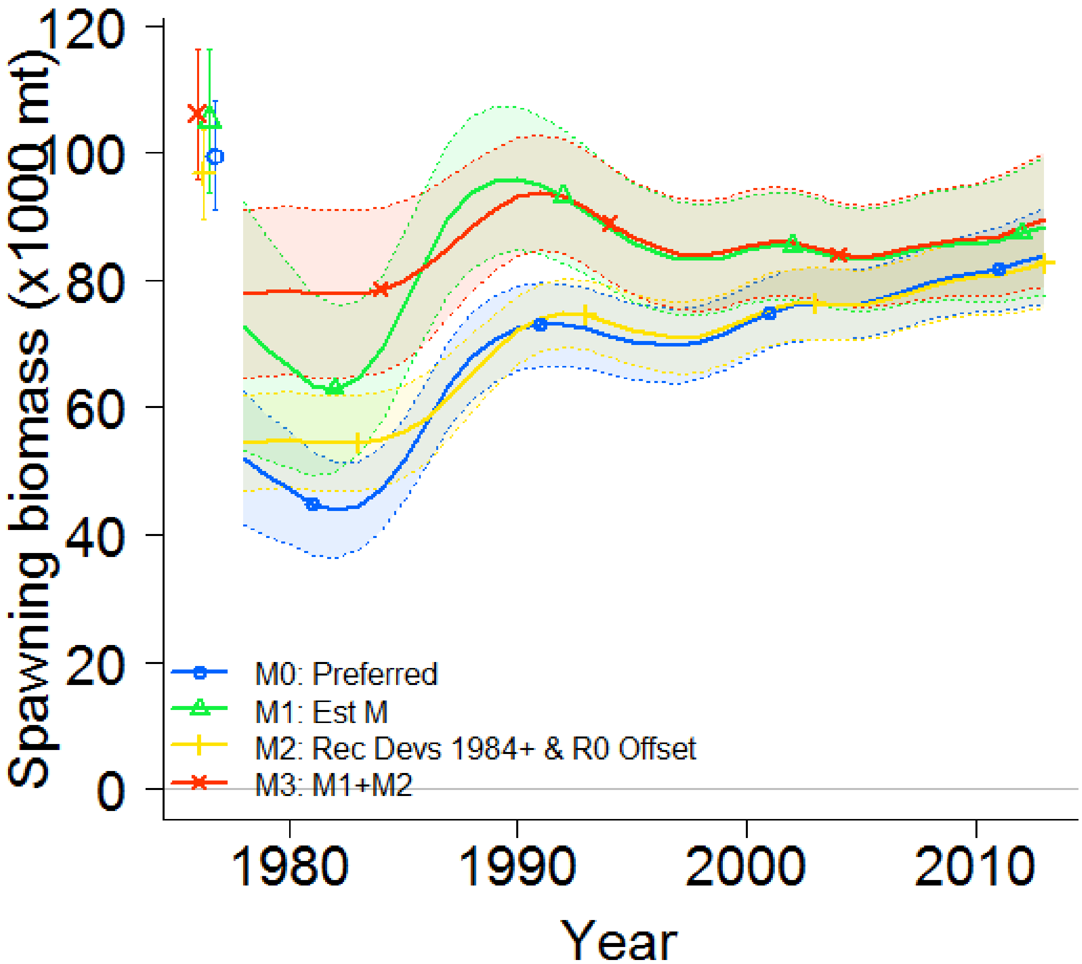


Figure 8.12. Time series of spawning biomass and 95% asymptotic confidence intervals for the four alternative models.

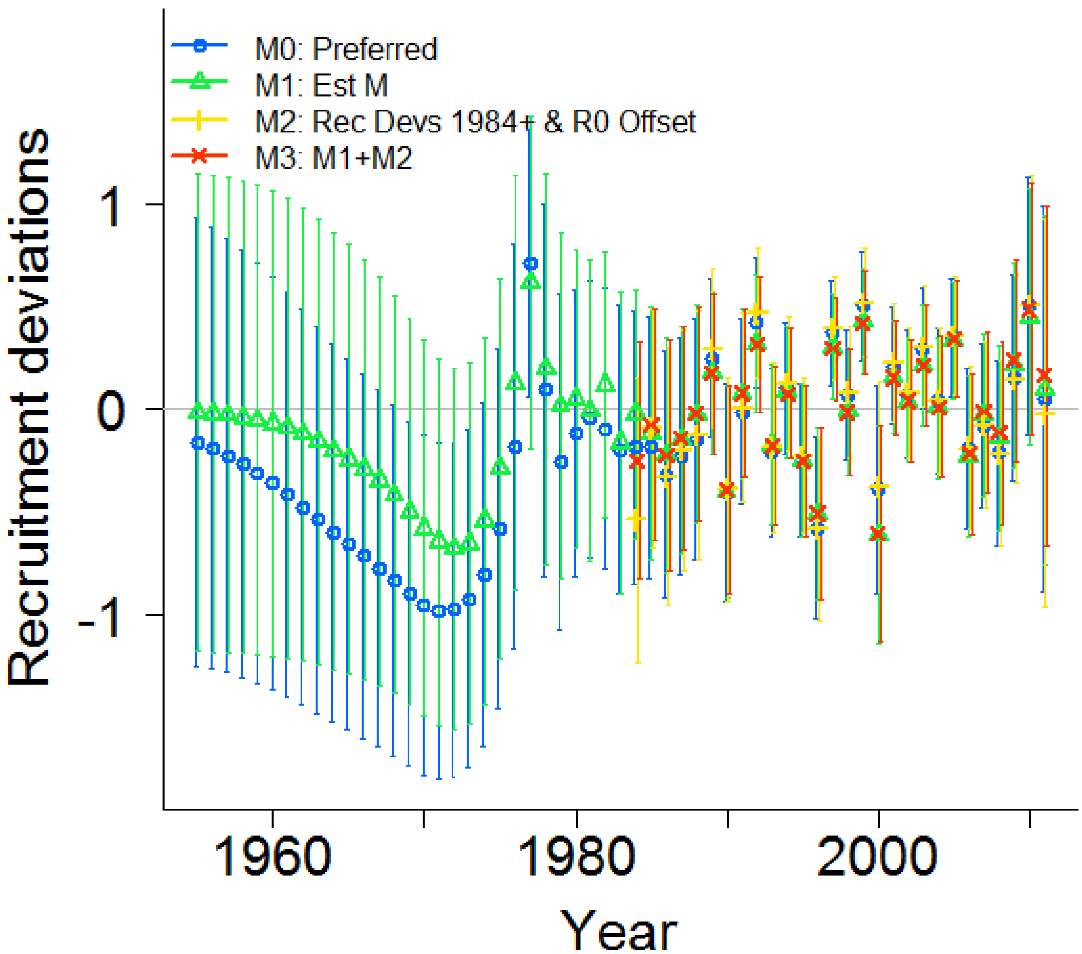


Figure 8.13. Recruitment deviations for years 1978-2012 and 95% asymptotic confidence intervals for the four alternative models.

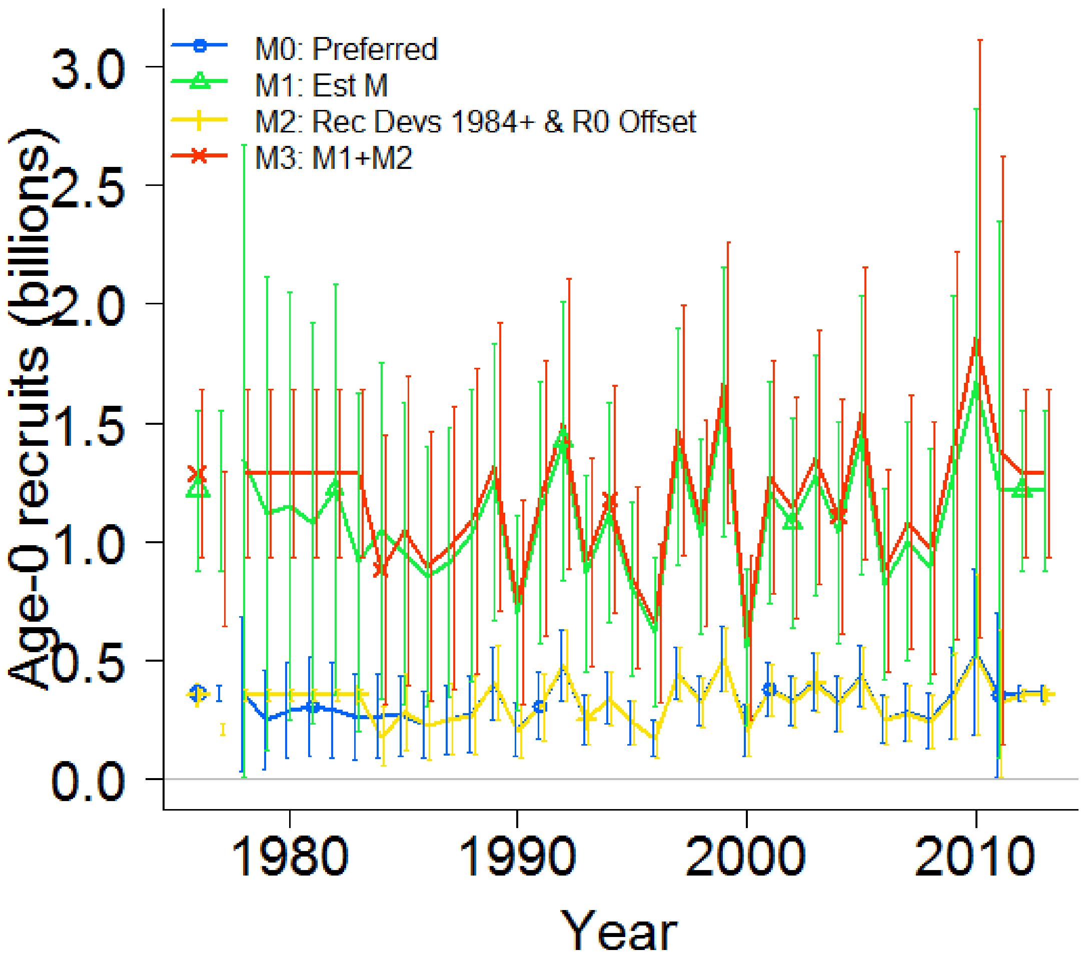


Figure 8.14. Time series of age-0 recruits and asymptotic 95% confidence intervals for the four alternative models.

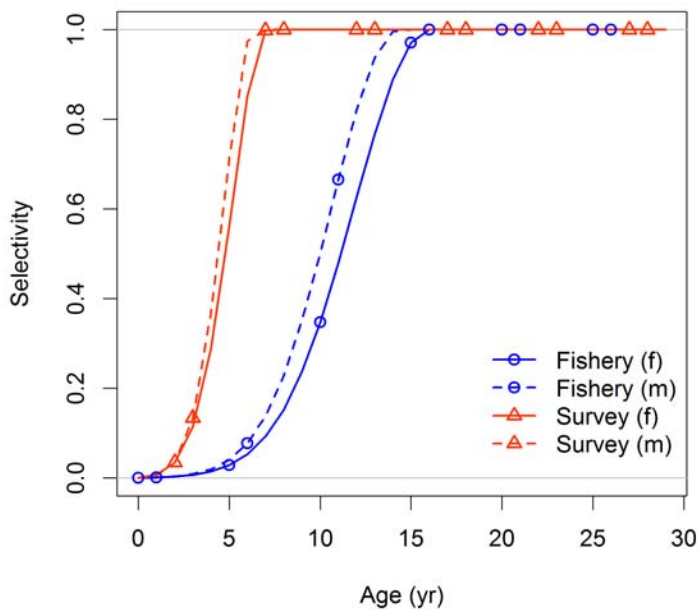


Figure 8.15. Selectivity curves for the fishery (blue lines) and the survey (red lines), and for females (solid lines) and males (dashed lines) for Model 0 (fixed natural mortality) with the curve restricted such that selectivity reaches 1 by age 16.

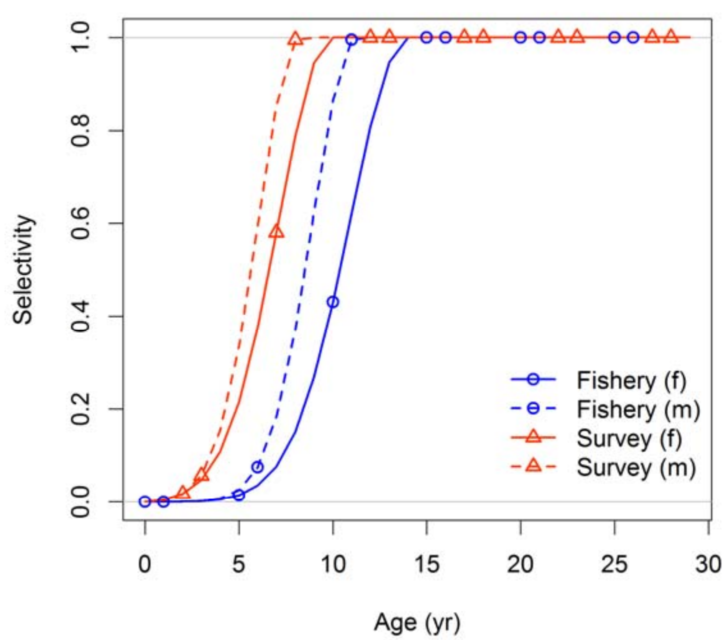


Figure 8.16. Selectivity curves for the fishery (blue lines) and the survey (red lines), and for females (solid lines) and males (dashed lines) for Model 1 (estimated natural mortality). The selectivity parameters are unconstrained.

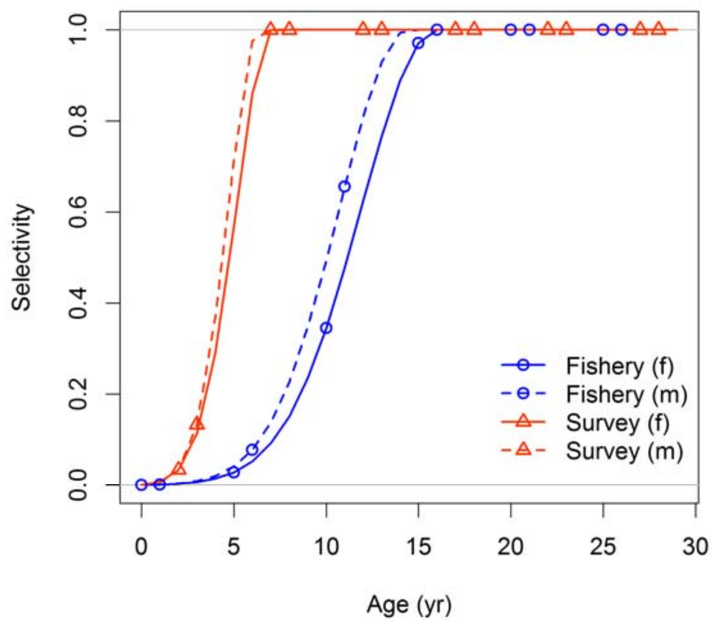


Figure 8.17. Selectivity curves for the fishery (blue lines) and the survey (red lines), and for females (solid lines) and males (dashed lines) for Model 2 (natural mortality is fixed and no early recruitment deviations are estimated). The selectivity curve was restricted such that selectivity reaches 1 by age 16.

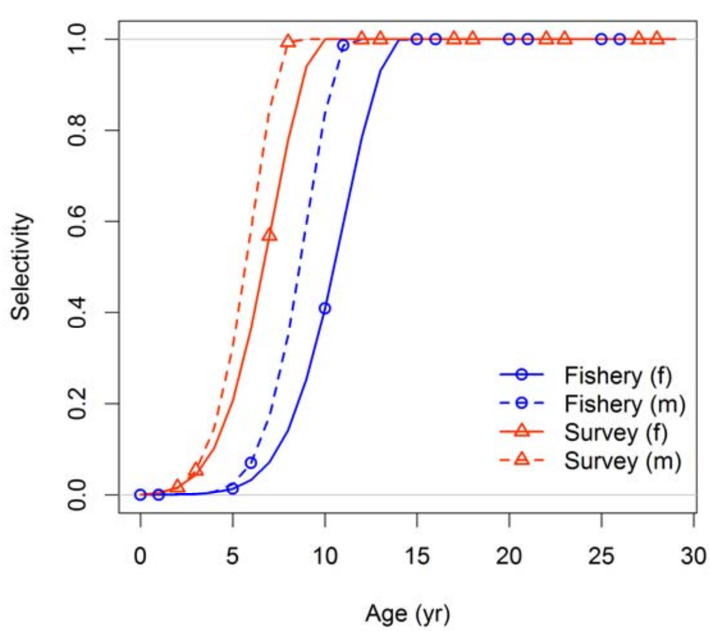


Figure 8.18. Selectivity curves for the fishery (blue lines) and the survey (red lines), and for females (solid lines) and males (dashed lines) for Model 3 (natural mortality is estimated and early recruitment deviations are not estimated; there are no restrictions on selectivity parameters).

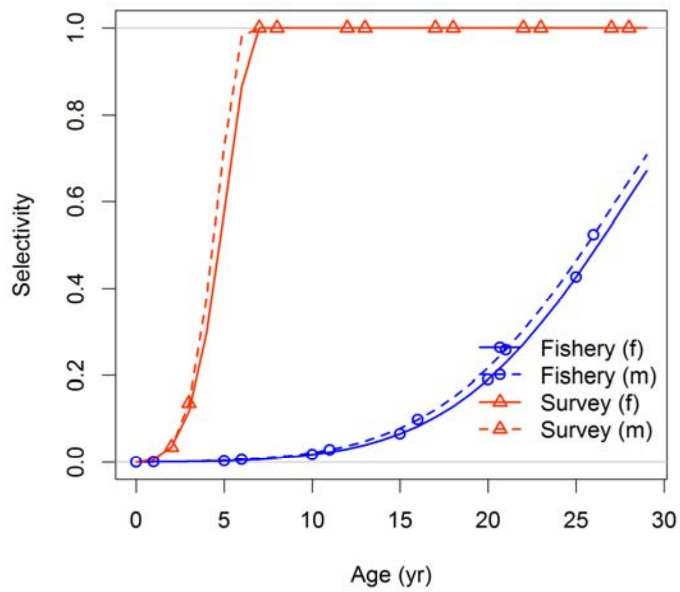


Figure 8.19. Selectivity curves for the fishery (blue lines) and the survey (red lines), and for females (solid lines) and males (dashed lines) for a model identical to Model 0 (fixed natural mortality), except without restrictions on the fishery selectivity curve.

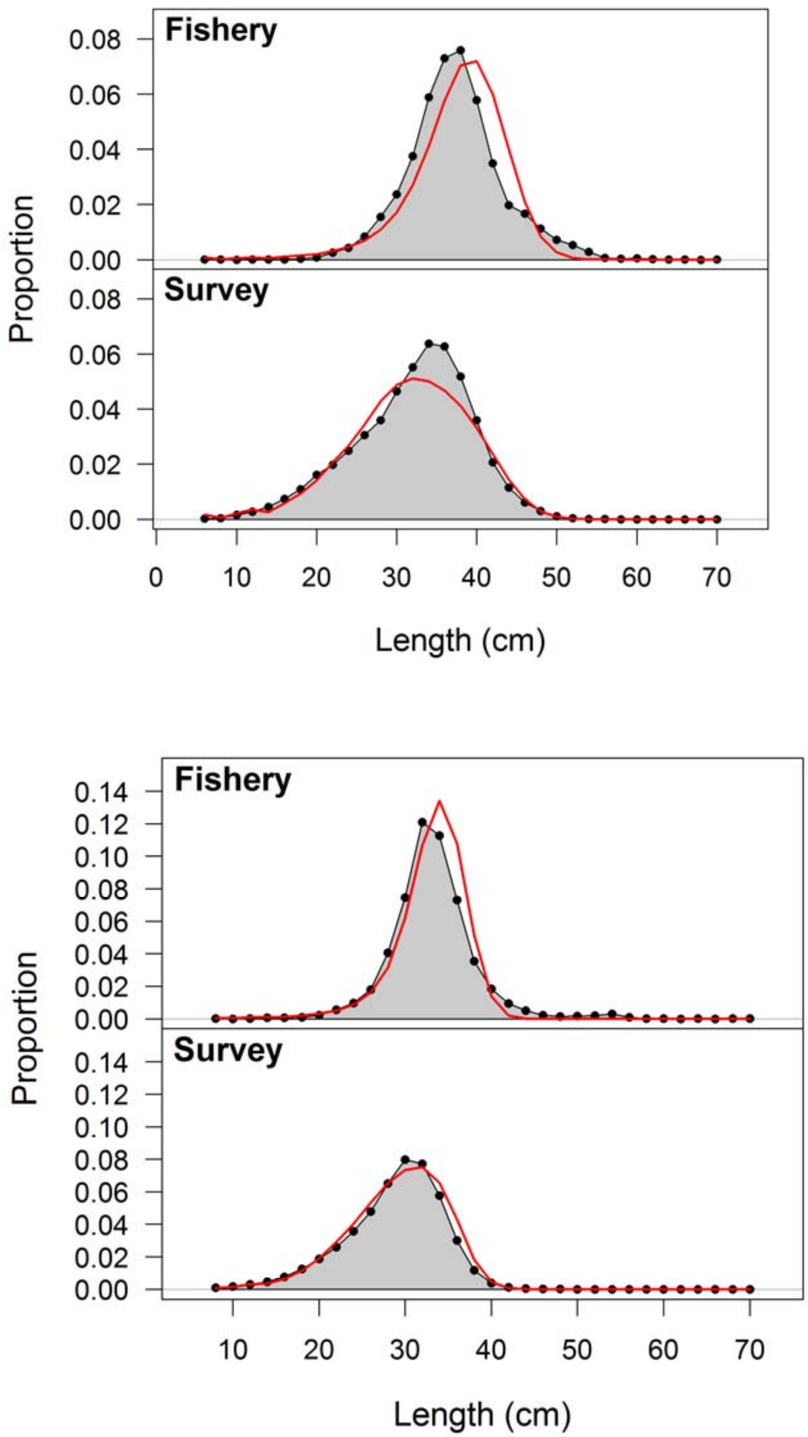
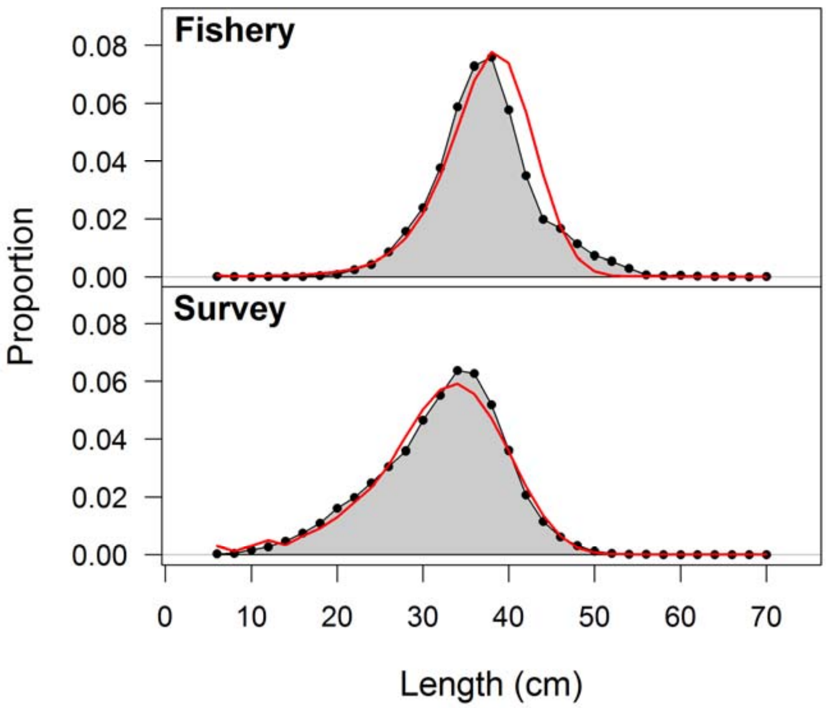


Figure 8.20. Observed (grey shaded area, black lines) and expected (red lines) proportions-at-length, aggregated over years for the fishery and survey and for females (upper panel) and males (lower panel) for Model 0 (fixed natural mortality, estimated early recruitment deviations).



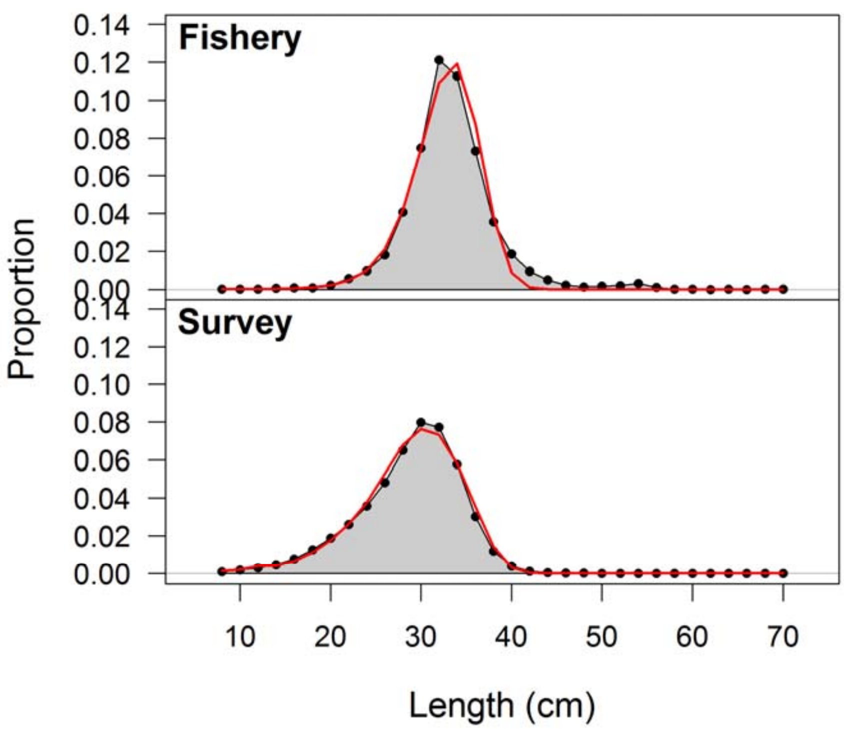
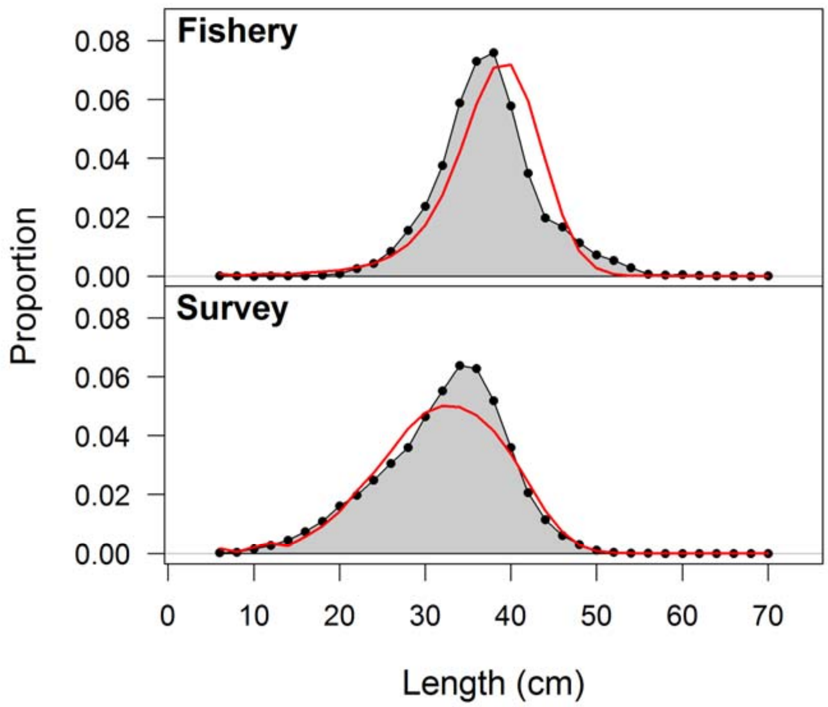


Figure 8.21. Observed (grey shaded area, black lines) and expected (red lines) proportions-at-length, aggregated over years for the fishery and survey and for females (upper panel) and males (lower panel) for Model 1 (estimated natural mortality).



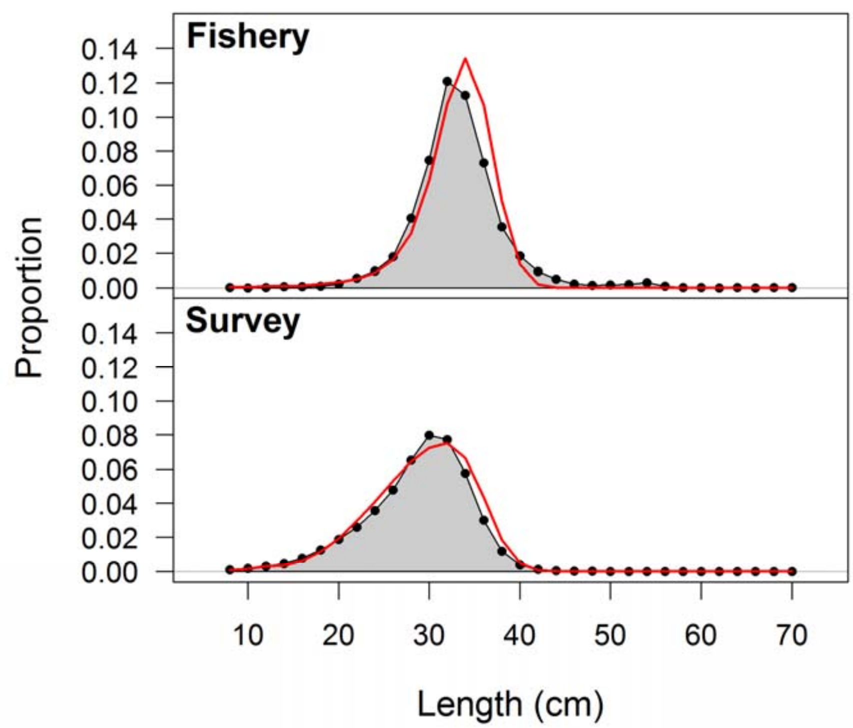
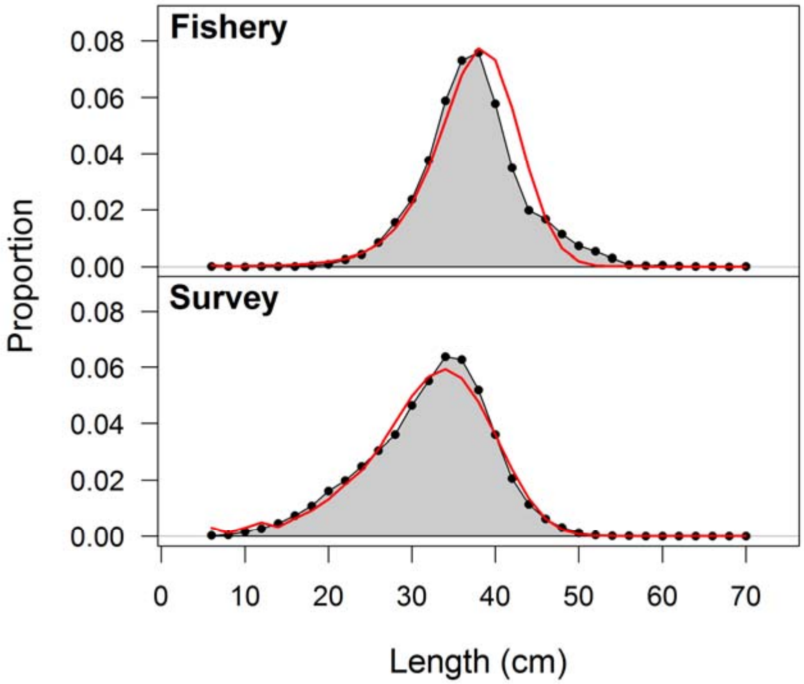


Figure 8.22. Observed (grey shaded area, black lines) and expected (red lines) proportions-at-length, aggregated over years for the fishery and survey and for females (upper panel) and males (lower panel) for Model 2 (fixed M, excluding early recruitment deviations).



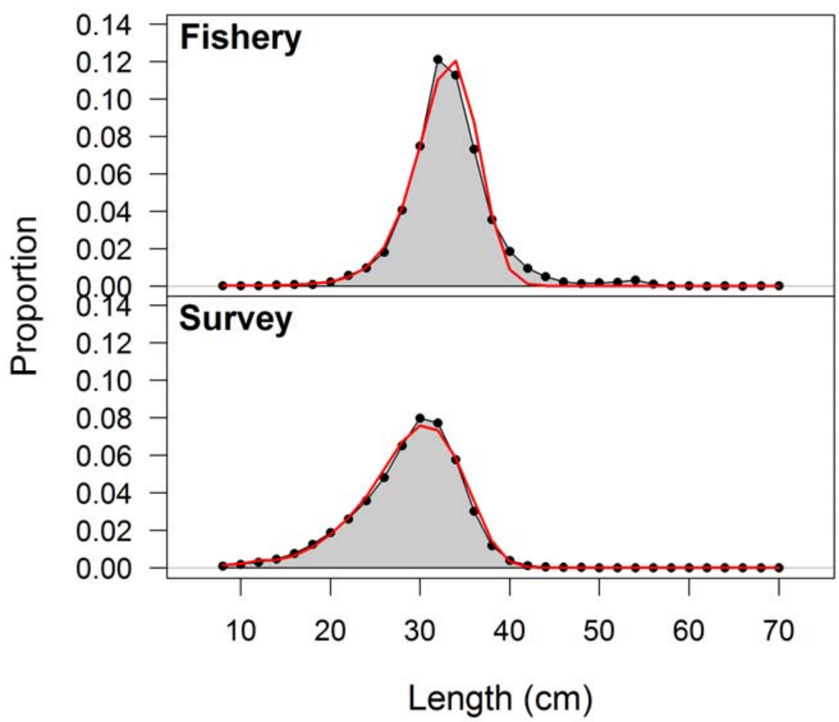


Figure 8.23. Observed (grey shaded area, black lines) and expected (red lines) proportions-at-length, aggregated over years for the fishery and survey and for females (upper panel) and males (lower panel) for Model 3 (estimated natural mortality, excluded early recruitment deviations).

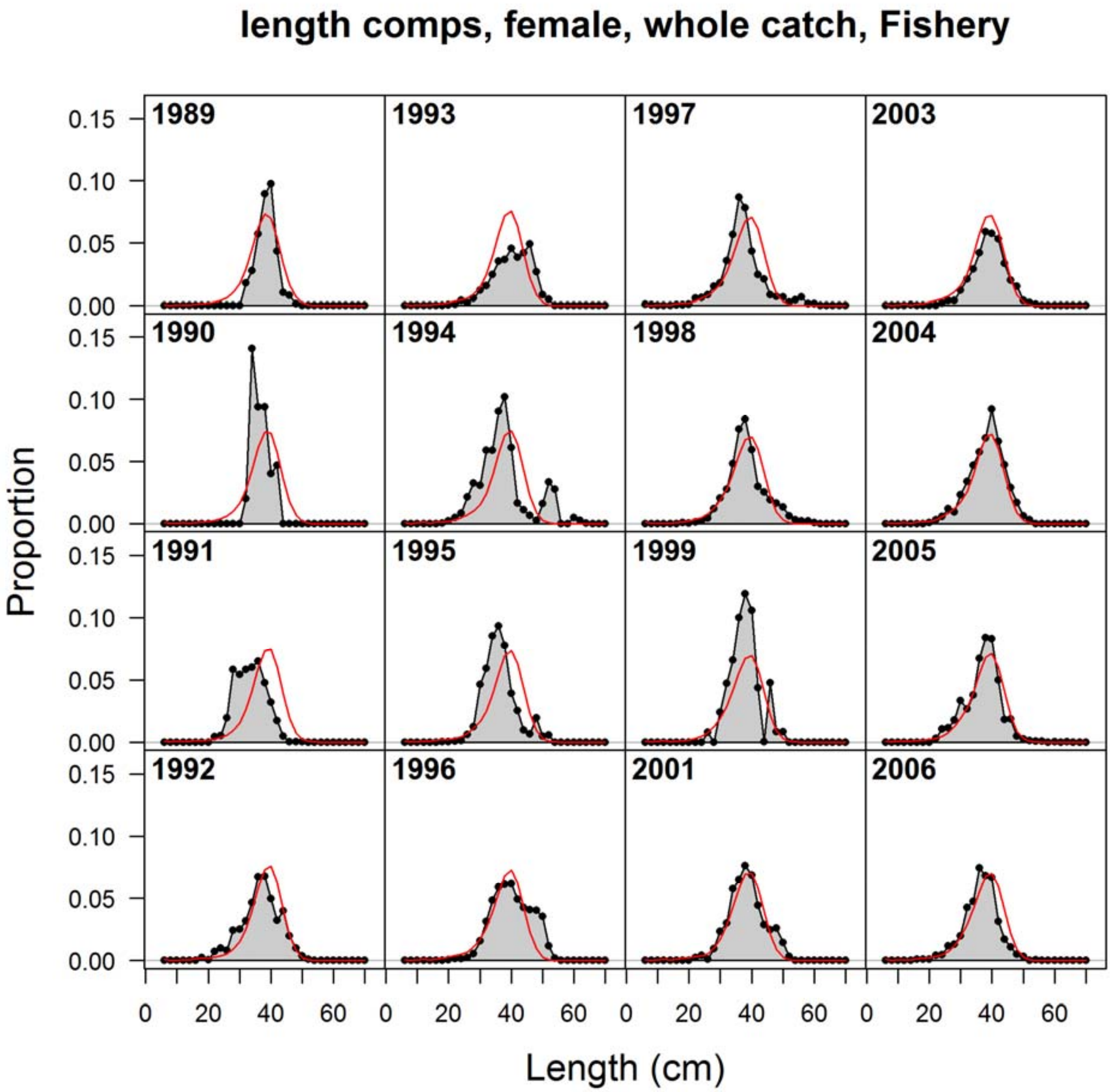


Figure 8.24. Observed (grey filled area and black line) and expected (red lines) female fishery length compositions for Model 0 (fixed natural mortality and estimated early recruitment deviations) for years 1989-2006.

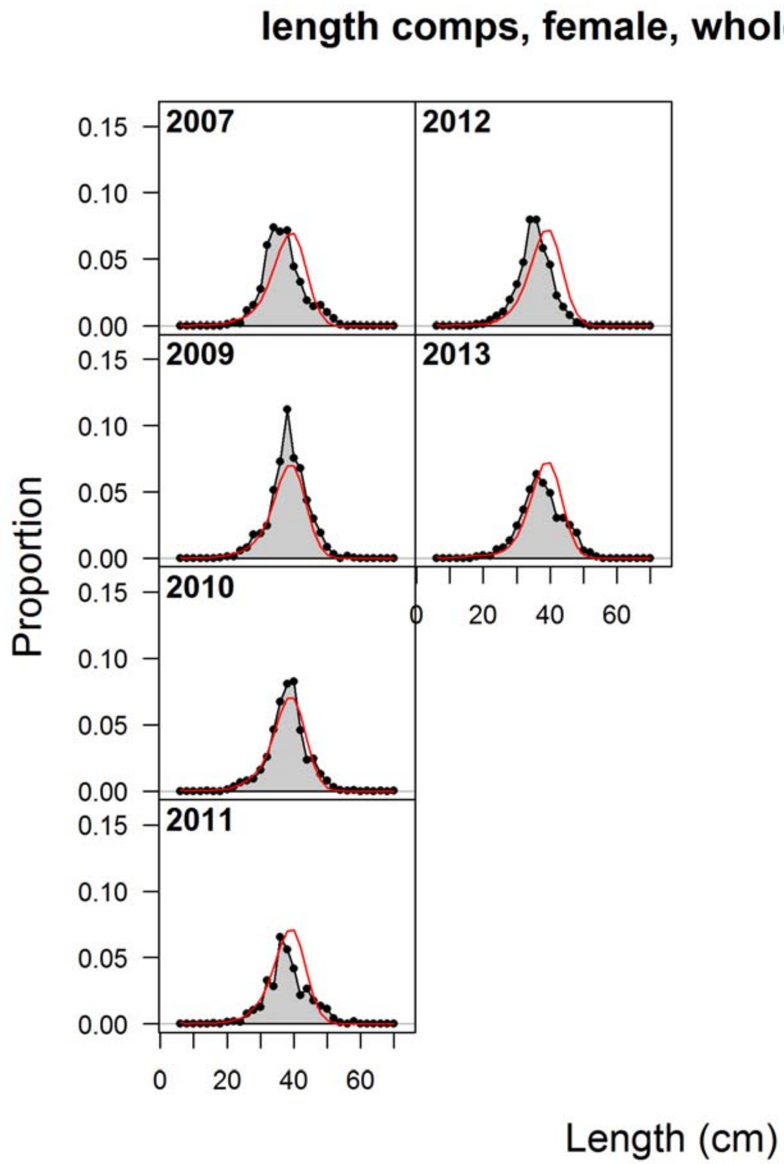


Figure 8.25. Observed (grey filled area and black line) and expected (red lines) female fishery length compositions for Model 0 (fixed natural mortality and estimated early recruitment deviations) for years 2007-2013.

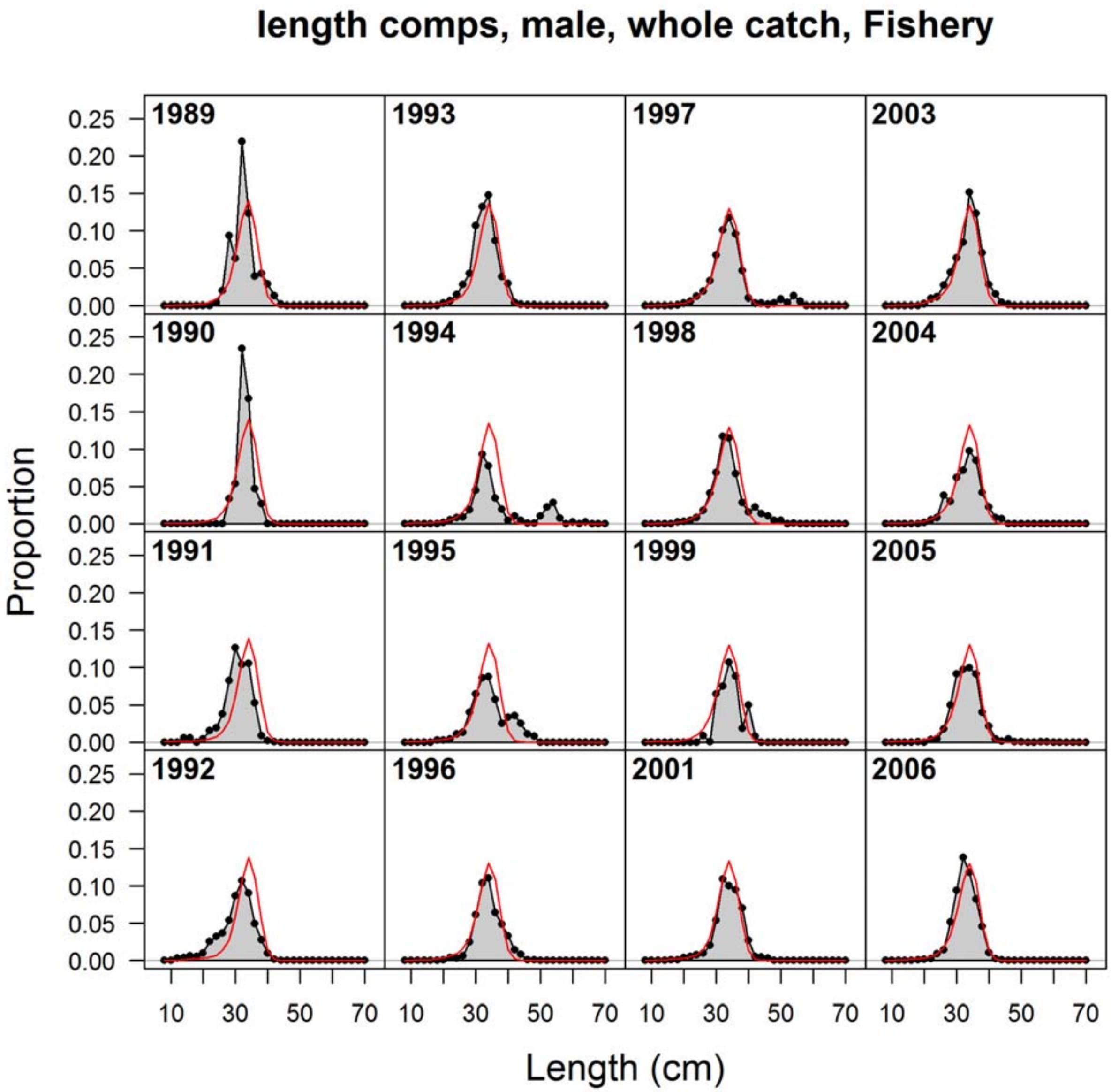


Figure 8.26. Observed (grey filled area and black line) and expected (red lines) male fishery length compositions for Model 0 (fixed natural mortality and estimated early recruitment deviations) for years 1989-2006.

