5. Assessment of the Deepwater Flatfish Stock in the Gulf of Alaska

By

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EXECUTIVE SUMMARY

Dover sole, Greenland turbot, and deepsea sole comprise the deepwater flatfish stock in the Gulf of Alaska. A stock assessment model is presented for Dover sole and management quantities are calculated for all three species. The summary of changes in assessment input and methodology refer to the Dover sole assessment model.

Summary of Changes in Assessment Inputs

(1) 1978-1983 and 2012-2013 catch data were included in the model
(2) 2011 catch was updated to include October – December catch in that year
(3) 2012 and 2013 fishery length composition data were added to the model
(4) The 2013 survey biomass index was added to the model
(5) Survey length composition data for 2013 were added to the model
(6) Survey age composition data within each length bin were used in the model instead of marginal age composition (combined over lengths); 2011 age composition data (within each length bin) were added to the model.
(7) 1984 and 1987 length- and age-at-length composition data were excluded from the model because survey methods differed in these years. The 1990 survey caught older fish, whereas the 1984 and 1987 surveys did not, indicating that the 1984 and 1987 surveys missed older fish that were present.
(8) 2001 length- and age-at-length composition data were excluded from the model because the survey excluded the eastern Gulf, which may have influenced the length- and age-at-length data.

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 5A includes a full description of the transition from the 2011 Dover sole assessment model to an equivalent model in SS3.

A random effects survey averaging approach (http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/2013/Sept/SAWG_2013_draft.pdf) was used to estimate biomass and variance in missing depth and management area strata in the bottom trawl survey biomass data and these estimates were included in the calculation of total survey biomass and variance (which is used as an absolute index of biomass in the assessment).

(2) The model included a "full coverage" survey fleet corresponding to the adjusted bottom trawl survey biomass and variance estimates described in (2) and bottom trawl survey composition data for 1999, 2003, 2005, 2009, 2011, and 2013 (years when the bottom trawl survey covered depths deeper than 500m).
(3) The model included a "shallow water coverage" survey fleet corresponding to length and age-at-length composition data for 1990, 1993, and 1996 (years when the bottom trawl survey excluded depths deeper than 500m). No bottom trawl survey biomass data were associated with the "shallow" survey fleet.
(4) 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.
(5) Parameters of the von-Bertlanffy growth curve were estimated within the model.
(6) The CV of length-at-age for the youngest and oldest fish were estimated within the model and used to define the age-length transition matrix.
(7) Fishery selectivity was estimated using length-based, sex-specific double-normal curves.
(8) Selectivity for the "full coverage" survey fleet was estimated using age-based, sex-specific double-normal curves that were forced to be asymptotic.
(9) Selectivity for the "shallow coverage" survey fleet was estimated using age-based, sex specific double-normal curves.
(10) Initial equilibrium F was estimated within the model.
(11) Ageing uncertainty was incorporated into the model using the ageing error matrix estimated based on age reads from the U.S. West Coast Dover sole age reading program (CAP). AFSC age-reading methods are equivalent to those used by CAP (Hicks & Wetzel, 2011). Future assessments should analyze AFSC Dover sole age-reading error.
(12) Recruitment deviations prior to 1984 ("early-period recruits") were estimated 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 for the assessment of the deepwater flatfish complex are compared to the key results from accepted 2011 assessment in the table below. The results for Dover sole are based on the author's recommended model and Tier 3a management.

Species	Quantity	As estimated or *specified last* year for:		As estimated or *recommended this* year for:	
		2013	2014	2014	2015
Dover sole	*M* (natural mortality rate)	0.085	0.085	0.085(f), 0.085(m)	0.085(f), 0.085(m)
	Tier	5	5	3a	3a
	Projected total (3+) biomass (t)	--	--	182,727	181,781
	Female spawning biomass (t)				
	Projected				
	Upper 95% confidence interval	--	--	66,181	67,078
	Point estimate	--	--	66,147	67,001
	Lower 95% confidence interval	--	--	66,126	66,945
	$B_{100\%}$	--	--	70,544	70,544
	$B_{40\%}$	--	--	28,218	28,218
	$B_{35\%}$	--	--	24,690	24,690
	F_{OFL}	0.085	0.085	0.12	0.12
	$maxF_{ABC}$	0.064	0.064	0.1	0.1
	F_{ABC}	0.064	0.064	0.1	0.1
	OFL (t)	4,943	6,590	15,915	15,711
	maxABC (t)	4,943	4,943	13,289	13,120
	ABC (t)	4,943	4,943	13,289	13,120
Greenland Turbot	Tier	6	6	6	6
	OFL (t)	238	238	238	238
	maxABC (t)	179	179	179	179
	ABC (t)	179	179	179	179
Deepsea Sole	Tier	6	6	6	6
	OFL (t)	6	6	6	6
	maxABC (t)	4	4	4	4
	ABC (t)	4	4	4	4
Deepwater Flatfish Complex	OFL (t)	5,187	6,834	16,159	15,955
	maxABC (t)	5,126	5,126	13,472	13,303
	ABC (t)	5,126	5,126	13,472	13,303
	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 specifies apportionment of ABCs among management areas. Area apportionment corresponds to the percentage of 2013 survey biomass in each area for Dover sole and to an estimate of 2013 catch by area for Greenland turbot and deepsea sole.

Quantity	Species	Western	Central	West Yakutat	Southeast	Total
Area Apportionment	Dover sole	1.18%	28.02%	41.54%	29.26%	100.00%
	Greenland turbot	81.17%	0.00%	6.40%	12.43%	100.00%
	Deepsea sole	0.00%	100.00%	0.00%	0.00%	100.00%
2014 ABC (t)	Dover sole	157	3,723	5,521	3,889	13,289
	Greenland turbot	145	0	11	22	179
	Deepsea sole	0	4	0	0	4
	Deepwater Flatfish	302	3,727	5,532	3,911	13,472
2015 ABC (t)	Dover sole	155	3,676	5,450	3,839	13,120
	Greenland turbot	145	0	11	22	179
	Deepsea sole	0	4	0	0	4
	Deepwater Flatfish	300	3,680	5,462	3,861	13,303

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 recommended examining whether the model would perform better if the maximum age was extended to older ages since the maximum observed age is 57. The maximum age in the current assessment model was changed to 59.

GPT (9/13 minutes): The Team recommended that the author continue to use the stock synthesis framework for both species [Dover and flathead sole] since it can accommodate past issues that have been raised. Also fits to the survey index data were much better. Assessments were conducted for both species (Dover and flathead sole) using the Stock Synthesis framework.

GPT (9/13 minutes): The Team recommended that the author ignore the composition data for the survey years which had incomplete coverage (i.e., when the SE GOA or deeper strata were omitted) and inflate the variance estimates for the expanded biomass indices. The Team recommended that authors of deep-water species work together to find a consistent method for treatment of survey years where coverage was incomplete. Gaps in depth and area strata were filled in and variance was inflated for these years using the survey averaging approach presented at the September Plan Team meeting. Model runs were conducted omitting composition data for survey years with incomplete coverage. However, the model was unable to fit to the survey index and could not estimate reliable recruitment deviations without the composition data for survey years with incomplete coverage. An alternative approach was used, where a separate selectivity curve was estimated using composition data only in years where only 0-500m depths were sampled. 2001 composition data were omitted from the model.

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. The SSC also endorses the Plan Team recommendations to list maturity studies as a research priority due to the large differences in maturity rates between studies in different regions. The SSC also agrees with Plan Team recommendations pertaining to survey expansion, and to disregarding composition data from* *earlier survey years that had incomplete spatial coverage.* Attachment 5B shows results from updating the previous assessment platform with the most current data and plots comparing results to those from the current assessment model using the new SS platform. An exploration of previous studies on Dover sole maturity was conducted and a maturity curve similar to that used in previous assessments was determined to be the best available representation of Dover sole maturity until new maturity data can be obtained and further study can be completed. See the response to GPT 9/13 minutes for a description of how composition data from survey years with incomplete spatial coverage were handled in the current assessment.

INTRODUCTION

The "flatfish" species complex previous to 1990 was managed as a unit in the Gulf of Alaska (GOA). It included the major flatfish species inhabiting the region, with the exception of Pacific halibut. The North Pacific Fishery Management Council divided the flatfish assemblage into four categories for management in 1990; "shallow flatfish" and "deep flatfish", flathead sole and arrowtooth flounder. This classification was made because of significant differences in halibut bycatch rates in directed fisheries targeting the shallow-water and deepwater flatfish species. Arrowtooth flounder, because of its present high abundance and low commercial value, was separated from the group and managed under a separate acceptable biological catch (ABC). Flathead sole were likewise assigned a separate ABC since they overlap the depth distributions of the shallow-water and deepwater groups. In 1993, rex sole was split out of the deepwater management category because of concerns regarding the bycatch of Pacific ocean perch in the rex sole target fishery.

The deepwater complex, the subject of this chapter, is composed of three species: Dover sole (*Microstomus pacificus*), Greenland turbot (*Reinhardtius hippoglossoides*) and deepsea sole (*Embassichthys bathybius*). Dover sole is by far the biomass-dominant in research trawl surveys and constitutes the majority of the fishery catch in the deepwater complex (typically over 98%). Little biological information exists for Greenland turbot or deepsea sole in the GOA. Better information exists for Dover sole, which allowed the construction of an age-structured assessment model in 2003 (Turnock, Wilderbuer, & Brown, 2003).

Greenland turbot have a circumpolar distribution and occur in both the Atlantic and Pacific Oceans. In the eastern Pacific, Greenland turbot are found from the Chukchi Sea through the Eastern Bering Sea and Aleutian Islands, in the Gulf of Alaska and south to northern Baja California. Greenland turbot are typically distributed from 200-1600 m in water temperatures from 1-4 degrees C, but have been taken at depths up to 2200 m.

Dover sole occur from Northern Baja California to the Bering Sea and the western Aleutian Islands; they exhibit a widespread distribution throughout the GOA (Hart, 1973; Miller & Lea, 1972). Adults are demersal and are mostly found at depths from 300 m to 1500 m.

Dover sole are batch spawners; spawning in the Gulf of Alaska has been observed from January through August, peaking in May (Hirschberger & Smith, 1983). The average 1 kg female may spawn 83,000 advanced yolked oocytes in about 9 batches (Hunter, Macewicz, Lo, & Kimbrell, 1992). Although the duration of the incubation period is unknown, eggs have been collected in plankton nets east of Kodiak Island in the summer (Kendall & Dunn, 1985). Larvae are large and have an extended pelagic phase that averages about 21 months (Markle, Harris, & Toole, 1992). They have been collected in bongo nets only in summer over mid-shelf and slope areas in the Gulf. The age or size at metamorphosis is unknown, but pelagic postlarvae as large as 48 mm have been reported and juveniles may still be pelagic at 10 cm (Hart, 1973). Juveniles less than 25 cm are rarely caught with the adult population in bottom trawl surveys (Martin & Clausen, 1995).

Dover sole move to deeper water as they age and older females may have seasonal migrations from deep water on the outer continental shelf and upper slope where spawning occurs to shallower water mid-shelf in summer time to feed (tagging data from California to British Columbia; Demory et al., 1984, Westrheim et al., 1992). Older male Dover sole may also migrate seasonally but to a lesser extent than females. The maximum observed age for Dover sole in the GOA is 59 years.

FISHERY

Description of the Directed Fishery

Since passage of the MFMCA in 1977, the flatfish fishery in the GOA has undergone substantial changes. Until 1981, annual harvests of flatfish were around 15,000 t, taken primarily as bycatch by foreign vessels targeting other species. Foreign fishing ceased in 1986 and joint venture fishing began to account for the majority of the catch. In 1987, the gulf-wide flatfish catch increased nearly four-fold, with joint venture fisheries accounting for all of the increase. Since 1988, only domestic fishing fleets are allowed to harvest flatfish. As foreign fishing ended, catches decreased to a low of 2,441 t in 1986. Catches subsequently increased under the joint venture and then domestic fleets to a high of 43,107 t in 1996. Catches then declined to 23,237 t in 1998 and were 22,700 t in 2004.

The GOA deepwater flatfish complex of species is caught in a directed fishery primarily using bottom trawls. Fewer than 20 shore-based catcher-type vessels participate in this fishery, together with about 6 catcher-processor vessels. Fishing seasons are driven by seasonal halibut PSC apportionments, with fishing occurring primarily in April and May because of higher catch rates and better prices. The deepwater flatfish complex catch is dominated by Dover sole (over 98%, typically; Table 5.1). Dover sole have been taken primarily in the Central Gulf in recent years, as well on the continental slope off Yakutat Bay in the eastern Gulf (based on fishery observer data).

Deepwater flatfish are also caught in pursuit of other bottom-dwelling species as bycatch. They are taken as bycatch in Pacific cod, bottom pollock and other flatfish fisheries. The gross discard rates for deepwater flatfish across all fisheries are relatively high, with 39% discarded in 2010 and 49% in 2011 (W. T. Stockhausen, Wilkins, M.E., Martin, M.H., 2011).

Historically, catch of Dover sole increased dramatically from a low of 23 t in 1986 to a high of almost 10,000 t in 1991 (Table 5.1, Figure 5.1). Following that maximum, annual catch has declined rather steadily. Catch of Greenland turbot has been sporadic and has been over than 100 t only 5 times since 1978. The highest catch of Greenland turbot (3,012 t) occurred in 1992, coinciding with the second highest catch of Dover sole (8,364 t) since 1978. This was followed by a catch of 16 t for Greenland turbot the next year. Annual catch has been less than 25 t since 1995. Deepsea sole is the least caught of the three deepwater flatfish species. It has been taken only intermittently, with less than a ton of annual catch occurring 14 times since 1978. The highest annual catch occurred in 1998 (38 t), but since then annual catch has been less than 3 t in every year, except for 2009 when 6 t were caught.

Annual catches of deepwater flatfish have been well below the TACs in recent years (Table 5.1 and Table 5.5). Annual TACs, in turn, have been set equal to their associated ABCs (Table 5.5). Limits on catch in the deepwater flatfish complex are driven by within-season closures of the directed fishery due to restrictions on halibut PSC, not attainment of the TAC (W. T. Stockhausen, Wilkins, M.E., Martin, M.H., 2011). Currently, ABCs for the entire complex are based on summing ABCs for the individual species. Tier 6 calculations are used to obtain species-specific contributions to the complex-level ABC and OFL for each year because population biomass estimates based on research trawl surveys for Greenland turbot and deepsea sole are considered unreliable and there is little basic biological information from these two species. As such, ABCs for Greenland turbot and deepsea sole are based on average historic catch levels and do not vary from year to year. Since 2003, the ABC for Dover sole has been based on an age-structured assessment model (Turnock et al., 2003).

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	1991-2004, 2009-2012 (2005-2008, 2013 data are excluded)
GOA survey bottom trawl	Catch per unit effort	Triennial: 1984-1999, Biennial: 2001-2013
GOA survey bottom trawl	Catch length composition	Triennial: 1990-1999, Biennial: 2003-2013 (1984, 1987, and 2001 data are excluded)
GOA survey bottom trawl	Catch age composition, conditioned on length	Triennial: 1990-1999, Biennial: 2003-2013 (1984, 1987, and 2001 data are excluded)

Fishery Data

Catch Biomass

The assessment included catch data from 1978 to October 19, 2013 (Table 5.1, column 3, Figure 5.1). Fishery catch per unit effort (CPUE) data were excluded because Dover sole are often taken as incidental catch and it is thought that the fishery CPUE data may not reflect abundance. Maps showing the spatial distribution of fishery CPUE from 2009 to 2013 are shown in Figure 5.2-Figure 5.6.

Catch Size Composition

Fishery length composition data were included in 2cm bins from 6-70cm in 1991-2004 and 2009-2012; data were omitted due to low sample size in 2005-2008 and 2013. Fishery length composition data were voluminous and can be accessed at http://www.afsc.noaa.gov/REFM/docs/2013/GOA_Dover_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 by strata are fully described in Wakabayashi (1985). Survey depth and area coverage was variable over time; the 1990, 1993, and 1996 surveys sampled only 0-500m depths, while the 2001 survey excluded the West Yakutat and Southeast management areas (the eastern Gulf). In addition, the 700-1000 meter depth range was sampled only in select survey years and areas (Table 5.2). A random effects model developed for survey averaging (presented at the September 2013 Plan Team Meeting, http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/2013/Sept/SAWG_2013_draft.pdf) was used to estimate survey biomass and variance in missing depth and area strata (Table 5.2). Table 5.3 describes the random effects model configurations and data used to estimate survey biomass and variance for each missing strata-year combination. The final survey biomass estimates and CVs used in the assessment are shown in

Table 5.4. Figure 5.7-Figure 5.9 show maps of survey CPUE in the GOA for the 2009, 2011, and 2013 surveys.

Survey Size and Age Composition

Sex-specific survey length composition data and 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_Dover_Composition_Data_And_SampleSize_2013.xlsx. 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.

ANALYTIC APPROACH

Model Structure

Tier 3 Model

The assessment was an age- and sex-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 age- and sex-structured population dynamics model (W. T. Stockhausen, Wilkins, & Martin, 2011). **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 5A.**

The bottom trawl survey was modeled as two separate surveys. A “full coverage” survey was modeled and fit to bottom trawl survey length and age-at-length composition data in years where depths greater than 500m were sampled, as well as bottom trawl survey biomass and variance estimates listed in

Table 5.4. An additional “shallow coverage” survey was modeled and fit to length and age-at-length composition data for years when the bottom trawl survey excluded depths deeper than 500m (1990, 1993, and 1996). Adjusted bottom trawl survey biomass data were only associated with the “full coverage” survey fleet, as the random effects modeling approach was used to transform these data to reflect a best available estimate of what would have been caught had all strata been sampled in all survey years. Selectivity curves in SS3 account for selectivity and availability. Therefore, separate selectivity curves were estimated for the “full coverage” and “shallow coverage” surveys because Dover sole move ontogenetically from shallow to deep depths and older ages are expected to be less available in a “shallow coverage” survey. Selectivity for both surveys was modeled with a double-normal curve and assumed to be age-based and sex-specific. Selectivity for the “full coverage” survey was assumed to be asymptotic, while selectivity for the “shallow coverage” allowed the potential for dome-shaped selectivity. Fishery selectivity was modeled with a double-normal length-based, sex-specific curve and allowed the potential for dome-shaped selectivity.

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.

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	0.5	1	0.5	1

The weights assigned in the 2011 assessment were used because it was thought that the model would not fit length-composition data as well as age-composition data. The same weights were used in assessments prior to 2011. In the current assessment, the assumptions about data-weighting were re-evaluated using a more formal approach for assessing variability in mean proportions-at-age and proportions-at-length (Francis, 2011). To account for process error (e.g. variance in selectivities among years), relative weights 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 current assessment used weights calculated using the Francis (2011) method, but fishery length-composition data were up-weighted slightly to improve model stability. The weights used were $\lambda =$ 0.4 for the fishery length composition data, $\lambda = 1.43$ for the full-coverage survey length-composition data, $\lambda =$ 1.4 for the shallow-coverage length-composition data, $\lambda = 0.79$ for the full-coverage survey age composition data, $\lambda = 0.702$ for the shallow-coverage 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 & Francis, 2010).

The effective sample sizes used were ½ of the number of lengths measured for the fishery length composition data (an approximation of the use of female and male sample size used in previous assessments). Effective sample sizes were equal among years (as for previous assessments), and set to 100 for survey length composition data. Sample size was used for effective sample sizes of the conditional age-at-length data. Future assessments should explore intra-haul correlation and the possibility of using the number of hauls as effective sample sizes for fishery and survey length-composition data (Pennington & Volstad, 1994).

Ageing Error Matrix

Ageing uncertainty was incorporated into the assessment model. An ageing error matrix estimated from age-read data from the U.S. West Coast Dover sole ageing program (CAP) and used in the 2011 U.S. West Coast Dover sole assessment (Hicks & Wetzel, 2011) was used. Future Dover sole assessments should analyze GOA Dover sole age-read data to develop an ageing error matrix to use in the assessment instead of the west coast matrix. However, the CAP and AFSC ageing programs employ equivalent methods where ages are determined based on break-and-burn methods and each otolith is aged by two readers. Hicks and Wetzel (2011) estimated an ageing error matrix using methods described in Punt et al. (2008) whereby a relationship between true and estimated age is modeled and used to construct a probability that an otolith is observed to be age *a'* given a true age *a*. The ageing error matrix estimated in Hicks and Wetzel (2011) and used in this assessment shows that ageing uncertainty increases non-linearly with age and does not include ageing bias (Table 5.6). Accounting for ageing error is an important addition to the assessment methods because many Dover sole otoliths are particularly difficult to age (Kastelle, Anderl, Kimura, & Johnston, 2008). Ignoring ageing error in assessments can lead to bias in estimation of management quantities (Reeves, 2003).

Recruitment Deviations

Recruitment deviations prior to 1984 ("early-period recruits") were estimated separately from main-period recruits (1984-2008) such that the vector of recruits for each period was subject to a sum-to-zero constraint, rather than forcing a sum-to-zero constraint across all recruitment deviations.

Model structures considered in this year's assessment

Many proposed model changes were presented at the 2013 September Plan Team meeting (Attachment 5A) and were subsequently explored using 2012-2013 data. The three models described below are included in the final assessment; all use the SS3 model framework and include most of the changes that were proposed and reviewed at the September Plan Team meeting (Attachment 5A).

Model 0 (Author's recommended model) implemented all of the changes described above, including estimation of recruitment deviations for an "early" time period from 1967-1983, prior to the availability of composition data.

Model 1 was as for Model 0, but excluded the estimation of early-period recruits and instead a different R_0 value was estimated during the early period. Recruitment deviations were estimated beginning in 1978. 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, but also forces the model to estimate an initial age composition that is at a fished equilibrium until 1978, which is likely unrealistic.

Model 2 was as for Model 0, but excluded the 1984 and 1987 survey biomass index data. Composition data for 1984 and 1987 were excluded from all models because they were not realistic and survey methods differed in these years; the 1984 and 1987 survey biomass index data may be unreliable for the same reasons.

Model 3 was as for Model 0, but excluded the 1984 and 1987 survey biomass index data and excluded the estimation of early-period recruits, estimating a different R_0 value during the early period. Recruitment deviations were estimated beginning in 1978.

Parameters Estimated Outside the Assessment Model

Natural Mortality

Natural mortality was fixed at 0.085. This value was used in previous accepted Dover sole assessment models (W. T. Stockhausen, Wilkins, M.E., Martin, M.H., 2011) and was estimated using the Hoenig method (Hoenig, 1983). Future assessments should re-evaluate natural mortality for GOA Dover sole.

Weight-Length Relationship

The weight-length relationship used in the assessment was estimated for GOA Dover sole by Abookire and Macewicz (2003). The relationship was $w_L = \alpha L^{\beta}$, where $\alpha = 2.9E-06$ and $\beta = 3.3369$, 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 $\gamma = -0.363$ and the age-at-50%-maturity was $a_{50} = 12.47$.

A logistic maturity-at-length relationship estimated in Abookire and Macewicz (2003) was converted into a maturity-at-age relationship using the mean length-at-age relationship estimated within the assessment model. The maturity curve does not influence the estimation of the mean length-at-age relationship because spawning stock biomass (SSB) is the only quantity influenced by maturity in the model and SSB does not influence model fits because no stock-recruitment relationship is used.

A maturity-at-length curve was not used because slow growing fish in the model never become large enough to mature, regardless of age. This is unrealistic. Abookire and Macewicz (2003) estimated maturity-at-age as well as a maturity-at-length. However, the relatively low sample size of aged fish used in the Abookire and Macewicz (2003) study, combined with the large magnitude of ageing error known to exist for Dover sole suggested that the maturity-at-age relationship estimated in the paper may be unreliable.

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 Dover sole assessments was approximately σ_R =0.49 and this value was used in the current assessment.

Catchability

Catchability was equal to 1, as for previous Dover sole assessments. Future assessments should explore this assumption further.

Select selectivity parameters

Selectivity parameter definitions and values are shown in Table 5.8.

Parameters Estimated Inside the Assessment Model

Parameters estimated within the assessment model are 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 59, and selectivity parameters for the fishery, the “full coverage” survey, and the “shallow-coverage” survey. The selectivity parameters are described in greater detail in Table 5.8.

RESULTS

Model Evaluation

Comparison among alternative models

Deciding whether to include or exclude survey biomass data points or early-period recruitment deviations depends on whether the survey biomass data points and early recruitment deviations are believable, rather than on which model best fits the data or leads to the best total likelihood. The values of likelihood components for a model including 1984 and 1987 survey biomass data cannot be compared to a model without these data because the objective function includes a different number of data points. However, the table of likelihood values can provide information on what likelihood components are most influenced by estimating early-period recruitment deviations and whether the decision to include or exclude early-period recruitment deviations has a substantial impact on the likelihood. Table 5.7 lists the total negative log likelihood and likelihood components for each model. Comparing Model 0 to Model 1 and Model 2 to Model 3 shows that estimating early-period recruitment deviations improves the total negative log likelihood and fits to the age composition data, but improvements in likelihood components are small. Models that include early-period recruitment deviations fit the recent years of survey biomass data more closely than models that don’t estimate early-period recruitment deviations (Figure 5.10). Early period recruitment deviations for both Models 0 and 2 exhibit a distinct pattern whereby the models estimate negative recruitment deviations at the start of the period and deviations grow until reaching a peak in 1967 and then decline towards zero in the mid-1970s (Figure 5.11). Model 2, which excludes 1984 and 1987 survey biomass data, estimates a very large, positive recruitment deviation in 1967 (Figure 5.11); the early-period recruitment deviations in this model improve the model fits to the survey biomass data (Table 5.7) and only marginally improve fits to age composition data. It seems that the large pulse of recruitment in 1967 allows Model 2 to fit both the higher survey biomass data in 1990-1996 and the most recent lower (but upward) trend in survey biomass more closely than for a model without early-period recruitment deviations (Figure 5.10), but fails to explain the age- or length-composition data better than does Model 3. This is an indication that the extreme 1967 recruitment pulse in Model 2 is an artifact of the model and may not be believable.

Models 2 and 3, which exclude 1984 and 1987 survey biomass data, fit the 1990-1996 survey biomass data more closely than the other models, but don’t substantially influence fits to the data in the more recent years of the time series (Figure 5.10) when comparing Model 2 to Model 0 (yellow and blue lines; models with early recruitment deviations) and comparing Model 3 to Model 1 (green and red lines; models without early recruitment deviations).

Estimates of age-0 recruits and spawning biomass are slightly lower in the most recent years when early-period recruitment deviations are included (Figure 5.12 & Figure 5.13).

The Author's Recommended Model (Model 0)

Model 0 was selected as the author's recommended model for the following reasons. Model 2, where early-period recruitment deviations were estimated and 1984 and 1987 survey biomass data were excluded, is the least believable of the four alternative models because of the very large recruitment deviation in 1967. However, excluding early-period recruitment deviations forces the model to assume that the initial age composition in 1978 was that of a population at a deterministic equilibrium, which is unrealistic. Among the alternative models, Model 0 led to the most reasonable estimates of early-period recruitment deviations, but also included 1984 and 1987 survey biomass data. Including or excluding the survey biomass data in 1984 and 1987 led to small differences in model fits to the survey biomass data and similar estimates of survey biomass between models from 2001 to 2013 (Figure 5.10). The CV of the survey biomass index in 1990 was larger than in other years because deeper depths were unsampled; Model 0 fits to survey biomass data show that expected survey biomass in 1990 was well within the confidence bounds of the 1990 data. Therefore, it seems reasonable to continue to use the 1984 and 1987 survey biomass data and Model 0 is recommended by the author.

Estimates of fishery selectivity for Model 0 were dome-shaped (Figure 5.15,

Table 5.10), suggesting that fewer Dover sole were caught at the deepest depths where the oldest Dover sole are found. However, standard deviations of parameter estimates determining the descending limb of the selectivity curve are very high. The full-coverage survey selectivity was restricted to be asymptotic because the composition data associated with these survey years covered depths up to 1000 m and therefore (theoretically) all ages (Figure 5.16, Table 5.11). Age-based Dover sole selectivity was used because sensitivity analyses using length-based selectivity curves showed that the oldest Dover sole were never selected in the full coverage survey years (due to variability in length at older ages); this inadvertently decreased catchability in the model. Estimates of selectivity for the shallow-water survey were dome-shaped and suggest that females were more available to the fishery than males at most ages when only shallow depths were sampled (Figure 5.16, Table 5.11); this is consistent with tagging studies showing that female Dover sole may move between deeper and shallower depths more than males to spawn and feed Demory et al., 1984; Westrheim et al., 1992). Estimates of selectivity for the shallow-water survey years correspond only to composition data and were not informed by an index of biomass.

Plots of observed and expected proportions-at-length for Model 0, aggregated over years, are shown in Figure 5.17 - Figure 5.18 and yearly fits to proportion-at-length data are shown in Figure 5.19-

Figure 5.23. Fits to aggregated fishery proportions-at-length are very close to the observed values for females and males. Fits to the aggregated proportions-at-length for the full coverage survey are reasonable, but the model expected more females between 40-50 cm than were observed; estimated aggregated proportions-at-length for the shallow water survey show that the model expected fewer 40-50cm females and fewer 35-45 cm males, but otherwise the estimated aggregated survey proportions-at-length were very close to the observed values.

Fits to conditional age-at-length data and variability in age-at-length are generally close to the observed mean length at age (Figure 5.24-Figure 5.29). Mean age-at-length observations do not always increase monotonically with length, indicating that data are variable (Figure 5.24-Figure 5.29).

Time Series Results

Time series results are shown in Table 5.15-Table 5.16 and Figure 5.30-Figure 5.31. A time series of numbers at age is available at http://www.afsc.noaa.gov/REFM/docs/2013/GOA_Dover_TimeSeries_of_NumbersAtAge_2013.xlsx. Age 3 recruitment, age 0 recruitment, and standard deviations of age 0 recruitment estimates are presented in Table 5.15 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 5.16. Figure 5.30 shows spawning stock biomass estimates and corresponding asymptotic 95% confidence intervals. Figure 5.31 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

Tier 3 Approach for Dover Sole

The reference fishing mortality rate for Dover 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 1978-2013 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{40\%}$ can be 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 Dover sole reference fishing mortality is defined in Tier 3a. For this tier, $FABC$ is constrained to be $\leq F_{40\%}$, and F_{OFL} is defined to be $F_{35\%}$. The values of these quantities are:

SSB 2013	66,147
$B_{40\%}$	28,218
$F_{40\%}$	0.1
max$Fabc$	0.1
$B_{35\%}$	24,690
$F_{35\%}$	0.12
F_{OFL}	0.12

Because the Dover 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 8.14 - Table 8.16.

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the Dover 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 66,147 t, more than 2 times $B_{35\%}$ (24,690 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 (28,950 t) is greater than $B_{35\%}$; thus, the stock is not approaching an overfished condition.

Area Allocation for Harvests

TACs for deepwater flatfish in the Gulf of Alaska are divided among four smaller management areas (Eastern, Central, West Yakutat and Southeast Outside). As in previous assessments, the proportion of historical catch among the management areas is used to apportion the total ABCs for Greenland turbot and deepsea sole. Area-specific ABCs for Dover sole are divided up over the four management areas by applying the fraction of 2013 survey biomass estimated for each area (relative to the total over all areas) to the 2014 and 2015 ABCs. The area-specific allocations for 2014 and 2015 are:

Quantity	Species	Western	Central	West Yakutat	Southeast	Total
Area Apportionment	Dover sole	1.18%	28.02%	41.54%	29.26%	100.00%
	Greenland turbot	81.17%	0.00%	6.40%	12.43%	100.00%
	Deepsea sole	0.00%	100.00%	0.00%	0.00%	100.00%
2014 ABC (t)	Dover sole	157	3,723	5,521	3,889	13,289
	Greenland turbot	145	0	11	22	179
	Deepsea sole	0	4	0	0	4
	Deepwater Flatfish	302	3,727	5,532	3,911	13,472
2015 ABC (t)	Dover sole	155	3,676	5,450	3,839	13,120
	Greenland turbot	145	0	11	22	179
	Deepsea sole	0	4	0	0	4
	Deepwater Flatfish	300	3,680	5,462	3,861	13,303

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TABLES

Table 5.1. Total and regional annual catch of GOA deepwater flatfish through October 19, 2013.

Year	Greenland turbot	Dover sole	Deepsea sole	Total
1978	51	827	5	883
1979	24	530	5	559
1980	57	570	2	629
1981	8	457	8	473
1982	23	457	31	511
1983	145	354	11	510
1984	18	132	1	151
1985	0	43	3	46
1986	0	23	0	23
1987	44	56	0	100
1988	256	1,087	0	1,343
1989	56	1,521	0	1,577
1990	0	2,348	30	2,378
1991	446	9,741	2	10,189
1992	3,012	8,364	3	11,379
1993	16	3,804	3	3,823
1994	17	3,108	4	3,129
1995	116	2,096	1	2,213
1996	15	2,177	0	2,192
1997	11	3,652	1	3,664
1998	18	2,230	38	2,286
1999	14	2,270	0	2,284
2000	23	961	1	985
2001	4	800	0	804
2002	5	554	0	559
2003	10	936	0	946
2004	1	679	1	681
2005	5	407	0	412
2006	12	390	3	405
2007	1	286	0	287
2008	1	561	1	563
2009	3	457	6	466
2010	0	544	0	544
2011	3	399	0	403
2012	0	295	0	295
2013	7	164	1	172

Table 5.2. Survey biomass by year, area, and depth (1 of 2 pages).

	Depth						
	101-200	1-100	201-300	301-500	501-700	701-1000	Total
WESTERN GOA							
1984	725	34	355	1,138	1,290	919	4,460
1987	108	5	32	1,103	1,267	108	2,623
1990	716	161	50	721			1,649
1993	1,044	172	154	1,001			2,371
1996	337	134	290	698			1,458
1999	56	7	43	651	685	0	1,442
2001	53	18	188	636			895
2003	541	194	270	811	1,333		3,149
2005	468	475	275	455	312	848	2,832
2007	405	78	110	468	208	1,056	2,325
2009	565	154	88	548	3,712	0	5,067
2011	146	235	8	134	311		833
2013	627	0	126	84	142		979
CENTRAL GOA							
1984	24,506	1,870	5,598	4,039	5,147	11,309	52,469
1987	12,728	1,260	8,587	3,706	6,757	1,539	34,577
1990	42,188	11,233	15,644	2,043			71,109
1993	24,054	3,937	10,883	4,640			43,515
1996	21,452	1,674	8,691	5,327			37,144
1999	14,068	3,619	8,085	4,779	2,889	716	34,155
2001	16,241	3,785	7,303	4,200			31,529
2003	23,005	2,842	10,070	4,629	8,738		49,283
2005	19,805	4,255	6,691	4,742	1,617	1,772	38,881
2007	22,417	1,834	9,543	4,437	3,604	1,655	43,490
2009	15,668	2,372	12,619	3,158	1,769	236	35,820
2011	14,528	1,810	15,131	2,578	1,501		35,548
2013	7,789	1,196	9,896	2,026	2,273		23,180

Table 5.2, continued. Survey biomass by year, area, and depth.

	Depth						
	101-200	1-100	201-300	301-500	501-700	701-1000	Total
SOUTHEASTERN GOA							
1984	806		1,087	1,044	1,139		4,076
1987	185	0	1,112	2,502	1,328		5,127
1990	1,005		2,038	2,097			5,140
1993	1,730		2,853	8,204			12,787
1996	1,366	1,338	3,026	5,432			11,162
1999	1,779	1,587	3,729	4,658	711	538	13,001
2003	3,032	3,710	2,271	5,405	838		15,256
2005	1,636	495	2,207	9,012	228	69	13,647
2007	1,309	103	5,812	4,457	224	216	12,120
2009	1,386	288	2,713	2,779	1,975	411	9,551
2011	3,870	108	2,309	9,418	767		16,473
2013	1,353	5,250	3,591	13,220	796		24,210
YAKUTAT							
1984	4,183	925	888	601	589	330	7,516
1987	12,810	3,137	2,307	1,623	1,190		21,067
1990	13,864	896	2,252	1,687			18,699
1993	17,171	651	6,040	3,015			26,877
1996	14,700	3,415	6,095	5,556			29,766
1999	12,647	1,219	7,719	2,230	1,765	68	25,647
2003	18,604	3,409	5,221	2,748	1,628		31,609
2005	10,704	1,429	8,502	3,565	977	0	25,177
2007	5,579	800	4,133	1,973	1,144	62	13,690
2009	8,867	3,720	8,266	2,816	2,169	0	25,838
2011	6,195	2,269	8,793	7,286	135		24,678
2013	6,575	18,105	7,587	1,774	329		34,371

Table 5.3. Description of random effects models and data used to estimate survey biomass and variance for missing strata-year combinations.

Random effects model	Missing Strata	Missing Years	Survey data used in random effects model to estimate biomass and variance for missing strata
1	Eastern, 0-500m	2001	Eastern, All survey years except 2001
2	All GOA, 500-700m	1990, 1993, 1996, 2001	All GOA, 1984, 1987, 1999, 2003, 2005, 2007, 2009, 2011
3	Western, 700-1000m	1990, 1993, 1996, 2001, 2003, 2011	Western, 1984, 1987, 1999, 2005, 2007, 2009
4	Central, 700-1000m	1990, 1993, 1996, 2001, 2003, 2011	Central, 1984, 1987, 1999, 2005, 2007, 2009
5	Eastern, 700-1000m	1987, 1990, 1993, 1996, 2001, 2003, 2011	Eastern, 1984, 1999, 2005, 2007, 2009

Table 5.4. Final survey biomass estimates and CVs used in the assessment, after an adjustment using the survey-averaging random effects model to estimate biomass in missing year-strata combinations.

Year	Biomass Estimate	CV
1984	68,521	0.09
1987	63,709	0.12
1990	107,286	0.13
1993	95,242	0.09
1996	88,351	0.08
1999	75,004	0.07
2001	80,068	0.12
2003	101,735	0.10
2005	80,538	0.08
2007	71,624	0.10
2009	77,327	0.08
2011	79,366	0.09
2013	82,739	0.22

Table 5.5. Time series of historical ABCs, TACs, OFLs, and percent of catch retained for the deepwater flatfish complex

Year	**ABC**	**TAC**	**OFL**	**Percent Retained**
1995	14,590	11,080	17,040	79%
1996	14,590	11,080	17,040	72%
1997	7,170	7,170	9,440	82%
1998	7,170	7,170	9,440	90%
1999	6,050	6,050	8,070	80%
2000	5,300	5,300	6,980	71%
2001	5,300	5,300	6,980	75%
2002	4,880	4,880	6,430	64%
2003	4,880	4,880	6,430	50%
2004	6,070	6,070	8,010	81%
2005	6,820	6,820	8,490	42%
2006	8,665	8,665	11,008	40%
2007	8,707	8,707	10,431	41%
2008	8,903	8,903	11,343	37%
2009	9,168	9,168	11,578	21%
2010	6,190	6,190	7,680	61%
2011	6,305	6,305	7,823	51%
2012	5,126	5,126	6,834	25%
2013	5,126	5,126	6,834	61%

Table 5.6. Ageing error uncertainty assumed in the assessment model.

True Age	Standard Deviation	True Age	Standard Deviation
0	0.210	30	4.224
1	0.210	31	4.464
2	0.284	32	4.715
3	0.361	33	4.975
4	0.441	34	5.247
5	0.525	35	5.530
6	0.612	36	5.824
7	0.703	37	6.131
8	0.797	38	6.450
9	0.896	39	6.783
10	0.998	40	7.129
11	1.105	41	7.490
12	1.216	42	7.866
13	1.332	43	8.257
14	1.452	44	8.664
15	1.578	45	9.089
16	1.709	46	9.531
17	1.845	47	9.991
18	1.987	48	10.470
19	2.134	49	10.969
20	2.288	50	11.489
21	2.448	51	12.031
22	2.615	52	12.594
23	2.789	53	13.182
24	2.970	54	13.793
25	3.158	55	14.430
26	3.354	56	15.093
27	3.559	57	15.784
28	3.771	58	16.503
29	3.993	59	17.252

Table 5.7. Total negative log likelihood and negative log likelihood components for each alternative model. Likelihoods components for models fitting to 1984 and 1987 survey biomass (shaded in grey) cannot be compared to those that don't fit to 1984 and 1987 survey biomass (no shading).

Likelihood Component	Model 0	Model 1	Model 2	Model 3
TOTAL	3,411	3,425	3,379	3,398
Survey	-11.43	-11.65	-20.19	-18.03
Length_comp	645	643	632	628
Age_comp	2,765	2,792	2,749	2,787
Recruitment	12.51	2.19	18.21	1.58

Table 5.8. Estimated and fixed double-normal selectivity parameters. "Estimated" indicates that the parameter was estimated within the assessment and a numeric value indicates a fixed parameter value.

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

Table 5.9. Final parameter estimates of growth and unfished recruitment parameters with corresponding standard deviations for the preferred model (Model 0) and three alternative models.

	Model 0		Model 1		Model 2		Model 3	
Parameter	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Length at age 2 (f)	22.547	0.656	22.503	0.653	22.440	0.660	22.444	0.654
Linf (f)	50.388	0.287	50.437	0.284	50.242	0.281	50.392	0.282
von Bertalanffy k (f)	0.148	0.007	0.148	0.007	0.150	0.007	0.148	0.007
CV in length at age 2 (f)	0.153	0.009	0.153	0.009	0.155	0.009	0.155	0.009
CV in length at age 59 (f)	0.101	0.003	0.101	0.003	0.101	0.003	0.101	0.003
Length at age 2 (m)	22.382	0.816	22.270	0.810	22.458	0.819	22.354	0.813
Linf (m)	43.583	0.172	43.625	0.172	43.461	0.169	43.552	0.171
von Bertalanffy k (m)	0.211	0.012	0.211	0.012	0.211	0.012	0.211	0.012
CV in length at age 2 (m)	0.168	0.010	0.168	0.010	0.168	0.010	0.168	0.010
CV in length at age 59 (m)	0.087	0.002	0.087	0.002	0.087	0.002	0.087	0.002
R0 (log space)	10.115	0.077	10.305	0.059	10.014	0.081	10.309	0.060
R0 offset (log space)	Fixed	NA	-0.0003	0.039	Fixed	NA	0.038	0.040

Table 5.10. Final fishery selectivity parameters for the preferred model (Model 0) and three 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)	49.18	0.88	49.23	0.85	48.95	0.81	49.04	0.85
Width: width of plateau	0.76	8.26	0.75	8.25	0.76	8.02	0.76	7.98
Ascending width (log space)	4.41	0.15	4.40	0.15	4.40	0.14	4.38	0.15
Descending width (log space)	1.39	257.86	1.38	259.14	1.33	267.55	1.32	271.17
Initial: selectivity at smallest length or age bin	-10	NA	-10	NA	-10	NA	-10	NA
Final: selectivity at largest length or age bin	0.44	117.47	0.44	117.48	0.43	117.48	0.43	117.50
Male Peak Offset	-11.70	0.90	-11.69	0.87	-11.58	0.85	-11.58	0.88
Male ascending width offset (log space)	-2.25	0.25	-2.23	0.25	-2.27	0.25	-2.24	0.25
Male descending width offset (log space)	0.00	335.41	0.00	335.41	0.00	335.41	0.00	335.41
Male "Final" offset (transformation required)	0.50	11.18	0.50	11.18	0.50	11.18	0.50	11.18
Male apical selectivity	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00

Table 5.11. (top) Final "full coverage" selectivity parameters for the preferred model (Model 0) and three alternative models. "Est" refers to the estimated value and "Std. Dev" is the standard deviation of the estimate; (bottom) As for (a), for final "shallow coverage" selectivity parameters.

	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)	45.00	0.03	45.00	0.03	45.00	0.05	45.00	0.04
Width: width of plateau	8.00	NA	8.00	NA	8.00	NA	8.00	NA
Ascending width (log space)	7.42	0.20	7.21	0.15	7.92	0.36	7.34	0.18
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	6.83	5.98	6.56	5.39	1.98	4.29	5.04	5.32
Male ascending width offset (log space)	2.05	1.99	1.30	0.79	9.22	79.52	1.34	0.97
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

	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)	20.97	0.88	21.58	1.06	20.71	0.77	21.28	1.19
Width: width of plateau	0.09	0.22	0.10	0.35	-0.01	0.24	0.19	0.29
Ascending width (log space)	5.09	0.21	5.07	0.20	5.19	0.24	5.10	0.23
Descending width (log space)	-1.30	13.27	-1.75	7.50	-1.20	14.48	-1.80	5.49
Initial: selectivity at smallest length or age bin	-498	11236	-498	11236	-498	11236	-497	11236
Final: selectivity at largest length or age bin	-5	0.53	-5	0.32	-5	0.67	-5	0.31
Male Peak Offset	-15.00	0.04	-15.00	0.04	-15.00	0.06	-15.00	0.04
Male ascending width offset (log space)	-3.83	0.61	-3.43	0.60	-4.11	0.60	-3.64	0.71
Male descending width offset (log space)	-2.35	34.74	3.29	6.81	-0.21	15.13	1.53	9.14
Male "Final" offset (transformation required)	0.04	1.20	0.02	0.60	0.06	1.83	0.02	0.60
Male apical selectivity	0.64	0.07	0.61	0.07	0.70	0.08	0.63	0.07

Table 5.12. Beginning-of-year length-at-age and weight-at-age for the recommended model

	Length		Weight			Length		Weight	
Age	Female	Male	Female	Male	Age	Female	Male	Female	Male
0	2.00	2.00	0.00	0.00	30	49.88	43.51	1.40	0.88
1	8.85	8.79	0.00	0.00	31	49.95	43.53	1.40	0.88
2	15.70	15.59	0.03	0.03	32	50.01	43.54	1.41	0.88
3	22.55	22.38	0.10	0.10	33	50.06	43.55	1.42	0.88
4	26.38	26.41	0.17	0.18	34	50.10	43.55	1.42	0.88
5	29.68	29.68	0.26	0.26	35	50.14	43.56	1.42	0.88
6	32.53	32.32	0.35	0.34	36	50.18	43.56	1.43	0.88
7	34.99	34.46	0.44	0.41	37	50.21	43.57	1.43	0.88
8	37.10	36.19	0.53	0.48	38	50.23	43.57	1.43	0.88
9	38.93	37.60	0.62	0.55	39	50.25	43.57	1.43	0.88
10	40.51	38.74	0.71	0.60	40	50.27	43.57	1.44	0.88
11	41.87	39.66	0.79	0.65	41	50.29	43.58	1.44	0.88
12	43.04	40.40	0.86	0.69	42	50.30	43.58	1.44	0.88
13	44.05	41.01	0.93	0.72	43	50.31	43.58	1.44	0.88
14	44.92	41.50	0.99	0.75	44	50.32	43.58	1.44	0.88
15	45.67	41.89	1.05	0.78	45	50.33	43.58	1.44	0.88
16	46.32	42.21	1.10	0.80	46	50.34	43.58	1.44	0.88
17	46.88	42.48	1.14	0.81	47	50.35	43.58	1.44	0.88
18	47.36	42.69	1.18	0.82	48	50.35	43.58	1.44	0.88
19	47.78	42.86	1.22	0.84	49	50.36	43.58	1.44	0.88
20	48.14	42.99	1.25	0.84	50	50.36	43.58	1.44	0.88
21	48.45	43.11	1.27	0.85	51	50.37	43.58	1.44	0.88
22	48.72	43.20	1.29	0.86	52	50.37	43.58	1.44	0.88
23	48.95	43.27	1.32	0.86	53	50.37	43.58	1.44	0.88
24	49.14	43.33	1.33	0.87	54	50.37	43.58	1.44	0.88
25	49.31	43.38	1.35	0.87	55	50.38	43.58	1.44	0.88
26	49.46	43.42	1.36	0.87	56	50.38	43.58	1.44	0.88
27	49.59	43.45	1.37	0.87	57	50.38	43.58	1.45	0.88
28	49.70	43.47	1.38	0.88	58	50.38	43.58	1.45	0.88
29	49.79	43.50	1.39	0.88	59	50.38	43.58	1.45	0.88

Table 5.13. Estimated recruitment deviations and standard deviations of the estimates for the recommended model (Model 0). Early-period recruitment deviations were estimated in 1947-1983; main-period recruitment deviations were estimated in 1984-2013.

