Chapter 2: Assessment of the Pacific Cod Stock in the Eastern Bering Sea

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EXECUTIVE SUMMARY

Summary of Changes in Assessment Inputs

Relative to the November edition of last year's BSAI SAFE report, the following substantive changes have been made in the EBS Pacific cod stock assessment.

Changes in the Input Data

1) Catch data for 1991-2015 were updated, and preliminary catch data for 2016 were incorporated.
2) Commercial fishery size composition data for 2015 were updated, and preliminary size composition data from the 2016 commercial fisheries were incorporated.
3) Size composition data from the 2016 EBS shelf bottom trawl survey were incorporated.
4) The numeric abundance estimate from the 2016 EBS shelf bottom trawl survey was incorporated (the 2016 estimate of 640 million fish was down about 35% from the 2015 estimate).
5) Age composition data from the 2015 EBS shelf bottom trawl survey were incorporated.
6) Mean length at age data from the 2015 EBS shelf bottom trawl survey were incorporated.
7) Seasonal catch per unit effort (CPUE) data for the trawl, longline, and pot fisheries from 2015 were updated, and preliminary CPUE data for the trawl, longline, and pot fisheries from 2016 were incorporated.
8) The time series (1997-2015, odd-numbered years only) of relative population numbers and size composition from the NMFS longline survey were incorporated into one model.

Changes in the Assessment Methodology

Many changes have been made or considered in the stock assessment model since the 2015 assessment (Thompson 2015). Six models were presented in this year's preliminary assessment (Appendix 2.1), as requested in May and June by the Joint Team Subcomittee on Pacific Cod Models and the SSC. After reviewing the preliminary assessment, the BSAI Plan Team and SSC requested that two models from the preliminary assessment (one of which is the base model that has been used for setting harvest specifications since the 2011 assessment) and four new models be presented in the final assessment. The assessment author recommends using one of the new models (Model 16.6) to set harvest specifications for 2017 and 2018.

Summary of Results

The principal results of the present assessment, based on the author's **new recommended model**, are listed in the table below (biomass and catch figures are in units of t) and compared with the corresponding quantities from last year's assessment as specified by the SSC:

Quantity	As estimated or *specified last* year for: 2016	2017	As estimated or *recommended this* year for: 2017*	2018*
M (natural mortality rate)	0.34	0.34	0.36	0.36
Tier	3a	3a	3a	3a
Projected total (age 0+) biomass (t)	1,830,000	1,780,000	1,260,000	1,110,000
Projected female spawning biomass (t)	466,000	530,000	327,000	340,000
$B_{100\%}$	806,000	806,000	620,000	620,000
$B_{40\%}$	323,000	323,000	248,000	248,000
$B_{35\%}$	282,000	282,000	217,000	217,000
F_{OFL}	0.35	0.35	0.38	0.38
$maxF_{ABC}$	0.30	0.30	0.31	0.31
F_{ABC}	0.22	0.22	0.31	0.31
OFL (t)	390,000	412,000	284,000	302,000
maxABC (t)	332,000	329,000	239,000	255,000
ABC (t)	255,000	255,000	239,000	255,000
Status	As determined *last* year for: 2014	2015	As determined *this* year for: 2015	2016
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

*Projections are based on assumed catches of 255,000 t, 203,000 t, and 212,000 t in 2016, 2017, and 2018, respectively.

Responses to SSC and Plan Team Comments on Assessments in General

Four comments on assessments in general were addressed in the preliminary assessment (Appendix 2.1). In the interest of efficiency, they are not repeated in this section. The SSC made three additional comments on assessments in general after the preliminary assessment was completed (note that numbering of comments here is continuous with numbering of comments in the preliminary assessment; note also that SSC comments directed to the Plan Teams rather than the assessment authors are not included here):

SSC14 (10/16 minutes): *"The SSC reminds groundfish and crab stock assessment authors to follow their respective guidelines for SAFE preparation."* Close attention was paid to the SAFE chapter guidelines as this assessment was being prepared.

SSC15 (10/16 minutes): *"The SSC found the model numbering in the Eastern Bering Sea (EBS) Pacific cod model extremely helpful and looks forward to having more standardized model numbering across all stock assessment documents."* This assessment continues to use the model numbering convention adopted in last year's final assessment and this year's preliminary assessment.

SSC16 (10/16 minutes): *"The SSC requests that stock assessment authors bookmark their assessment documents and commends those that have already adopted this practice."* This assessment is fully bookmarked.

Responses to SSC and Plan Team Comments Specific to this Assessment

Eleven comments specific to this assessment, some of which contained multiple parts, were addressed in the preliminary assessment (Appendix 2.1). In the interest of efficiency, they are not repeated in this section, with three exceptions: comments SSC7, SSC8, and SSC12. These three comments, along with BSAI Plan Team (BPT) and SSC comments that were developed following completion of the preliminary assessment, are shown below.

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."* Model fit and retrospective performance are considered in selection of the final model (see "Choice of Final Model," under "Model Evaluation" in the "Results" section).

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."* The status quo model was not given automatic preference in this assessment.

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."* In addition to the standard comparison of the spawning biomass and age 0 recruitment time series from the current assessment and last year's assessment, this assessment includes a retrospective analysis of the spawning biomass time series from all assessments since 2006 (Figure 2.15).

BPT1 (9/16 minutes): *"The Team recommends bringing forward as many of the following six models, listed in prioritized order, as time permits, but Models 11.5 and 16.1 at a minimum:*

A. Model 11.5
B. Model 16.1
C. Model 16.1 without empirical weight-at-age
D. Model 16.1 without empirical weight-at-age and including NMFS LL survey
E. Model 16.1 with time-varying survey selectivity
F. Model 16.1 with time-varying fishery selectivity"

All six of the Team's recommended models are included in this assessment. The "placeholder" names for the last four models in the above list (C, D, E, and F) have been replaced by the "final" model names 16.6, 16.7, 16.8, and 16.9. See also comment SSC17.

SSC17 (10/16 minutes): *"The SSC agrees with the Plan Team recommendation to focus on model 16.1 for this assessment cycle and explore additional modifications as time allows. If time is available, we agree with the Plan Team that examining the incremental effects of empirical weight-at-age data and NMFS longline survey data in the model are reasonable next steps."* All of the Team's recommended models are presented in this assessment, including Model 16.1 and models that examine the incremental effects of empirical weight-at-age data (Model 16.6) and NMFS longline survey data (Model 16.7). See also comment BPT1.

SSC18 (10/16 minutes): *"The observed discrepancies among different models in these assessments are a good – if perhaps extreme – example of the model uncertainty that pervades most assessments. This* *uncertainty is largely ignored once a model is approved for specifications. We encourage the authors and Plan Teams to consider approaches such as multi-model inference to account for at least some of the structural uncertainty. We recommend that a working group be formed to address such approaches."* The procedure used to select a final model for this assessment includes a model-averaging aspect (see "Choice of Final Model," under "Model Evaluation" in the "Results" section).

SSC19 (10/16 minutes): *"Regarding the mid-year model vetting process, the SSC re-iterates its recommendation from June to continue for now. The process has proven useful for the industry as an avenue to provide formal input and for the author to prioritize the range of model options to consider."* Planning for next year's assessment will include continuation of the mid-year model vetting process.

SSC20 (10/16 minutes): *"With regard to data weighting, the SSC recommends that the authors consider computing effective sample sizes based on the number of hauls that were sampled for lengths and weights, rather than the number of individual fish."* Because none of the SSC's requested models included computation of effective sample sizes on the basis of the number of sampled hauls, this recommendation will be forwarded to the Joint Team Subcommittee on Pacific Cod Models for consideration at next year's meeting (see comment SSC19).

SSC21 (10/16 minutes): *"The SSC notes that, in spite of the concerns over dome-shaped survey selectivity in the survey, there are many potential mechanisms relating to the availability of larger fish to the survey gear that could result in these patterns, regardless of the efficiency of the trawl gear to capture large fish in its path. For example, in the Bering Sea the patterns could be due to larger Pacific cod being distributed in deeper waters or in the northern Bering Sea at the time of the survey. The northern Bering Sea survey planned for 2017 should provide additional information on the latter possibility."* Data from the 2017 trawl survey of the northern Bering Sea will be examined when they become available.

SSC22 (10/16 minutes): *"Although there is genetic evidence for stock structuring within the Pacific cod population among regions, the uncertainty in model scale for all three regions seems to suggest that some sharing of information among the three assessments might be helpful. Over the long term, authors could consider whether a joint assessment recognizing the population structuring, but simultaneously estimating key population parameters (e.g., natural mortality, catchability or others) might lend more stability and consistency of assumptions for this species."* This recommendation will be forwarded to the Joint Team Subcommittee on Pacific Cod Models for consideration at next year's meeting (see comment SSC19).

INTRODUCTION

General

Pacific cod (*Gadus macrocephalus*) is a transoceanic species, occurring at depths from shoreline to 500 m. The southern limit of the species' distribution is about 34° N latitude, with a northern limit of about 65° N latitude (Lauth 2011). Pacific cod is distributed widely over the eastern Bering Sea (EBS) as well as in the Aleutian Islands (AI) area. Tagging studies (e.g., Shimada and Kimura 1994) have demonstrated significant migration both within and between the EBS, AI, and Gulf of Alaska (GOA). However, recent research indicates the existence of discrete stocks in the EBS and AI (Canino et al. 2005, Cunningham et al. 2009, Canino et al. 2010, Spies 2012). Although the resource in the combined EBS and AI (BSAI) region had been managed as a single unit from 1977 through 2013, separate harvest specifications have been set for the two areas since the 2014 season.