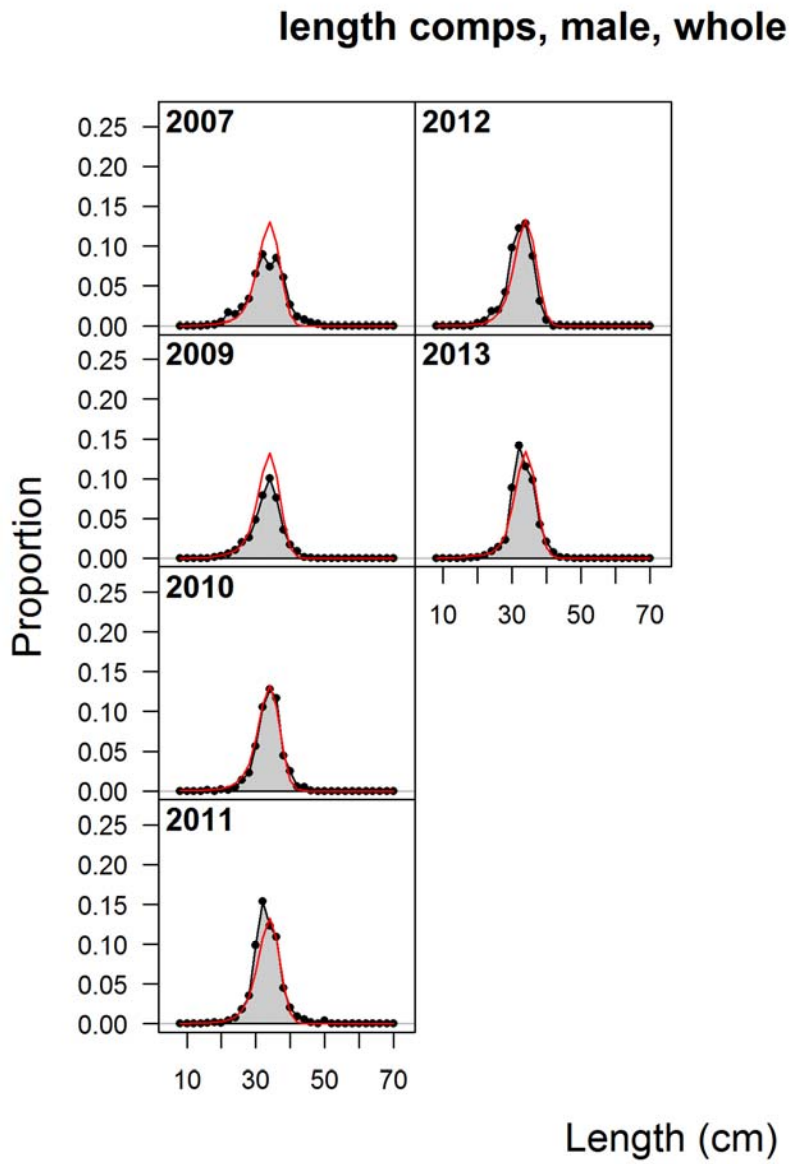


Figure 8.27. Observed (grey filled area and black line) and expected (red lines) male fishery length compositions for Model 0 (fixed natural mortality and estimated early recruitment deviations) for years 2007-2013.

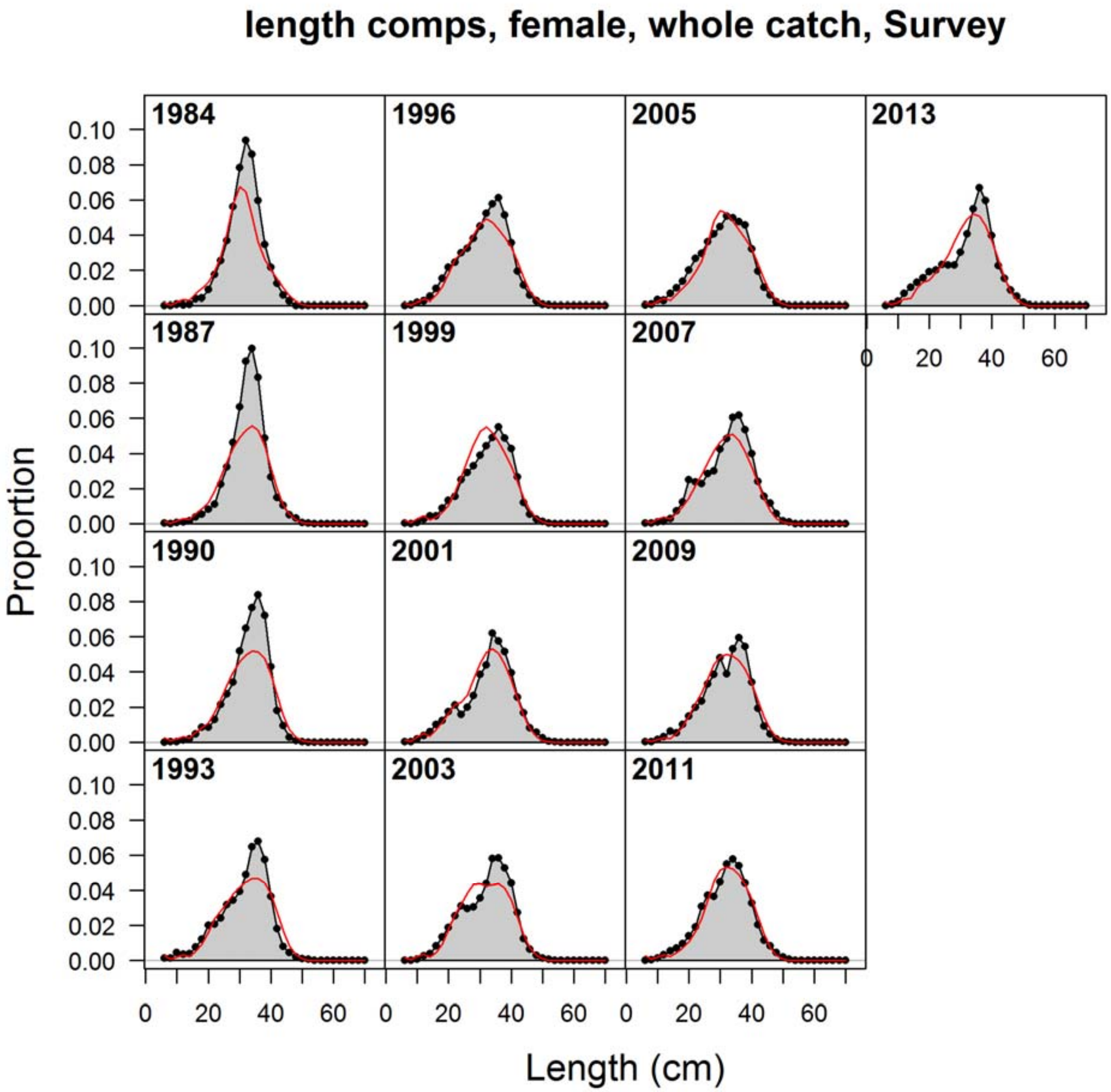


Figure 8.28. Observed (grey filled area and black line) and expected (red lines) female survey length compositions for Model 0 (fixed natural mortality and estimated early recruitment deviations).

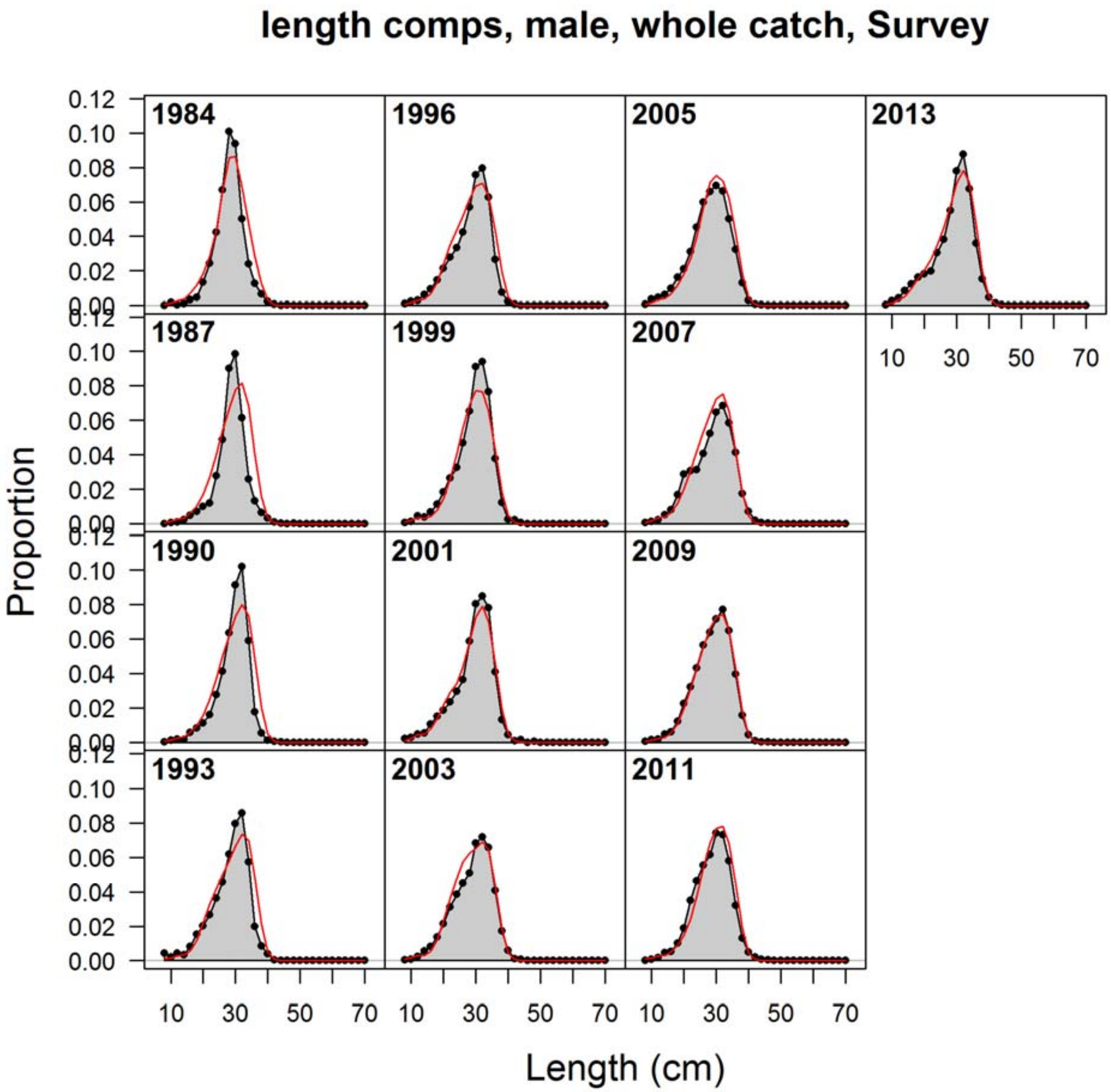


Figure 8.29. Observed (grey filled area and black line) and expected (red lines) male survey length compositions for Model 0 (fixed natural mortality and estimated early recruitment deviations).

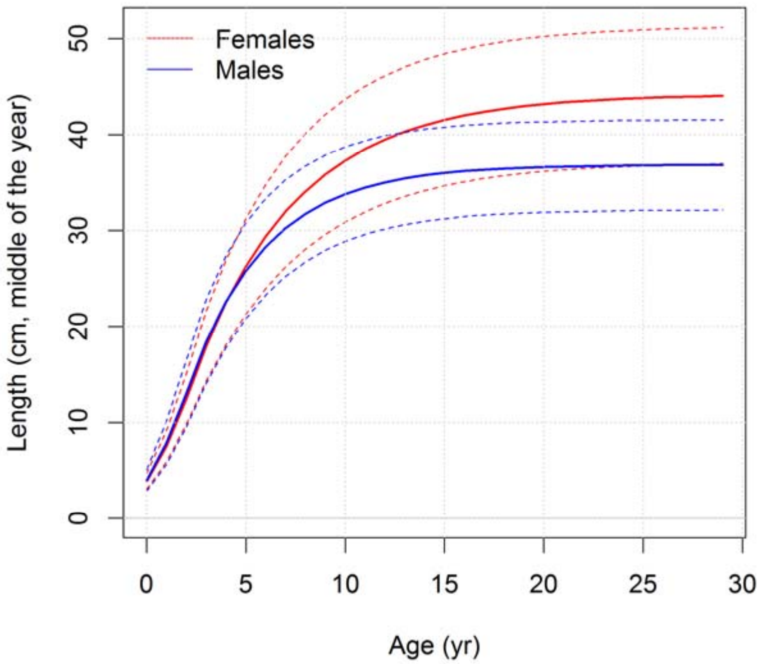


Figure 8.30. Estimated length-at-age for females (red) and males (blue) and 95% intervals (dotted lines) for Model 0 (estimated natural mortality and early recruitment deviations).

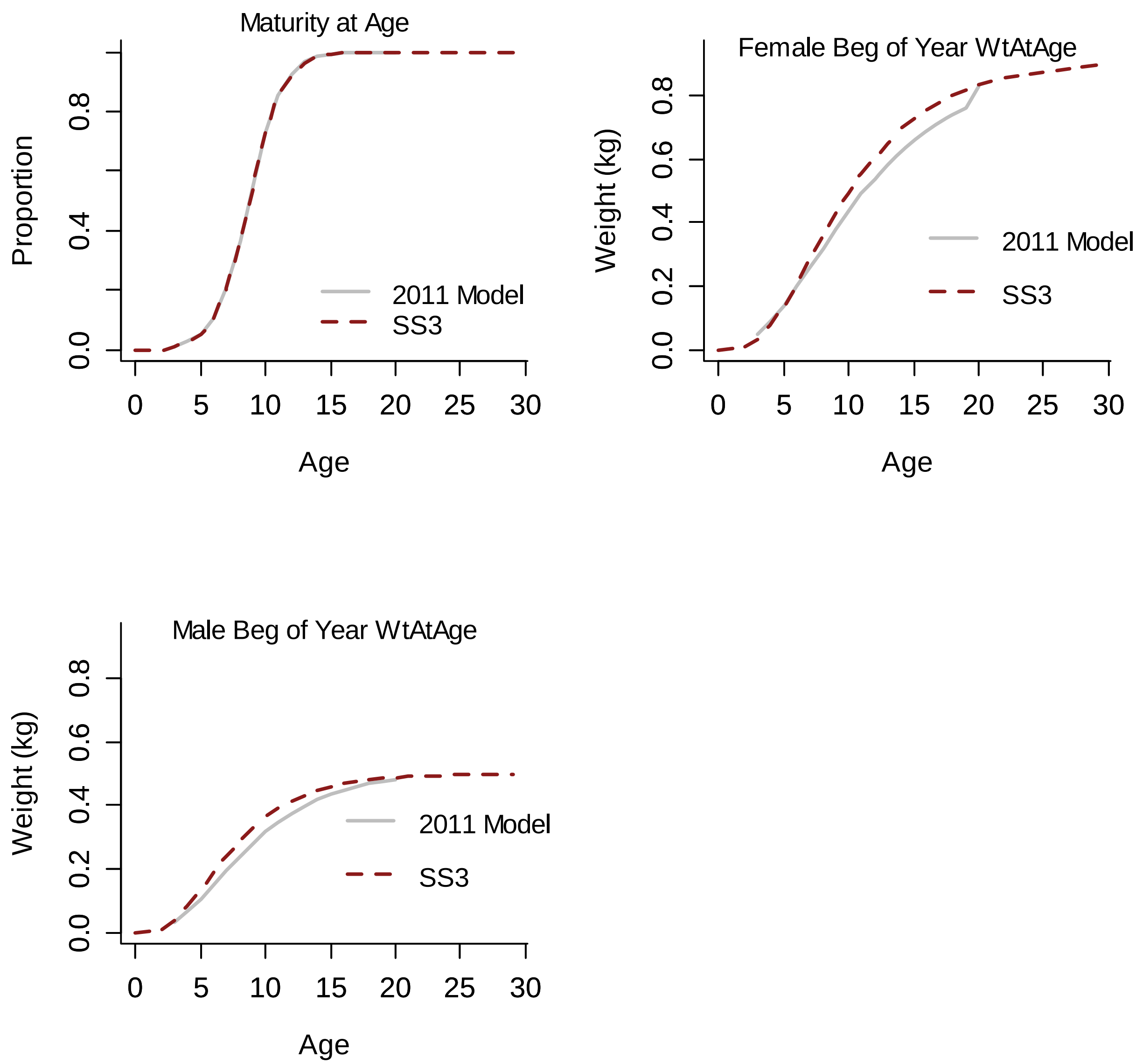


Figure 8.31. Maturity-at-age, female and male weight-at-age at the beginning of the year for Model 0 (red dashed lines) and the previous assessment model. Maturity-at-age was fixed.

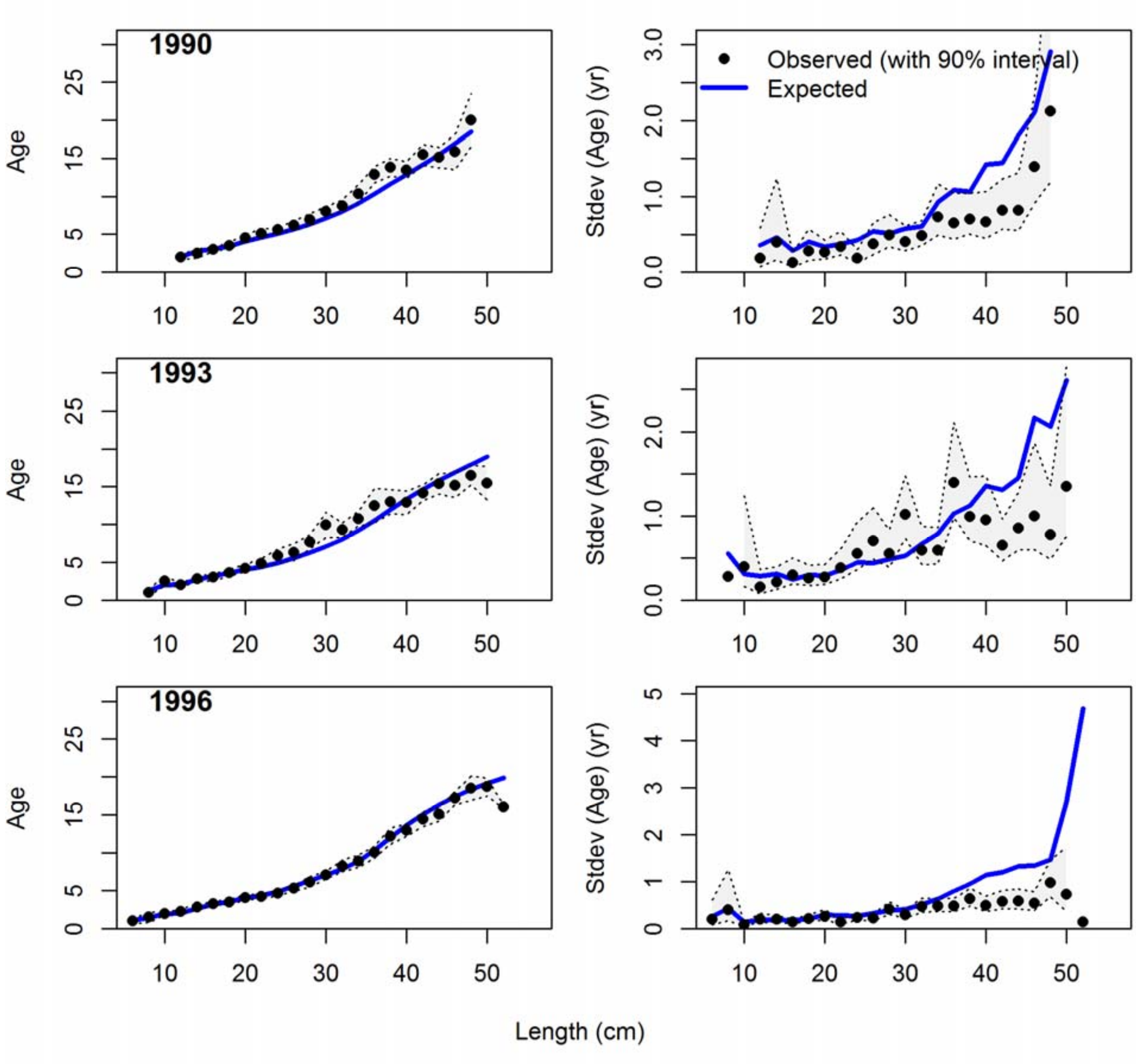


Figure 8.32. Observed and expected female mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for Model 0 (fixed natural mortality and estimated early recruitment deviations) for years 1990-1996.

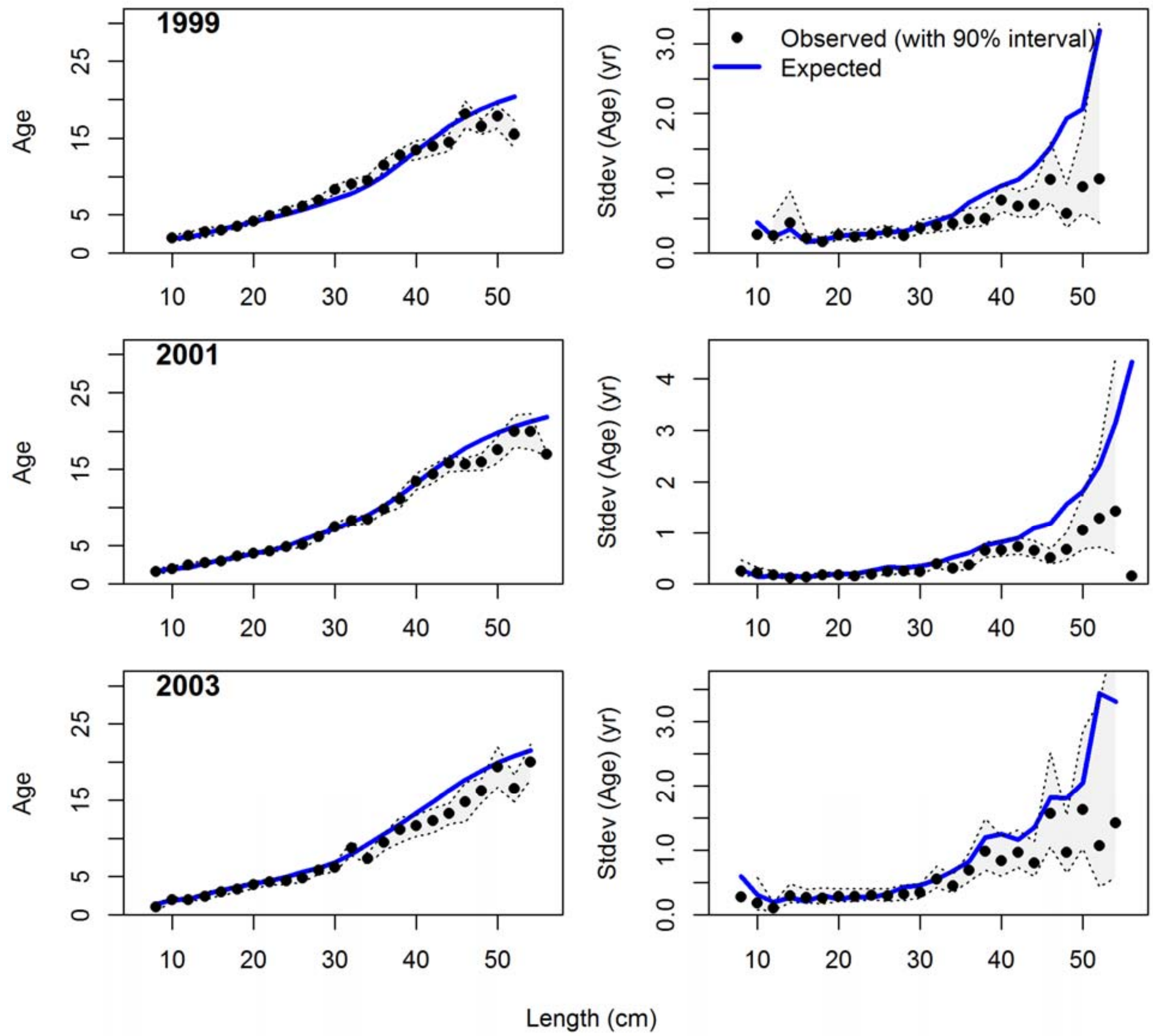


Figure 8.33. Observed and expected female mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for Model 0 (fixed natural mortality and estimated early recruitment deviations) for years 1999-2003.

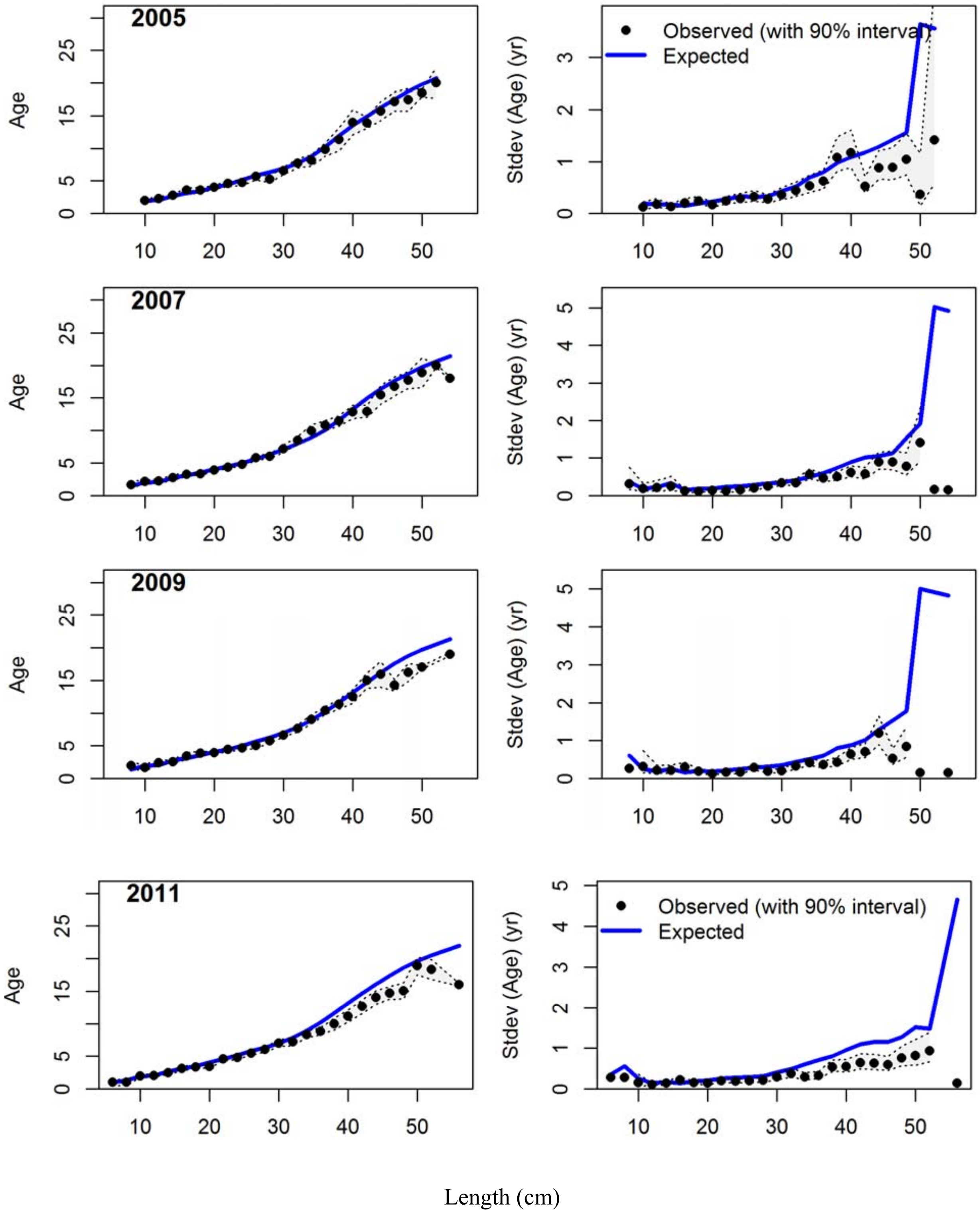


Figure 8.34. Observed and expected female mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for Model 0 (fixed natural mortality and estimated early recruitment deviations) for years 2005-2011.

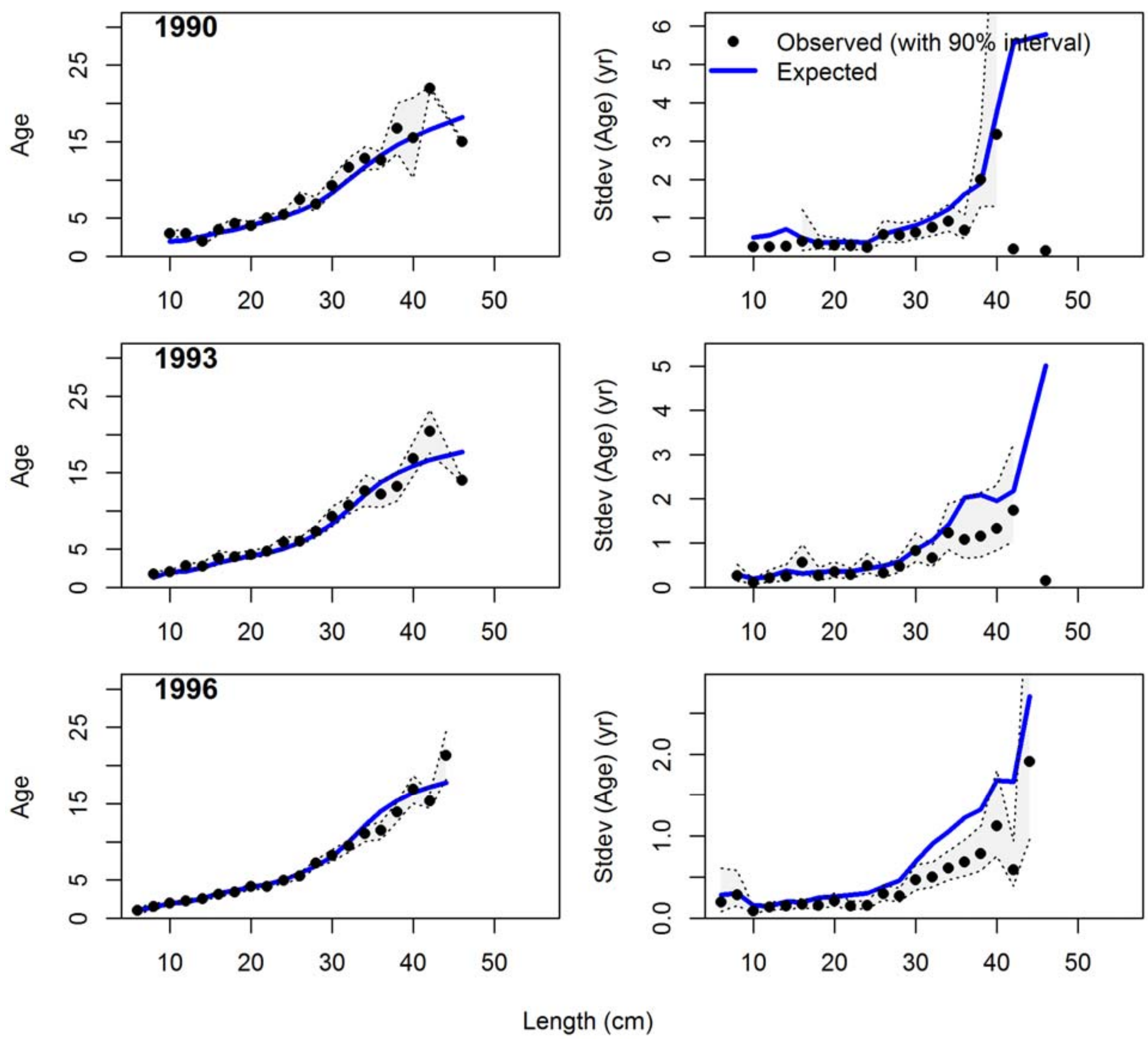


Figure 8.35. Observed and expected male mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for Model 0 (fixed natural mortality and estimated early recruitment deviations) for years 1990-1996.

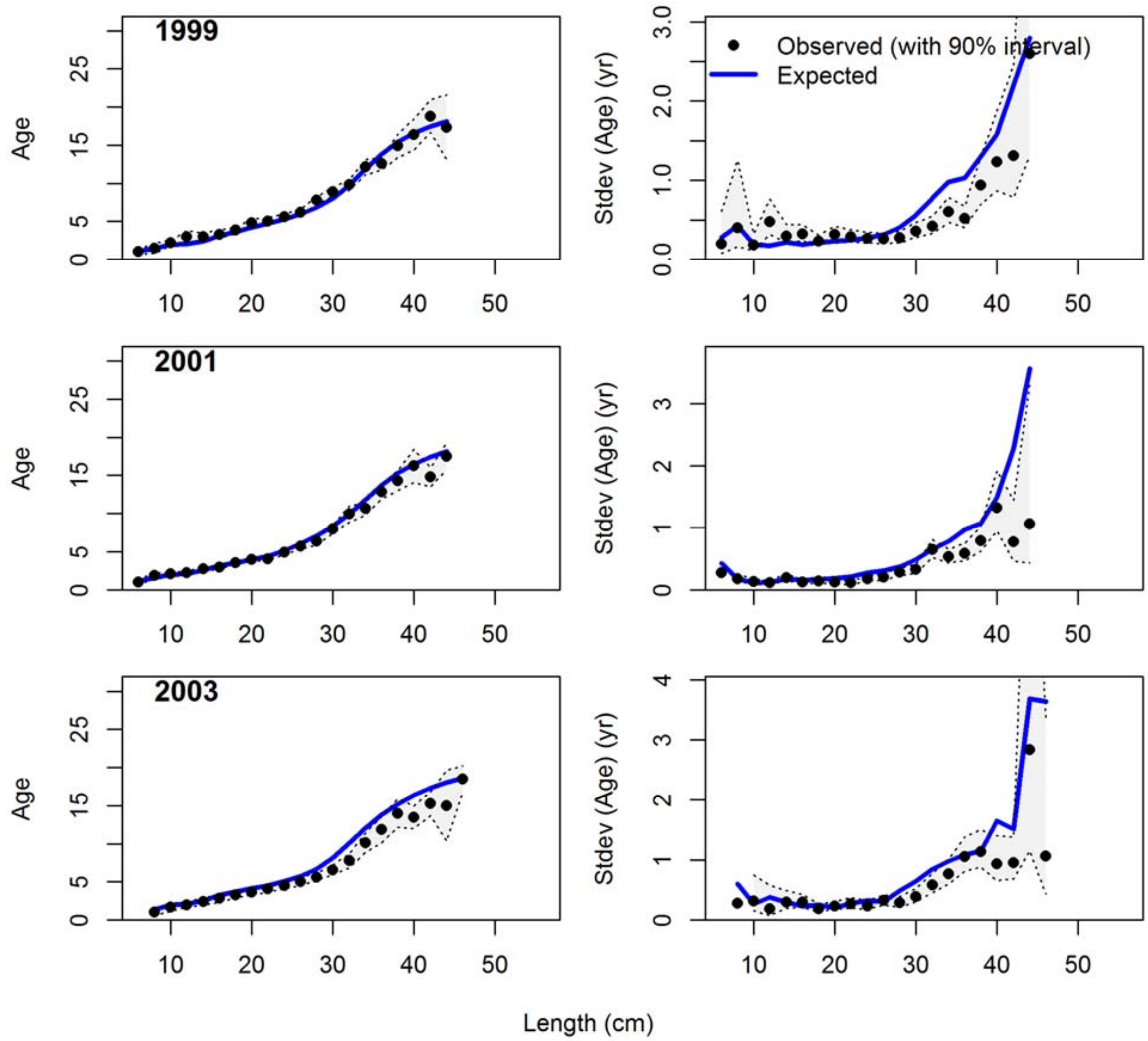
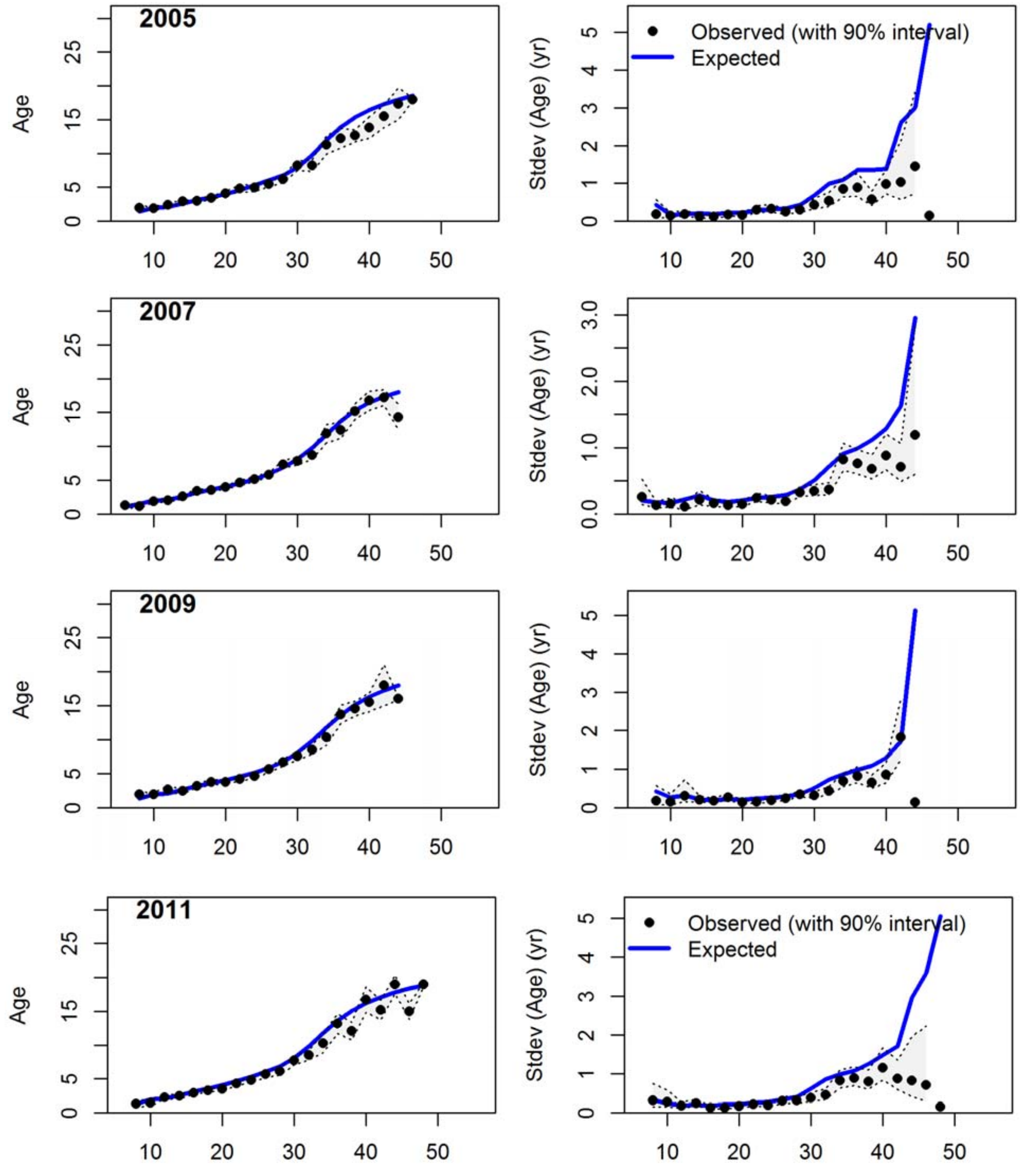


Figure 8.36. Observed and expected male mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for Model 0 (fixed natural mortality and estimated early recruitment deviations) for years 1999-2003.



Length (cm)

Figure 8.37. Observed and expected male mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for Model 0 (fixed natural mortality and estimated early recruitment deviations) for years 2005-2011.

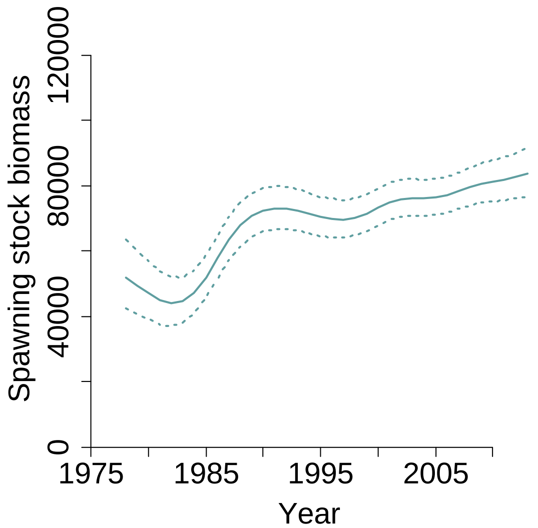


Figure 8.38. Time series of spawning stock biomass (solid line) and asymptotic 95% confidence intervals (dotted lines) for Model 0.

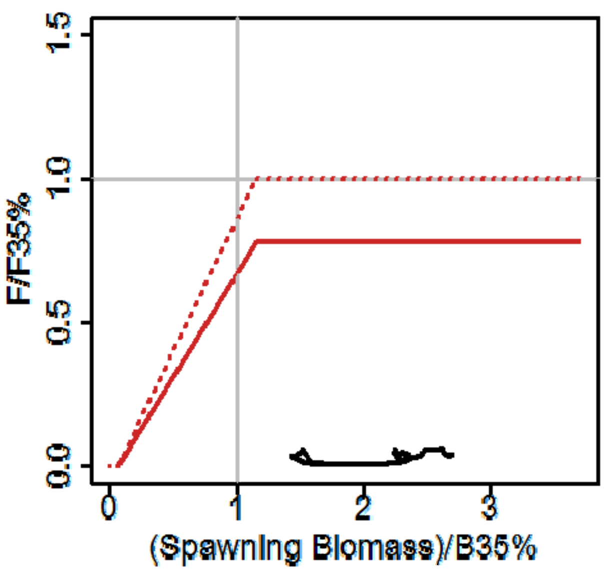


Figure 8.39. Spawning stock biomass relative to B35% and fishing mortality (F) relative to F35% from 1978-2012 (solid black line), the OFL control rule (dotted red line), the maxABC control rule (solid red line), B35% (vertical grey line), and F35% (horizontal grey line) for Model 0 (fixed natural mortality and estimated early recruitment deviations).

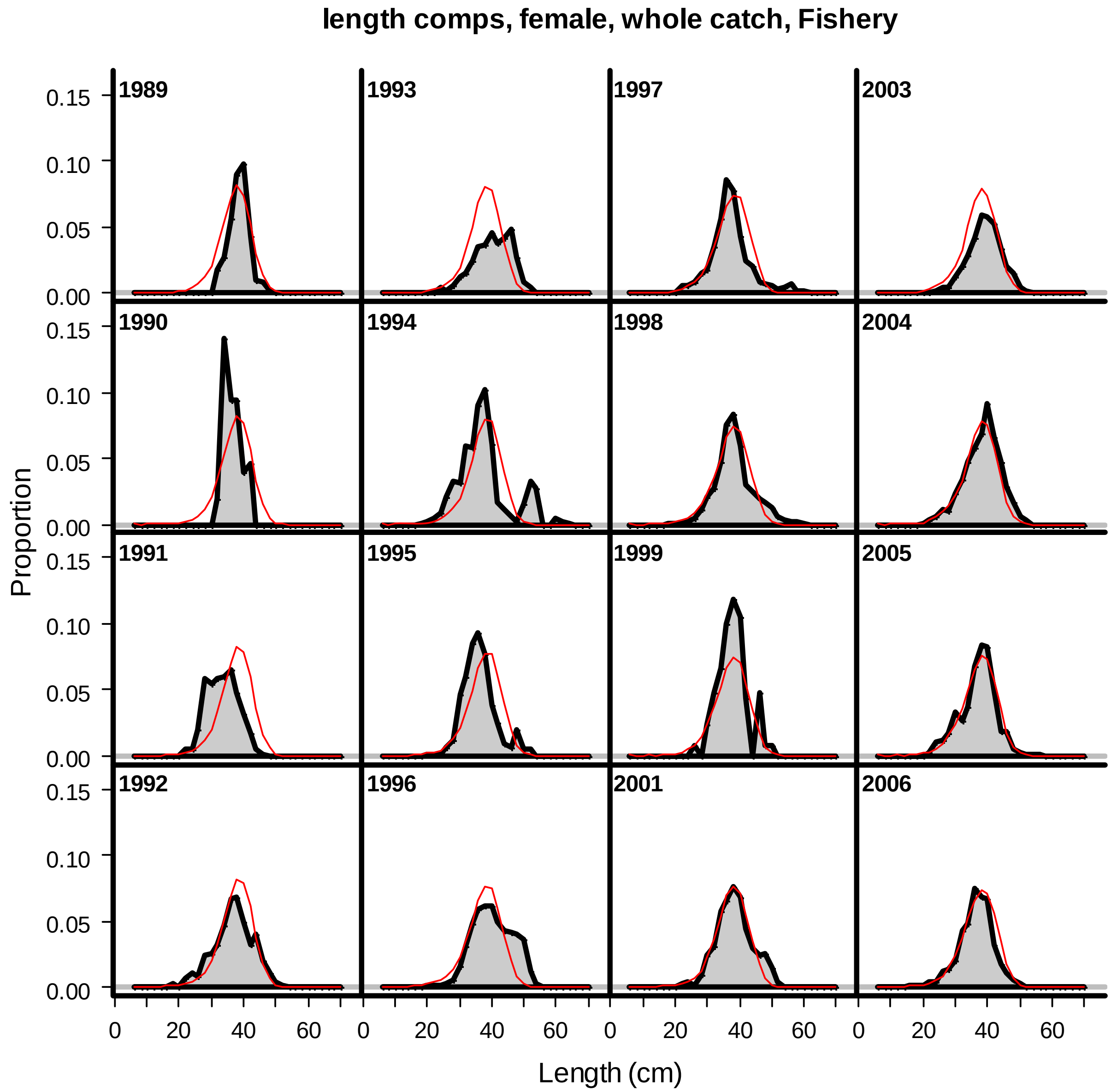


Figure 8.40. Observed (grey filled area and black line) and expected (red lines) female fishery proportions-at-length for Model 1 (estimated natural mortality and early recruitment deviations) for years 1989-2006.