Year	Recruitment Deviations	Std. Dev.	Year	Recruitment Deviations	Std. Dev.
1947	-0.314	0.425	1981	0.245	0.485
1948	-0.326	0.423	1982	0.474	0.548
1949	-0.333	0.422	1983	0.799	0.471
1950	-0.339	0.421	1984	0.247	0.493
1951	-0.341	0.422	1985	-0.013	0.439
1952	-0.358	0.418	1986	0.267	0.394
1953	-0.345	0.420	1987	0.385	0.331
1954	-0.326	0.423	1988	-0.124	0.338
1955	-0.271	0.431	1989	-0.531	0.312
1956	-0.220	0.439	1990	-0.667	0.311
1957	-0.151	0.451	1991	-0.096	0.223
1958	-0.064	0.468	1992	-0.716	0.304
1959	0.049	0.494	1993	-0.143	0.255
1960	0.194	0.530	1994	0.182	0.249
1961	0.375	0.595	1995	0.178	0.253
1962	0.620	0.738	1996	-0.196	0.330
1963	0.844	1.002	1997	0.398	0.244
1964	0.844	1.006	1998	0.299	0.282
1965	0.644	0.763	1999	1.355	0.135
1966	0.482	0.645	2000	0.135	0.260
1967	0.358	0.581	2001	-0.055	0.266
1968	0.263	0.541	2002	0.461	0.212
1969	0.185	0.513	2003	0.398	0.265
1970	0.111	0.492	2004	1.066	0.180
1971	0.040	0.474	2005	-0.052	0.306
1972	-0.017	0.462	2006	-0.365	0.303
1973	-0.039	0.455	2007	-0.361	0.292
1974	-0.009	0.458	2008	-0.945	0.345
1975	0.073	0.468	2009	-0.560	0.398
1976	0.176	0.480	2010	-0.176	0.423
1977	0.228	0.486	2011	-0.089	0.431
1978	0.197	0.479	2012	-0.223	0.437
1979	0.144	0.469	2013	-0.061	0.475
1980	0.138	0.469			

Table 5.14. Estimated fishing mortality rates and standard deviations of the estimates for the preferred model (M0).

Year	Fishing Mortality	Std. Dev.	Year	Fishing Mortality	Std. Dev.
Initial F	0.0045	0.0004	1995	0.0162	0.0008
1978	0.0056	0.0003	1996	0.0172	0.0009
1979	0.0036	0.0002	1997	0.0297	0.0015
1980	0.0039	0.0002	1998	0.0187	0.0010
1981	0.0031	0.0002	1999	0.0196	0.0011
1982	0.0031	0.0002	2000	0.0084	0.0005
1983	0.0024	0.0001	2001	0.0071	0.0004
1984	0.0009	0.0000	2002	0.0049	0.0003
1985	0.0003	0.0000	2003	0.0083	0.0005
1986	0.0002	0.0000	2004	0.0059	0.0004
1987	0.0004	0.0000	2005	0.0035	0.0002
1988	0.0074	0.0003	2006	0.0032	0.0002
1989	0.0103	0.0004	2007	0.0023	0.0002
1990	0.0159	0.0007	2008	0.0044	0.0003
1991	0.0677	0.0030	2009	0.0035	0.0003
1992	0.0607	0.0028	2010	0.0040	0.0003
1993	0.0284	0.0014	2011	0.0029	0.0002
1994	0.0236	0.0012	2012	0.0021	0.0002

Table 5.15. Time series of age 3 and age 0 recruits and standard deviation of age 0 recruits for the previous and current assessment models.

	2011 Assessment			*2013 Assessment*		
Year	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. dev**	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. dev**
1978				20,599	30,102	14,315
1979				22,826	28,419	13,265
1980				24,062	27,993	13,081
1981		81,449	8,099	23,326	30,871	14,941
1982		93,839	8,909	22,023	38,495	21,094
1983		65,050	6,614	21,692	52,794	24,445
1984	44,700	42,638	4,725	23,923	30,119	14,980
1985	51,500	36,260	4,455	29,831	23,016	10,189
1986	35,700	26,421	3,240	40,911	30,170	11,904
1987	23,400	25,692	3,240	23,339	33,632	11,141
1988	19,900	28,972	3,780	17,835	20,044	6,840
1989	14,500	24,052	3,375	23,379	13,305	4,194
1990	14,100	26,967	3,780	26,062	11,618	3,658
1991	15,900	39,358	5,399	15,532	20,563	4,680
1992	13,200	29,518	4,455	10,310	11,064	3,440
1993	14,800	33,891	4,725	9,003	19,628	5,121
1994	21,600	54,846	7,154	15,934	27,154	6,947
1995	16,200	60,130	7,559	8,573	27,054	7,048
1996	18,600	55,028	7,154	15,210	18,599	6,291
1997	30,100	70,516	9,179	21,042	33,715	8,506
1998	33,000	79,809	10,259	20,965	30,520	8,933
1999	30,200	124,086	15,253	14,413	87,748	13,388
2000	38,700	90,742	12,419	26,126	25,914	7,078
2001	43,800	51,930	9,314	23,650	21,420	5,980
2002	68,100	57,761	9,989	67,997	35,911	8,158
2003	49,800	58,672	11,609	20,081	33,687	9,382
2004	28,500	71,427	13,364	16,599	65,737	13,165
2005	31,700	30,247	9,314	27,828	21,820	6,984
2006	32,200	23,505	5,939	26,104	16,192	5,145
2007	39,200	36,807	10,664	50,941	16,502	5,085
2008	16,600	36,260	10,259	16,909	9,339	3,356
2009	12,900			12,548	13,929	5,727
2010	20,200			12,787	20,715	9,010
2011	19,900			7,237	22,594	10,000
2012				10,793	19,760	8,870
2013				16,052	23,256	
Average	28,536	51,995		21,846	27,594	

Table 5.16. Time series of age 3+ total biomass, spawning biomass, and standard deviation of spawning biomass for the 2011 assessment and this year's assessment

	2011 Assessment			*2013 Assessment*		
Year	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**
1978				150,904	68,209	4,072
1979				185,711	69,750	3,989
1980				185,077	71,027	3,892
1981				184,742	71,905	3,783
1982				184,336	72,470	3,670
1983				183,944	72,729	3,555
1984	202,600	62,800	2,800	183,503	72,795	3,443
1985	211,300	63,600	2,800	183,358	72,796	3,338
1986	218,300	64,900	2,800	184,127	72,762	3,242
1987	223,300	66,600	2,900	186,554	72,706	3,155
1988	226,600	68,900	2,900	188,222	72,661	3,079
1989	226,400	71,100	3,100	189,251	72,278	3,013
1990	224,300	73,400	3,200	189,456	71,833	2,961
1991	220,500	75,500	3,400	189,393	71,174	2,923
1992	209,500	74,500	3,500	187,522	67,776	2,888
1993	199,400	73,900	3,700	177,928	65,059	2,876
1994	194,100	75,100	3,900	168,975	64,190	2,886
1995	188,700	76,100	4,100	164,339	63,574	2,906
1996	184,700	76,600	4,300	159,389	63,278	2,932
1997	182,600	76,200	4,400	155,549	62,812	2,960
1998	180,200	74,300	4,400	152,196	61,559	2,988
1999	179,200	73,700	4,400	147,904	60,684	3,012
2000	181,600	70,700	4,500	144,763	59,612	3,032
2001	186,200	69,300	4,500	142,898	58,946	3,049
2002	195,800	68,100	4,500	142,716	58,321	3,070
2003	204,600	67,200	4,500	147,785	57,781	3,094
2004	211,100	66,400	4,600	151,086	57,174	3,131
2005	217,700	66,200	4,800	153,738	56,874	3,187
2006	223,500	66,800	5,000	157,353	56,939	3,268
2007	229,500	68,100	5,300	161,071	57,353	3,383
2008	231,500	70,100	5,700	167,239	58,116	3,532
2009	231,600	72,700	6,100	171,218	59,090	3,716
2010	231,300	76,000	6,700	173,726	60,361	3,931
2011	229,600	79,500	7,300	175,221	61,765	4,170
2012				174,950	63,279	4,422
2013				173,853	64,776	4,673
2014				182,727	66,147	0

Table 5.17. 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	64,776	64,776	64,776	64,776	64,776	64,776	64,776
2014	66,147	66,147	66,147	66,147	66,147	66,147	66,147
2015	62,310	62,310	67,211	66,072	67,357	61,313	62,310
2016	58,504	58,504	67,969	65,704	68,261	56,669	58,504
2017	54,743	54,743	68,388	65,027	68,825	52,221	53,859
2018	51,072	51,072	68,466	64,059	69,044	48,007	49,456
2019	47,566	47,566	68,245	62,861	68,958	44,093	45,365
2020	44,314	44,314	67,800	61,520	68,640	40,553	41,660
2021	41,396	41,396	67,231	60,142	68,189	37,451	38,407
2022	38,869	38,869	66,637	58,826	67,702	34,821	35,640
2023	36,750	36,750	66,098	57,645	67,261	32,658	33,355
2024	35,023	35,023	65,668	56,643	66,920	30,928	31,519
2025	33,644	33,644	65,367	55,827	66,701	29,573	30,070
2026	32,561	32,561	65,193	55,188	66,603	28,541	28,950

Table 5.18. 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	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	0.10	0.10	0.00	0.02	0.00	0.12	0.10
2015	0.10	0.10	0.00	0.02	0.00	0.12	0.10
2016	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2017	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2018	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2019	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2020	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2021	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2022	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2023	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2024	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2025	0.10	0.10	0.00	0.02	0.00	0.12	0.12
2026	0.10	0.10	0.00	0.02	0.00	0.12	0.12

Table 5.19 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	212	212	212	212	212	212	212
2014	13,289	13,289	382	3,382	-	15,915	13,289
2015	12,179	12,179	379	3,292	-	14,345	12,179
2016	11,168	11,168	375	3,200	-	12,948	13,374
2017	10,288	10,288	371	3,115	-	11,753	12,120
2018	9,547	9,547	367	3,040	-	10,762	11,076
2019	8,935	8,935	365	2,978	-	9,957	10,224
2020	8,437	8,437	363	2,926	-	9,312	9,537
2021	8,034	8,034	362	2,885	-	8,799	8,988
2022	7,709	7,709	362	2,851	-	8,392	8,551
2023	7,449	7,449	362	2,825	-	8,071	8,203
2024	7,240	7,240	363	2,804	-	7,816	7,928
2025	7,071	7,071	363	2,787	-	7,573	7,686
2026	6,934	6,934	364	2,773	-	7,311	7,427

FIGURES

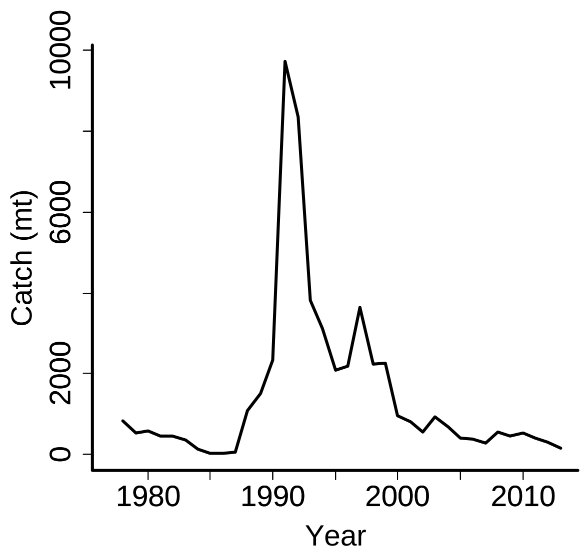


Figure 5.1. Catch biomass of Dover sole in metric tons 1978-2013 (as of October 19, 2013).

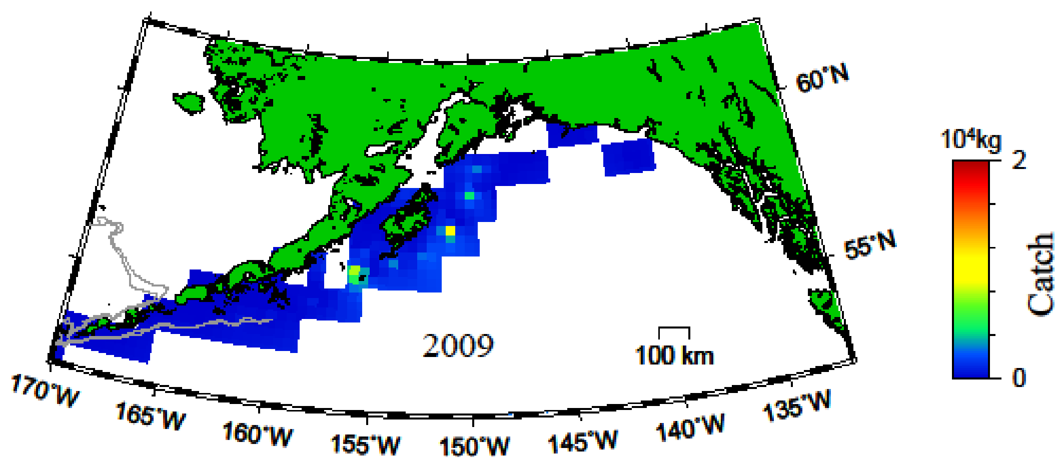


Figure 5.2. 2009 GOA Dover sole fishery CPUE.

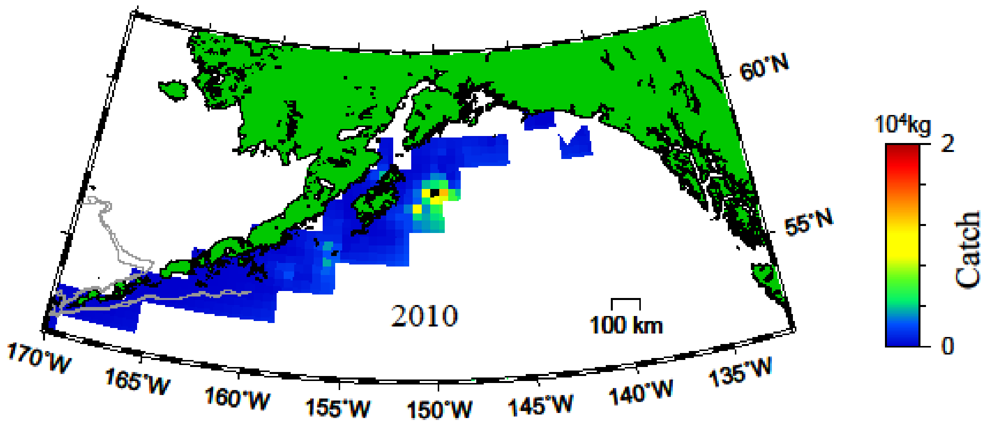


Figure 5.3. 2010 GOA Dover sole fishery CPUE.

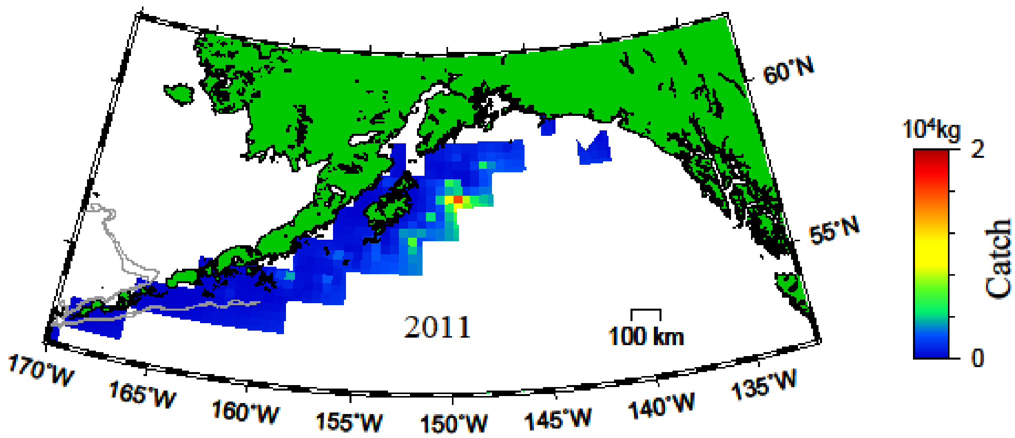


Figure 5.4. 2011 GOA Dover sole fishery CPUE.

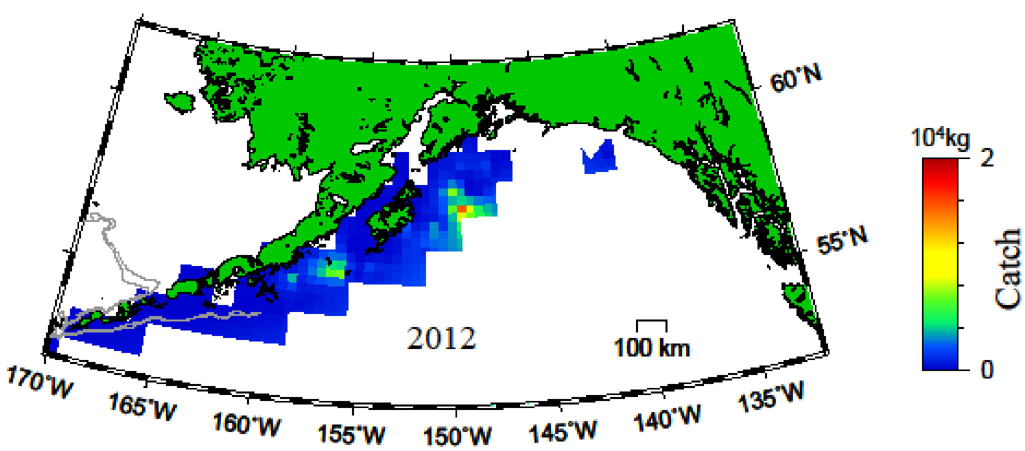


Figure 5.5. 2012 GOA Dover sole fishery CPUE.

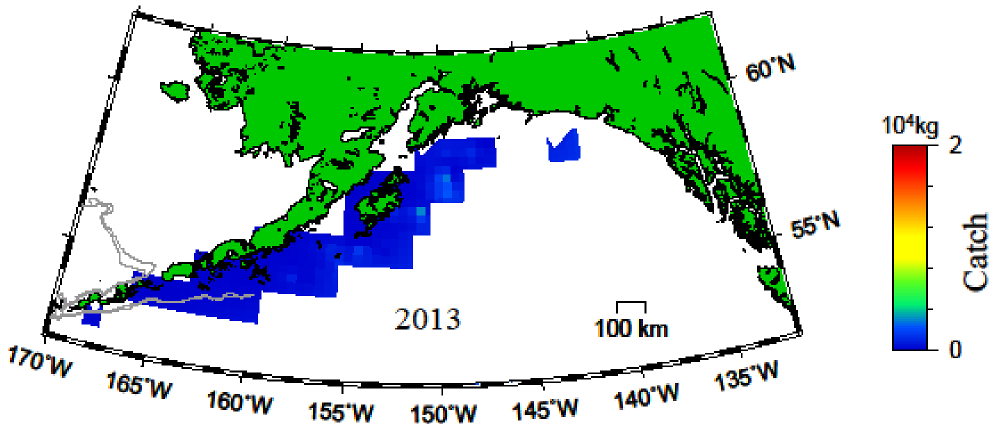


Figure 5.6. 2013 GOA Dover sole fishery CPUE.

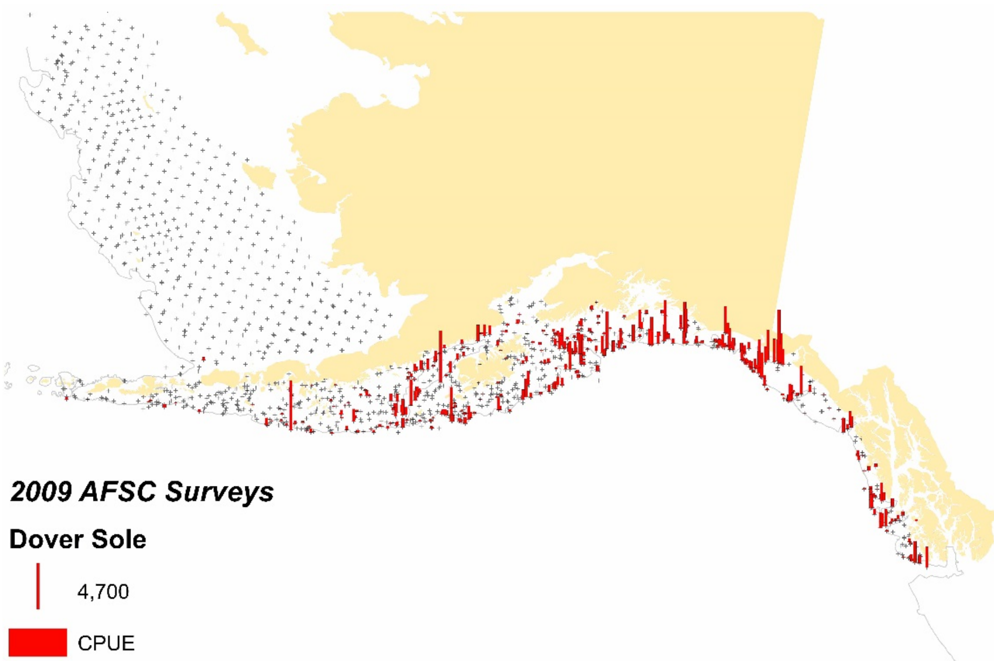


Figure 5.7. Survey CPUE for GOA Dover sole in 2009 from the AFSC bottom trawl survey.

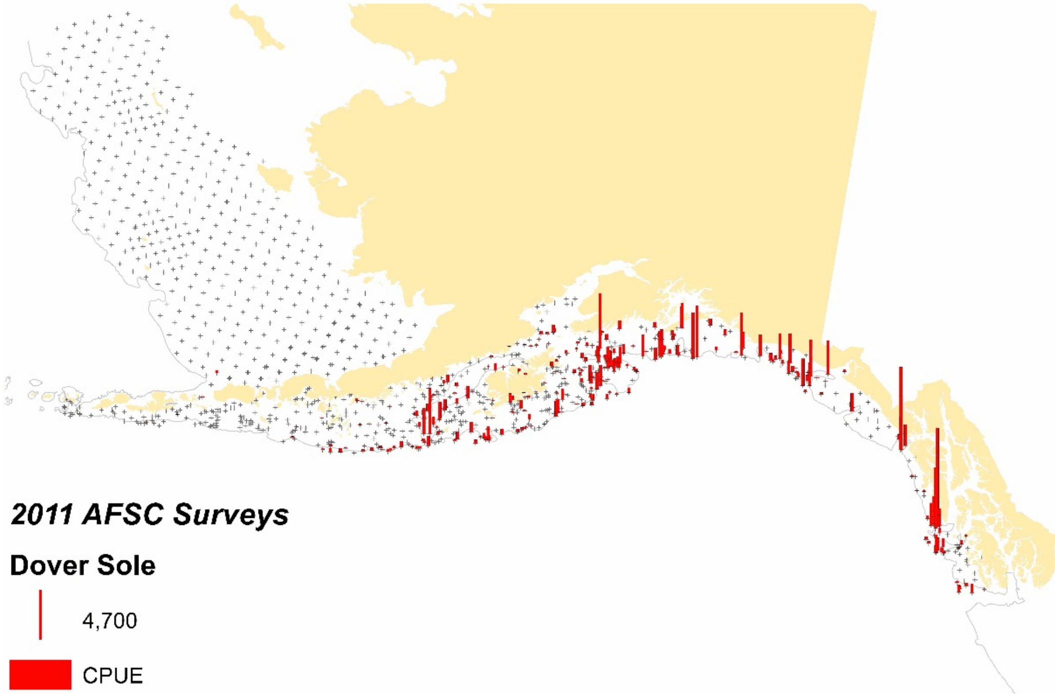


Figure 5.8. Survey CPUE for GOA Dover sole in 2011 from the AFSC bottom trawl survey.

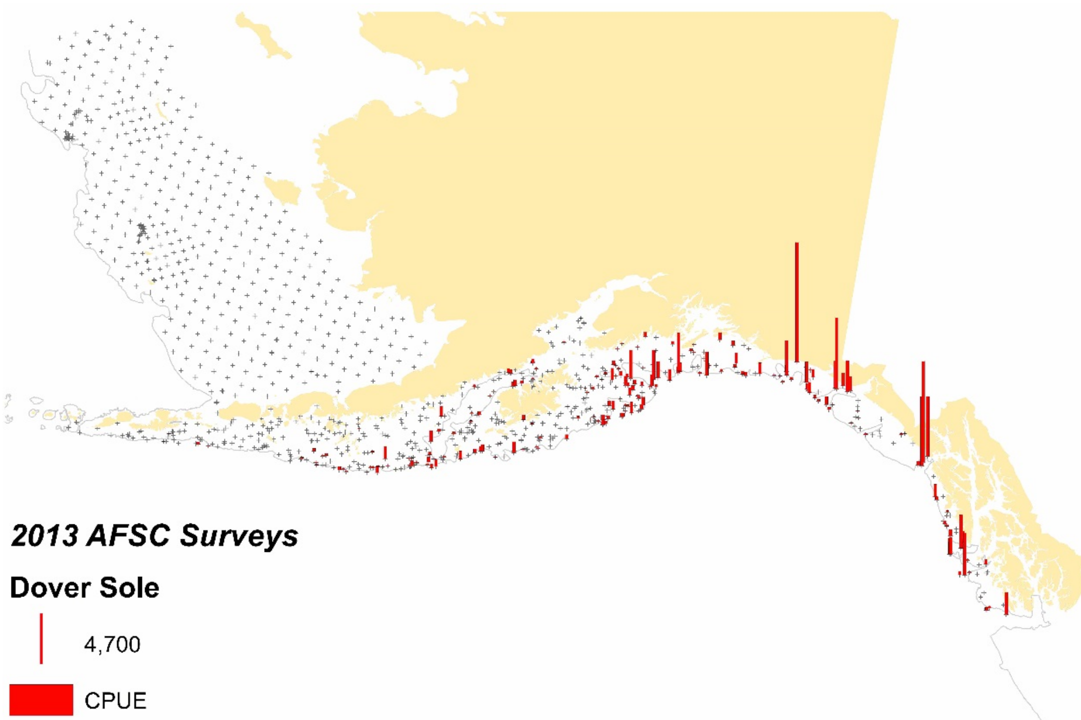


Figure 5.9. Survey CPUE for GOA Dover sole in 2013 from the AFSC bottom trawl survey.

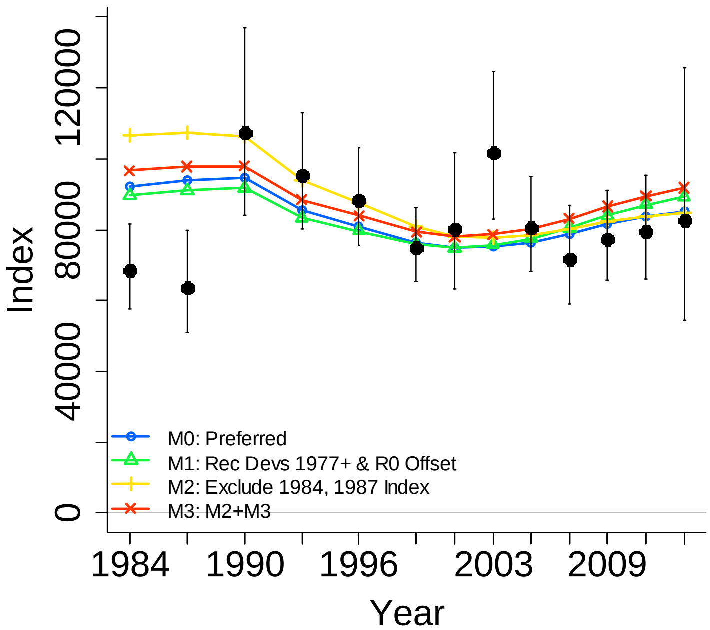


Figure 5.10. Survey biomass index (black dots), asymptotic 95% confidence intervals (vertical black lines), and estimated survey biomass for the author's preferred model (M0) and the three alternatives (solid lines).

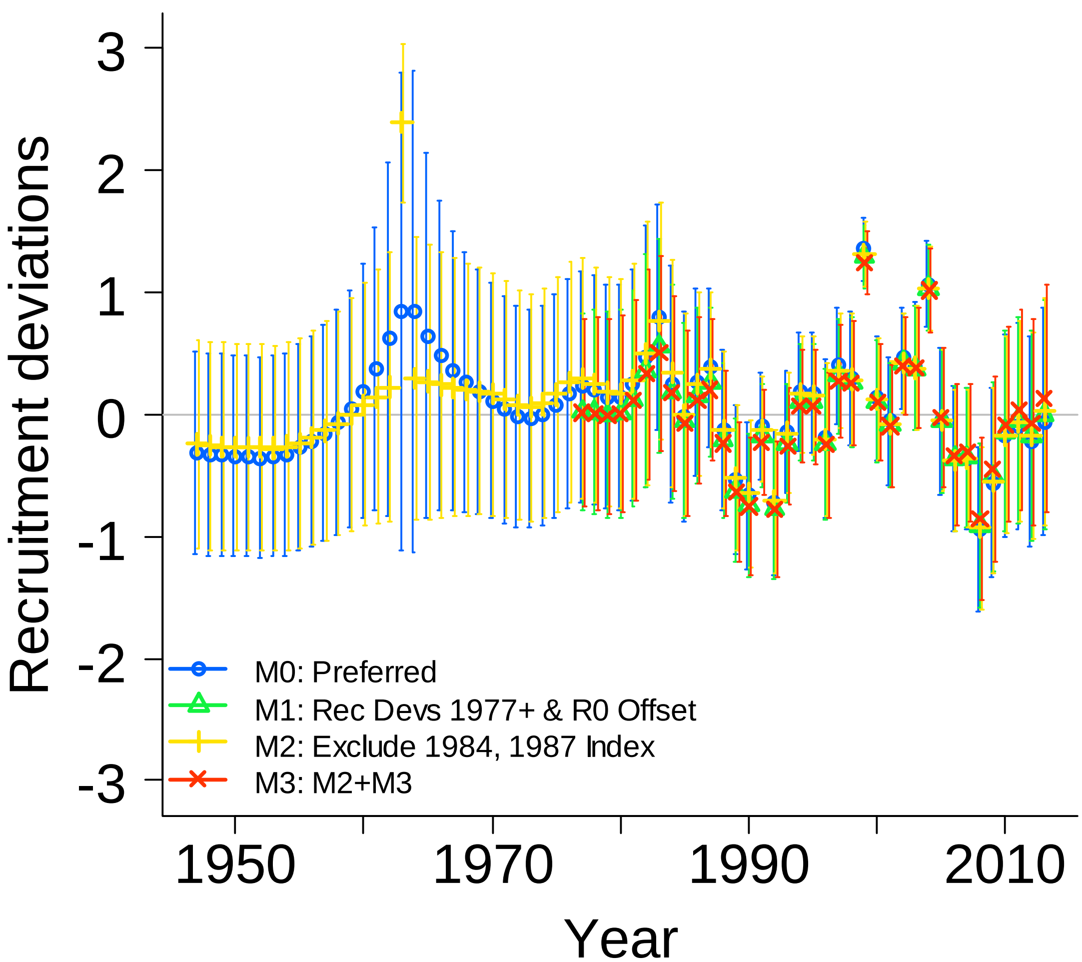


Figure 5.11. Recruitment deviations for years 1947-2012 and 95% asymptotic confidence intervals for the preferred model (M0) and the three alternative models.

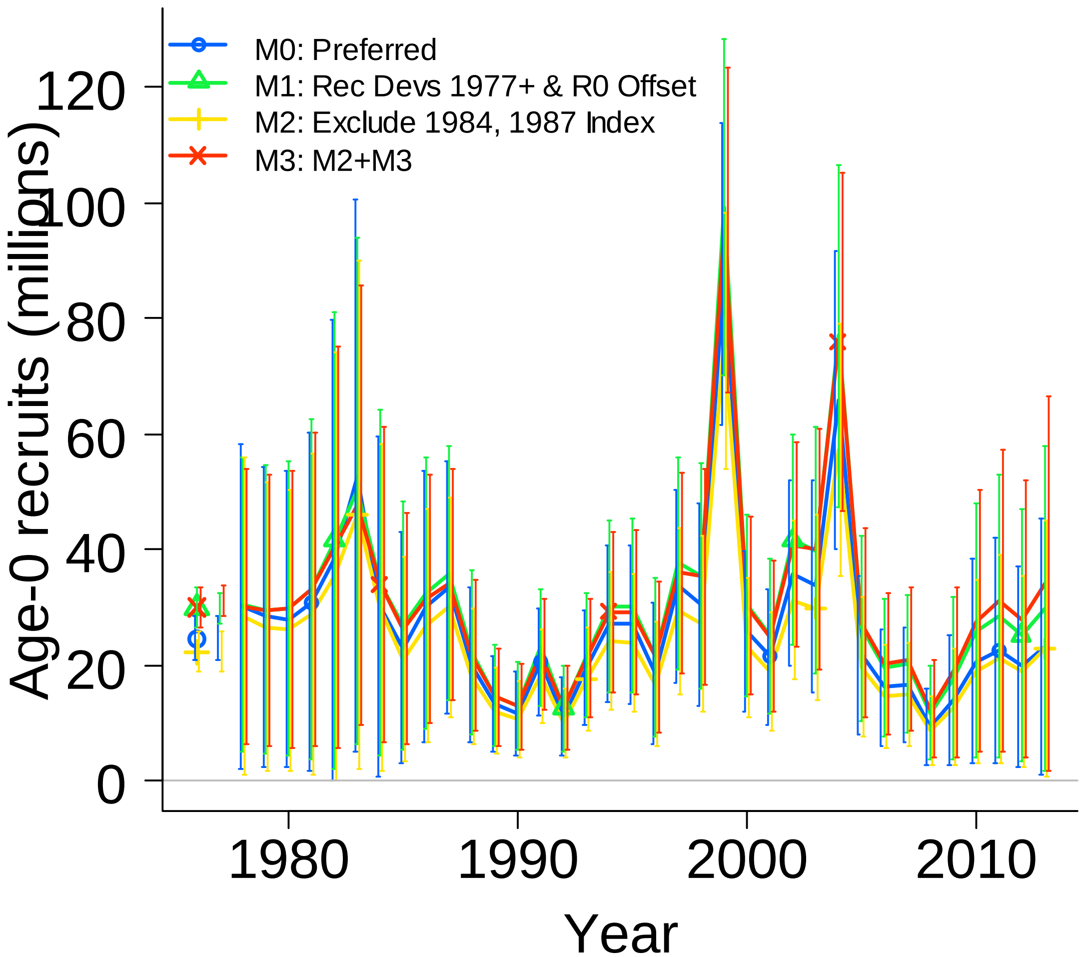


Figure 5.12. Time series of age 0 recruits and asymptotic 95% confidence intervals for the preferred model (blue line) and three alternative models.

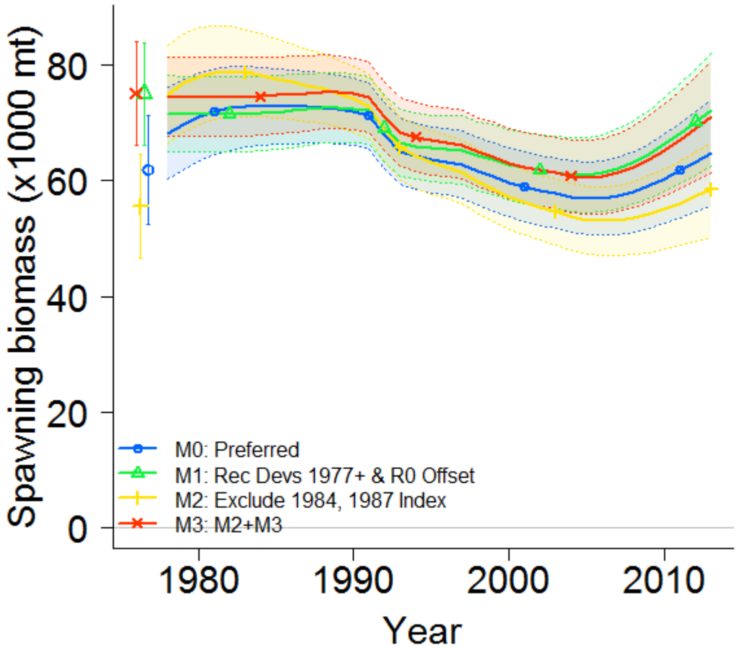


Figure 5.13. Time series of spawning biomass and 95% asymptotic confidence intervals for the preferred model (blue) and three alternative models.

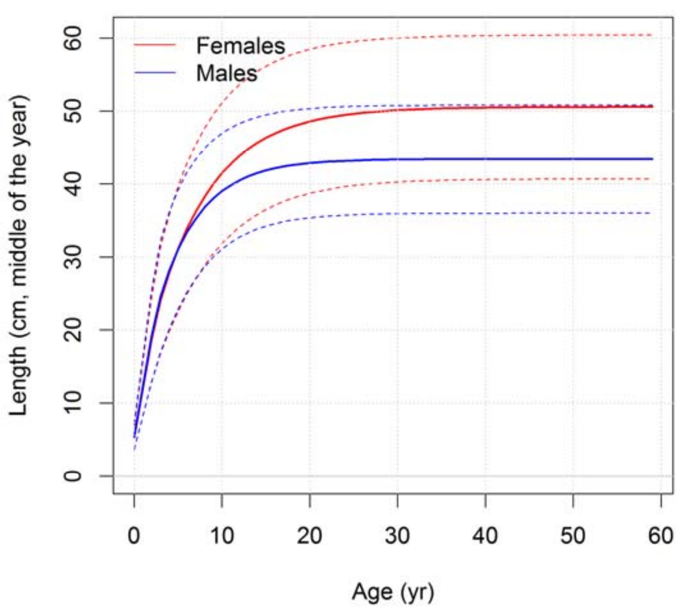


Figure 5.14. Estimated mean length-at-age (solid lines) and variability about the length at age curve (dashed lines) defined by the estimated CVs of length at age 2 and 59 for females (red) and males (blue) for Model 0.

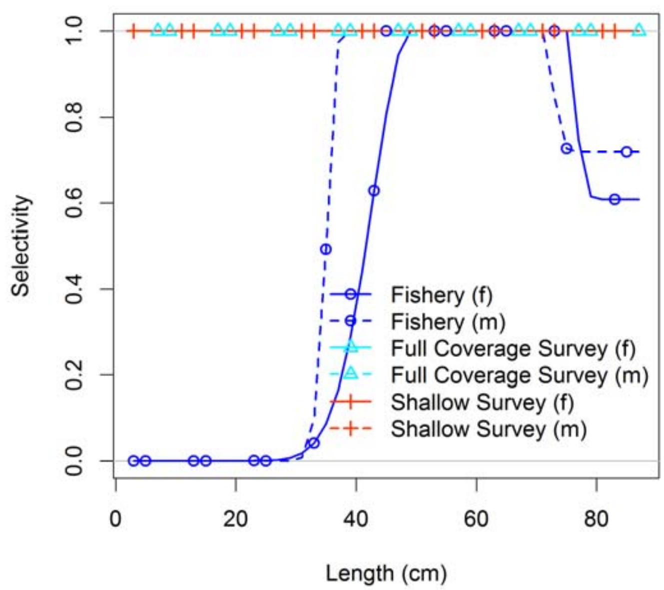


Figure 5.15. Sex-specific, length-based, dome-shaped fishery selectivity for the author's recommended model (Model 0) for females (solid line) and males (dashed lines).

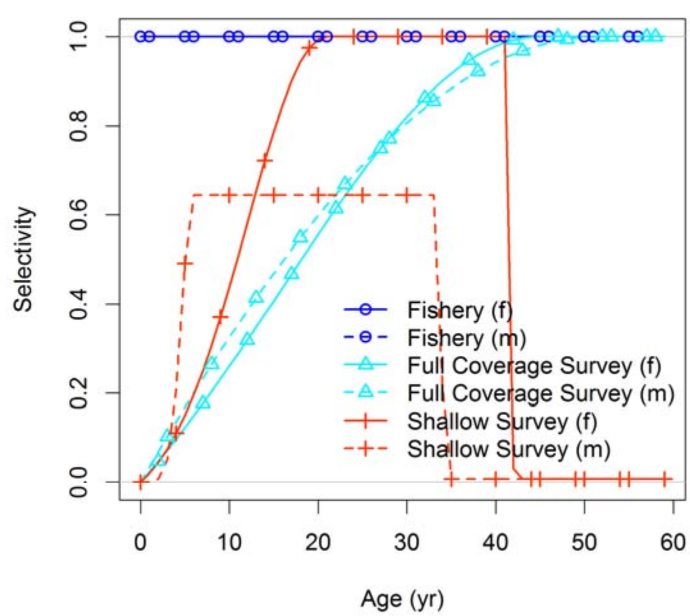


Figure 5.16. Selectivity for the full coverage survey (turquoise lines, triangles) and for the shallow-water survey (red lines, "+" symbols) for females (solid lines) and males (dashed lines) for the author's recommended model (Model 0).

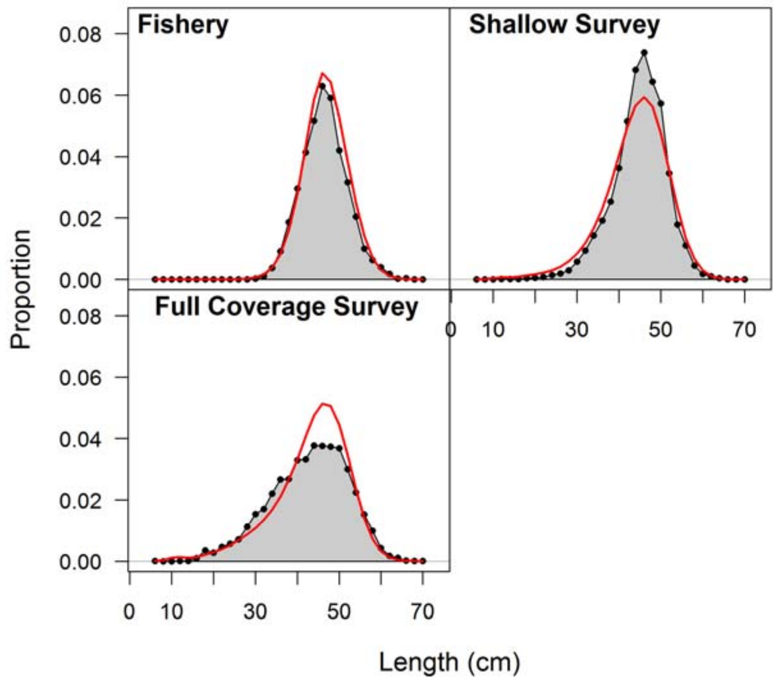


Figure 5.17. Female observed (black lines, dots, and shaded areas) and expected (red lines) proportions-at-length, aggregated over years for the fishery, the full coverage survey, and the shallow coverage survey for the author's recommended model (Model 0).

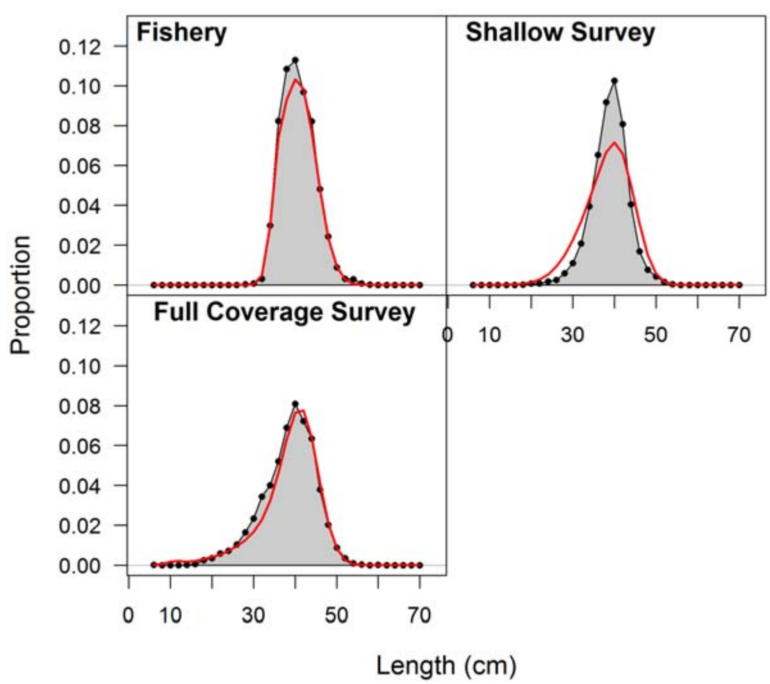


Figure 5.18. Male observed (black lines, dots, and shaded areas) and expected (red lines) proportions-at-length, aggregated over years for the fishery, the full coverage survey, and the shallow coverage survey for the author's recommended model (Model 0).

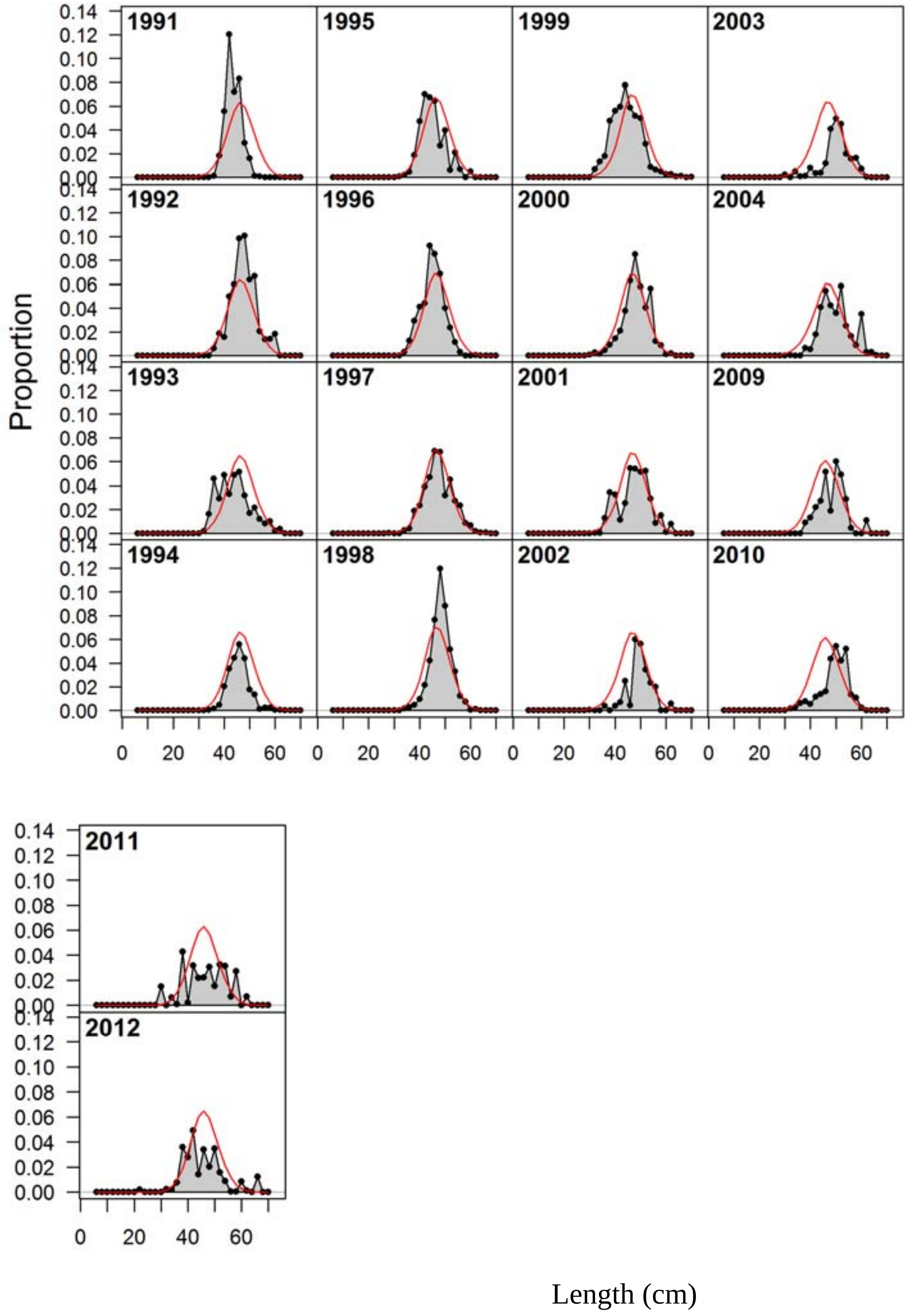


Figure 5.19. Female observed (black lines, dots, and shaded areas) and expected (red lines) yearly fishery proportions-at-length for the author's recommended model (Model 0).

