AN EXPLORATION OF ALTERNATIVE GULF OF ALASKA FLATHEAD SOLE ASSESSMENT MODELS

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INTRODUCTION

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

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

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

DATA GAPS AND RESEARCH PRIORITIES FROM PREVIOUS ASSESSMENTS

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

One currently unfulfilled SSC request exists:

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

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

(1) SS3 is used by many scientists worldwide, which provides an ad-hoc quality control system for identifying bugs in the code.
(2) A request from previous authors concerning the flathead sole assessments was that the age-length transition matrices and other growth parameters be re-examined and

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potentially estimated within the model. The 2011 model had limited capability to do this, but such flexibility is included in the SS3 framework.

(3) Mean weight-at-age data can be included in the SS3 model and can be used as a likelihood component to help estimate growth. Since these data are available for GOA flathead sole, their use within the assessment model would be advantageous.

(4) SS3 has many options for specifying the functional form of selectivity curves and these could be used to explore length-based fishery and survey selectivity for flathead sole, which may be a more accurate reflection of the selection process than the age-based selectivity functions used in previous assessments.

(5) SS3 allows for specification of ageing error. Ageing error is ignored in the current model.

(6) SS3 allows for multiple survey and fishing fleets to be included in the model. This feature would be needed to explore the inclusion of the ADF&G bottom trawl survey in future assessments; the previous model accommodated only one fishery and one survey.

(7) SS3 accommodates age-composition data for ages 0-2. The previous assessment model omitted data for fish below age 3. Including data for ages 0-2 may inform recruitment estimates and age-based selectivity at young ages.

(8) SS3 allows for calculation of mid-year weight-at-age, which is an improvement over the 2011 model because it more accurately matches biological processes that occur during the year with respect to the timing of fishing. In previous models, exploitable biomass was calculated based on beginning-of-the-year weight-at-age, but fishing occurs over 7 months from January-November, and therefore using mid-year weight-at-age to calculate exploitable biomass may be more accurate.

(9) The previous assessment model assumed the stock was unfished prior to the model start year, but we know that fishing occurred before 1984. SS3 allows the user to estimate an initial fishing mortality rate to account for fishing prior to the availability of catch data.

(10) SS3 offers a “jitter” option, which allows for initial parameter values to be adjusted by a random deviate. Iteratively running the model with the “jitter” option turned on allows the user to start the model from a wide range of initial values so as to identify the best objective function value.

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

Matching population dynamics between models

Mean recruitment

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

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

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

Selectivity

The 2011 model assumed sex-specific age-based logistic selectivity functions for fishery and survey selectivity. Although SS3 has logistic, sex-specific selectivity, it was found that the specification of male logistic age-based selectivity in SS3 was difficult to cast into a logistic shape. Sex-specific length-based logistic selectivity can be specified such that selectivity can be estimated for both sexes while retaining the logistic shape, or age-based double normal selectivity curves could be specified with a large value for the standard deviation of the descending limb such that asymptotic, logistic-like, sex-specific selectivity could be estimated. In the interest of matching the 2011 model as closely as possible, the age-based, sex-specific double normal selectivity curves without descending limbs were used for fishery and survey selectivity curves. The fishery selectivity curves were matched as closely as possible to the age-based logistic curves from the 2011 model for the purpose of comparing population dynamics between the models (Figure 1). Figure 1 shows that the double-normal selectivity curves can approximate the logistic curves from the 2011 model, but the shapes are slightly different and this results in small differences in population dynamics between the 2011 and SS3 models (Figure 2). Figure 2 shows that spawning stock biomass (SSB) is nearly, but not exactly the same between models in equivalent deterministic runs. Figure 3 shows that survey biomass is also almost exactly the same between models in equivalent deterministic runs. The very small differences in spawning stock biomass in Figure 2 can be explained by the differences in fishery selectivity curves shown in Figure 1, as further equivalent deterministic runs (conducted for Dover sole) using selectivity curves that matched more exactly (but were still logistic for the 2011 model and double-normal for the SS3 model; Figure 4) led to the same time series of SSB for both models (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 0.60. The 2011 model estimated recruits (age 3) freely (i.e. no σ_R) and this constitutes a difference between the models.

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

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

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

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

Data used in SS3 and the 2011 Model

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

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

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

Parameter Estimation in SS3 and the 2011 Model

Parameters Estimated Inside the Assessment Model

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

Likelihood component for survey biomass index

Table 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 14cm. Therefore, the values of these likelihood components cannot be compared directly between the 2011 model and SS3, but are expected to have similar influences on model fits. The fits to age- and length-composition data are very similar among models (Figure 12-Figure 14). The addition of age 0-2 and small length data included in the SS3 model likely contribute to differences in numbers at age 3 and selectivity parameter estimates. There is no easy way to test the extent to which the

additional data contributes to differences, as the 2011 model does not accept the additional data, while it is required for the SS3 model.

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

ANALYTIC APPROACH: PROPOSED ALTERNATIVE SS3 MODELS

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

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

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

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

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

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

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

Further proposed alternative models

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

- Estimating growth parameters internally to re-evaluate the age-length transition matrices and other growth relationships with inclusion of the most recent data.
- Adding mean weight-at-age data to the assessment and estimating growth parameters internally. Data on mean weight-at-age are available, but are not currently being used in

analyses of GOA flathead sole. Mean weight-at-age is expected to inform estimates of growth parameters.

- Estimating growth parameters and the age-length transition matrix outside of the model using data that includes the most recent years.
- Including ageing error in the model: the previous assessment models ignored ageing error. The CVs about the length-at-age relationship are quite large. This implies that there are some age 3 fish that are the same length as some age 20+ fish, which is likely untrue and could potentially be attributed to ageing error.
- Re-evaluating effective sample sizes for age- and length-composition data. There are abrupt year-to-year changes in age-compositions that occur in the observations that are likely due to observation error. Using high effective sample sizes may exclude some process errors which should be considered.

RESULTS: TRANSITION OF 2011 MODEL INTO AN EQUIVALENT SS3 MODEL

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

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

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

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

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

RESULTS: PROPOSED ALTERNATIVE SS3 MODELS

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

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

LITERATURE CITED

Methot, R. D. and C. R. Wetzel. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fisheries Research **142**:86-99.

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

TABLES

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

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

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

FIGURES

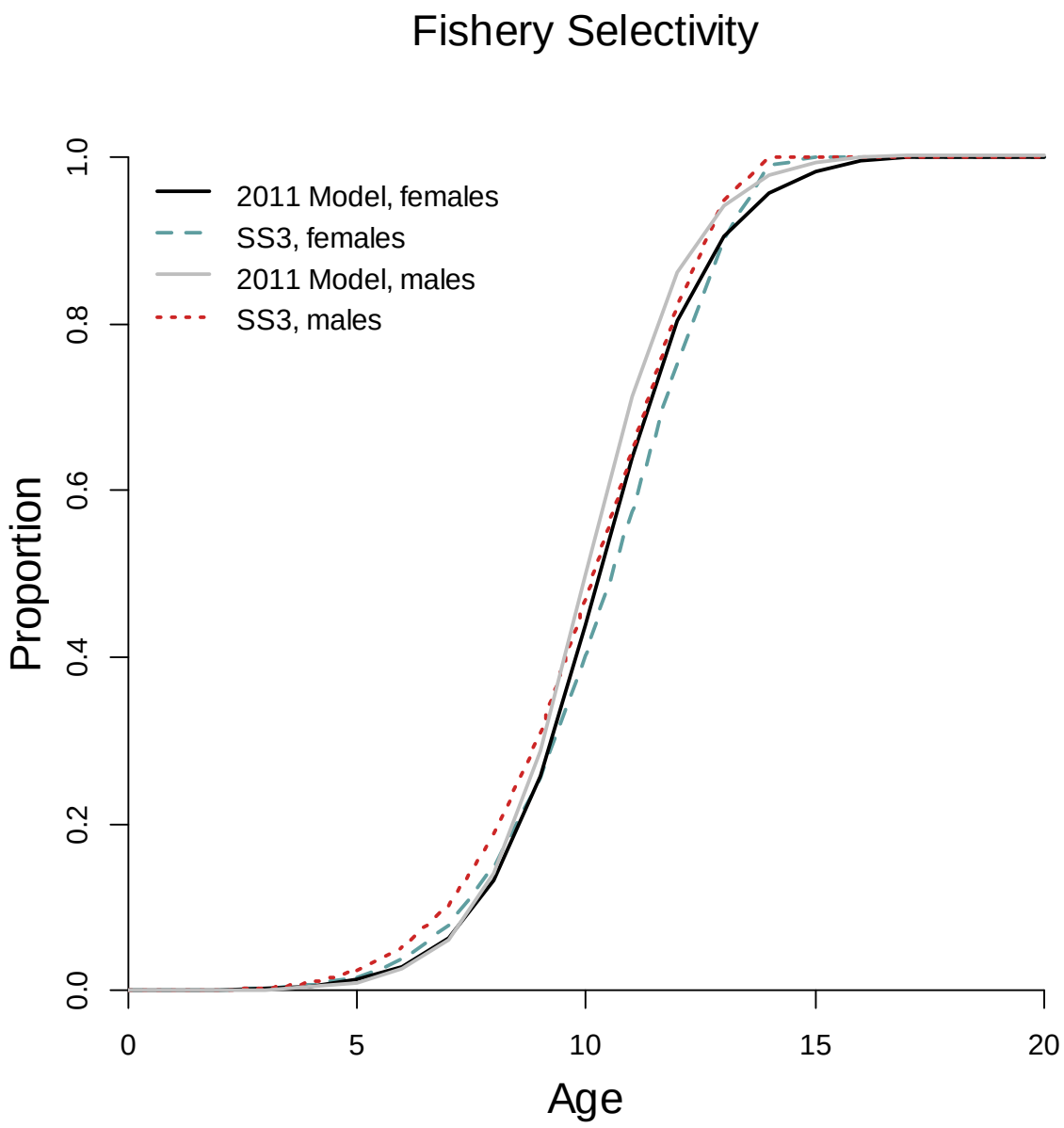


Figure 1.SS3 double-normal selectivity curves matched as closely as possible to the 2011 model's logistic fishery selectivity curves (the standard deviation of the descending limb of the selectivity curves was fixed at a large value to create an asymptotic curve).

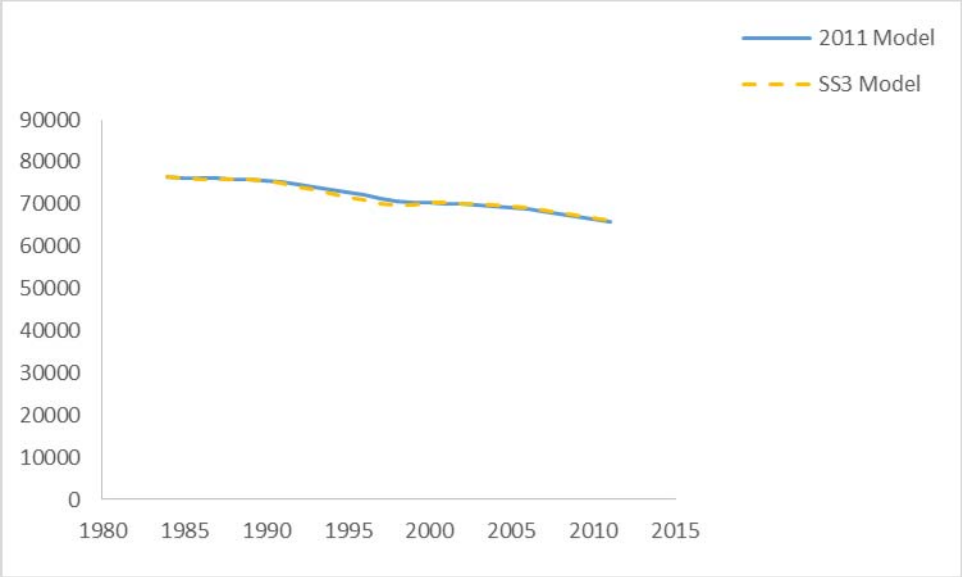


Figure 2.Spawning stock biomass for a deterministic run of the 2011 and SS3 models with parameters in both models fixed at the MLEs for the 2011 model with flathead sole catch history and no recruitment deviations. Fishery selectivity curves for the models were forced to match as closely as possible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

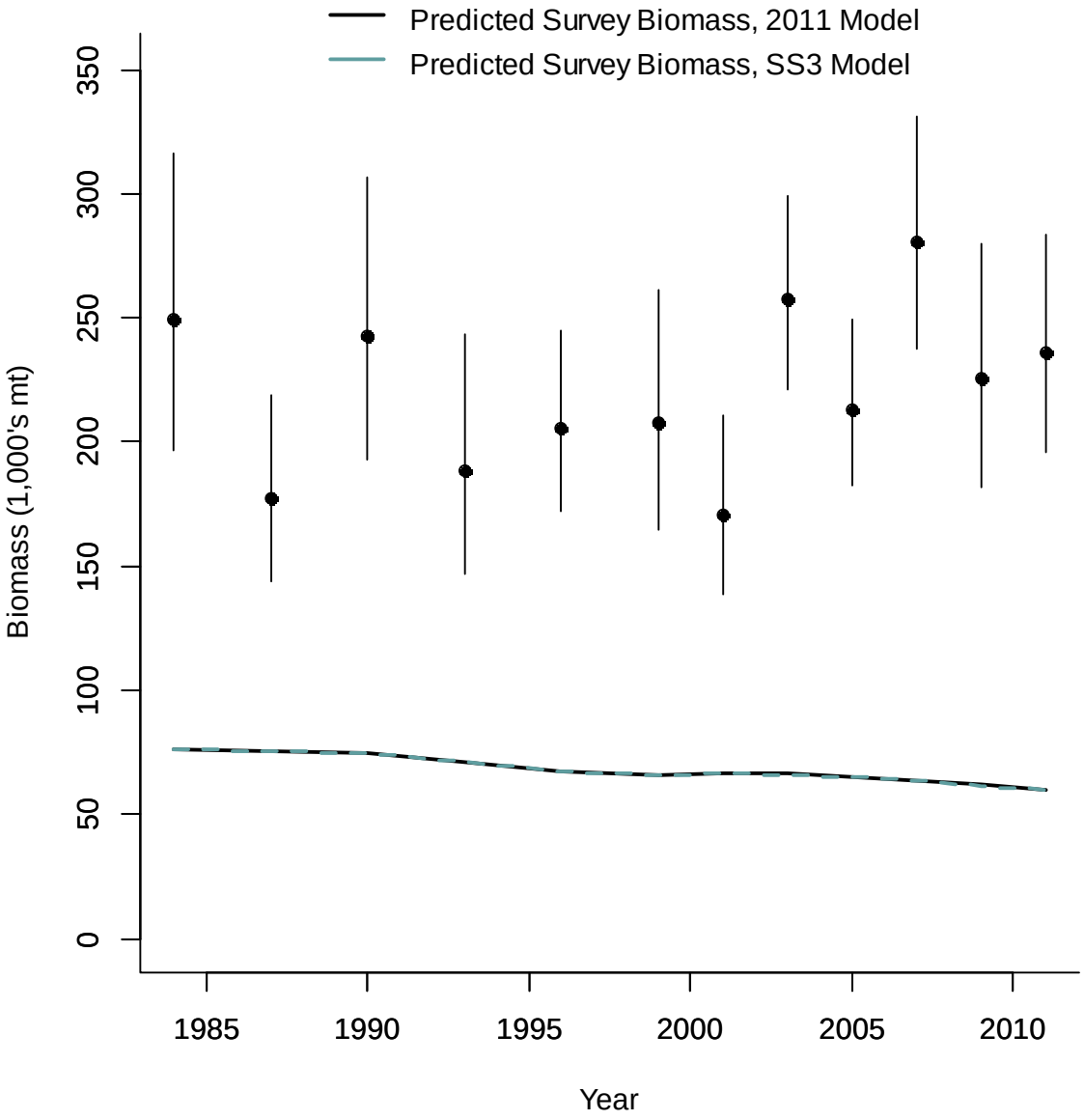


Figure 3. Survey biomass for a deterministic run of the 2011 and SS3 models with parameters in both models fixed at the MLEs for the 2011 model with flathead sole catch history, no recruitment deviations, and no estimation. Fishery selectivity curves for the models were forced to match as closely as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

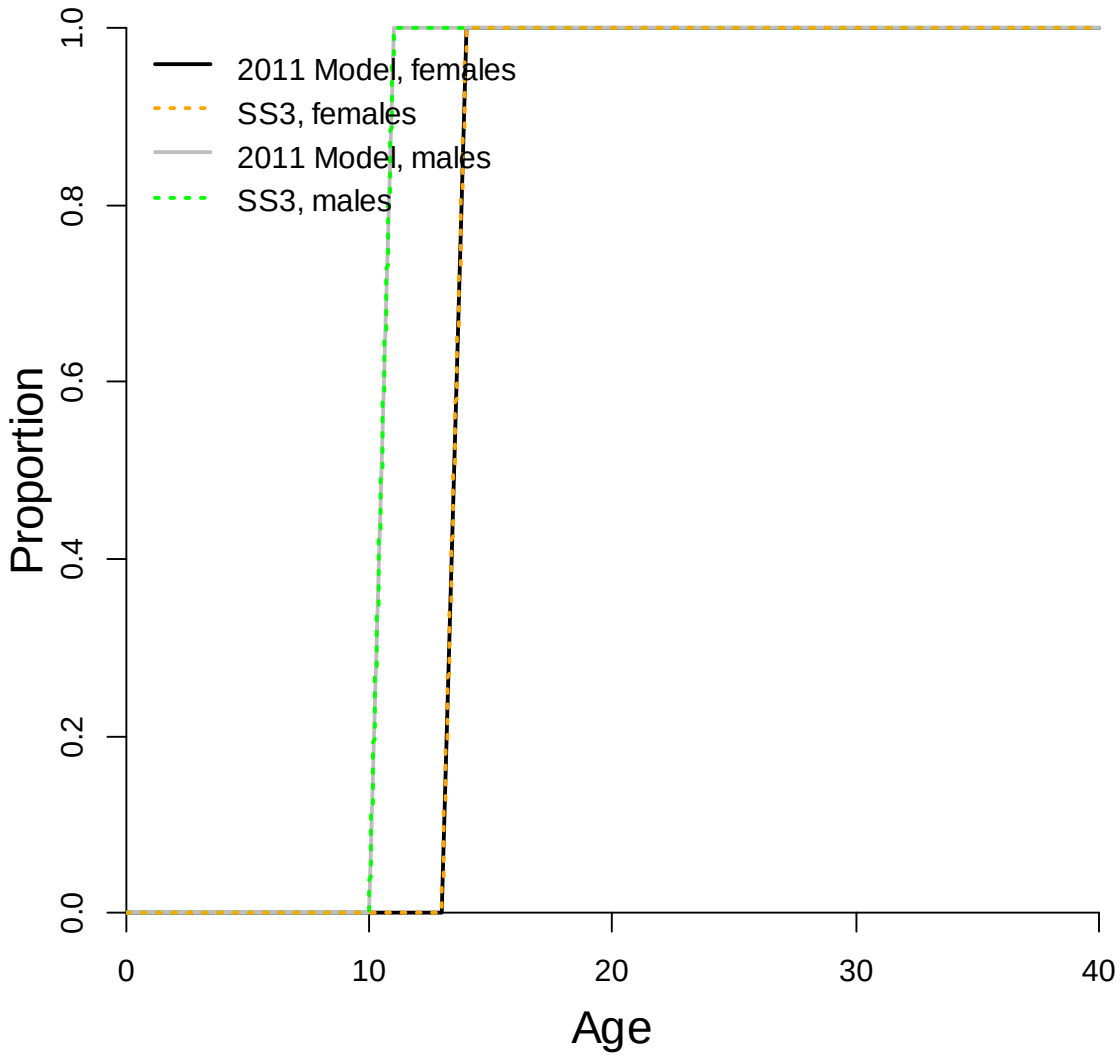


Figure 4. Fishery selectivity used in deterministic runs (the same as the final estimate for fishery selectivity in the 2011 model). The SS3 selectivity curves pictured were created using a double-normal selectivity curve with no descending limb; the 2011 model selectivity curves are logistic.

