Appendix 2.1:
Preliminary assessment of the Pacific cod stock in the eastern Bering Sea

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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 eastern Bering Sea (EBS, Thompson 2015). Many of those comments were informed by the results of a CIE review of the EBS 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authors and PTs to follow the model numbering scheme adopted at the December 2014 meeting.*" Given that comment SSC1 superseded the model numbering scheme adopted at the December 2014 meeting, it seems reasonable to assume that inclusion of this comment in the 12/15 minutes was an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.*" Results described by Punt (in press) were used to choose a data-weighting method for Model 16.5.

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.

Responses to SSC and Plan Team comments specific to Eastern Bering Sea 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): *"The SSC was encouraged by the author's explanation that dome-shaped selectivity may, in part, be explained by the possibility that some of older fish may be residing in the northern Bering Sea (NBS) at the time of the survey. This is supported by the size composition of the fish in the 2010 NBS trawl survey, which suggested that up to 40% of the fish in some larger size classes reside in this area, although the overall proportion in the NBS was small. The SSC encourages the author to further examine Pacific cod catches from trawl surveys conducted triennially by the National Marine Fisheries Service (NMFS) (1976-1991) and by the Alaska Department of Fish & Game (1996 to the present) to monitor the distribution and abundance of red king crab and demersal fish (see: Hamazaki, T., Fair, L., Watson, L., Brennan, E., 2005. Analyses of Bering Sea bottom-trawl surveys in Norton Sound: absence of regime shift effect on epifauna and demersal fish. ICES Journal of Marine Science 62, 1597-1602). While the 2010 bottom trawl survey in the NBS found relatively few Pacific cod (3% of total biomass), it is possible that the proportion of Pacific cod that are outside the standard survey area was higher in other years. A second possibility is that older Pacific cod migrate to nearshore areas to feed in the summer, making them unavailable to the survey."* The JTS recommended postponing this examination until 2017, when another survey of the northern Bering Sea is scheduled.

SSC6 (12/15 minutes): *"The SSC noted that the iteratively tuned, time-varying parameters in the model have not been updated since 2009. The author confirmed that the currently assumed standard deviations of two dev vectors (log of age-0 recruitment and a parameter corresponding to the ascending part of the selectivity curve) may no longer match the standard deviations of these vectors, which could contribute to retrospective bias. The SSC looks forward to a new paper on this issue that the author is preparing."* The paper is in revision following initial journal review.

SSC7 (12/15 minutes): *"While the model selection criteria proposed by the author are reasonable, we note that these criteria do not take into account the model fit itself. Model fit and retrospective performance should be more strongly considered in the selection of a final model for specifications."* Although selection of a final model is not addressed in this preliminary assessment, retrospective analyses are presented for all models.

SSC8 (12/15 minutes): *"Although the SSC has repeatedly stressed the need to incrementally evaluate model changes, the SSC did not intend this to imply an automatic preference for the status quo model (as implied by the authors criterion #1) if alternatives with better performance are available."* This comment will be addressed in the final assessment.

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

- *Model 1: BS Model 11.5, the final model from 2015 (same as the final models from 2011-2014)*
- *Model 2: Like BS Model 15.6, 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.*
    - *Force trawl survey selectivity to be asymptotic.*
    - *Do not allow strange selectivity patterns.*

    - *Use empirical weight at age.*
- *Model 3: Like BS Model 15.6, but including the IPHC longline survey data and other features, specifically:*
    - *Do not allow strange selectivity patterns.*
    - *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 and two features not included in either Model 3 or 4, specifically:*
    - *Start including fishery agecomp data.*
    - *Use empirical weight at age.*
- *Model 6: Like Model 5 above, but including two features not included in Model 5, specifically:*
    - *Use either Francis or harmonic mean weighting.*
    - *Explore age-specific M (e.g., using Lorenzen function)."*

All of the requested models are included in this preliminary assessment (see also comment SSC9). 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. For Model 6, harmonic mean weighting (Punt in press) and the age-specific natural mortality function proposed by Lorenzen (1996, 2011) were used. 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:	11.5	16.1	16.2	16.3	16.4	16.5

JTS2 (5/16 minutes): *"For the EBS, the JTS recommended that the following non-model analysis be conducted for this year's preliminary assessment:*

- *Non-model analysis 1: Verify that the trawl survey data sometimes include age 0 fish."*

Although very rare (5 records in 1984 and 1 record in 2002), the trawl survey data do sometimes include age 0 fish, as confirmed this summer by AFSC RACE and Age and Growth personnel (pers. commun., Dan Nichol (RACE) and Delsa Anderl (Age and Growth)).

SSC9 (6/16 minutes): *"The SSC accepts the JTS recommendations for models to bring forward in the 2016 assessment…."* See comment JTS1.

SSC10 (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 2.1.8.

SSC11 (6/16 minutes): *"The SSC encourages the use of empirical weight-at-age data in some of the model variants, but notes that this requires precise aging data."* Empirical weight-at-age data are used in

Models 16.1, 16.4, and 16.5. Some issues involved in generating these data are discussed in the "Data" section..

SSC12 (6/16 minutes): "*The SSC encourages the author to conduct a retrospective analysis across historically used models in addition to the standard retrospective analysis using the current model.*" The requested analysis is not included in this preliminary assessment. It may be noted that there have been no changes in the accepted model since 2011. Barring any changes in this request, the analysis will be included in the final assessment.

SSC13 (6/16 minutes): "*The SSC encourages further work (outside the model) to examine potential causes for the apparent dome-shaped selectivity in most models. Research on these older 'missing' fish could include analysis of existing northern Bering Sea survey data, as noted in last December's minutes, and an analysis of slope survey data to examine if older fish descend to deeper waters as suggested in public testimony.*" See comment SSC5.

Data

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

- the addition of "empirical" weight-at-age data in Models 16.1, 16.4, and 16.5;
- the addition of IPHC survey data (abundance index and size composition) in Models 16.2, 16.4, and 16.5; and
- the addition of NMFS longline survey data (abundance index and size composition) in Models 16.3, 16.4, and 16.5.

The following table summarizes the sources, types, and years of data included in the data file for one or more of the stock assessment models (italics denote data *not* included in last year's assessment):

Source	Type	Years
Fishery	Catch biomass	1977-2015
Fishery	Catch size composition	1977-2015
Fishery	Catch per unit effort	1991-2015
Fishery	*Empirical weight at age*	*2008-2011*
EBS shelf bottom trawl survey	Relative abundance	1982-2015
EBS shelf bottom trawl survey	Size composition	1982-2015
EBS shelf bottom trawl survey	Age composition	1994-2014
EBS shelf bottom trawl survey	Mean size at age	1994-2014
EBS shelf bottom trawl survey	*Empirical weight at age*	*1998-2014*
IPHC longline survey	*Relative abundance*	*1997-2014*
IPHC longline survey	*Size composition*	*2008-2009, 2011-2015*
NMFS longline survey	*Relative abundance*	*1997-2015 (odd years only)*
NMFS longline survey	*Size composition*	*1997-2015 (odd years only)*

Empirical weight-at-age estimates were computed using a two-stage bootstrap procedure (J. Ianelli, AFSC, pers. commun.) from the available age data, resulting in the values shown in Table 2.1.1. Four possible concerns might be noted with respect to these data:

1. No smoothing was applied to the estimates, even though they exhibit a fair amount of variability. For example, in the set of mid-year survey estimates, 18% of the cells differ from their respective age-specific time series average by 20% or more (not counting age 0); and in the set of fishery estimates, 34% of the cells differ from their respective age-specific time series average by 20% or more (not counting ages 0 or 1).
2. Age data exist for only 17 of the 34 years in the survey time series and only 4 of the 39 years in the fishery time series. Long-term averages were used for all years with no age data.
3. The fishery age data come primarily from the longline fishery, and may not be representative of the overall fishery.
4. Because the trawl survey takes place in summer, beginning-of-year population weights at age were calculated by averaging mid-year weight(age,year) and mid-year weight(age−1,year−1), implying that weight at age changes linearly within each one-year interval.

Relative abundance data from the IPHC and NMFS longline surveys are shown in Table 2.1.2, and size composition data from those two surveys are shown in Table 2.1.3.

Because the models presented in this preliminary assessment include various methods for tuning the input sample sizes for size and age composition data (see next section), a review of the current methods for specifying these input sample sizes is presented here: For the 2007 assessment, the harmonic means from a bootstrap analysis of the available fishery length data from 1990-2006 were computed. The harmonic means were smaller than the actual sample sizes, but still ranged well into the thousands. Analysis of the harmonic means revealed that, except when the actual sample size was very small (less than about 400), they tended to be very nearly proportional to the actual sample sizes, with the coefficient of proportionality dependent on whether the data were collected prior to 1999. For the years prior to 1999 the ratio was consistently very close to 0.16, and for the years after 1998 the ratio was consistently very close to 0.34. Thus, ever since the 2007 assessment (with some minor modifications through the years), input sample sizes have been set according to the following three-step process. First, records with actual sample sizes less than 400 are omitted. Second, sample sizes for fishery length compositions from years prior to 1999 are tentatively set at 16% of the actual sample sizes, and sample sizes for fishery length compositions since 1999 and sample sizes for all survey length compositions are tentatively set at 34% of the actual sample sizes. Third, all sample sizes are adjusted proportionally so that the average is 300. 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 11.5 has been the accepted model since 2011. The other five models (Models 16.1-16.5) are all variants of Model 15.6, which was introduced in last year's preliminary assessment (where it was labeled "Model 6"). Details of Models 11.5 and 15.6 are described in their respective subsections below. 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 Eastern Bering Sea 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).

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, the default λ value of 1.0 for all data components was sufficient to satisfy this criterion, so no adjustments to any of the λ values were necessary.
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):

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

    and

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

where

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

$Pobs_{a,y}$ 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, and finally by switching to a logistic function. The logistic function (for both the fishery and the survey) gave a reasonable fit to the fishery size composition data, the survey size composition data, and the survey age composition data, so it was retained as the final functional form.

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:

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

   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 15.6 in last year's assessment until the threshold value of 0.05 was satisfied.

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 annual catchability deviations (trawl survey only) in Models 16.2-16.5 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, trawl survey catchability in Model 11.5) were likewise described in last year's final assessment (Thompson 2015), and were not re-estimated for this preliminary assessment.

Model 11.5: main features

Some of the main features characterizing Model 11.5 are as follow:

1. Age- and time-invariant natural mortality, estimated outside the model
2. Parameters governing time-invariant mean length at age estimated internally
3. Parameters governing width of length-at-age distribution (for a given mean) estimated internally
4. Ageing bias parameters estimated internally
5. Gear-and-season-specific catch and selectivity for the fisheries
6. Double normal selectivity for the fisheries and survey, with parameterization as follows:
   P1. *beginning_of_peak_region* (where the curve first reaches a value of 1.0)
   P2. *width_of_peak_region* (where the curve first departs from a value of 1.0)
   P3. *ascending_width* (equal to twice the variance of the underlying normal distribution)
   P4. *descending_width* (equal to twice the variance of the underlying normal distribution)
   P5. *initial_selectivity* (at minimum length/age)
   P6. *final_selectivity* (at maximum length/age)
   All parameters except *beginning_of_peak_region* are transformed: The *ascending_width* and *descending_width* are log-transformed and the other three parameters are logit-transformed.
7. Length-based selectivity for the fisheries
8. Age-based selectivity for the survey
9. Fishery selectivity estimated for "blocks" of years

10. Survey selectivity constant over time, except with annual *dev*s for the *ascending_width* parameter
11. Survey size composition data used in all years, including those years with age composition data (at the request of Plan Team members, inclusion of survey size composition data in all years was instituted in the 2011 assessment and has been retained ever since, based on the view that the costs of double-counting are outweighed by the benefits of including this information for estimation of growth parameters)
12. Fishery CPUE data included but not used for estimation
13. Mean size at age included but not used for estimation

Model 11.5: iterative tuning

Iterative tuning of time-varying parameters

The standard deviations of the two *dev* vectors in Model 11.5 (the log of age 0 recruitment and the survey *ascending_width* parameter, both additive) were estimated iteratively during the 2009 assessment by tuning the specified σ term for each vector to the standard deviation of the elements in that vector. Although this method is more justifiable than simply guessing at the value of σ, it is known to be biased low, and in the worst case may return a value of zero even when the true value is substantially greater than zero (Maunder and Deriso 2003, Thompson in prep.).

Per request of the BSAI Plan Team, the values of these σ terms (0.57 and 0.07, respectively) have been held constant in Model 11.5 and its predecessors ever since the 2009 assessment.

Iterative tuning of survey catchability

Survey catchability was estimated iteratively during the 2009 assessment by tuning *Q* so that the average of the product of *Q* and survey selectivity across the 60-81 cm size range matched the point estimate of 0.47 given by Nichol et al. (2007).

Per request of the BSAI Plan Team, this value of *Q* (0.77) has been held constant in Model 11.5 and its predecessors ever since the 2009 assessment.

Model 15.6: main features

Note that Model 15.6 was not among the models requested by the JTS and SSC for this preliminary assessment. However, it provides the starting point for Models 16.1-16.5, so it is appropriate to review its features.

Except for procedures related to iterative tuning (see next section), the main differences between Model 15.6 and Model 11.5 were as follow:

1. Each year consisted of a single season instead of five.
2. A single fishery was defined instead of nine season-and-gear-specific fisheries.
3. Composition data were given a weight of unity if the harmonic mean of the effective sample size was greater than the mean input sample size of 300; otherwise, composition data were weighted by tuning the mean input sample size to the harmonic mean of the effective sample size.
4. The survey was assumed to sample age 1 fish at true age 1.5 instead of 1.41667.
5. Initial abundances were estimated for the first 20 age groups instead of the first three.
6. The natural mortality rate was estimated internally.
7. The SS feature known as "Fballpark" was turned off (this feature, which functions something like a very weak prior distribution on the fishing mortality rate in some specified year, did not appear

to be providing any benefit in terms of model performance, and what little impact it had on resulting estimates was not easily justified).

8. The base value of survey catchability was estimated internally.
9. Survey catchability was allowed to vary annually.
10. Selectivity for both the fishery and the survey were allowed to vary annually.
11. 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.
12. Selectivity at ages 9+ was constrained to equal selectivity at age 8 for both the fishery and the survey.

Model 15.6: iterative tuning

Note that the iterative tuning described in this section pertains to the development of Model 15.6 in last year's preliminary assessment. The values resulting from last year's tuning were, with a very few exceptions, retained for Models 16.1-16.5.

All iterative tuning procedures described below were undertaken simultaneously.

Iterative tuning of prior distributions for selectivity parameters

Initially, the model was run with recruitment as the only time-varying quantity, with the standard deviation of log-scale recruitment estimated internally (i.e., as a free parameter), and with large standard deviations in the prior distributions for all selectivity parameters.

Once the initial model converged, 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 catchability

Although conceptually similar to a *dev* vector, SS treats each annual deviation in ln(Q) as a true parameter, with its own prior distribution. Because SS works in terms of $\ln(Q)$ rather than Q, normal prior distributions were assumed for all annual deviations. To be parsimonious, a single σ was assumed for all such prior distributions.

Unlike the size composition or age composition data sets, the time series of survey abundance data includes not only a series of expected values, but a corresponding series of standard errors as well. This fact formed the basis for the iterative tuning of the σ term for time-varying Q in Model 15.6. The procedure involved iteratively adjusting σ until the root-mean-squared-standardized-residual for survey abundance equaled unity.

Iterative tuning of time-varying parameters other than catchability

The following algorithm was used in Model 15.6 (Thompson in prep.; note that this is a multivariate generalization of one of the methods mentioned by Methot and Taylor (2011, *viz*., the third method listed on p. 1749)):

1. Set initial guesses for the σs.
2. Run SS.
3. Compute the covariance matrix (**V1**) of the set of *dev* vectors (e.g., element {*i*,*j*} is equal to the covariance between the subsets of the *i*th *dev* vector and the *j*th *dev* vector consisting of years that those two vectors have in common).
4. Compute the covariance matrix of the parameters (the negative inverse of the Hessian matrix).
5. Extract the part of the covariance matrix of the parameters corresponding to the *dev* vectors, using only those years common to all *dev* vectors.
6. Average the values in the matrix obtained in step 5 across years to obtain an "average" covariance matrix (**V2**).
7. Compute the vector of σs corresponding to **V1**+**V2**.
8. Return to step 2 and repeat until the σs converge.

To speed the above algorithm, the σs obtained in step 7 were sometimes substituted with values obtained by extrapolation or interpolation based on previous runs.

Unfortunately, given the way that selectivity pattern #17 is implemented in SS, large gradients can result, particularly if sufficiently large *dev*s occur at or adjacent to the age of peak selectivity. In the event that a large gradient appeared to be unavoidable during the tuning process, selectivity *dev* vectors were eliminated, one at a time (usually starting at the oldest ages and working downward), until the large gradients disappeared.

Results

Overview

The following table summarizes the status of the stock as estimated by the six models ("Value" is the point estimate, "SD" is the standard deviation of the point estimate, "CV" is the ratio of SD to the point estimate, "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 11.5			Model 16.1			Model 16.2		
Quantity	Value	SD	CV	Value	SD	CV	Value	SD	CV
FSB 2016	457,341	30,739	0.07	414,941	40,176	0.10	399,149	67,976	0.17
Bratio 2016	0.61	0.03	0.06	0.57	0.06	0.10	0.46	0.07	0.15

	Model 16.3			Model 16.4			Model 16.5		
Quantity	Value	SD	CV	Value	SD	CV	Value	SD	CV
FSB 2016	196,753	25,016	0.13	154,877	15,482	0.10	133,142	12,167	0.09
Bratio 2016	0.21	0.03	0.14	0.14	0.02	0.12	0.09	0.01	0.11

The six models span wide ranges for these quantities. Estimates of FSB 2016 range from 133,000 t (Model 16.5) to 457,000 t (Model 11.5), and estimates of Bratio 2016 range from 0.09 (Model 16.5) to 0.61 (Model Model 11.5). The quantities FSB 2016 and Bratio 2016 tend to covary directly in these models.

Goodness of fit

Objective function values and parameter counts are shown for each model in Table 2.1.4a, and multipliers used to adjust multinomial sample sizes are shown in Table 2.1.4b. 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, 16.4, and 16.5 to the IPHC longline survey abundance data; and Figure 2.1.1c shows the fits of Models 16.3, 16.4, and 16.5 to the NMFS longline survey abundance data.

Table 2.1.5 shows goodness of fit for the survey abundance data. 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, Models 16.2-16.5 all give root mean squared errors close to σave. Models 16.1-16.5 all give mean normalized residuals close to zero, standard deviation of normalized residuals close to unity, and correlations greater close to 0.90 or better. The three models that use the IPHC longline survey data all give mean normalized residuals close to zero and 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 0.42-0.46 range). However, as with previous attempts to use the IPHC longline survey data, all three of these models give negative correlations. The three models that use the NMFS longline survey data all fit those data fairly well, although the mean normalized residuals from all three of these models is substantially negative, ranging from -0.14 to -0.22 (note that, although these models were all given the opportunity to inflate the input σ values by an internally estimated amount, Model 16.3 estimated this additional amount at a very small value (0.01), and the estimates from Models 16.4 and 16.5 tended to become pinned at the lower bound of zero, so estimation of this additional σ was ultimately turned off in the latter two models).

Sample size ratios for the size composition data are shown in Table 2.1.6 (note that input sample sizes are the same for all models except 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.
- 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 in most cases. Exceptions consist of the Aug-Dec longline fishery in Model 11.5, and all components in Model 16.5, which was tuned explicitly so as to set these ratios equal to unity.

Sample size ratios for the survey age composition data are shown in Table 2.1.7a (all models) and for the fishery age composition data in Table 2.1.7b (Models 16.4 and 16.5 only). Note that input sample sizes for the survey data differ for several models: For Models 11.5 and 16.1, input sample sizes were scaled to the conventional mean of 300; for Models 16.2-16.4, input sample sizes were left at the values tuned in *last year's assessment* for Model 15.6 so that H(Neff)/A(Ninp)=; and for Model 16.5, arithmetic mean input sample sizes were tuned *in this year's assessment* so that H(Neff)/A(Ninp)=1. The input sample sizes for the fishery data also differ between the two models that use those data: For Model 16.4, mean input sample sizes were assumed equal to mean input sample size for the survey agecomp data; while for

Model 16.5, input sample sizes were tuned *in this year's assessment* so that H(Neff)/A(Ninp)=1. The results can be summarized as follows:

- Measured as the ratio of the arithmetic means, Models 16.2-16.5 give values greater than unity for the survey age composition data (Models 11.5 and 16.1 do not), and Model 16.5 is the only one of the two models using fishery age composition data to achieve a value greater than unity.
- Measured as the ratio of the *harmonic* mean effective sample size to the arithmetic mean input sample size, Model 16.5 gives values essentially equal to unity for both the survey and fishery age composition data (as this was the tuning criterion for that model), while the other models all give values much less than unity. Note that Punt (in press) concluded that the harmonic mean was a much more appropriate numerator than the arithmetic mean.

Figure 2.1.2 shows the fits to the survey age composition data (all models), and Figure 2.1.3 shows the fits to the fishery age composition data (Models 16.4 and 16.5 only).

Parameter estimates, time series, and retrospective analysis

Table 2.1.8 lists key parameters estimated internally in at least one of the models, along with their standard deviations.

In Model 16.5, the natural mortality rate M varies as a function of age, following the approach described by Lorenzen (1996, 2011). The entry for this model in Table 2.1.8 corresponds to the value at the age at 50% maturity (rounded to the nearest integer, 5). The full schedule of M values for Model 16.5 is shown below:

Age:	0	1	2	3	4	5	6	7	8	9	10
M:	1.022	0.548	0.337	0.259	0.218	0.194	0.178	0.167	0.159	0.153	0.149

Age:		11	12	13	14	15	16	17	18	19	20
M:		0.146	0.143	0.141	0.140	0.139	0.138	0.137	0.136	0.136	0.135

The estimates of log catchability for the trawl survey shown in Table 2.1.8 map into the following estimates of catchability on the natural scale, spanning the range 0.643 (Model 16.1) to 1.590 (Model 16.5):

Model 11.5		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	Est.	SD
0.770	n/a	0.643	0.063	1.050	0.108	1.581	0.075	1.343	0.065	1.590	0.046

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. All models estimate strongly domed trawl survey selectivity schedules, which is difficult to reconcile with the results of field experiments summarized by Weinberg et al. (2016).