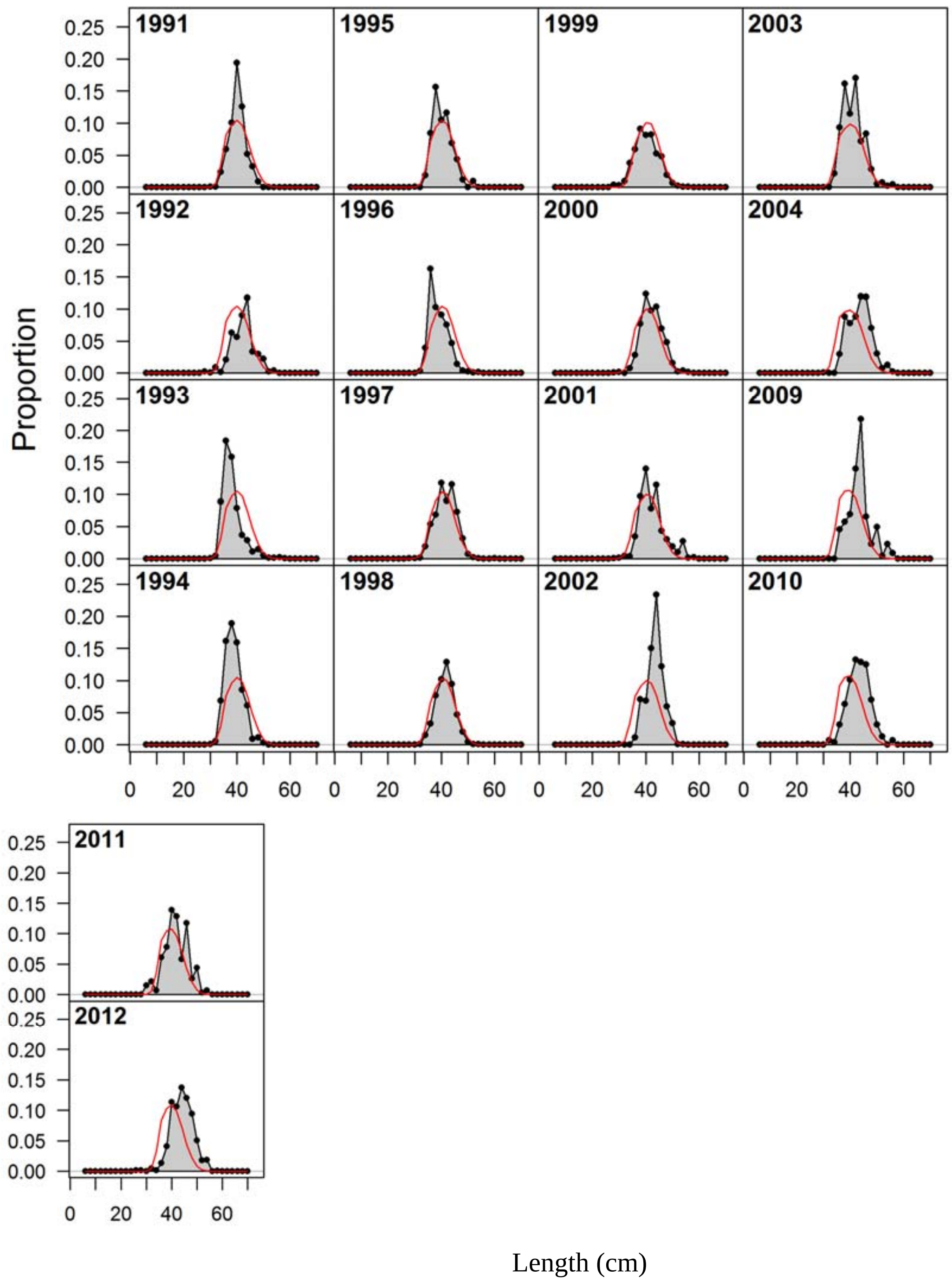


Figure 5.20. Male observed (black lines, dots, and shaded areas) and expected (red lines) yearly fishery proportions-at-length for each year of data included in the objective function for the author's recommended model (Model 0).

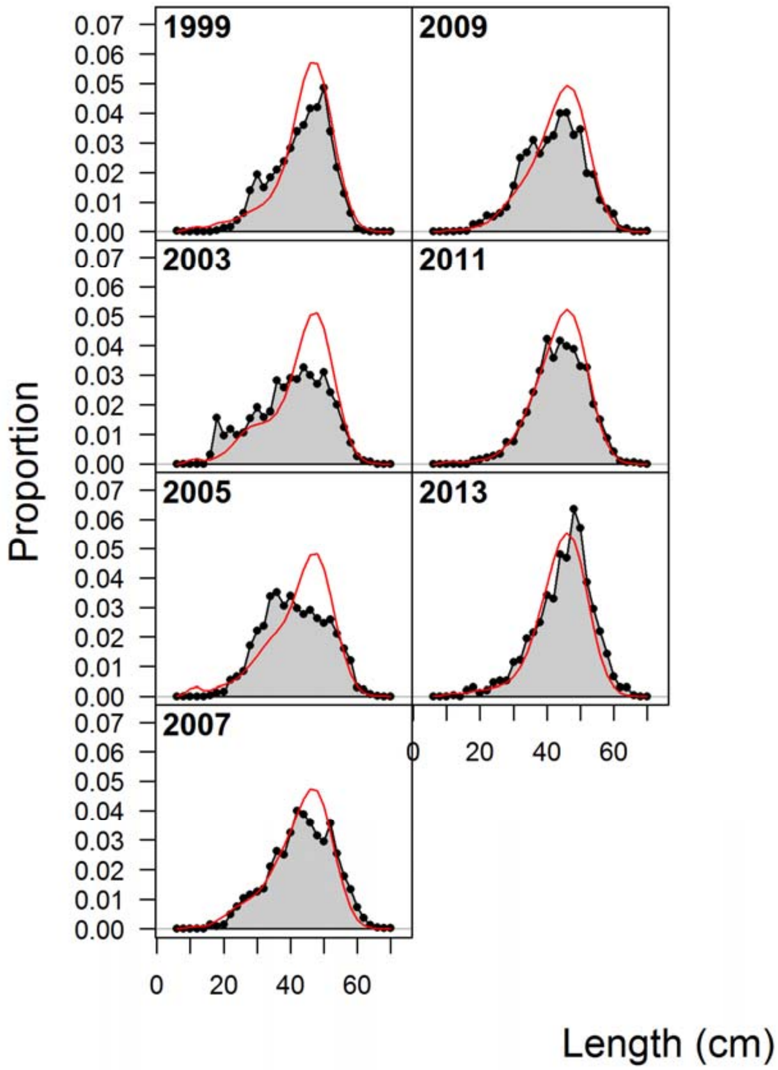


Figure 5.21. Female observed (black lines, dots, and shaded areas) and expected (red lines) yearly "full coverage survey" proportions-at-length for the author's recommended model (Model 0).

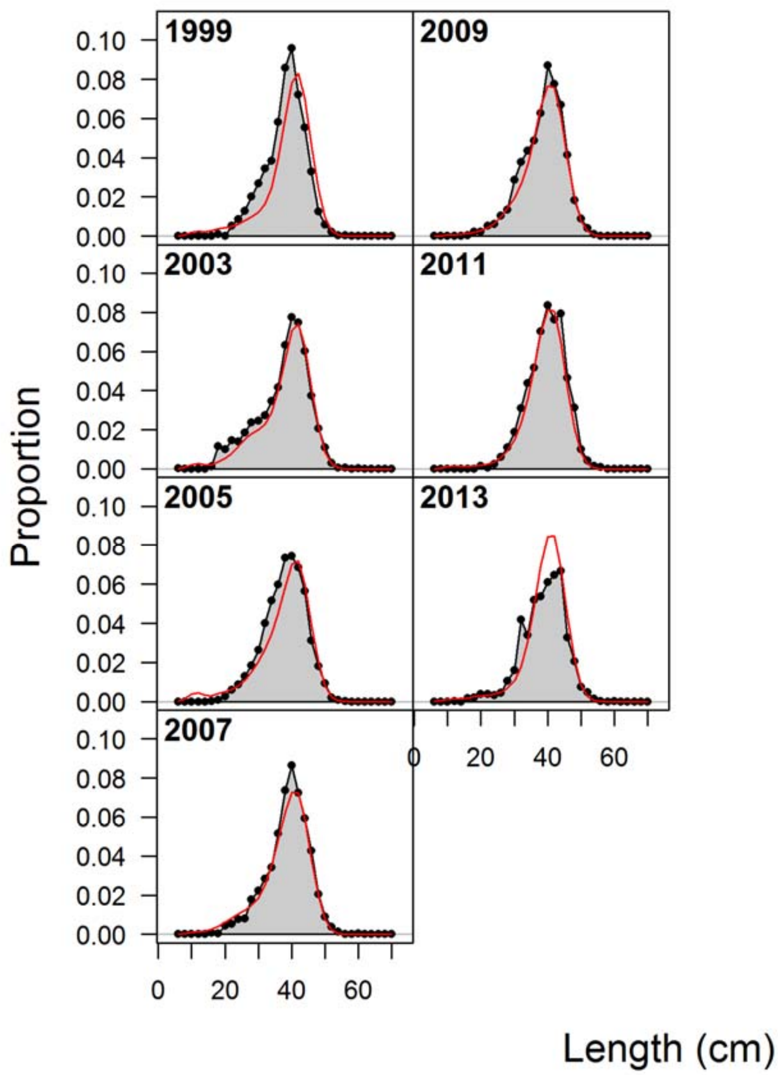
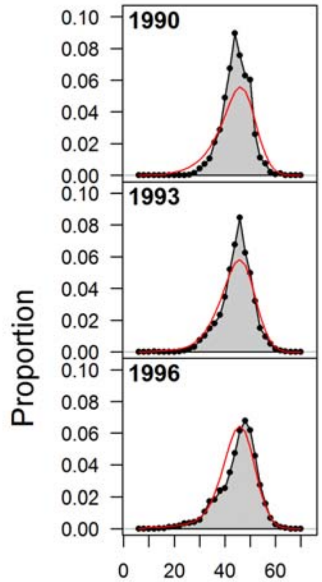
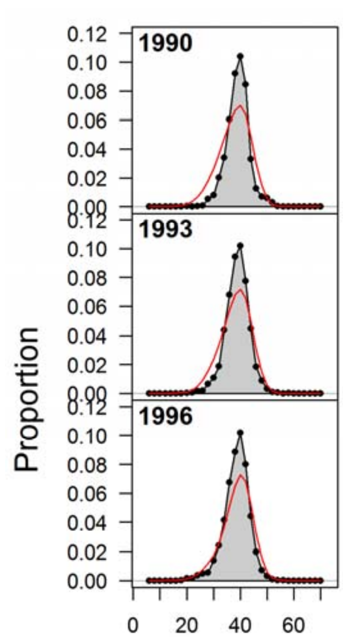


Figure 5.22. Male observed (black lines, dots, and shaded areas) and expected (red lines) yearly "full coverage survey" proportions-at-length for the author's recommended model (Model 0).





Length (cm)

Figure 5.23. Female (top panel) and male (bottom panel) observed (black lines, dots, and shaded areas) and expected (red lines) yearly "shallow coverage survey" proportions-at-length for the author's recommended model (Model 0).

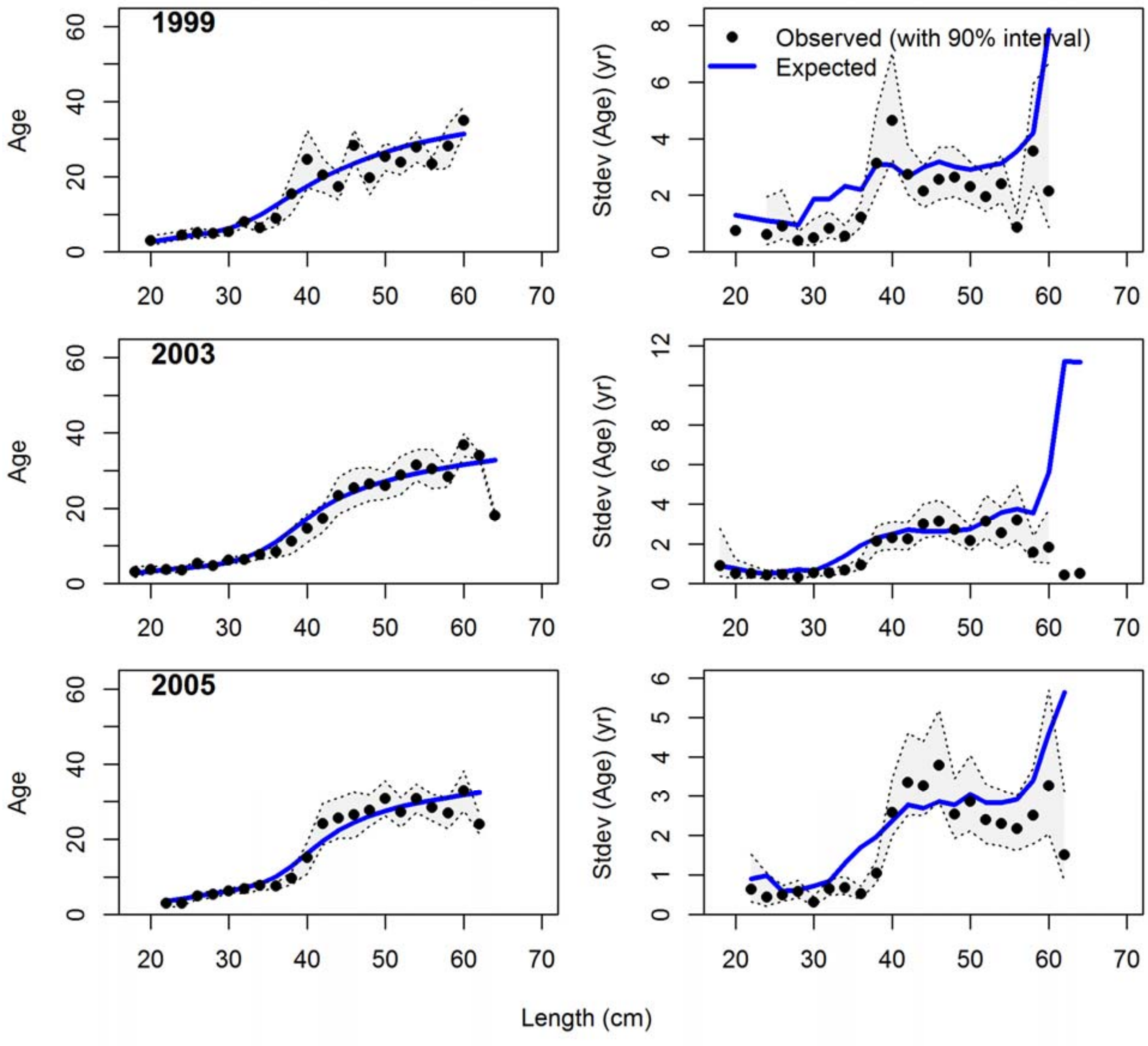


Figure 5.24. Observed and expected female mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the full coverage survey (1 of 2).

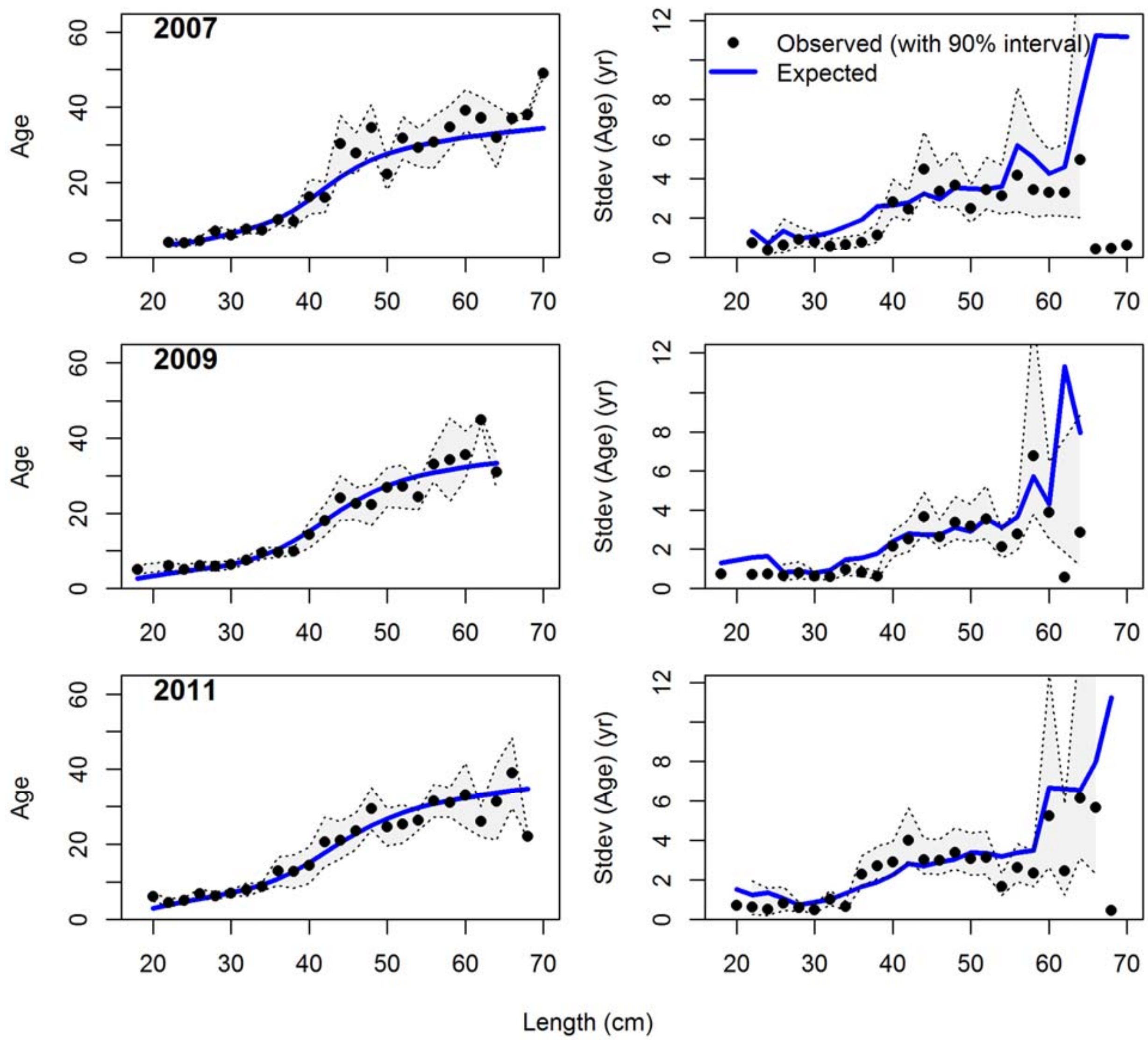


Figure 5.25. Observed and expected female mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the full coverage survey (2 of 2).

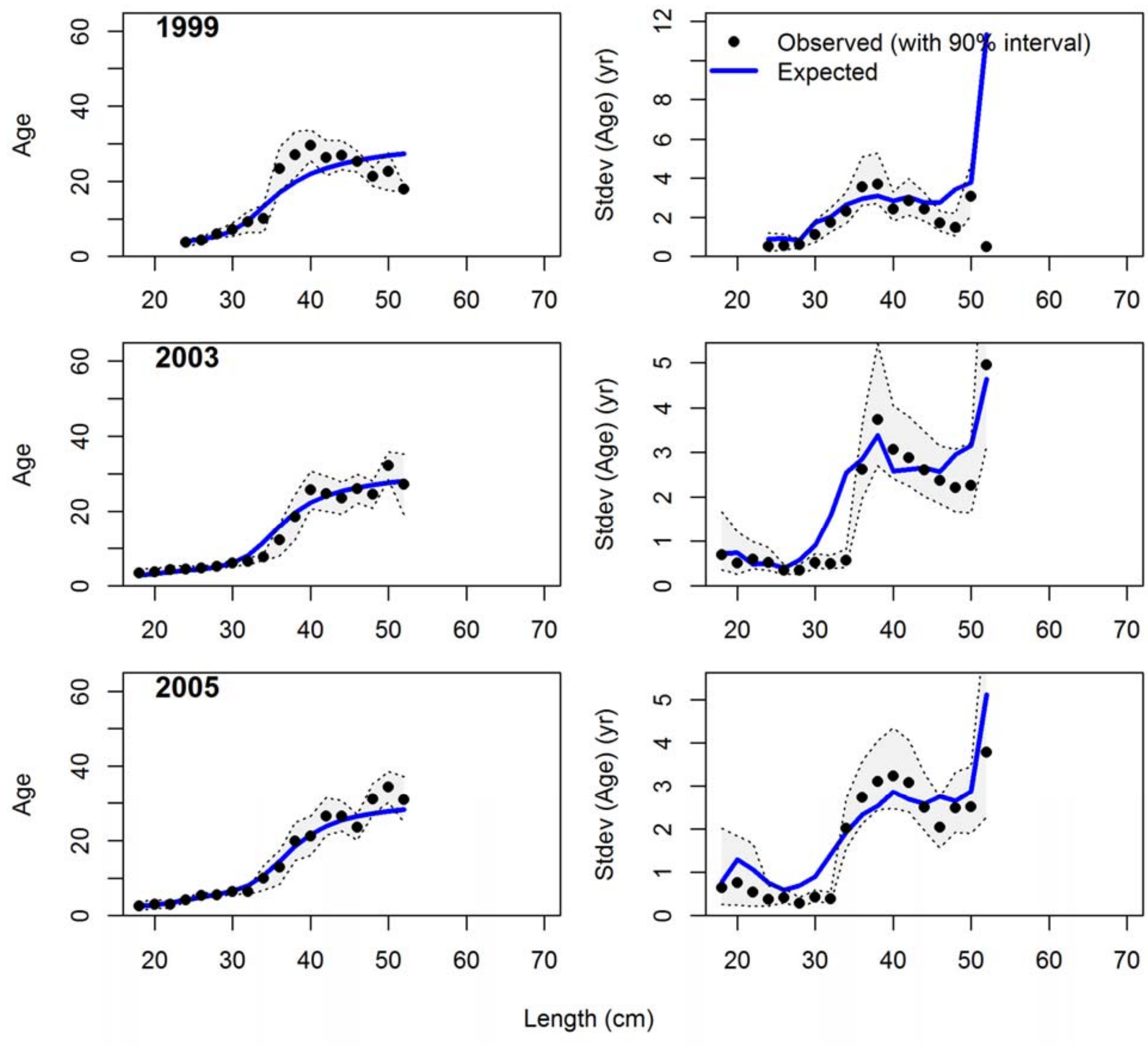


Figure 5.26. Observed and expected male mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the full coverage survey (1 of 2).

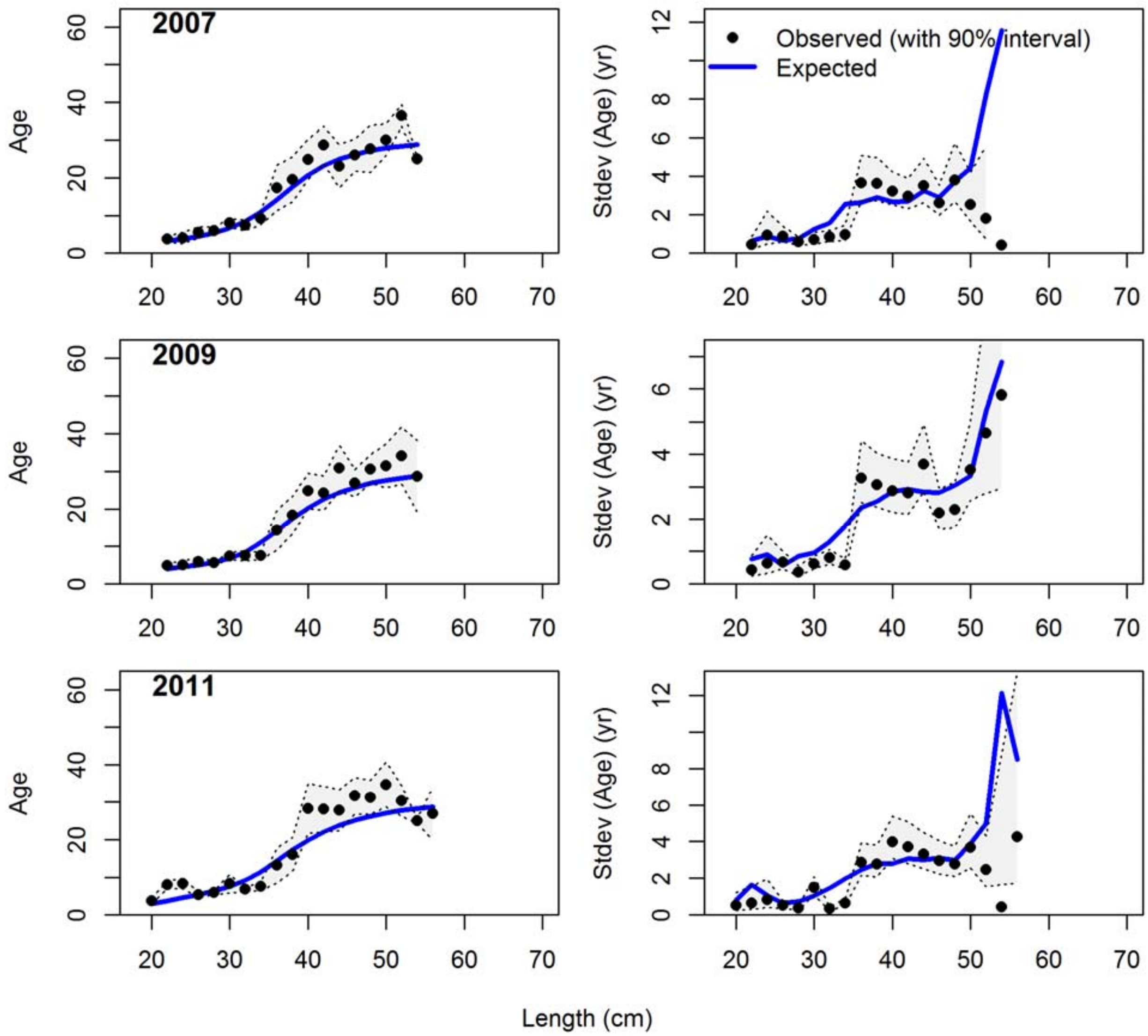


Figure 5.27. Observed and expected male mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the full coverage survey (2 of 2).

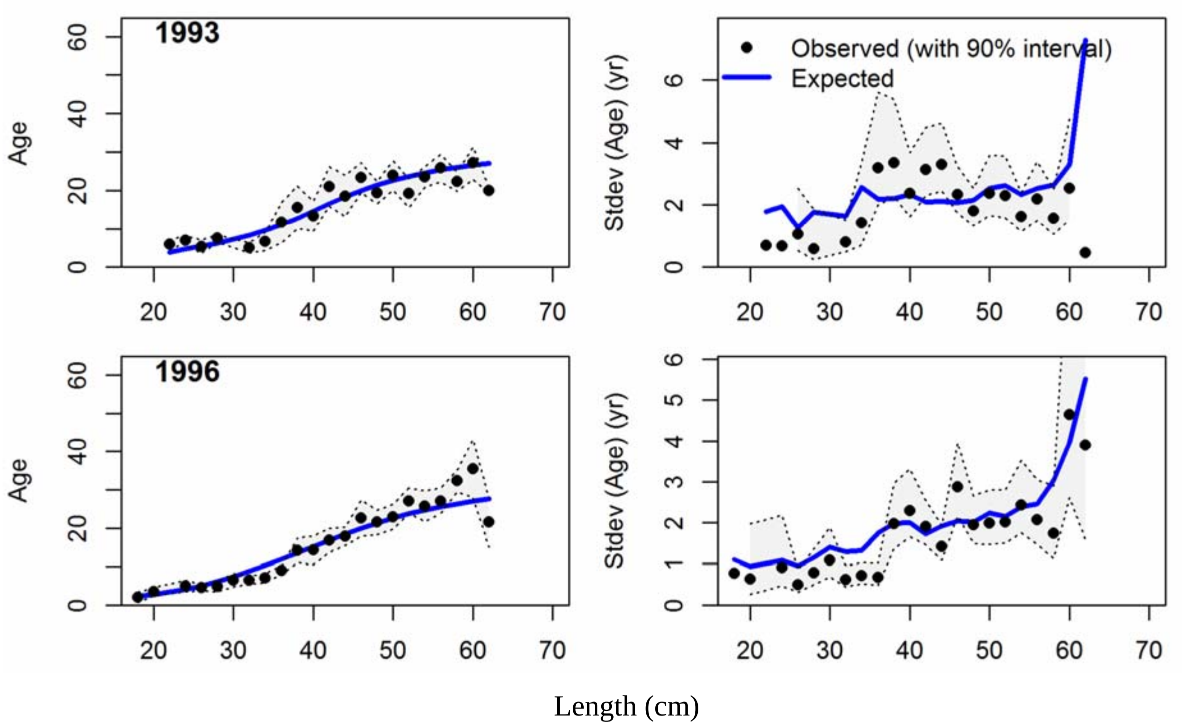


Figure 5.28. Observed and expected female mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the shallow coverage survey.

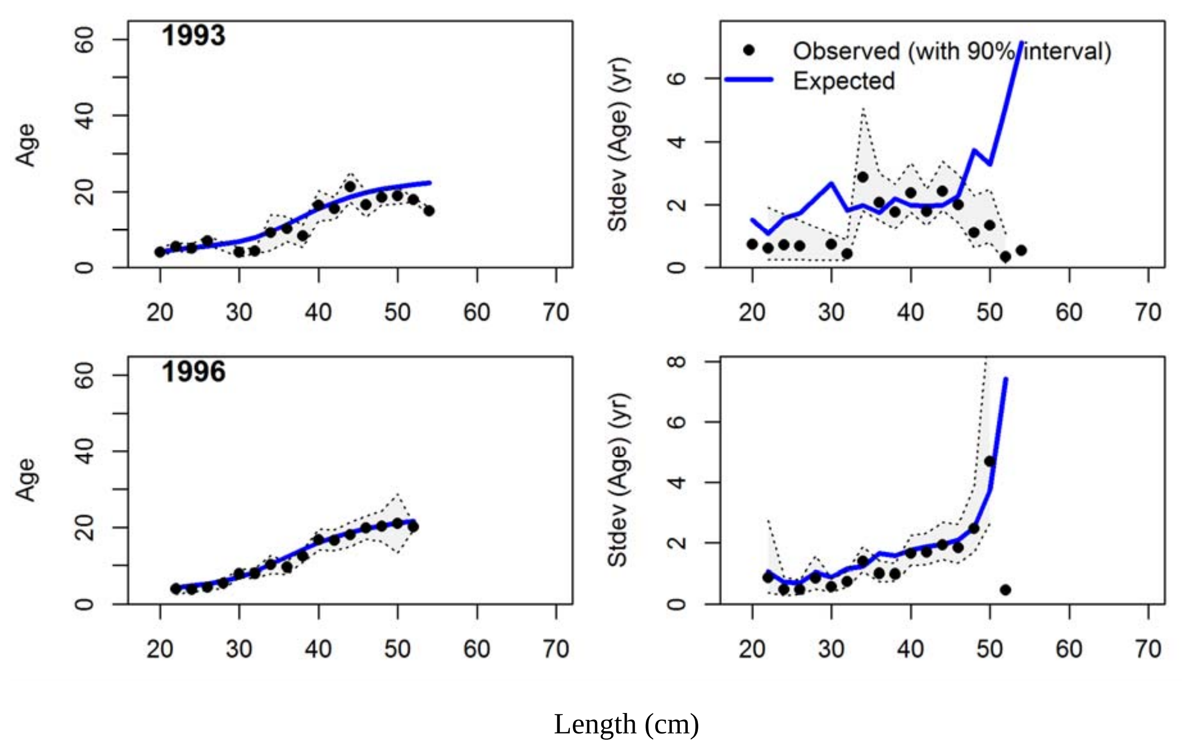


Figure 5.29. Observed and expected male mean age-at-length with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the shallow coverage survey.

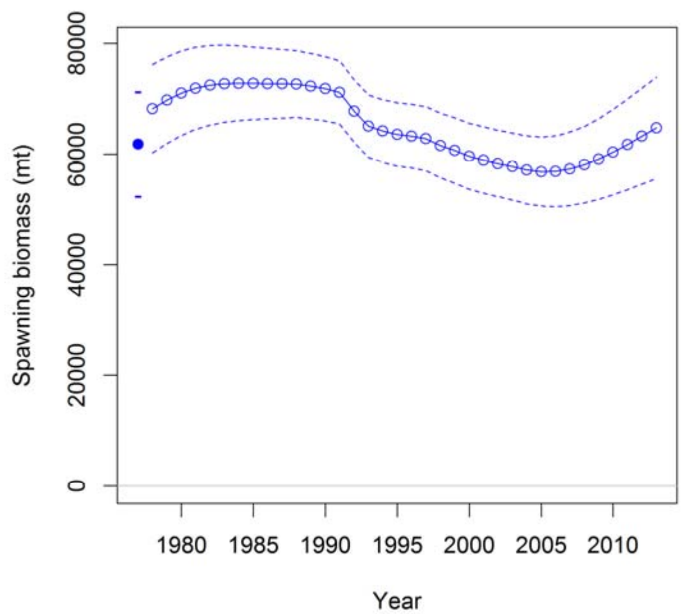


Figure 5.30. Time series of estimated spawning stock biomass (mt) over time (solid blue line and circles) and asymptotic 95% confidence intervals (blue dashed lines) for the author's recommended model (Model 0).

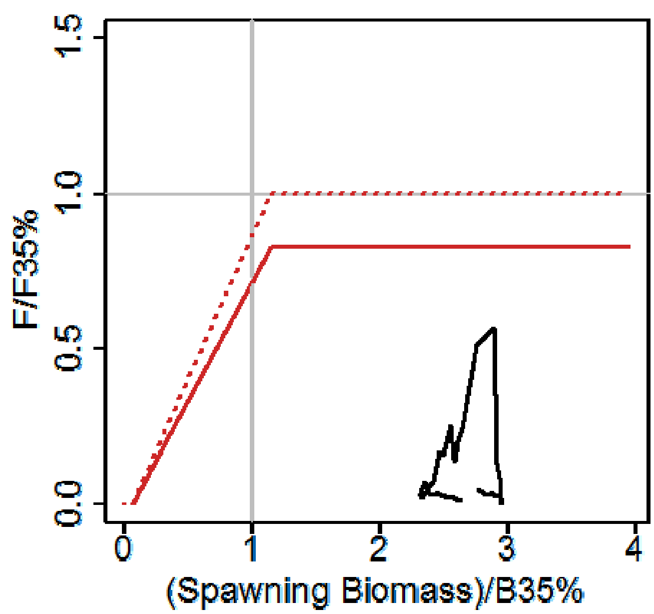


Figure 5.31. Spawning stock biomass relative to $B_{35\%}$ and fishing mortality (F) relative to $F_{35\%}$ from 1978-2012 (solid black line), the OFL control rule (dotted red line), the maxABC control rule (solid red line), $B_{35\%}$ (vertical grey line), and $F_{35\%}$ (horizontal grey line).

Attachment 5A: An Exploration of Alternative Gulf of Alaska Dover Sole Assessment Models

By Carey McGilliard

INTRODUCTION

The purpose of this document is to outline a proposed change from conducting assessments using the previously used Dover 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 3-40 (age 40 was a plus group) and excluded data for fish below age 3 and 18cm in length.

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

SSC AND PLAN TEAM COMMENTS ON PREVIOUS ASSESSMENTS

In 2011, Gulf of Alaska (GOA) Dover sole was managed as a Tier 5 species on the recommendation of the assessment authors due to decreased confidence in the 2011 and 2009 age-structured assessment models. MCMC analysis conducted in 2011 showed that the likelihood for the accepted 2009 model was a local maximum (Stockhausen et al. 2011).

Previous assessment authors suggested that growth rates, natural mortality rates, and age and size classes used in the model be re-evaluated. In addition, authors suggest that alternative selectivity functions be explored and that ageing error and internal estimation of growth be considered.

Two currently unfulfilled SSC requests exist:

1. SSC comment: "*Because adjacent age-classes are likely to overlap in size and spatial distribution, the fishery selectivity curves estimated by the model seem implausibly steep, possibly indicating mis-specification of the age-length conversion matrices. The SSC requests that the growth model and age-length conversion matrices be re-evaluated in the next assessment.*"
2. 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 Dover sole assessments was unable to address these concerns, but these can be readily explored using SS3. Relative to the 2011 model, SS3 offers the following features:

(1) The 2011 assessment found that the 2009 assessment had reached a "local minimum" for the objective function. 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.

(2) A request concerning the previous Dover 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 Dover 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 selectivity for Dover sole, which may be a more accurate reflection of the selection process than the knife-edge, age-based fishery selectivity estimated in previous assessments.

(5) SS3 allows for specification of ageing error. Ageing error is ignored in the current model, but Dover sole are known to be one of the harder species to age (Abookire and Macewicz 2003).

(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 timing of fishing.

(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 is used by many scientists worldwide, which provides an ad-hoc quality control system for identifying bugs in the code.

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 R_0 (unfished recruitment $(\ln(R_0))$ that is estimated in SS3 was determined (Equation 1), where M is natural mortality.

(1) $$\ln(R_0) = \ln\left(\frac{2\bar{R}}{1000}\right) + 3M$$

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 with fixed parameters at their maximum likelihood estimates (MLEs) from the 2011 model. This was to ensure that both models had the same behavior in the absence of estimation. Equation 1 was required to ensure 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 with no descending limbs were used for fishery and survey selectivity curves. The fishery selectivity curves in SS3 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 and are a near-exact match (but were logistic for the 2011 model and double-normal for the SS3 model; Figure 1). Deterministic runs conducted for Dover sole using the fishery selectivity curves in Figure 1 led to the same time series of SSB for both models (Figure 2), indicating that the population dynamics of the models are the same. Figure 4 shows an example of double-normal selectivity curves that match the shape of the logistic curves from the 2011 model to some degree. The slight mis-specification of selectivity curves in SS3 results in small differences in population dynamics between the 2011 and SS3 models that are evident in the estimates of SSB over time (Figure 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 0.49. 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 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 Dover 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 2 and Figure 3).

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 Dover sole assessment model (Stockhausen et al. 2011, page 758) 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 18cm were included in the lowest (18-20cm) length bin.

In 1990, 1993, 1996, and 2001, surveys covered a more restricted depth range than in other years. This was handled in the 2011 model by inflating survey biomass estimates by year-specific availability factors in years when only shallower water was surveyed and estimating a separate survey selectivity curve for those years. Likewise, in SS3, separate a separate selectivity curve was specified for the years when only shallower waters were covered and the same availability factors were used. This was accomplished by defining a second survey for those years.

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, full coverage survey years, and shallow water survey years 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 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 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 18cm. 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 13-Figure 15). 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. Both models allow for estimating early-period (1947-1983), main-period (1984-2008), and late-period (2008-2011) recruitment deviations as separate likelihood components, but the 2011 model also includes the early period recruitment deviations in the likelihood component for the main-period (Table 2). There is no way to include early period recruits in both an early-period and main-period likelihood component in SS3. In the 2011 model, the recruitment deviations for the main and late time periods must sum to 0. The purpose of defining recruitment periods is that the recruitment deviations from one time period cannot influence the recruitment deviations from another time period by way of forcing the deviations to sum to 0. In SS3, only the main-period recruitment deviations have a formal sum-to-0 constraint, but it is expected that the early- and late-period recruits will come close to summing to 0. The likelihood components for early recruits have a weighting of 2x the value of that likelihood component and the late-period recruits have a weighting of 3x the value of the early-period likelihood component in the 2011 model, while both have a weighting of 1 in SS3. SS3 does not allow the user to adjust the weighting of the likelihood components for early-period recruitment deviations. Runs of the 2011 model with re-weighting of the early- and late-period recruitment likelihood components to 1 show that the likelihood weightings do not make a noticeable difference in estimation and model fits. The inclusion of early-period recruitment deviations as a separate likelihood component as well as part of the main-period recruitment deviations likely contributes to differences in initial numbers of recruits and SSB. Differences between models are smallest when including early-period recruits as a separate likelihood component and not in the main-period likelihood component in SS3, rather than vice versa. In addition, including early-period recruits as a separate likelihood component prevents the early-period recruitment deviations from influencing the values of main-period recruitment deviations; this is sensible because any fishing prior to 1984 is taken into account using early-period recruitment deviations (as the models assume that no fishing occurred prior to 1984) and thus tend to be negative and fewer data exist to inform early-period recruitment deviations.

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 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. Fishing 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 with no 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: Internal specification of growth parameters. The transitional SS3 model used empirical estimates of age-specific maturity and body weight. This model also was configured to have the same values to use at both the beginning *and* middle of the year. Internally specifying growth parameters allows the model to account for fish growth throughout the year by calculating weight-at-age in the middle of the year, which is used to calculate exploitable biomass.

M4: A combination of M1, M2, and M3, where growth parameters are specified internally, an initial equilibrium fishing mortality rate is calculated, and fishery selectivity is a logistic, sex-specific, length-based function.

M5: As for M4, but with length-based, logistic, sex-specific selectivity for the two surveys (as well as for the fishery).

Further proposed alternative models

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

- Adding mean weight-at-age data to the assessment and estimating growth parameters internally, given that there is a mismatch between the Abookire & Macewicz (2003) growth relationships and those used in the assessment model. Estimating growth in addition to parameters that are currently estimated in the transitional SS3 model without the addition of mean weight-at-age data resulted in poor fits to the data.
- Estimating growth parameters and the age-length transition matrix outside of the model, given the mismatch between the Abookire & Macewicz (2003) maturity ogive and von Bertlanffy growth curve and those used in the assessment model. Fitting the transitional SS3 model to the data using the Abookire & Macewicz (2003) growth relationships (including their weight-length relationship, which is already used in the transitional SS3 model) resulted in very a poor fit to the data.

- 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 such high effective sample sizes may exclude some process errors which should be considered.
- Exploring alternative methods for handling years where the survey sampled only shallow water. The current method assumes that if more area were surveyed, the same biomass of fish per area would have been caught and the same proportions of ages and lengths would have been sampled. However, Dover sole moves ontogenetically and spatial dynamics are sex-specific. The shallow-water survey years are handled as a separate survey in SS3. Alternative models could explore estimating catchability or allowing for the estimation of dome-shaped selectivity for the shallow-water survey instead of adjusting survey biomass data points by an availability factor.

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 starting in the late 1990s (Figure 7). Numbers at age 3 in the last few 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 in the most recent years were similar in the two models, but the SS3 model resulted in larger estimates for SSB than those estimated by the 2011 model in most years (Figure 8). The fishery selectivity curves were nearly identical and thus cannot explain the differences in the trajectories of SSB (Figure 9). SS3 selectivity estimates resulted in lower proportions of older fish available to the survey compared to the 2011 model (Figure 10 & Figure 11). This may partially explain why SSB estimates in most years were higher for the SS3 results. Figure 12 shows observed and predicted survey biomass for the 2011 and SS3 models. The negative log likelihood for the survey biomass obtained with SS3 (-9.77) was substantially lower than that from the 2011 model (9.15), indicating that the SS3 model fit those data much better. This was apparent for the surveys conducted from 2006 to 2010 and from 1991 to 1995. In general, fits to age- and length-composition data are similar for both models (Figure 13-Figure 15), with some differences in predicted proportions-at-age for age 35-40+ fish (Figure 13) which resulted from differences in binning the age data. The 2011 model binned ages 35-39, while the data input to SS3 had separate age bins for each age up to age 40+; therefore, the age-composition data and expected values from the 2011 model look very large in Figure 13 for ages 35-40, as these are data points for two lumped age groups (35-39 and 40+), while the predicted age compositions for older ages from the SS3 model look small until age 40+ because an expected proportion (and a data point) exists for each older age that is younger than the plus group.

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 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-normalized the selectivity curves such that the largest selectivity occurs at 1. The asymptotic double-normal can approximate the logistic curve, but varied slightly. Numbers at age 3, SSB, and model fits for the SS3 model were similar to the 2011 model when fixing selectivity in the SS3 model to approximate the selectivity curves estimated in the 2011 model (Figure 16-Figure 21). However, SS3 selectivity estimates affected the fit to the data (Figure 9 & Figure 10) and the negative log likelihood for SS3's best model was –lnL = 1,282, while the negative log likelihood for the SS3 model with selectivity fixed to the curves most like those estimated in the 2011 model was –lnL = 2,670. 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. SS3 runs conducted with a restriction that peak selectivity must equal 1 (and be asymptotic) estimated survey selectivity curves with selection occurring at smaller ages (e.g. Figure 22), leading to a poor fit to the survey data (Figure 23) and with a –lnL = 2586.

(2) The configuration of the likelihood components for early-period and main-period recruitment deviations differs between models. 2011 and SS3 model runs without recruitment deviations (recruitment deviations and weights for the recruitment likelihood components are set to 0) show that differences still exist between the models (Figure 24-Figure 28).

(3) 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, separate age bins for ages 35-39 (rather than one lumped age bin), and length-compositions for lengths 0-17cm.

RESULTS: PROPOSED ALTERNATIVE SS3 MODELS

Table 3 shows the negative log likelihood components for each of the proposed alternative models (M1-M5) and the transitional SS3 model (M0). Figure 29- Figure 31 show a comparison of recruitment, recruitment deviations, and SSB for the proposed alternative models. All alternative models (M1-M5) had lower negative log likelihoods than the transitional SS3 model (M0). All models exhibited the same general trends over time in SSB and recruitment, but differences occurred in absolute numbers of recruits and SSB (Figure 29-Figure 31) with model M5 estimating the highest SSB and number of recruits and M3 the lowest SSB. Model M5, which estimates length-based, logistic, sex-specific selectivity, led to the lowest total negative log likelihood of any of the models, including the transitional SS3 model (Table 3). Model M5 did not fit the survey biomass index as well as the other models (Figure 43), but fit the age- and length composition data better (Table 3, Figure 44-Figure 48).

The selectivity curves for each model are shown in Figure 32-Figure 36. The length-based fishery selectivity curves that were estimated in models M1 and M4-M5 are similar to one another in each alternative model (Figure 32, Figure 35-Figure 36).

Models M4 and M5 led to the best total negative log likelihood values of the proposed models (-lnL = 1212.75 and 1183.51, respectively). Diagnostic plots for model M4 are shown in Figure 37-Figure 42 and the same plots are shown for model M5 in Figure 43-Figure 48. Model M4 was the best fit to the survey biomass index (-lnL = -12.38; Table 3; Figure 37), but did not fit the age- and length-composition data as well as model M5 (model M5 had a survey biomass index of -lnL = -6.74121; Table 3; Figure 43). The fits to the shallow-water survey length composition data were particularly poor for very young lengths for model M4; model M5 fits to the shallow-water survey length-composition data (where survey selectivity is length-based) were better.

An additional model run like model M4 was conducted, where the descending limb of the double-normal age-based selectivity curves were estimated; the resulting selectivity curves and other model results were identical to model M4, where age-based double-normal selectivity was forced to be asymptotic.

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TABLES

Table 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 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)	$\sum_{t \in survey\ f} \frac{(\ln(\text{I}_{t,f}) - \ln(SB_{t,f}))^2}{2\ln(CV_{t,f}^2 + 1)}$	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 (0.5, 0.5)	$\sum_t \sum_x \sum_l n_{2,t,x,f} p_{t,x,f,l} \ln\left(\frac{p_{t,x,f,l}}{\hat{p}_{t,x,f,l}}\right)$	As for SS3
Main period recruits (1,1)	$\frac{1}{2}\left(\sum_{t=1984}^{2008}\left(\frac{\tilde{R}_t^2}{\sigma_R^2} + b_t \ln(\sigma_R^2)\right)\right)$ (sum to 0 constraint)	$\sum_{t=1947}^{2008} \tilde{R}_t^2$ (sum to 0 constraint)
Early period recruits (1,2)	$\frac{1}{2}\left(\sum_{t=1947}^{1983}\left(\frac{\tilde{R}_t^2}{\sigma_R^2} + \ln(\sigma_R^2)\right)\right)$	$\sum_{t=1947}^{1983} \tilde{R}_t^2$ (sum to 0 constraint)
Late period recruits (1,3)	$\frac{1}{2}\left(\sum_{t=2009}^{2011}\left(\frac{\tilde{R}_t^2}{\sigma_R^2} + \ln(\sigma_R^2)\right)\right)$	$\sum_{t=2009}^{2011} \tilde{R}_t^2$ (sum to 0 constraint)
Catch (30,30)	$\sum_t \frac{(\ln(\text{C}_t^{obs}) - \ln(\hat{\text{C}}_t))^2}{2\sigma_{t,f}^2}$	$\sum_t (\ln(\text{C}_t^{obs}) - \ln(\hat{\text{C}}_t))^2$

Table 3. Components of the negative log(likelihood) for each alternative proposed SS3 model. M0-M5 are the alternative model descriptors, which are described in full in the section "Analytic Approach: Proposed Alternative SS3 Models" on page 7. 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	M1	M2	M3	M4	M5
Total (not always comparable to the transitional model)	1281.56	1216.90	1275.38 (but add'l component)	1281.94	1212.75 (but add'l component)	1183.51 (but add'l comonent)
Initial Equilibrium Catch	NA	NA	0.0020	NA	0.0014	8.96E-05
Survey Biomass	-9.7695	-10.8824	-11.2050	-9.5223	-12.3772	-6.74121
Length Composition	847.0220	775.6090	846.8010	847.07	778.3310	773.034
Age Composition	445.6960	455.3270	442.6560	445.81	451.7830	429.217
Recruitment	-1.5099	-3.1827	-2.9911	-1.5326	-5.0088	-12.0118

FIGURES

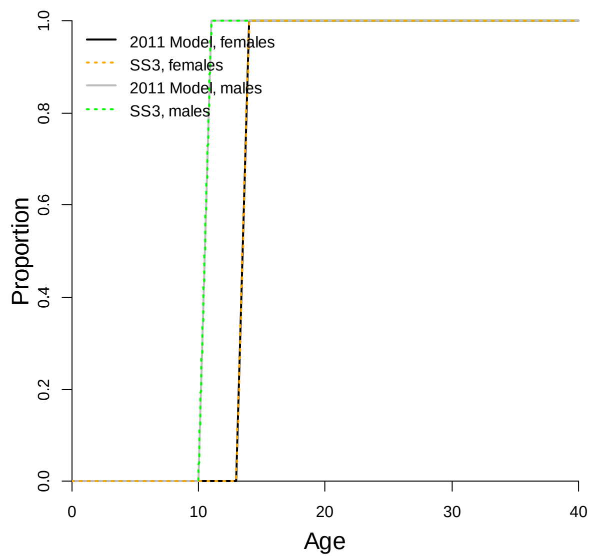


Figure 1. Fishery selectivity for Dover sole used in deterministic runs to match population dynamics between the 2011 and SS3 models. Selectivity curves are fixed at MLEs for fishery selectivity from the 2011 model. The SS3 selectivity curves pictured were created using a double-normal selectivity functional form with no descending limb; the 2011 model selectivity curves are logistic.

