Appendix 2.1: Preliminary assessment of the Pacific cod stock in the Aleutian Islands

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Introduction

This document represents an effort to respond to comments made by the Joint Team Subcommittee on Pacific cod models (JTS), and the SSC on last year's assessment of the Pacific cod (*Gadus macrocephalus*) stock in the Aleutian Islands (AI) region (Thompson and Palsson 2015). Many of those comments were informed by the results of a CIE review of the AI Pacific cod assessment conducted during February 16-19, 2016. The website located at http://tinyurl.com/Pcod-cie-2016 contains every file vetted during the review process as well as the final reports from the three reviewers.

Responses to SSC and Plan Team comments on assessments in general

SSC1 (10/15 minutes): "*The Team Procedures document clarifies that the proposed development and testing of a naming convention should focus on tracking the modeling configurations used for a particular stock assessment. The rationale for this request is two-fold. First, it will help us understand how long it has been since a benchmark change in model configuration has occurred; second, it will help the reviewers and public to track model changes. Of the options presented in the Joint Plan Teams minutes, the SSC agrees that Option 4 has several advantages and recommends that this Option be advanced next year.*" As in last year's final assessment, Option 4a was used to number models in this preliminary assessment.

SSC2 (12/15 minutes): "*The SSC reminds the authors and PTs to follow the model numbering scheme adopted at the December 2014 meeting.*" Given that comment SSC1 superseded the model numbering scheme adopted at the December 2014 meeting, it seems reasonable to assume that inclusion of this comment in the 12/15 minutes was an error.

SSC3 (12/15 minutes): "*Many assessments are currently exploring ways to improve model performance by re-weighting historic survey data. The SSC encourages the authors and PTs to refer to the forthcoming CAPAM data-weighting workshop report.*" Model 16.1 is the only model in this preliminary assessment that involves re-weighting survey data. The procedure used for this re-weighting is described under "Model Structures."

SSC4 (12/15 minutes): "*The SSC recommends that assessment authors work with AFSC's survey program scientist to develop some objective criteria to inform the best approaches for calculating Q with respect to information provided by previous survey trawl performance studies (e.g. Somerton and Munro 2001), and fish-temperature relationships which may impact Q.*" The recent paper by Weinberg et al. (2016) is an example of the suggested collaboration. Although it dealt with survey trawl performance studies in the eastern Bering Sea, it might serve as a model for future collaborations dealing with the Aleutian Islands trawl survey.

Responses to SSC and Plan Team comments specific to Aleutian Islands Pacific cod

Note: Following the procedure initiated in 2014, the task of developing recommendations for models to be included in this year's preliminary Pacific cod assessments (subject to review and potential revision by the SSC) was delegated to the JTS rather than the full Joint Plan Teams.

SSC5 (12/15 minutes): *"One additional recommendation from the SSC is to examine weights-at-age of Pacific cod by area."* This recommendation will be addressed in the final assessment.

JTS1 (5/16 minutes): *"For the AI, the JTS recommended that the following models be developed for this year's preliminary assessment:*

- *Model 1: AI Model 13.4, the final model from 2015 (Tier 5 random effects model)*
- *Model 2: Like AI Model 15.7, but simplified as follows:*
    - *Weight abundance indices more heavily than sizecomps.*
    - *Use the simplest selectivity form that gives a reasonable fit.*
    - *Do not allow survey selectivity to vary with time.*
    - *Do not allow survey catchability to vary with time.*
    - *Do not allow strange selectivity patterns.*
    - *Estimate trawl survey catchability internally with a fairly non-informative prior.*
- *Model 3: Like AI Model 15.7, but including the IPHC longline survey data and other features, specifically:*
    - *Do now allow strange selectivity patterns.*
    - *Estimate trawl survey catchability internally with a fairly non-informative prior.*
    - *Estimate catchability of new surveys internally with non-restrictive priors.*
    - *Include additional data sets to increase confidence in model results.*
    - *Include IPHC longline survey, with "extra SD."*
- *Model 4: Like Model 3 above, but including the NMFS longline survey instead of the IPHC longline survey*.
- *Model 5: Like Models 3 and 4 above, but including both the IPHC and NMFS longline survey data.*
- *Model 6: Like AI Model 15.7, except:*
    - *Use the post-1994 AI time series (instead of the post-1986 time series).*
    - *Do not allow strange selectivity patterns.*
    - *Estimate trawl survey catchability internally with a fairly non-informative prior."*

All of the requested models are included in this preliminary assessment (see also comment SSC6). Note that some points in the above lists of features may be somewhat duplicative, but were included by the JTS in order to address specific comments made by CIE reviewers. As noted in the JTS meeting minutes, the model numbers used above were intended just as placeholders, until final model numbers could be assigned, following the adopted model numbering convention (see comment SSC1). Application of the numbering convention resulted in the following model numbers:

JTS "placeholder" model number:	1	2	3	4	5	6
Final model number:	13.4	16.1	16.2	16.3	16.4	16.5

SSC6 (6/16 minutes): *"The SSC accepts the JTS recommendations for models to bring forward in the 2016 assessment…."* See comment JTS1.

SSC7 (6/16 minutes): "*The SSC agrees with CIE recommendations to use all reasonable data sources that are available, although the use of the longline survey data in the model has been attempted in the past with little success. As the author noted, survey indices were generally negatively correlated with model-estimated biomass in past assessments. The use of 'extra SD' in the proposed models for both regions is a reasonable approach to deal with this issue.*" Internally estimated increments to the log-scale standard errors for the IPHC and NMFS longline survey indices are reported in Table 2.1.7.

Data

The data used in this preliminary assessment are identical to those used in last year's final assessment (Thompson and Palsson 2015), except for:

- the addition of IPHC survey data (abundance index and size composition) in Models 16.2 and 16.4; and
- the addition of NMFS longline survey data (abundance index and size composition) in Models 16.3 and 16.4.

The following table summarizes the sources, types, and years of data included in the data file for the Tier 5 model—Model 13.4:

Source	Type	Years
AI bottom trawl survey	Biomass	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014

The following table summarizes the sources, types, and years of data included in the data files for at least one of the Tier 3 models—Models 16.1-16.5 (italics denote data *not* included in last year's assessment):

Source	Type	Years
Fishery	Catch biomass	1977-2015
Fishery	Size composition	1978-1979, 1982-1985, 1990-2015
AI bottom trawl survey	Numerical abundance	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014
AI bottom trawl survey	Size composition	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014
AI bottom trawl survey	Age composition	2002, 2006, 2010, 2012, 2014
IPHC longline survey	*Relative abundance*	*1997-2014*
IPHC longline survey	*Size composition*	*2015*
NMFS longline survey	*Relative abundance*	*1996-2014 (even years only)*
NMFS longline survey	*Size composition*	*1996-2014 (even years only)*

Relative abundance data from the IPHC and NMFS longline surveys are shown in Table 2.1.1, and size composition data from those two surveys are shown in Table 2.1.2.

Multinomial input sample sizes were specified using procedures similar to those used in the EBS Pacific cod assessment (Thompson 2015): 1) Records with fewer than 400 observations were omitted. 2) The sample sizes for fishery length compositions from years prior to 1999 were tentatively set at 16% of the actual sample size, and the sample sizes for fishery length compositions after 1998 and all survey length compositions were tentatively set at 34% of the actual sample size. 3) All sample sizes were adjusted proportionally to achieve a within-fleet average sample size of 300 (i.e., the fishery sample sizes average

300, as do the survey sample sizes). Age composition input sample sizes are obtained by scaling the number of otoliths read so that the average is 300.

Model structures

All of the models presented in this preliminary assessment were developed using Stock Synthesis (SS, Methot and Wetzel 2013). The version used to run all models was SS V3.24u, as compiled on 8/29/2014. Stock Synthesis is programmed using the ADMB software package (Fournier et al. 2012). The user manual for SS V3.24s, along with a "change log" documenting revisions between V3.24s and V3.24u, is available at:
https://drive.google.com/a/noaa.gov/?tab=mo#folders/0Bz1UsDoLaOMLN2FiOTI3MWQtZDQwOS00YWZkLThmNmEtMTk2NTA2M2FjYWVh.

Developing the models requested by the Joint Team Subcommittee

Six models are presented in this preliminary assessment. Model 13.4 is a Tier 5 model and has been the accepted model since 2013. The other five models (Models 16.1-16.5) are all Tier 3 models, and are variants of Model 15.7, which was introduced in last year's final assessment as a modification of Model 15.3 from last year's preliminary assessment (where it was labeled "Model 3").

Details of Model 15.7 are described in the next two subsections. The distinguishing features of Models 16.1-16.5 were listed above (see comment JPT1 under "Responses to SSC and Plan Team comments specific to Aleutian Islands Pacific cod," above).

In the minutes of its May 2016 meeting, the JTS recognized that some of the terms used in the descriptions of its requested models were somewhat subjective and that, in making those requests, the assessment author would need to determine:

1. How to measure the "weight" assigned to abundance indices and size composition data in the same units (Model 16.1).
2. What constitutes a "reasonable fit" to the size/age composition data (Model 16.1).
3. What constitutes a "strange" selectivity pattern (Models 16.1-16.5).
4. What constitutes a "fairly non-informative prior" (Models 16.1-16.5).

These issues were addressed as follows:

1. The relative "weight" assigned to abundance indices and size composition data was determined by comparing the average spawning biomasses from three models:
   A. a model with a specified set of likelihood "emphasis" (λ) values, with each $\lambda \geq 1.0$;
   B. a model in which λ for the abundance data was set equal to 0.01 while each λ for the size composition data (fishery and survey) was left at the value specified in model A; and
   C. a model in which each λ for the size composition data (fishery and survey) was set equal to 0.01 while each λ for the abundance data was left at the value specified in model B.

   Model B was taken to represent model A with the *abundance* data "turned off," while model C was taken to represent model A with the *size composition* data "turned off" (a λ value of 0.01 rather than 0 was used for to represent "turning off" a data component because some parameters might prove inestimable if that data component were removed entirely). The abundance data in model A were determined to receive greater weight than the size composition data in that model if the absolute value of the proportional change in spawning biomass between models B and A exceeded the analogous value between models C and A. The JTS requested that this criterion (giving greater weight to abundance data than size composition data) be included in Model 16.1

only. As it turned out, leaving λ at the default value of 1.0 for all data components was insufficient to satisfy this criterion. However, by leaving λ for the size composition components (fishery and trawl survey) at the default value of 1.0 and increasing λ on all other components to 2.0 was sufficient to satisfy this criterion.

2. To focus on the ability of a particular functional form to fit the data, independent of the absolute values of the sample sizes specified for the associated multinomial distribution or λ values, weighted coefficients of determination (R^2), computed on both the raw and logit scales, were used to measure goodness of fit (the equations below are written in terms of age composition; the equations for size compositions are analogous):

$$R^2 = \sum_{y=ymin}^{ymax} \left(w_y \cdot \left(1 - \frac{\sum_{a=0}^{amax} \left(Pobs_{a,y} - Pest_{a,y} \right)^2}{\sum_{a=0}^{amax} \left(Pobs_{a,y} - Pobs_{ave,y} \right)^2} \right) \right) \quad ,$$

and

$$R^2 = \sum_{y=ymin}^{ymax} \left(w_y \cdot \left(1 - \frac{\sum_{a=0}^{amax} \left(logit\left(Pobs_{a,y} \right) - logit\left(Pest_{a,y} \right) \right)^2}{\sum_{a=0}^{amax} \left(logit\left(Pobs_{a,y} \right) - logit\left(Pobs_{ave,y} \right) \right)^2} \right) \right) \quad ,$$

where

$$w_y = \frac{n_y}{\sum_{i=ymin}^{ymax} n_i} \quad ,$$

$Pobs_{a,y}$ represents the observed proportion at age a in year y, $Pobs_{ave,y}$ represents the average (across ages) observed proportion in year y, $Pest_{a,y}$ represents the estimated proportion at age a in year y, and n_y represents the specified multinomial sample size in year y. To guard against the possibility of achieving misleadingly high R^2 values by extending the size or age range beyond the sizes or ages actually observed, the data were filtered by removing all records with $Pobs_{a,y} < 0.001$ prior to computing the R^2 values. A fit was determined to be "reasonable" if it yielded *both* an R^2 value of at least 0.99 on the raw scale *and* an R^2 value of at least 0.70 on the logit scale. As with #1 above, the JTS requested that this criterion (simplest selectivity function that gives a reasonable fit) be included in Model 16.1 only. Because the "random walk with respect to age" selectivity function gave a reasonable fit, the function was simplified in successive steps first by removing all time-variability, then by switching to a double-normal function. However, neither of these changes resulted in a reasonable fit, so the random walk functional form with time-variability (for the fishery only) was retained.

3. In general, a "strange" selectivity pattern was defined here as one which was non-monotonic (i.e., where the signs of adjacent first differences changed), particularly if the first differences associated with sign changes were large (in absolute value), and particularly if sign changes in first differences occurred at relatively early ages. Specifically, an index of "strangeness" was defined as follows:

A. Age-specific weighting factors P_a were calculated as the equilibrium unfished numbers at age expressed as a proportion of equilibrium unfished numbers.
B. For each year, age-specific first differences in selectivity $\Delta_{a,y}$ were calculated.
C. "Strangeness" was then calculated as:

$$\left(\frac{1}{ymax-ymin+1}\right)\cdot\sum_{y=ymin}^{ymax}\sqrt{\sum_{a=2}^{amax}\left(P_a\cdot\left(\left(sign\left(\Delta_{a,y}\right)\neq sign\left(\Delta_{a-1,y}\right)\right)\cdot\left(\Delta_a\right)^2\right)\right)} \quad ,$$

where the expression $sign\left(\Delta_{a,y}\right)\neq sign\left(\Delta_{a-1,y}\right)$ returned a value of 1 if the sign of $\Delta_{a,y}$ differed from the sign of $\Delta_{a-1,y}$ and a value of 0 otherwise. This index attains a minimum of 0 when selectivity is constant across age (or varies monotonically) and a maximum of 1 if selectivity alternates between values of 0 and 1 at all pairs of adjacent ages.

A time series of selectivity at age (for a given fleet) was determined to be "strange" if the index described above exceeded a value of 0.05. If a model produced a "strange" selectivity pattern, the standard deviations of the prior distributions for the selectivity parameters and the standard deviations of any selectivity *dev* vectors were decreased proportionally relative to the values estimated for Model 15.7 in last year's assessment until the threshold value of 0.05 was satisfied.

4. The phrase "fairly non-informative prior" was interpreted as meaning a non-constraining uniform prior distribution.

As in previous assessments, development of the final versions of all models included calculation of the Hessian matrix and a requirement that all models pass a "jitter" test of 50 runs. In the event that a jitter run produced a better value for the objective function than the base run, then:

1. The model was re-run starting from the final parameter file from the best jitter run.
2. The resulting new control file, with the parameter estimates from the best jitter run incorporated as starting values, became the new base run.
3. The entire process (starting with a new set of jitter runs) was repeated until no jitter run produced a better value for the objective function than the most recent base run.

One difference from previous assessments is that, for this preliminary assessment, an attempt was made to standardize the bounds within which individual parameters were "jittered." Specifically, once a model was ready to be subjected to the jitter test, the bounds for each parameter in the model were adjusted to match the 99.9% confidence interval (based on the normal approximation obtained by inverting the Hessian matrix). A jitter rate (equal to half the standard deviation of the logit-scale distribution from which "jittered" parameter values are drawn) was set at 1.0 for all models. Standardizing the jittering process in this manner may not explore parameter space as thoroughly as in previous assessments; however, it should make the jitter rate more interpretable, and show the extent to which the identified minimum (local or otherwise) is well behaved.

Except for selectivity parameters and *dev* vectors in all models, all parameters were estimated with uniform prior distributions.

All selectivity *dev*s were assumed to be additive (SS automatically assumes log recruitment *dev*s to be additive).

Parameters estimated outside the assessment model (e.g., weight-at-length parameters, maturity-at-age parameters, ageing error matrix,) were likewise described in last year's final assessment (Thompson and Palsson 2015), and were not re-estimated for this preliminary assessment. In particular, the natural mortality rate M was fixed at a value of 0.34 in Models 16.1-16.5, matching the value used in the EBS Pacific cod assessment.

Model 15.7 Structure: Main Features

Model 15.7 bears some similarities to the model that has been accepted for use in management of the EBS Pacific cod stock since 2011 (Thompson 2015). Some of the main differences between Model 15.7 and the 2011-2015 EBS model are as follow:

1. In the data file, length bins (1 cm each) were extended out to 150 cm instead of 120 cm, because of the higher proportion of large fish observed in the AI.
2. Each year consisted of a single season instead of five.
3. A single fishery was defined instead of nine season-and-gear-specific fisheries.
4. The survey was assumed to sample age 1 fish at true age 1.5 instead of 1.41667.
5. The standard deviation of log-scale age 0 recruitment (σ_R) was estimated internally instead of being estimated outside the model.
6. Log-scale survey catchability (ln(Q)) was estimated internally instead of being estimated outside the model, using a normal prior distribution with μ=0.00 and σ=0.11 (values of prior parameters were obtained by averaging the values of the prior parameters from other age-structured AI groundfish assessments).
7. Initial abundances were estimated for the first ten age groups instead of the first three.
8. Selectivity for both the fishery and survey was modeled using a random walk with respect to age (SS selectivity-at-age pattern #17) instead of the usual double normal.
9. A normal prior distribution for each selectivity parameter was used, tuned so that the schedule of prior means (across age) was consistent with logistic selectivity, with a constant (across age) prior standard deviation.
10. Potentially, each selectivity parameter was allowed to be time-varying with annual additive *dev*s (normally distributed random deviations added to the base value of their respective parameter).

Model 15.7 Structure: Iterative Tuning

For Model 15.7, the parameters described in this section were tuned most recently in the 2014 preliminary assessment.

Iterative Tuning of Prior Distributions for Selectivity Parameters

Before allowing time-variability in any selectivity parameters, a pair of transformed logistic curves was fit to the point estimates of the fishery and survey selectivity schedules (a *transformed* logistic curve was used because the selectivity parameters in pattern #17 consist of the backward first differences of selectivity on the log scale, rather than selectivity itself; Thompson and Palsson 2013). The respective transformed logistic curve (fishery or survey) was then used to specify a new set of means for the selectivity prior distributions (one for each age). A constant (across age) prior standard deviation was then computed such that no age had a prior CV (on the selectivity scale, not the transformed scale) less than 50%, and at least one age had a prior CV of exactly 50%.

The model was then run with the new set of prior means and constant prior standard deviations (one for the fishery, one for the survey), then a new pair of transformed logistic curves was fit to the results, and the process was repeated until convergence was achieved.