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. Mohn's ρ (revised) values for the models are shown below:

Model 11.5	Model 16.1	Model 16.2	Model 16.3	Model 16.4	Model 16.5
0.475	0.108	0.122	-0.069	0.047	0.130

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Tables

Table 2.1.1a—Empirical weight at age for the population (kg). Weights in years with no data were assumed equal to the time series average.

Mid-year population (assumed to be represented by the survey)

Year	0	1	2	3	4	5	6	7	8	9	10	11	12+
1998	0.00998	0.03031	0.28786	0.57498	1.34596	2.41074	3.63180	4.21474	6.07145	9.48271	9.63297	10.35847	10.34591
1999	0.00899	0.02975	0.23180	0.64063	1.00586	1.94912	3.19931	4.24325	5.92678	6.62555	10.28628	9.30312	11.01461
2000	0.00923	0.02719	0.26119	0.55903	1.15590	1.75550	2.38551	4.65000	4.96850	7.55933	7.04082	6.69292	11.11449
2001	0.01002	0.04835	0.29901	0.50036	1.20808	1.89331	2.69627	3.39956	5.52989	7.36904	5.72057	8.71575	10.28275
2002	0.00980	0.03695	0.25876	0.49530	1.08671	1.88860	2.87333	3.85336	4.53517	6.51294	10.38147	10.12309	11.28232
2003	0.00999	0.05025	0.26101	0.74333	1.27478	2.11556	3.38217	4.36719	5.33931	7.32482	7.66614	7.54419	6.11988
2004	0.01015	0.04374	0.26757	0.56628	1.30774	2.12083	3.23492	4.16120	5.16134	7.67440	8.71412	8.39726	11.14933
2005	0.00973	0.05328	0.17234	0.60838	1.23215	2.05120	3.08502	4.52856	5.96756	6.86777	9.20336	8.45074	10.31994
2006	0.00968	0.02849	0.27966	0.58066	1.14618	1.91756	3.11939	4.68658	6.79608	8.00201	8.82361	10.45918	11.62473
2007	0.00973	0.02702	0.28484	0.72057	1.44073	2.41451	3.53216	5.01613	6.90555	7.39105	10.65904	9.62044	9.89080
2008	0.00985	0.02844	0.24745	0.71837	1.68031	2.59784	3.36087	4.60989	6.17281	6.84603	8.54395	10.83814	9.66511
2009	0.00949	0.02148	0.27761	0.76664	1.45560	2.34835	3.25543	4.21250	5.32347	6.70273	8.77372	8.44027	9.28363
2010	0.00972	0.02982	0.26814	0.84713	1.69584	2.33270	3.32758	4.10257	6.34880	6.54702	9.02960	8.11057	11.81749
2011	0.00979	0.05044	0.35786	0.88458	1.70856	2.79529	3.63364	4.59066	5.51827	7.80137	7.22967	7.33689	11.18761
2012	0.00984	0.02155	0.31056	0.90135	1.62013	2.50125	3.58963	4.38997	6.08762	6.56512	9.62029	9.96183	10.90289
2013	0.00968	0.02978	0.22017	0.87182	1.38144	2.67502	3.34309	4.96482	5.40016	6.77607	8.93127	7.92271	10.71269
2014	0.01000	0.04617	0.31459	0.90396	1.48265	2.56694	3.47574	4.15903	5.91011	7.44386	8.21912	10.23339	8.25589
Ave:	0.00974	0.03651	0.27661	0.69849	1.36889	2.26085	3.25998	4.42322	5.85840	7.44757	8.91945	9.10880	10.28900

Beginning-of-year population (assumed to equal the average of w(age,year) and w(age-1,year-1) in the above)

Year	0	1	2	3	4	5	6	7	8	9	10	11	12+
1999	0	0.01986	0.13105	0.46425	0.79042	1.64754	2.80502	3.93752	5.07076	6.34850	9.88449	9.46805	10.68654
2000	0	0.01809	0.14547	0.39542	0.89826	1.38068	2.16731	3.92465	4.60587	6.74305	6.83318	8.48960	10.20881
2001	0	0.02879	0.16310	0.38077	0.88356	1.52460	2.22588	2.89254	5.08994	6.16877	6.63995	7.87829	8.48784
2002	0	0.02348	0.15356	0.39715	0.79353	1.54834	2.38332	3.27481	3.96737	6.02142	8.87525	7.92183	9.99904
2003	0	0.03003	0.14898	0.50104	0.88504	1.60113	2.63539	3.62026	4.59633	5.93000	7.08954	8.96283	8.12148
2004	0	0.02686	0.15891	0.41364	1.02554	1.69780	2.67524	3.77169	4.76426	6.50685	8.01947	8.03170	9.34676
2005	0	0.03172	0.10804	0.43797	0.89921	1.67947	2.60293	3.88174	5.06438	6.01455	8.43888	8.58243	9.35860
2006	0	0.01911	0.16647	0.37650	0.87728	1.57486	2.58529	3.88580	5.66232	6.98479	7.84569	9.83127	10.03773
2007	0	0.01835	0.15667	0.50011	1.01070	1.78035	2.72486	4.06776	5.79606	7.09357	9.33052	9.22202	10.17499
2008	0	0.01908	0.13723	0.50161	1.20044	2.01929	2.88769	4.07103	5.59447	6.87579	7.96750	10.74859	9.64277
2009	0	0.01566	0.15302	0.50704	1.08699	2.01433	2.92663	3.78669	4.96668	6.43777	7.80988	8.49211	10.06088
2010	0	0.01966	0.14481	0.56237	1.23124	1.89415	2.83796	3.67900	5.28065	5.93525	7.86616	8.44215	10.12888
2011	0	0.03008	0.19384	0.57636	1.27785	2.24557	2.98317	3.95912	4.81042	7.07509	6.88835	8.18324	9.64909
2012	0	0.01567	0.18050	0.62961	1.25236	2.10491	3.19246	4.01181	5.33914	6.04170	8.71083	8.59575	9.11989
2013	0	0.01981	0.12086	0.59119	1.14140	2.14758	2.92217	4.27722	4.89507	6.43185	7.74820	8.77150	10.33726
2014	0	0.02793	0.17219	0.56206	1.17724	1.97419	3.07538	3.75106	5.43746	6.42201	7.49760	9.58233	8.08930
Ave:	0	0.02276	0.15217	0.48732	1.02694	1.80217	2.72692	3.79954	5.05883	6.43943	7.96534	8.82523	9.59062

Table 2.1.1b—Empirical weight at age for the fishery (kg). Weights at age in years with no data were assumed equal to the time series average.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12+
2008	0	0	0.00066	1.42044	2.00646	2.93810	3.78537	5.02224	6.66598	7.14621	8.50707	10.00366	5.22370
2009	0	0	0.52358	1.48214	2.13895	3.09177	3.98118	5.25889	5.53492	8.92676	8.71459	7.87592	7.99262
2010	0	0	0.78678	1.63473	2.33971	3.04616	3.96101	5.37651	5.92141	5.51816	11.94570	3.82506	4.14191
2011	0	0	0.00066	1.27767	2.21042	3.24410	4.25569	5.63710	7.52856	6.17703	3.01784	4.44490	3.53656
Ave:	0	0	0.65518	1.45374	2.17388	3.08003	3.99581	5.32368	6.41272	6.94204	8.04630	6.53738	5.22370

Table 2.1.2—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	61,309	0.062
1998	85,429	0.115
1999	12,907	0.294
2000	72,237	0.097
2001	85,096	0.093
2002	101,998	0.107
2003	111,880	0.079
2004	116,604	0.097
2005	67,446	0.092
2006	109,217	0.083
2007	107,141	0.083
2008	114,508	0.077
2009	104,931	0.092
2010	76,881	0.112
2011	75,284	0.094
2012	78,135	0.083
2013	84,194	0.078
2014	87,472	0.062

NMFS longline survey		
Year	RPN	σ
1997	174,388	0.108
1999	122,984	0.106
2001	142,531	0.132
2003	173,070	0.115
2005	89,561	0.216
2007	102,653	0.146
2009	82,798	0.231
2011	120,673	0.188
2013	154,310	0.244
2015	125,796	0.206

Table 2.1.3a—Size (cm) composition data from the IPHC longline survey. No fish were observed at lengths smaller than 21 cm.

Len	2008	2009	2011	2012	2013	2014	2015	Len	2008	2009	2011	2012	2013	2014	2015
21	0	0	0	0	0	0	0	71	141	180	149	162	338	241	343
22	0	0	0	0	0	0	0	72	165	158	154	163	323	235	287
23	0	0	0	0	0	0	0	73	170	145	168	164	294	223	271
24	0	0	0	1	0	0	0	74	145	139	125	131	235	225	251
25	0	0	0	0	0	0	0	75	125	135	123	141	207	238	203
26	0	0	0	0	0	0	0	76	103	109	93	125	156	177	177
27	0	0	0	0	0	0	0	77	114	142	82	118	173	187	149
28	0	0	0	0	0	0	0	78	107	114	59	105	130	185	144
29	0	0	0	0	0	0	0	79	101	103	45	86	100	138	127
30	0	0	0	0	1	0	0	80	99	92	51	69	97	135	120
31	0	0	0	0	0	0	0	81	75	75	50	69	76	100	112
32	0	0	0	0	0	0	0	82	94	97	48	59	86	106	98
33	0	0	0	0	0	0	0	83	106	77	47	50	63	77	93
34	0	0	0	0	0	0	0	84	93	83	42	46	51	56	75
35	0	0	0	0	0	1	0	85	75	84	35	52	57	60	76
36	0	0	0	0	0	0	0	86	91	69	39	34	50	51	73
37	0	0	0	0	0	0	0	87	101	76	39	34	37	40	62
38	0	0	0	0	0	0	0	88	96	78	33	31	39	34	51
39	0	0	0	0	0	0	0	89	75	71	17	46	25	20	55
40	0	0	0	0	0	0	0	90	97	61	29	45	28	30	48
41	0	1	1	0	0	0	0	91	93	66	29	28	26	21	34
42	1	0	0	0	0	1	0	92	91	57	28	22	28	17	28
43	0	4	1	0	2	1	0	93	87	68	17	33	31	20	25
44	1	4	3	2	3	0	1	94	81	58	14	29	13	20	12
45	1	4	4	2	1	2	3	95	74	73	16	27	16	19	18
46	3	17	2	2	0	2	2	96	55	54	18	15	12	11	12
47	4	18	8	4	4	4	7	97	74	68	21	13	14	9	12
48	4	28	4	6	5	14	9	98	64	39	24	14	11	13	10
49	7	23	11	8	13	7	23	99	51	60	14	17	12	7	11
50	6	40	17	9	10	19	25	100	44	40	20	15	5	2	14
51	12	47	15	21	16	20	42	101	39	45	8	8	9	6	7
52	15	48	25	44	36	30	34	102	23	43	9	16	4	4	9
53	16	63	20	61	33	27	60	103	15	38	8	15	7	3	4
54	22	49	17	85	35	43	97	104	18	18	6	6	3	2	3
55	42	58	37	101	55	65	91	105	17	23	11	5	5	2	2
56	31	69	47	101	61	64	125	106	7	10	6	1	4	0	2
57	67	90	47	109	105	94	179	107	7	16	4	6	1	1	2
58	69	104	76	139	128	116	210	108	3	11	3	2	2	0	0
59	75	137	85	127	154	143	246	109	2	5	7	1	0	0	0
60	101	126	111	125	204	189	260	110	0	1	3	0	0	0	0
61	113	176	146	164	238	222	293	111	2	3	1	0	1	1	0
62	156	173	154	120	277	275	307	112	3	2	1	0	0	1	0
63	161	195	164	174	345	250	289	113	0	1	0	0	0	0	0
64	142	186	167	166	343	260	278	114	0	0	0	1	0	0	0
65	160	204	184	204	389	288	270	115	0	0	1	0	0	0	0
66	154	187	220	155	439	240	281	116	0	0	0	0	0	0	0
67	154	194	235	189	415	232	293	117	0	0	0	0	0	0	0
68	179	203	193	168	441	246	264	118	0	0	0	0	0	0	0
69	188	206	210	171	389	229	271	119	0	0	0	0	0	0	0
70	186	183	201	182	400	242	252	120	0	0	0	0	0	0	0

Table 2.1.3b—Size (cm) composition data from the NMFS longline survey (page 1 of 2). No fish were observed at lengths smaller than 21 cm.

Len	1997	1999	2001	2003	2005	2007	2009	2011	2013	2015
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	1	0	0
31	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	1	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0
37	0	1	0	1	0	0	1	2	0	0
38	0	0	0	0	0	0	4	2	1	0
39	0	1	4	1	0	2	3	1	1	0
40	0	3	2	0	3	2	9	6	0	0
41	0	7	4	13	5	5	14	17	2	1
42	6	6	5	15	2	9	26	32	2	2
43	1	40	12	24	9	29	44	66	1	1
44	6	39	12	40	15	49	88	130	8	4
45	4	80	21	74	15	70	112	184	6	15
46	10	126	30	93	22	95	184	199	20	25
47	21	191	46	137	16	118	217	225	30	45
48	28	196	57	179	48	143	215	189	71	75
49	48	238	90	258	37	178	259	207	89	107
50	70	260	83	273	79	150	282	213	102	153
51	89	250	104	367	101	202	270	196	141	183
52	113	275	157	388	117	191	240	178	161	228
53	164	268	199	413	158	197	215	177	163	297
54	160	251	210	460	152	154	244	183	168	355
55	227	316	263	447	175	161	212	217	151	431
56	216	356	315	470	163	192	204	242	143	522
57	232	346	335	437	201	176	215	288	151	538
58	244	303	354	398	215	226	219	330	178	604
59	270	322	384	434	229	216	246	348	195	530
60	274	362	412	464	247	243	254	406	238	520
61	338	417	440	473	248	254	278	445	305	404
62	385	401	480	501	273	244	296	442	388	428
63	410	457	482	484	274	301	277	412	475	386
64	423	428	488	479	317	265	270	386	477	384
65	546	498	517	427	297	262	260	384	535	345
66	479	439	496	350	316	236	225	358	513	321
67	561	404	577	325	306	243	187	317	529	283
68	602	367	558	276	263	188	167	269	533	258
69	581	338	489	209	273	204	174	223	483	250
70	481	296	447	187	272	194	127	167	385	271

Table 2.1.3b—Size (cm) composition data from the NMFS longline survey (page 2 of 2).

Len	1997	1999	2001	2003	2005	2007	2009	2011	2013	2015
71	490	255	376	151	225	136	130	162	313	232
72	395	214	380	113	197	156	113	125	267	189
73	389	197	280	97	171	143	116	99	182	164
74	276	160	245	95	181	136	112	52	164	152
75	236	167	180	66	144	99	93	52	109	121
76	164	115	142	52	102	77	78	39	72	102
77	144	87	111	48	128	95	64	26	45	63
78	101	78	123	37	67	83	50	18	35	75
79	70	54	80	36	74	76	49	11	38	57
80	66	46	59	30	68	62	46	12	28	51
81	55	36	52	30	55	57	27	11	20	47
82	32	28	37	31	44	58	25	9	8	44
83	28	19	30	18	30	66	31	7	12	25
84	29	20	25	8	37	41	23	9	5	23
85	24	15	28	10	18	42	18	4	13	25
86	17	13	18	9	21	46	10	4	5	20
87	23	4	8	10	15	39	7	5	6	18
88	16	16	6	8	13	43	7	8	3	10
89	16	8	15	5	15	43	9	7	4	16
90	18	13	10	4	13	31	7	2	4	8
91	12	3	5	6	9	30	7	6	0	7
92	7	5	2	4	6	22	10	5	4	9
93	8	3	3	2	7	26	9	1	2	4
94	9	3	3	3	5	23	7	2	4	7
95	13	1	0	2	4	25	3	4	2	5
96	11	2	6	2	1	20	4	5	2	0
97	6	2	4	1	1	17	7	1	2	1
98	3	1	1	2	1	16	6	1	1	1
99	6	0	1	1	1	15	7	2	0	3
100	3	2	4	2	0	12	2	1	1	2
101	3	2	1	1	1	6	5	0	1	2
102	3	1	2	1	0	4	1	1	0	2
103	1	2	1	1	2	5	1	1	1	2
104	3	3	1	0	0	3	7	0	0	0
105	1	0	0	0	1	4	3	2	2	0
106	1	2	0	1	1	2	0	1	2	0
107	0	0	0	0	0	2	1	0	1	0
108	1	0	0	0	0	1	0	0	0	0
109	1	1	0	0	0	0	2	0	0	0
110	1	0	0	0	0	2	0	0	0	0
111	0	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	0	0	0	0
113	0	0	1	0	0	0	0	0	0	0
114	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0
116	0	0	0	0	0	0	0	0	0	0
117	0	0	0	0	0	0	0	0	0	0
118	0	0	0	0	0	0	0	0	0	0
119	0	0	0	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0	0	0	0

Table 2.1.4a—Objective function values and parameter counts. Note that fishery CPUE likelihoods are calculated, but not used, in Model 11.5.

	Aggregated data components					
Obj. function component	M11.5	M16.1	M16.2	M16.3	M16.4	M16.5
Catch	0.00	0.00	0.00	0.00	0.00	0.00
Equilibrium catch	0.01	0.00	0.00	0.00	0.01	0.03
Survey abundance index	-6.87	-20.68	-65.07	-68.95	-72.68	-63.49
Size composition	5235.34	1332.77	1203.53	1359.81	1595.14	2144.84
Age composition	145.88	230.60	87.74	67.26	111.19	72.49
Recruitment	22.19	4.55	-4.05	-0.40	5.28	44.64
Priors	0.00	0.00	158.73	304.00	480.69	784.12
"Softbounds"	0.03	0.01	0.00	0.00	0.00	0.00
Deviations	20.31	0.00	96.61	55.82	59.85	118.88
"F ballpark"	0.00	n/a	n/a	n/a	n/a	n/a
Total	5416.88	1547.24	1477.49	1717.55	2179.47	3101.51

	Abundance index, broken down by fleet					
Fleet	M11.5	M16.1	M16.2	M16.3	M16.4	M16.5
Fishery						
Shelf trawl survey	-6.87	-20.68	-60.23	-56.56	-53.86	-45.64
IPHC longline survey			-4.84		-13.44	-13.85
NMFS longline survey				-12.39	-5.39	-3.99
Total	-6.87	-20.68	-65.07	-68.95	-72.68	-63.49

	Size composition, broken down by fleet					
Fleet	M11.5	M16.1	M16.2	M16.3	M16.4	M16.5
Fishery	4306.84	361.13	199.16	184.48	233.94	390.63
Shelf trawl survey	928.51	971.64	869.23	835.76	857.90	988.61
IPHC longline survey			135.14		364.40	493.74
NMFS longline survey				339.58	138.90	271.86
Total	5235.34	1332.77	1203.53	1359.81	1595.14	2144.84

	Age composition, broken down by fleet					
Fleet	M11.5	M16.1	M16.2	M16.3	M16.4	M16.5
Fishery					37.97	13.58
Shelf trawl survey	145.88	230.60	87.74	67.26	73.22	58.91
IPHC longline survey						
NMFS longline survey						
Total	145.88	230.60	87.74	67.26	111.19	72.49

Parameter counts	M11.5	M16.1	M16.2	M16.3	M16.4	M16.5
Unconstrained parameters	115	18	15	15	16	16
Parameters with priors	0	0	55	55	62	62
Constrained deviations	73	58	286	286	286	286
Total	188	76	356	356	364	364

Table 2.1.4b—Multinomial sample size multipliers.

	Sizecomp multinomial sample size multipliers			
Model	Fishery	Trawl survey	IPHC longline survey	NMFS longline survey
11.5	1	1	n/a	n/a
16.1	1	1	n/a	n/a
16.2	1	1	1	n/a
16.3	1	1	n/a	1
16.4	1	1	1	1
16.5	2.01	1.07	1.52	3.65

	Agecomp multinomial sample size multipliers			
Model	Fishery	Trawl survey	IPHC longline survey	NMFS longline survey
11.5	n/a	1	n/a	n/a
16.1	n/a	1	n/a	n/a
16.2	n/a	0.492	n/a	n/a
16.3	n/a	0.492	n/a	n/a
16.4	0.492	0.492	n/a	n/a
16.5	0.12	0.30	n/a	n/a

Table 2.1.5—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.
11.5	Trawl	0.11	0.22	0.95	1.80	0.78
16.1	Trawl	0.11	0.19	0.07	1.82	0.78
16.2	Trawl	0.11	0.11	0.09	1.00	0.93
16.3	Trawl	0.11	0.13	0.10	1.10	0.91
16.4	Trawl	0.11	0.14	0.10	1.17	0.90
16.5	Trawl	0.11	0.15	0.07	1.36	0.88
16.2	IPHC LL	0.43	0.56	-0.05	1.07	-0.12
16.4	IPHC LL	0.42	0.55	-0.06	1.08	-0.14
16.5	IPHC LL	0.46	0.58	-0.05	1.07	-0.14
16.3	NMFS LL	0.18	0.19	-0.22	0.99	0.70
16.4	NMFS LL	0.17	0.16	-0.19	0.96	0.77
16.5	NMFS LL	0.17	0.15	-0.14	0.93	0.82

Table 2.1.6—Statistics related to effective sample sizes (Neff) for length composition data. Nrec = no. records, A(·) = arithmetic mean, H(·) = harmonic mean, Ninp = input sample size. Input sample sizes were adjusted for Model 16.5 (tuned so that H(Neff)/A(Ninp)=1.00).