Pacific cod is not known to exhibit any special life history characteristics that would require it to be assessed or managed differently from other groundfish stocks in the EBS.

Review of Life History

Pacific cod eggs are demersal and adhesive. Eggs hatch in about 15 to 20 days. Spawning takes place in the sublittoral-bathyal zone (40 to 290 m) near bottom. Eggs sink to the bottom after fertilization and are somewhat adhesive. Optimal temperature for incubation is 3° to 6°C, optimal salinity is 13 to 23 parts per thousand (ppt), and optimal oxygen concentration is from 2 to 3 ppm to saturation. Little is known about the optimal substrate type for egg incubation.

Little is known about the distribution of Pacific cod larvae, which undergo metamorphosis at about 25 to 35 mm. Larvae are epipelagic, occurring primarily in the upper 45 m of the water column shortly after hatching, moving downward in the water column as they grow.

Juveniles occur mostly over the inner continental shelf at depths of 60 to 150 m. Adults occur in depths from the shoreline to 500 m, although occurrence in depths greater than 300 m is fairly rare. Preferred substrate is soft sediment, from mud and clay to sand. Average depth of occurrence tends to vary directly with age for at least the first few years of life. Neidetcher et al. (2014) have identified spawning locations throughout the Bering Sea and Aleutian Islands.

It is conceivable that mortality rates, both fishing and natural, may vary with age in Pacific cod. In particular, very young fish likely have higher natural mortality rates than older fish (note that this may not be particularly important from the perspective of single-species stock assessment, so long as these higher natural mortality rates do not occur at ages or sizes that are present in substantial numbers in the data). For example, Leslie matrix analysis of a Pacific cod stock occurring off Korea estimated the instantaneous natural mortality rate of 0-year-olds at 2.49% per day (Jung et al. 2009). This may be compared to a mean estimate for age 0 Atlantic cod (*Gadus morhua*) in Newfoundland of 4.17% per day, with a 95% confidence interval ranging from about 3.31% to 5.03% (Robert Gregory, DFO, *pers. commun.*); and age 0 Greenland cod (*Gadus ogac*) of 2.12% per day, with a 95% confidence interval ranging from about 1.56% to 2.68% (Robert Gregory and Corey Morris, DFO, *pers. commun.*).

Although little is known about the likelihood of age-dependent natural mortality in adult Pacific cod, it has been suggested that Atlantic cod may exhibit increasing natural mortality with age (Greer-Walker 1970).

At least one study (Ueda et al. 2006) indicates that age 2 Pacific cod may congregate more, relative to age 1 Pacific cod, in areas where trawling efficiency is reduced (e.g., areas of rough substrate), causing their selectivity to decrease. Also, Atlantic cod have been shown to dive in response to a passing vessel (Ona and Godø 1990, Handegard and Tjøstheim 2005), which may complicate attempts to estimate catchability (Q) or selectivity. It is not known whether Pacific cod exhibit a similar response.

As noted above, Pacific cod are known to undertake seasonal migrations, the timing and duration of which may be variable (Savin 2008).

FISHERY

Description of the Directed Fishery

During the early 1960s, a Japanese longline fishery harvested EBS Pacific cod for the frozen fish market. Beginning in 1964, the Japanese trawl fishery for walleye pollock (*Theragra chalcogramma*) expanded and cod became an important bycatch species and an occasional target species when high concentrations were detected during pollock operations. By the time that the Magnuson Fishery Conservation and Management Act went into effect in 1977, foreign catches of Pacific cod had consistently been in the

30,000-70,000 t range for a full decade. In 1981, a U.S. domestic trawl fishery and several joint venture fisheries began operations in the EBS. The foreign and joint venture sectors dominated catches through 1988, but by 1989 the domestic sector was dominant and by 1991 the foreign and joint venture sectors had been displaced entirely.

Presently, the Pacific cod stock is exploited by a multiple-gear fishery, including trawl, longline, pot, and jig components (although catches by jig gear are very small in comparison to the other three main gear types, with an average annual catch of less than 200 t since 1992). The breakdown of catch by gear during the most recent complete five-year period (2011-2015) is as follows: longline gear accounted for an average of 54% of the catch, trawl gear accounted for an average of 31%, and pot gear accounted for an average of 14% (percentages do not sum to 100 due to rounding).

In the EBS, Pacific cod are caught throughout much of the continental shelf, with NMFS statistical areas 509, 513, 517, 519, and 521 each accounting for at least 5% of the average catch over the most recent 5-year period (2011-2015).

Catches of Pacific cod taken in the EBS for the periods 1964-1980, 1981-1990, and 1991-2016 are shown in Tables 2.1a, 2.1b, and 2.1c, respectively. The catches in Tables 2.1a and 2.1b are broken down by fleet sector (foreign, joint venture, domestic annual processing). The catches in Table 2.1b are also broken down by gear to the extent possible. The catches in Table 2.1c are broken down by gear.

Appendix 2.2 contains an economic performance report on the BSAI Pacific cod fishery.

Effort and CPUE

Figures 2.1 and 2.2 show, subject to confidentiality restrictions, the approximate locations in which hauls or sets sampled during 2015 and 2016 contained Pacific cod. To create these figures, the areas managed under the FMP were divided into 20 km × 20 km squares. For each gear type, a square is shaded if hauls/sets containing Pacific cod from more than two distinct vessels were sampled in it during the respective gear/season/year (Figure 2.1) or gear/year (Figure 2.2). Figure 2.1 shows locations of sampled EBS hauls/sets containing Pacific cod for trawl, longline, and pot gear, for the January-April, May-July, and August-December seasons. Figure 2.2 shows locations of sampled EBS hauls/sets for the same gear types, but aggregated across seasons. More squares are shaded in Figure 2.2 than in Figure 2.1 because aggregating across seasons increases the number of squares that satisfy the confidentiality constraint.

Various gear-specific time series of fishery catch per unit effort (CPUE) are plotted in Figure 2.3. Based on linear regressions over the last 10 years (i.e., beginning in 2006), the slopes for 11 out of the 14 plots are positive and 3 are negative. However, only 3 of the positive slopes and 2 of the negative slopes are statistically significant at the 95% level.

Discards

The catches shown in Tables 2.1b and 2.1c include estimated discards. Discards of Pacific cod in the EBS Pacific cod fisheries are shown for each year 1991-2016 in Table 2.2. Amendment 49, which mandated increased retention and utilization of Pacific cod, was implemented in 1998. From 1991-1997, discard rates in the Pacific cod fishery averaged about 4.9%. Since then, they have averaged about 1.4%.

Management History

The history of acceptable biological catch (ABC), overfishing level (OFL), and total allowable catch (TAC) levels is summarized and compared with the time series of aggregate (i.e., all-gear, combined area) commercial catches in Table 2.3. Note that, prior to 2014, this time series pertains to the combined BSAI region, so the catch time series differs from that shown in Table 2.1, which pertains to the EBS only.

From 1980 through 2015, TAC averaged about 84% of ABC (ABC was not specified prior to 1980), and from 1980 through 2015, commercial catch averaged about 92% of TAC. In 10 of these 36 years, TAC equaled ABC exactly, and in 8 of these 36 years, catch exceeded TAC (by an average of 3%). However, three of those overages occurred in 2007, 2008, and 2010, when TAC was reduced by 3% to account for a small, State-managed fishery inside State of Alaska waters within the AI subarea (similar reductions have been made in all years since 2006); thus, while the combined Federal and State catch exceeded the Federal TAC in 2007, 2008, and 2010 by about 2% or less, the overall target catch (Federal TAC plus State GHL) was *not* exceeded.

Total catch has been less than OFL in every year since 1993.

Changes in ABC over time are typically attributable to three factors: 1) changes in resource abundance, 2) changes in management strategy, and 3) changes in the stock assessment model. Assessments conducted prior to 1985 consisted of simple projections of current survey numbers at age. In 1985, the assessment was expanded to consider all survey numbers at age from 1979-1985. From 1985-1991, the assessment was conducted using an *ad hoc* separable age-structured model. In 1992, the assessment was conducted using the Stock Synthesis modeling software (Methot 1986, 1990) with age-based data. All assessments from 1993 through 2003 continued to use the Stock Synthesis modeling software, but with length-based data. Age data based on a revised ageing protocol were added to the model in the 2004 assessment. At about that time, a major upgrade in the Stock Synthesis architecture resulted in a substantially new product, at that time labeled “SS2” (Methot 2005). The assessment was migrated to SS2 in 2005. Changes to model structure were made annually through 2011, but the base model has remained constant since then (see Appendix 2.3). A note on software nomenclature: The label “SS2” was dropped in 2008. Since then, the program has been known simply as “Stock Synthesis” or “SS,” with several versions typically produced each year, each given an alpha-numeric label.

Beginning with the 2014 fishery, the Board of Fisheries for the State of Alaska has established guideline harvest levels (GHLs) in State waters between 164 and 167 degrees west longitude in the EBS subarea (these have supplemented GHLs that had been set aside for the Aleutian Islands subarea since 2006). The table below shows the formulas that have been used to set the State GHL for the EBS (including the formula anticipated for setting the 2017 GHL):

Year	Formula
2014	0.03 × (EBS ABC + AI ABC)
2015	0.03 × (EBS ABC + AI ABC)
2016	0.064 × EBS ABC
2017	0.064 × EBS ABC

Table 2.4 lists all implemented amendments to the BSAI Groundfish FMP that reference Pacific cod explicitly. The final rule implementing Amendment 113, which deals with the fishery for Pacific cod in the Aleutian Islands, has not been published as of this writing. The proposed rule is available at https://alaskafisheries.noaa.gov/sites/default/files/81fr50444.pdf.