Iterative Tuning of Time-Varying Selectivity Parameters

Two main loops were involved in the iterative tuning of time-varying selectivity parameters. These loops were designed to produce the quantities needed in order to use the method of Thompson and Lauth (2012, Annex 2.1.1; also Thompson in prep.) for estimating the standard deviation of a *dev* vector:

1. Compute an "unconstrained" estimate of the standard deviation of the set of year-specific *dev*s associated with each age. The purpose of this loop was to determine the vector of *dev*s that would be obtained if they were completely unconstrained by their respective σ. This was not always a straightforward process, as estimating a large matrix of age×year *dev*s is difficult if the *dev*s are unconstrained. In general, though, the procedure was to begin with a small (constant across age) value of σ; calculate the standard deviation of the estimated *dev*s; then increase the value of σ gradually until the standard deviation of the estimated *dev*s reached an asymptote.
2. Compute an "iterated" estimate of the standard deviation of the set of year-specific *dev*s associated with each age. This loop began with each σ set at the unconstrained value estimated in the first loop. The standard deviation of the estimated *dev*s then became the age-specific σ for the next run, and the process was repeated until convergence was achieved.

The iteration was conducted separately for the fishery and survey.

Selectivity *dev* vectors for most ages were "tuned out" during the second loop (i.e., the σs converged on zero). Specifically, selectivity *dev* vectors for all ages were tuned out except ages 4 and 6 for the fishery and ages 2, 3, and 7 for the survey.

Results

Overview

The following table summarizes the status of the stock as estimated by Models 16.1-16.5 ("Value" is the point estimate, "CV" is the ratio of the standard deviation of the point estimate to the point estimate itself, "FSB 2016" is female spawning biomass in 2016 (t), and "Bratio 2016" is the ratio of FSB 2016 to $B_{100\%}$; color shading for FSB 2016 and Bratio 2016 extends from red (low) to green (high) for each quantity):

	Model 16.1		Model 16.2		Model 16.3		Model 16.4		Model 16.5	
Quantity	Value	CV	Value	CV	Value	CV	Value	CV	Value	CV
FSB 2016	84,234	0.12	451,880	0.45	85,869	0.19	198,934	0.23	172,307	0.25
Bratio 2016	0.46	0.09	0.62	0.15	0.29	0.13	0.47	0.10	0.47	0.13

These five models span wide ranges for these quantities. Estimates of FSB 2016 range from 84,000 t (Model 16.1) to 452,000 t (Model 16.2), and estimates of Bratio 2016 range from 0.29 (Model 16.3) to 0.62 (Model Model 16.2). The quantities FSB 2016 and Bratio 2016 tend to covary directly in these models (Model 16.1 is an exception). Although not directly comparable to female spawning biomass, Model 13.4 estimates a current trawl survey biomass of 69,000 t, with a CV of 0.16.

Goodness of fit

Objective function values and parameter counts are shown for each model in Table 2.1.3a, and multipliers used to adjust multinomial sample sizes are shown in Table 2.1.3b. Objective function values are not directly comparable across models, because different data files are used for some models, different constraints are imposed, and the number and types of parameters vary considerably.

Figure 2.1.1a shows the fits of all six models to the trawl survey abundance data; Figure 2.1.1b shows the fits of Models 16.2, and 16.4 to the IPHC longline survey abundance data; and Figure 2.1.1c shows the fits of Models 16.3 and 16.4 to the NMFS longline survey abundance data.

Table 2.1.4 shows goodness of fit for the survey abundance data (Models 16.1-16.5). Four measures are shown: root mean squared error (for comparison, the average log-scale standard error "σave" is also shown), mean normalized residual, standard deviation of normalized residuals, and correlation (observed:estimated). For the trawl survey data, Model 16.2 gives a root mean squared error close to σave, while all of the others give higher RMSEs. Models 16.2-16.5 all give mean normalized residuals in the +/– 0.1 range. Models 16.1-16.5 all give standard deviation of normalized residuals greater than unity. Models 16.2-16.4 give correlations greater close to 0.90 or better. The two models that use the IPHC longline survey data both give mean normalized residuals close to zero, standard deviation of normalized residuals close to unity (note that these models inflate the input σ values by an internally estimated amount, and the resulting estimates of σave are fairly high, in the 0.42-0.42 range), and correlations in the 0.46-0.54 range. The two models that use the NMFS longline survey data perform similarly to those that use the IPHC data.

Sample size ratios for the size composition data (Models 16.1-16.5) are shown in Table 2.1.5 (note that input sample sizes are the same for all models except for the trawl survey data in Model 16.5). These results can be summarized as follows:

- Measured as the ratio of the *arithmetic* mean effective sample size to the arithmetic mean input, the models give values well in excess of unity for all components except the NMFS longline survey, where the ratios obtained by Models 16.3 and 16.4 are both in the 0.63-0.64 range.
- Measured as the ratio of the *harmonic* mean effective sample size to the arithmetic mean input sample size, all models give noticeably smaller values, but still in excess of unity for all cases except, again, the NMFS longline survey.

Sample size ratios for the survey age composition data are shown in Table 2.1.6 (Models 16.1-16.5). Measured either as the ratio of the arithmetic means or the ratio of the harmonic mean effective sample size to the arithmetic mean input sample size, all of the models give values of 0.50 or less.

Figure 2.1.2 shows the fits to the survey *size* composition data, and Figure 2.1.3 shows the fits to the survey *age* composition data (Models 16.1-16.5 in both cases).

Parameter estimates, time series, and retrospective analysis

Table 2.1.7 lists key parameters estimated internally in at least one of the models, along with their standard deviations. Note that the natural mortality rate *M* was not estimated in any of the models, but was instead fixed at a value of 0.34, based on the assessment of Pacific cod in the eastern Bering Sea (Thompson 2015). The estimates of log catchability for the trawl survey shown in Table 2.1.7 map into the following estimates of catchability on the natural scale, spanning the range 0.161 (Model 16.2) to 0.527 (Model 16.1):

Model 16.1		Model 16.2		Model 16.3		Model 16.4		Model 16.5	
Est.	SD	Est.	SD	Est.	SD	Est.	SD	Est.	SD
0.527	0.079	0.161	0.409	0.452	0.119	0.300	0.180	0.355	0.197

Selectivity schedules are plotted for the fishery in Figure 2.1.4, the trawl survey in Figure 2.1.5a, the IPHC longline survey in Figure 2.1.5b, and the NMFS longline survey in Figure 2.1.5c.

Time series estimated by the models are shown for total biomass, female spawning biomass relative to $B_{100\%}$, age 0 recruitment, and fishing mortality relative to $F_{40\%}$ in Figures 2.1.6, 2.1.7, 2.1.8, and 2.1.9, respectively.

Figure 2.1.10 shows 10-year retrospectives of spawning biomass for each of the models, including Model 13.4 (where survey biomass is used in place of spawning biomass). Mohn's ρ (revised) values for the models are shown below:

Model 13.4	Model 16.1	Model 16.2	Model 16.3	Model 16.4	Model 16.5
-0.034	0.015	-0.296	-0.245	-0.397	-0.106

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Tables

Table 2.1.1—Relative abundance data for the IPHC and NMFS longline surveys, with log-scale standard errors (σ). Note that the σ values shown here may be incremented by an amount estimated by any of the models that use these data (Models 16.2-16.5).

IPHC longline survey		
Year	RPN	σ
1997	7,028	0.118
1998	7,880	0.121
1999	6,499	0.124
2000	5,588	0.113
2001	4,174	0.138
2002	2,374	0.156
2003	2,795	0.171
2004	2,383	0.161
2005	3,408	0.177
2006	6,331	0.136
2007	4,833	0.126
2008	4,496	0.119
2009	3,774	0.138
2010	1,748	0.164
2011	3,364	0.133
2012	1,580	0.215
2013	2,627	0.136
2014	2,642	0.158

NMFS longline survey		
Year	RPN	σ
1996	70,806	0.156
1998	120,261	0.11
2000	150,949	0.135
2002	77,785	0.19
2004	61,044	0.219
2006	93,534	0.127
2008	69,314	0.231
2010	74,658	0.16
2012	76,033	0.152
2014	92,363	0.289

Table 2.1.2—Size (cm) composition data from the NMFS and IPHC longline surveys. No fish were observed at lengths smaller than 21 cm (page 1 of 2).

	NMFS										IPHC
Len	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2015
21	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	1	0	0	0	0
32	1	0	0	0	0	0	0	1	0	0	0
33	1	4	0	0	0	0	0	0	0	0	0
34	0	0	0	0	1	0	0	0	0	0	0
35	0	2	2	2	0	0	0	0	0	1	0
36	0	4	3	0	0	0	1	0	0	5	0
37	1	6	2	2	1	0	0	0	1	1	0
38	3	8	2	5	0	0	2	7	1	2	0
39	9	15	3	13	1	0	1	8	2	6	0
40	18	7	12	24	0	1	1	14	1	6	2
41	32	21	16	34	6	2	3	25	1	7	0
42	49	36	21	43	7	4	4	40	0	5	1
43	86	42	28	58	4	1	9	62	1	10	1
44	113	48	47	67	14	10	13	90	6	10	2
45	135	92	66	67	10	25	40	151	12	16	1
46	153	110	86	101	18	40	54	155	13	15	0
47	187	92	120	109	25	68	59	195	17	19	4
48	178	117	122	107	27	75	79	190	40	44	7
49	200	149	123	137	37	102	93	244	35	56	9
50	188	134	94	160	64	122	109	186	38	79	11
51	170	134	117	156	71	118	133	196	49	80	14
52	179	124	125	166	98	140	136	171	68	133	18
53	160	131	150	170	106	143	143	142	79	125	23
54	166	120	155	173	152	148	149	138	73	120	24
55	177	118	211	195	133	135	127	122	117	120	30
56	163	142	255	174	170	121	118	106	100	134	33
57	161	146	329	187	171	131	99	117	134	125	39
58	198	144	382	155	201	156	80	124	175	110	51
59	201	185	398	141	204	163	92	151	237	126	56
60	189	200	399	94	240	205	121	143	248	142	57
61	206	240	428	89	226	247	120	198	289	170	79
62	253	246	406	82	210	236	129	186	295	213	76
63	246	289	403	99	196	260	124	197	323	198	79
64	225	265	363	103	183	279	157	231	304	210	86
65	244	307	317	121	182	252	161	257	334	209	92
66	221	315	296	96	183	235	180	209	285	213	85
67	240	312	264	103	162	232	173	202	291	202	96
68	184	292	235	113	148	229	206	213	246	187	93
69	213	261	203	122	140	217	151	188	227	188	75
70	189	236	161	121	102	188	140	183	176	143	90

Table 2.1.2—Size (cm) composition data from the NMFS and IPHC longline surveys. No fish were observed at lengths smaller than 21 cm (page 2 of 2).

	NMFS										IPHC
Len	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2015
71	137	199	142	121	68	194	129	143	171	160	76
72	140	148	122	126	76	161	97	104	150	157	77
73	110	135	109	104	74	144	90	99	144	139	75
74	102	94	88	107	49	156	70	59	93	119	55
75	86	76	70	116	41	129	78	83	91	92	69
76	74	67	63	114	40	125	45	45	64	69	60
77	41	60	32	89	35	95	42	58	51	63	57
78	53	34	35	104	23	117	33	37	42	55	51
79	44	38	31	86	26	98	30	41	29	48	53
80	24	23	24	77	25	90	22	24	15	33	54
81	26	35	21	58	20	78	22	17	18	40	43
82	19	16	14	56	14	75	17	13	17	26	39
83	18	16	7	47	15	84	11	11	13	21	47
84	20	11	13	43	10	61	11	10	6	18	48
85	18	12	12	29	8	54	13	15	10	10	46
86	13	4	5	23	5	57	12	5	6	9	33
87	15	7	9	15	10	51	15	6	4	11	34
88	12	11	1	5	5	55	5	3	3	9	34
89	9	6	3	7	4	29	6	3	6	5	26
90	6	6	4	3	9	33	8	0	2	6	19
91	6	6	3	6	5	30	3	2	3	4	33
92	6	4	5	1	1	27	9	3	1	2	21
93	3	2	1	0	1	18	4	1	2	2	19
94	8	7	0	0	4	17	5	0	1	2	18
95	4	3	1	1	2	22	2	1	4	2	18
96	2	2	2	2	2	7	0	1	1	1	17
97	3	4	1	0	1	3	4	1	1	0	24
98	5	3	0	1	0	8	2	0	0	0	8
99	2	4	1	0	0	3	0	1	0	1	12
100	0	1	0	0	1	2	0	0	0	1	10
101	3	1	2	1	1	1	0	1	1	0	17
102	0	0	0	0	0	0	2	0	1	0	14
103	0	0	1	0	0	1	1	0	0	0	6
104	1	1	1	0	0	1	0	0	0	1	11
105	0	1	1	0	0	1	2	1	0	0	6
106	0	0	0	0	0	0	1	1	0	0	5
107	0	2	0	0	0	0	0	0	0	1	5
108	1	0	0	0	0	1	1	0	0	0	6
109	1	0	0	0	0	0	0	0	0	0	5
110	0	0	0	0	0	0	0	0	0	0	3
111	0	0	0	0	0	0	0	0	0	0	2
112	0	0	0	0	0	0	0	0	0	0	0
113	0	0	0	0	0	0	0	0	0	0	1
114	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0	0
116	0	0	0	0	0	0	0	0	0	0	0
117	0	0	0	0	0	0	0	0	0	0	1
118	0	0	0	0	0	0	0	0	0	0	0
119	0	0	0	0	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0	0	0	0	0

Table 2.1.3a—Objective function values and parameter counts for Models 16.1-16.5.

	Aggregated data components				
Obj. function component	M16.1	M16.2	M16.3	M16.4	M16.5
Catch	0.00	0.00	0.00	0.00	0.00
Equilibrium catch	0.00	0.00	0.00	0.00	0.00
Survey abundance index	-2.60	-16.33	6.93	-18.12	-4.21
Size composition	779.91	846.84	1678.53	1677.15	686.70
Age composition	151.86	113.24	110.19	72.12	108.99
Recruitment	18.78	9.23	21.43	18.22	15.04
Priors	97.63	95.08	489.83	492.93	70.66
"Softbounds"	0.00	0.00	0.00	0.00	0.00
Deviations	30.92	118.38	119.65	95.56	100.96
Total	1076.49	1166.44	2426.56	2337.88	978.15

	Abundance index, broken down by fleet				
Fleet	M16.1	M16.2	M16.3	M16.4	M16.5
Fishery					
Shelf trawl survey	-2.60	-10.03	9.92	-5.53	-4.21
IPHC longline survey		-6.30		-5.69	
NMFS longline survey			-2.99	-6.90	
Total	-2.60	-16.33	6.93	-18.12	-4.21

	Size composition, broken down by fleet				
Fleet	M16.1	M16.2	M16.3	M16.4	M16.5
Fishery	222.32	560.83	615.30	614.49	530.34
Shelf trawl survey	557.59	244.76	264.70	235.05	156.36
IPHC longline survey		41.24		788.42	
NMFS longline survey			798.53	39.20	
Total	779.91	846.84	1678.53	1677.15	686.70

Parameter counts	M16.1	M16.2	M16.3	M16.4	M16.5
Unconstrained parameters	11	13	13	15	11
Parameters with priors	16	24	24	32	16
Constrained deviations	123	172	172	172	160
Total	150	209	209	219	187

Table 2.1.3b—Multinomial sample size multipliers for Models 16.1-16.5

	Sizecomp multinomial sample size multipliers			
Model	Fishery	Trawl survey	IPHC longline survey	NMFS longline survey
16.1	1	1	n/a	n/a
16.2	4.2592	0.8273	1	n/a
16.3	4.2592	0.8273	n/a	1
16.4	4.2592	0.8273	1	1
16.5	4.2592	0.8273	n/a	n/a

	Agecomp multinomial sample size multipliers			
Model	Fishery	Trawl survey	IPHC longline survey	NMFS longline survey
16.1	n/a	1	n/a	n/a
16.2	n/a	1	n/a	n/a
16.3	n/a	1	n/a	n/a
16.4	n/a	1	n/a	n/a
16.5	n/a	1	n/a	n/a

Table 2.1.4—Various goodness-of-fit measures for survey abundance data. σave = mean log-scale standard error, RMSE = root mean squared error, MNR = mean normalized residual, SDNR = standard deviation of normalized residuals, Corr. = correlation (observed:estimated).

Model	Survey	σave	RMSE	MNR	SDNR	Corr.
16.1	Trawl	0.18	0.34	0.16	1.79	0.61
16.2	Trawl	0.18	0.20	0.07	1.22	0.91
16.3	Trawl	0.18	0.35	-0.10	2.34	0.85
16.4	Trawl	0.18	0.24	0.00	1.55	0.90
16.5	Trawl	0.18	0.25	-0.03	1.63	0.72
16.2	IPHC LL	0.42	0.44	-0.04	1.01	0.46
16.4	IPHC LL	0.41	0.42	-0.04	1.01	0.54
16.3	NMFS LL	0.44	0.49	0.03	1.04	0.50
16.4	NMFS LL	0.34	0.38	0.02	1.03	0.53

Table 2.1.5—Statistics related to effective sample sizes (Neff) for length composition data. Nrec = no. records, A(·) = arithmetic mean, H(·) = harmonic mean, Ninp = input sample size.