				Ratios	
Model	Fleet	Nrec	A(Ninp)	A(Neff)/A(Ninp)	H(Neff)/A(Ninp)
11.5	Jan-Apr trawl fish.	68	314	2.92	1.53
11.5	May-Jul trawl fish.	35	62	7.26	3.32
11.5	Aug-Dec trawl fish.	38	44	6.00	3.24
11.5	Jan-Apr longline fish.	72	476	3.99	1.18
11.5	May-Jul longline fish.	35	252	5.16	3.00
11.5	Aug-Dec longline fish.	67	673	3.09	0.89
11.5	Jan-Apr pot fish.	40	129	9.71	3.37
11.5	May-Jul pot fish.	17	129	7.72	1.72
11.5	Aug-Dec pot fish.	40	84	7.25	2.75
16.1	Fishery	39	300	5.61	1.86
16.2	Fishery	39	300	10.31	2.35
16.3	Fishery	39	300	14.34	2.17
16.4	Fishery	39	300	11.25	1.91
16.5	Fishery	39	603	5.87	1.00
11.5	Trawl survey	34	286	1.66	1.03
16.1	Trawl survey	34	300	1.57	1.01
16.2	Trawl survey	34	300	1.88	1.15
16.3	Trawl survey	34	300	2.01	1.17
16.4	Trawl survey	34	300	1.97	1.14
16.5	Trawl survey	34	321	1.75	1.00
16.2	IPHC longline survey	7	300	2.41	2.03
16.4	IPHC longline survey	7	300	2.58	2.16
16.5	IPHC longline survey	7	1094	1.13	1.00
16.3	NMFS longline survey	10	300	1.93	1.31
16.4	NMFS longline survey	10	300	1.80	1.28
16.5	NMFS longline survey	10	456	1.31	1.00

Table 2.1.7a—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. For Models 16.2-16.4, arithmetic mean input sample sizes were left at the values tuned in *last year's assessment* for Model 15.6 so that H(Neff)/A(Ninp)=1 (tan shading). For Model 16.5, arithmetic mean input sample sizes were tuned *in this year's assessment* so that H(Neff)/A(Ninp)=1 (green shading).

Trawl survey age compositions

	Model 11.5		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	In. N	Eff. N
1994	201	437	201	209	99	211	99	210	99	155	60	186
1995	160	37	160	29	79	39	79	47	79	62	48	44
1996	200	342	200	69	98	156	98	240	98	198	60	103
1997	202	149	202	47	99	226	99	279	99	175	61	147
1998	178	1116	178	89	88	160	88	1913	88	1346	53	800
1999	241	125	241	59	119	79	119	111	119	76	72	83
2000	241	115	241	60	119	84	119	55	119	48	72	44
2001	258	99	258	37	127	73	127	85	127	79	77	89
2002	244	90	244	40	120	52	120	77	120	62	73	57
2003	354	266	354	797	174	1699	174	613	174	792	106	1212
2004	279	31	279	35	137	38	137	47	137	43	84	44
2005	359	395	359	184	177	388	177	379	177	360	108	319
2006	365	147	365	54	180	98	180	177	180	130	110	85
2007	404	61	404	11	199	34	199	477	199	270	121	107
2008	340	250	340	137	167	375	167	278	167	379	102	107
2009	396	94	396	168	195	214	195	303	195	500	119	210
2010	363	94	363	210	179	218	179	190	179	190	109	124
2011	352	151	352	121	173	99	173	92	173	120	106	46
2012	365	98	365	82	180	79	180	97	180	107	110	59
2013	398	122	398	141	196	107	196	116	196	95	119	85
2014	399	483	399	285	196	417	196	392	196	355	120	369
Mean	300	224	300	136	148	231	148	294	148	264	90	206
Harm.		109		58		95		128		119		90
Ratio1		0.75		0.45		1.56		1.99		1.79		2.29
Ratio2		0.36		0.19		0.64		0.87		0.81		1.00

Table 2.1.7b—Statistics related to effective sample size (Eff. N) for *fishery* 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. For Model 16.4, arithmetic mean input sample size for the fishery agecomp data was assumed equal to arithmetic mean input sample size for the survey agecomp data (purple shading). For Model 16.5, arithmetic mean input sample sizes were tuned *in this year's assessment* so that H(Neff)/A(Ninp)=1 (green shading).

Fishery age compositions

					Model 16.4		Model 16.5	
Year					In. N	Eff. N	In. N	Eff. N
2008					130	75	32	59
2009					127	44	31	25
2010					111	71	27	31
2011					222	79	54	41
Mean					148	67	36	39
Harm.						64		35
Ratio1						0.46		1.08
Ratio2						0.43		0.98

Table 2.1.8—Estimates ("Est.") of key parameters and their standard deviations ("SD"). A blank indicates that the parameter (row) was not used in that model (column). A "_" symbol under SD. indicates that the parameter (row) was fixed (not estimated) in that model (column).

	Model 11.5		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	Est.	SD
Natural mortality	0.340	_	0.373	0.012	0.300	0.020	0.230	0.015	0.216	0.013	0.194	0.010
Length at age 1 (cm)	14.244	0.104	16.323	0.086	16.397	0.087	16.392	0.087	16.420	0.088	16.465	0.086
Asymptotic length (cm)	92.513	0.493	98.211	1.848	97.879	1.343	95.326	1.335	98.524	1.242	98.169	0.847
Brody growth coefficient	0.240	0.002	0.199	0.012	0.214	0.010	0.229	0.011	0.209	0.009	0.222	0.007
Richards growth coefficient			1.058	0.049	0.985	0.044	0.961	0.043	1.031	0.039	0.986	0.032
SD of length at age 1 (cm)	3.537	0.066	3.375	0.057	3.489	0.057	3.508	0.057	3.566	0.058	3.619	0.055
SD of length at age 20 (cm)	9.776	0.152	9.863	0.279	7.688	0.228	7.293	0.211	6.959	0.200	6.651	0.147
Ageing bias at age 1 (years)	0.333	0.013	0.320	0.013	0.287	0.025	0.285	0.027	0.295	0.026	0.277	0.032
Ageing bias at age 20 (years)	0.354	0.148	0.340	0.159	0.703	0.254	0.753	0.264	0.281	0.235	0.910	0.306
ln(mean post-1976 recruitment)	13.196	0.019	13.580	0.104	12.949	0.167	12.328	0.107	12.458	0.093	13.563	0.145
Sigma_R	0.570	_	0.644	0.068	0.603	_	0.603	_	0.603	_	0.603	_
ln(pre-1977 recruitment offset)	-1.151	0.130	-1.071	0.228	-0.559	0.172	-0.616	0.137	-0.699	0.126	-0.718	0.096
Initial F (Jan-Apr trawl fishery)	0.657	0.140										
Initial F (fishery)			0.126	0.045	0.080	0.020	0.087	0.020	0.082	0.016	0.069	0.012
"Extra SD" for NMFS LL survey					0.335	0.079			0.000	_	0.000	_
"Extra SD" for IPHC LL survey							0.011	0.041	0.316	0.076	0.355	0.082
Base ln(Q) for trawl survey	-0.261	_	-0.441	0.063	0.049	0.108	0.458	0.074	0.295	0.065	0.464	0.046
Base ln(Q) for NMFS LL survey					-0.002	0.170			0.068	0.066	0.354	0.057
Base ln(Q) for IPHC LL survey							0.324	0.081	0.324	0.158	0.562	0.141

Figures

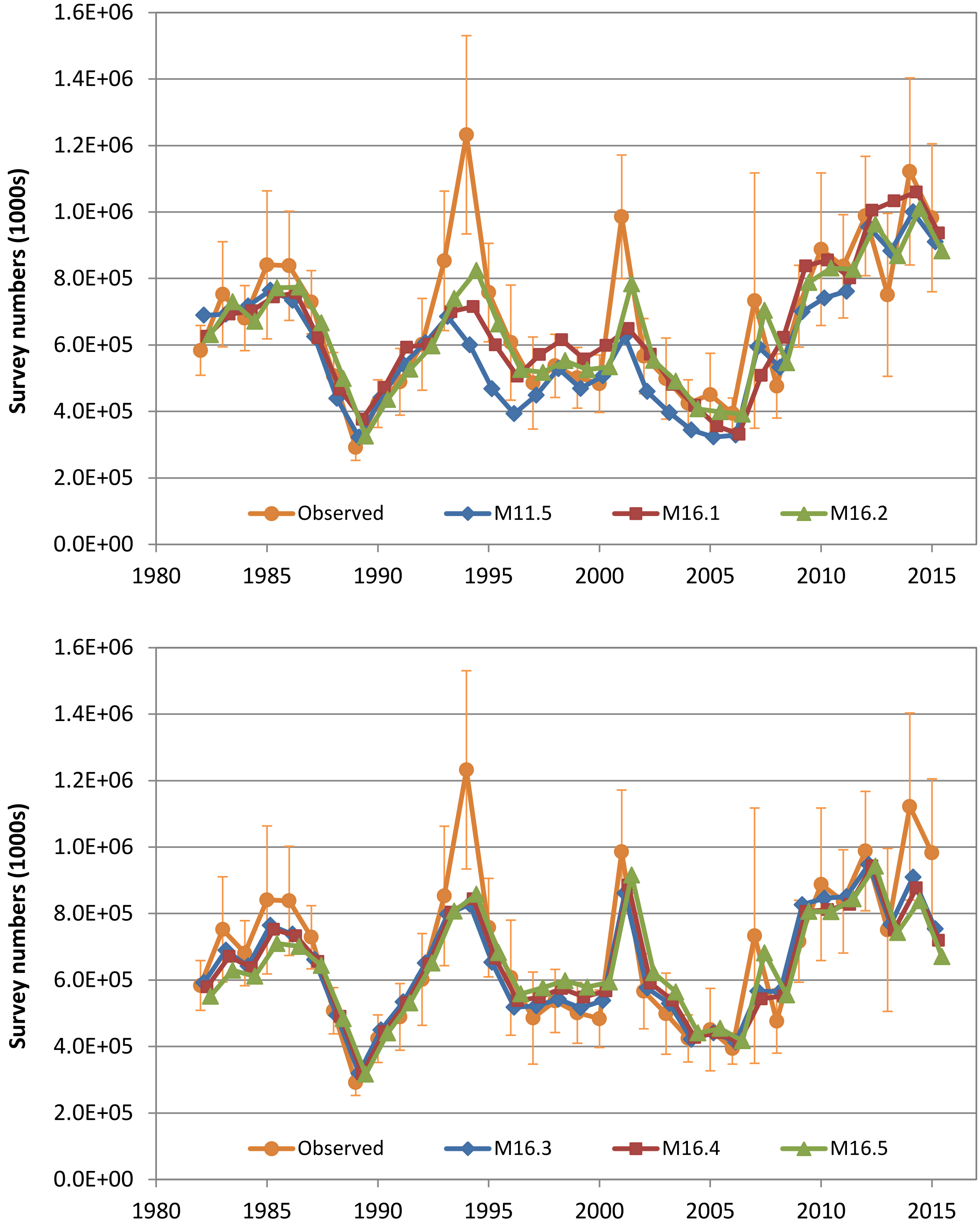


Figure 2.1.1a—Model fits to the trawl survey abundance time series. Upper panel: Models 11.5, 16.1, and 16.2. Lower panel: Models 16.3-16.5. Survey time series shows 95% confidence interval.

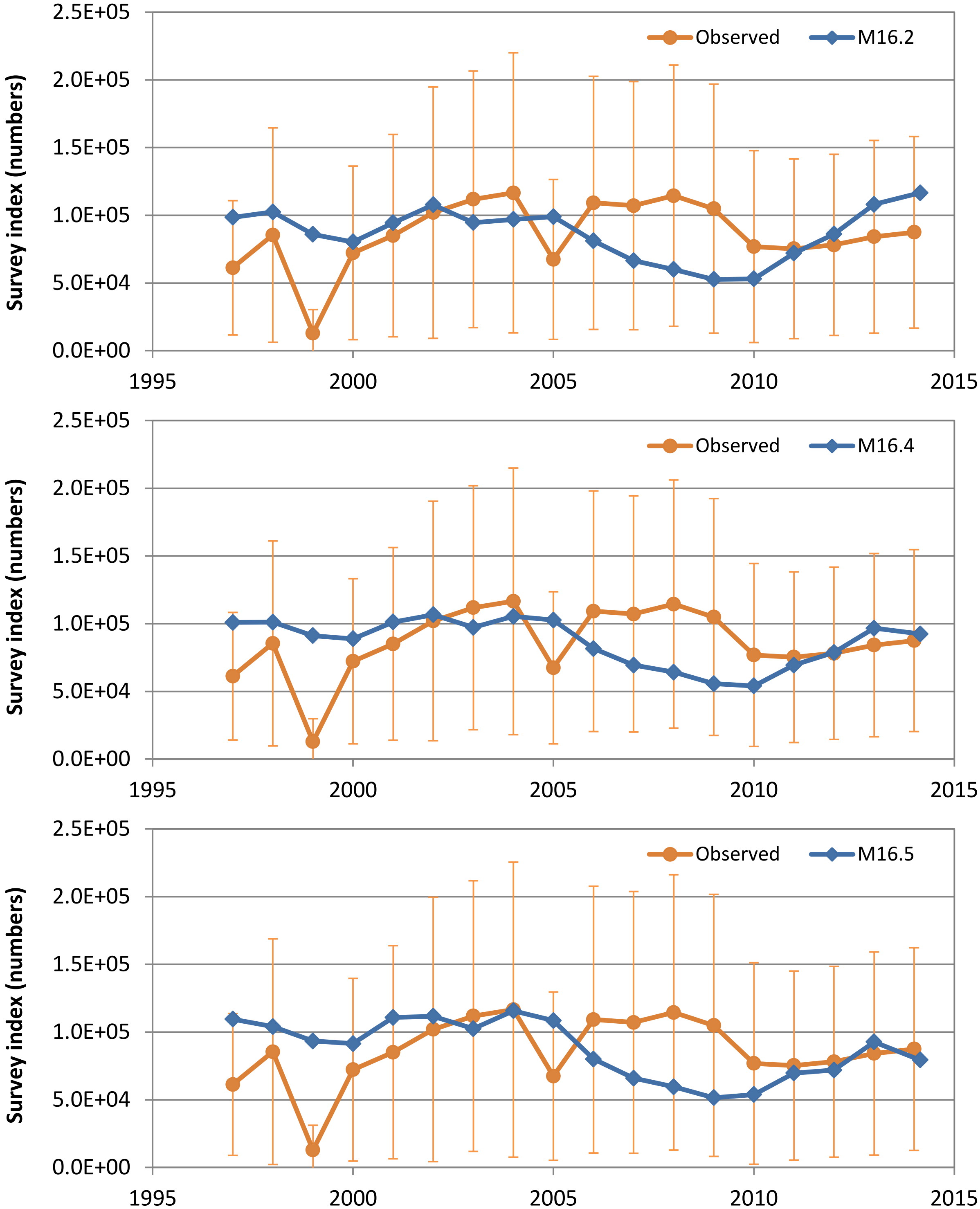


Figure 2.1.1b—Model fits to the IPHC longline survey abundance time series (Models 16.2, 16.4, and 16.5 only). Survey time series shows 95% confidence interval, which differs between models.

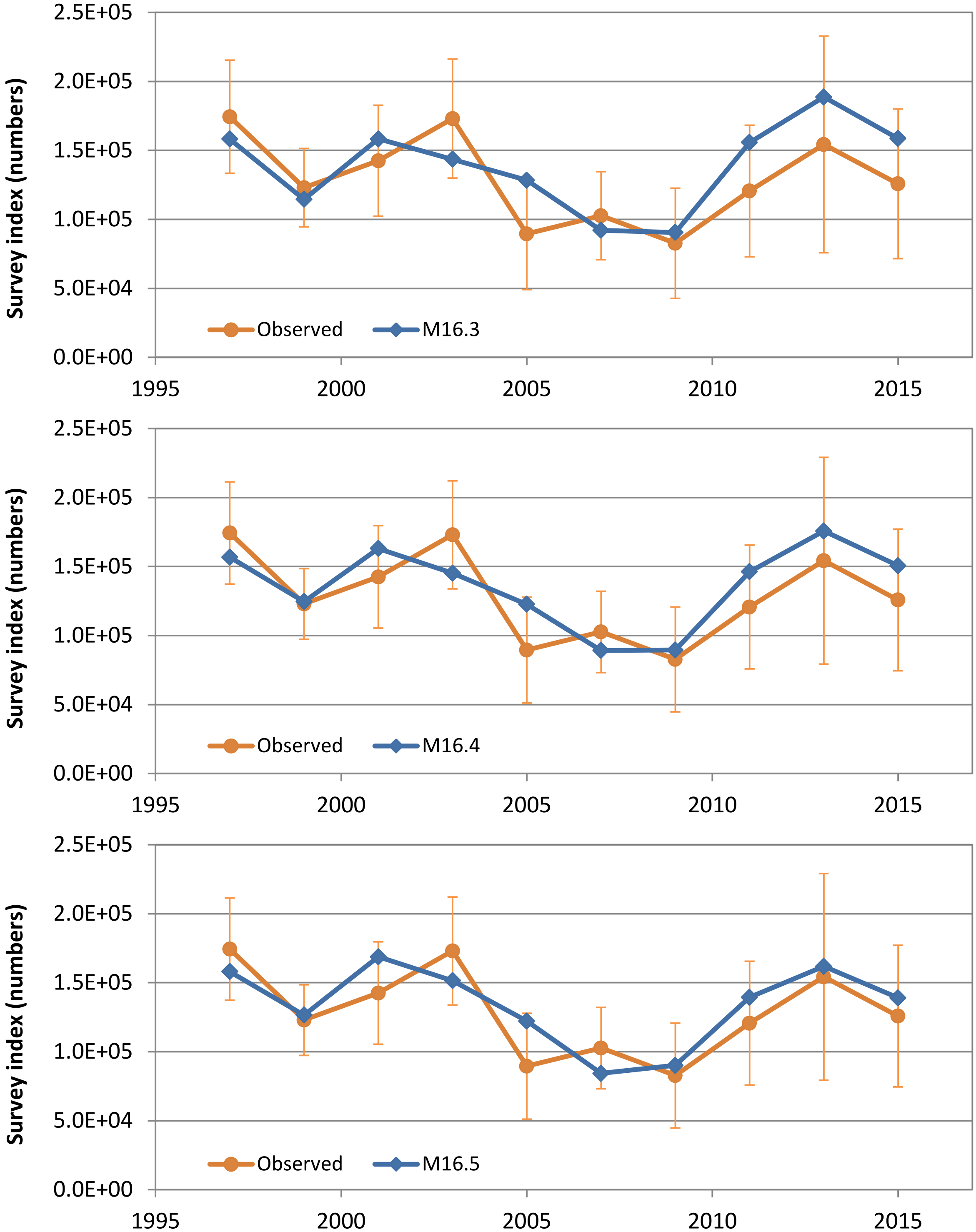


Figure 2.1.1c—Model fits to the NMFS longline survey abundance time series (Models 16.3, 16.4, and 16.5 only). Survey time series shows 95% confidence interval, which differs between models.

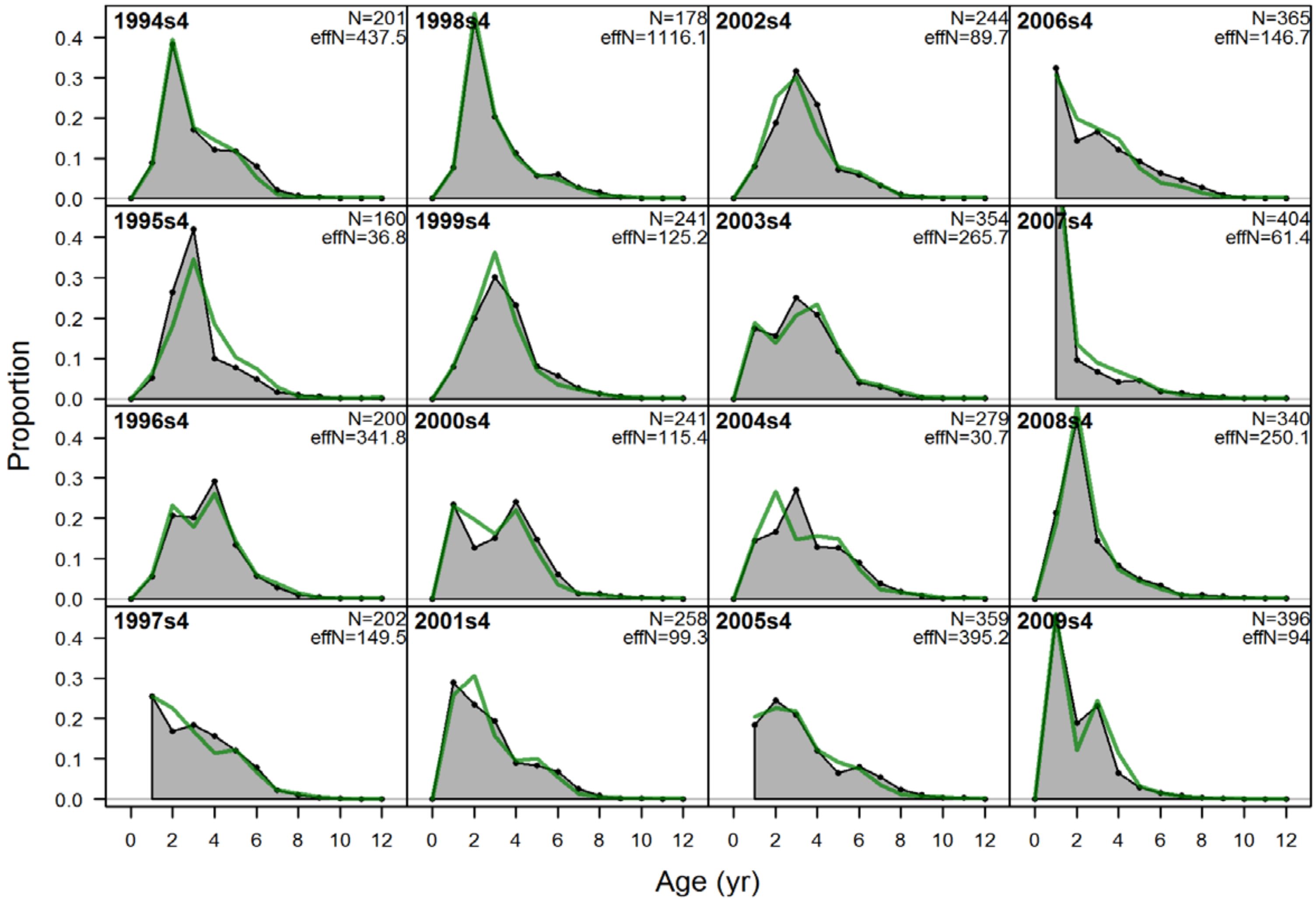


Figure 2.1.2a—Model 11.5 fits to trawl survey age composition data (page 1 of 2).