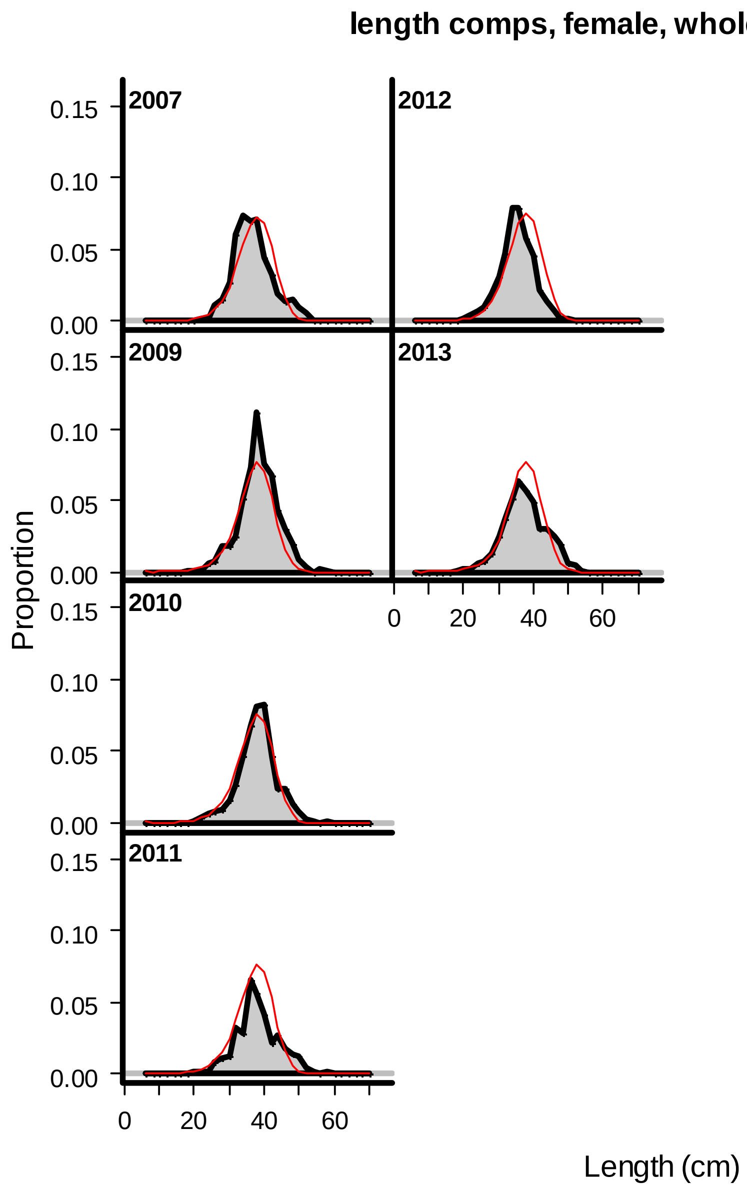


Figure 8.41. Observed (grey filled area and black line) and expected (red lines) female fishery proportions-at-length for Model 1 (estimated natural mortality and early recruitment deviations) for years 2007-2013.

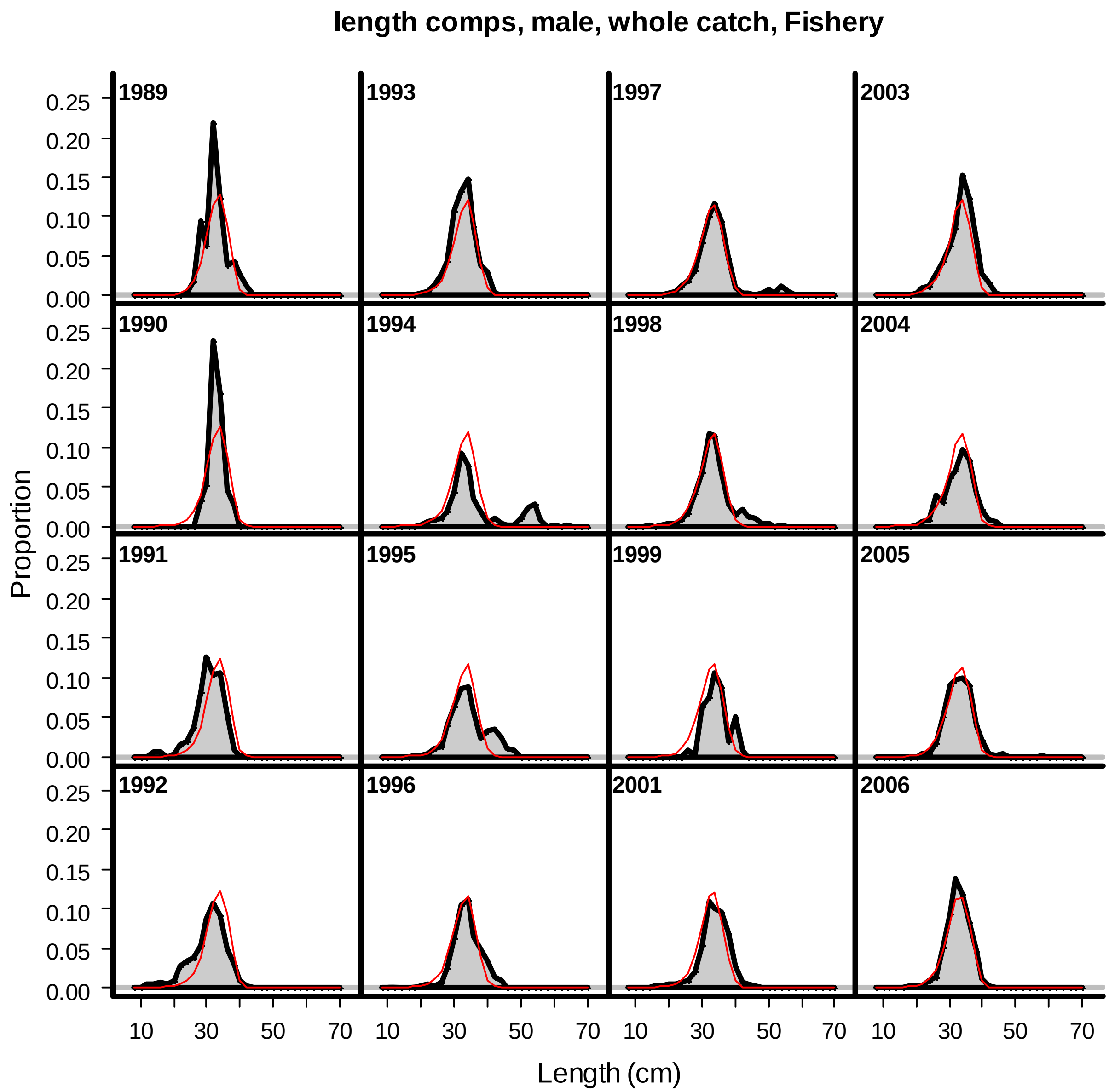


Figure 8.42. Observed (grey filled area and black line) and expected (red lines) male fishery length compositions for Model 1 (estimated natural mortality and early recruitment deviations) for years 1989-2006.

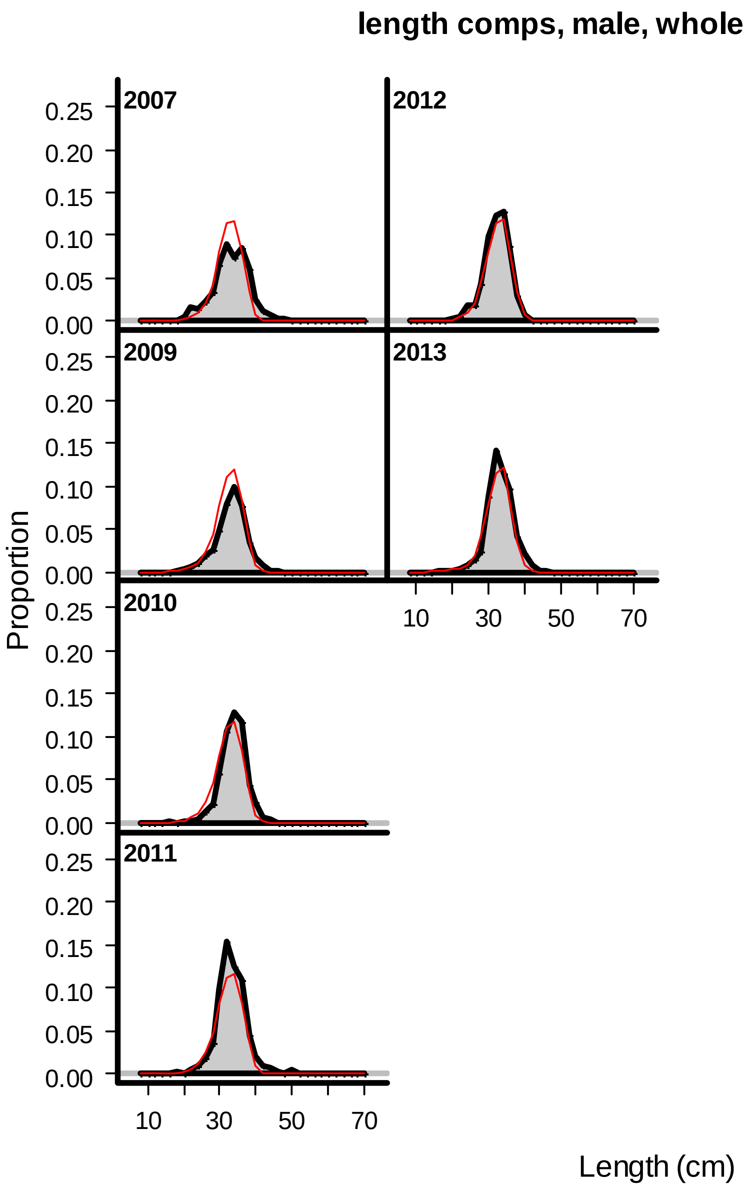


Figure 8.43. Observed (grey filled area and black line) and expected (red lines) male fishery length compositions for Model 1 (estimated natural mortality and early recruitment deviations) for years 2007-2013.

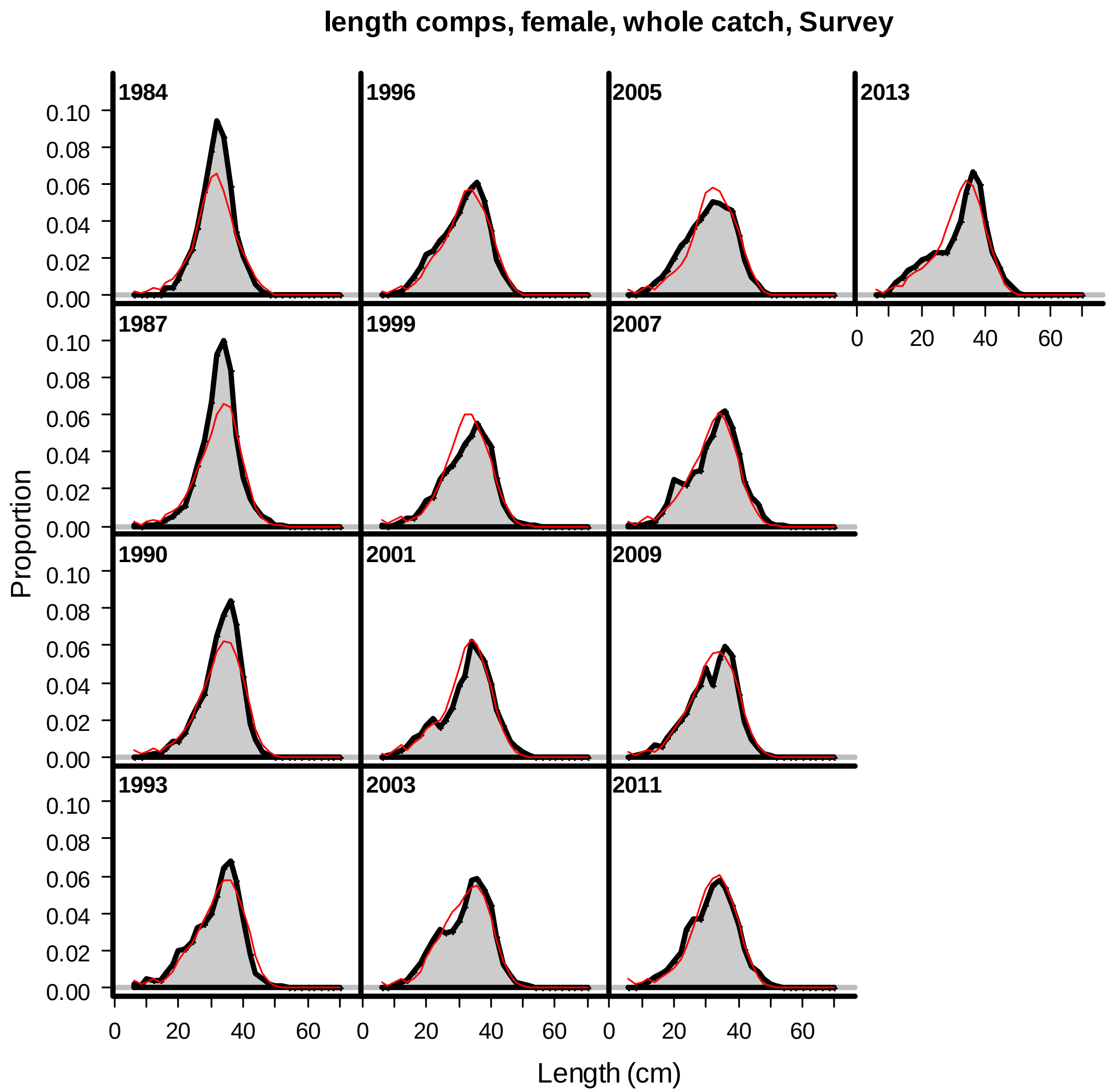


Figure 8.44. Observed (grey filled area and black lines) and expected (red lines) female survey length compositions Model 1(estimated natural mortality and early recruitment deviations) for each year of length composition data included in the objective function.

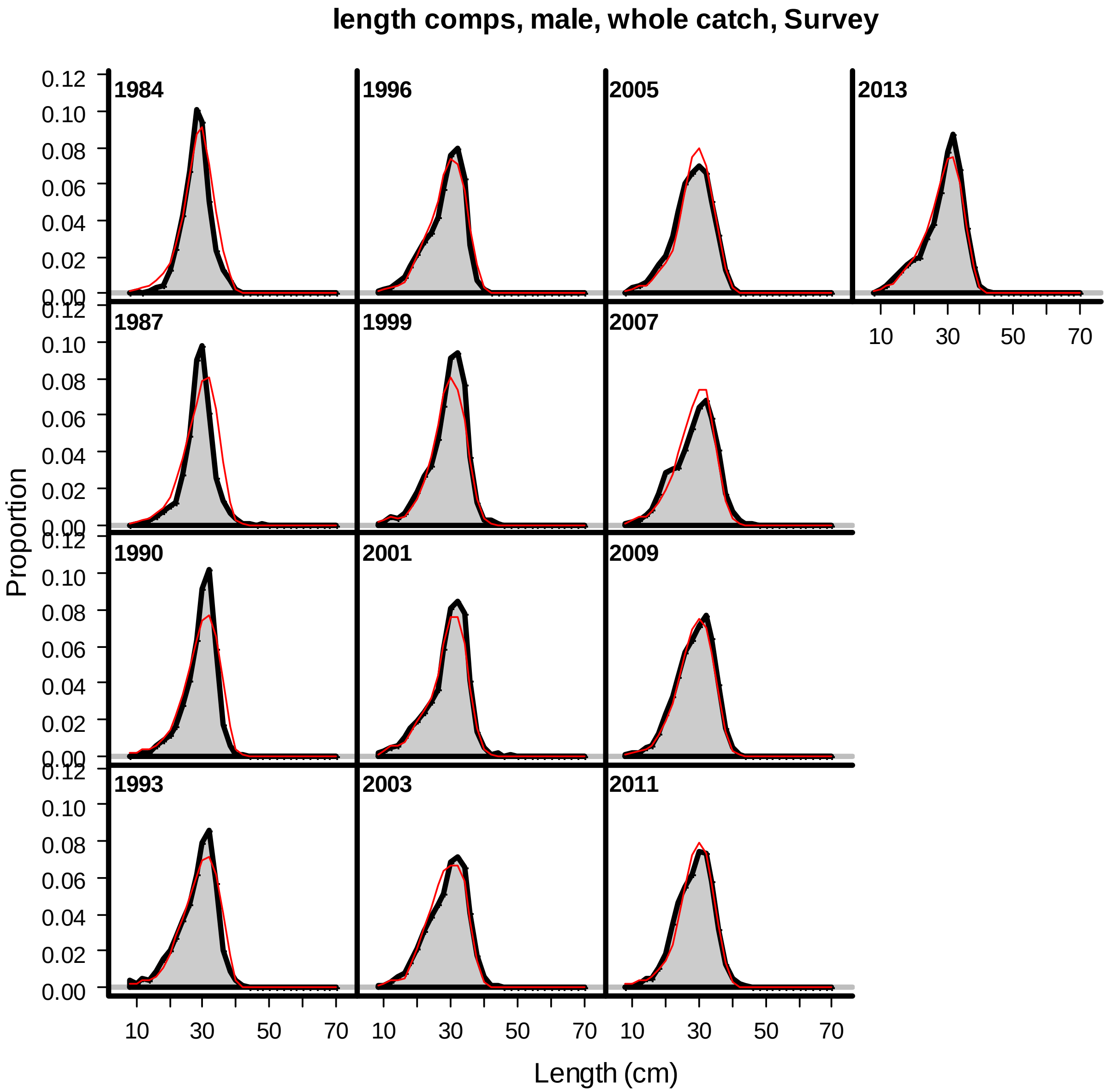


Figure 8.45. As for Figure 8.44, but for males: observed (grey filled area and black lines) and expected (red lines) male survey length compositions for Model 1 (estimated natural mortality and early recruitment deviations) for each year of length composition data included in the objective function.

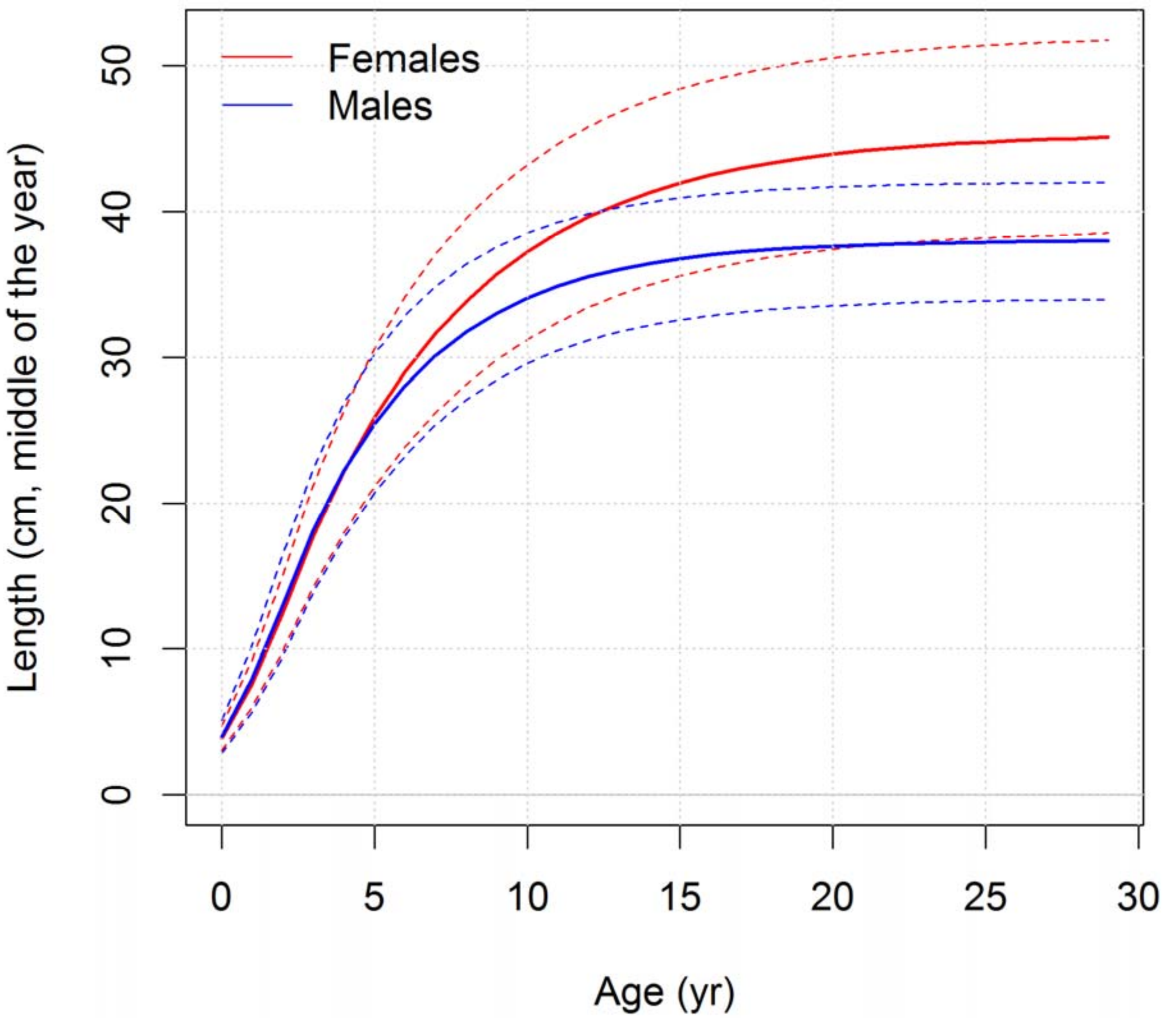


Figure 8.46. Estimated length-at-age for females (red) and males (blue) and 95% intervals (dotted lines) for Model 1 (estimated natural mortality and early recruitment deviations).

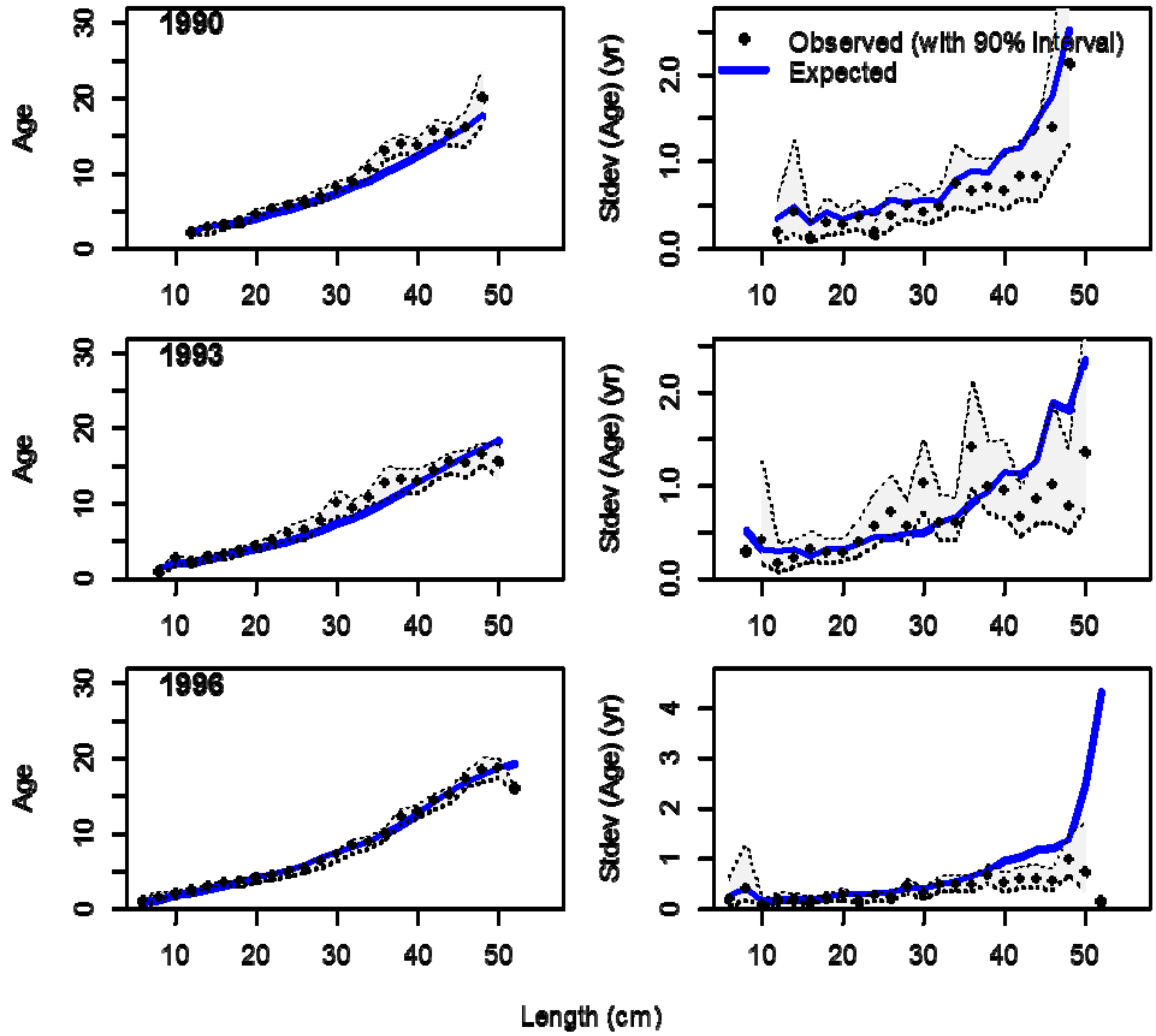


Figure 8.47. Observed and expected female mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for Model 1 (estimated natural mortality and early recruitment deviations) for years 1990-1996.

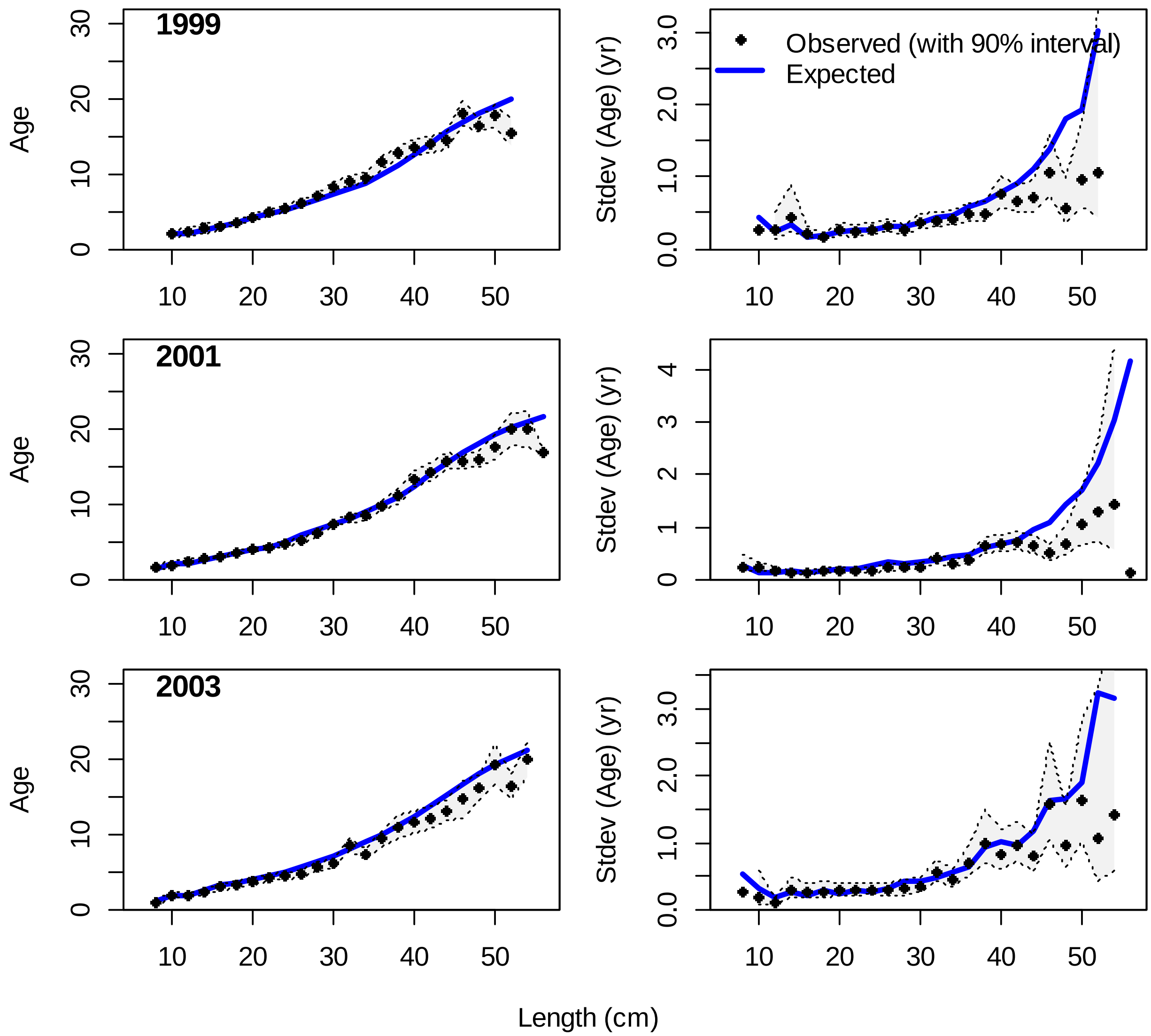


Figure 8.48. Observed and expected female mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for Model 1 (estimated natural mortality and early recruitment deviations) for years 1999-2003.

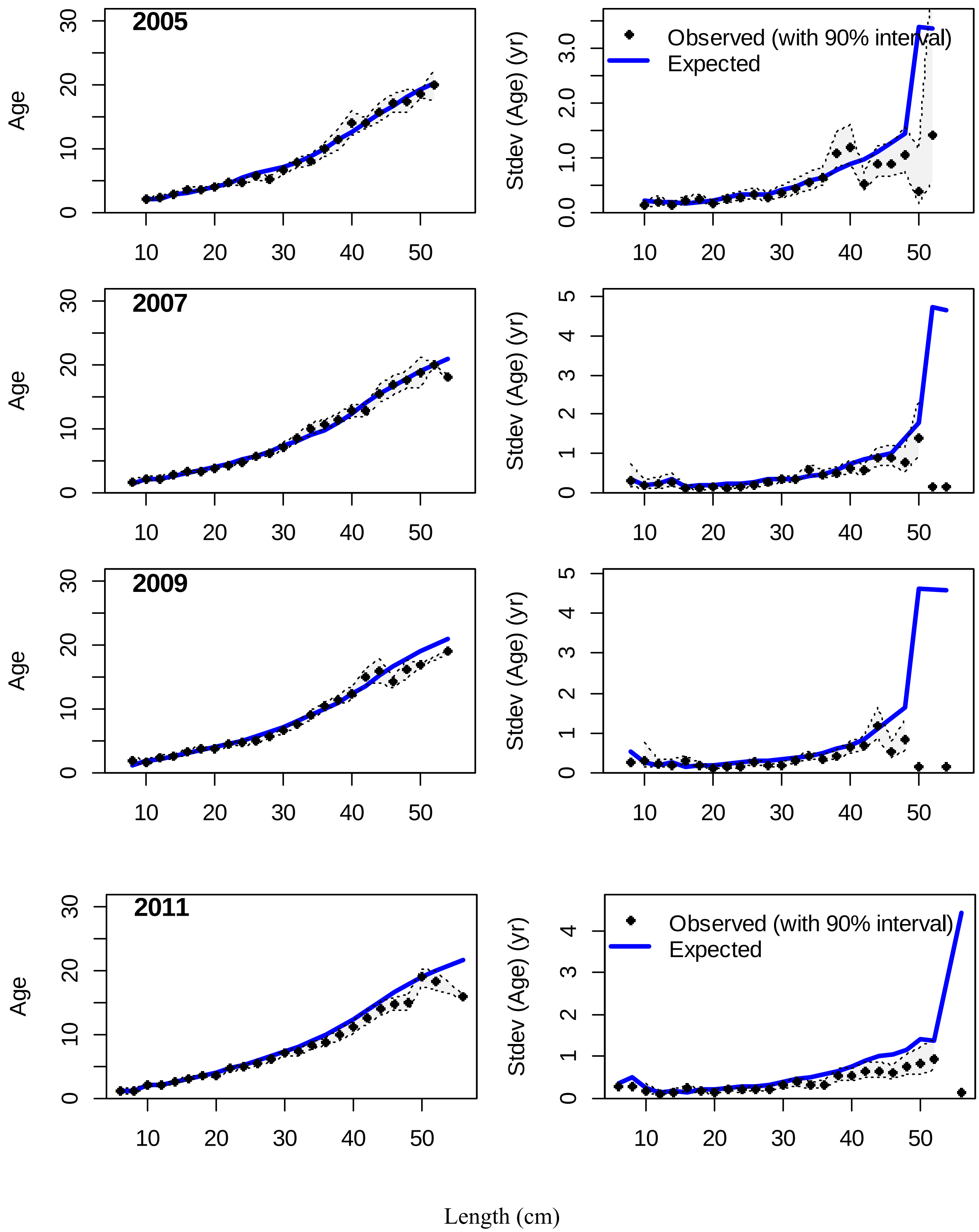


Figure 8.49. Observed and expected female mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for Model 1 (estimated natural mortality and early recruitment deviations) for years 2005-2011.

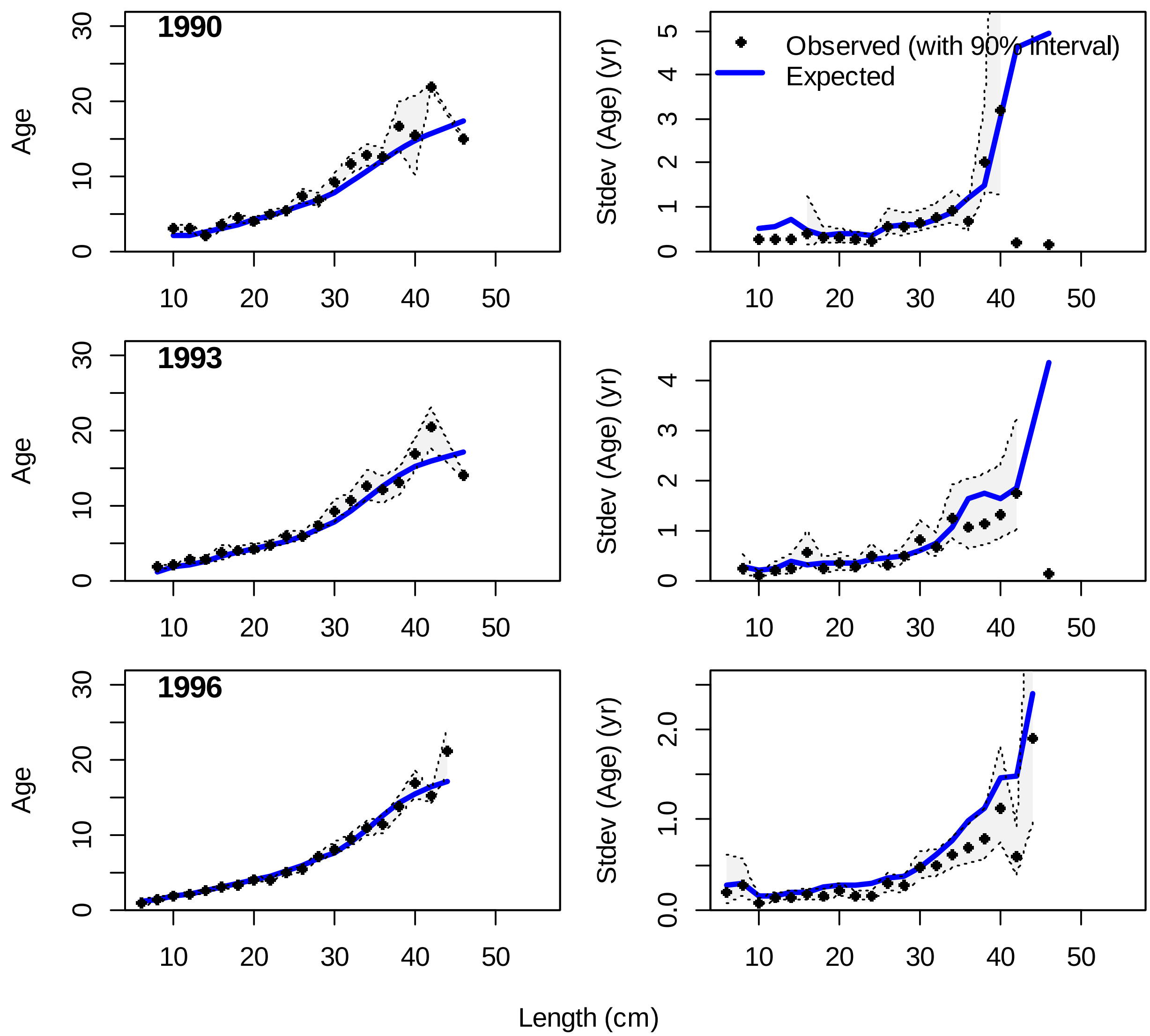


Figure 8.50. Observed and expected male mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for Model 1 (estimated natural mortality and early recruitment deviations) for years 1990-1996.

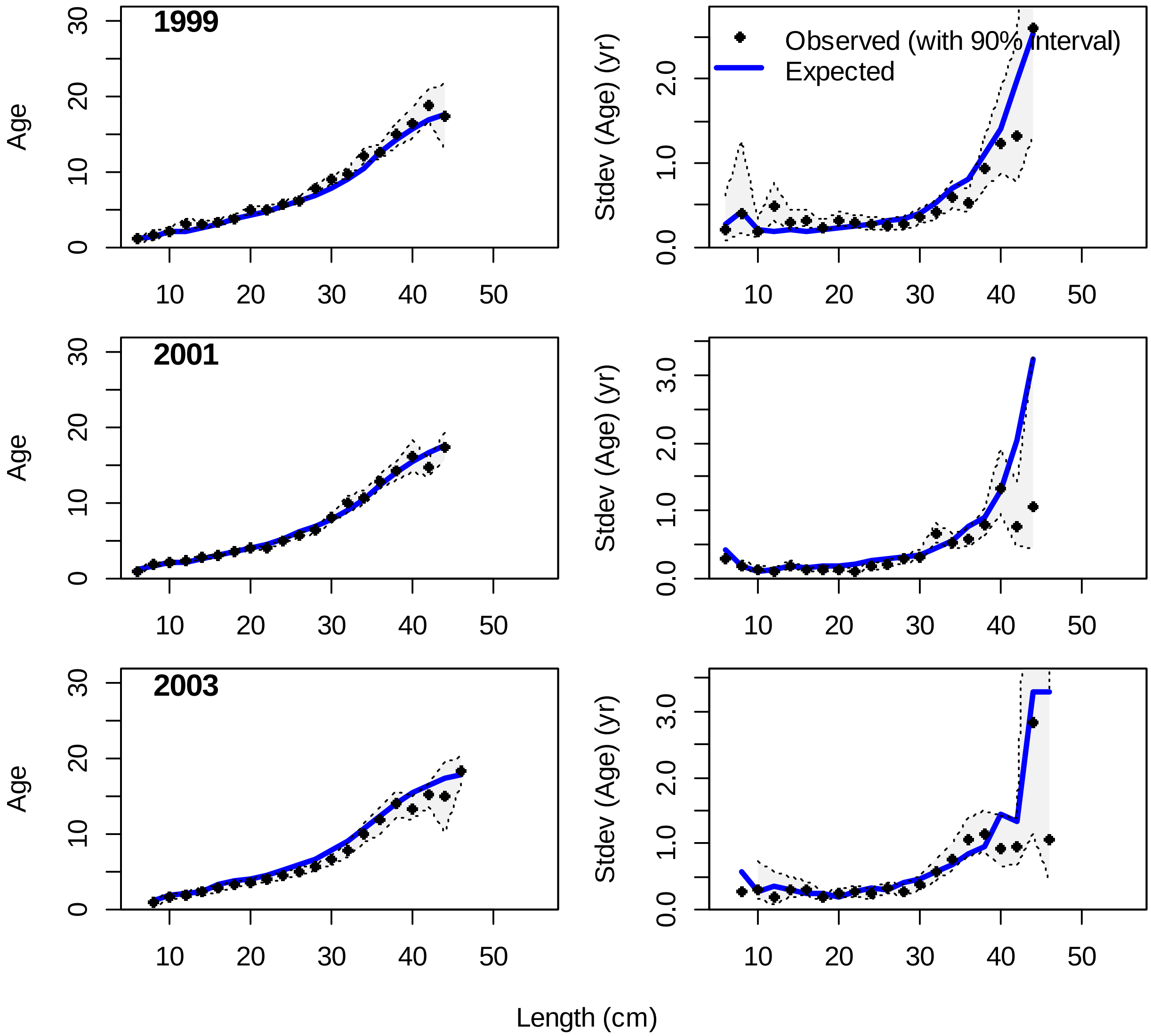


Figure 8.51. Observed and expected male mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for Model 1 (estimated natural mortality and early recruitment deviations) for years 1999-2003.

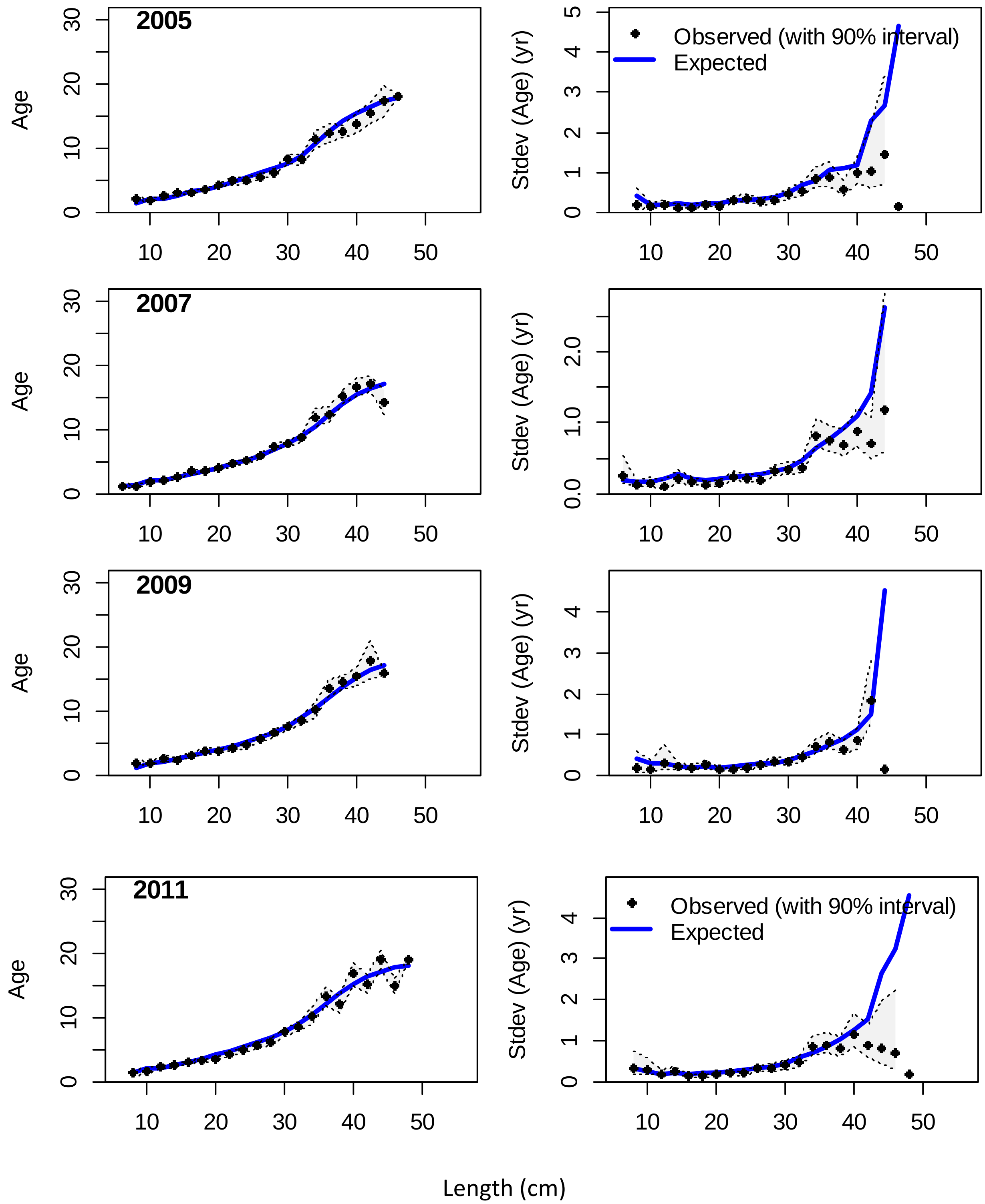


Figure 8.52. Observed and expected male mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for Model 1 (estimated natural mortality and early recruitment deviations) for years 2005-2011.