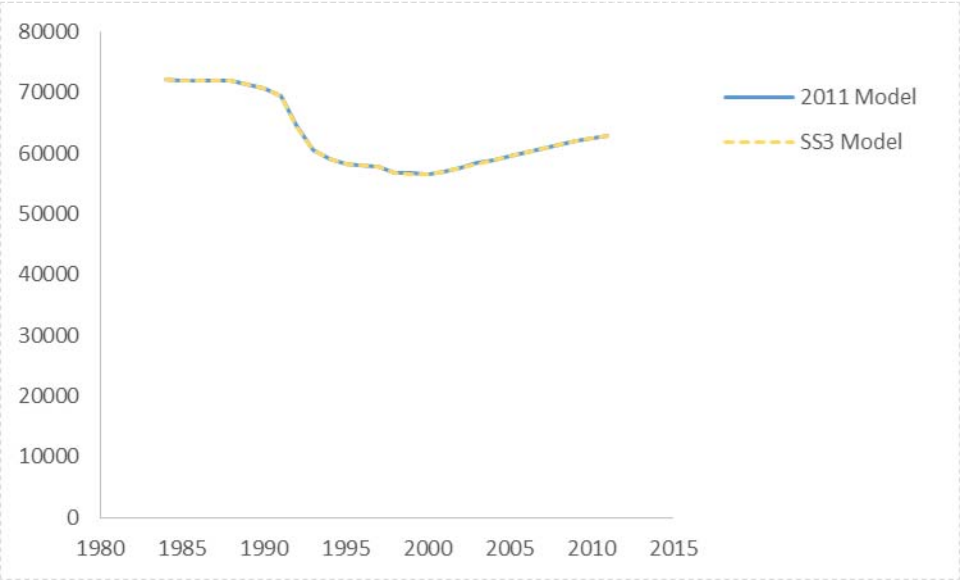


Figure 5. Spawning stock biomass for a deterministic run of the 2011 and SS3 models with parameters fixed at the MLEs for the 2011 Dover sole model with Dover sole catch history and no recruitment deviations. Fishery selectivity curves for the models were forced to match as closely as possible (Figure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

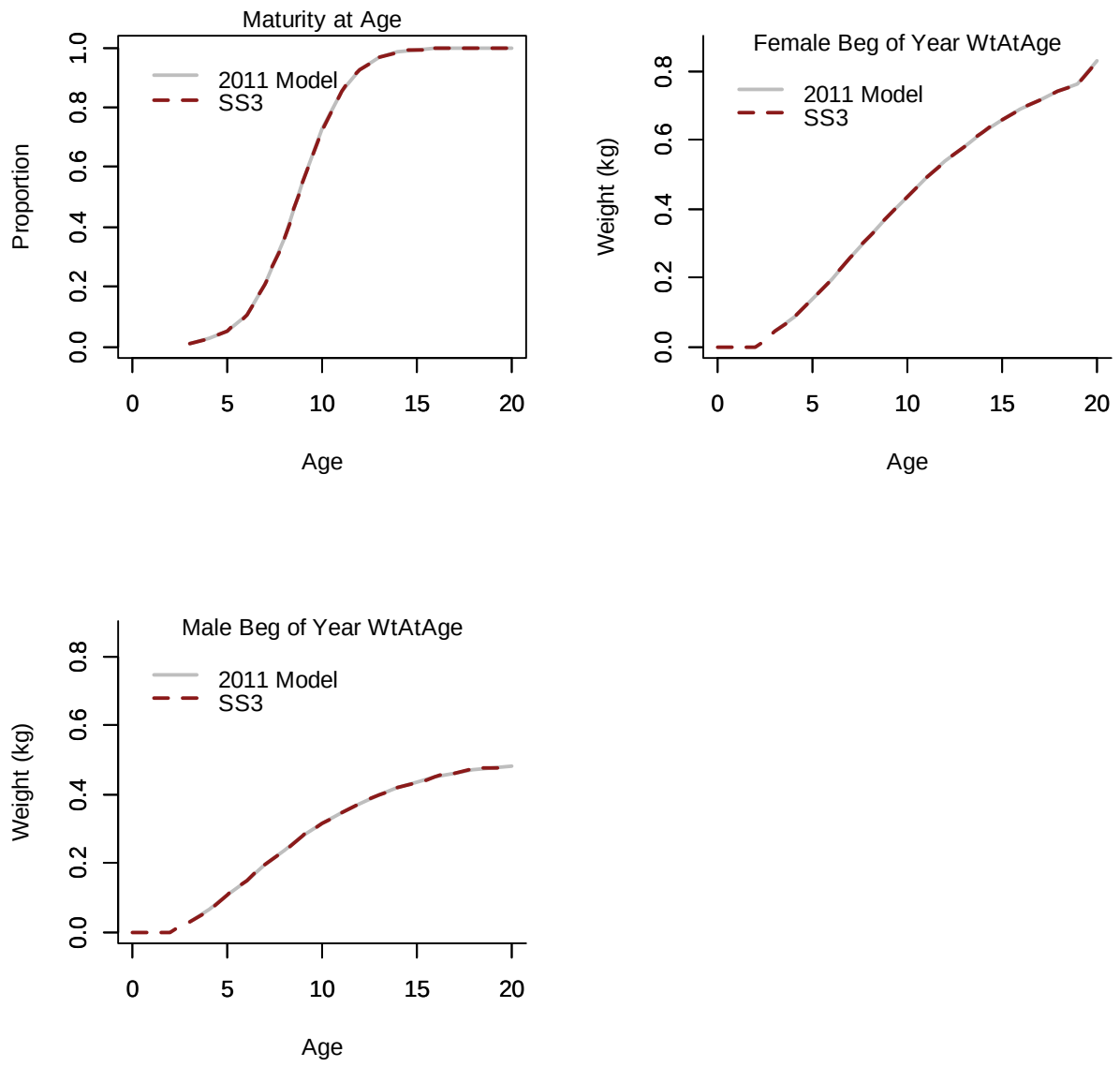


Figure 6. Maturity-at-age and weight-at-age for the 2011 model and an equivalent SS3 model.

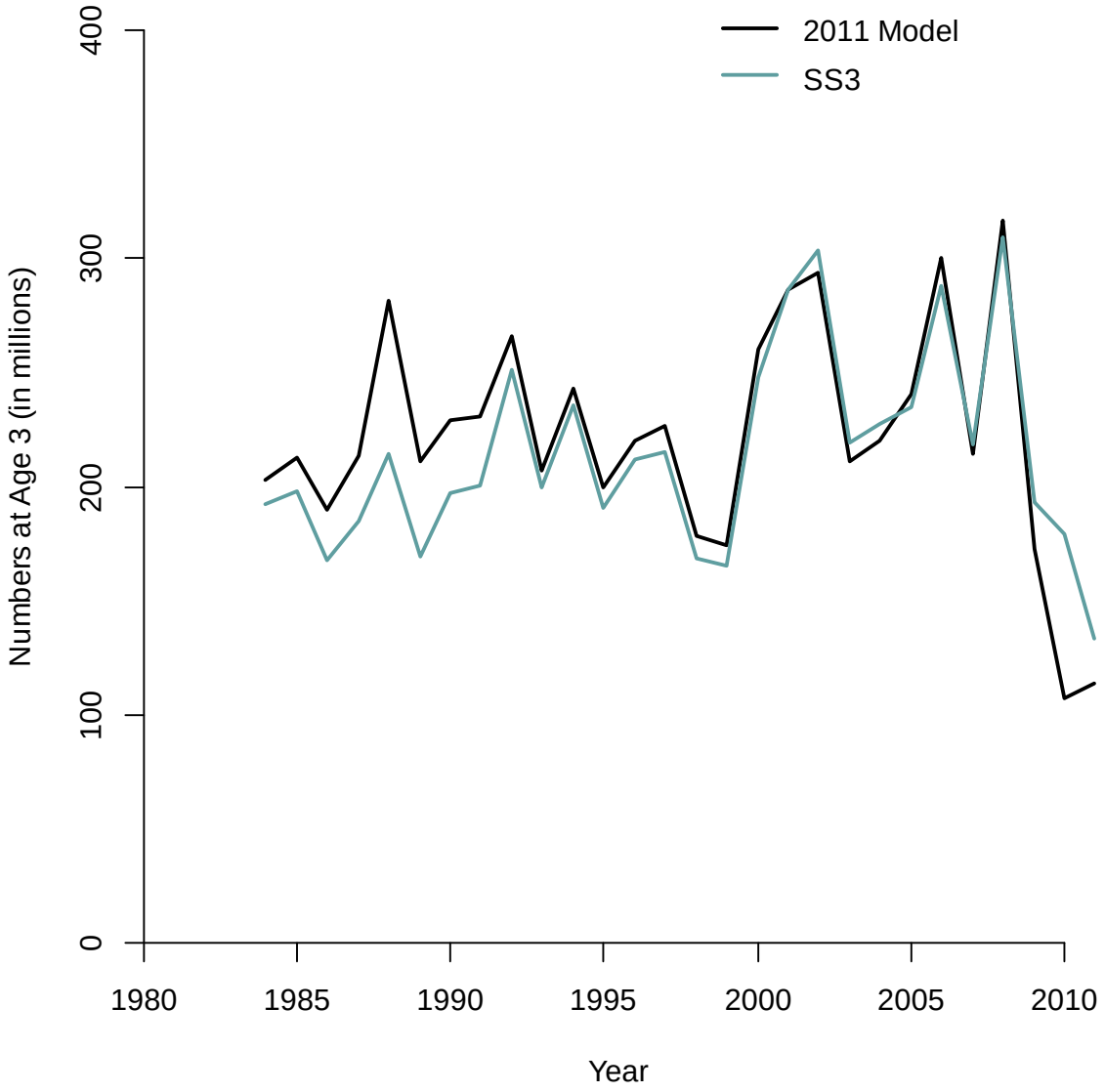


Figure 7. Numbers at age 3 for the 2011 model (black line) and an equivalent SS3 run (blue line). Both models estimate the log of mean recruitment, recruitment deviations for 1967-2011, fishing mortality rates, and asymptotic selectivity parameters (logistic for the 2011 model and double-normal for SS3).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

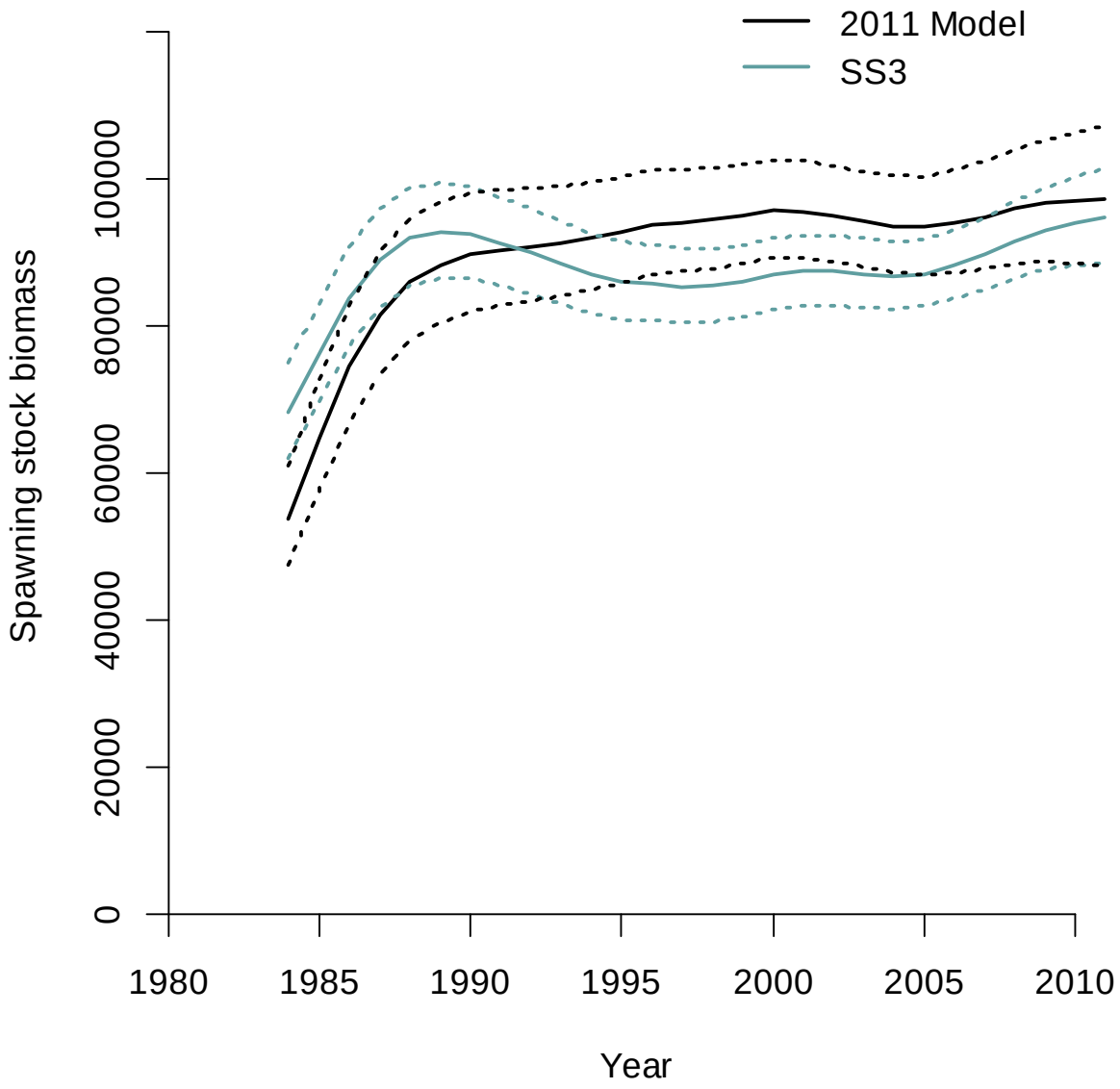


Figure 8. Spawning stock biomass (solid lines) and asymptotic 95% confidence intervals (dotted lines) for the 2011 model (black lines) and SS3 (blue lines) for an equivalent SS3 model.

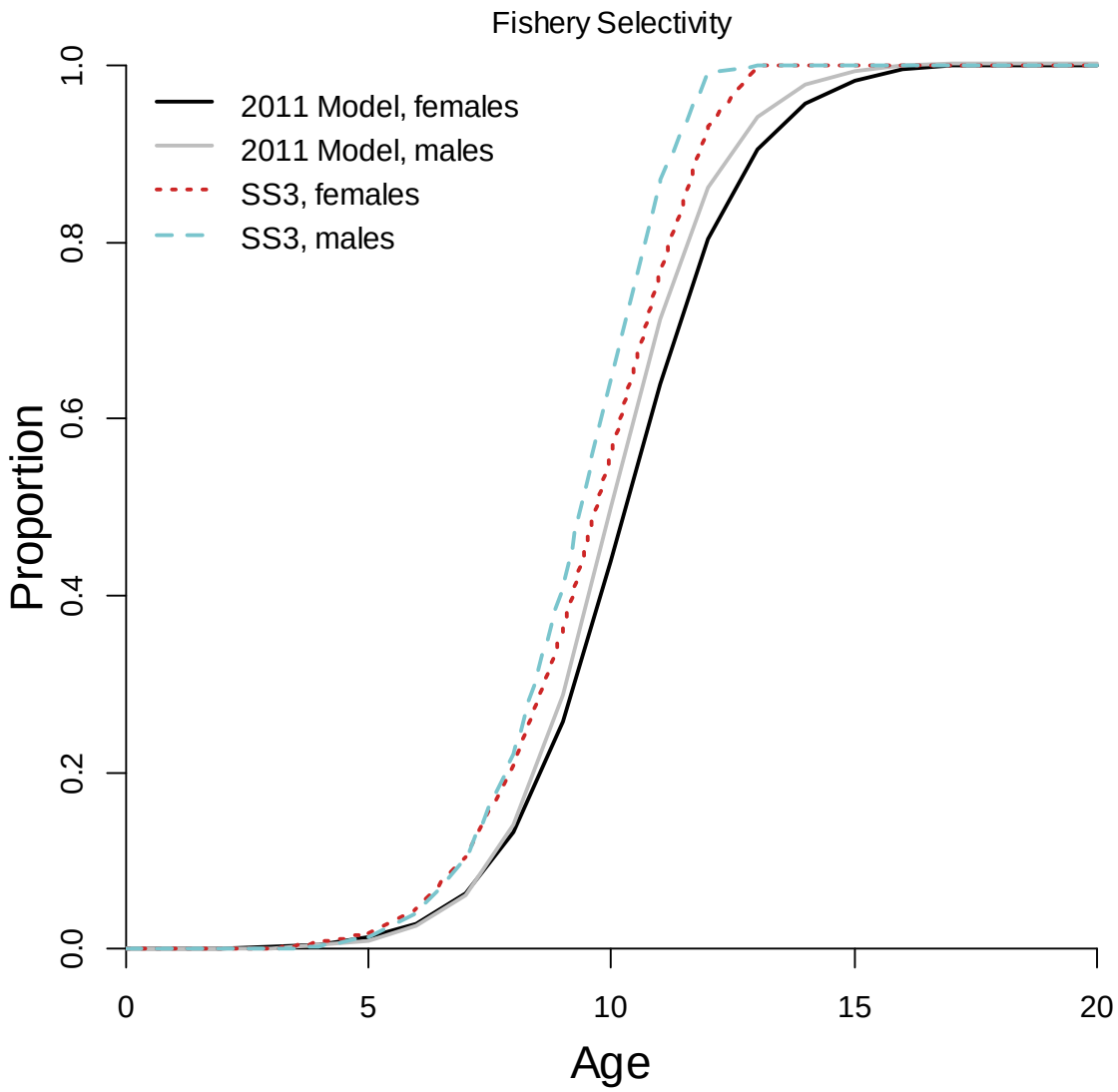


Figure 9. Fishery selectivity for the 2011 model (solid lines) and an equivalent SS3 model run (dotted and dashed lines).

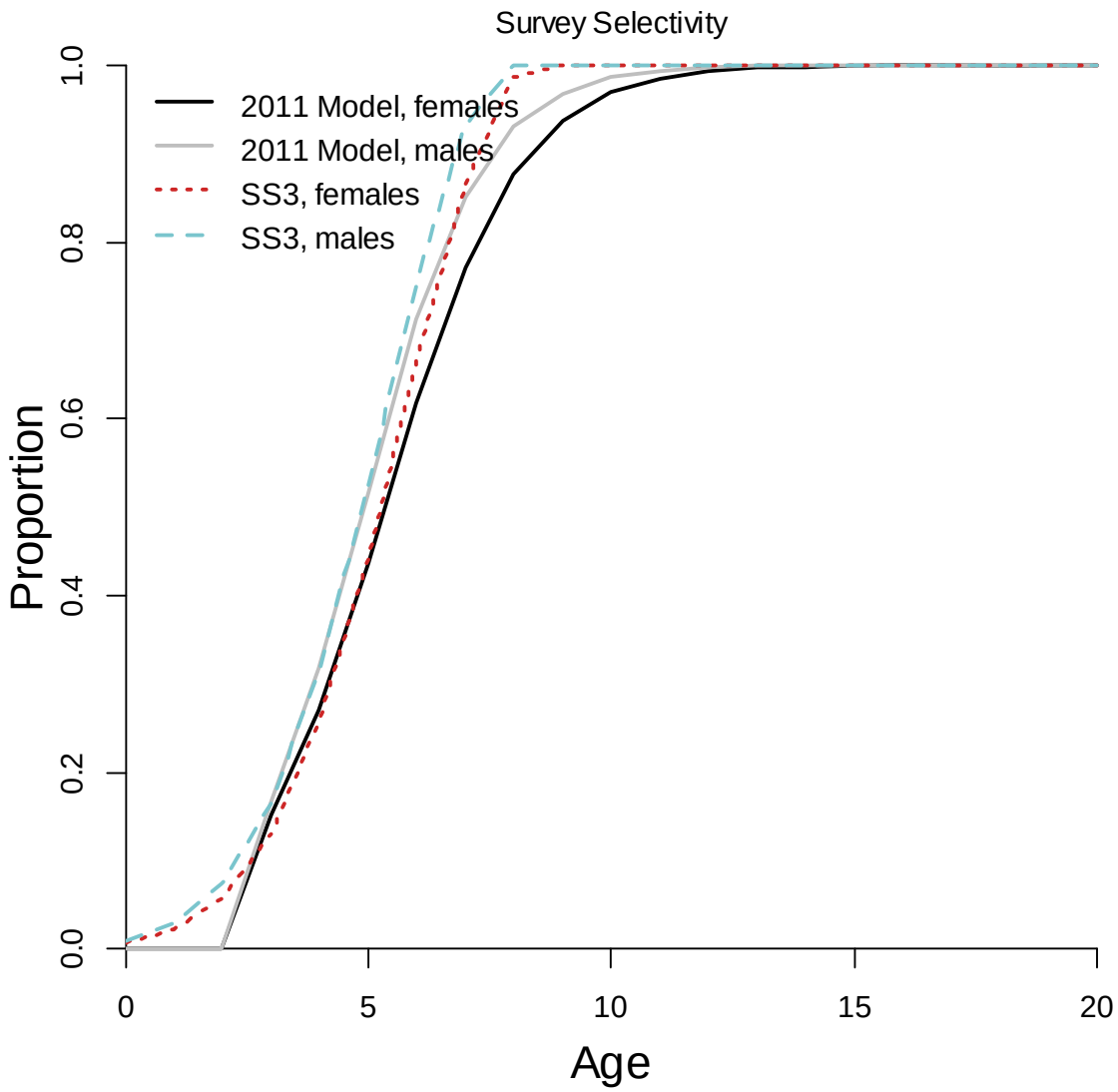


Figure 10. Survey selectivity for the 2011 model (solid lines) and an equivalent SS3 model run (dotted and dashed lines).