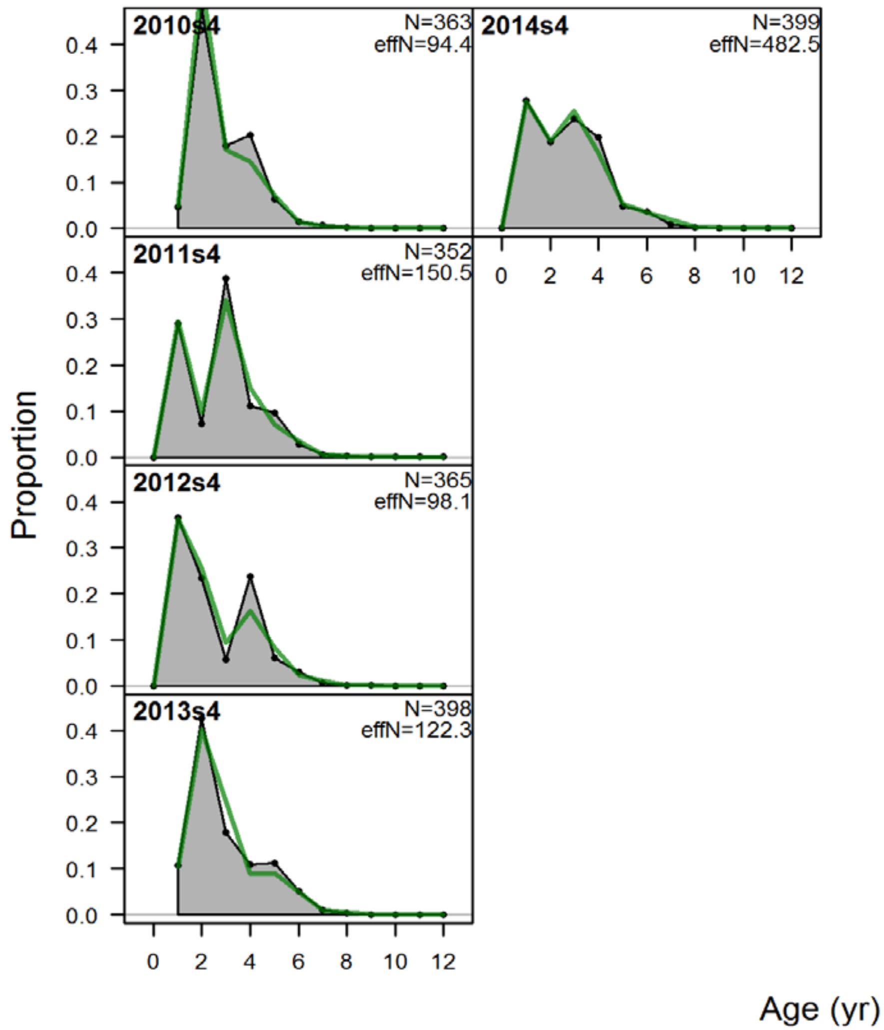


Figure 2.1.2a—Model 11.5 fits to trawl survey age composition data (page 2 of 2).

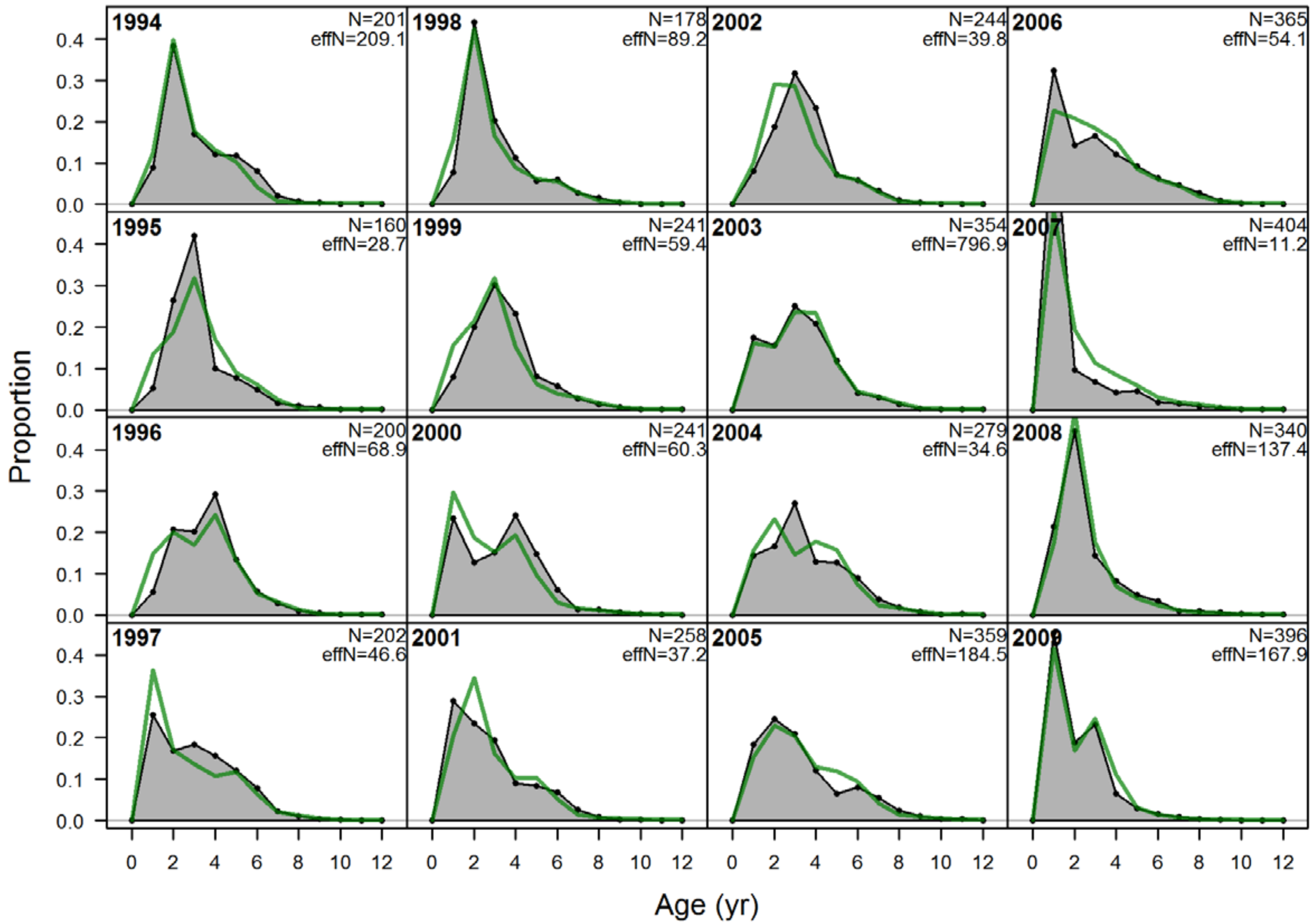


Figure 2.1.2b—Model 16.1 fits to trawl survey age composition data (page 1 of 2).

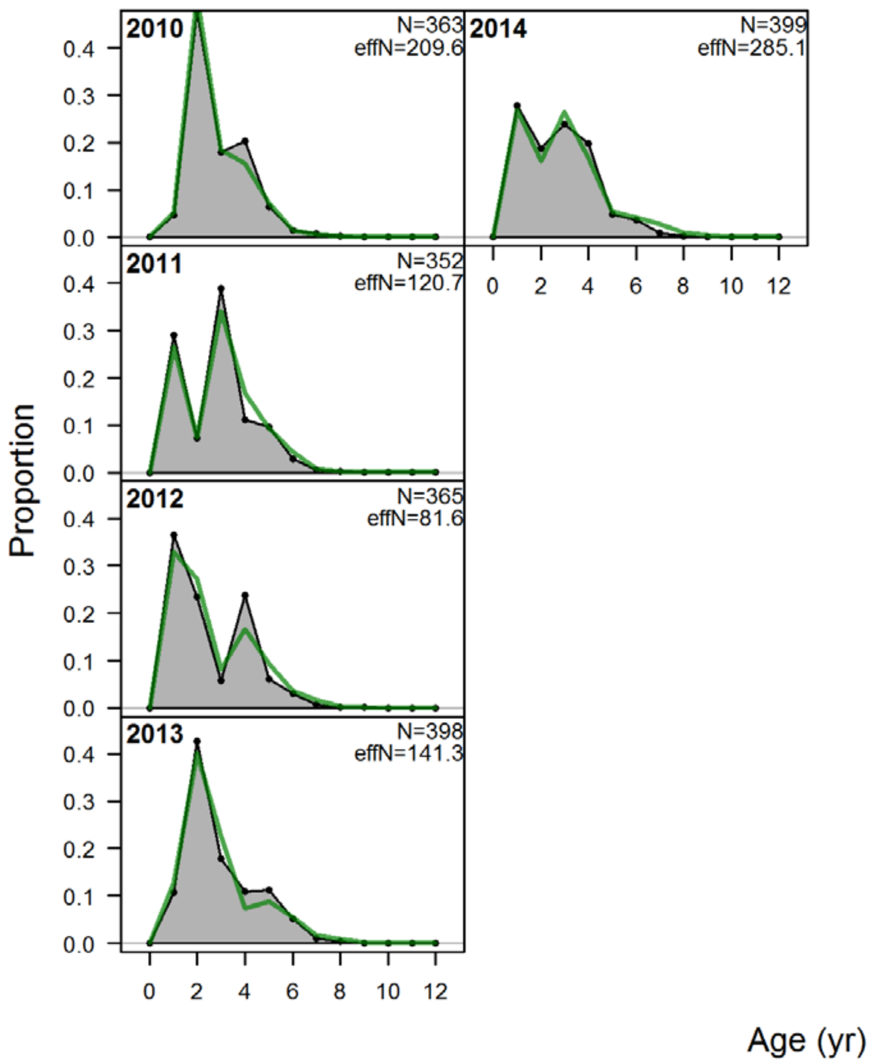


Figure 2.1.2b—Model 16.1 fits to trawl survey age composition data (page 2 of 2).

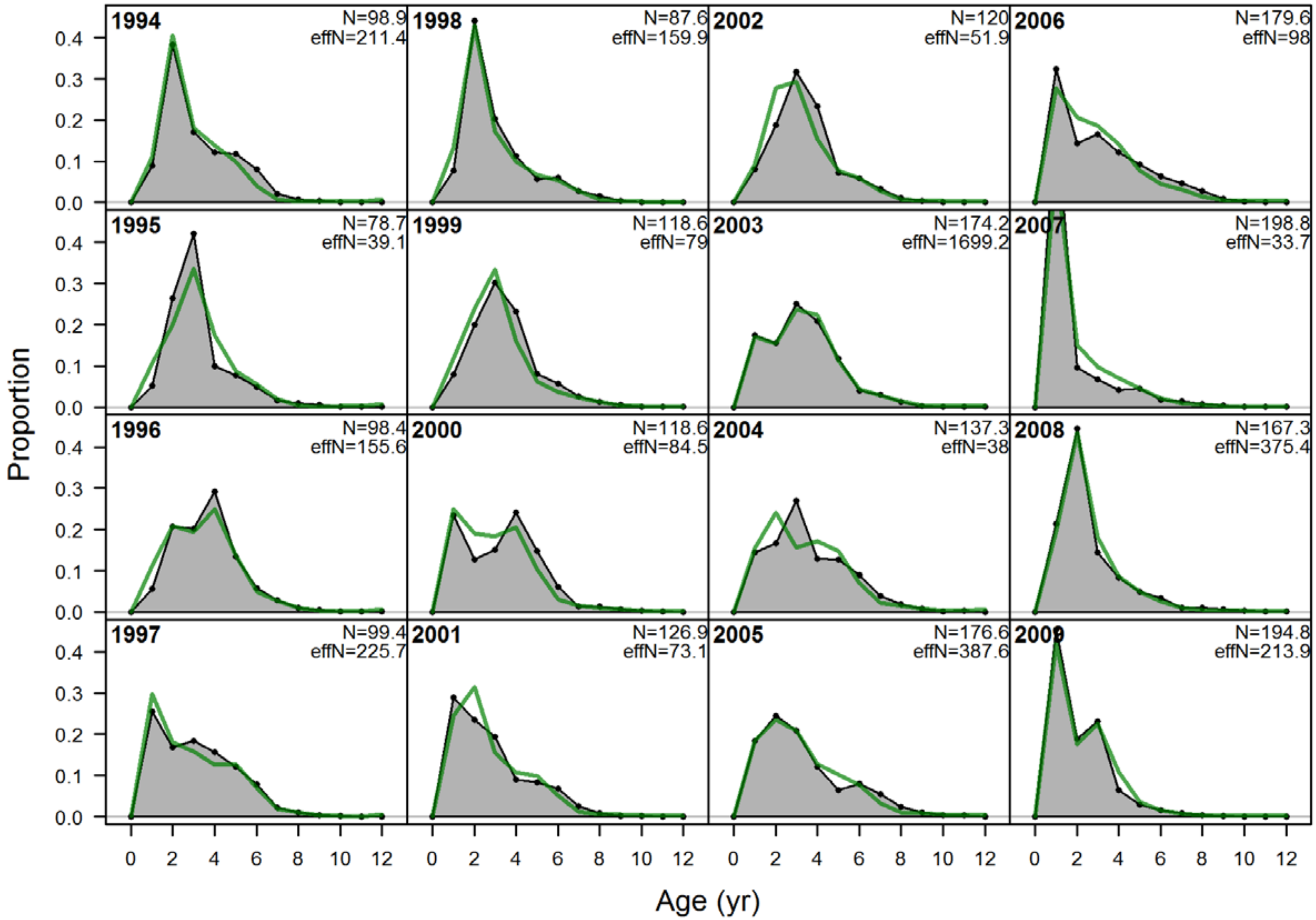


Figure 2.1.2c—Model 16.2 fits to trawl survey age composition data (page 1 of 2).

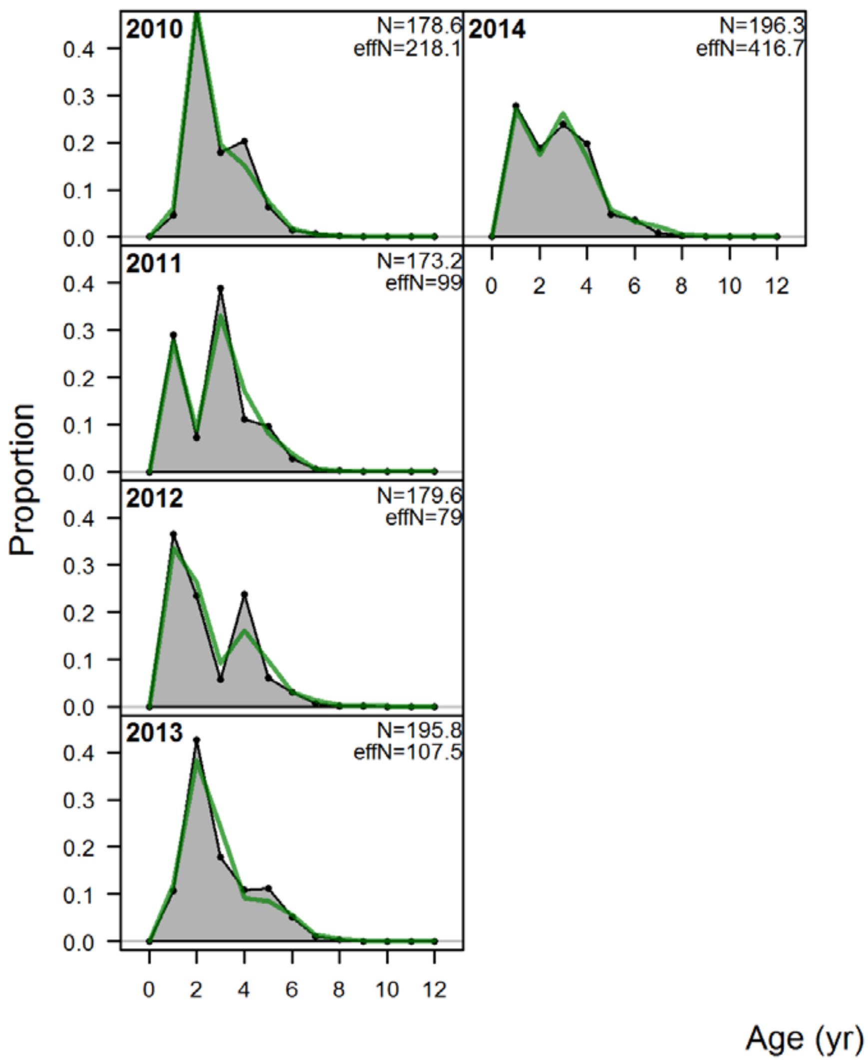


Figure 2.1.2c—Model 16.2 fits to trawl survey age composition data (page 2 of 2).

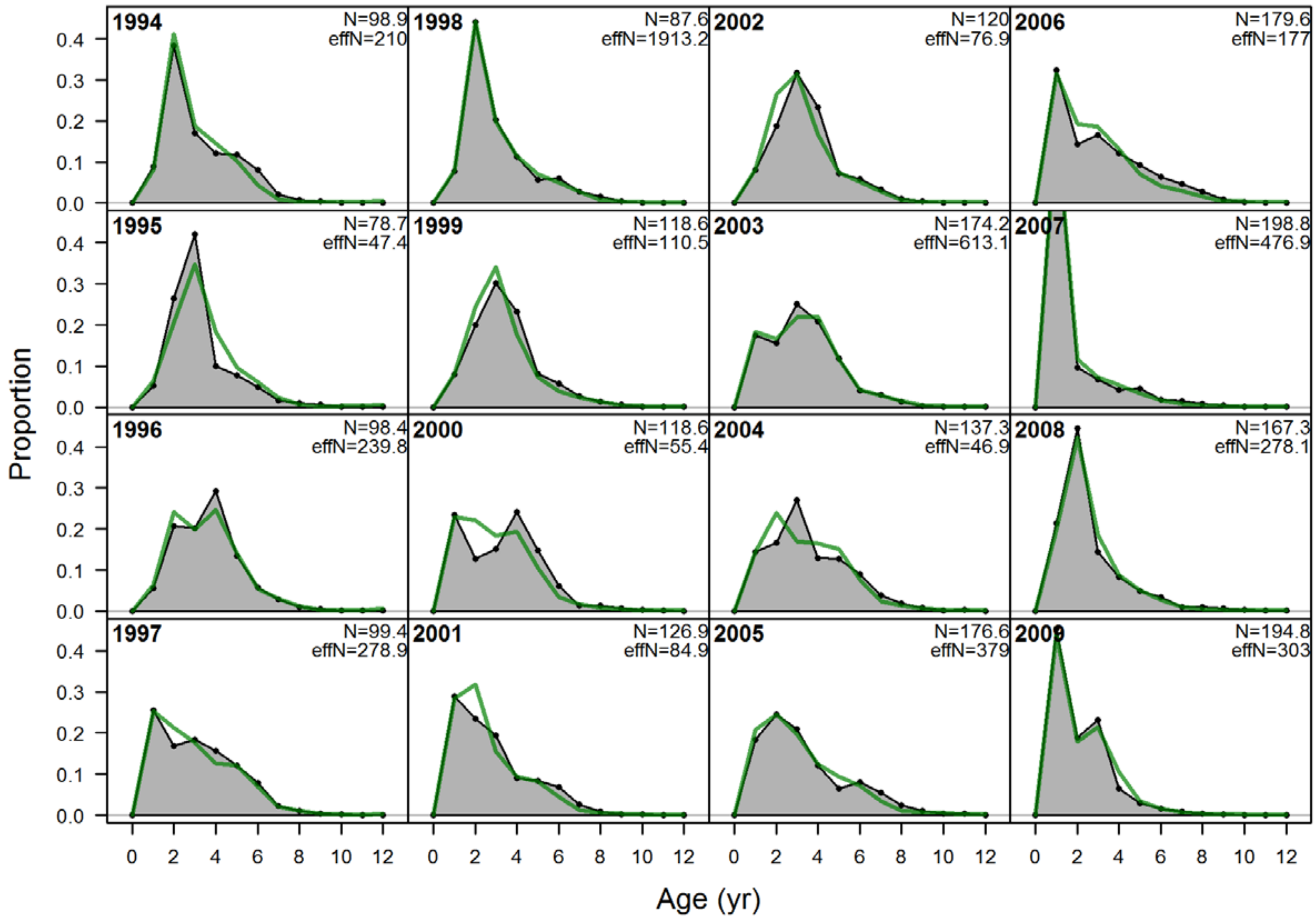


Figure 2.1.2d—Model 16.3 fits to trawl survey age composition data (page 1 of 2).

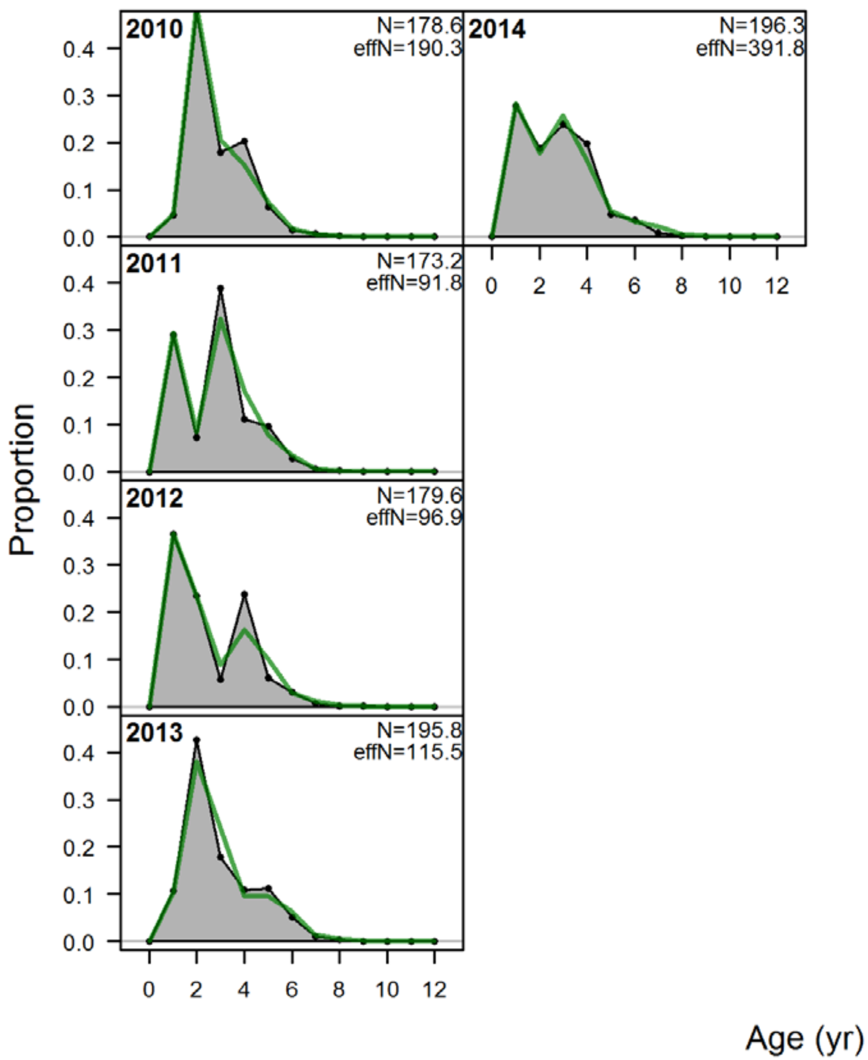


Figure 2.1.2d—Model 16.3 fits to trawl survey age composition data (page 2 of 2).