DATA

This section describes data used in the current stock assessment models. It does not attempt to summarize all available data pertaining to Pacific cod in the EBS.

The following table summarizes the sources, types, and years of data included in the data file for at least one of the stock assessment models:

Source	Type	Years
Fishery	Catch biomass	1977-2016
Fishery	Catch size composition	1977-2016
Fishery	Catch per unit effort	1991-2016
EBS shelf bottom trawl survey	Numerical abundance	1982-2016
EBS shelf bottom trawl survey	Size composition	1982-2016
EBS shelf bottom trawl survey	Age composition	1994-2015
EBS shelf bottom trawl survey	Mean size at age	1994-2015
NMFS longline survey	Relative population number	1997-2015 (odd years only)
NMFS longline survey	Size composition	1997-2015 (odd years only)

Fishery

Catch Biomass

Catches taken in the EBS for the period 1977-2016 are shown for the three main gear types in Table 2.5. Table 2.5 makes use of two different types of season: catch seasons and selectivity seasons. The catch seasons are defined as January-February, March-April, May-July, August-October, and November-December. Three selectivity seasons are defined by combining catch seasons 1 and 2 into selectivity season 1, equating catch season 3 with selectivity season 2, and combining catch seasons 4 and 5 into selectivity season 3. The catch seasons were the result of a statistical analysis described in the 2010 assessment (Thompson et al. 2010), and the selectivity seasons were chosen to correspond as closely as possible to the traditional seasons used in assessments prior to 2010 (given the revised catch seasons).

In years for which estimates of the distribution by gear or period were not available, proxies based on other years' distributions were used to create Table 2.5. Catches for the years 1977-1980 may or may not include discards.

The 2014 assessment included an evaluation of 12 methods for projecting year-end catch for the last year in the time series (Thompson 2014). It turned out that the best estimator was simply to set the current year's catch during seasons 4-5 equal to the previous year's catch during those same seasons (up to the TAC for the current year). In Table 2.5, catches for the August-October and November-December seasons of 2016 were estimated by this method, except that ABC was used as the upper limit rather than TAC, due to the 6.4% GHL in the State-managed fishery. The other catches shown in Table 2.5 consist of "official" data from the NMFS Alaska Region. However, other removals of Pacific cod are known to have occurred over the years, including removals due to subsistence fishing, scientific research, and fisheries managed under other FMPs. Estimates of such other removals are shown in Appendix 2.4.

Catch Size Composition

Fishery size compositions are presently available, by gear, for at least one gear type in every year from 1977 through the first part of 2016. Beginning with the 2010 assessment (Thompson et al. 2010), size composition data have been based on 1-cm bins ranging from 4 to 120 cm. Because displaying these data would add a large number of pages to the present document, they are not shown here but are available at: http://www.afsc.noaa.gov/REFM/Docs/2016/EBS_Pcod_fishery_sizecomp_data.xlsx.

Catch Per Unit Effort

Fishery catch per unit effort data are available by gear and season for the years 1991-2016 and are shown in Table 2.6. Units are kg/minute for trawl gear, kg/hook for longline gear, and kg/pot for pot gear; data for 2016 are partial. The "sigma" values shown in the tables are intended only to give an idea of the relative variability of the respective point estimates, and are not actually used in any of the analyses presented here.

Weight at Age

Four years of mean-weight-at-age data are available from the fishery. Most of these come from the longline fishery. The weight-at-age estimation procedure involves a two-stage bootstrap resampling of the data (James Ianelli, AFSC, pers. commun.). Observed tows were first selected with replacement, followed by re-sampling actual lengths and age specimens given those set of tows. Catch (in biomass) within each stratum is also used to compute the relative weights of length and age samples. For each bootstrap sample, the methods outlined in Kimura (1990) were used to compute estimates. The resulting data (in kg) are shown below (no data available for ages 0 or 1):

Year	2	3	4	5	6	7	8	9	10	11	12+
2008	0.001	1.420	2.006	2.938	3.785	5.022	6.666	7.146	8.507	10.004	5.224
2009	0.524	1.482	2.139	3.092	3.981	5.259	5.535	8.927	8.715	7.876	7.993
2010	0.787	1.635	2.340	3.046	3.961	5.377	5.921	5.518	11.946	3.825	4.142
2011	0.001	1.278	2.210	3.244	4.256	5.637	7.529	6.177	3.018	4.445	3.537
Ave:	0.655	1.454	2.174	3.080	3.996	5.324	6.413	6.942	8.046	6.537	5.224

Survey

EBS Shelf Bottom Trawl Survey

Population Indices

Strata 1-6 of the EBS shelf bottom trawl survey have been sampled annually since 1982, and comprise the standard survey area used in this assessment. Beginning in 1987, strata 8 and 9, located to the northwest of the standard survey area, have also been sampled annually. Although strata 8 and 9 do contain Pacific cod, the biomass contained in those strata is typically a small fraction of that contained in the overall survey area (i.e., strata 1-6 plus strata 8-9), averaging less than 3% over the time series. Rather than estimate separate catchability and selectivity parameters for the pre-1987 (strata 1-6) and post-1986 (strata 1-6 plus strata 8-9) portions of the time series, the assessment models for EBS Pacific cod have always used data from strata 1-6 only.

Estimates of total abundance (both in biomass and numbers of fish) obtained from the trawl survey are shown in Table 2.7, together with their respective standard errors. Upper and lower 95% confidence intervals are also shown for the biomass estimates. Survey results indicate that biomass remained relatively constant from 1982 through 1988. The highest biomass ever observed by the survey was the 1994 estimate of 1,368,120 t. Following the high observation in 1994, the survey biomass estimate declined steadily through 1998. The survey biomass estimates remained in the 596,000-619,000 t range from 2002 through 2005. However, the survey biomass estimates dropped after 2005, producing an all-time low in 2007 and again in 2008. Estimated biomass more than doubled between 2009 and 2010, then remained relatively stable for the next three years, followed by another large increase (36%) in 2014, which was sustained through 2015. The 2016 estimate of 944,621 t represented a 14% drop relative to 2015, although it is still 20% above average for the time series.

Numerical abundance has shown more variability than biomass, with a mean squared relative inter-annual change of 0.31 for biomass and 0.36 for abundance. The estimates from 2009-2015 were uniformly above average; the estimate for each of those years was at least 7% above average for the time series, with a mean of 26% above average. The estimate for 2016, however, was 4% below average.

Size and Age Composition

The size compositions from the EBS shelf bottom trawl survey for the years 1982-2016 are shown in Table 2.8 (actual numbers of fish measured are shown in column 2 on the first page). The data are shown according to the 1-cm bins described above for fishery size composition data. Rows in Table 2.8 sum to the actual number of fish measured in each year (subject to slight rounding error).

Age compositions from the 1994-2015 surveys are available. The age compositions and actual sample sizes are shown in Table 2.9.

Mean Length at Age and Weight at Age

Mean-length-at-age data are available for all of the years in which age compositions are available. These are shown, along with sample sizes, in Table 2.10.

Mean-weight-at-age data are also available for all of the years in which age compositions are available. These are shown in Table 2.11.

NMFS Longline Survey

Relative Population Number

Table 2.12 shows NMFS longline survey estimates of relative population number for 1997-2015 (odd-numbered years only), together with their respective standard errors and upper and lower 95% confidence intervals. The time series reached a high of 204,250 in 1997 and a low of 95,553 in 2009. The most recent estimate of 157,996 (in 2015) was 4% above the average for the time series.

Size Composition

The size compositions from the NMFS longline survey for the years 1997-2015 are shown in Table 2.9b (actual numbers of fish measured are shown in column 2 in the upper panel). These data are shown according to the 1-cm bins described above for fishery size composition data. Rows in Table 2.13 sum to the actual number of fish measured in each year (subject to slight rounding error).

ANALYTIC APPROACH

General Model Structure

Although Pacific cod in the EBS and AI were managed on a BSAI-wide basis through 2013, the stock assessment model has always been configured for the EBS stock only. Since 1992, the assessment model has always been developed under some version of the SS modeling framework (technical details given in Methot and Wetzel 2013; see especially Appendix A to that paper). Beginning with the 2005 assessment, the EBS Pacific cod models have all used versions of SS based on the ADMB software package (Fournier et al. 2012). A history of previous model structures, including details of the model used to set harvest specifications for this year, is given in Appendix 2.3.

Version 3.24u (compiled on 08/29/14) of SS was used to run the models in this assessment. The relevant user manual can be obtained at
https://www.st.nmfs.noaa.gov/Assets/science_program/SS_User_Manual_3.24s.pdf .

Description of Alternative Models

As in the final 2015 assessment and this year's preliminary assessment, model numbering follows the protocol given by Option A in the SAFE chapter guidelines. The goal of this protocol is to make it easy to distinguish between major and minor changes in models and to identify the years in which major model changes were introduced. Names of models constituting *major* changes get linked to the year that they are introduced (e.g., Model 11.5 is one of at least five models introduced in 2011 that constituted a major change from the then-current base model), while names of models constituting *minor* changes get linked to the model that they modify (e.g., Model 11.5a would refer to a model that constituted a minor change from Model 11.5). Names of all final models adopted since the first application of an ADMB-based version of SS (in 2005) were translated according to the current naming convention in Table 2.11 of the 2015 assessment (Thompson 2015).