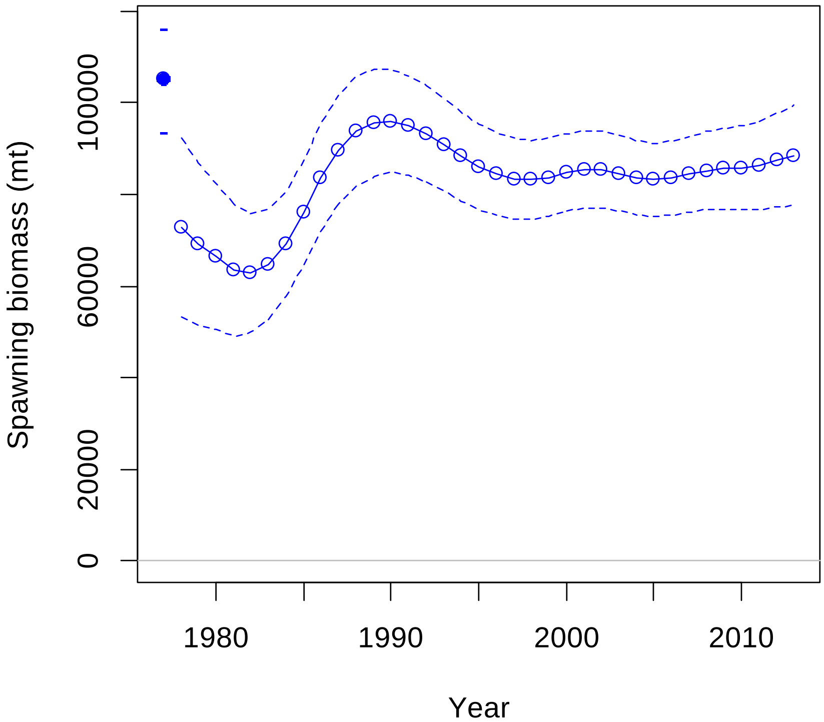


Figure 8.53. Time series of spawning biomass in metric tons (mt) and 95% asymptotic confidence intervals for Model 1 (estimated natural mortality and early recruitment deviations).

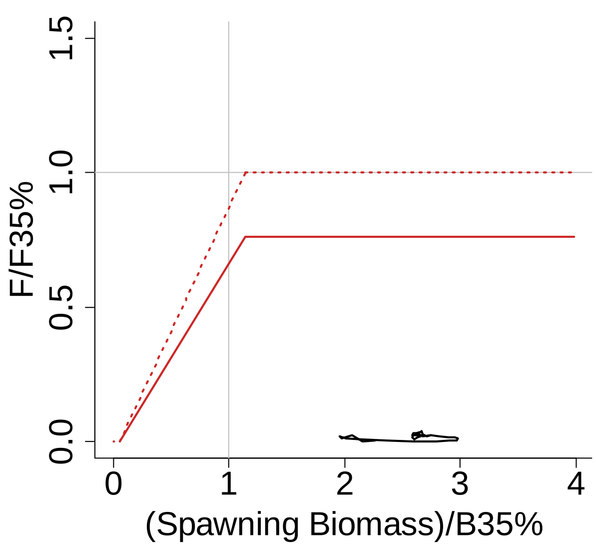


Figure 8.54. Spawning stock biomass relative to B35% and fishing mortality (F) relative to F35% from 1978-2012 (solid black line), the OFL control rule (dotted red line), the maxABC control rule (solid red line), B35% (vertical grey line), and F35% (horizontal grey line) for Model 1 (estimated natural mortality and early recruitment deviations).

Attachment 8A. September Safe document: an exploration of alternative models for GOA flathead sole

By Carey McGilliard

INTRODUCTION

The purpose of this document is to outline a proposed change from conducting assessments using the previously used flathead sole assessment model framework to conducting assessments using Stock Synthesis version 3.24o (SS3; Methot and Wetzel 2013).

Previous assessments were conducted using an ADMB-based age- and sex-structured population dynamics model with length-at-age, weight-at-length, maturity-at-age, and age-length transition matrices estimated outside of the model. The previous model estimated the log of mean recruitment, parameters for logistic age- and sex-specific selectivity curves for the fishery and survey, recruitment deviations, and yearly fishing mortality rates. The model included ages 3-20 and excluded data for fish below age 3 and 14 cm in length.

SS3 is a flexible assessment model framework that extends the capabilities of the 2011 flathead sole assessment model to address the concerns of the GOA Plan Team, the SSC, and previous flathead sole assessment authors, mentioned below. Although we do not expect that all concerns can addressed within the time-frame for the 2013 assessment cycle, this document outlines the work that was done to transition the flathead sole assessment from the previous assessment framework to SS3. In addition, proposed alternative models that address some previous concerns about the flathead sole assessment by using the extensive suite of modeling options available in SS3 are discussed.

DATA GAPS AND RESEARCH PRIORITIES FROM PREVIOUS ASSESSMENTS

Previous assessment authors suggest that the age-length transition matrices and other growth relationships used in the model are several years old and should be re-evaluated based on recent data. The previous authors recommend exploring estimation of growth relationships within the model. In addition, authors suggest that alternative selectivity functions be explored, including length-based fishery and survey selectivity, as well as functional forms other than the logistic curve.

One currently unfulfilled SSC request exists:

> SSC request: *The SSC requested that the next round of assessments consider the possible use of ADF&G bottom trawl survey data to expand the spatial and depth coverage.*

The previous framework for conducting flathead sole assessments was unable to estimate growth or length-based selectivity, and accommodated only one survey. All of these concerns can be readily explored using SS3. Relative to the 2011 model, SS3 offers the following features:

(1) SS3 is used by many scientists worldwide, which provides an ad-hoc quality control system for identifying bugs in the code.
(2) A request from previous authors concerning the flathead sole assessments was that the age-length transition matrices and other growth parameters be re-examined and potentially estimated within the model. The 2011 model had limited capability to do this, but such flexibility is included in the SS3 framework.

(3) Mean weight-at-age data can be included in the SS3 model and can be used as a likelihood component to help estimate growth. Since these data are available for GOA flathead sole, their use within the assessment model would be advantageous.
(4) SS3 has many options for specifying the functional form of selectivity curves and these could be used to explore length-based fishery and survey selectivity for flathead sole, which may be a more accurate reflection of the selection process than the age-based selectivity functions used in previous assessments.
(5) SS3 allows for specification of ageing error. Ageing error is ignored in the current model.
(6) SS3 allows for multiple survey and fishing fleets to be included in the model. This feature would be needed to explore the inclusion of the ADF&G bottom trawl survey in future assessments; the previous model accommodated only one fishery and one survey.
(7) SS3 accommodates age-composition data for ages 0-2. The previous assessment model omitted data for fish below age 3. Including data for ages 0-2 may inform recruitment estimates and age-based selectivity at young ages.
(8) SS3 allows for calculation of mid-year weight-at-age, which is an improvement over the 2011 model because it more accurately matches biological processes that occur during the year with respect to the timing of fishing. In previous models, exploitable biomass was calculated based on beginning-of-the-year weight-at-age, but fishing occurs over 7 months from January-November, and therefore using mid-year weight-at-age to calculate exploitable biomass may be more accurate.
(9) The previous assessment model assumed the stock was unfished prior to the model start year, but we know that fishing occurred before 1984. SS3 allows the user to estimate an initial fishing mortality rate to account for fishing prior to the availability of catch data.
(10) SS3 offers a "jitter" option, which allows for initial parameter values to be adjusted by a random deviate. Iteratively running the model with the "jitter" option turned on allows the user to start the model from a wide range of initial values so as to identify the best objective function value.

ANALYTIC APPROACH: TRANSITION OF 2011 MODEL INTO AN EQUIVALENT SS3 MODEL

Matching population dynamics between models

Mean recruitment

Several steps were taken to build an SS3 model with population dynamics that matched those of the 2011 model using deterministic models with no estimation of parameters and no recruitment deviations. First, the relationship between the log of mean recruitment estimated in the 2011 model ($\ln(\bar{R})$) and the log of R0 (unfished recruitment; $\ln(R_0)$) that is estimated in SS3 was determined (Equation 1), where M is natural mortality.

(1) $$\ln(R_0) = \ln(2\bar{\mathrm{R}}/1000) + 3M$$

The $\ln(\bar{R})$ estimated in the 2011 model refers to female mean recruitment of age 3 individuals, while $\ln(R_0)$ refers to total recruitment (males and females) of age 0 individuals in thousands; both models assume a 1:1 sex ratio (but any sex ratio can be specified in SS3; a different sex ratio would change Equation 1). Using Equation 1, equivalent deterministic runs were conducted, where both models were run with no recruitment deviations and no parameter estimation. Parameters were fixed at the maximum likelihood estimates (MLEs) from the 2011 model to ensure that both models had the same behavior in the absence of estimation. Equation 1 ensures that numbers at age 3 and above are the same in both models for an unfished population.

Selectivity

The 2011 model assumed sex-specific age-based logistic selectivity functions for fishery and survey selectivity. Although SS3 has logistic, sex-specific selectivity, it was found that the specification of male logistic age-based selectivity in SS3 was difficult to cast into a logistic shape. Sex-specific length-based logistic selectivity can be specified such that selectivity can be estimated for both sexes while retaining the logistic shape, or age-based double normal selectivity curves could be specified with a large value for the standard deviation of the descending limb such that asymptotic, logistic-like, sex-specific selectivity could be estimated. In the interest of matching the 2011 model as closely as possible, the age-based, sex-specific double normal selectivity curves without descending limbs were used for fishery and survey selectivity curves. The fishery selectivity curves were matched as closely as possible to the age-based logistic curves from the 2011 model for the purpose of comparing population dynamics between the models (Figure 8A.1). Figure 8A.1 shows that the double-normal selectivity curves can approximate the logistic curves from the 2011 model, but the shapes are slightly different and this results in small differences in population dynamics between the 2011 and SS3 models (Figure 8A.2). Figure 8A.2 shows that spawning stock biomass (SSB) is nearly, but not exactly the same between models in equivalent deterministic runs. Figure 8A.3 shows that survey biomass is also almost exactly the same between models in equivalent deterministic runs. The very small differences in spawning stock biomass in Figure 8A.2 can be explained by the differences in fishery selectivity curves shown in Figure 8A.1, as further equivalent deterministic runs (conducted for Dover sole) using selectivity curves that matched more exactly (but were still logistic for the 2011 model and double-normal for the SS3 model; Figure 8A.4) led to the same time series of SSB for both models (Figure 8A.5).

Stock-Recruitment

The 2011 model estimated recruits as median-unbiased recruitment deviations from their mean value. The SS3 model was configured similarly by specifying a Beverton-Holt stock-recruitment curve with a steepness of 1. SS3 estimates mean-unbiased recruitment deviations by specifying σ_R and applying a bias adjustment factor. For the deterministic runs, σ_R was set to 1.0E-06, and for runs when recruitment deviations were estimated, σ_R was set to 0.60. The 2011 model estimated recruits (age 3) freely (i.e. no σ_R) and this constitutes a difference between the models.

Growth

The 2011 model used empirical estimates of maturity-at-age sex-specific somatic weight-at-age. SS3 also can use similar empirically specified values for the calculation of spawning stock biomass and biomass-at-age (Figure 8A.6). A benefit of using the SS3 framework is the ability to specify and estimate growth parameters internally. When growth parameters are specified (instead of age-specific schedules), small differences arise between models because SS3 uses the beginning of the year weight-at-age to calculate SSB (like in the 2011 model), but uses mid-year weight-at-age to calculate exploitable and survey biomass (the 2011 model uses beginning-of-the-year weight-at-age for all calculations).

In addition, age-length transition matrices were specified directly in the 2011 model whereas in SS3 they are computed from specified von-Bertalanffy growth curve parameters and CVs in length-at-age. To match population dynamics between models, the CVs of the youngest and oldest age classes were estimated externally and specified within SS3. The resulting age-length transition matrices output from SS3 runs were examined to check that they closely matched those used in 2011. A request concerning the previous flathead sole assessments was that the age-length transition matrices and other growth parameters be re-examined and potentially estimated within the model. SS3 provides ample flexibility to explore growth relationships whereas this option was unavailable in the 2011 model.

Biomass

Differences in total biomass will occur between the models because SS3 includes ages 0-2. However, SSB and survey biomass were shown to be matched precisely between models when run deterministically when selectivity curves match between models and other parameters are fixed (Figure 8A.3 & Figure 8A.5).

Timing

Both the SS3 and 2011 model calculated spawning stock biomass, survey biomass, and recruitment at the beginning of the year. SS3 calculates exploitable biomass in the middle of the year, but a vector for weight-at-age was manually provided to SS3, which forced the model to use beginning-of-the year weight-at-age in the exploitable biomass calculation to match the 2011 model as closely as possible.

DATA USED IN SS3 AND THE 2011 MODEL

The same data used in the 2011 flathead sole assessment model (Stockhausen et al. 2011, page 757) were used in the SS3 model: survey biomass, survey age- and length-compositions (triennial for 1984-1999 and biennial for 2001-2011), fishery length-composition data (1985-2011), and catch history (1984-2011). An important difference between the 2011 model and SS3 is that the youngest age class in the 2011 model (age 3) represents only age 3 individuals, while

SS3 population dynamics begin at age 0 and consider the lowest age and length bins of data to be the proportion of individuals ages 0-3 and lengths 0-the upper limit of the lowest length bin, respectively. Therefore, age- and length-composition data must include ages 0-2 and any lengths no matter how small in SS3, while the 2011 model omitted data on ages 0-2 (and excluded data on fish smaller than 18cm). That SS3 included data on ages 0-2 likely informs estimates of selectivity at the lowest ages and hence improves recruitment estimates (especially in the most recent years). Ignoring this difference between models will result in extreme differences between expected and observed age- and length-compositions for the youngest age and length bins when selectivity at these ages and lengths is greater than 0. An alternative solution to including additional data in SS3 model runs was to specify an additional selectivity-at-length curve as a knife-edge curve with selectivity equal to zero at lengths where fish are likely to be younger than age 3 (in SS3 it is possible to specify selectivity-at-age and at-length at the same time). This was a coarse solution, as fish at age 3 are a variety of lengths and it required internal specification of growth parameters, which meant that maturity-at-age and weight-at-age would not be an exact match between the 2011 model and the SS3 model. Therefore, the SS3 model was set up to match the 2011 model, but included data on proportions at ages 0-2. Likewise, proportions at lengths smaller than 14cm were included in the lowest (14-16cm) length bin.

In 2001, surveys covered a more restricted depth range than in other years and it is thought that the survey did not cover the range of flathead sole. This was handled in the 2011 model and in SS3 by inflating survey biomass estimate by assuming that the survey covered 90% of the stock's range.

PARAMETER ESTIMATION IN SS3 AND THE 2011 MODEL

Parameters Estimated Inside the Assessment Model

SS3 and 2011 model runs were conducted with estimation of the log of mean recruitment, recruitment deviations, fishing mortality rates (using the same empirical growth vectors in both models), and selectivity parameters. Selectivity parameters for the fishery and survey were estimated; the location of peak selectivity and the width of the ascending limb of the selectivity curve were estimated in SS3 and the age at 50% selection as well as the slope of the logistic selectivity curves were estimated in the 2011 model.

Likelihood component for survey biomass index

Table 8A.2 lists the likelihood components used in SS3 and the 2011 model. The likelihood component for the survey biomass index and the data used to calculate the survey biomass likelihood component are the same for both models. The 2011 model and SS3 survey biomass values match almost exactly in a deterministic model with no estimation (Figure 8A.3).

Age- and length-composition likelihood components

The age- and length-composition likelihood components in SS3 are identical to those in the 2011 model. However, as noted above, the observations of survey proportions-at-age and proportions-at-length differ among models in that the data given to SS3 includes the data given to the 2011 model in addition to the proportions of age 0-2 fish and lengths below 14cm. Therefore, the values of these likelihood components cannot be compared directly between the 2011 model and SS3, but are expected to have similar influences on model fits. The fits to age- and length-composition data are very similar among models (Figure 8A.12-Figure 8A.14). The addition of age 0-2 and small length data included in the SS3 model likely contribute to differences in numbers at age 3 and selectivity parameter estimates. There is no easy way to test the extent to which the additional data contributes to differences, as the 2011 model does not accept the additional data, while it is required for the SS3 model.

Recruitment likelihood components

Recruitment likelihood components differ slightly between models. The 2011 model does not include a CV for recruitment deviations. In SS3 and in the 2011 model, the “main period” recruitment deviations must sum to 0 and recruitment deviations for all years (1967-2011) were included in the main period. No early or late-period recruitment deviations were included in either model.

ANALYTIC APPROACH: PROPOSED ALTERNATIVE SS3 MODELS

The following models are proposed alternatives to the transitional SS3 model that was constructed to match the dynamics of the 2011 model:

M0: The transitional SS3 model described above (the SS3 model that best matches the dynamics of the 2011 model)

M1: Length-based, logistic, sex-specific fishery selectivity. The fishery data consist only of length compositions and therefore the model may be able to estimate length-based selectivity more effectively than age-based selectivity. Fishery selectivity may be more a process of length (e.g. due to the net’s mesh size) than age (where multiple ages of fish are the same length). SS3 is able to estimate length-based, sex-specific, logistic fishery selectivity, so there is no need to use a double-normal curve without a descending limb for this alternative.

M2: Estimate an initial equilibrium fishing mortality rate. The transitional SS3 model assumes that the stock was unfished prior to the model start year (1984) even though fishing occurred before 1984. In the transitional model, estimates of recruitment for years prior to 1984 were below average, which may be an artifact to account for fishing that occurred prior to 1984.

M3: Length-based, logistic, sex-specific selectivity for the fishery and the survey.

M4: A combination of M2, and M3, where an initial equilibrium fishing mortality rate is calculated, and both the fishery and survey selectivity selectivity are estimated using logistic, sex-specific, length-based functions.

In addition, models that estimated recruitment deviations for an early period (1967-1983, for which there are no data) separately from the main recruitment period were explored so that recruitment deviations from years with little information would not influence the estimates of recruitment deviations in the period over which more information is available by way of the constraint that deviations must sum to 0. These models did not lead to a better fit to the data.

FURTHER PROPOSED ALTERNATIVE MODELS

The SS3 model framework facilitates the potential for the following analyses to be conducted:

- Estimating growth parameters internally to re-evaluate the age-length transition matrices and other growth relationships with inclusion of the most recent data.

- Adding mean weight-at-age data to the assessment and estimating growth parameters internally. Data on mean weight-at-age are available, but are not currently being used in analyses of GOA flathead sole. Mean weight-at-age is expected to inform estimates of growth parameters.
- Estimating growth parameters and the age-length transition matrix outside of the model using data that includes the most recent years.
- Including ageing error in the model: the previous assessment models ignored ageing error. The CVs about the length-at-age relationship are quite large. This implies that there are some age 3 fish that are the same length as some age 20+ fish, which is likely untrue and could potentially be attributed to ageing error.
- Re-evaluating effective sample sizes for age- and length-composition data. There are abrupt year-to-year changes in age-compositions that occur in the observations that are likely due to observation error. Using high effective sample sizes may exclude some process errors which should be considered.

RESULTS: TRANSITION OF 2011 MODEL INTO AN EQUIVALENT SS3 MODEL

The 2011 and SS3 models each estimated a similar time series of numbers at age 3 (considered recruits in the 2011 model), but the SS3 model estimated fewer numbers at age 3 than the 2011 model early in the time series (Figure 8A.7). Numbers at age 3 in the last two years of the time series were the most different between the models. However, data available to estimate recruitment in these years was limited. SSB estimates were similar, but not the same in the two models. SS3 estimated smaller values for SSB than those estimated by the 2011 model in most years represented in the time series (except for the initial years; Figure 8A.8). The fishery and survey selectivity curves for both males and females were shifted slightly to the left by 0-2 ages and were slightly steeper in the SS3 model than in the 2011 model (Figure 8A.9 & Figure 8A.10). This may explain why SSB was slightly lower for the SS3 model than for 2011 model (Figure 8A.8): the 2011 model estimates that there are more fish out there that aren't being caught in the fishery or the survey than in the SS3 model. Figure 8A.11 shows observed and predicted survey biomass for the 2011 and SS3 models. The negative log likelihoods for the survey biomass likelihood component indicate that the SS3 model fit to the survey biomass data (-lnL = -6.71) was better than the fit from the 2011 model (-lnL = +14.0). The predicted survey biomass from the SS3 model appeared to be a better fit to the data for surveys conducted from 1993 – 2001. In general, fits to age- and length-composition data were similar for both models (Figure 8A.12-Figure 8A.14).

Summary and discussion of differences between the SS3 Model and 2011 Model

The differences between the configurations of the 2011 model and the SS3 model are:

(1) Both models used asymptotic selectivity curves, but the SS3 selectivity curves were parameterized with a double-normal function with no descending limb (the standard deviation for the descending limb was set to a very high value), while the selectivity curves for the 2011 model were logistic. In addition, the 2011 model re-normalizes the selectivity curves such that the largest selectivity occurred at 1. The asymptotic double-normal can approximate the logistic curve, but varied slightly. SS3 does not have an option for normalizing the selectivity curves such that the greatest selectivity is always equal to 1, but the curve can be specified such that the peak value is at 1. In addition, selectivity below age 3 cannot be fixed at 0 unless using a cubic spline selectivity approach, which would add other difficulties to the assessment.

(2) SS3 population dynamics begin at age 0 and 2011 model dynamics begin at age 3. The SS3 model is given additional data, which consist of survey age-compositions for ages 0-2 and length-compositions for lengths 0-13cm.

RESULTS: PROPOSED ALTERNATIVE SS3 MODELS

Table 8A.3 shows the negative log likelihood components for each of the proposed alternative models (M0-M4). All alternative models (M1-M4) had lower negative log likelihoods than the transitional SS3 model (M0). Negative log likelihoods were best for alternative models M3 and M4 (the two proposed alternative models that estimated length-based, logistic, sex-specific fishery and survey selectivity). Models M3 and M4 had better fits to the length-composition likelihood component than the other models, while models M0 and M2 had the best fits to the survey biomass likelihood component (Table 8A.3). However, fits to the survey biomass data were similar among alternative models (Figure 8A.18). Model M3 and M4 led to the highest estimated number of recruits and SSB (Figure 8A.15 & Figure 8A.17). Estimated recruitment deviations were similar among models (Figure 8A.16).

Proposed alternative model M4, which estimated an initial equilibrium fishing mortality rate and length-based, logistic, sex-specific fishery and survey selectivity, led to the best negative log likelihood of all of the SS3 models and a comparison to the 2011 model, including fits to the age- and length-composition data are shown in Figure 8A.23-Figure 8A.28. Model M4 and the 2011 model led to very similar estimates of SSB (Figure 8A.24). Fits to age- and length-composition data were similar for the two models (Figure 8A.26-Figure 8A.28).

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Stockhausen, W.T., M.E. Wilkins and M.H. Martin. 2011. 8. Gulf of Alaska Flathead Sole. In Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Gulf of Alaska. pp. 753-820. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage AK 99510.

TABLES

Table 8A.1. Symbols used in this document.

Symbol	Meaning
x	sex
a	age
f	fleet (fishery or survey)
t	time
$S_{f,x,a}$	Selectivity for fleet *f*, sex *x*, and age *a*
$N_{t,x,a}$	Numbers at age *a*, time *t*, and sex *s*
w_a	Weight at age *a*
$Z_{t,x,a}$	Total mortality at age *a*, sex *s*, and time *t*
timing	The timing of the survey during the year
$I_{t,f}$	Observed survey biomass at time *t* for fleet *f*
$SB_{t,f}$	Predicted survey biomass at time *t* for fleet *f*
$CV_{t,f}$	CV of observed survey biomass at time *t* for fleet *f*
$n_{t,x,f}$	Number of age-composition observations at time *t* for sex *x* and fleet *f*
$p_{t,x,f,a}$	Observed proportion at age *a*, time *t*, fleet *f*, and sex *x*
$\hat{p}_{t,x,f,a}$	Predicted proportion at age *a*, time *t*, fleet *f*, and sex *x*
$n_{2,t,x,f}$	Number of length-composition observations at time *t* for sex *x* and fleet *f*
$p_{t,x,f,l}$	Observed proportion at length *l*, time *t*, fleet *f*, and sex *x*
$\hat{p}_{t,x,f,l}$	Predicted proportion at length *l*, time *t*, fleet *f*, and sex *x*
$\tilde{R}_t$	Estimated mean recruitment in year *t*
σ_R	Recruitment CV (specified in SS3 only)
b_t	Bias adjustment factor at time *t* (specified in SS3 only)
C_t^{obs}	Observed catch at time *t*
$\hat{C}_t$	Predicted catch at time *t*
$\sigma_{t,f}$	Standard error of catch at time *t* for fleet *f* (specified for SS3 only)

Table 8A.2. Likelihood components used in the 2011 and SS3 models. Numbers in the component column are likelihood component weightings for: (SS3, 2011 Model).

Component	SS3	2011 Model
Survey biomass $(SB_{t,f})$ equation	$\sum_x \sum_a S_{f,x,a} N_{t,x,a} w_a \exp(-\text{timing}(Z_{t,x,a}))$	$\sum_x \sum_a S_{f,x,a} N_{t,x,a} w_a$
Survey biomass likelihood (1,1)	$\sum_{t \in survey\ f} \frac{(\ln(\mathrm{I}_{t,f}) - \ln(SB_{t,f}))^2}{2\ln(CV_{t,f}^2 + 1)}$	As for SS3
Age composition (1, 1)	$\sum_t \sum_x \sum_a n_{t,x,f}\, p_{t,x,f,a} \ln\left(\frac{p_{t,x,f,a}}{\hat{p}_{t,x,f,a}}\right)$	As for SS3
Length Composition (1,1)	$\sum_t \sum_x \sum_l n_{2,t,x,f}\, p_{t,x,f,l} \ln\left(\frac{p_{t,x,f,l}}{\hat{p}_{t,x,f,l}}\right)$	As for SS3
Main period recruits (1,1)	$\frac{1}{2}\left(\sum_{t=1967}^{2011}\left(\frac{\tilde{R}_t^2}{\sigma_R^2} + b_t \ln(\sigma_R^2)\right)\right)$ (sum to 0 constraint)	$\sum_{t=1967}^{2011} \tilde{R}_t^2$ (sum to 0 constraint)
Catch (30,30)	$\sum_t \frac{(\ln(\mathrm{C}_t^{obs}) - \ln(\hat{\mathrm{C}}_t))^2}{2\sigma_{t,f}^2}$	$\sum_t (\ln(\mathrm{C}_t^{obs}) - \ln(\hat{\mathrm{C}}_t))^2$

Table 8A.3. Components of the negative log(likelihood) for each alternative proposed SS3 model. M0-M4 are the alternative model descriptors, which are described in full in the section "Analytic Approach: Proposed Alternative SS3 Models" on page 6. The "Total" likelihoods marked "but add'l component" include an additional likelihood component for initial equilibrium catch and therefore the likelihoods cannot be compared directly to those alternative models where a component for initial equilibrium catch was not estimated. However, the contribution of the initial equilibrium catch likelihood component to the total negative log(likelihood) is very small in each case.

Likelihood component	M0: Base Case	M1	M2	M3	M4
Total (not always comparable to the transitional model)	667.419	652.857	663.375 (but add'l component)	641.471	637.855 (but add'l component)
Initial Equilibrium Catch		NA	0.000951959		0.000767171
Survey Biomass	-6.70951	-5.33251	-6.72469	-4.74592	-4.5957
Length Composition	519.345	496.413	516.659	486.471	484.249
Age Composition	160.548	167.396	159.916	166.139	165.535
Recruitment	-6.01594	-5.77063	-6.72534	-6.39456	-7.33513

FIGURES

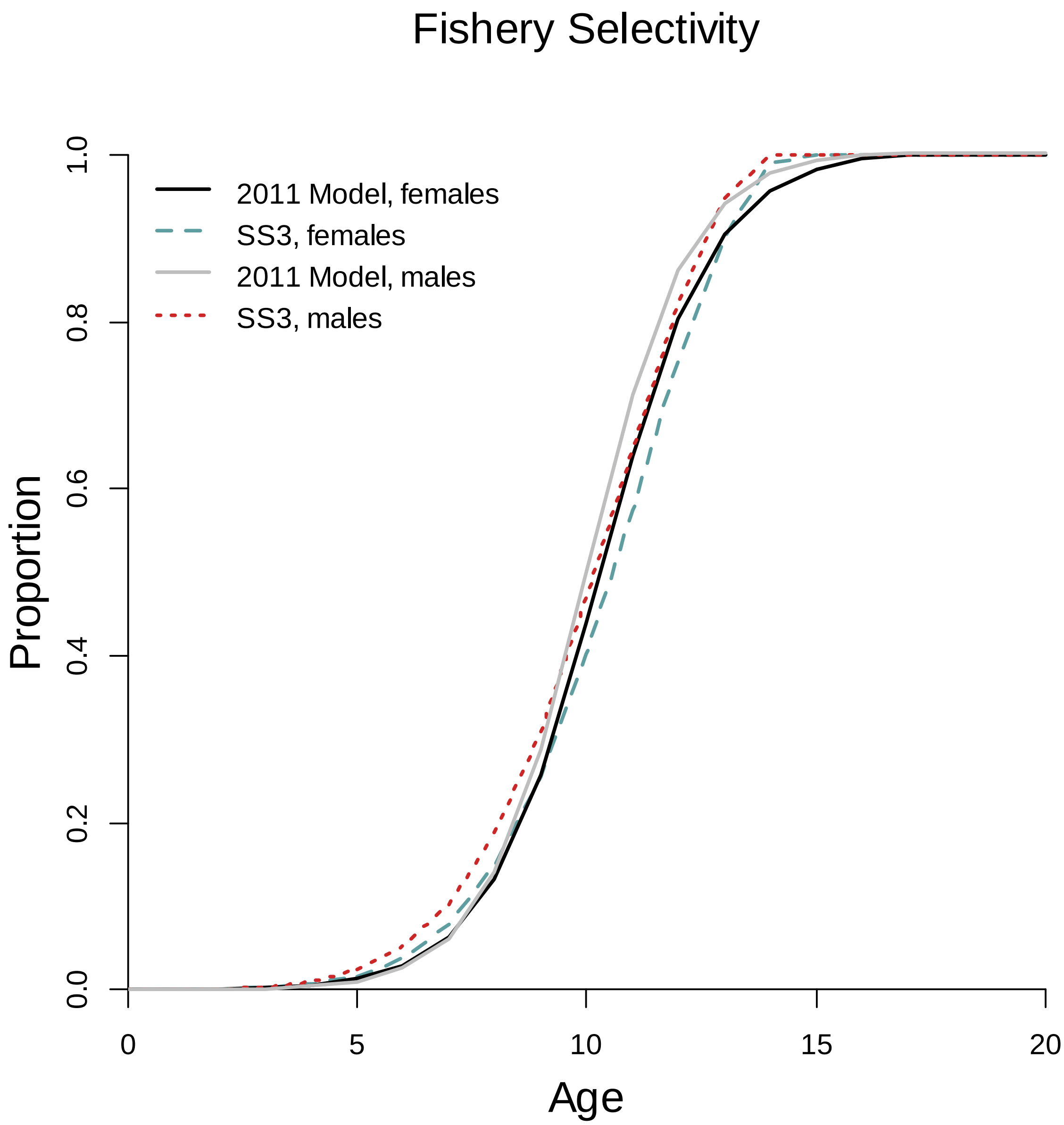


Figure 8A.1.SS3 double-normal selectivity curves matched as closely as possible to the 2011 model's logistic fishery selectivity curves (the standard deviation of the descending limb of the selectivity curves was fixed at a large value to create an asymptotic curve).

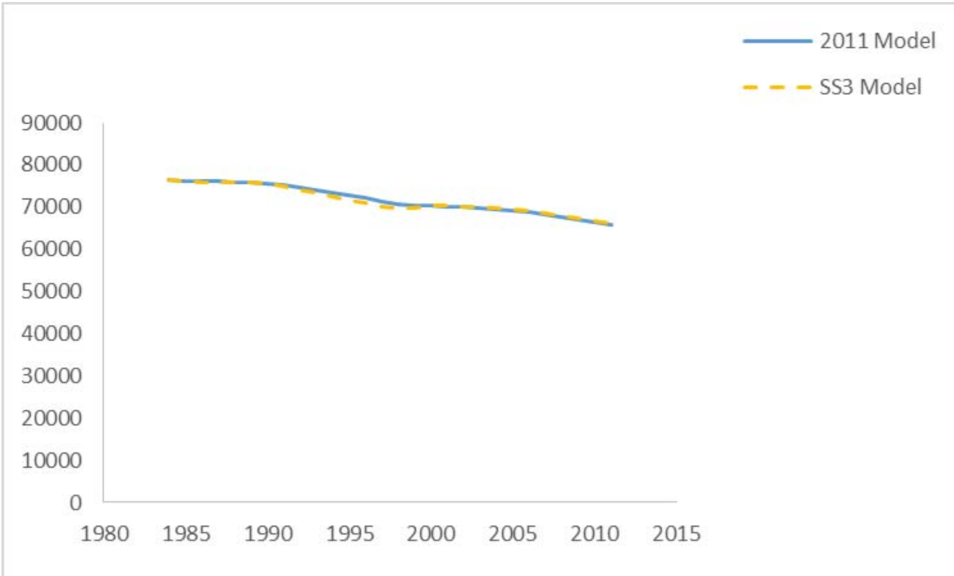


Figure 8A.2.Spawning stock biomass for a deterministic run of the 2011 and SS3 models with parameters in both models fixed at the MLEs for the 2011 model with flathead sole catch history and no recruitment deviations. Fishery selectivity curves for the models were forced to match as closely as possible (Figure 8A.1).

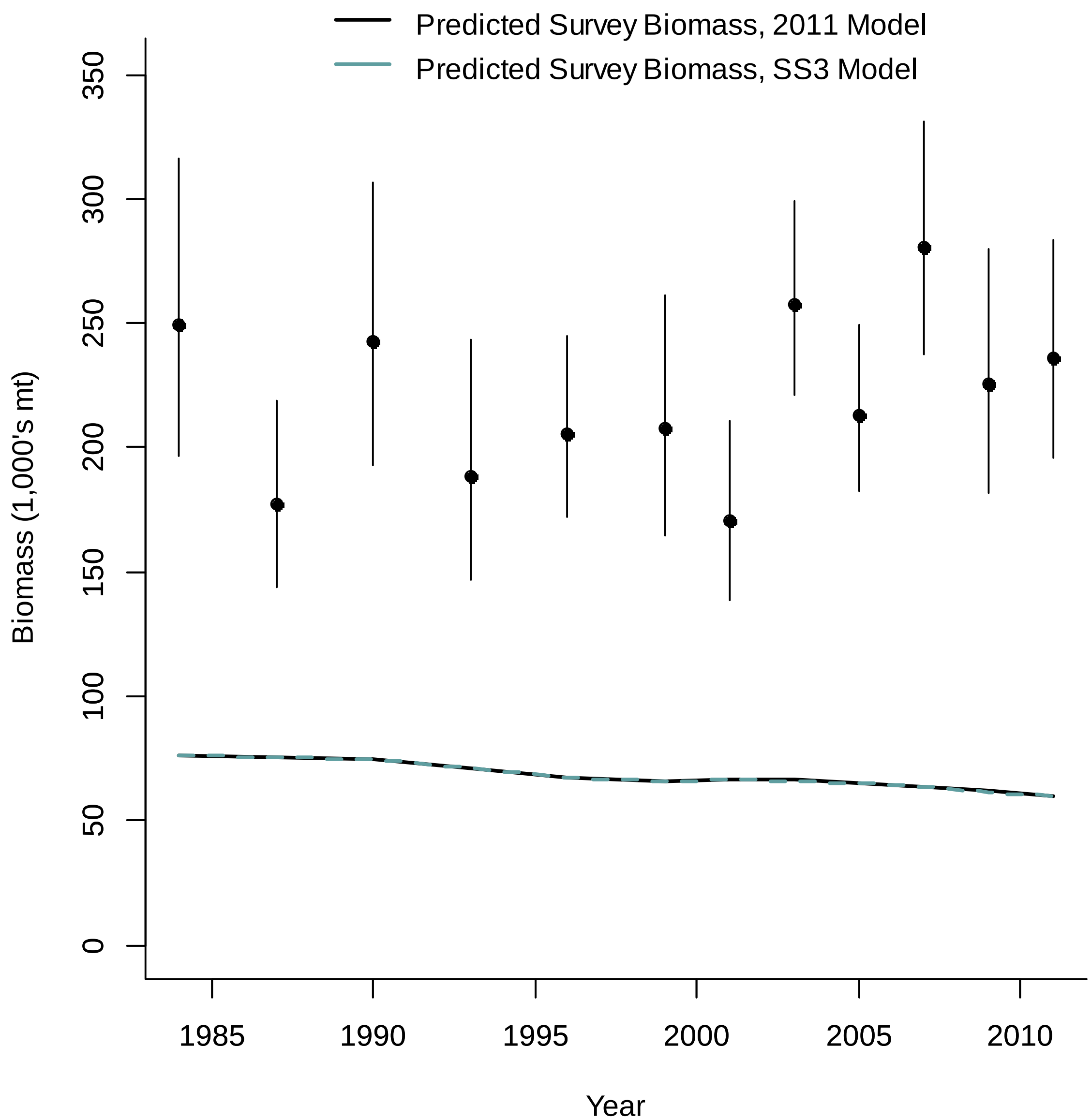


Figure 8A.3. Survey biomass for a deterministic run of the 2011 and SS3 models with parameters in both models fixed at the MLEs for the 2011 model with flathead sole catch history, no recruitment deviations, and no estimation. Fishery selectivity curves for the models were forced to match as closely as possible (Figure 8A.1).

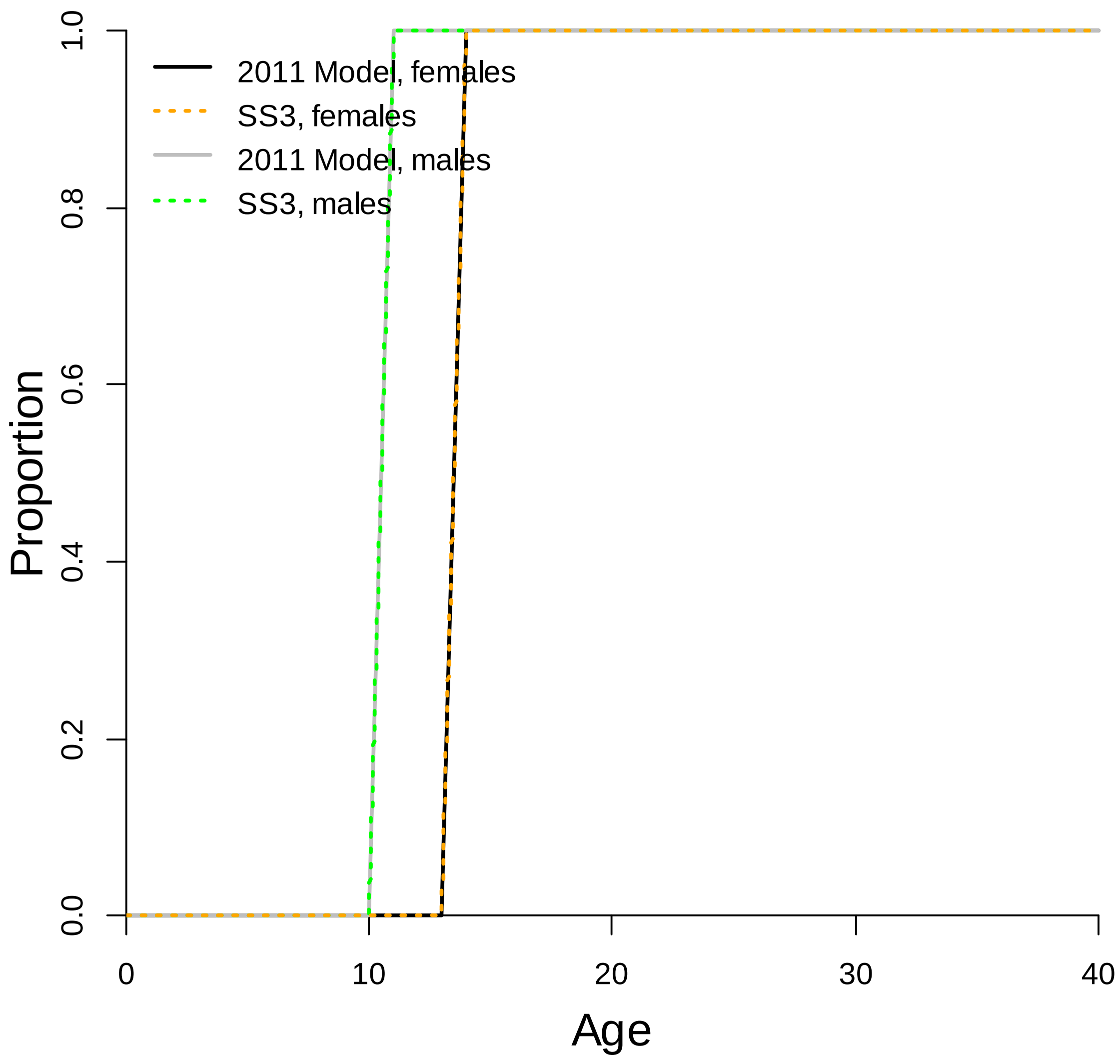


Figure 8A.4. Fishery selectivity used in deterministic runs (the same as the final estimate for fishery selectivity in the 2011 model). The SS3 selectivity curves pictured were created using a double-normal selectivity curve with no descending limb; the 2011 model selectivity curves are logistic.

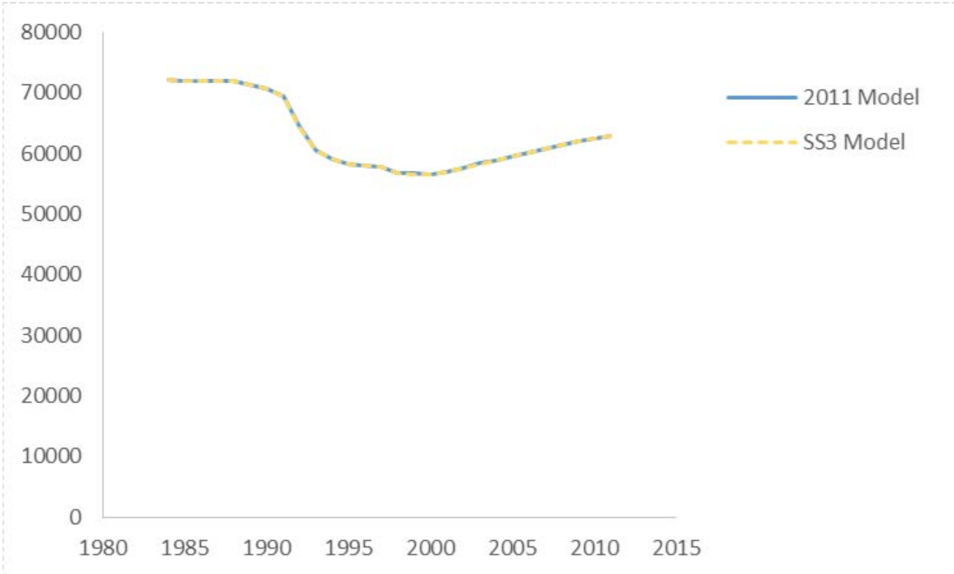


Figure 8A.5. Spawning stock biomass for a deterministic run of the 2011 and SS3 models with parameters fixed at the MLEs for the 2011 Dover sole model with Dover sole catch history and no recruitment deviations. Fishery selectivity curves for the models were forced to match as closely as possible (Figure 8A.4).