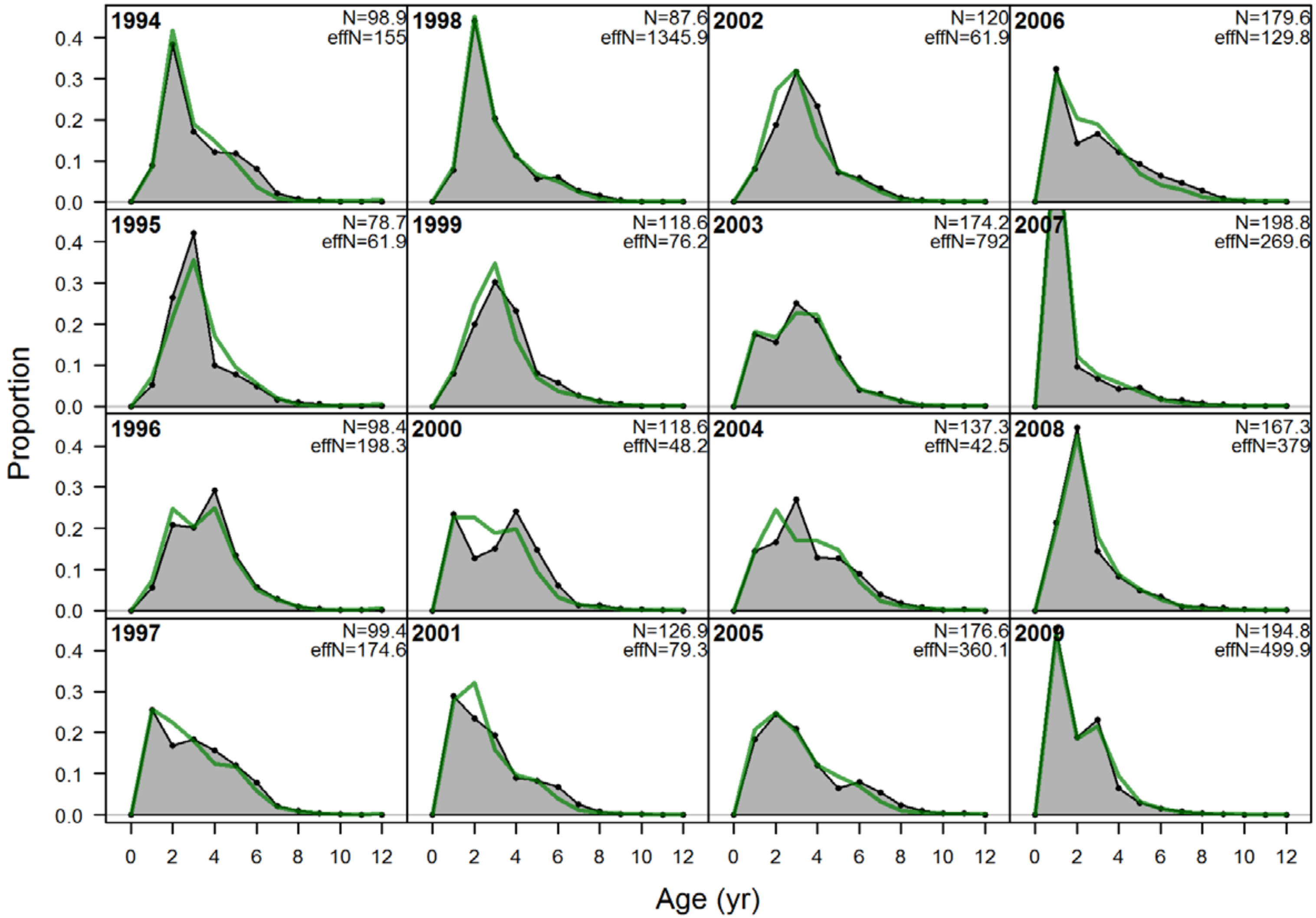


Figure 2.1.2e—Model 16.4 fits to trawl survey age composition data (page 1 of 2).

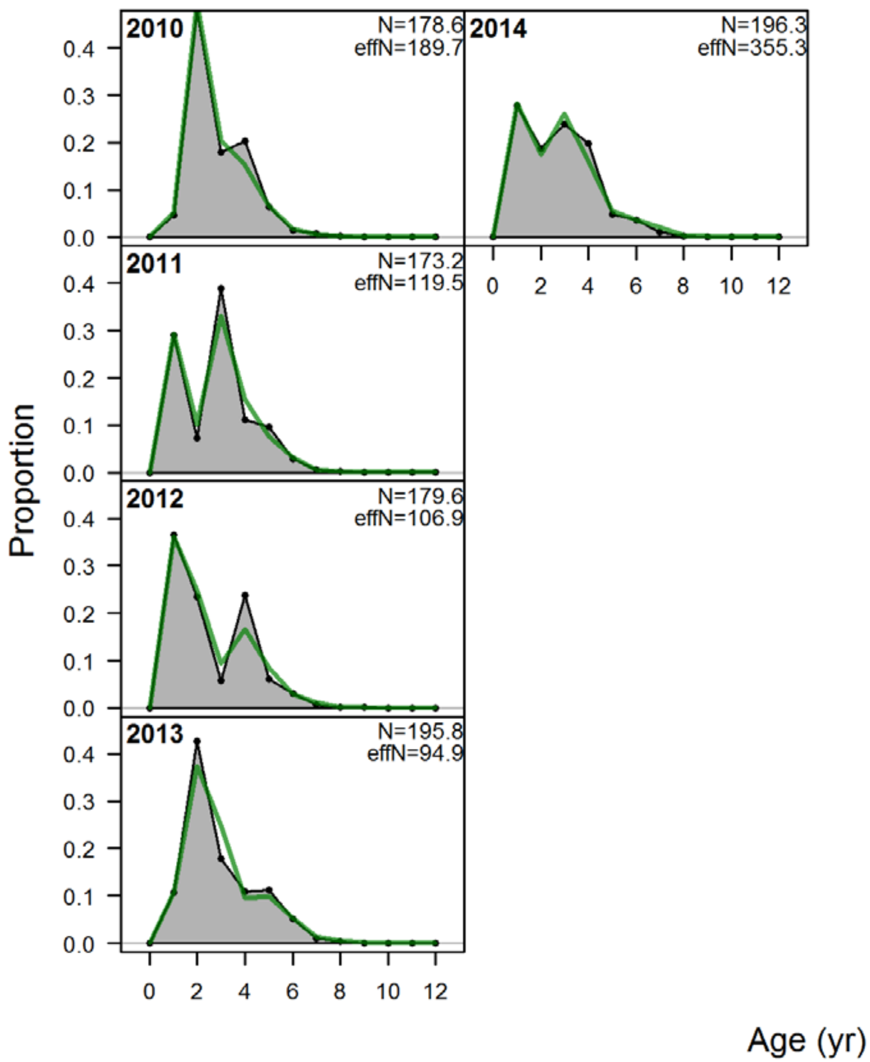


Figure 2.1.2e—Model 16.4 fits to trawl survey age composition data (page 2 of 2).

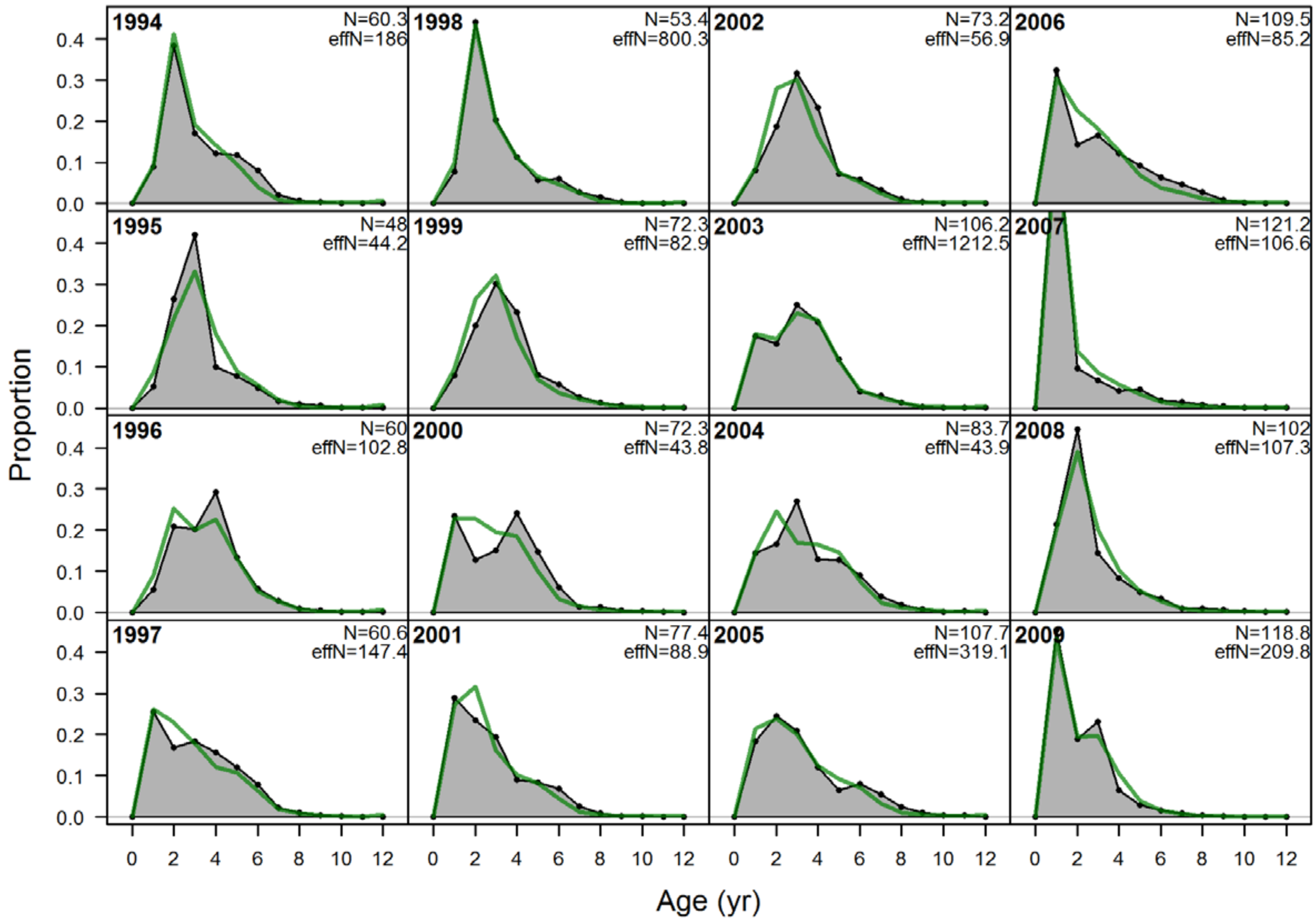


Figure 2.1.2f—Model 16.5 fits to trawl survey age composition data (page 1 of 2).

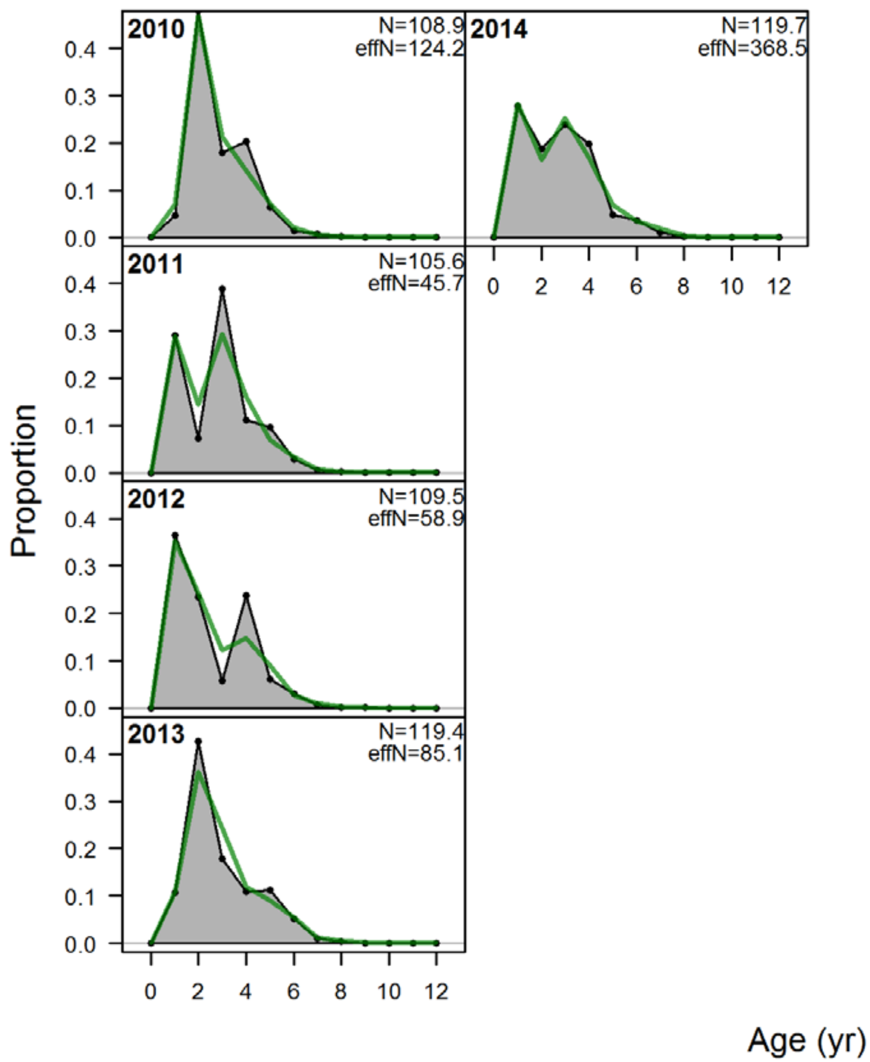


Figure 2.1.2f—Model 16.5 fits to trawl survey age composition data (page 2 of 2).

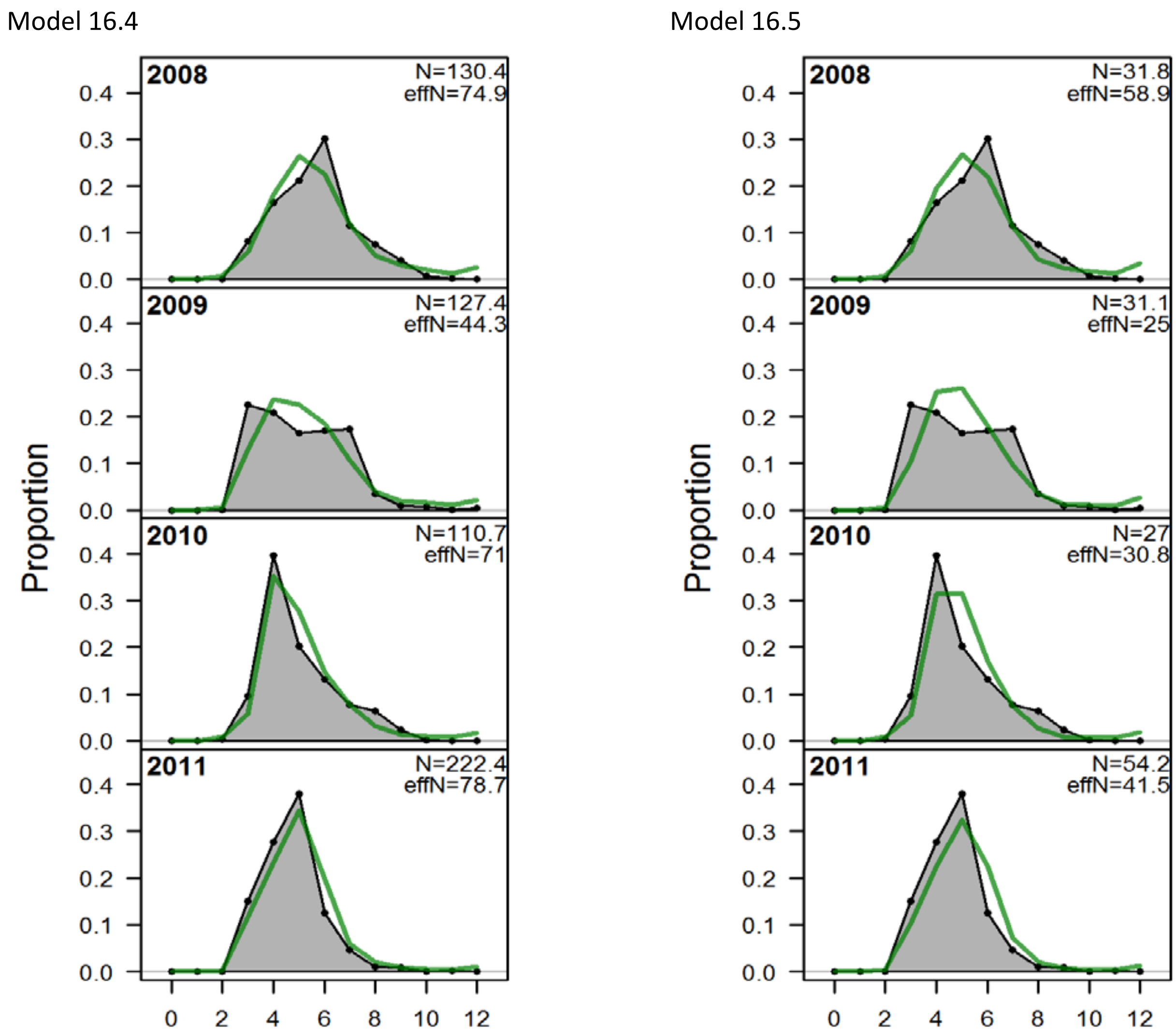


Figure 2.1.3—Model fits to fishery age composition data (Models 16.4 and 16.5 only).

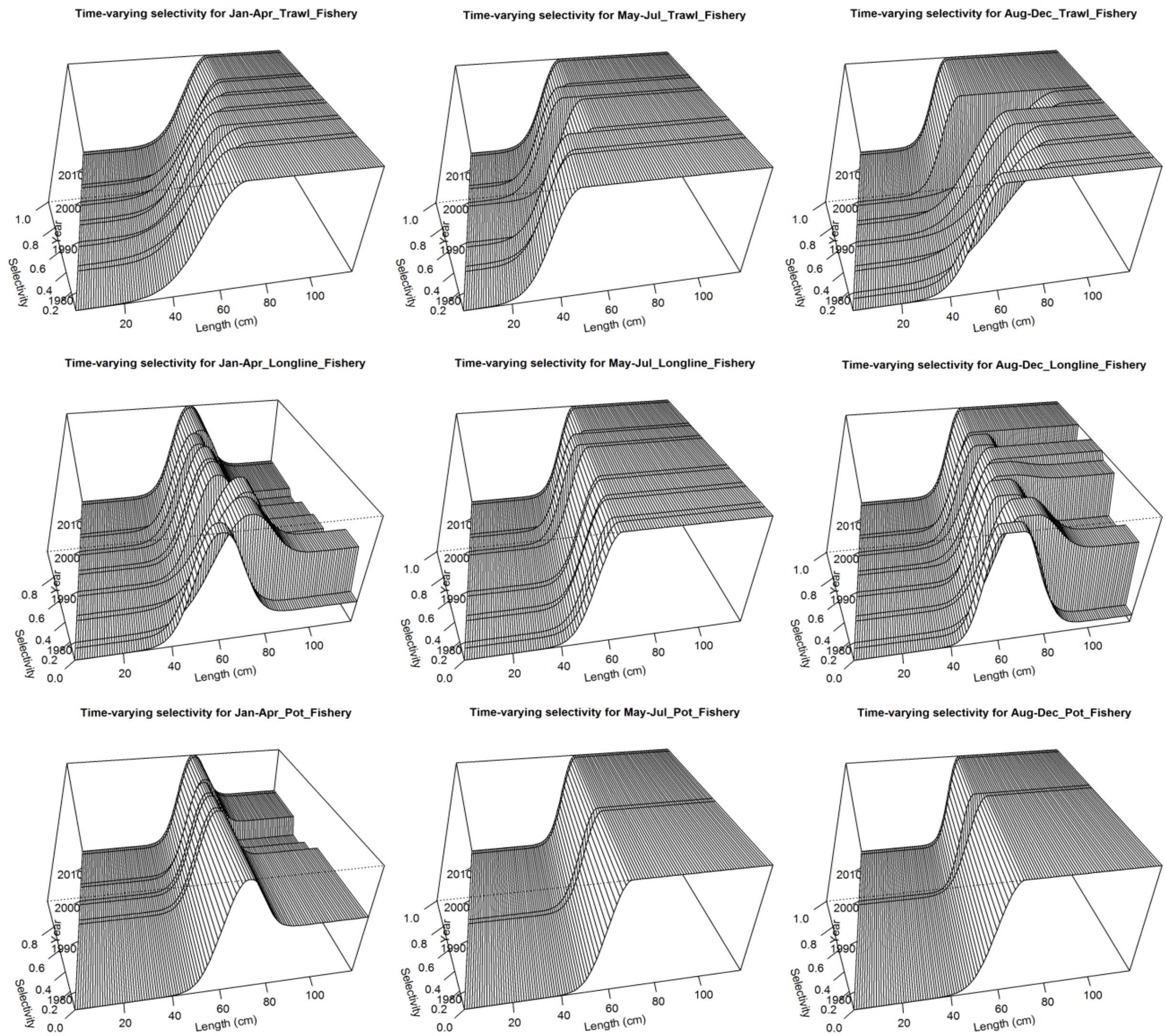


Figure 2.1.4a—Gear-and-season-specific fishery selectivity as estimated by Model 11.5.