				Ratios	
Model	Fleet	Nrec	A(Ninp)	A(Neff)/A(Ninp)	H(Neff)/A(Ninp)
16.1	Fishery	32	300	6.94	3.54
16.2	Fishery	32	1278	3.11	1.13
16.3	Fishery	32	1278	2.76	1.03
16.4	Fishery	32	1278	2.72	1.04
16.5	Fishery	32	1278	3.18	1.08
16.1	Trawl survey	10	300	1.99	1.50
16.2	Trawl survey	10	248	2.46	1.87
16.3	Trawl survey	10	248	2.23	1.61
16.4	Trawl survey	10	248	2.76	1.82
16.5	Trawl survey	8	212	2.86	2.66
16.2	IPHC longline survey	1	300	1.64	1.64
16.4	IPHC longline survey	1	300	1.79	1.79
16.3	NMFS longline survey	10	300	0.63	0.56
16.4	NMFS longline survey	10	300	0.64	0.58

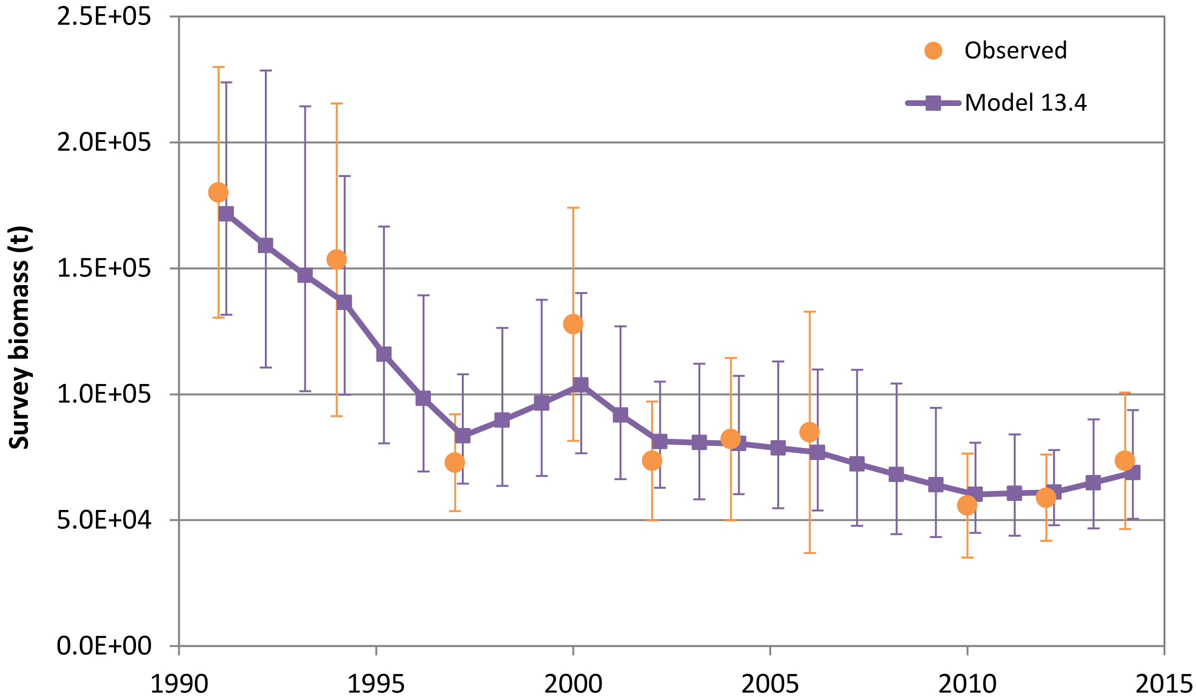
Table 2.1.6—Statistics related to effective sample size (Eff. N) for survey age composition data. "In. N" = input sample size, Mean = arithmetic mean, Harm. = harmonic mean, Ratio1 = arithmetic mean effective sample size divided by arithmetic mean input sample size, Ratio2 = harmonic mean effective sample size divided by arithmetic mean input sample size.

	Model 16.1		Model 16.2		Model 16.3		Model 16.4		Model 16.5	
Year	In. N	Eff. N	In. N	Eff. N	In. N	Eff. N	In. N	Eff. N	In. N	Eff. N
2002	168	70	168	190	168	157	168	179	168	234
2006	391	321	391	81	391	79	391	164	391	76
2010	345	40	345	31	345	23	345	33	345	30
2012	307	123	307	118	307	108	307	276	307	121
2014	289	82	289	64	289	121	289	102	289	82
Mean	300	127	300	97	300	97	300	151	300	109
Harm.		79		67		63		91		71
Ratio1		0.42		0.32		0.32		0.50		0.36
Ratio2		0.26		0.22		0.21		0.30		0.24

Table 2.1.7—Estimates ("Est.") of key parameters and their standard deviations ("SD"). A blank indicates that the parameter (row) was not used in that model (column). The natural mortality rate *M* was not estimated in any of the models, but was instead fixed at a value of 0.34 borrowed from the assessment of Pacific cod in the eastern Bering Sea (Thompson 2015).

	Model 16.1		Model 16.2		Model 16.3		Model 16.4		Model 16.5	
Parameter	Est.	SD	Est.	SD	Est.	SD	Est.	SD	Est.	SD
Length at age 1 (cm)	18.050	0.129	18.003	0.254	19.368	0.275	19.228	0.262	19.450	0.474
Asymptotic length (cm)	107.795	1.315	107.507	0.652	111.453	0.796	109.874	0.699	110.692	0.909
Brody growth coefficient	0.217	0.005	0.227	0.003	0.203	0.003	0.207	0.003	0.219	0.004
SD of length at age 1 (cm)	2.815	0.088	4.157	0.194	4.125	0.192	4.037	0.182	5.807	0.306
SD of length at age 20 (cm)	11.318	0.375	6.679	0.226	6.170	0.262	6.165	0.241	5.493	0.270
Ageing bias at age 1 (years)	0.431	0.014	0.422	0.021	0.417	0.023	0.426	0.022	0.430	0.020
Ageing bias at age 20 (years)	-1.549	0.350	-0.275	0.431	-1.568	0.556	-0.990	0.443	0.210	0.378
ln(mean recruitment)	10.716	0.072	12.072	0.383	11.156	0.110	11.549	0.165	11.313	0.183
Sigma_R	0.731	0.065	0.647	0.071	0.795	0.072	0.715	0.066	0.740	0.083
Initial F	0.049	0.005	0.008	0.003	0.023	0.003	0.014	0.003	0.017	0.003
"Extra SD" for NMFS LL survey					0.260	0.107	0.160	0.080		
"Extra SD" for IPHC LL survey			0.280	0.072			0.266	0.069		
Base ln(Q) for trawl survey	-0.640	0.079	-1.827	0.393	-0.795	0.119	-1.205	0.179	-1.035	0.195
Base ln(Q) for NMFS LL survey					0.697	0.170	0.230	0.197		
Base ln(Q) for IPHC LL survey			-3.369	0.417			-2.798	0.212		

Figures



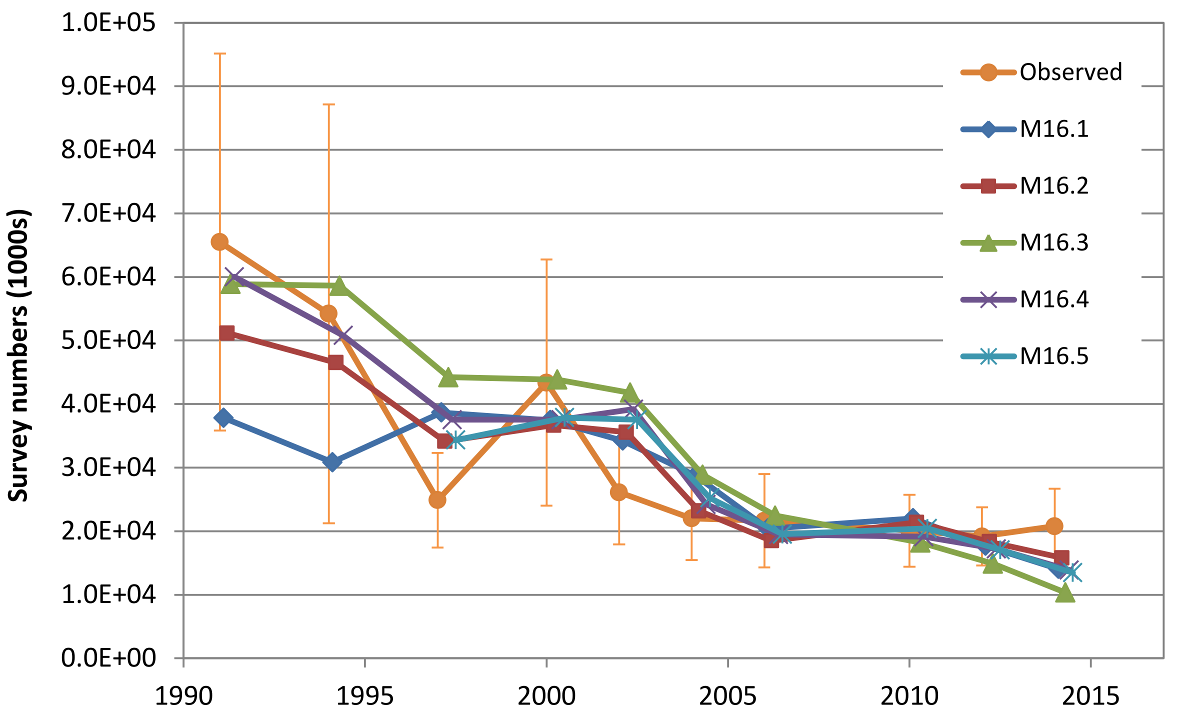


Figure 2.1.1a—Model fits to the trawl survey indices. Upper panel: fit of Model 13.4 to trawl survey biomass; lower panel: fits of Models 16.1-16.5 to trawl survey abundance.

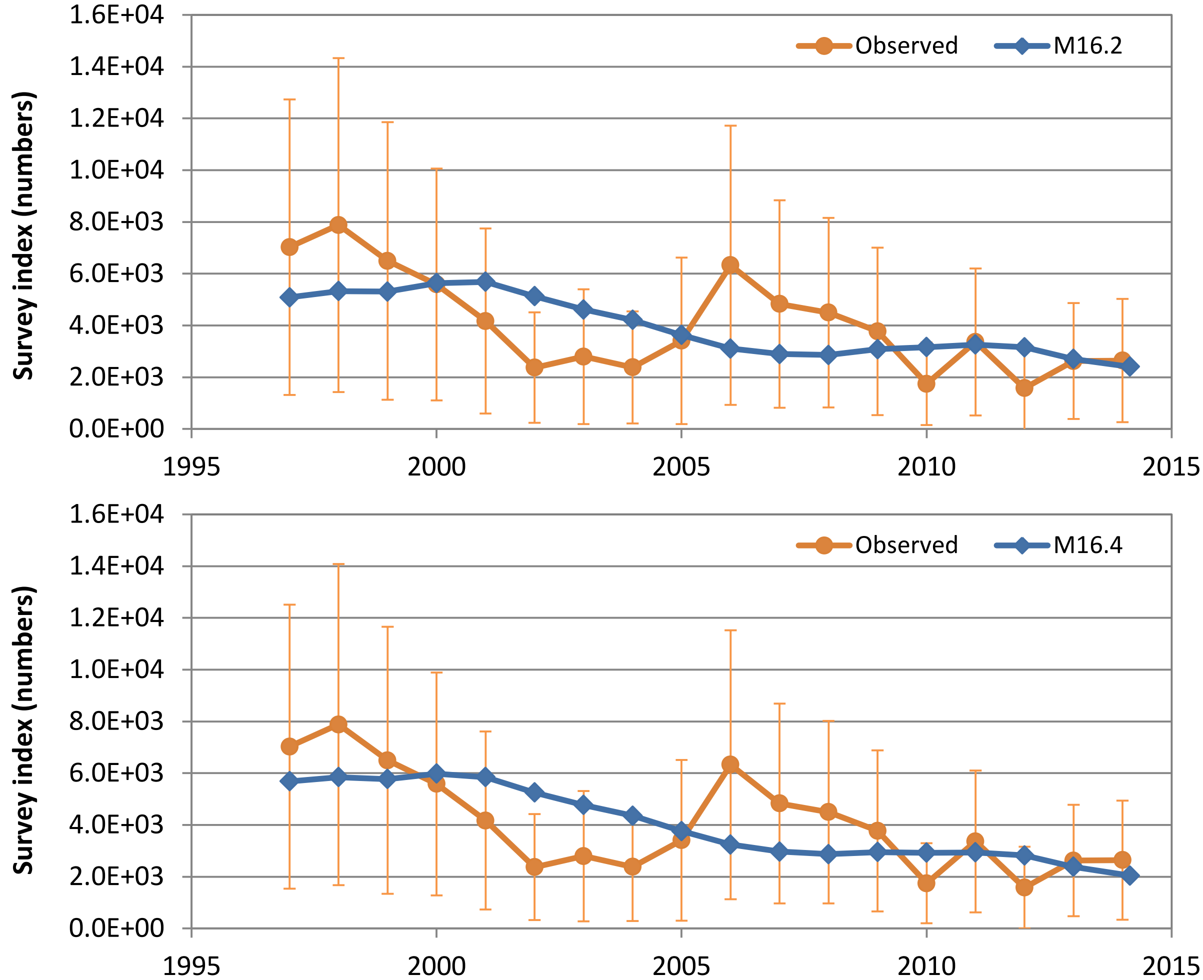


Figure 2.1.1b—Model fits to the IPHC longline survey abundance time series (Models 16.2 and 16.4 only). Survey time series shows 95% confidence interval, which differs between models.

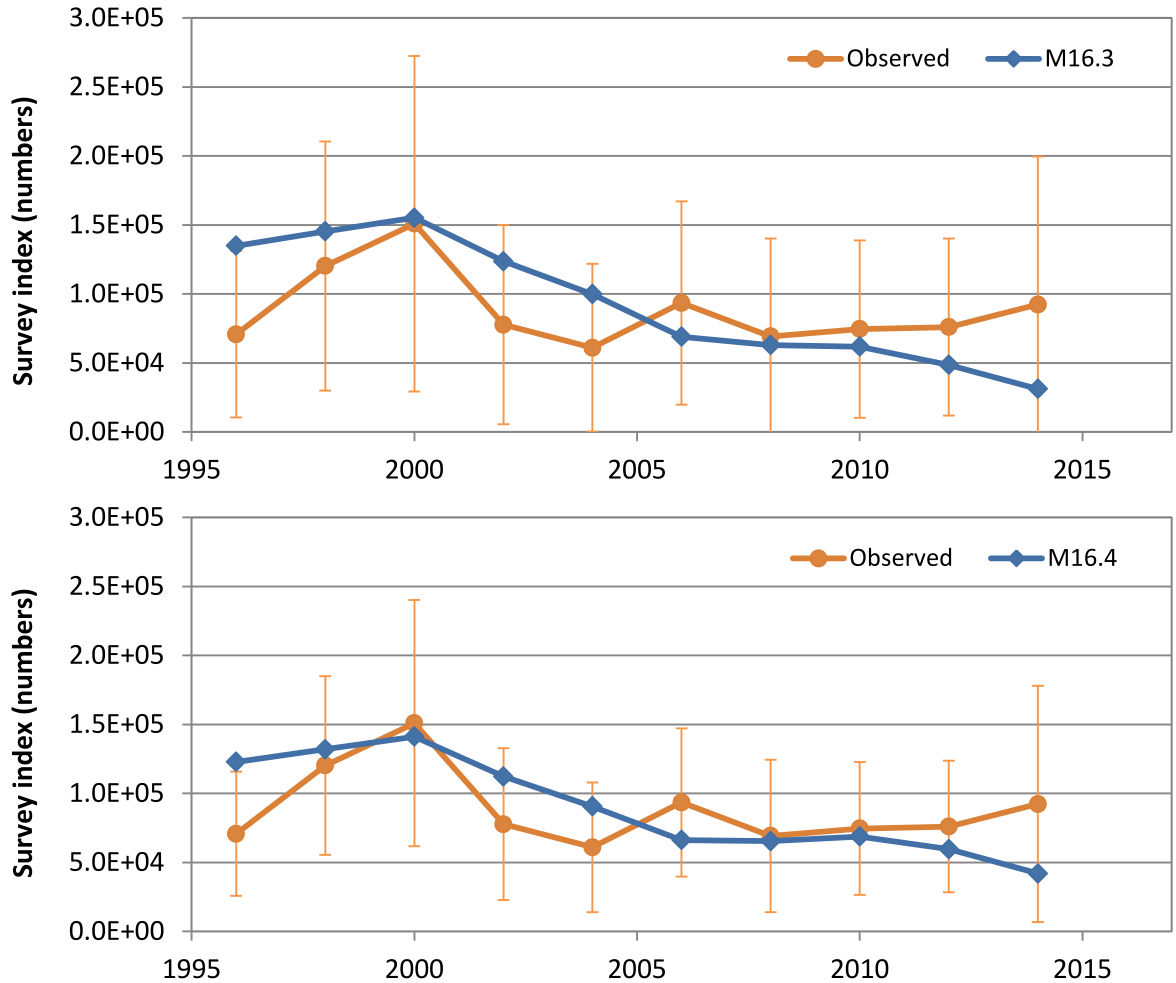


Figure 2.1.1c—Model fits to the NMFS longline survey abundance time series (Models 16.3 and 16.4 only). Survey time series shows 95% confidence interval, which differs between models.

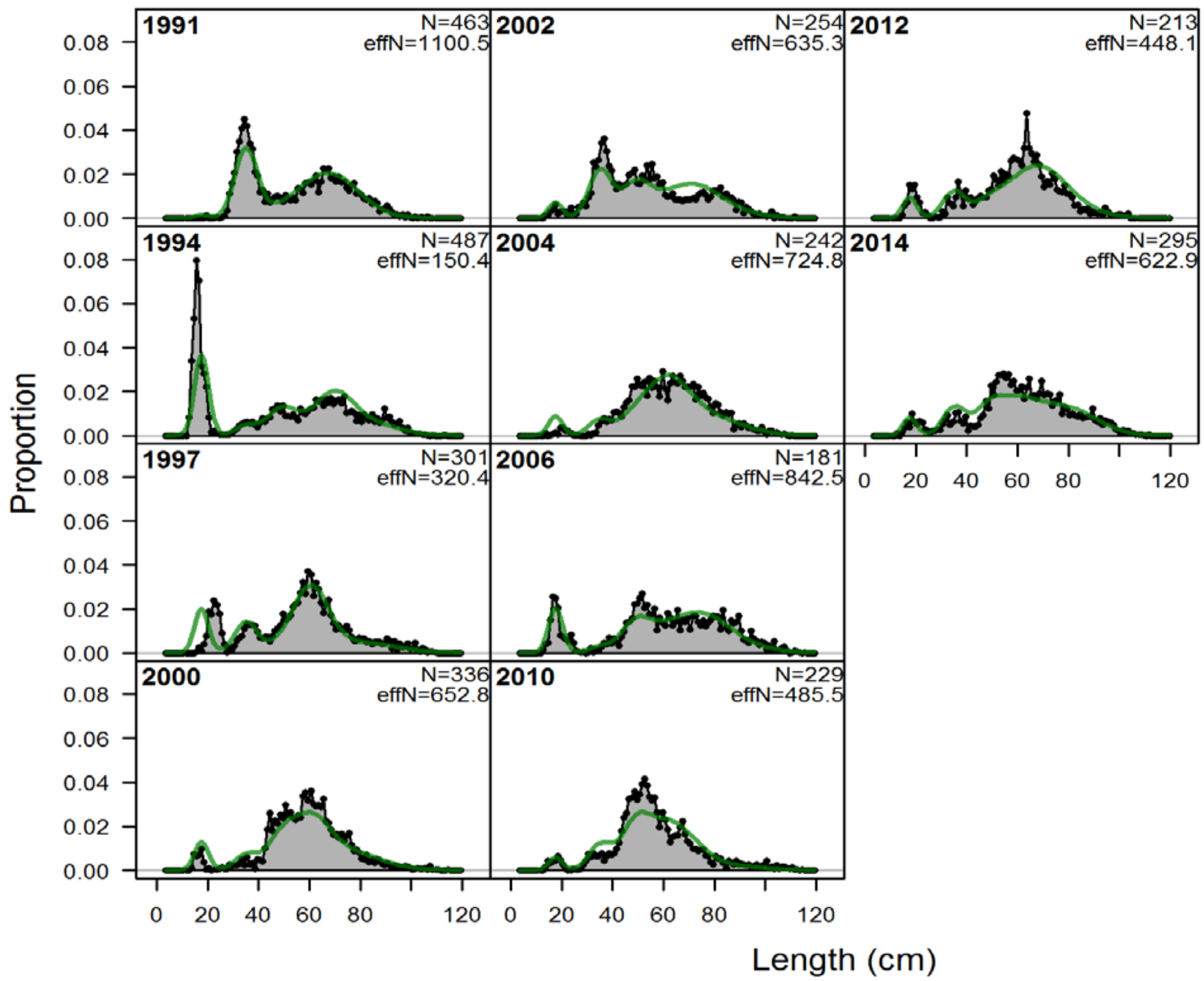


Figure 2.1.2a—Model 16.1 fits to trawl survey size composition data.