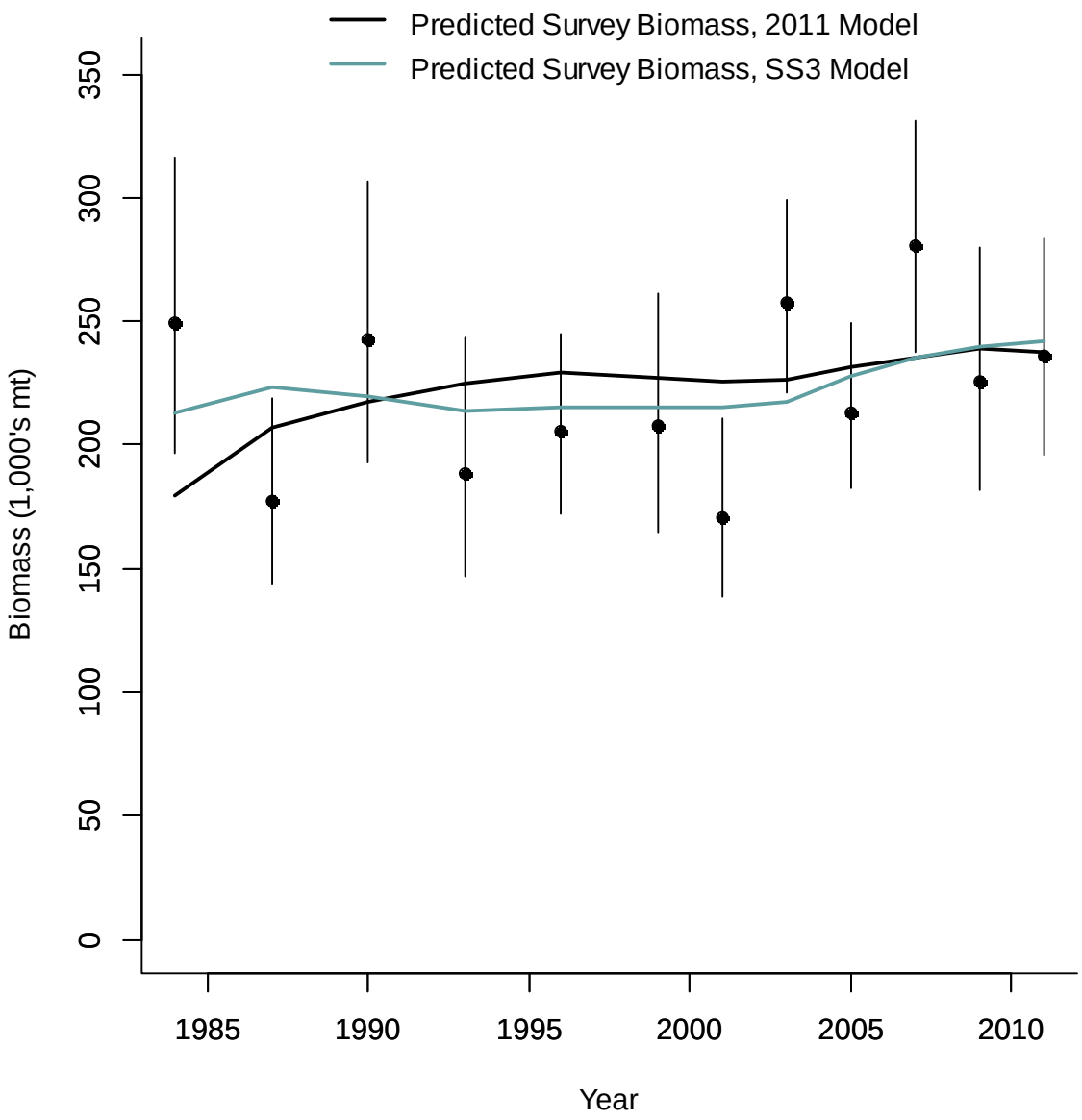
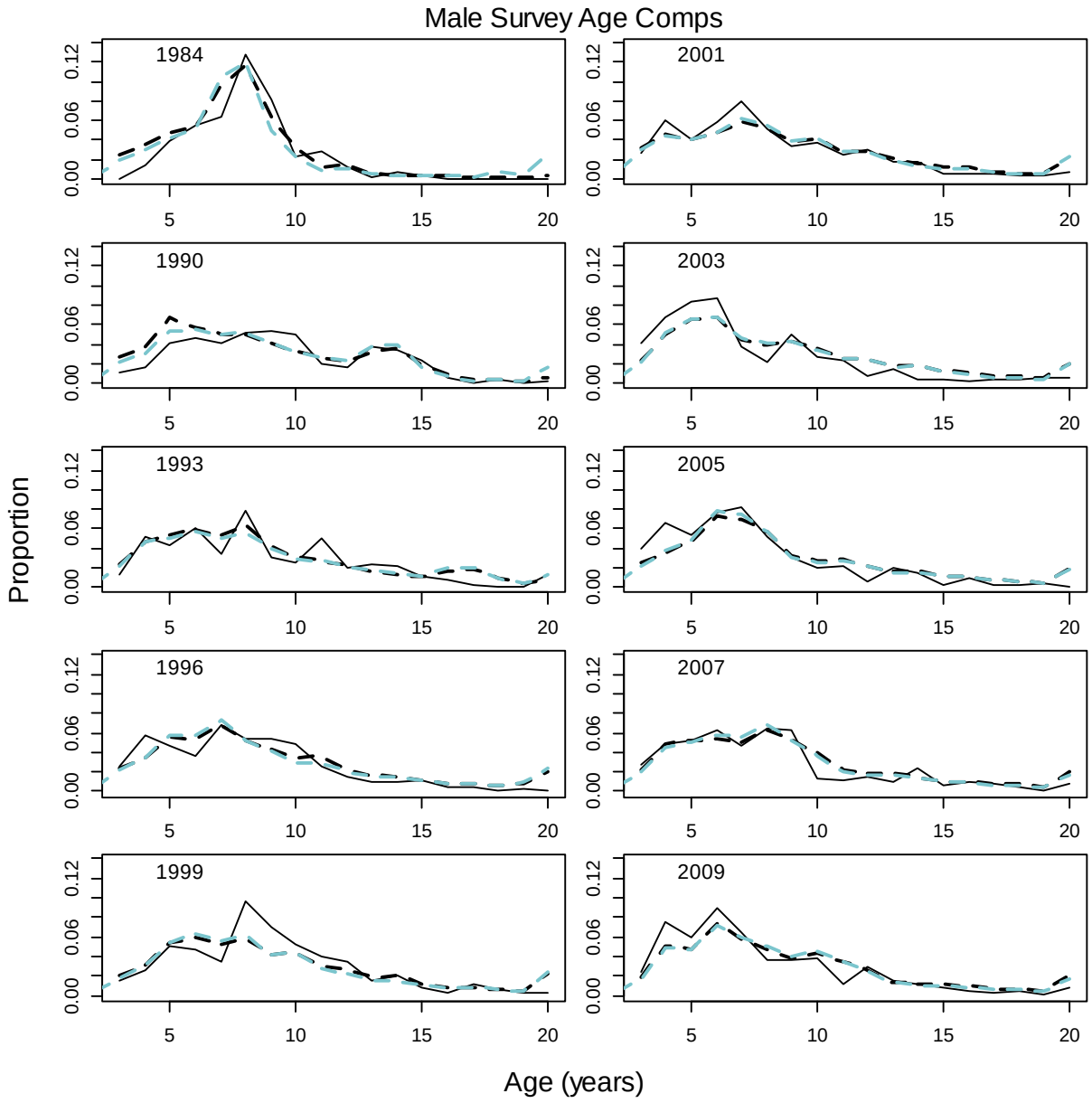


Figure 11. Observed survey biomass (black dots) with 95% asymptotic confidence intervals (vertical black lines) and predicted survey biomass from the 2011 model (black line) and an equivalent SS3 model (blue line).


Male Survey Age Comps
1984
2001
1990
2003
1993
2005
1996
2007
1999
2009
Proportion
Age (years)
0.00
0.06
0.12
5
10
15
20

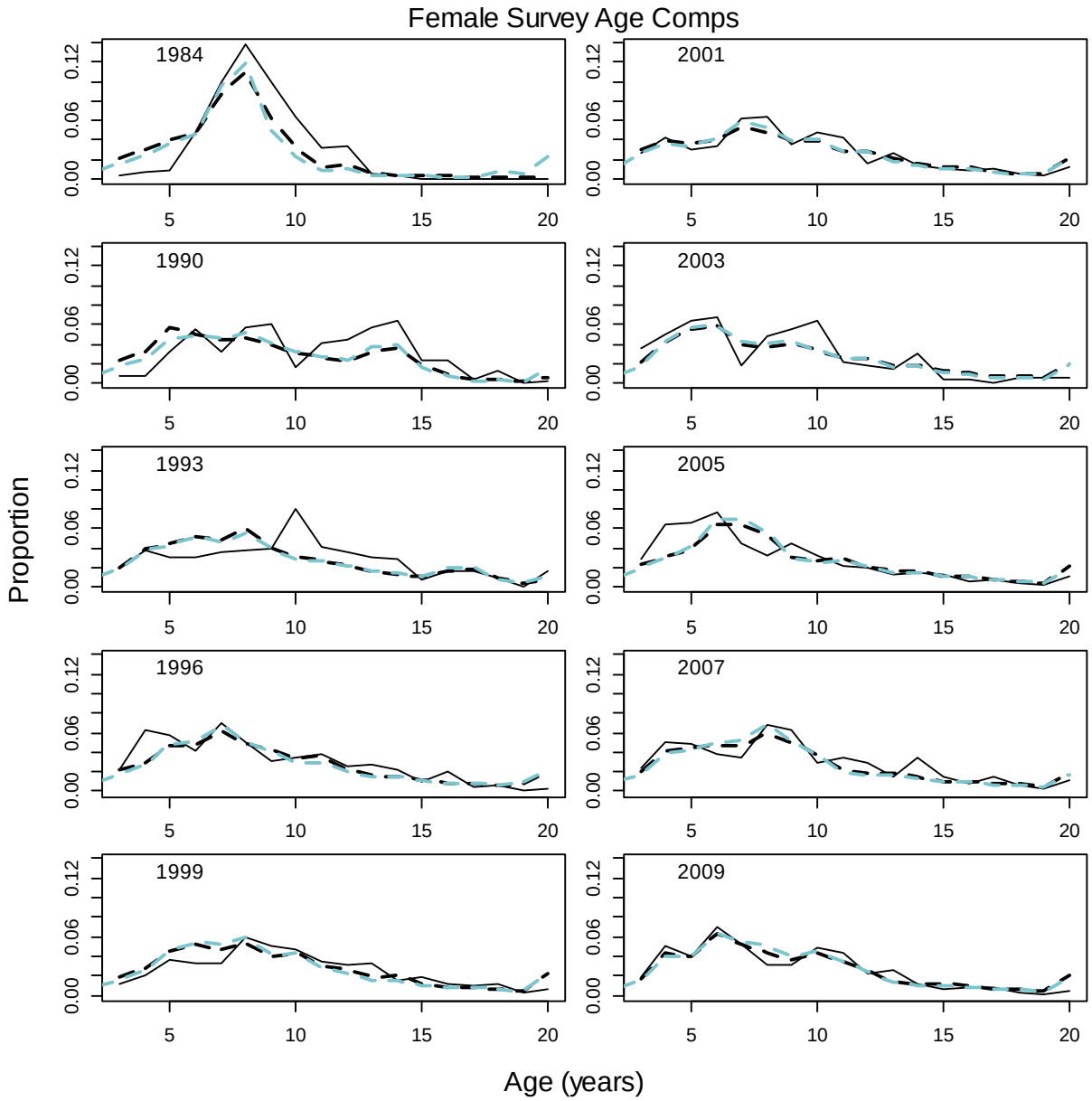
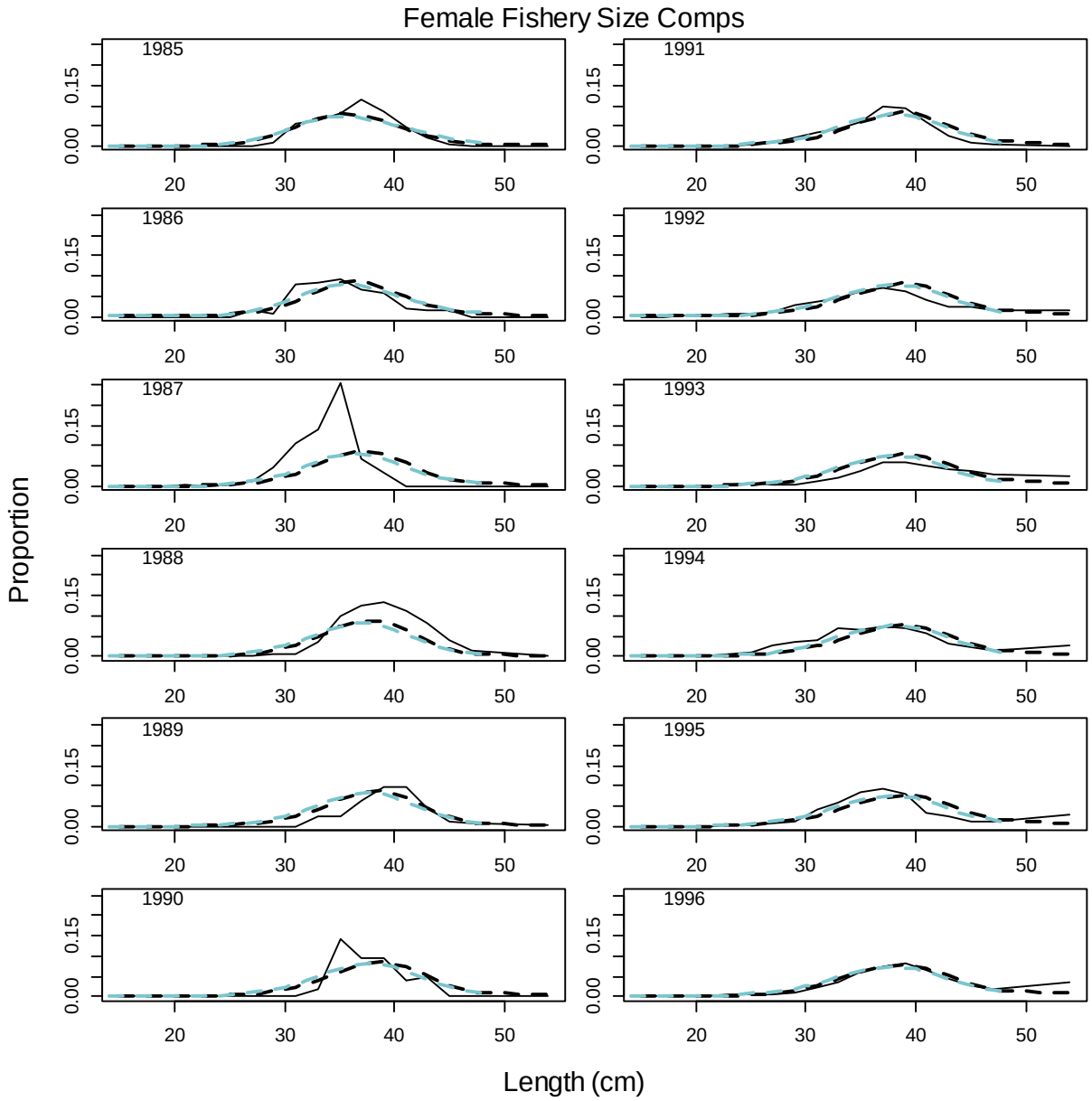
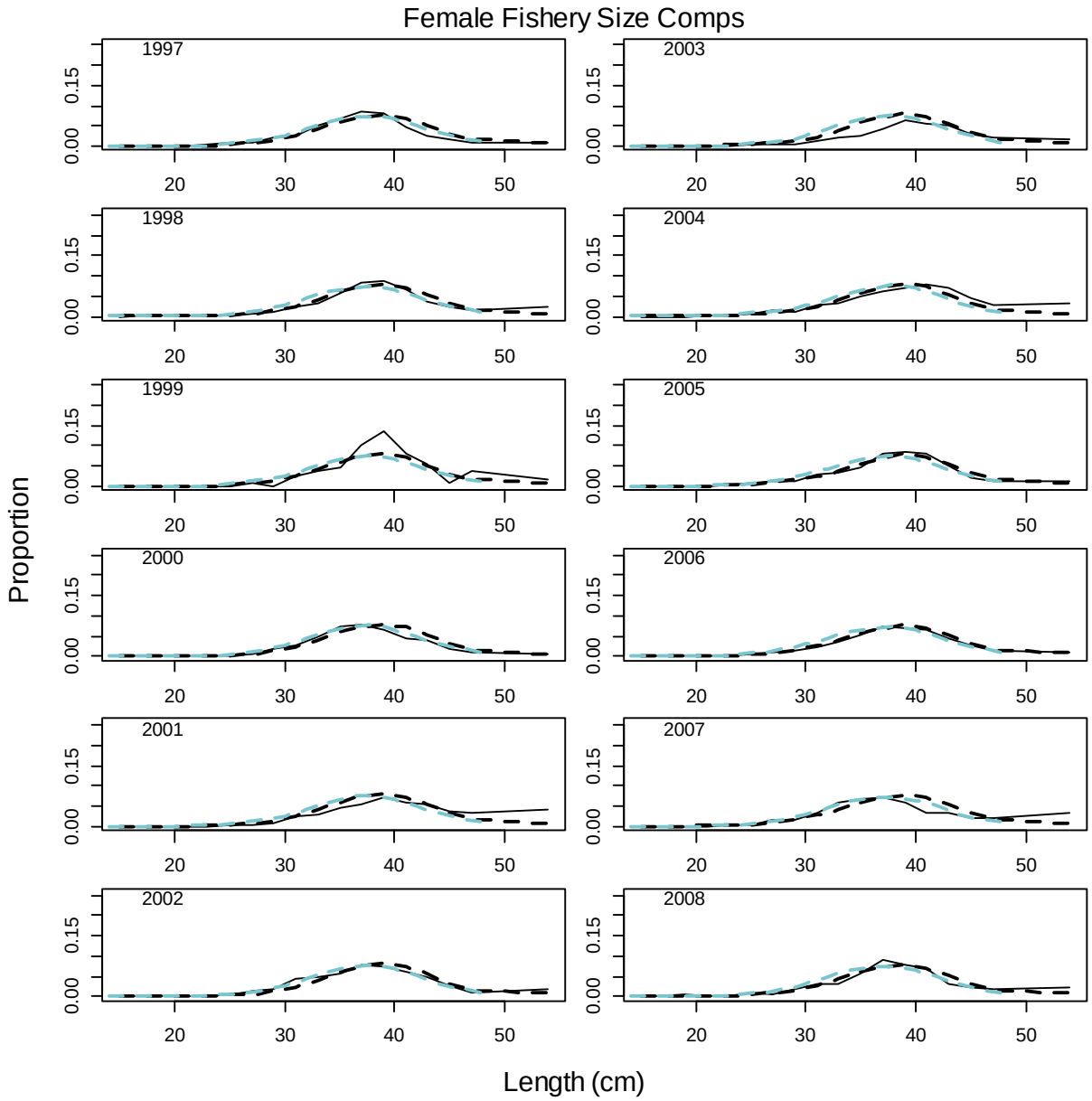
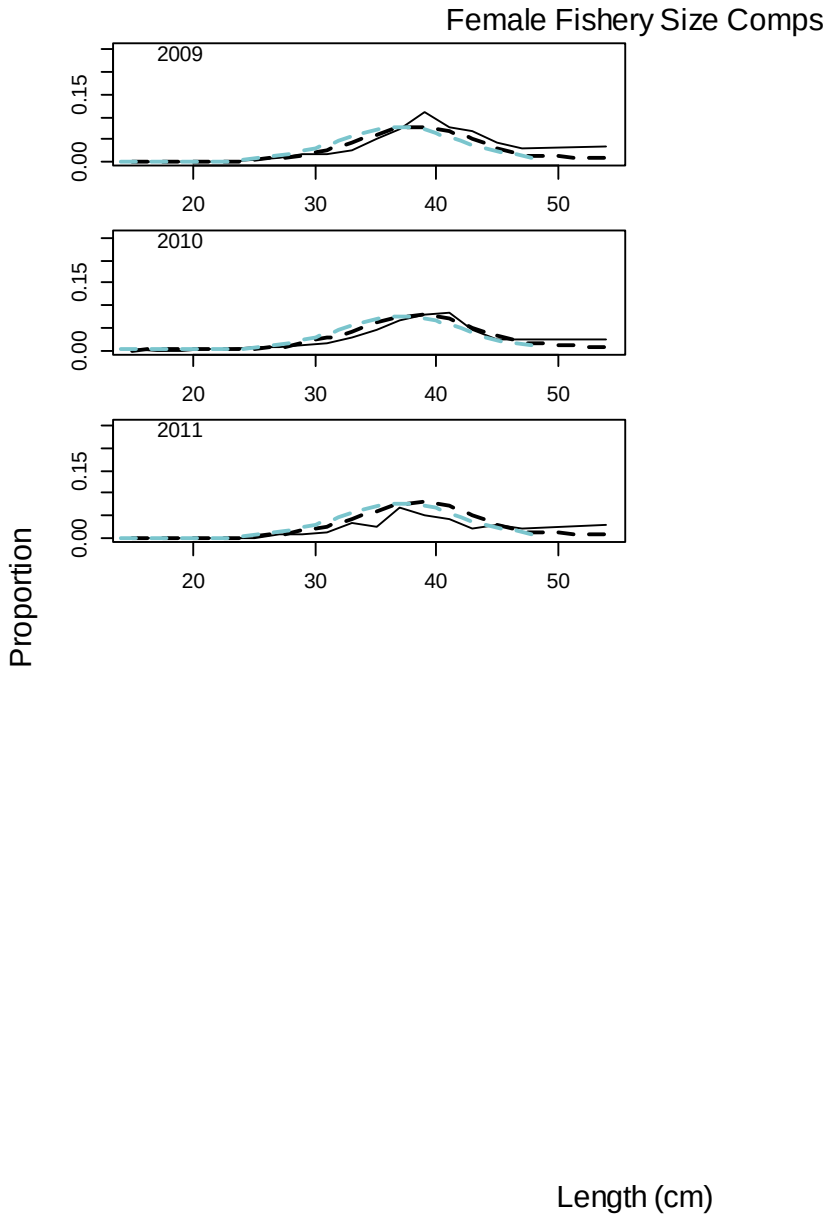
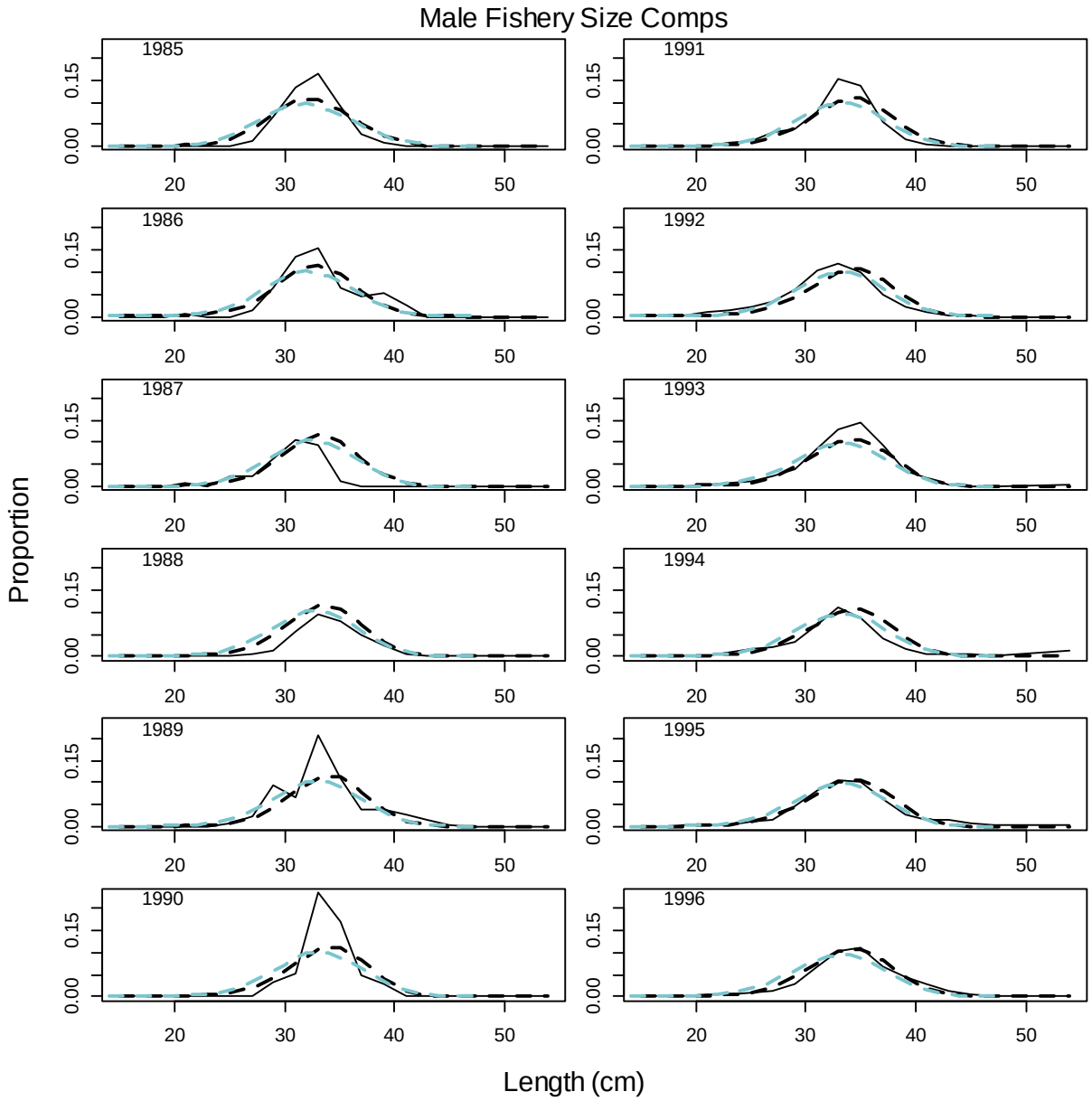