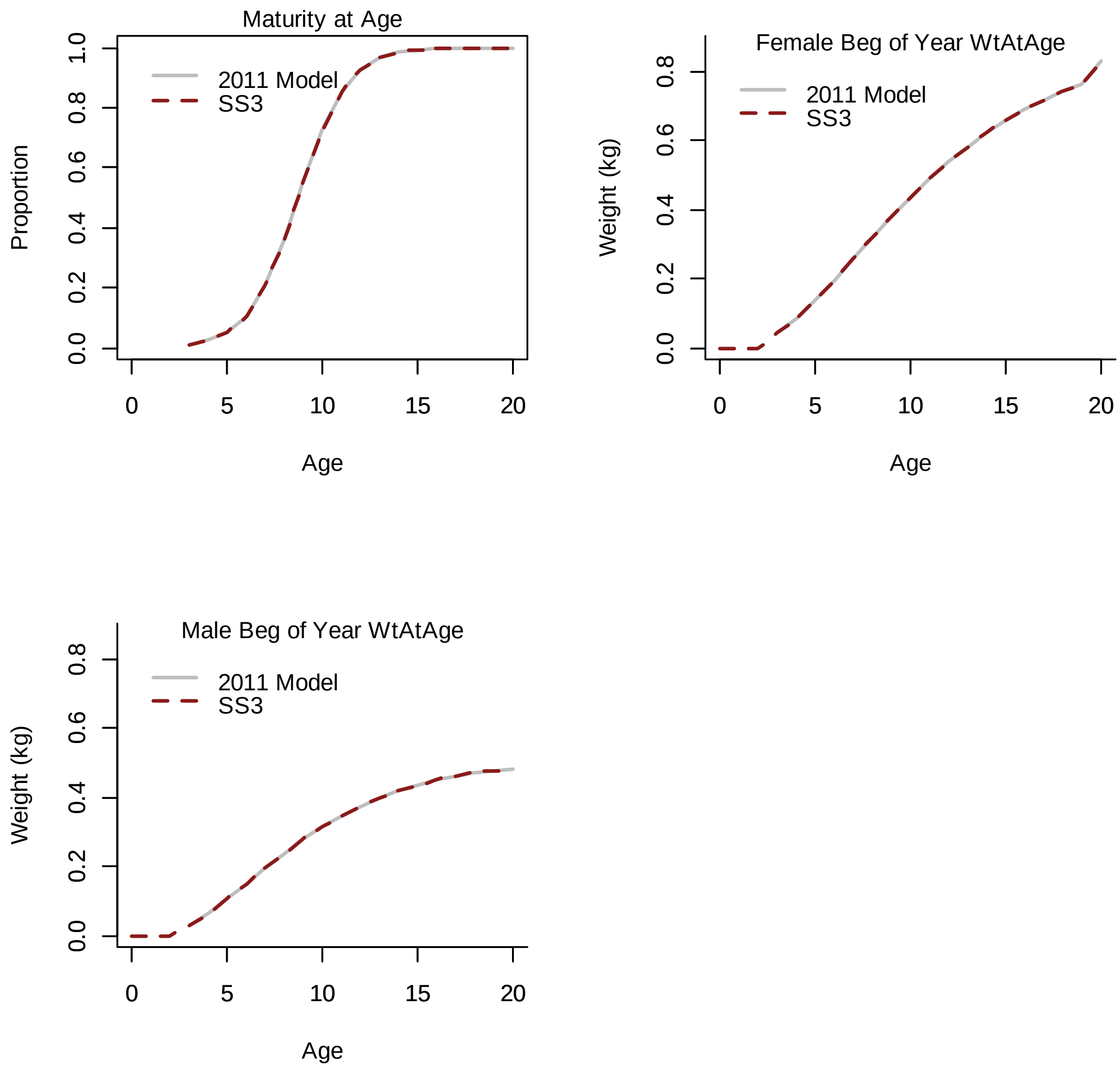


Figure 8A.6. Maturity-at-age and weight-at-age for the 2011 model and an equivalent SS3 model.

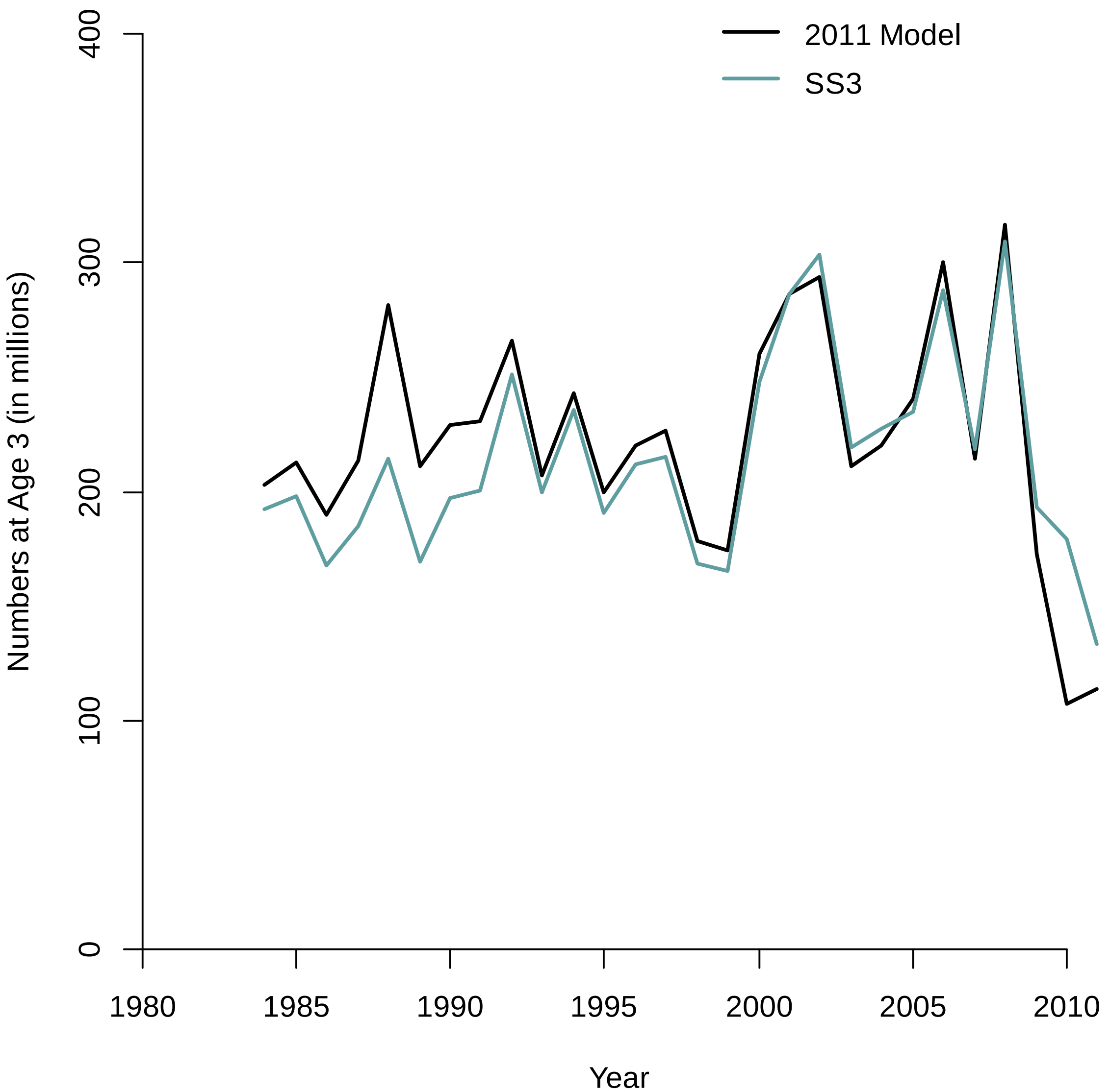


Figure 8A.7. Numbers at age 3 for the 2011 model (black line) and an equivalent SS3 run (blue line). Both models estimate the log of mean recruitment, recruitment deviations for 1967-2011, fishing mortality rates, and asymptotic selectivity parameters (logistic for the 2011 model and double-normal for SS3). Survey data for ages 0-2 and lengths 0-14cm are included in the SS3 model, but not the 2011 model.

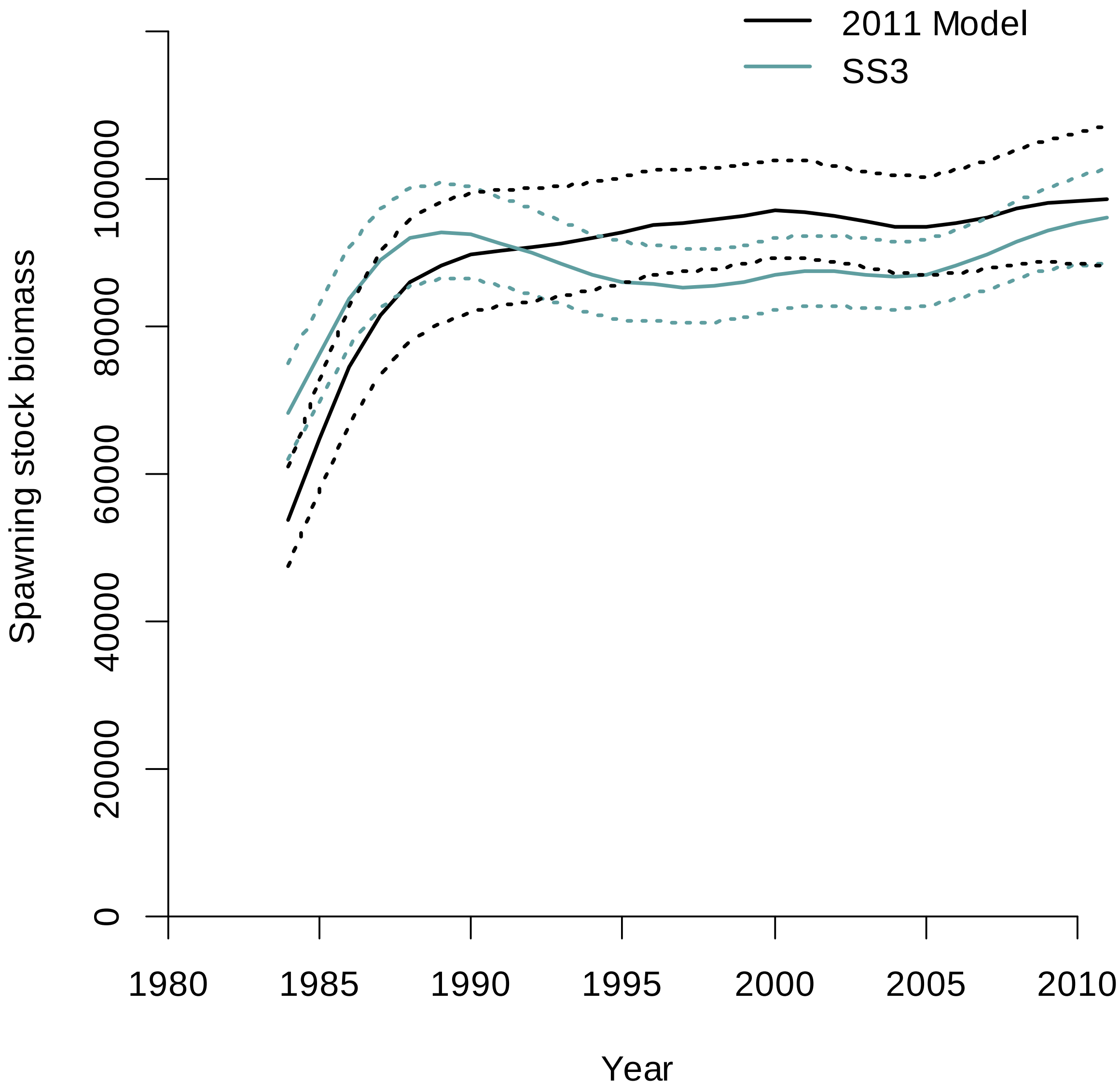


Figure 8A.8. Spawning stock biomass (solid lines) and asymptotic 95% confidence intervals (dotted lines) for the 2011 model (black lines) and SS3 (blue lines) for an equivalent SS3 model.

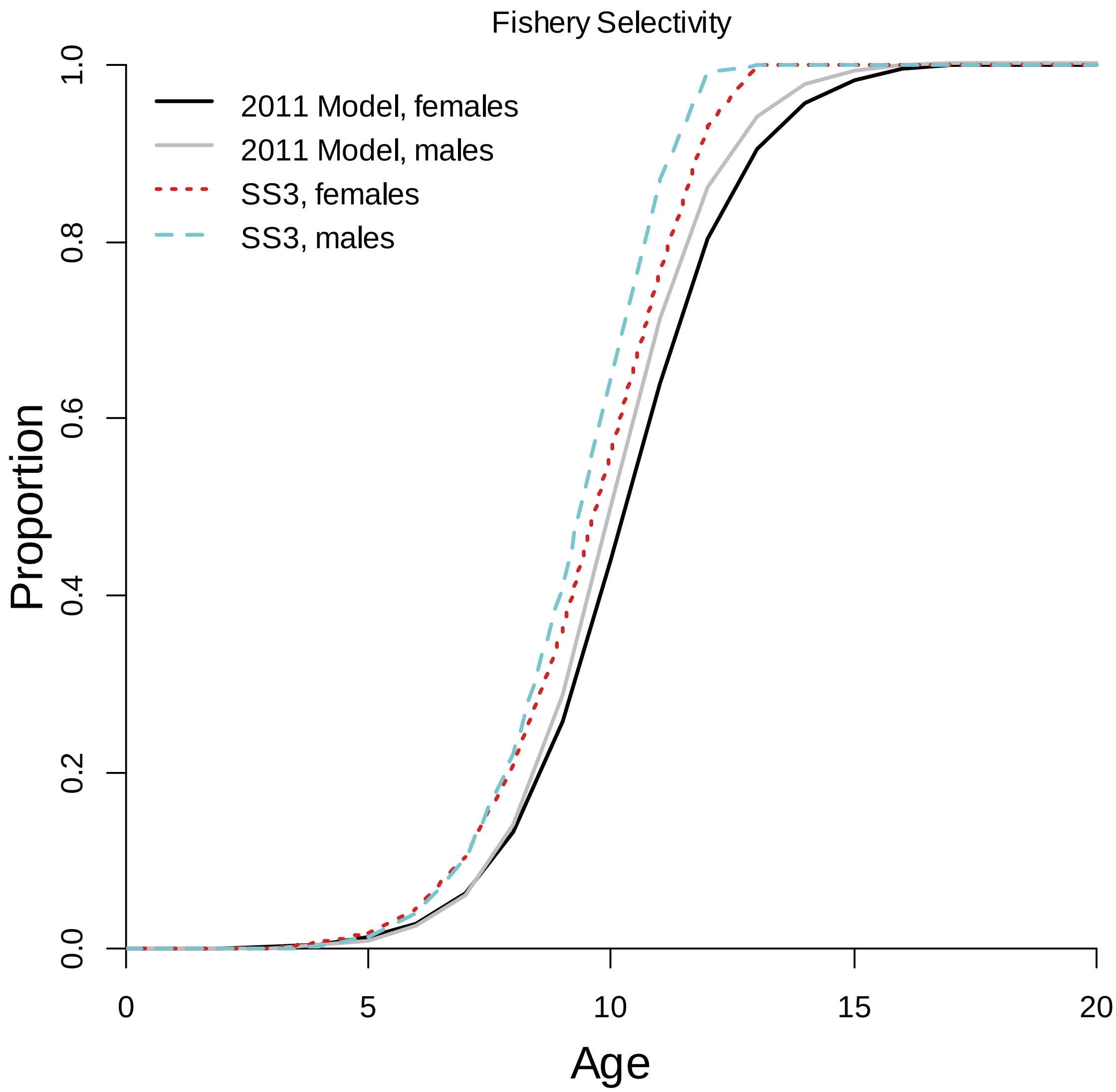


Figure 8A.9. Fishery selectivity for the 2011 model (solid lines) and an equivalent SS3 model run (dotted and dashed lines).

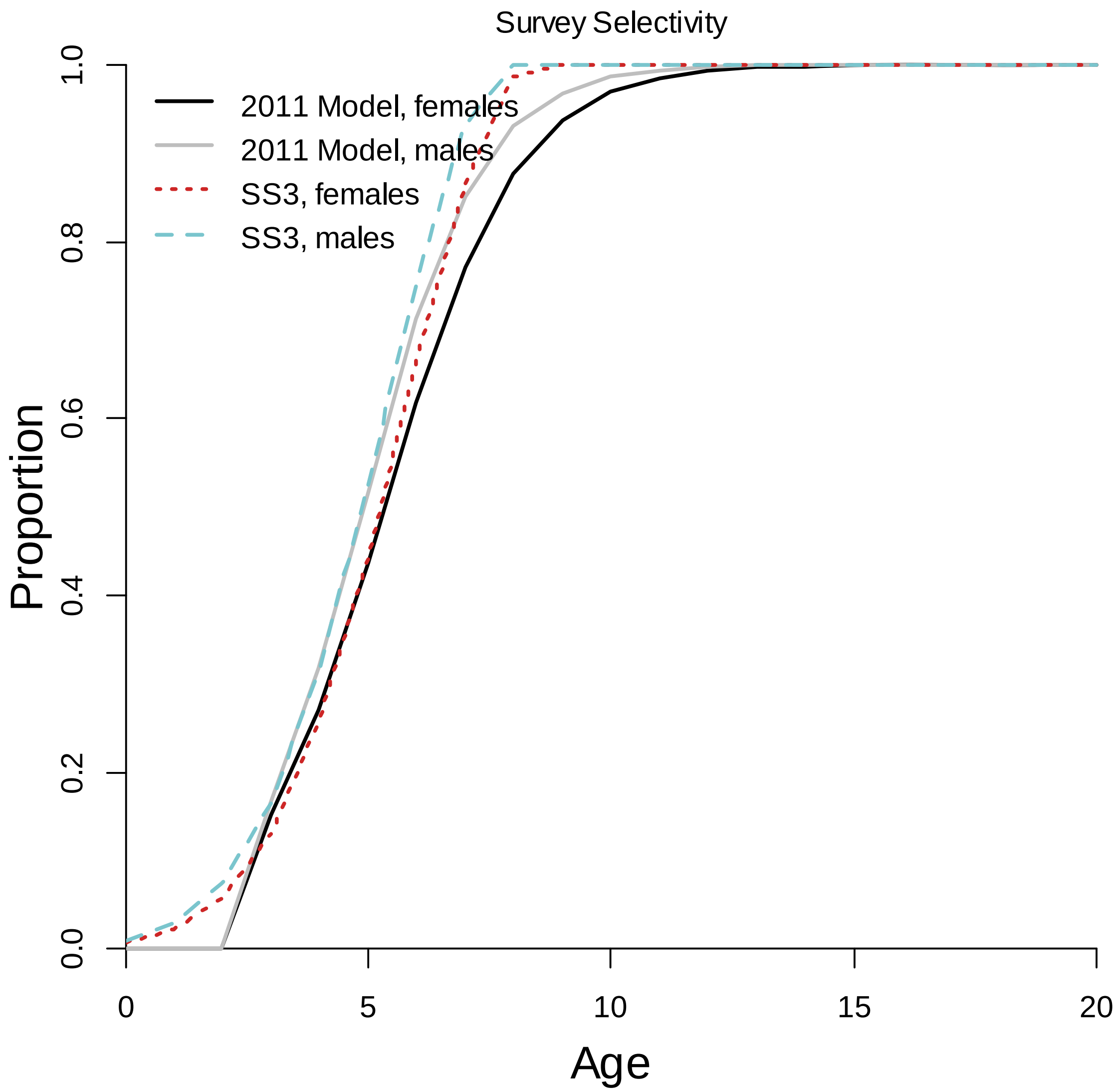


Figure 8A.10. Survey selectivity for the 2011 model (solid lines) and an equivalent SS3 model run (dotted and dashed lines).

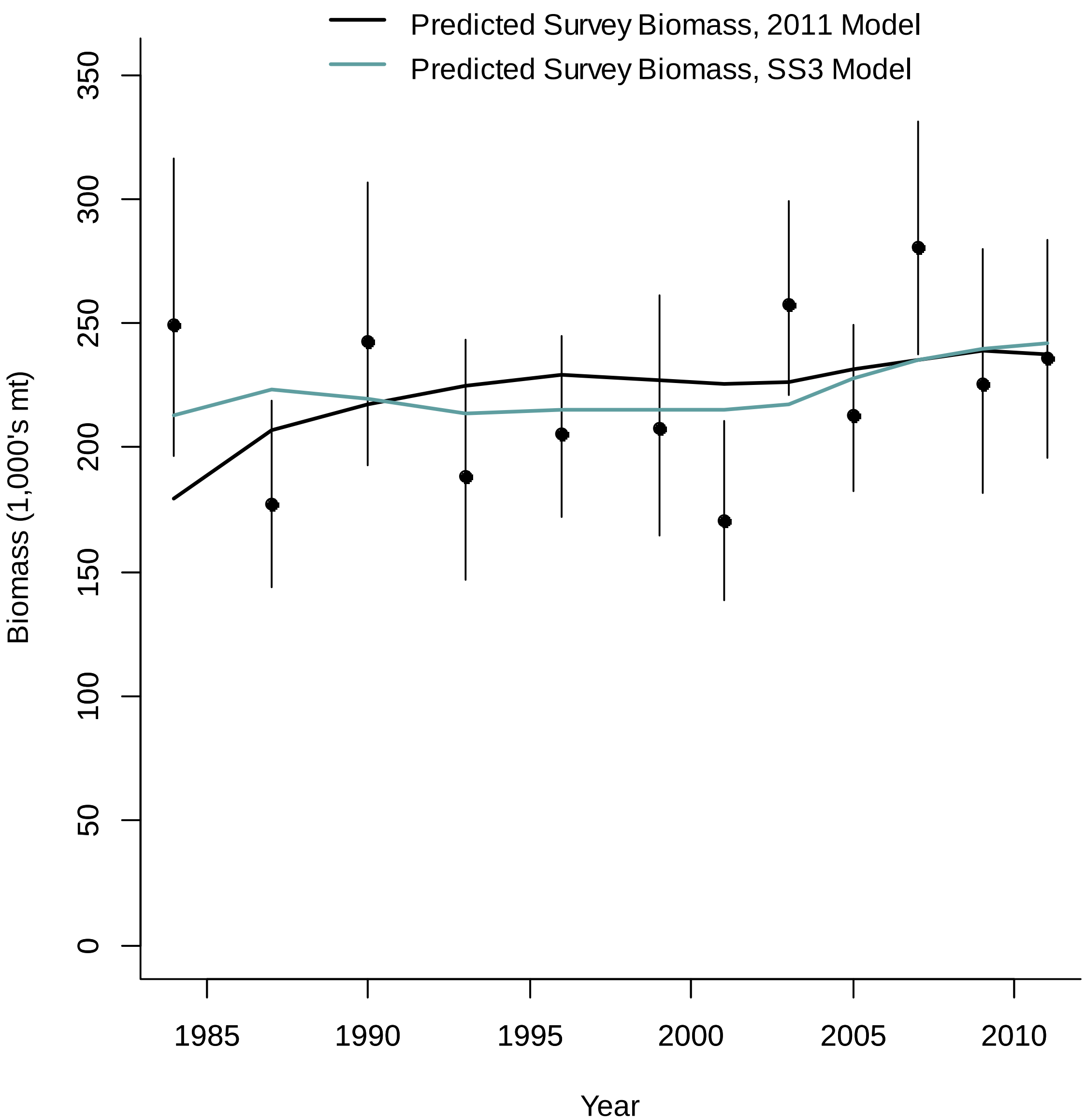


Figure 8A.11. Observed survey biomass (black dots) with 95% asymptotic confidence intervals (vertical black lines) and predicted survey biomass from the 2011 model (black line) and an equivalent SS3 model (blue line).

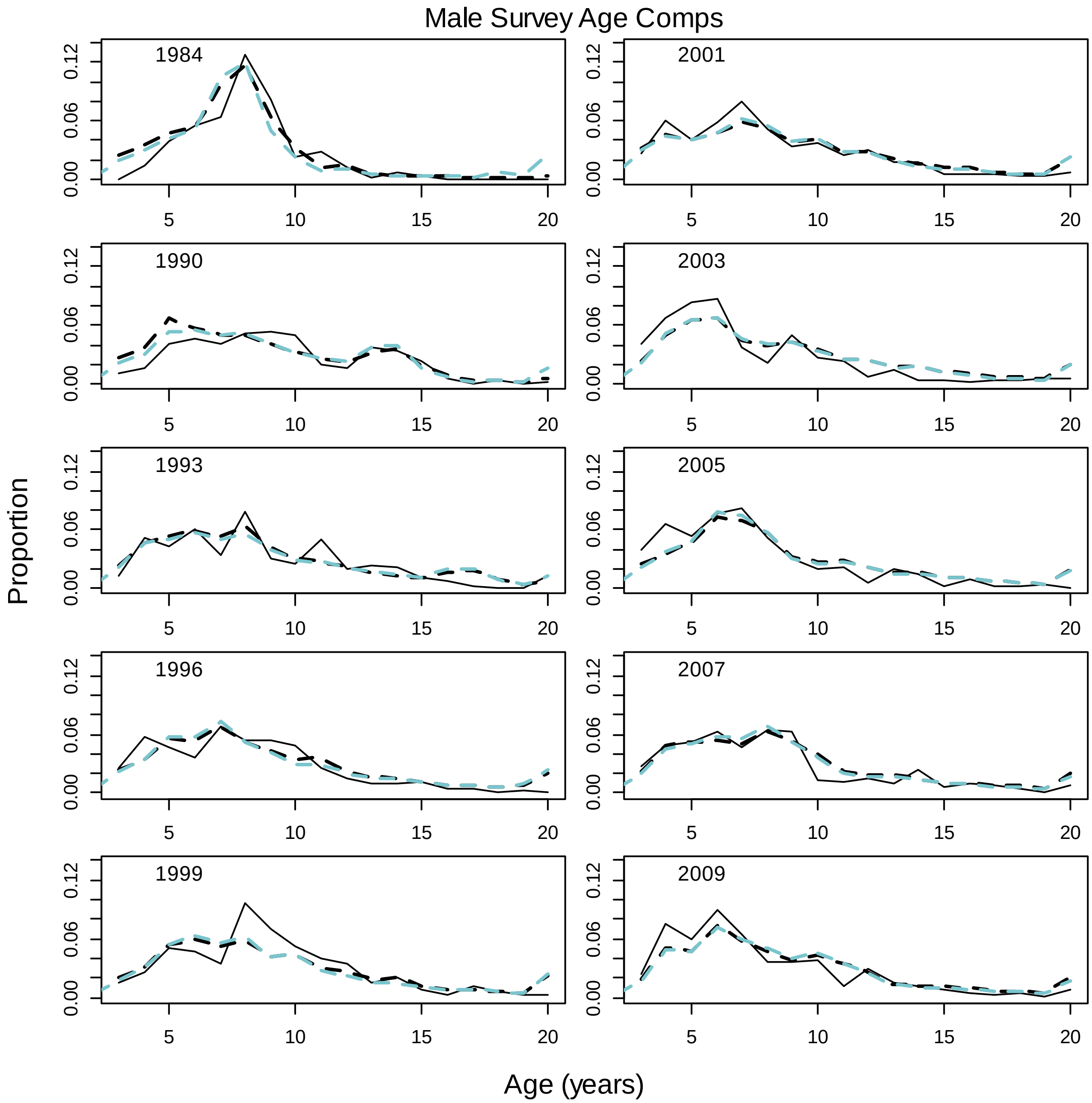


Figure 8.A12 Observed (solid black lines) and predicted (dashed lines) survey proportions-at-age for the 2011 model (dashed black lines) and an equivalent SS3 model run (dashed blue lines) for males (first panel) and females (second panel, next page).

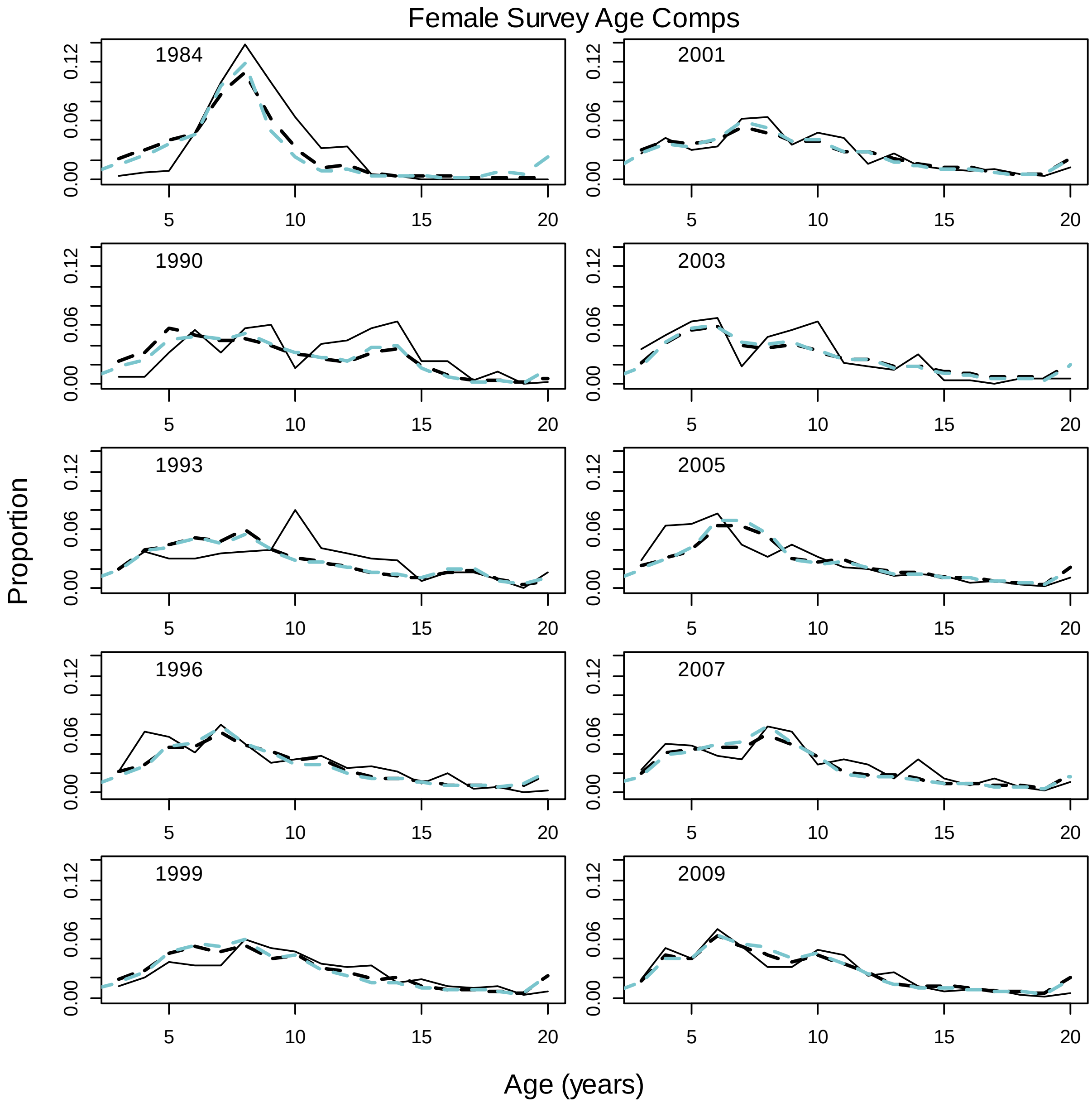


Figure 8A.12, continued.

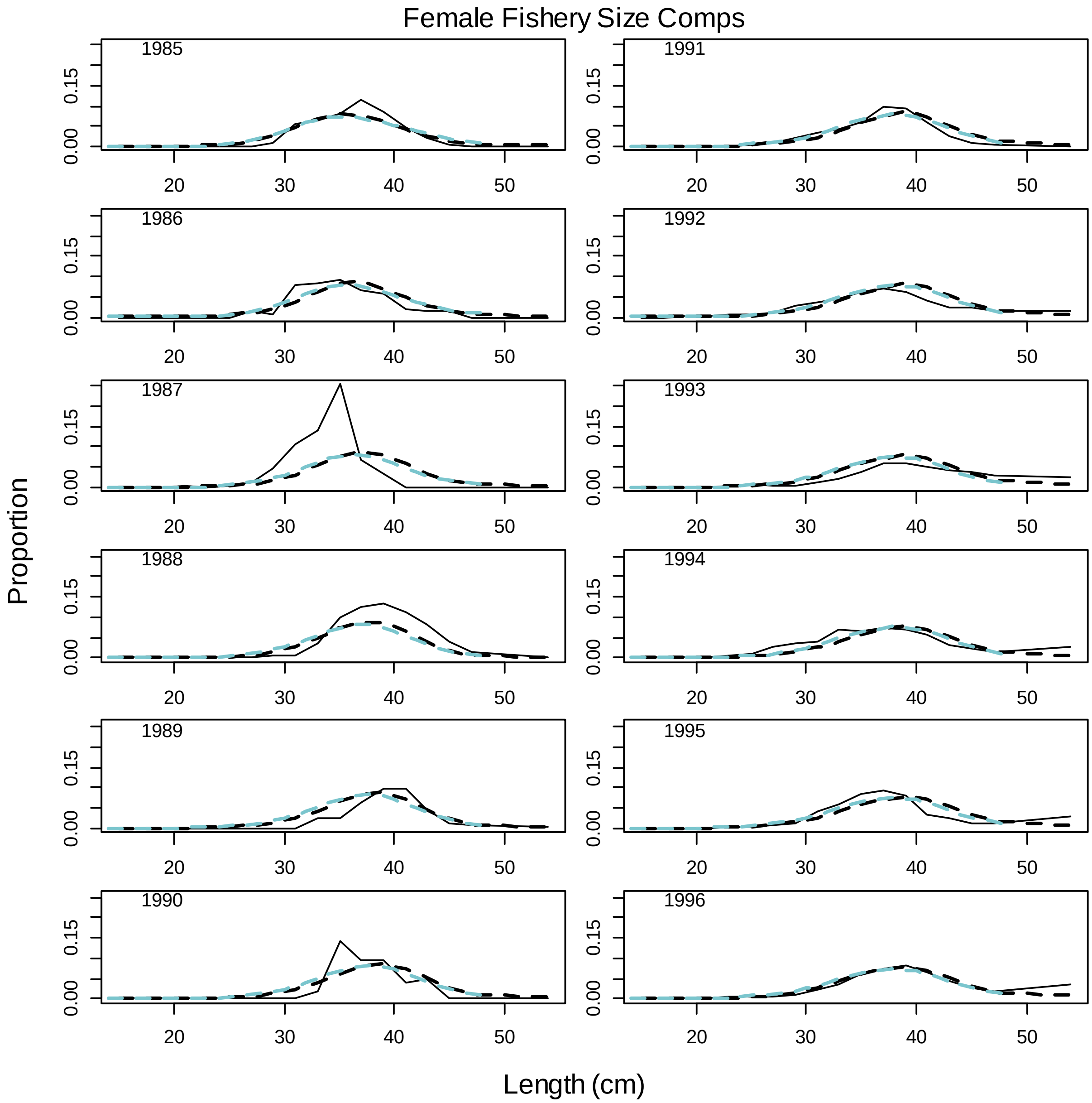


Figure 8A.13. (1 of 6) Observed (solid black lines) and predicted (dashed lines) fishery proportions-at-length for the 2011 model (dashed black lines) and an equivalent SS3 model run (dashed blue lines) for females (first set of panels) and males (second set of panels).

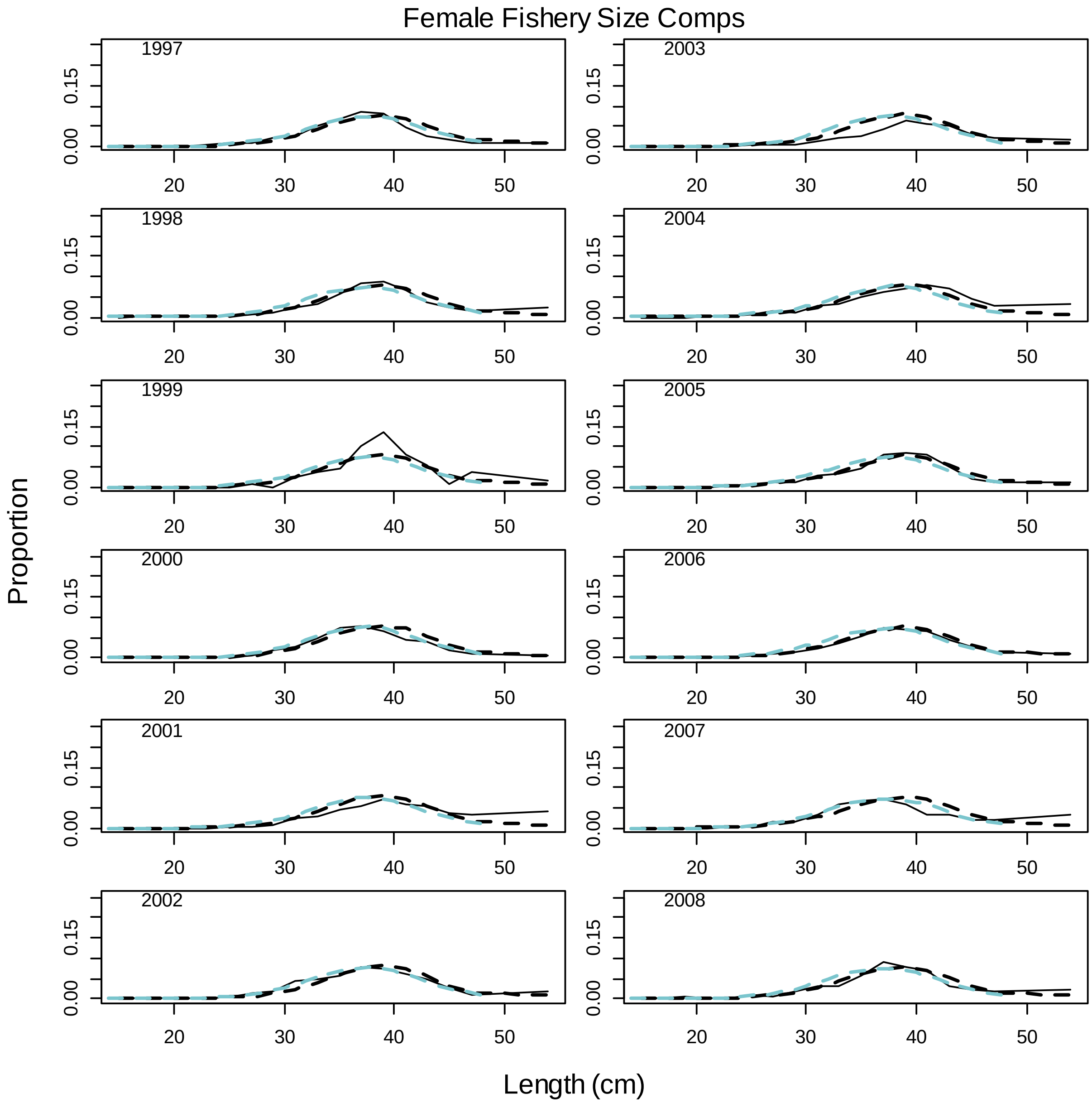


Figure 8A.13. (2 of 6)

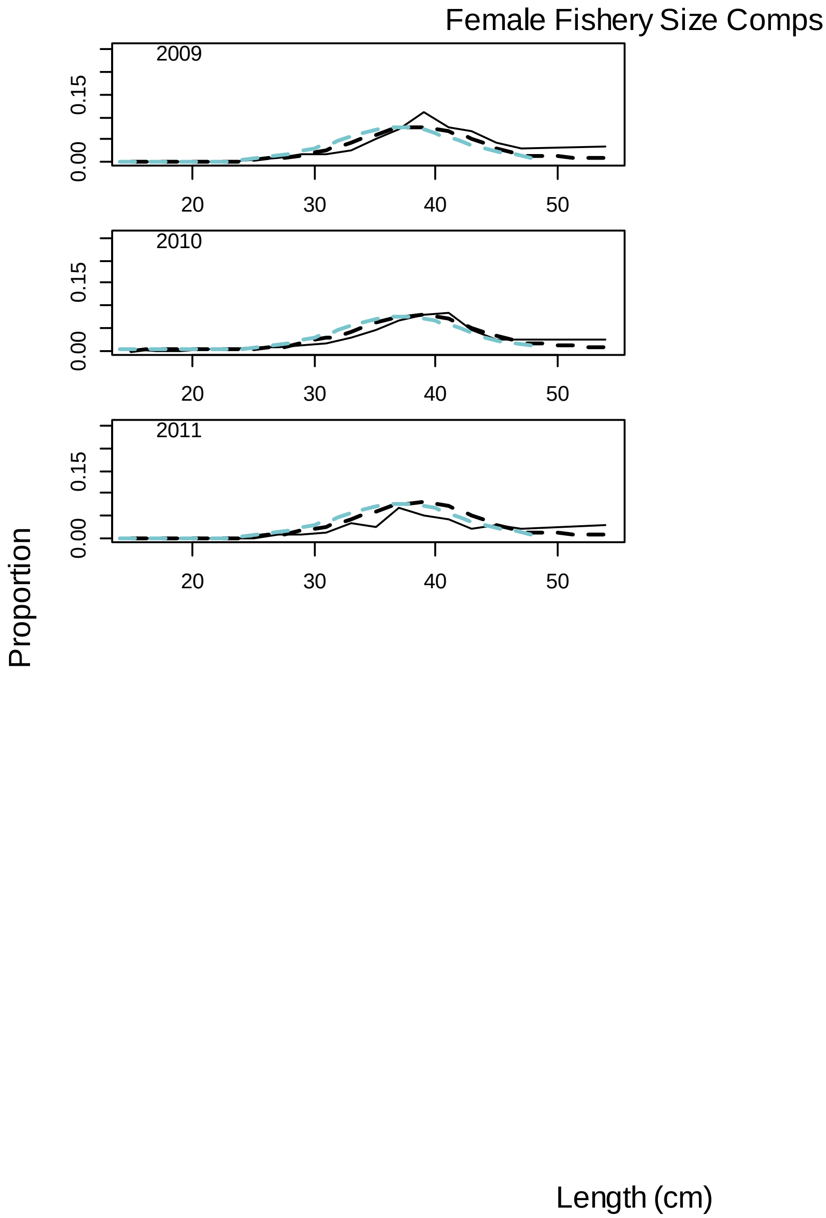


Figure 8A.13. (3 of 6)

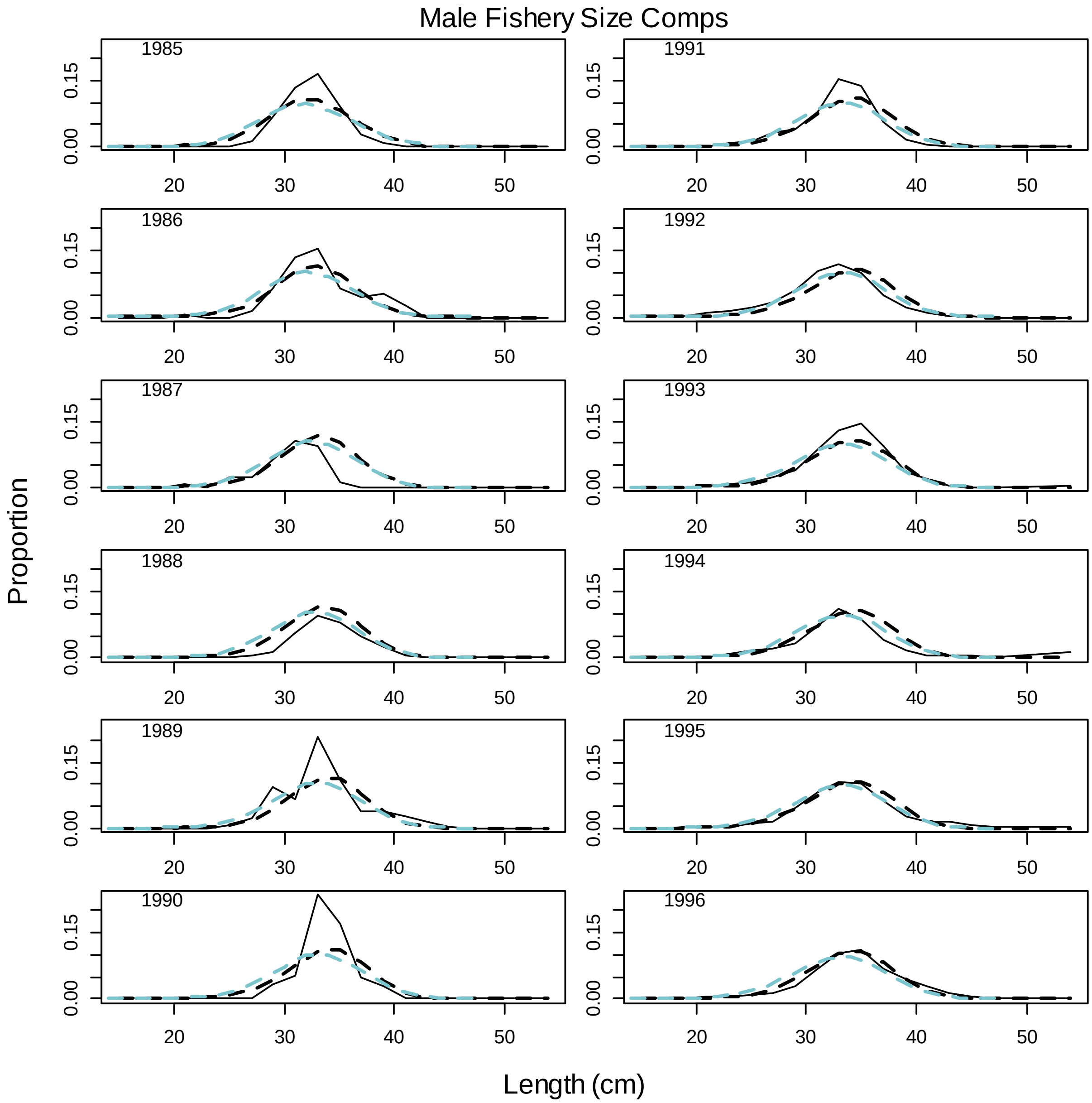


Figure 8A.13. (4 of 6)