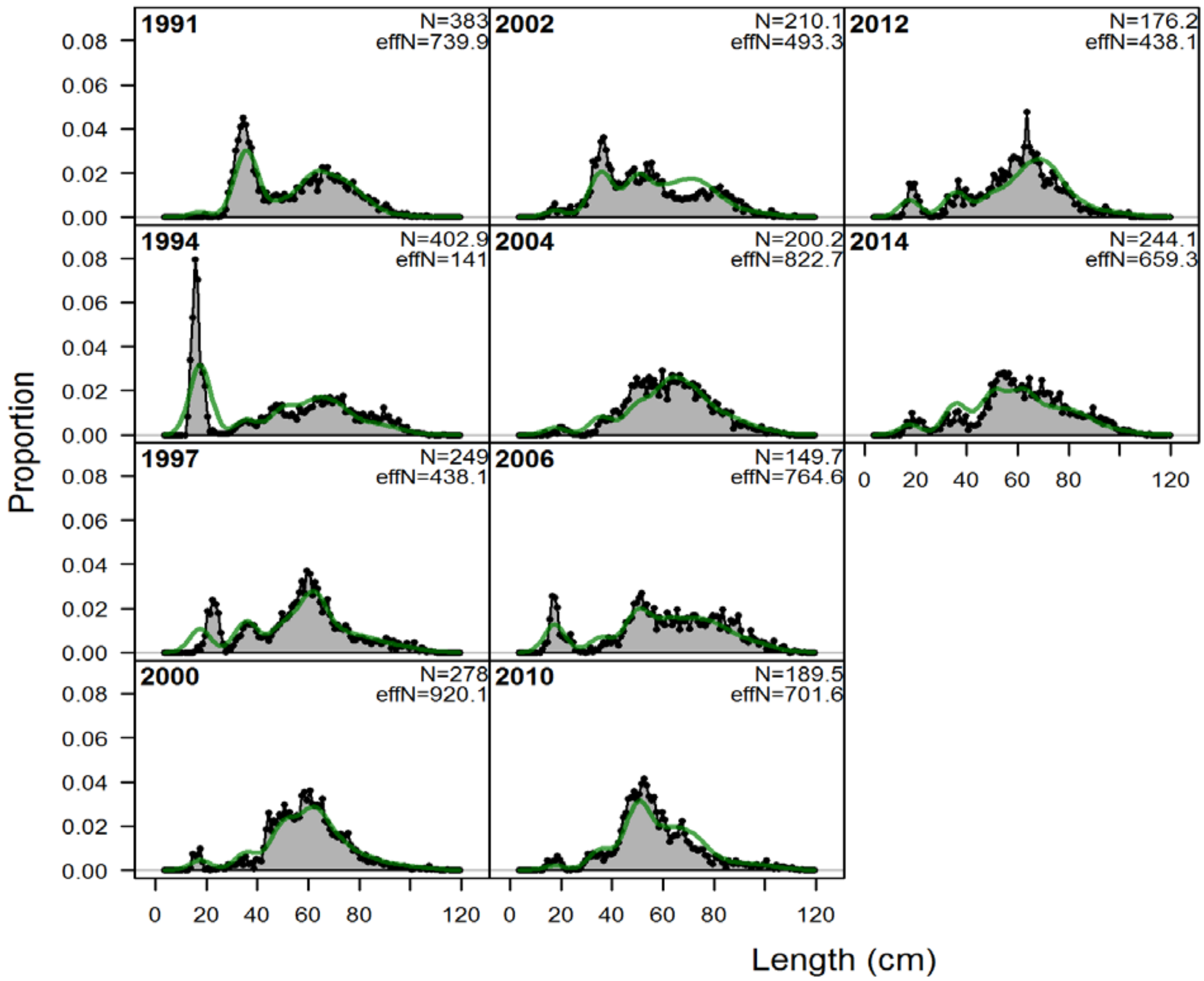


Figure 2.1.2b—Model 16.2 fits to trawl survey size composition data.

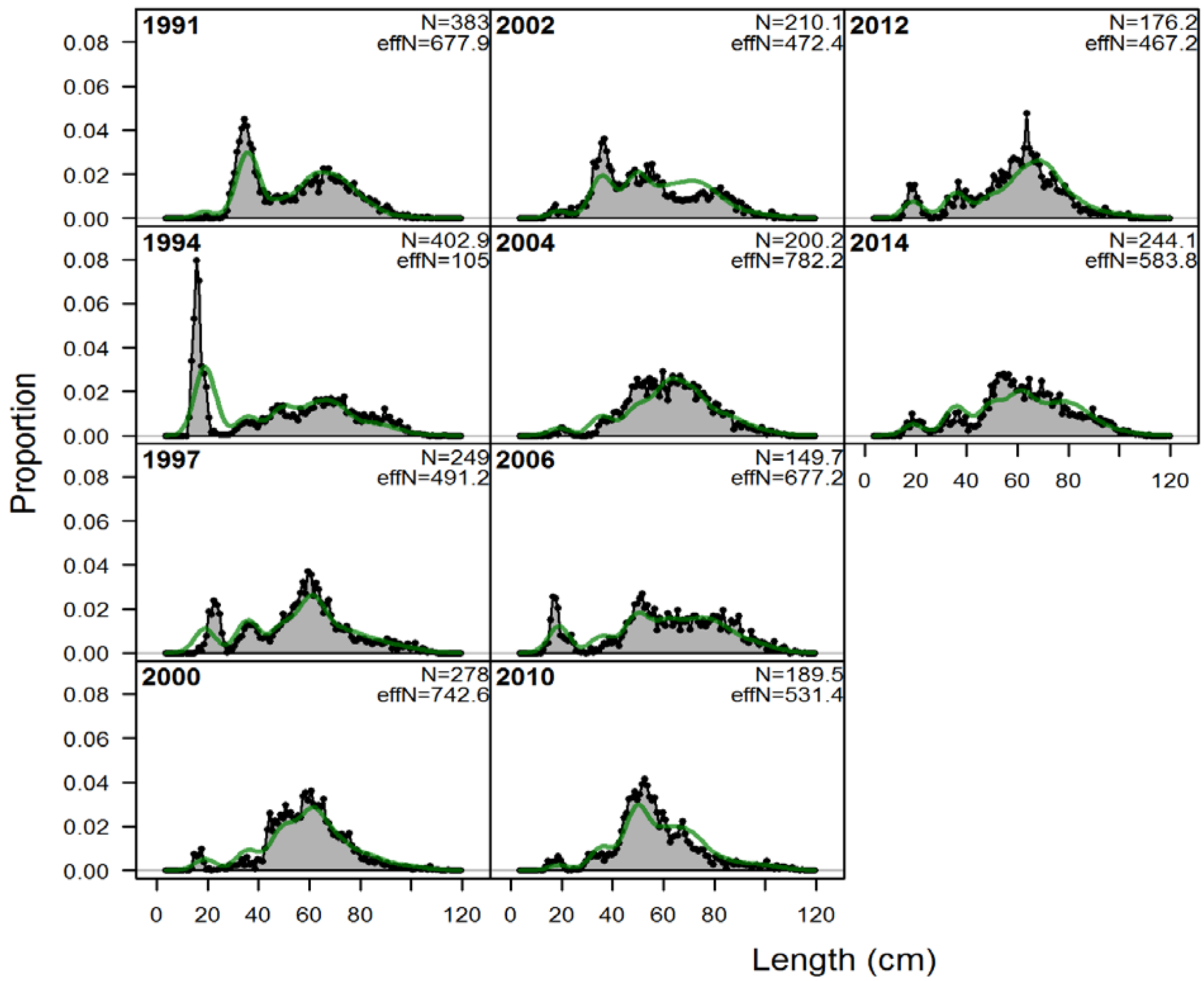


Figure 2.1.2c—Model 16.3 fits to trawl survey size composition data.

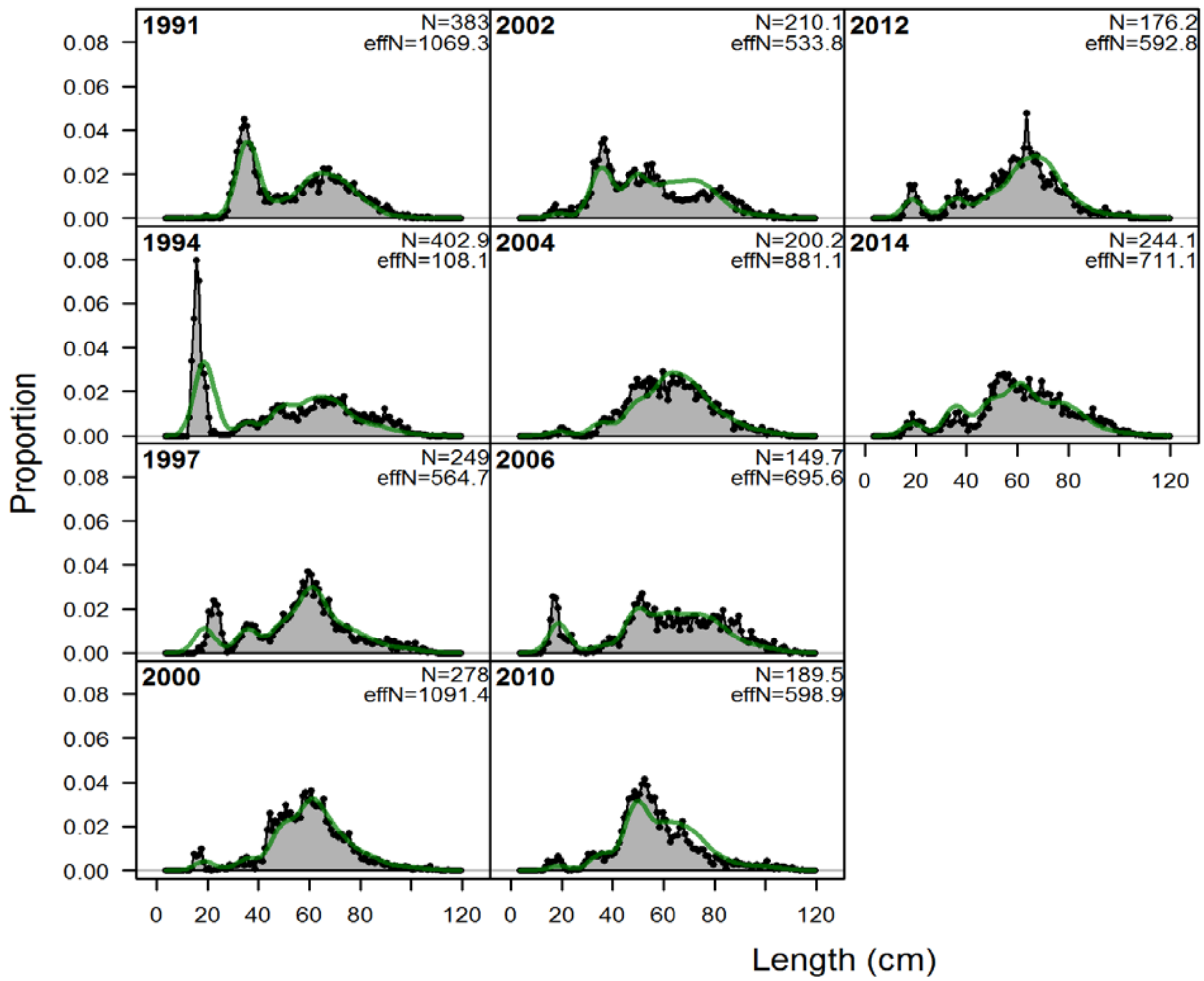


Figure 2.1.2d—Model 16.4 fits to trawl survey size composition data.

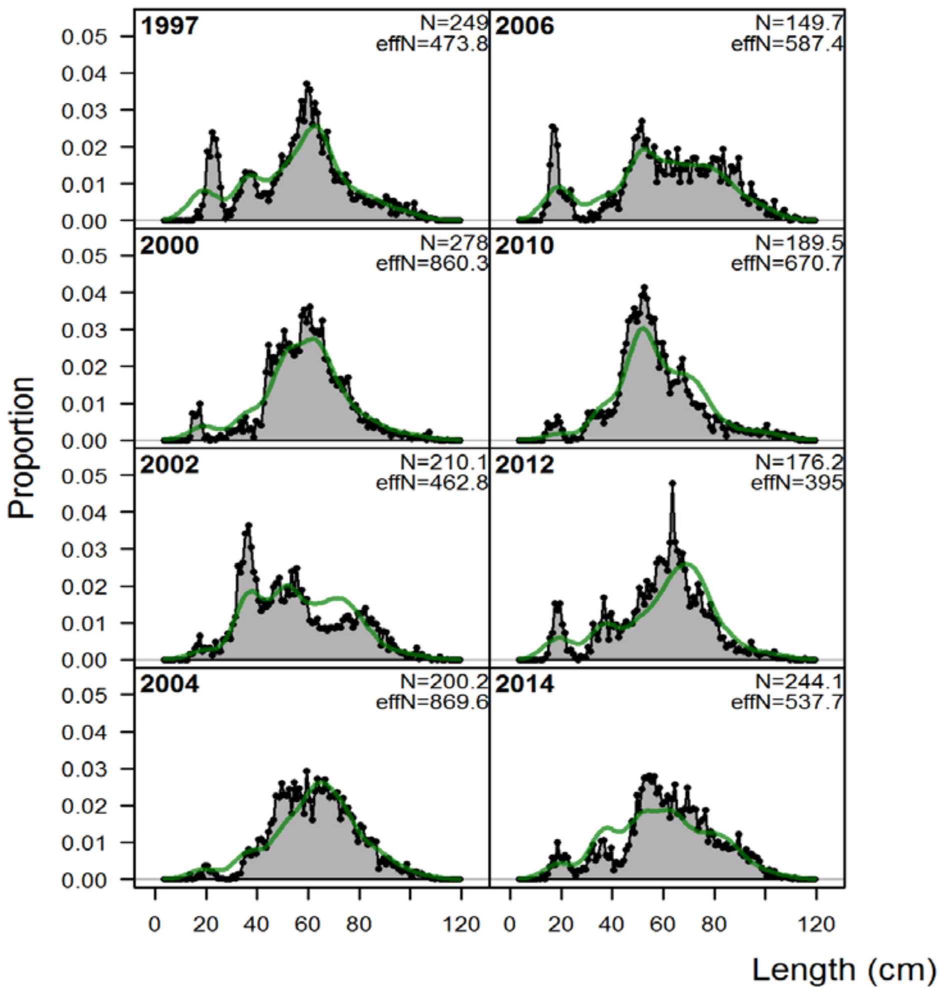


Figure 2.1.2e—Model 16.5 fits to trawl survey size composition data.

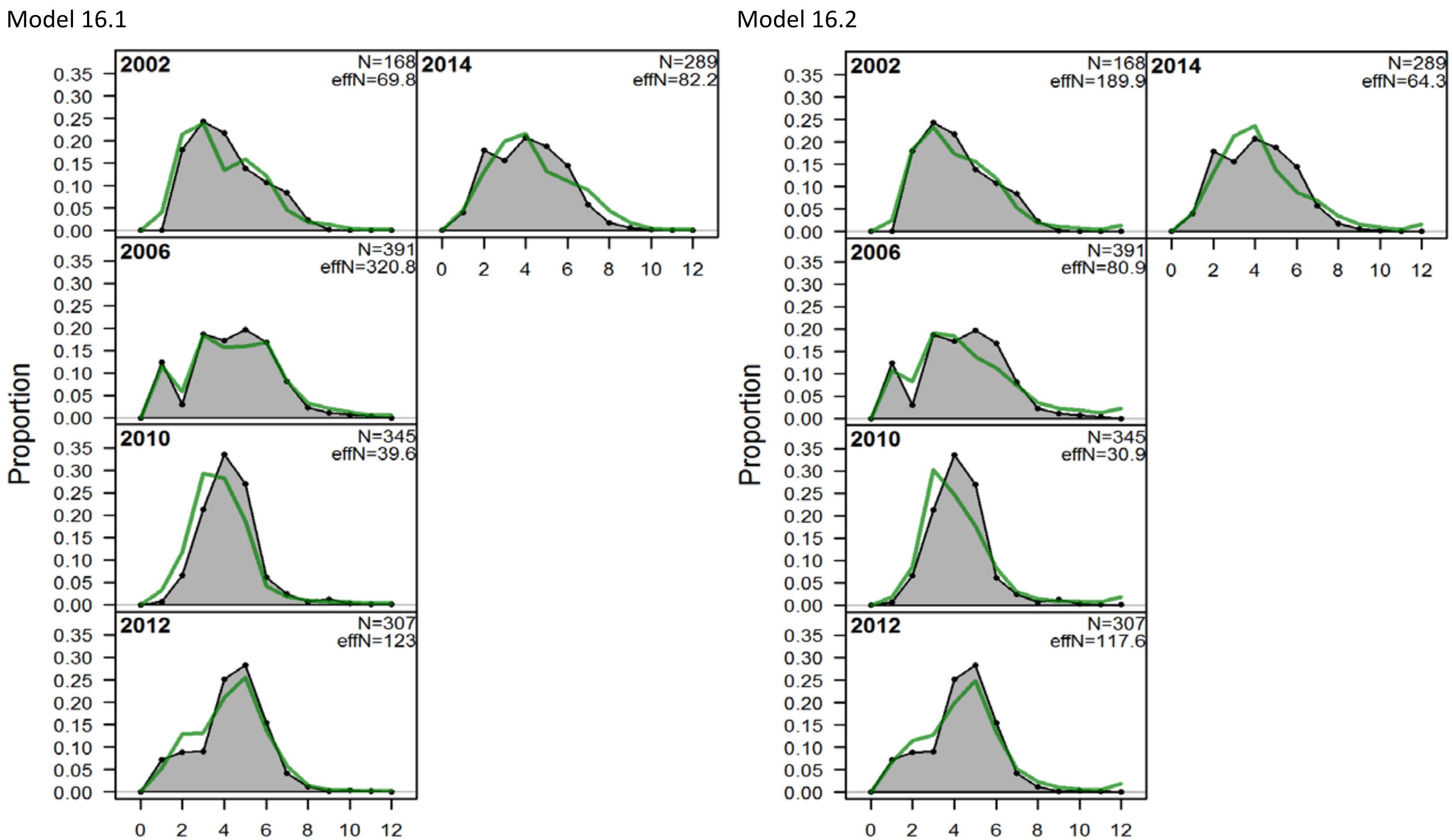


Figure 2.1.3—Model fits to trawl survey age composition data (page 1 of 3).