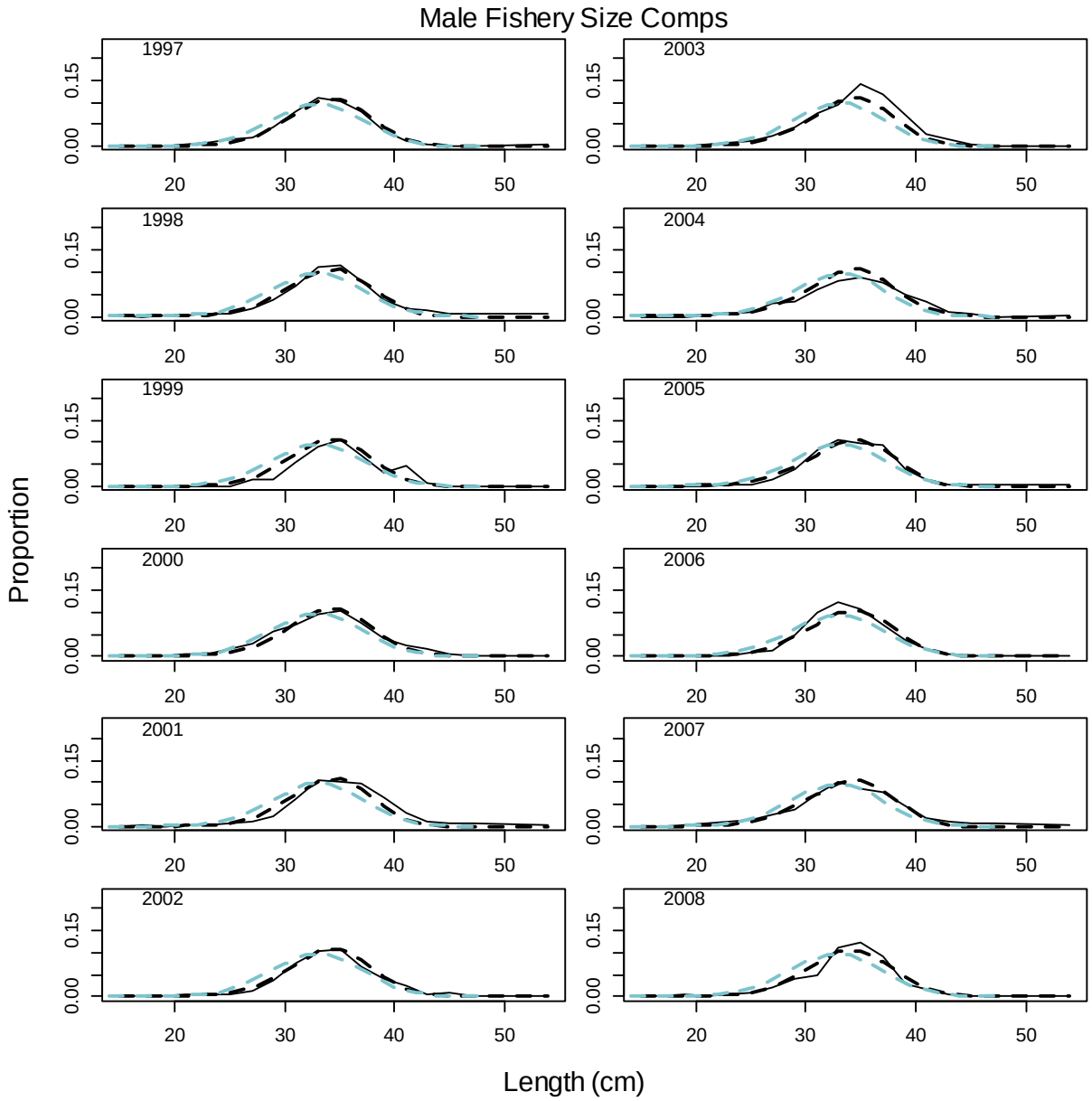
Figure 12. Observed (solid black lines) and predicted (dashed lines) survey proportions-at-age for the 2011 model (dashed black lines) and an equivalent SS3 model run (dashed blue lines) for males (first panel) and females (second panel).


Female Fishery Size Comps
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
Proportion
Length (cm)
0.00
0.15
20
30
40
50


Female Fishery Size Comps
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
0.00
0.15
20
30
40
50
Proportion
Length (cm)


Female Fishery Size Comps
2009
2010
2011
0.00
0.15
20
30
40
50
Proportion
Length (cm)


Male Fishery Size Comps
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
0.00
0.15
20
30
40
50
Proportion
Length (cm)


Male Fishery Size Comps
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Proportion
Length (cm)
0.00
0.15
20
30
40
50

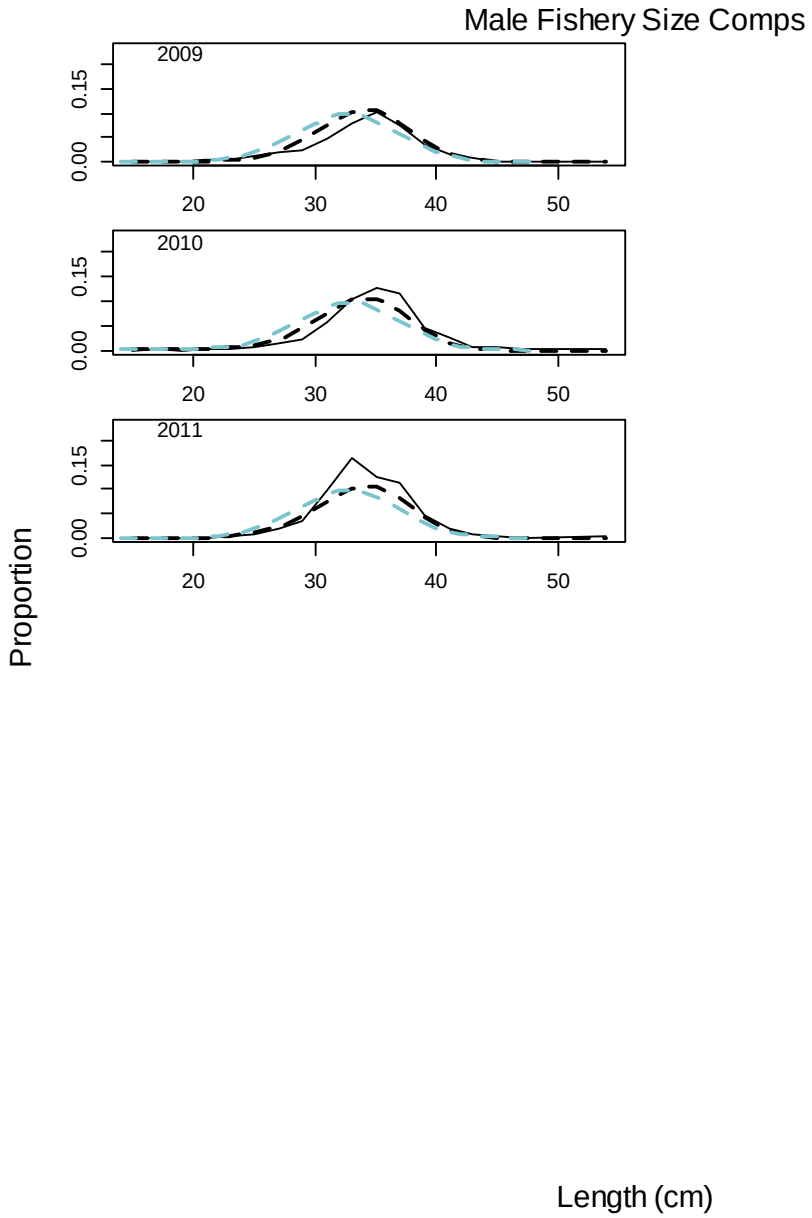
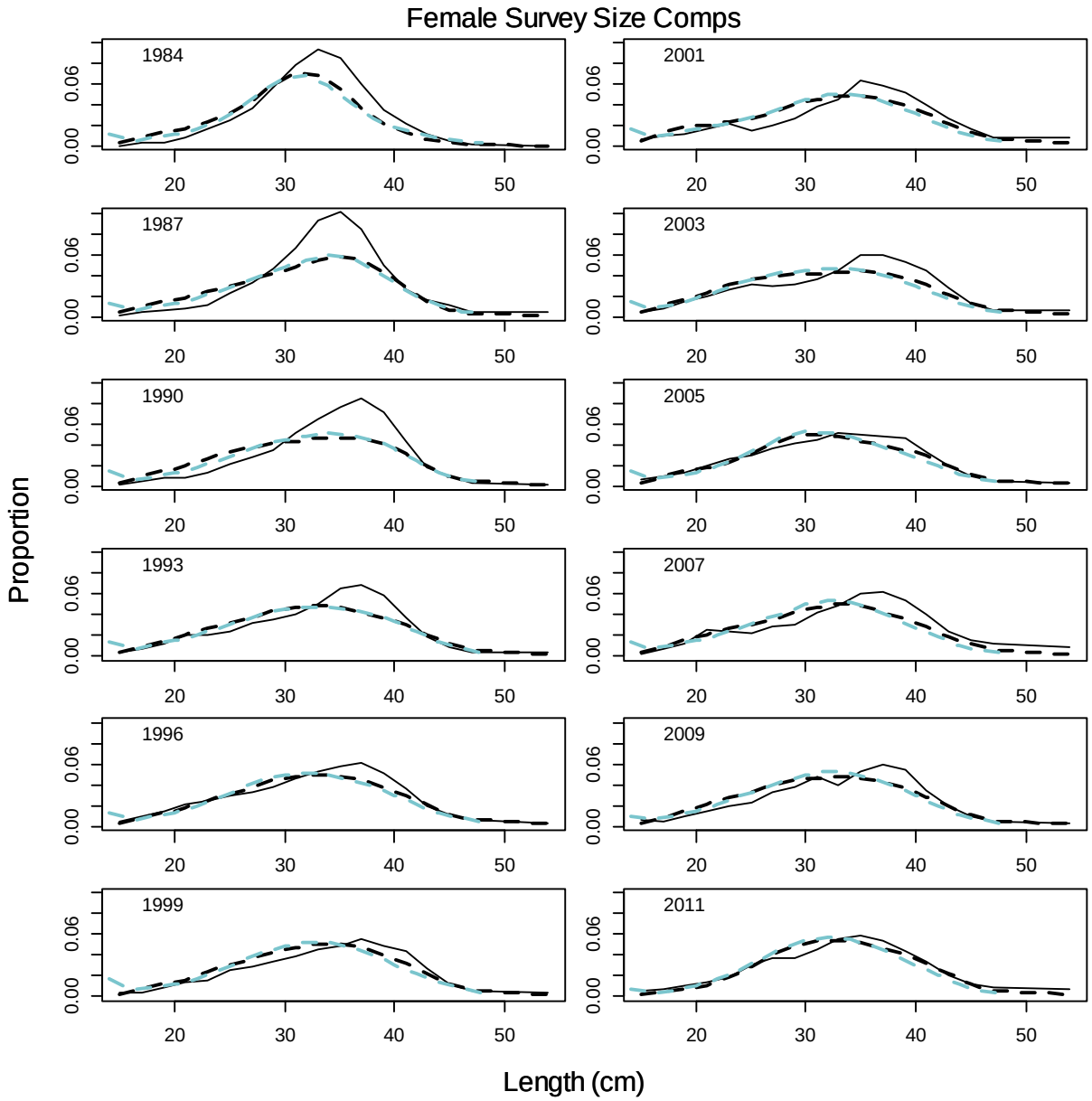


Figure 13. Observed (solid black lines) and predicted (dashed lines) fishery proportions-at-length for the 2011 model (dashed black lines) and an equivalent SS3 model run (dashed blue lines) for females (first set of panels) and males (second set of panels).