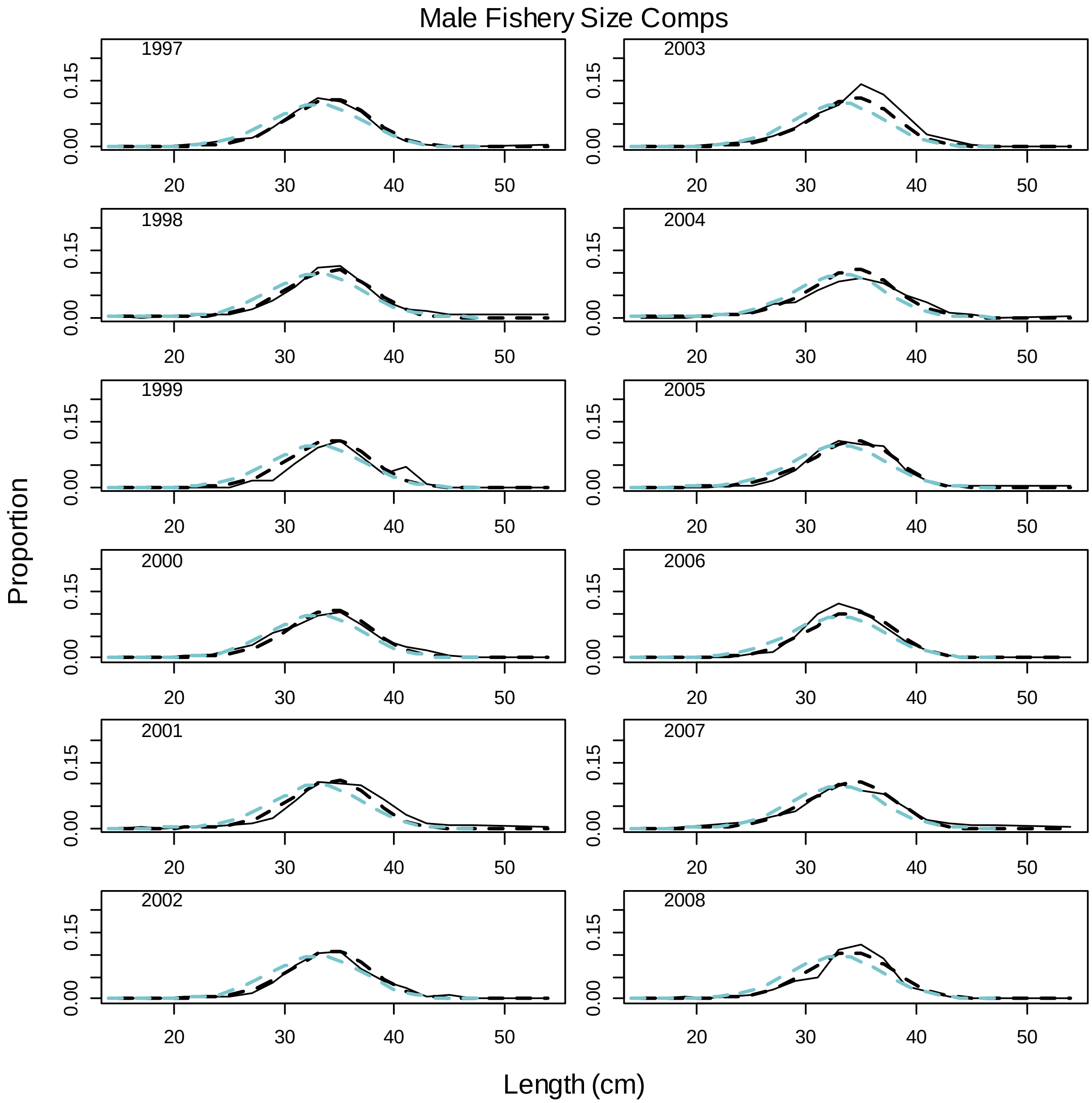


Figure 8A.13. (5 of 6)

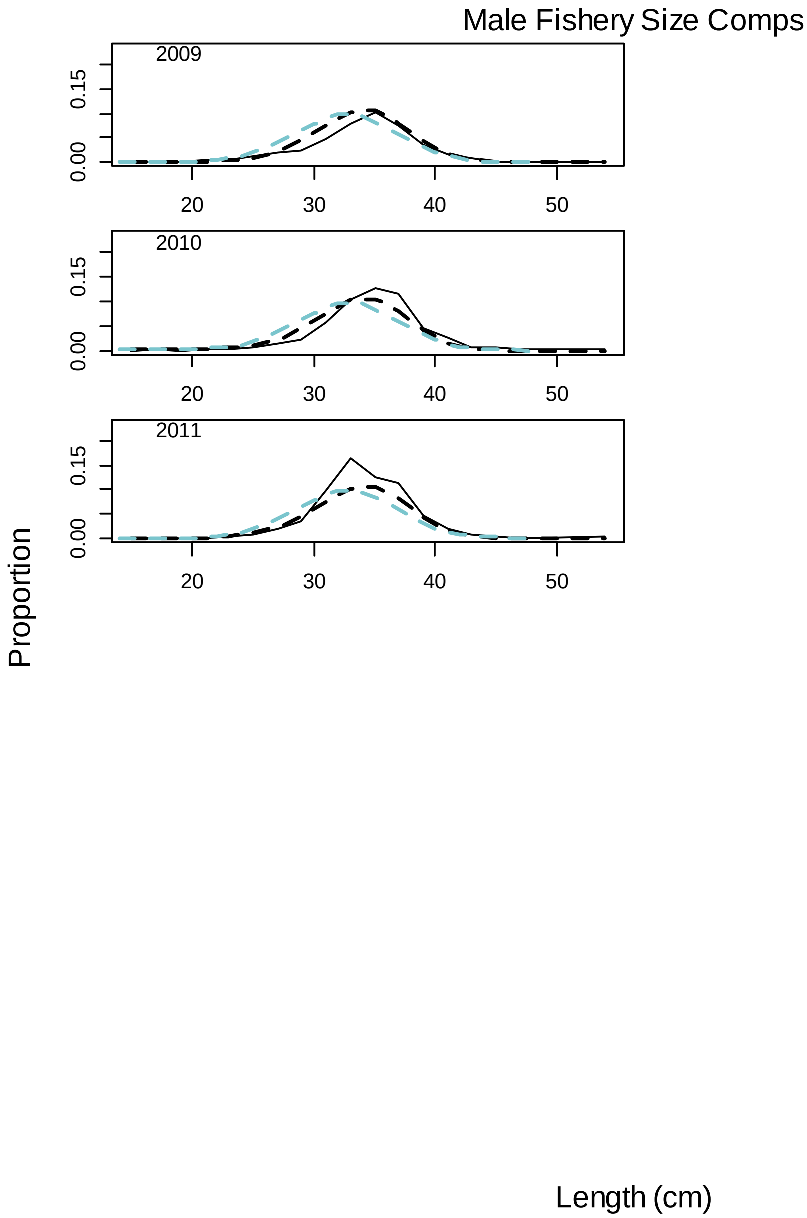


Figure 8A.13 (6 of 6).

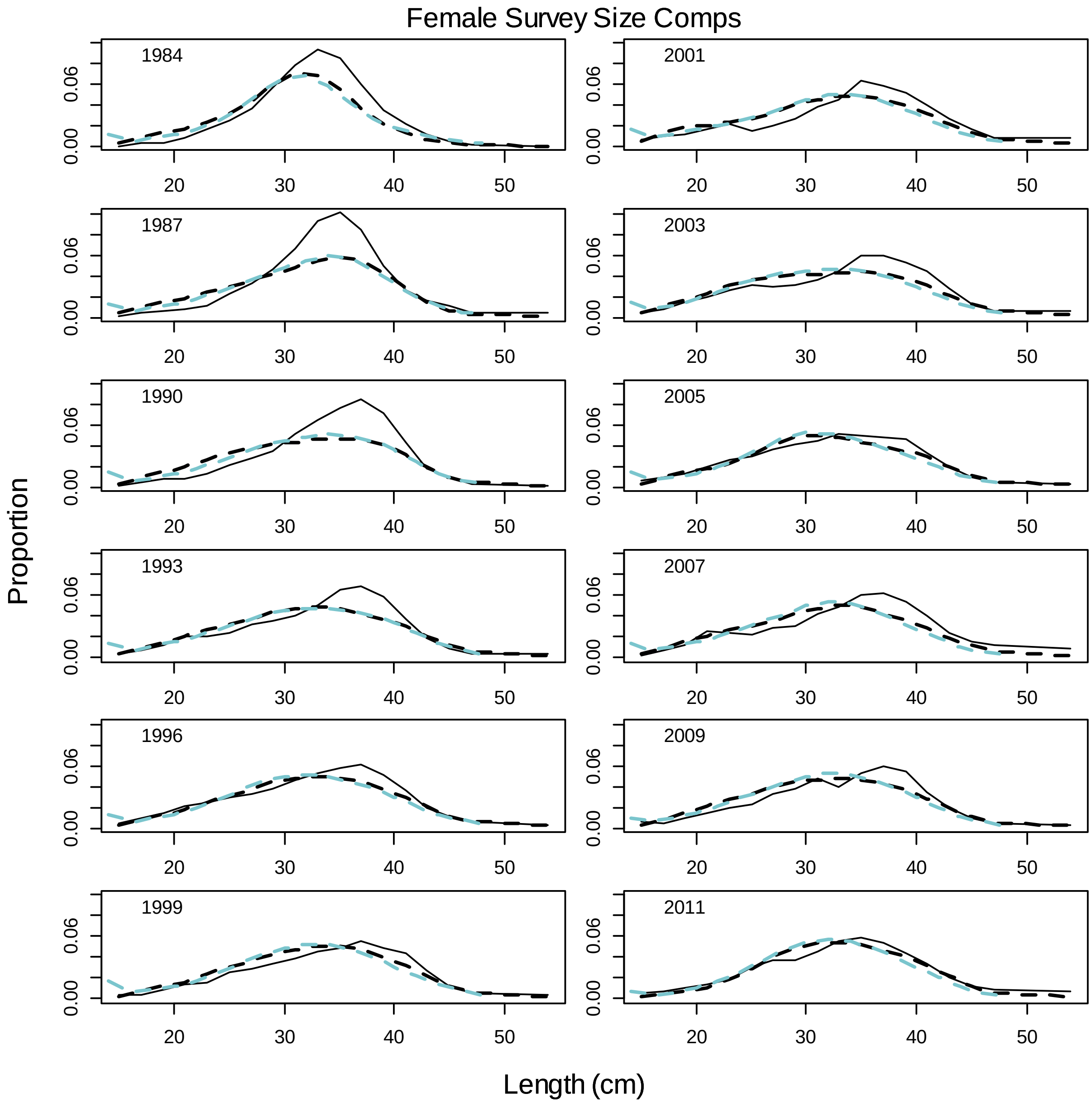


Figure 8A.14. (1 of 2) Observed (solid black lines) and predicted (dashed lines) survey proportions-at-length for the 2011 model (dashed black lines) and an equivalent SS3 model run (dashed blue lines) for females (first set of panels) and males (second set of panels).

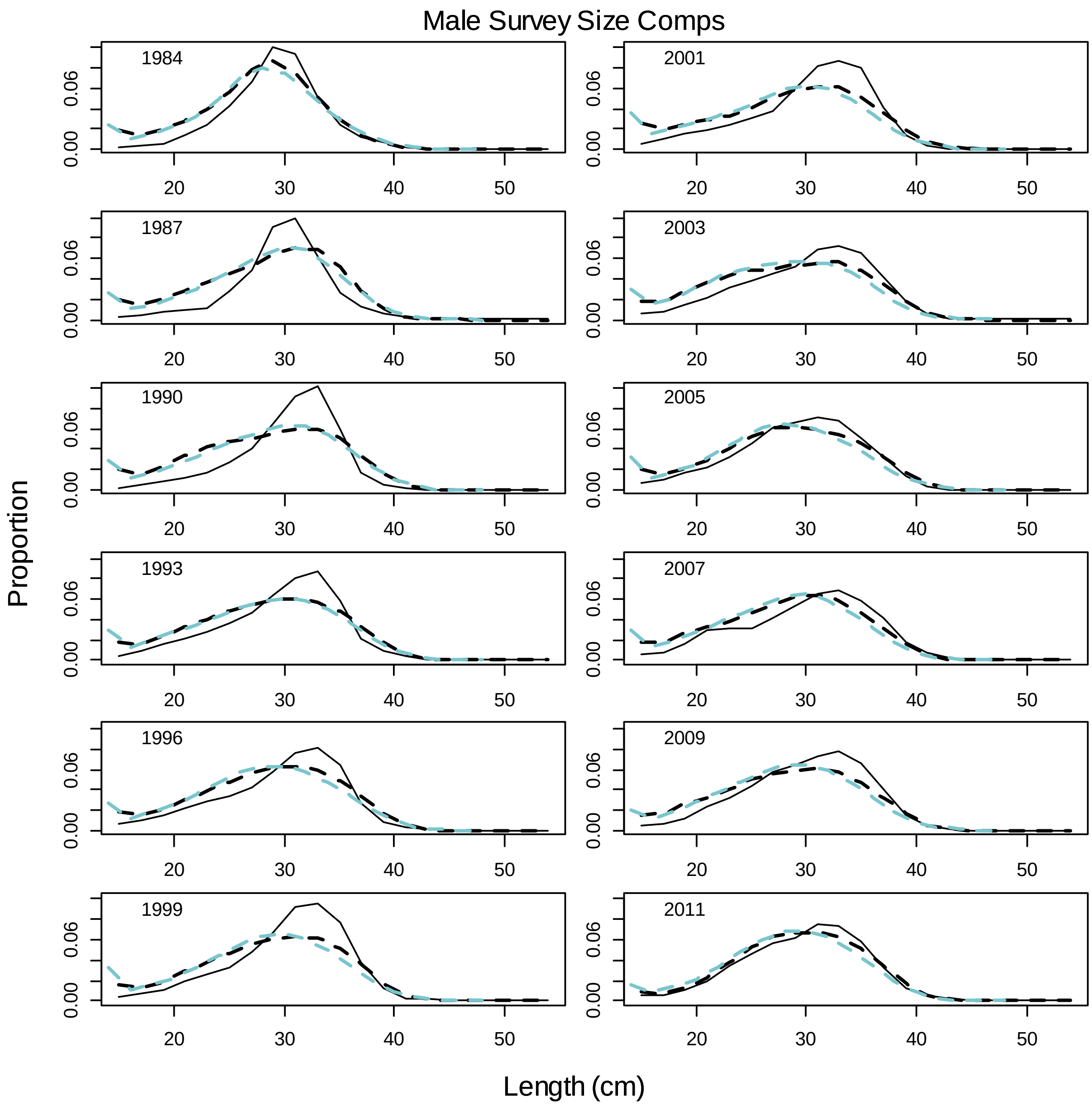


Figure 8A.14. (2 of 2)

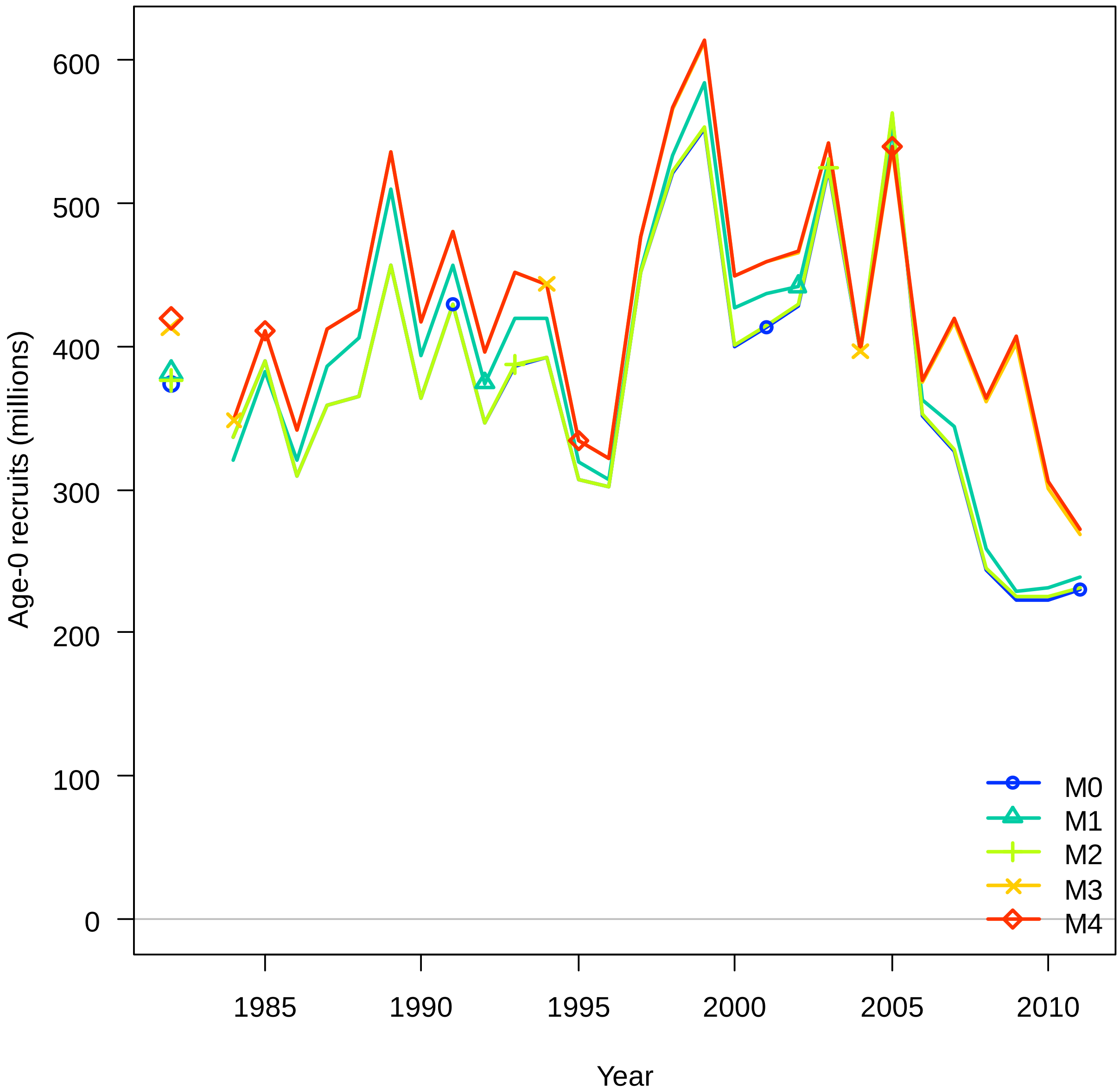


Figure 8A.15. Age 0 recruits for each alternative SS3 model. M0 is the transitional SS3 model that best matches the 2011 model. The leftmost group of vertical lines shows the log of mean recruitment.

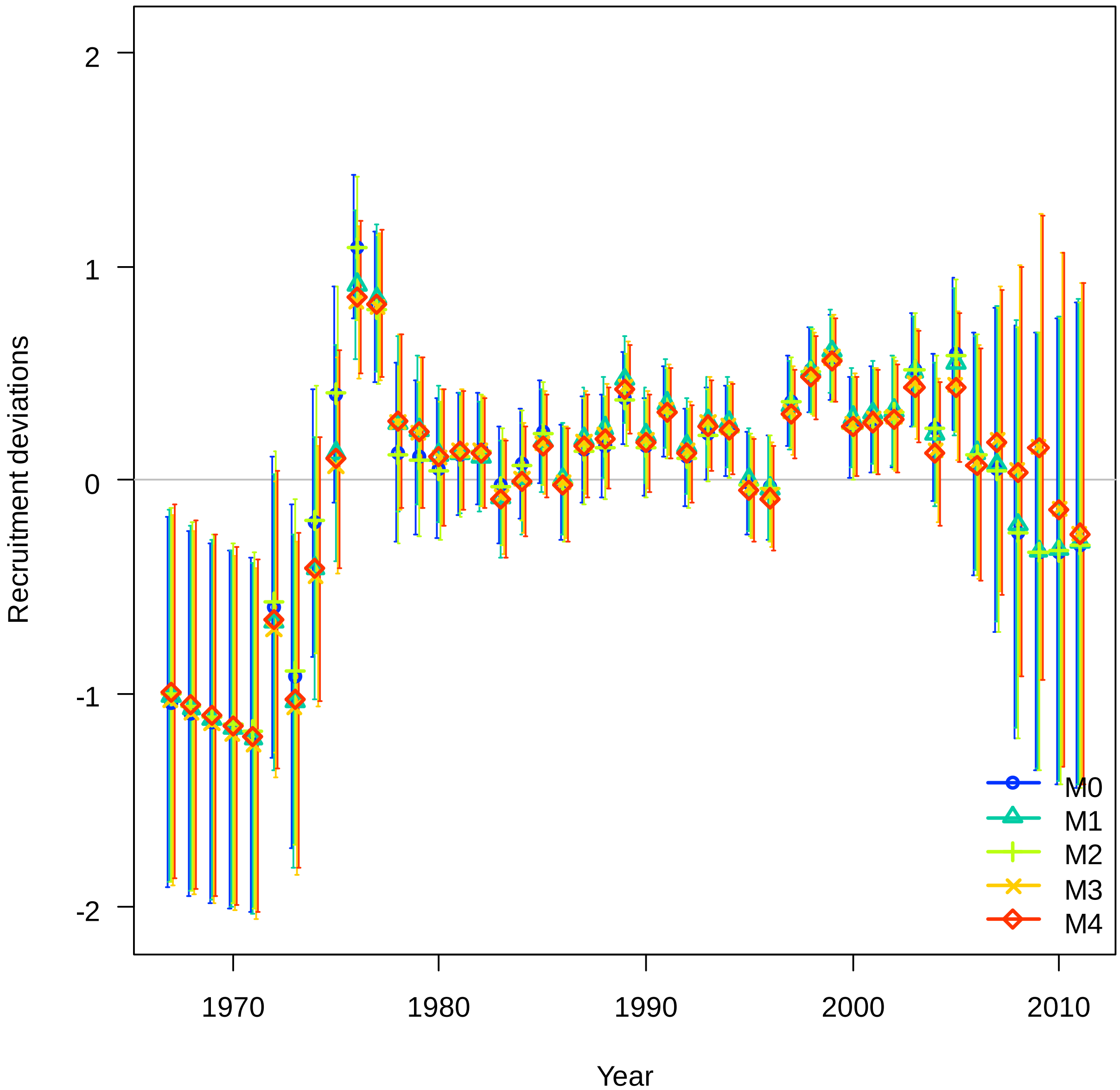


Figure 8A.16. Estimated recruitment deviations and 95% asymptotic confidence intervals for each alternative SS3 model. M0 is the transitional SS3 model that best matches the 2011 model.

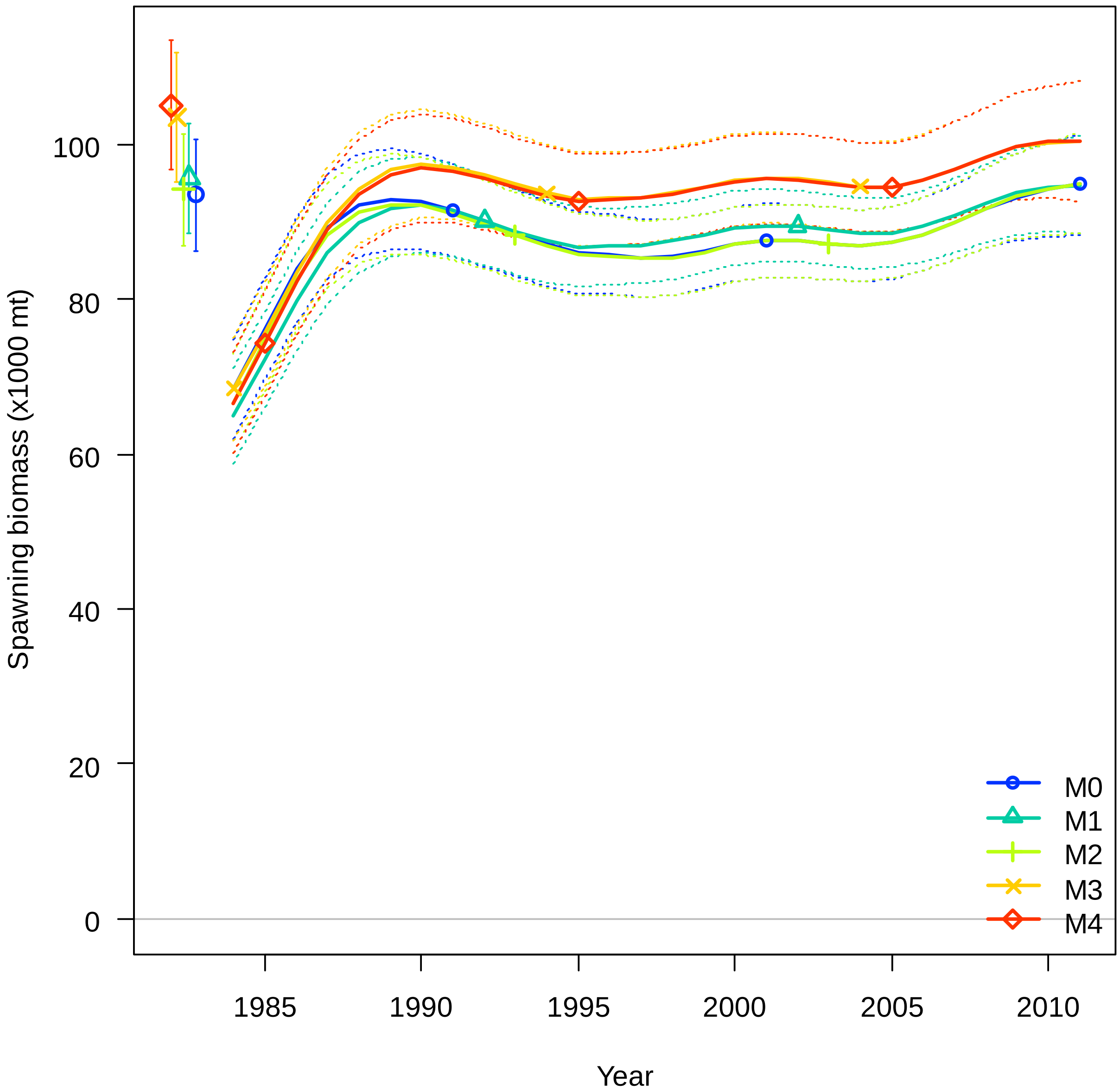


Figure 8A.17. Spawning stock biomass (solid lines) and 95% asymptotic confidence intervals (dotted lines) over time for each alternative SS3 model. M0 is the transitional SS3 model that best matches the 2011 model.

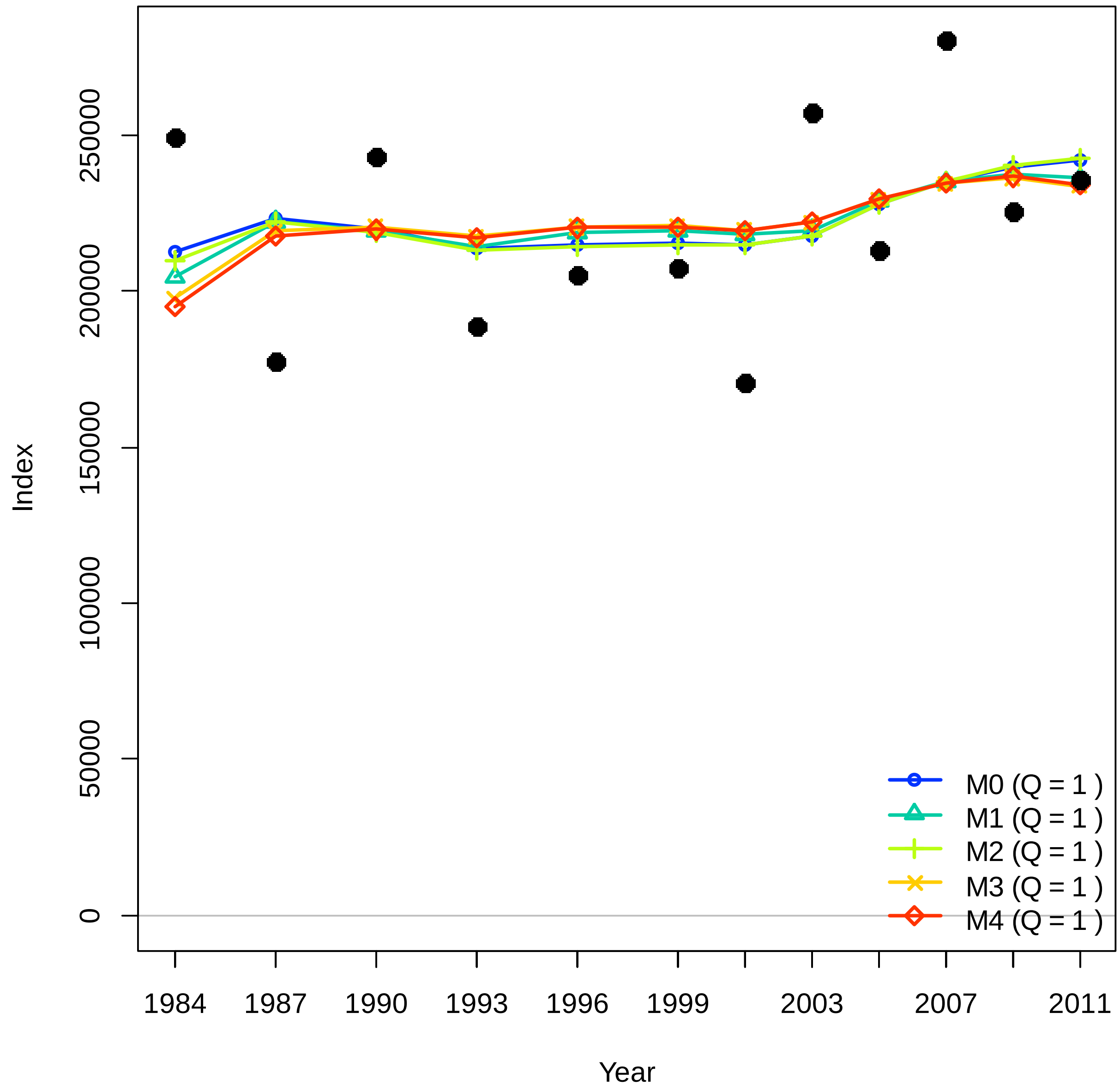


Figure 8A.18. Observed (black dots) and predicted (lines) survey biomass for each proposed alternative model. M0 is the transitional model that best matches the 2011 assessment model.

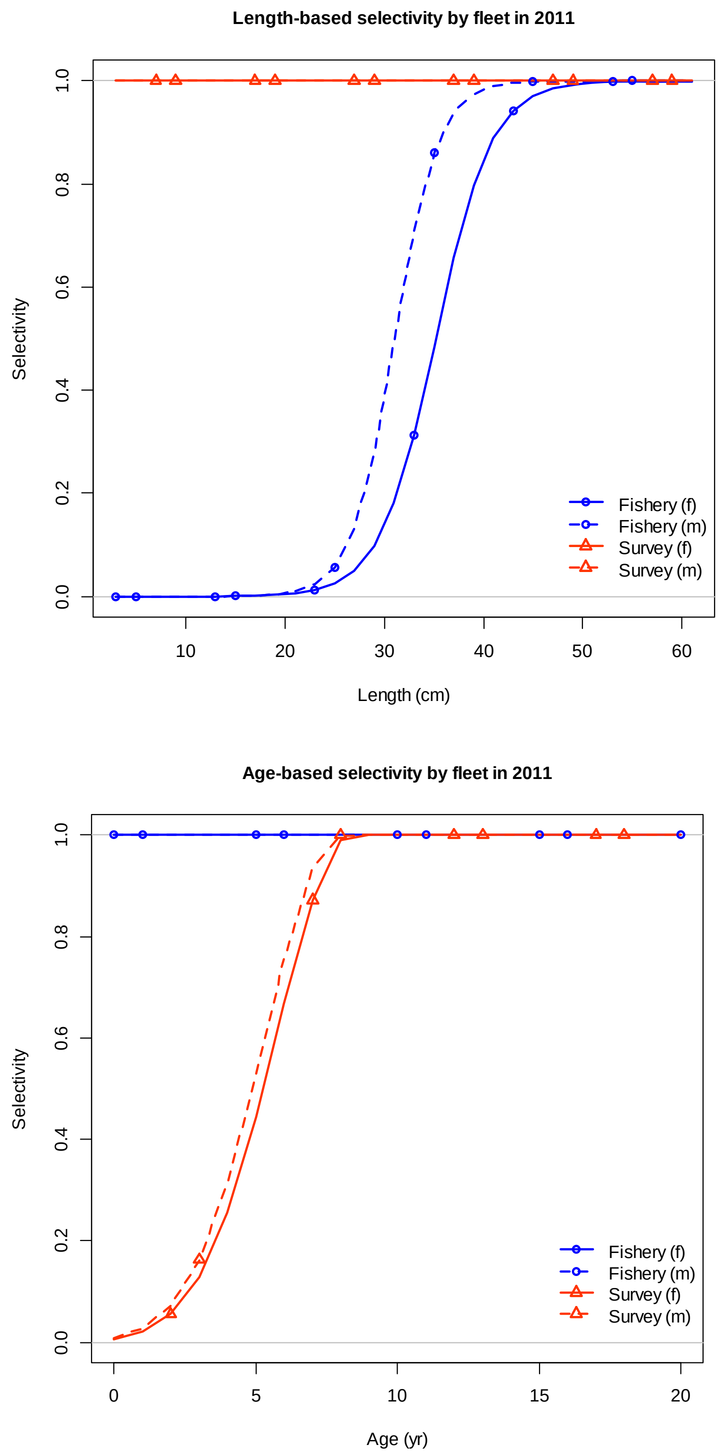


Figure 8A.19. Length-based fishery and age-based survey selectivity curves for proposed alternative model M1: as for the transitional SS3 model, but with length-based, logistic fishery selectivity.

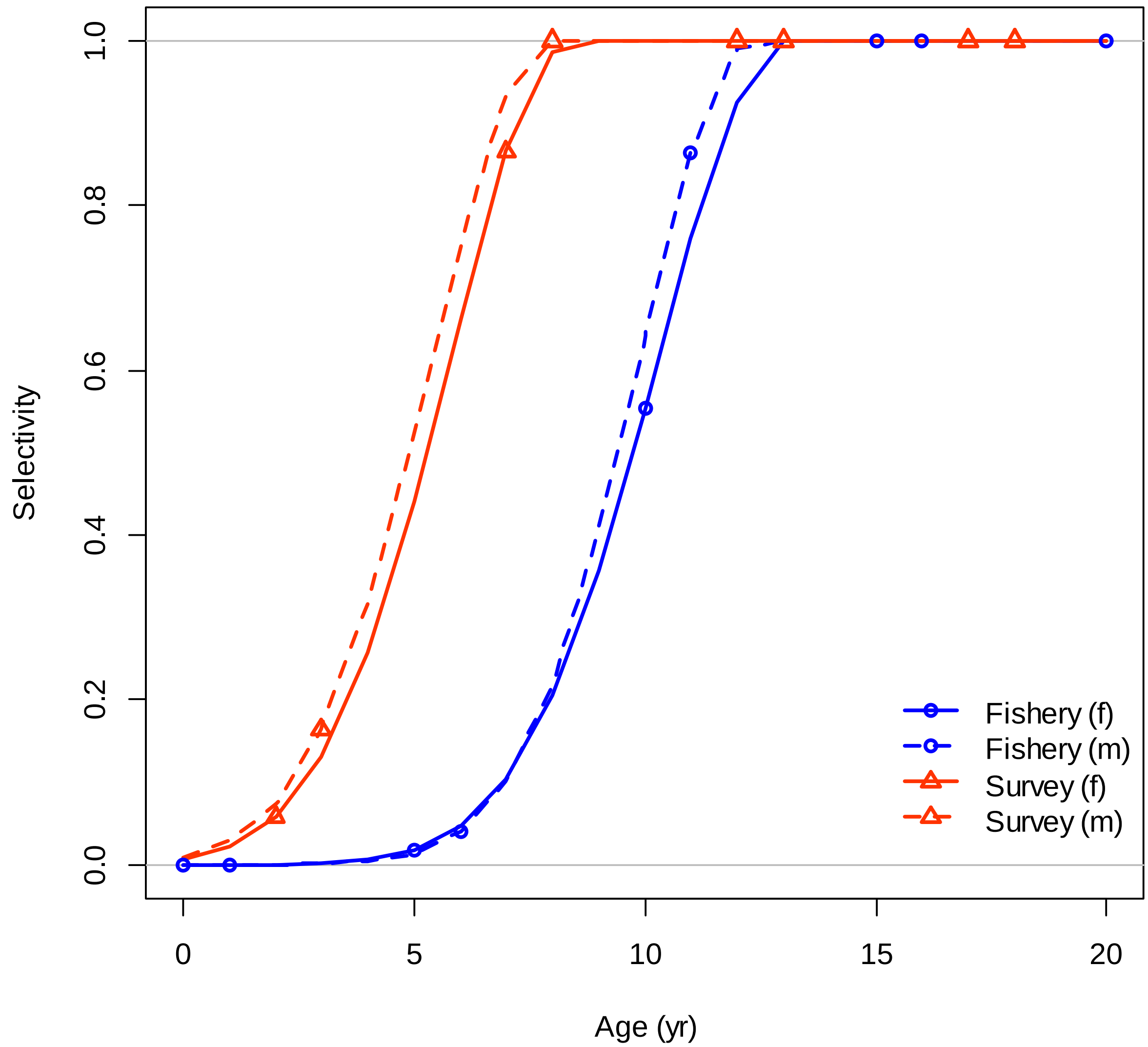


Figure 8A.20. Age-based double-normal fishery and survey selectivity for proposed alternative model M2 (as for the transitional SS3 model, but with an initial equilibrium fishing mortality rate estimated).

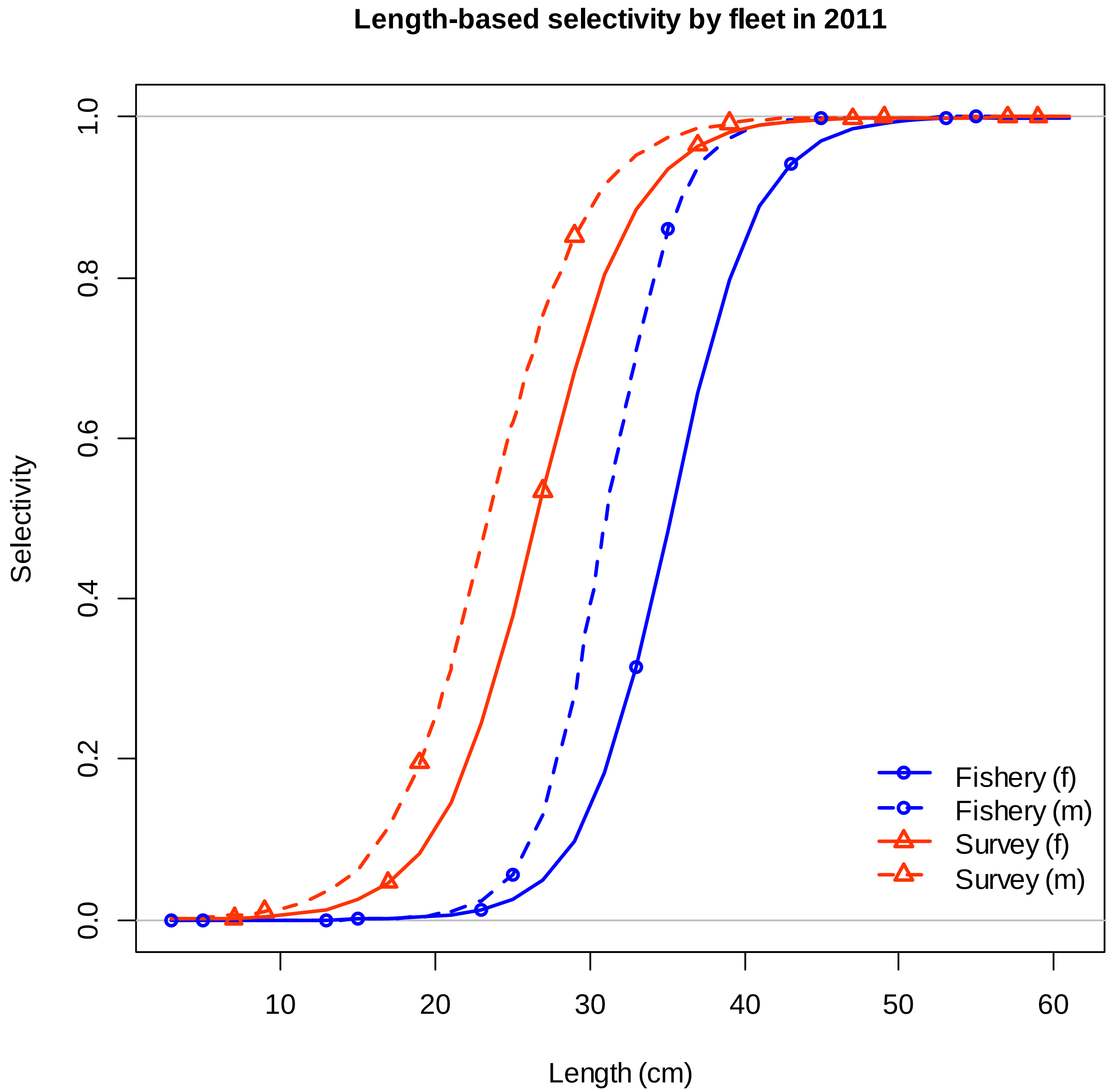


Figure 8A.21. Length-based logistic fishery selectivity for proposed alternative model M3 (as for the transitional SS3 model, but with length-based, logistic, sex-specific selectivity for the fishery and the survey).

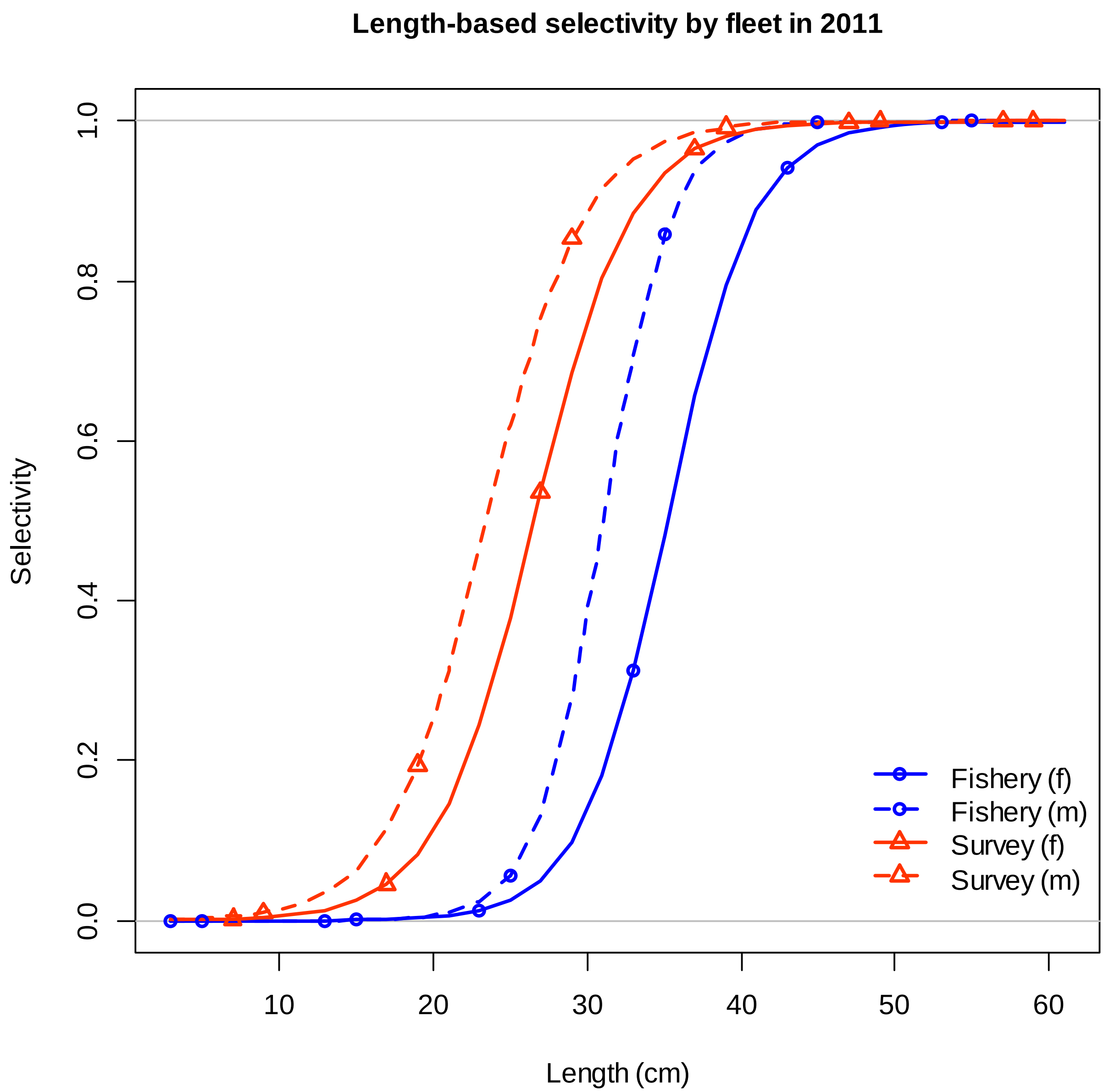


Figure 8A.22. Length-based fishery and survey selectivity for model M4 (as for the transitional SS3 model, but with estimation of an initial equilibrium fishing mortality rate and length-based, logistic, sex-specific selectivity for the fishery and the survey).