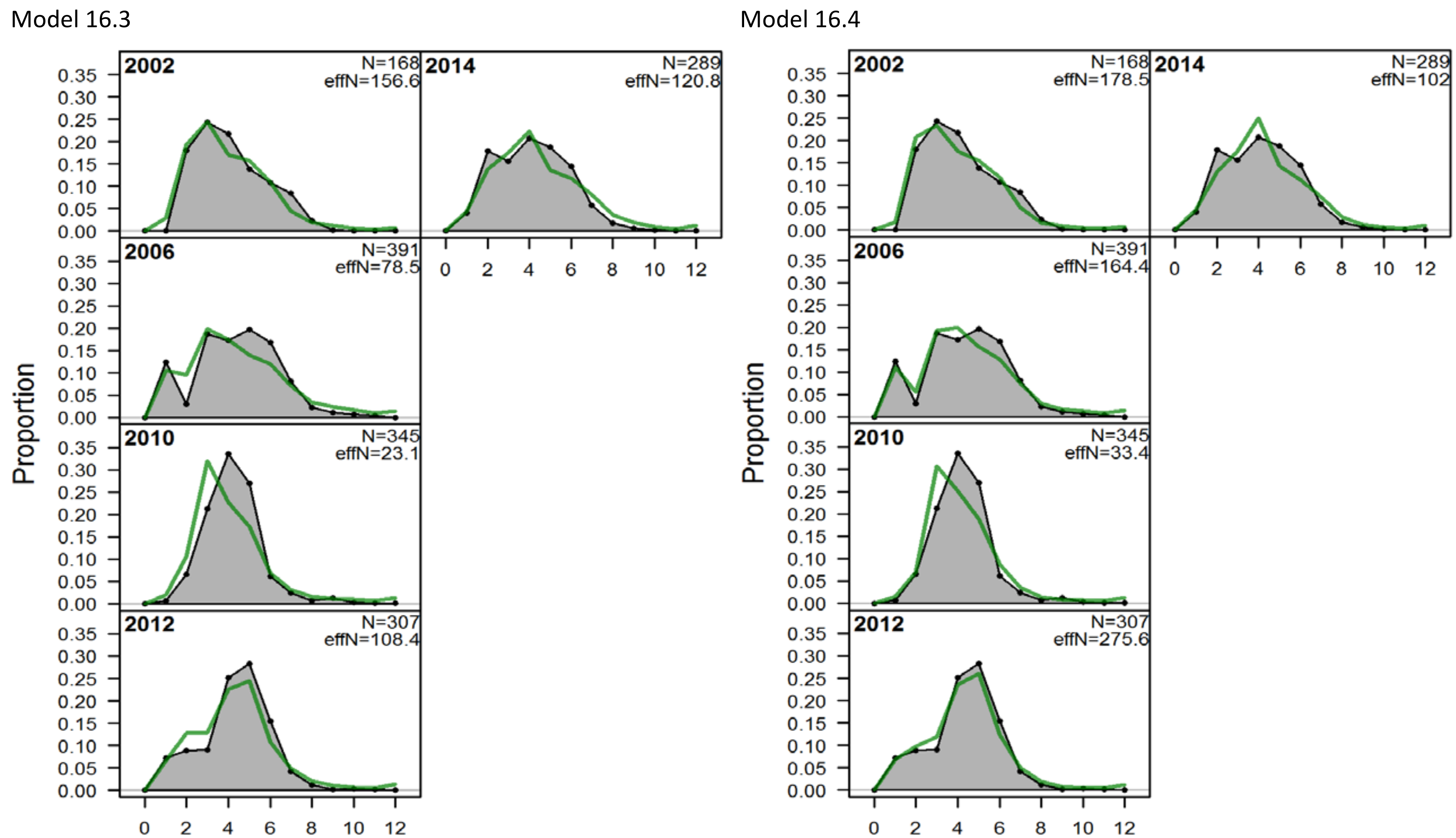


Figure 2.1.3—Model fits to trawl survey age composition data (page 2 of 3).

Model 16.5

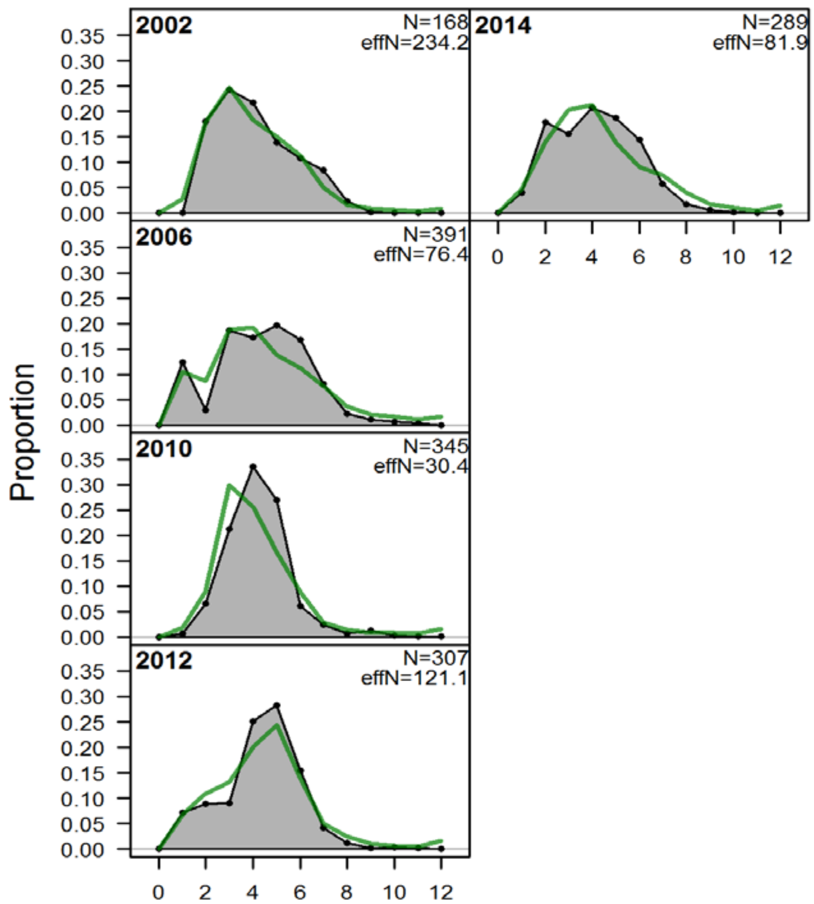


Figure 2.1.3—Model fits to trawl survey age composition data (page 3 of 3).

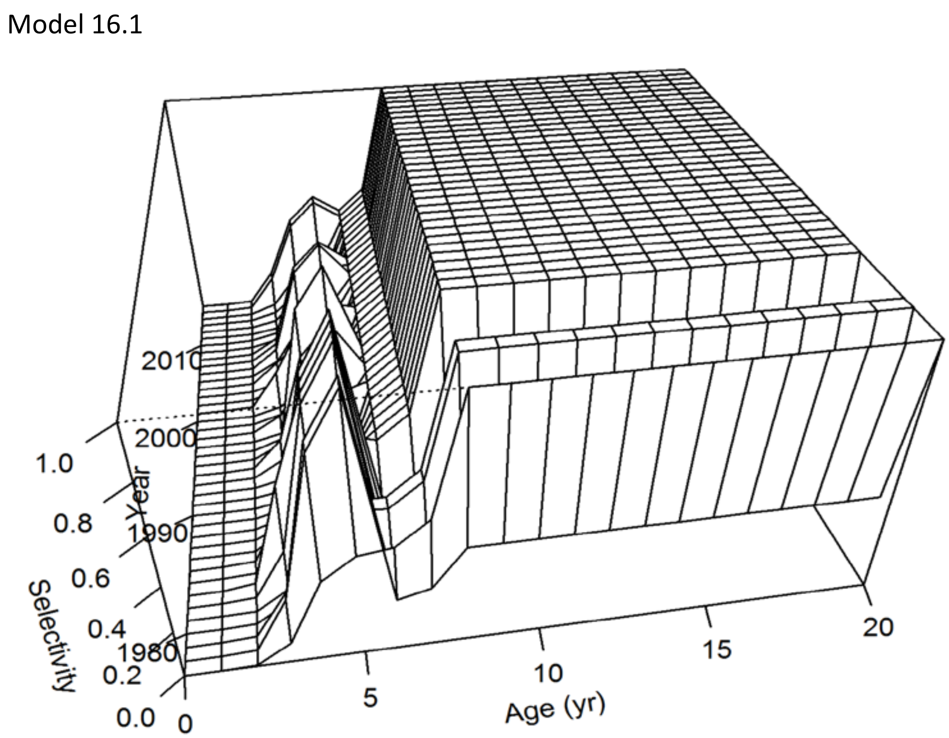
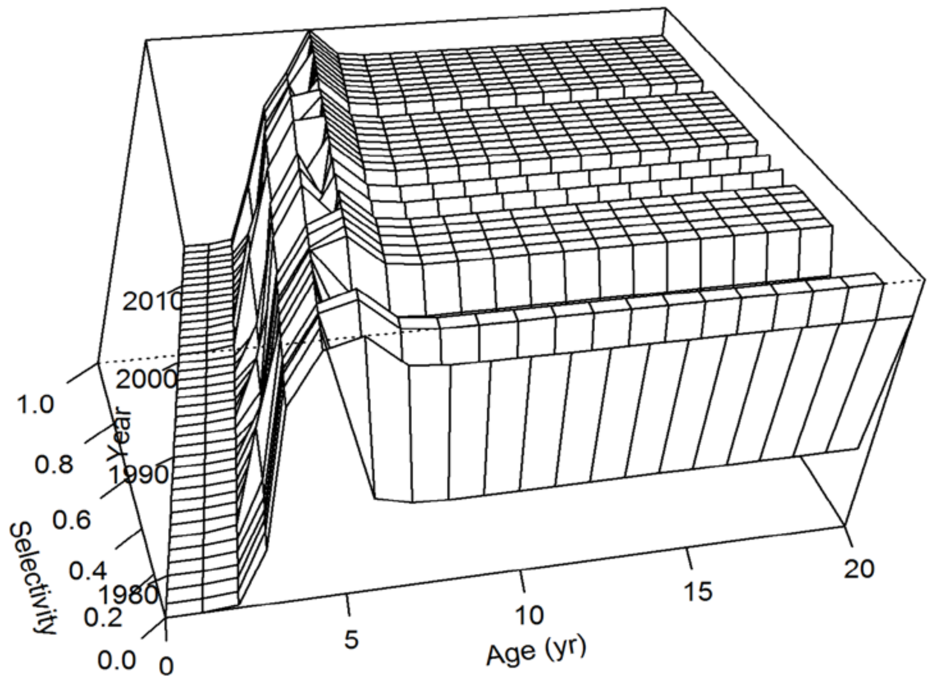


Figure 2.1.4—Fishery selectivity (page 1 of 3).

Model 16.2



Model 16.3

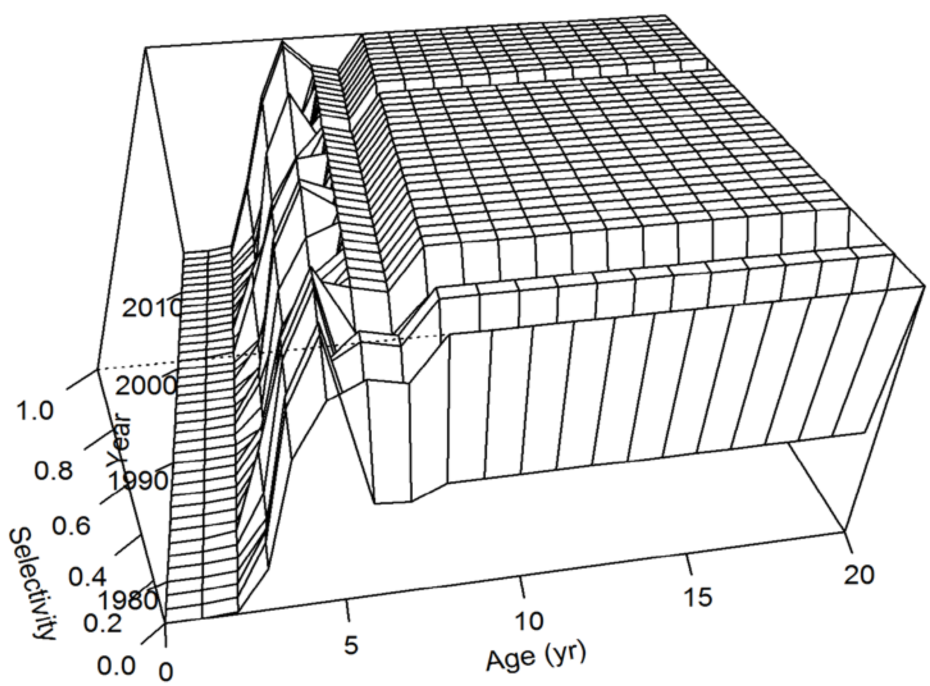
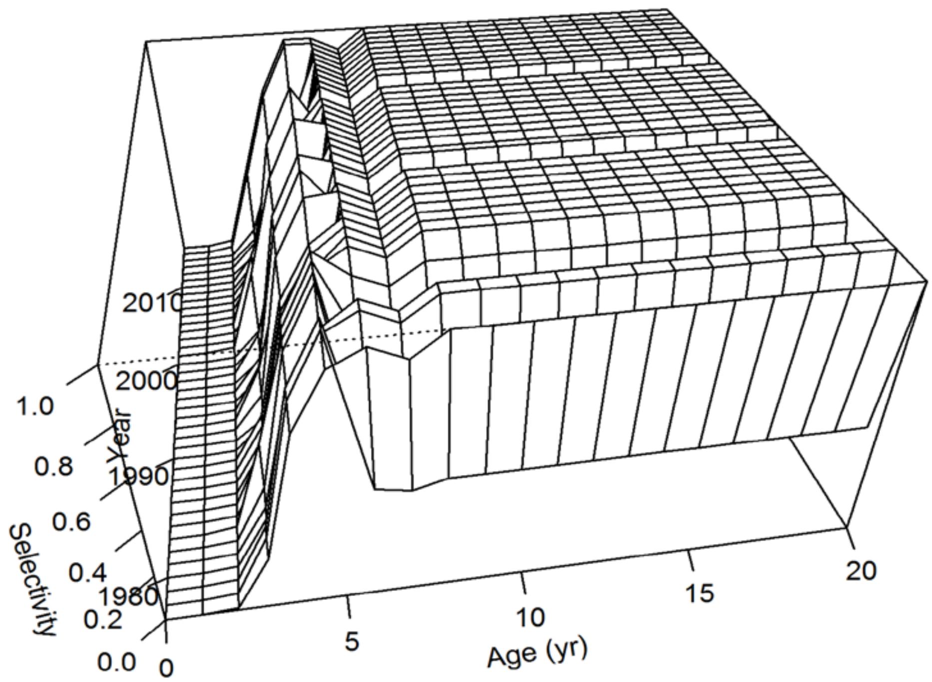


Figure 2.1.4—Fishery selectivity (page 2 of 3).

Model 16.4



Model 16.5

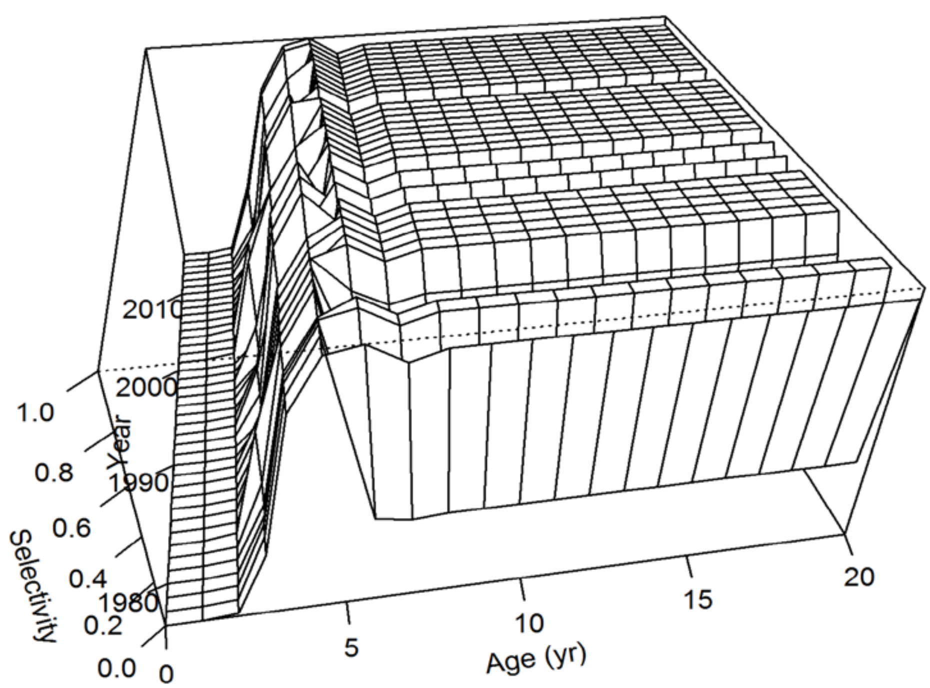


Figure 2.1.4—Fishery selectivity (page 3 of 3).