Female Survey Size Comps
1984
2001
1987
2003
1990
2005
1993
2007
1996
2009
1999
2011
0.00
0.06
20
30
40
50
Proportion
Length (cm)

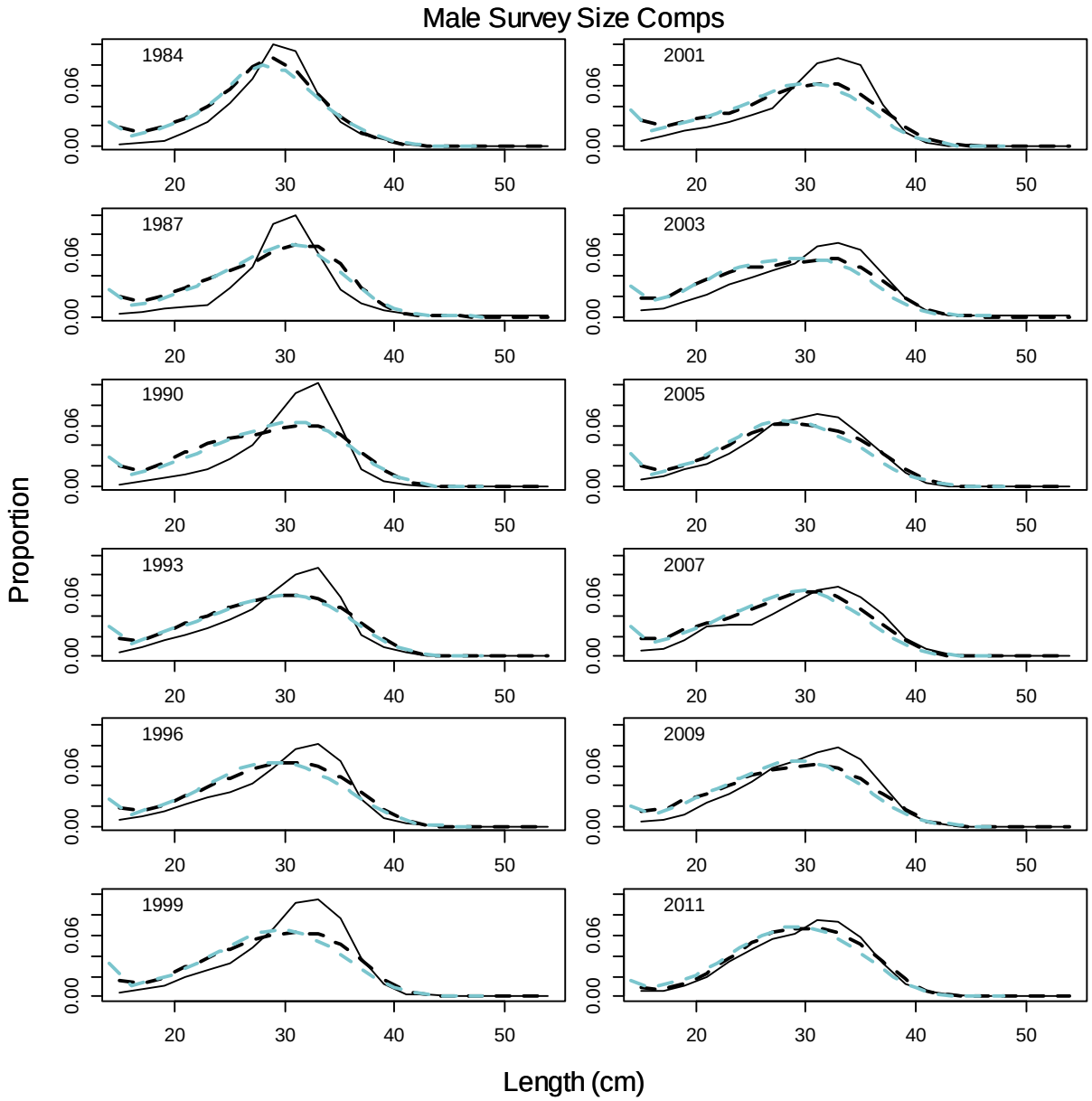


Figure 14. Observed (solid black lines) and predicted (dashed lines) survey proportions-at-length for the 2011 model (dashed black lines) and an equivalent SS3 model run (dashed blue lines) for females (first set of panels) and males (second set of panels).

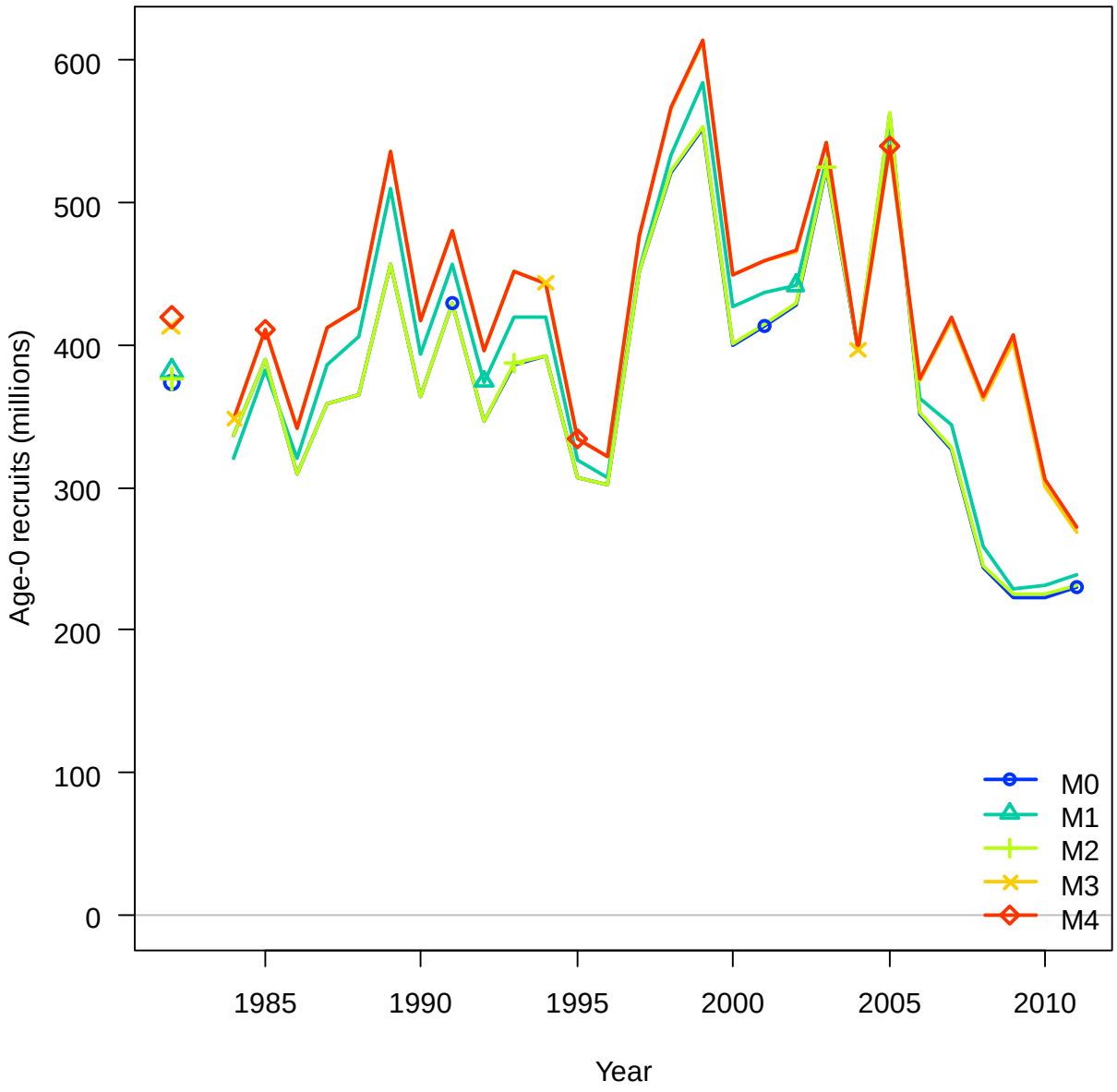


Figure 15. Age 0 recruits for each alternative SS3 model. M0 is the transitional SS3 model that best matches the 2011 model. The leftmost group of vertical lines shows the log of mean recruitment.

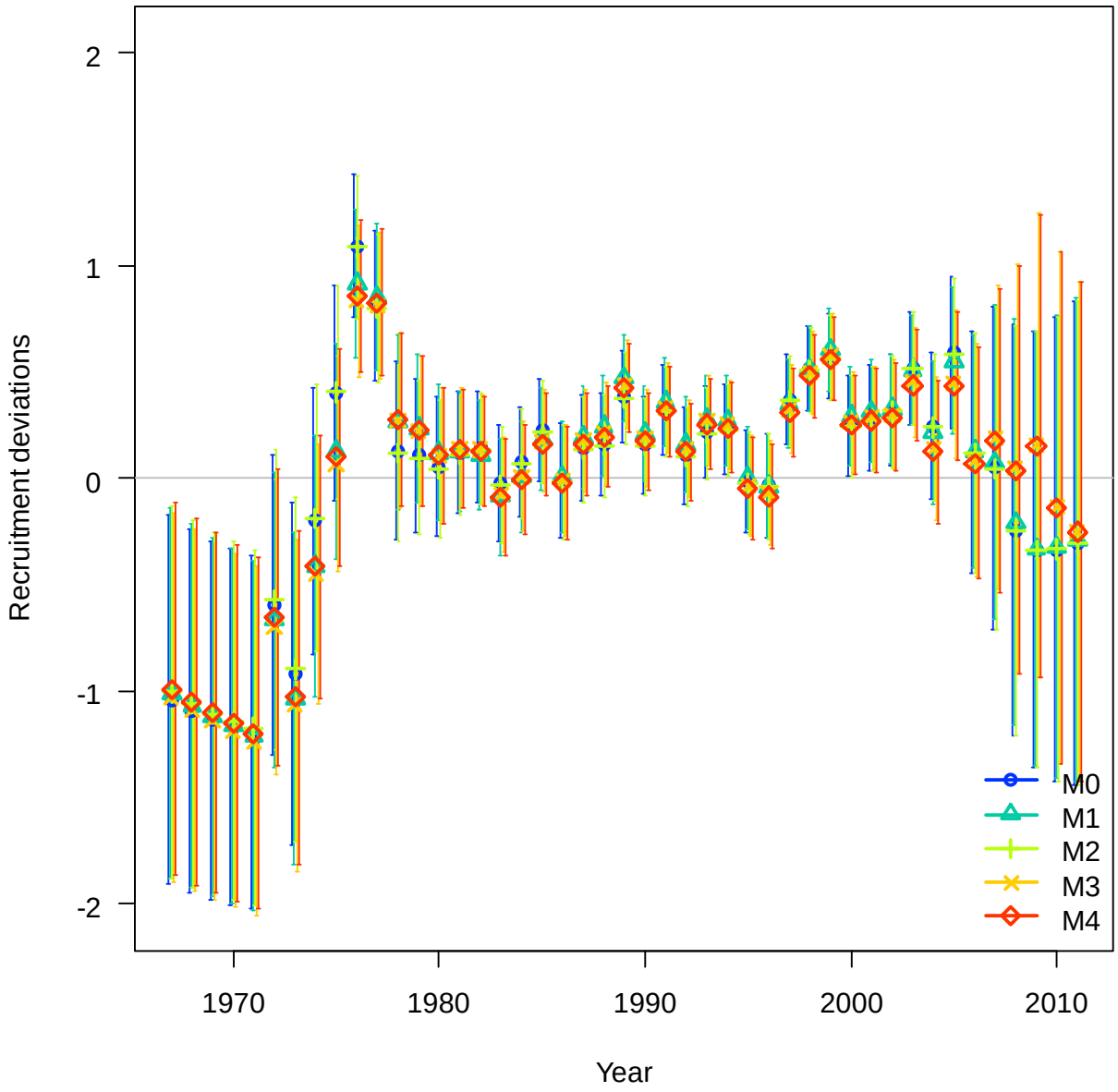


Figure 16. Estimated recruitment deviations and 95% asymptotic confidence intervals for each alternative SS3 model. M0 is the transitional SS3 model that best matches the 2011 model.

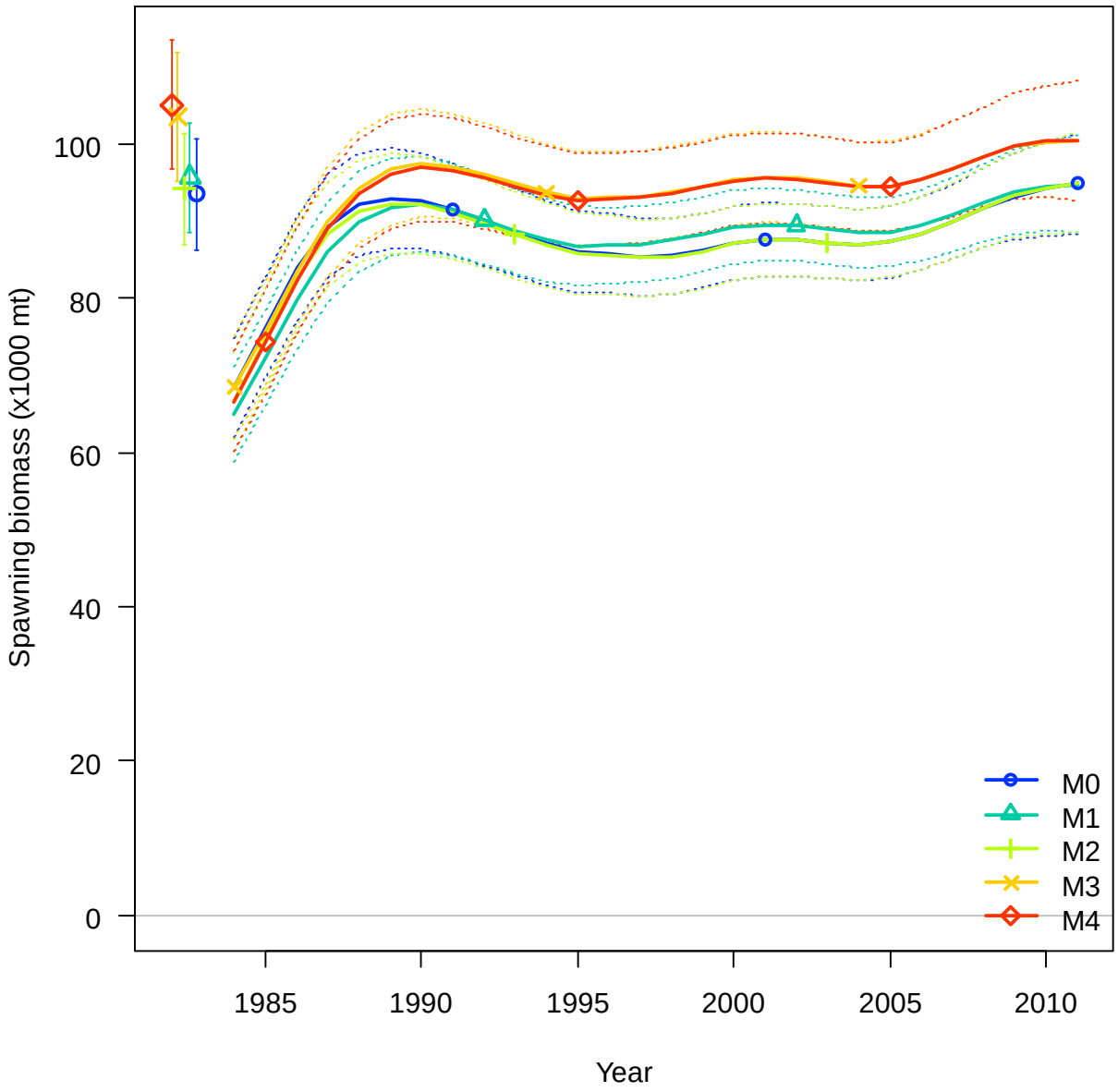


Figure 17. Spawning stock biomass (solid lines) and 95% asymptotic confidence intervals (dotted lines) over time for each alternative SS3 model. M0 is the transitional SS3 model that best matches the 2011 model.

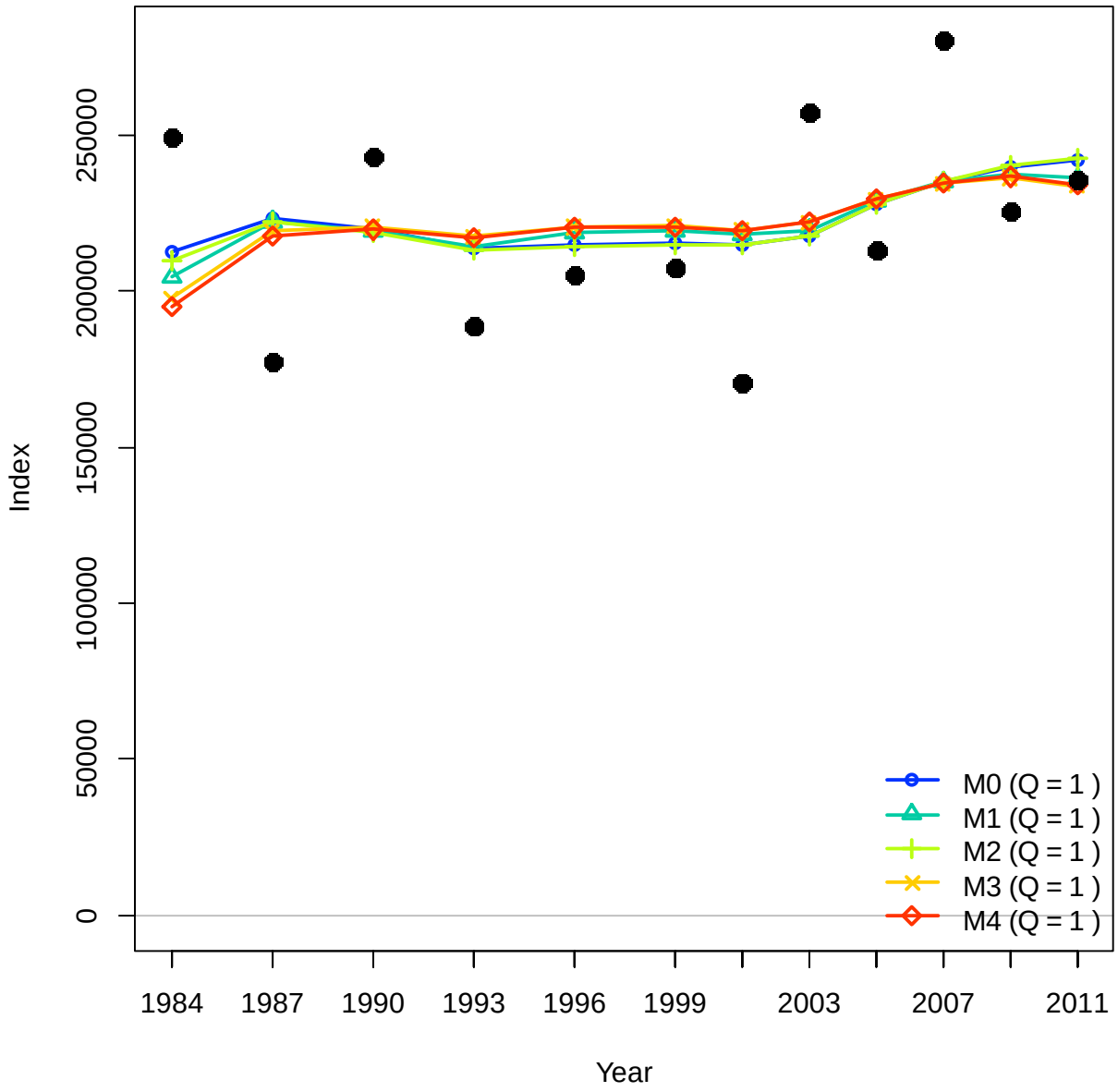


Figure 18. Observed (black dots) and predicted (lines) survey biomass for each proposed alternative model. M0 is the transitional model that best matches the 2011 assessment model.

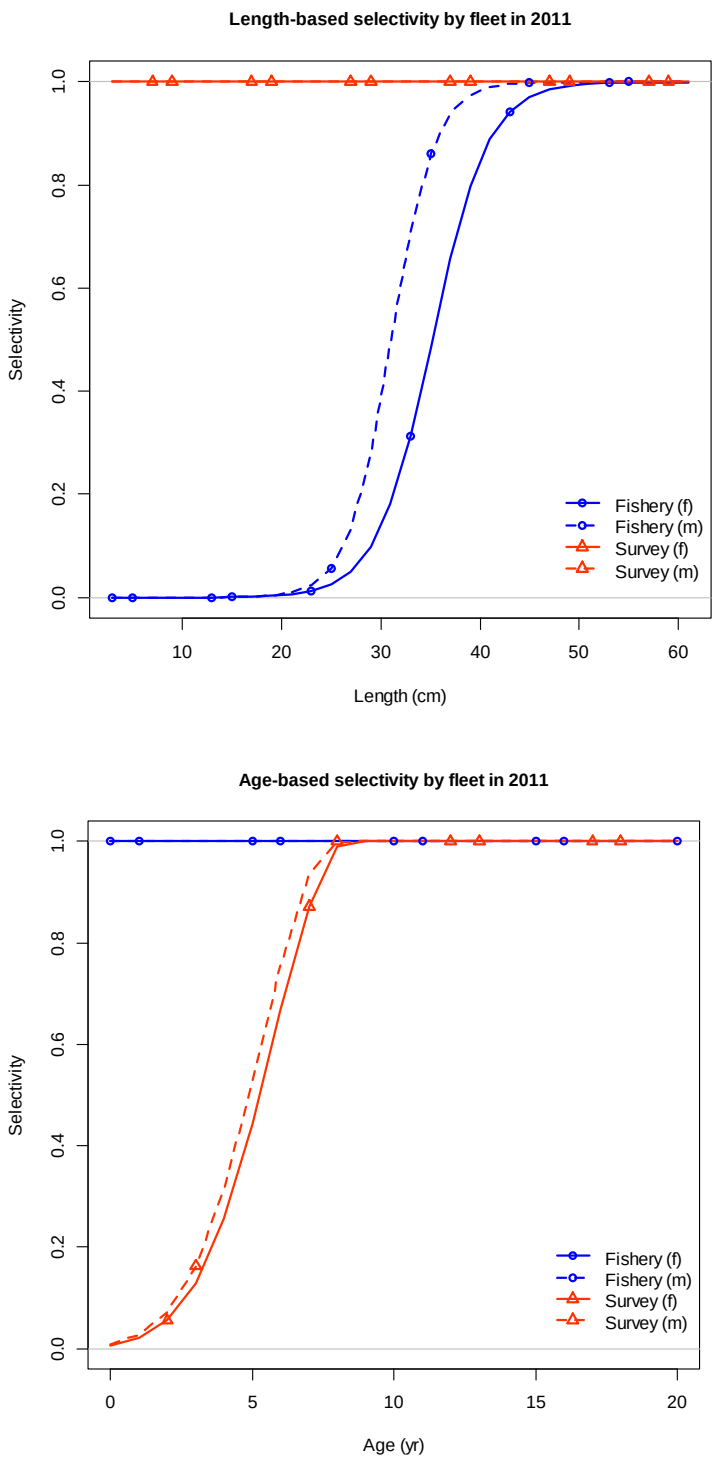


Figure 19. Length-based fishery and age-based survey selectivity curves for proposed alternative model M1: as for the transitional SS3 model, but with length-based, logistic fishery selectivity.