This year's preliminary assessment included Model 11.5, which has been the accepted model since 2011, and five new models (Models 16.1-16.5). Per request of the BSAI Plan Team and SSC (see comments BPT1 and SSC19), six models are presented in this final assessment: Models 11.5 and Model 16.1 from the preliminary assessment, and four variants of Model 16.1 (the paragraphs following this list describe the features of these models in greater detail):

- Model 16.6: Model 16.1 without empirical weight at age
- Model 16.7: Model 16.1 without empirical weight at age and including the NMFS LL survey
- Model 16.8: Model 16.1 with time-varying survey selectivity
- Model 16.9: Model 16.1 with time-varying fishery selectivity

Detailed descriptions of Models 11.5 and 16.1 are given in Appendix 2.1, and a comparison of their key features is provided in Table 2.14. Basically, Model 11.5 is a multi-gear, multi-season model using a time-variant, potentially domed (6-parameter double normal) selectivity function, with the natural mortality rate (*M*) and the trawl survey catchability coefficient (*Q*) fixed outside the model (the latter based on the results of Nichol et al. (2007)); while Model 16.1 is single-gear, single-season model using a time-invariant, asymptotic (2-parameter logistic) selectivity function, with *M* and *Q* estimated inside the model.

Empirical weight at age was first explored for the EBS Pacific cod stock in this year's preliminary assessment. Some key similarities and differences between the models *without* empirical weight at age (Models 11.5, 16.6, and 16.7) and those *with* empirical weight at age (Models 16.1, 16.8, and 16.9) are as follow: All six models estimate (internally) a time-invariant relationship between mean length and age, which is used for fitting the size composition data, among other things. Models *without* empirical weight at age use externally estimated parameters describing a weight-at-length relationship (seasonally varying but constant across years in the case of Model 11.5, annually varying in the cases of Models 16.6 and 16.7) in combination with the internally estimated length-at-age relationship to compute weight at age. Models *with* empirical weight at age bypass the link between weight at age and length at age, and instead use externally estimated, time-varying schedules of weight at age directly.

In Model 16.7, logistic selectivity was assumed for the NMFS longline survey, just as for fishery and trawl survey selectivity.

Time-varying selectivity in Models 16.8 and 16.9 was implemented in the form of annual deviations from a base selectivity function. The "sigma" parameters governing the extent to which selectivity *dev*s can vary from zero (specified as inputs to the model, not estimated internally) in Models 16.8 and 16.9 were set at large values to maximize those models' ability to fit the data, essentially treating each *dev* as an unconstrained parameter. Values of the sigma parameters were increased across several trial runs of each model until the resulting estimate of 2016 spawning biomass did not change (to 3 significant digits) with further increases (see "Parameter Estimates" in the "Results" section).

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.

The preliminary assessment described a change in the method used for the jitter analysis, involving an attempt 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 *dev* vectors in all models, all parameters were estimated with uniform prior distributions. All *dev*s were assumed to be additive.

Parameters Estimated Outside the Assessment Model

Natural Mortality

A value of 0.34 has been used for the natural mortality rate *M* in all BSAI Pacific cod stock assessments since 2007. This value was based on Equation 7 of Jensen (1996) and an age at maturity of 4.9 years (Stark 2007). In response to a request from the SSC, the 2008 assessment included a discussion of alternative values and a justification for the value chosen (Thompson et al. 2008). However, it should be emphasized that, even if Jensen's Equation 7 is exactly right, variability in the estimate of the age at maturity implies that the point of estimate of 0.34 is accompanied by some level of uncertainty. Using the variance for the age at 50% maturity published by Stark (0.0663), the 95% confidence interval for *M* extends from about 0.30 to 0.38.

The value of 0.34 adopted in 2007 replaced the value of 0.37 that had been used in all BSAI Pacific cod stock assessments from 1993 through 2006.

For historical completeness, some other published estimates of *M* for Pacific cod are shown below:

Area	Author	Year	Value
Eastern Bering Sea	Low	1974	0.30-0.45
	Wespestad et al.	1982	0.70
	Bakkala and Wespestad	1985	0.45
	Thompson and Shimada	1990	0.29
	Thompson and Methot	1993	0.37
Gulf of Alaska	Thompson and Zenger	1993	0.27
	Thompson and Zenger	1995	0.50
British Columbia	Ketchen	1964	0.83-0.99
	Fournier	1983	0.65

Model 11.5 in this assessment fixes M at the value of 0.34 used since 2007. Models in the 16.x series estimate M internally.

Variability in Estimated Age

Variability in estimated age in SS is based on the standard deviation of estimated age between “reader” and “tester” age determinations. Weighted least squares regression has been used in the past several assessments to estimate a proportional relationship between standard deviation and age. The regression was recomputed this year over ages 1 through 13, yielding an estimated slope of 0.0852 (i.e, the standard deviation of estimated age was modeled as 0.0852 × age) and a weighted R^2 of 0.98. This regression corresponds to a standard deviation at age 1 of 0.085 and a standard deviation at age 20 of 1.705. These parameters were used for the models in the present assessment.

Weight at Length

Long-term base values along with annual and seasonal deviations of the parameters governing the weight-at-length schedule were estimated in the 2012 assessment using the method described in Annex 2.1.2 of Thompson and Lauth (2012), based on fishery data collected from 1974 through 2011. The same method was used this year to update all weight-length parameters using fishery data through 2015.

Using the functional form weight = $\alpha \times \text{length}^{\beta}$, where weight is measured in kg and length is measured in cm, the long-term base values for the parameters were estimated as α = 5.64006E-06 and β = 3.183145.

Seasonal additive log-scale offsets from the base parameter values (used in Model 11.5 only) were re-estimated in this year’s preliminary assessment, resulting in the following values:

Season:	Jan-Feb	Mar-Apr	May-Jul	Aug-Oct	Nov-Dec
α:	-2.277E-02	2.893E-03	1.913E-02	2.261E-03	-1.416E-02
β:	5.219E-03	-6.735E-04	-4.500E-03	-5.263E-04	3.262E-03

Models in the 16.x series allow for *inter*-annual, but not *intra*-annual, variability in weight-length parameters. Values of annual additive offsets from the base α and β values are shown in Table 2.15.

Weight at Age

Begin-year mean weight at age in the population was estimated outside the assessment model by linearly interpolating the survey mean weights at age shown in Table 2.11. The results of the interpolation are shown in Table 2.16. These values were used in Models 16.1, 16.8, and 16.9. Weight at age in Models 11.5, 16.6, and 16.7 was determined by the internally estimated length-at-age parameters and the externally estimated weight-at-length parameters described immediately above.

Maturity

A detailed history and evaluation of parameter values used to describe the maturity schedule for BSAI Pacific cod was presented in the 2005 assessment (Thompson and Dorn 2005). A length-based maturity schedule was used for many years. The parameter values used for the length-based maturity schedule in the 2005 and 2006 assessments were set on the basis of a study by Stark (2007) at the following values: length at 50% maturity = 58 cm and slope of linearized logistic equation = –0.132. However, in 2007, changes in SS allowed for use of either a length-based or an age-based maturity schedule. Beginning with the 2007 assessment, the accepted model has used an age-based schedule with intercept = 4.88 years and slope = –0.965 (Stark 2007). The use of an age-based rather than a length-based schedule follows a recommendation from the maturity study's author (James Stark, Alaska Fisheries Science Center, *pers. commun.*). The age-based parameters were retained for the models in the present assessment.

Stock-Recruitment "Steepness"

Following the standard Tier 3 approach, both models assume that there is no relationship between stock and recruitment, so the "steepness" parameter is set at 1.0 in each.

Parameters Estimated Inside the Assessment Model

A total of 190 parameters were estimated inside SS for Model 11.5. These include:

1. all three von Bertalanffy growth parameters
2. standard deviation of length at ages 1 and 20
3. mean ageing bias at ages 1 and 20
4. log mean recruitment since the 1976-1977 regime shift
5. offset for log-scale mean recruitment before the 1976-1977 regime shift
6. *dev*s for log-scale initial (i.e., 1977) abundance at ages 1 through 3
7. annual log-scale recruitment *dev*s
8. initial (equilibrium) fishing mortality for the Jan-Apr trawl fishery
9. base values for all trawl survey selectivity parameters
10. gear-, season-, and-block-specific selectivity parameters for nine fisheries
11. annual *dev*s for the *ascending_width* parameter of the trawl survey selectivity function

Parameter counts for models in the 16.x series were as follow:

Model 16.1	Model 16.6	Model 16.7	Model 16.8	Model 16.9
77	77	80	109	157

Parameters in items #1-9 in the above list were also estimated by all models in the 16.x series, except that the initial fishing mortality rate pertained to the entire fishery, not just the Jan-Apr trawl fishery, and the trawl survey selectivity function involved only two parameters rather than five (the single exception occurred in Model 16.8, where the parameter representing the difference in the ages of 95% and 50% selection was fixed at a value of 0.01—see "Parameter Estimates" in the "Results" section). In addition, the following parameters were also estimated by all models in the 16.x series:

1. natural mortality rate
2. Richards growth parameter
3. log-scale recruitment standard deviation (σ_R)
4. *dev*s for log-scale initial (i.e., 1977) abundance at ages 4 through 20
5. log catchability for the trawl survey

6. base values for both fishery selectivity parameters

Model-specific parameters in the 16.x series were as follow:

- log catchability for the NMFS longline survey (Model 16.7)
- values for both parameters of the NMFS longline survey selectivity function (Model 16.7)
- annual *dev*s for the *A50%* parameter of the trawl survey selectivity function (Model 16.8)
- annual *dev*s for both parameters of the fishery selectivity function (Model 16.8)

In all models, uniform prior distributions were used for all parameters, except that *dev* vectors were constrained by input standard deviations, which are somewhat analogous to a joint prior distribution.