Model 16.1

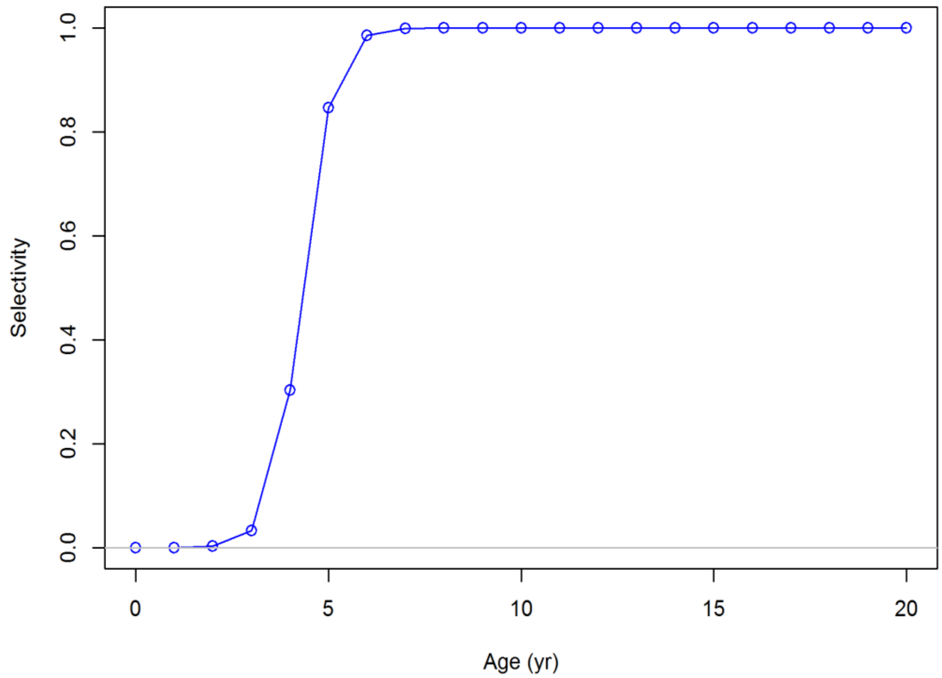
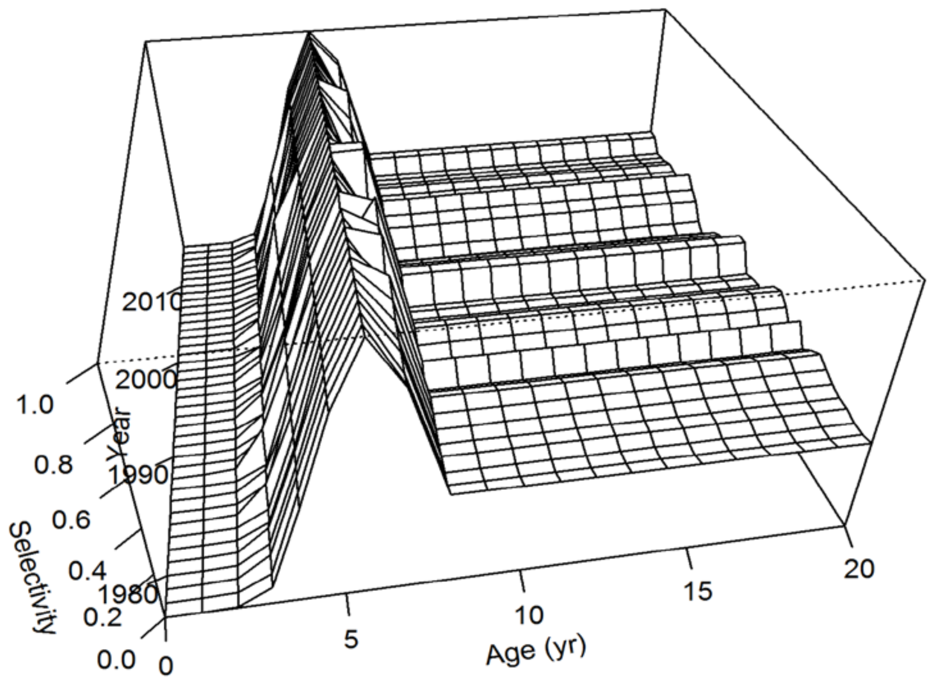


Figure 2.1.4b—Fishery selectivity as estimated by Model 16.1.

Model 16.2



Model 16.3

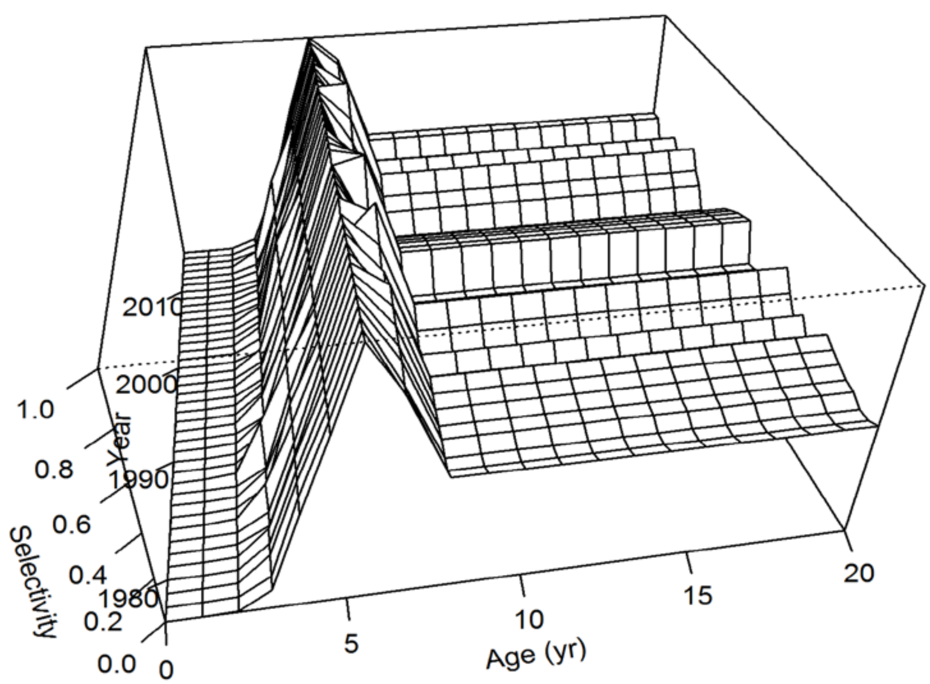


Figure 2.1.4c—Fishery selectivity as estimated by Models 16.2 and 16.3.

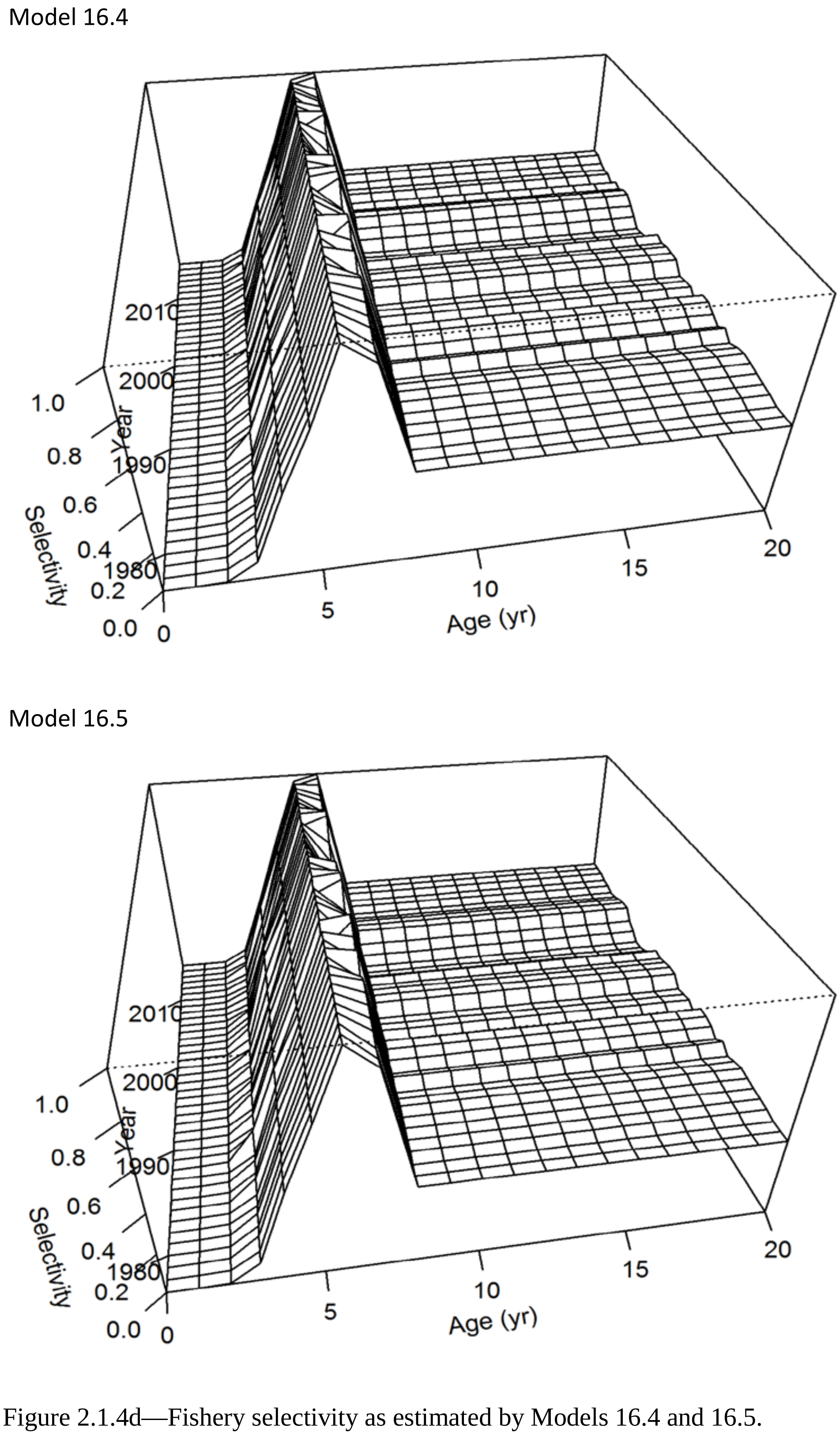
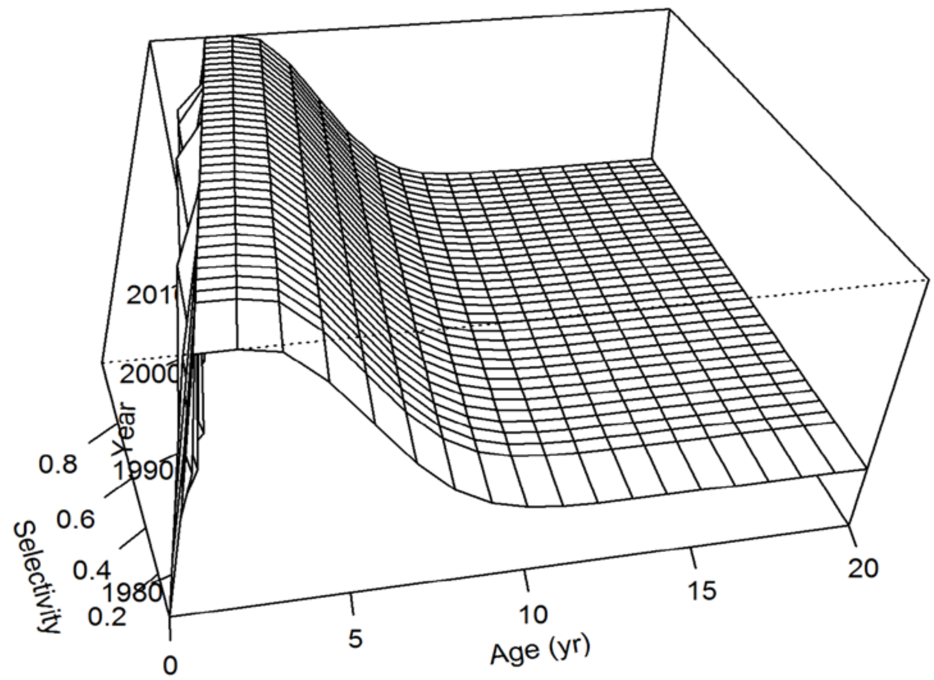


Figure 2.1.4d—Fishery selectivity as estimated by Models 16.4 and 16.5.

Model 11.5



Model 16.1

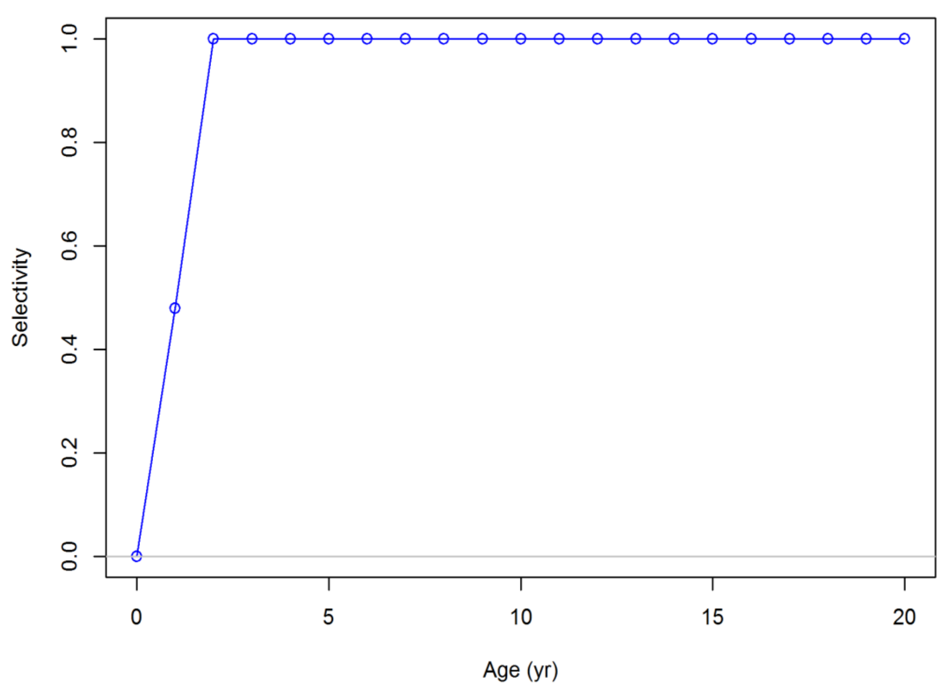
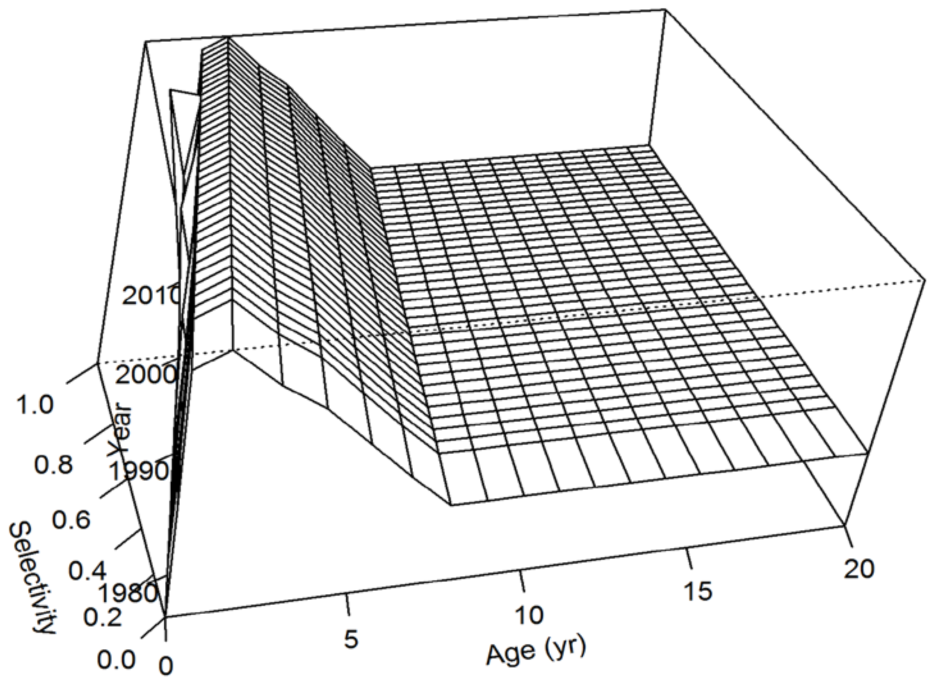


Figure 2.1.5a—Trawl survey selectivity (page 1 of 3).

Model 16.2



Model 16.3

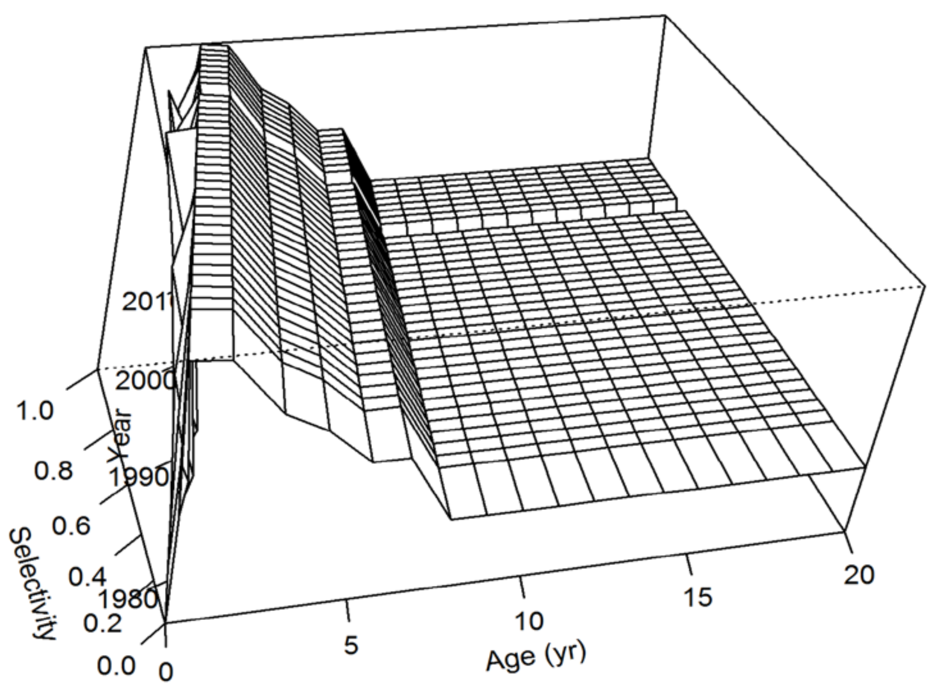
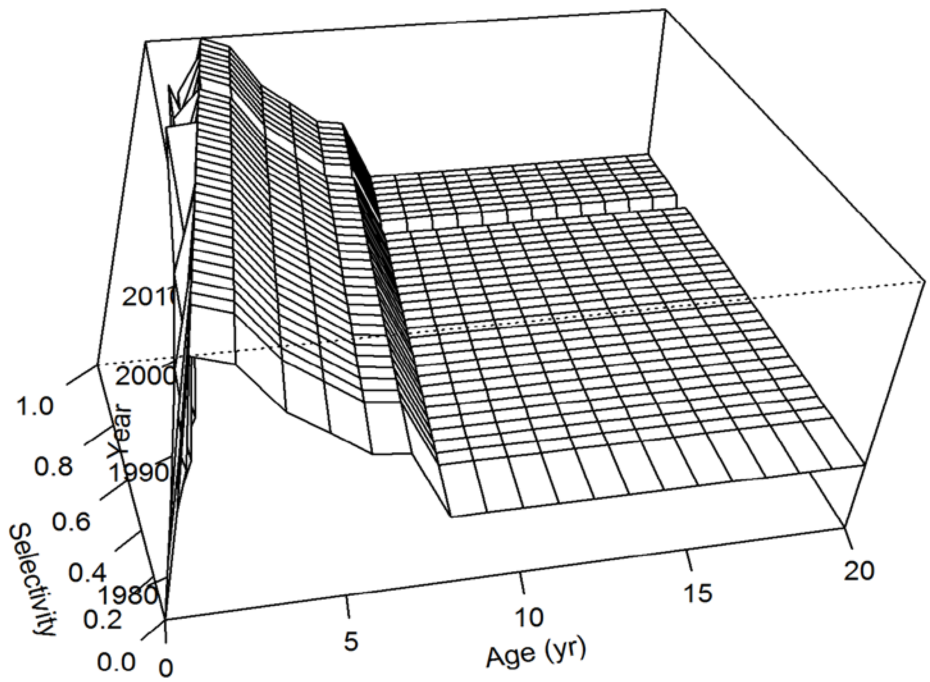


Figure 2.1.5a—Trawl survey selectivity (page 2 of 3).