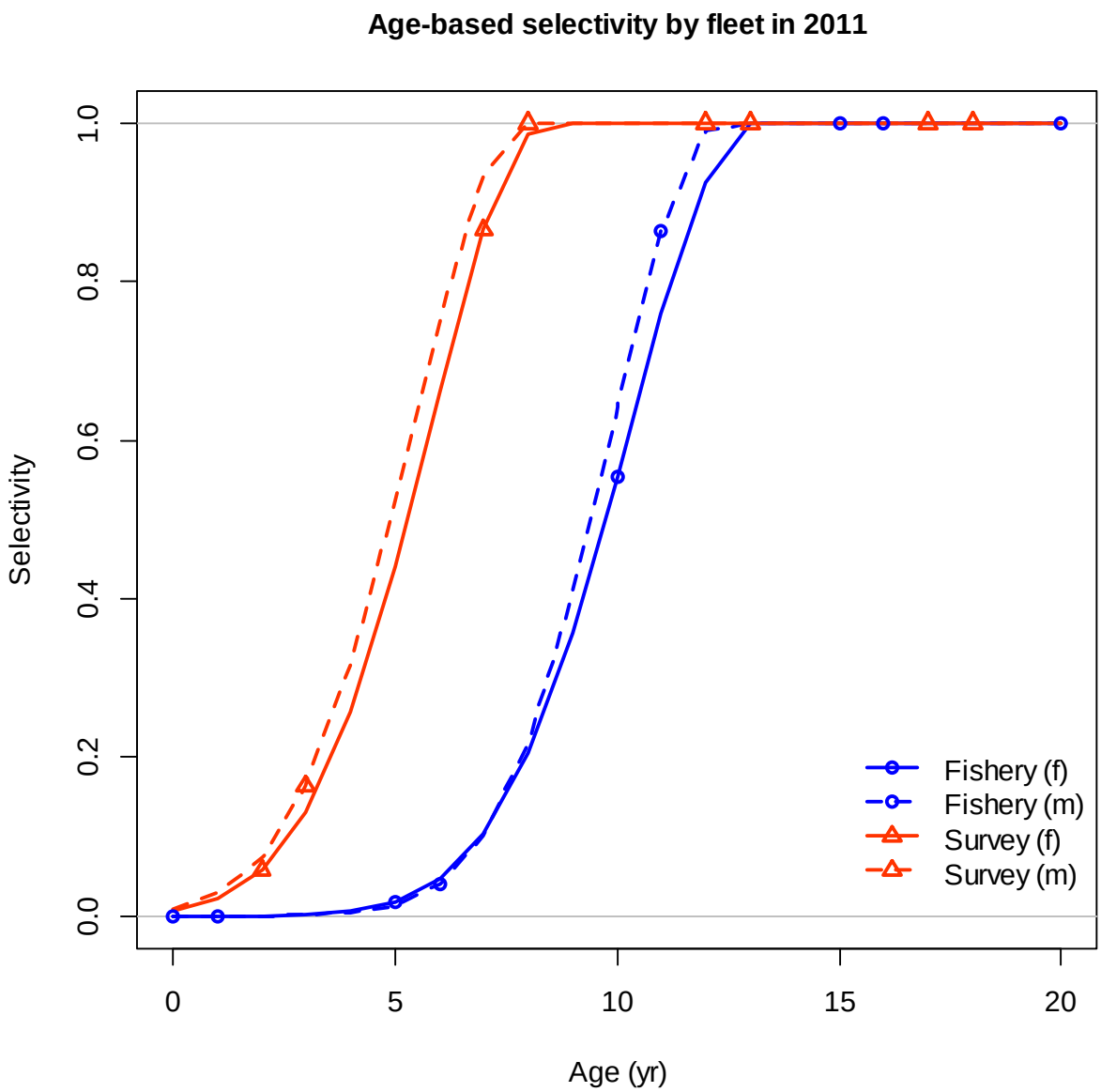


Figure 20. Age-based double-normal fishery and survey selectivity for proposed alternative model M2 (as for the transitional SS3 model, but with an initial equilibrium fishing mortality rate estimated).

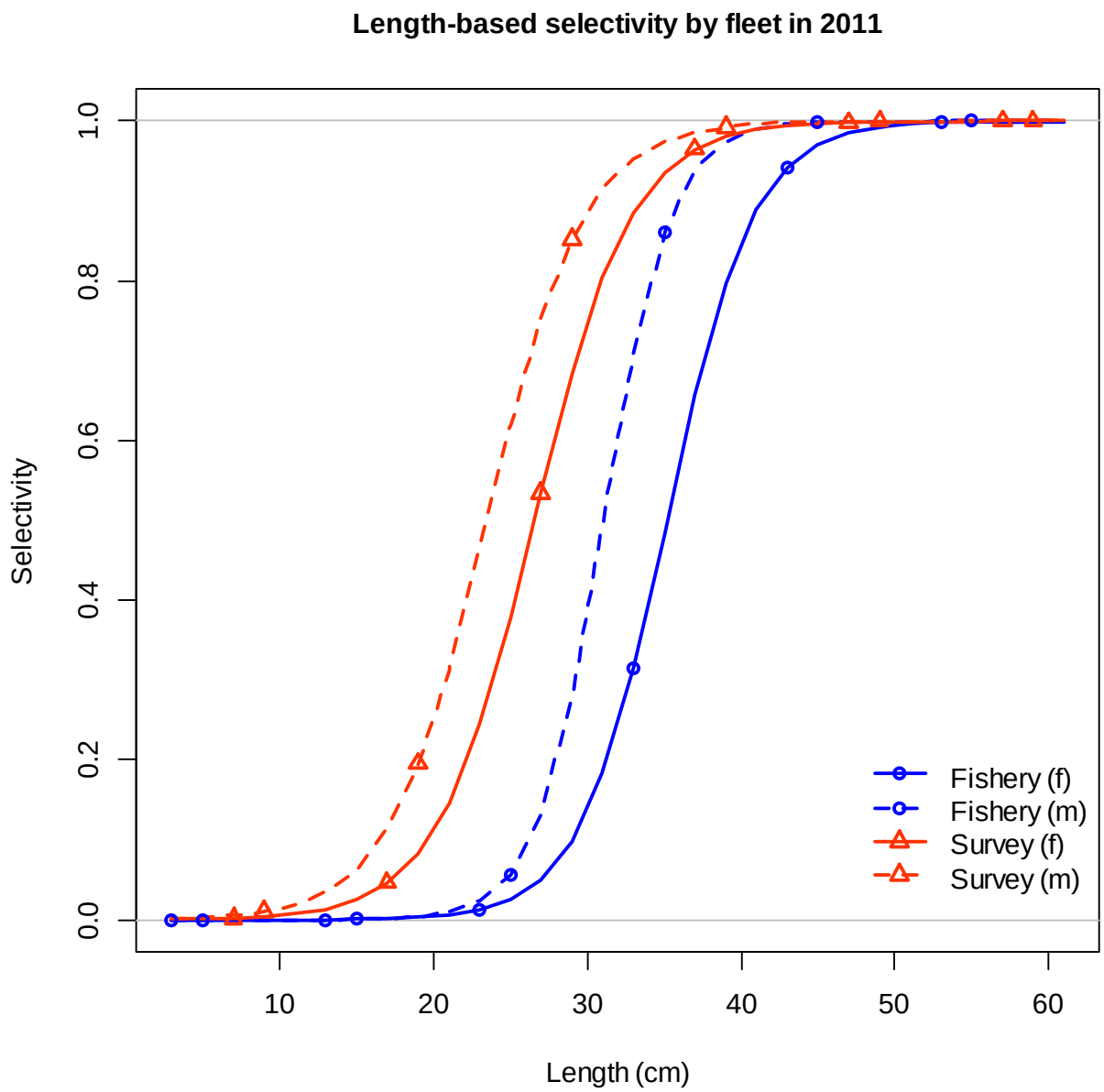


Figure 21. Length-based logistic fishery selectivity for proposed alternative model M3 (as for the transitional SS3 model, but with length-based, logistic, sex-specific selectivity for the fishery and the survey).

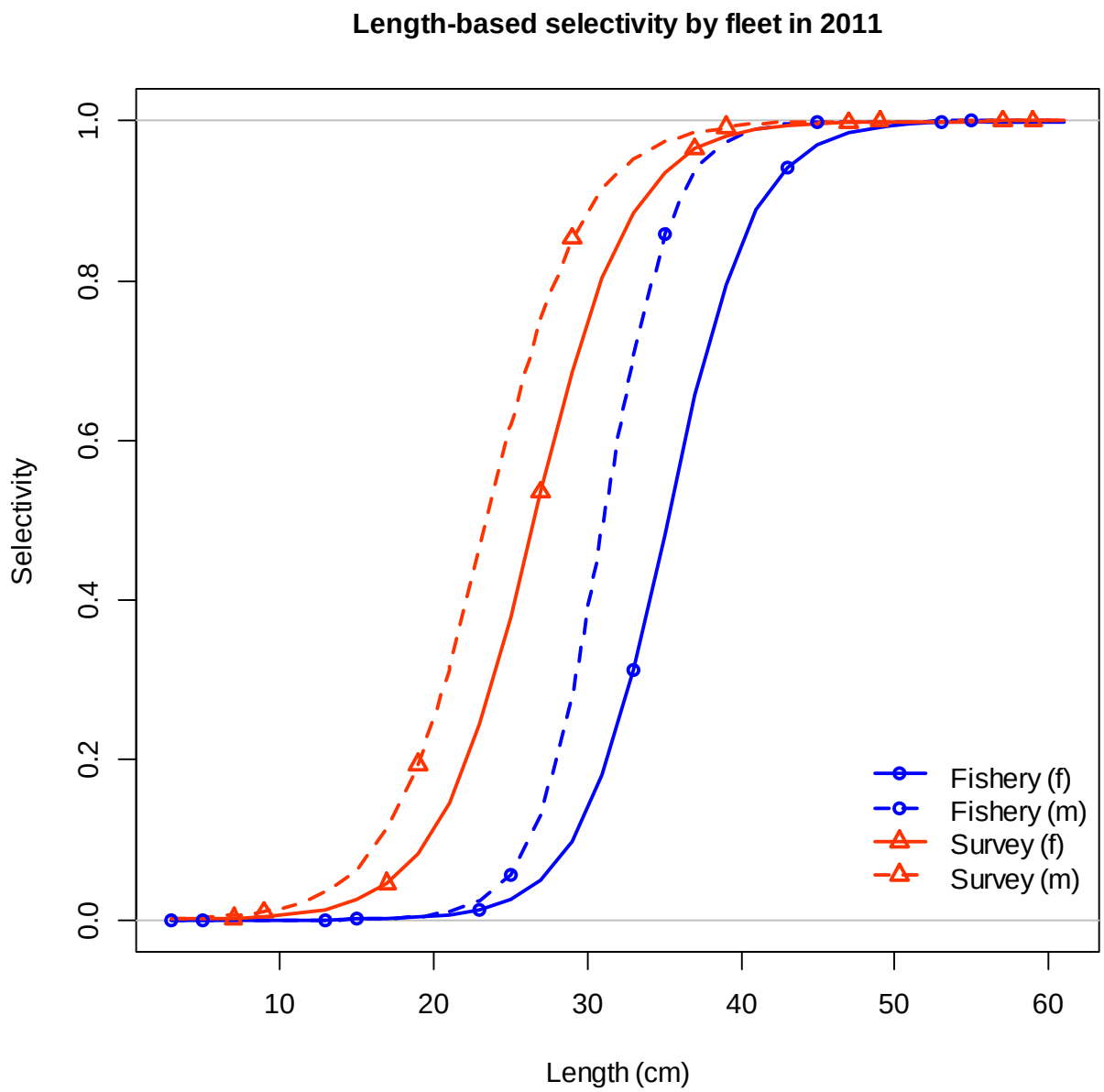


Figure 22. Length-based fishery and survey selectivity for model M4 (as for the transitional SS3 model, but with estimation of an initial equilibrium fishing mortality rate and length-based, logistic, sex-specific selectivity for the fishery and the survey).

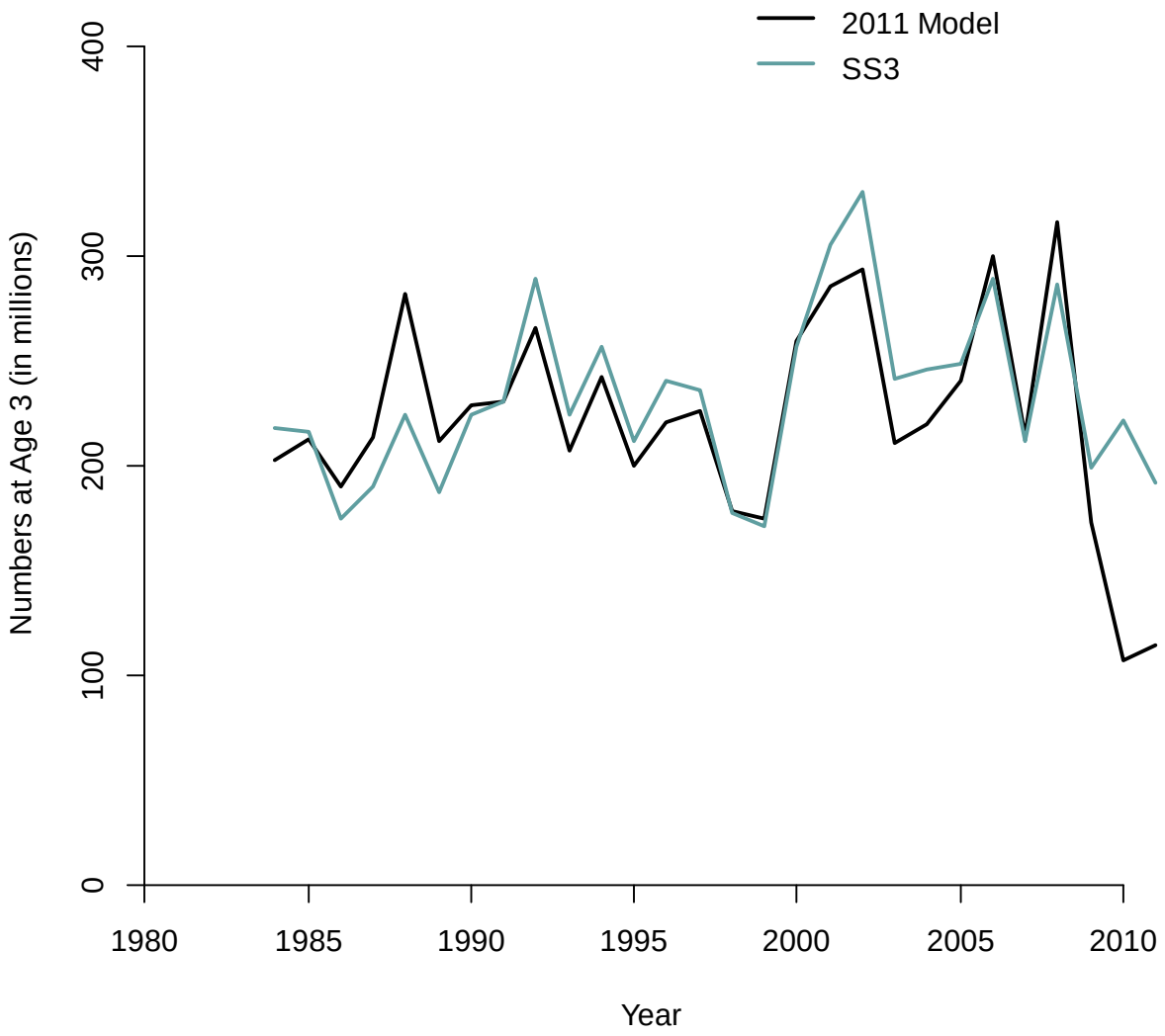


Figure 23. Comparison of numbers at age 3 for the 2011 model and proposed alternative model M4.

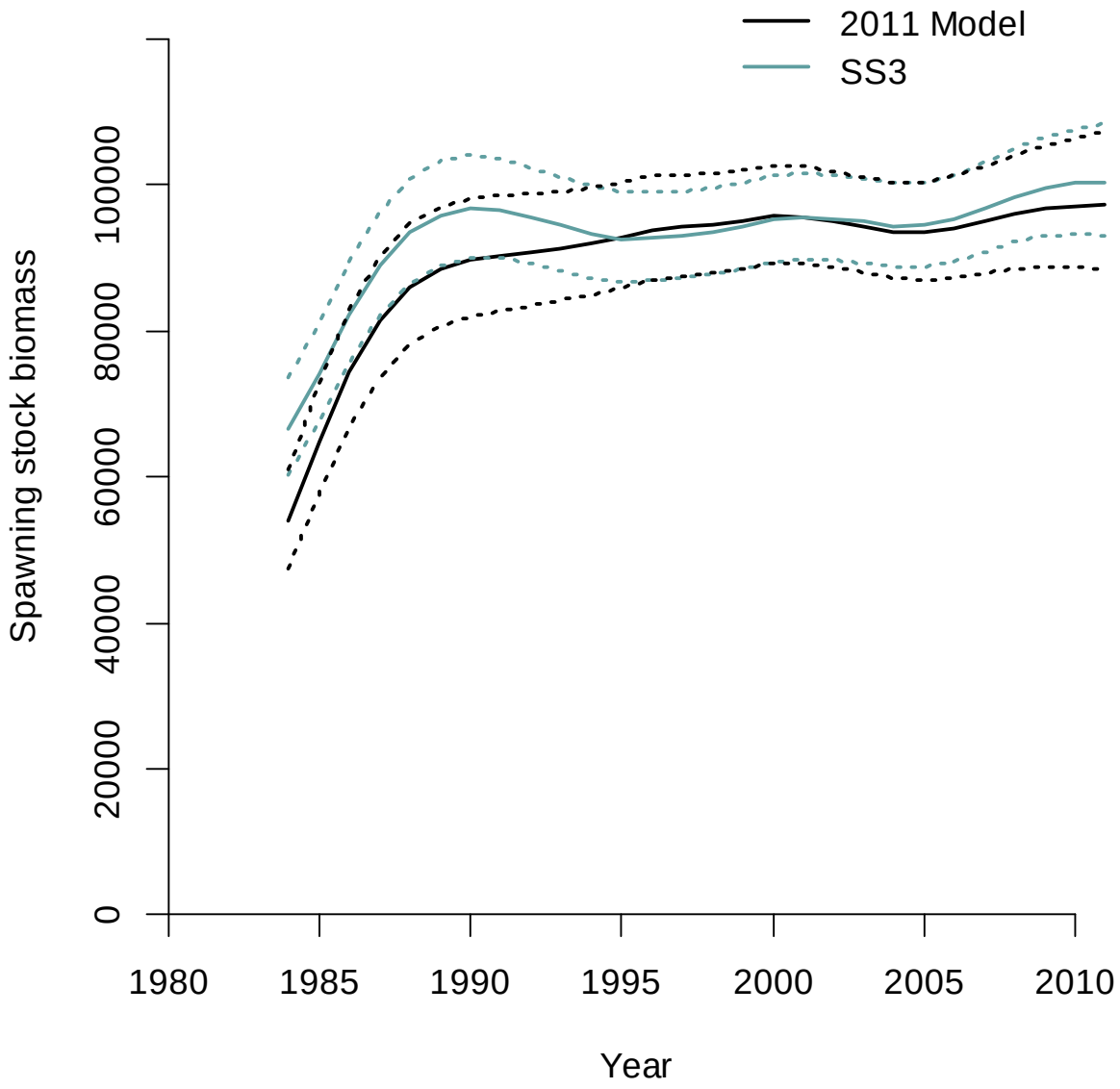


Figure 24. Comparison of SSB (solid lines) and 95% asymptotic confidence intervals (dotted lines) for the 2011 assessment model and proposed alternative model M4.