For all parameters estimated within individual SS runs, the estimator used was the mode of the logarithm of the joint posterior distribution, which was in turn calculated as the sum of the logarithms of the parameter-specific prior distributions and the logarithm of the likelihood function.

In addition to the above, the full set fishing mortality rates were also estimated internally (year-, season-, and gear-specific for Model 11.5; only year-specific for Models in the 16.x series), but not in the same sense as the above parameters. The fishing mortality rates are determined (almost) exactly as functions of other model parameters, because SS assumes that the input total catch data are true values rather than estimates, so the fishing mortality rates can be computed algebraically given the other parameter values and the input catch data. An option does exist in SS for treating the fishing mortality rates as full parameters, but previous explorations have indicated that adding these parameters has almost no effect on other model output (Methot and Wetzell 2013).

Objective Function Components

All models in this assessment include likelihood components for catch, initial (equilibrium) catch, trawl survey relative abundance, fishery and trawl survey size composition, survey age composition, recruitment, “softbounds” (equivalent to an extremely weak prior distribution used to keep parameters from hitting bounds), and parameter deviations. In addition, Model 11.5 includes an objective function component called “F ballpark,” which acts like a weak prior distribution on fishing mortality in a user-specified year.

In SS, emphasis factors are specified to determine which likelihood components receive the greatest attention during the parameter estimation process. As in previous assessments, all likelihood components were given an emphasis of 1.0 here.

Use of Size Composition Data in Parameter Estimation

Size composition data are assumed to be drawn from a multinomial distribution specific to a particular year, gear, and season within the year (Model 11.5) or just year (Models 16.x). In the parameter estimation process, SS weights a given size composition observation according to the emphasis associated with the respective likelihood component and the sample size specified for the multinomial distribution from which the data are assumed to be drawn. In developing the model upon which SS was originally based, Fournier and Archibald (1982) suggested truncating the multinomial sample size at a value of 400 in order to compensate for contingencies which cause the sampling process to depart from the process that gives rise to the multinomial distribution. For many years, the Pacific cod assessments assumed a multinomial sample size equal to the square root of the true length sample size, rather than the true length sample size itself. Given the true length sample sizes observed in the EBS Pacific cod data, this procedure tended to give values somewhat below 400 while still providing SS with usable information regarding the appropriate effort to devote to fitting individual length samples.

Although the "square root rule" for specifying multinomial sample sizes gave reasonable values, the rule itself was largely *ad hoc*. In an attempt to move toward a more statistically based specification, the 2007 assessment used the harmonic means from a bootstrap analysis of the available fishery length data from 1990-2006 (Thompson et al. 2007). The harmonic means were smaller than the actual sample sizes, but still ranged well into the thousands. A multinomial sample size in the thousands would likely overemphasize the size composition data. As a compromise, the harmonic means were rescaled proportionally in the 2007 assessment so that the average value (across all samples) was 300. However, the question then remained of what to do about years not covered by the bootstrap analysis (2007 and pre-1990) and what to do about the survey samples. The solution adopted in the 2007 assessment was based on an observed consistency in the ratios between the harmonic means (the raw harmonic means, not the rescaled harmonic means) and the actual sample sizes: Whenever the actual sample size exceeded about 400 fish, for the years prior to 1999 the ratio was very consistently close to 0.16, and for the years after 1998 the ratio was very consistently close to 0.34.

This consistency was used to specify the missing values as follows: For fishery data, records with actual sample sizes less than 400 were omitted. Then, 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 from 2007 were tentatively set at 34% of the actual sample size. For the pre-1982 trawl survey, length compositions were tentatively set at 16% of an assumed sample size of 10,000. For the post-1981 trawl survey length compositions, sample sizes were tentatively set at 34% of the actual sample size. Then, with sample sizes for fishery length compositions from 1990-2007 tentatively set at their bootstrap harmonic means (not rescaled), all sample sizes were adjusted proportionally so that the average was 300.

The same procedure was used in the 2008 and 2009 assessments. For the 2010 assessment, however, this procedure had to be modified somewhat, because the bootstrap values for the 1990-2006 size composition data did not match the new bin and seasonal structures. To be as consistent as possible with the approach used to set sample sizes in the 2008 and 2009 assessments, the 2010 and 2011 assessments set sample sizes by applying the 16/34% rule for *all* size composition records with actual sample sizes greater than 400 (not just those lying outside the set of 1990-2006 fishery data), then rescaling proportionally to achieve an average sample size of 300. The same procedure was used for the 2012-2015 assessments, except the pre-1982 trawl survey data were no longer used. Model 11.5 in this year's assessment uses the same procedure as the 2012-2015 assessments. Models 16.x use a similar procedure, except that the input sample sizes for the fishery and trawl survey (and NMFS longline survey, in the case of Model 16.7) are scaled so that the average is 300 *for each*, rather than 300 for all size composition data combined. The full sets of input sample sizes are shown in Table 2.17.

Use of Age Composition Data in Parameter Estimation

Like the size composition data, the age composition data are assumed to be drawn from a multinomial distribution specific to a particular gear, year, and season within the year. Age composition data are input in the same way for all of the models. Input sample sizes for the multinomial distributions were computed by scaling the actual number of otoliths read in each year (Table 2.9, column 2) proportionally such that the average of the input sample sizes was equal to 300, giving the following:

Year:	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
N:	204	163	203	205	181	246	246	263	248	361	284

Year:	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
N:	365	371	412	346	403	369	358	372	405	349	244

Use of Fishery CPUE and Survey Relative Abundance Data in Parameter Estimation

Fishery CPUE data are included in the Model 11.5 for comparative purposes only, and are not included at all in Models 16.x. Their respective catchabilities (in Model 11.5) are estimated analytically, not statistically.

For the surveys, each year's survey abundance estimate is assumed to be drawn from a lognormal distribution specific to that year. The model's estimate of survey abundance in a given year serves as the geometric mean for that year's lognormal distribution, and the ratio of the survey abundance estimate's standard error to the survey abundance estimate itself serves as the distribution's coefficient of variation, which is then transformed into the "sigma" parameter for the lognormal distribution.

Use of Recruitment Deviation "Data" in Parameter Estimation

The likelihood component for recruitment is different from traditional likelihoods because it does not involve "data" in the same sense that traditional likelihoods do. Instead, the log-scale recruitment *dev* plays the role of the datum in a normal distribution with mean zero and specified (or estimated) standard deviation; but, of course, the *dev*s are parameters, not data.

RESULTS

Model Evaluation

The two models used in this assessment are described under "Model Structure" above.

Goodness of Fit, Parameter Estimates, and Derived Quantities

<u>Goodness of Fit</u>

Table 2.18 shows the objective function value for each data component and sub-component in each model. The first part of the table shows negative log-likelihoods for the aggregate data components. The second and third parts of the table break down the size composition and survey abundance index components into fleet-specific values. Models 16.1, 16.7, and 16.8 use the same data sets (including the empirical weight-at-age data), so their objective function values are directly comparable. However, each data set used in the other three models is unique to the respective model, so the objective function values from Models 11.5, 16.6, and 16.7 are not comparable to any other model. Table 2.18 also shows parameter counts for the models, including separate counts for true parameters and constrained *dev*s.

Table 2.19 provides alternative measures of how well the model fits the fishery CPUE (Model 11.5 only) and survey relative abundance data. The column labeled "σave" shows the average of the log-scale standard deviations provided as part of the data. The four right-hand columns show root mean squared errors (RMSE; values closer to σave are better), mean normalized residuals (MNR; values closer to zero are better), standard deviations of normalized residuals (SDNR; values closer to unity are better), and correlations between observed and estimated values (values to unity are better). The first 9 rows of Table 2.19 pertain to the fishery CPUE data. Although Model 11.5 does not actually attempt to fit these data (only the survey CPUE are used), of the 9 correlations with fishery CPUE, all but one are positive. The next 6 lines pertain to the trawl survey index data, which all of the models try to fit. Except for Model 11.5, all of the models give MNRs fairly close to zero for the trawl survey data. However, all of the models give RMSEs quite a bit higher than σave and SDNRs quite a bit higher than unity for the trawl survey data. The last row pertains to the NMFS longline survey (Model 16.7 only).

Figure 2.4a shows the models' fits to the trawl survey abundance data. The proportions of years in which each model's estimate falls within the respective 95% confidence interval are shown below:

Model 11.5	Model 16.1	Model 16.6	Model 16.7	Model 16.8	Model 16.9
0.80	0.77	0.74	0.80	0.89	0.74

Figure 2.4b shows Model 16.7's fit to the NMFS longline survey abundance data. Model 16.7's estimates fall within the respective 95% confidence interval 80% of the time.

Table 2.20 shows how output "effective" sample sizes ("Neff," McAllister and Ianelli 1997) compare to input sample sizes ("Ninp") for the size composition data. Three sets of ratios are provided for each fleet: 1) the arithmetic mean ("A") of the Neff/Ninp ratio, 2) the ratio of arithmetic mean Neff to arithmetic mean Ninp, and 3) the ratio of harmonic mean ("H") Neff to arithmetic mean Ninp. All of the models give ratios greater (usually *much* greater) than or equal to unity for all cases for all three measures, except for the Aug-Dec longline fishery in Model 11.5, where the ratio with the harmonic mean in the numerator is only 0.91. In the case of the survey(s), the ratio with the harmonic mean in the numerator ranges is either equal to or slightly greater than unity for all models (range: 1.00 to 1.15).