Model 16.4



Model 16.5

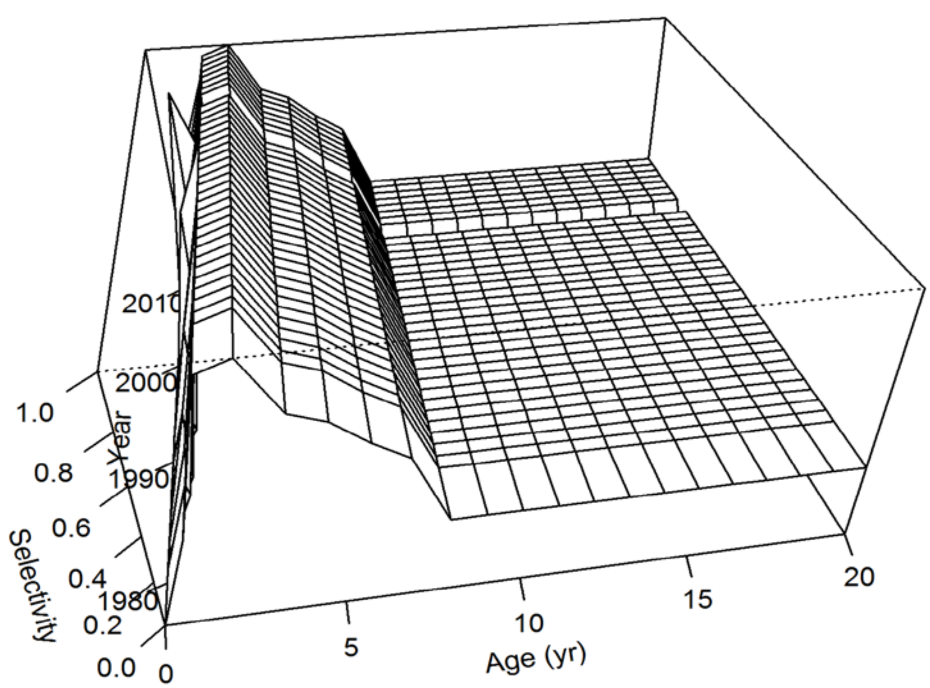
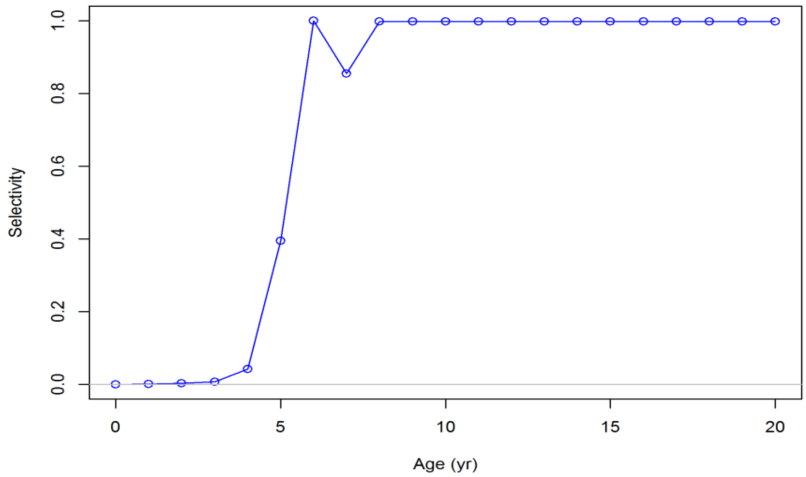
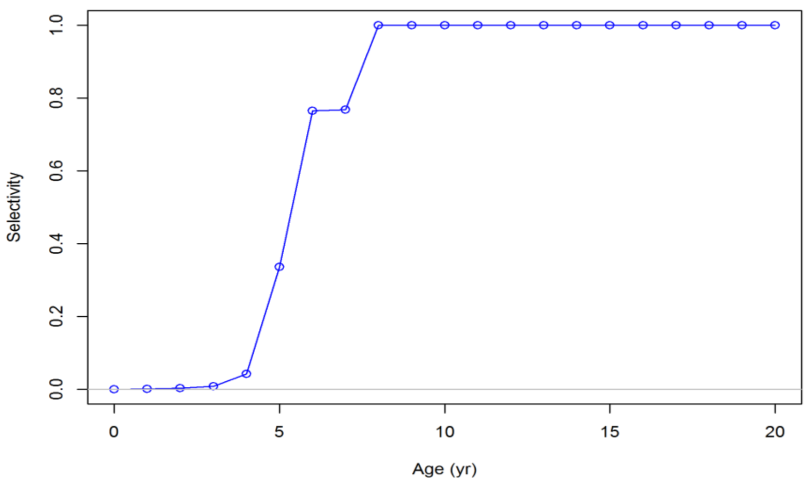


Figure 2.1.5a—Trawl survey selectivity (page 3 of 3).

Model 16.2



Model 16.4



Model 16.5

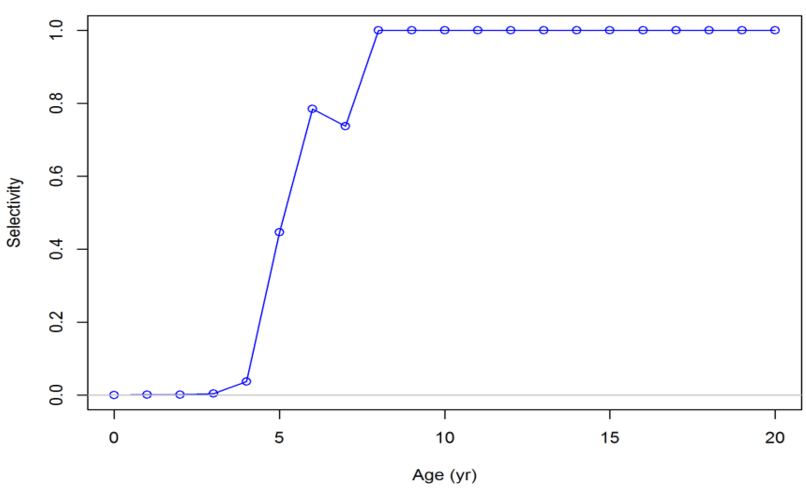
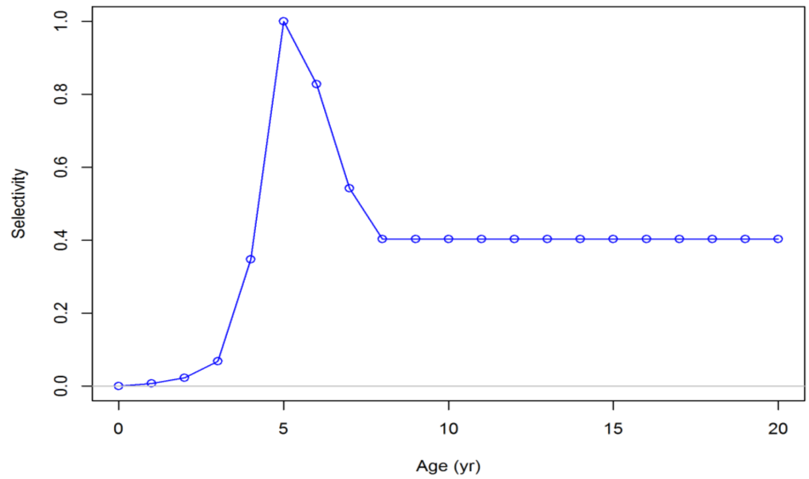
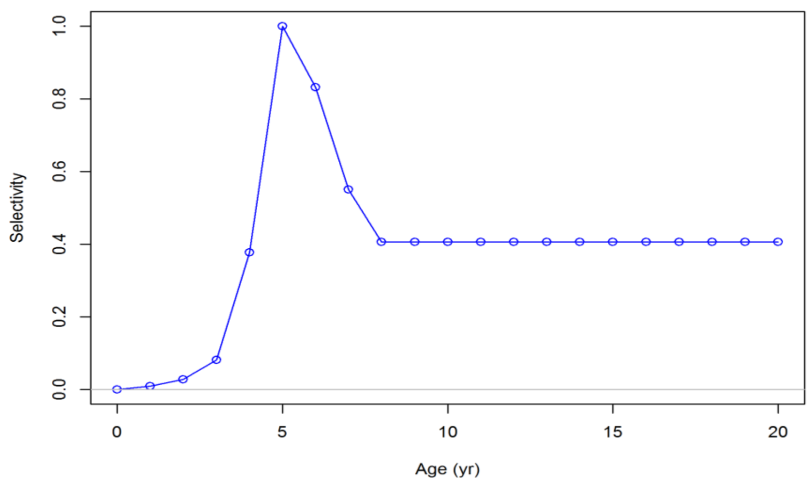


Figure 2.1.5b—IPHC longline survey selectivity.

Model 16.3



Model 16.4



Model 16.5

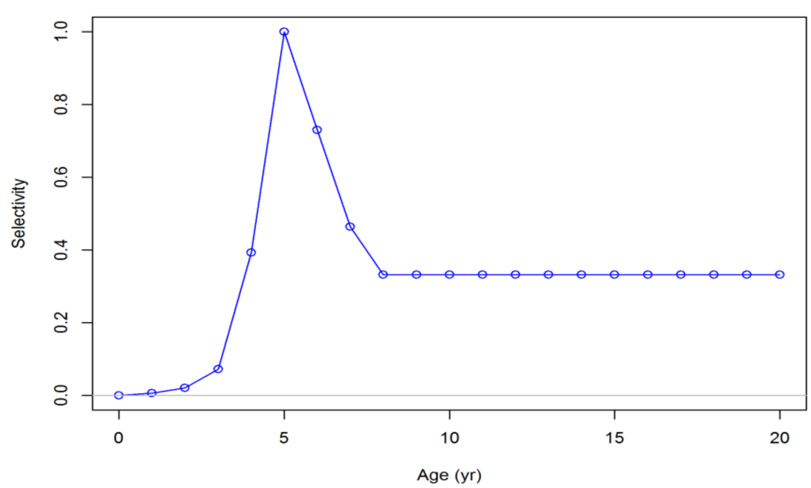


Figure 2.1.5c—NMFS longline survey selectivity.

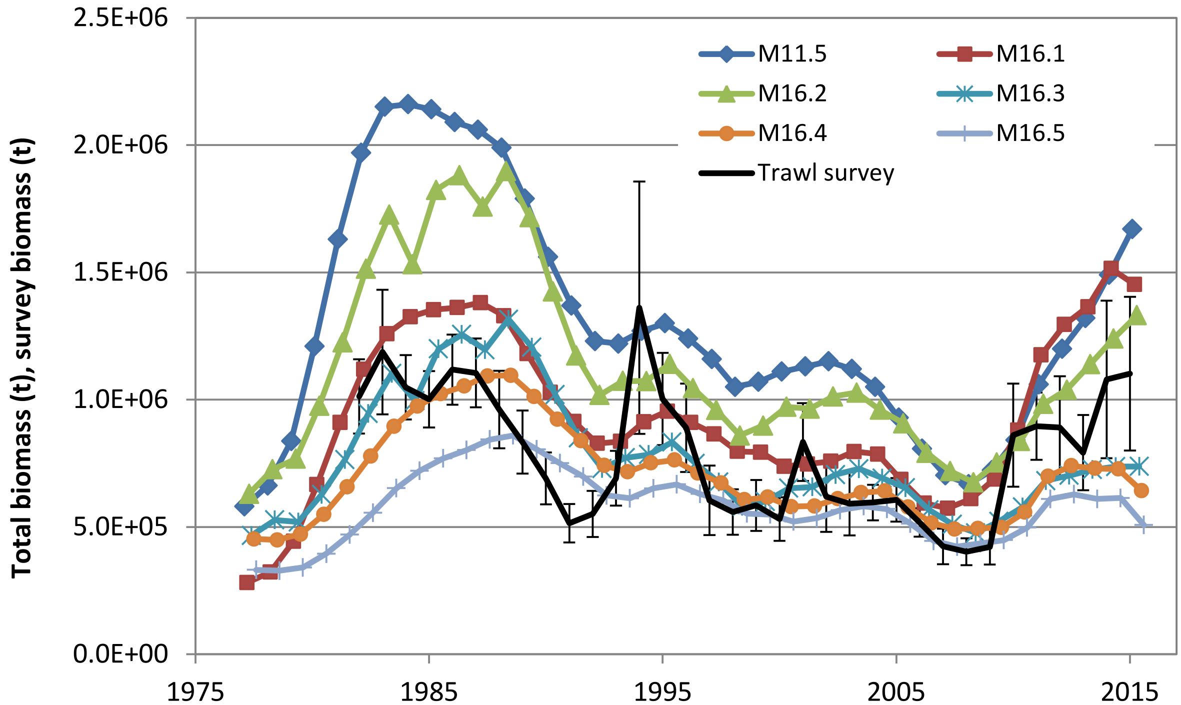


Figure 2.1.6—Total biomass time series as estimated by each of the models. Survey biomass (with 95% confidence interval) shown for comparison.

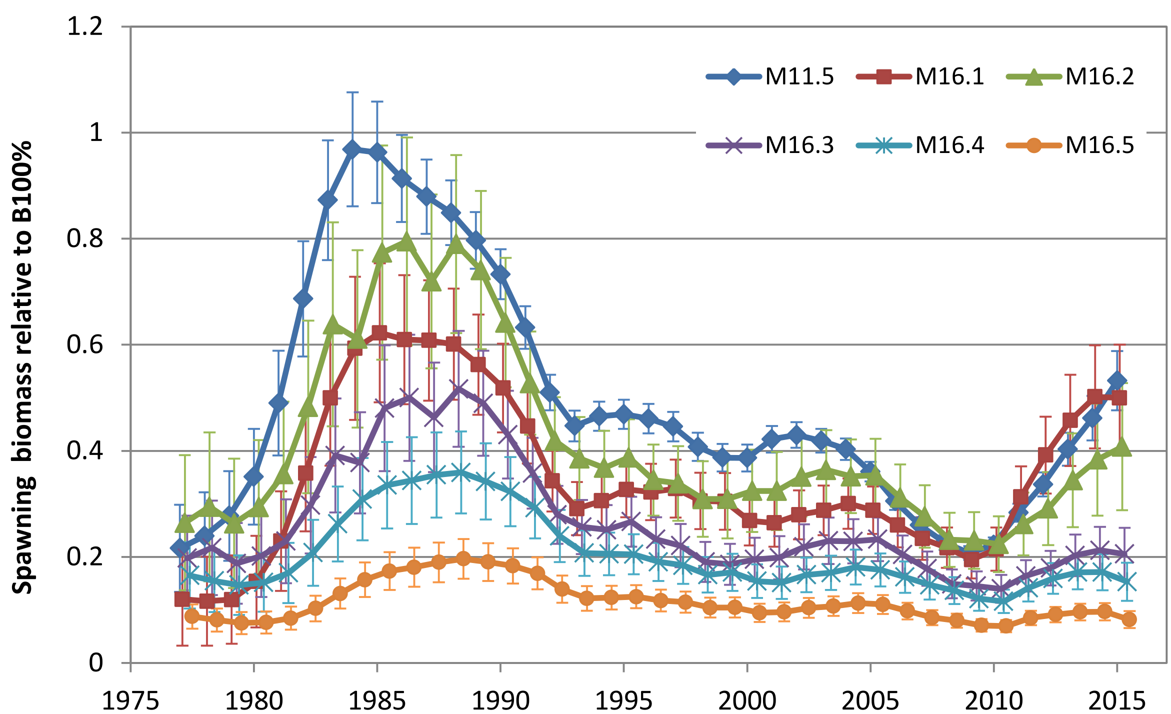


Figure 2.1.7—Time series of spawning biomass relative to $B_{100\%}$ for each of the models, with 95% confidence intervals.

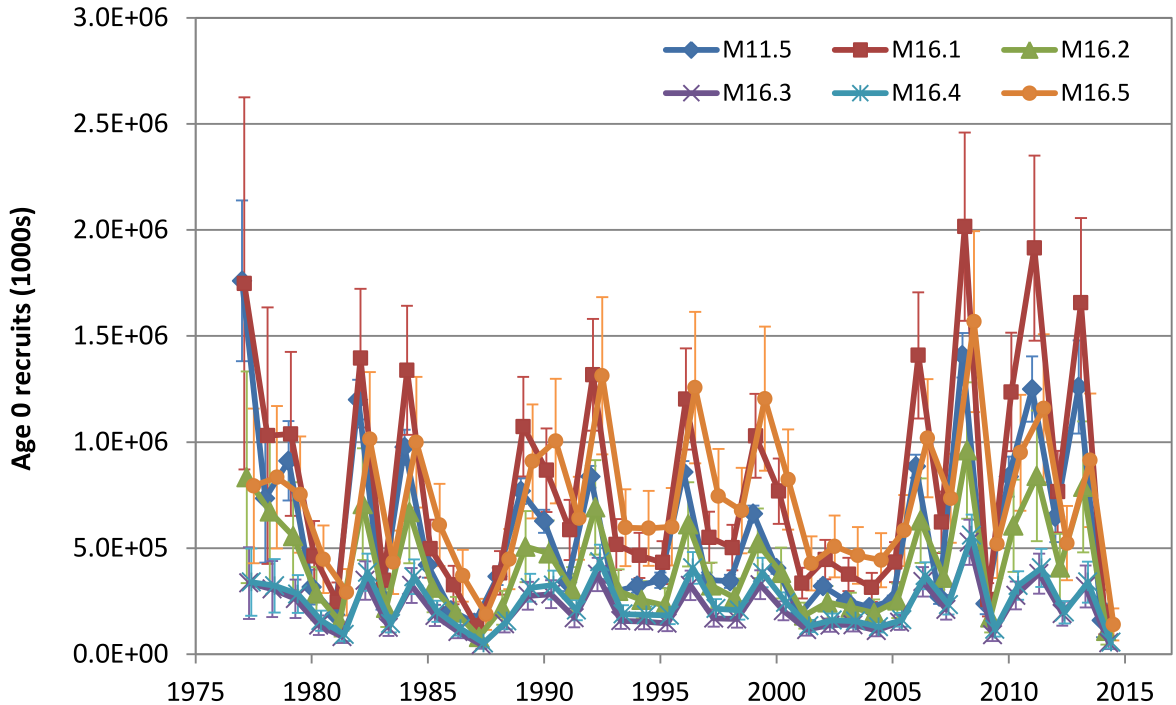


Figure 2.1.8—Age 0 recruitment (1000s of fish) for each model.

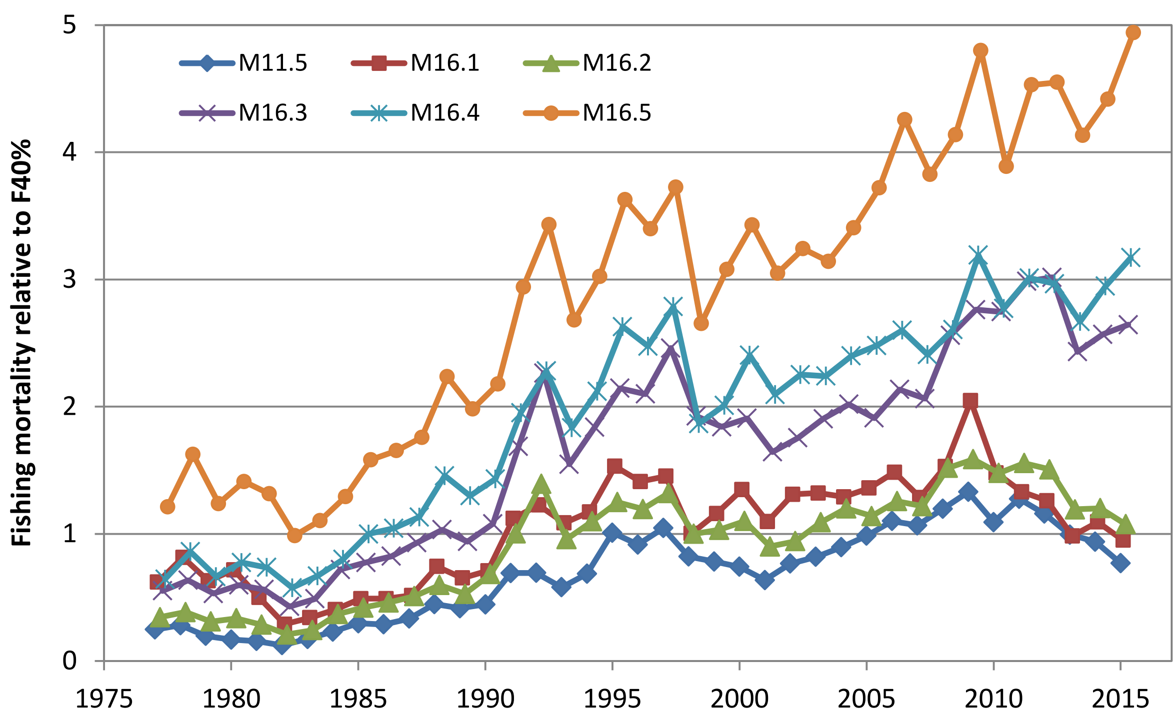


Figure 2.1.9—Time series of the ratio of full-selection fishing morality to $F_{40\%}$.

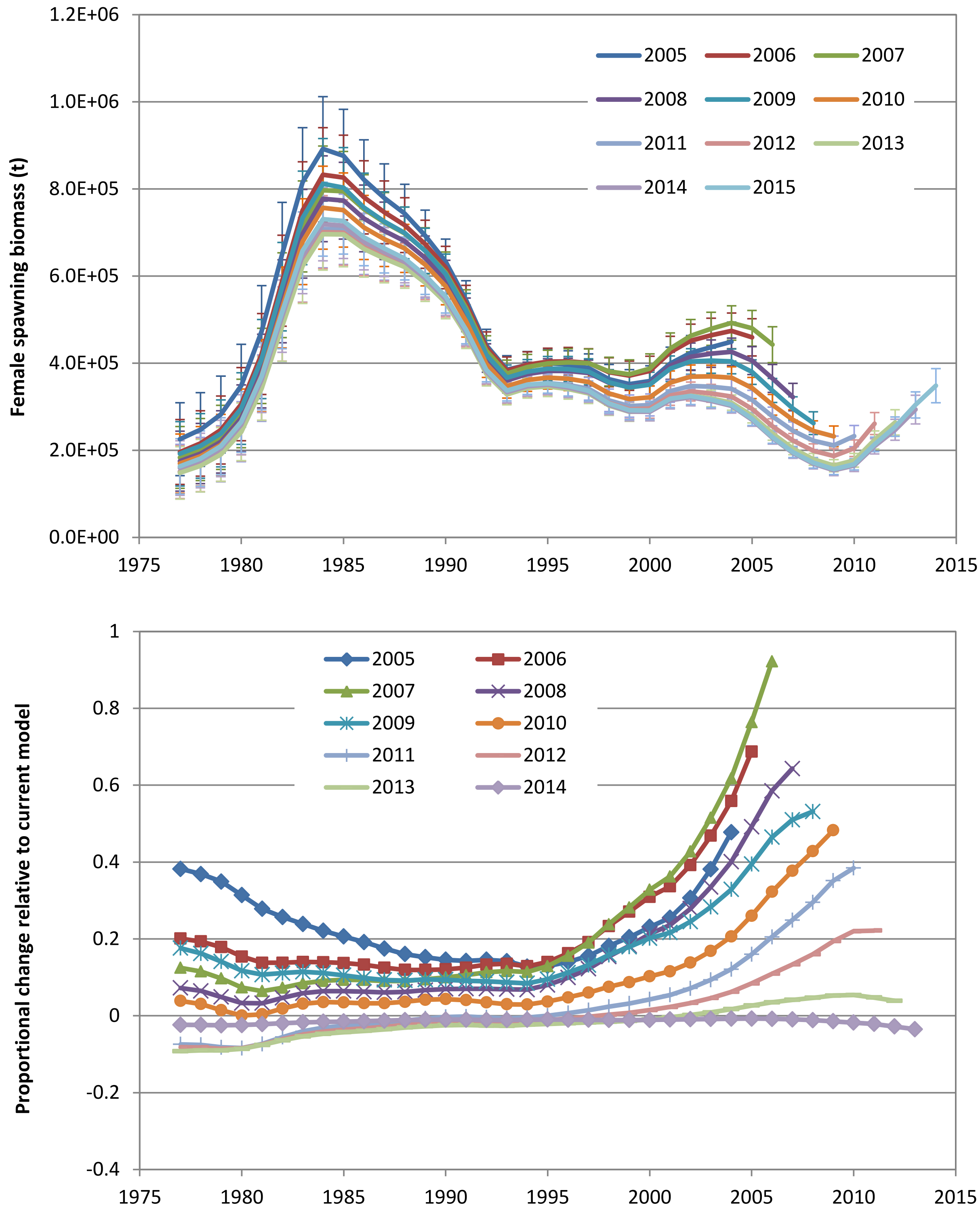


Figure 2.1.10a—Ten-year spawning biomass retrospective analysis of Model 11.5.