Model 16.1

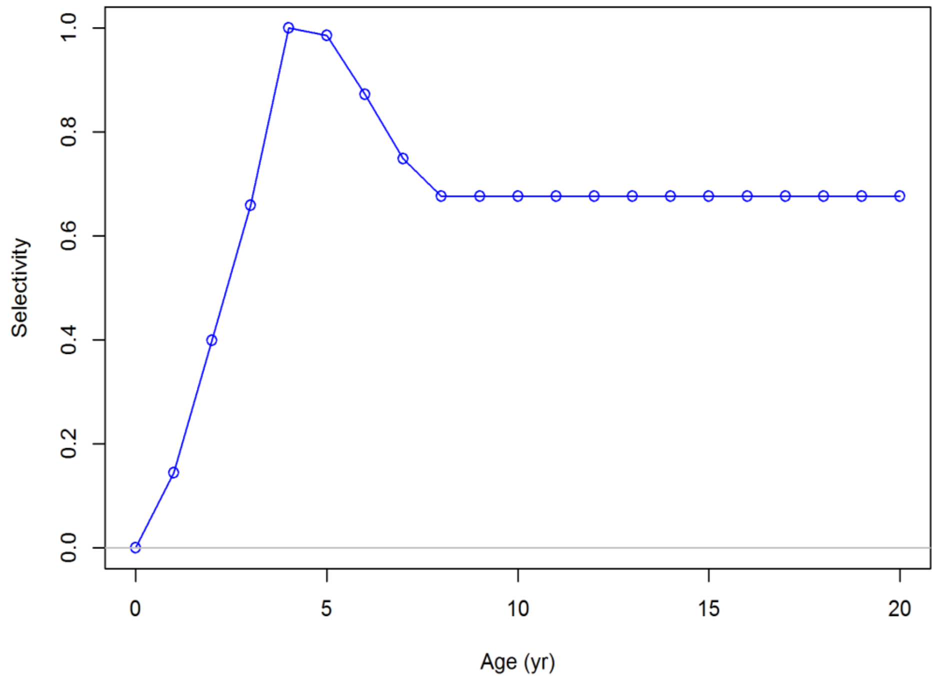
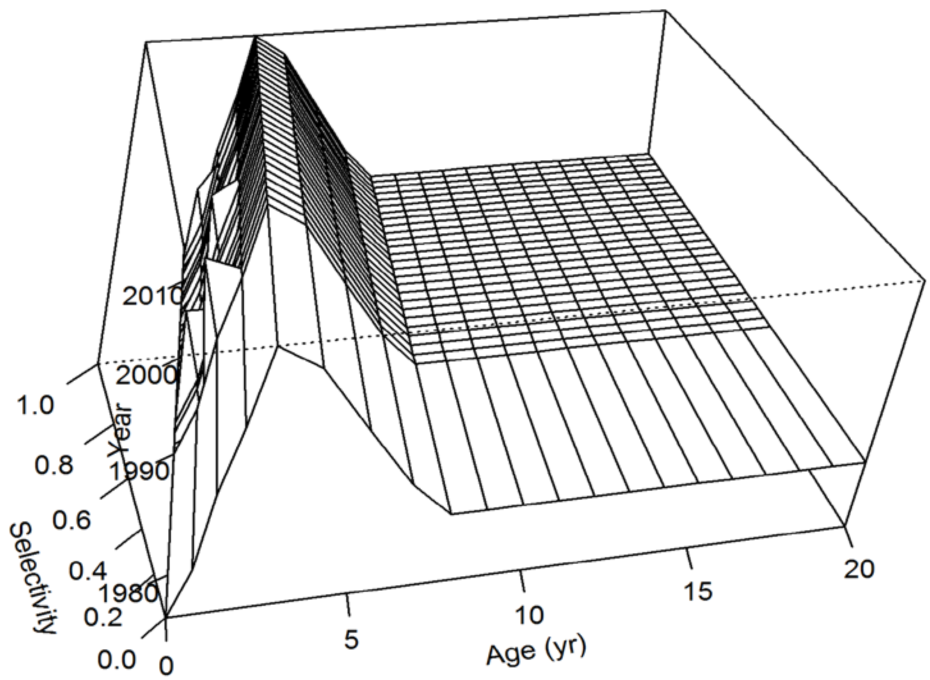


Figure 2.1.5a—Trawl survey selectivity (page 1 of 3).

Model 16.2



Model 16.3

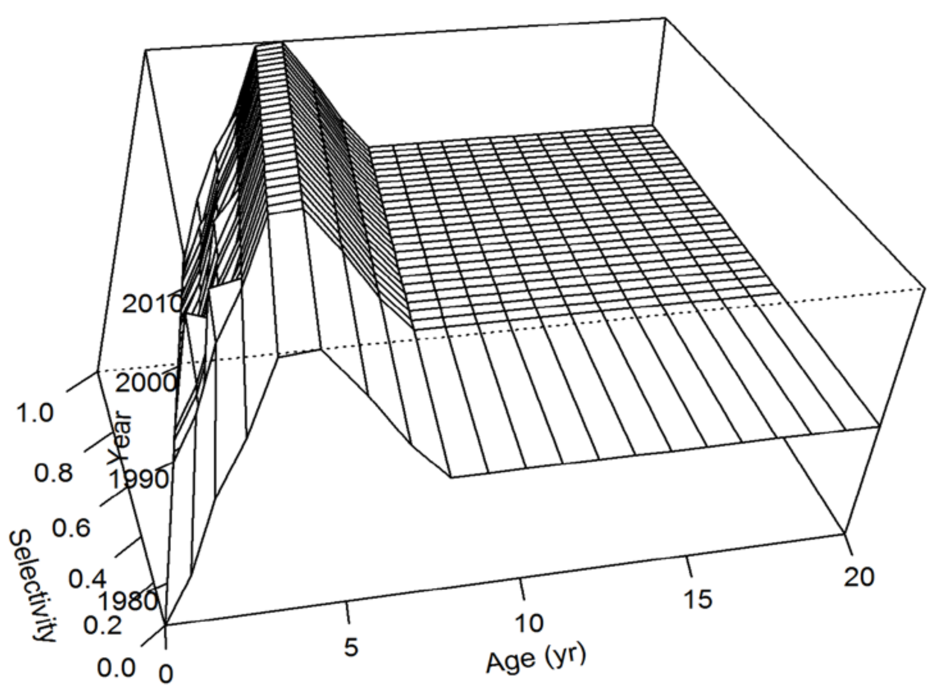
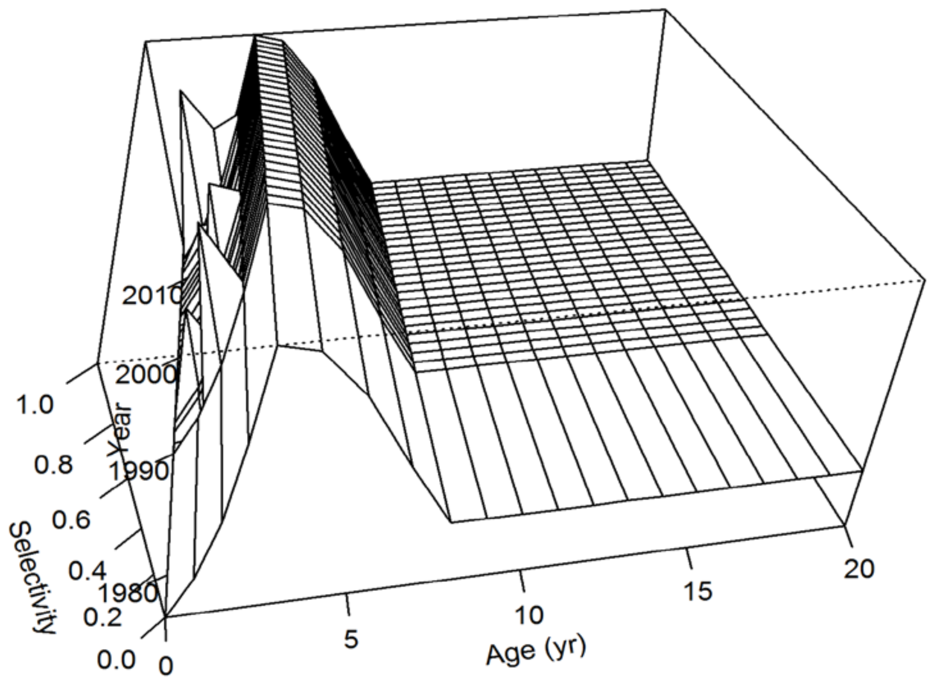


Figure 2.1.5a—Trawl survey selectivity (page 2 of 3).

Model 16.4



Model 16.5

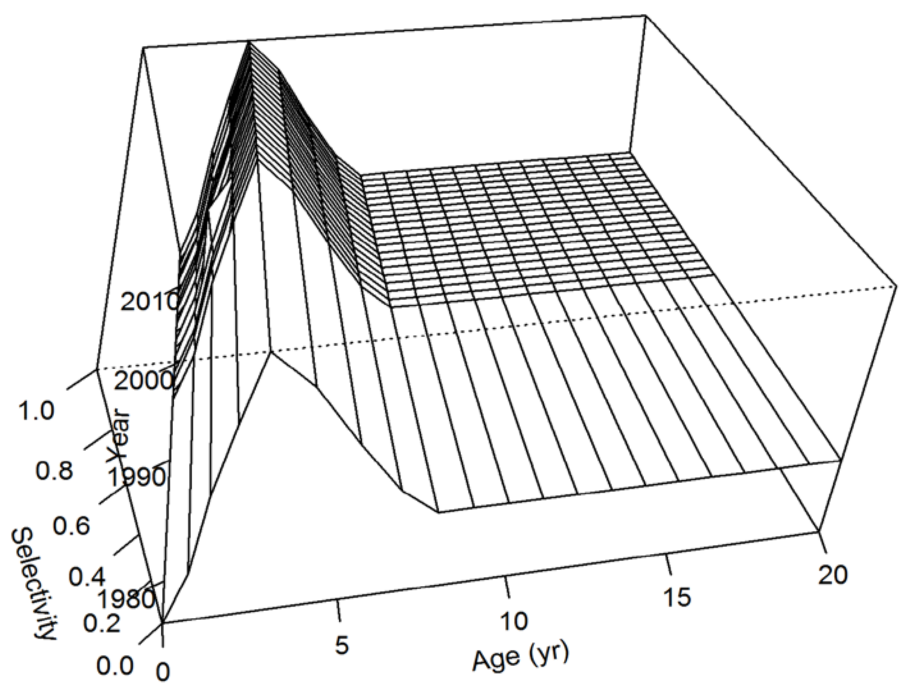
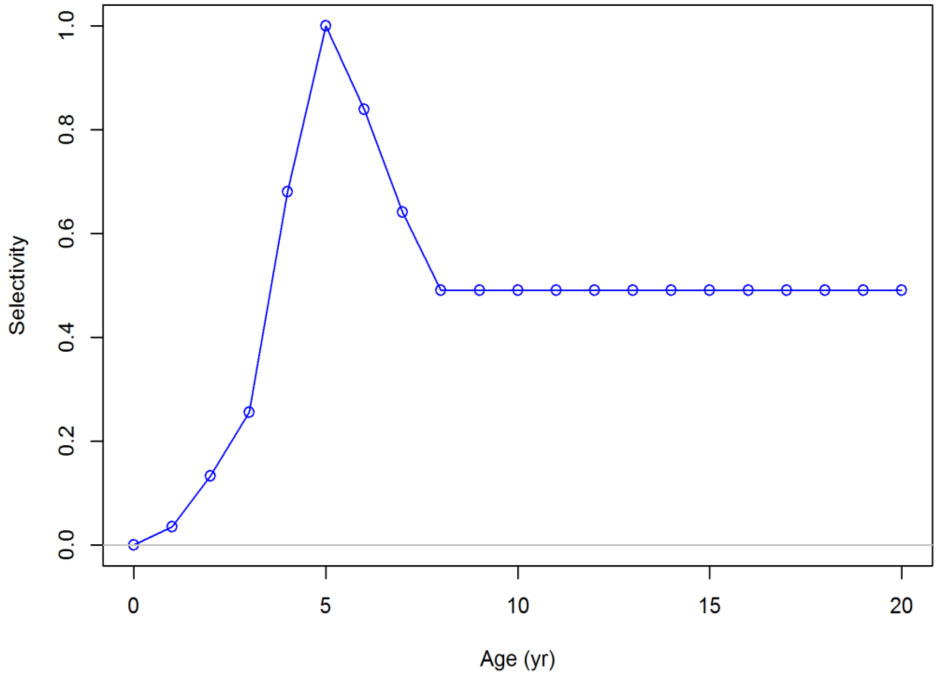


Figure 2.1.5a—Trawl survey selectivity (page 3 of 3).

Model 16.2



Model 16.4

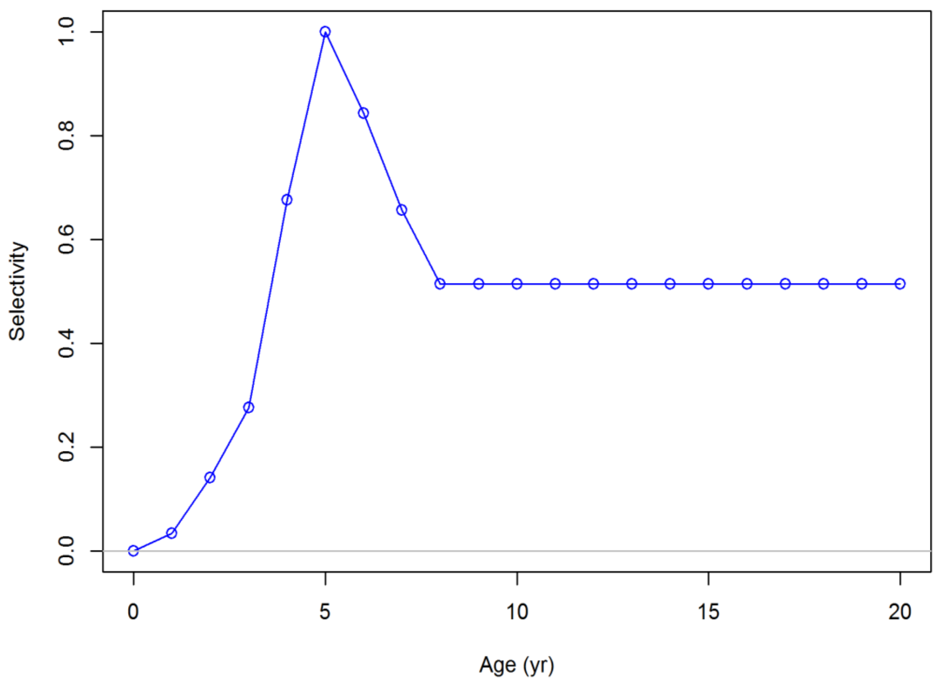
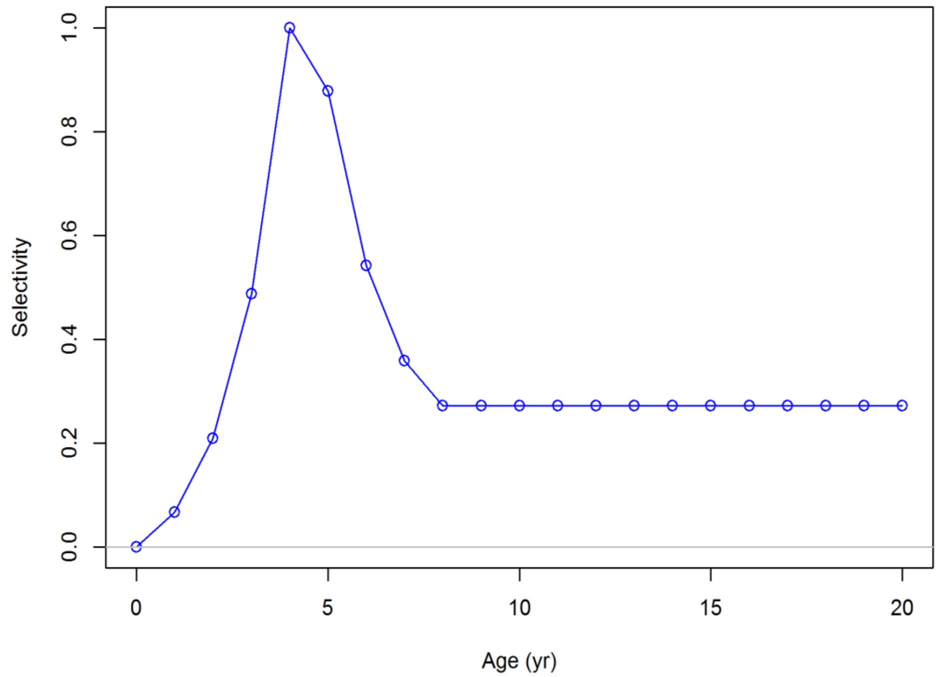


Figure 2.1.5b—IPHC longline survey selectivity.

Model 16.3



Model 16.4

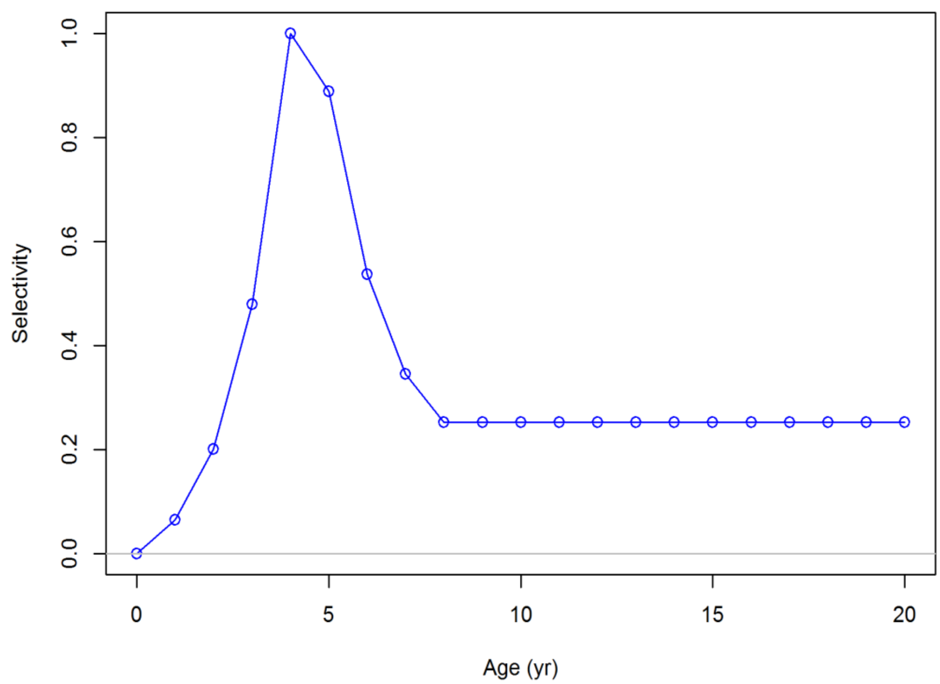


Figure 2.1.5c—NMFS longline survey selectivity.