Table 2.21 provides a similar analysis for the age composition data, except that the rows in the main part of this table correspond to individual records rather than fisheries or surveys (all age composition data in the models come from the trawl survey). The bottom two rows in the table show the ratios of the means (using the arithmetic mean as the numerator in the next-to-last row and the harmonic mean in the last row). For Models 11.5, 16.1, and 16.6, the ratio with the harmonic mean in the numerator is quite a bit less than unity. For Model 16.1, even the ratio with the arithmetic mean in the numerator is quite a bit less than unity.

The models' fits to the age composition data are shown for each year in Figure 2.5 and aggregated across years in Figure 2.6. Because of the large number of size composition records (n=459 for Model 11.5, n=75 for all models in the 16.x series except Model 16.7, n=85 for Model 16.7), figures showing the models' fits to each record are not included in this document, but are available at: http://www.afsc.noaa.gov/REFM/Docs/2016/EBS_Pcod_sizecomp_fits.xlsx. Time-aggregated size composition fits are shown in Figure 2.7.

Estimates of mean size at ages 1 through 3 (at the time of the survey) from the model are compared to the long-term average survey size composition (through 50 cm) in Figure 2.8. All of the models tend to match the modes, within one or two cm (the estimates from the models in the 16.x series tend to be so close to each other that only the minima and maxima for those models are shown). Model 11.5's fits to the mean-size-at-age data are shown in Figure 2.9 (recall that this model does not actually attempt to fit these data, and the models in the 16.x series do not include these data at all).

Parameter Estimates

Table 2.22 displays all of the parameters (except fishing mortality rates, because these are functions of other parameters) estimated internally in the model, along with the standard deviations of those estimates. Table 2.22 consists of the following parts:

- Table 2.22a shows scalar parameters for all models
- Table 2.22b shows *dev*s for the initial (1977) age composition for all models
- Table 2.22c shows annual log-scale recruitment *dev*s for all models
  - These are plotted in Figure 2.10
- Table 2.22d shows fishery selectivity parameters for Model 11.5
- Table 2.22e shows survey selectivity parameters (including annual *dev*s) for Model 11.5
- Table 2.22f shows main selectivity parameters for models in the 16.x series
- Table 2.22g shows annual selectivity devs for Models 16.8 and 16.9
  - The values in this part of the table may be difficult to interpret, because the estimates are logit-transformed within the bounds (–10,10), with very large input sigma values (σ=10 for A50% in Model 16.8, σ=100 for both parameters in Model 16.9)

As noted under "Parameters Estimated Inside the Assessment Model" in the "Analytic Approach" section, the parameter representing the difference in the ages of 95% and 50% selection for the trawl survey in Model 16.8 was fixed at a value of 0.01. Fixing the value of this parameter was necessary because otherwise it tended to approach zero and the value of the A50% parameter tended to approach unity, meaning that even very small *dev*s produced large changes in selectivity at age 1, and rounding errors appeared to be a problem.

The log-scale trawl survey catchability estimates shown in Table 2.22a imply the following values of *Q* on the back-transformed (natural) scale:

Model 11.5		Model 16.1		Model 16.6		Model 16.7		Model 16.8		Model 16.9	
Est.	CV	Est.	CV	Est.	CV	Est.	CV	Est.	CV	Est.	CV
0.77	n/a	0.61	0.062	0.88	0.065	1.03	0.056	0.66	0.056	0.61	0.061

Table 2.23 shows estimates of fishing mortality. Table 2.23a shows fishing mortality by year in all models, and Table 2.23b shows full-selection seasonal fishing mortality rates for each gear, season, and year in Model 11.5 only.

Derived Quantities

Figure 2.11a shows the time series of female spawning biomass relative to $B_{100\%}$ as estimated by each model, and Figure 2.11b shows the time series of total biomass as estimated by each model, along with the time series of observed survey biomass. Average (across years) ratios of total biomass (as estimated by the models) to survey biomass (as specified in the data) are shown below:

Model 11.5	Model 16.1	Model 16.6	Model 16.7	Model 16.8	Model 16.9
1.74	1.32	1.24	1.05	1.21	1.36

Figure 2.12a shows survey selectivity as estimated by the models (base values for Models 11.5 and 16.8, as those models exhibit time-varying survey selectivity). Model 11.5 allows survey selectivity to be dome-shaped, while all models in the 16.x series force it to be asymptotic. Figure 2.12b shows how trawl survey selectivity varies over time in Models 11.5 and 16.8.

Figure 2.13a shows gear-, season-, and block-specific fishery selectivity as estimated by Model 11.5. In general, selectivities that are not forced to be asymptotic tend to show decreasing selectivity at large size in Model 11.5. Figure 2.13b shows fishery selectivity as estimated by the models in the 16.x series (base values for Model 16.9; note that Model 11.5 does not include base values for fishery selectivity, because each block-specific fishery selectivity parameter is estimated independently). Figure 2.13c shows how fishery selectivity varies over time in Model 16.9.

Table 2.24 contains selected output from the standard projection model, based on SS parameter estimates from the two models, along with the probability that the maximum permissible ABC in each of the next two years will exceed the corresponding true-but-unknown OFL and the probability that the stock will fall below $B_{20\%}$ in each of the next five years (probabilities are given by SS rather than the standard projection model). Note that some of the quantities in Table 2.24 are conditional on catches estimated under Scenario 2 (“author’s F”) in the “Harvest Recommendations” section.

Choice of Final Model

Retrospective Analysis

The SSC has recommended that retrospective performance be considered in the selection of a final model (comment SSC7). Retrospective analyses for all of the models are shown in Figure 2.14. Values of ρ (Mohn 1999, equation corrected in the 2013 Retrospective Working Group report) are shown below:

Model:	11.5	16.1	16.6	16.7	16.8	16.9
ρ:	0.475	0.194	0.147	0.144	0.094	0.250

Model 16.8 has the lowest value of ρ (0.094), and Model 11.5 has by far the highest (0.475).

Although any amount of retrospective bias is undesirable, eliminating such bias entirely is typically an extremely difficult task, which raises the question of how much retrospective bias is acceptable. Hurtado-Ferro et al. (2015) suggest that, for a stock with a natural mortality rate of 0.2, values of ρ higher than 0.20 or lower than –0.15 should be “cause for concern,” while for a stock with a natural mortality rate of 0.4, values of ρ higher than 0.30 or lower than –0.22 should be “cause for concern.” Interpolating the upper limits (because all values of ρ in the above table are positive) of this rule of thumb gives the relationship $\rho\text{max} = 0.1 + 0.5M$. The values of M estimated by the models (or assumed, in the case of Model 11.5) imply the following values of ρmax:

Model:	11.5	16.1	16.6	16.7	16.8	16.9
M:	0.340	0.378	0.363	0.344	0.375	0.376
ρmax:	0.270	0.289	0.282	0.272	0.288	0.288

Model 11.5 is the only model where ρ exceeds the ρmax associated with the model’s value of M.

Other Considerations Regarding Individual Models

All of the models give good fits to the size composition data, but only models 16.7, 16.8, and 16.9 give good fits to the age composition data (based on the ratio of the harmonic mean effective sample size to the arithmetic mean input sample size), and none of the models gives a particularly good fit to the trawl survey abundance data (insofar as they all give RMSEs at least 49% higher than σave and SDNRs of at least 1.47).

Based on AIC, Model 16.9 would be strongly preferred over 16.1, and Model 16.8 would be strongly preferred over either Model 16.1 or Model 16.9. Use of AIC to make comparisons involving any of the other models is not meaningful, due to the fact that they use different data sets.

Only two of the models (11.5 and 16.9) allow time-varying fishery selectivity. Lack of time-varying fishery selectivity in the other four models may be problematic, given that the various gear types likely have different selectivity schedules and the proportions of the catch taken by the various gear types has changed considerably over time. For example, over the period 1991-2016, the proportions of the catch taken by trawl, longline, and pot gear have ranged from 0.24-0.62, 0.37-0.66, and 0.02-0.14, respectively.

Similarly, only two of the models (11.5 and 16.8) allow time-varying survey selectivity, and none of the models allow time-varying survey catchability. Lack of time-varying survey selectivity or catchability may be problematic, given that none of the models gives an acceptable fit to the trawl survey index.

Also on the subject of selectivity, none of the models in the 16.x series allows for the possibility of dome-shaped selectivity for either the trawl survey or the fishery (or the NMFS longline survey, in the case of Model 16.7), whereas the BSAI Plan Team and SSC have recently supported allowing for this possibility, at least for the trawl survey:

> BPT (9/15): *"The model estimates of lower survey selectivity at larger sizes/ages result from the subsequent commercial catches of larger fish that must have been present at the time of the survey but were not caught in the survey in proportion to their abundance, so dome-shaped survey selectivity seems inescapable."*

> SSC (10/16): *"The SSC notes that, in spite of the concerns over dome-shaped selectivity in the survey, there are many potential mechanisms relating to the availability of larger fish to the survey gear that could result in these patterns, regardless of the efficiency of the trawl gear to capture large fish in its path."*

Models 16.1, 16.8, and 16.9 fix the time series of weight at age at externally estimated values, rather than using internally estimated length at age (time-invariant for all models) and externally estimated weight at length (time-invariant in the case of Model 11.5, time-varying in the cases of Models 16.6 and 16.7) to determine the time series of weight at age. Assuming that the estimates are accurate, the main advantage of using externally estimated weight at age is that this method integrates any changes in the length-at-age and weight-at-length relationships without having to estimate them inside the model. Disadvantages (in the context of the present assessment) include the following:

1. No smoothing was applied to the estimates, even though they exhibit a fair amount of variability, at least some of which seem implausible. For example, 10% of the within-cohort changes in weight from ages a to a+1 are negative.
2. Age data exist for only 18 of the 35 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.
5. Consistent with the last several assessments, all of the models in this year's assessment estimate a positive ageing bias (Table 2.22a), a finding which was recently confirmed by Kastelle et al. (2017) on the basis of stable isotope analysis, meaning that the empirical weights at age are likely biased downward.