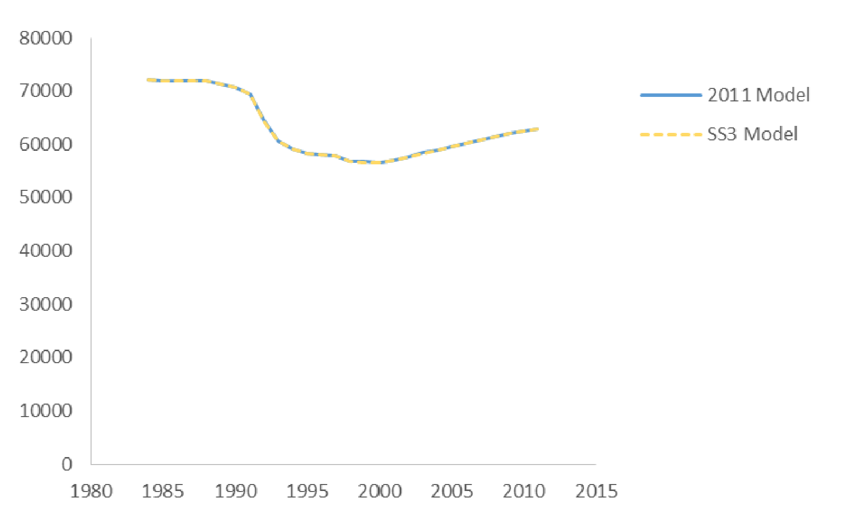


Figure 2. Spawning stock biomass for a deterministic run of the 2011 and SS3 models with parameters fixed at the MLEs for the 2011 Dover sole model with Dover sole catch history and no recruitment deviations. Fishery selectivity curves for the models were forced to match as closely as possible (Figure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

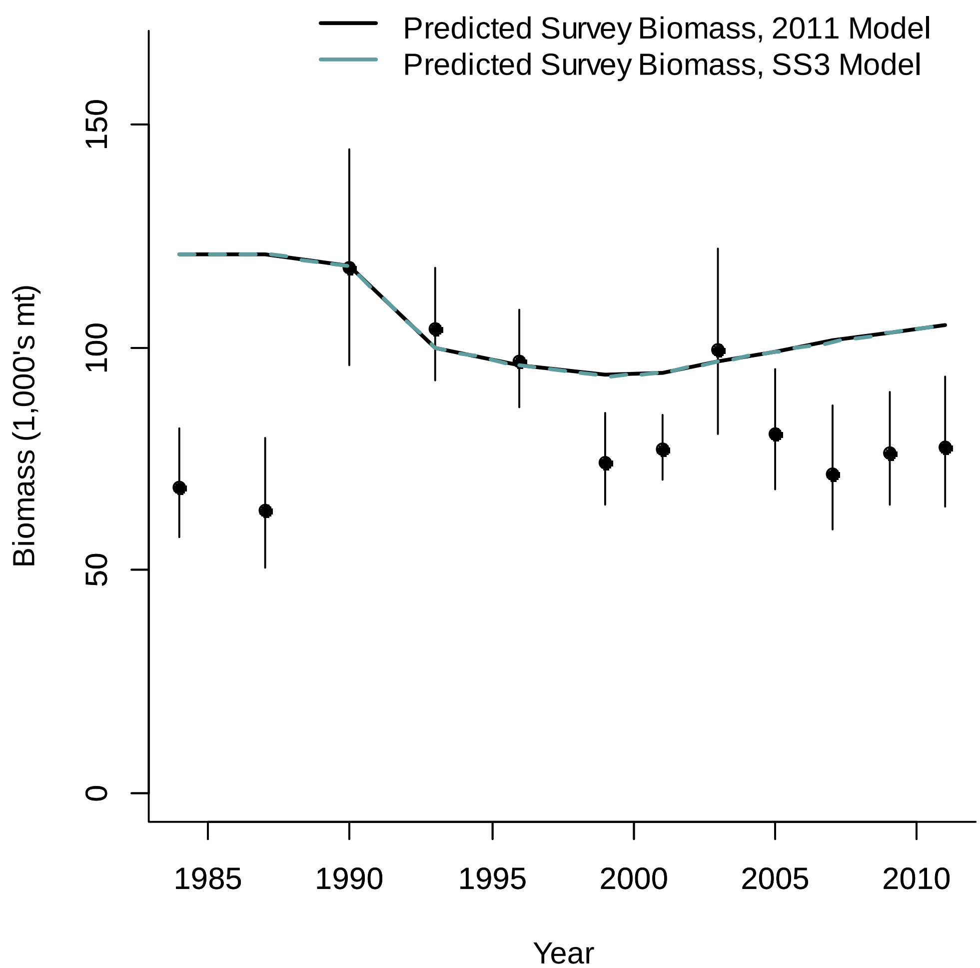


Figure 3. Survey biomass for the 2011 model (black solid line) and the SS3 model (blue dashed line) for a deterministic run with no estimation, parameters fixed at the same values in both models, and fishery and survey selectivity curves in both models fixed to the curve shown in Figure 1.

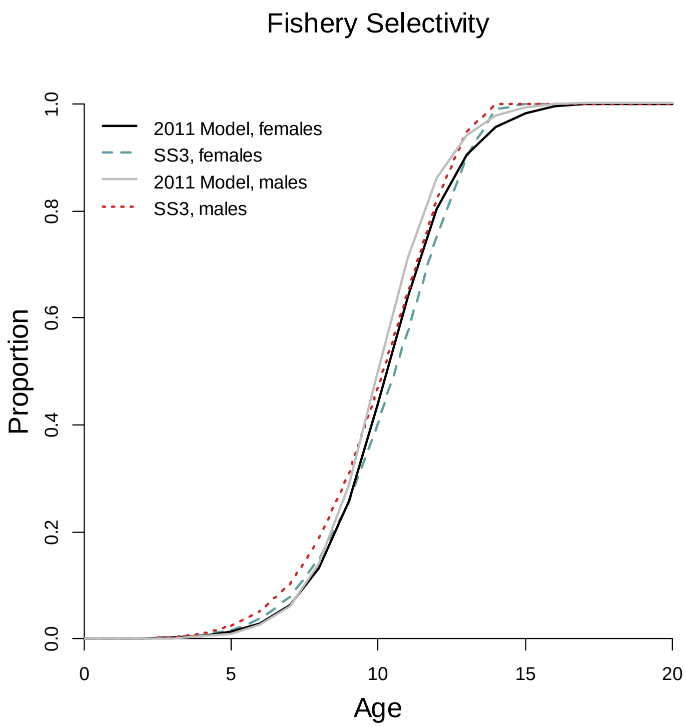


Figure 4. Example SS3 double-normal selectivity curves that fail to match the 2011 model's logistic fishery selectivity curves exactly (the standard deviation of the descending limb of the selectivity curves was fixed at a large value to create an asymptotic curve).

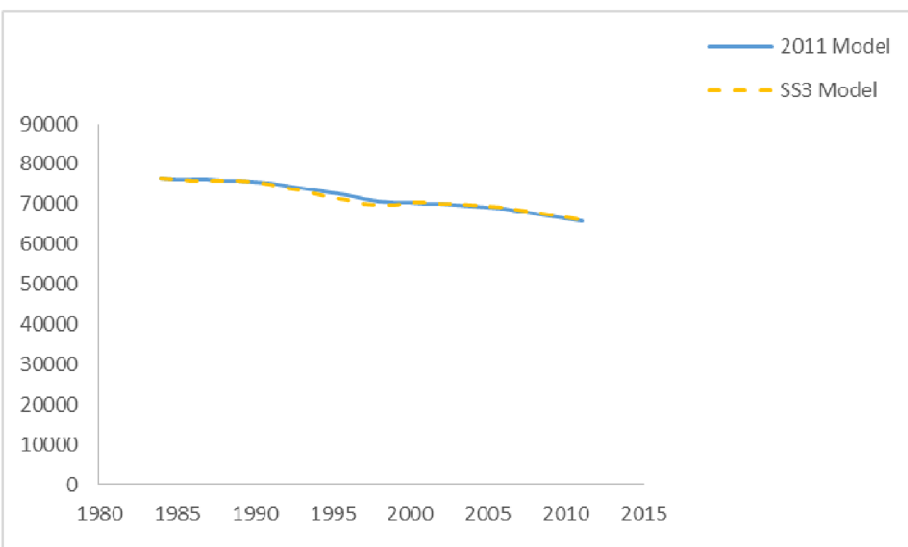


Figure 5. Spawning stock biomass for a deterministic run of the 2011 and SS3 models with parameters in both models fixed at the same values, using flathead sole catch history with no recruitment deviations. Fishery selectivity curves for the models were forced to match as closely as possible, but are not an exact match (Figure 4).

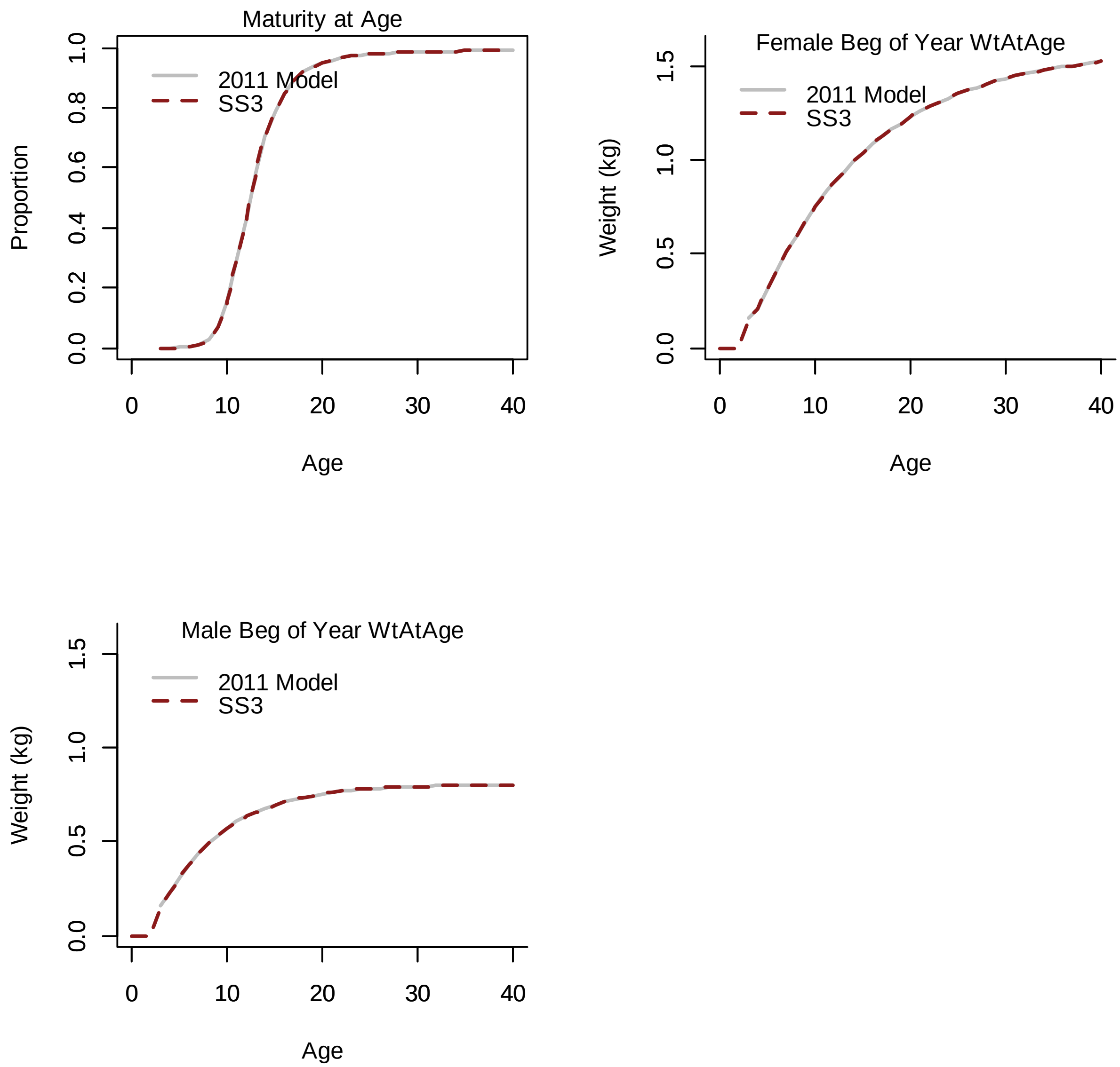


Figure 6. Maturity and weight-at-age for males and females (also used as mid-year weight at age) for the 2011 model and an equivalent SS3 model. The lines match perfectly because both models use empirical vectors for each of the three relationships.

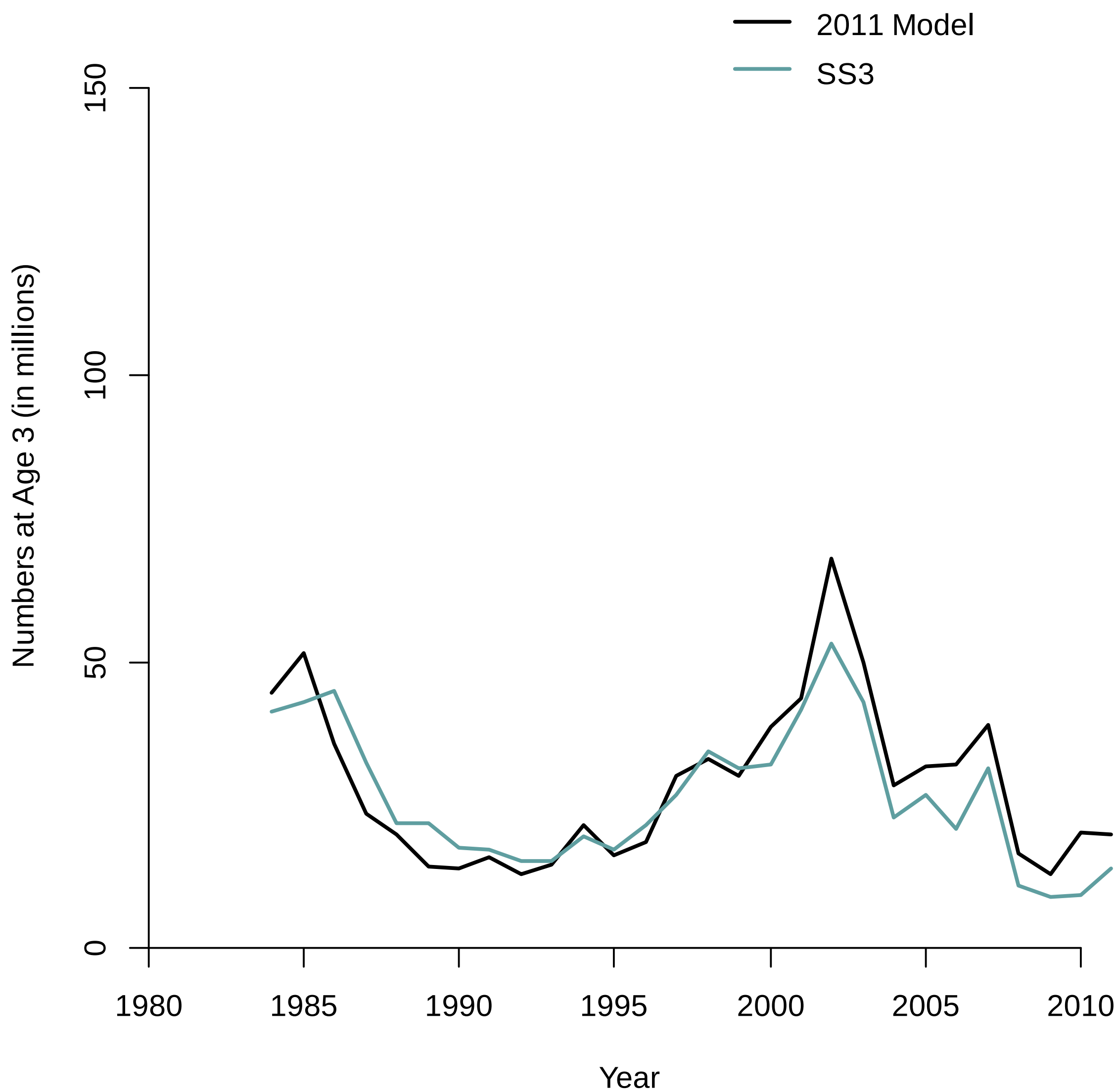


Figure 7. Numbers at age 3 for the 2011 model (black line) and an equivalent SS3 run (blue line). Both models estimate the log of mean recruitment, recruitment deviations for 1984-2011, an early period of recruitment deviations starting in 1964, fishing mortality rates, and asymptotic selectivity parameters (logistic for the 2011 model and double-normal for SS3). Survey data for ages 0-2 and lengths 0-18cm are included in the SS3 model, but not the 2011 model.

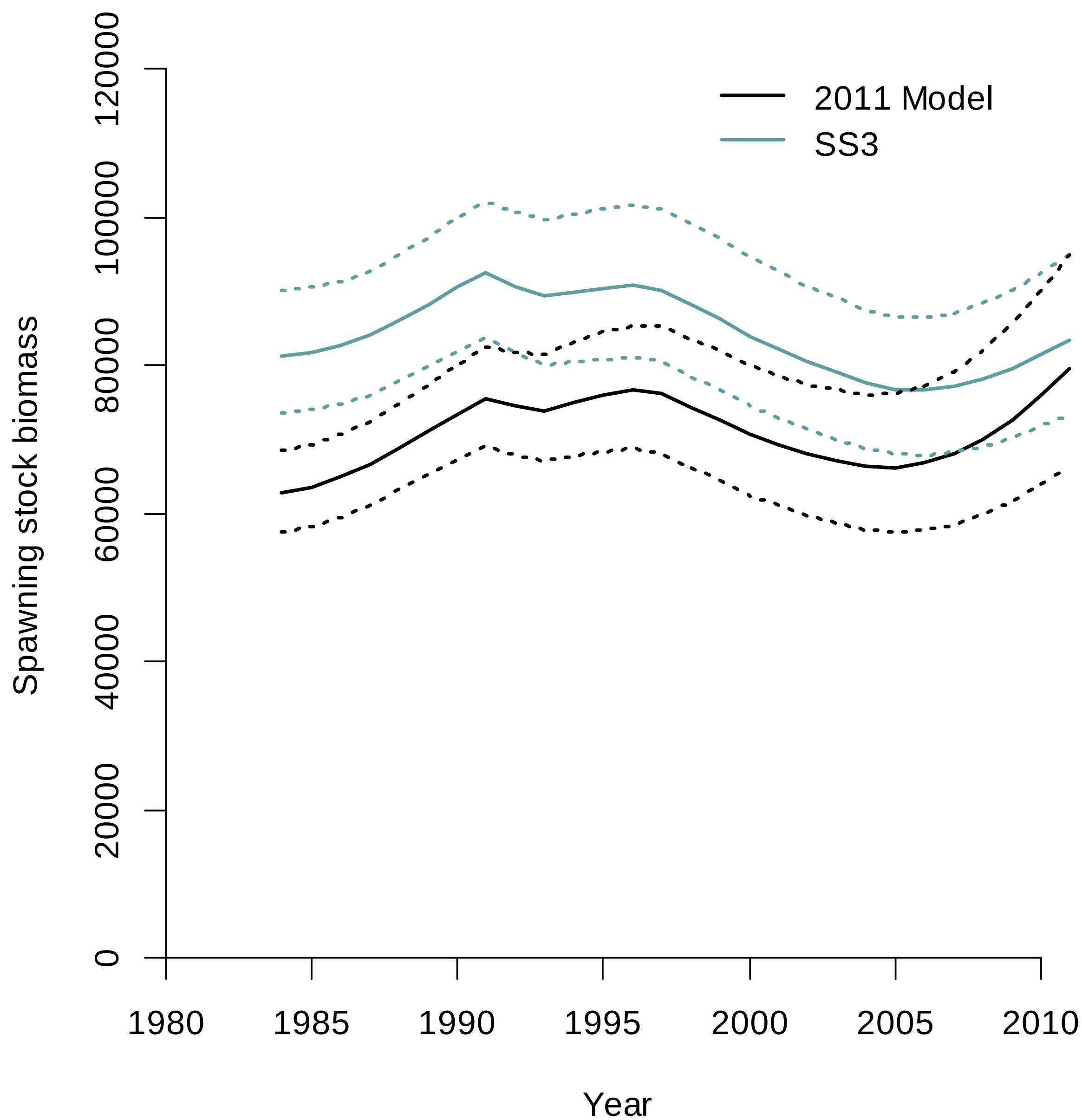


Figure 8. Spawning stock biomass (solid lines) and asymptotic 95% confidence intervals (dotted lines) for the 2011 model (black lines) and SS3 (blue lines) for an equivalent SS3 model. Both models estimate the log of mean recruitment, recruitment deviations for 1984-2011, an early period of recruitment deviations starting in 1964, 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 0-18cm are included in the SS3 model, but not the 2011 model.

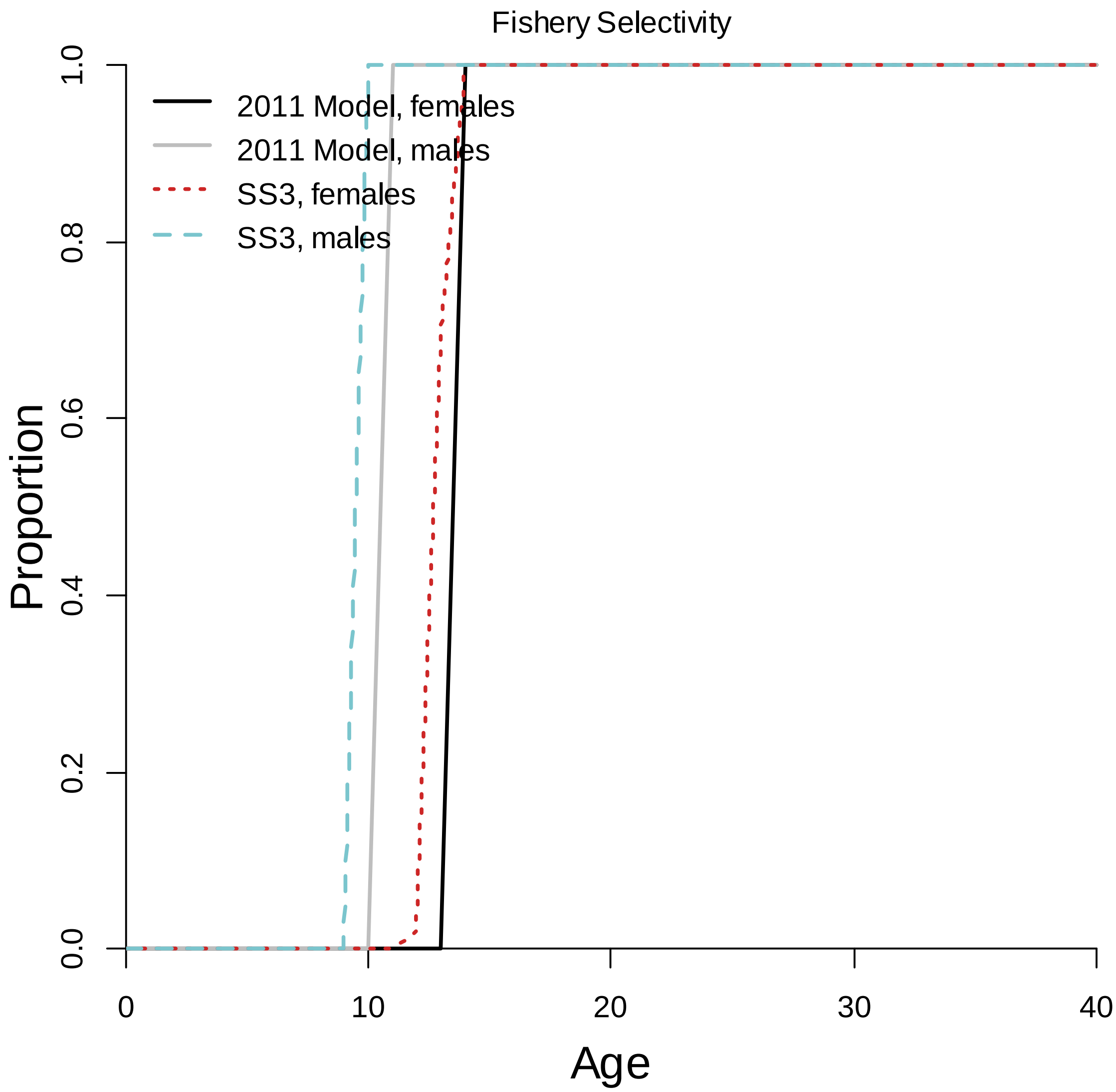


Figure 9. Fishery selectivity for the 2011 model (solid lines) and an equivalent SS3 model run (dotted and dashed lines).

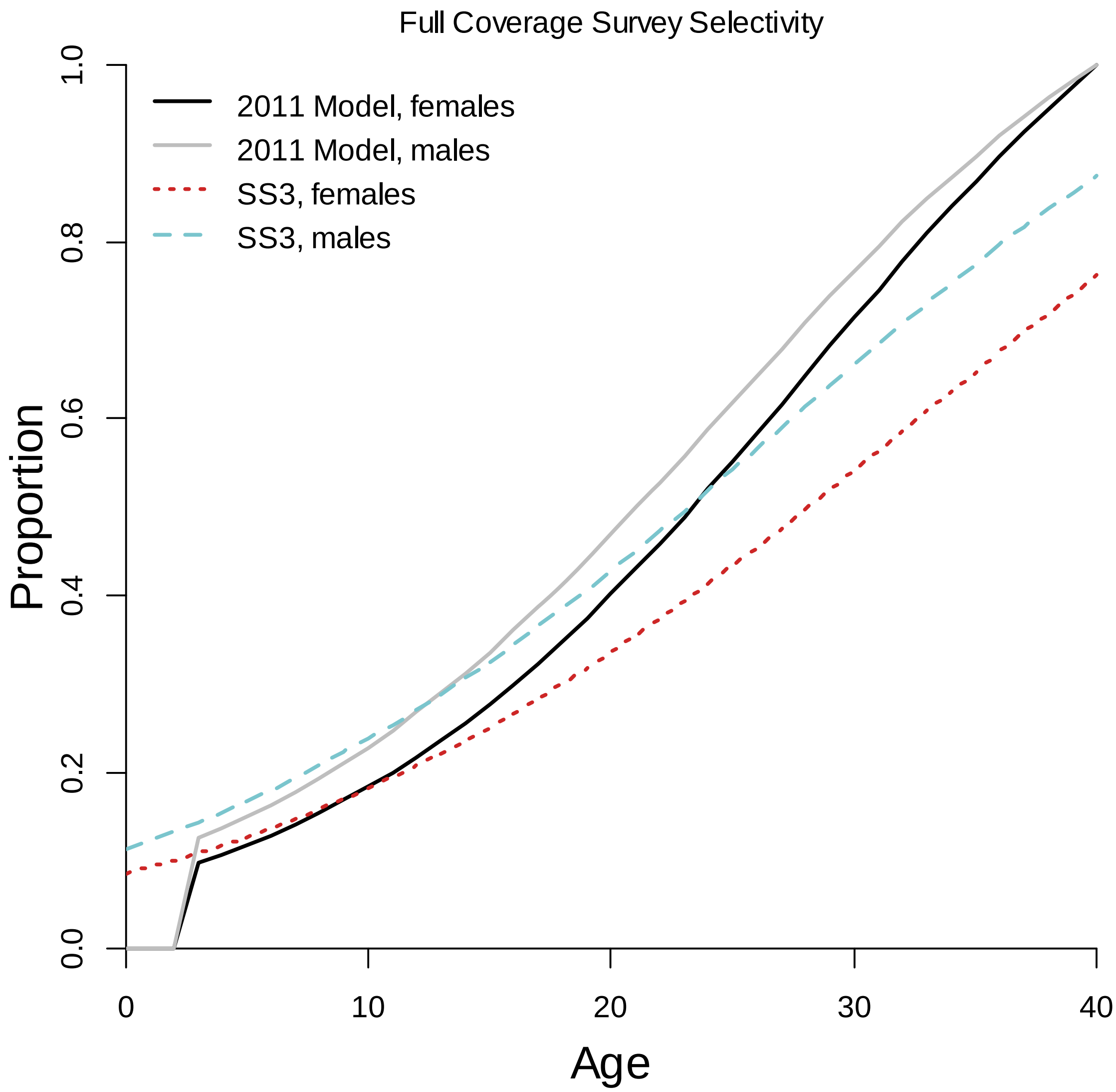


Figure 10. Survey selectivity for the 2011 model (solid lines) and an equivalent SS3 model run (dotted and dashed lines) for years with fuller survey coverage.

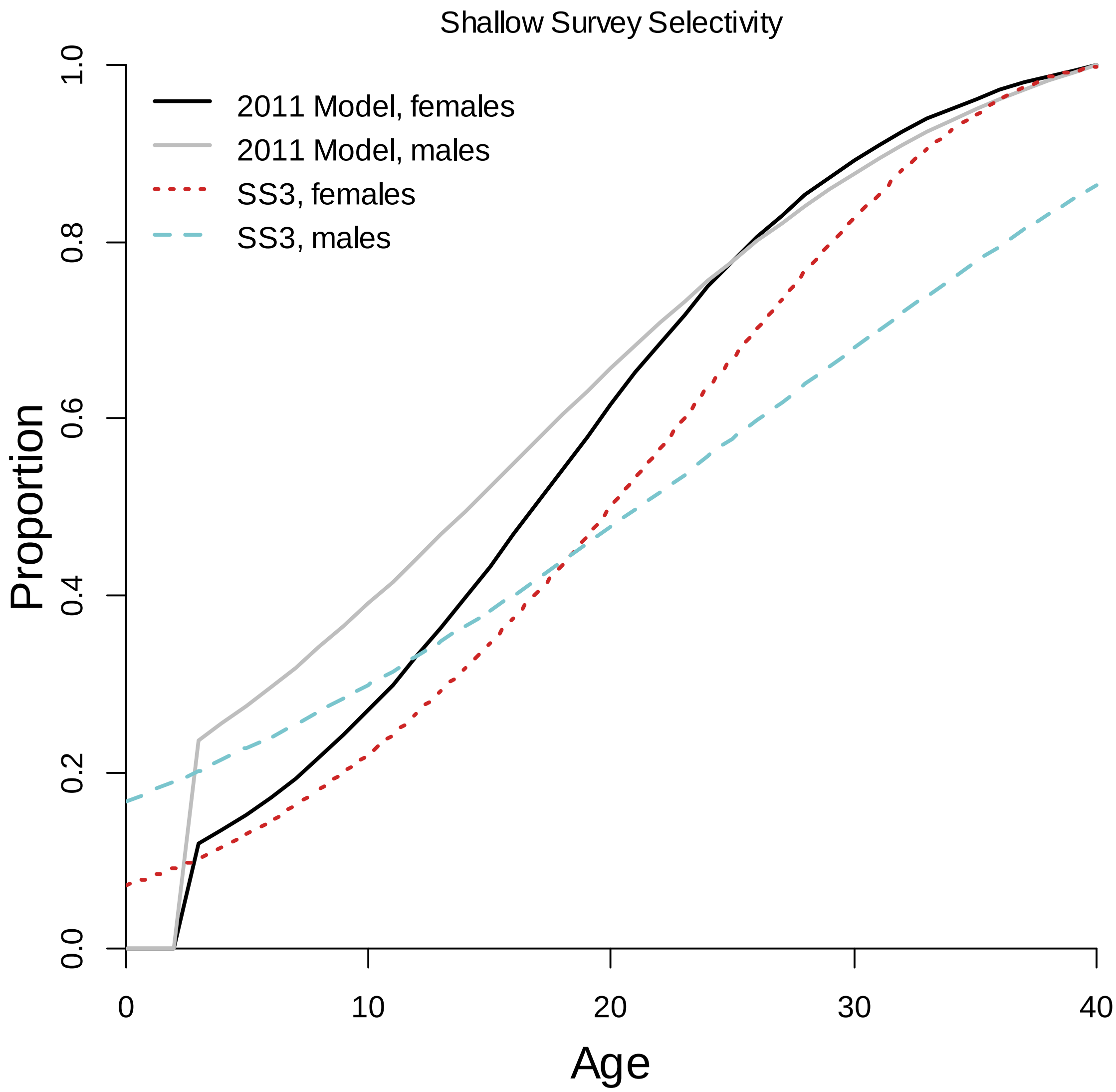


Figure 11. Survey selectivity for the 2011 model (solid lines) and an equivalent SS3 model run (dotted and dashed lines) for years with only shallower water survey coverage.

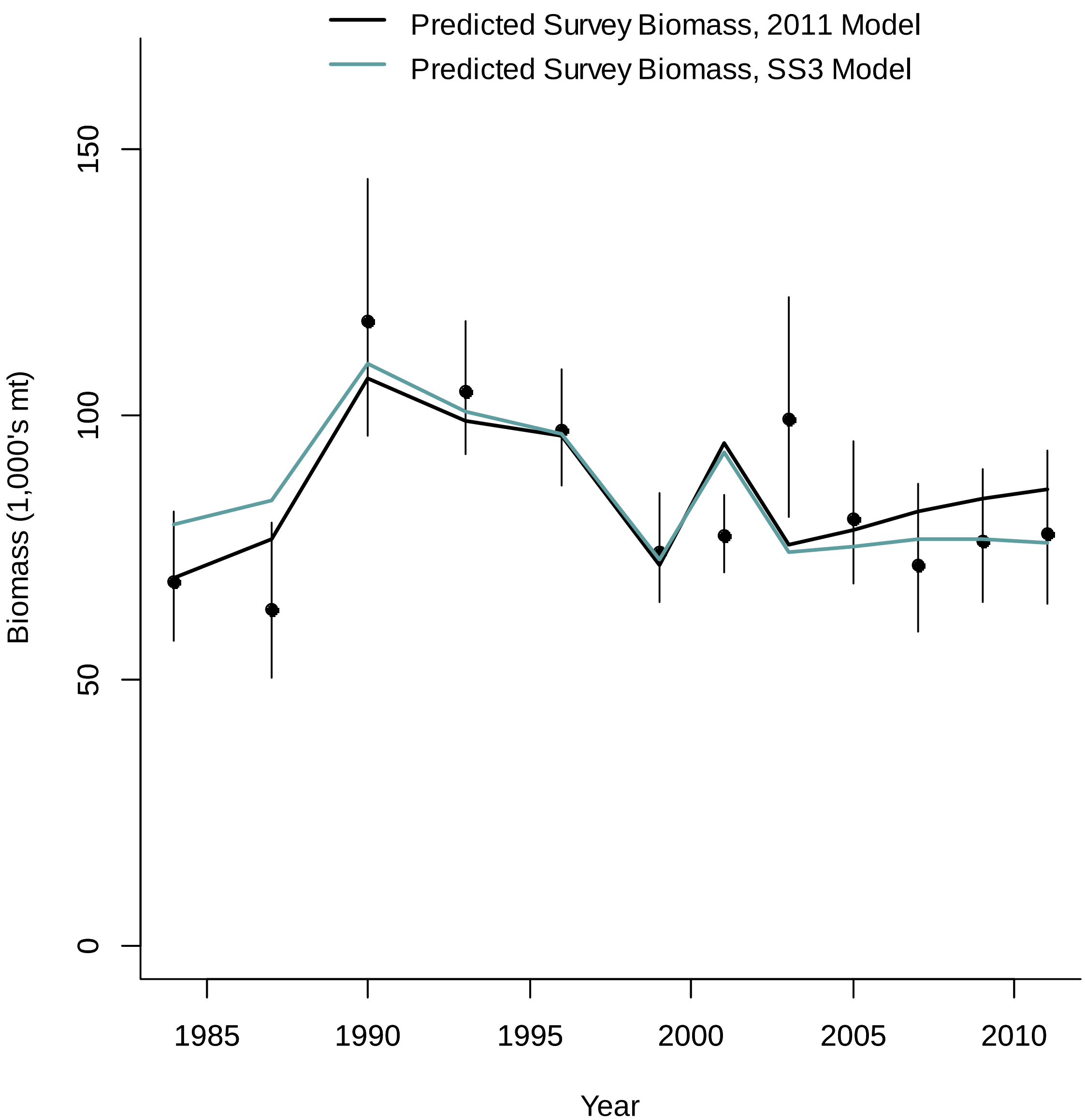


Figure 12. Observed survey biomass (black dots) with 95% asymptotic confidence intervals (vertical black lines) and predicted survey biomass from the 2011 model (black line) and an equivalent SS3 model (blue line).

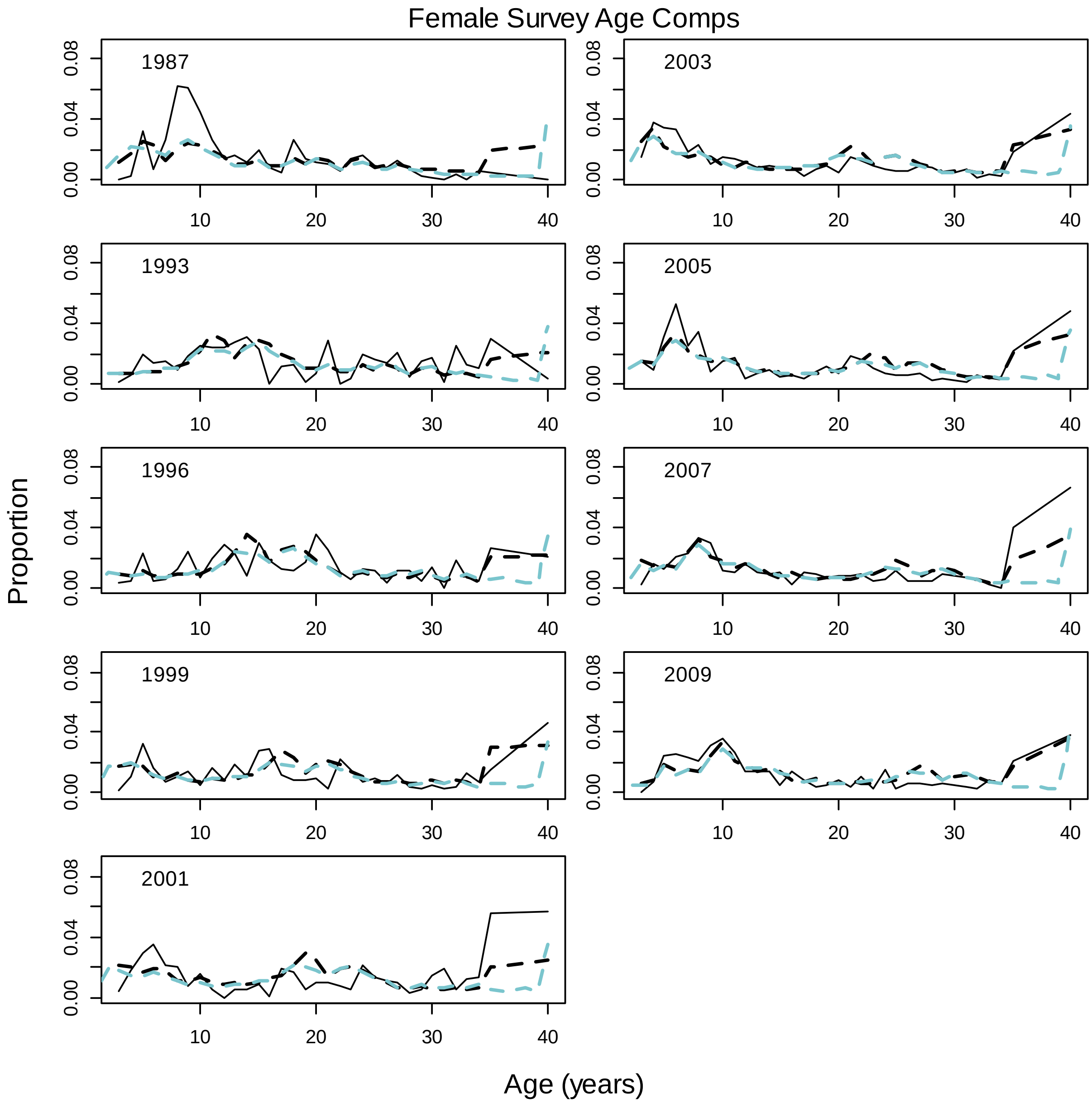


Figure 13. (1 of 2) Observed (2011 model; solid black lines) and predicted (dashed lines) survey proportions-at-age for the 2011 model (dashed black lines) and an equivalent SS3 model run (dashed blue lines) for females (first panel) and males (second panel). The SS3 model included data for age 0-2 individuals and ages 35-40 were each separate age bins, while the 2011 model included data from ages 3-40 with an age 35 bin that included ages 35-39. Expectations for the SS3 model therefore do not match those from the 2011 model (or the 2011 data) for ages 35-39 and 0-2.

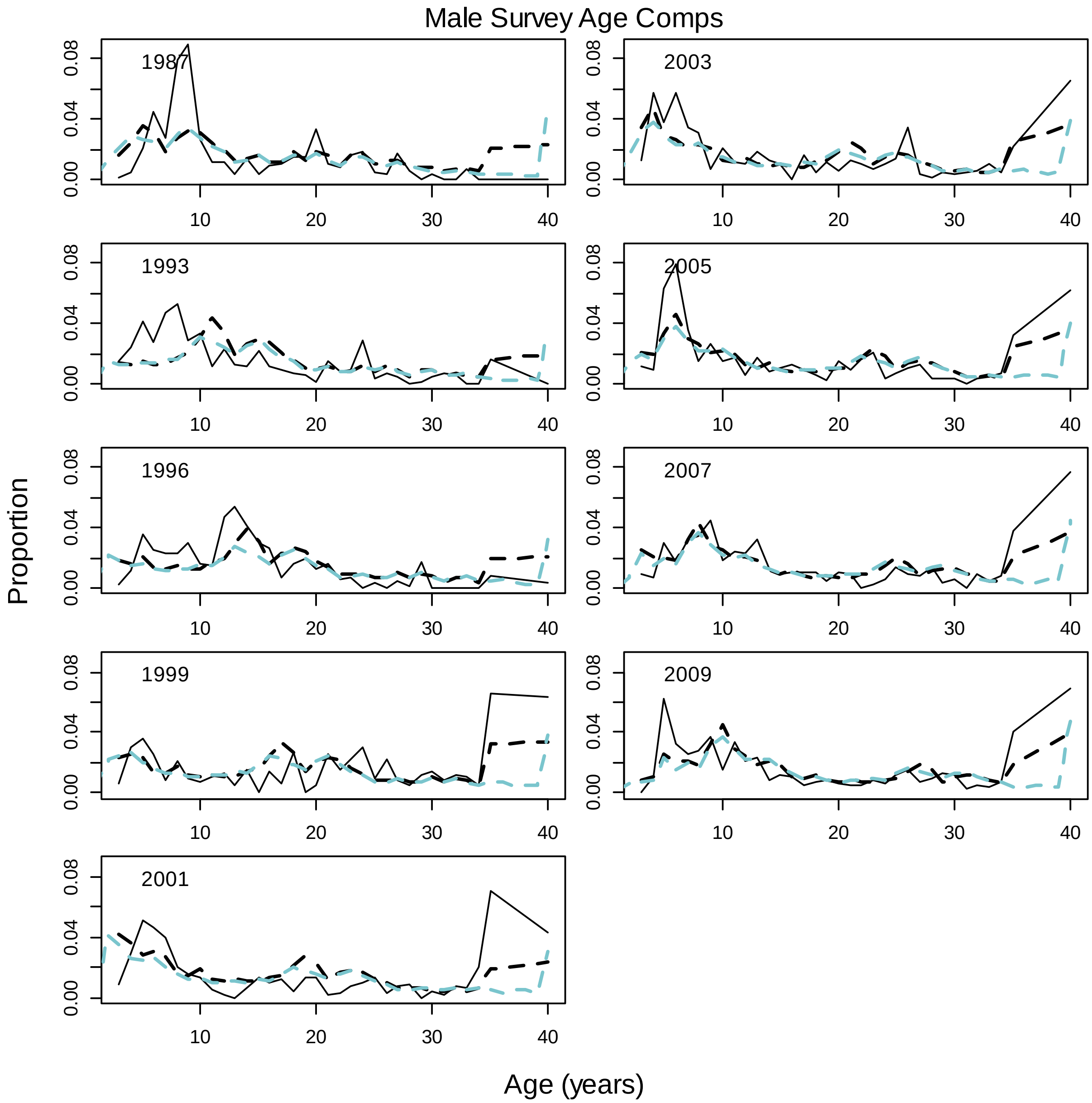


Figure 13, continued (2 of 2)

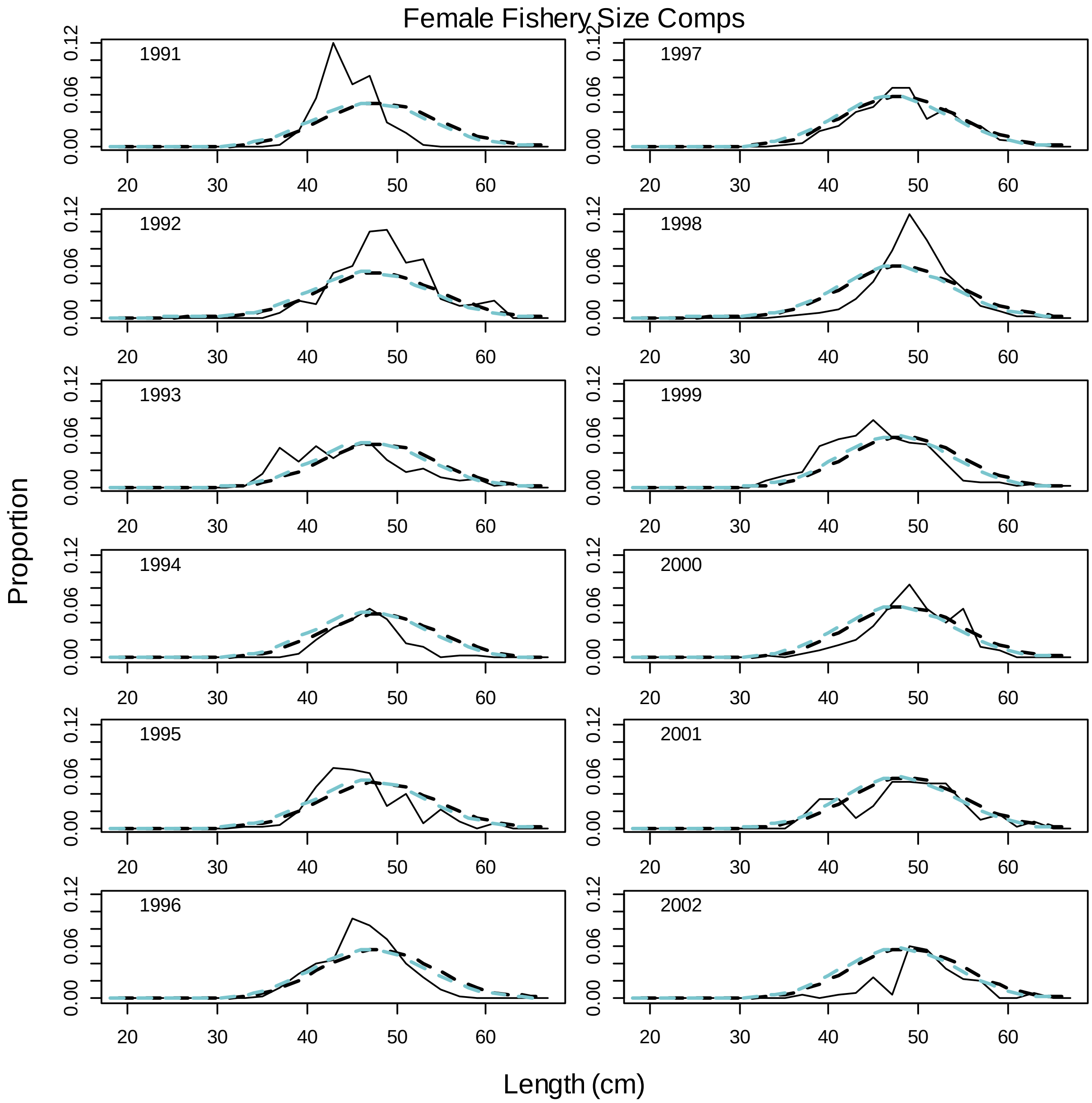


Figure 14. (1 of 4) Observed (solid black lines) and predicted (dashed lines) fishery proportions-at-length for the 2011 model (dashed black lines) and an equivalent SS3 model run (dashed blue lines) for females (first set of panels) and males (second set of panels).