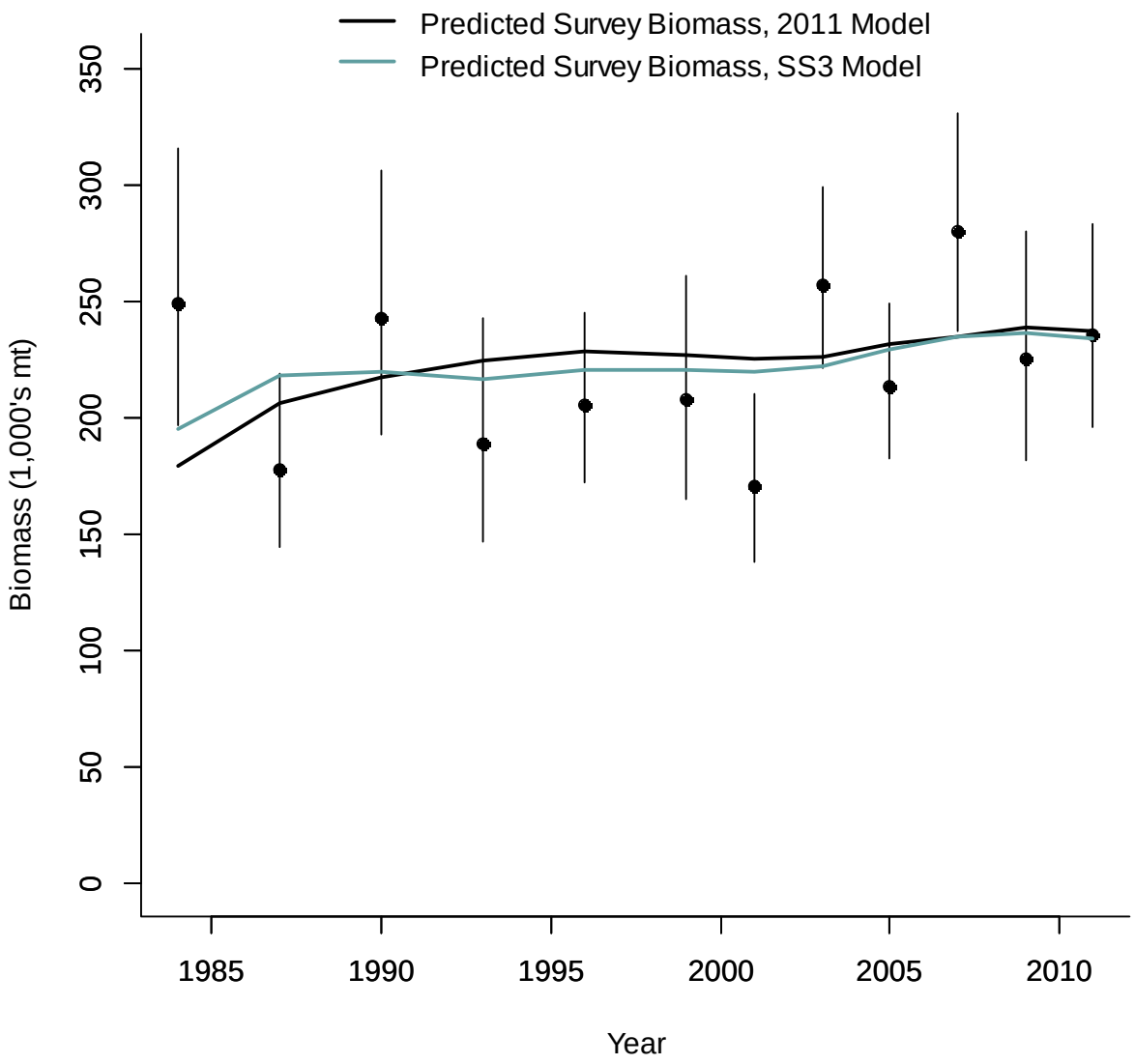
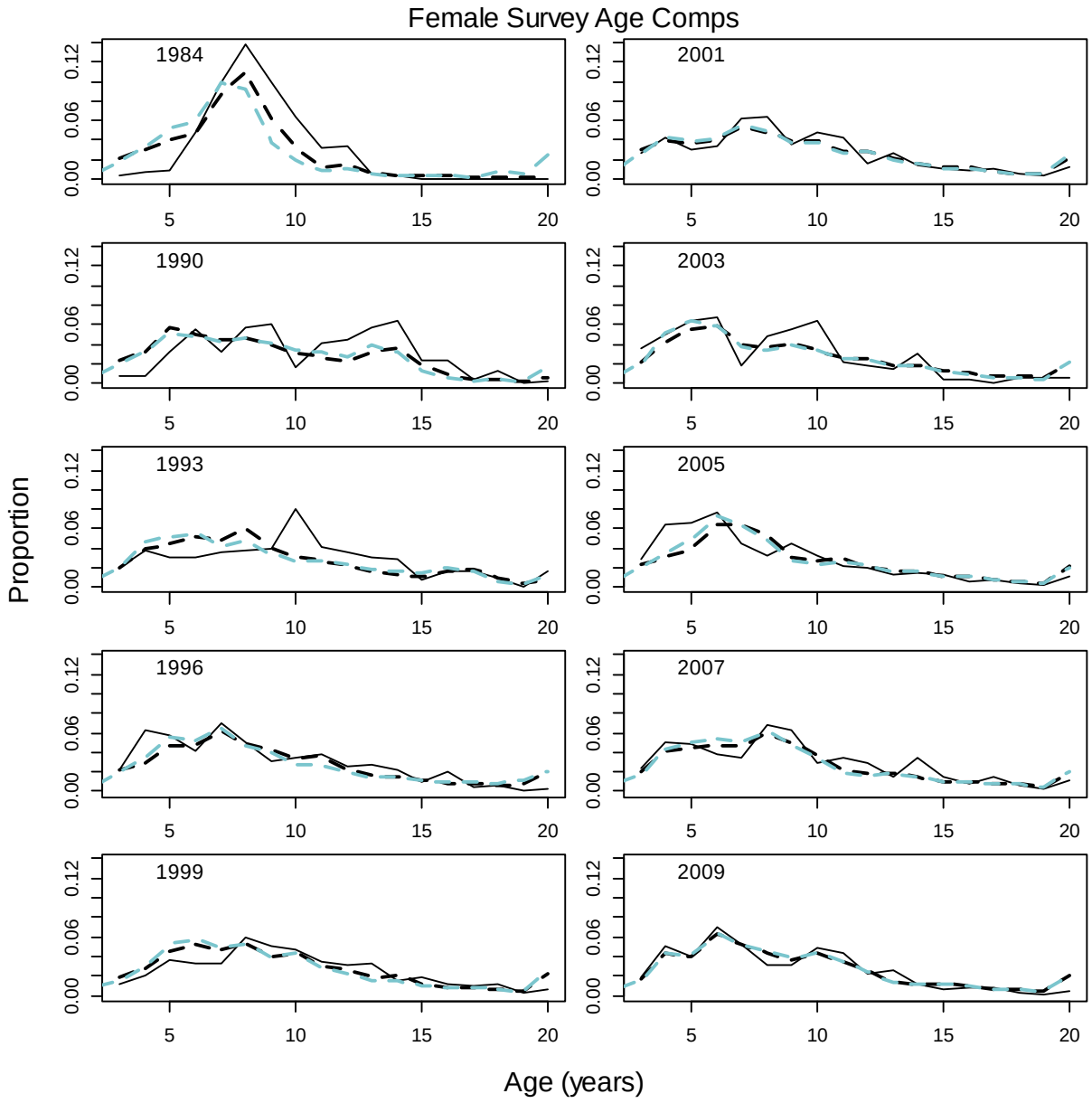


Figure 25. Observed survey biomass (black dots) with 95% asymptotic confidence intervals (vertical black lines) and predicted survey biomass from the 2011 model (black line) and proposed alternative model M4 (blue line).


Female Survey Age Comps
1984
2001
1990
2003
1993
2005
1996
2007
1999
2009
Proportion
Age (years)
0.00
0.06
0.12
5
10
15
20

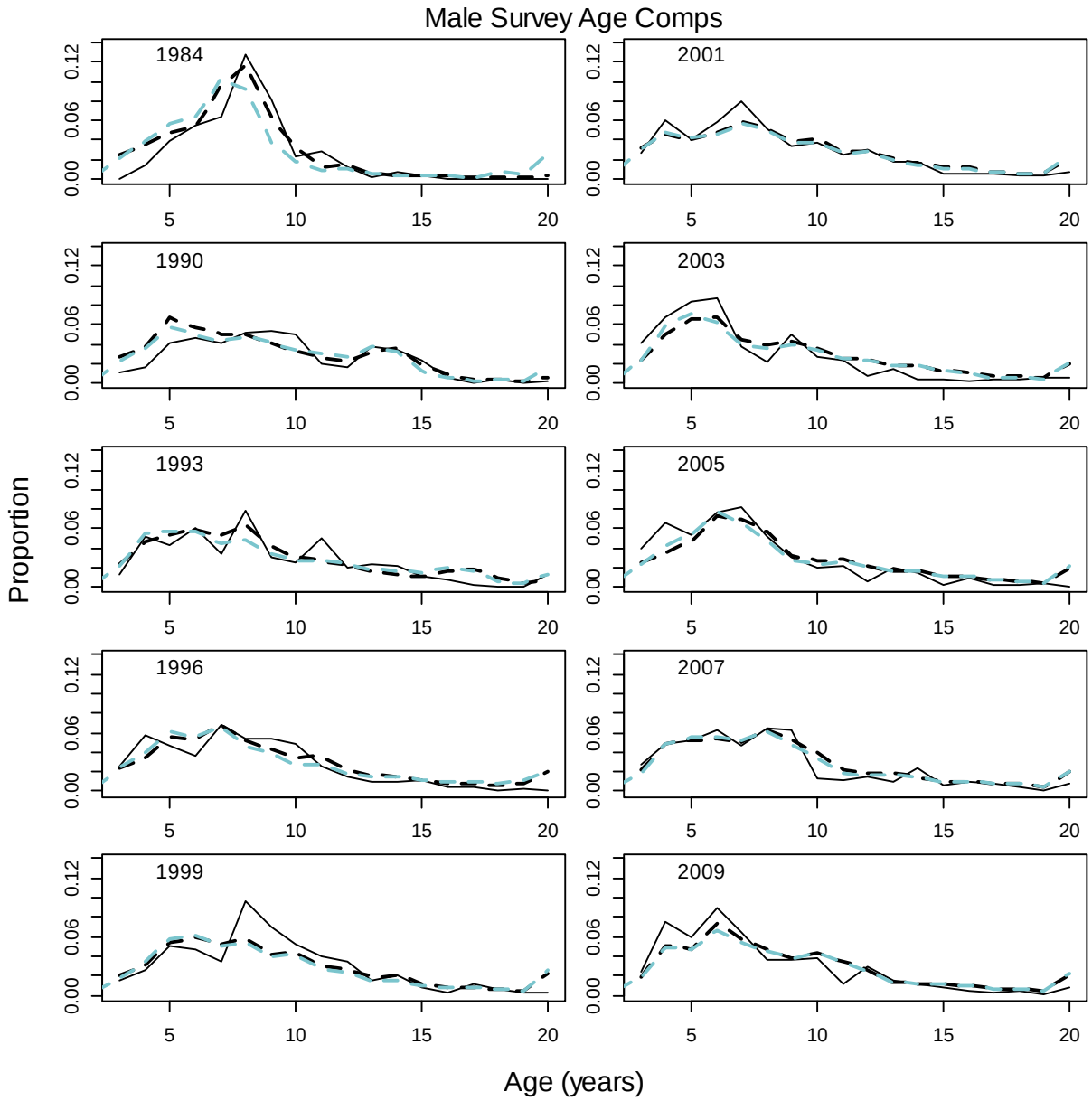
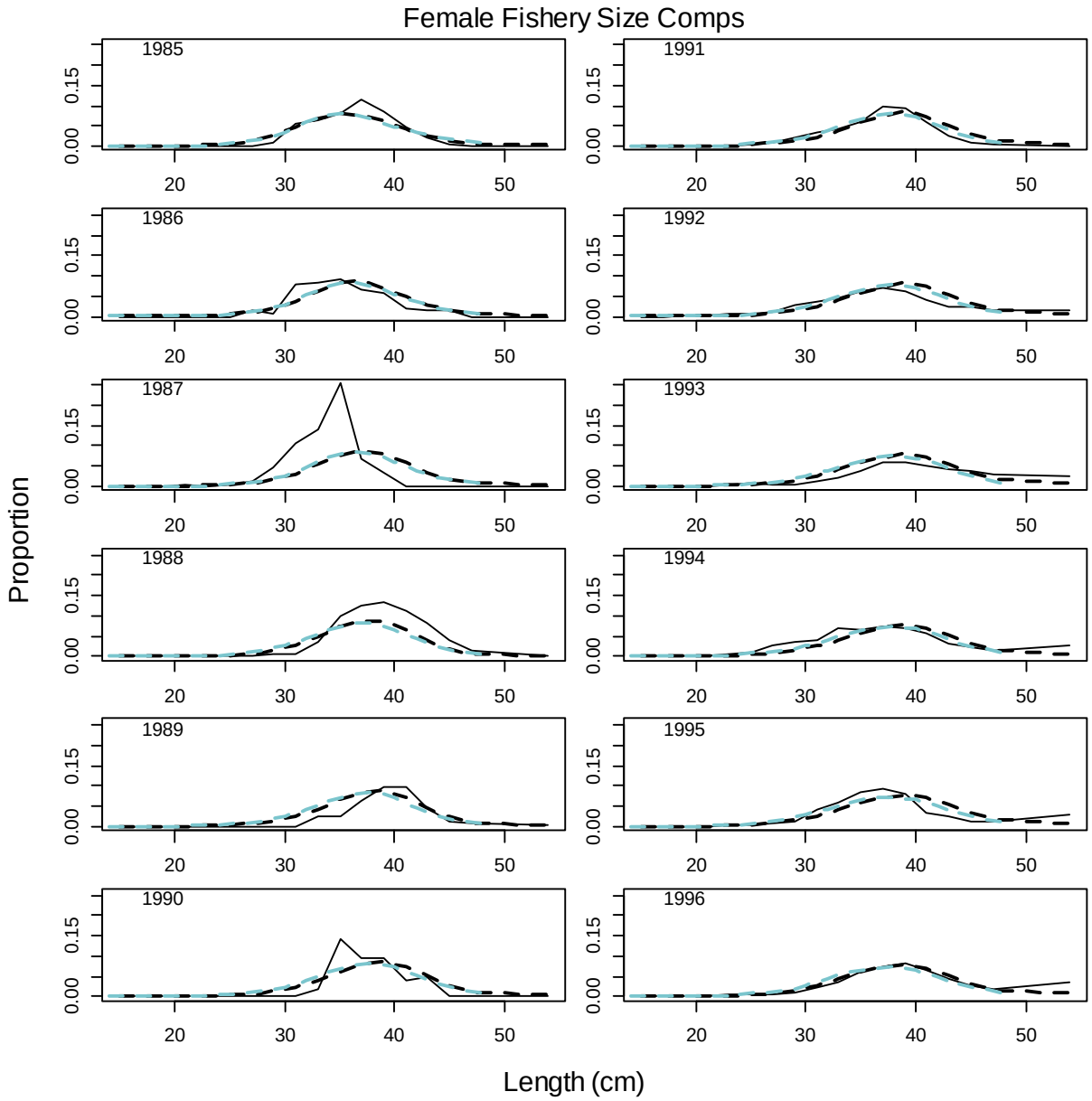
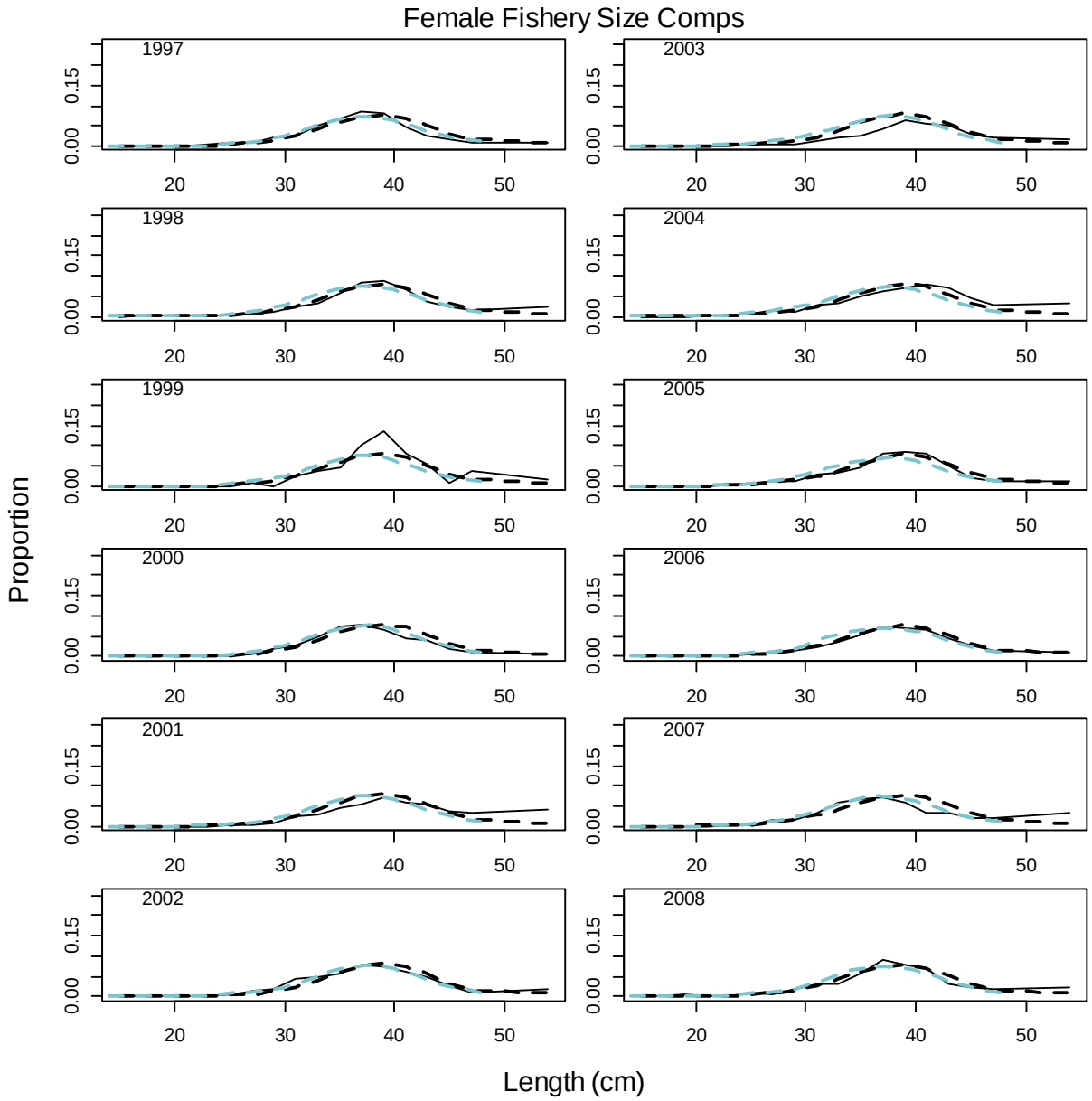
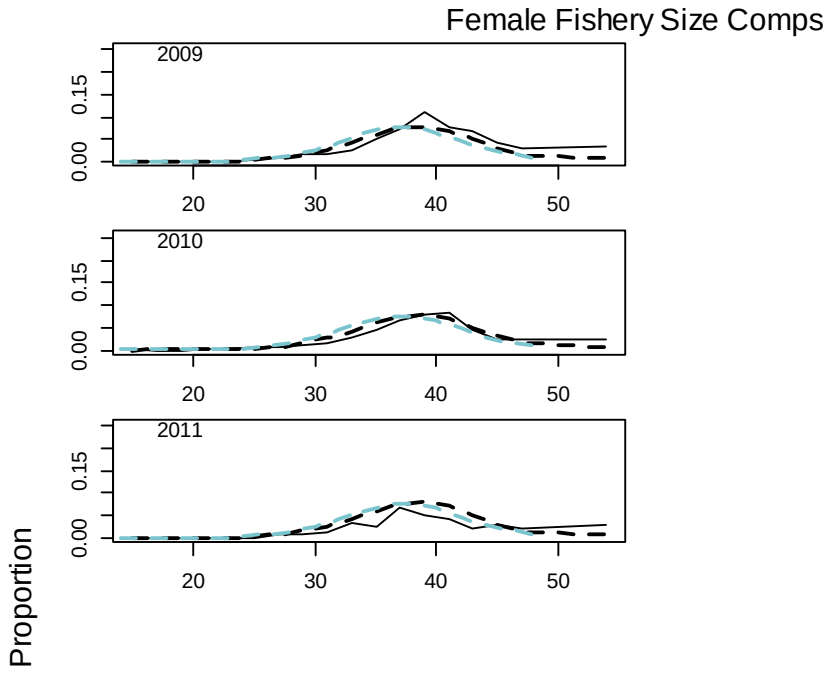