It may be advisable to examine more statistically sophisticated approaches for estimating weight at age outside of the assessment model, such as those that have been explored for the EBS walleye pollock assessment (Ianelli, this volume).

Also on the subject of statistical sophistication, it may be noted that considerable effort has been expended in the last five years toward developing alternatives to Model 11.5 that incorporate state-of-the-art statistical methodology. In contrast, all of the models in the 16.x series eschew these developments in favor of *ad hoc* definitions of "reasonable" fits to composition data and "non-strange" selectivity patterns.

Model Averaging Considerations

Although none of the models included in this assessment contains all of the features or exhibits all of the performances that might be desired, it is still necessary to choose a final model, and model averaging considerations may provide some guidance for doing so.

In the context of the EBS Pacific cod assessment models, the SSC's first reference to use of model averaging came in December, 2008:

> *"Consider the strengths and weaknesses of model averaging as an alternative to model selection…."*

The above request resulted in the inclusion of a discussion of model averaging in the 2009 assessment (Thompson et al. 2009, p. 401-403). At the time of the 2009 assessment, the practice was to include, to the extent possible, every model that was requested by anyone. One of the concerns expressed in the discussion was that the resulting set of models might be biased, in which case a model averaging approach could easily lead to a worse estimate than simply choosing the best single model. The discussion concluded with the statement, "Therefore, even though model averaging appears to have considerable potential in principle, the approach should not be implemented for the Pacific cod assessments until outstanding issues, such as a protocol for choosing a representative set of models, have been resolved." However, given that the set of models included in the present assessment was the result of a formal, scientific vetting process, the concern about possible bias should be lessened somewhat, even though the resulting set of models is still, in all likelihood, significantly non-random.

Individual members of the SSC have advocated a model averaging approach for the EBS Pacific cod assessment at various times during the last few years, with the SSC as a whole making the following recommendation at this year's October meeting (comment SSC18):

> *"The observed discrepancies among different models in these assessments are a good – if perhaps extreme – example of the model uncertainty that pervades most assessments. This uncertainty is largely ignored once a model is approved for specifications. We encourage the authors and Plan Teams to consider approaches such as multi-model inference to account for at least some of the structural uncertainty."*

Another potential difficulty with a model averaging approach involves reconciling such an approach with the management framework described in the FMP. The SSC acknowledged this potential difficulty at this year's June meeting:

> *"The time may be right for a workshop … on how to select and weight models for ensemble modeling and* ***how to use an ensemble approach with our current harvest control rules****"* (emphasis added).

As an appropriate method for using a full model averaging approach in the context of the current management framework has yet to be determined, a possible short-term compromise would be to choose the single model that gives a 2017 maximum permissible ABC closest to the average across all models. This implies an equal weighting of models, which is a departure from traditional model averaging technique (e.g., Buckland et al. 1997, Hoeting et al. 1999, Burnham and Anderson 2004). However, Stewart and Martell (2015) argued that developing a statistically rigorous method for weighting assessment models with different data sets and different likelihood functions is an extremely challenging task, and that equal weighting may prove to be a reasonable way forward for the time being, particularly if the models in the ensemble have been chosen carefully. The average 2017 maximum permissible ABC across all models is 246,500 t. If it is determined that Model 11.5 is no longer credible, the average across all models in the 16.x series is 228,200 t. In either case, the single model whose 2017 maximum permissible ABC comes closest to the average is Model 16.6 (2017 maximum permissible ABC = 239,000 t).

Final Model: Conclusion

Given that each of the models has something to commend it but each also leaves something to be desired, and that a full model averaging approach does not seem possible at this time, it is reasonable to choose Model 16.6 as the final model, because its 2017 maximum permissible ABC comes closest to the average across all models.

In addition to the within-model retrospective analyses shown in Figure 2.14, Figure 2.15 provides a retrospective look at how the estimated spawning biomass time series has changed between assessments since 2006 (i.e., considering changes in both data and model), as requested by the SSC (see comment SSC12). Note that major model changes occurred in 2007, 2008, 2010, 2011, and 2016; and a minor model change occurred in 2009.

Final Parameter Estimates and Associated Schedules

As noted previously, estimates of all statistically estimated parameters (except fishing mortality rates) are shown for all models in Table 2.22. Estimates of annual fishing mortality rates are shown for all models in Table 2.23a.

Schedules of begin-year length at age, mid-year length at age, and selectivity at age (both fishery and trawl survey) from Model 16.6 are shown in Table 2.25.

Schedules of time-varying weight at age from Model 16.6 are shown in Table 2.26.

Time Series Results

Definitions

The biomass estimates presented here will be defined in three ways: 1) age 0+ biomass, consisting of the biomass of all fish aged 0 years or greater in January of a given year; 2) age 3+ biomass, consisting of the biomass of all fish aged 3 years or greater in January of a given year; and 3) spawning biomass, consisting of the biomass of all spawning females in a given year. The recruitment estimates presented here will be defined as numbers of age 0 fish in a given year. To supplement the full-selection fishing mortality rates already shown in Table 2.23, an alternative "effective" fishing mortality rate will be provided here, defined for each age and time as $-\ln(N_{a+1,t+1}/N_{a,t})-M$, where N = number of fish, a = age measured in years, t = time measured in years, and M = instantaneous natural mortality rate. In addition, the ratio of full-selection fishing mortality to $F_{35\%}$ will be provided.

Biomass

Table 2.27 shows the time series of age 0+, age 3+, and female spawning biomass since 1977 as estimated last year and this year (projections through 2017 are also shown for this year's assessment). The estimated spawning biomass time series are accompanied by their respective standard deviations.

The estimated time series of age 0+ and female spawning biomass are shown, together with the observed time series of trawl survey biomass, in Figure 2.16. Confidence intervals are shown for estimates of female spawning biomass and for the trawl survey biomass estimates.

Recruitment and Numbers at Age

Table 2.28 shows the time series of age 0 recruitment (1000s of fish) for the years since 1977 as estimated last year and this year. Both estimated time series are accompanied by their respective standard deviations.

For the time series as a whole, the largest year class appears to have been the 2008 cohort, and the year classes since 2008 include top three year classes of all time (2008, 2011, and 2013). The set of year classes comprising the top ten is the same this year as last year, except that the 1992 cohort has been added to the list and the 1979 cohort has been removed.

Recruitment estimates for the entire time series (1977-2015) are shown in Figure 2.17, along with their respective 95% confidence intervals.

The coefficient of autocorrelation for the recruitment time series is –0.11.

To date, it has not been possible to estimate a reliable stock-recruitment relationship for this stock. A possible relationship between recruitment and an environmental index is discussed in the "Ecosystem Considerations" section, under "Ecosystem Effects on the Stock."

The estimated time series of numbers at age is shown in Table 2.29.

Fishing Mortality

Table 2.30 shows "effective" fishing mortality by age and year for ages 1-19 and years since 1977.

Figure 2.18 plots the estimated/projected trajectory of relative fishing mortality ($F/F_{35\%}$) and relative female spawning biomass ($B/B_{35\%}$) from 1977 through 2018 based on full-selection fishing mortality, overlaid with the current harvest control rules. Projected values for 2016 and 2017 are from Scenario 2 under "Harvest Recommendations," below. It should be noted that, except for the projection years, these trajectories based on SS output, which may not match the estimates obtained by the standard projection program exactly.

Harvest Recommendations

The results presented in this section are based on Model 16.6. Because the structure of this model differs substantively from Model 11.5 (the model accepted for the last five years by the SSC), a set of parallel results for the items in this section, based on Model 11.5, is provided in Appendix 2.5.

Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines the "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. Because reliable estimates of reference points related to maximum sustainable yield (MSY) are currently not available but reliable estimates of reference points related to spawning per recruit are available, Pacific cod in the EBS have generally been managed under Tier 3 of Amendment 56. Tier 3 uses the following reference points: $B_{40\%}$, equal to 40% of the equilibrium spawning biomass that would be obtained in the absence of fishing; $F_{35\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 35% of the level that would be obtained in the absence of fishing; and $F_{40\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 40% of the level that would be obtained in the absence of fishing. The following formulae apply under Tier 3:

3a) Stock status: $B/B_{40\%} > 1$

$F_{OFL} = F_{35\%}$

$F_{ABC} \leq F_{40\%}$

3b) Stock status: $0.05 < B/B_{40\%} \leq 1$

$F_{OFL} = F_{35\%} \times (B/B_{40\%} - 0.05) \times 1/0.95$

$F_{ABC} \leq F_{40\%} \times (B/B_{40\%} - 0.05) \times 1/0.95$

3c) Stock status: $B/B_{40\%} \leq 0.05$

$F_{OFL} = 0$

$F_{ABC} = 0$

Model 16.6's estimates $F_{35\%}$ and $F_{40\%}$ are 0.38 and 0.31, respectively.