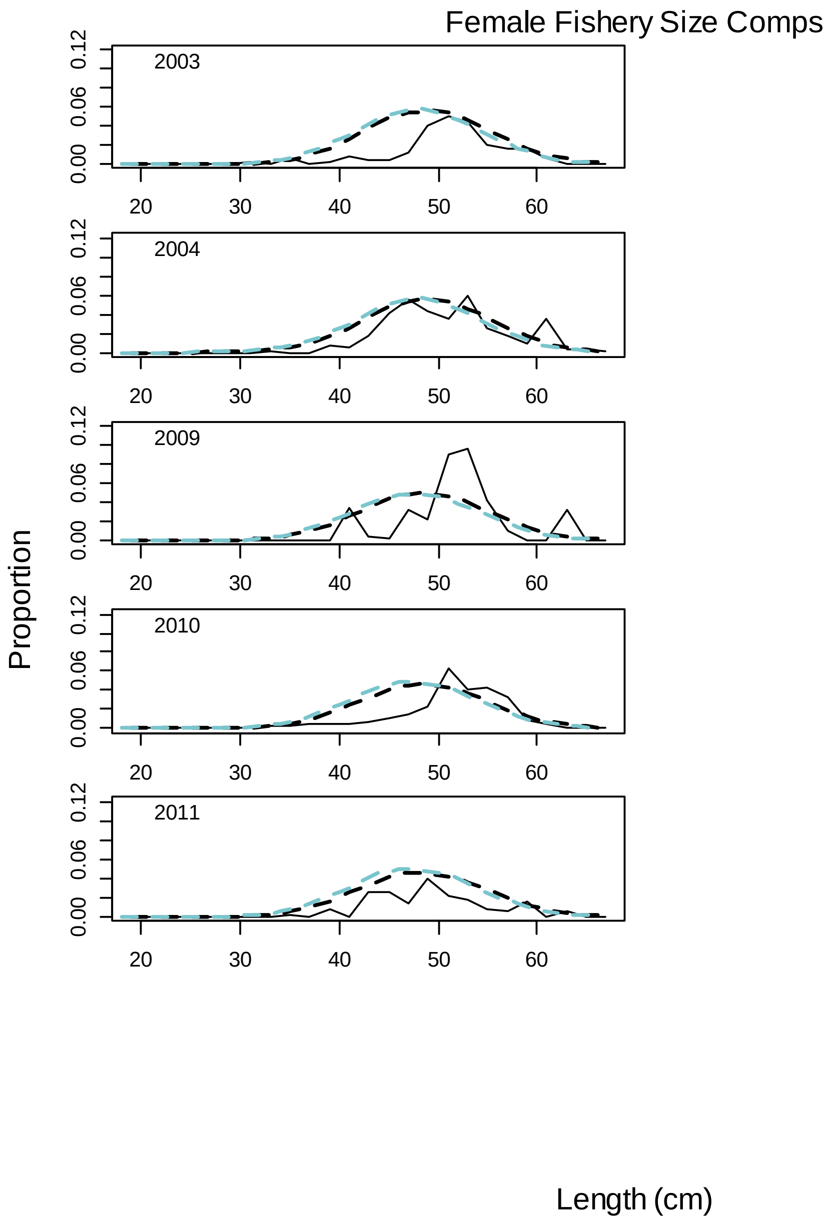


Figure 14, continued (2 of 4)

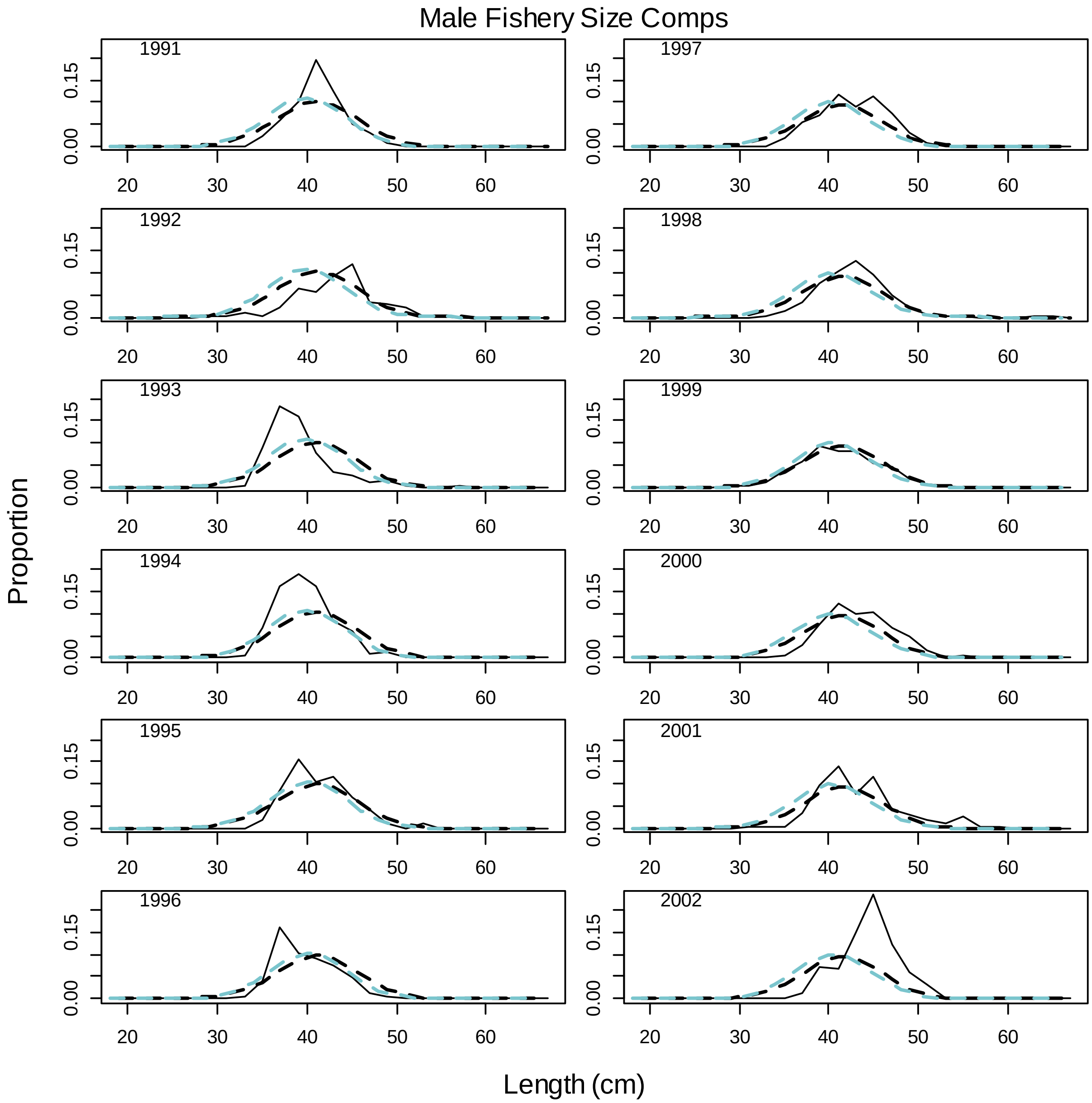


Figure 14, continued (3 of 4)

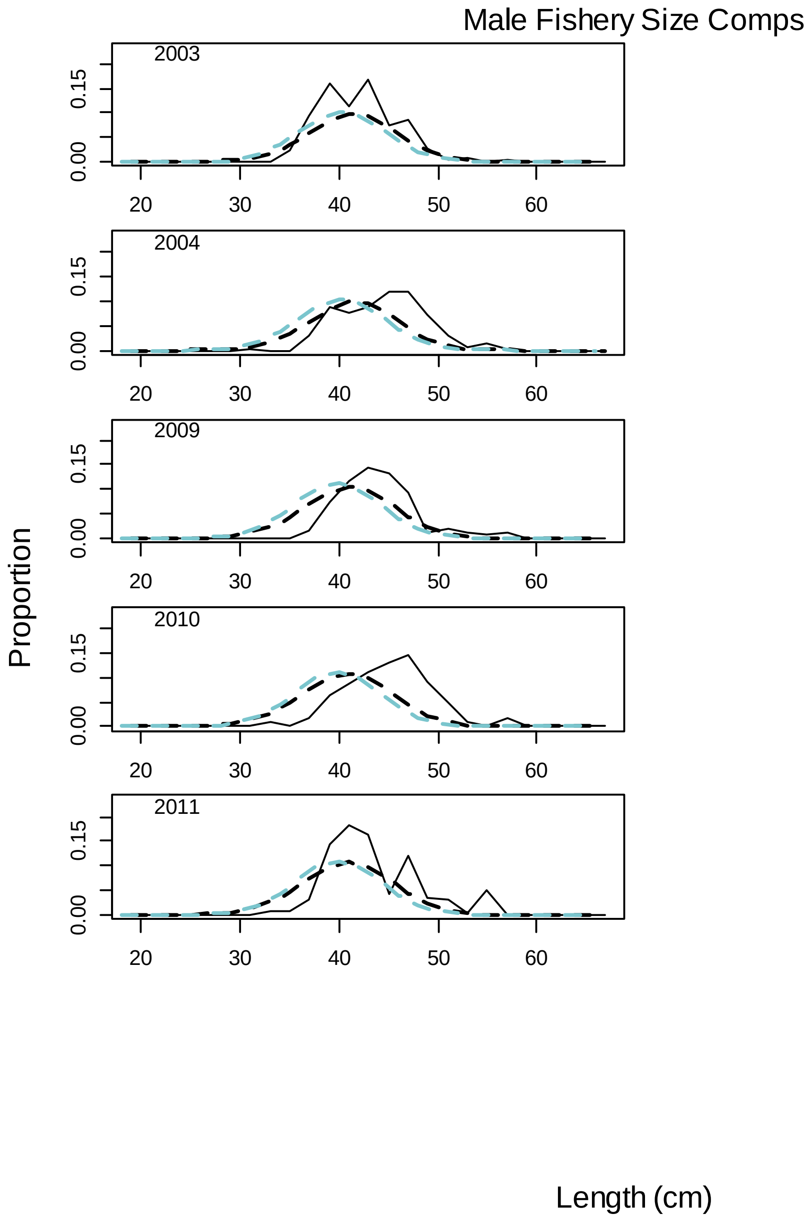


Figure 14, continued (4 of 4)

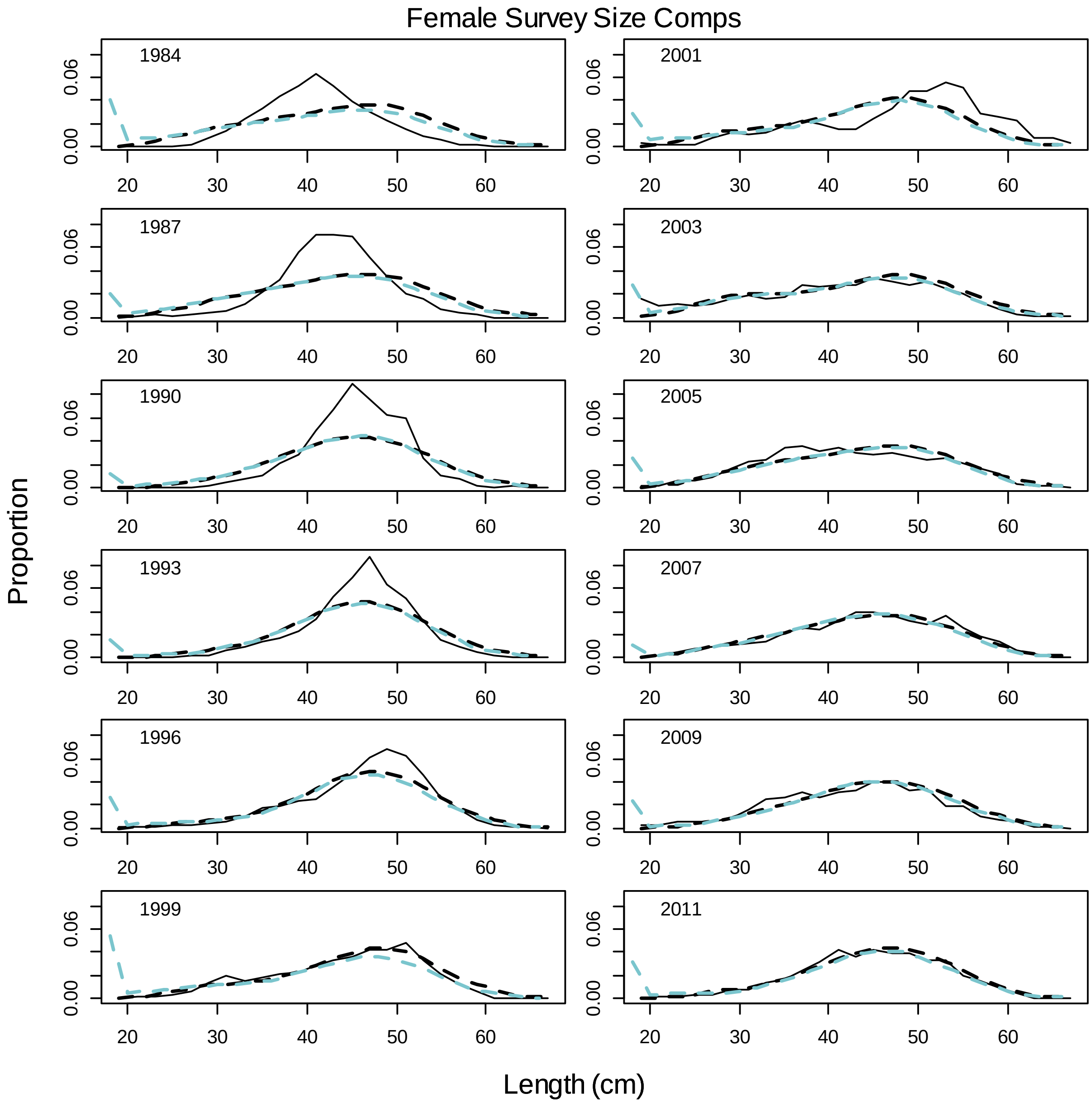


Figure 15. (1 of 2) Observed (solid black lines) and predicted (dashed lines) survey proportions-at-length for the 2011 model (dashed black lines) and an equivalent SS3 model run (dashed blue lines) for females (first set of panels) and males (second set of panels).

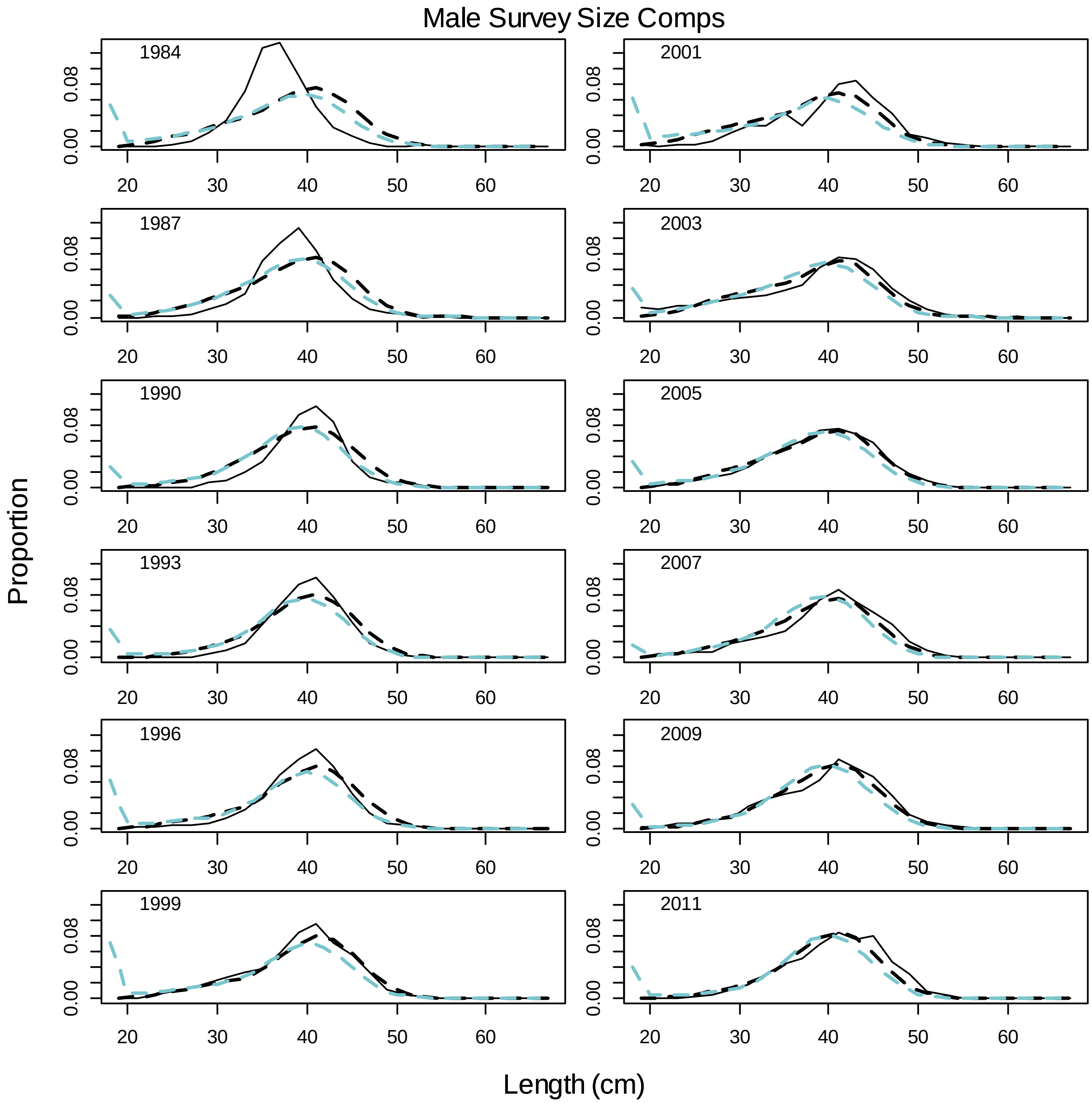


Figure 15, continued (2 of 2)

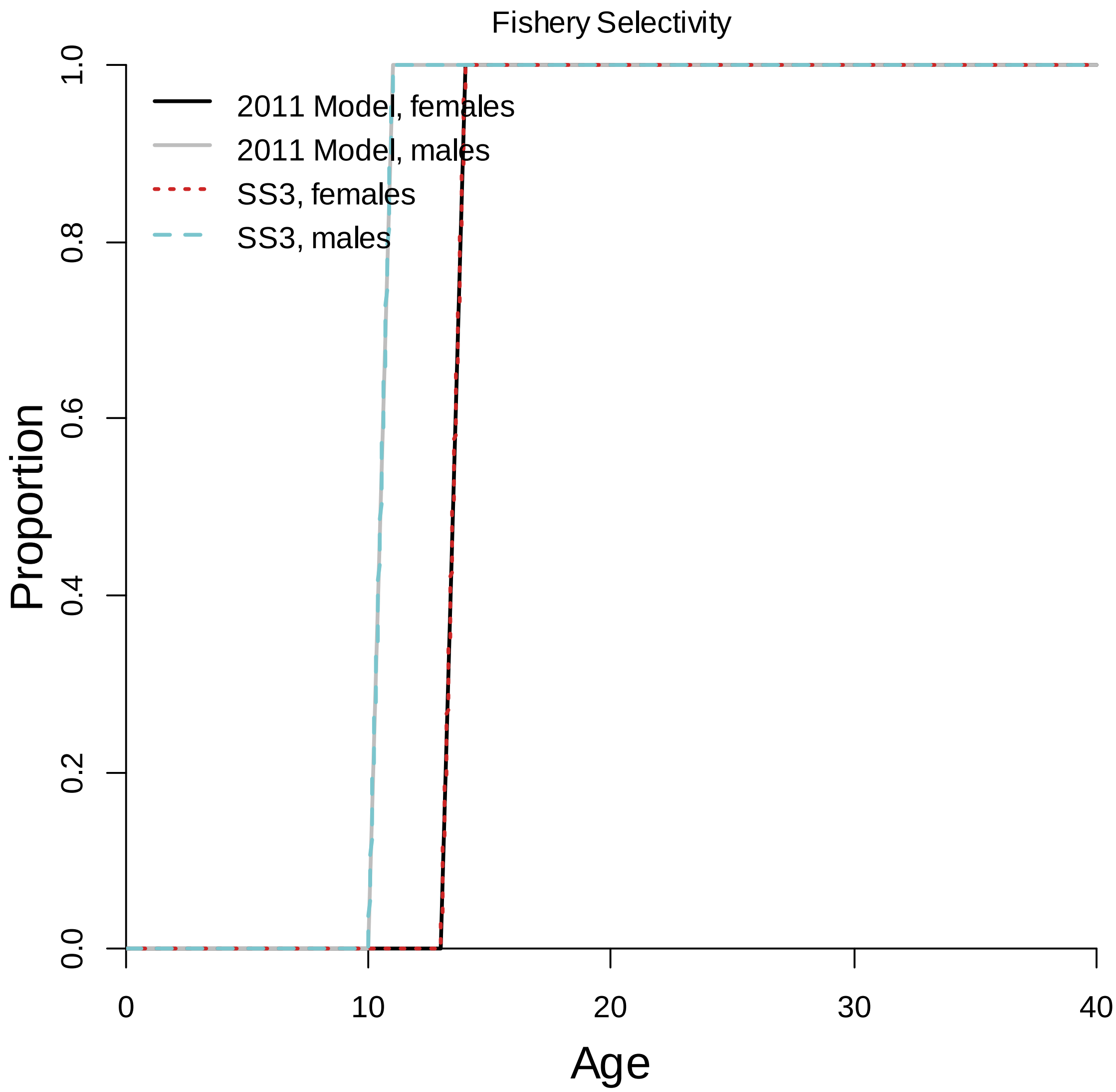


Figure 16. Fishery selectivity for the 2011 models and an SS3 model with selectivity fixed to be as similar as possible to the selectivity curves estimated in the 2011 model.

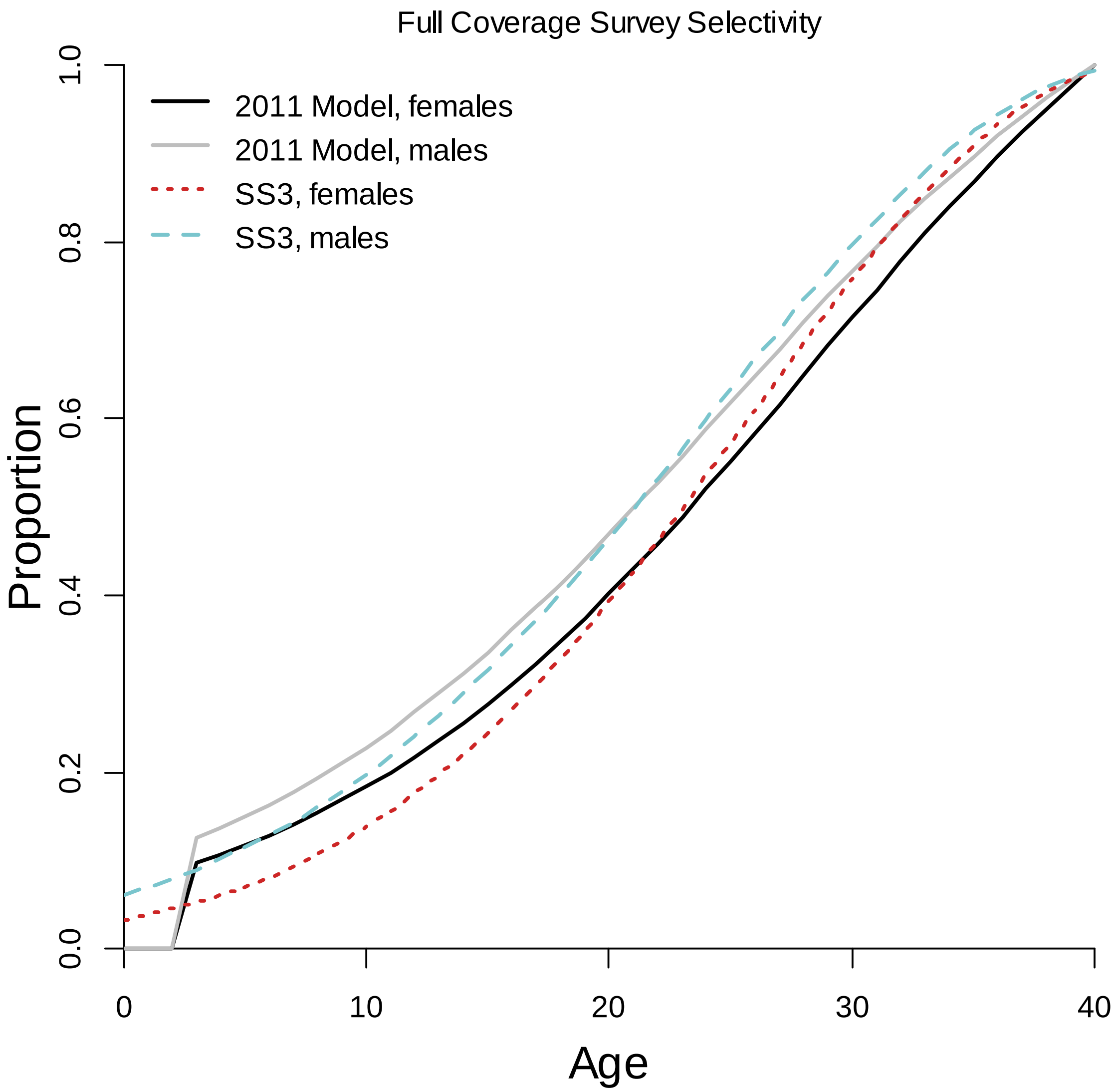


Figure 17. Full coverage survey selectivity for the 2011 models and an SS3 model with selectivity fixed to be as similar as possible to the selectivity curves estimated in the 2011 model.

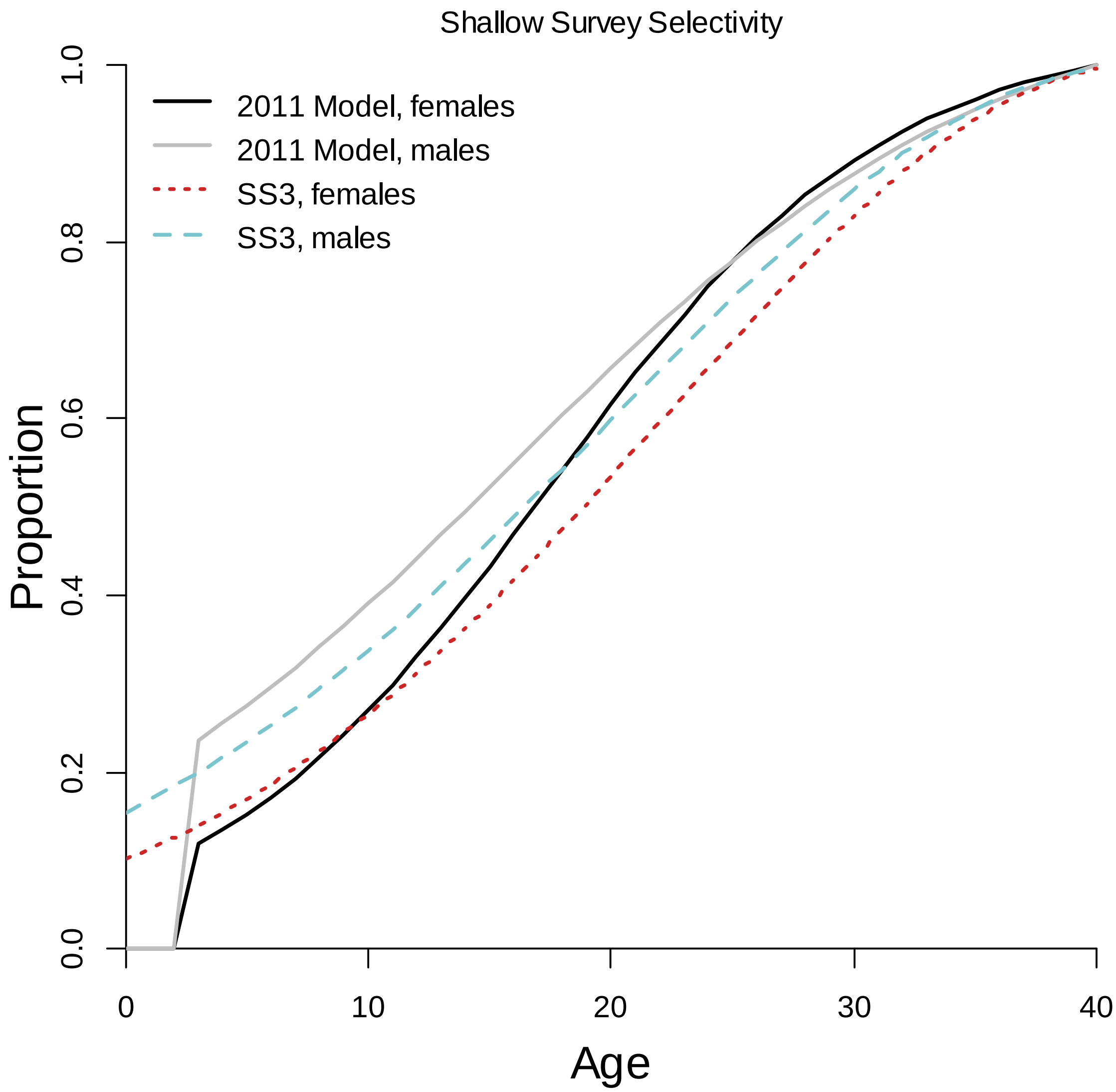


Figure 18. Shallow water survey selectivity for the 2011 models and an SS3 model with selectivity fixed to be as similar as possible to the selectivity curves estimated in the 2011 model.

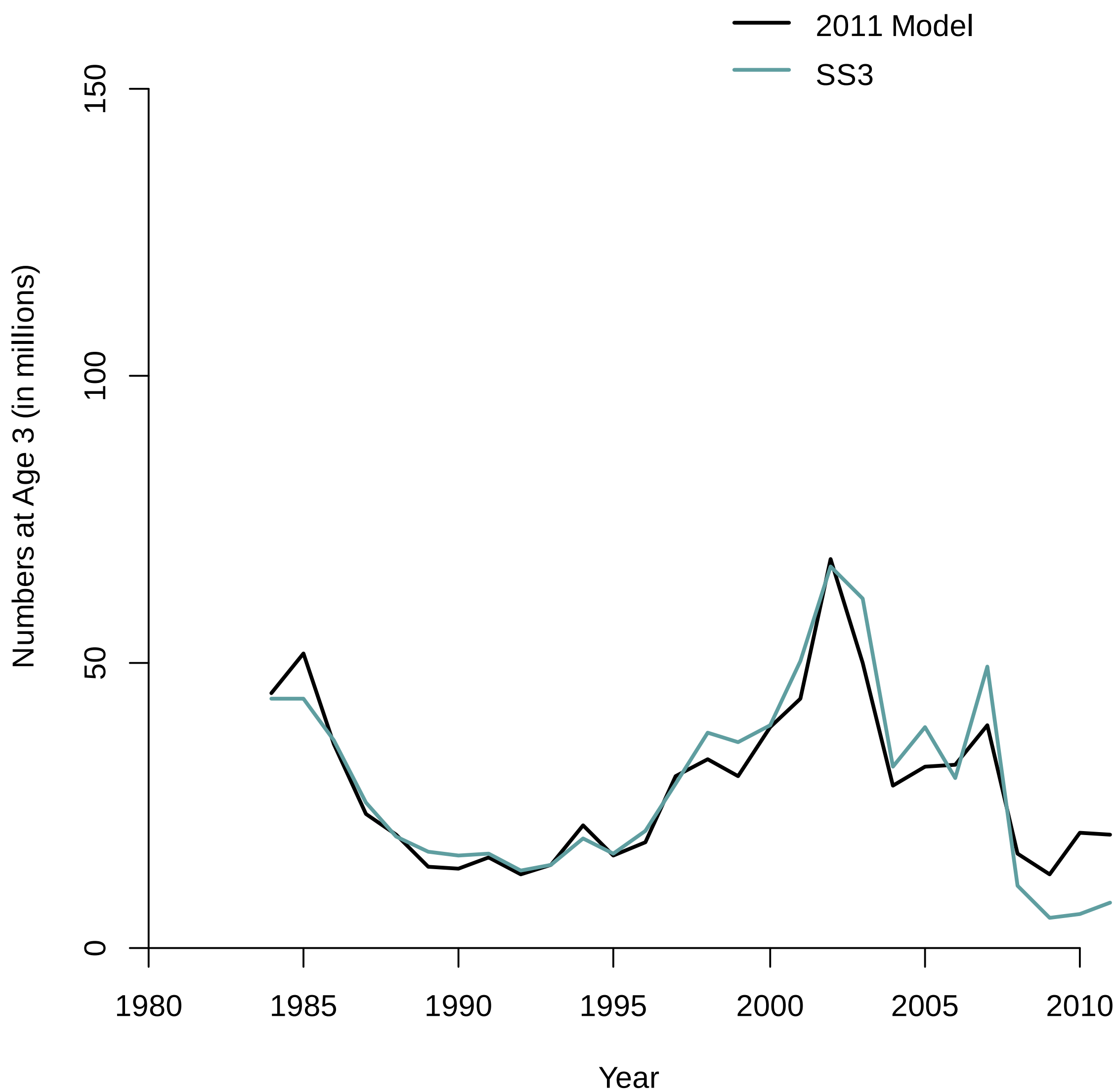


Figure 19. Numbers at age 3 for the 2011 models and an SS3 model with selectivity fixed to be as similar as possible to the selectivity curves estimated in the 2011 model.

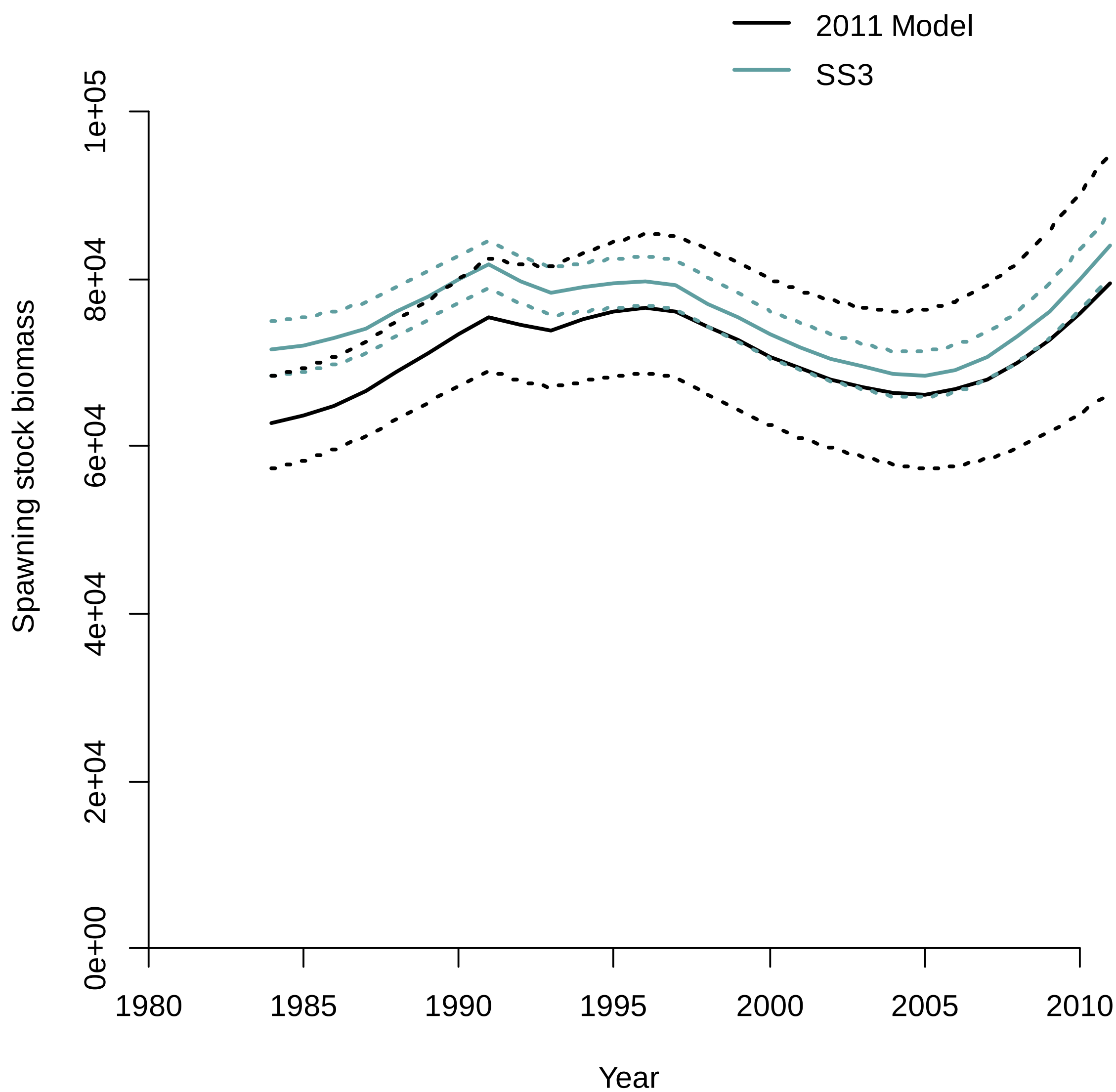


Figure 20. Spawning stock biomass (solid lines) and 95% asymptotic confidence intervals (dotted lines) for the 2011 models (black lines) and an SS3 model (blue lines) with selectivity fixed to be as similar as possible to the selectivity curves estimated in the 2011 model.

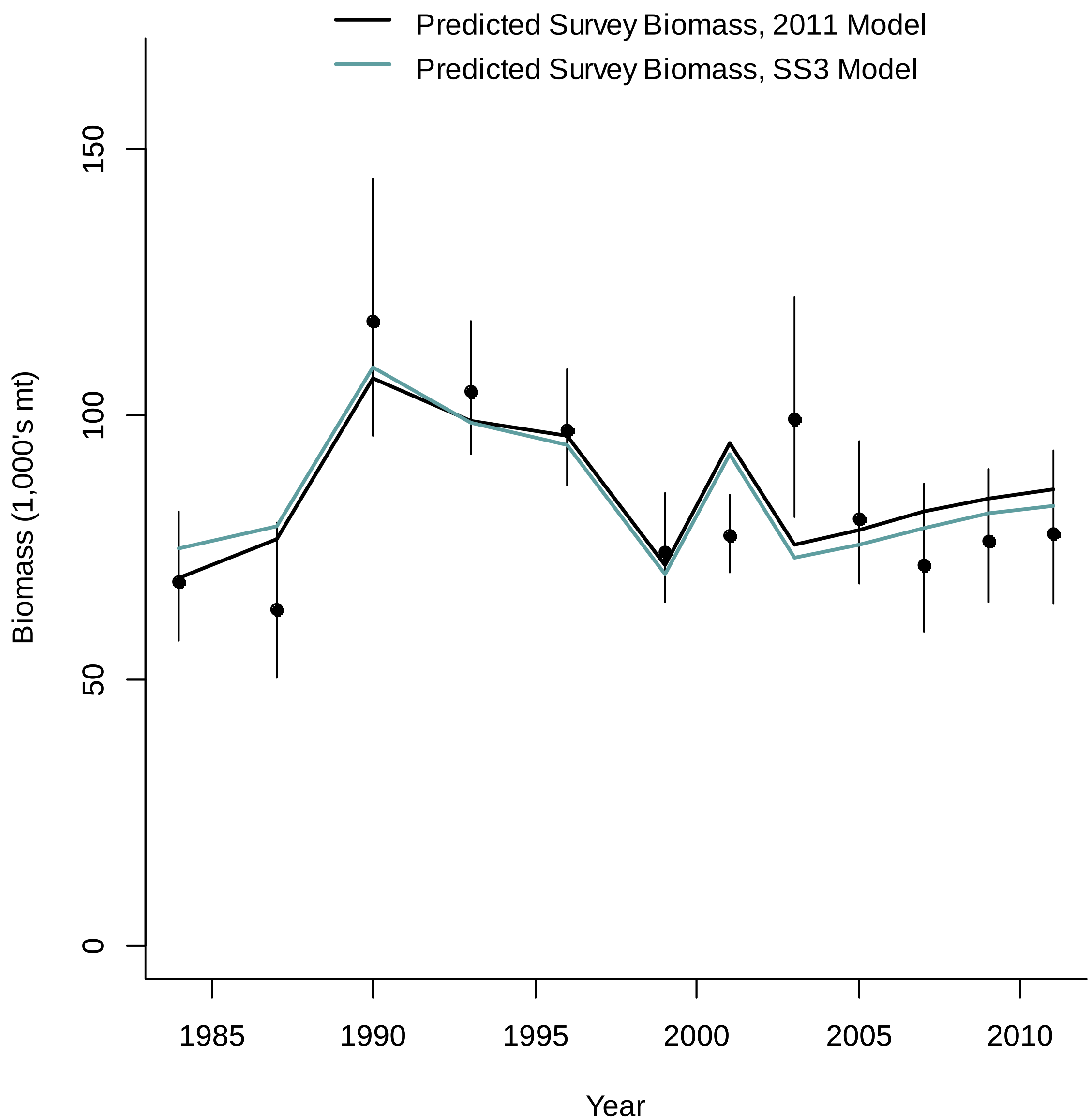


Figure 21. Observed survey biomass (black dots) with 95% asymptotic confidence intervals (vertical black lines) and predicted survey biomass for the 2011 models (black lines) and an SS3 model (blue lines) with selectivity fixed to be as similar as possible to the selectivity curves estimated in the 2011 model.

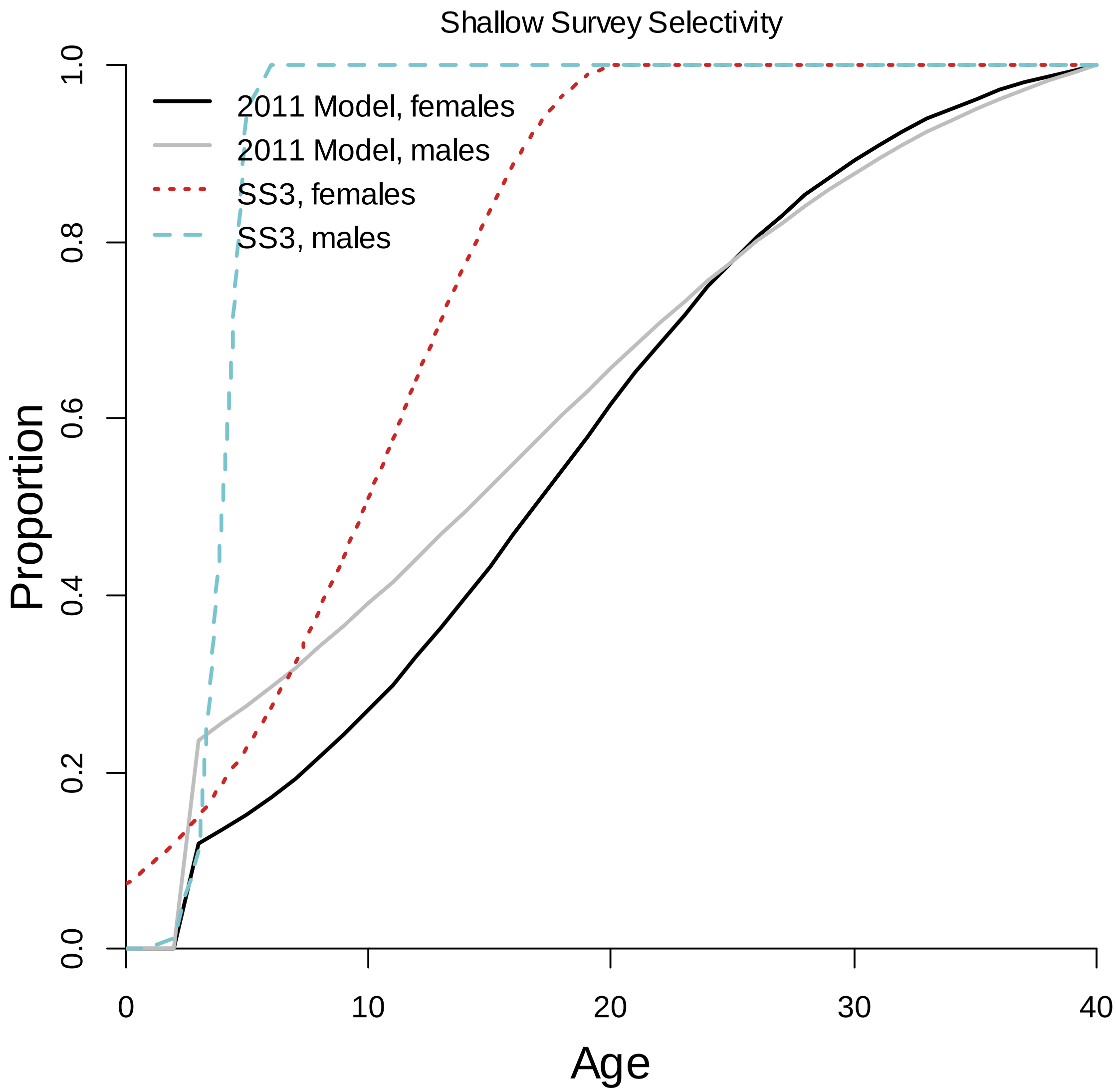


Figure 22. Shallow water survey selectivity for the 2011 model and an SS3 model with estimation of selectivity restricted such that it must reach 1 at or below age 40.