Figure 8A.23. Comparison of numbers at age 3 for the 2011 model and proposed alternative model M4.

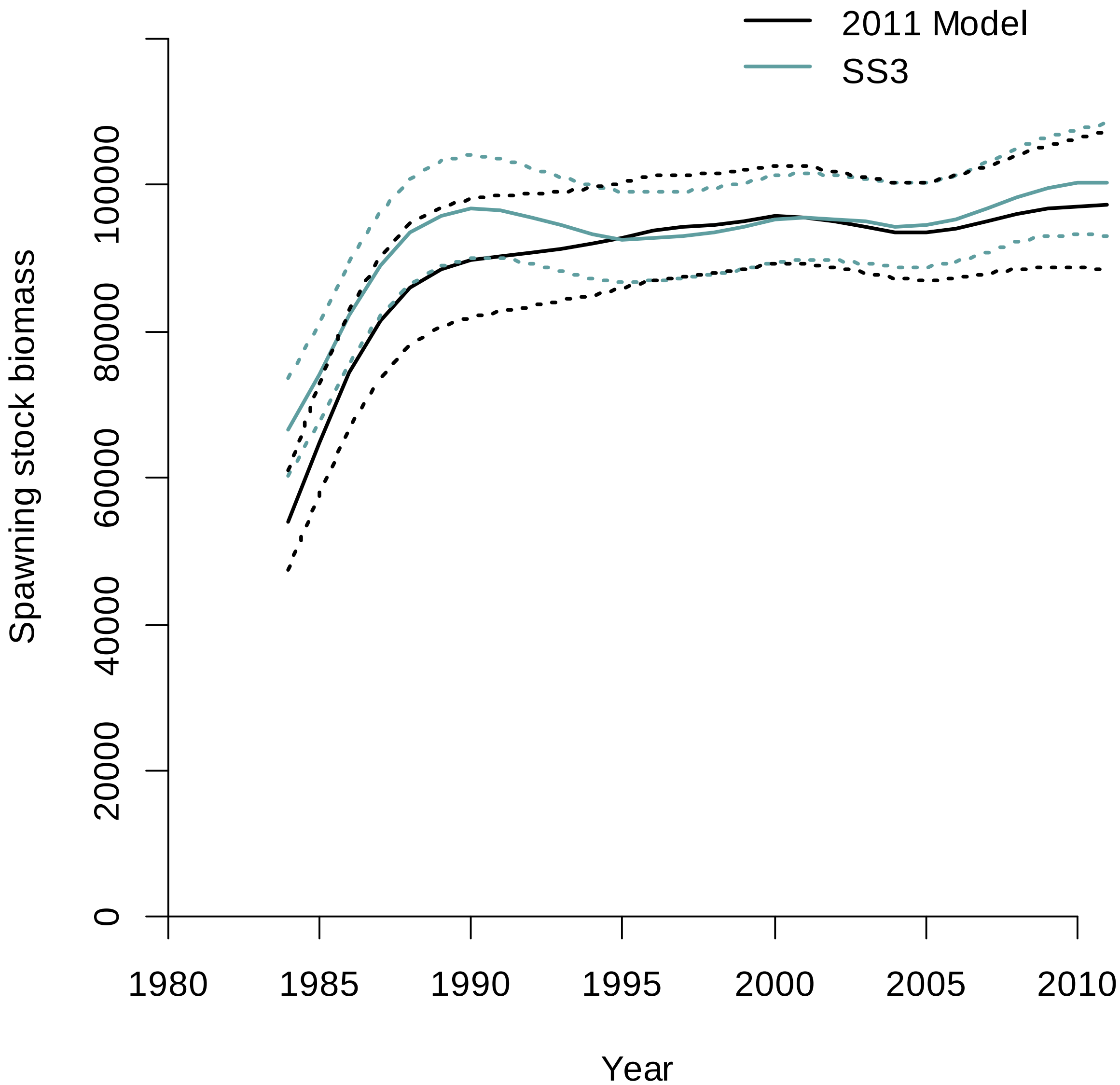


Figure 8A.24. Comparison of SSB (solid lines) and 95% asymptotic confidence intervals (dotted lines) for the 2011 assessment model and proposed alternative model M4.

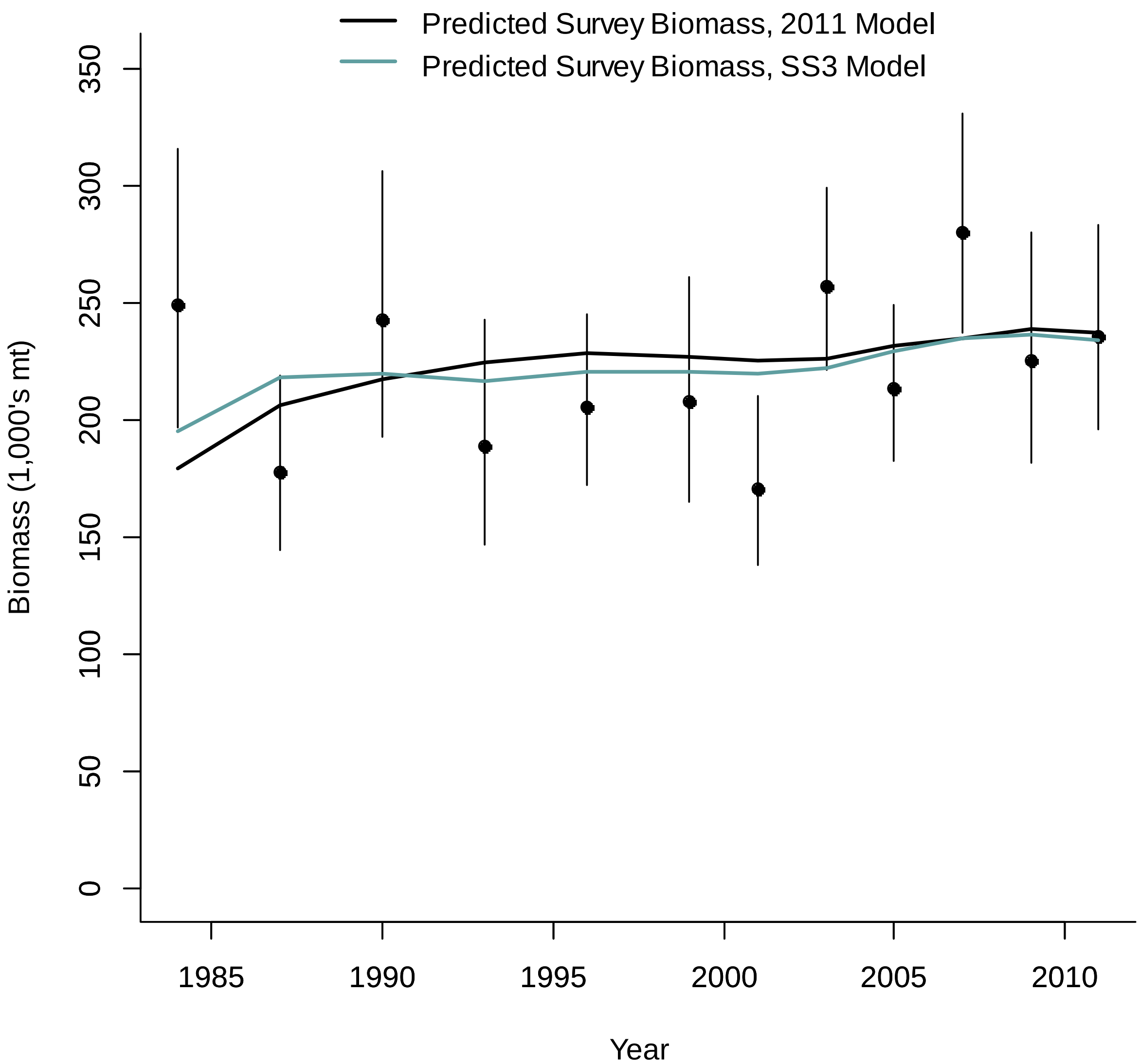


Figure 8A.25. Observed survey biomass (black dots) with 95% asymptotic confidence intervals (vertical black lines) and predicted survey biomass from the 2011 model (black line) and proposed alternative model M4 (blue line).

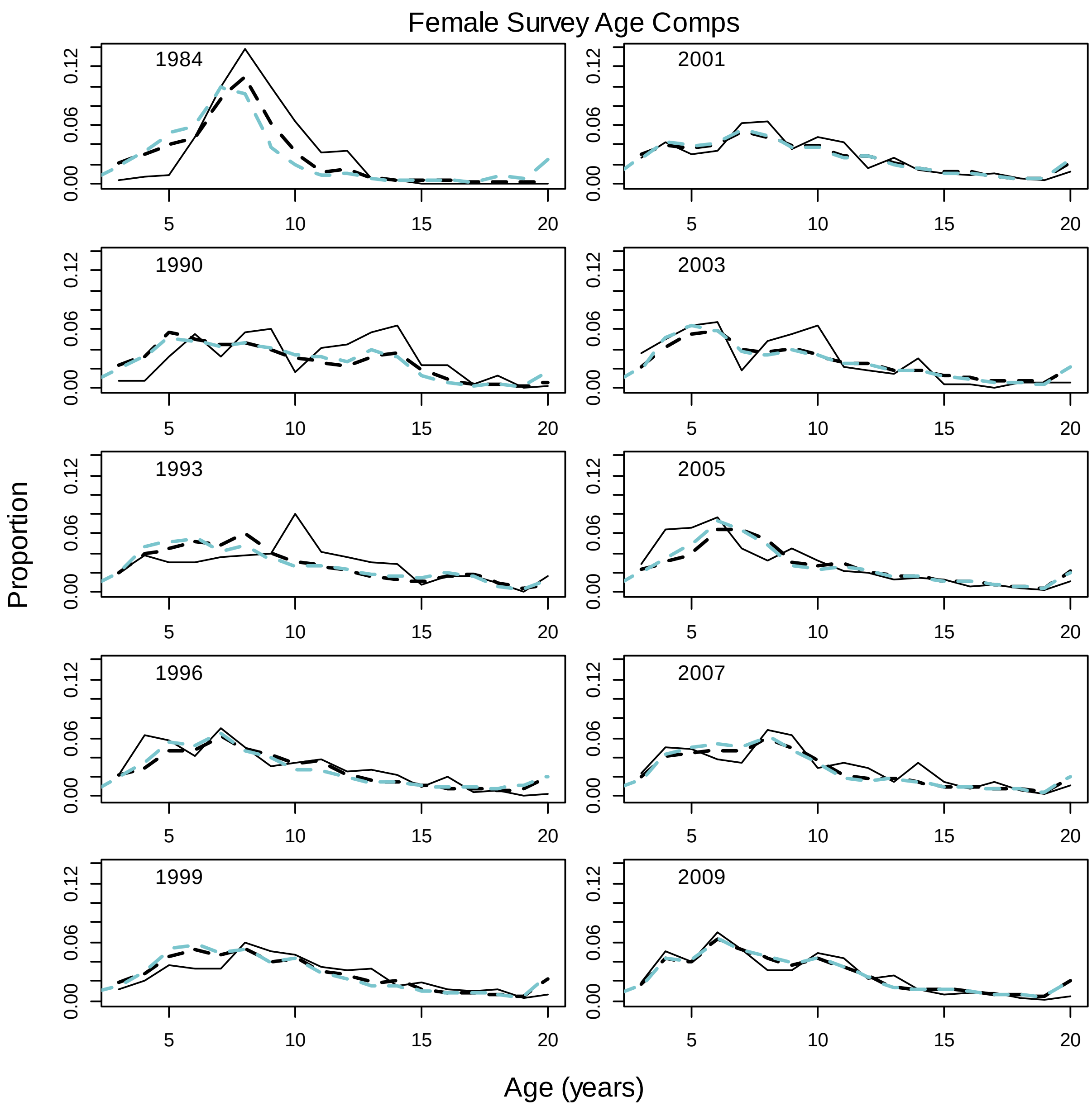


Figure 8A.26. (1 of 2) Observed (solid black lines) and predicted (dashed lines) survey proportions-at-age for the 2011 model (dashed black lines) and proposed alternative model M4 (dashed blue lines) for females (first panel) and males (second panel).

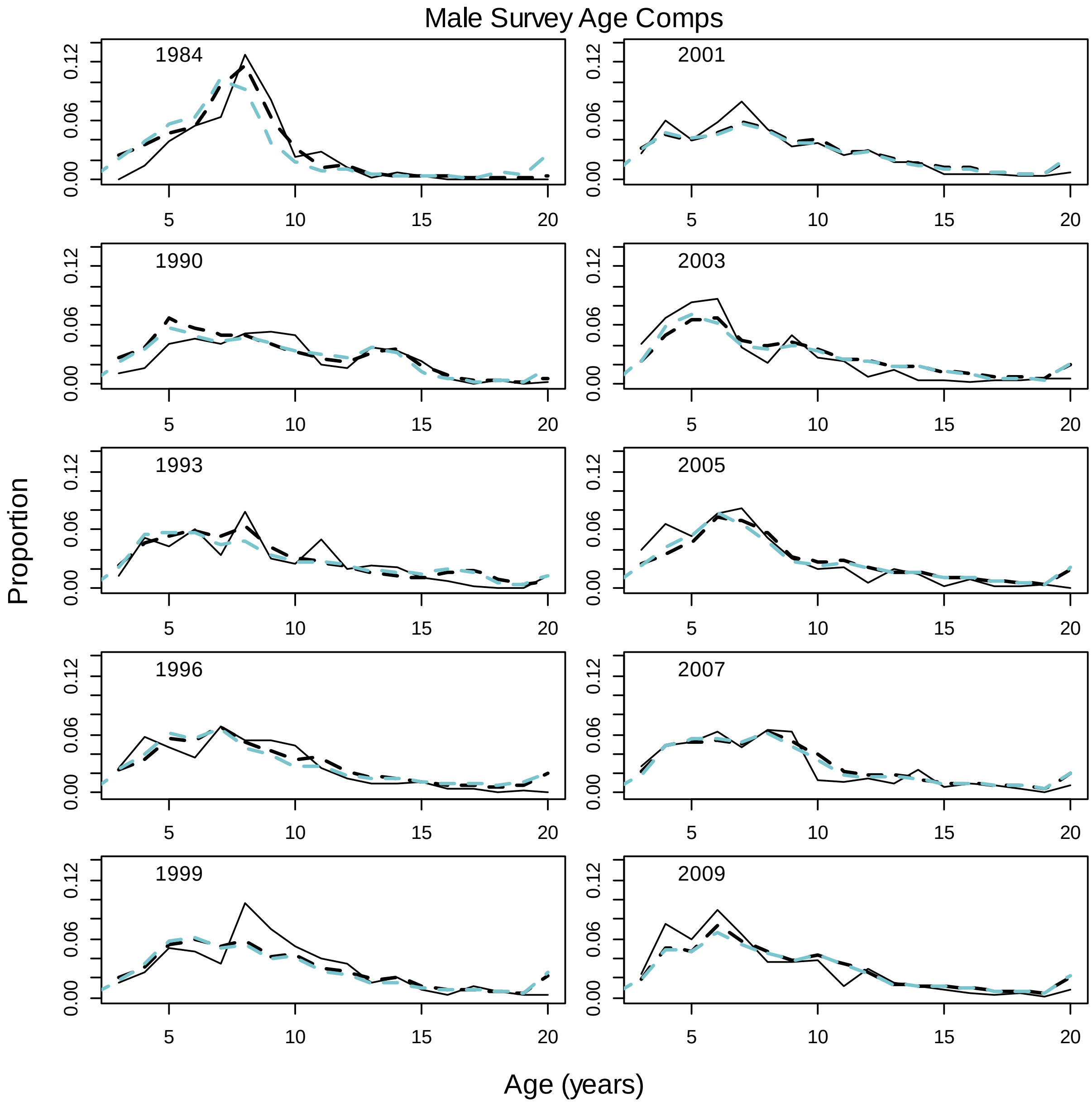


Figure 8A.26. (2 of 2)

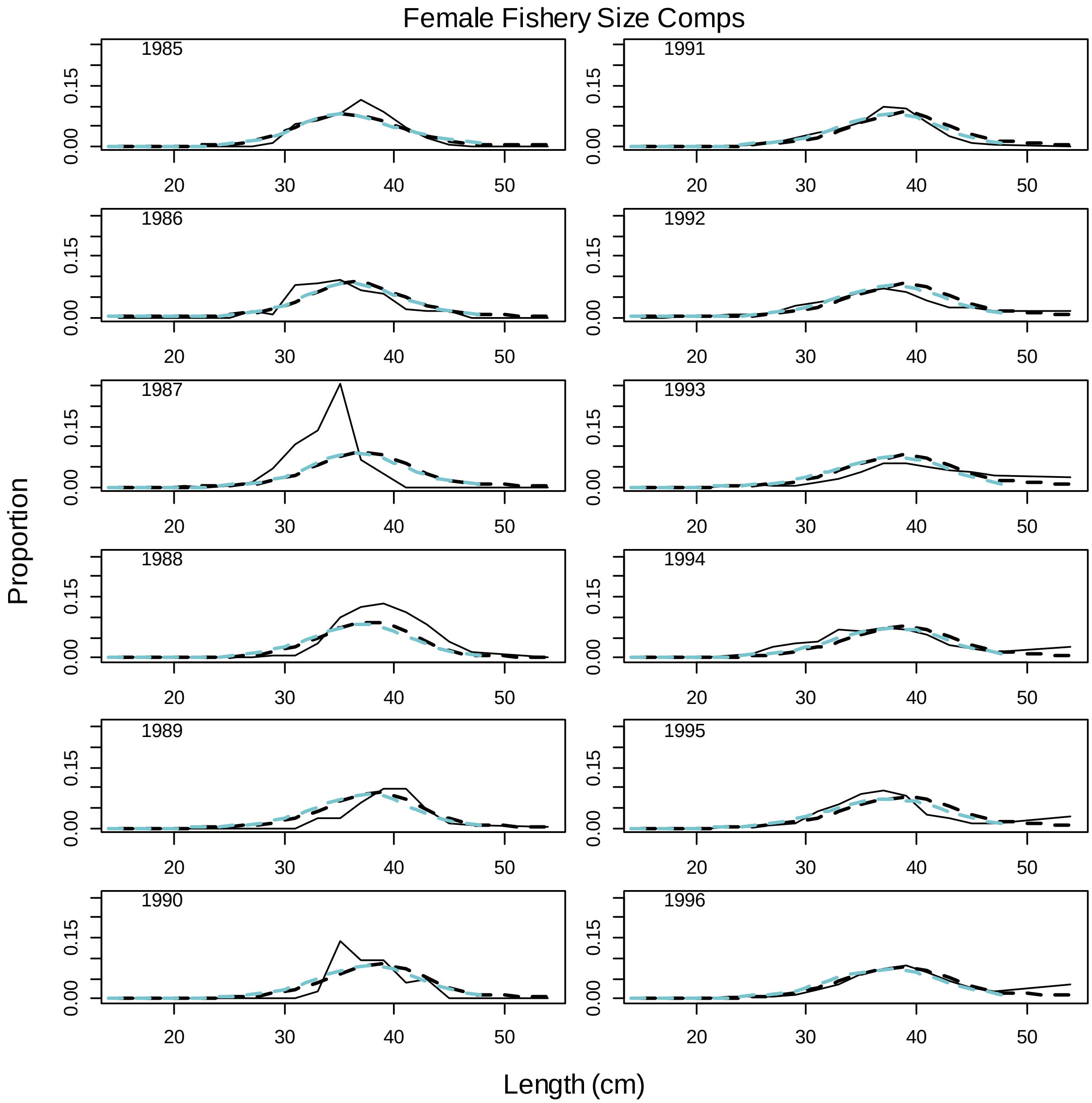


Figure 8A.27. (1 of 6) Observed (solid black lines) and predicted (dashed lines) fishery proportions-at-length for the 2011 model (dashed black lines) and proposed alternative model M4 (dashed blue lines) for females (first set of panels) and males (second set of panels).

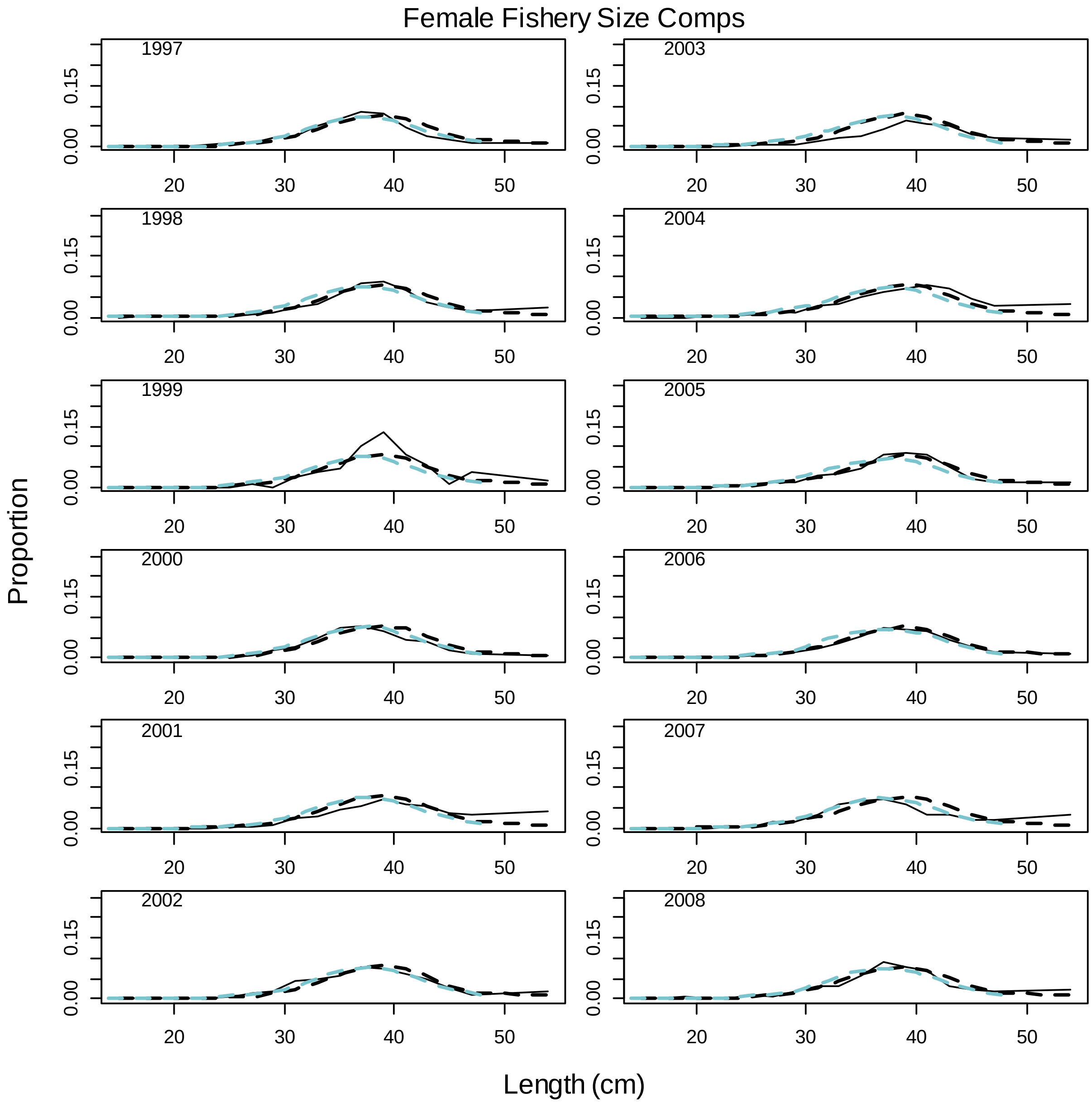


Figure 8A.27. (2 of 6)

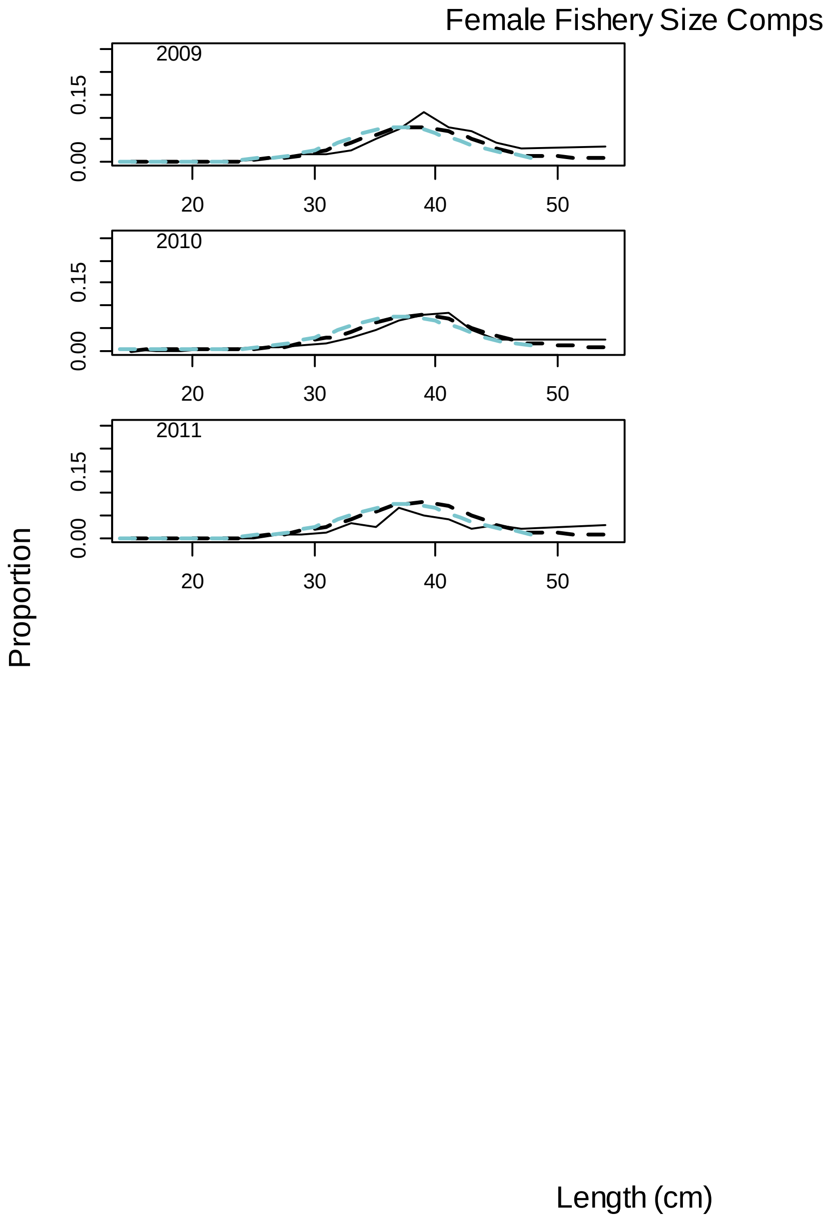


Figure 8A.27. (3 of 6)

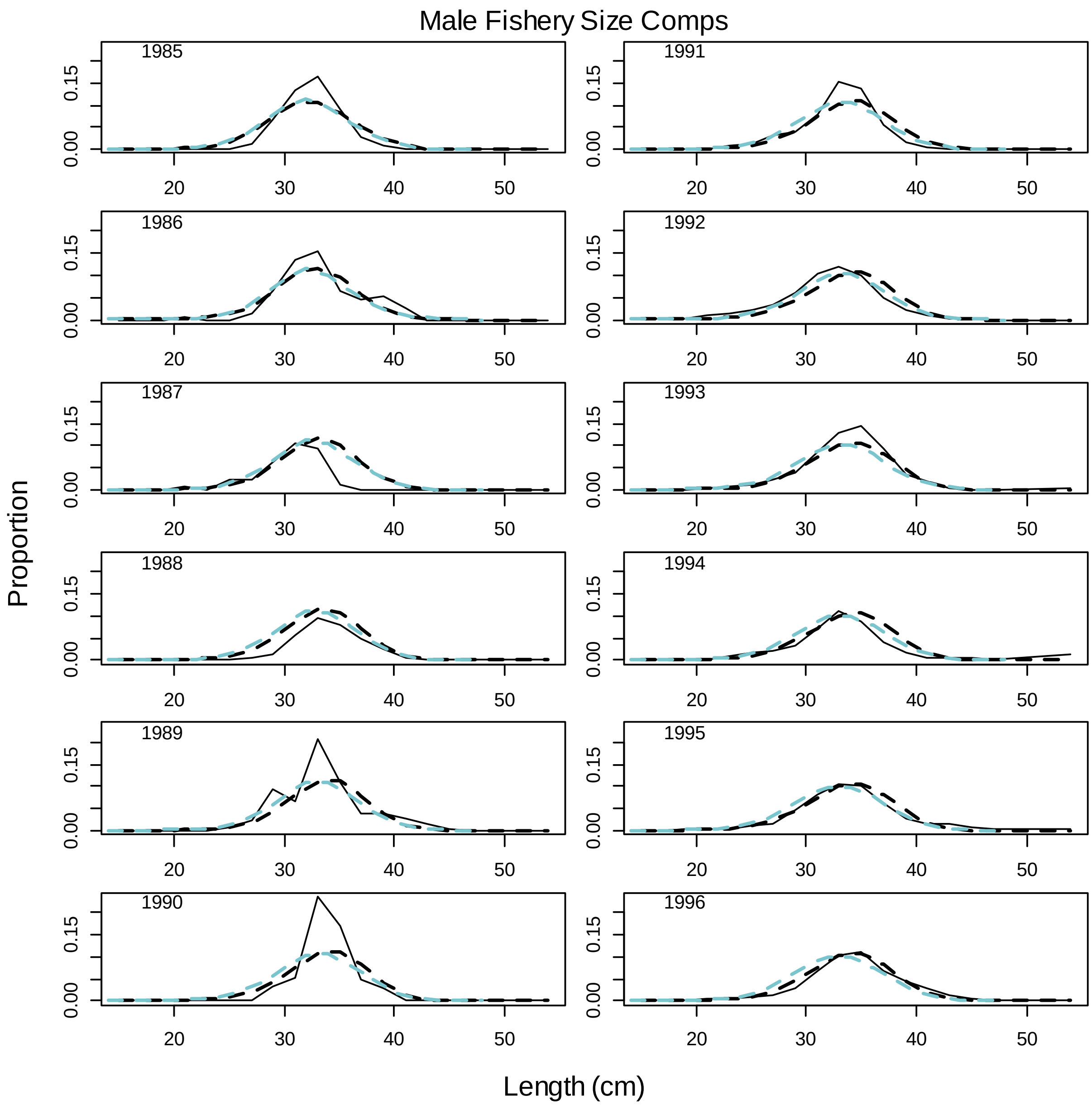


Figure 8A.27. (4 of 6)

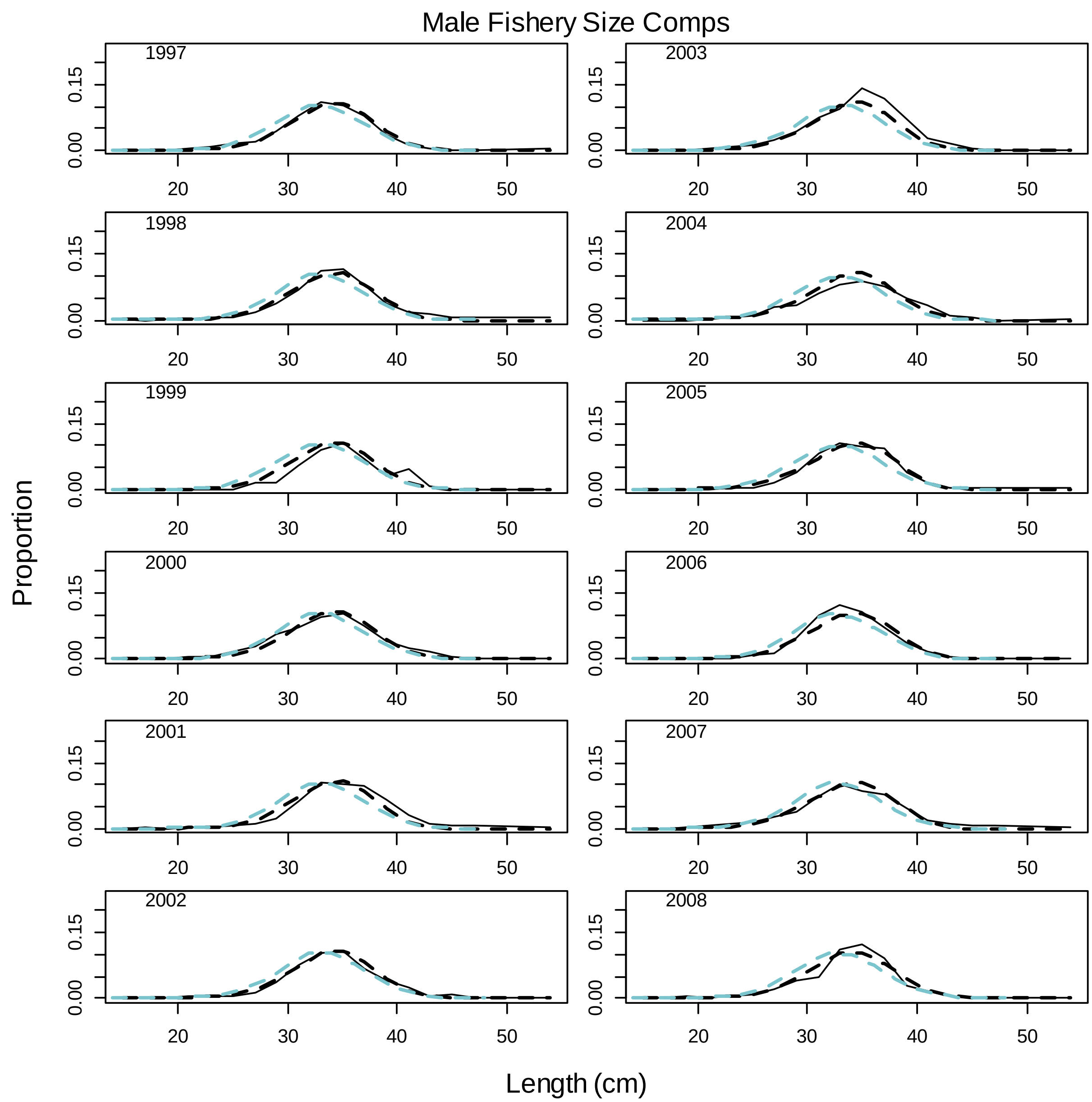


Figure 8A.27. (5 of 6)

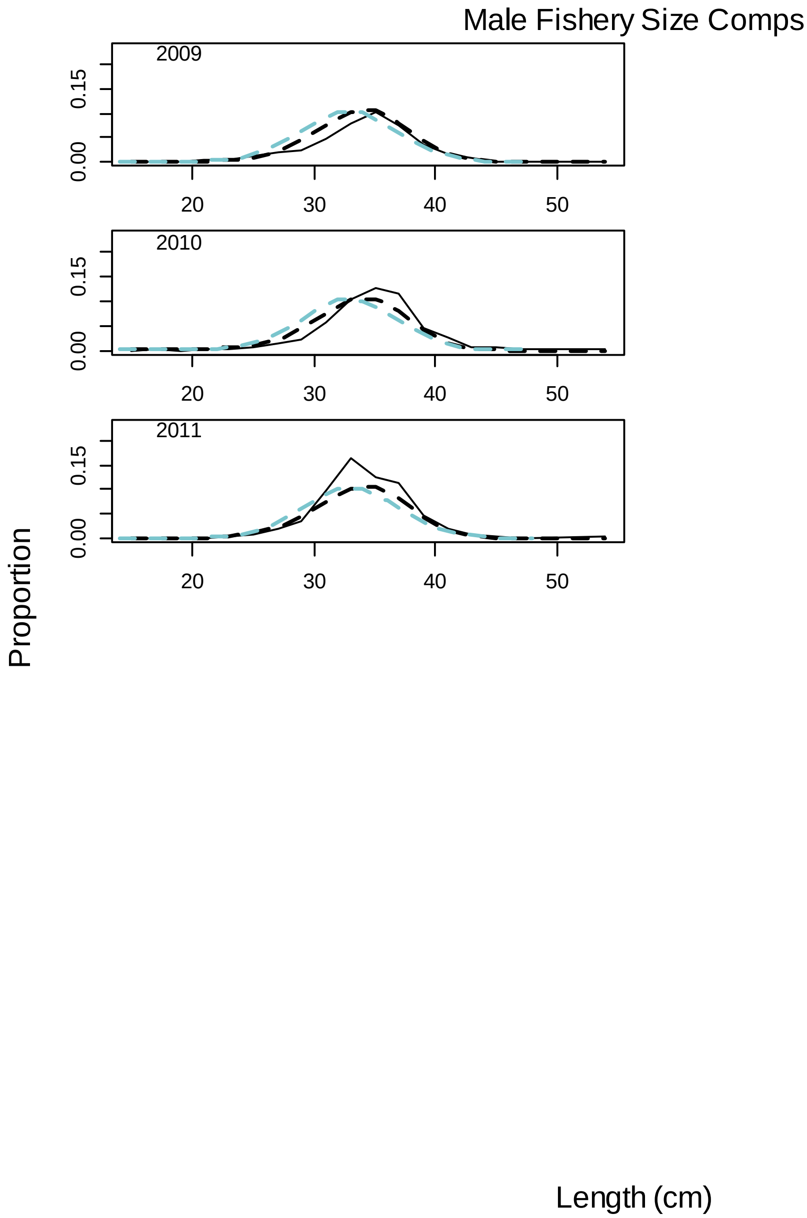


Figure 8A.27. (6 of 6)

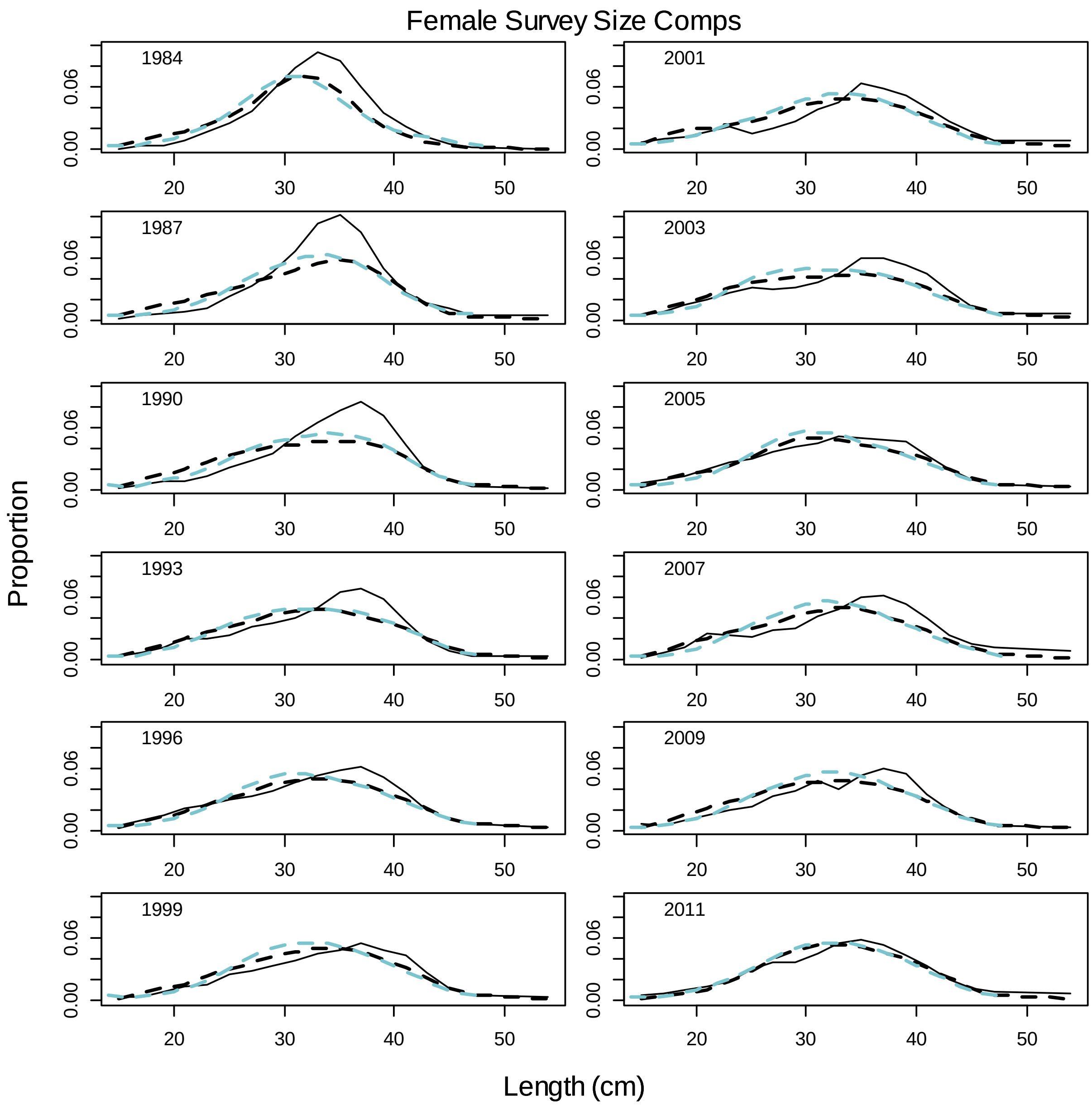


Figure 8A.28. (1 of 2) Observed (solid black lines) and predicted (dashed lines) survey proportions-at-length for the 2011 model (dashed black lines) and proposed alternative model M4 (dashed blue lines) for females (first set of panels) and males (second set of panels).

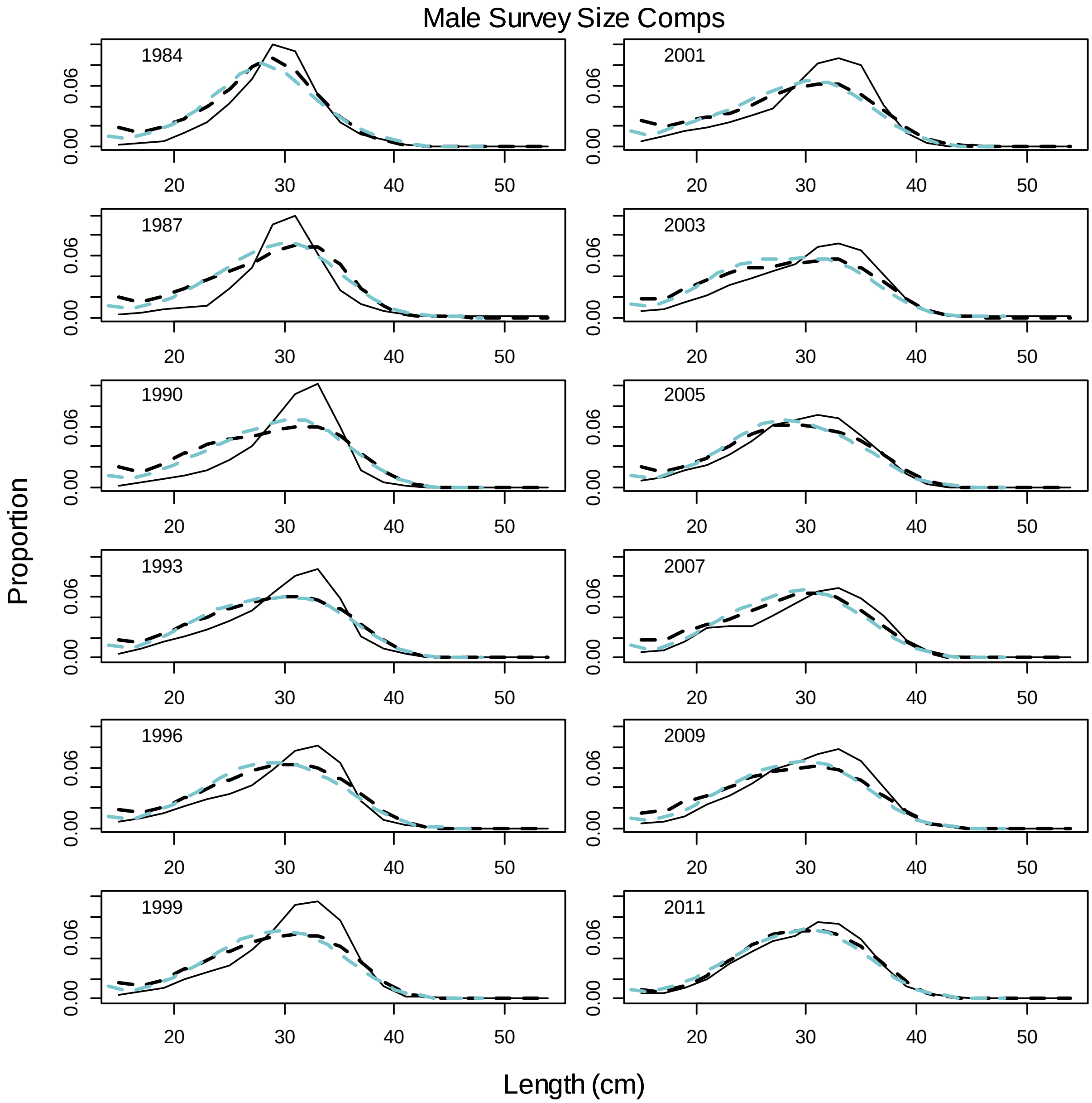


Figure 8A.28. (2 of 2)

Attachment 8b. A comparison of the previous assessment model updated with 2013 data to the current recommended assessment model

The most recent accepted assessment model for GOA flathead sole (the 2011 model) was updated and run with 2013 data. This section compares the results of a run of the previous assessment model with 2013 data to the author's recommended model for 2013. Below are executive summary tables that result from using the previous assessment model, projection model results based on the previous assessment model (Table 8B.1 – 8B.3), and plots comparing growth relationships, recruitment, spawning biomass, and fits biomass and composition data.