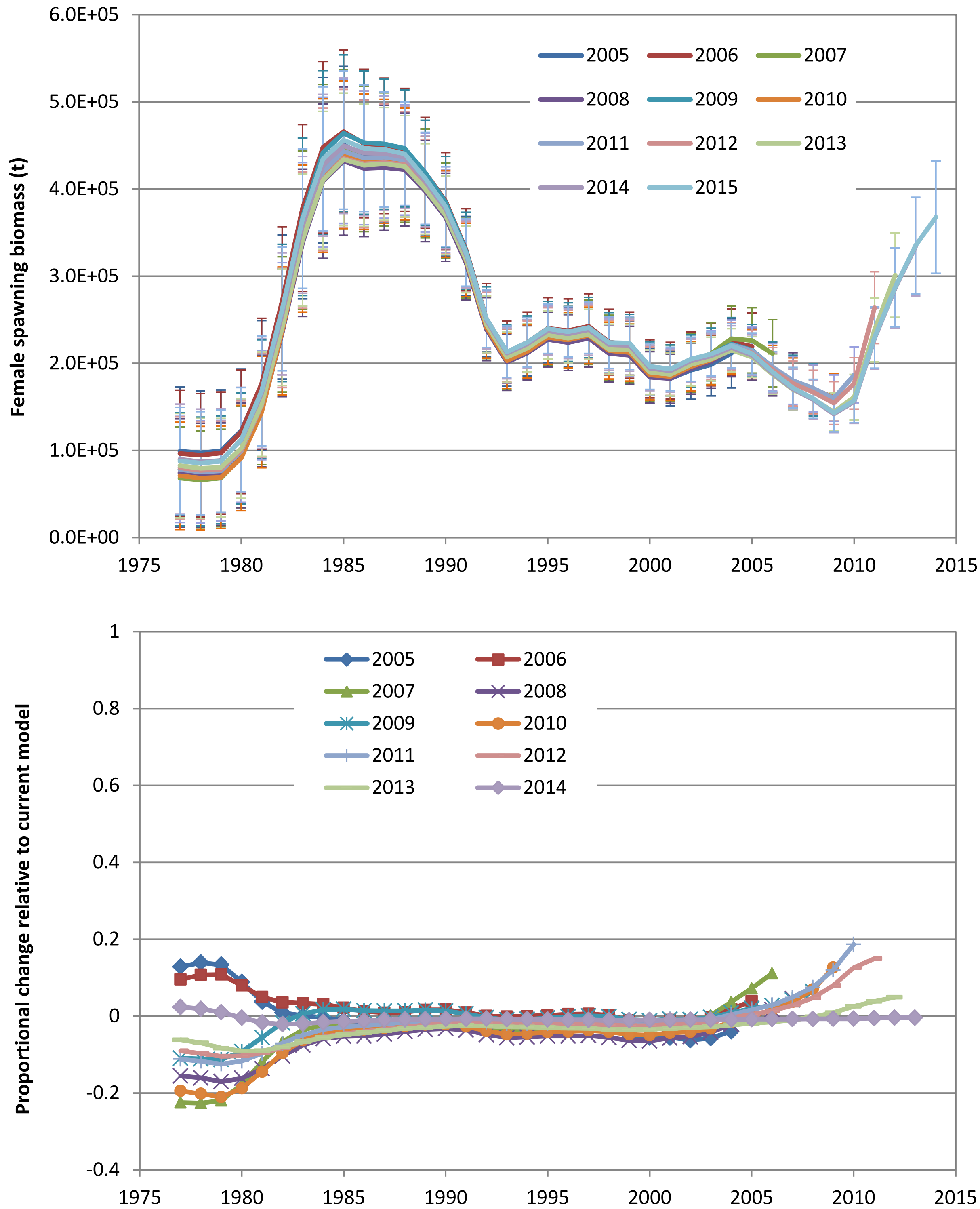
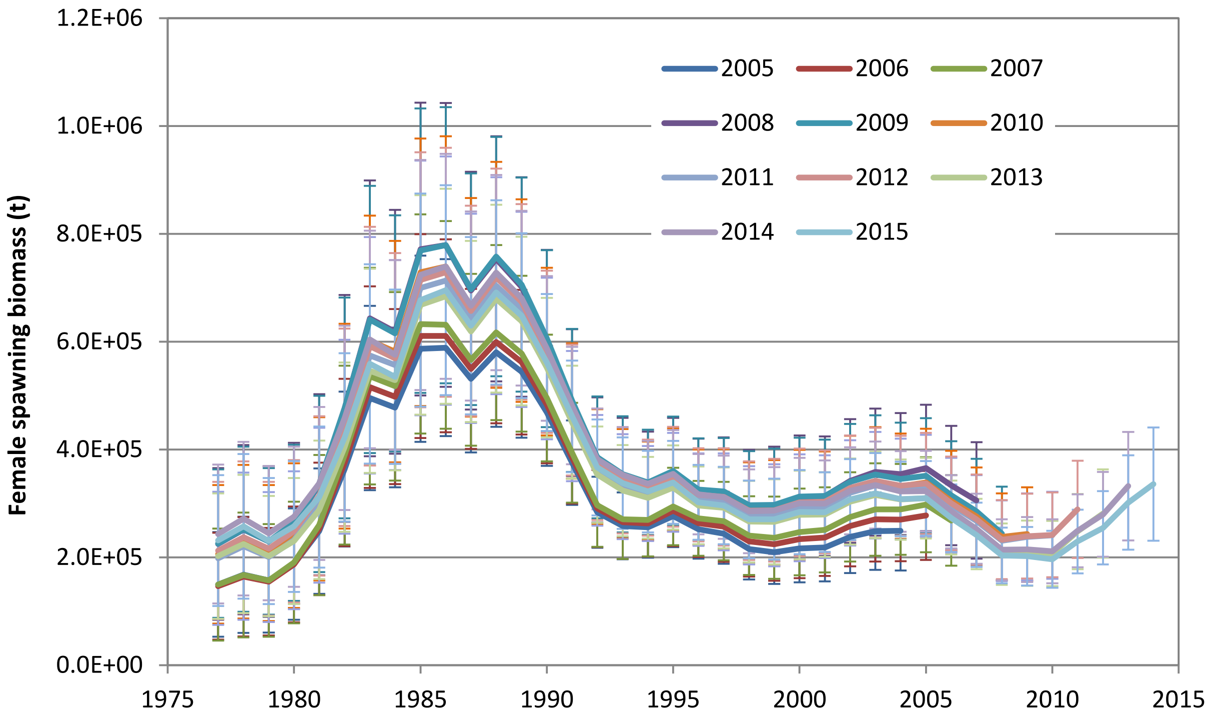


Figure 2.1.10b—Ten-year spawning biomass retrospective analysis of Model 16.1.



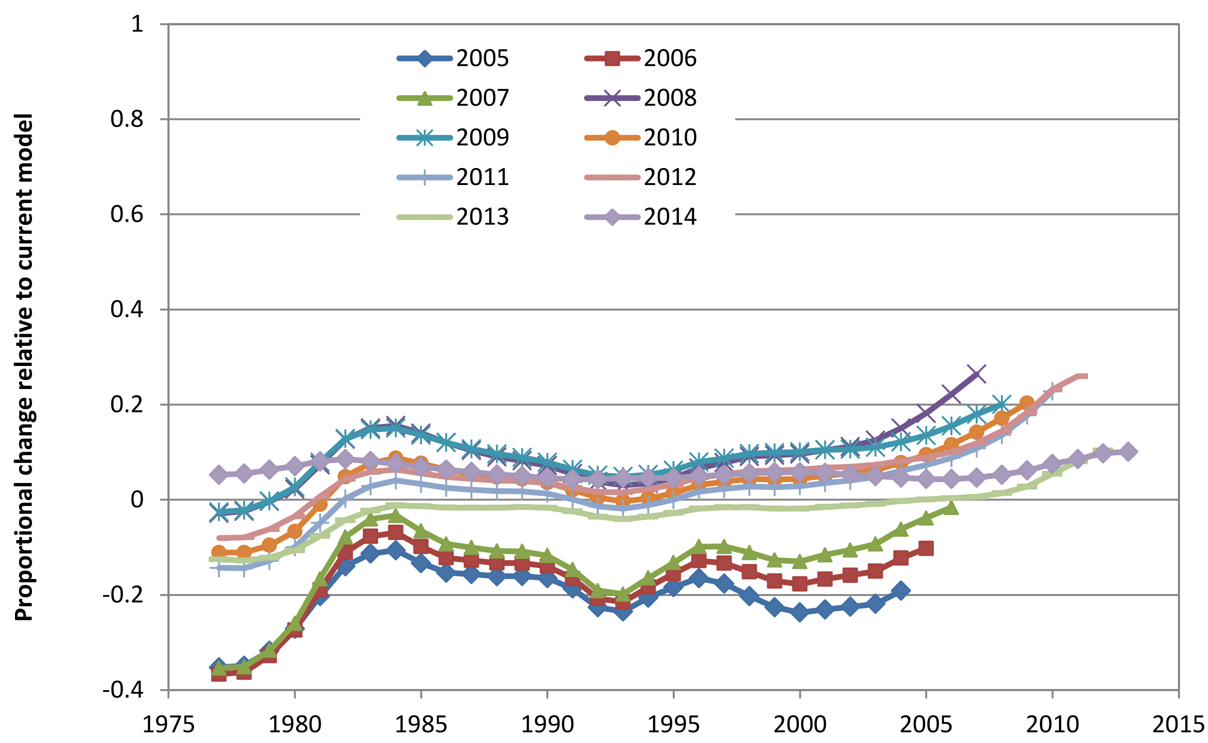


Figure 2.1.10c—Ten-year spawning biomass retrospective analysis of Model 16.2.

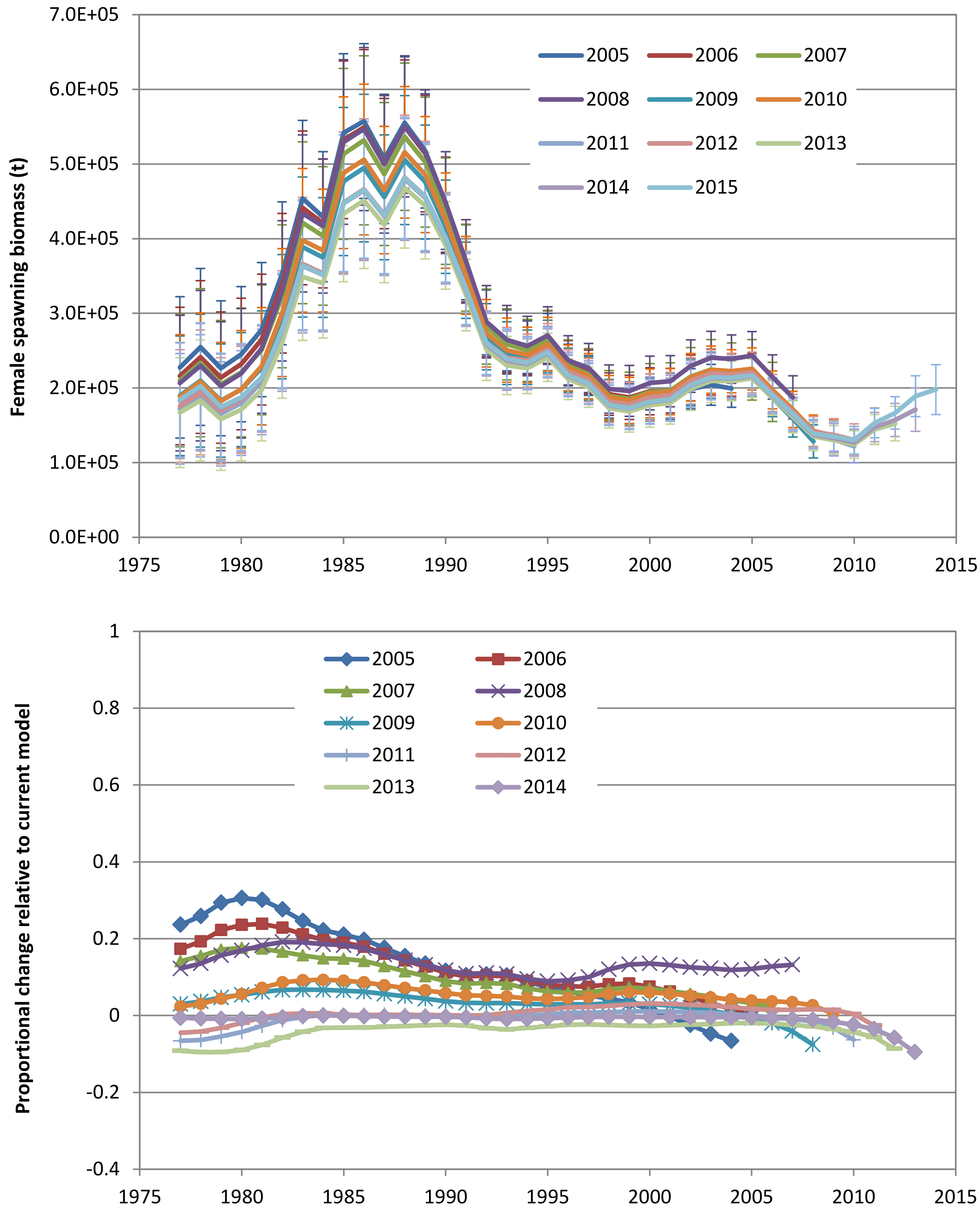


Figure 2.1.10d—Ten-year spawning biomass retrospective analysis of Model 16.3.

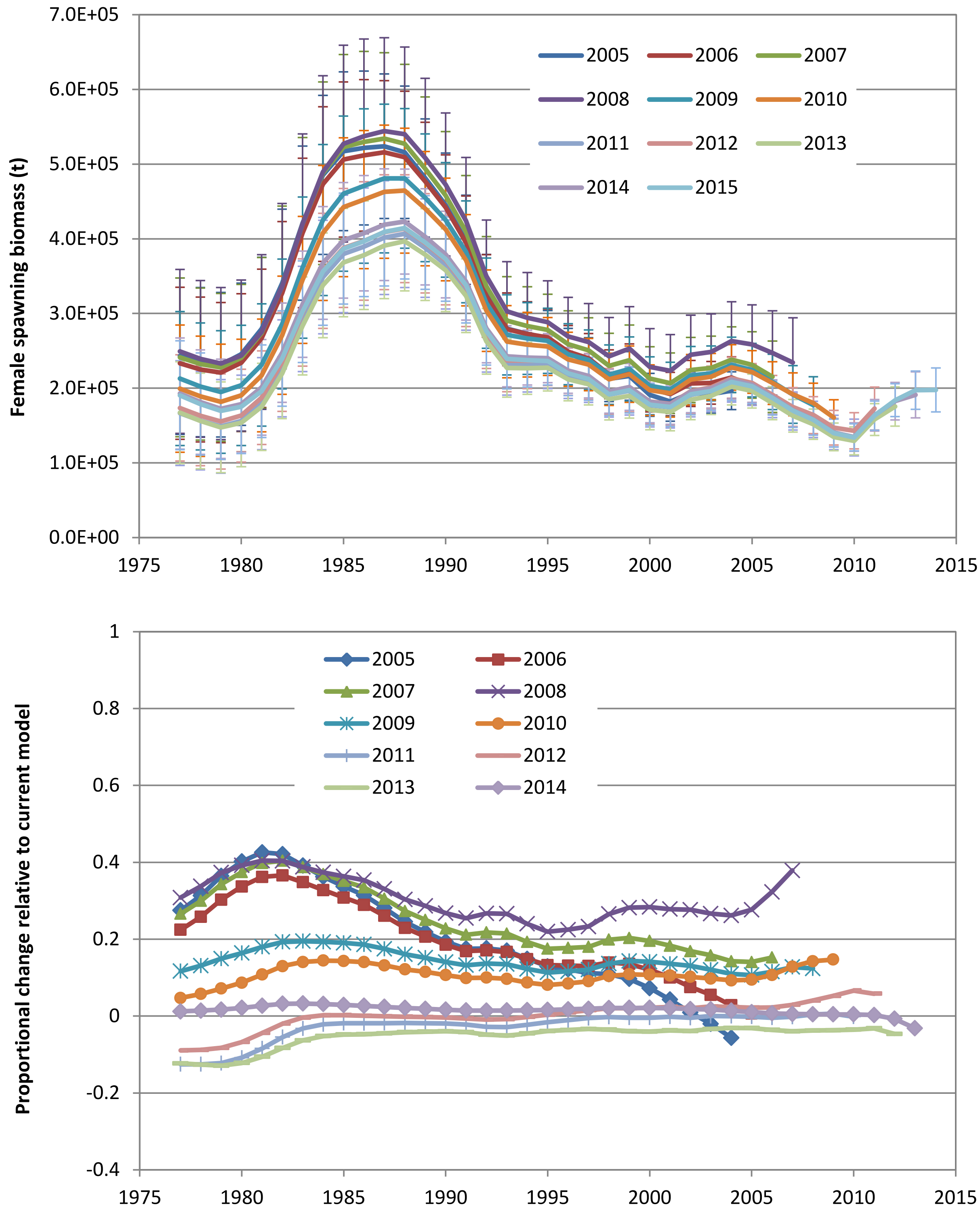


Figure 2.1.10e—Ten-year spawning biomass retrospective analysis of Model 16.4.

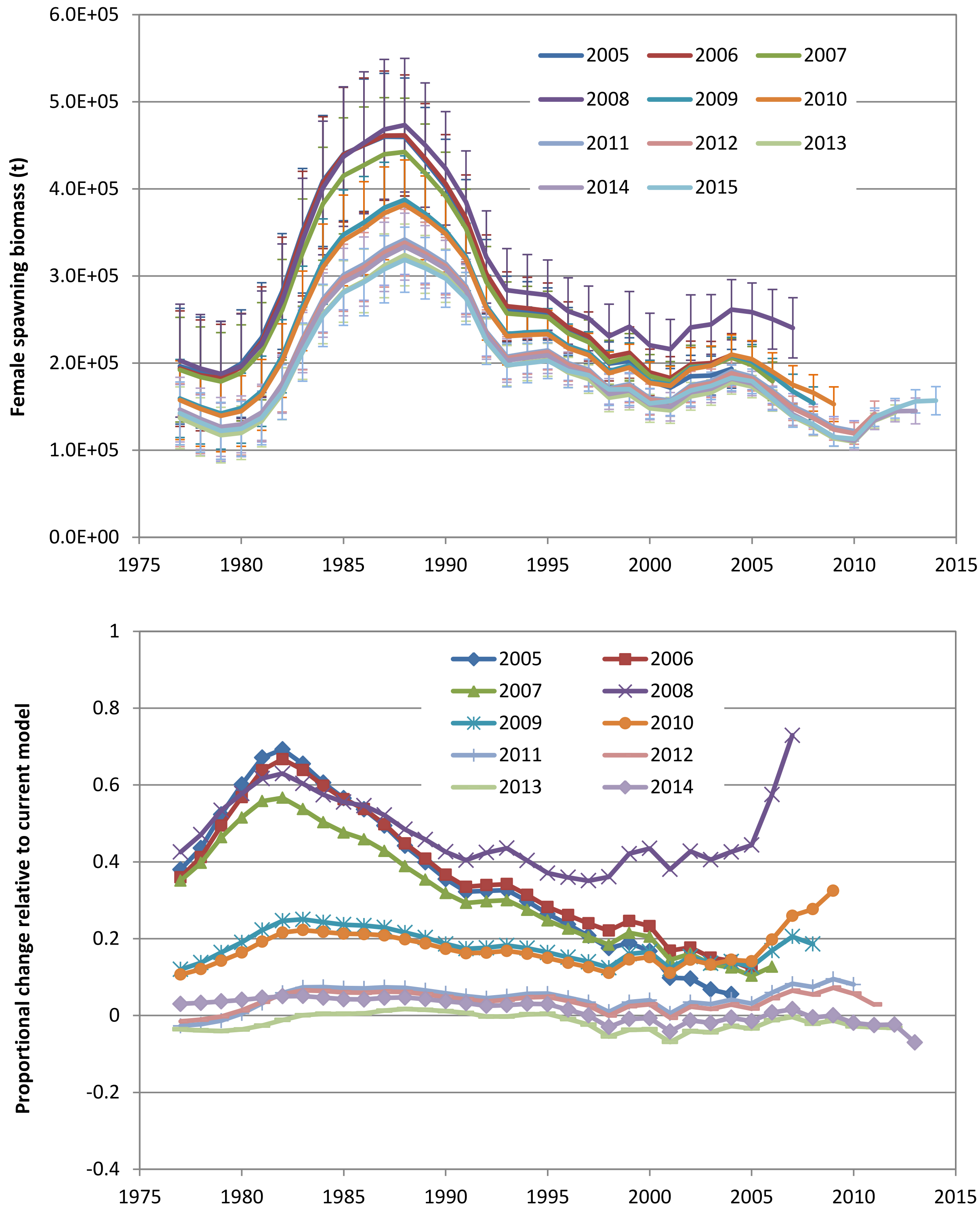


Figure 2.1.10f—Ten-year spawning biomass retrospective analysis of Model 16.5.