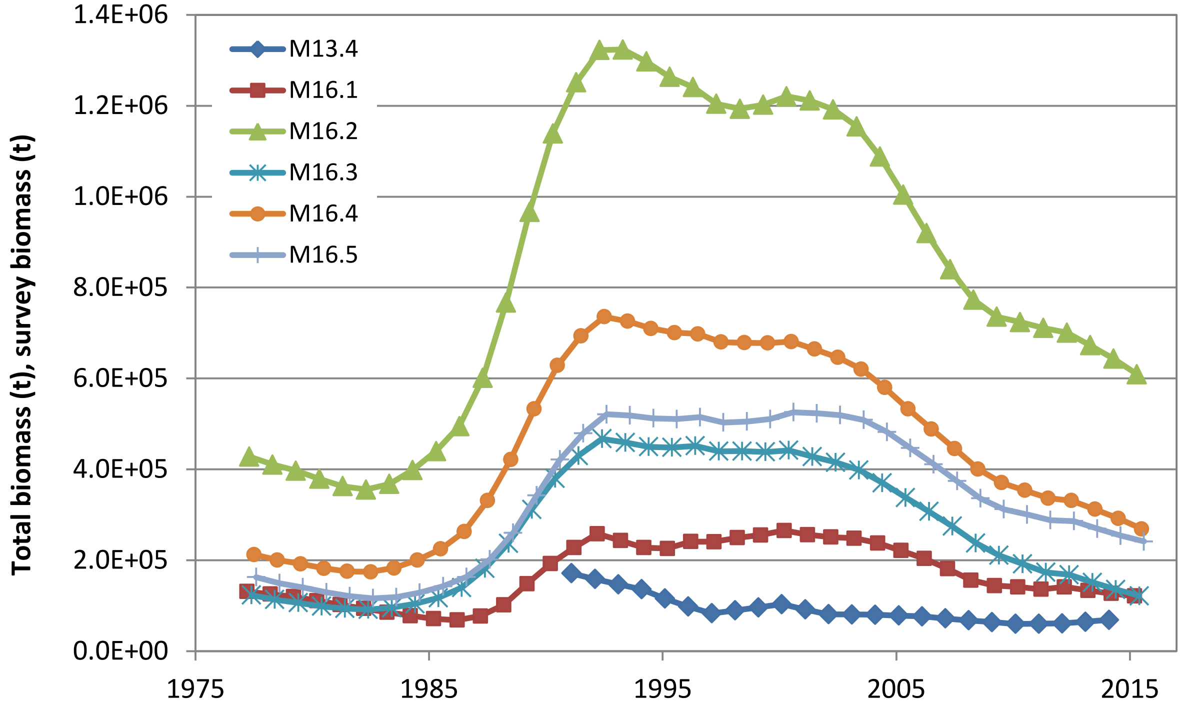


Figure 2.1.6—Total biomass time series as estimated by each of the models.

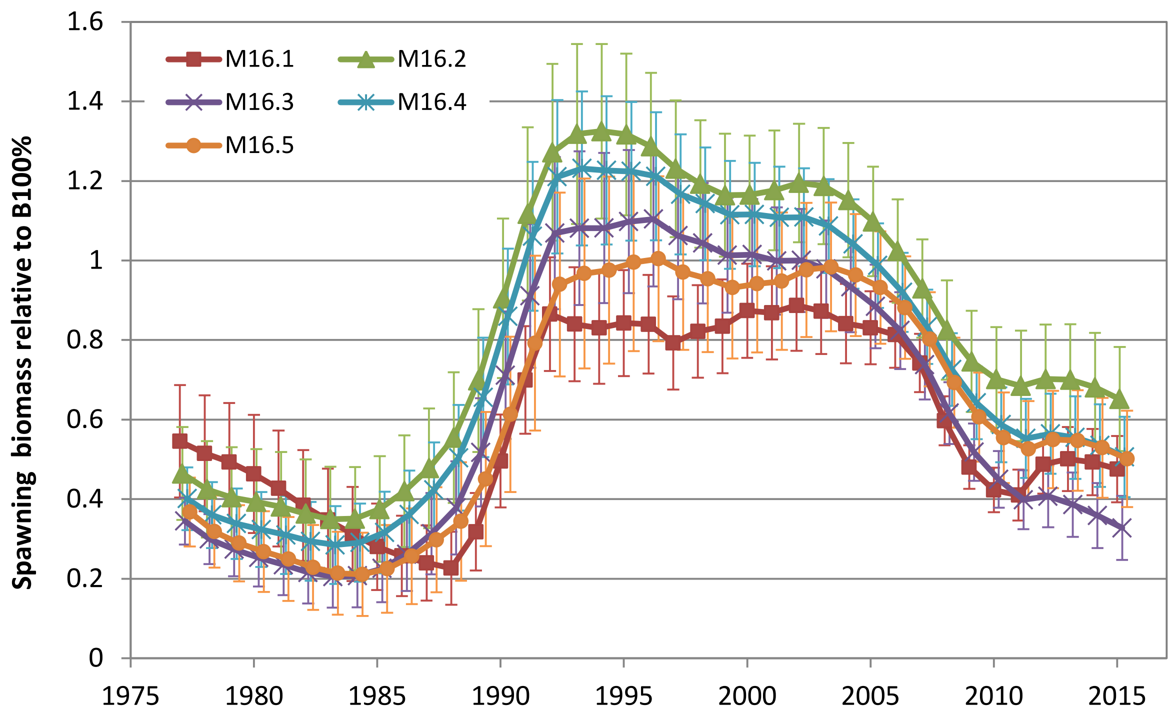


Figure 2.1.7—Time series of spawning biomass relative to $B_{100\%}$ for each of the models, with 95% confidence intervals.

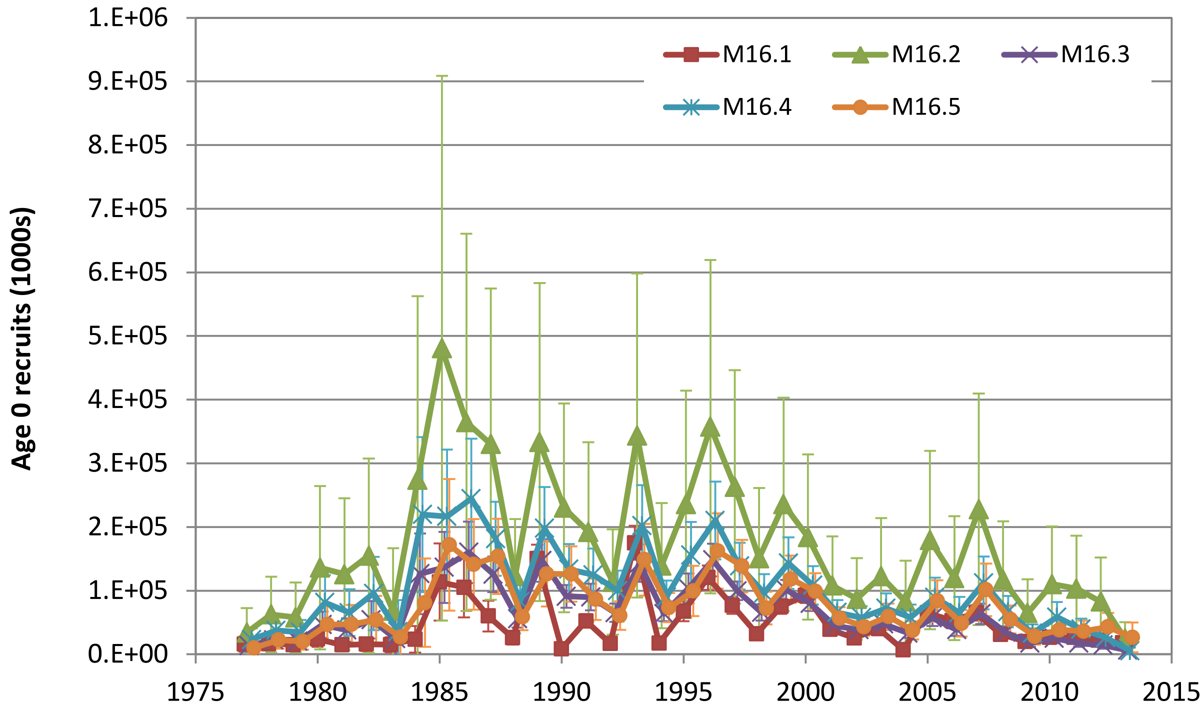


Figure 2.1.8—Age 0 recruitment (1000s of fish) for each model.

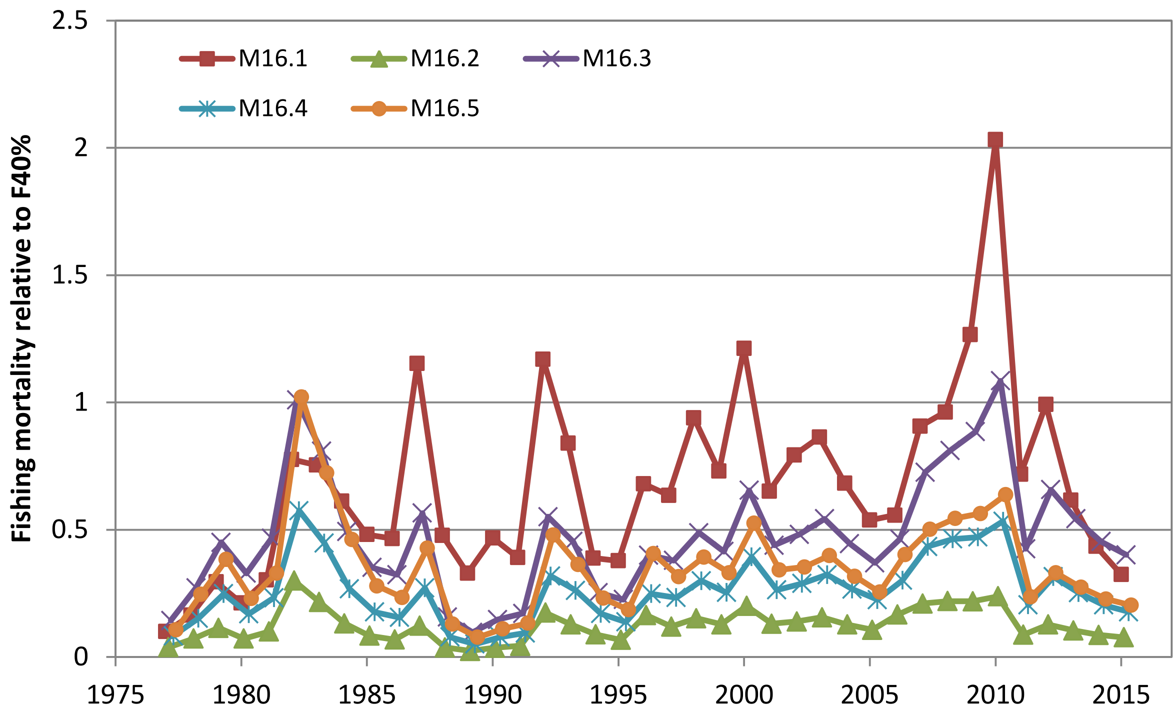
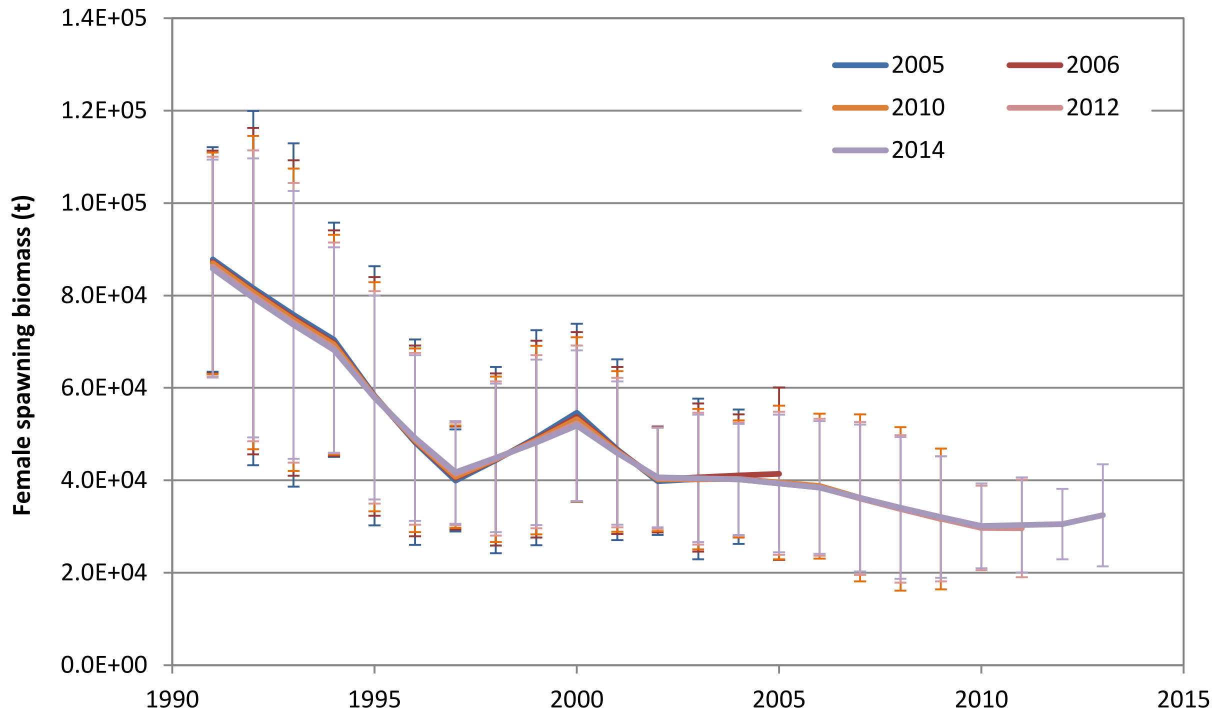


Figure 2.1.9—Time series of the ratio of full-selection fishing morality to $F_{40\%}$.



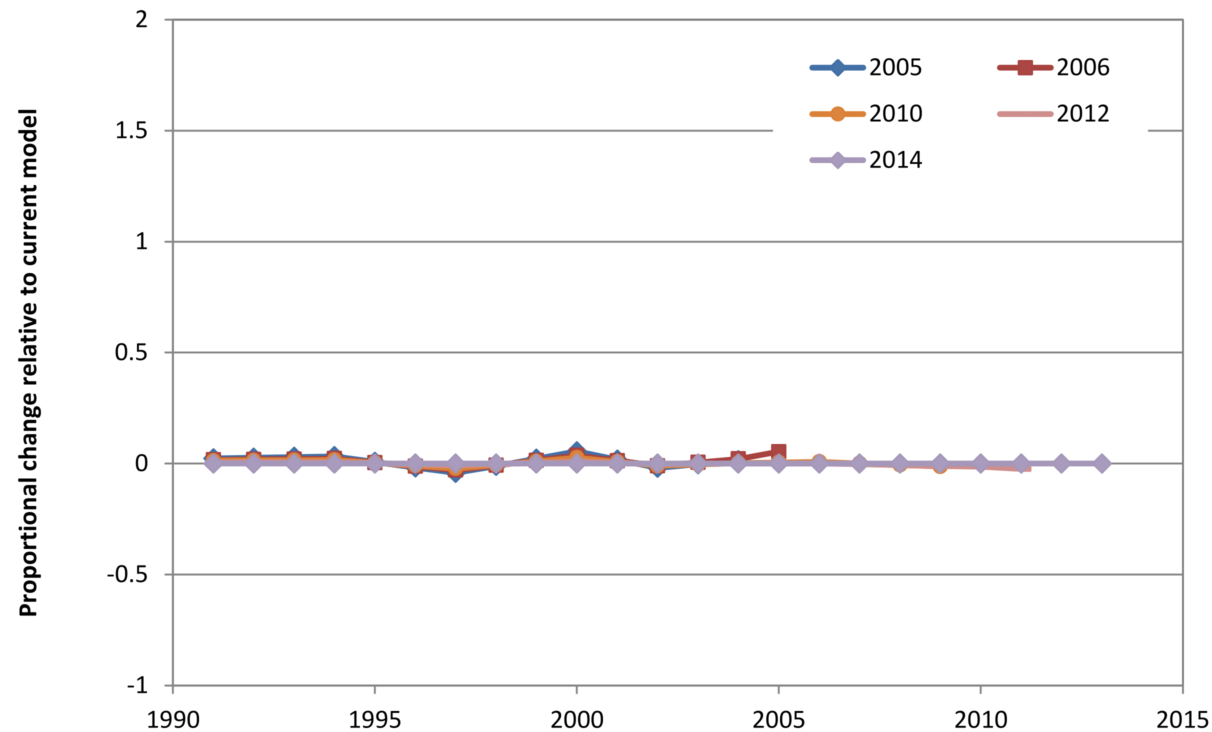


Figure 2.1.10a—Ten-year survey biomass retrospective analysis of Model 13.4.

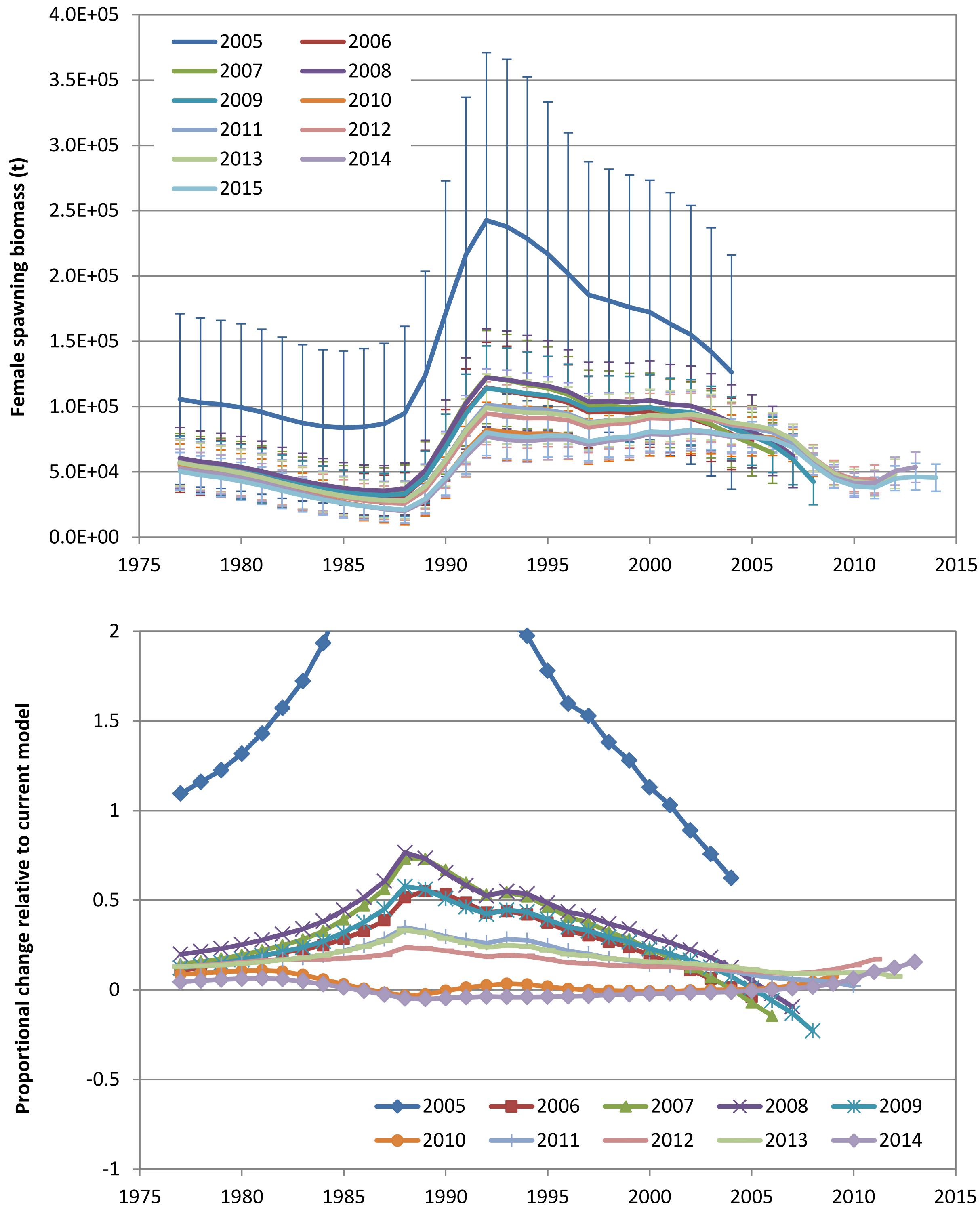


Figure 2.1.10b—Ten-year spawning biomass retrospective analysis of Model 16.1.