The key results of the 2013 assessment, based on the previous accepted assessment model, are compared to the key results of the accepted 2011 assessment model in the table below.

Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
	2013	2014	2014	2015
M (natural mortality rate)	0.2	0.2	0.2	0.2
Tier	3a	3a	3a	3a
Projected total (3+) biomass (t)	288,538	285,128	265,505	261,904
Female spawning biomass (t)				
Projected				
Upper 95% confidence interval	--		96,799	95,773
Point estimate	106,377	107,178	96,782	95,714
Lower 95% confidence interval	--		96,768	95,661
$B_{100\%}$	103,868	103,868	100,455	100,455
$B_{40\%}$	41,547	41,547	40,182	40,182
$B_{35\%}$	36,354	36,354	35,159	35,159
F_{OFL}	0.593	0.593	0.56	0.56
$maxF_{ABC}$	0.45	0.45	0.43	0.43
F_{ABC}	0.45	0.45	0.43	0.43
OFL (t)	61,036	62,296	54,641	54,511
maxABC (t)	48,738	49,771	43,780	43,701
ABC (t)	48,738	49,771	43,780	43,701
Status	As determined in 2012 for:		As determined in 2013 for:	
	2011	2012	2012	2013
Overfishing	no	n/a	no	n/a
Overfished	n/a	no	n/a	no
Approaching overfished	n/a	no	n/a	no

Harvest Recommendations Based on the Previous Accepted Assessment

The reference fishing mortality rate for flathead sole is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{40\%}$, $F_{35\%}$, and $SPR_{40\%}$ were obtained from a spawner-per recruit analysis. Assuming that the average recruitment from the 1983-2010 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{40\%}$ is calculated as the product of $SPR_{40\%}$ times the equilibrium number of recruits. Since reliable estimates of the 2013 spawning biomass (B), $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and $B>B_{40\%}$, the flathead sole reference fishing mortality is defined in Tier 3a. For this tier, F_{ABC} is constrained to be $\leq F_{40\%}$, and F_{OFL} is defined to be $F_{35\%}$. The values of these quantities are:

SSB 2013	96,782
$B_{40\%}$	40,182
$F_{40\%}$	0.43
max*Fabc*	0.43
$B_{35\%}$	35,159
$F_{35\%}$	0.56
F_{OFL}	0.56

The results of scenarios 6 & 7 indicate that the stock is not overfished and is not approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2014 of scenario 6 is 96,782 t, more than 2 times *B35%* (35,159 t). Thus the stock is not currently overfished. With regard to whether the stock is approaching an overfished condition, the expected spawning stock size in the year 2026 of scenario 7 (36,882 t) is greater than *B35%*; thus, the stock is not approaching an overfished condition.

ATTACHMENT 8B TABLES

Table 8B.1. Projected spawning biomass based on the previous (2011) assessment model for the seven harvest scenarios listed in the "Harvest Recommendations" section

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2013	96,393	96,393	96,393	96,393	96,393	96,393	96,393
2014	96,782	96,782	96,782	96,782	96,782	96,782	96,782
2015	74,782	74,782	96,139	92,926	97,747	69,167	74,782
2016	59,929	59,929	94,687	88,769	97,741	52,520	59,929
2017	50,146	50,146	92,874	84,757	97,192	42,654	46,828
2018	44,154	44,154	91,139	81,312	96,522	37,244	39,540
2019	41,011	41,011	89,866	78,767	96,117	35,389	36,193
2020	39,796	39,796	89,118	77,119	96,053	35,412	35,665
2021	39,721	39,721	88,868	76,224	96,349	36,005	36,050
2022	40,001	40,001	88,904	75,787	96,827	36,530	36,511
2023	40,264	40,264	89,081	75,597	97,374	36,812	36,784
2024	40,420	40,420	89,265	75,499	97,861	36,906	36,886
2025	40,488	40,488	89,446	75,453	98,299	36,909	36,898
2026	40,509	40,509	89,574	75,410	98,632	36,887	36,882

Table 8B.2. Projected fishing mortality rates based on the previous (2011) assessment model for the seven harvest scenarios listed in the "Harvest Recommendations" section

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2013	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2014	0.43	0.43	0.03	0.08	0.00	0.56	0.43
2015	0.43	0.43	0.03	0.08	0.00	0.56	0.43
2016	0.43	0.43	0.03	0.08	0.00	0.56	0.56
2017	0.43	0.43	0.03	0.08	0.00	0.56	0.56
2018	0.43	0.43	0.03	0.08	0.00	0.52	0.55
2019	0.43	0.43	0.03	0.08	0.00	0.49	0.50
2020	0.42	0.42	0.03	0.08	0.00	0.49	0.49
2021	0.42	0.42	0.03	0.08	0.00	0.50	0.50
2022	0.42	0.42	0.03	0.08	0.00	0.51	0.51
2023	0.42	0.42	0.03	0.08	0.00	0.51	0.51
2024	0.42	0.42	0.03	0.08	0.00	0.51	0.51
2025	0.42	0.42	0.03	0.08	0.00	0.51	0.51
2026	0.42	0.42	0.03	0.08	0.00	0.51	0.51

Table 8B.3. Projected catches based on the previous (2011) assessment model for the seven harvest scenarios listed in the "Harvest Recommendations" section

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2013	2,861	2,861	2,861	2,861	2,861	2,861	2,861
2014	43,780	43,780	3,038	9,121	-	54,641	43,780
2015	33,061	33,061	3,053	8,816	-	37,803	33,061
2016	25,821	25,821	3,036	8,461	-	27,693	32,310
2017	20,943	20,943	2,988	8,069	-	21,608	24,211
2018	17,803	17,803	2,923	7,681	-	16,926	19,254
2019	15,981	15,981	2,859	7,348	-	14,897	15,676
2020	14,953	14,953	2,811	7,109	-	14,728	14,976
2021	14,773	14,773	2,787	6,970	-	15,207	15,255
2022	14,926	14,926	2,782	6,904	-	15,695	15,679
2023	15,101	15,101	2,786	6,878	-	15,973	15,947
2024	15,212	15,212	2,793	6,869	-	16,073	16,054
2025	15,265	15,265	2,800	6,866	-	16,081	16,071
2026	15,278	15,278	2,806	6,864	-	16,061	16,056

ATTACHMENT 8B FIGURES

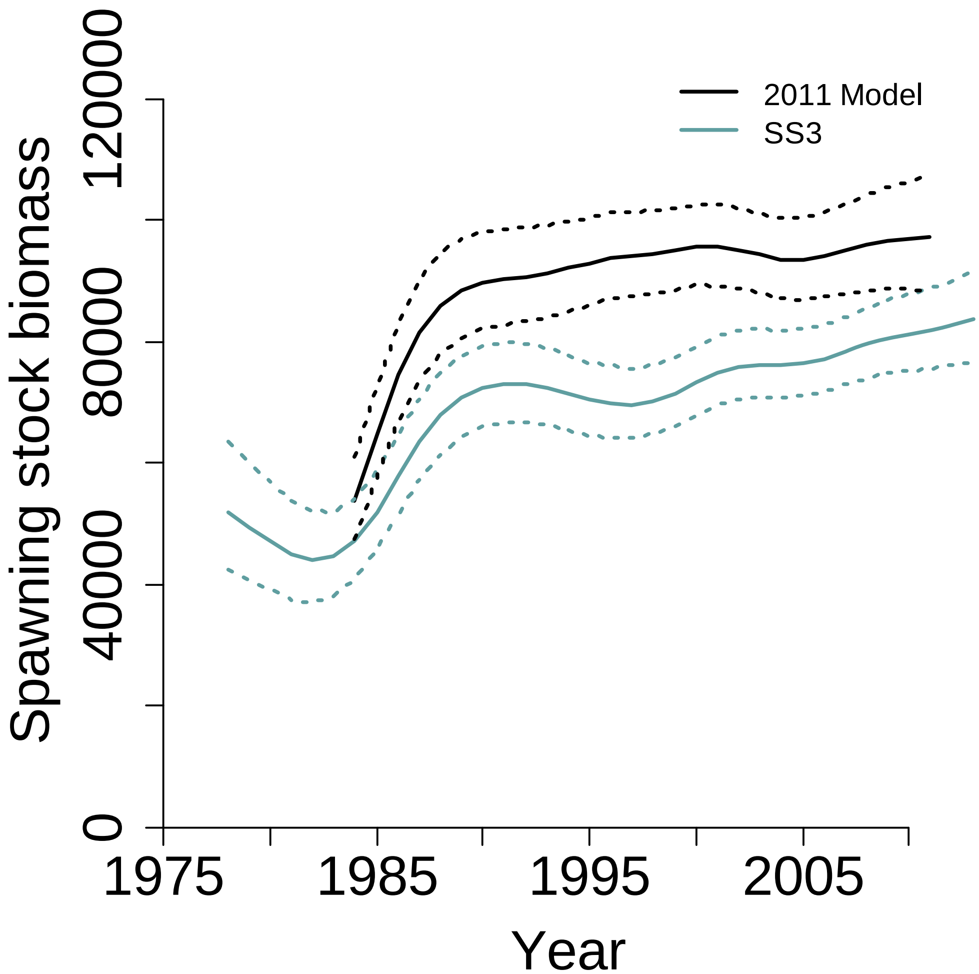


Figure 8B.1. Time series of spawning stock biomass (solid lines) and 95% asymptotic confidence intervals (dotted lines) for the recommended model (blue lines) and the previous assessment model (black lines).

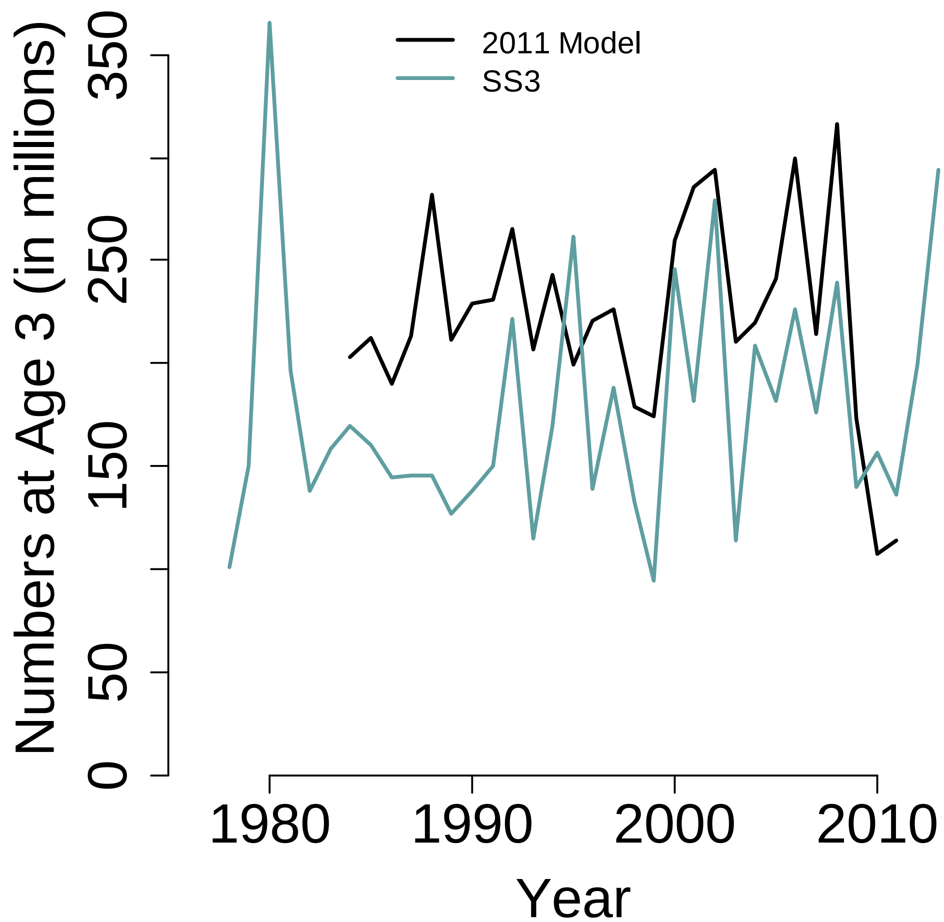
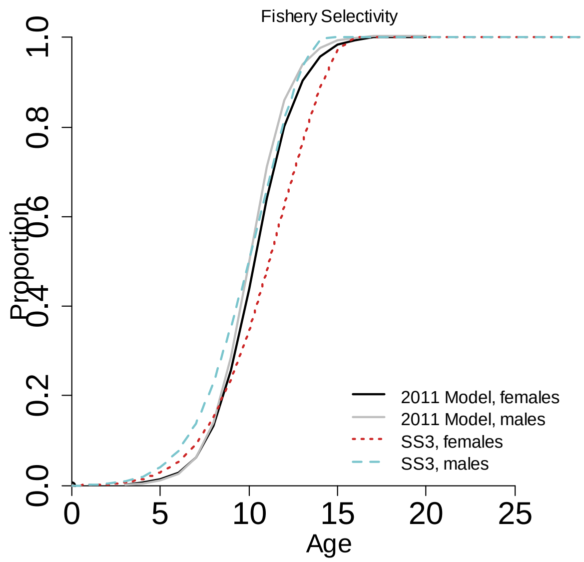


Figure 8B.2. Time series of age 3 recruitment for the recommended model (blue line) and the previous assessment model (black line).



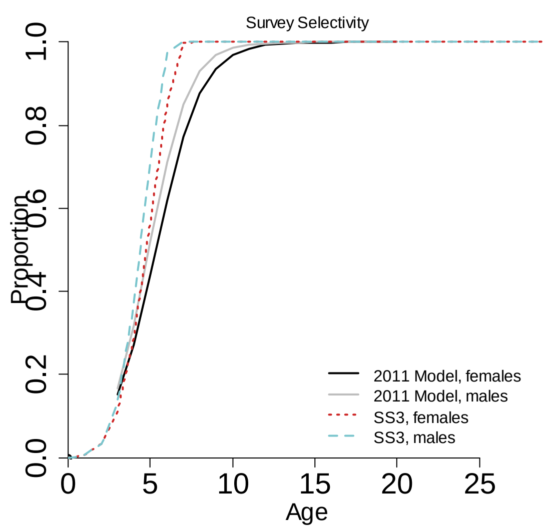


Figure 8B.3. Fishery (top panel) and survey (bottom panel) selectivity at age by sex for the recommended model and previous model. Selectivity curves in the previous model are logistic and normalized so that maximum selectivity within the age range must equal 1.

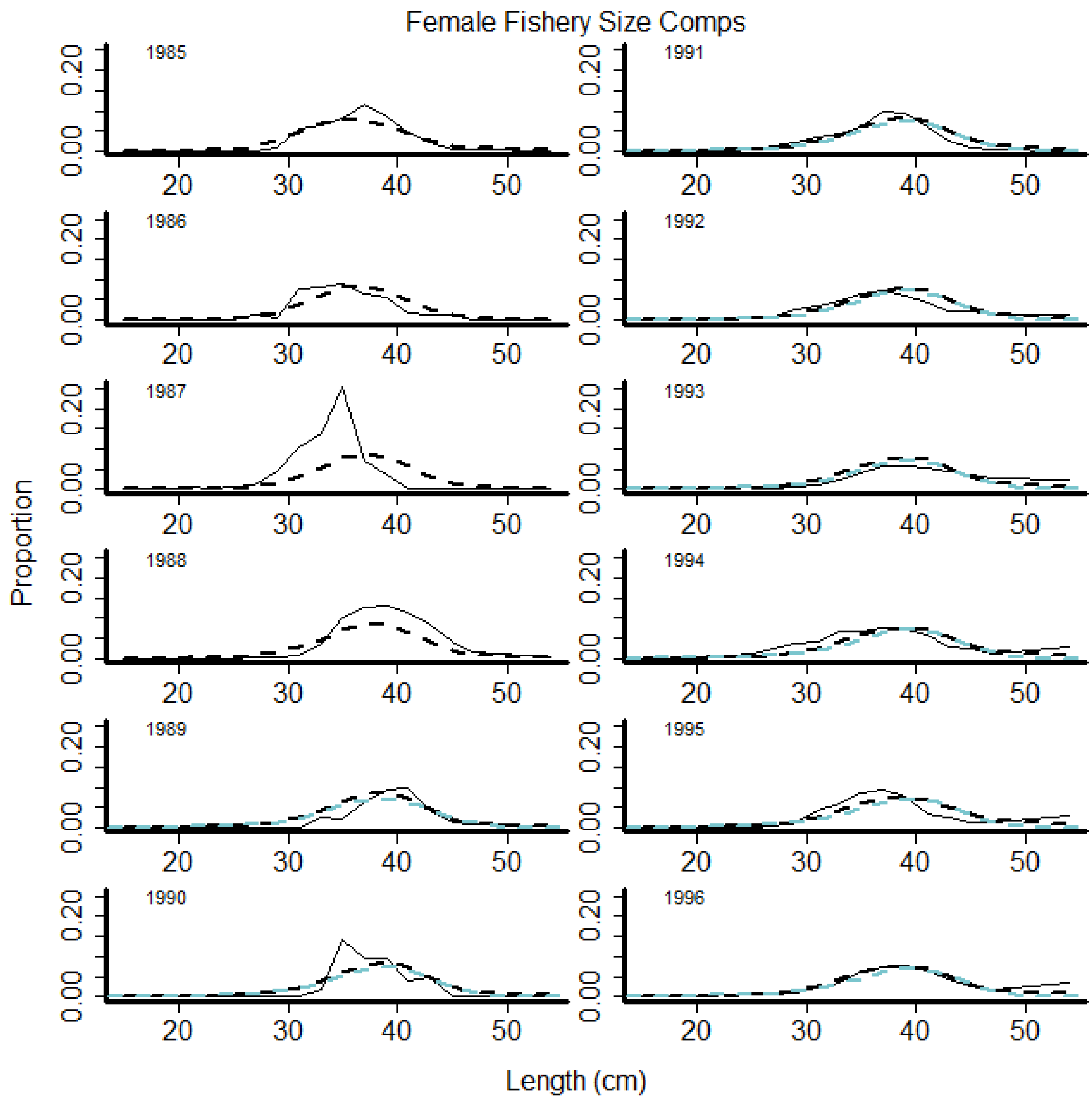


Figure 8B.4. (1 of 3) Observed (solid black lines) and predicted (dashed lines) fishery proportions-at-length for females for the current assessment model (blue dashed lines) and the previous assessment model updated with 2013 data (black dashed lines).

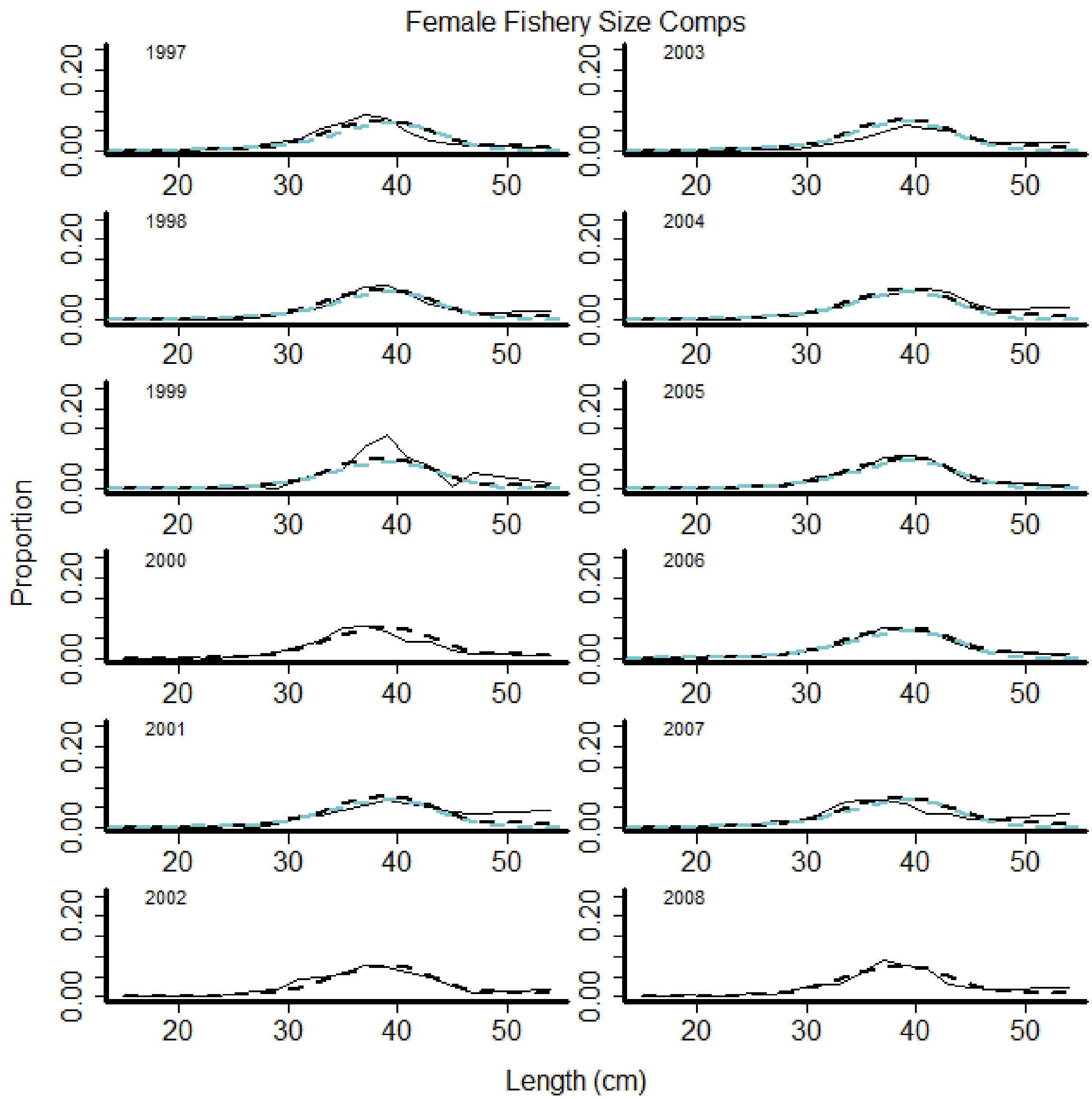


Figure 8B.4. (2 of 3)

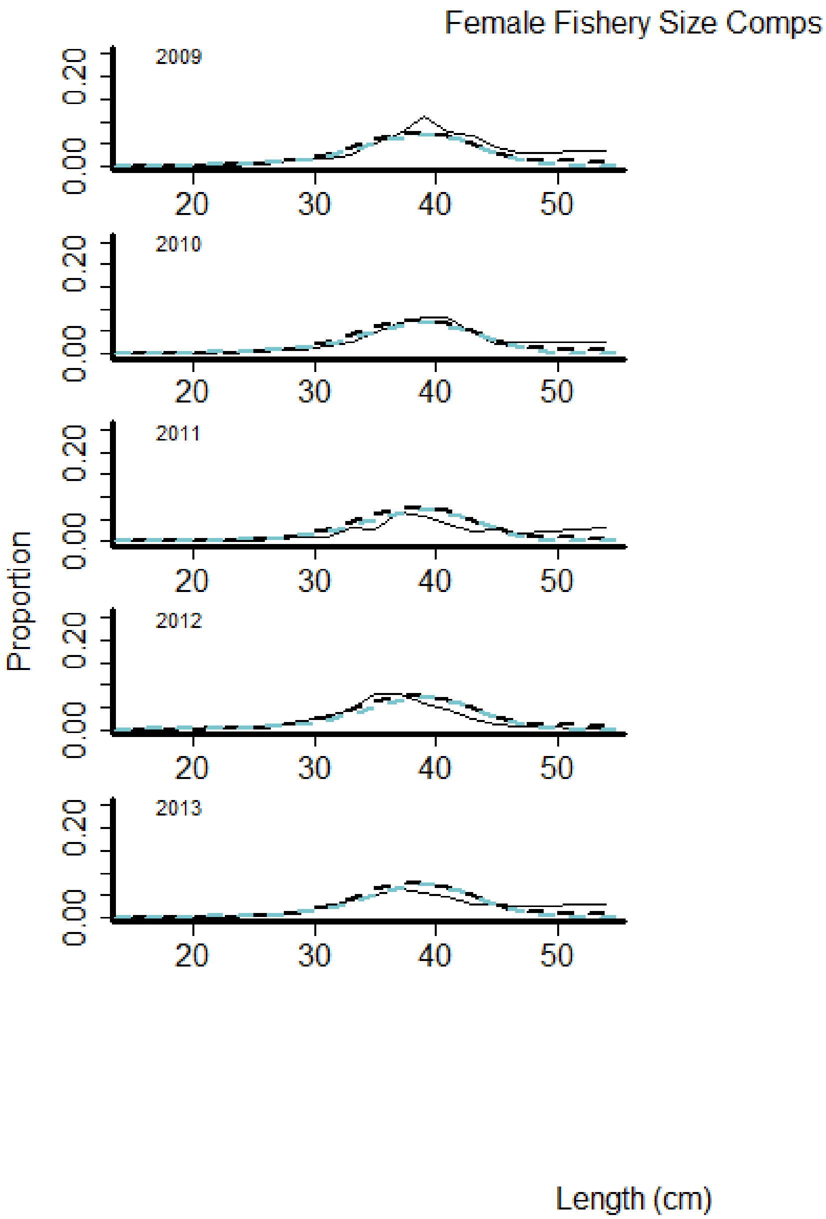


Figure 8B.4. (3 of 3)

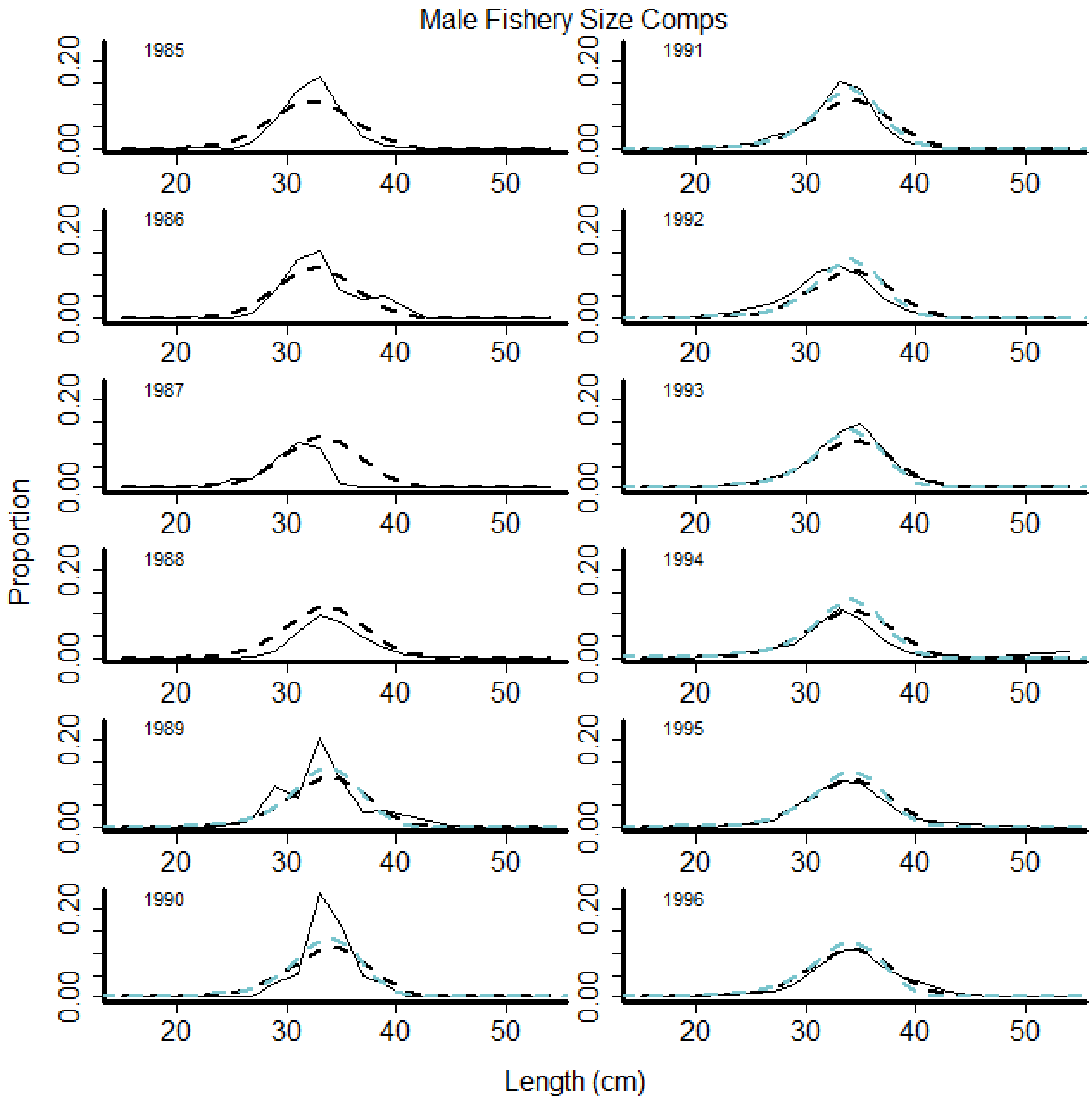


Figure 8B.5. (1 of 3) Observed (solid black lines) and predicted (dashed lines) fishery proportions-at-length for males for the current assessment model (blue dashed lines) and the previous assessment model updated with 2013 data (black dashed lines).

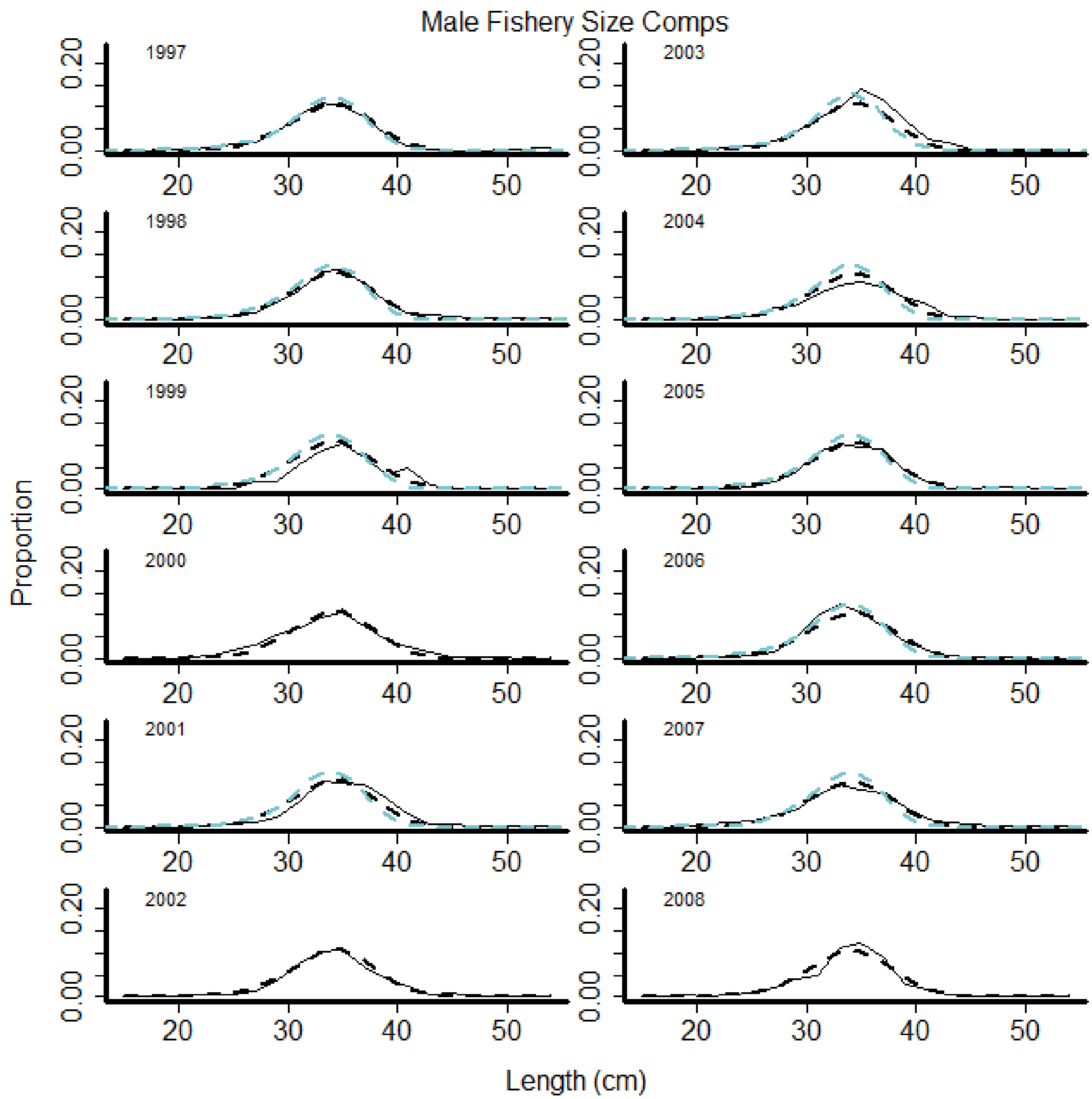


Figure 8B.5. (2 of 3)

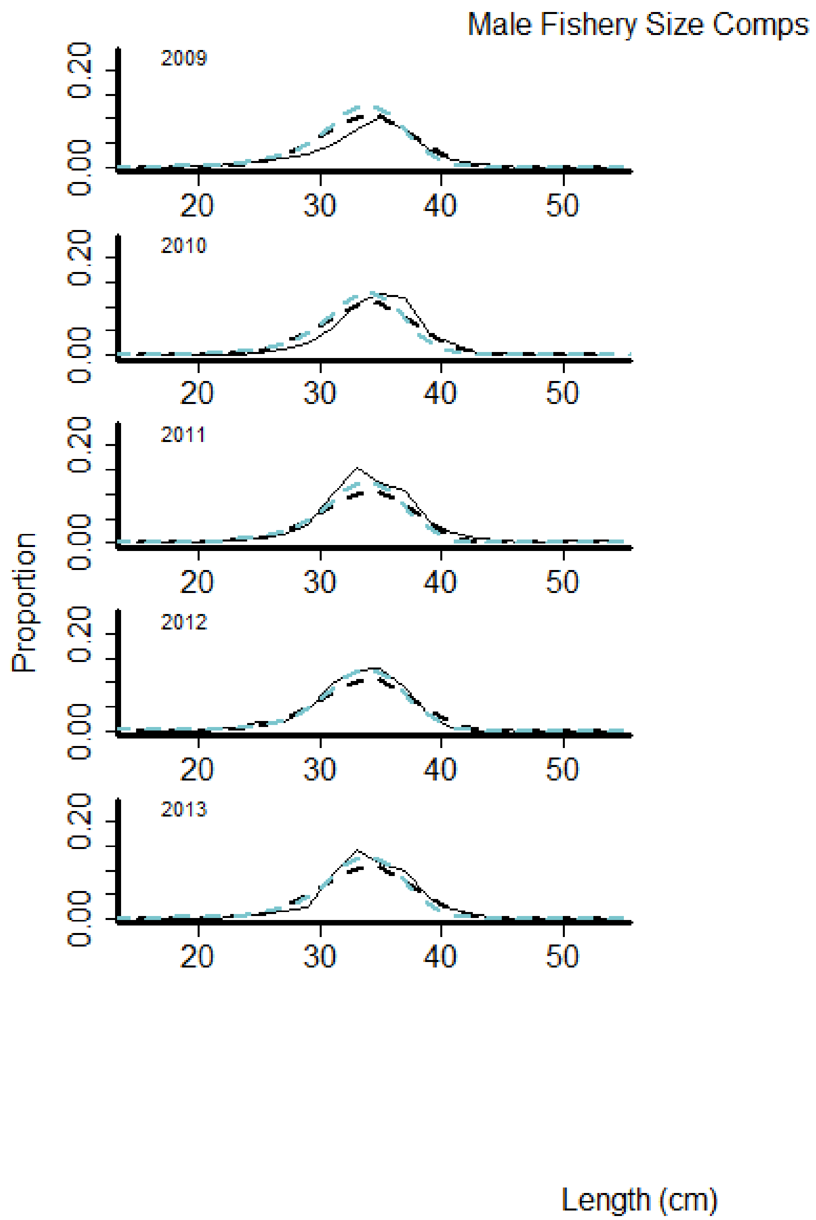


Figure 8B.5. (3 of 3)

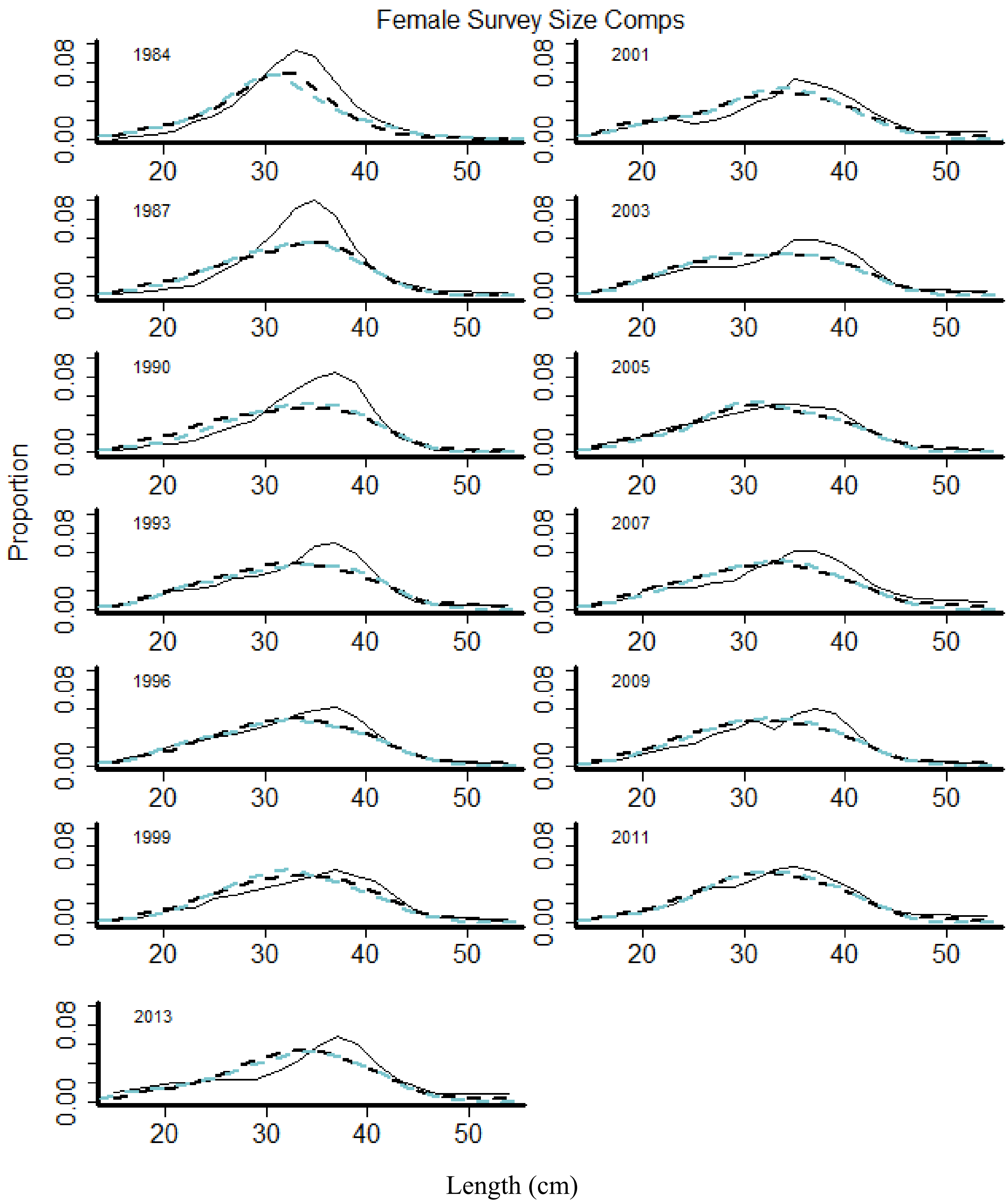


Figure 8B.6. Observed (solid black lines) and predicted (dashed lines) survey proportions-at-length for females for the current assessment model (blue dashed lines) and the previous assessment model updated with 2013 data (black dashed lines).

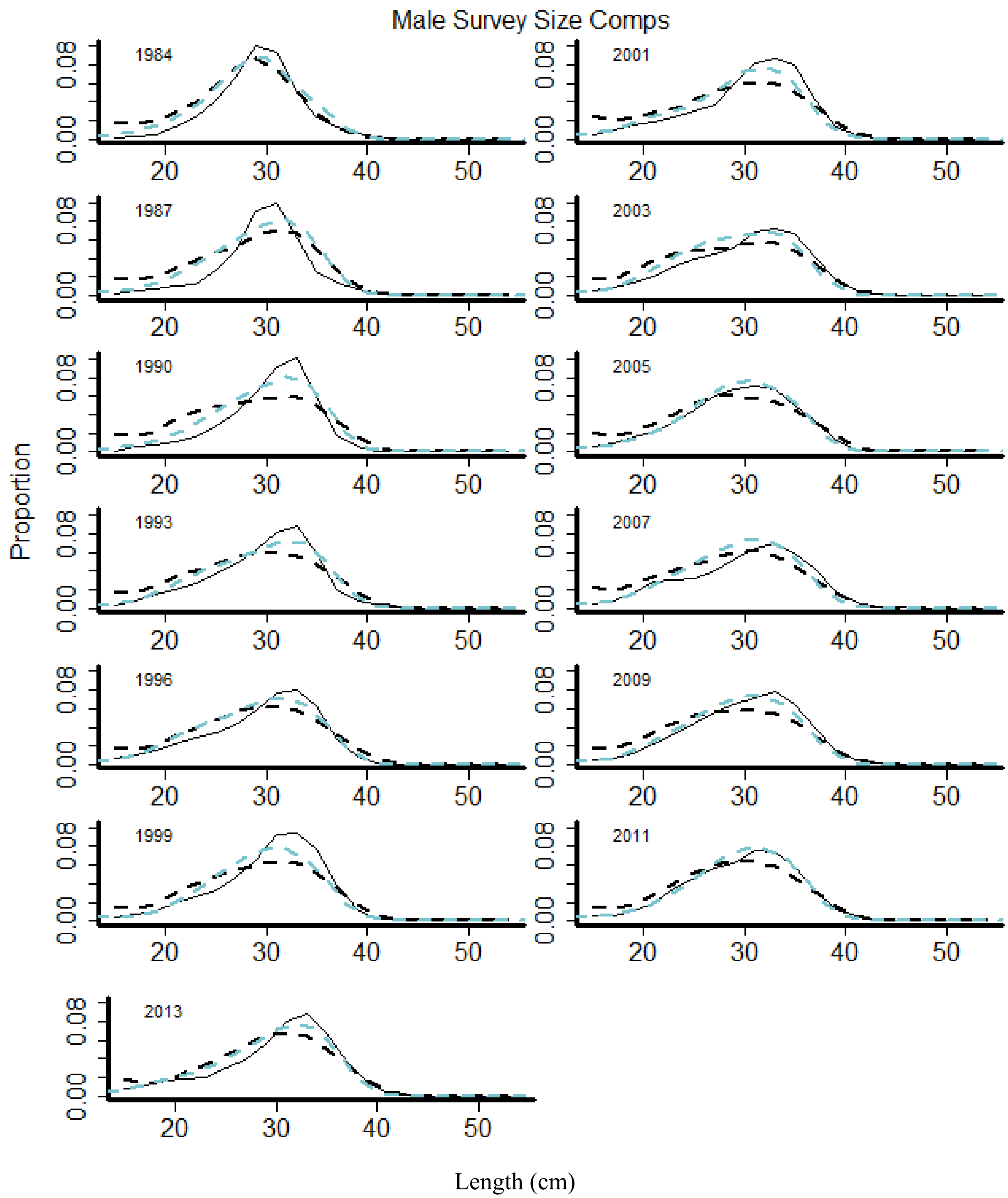


Figure 8B.7. Observed (solid black lines) and predicted (dashed lines) survey proportions-at-length for males for the current assessment model (blue dashed lines) and the previous assessment model updated with 2013 data (black dashed lines).

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