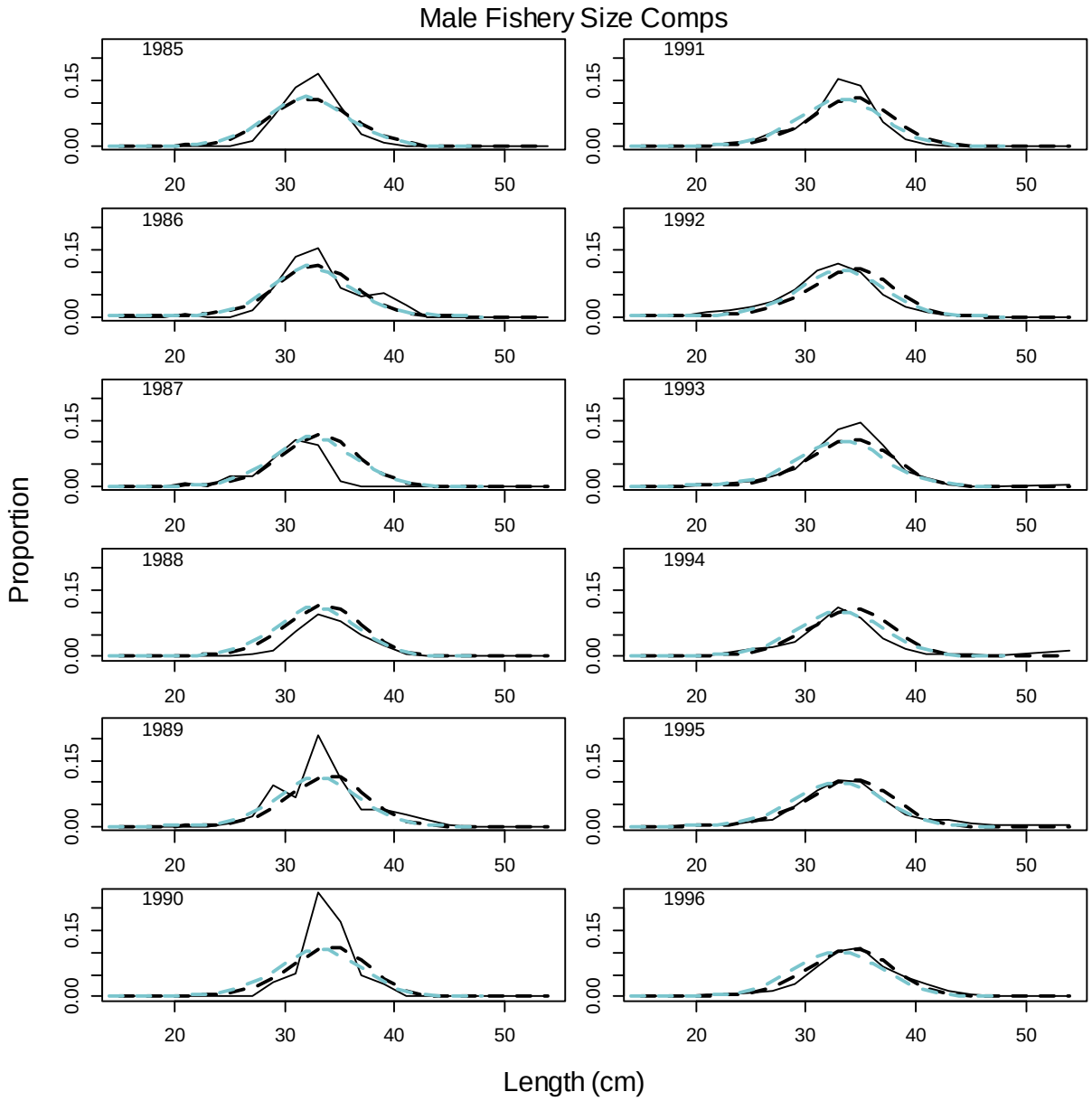
Figure 26. Observed (solid black lines) and predicted (dashed lines) survey proportions-at-age for the 2011 model (dashed black lines) and proposed alternative model M4 (dashed blue lines) for females (first panel) and males (second panel).

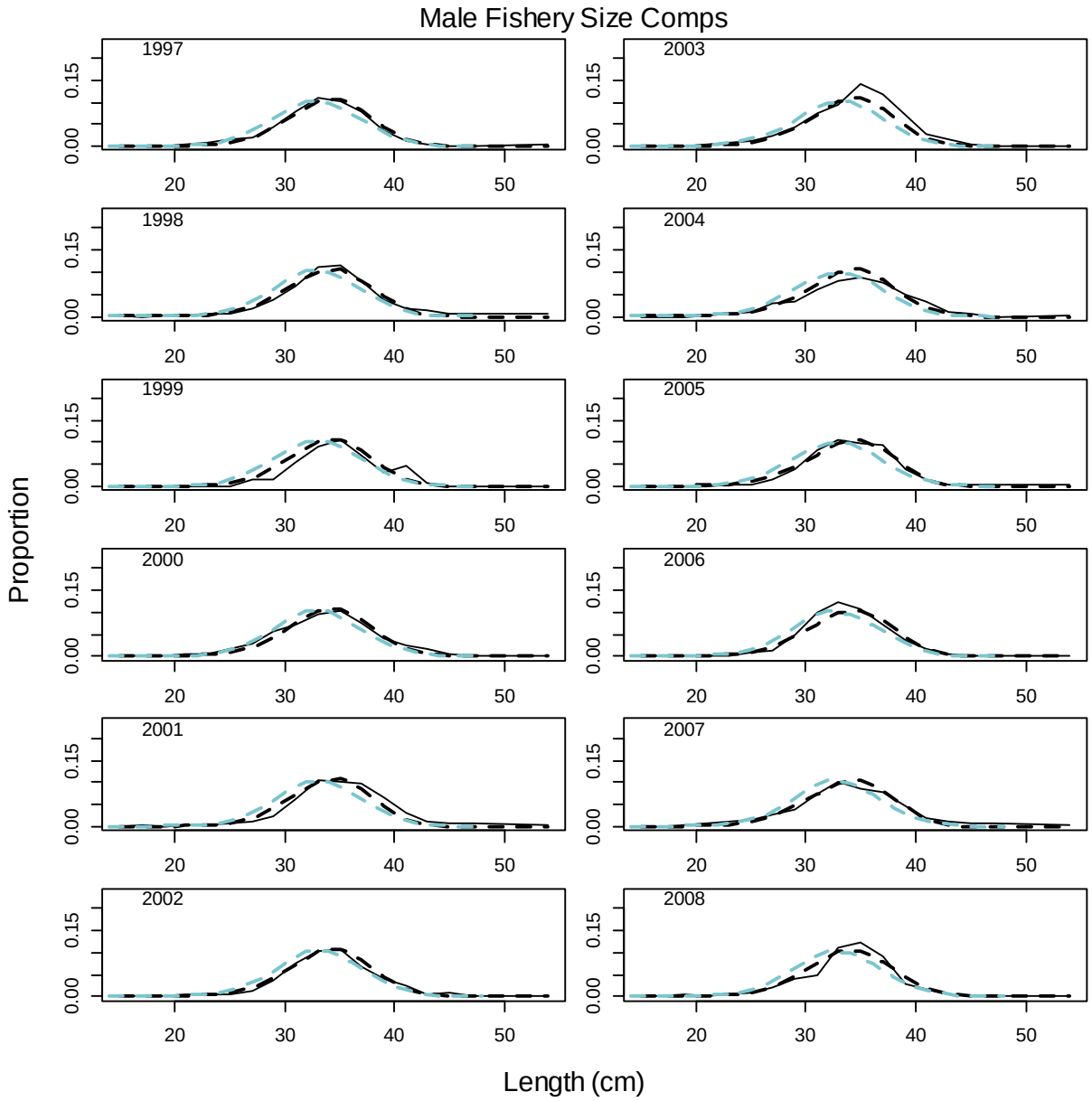

Female Fishery Size Comps
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
Proportion
Length (cm)
0.00
0.15
20
30
40
50


Female Fishery Size Comps
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Proportion
Length (cm)
0.00
0.15
20
30
40
50


Female Fishery Size Comps
2009
2010
2011
0.00
0.15
20
30
40
50
Proportion

Length (cm)


Male Fishery Size Comps
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
Proportion
Length (cm)
0.00
0.15
20
30
40
50


Male Fishery Size Comps
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Proportion
Length (cm)
0.00
0.15
20
30
40
50

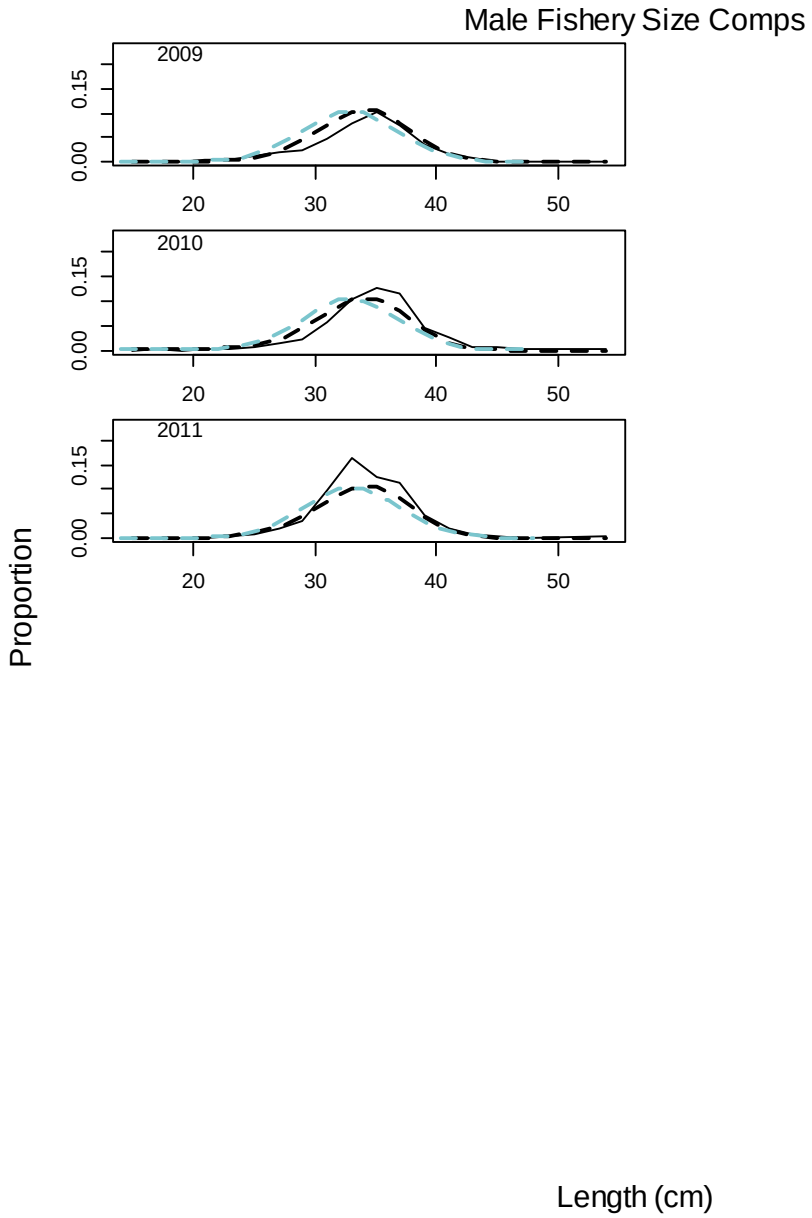
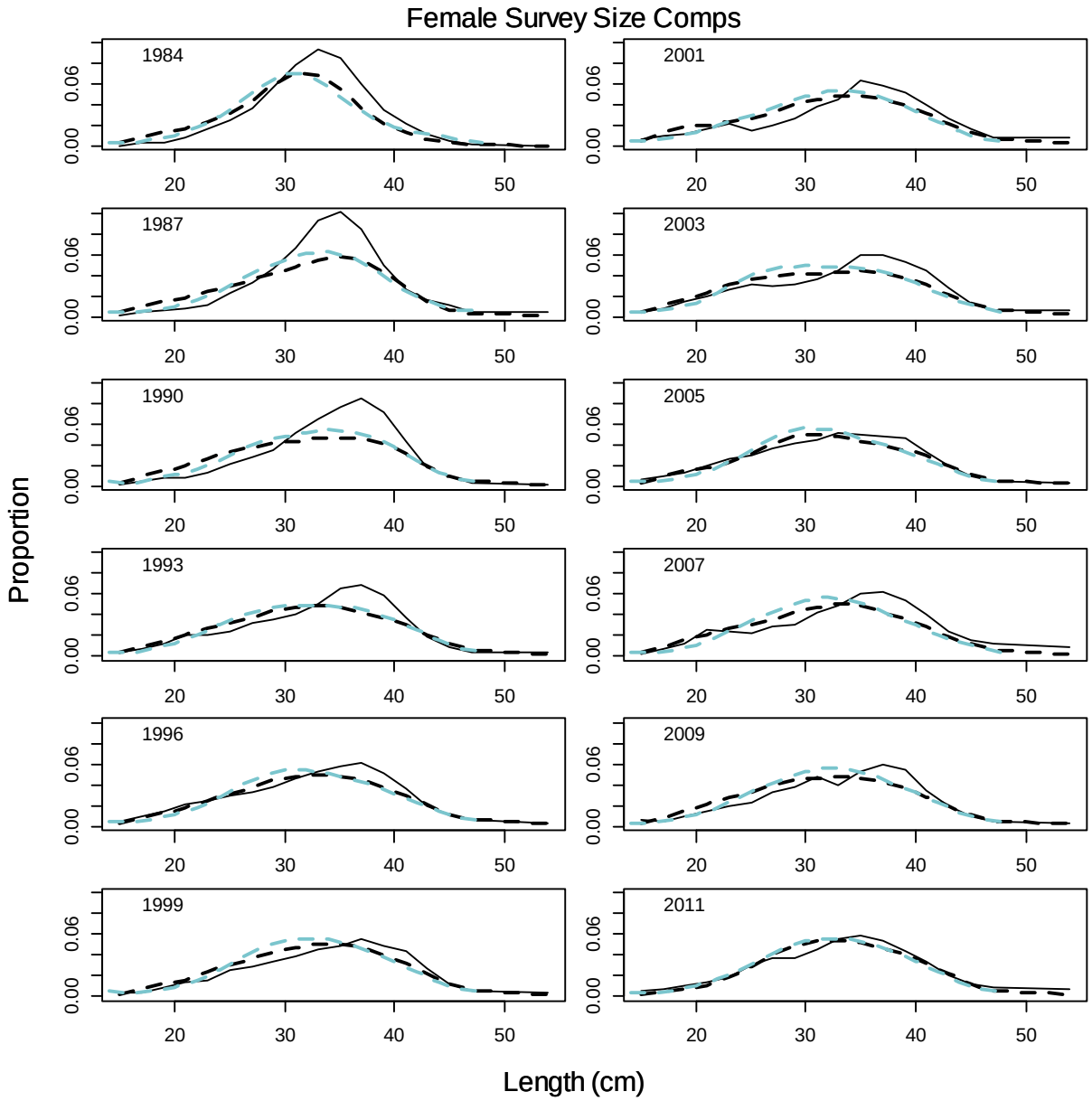


Figure 27. Observed (solid black lines) and predicted (dashed lines) fishery proportions-at-length for the 2011 model (dashed black lines) and proposed alternative model M4 (dashed blue lines) for females (first set of panels) and males (second set of panels).


Female Survey Size Comps
1984
2001
1987
2003
1990
2005
1993
2007
1996
2009
1999
2011
0.00
0.06
20
30
40
50
Proportion
Length (cm)

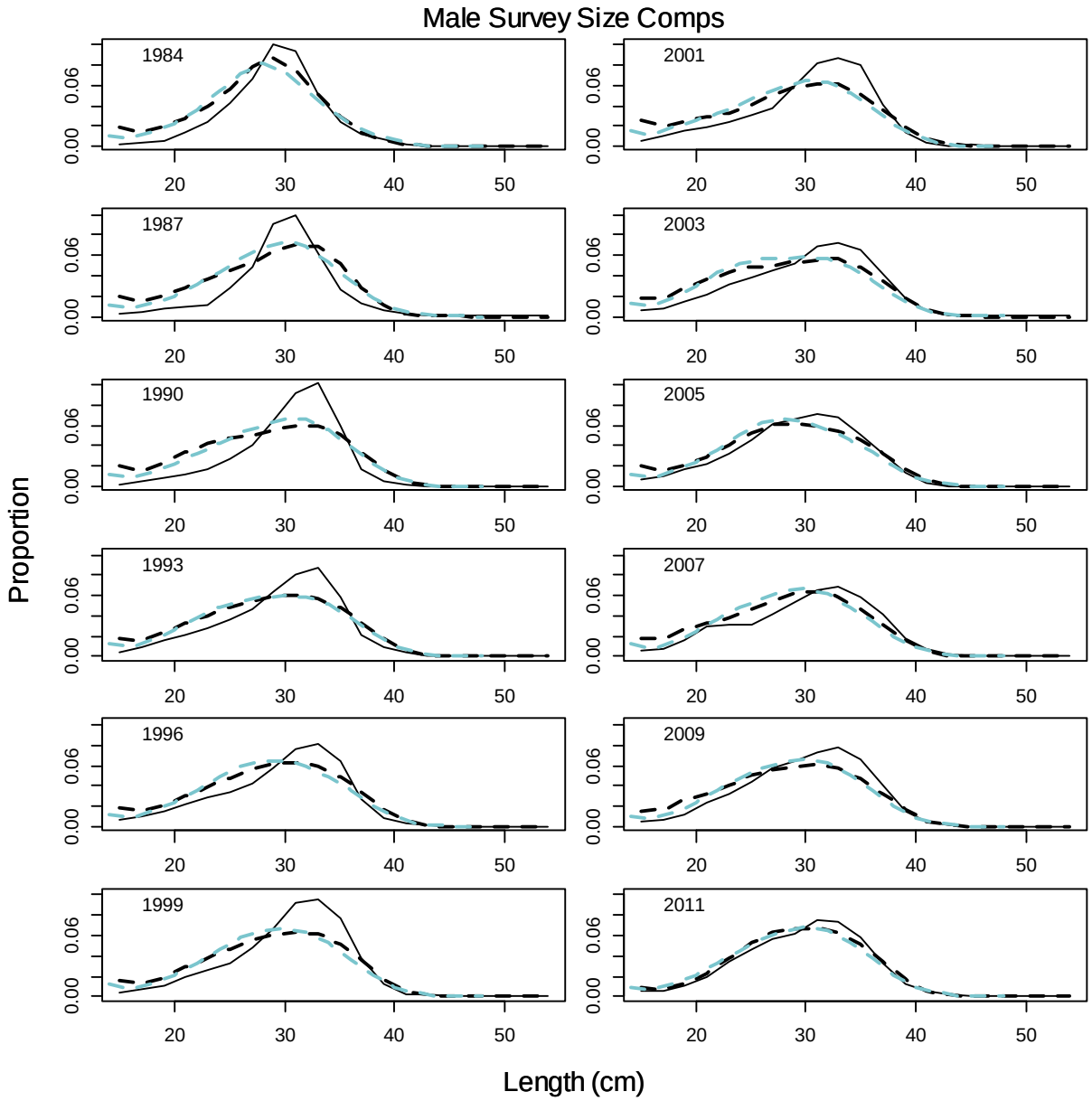


Figure 28. Observed (solid black lines) and predicted (dashed lines) survey proportions-at-length for the 2011 model (dashed black lines) and proposed alternative model M4 (dashed blue lines) for females (first set of panels) and males (second set of panels).