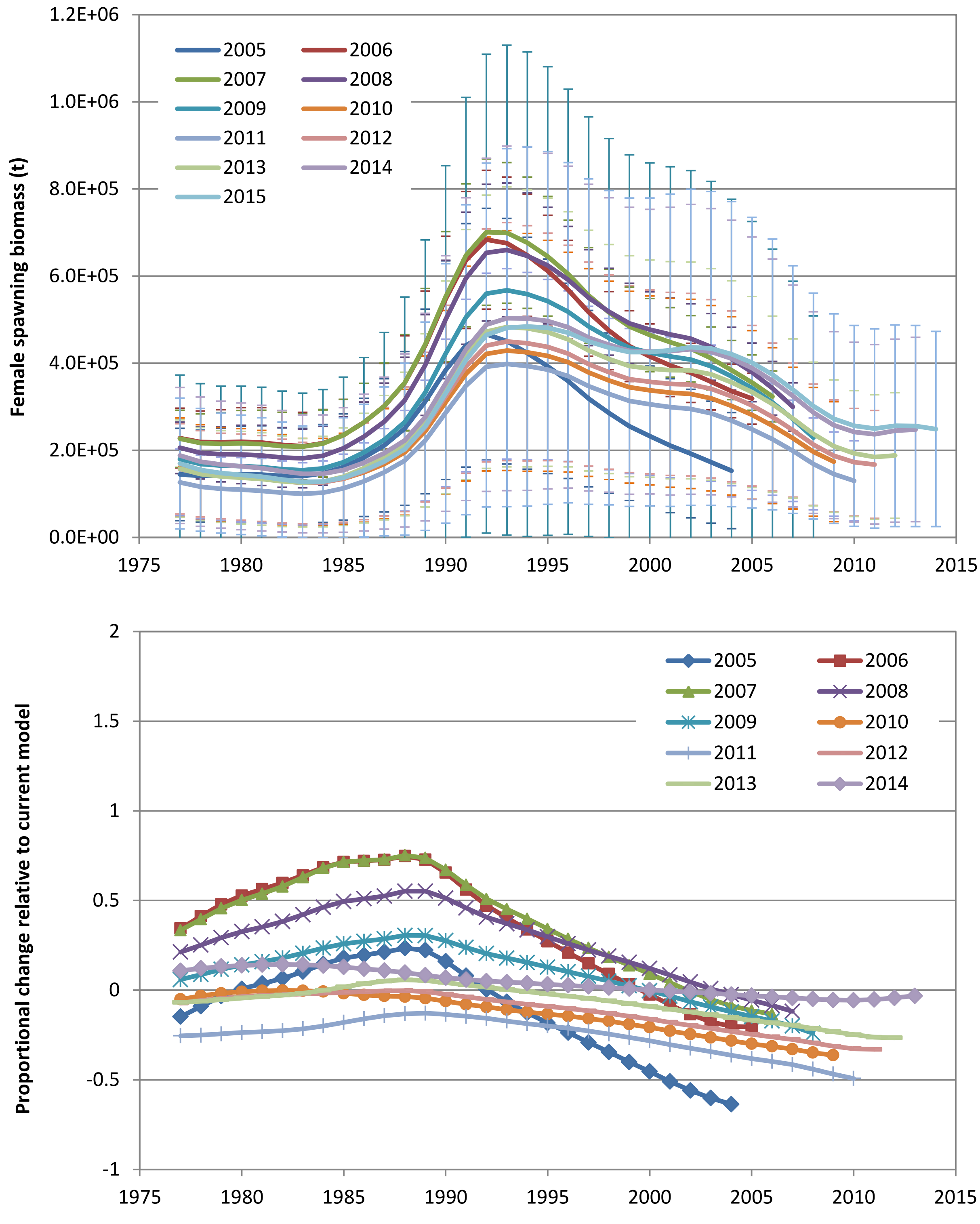
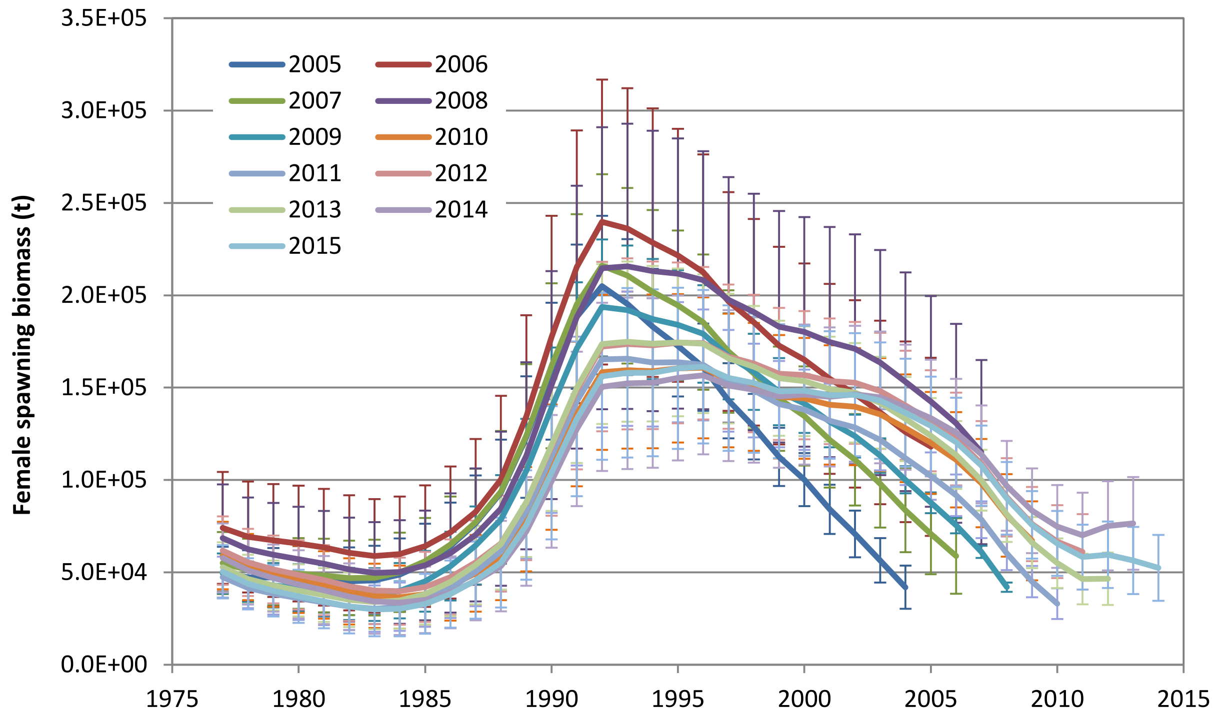


Figure 2.1.10c—Ten-year spawning biomass retrospective analysis of Model 16.2.



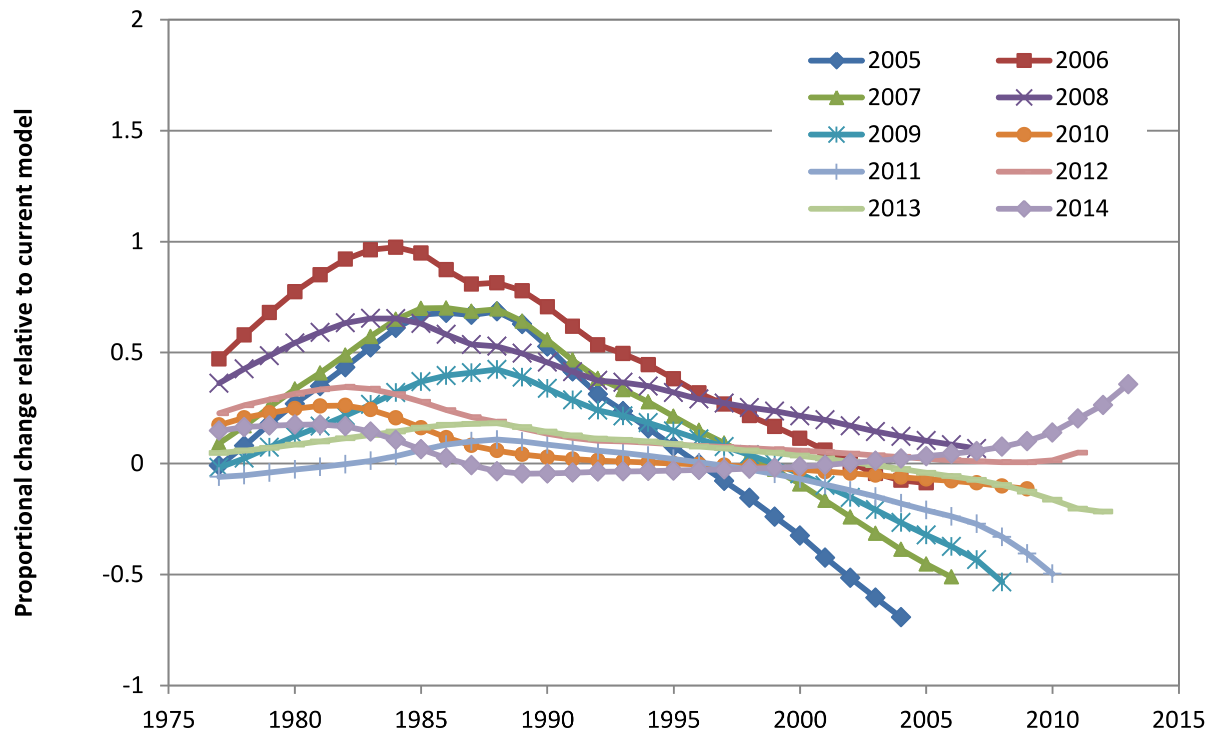


Figure 2.1.10d—Ten-year spawning biomass retrospective analysis of Model 16.3.

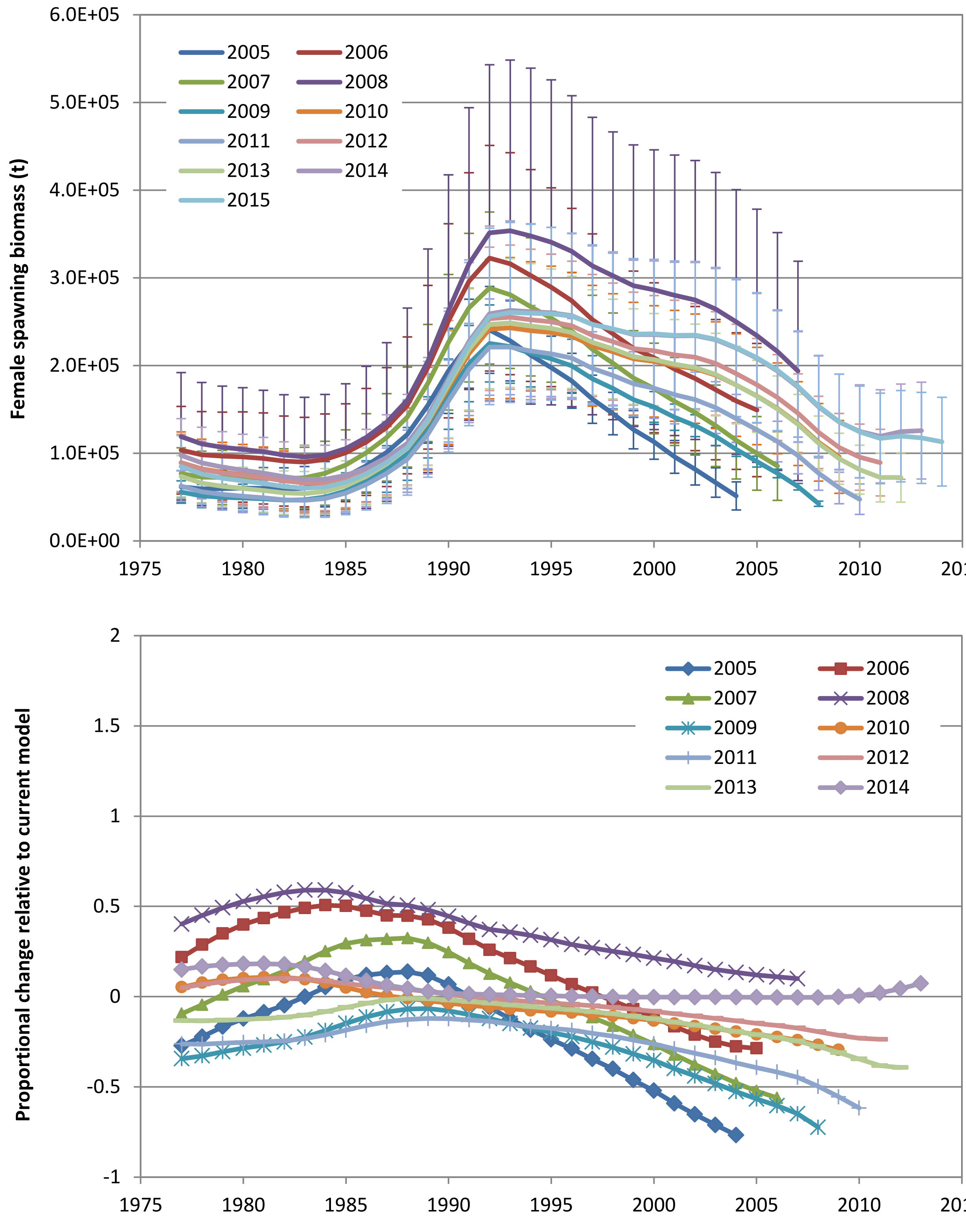


Figure 2.1.10e—Ten-year spawning biomass retrospective analysis of Model 16.4.

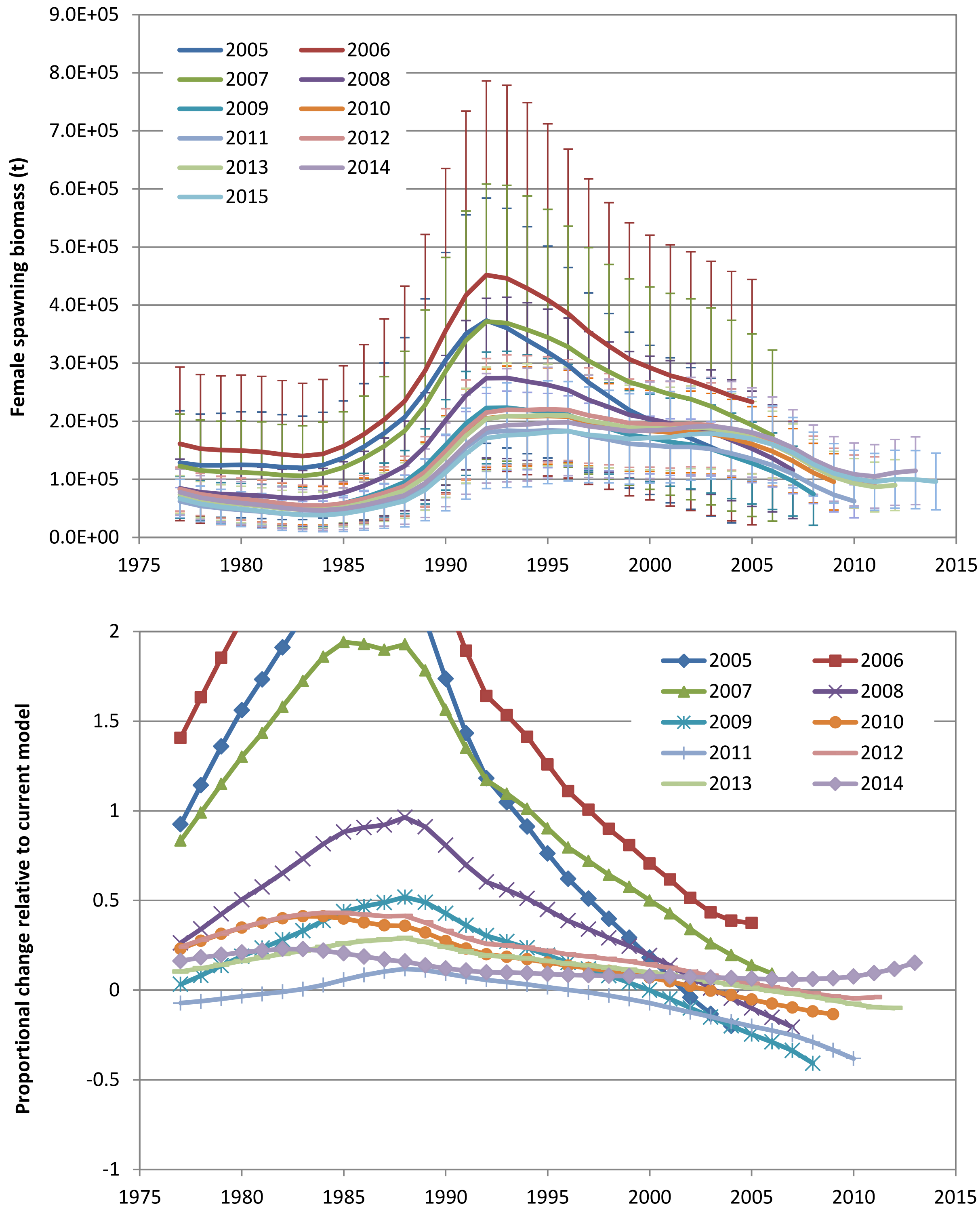


Figure 2.1.10f—Ten-year spawning biomass retrospective analysis of Model 16.5.