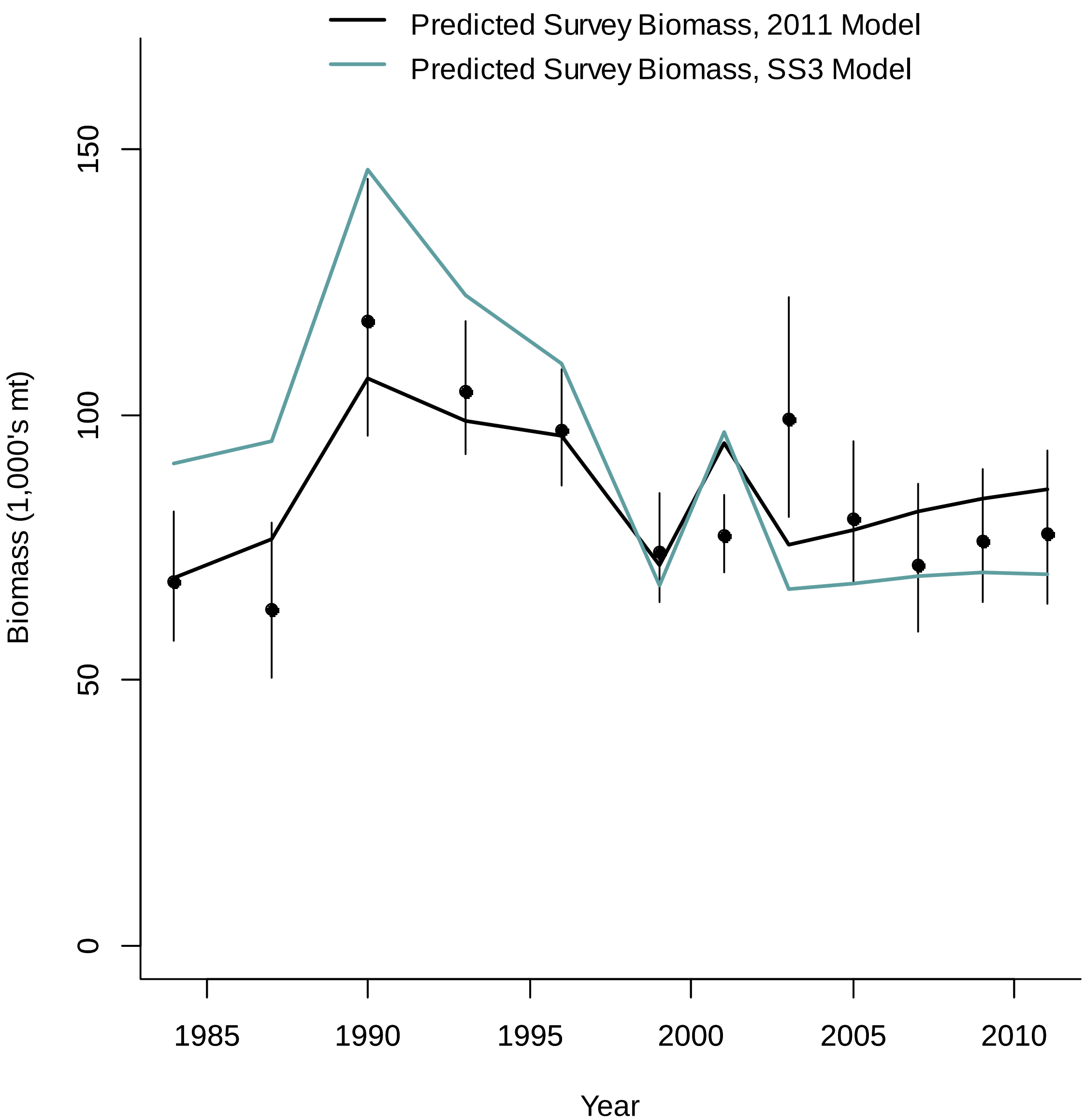


Figure 23. Observed survey biomass (black dots) with 95% asymptotic confidence intervals (vertical black lines) and predicted survey biomass for the 2011 models (black lines) and an SS3 model (blue lines) with estimation of selectivity restricted such that it must reach 1 at or below age 40.

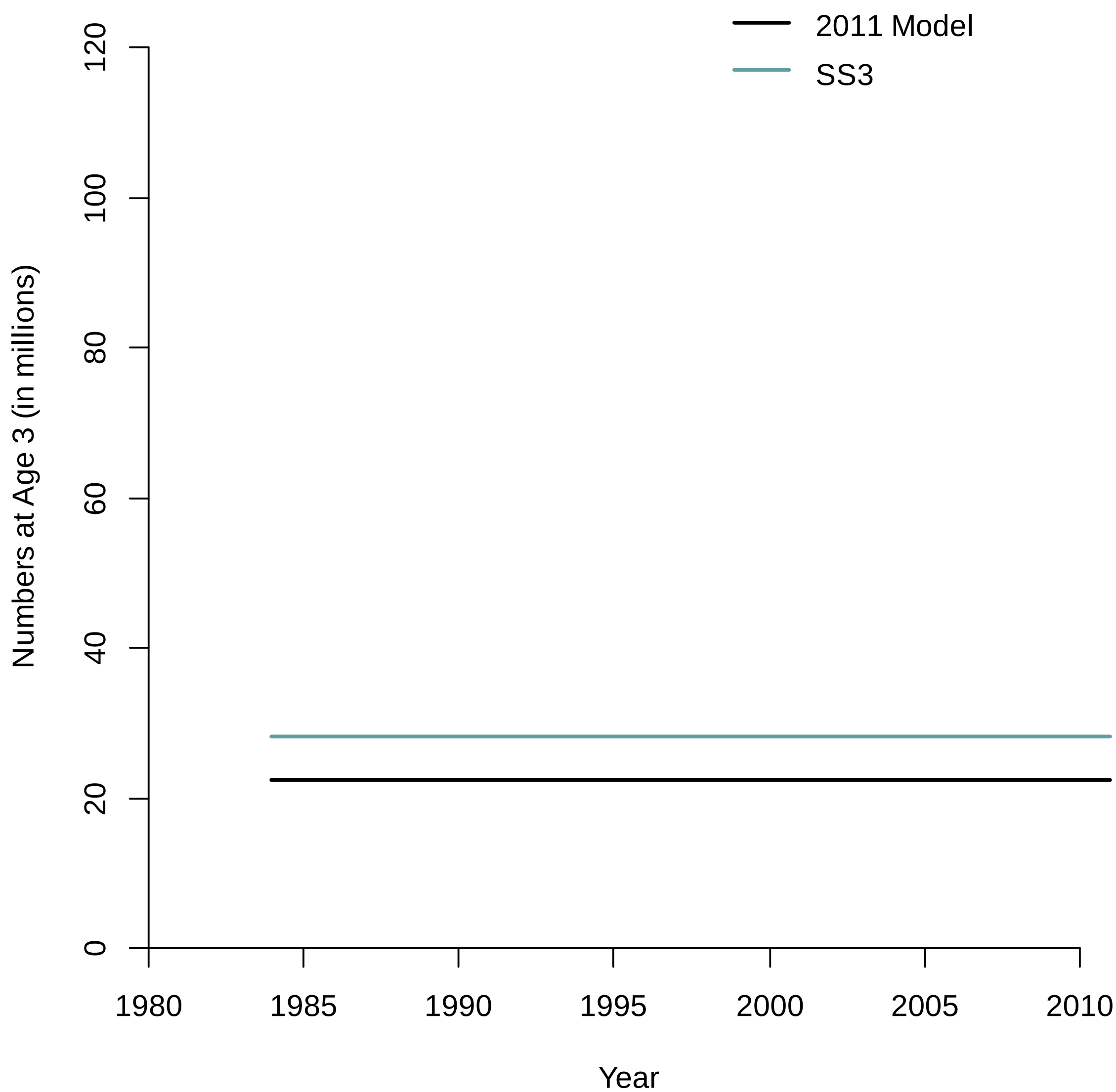


Figure 24. Numbers at age 3 for runs of the SS3 and 2011 models without estimation of recruitment deviations.

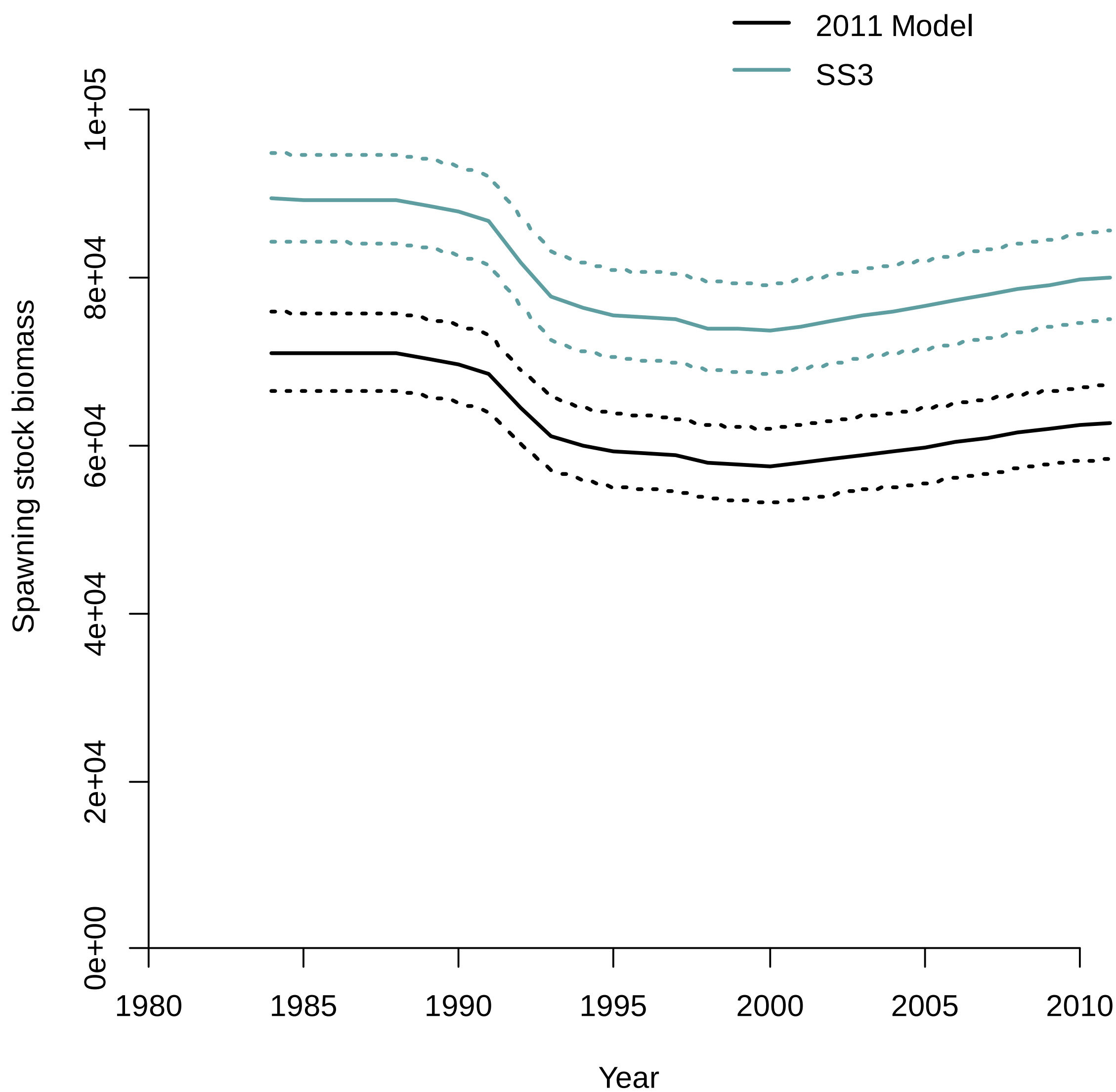


Figure 25. Spawning stock biomass for runs of the SS3 and 2011 models without estimation of recruitment deviations.

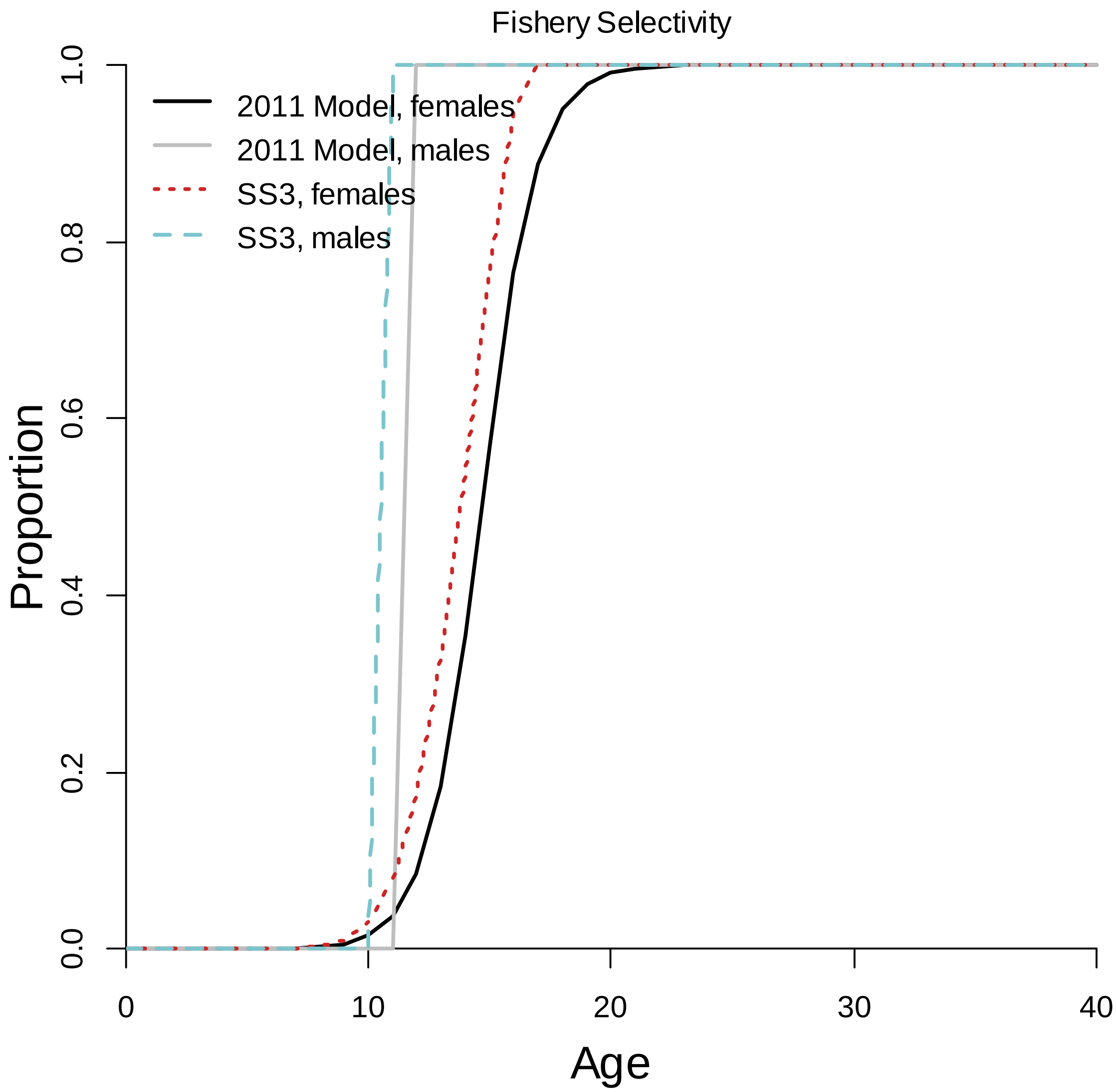


Figure 26. Fishery selectivity for runs of the SS3 and 2011 models without estimation of recruitment deviations.

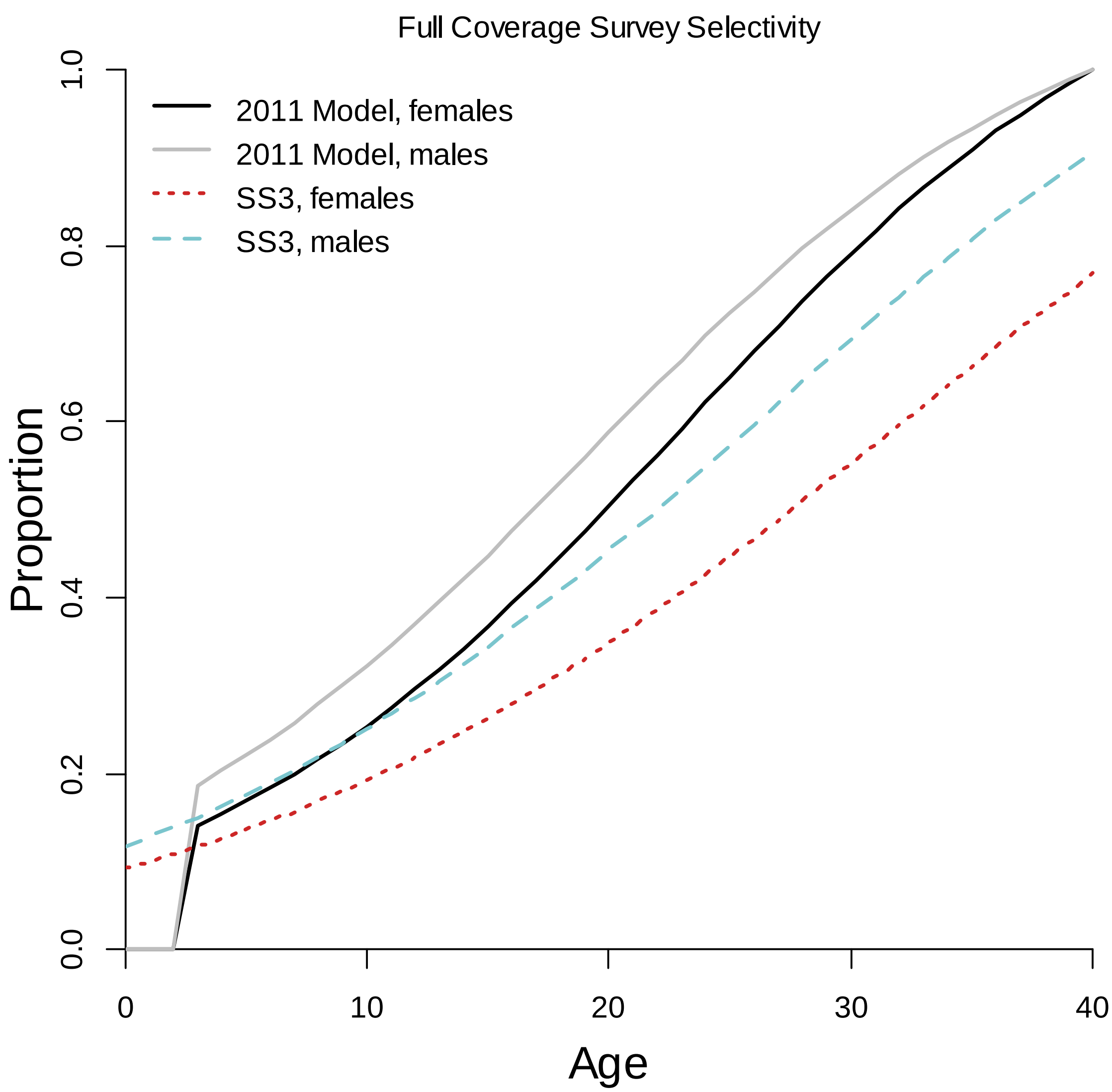


Figure 27. Full coverage survey selectivity for runs of the SS3 and 2011 models without estimation of recruitment deviations.

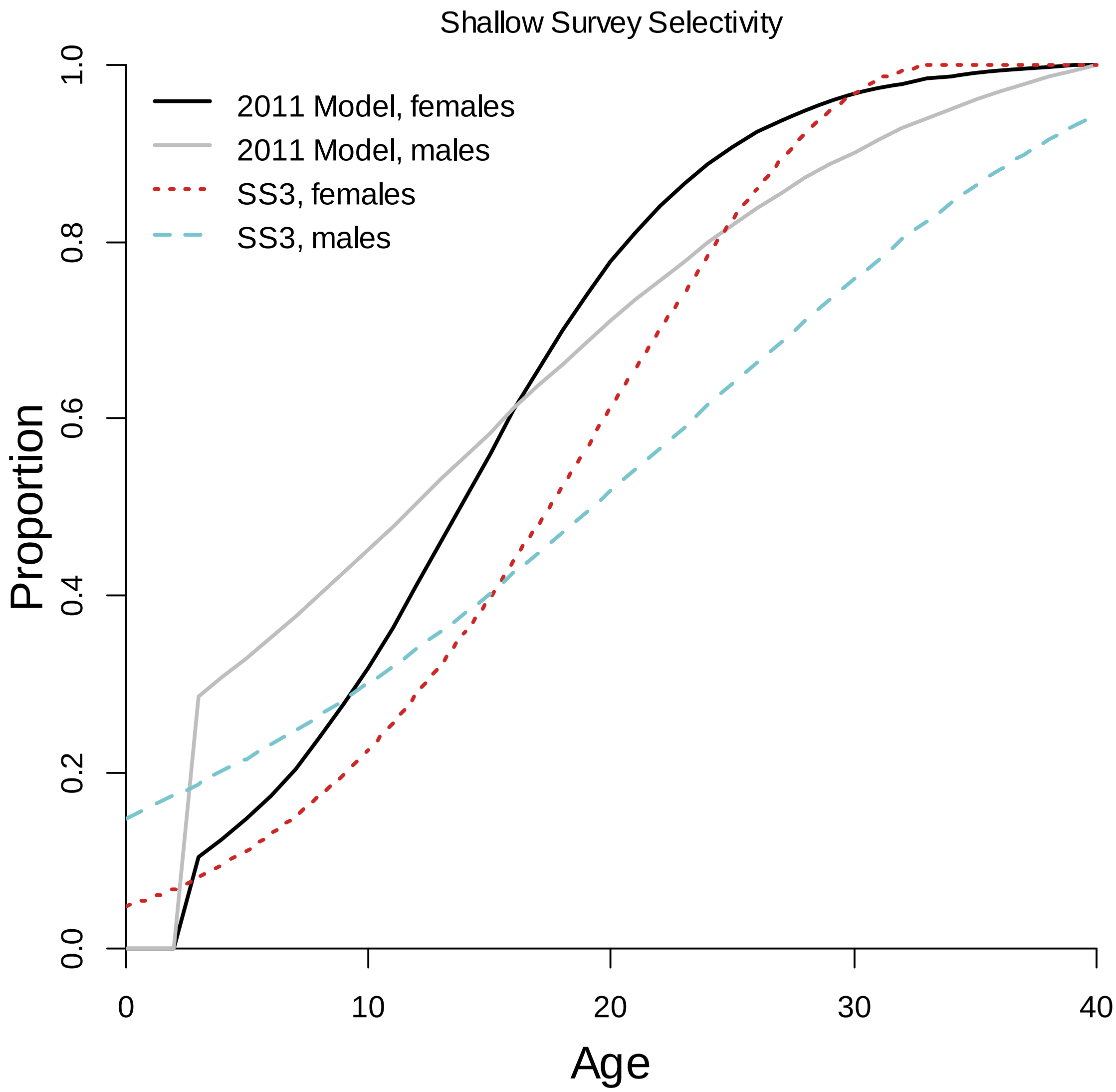


Figure 28. Shallow water survey selectivity for runs of the SS3 and 2011 models without estimation of recruitment deviations.

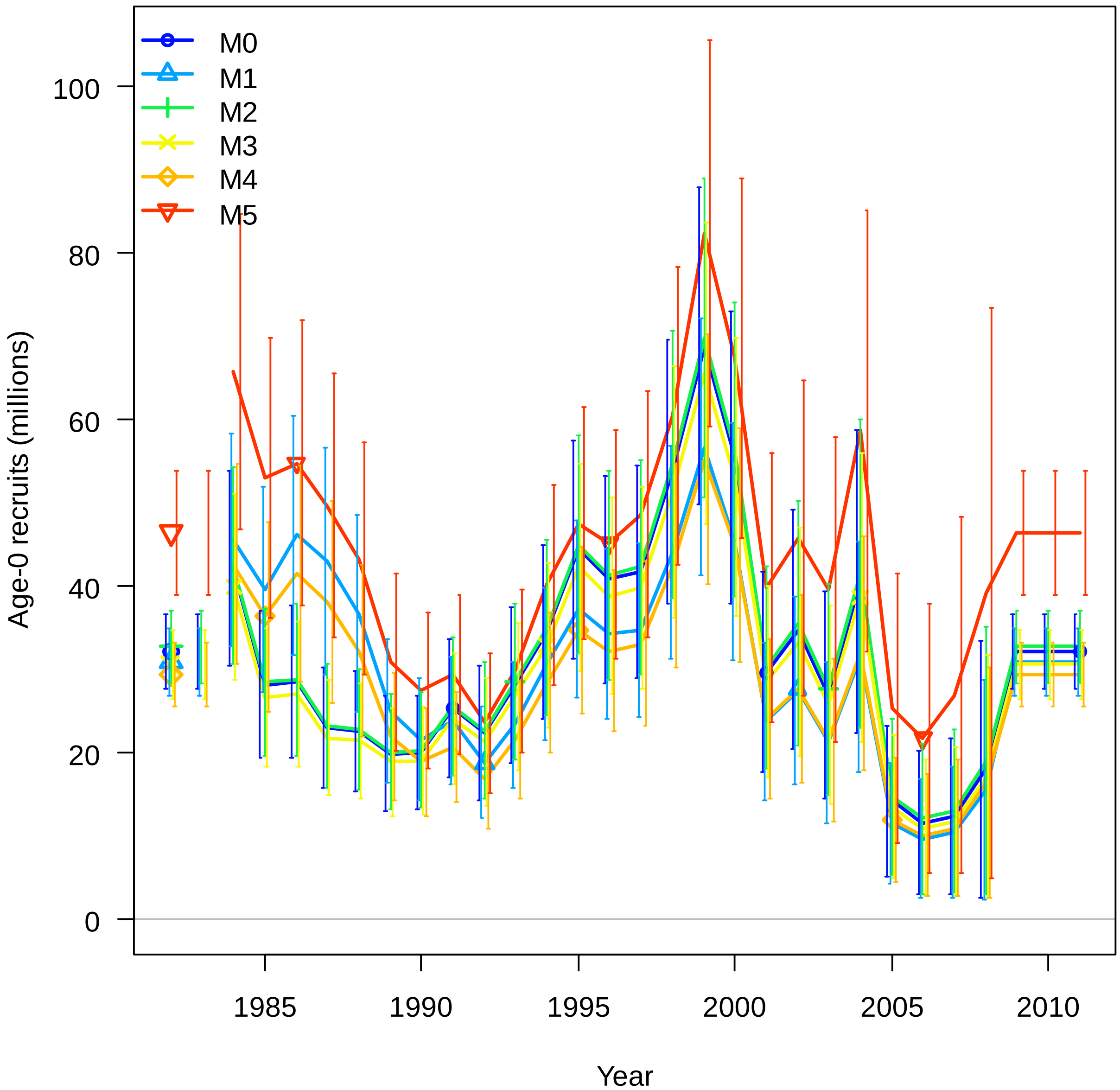


Figure 29. Age 0 recruits and 95% asymptotic confidence intervals for each alternative SS3 model. M0 is the transitional SS3 model that best matches the 2011 model. The leftmost group of vertical lines shows the log of mean recruitment.

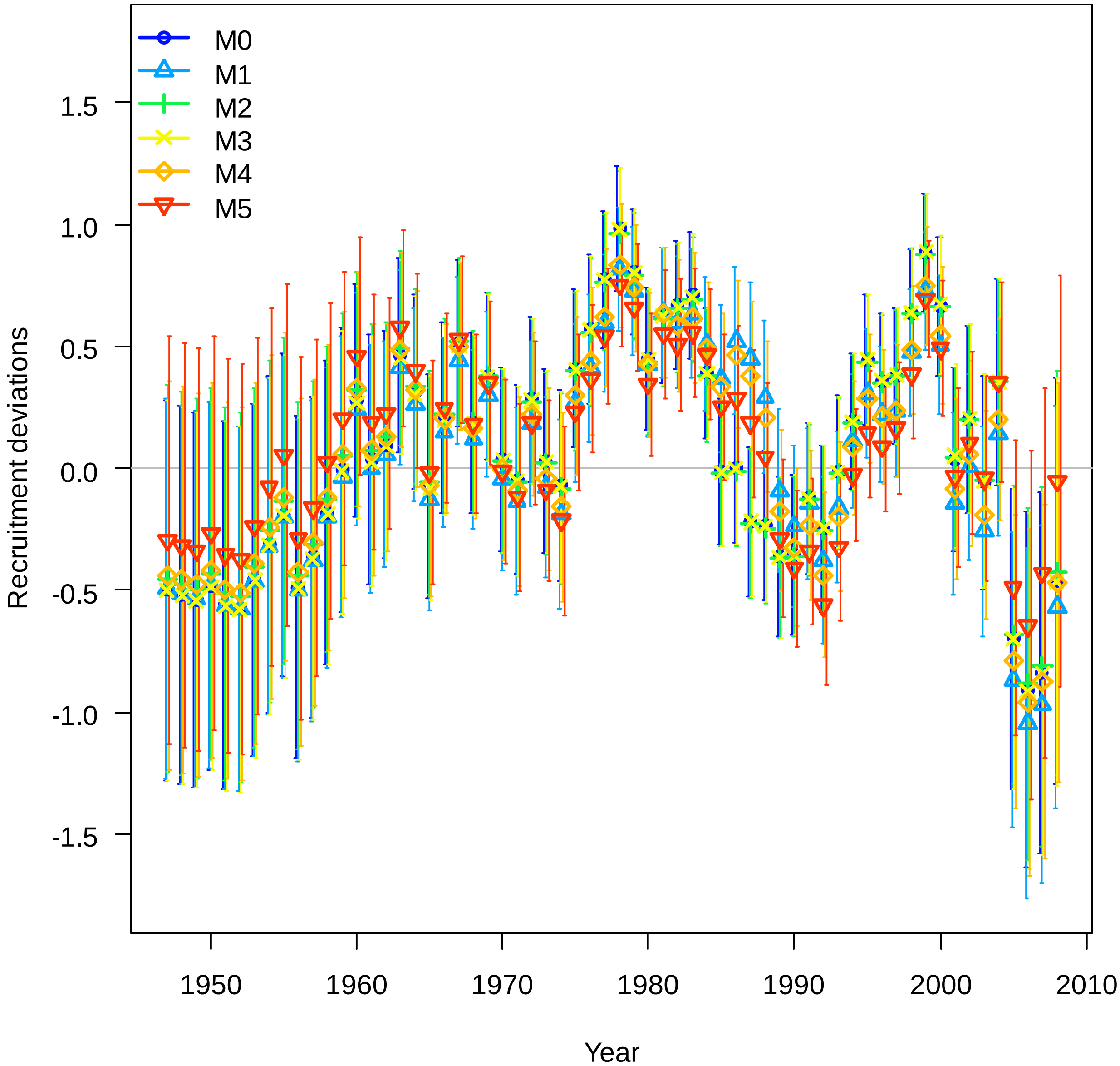


Figure 30. Estimated recruitment deviations and 95% asymptotic confidence intervals for each alternative SS3 model. M0 is the transitional SS3 model that best matches the 2011 model.

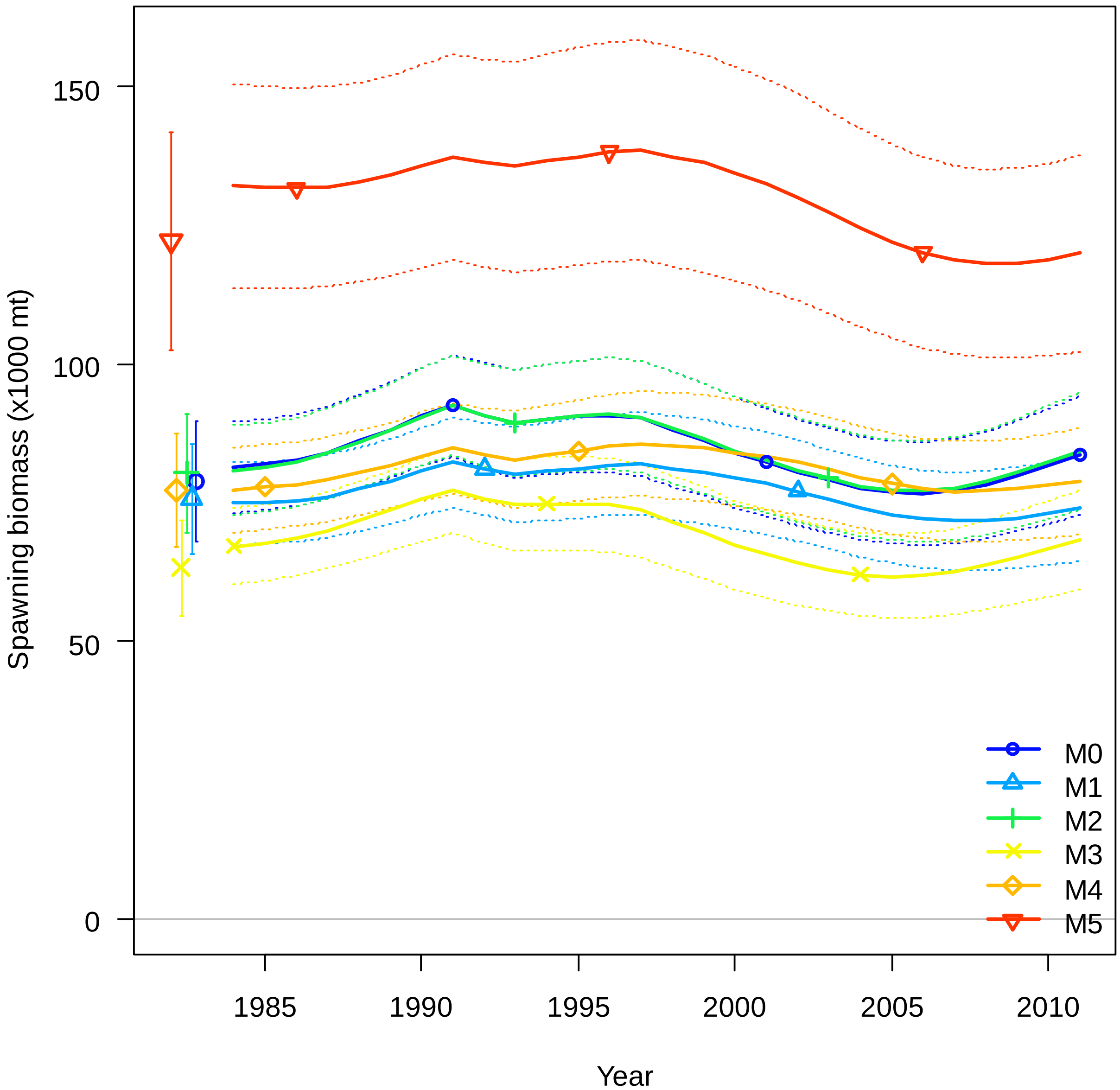
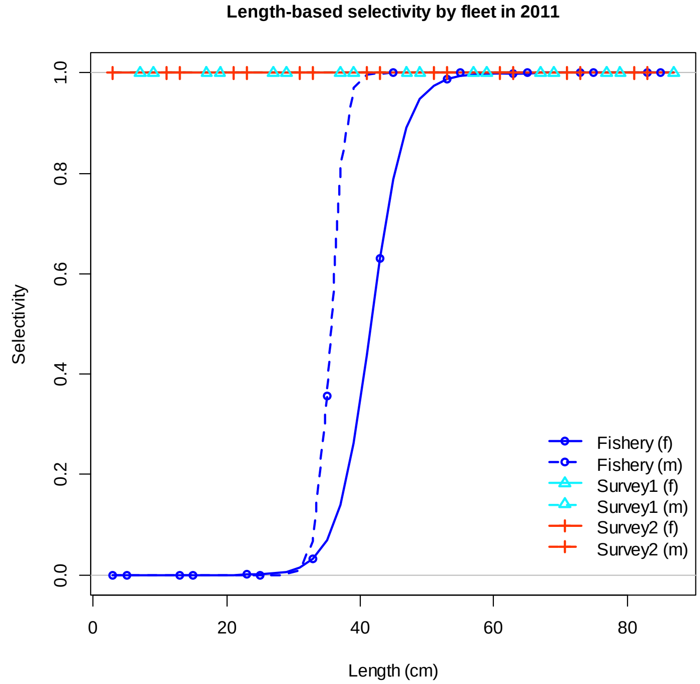


Figure 31. Spawning stock biomass (solid lines) and 95% asymptotic confidence intervals (dotted lines) over time for each alternative SS3 model. M0 is the transitional SS3 model that best matches the 2011 model.



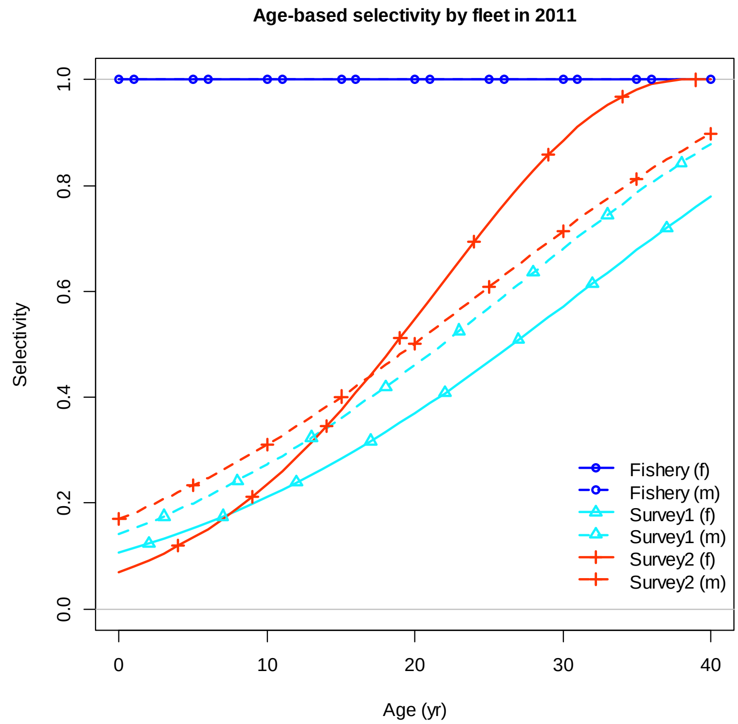


Figure 32. Length-based fishery selectivity (top panel) and age-based survey selectivity (bottom panel) for model M1 (as for the transitional SS3 model, but with length-based, logistic, sex-specific fishery selectivity).

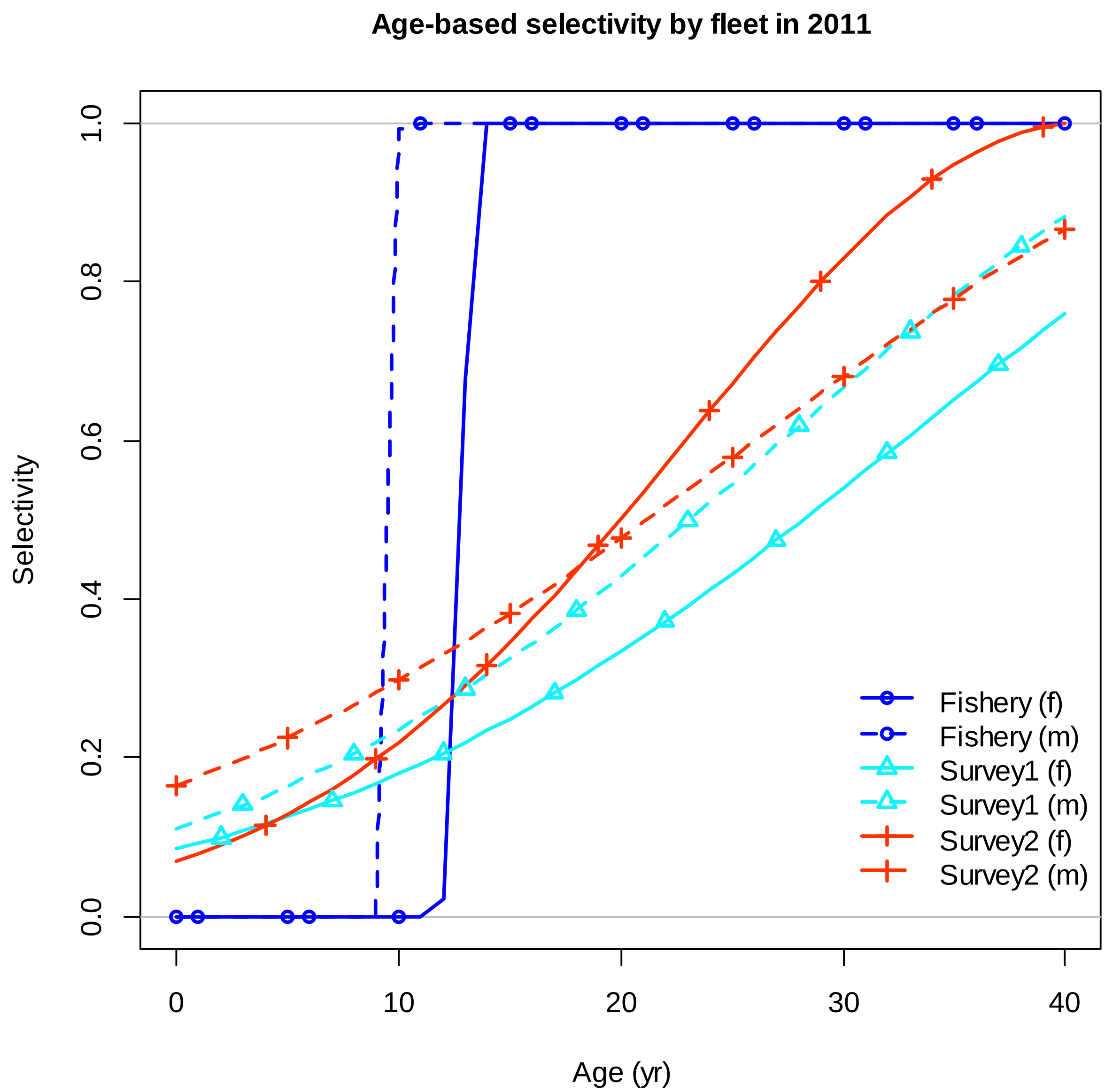


Figure 33. Fishery and survey selectivity curves for model M2 (as for the transitional SS3 model, but estimates an initial fishing mortality rate).

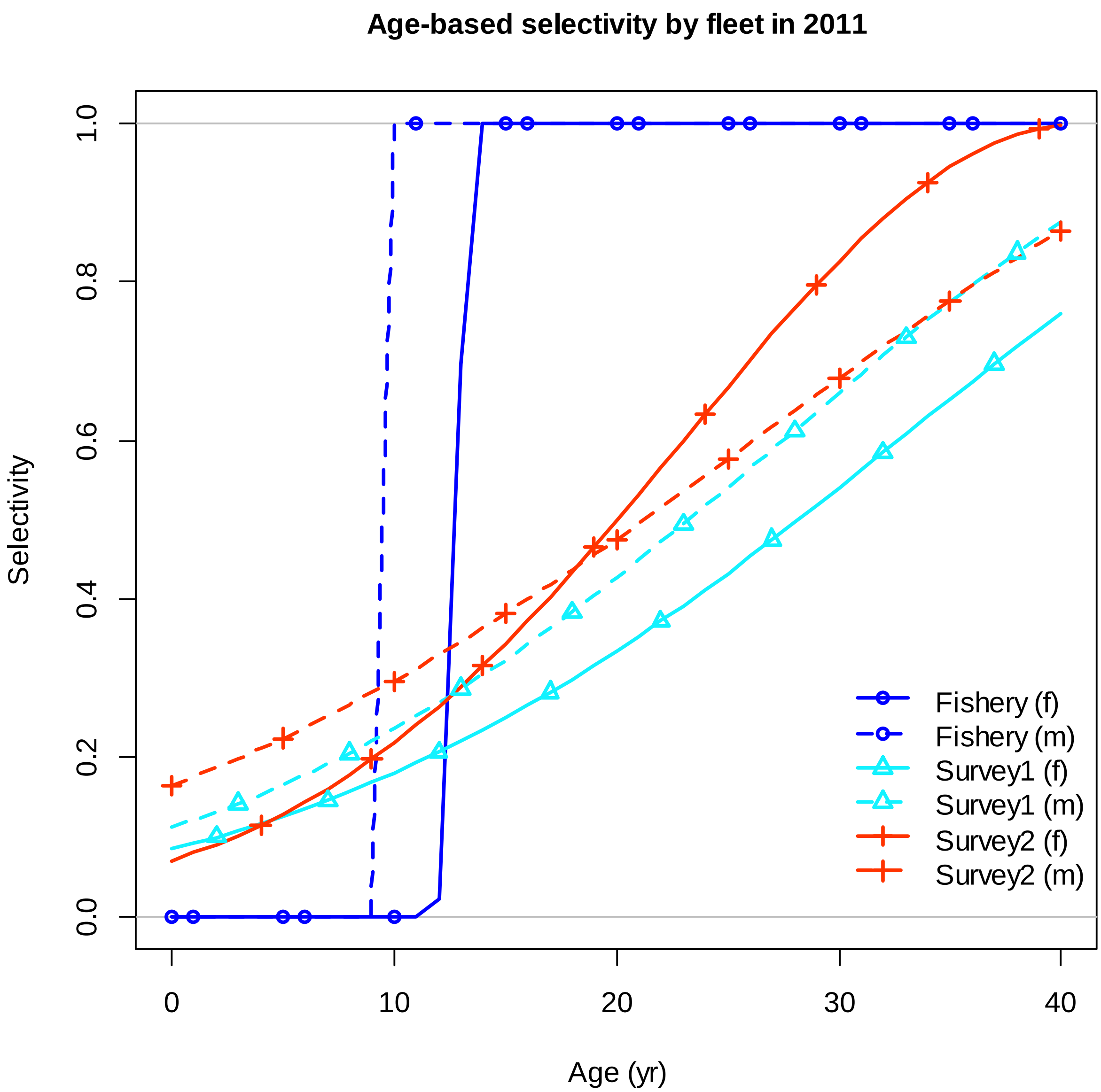
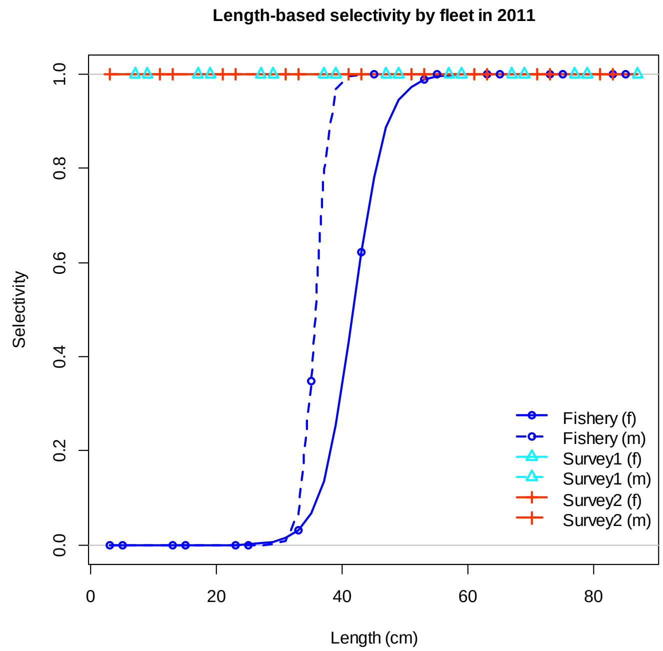


Figure 34. Selectivity curves for model M3 (as for the transitional SS3 model, but with fixed internal growth parameters specified).



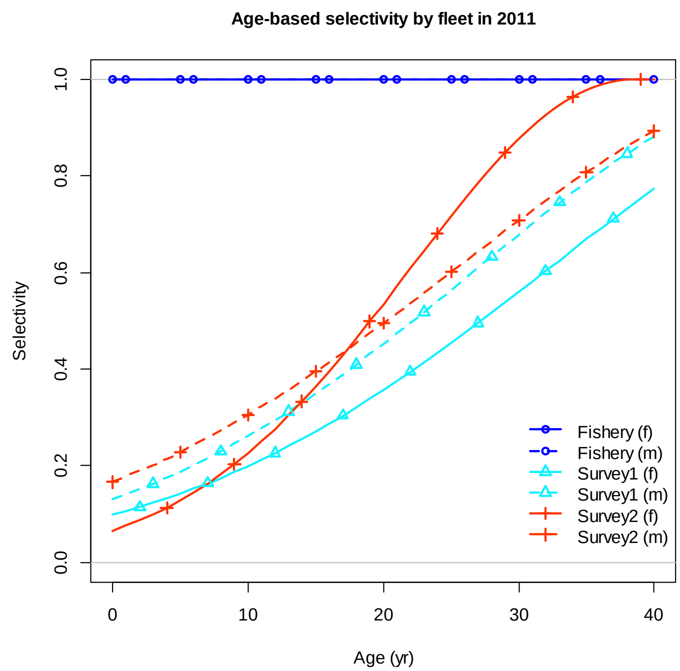


Figure 35. Selectivity curves for model M4 (as for the transitional SS3 model, but with fixed internal growth parameters, estimated initial equilibrium F, and length-based, logistic, sex-specific fishery selectivity). The top panel shows length-based fishery selectivity and the bottom panel shows age-based survey selectivity.

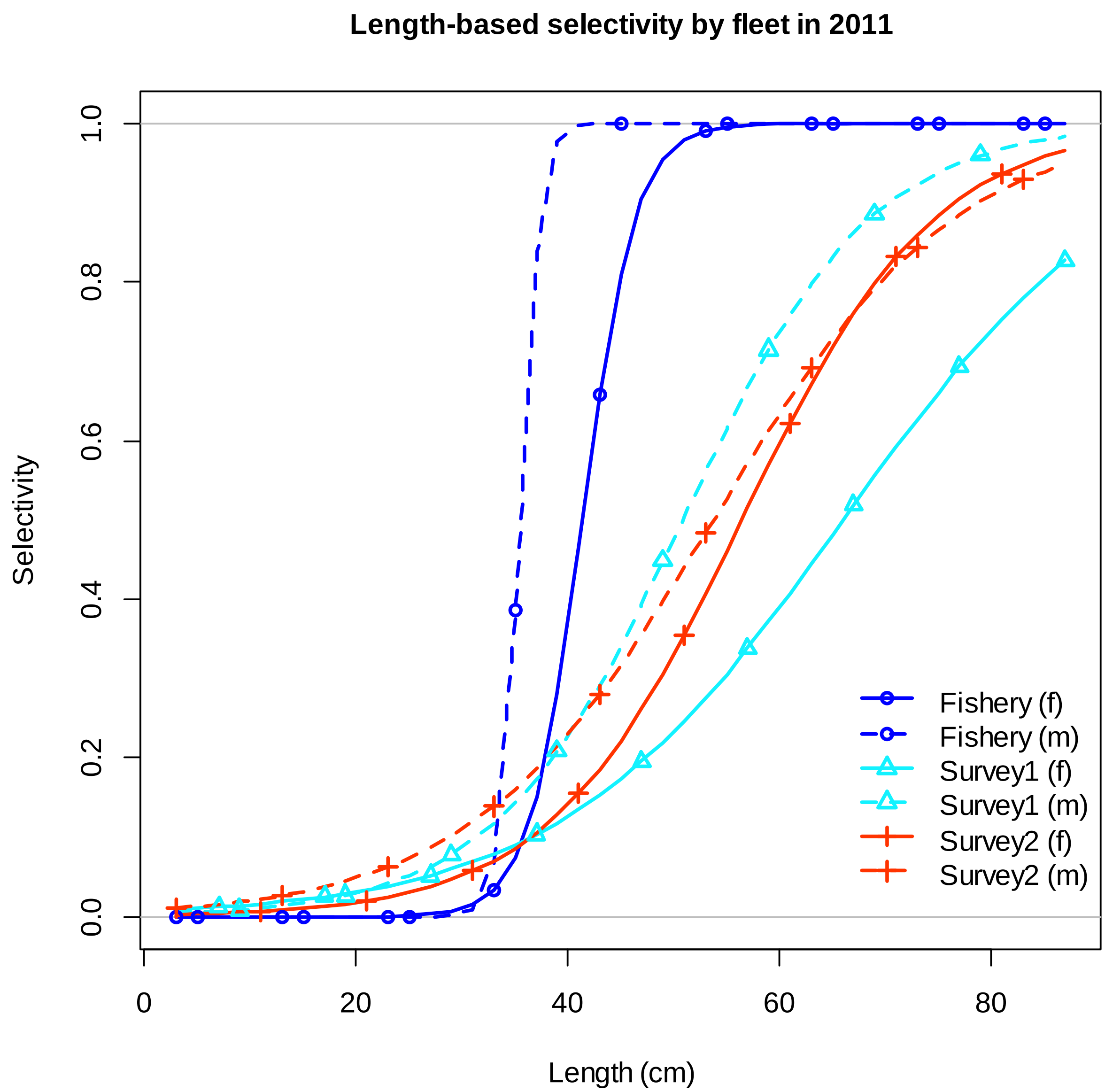


Figure 36. Length-based, logistic, sex-specific selectivity for the fishery, the full coverage survey (Survey1) and the shallow-water survey (Survey2) for model M5 (M5: internal, fixed growth parameters, estimation of initial equilibrium F, and length-based selectivity for the fishery and both surveys).

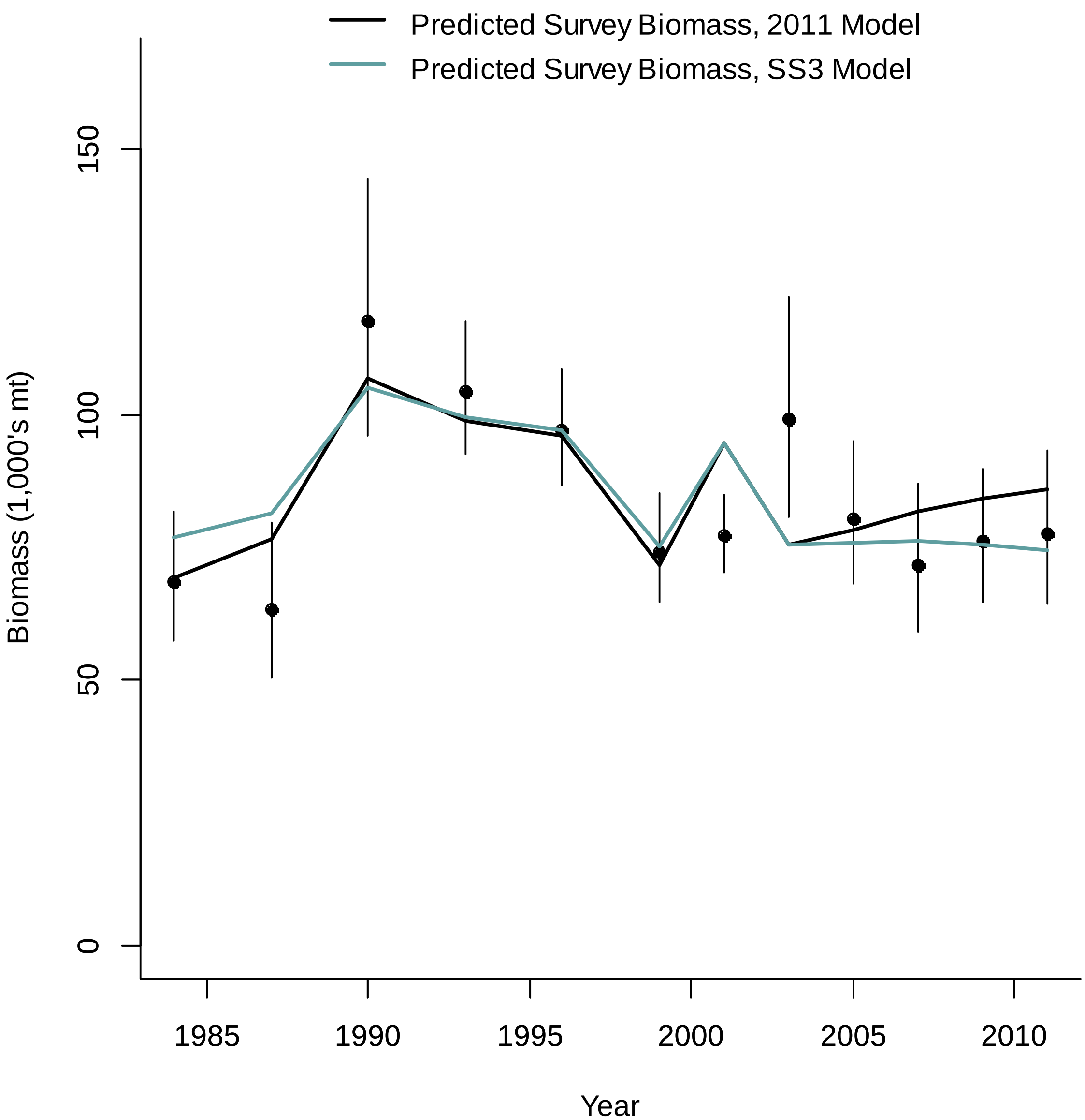


Figure 37. Observed survey biomass (black dots) with 95% asymptotic confidence intervals (vertical black lines) and predicted survey biomass for the proposed alternative model M4 (as for the transitional SS3 model, but with fixed internal growth parameters, estimated initial equilibrium F, and length-based, logistic, sex-specific fishery selectivity; blue lines) and the 2011 model (black lines).

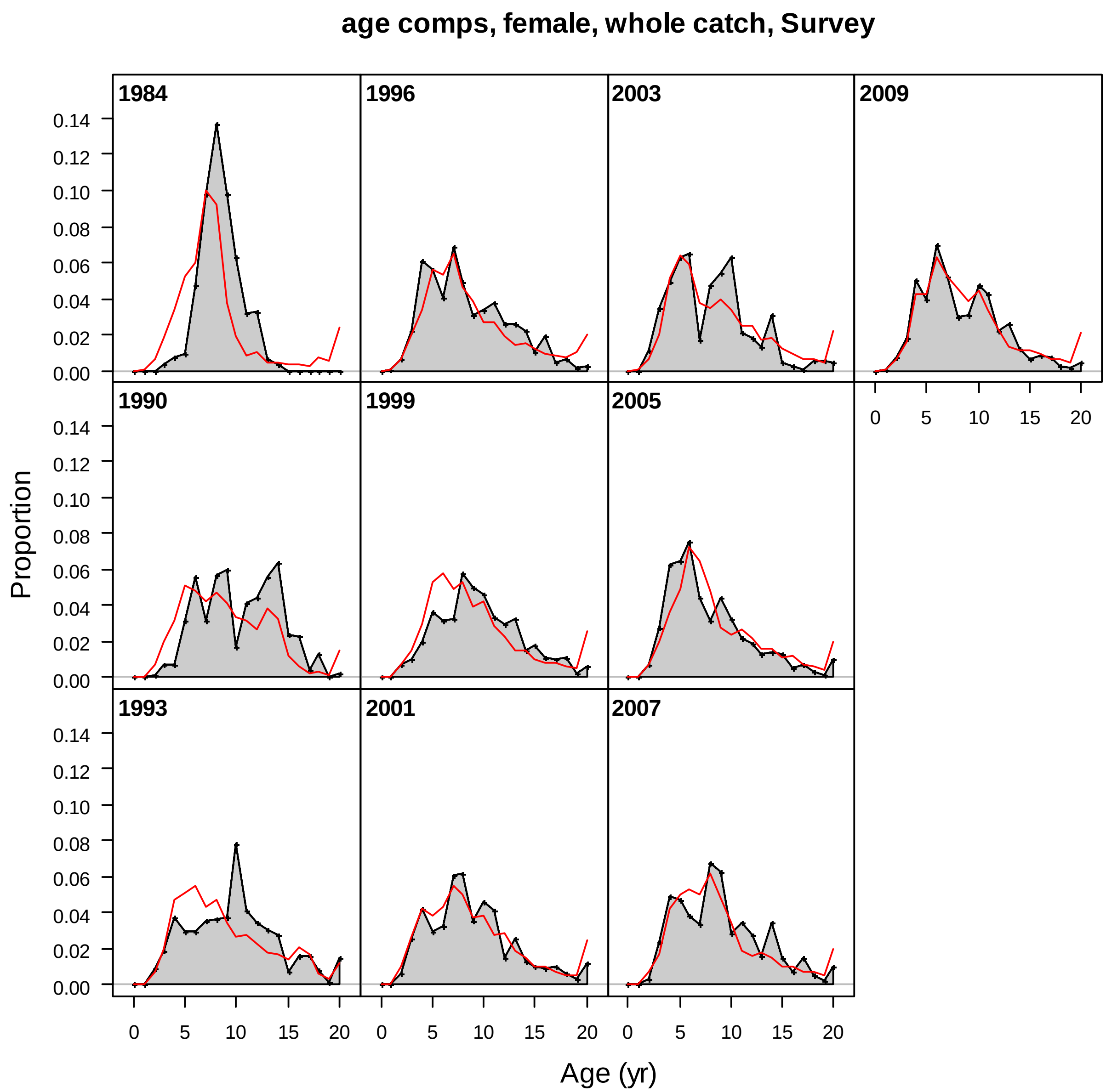


Figure 38. (1 of 2) Observed (solid black lines and grey shaded area) and predicted (red lines) full-coverage survey proportions-at-age for proposed alternative model M4 (where growth parameters are specified internally, an initial equilibrium fishing mortality rate is calculated, and fishery selectivity is a logistic, sex-specific, length-based function) for females (first panel) and males (second panel).

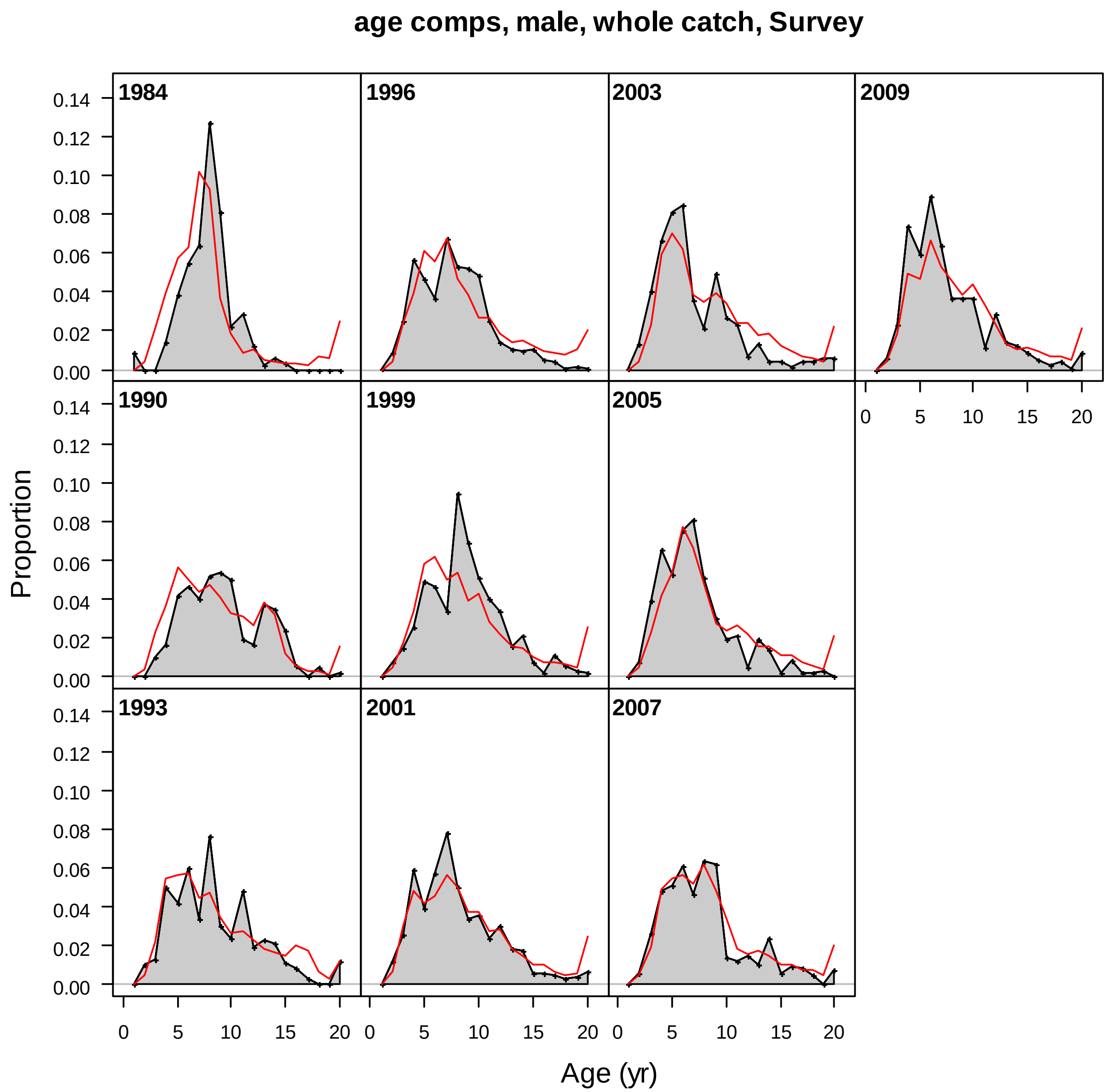


Figure 38, continued (2 of 2)

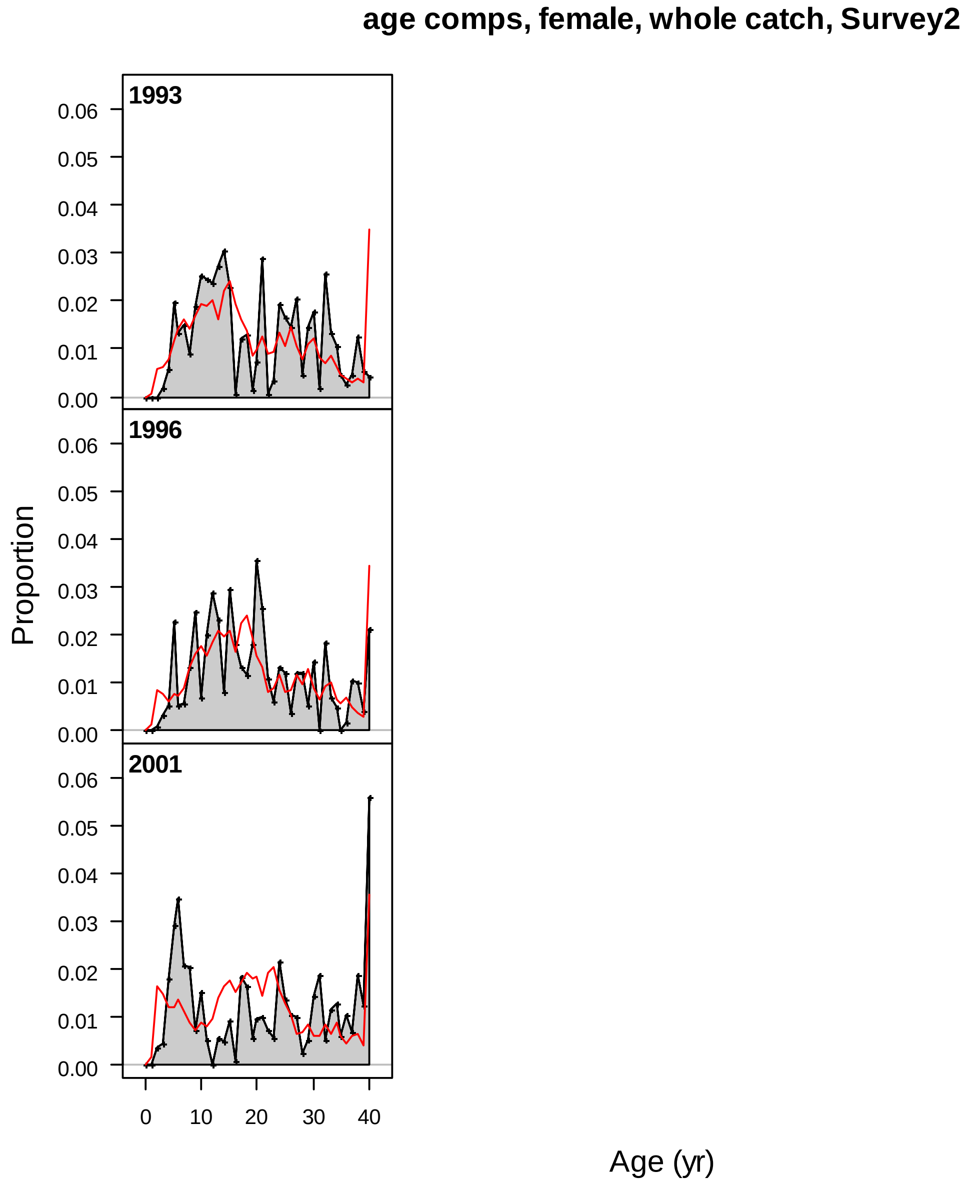


Figure 39. (1 of 2) Observed (solid black lines and grey shaded area) and predicted (red lines) shallow-water survey proportions-at-age for proposed alternative model M4 (where growth parameters are specified internally, an initial equilibrium fishing mortality rate is calculated, and fishery selectivity is a logistic, sex-specific, length-based function) for females (first panel) and males (second panel).

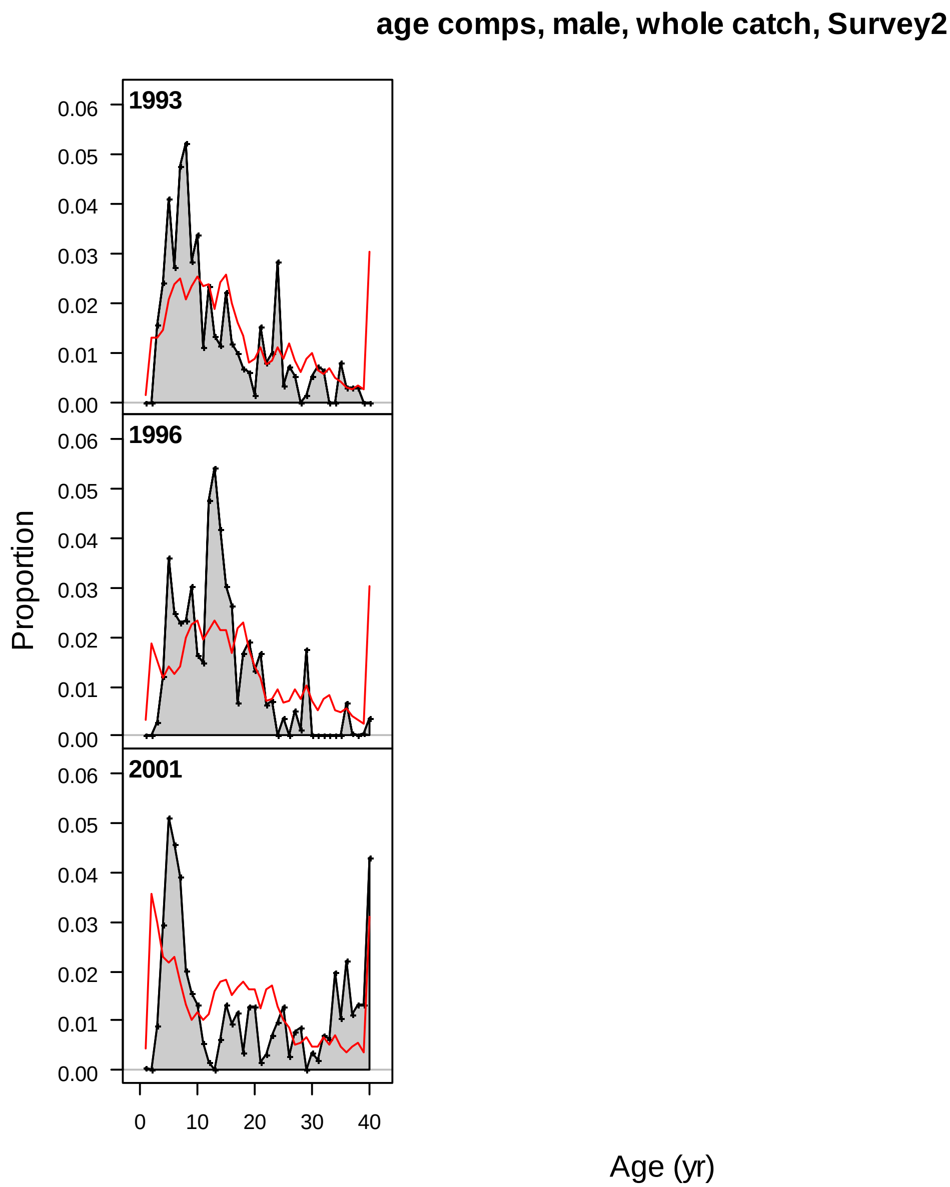


Figure 39, continued (2 of 2)

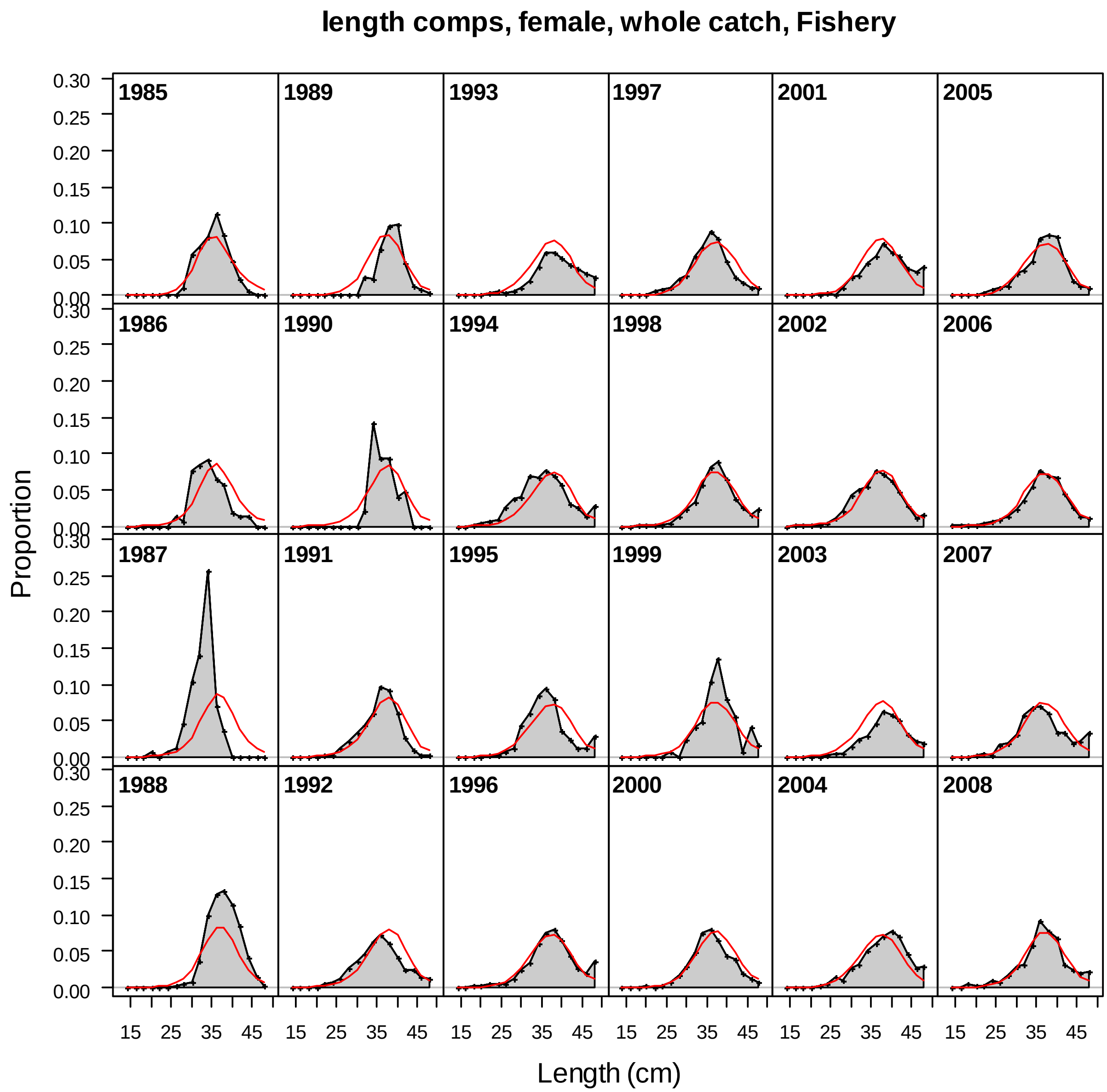


Figure 40. (1 of 4) Observed (solid black lines and grey shaded area) and predicted (red lines) fishery proportions-at-length proposed alternative model M4 (where growth parameters are specified internally, an initial equilibrium fishing mortality rate is calculated, and fishery selectivity is a logistic, sex-specific, length-based function) for females (first set of panels) and males (second set of panels).

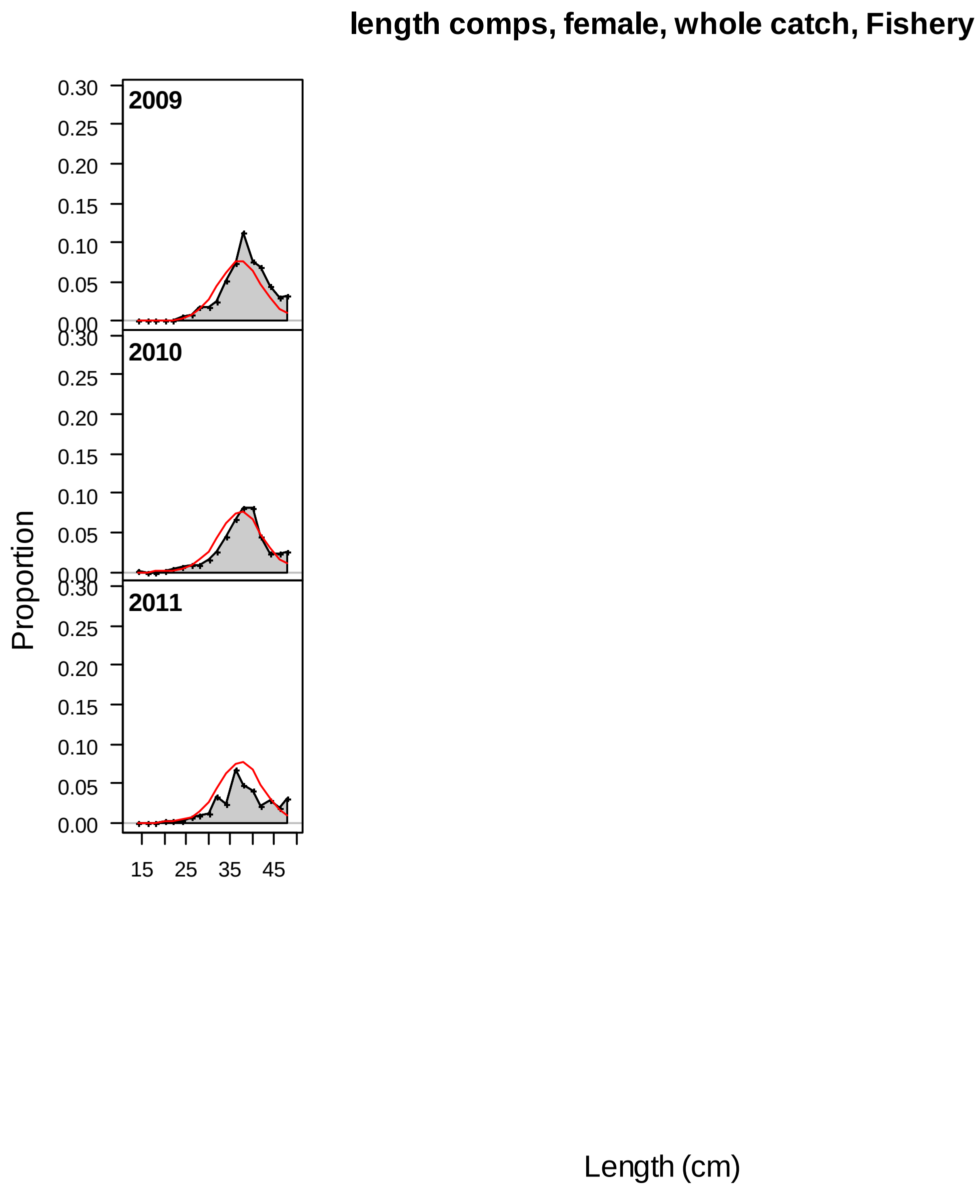


Figure 40, continued (2 of 4)

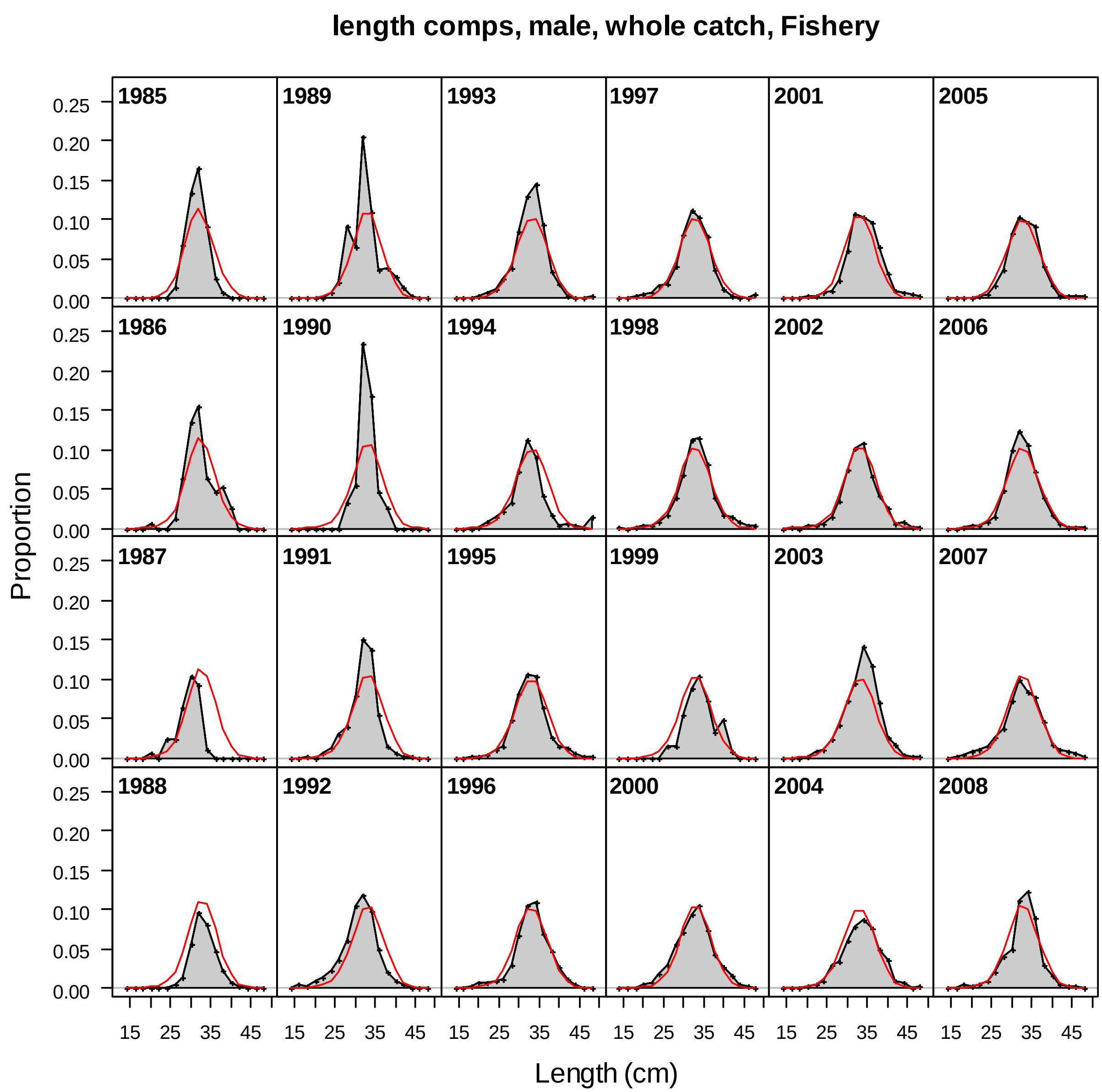


Figure 40, continued (3 of 4)

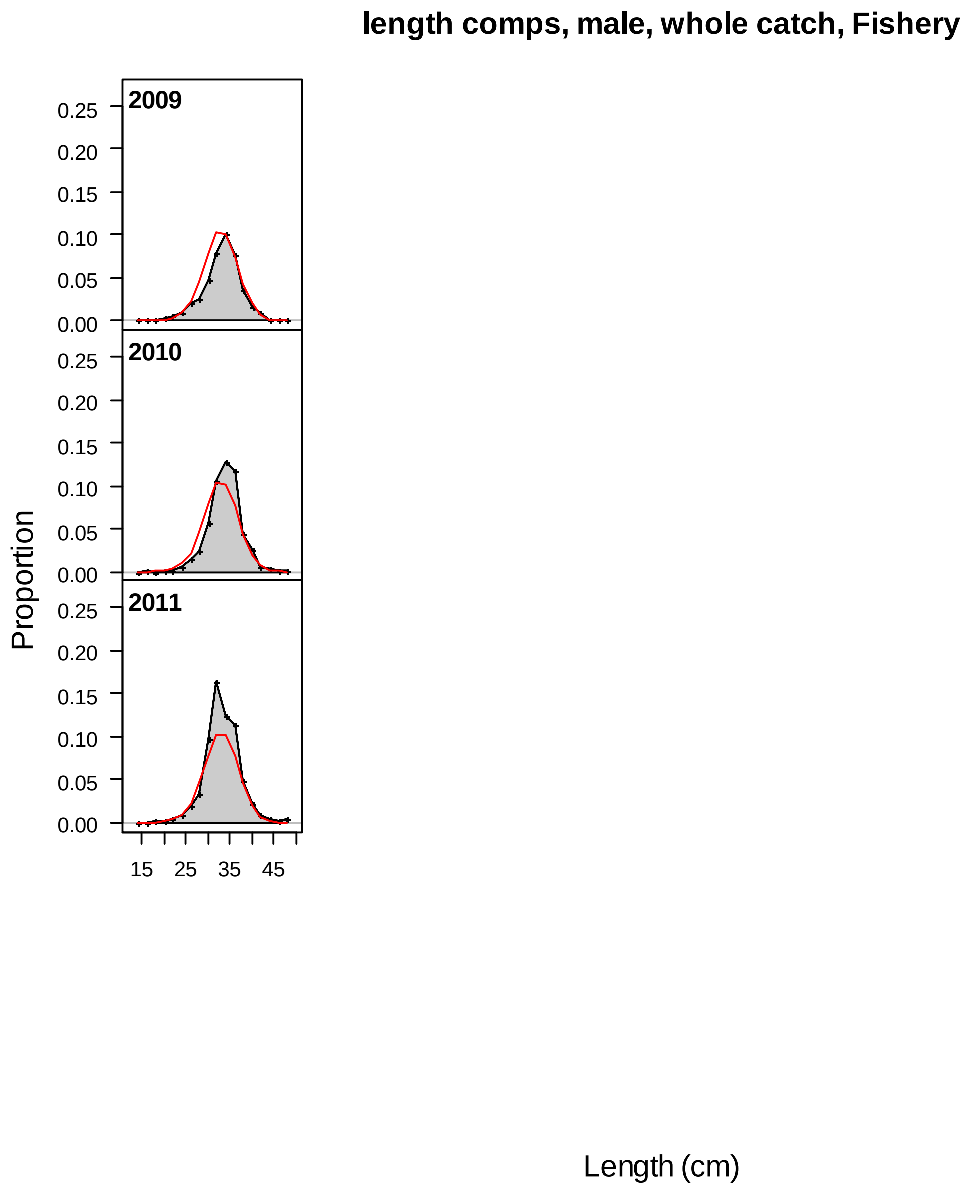


Figure 40, continued (4 of 4)

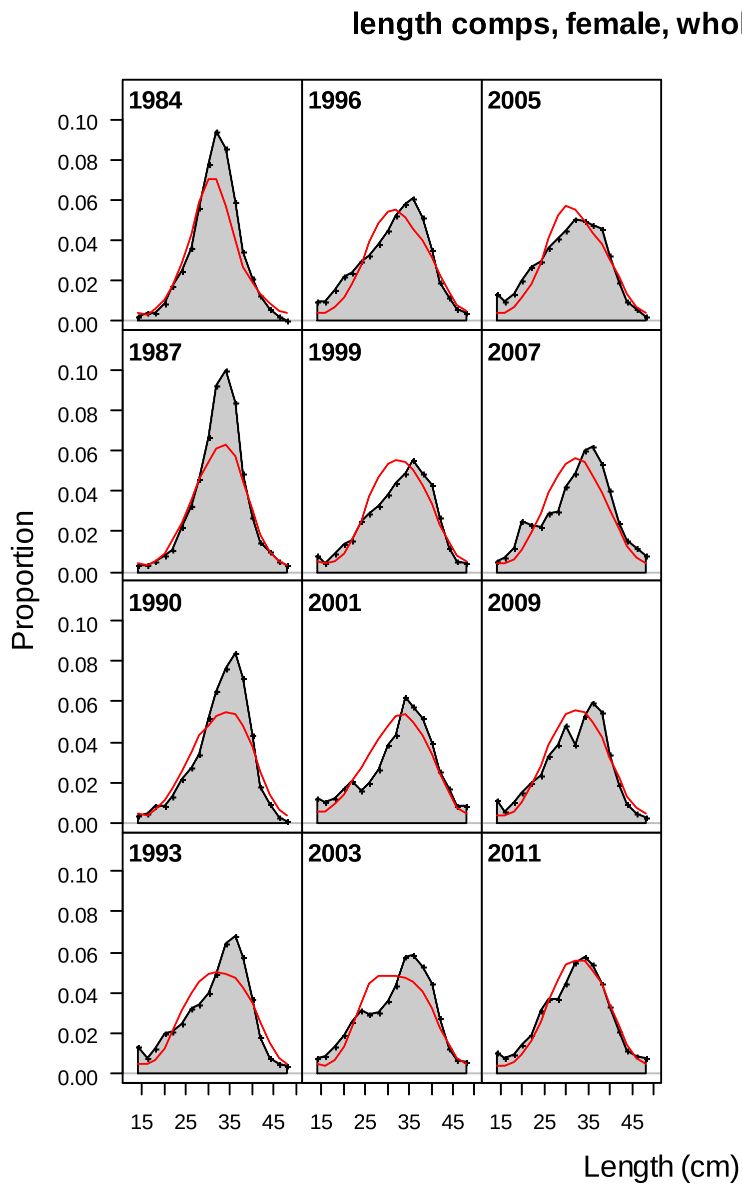


Figure 41. (1 of 2) Observed (solid black lines and grey shaded area) and predicted (red lines) full-coverage survey proportions-at-length for proposed alternative model M4 (where growth parameters are specified internally, an initial equilibrium fishing mortality rate is calculated, and fishery selectivity is a logistic, sex-specific, length-based function) for females (first set of panels) and males (second set of panels).

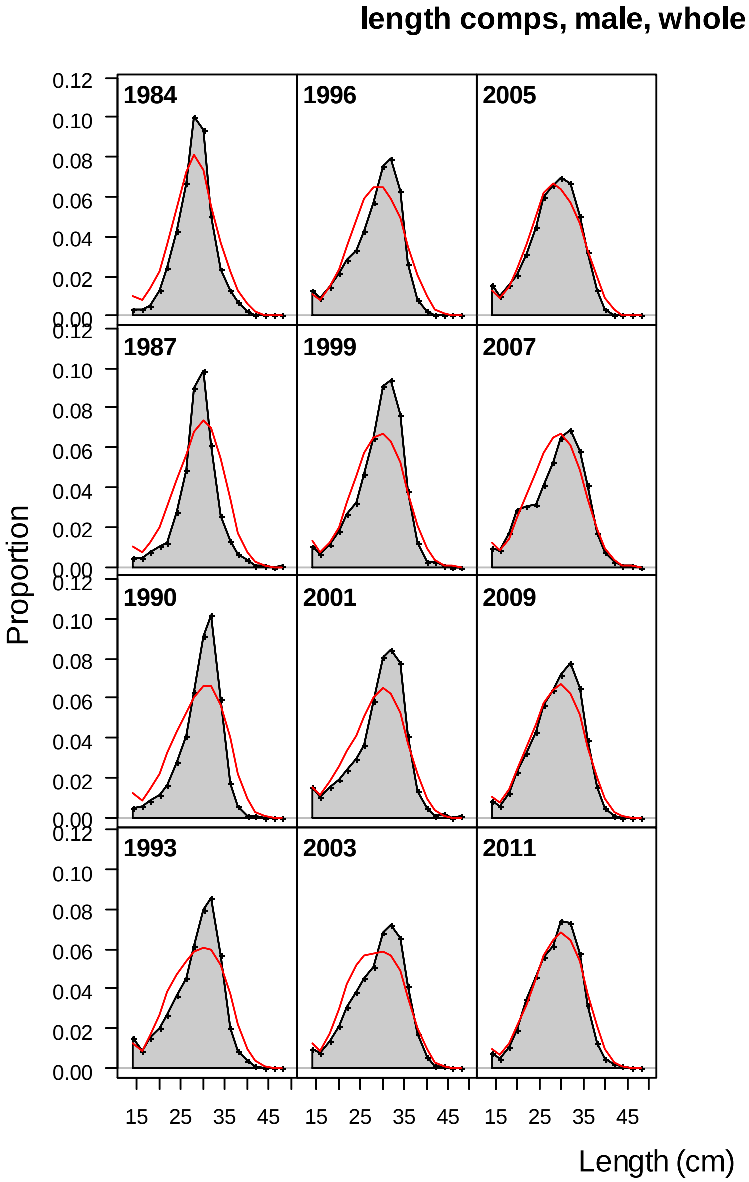


Figure 41, continued (2 of 2)

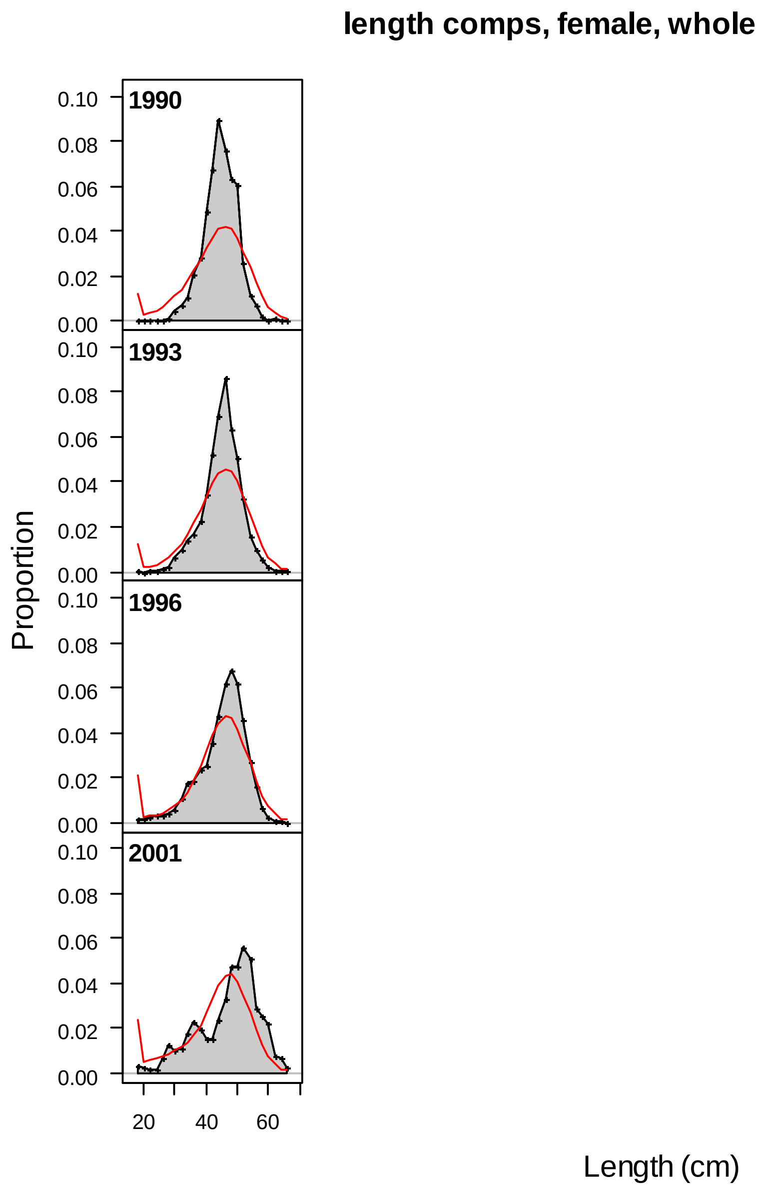


Figure 42. (1 of 2) Observed (solid black lines and grey shaded area) and predicted (red lines) shallow-water survey proportions-at-length for proposed alternative model M4 (where growth parameters are specified internally, an initial equilibrium fishing mortality rate is calculated, and fishery selectivity is a logistic, sex-specific, length-based function) for females (first set of panels) and males (second set of panels).

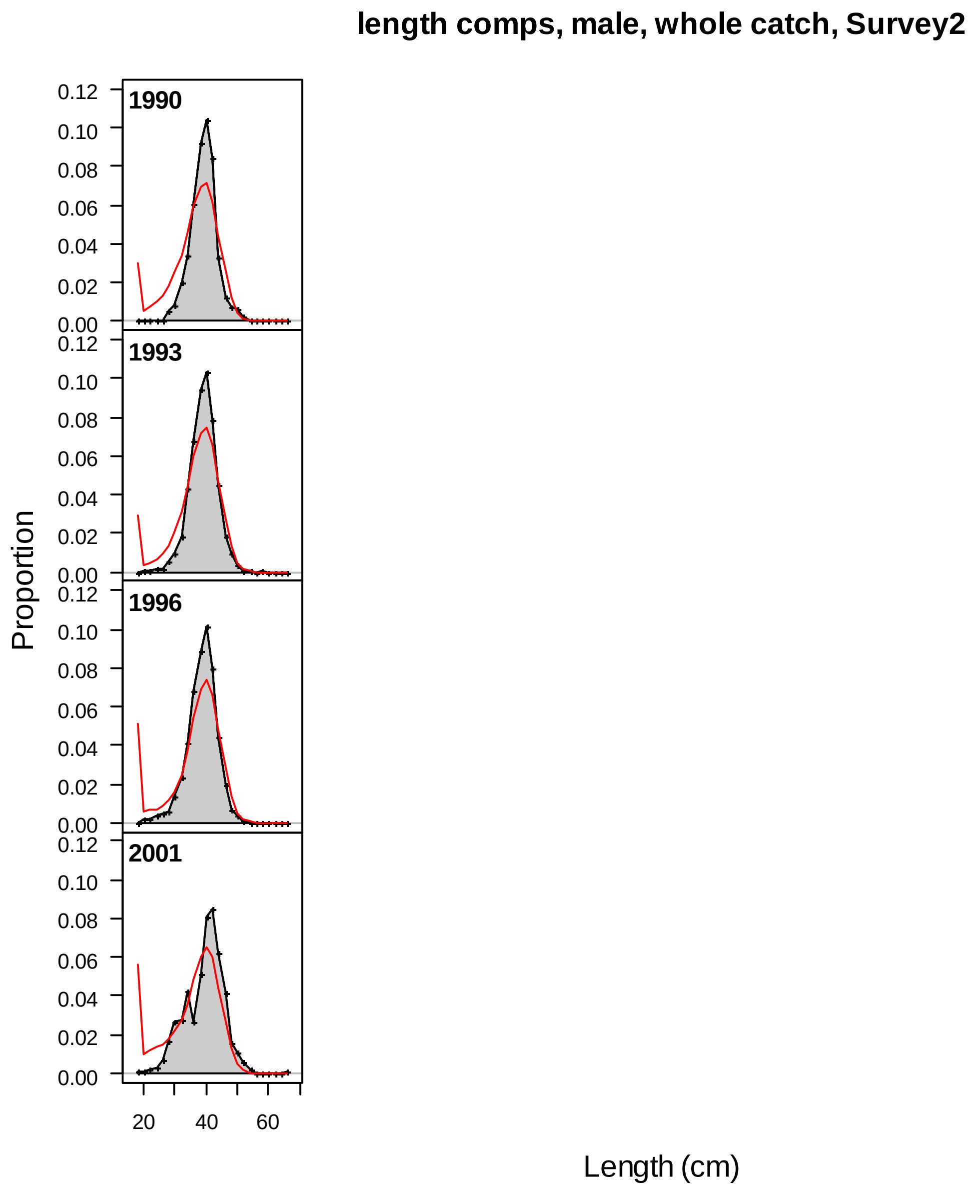


Figure 42, continued (2 of 2)

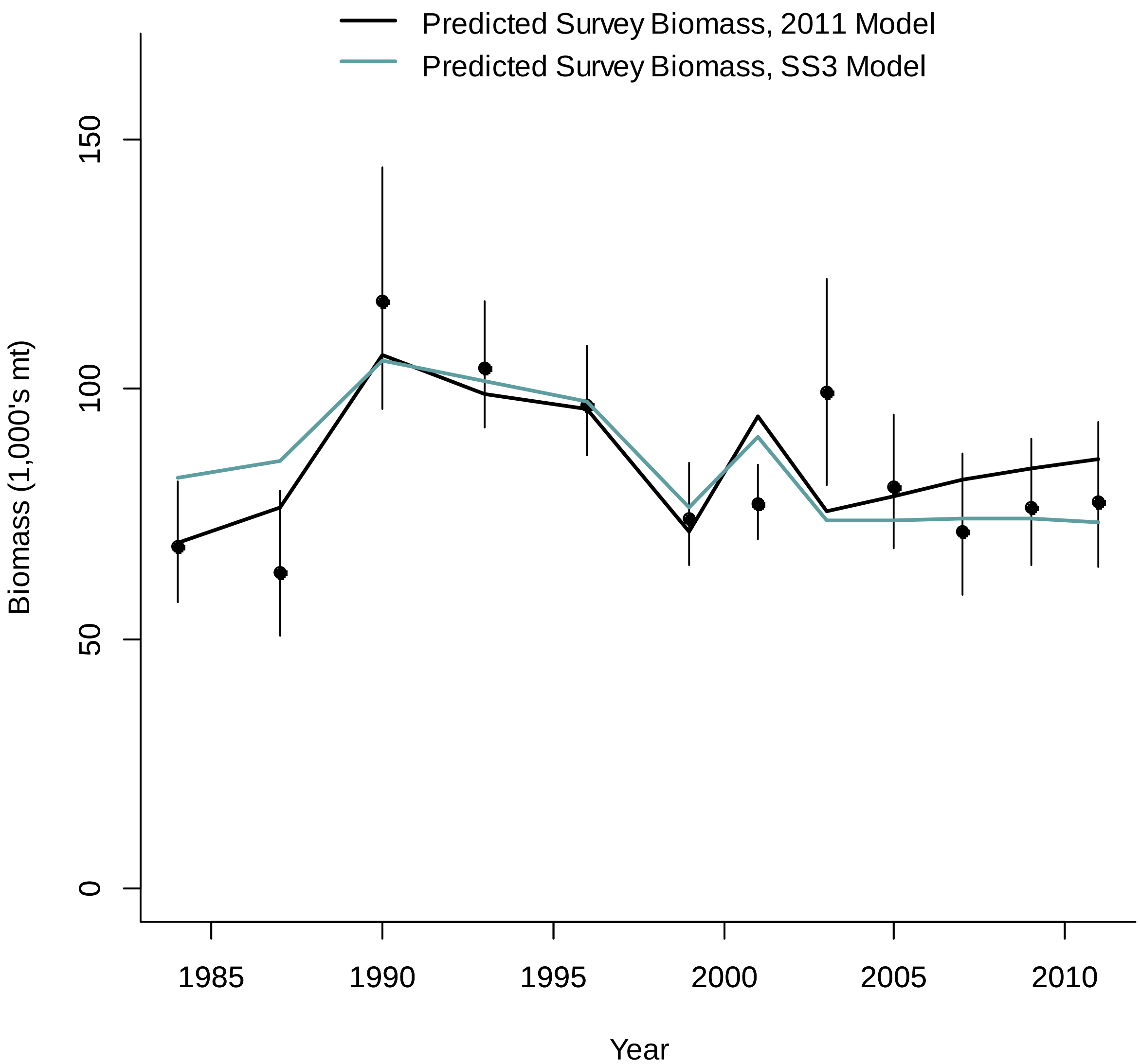


Figure 43. Observed survey biomass (black dots) with 95% asymptotic confidence intervals (vertical black lines) and predicted survey biomass for the proposed alternative model M5 (as for the transitional SS3 model, but with fixed internal growth parameters, estimated initial equilibrium F, and length-based, logistic, sex-specific fishery AND survey selectivity; blue lines) and the 2011 model (black lines).

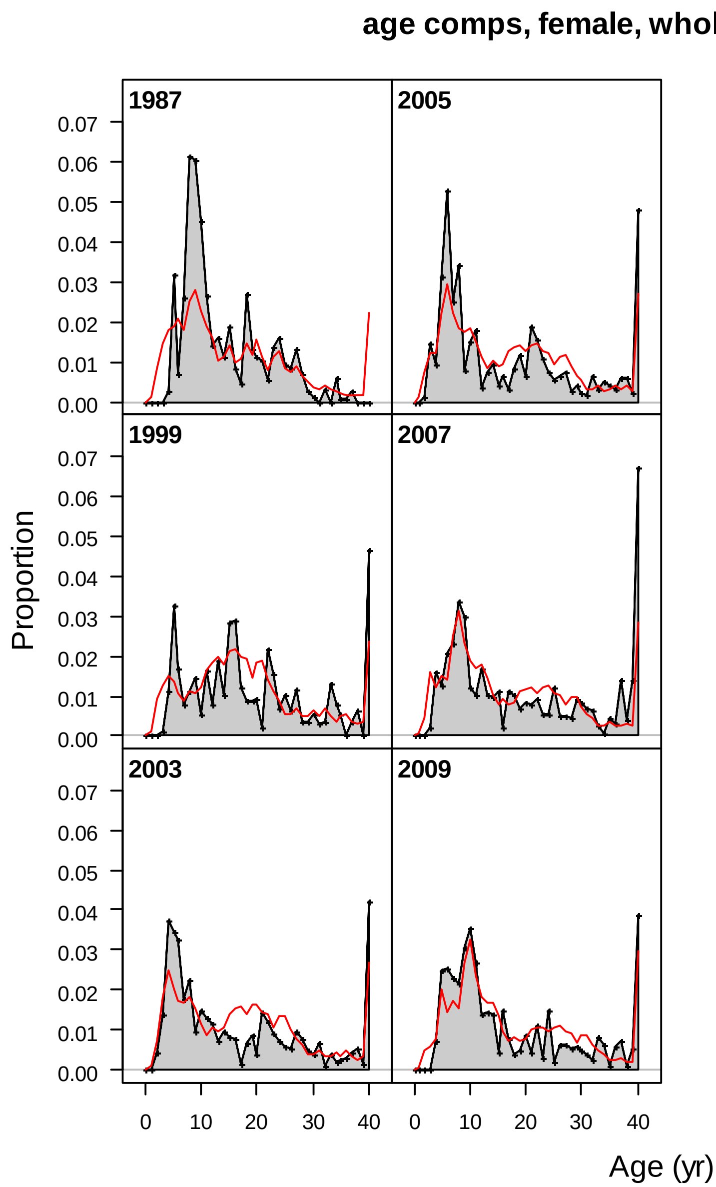


Figure 44. (1 of 2) Observed (solid black lines and grey shaded area) and predicted (red lines) full-coverage survey proportions-at-age for proposed alternative model M5 (where growth parameters are specified internally, an initial equilibrium fishing mortality rate is calculated, and fishery AND survey selectivity are logistic, sex-specific, length-based functions) for females (first panel) and males (second panel).

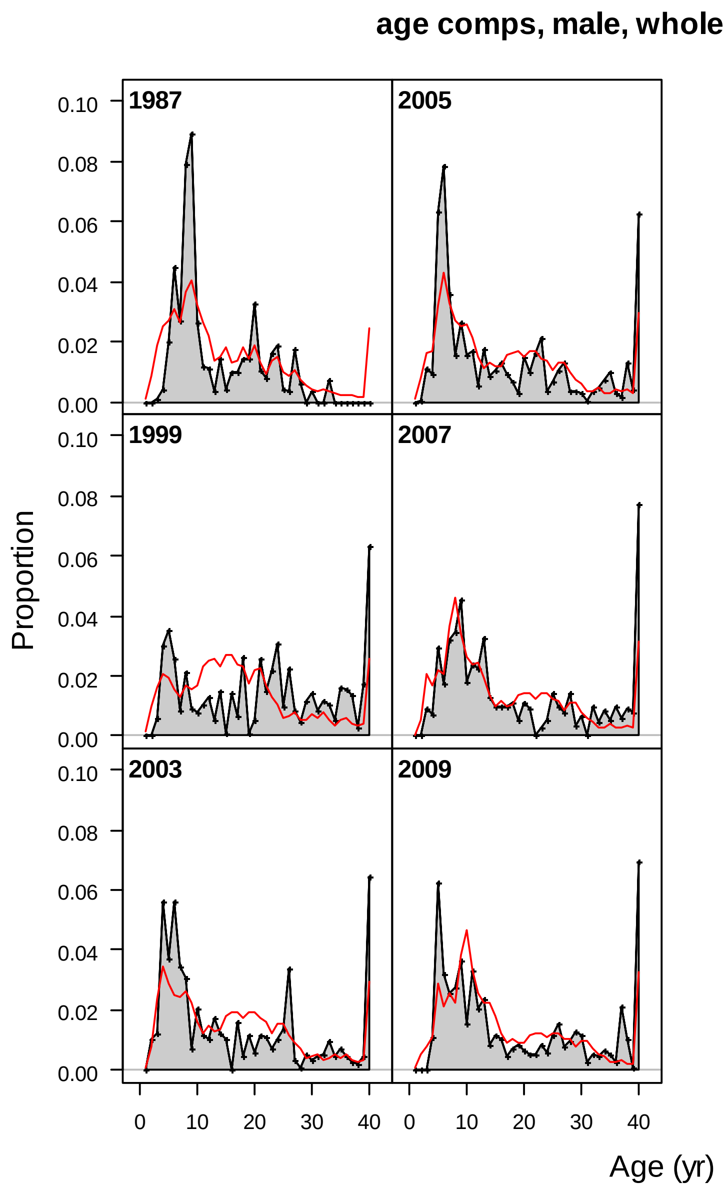


Figure 44, continued (2 of 2)

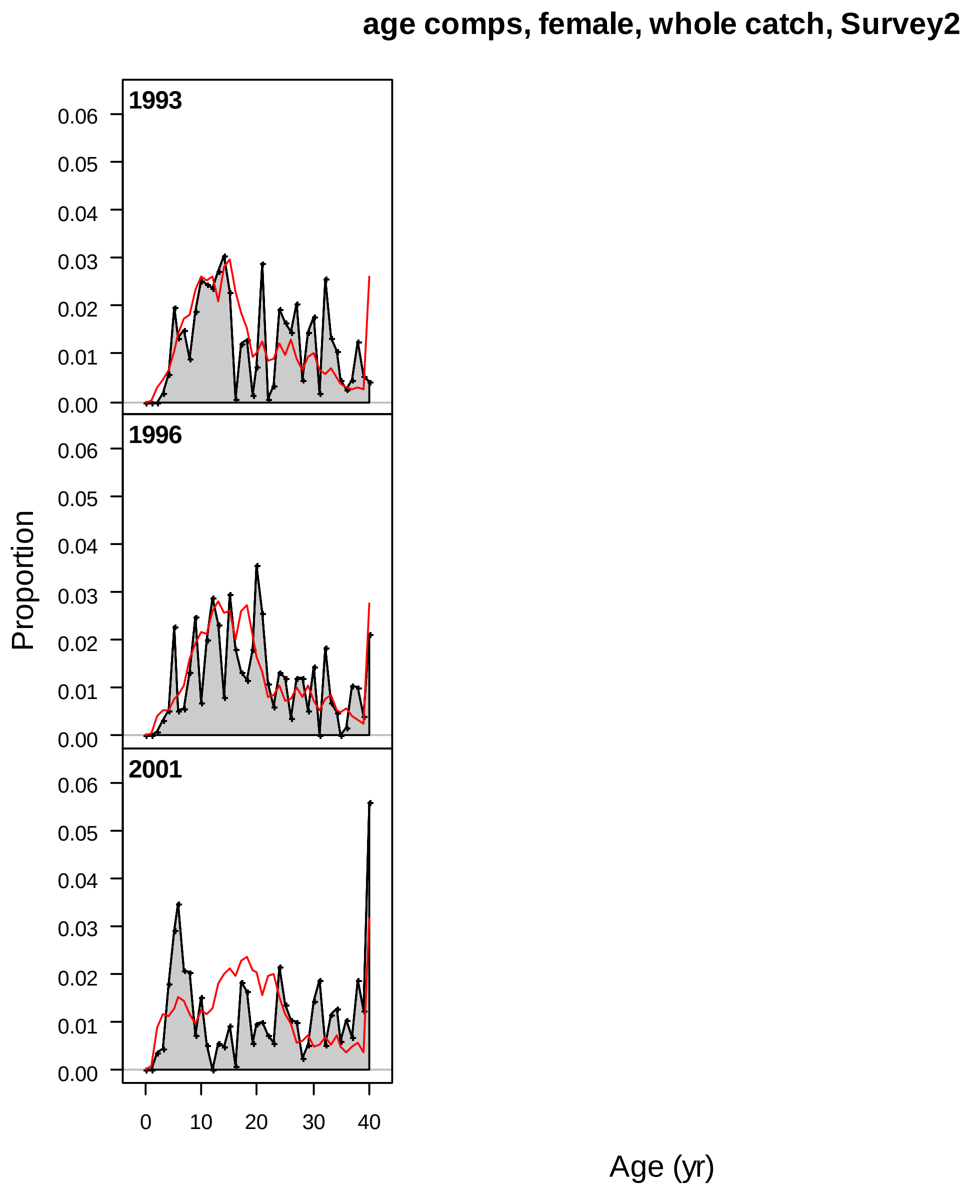


Figure 45. (1 of 2) Observed (solid black lines and grey shaded area) and predicted (red lines) shallow-water survey proportions-at-age for proposed alternative model M5 (where growth parameters are specified internally, an initial equilibrium fishing mortality rate is calculated, and fishery AND survey selectivity are logistic, sex-specific, length-based functions) for females (first panel) and males (second panel).

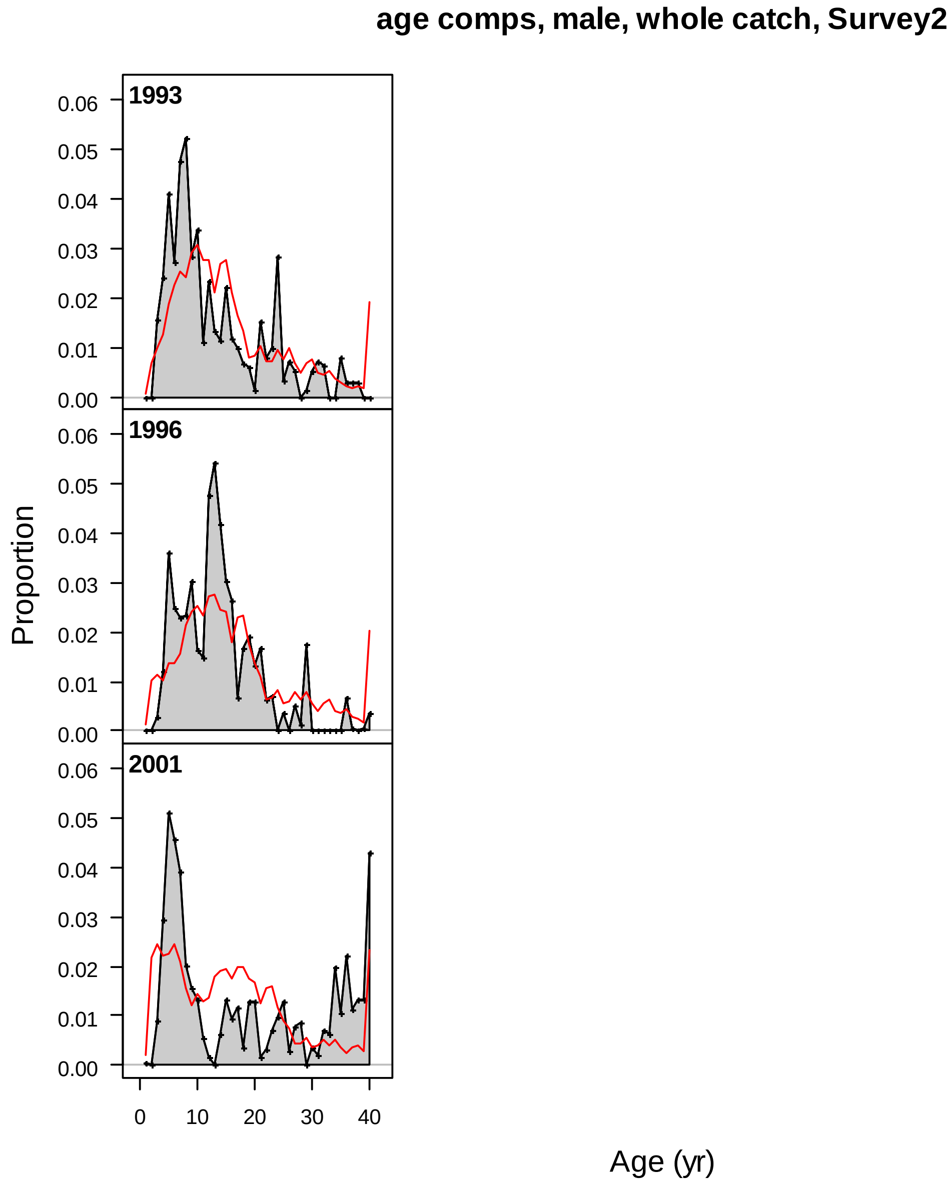


Figure 45, continued (2 of 2)

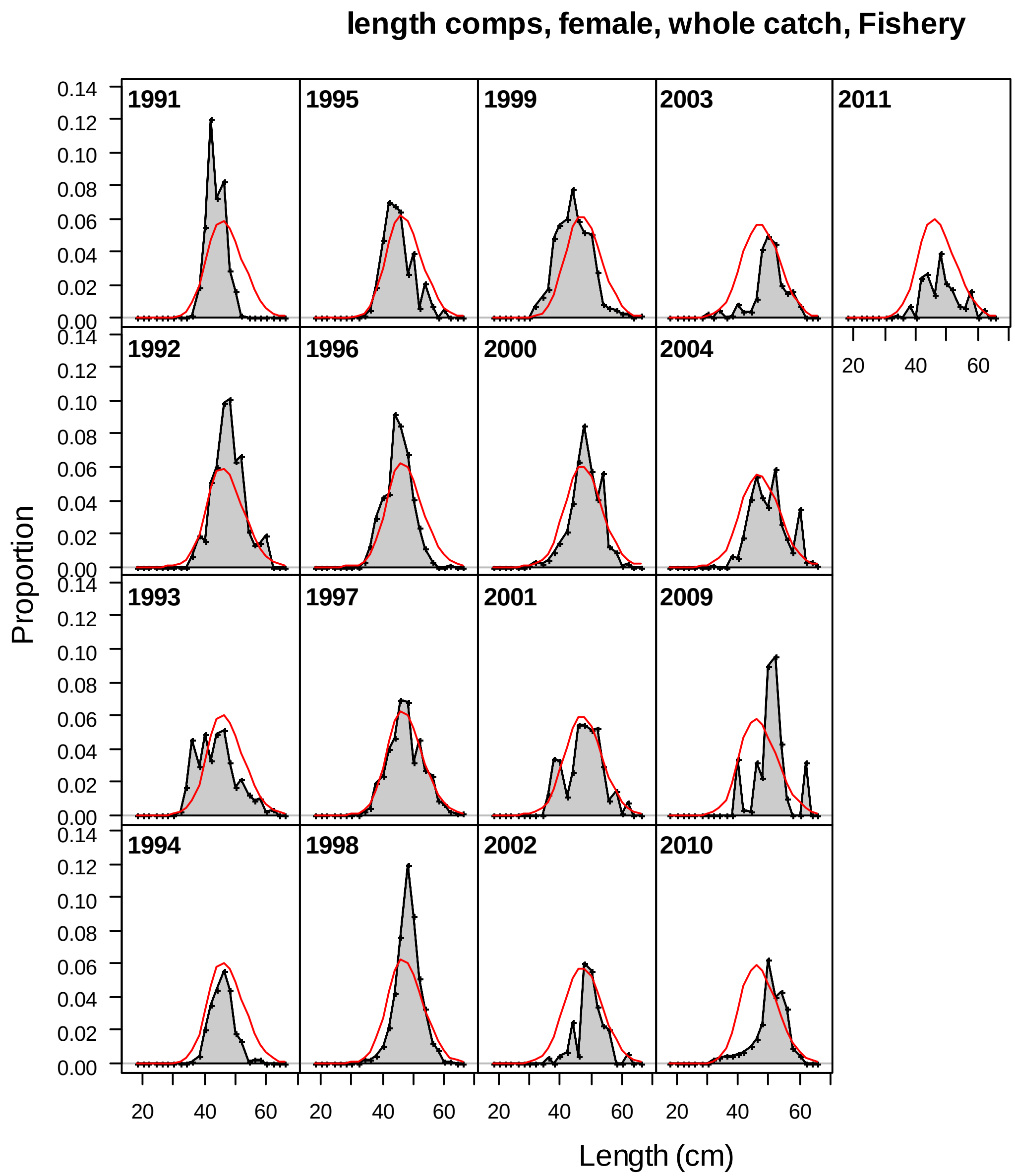


Figure 46. (1 of 2) Observed (solid black lines and grey shaded area) and predicted (red lines) fishery proportions-at-length for proposed alternative model M5 (where growth parameters are specified internally, an initial equilibrium fishing mortality rate is calculated, and fishery AND survey selectivity are logistic, sex-specific, length-based functions) for females (first panel) and males (second panel).

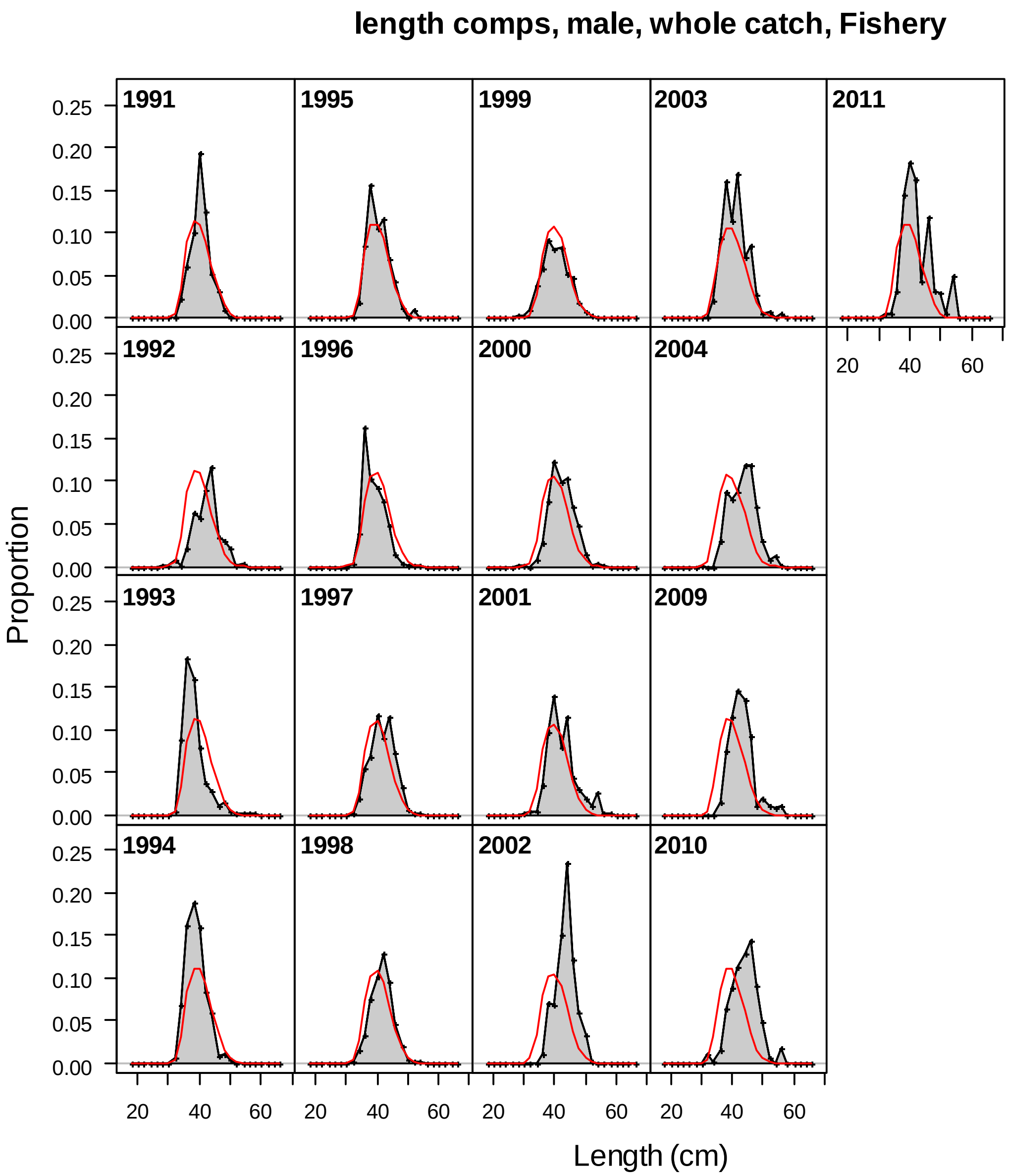


Figure 46, continued (2 of 2)

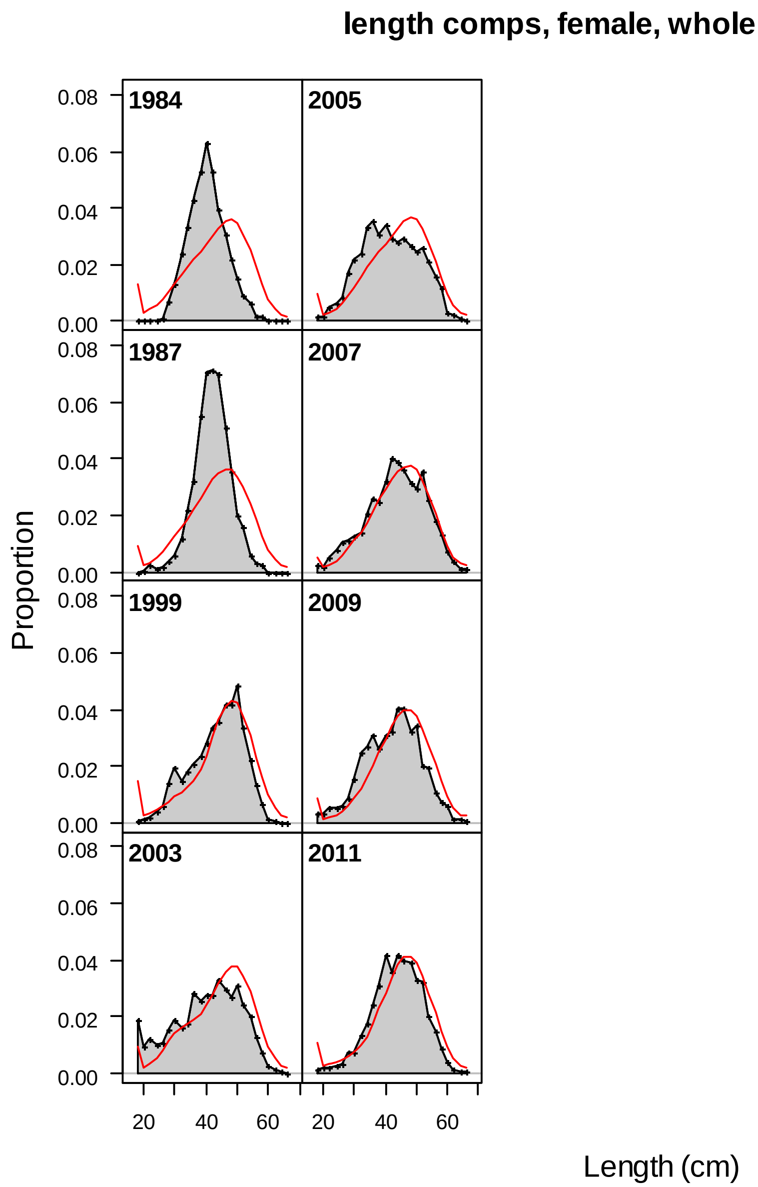


Figure 47. (1 of 2) Observed (solid black lines and grey shaded area) and predicted (red lines) full-coverage survey proportions-at-length for proposed alternative model M5 (where growth parameters are specified internally, an initial equilibrium fishing mortality rate is calculated, and fishery AND survey selectivity are logistic, sex-specific, length-based functions) for females (first panel) and males (second panel).

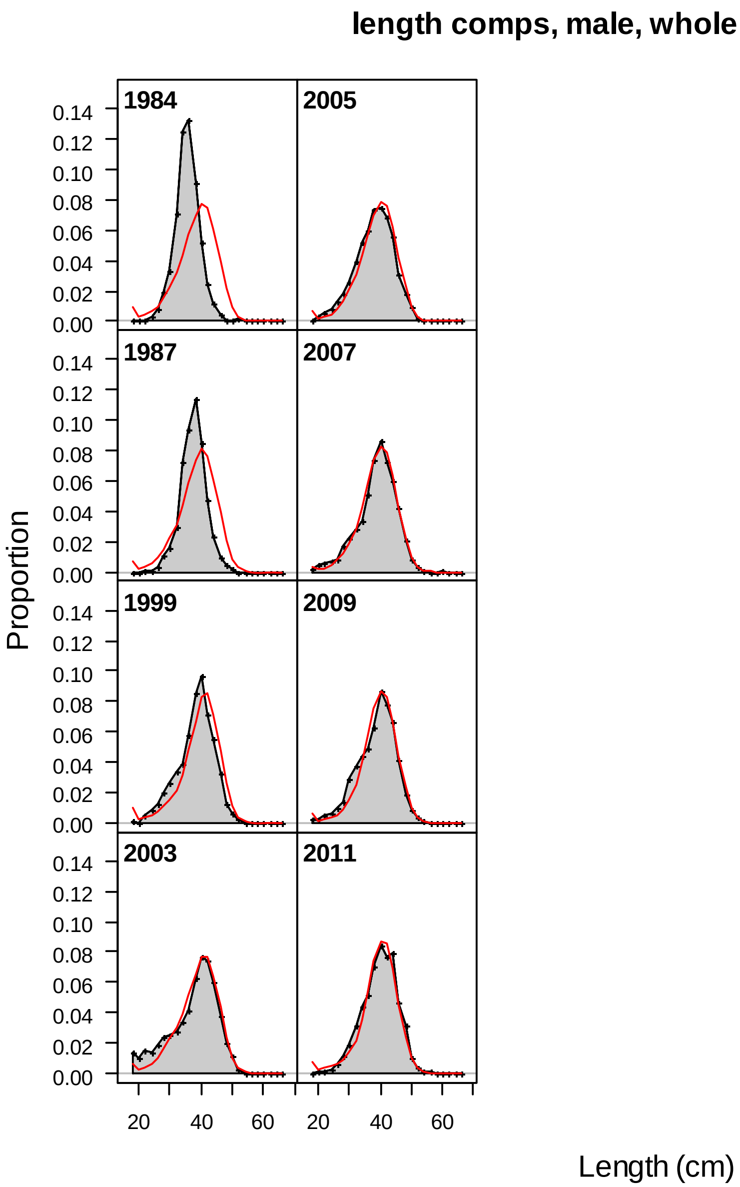


Figure 47, continued (2 of 2)

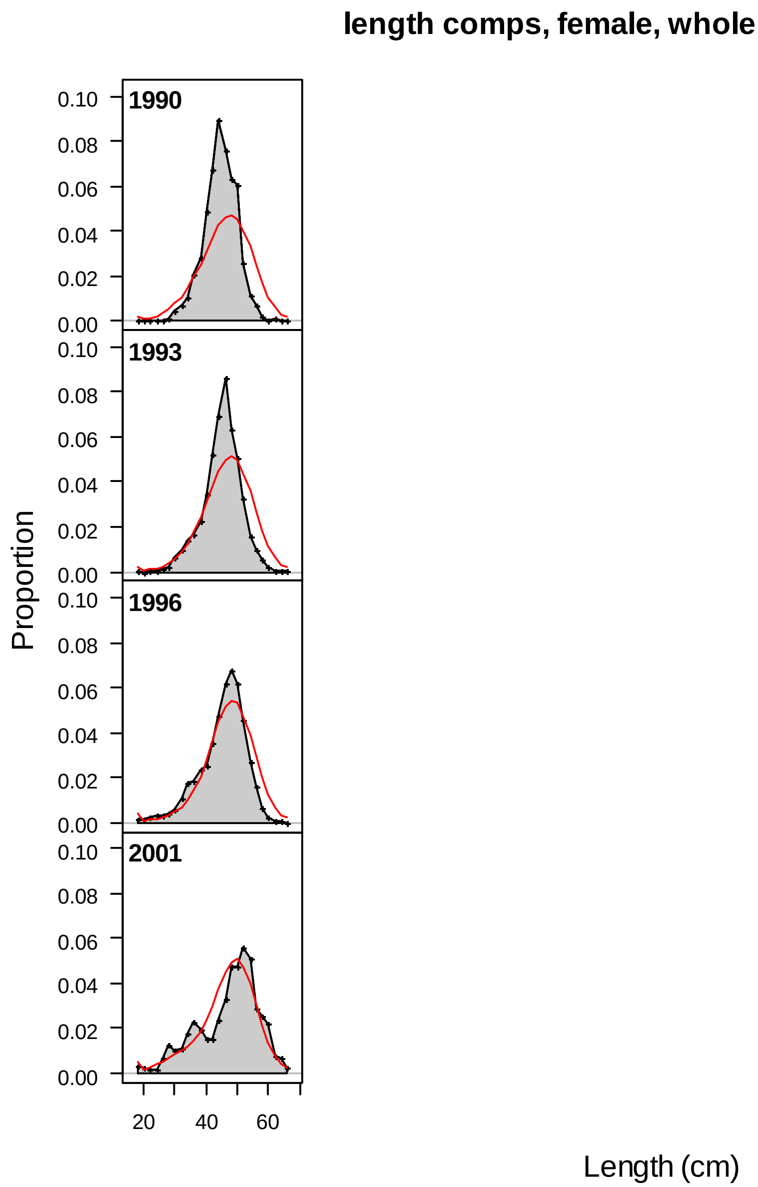


Figure 48. (1 of 2) Observed (solid black lines and grey shaded area) and predicted (red lines) shallow-water survey proportions-at-length for proposed alternative model M5 (where growth parameters are specified internally, an initial equilibrium fishing mortality rate is calculated, and fishery AND survey selectivity are logistic, sex-specific, length-based functions) for females (first panel) and males (second panel).

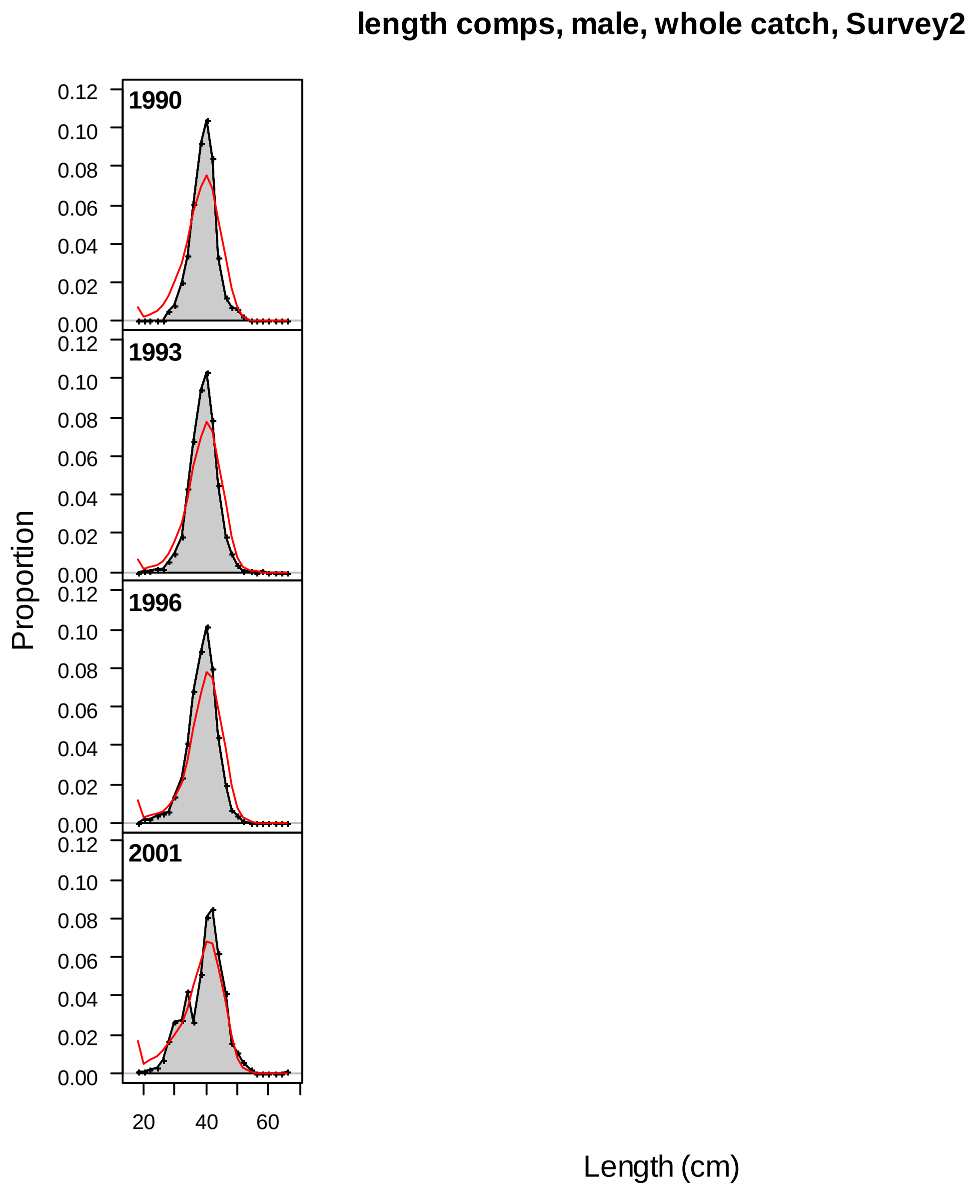


Figure 48, continued (2 of 2)

Attachment 5B. 2013 Results from the Previous Assessment Model

The previous assessment model for GOA Dover 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. The previous model updated with 2012 and 2013 data led to an unrealistic male fishery selectivity curve (knife edge selectivity at age 30). The projection model failed when using the estimated male fishery selectivity because the predicted 2013 catch (212 mt) was not achievable, regardless of F. In addition, the 2011 model was not used for management (Dover sole was managed as a Tier 5 species) due to a lack of confidence in the assessment model. Therefore, the author does not recommend using the 2011 model updated with 2012-2013 data to manage Dover sole in 2013 and harvest recommendations cannot be provided without making changes to the previous model.

Below are plots comparing selectivity curves, growth relationships, recruitment, spawning biomass, and fits to survey biomass and composition data for the previous assessment model updated with 2012-2013 data.

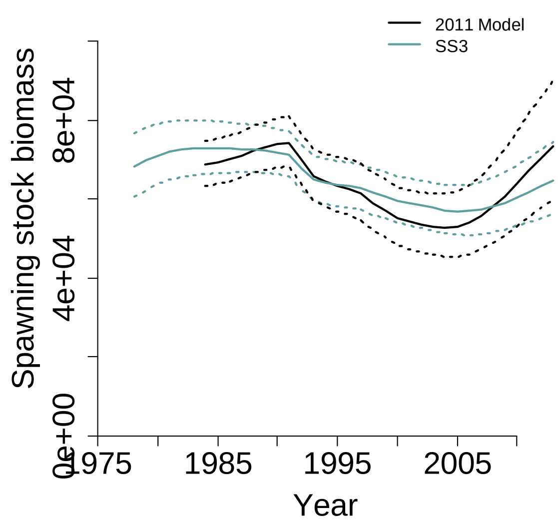


Figure 5B.1. Time series of spawning stock biomass (solid lines) and 95% asymptotic confidence intervals (dotted lines) for the recommended model (blue lines) and the previous assessment model (black lines).

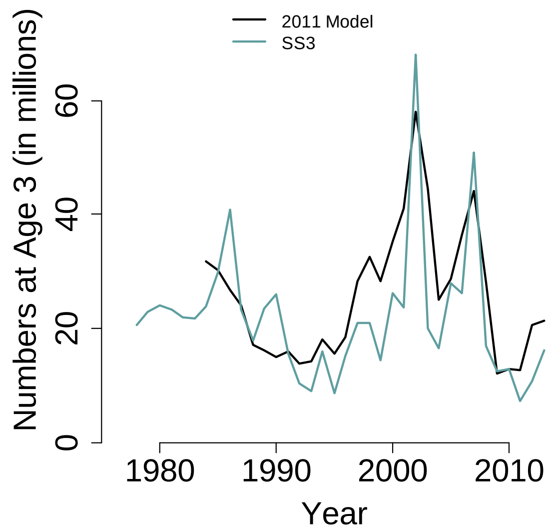


Figure 5B.2. Time series of age 3 recruitment for the recommended model (blue line) and the previous assessment model (black line).

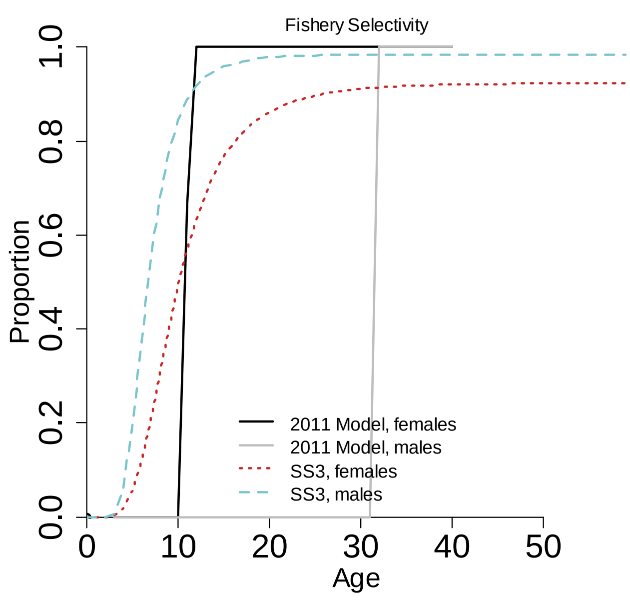
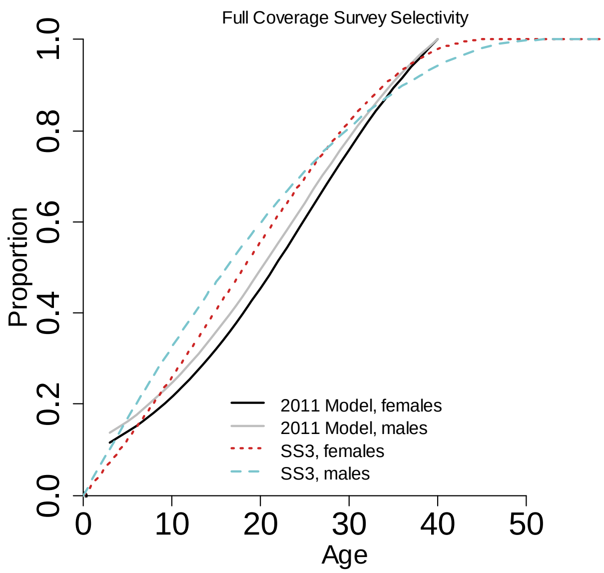


Figure 5B.3 (a). Fishery selectivity at age by sex for the recommended model and previous model. Selectivity curves in the previous model are logistic and normalized so that maximum selectivity within the age range must equal 1.



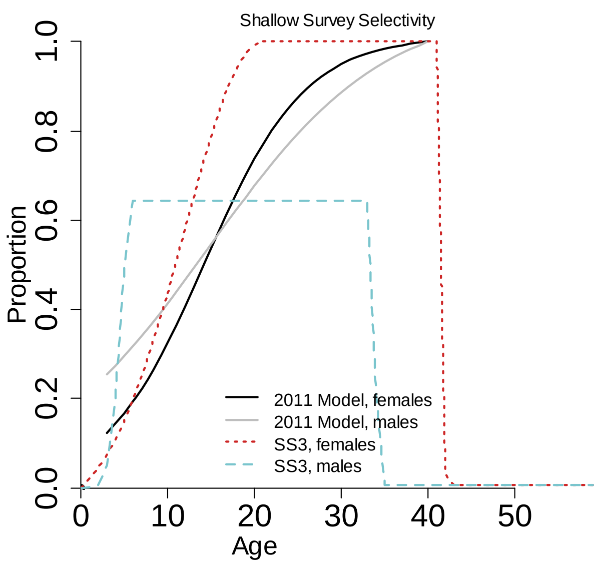


Figure 5B.3 (b). Full-coverage (top panel) and shallow-water (bottom panel) survey selectivity for the recommended and previous models. Selectivity curves in the previous model are logistic and normalized so that maximum selectivity within the age range must equal 1. Shallow-water survey selectivity curves are estimated based on the biomass index and length- and age-composition data for those years, while the shallow-water coverage survey for the recommended model is not associated with the biomass index.

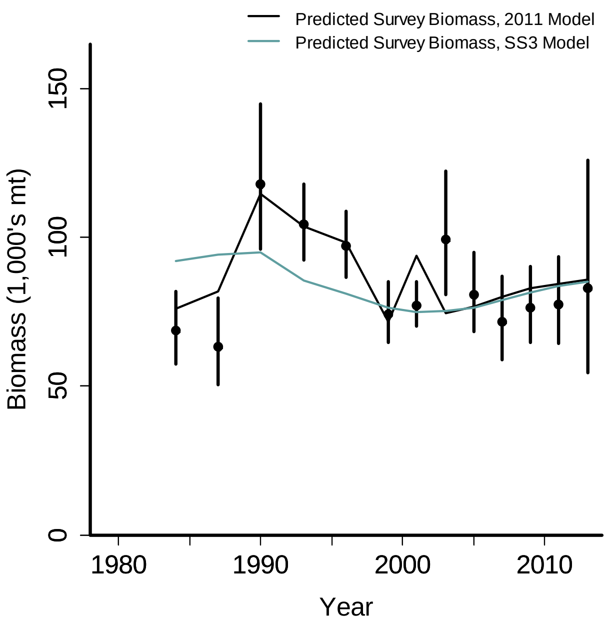


Figure 5B.4. Observed survey biomass (black dots) with 95% asymptotic confidence intervals (vertical black lines) and predicted survey biomass for the previous model (black line) and the recommended model (blue line).

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