Model 16.6's estimates of $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 620,000 t, 248,000 t, and 217,000 t, respectively.

Specification of OFL and Maximum Permissible ABC

Given the assumptions of Scenario 2 (below), female spawning biomass for 2017 and 2018 is estimated by Model 16.6 to be well above the $B_{40\%}$ value of 248,000 t, thereby placing Pacific cod in sub-tier "a" of Tier 3 for both 2017 and 2018. Given this, Model 16.6 estimates OFL, maximum permissible ABC, and the associated fishing mortality rates for 2017 and 2018 as follows:

Year	Overfishing Level	Maximum Permissible ABC
2017	OFL = 284,000 t	maxABC = 239,000 t
2018	OFL = 302,000 t	maxABC = 255,000 t
2017	*FOFL* = 0.38	*maxFABC* = 0.31
2018	*FOFL* = 0.38	*maxFABC* = 0.31

The age 0+ biomass projections for 2017 and 2018 from Model 16.6 (using SS rather than the standard projection model) are 1,260,000 t and 1,110,000 t.

For comparison, the age 3+ biomass projections for 2017 and 2018 from Model 16.6 (again using SS) are 1,230,000 t and 1,060,000 t.

Standard Harvest Scenarios, Projection Methodology, and Projection Results

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with an estimated vector of numbers at age for January 1, 2017. This requires an appropriate estimate of total catch for 2016. Because each year's stock assessment is finalized before complete (i.e., year-long) catch data are available for that year, it is necessary to extrapolate the available catch data through the end of the year. Year-end catch for 2016 was estimated to equal the ABC, at a value of 255,000 t, using the method described under "Catch Biomass" in the "Data" section.

In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Except for the first projection year under Scenario 2 (see paragraph below), total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

For predicting future catches under Scenario 2, the 2014 assessment (Thompson 2014) described development of the following estimator for future total catch as a function of future ABC: For ABC≥148,000 t, catch = 59,200 t + 0.6×ABC; for ABC<148,000 t, catch = ABC. This estimator was used again in the present assessment, giving a catch of 202,655 t for 2017.

Five of the seven standard scenarios are sometimes used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TACs for 2017 and 2018, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

> *Scenario 1*: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
>
> *Scenario 2*: In all future years, F is set equal to a constant fraction ("author's F") of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2017 recommended in the assessment to the *max* F_{ABC} for 2017, and where catches for 2017 and 2018 are estimated at their most likely values given the 2017 and 2018 maximum permissible ABCs under this scenario. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment; also, catch tends not to equal ABC exactly.)
>
> *Scenario 3*: In all future years, F is set equal to the 2011-2015 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
>
> *Scenario 4*: In all future years, the upper bound on F_{ABC} is set at $F_{60\%}$. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is 1) above its MSY level in 2016 or 2) above 1/2 of its MSY level in 2016 and expected to be above its MSY level in 2026 under this scenario, then the stock is not overfished.)

Scenario 7: In 2017 and 2018, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) above its MSY level in 2018 or 2) above 1/2 of its MSY level in 2018 and expected to be above its MSY level in 2028 under this scenario, then the stock is not approaching an overfished condition.)

Projections corresponding to the standard scenarios are shown for Model 16.6 in Tables 2.31-2.37.

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2017, it does not provide the best estimate of OFL for 2017, because the mean 2017 catch under Scenario 6 is predicated on the 2017 catch being equal to the 2017 OFL, whereas the actual 2017 catch will likely be less than the 2017 OFL. Tables 2.24 and 2.32 contain the appropriate one- and two-year ahead projections for both ABC and OFL under Model 16.6.

ABC Recommendation

Since 2005, the SSC has set ABC at the maximum permissible level every year with the exceptions of the 2007, 2014, and 2015 assessment cycles, when, in each case, the SSC held the ABCs for the next two years constant at the then-current level. Specifications for 2006-2011 were set under Tier 3b, and specifications for 2012-2017 were set under Tier 3a.

In the present assessment, spawning biomass is estimated to be well above $B_{40\%}$, and is projected to remain so for at least the next couple of years. This high biomass is largely the result of the 2006, 2008, 2011, and 2013 year classes, whose strengths have now been confirmed by multiple surveys.

The two concerns that resulted in the decisions during the 2014 and 2015 assessment cycles to keep ABC constant at the 2014 level no longer remain. The first of these was doubt over reliability the sharply declining right-hand limb of the trawl survey selectivity function as estimated by Model 11.5 and the low value of catchability (0.77) assumed in that model. However, Model 16.6 assumes asymptotic trawl survey selectivity, and catchability is freely estimated at a value of 0.88. The second was the large and positive retrospective bias in Model 11.5's estimates of current-year spawning biomass. However, the retrospective bias exhibited by Model 16.6, while still positive, is much lower than that of Model 11.5 (0.147 versus 0.475), and is within the range cited by Hurtado-Ferro et al. (2015) as not being cause for concern.

Because the previous concerns no longer remain, it seems appropriate to set ABC for 2017 and 2018 at the maximum permissible levels (Scenario 2) of 239,000 t and 255,000 t.

Area Allocation of Harvests

No recommendations are made regarding area allocation of harvests.

Status Determination

Under the MSFCMA, the Secretary of Commerce is required to report on the status of each U.S. fishery with respect to overfishing. This report involves the answers to three questions: 1) Is the stock being subjected to overfishing? 2) Is the stock currently overfished? 3) Is the stock approaching an overfished condition?

Is the stock being subjected to overfishing? The official catch estimate for the most recent complete year (2015) is 232,832 t. This is less than the 2015 OFL of 346,000 t. Therefore, the EBS Pacific cod stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest Scenarios #6 and #7 are used in these determinations as follows:

Is the stock currently overfished? This depends on the stock's estimated spawning biomass in 2016:

a. If spawning biomass for 2016 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2016 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c. If spawning biomass for 2016 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 2.36). If the mean spawning biomass for 2026 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario #7 (Table 2.37):

a. If the mean spawning biomass for 2018 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2018 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2018 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2028. If the mean spawning biomass for 2028 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

Based on the above criteria and Tables 2.36 and 2.37, the stock is not overfished and is not approaching an overfished condition.

ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on the Stock

A primary ecosystem phenomenon affecting the Pacific cod stock seems to be the occurrence of periodic "regime shifts," in which central tendencies of key variables in the physical environment change on a scale spanning several years to a few decades (Zador, 2011). One well-documented example of such a regime shift occurred in 1977, and shifts occurring in 1989 and 1999 have also been suggested (e.g., Hare and Mantua 2000). In the present assessment, an attempt was made to estimate the change in mean recruitment of EBS Pacific cod associated with the 1977 regime shift. According to the assessment model, pre-1977 mean recruitment was only about 31% of post-1976 mean recruitment. Establishing a link between environment and recruitment within a particular regime is more difficult. In the 2004 assessment (Thompson and Dorn 2004), for example, the correlations between age 1 recruits spawned since 1977 and monthly values of the Pacific Decadal Oscillation (Mantua et al. 1997) were computed and found to be very weak.

In the 2012 assessment, annual log-scale recruitment *dev*s estimated by the assessment model were regressed against each of several environmental indices summarized by Zador (2011). The highest univariate correlation was obtained for the spring-summer North Pacific Index (NPI), which was developed by Trenberth and Hurrell (1994). The NPI is the area-weighted sea level pressure over the region 30°N-65°N, 160°E-140°W. Further investigations were conducted with monthly NPI data from the Climate Analysis Section of the National Center for Atmospheric Research. The best univariate model obtained in the 2012 analysis was a linear regression of recruitment *dev*s from 1977-2011 against the October-December average NPI (from the same year). Vestfals et al. (2014) have also noted a positive correlation between Pacific cod recruitment and the NPI, although not the October-December average NPI in particular.

In each assessment since 2012, the regression analysis has been updated. This year's regression resulted in a correlation of 0.55 (R^2=0.30). The time series, regression line, and 95% confidence interval from this year's regression are shown in the upper panel of Figure 2.19. According to this regression, the probability of the 2015 year class being higher than the median for the time series is 51%. However, the datum for 2015 (magenta diamond in the upper panel) falls quite a bit below the predicted value from the regression. This marks the first time in the last 11 years (cohorts) that the sign of the *dev* estimated by the assessment model differs from the sign predicted by the regression (although the *dev* predicted by the regression is extremely close to zero: 0.014).

In each assessment since 2013, the main regression analysis has been accompanied by a cross-validation analysis involving creation of 100,000 "training" data sets, each one obtained by randomly sub-sampling 50% of the data without replacement. A regression was performed on each of the training sets, and then the performance of each regression was computed against the corresponding "test" (i.e., non-training) data set. When the NPI *was not* included as an explanatory variable (i.e., only the intercept of the regression was estimated), the RMSE (computed across all 100,000 test data sets) was 0.68, but when the NPI *was* included as an explanatory variable, the RMSE was reduced to 0.59. The distribution of slope parameter estimates from the cross-validation is shown in the middle panel of Figure 2.19. Note that the entire distribution is well above zero, indicating that the observed correlation is very unlikely to be entirely spurious. Two years, 1990 and 2002 (yellow and green diamonds in the upper panel), turned out to be far more influential than any other year in determining the magnitude of the estimated slope, and both of these influences were negative (lower panel of Figure 2.19). In other words, the positive slope is not due to the influence of outliers; if anything, the outliers are making the relationship appear less strong than would be the case without them.

The prey and predators of Pacific cod have been described or reviewed by Albers and Anderson (1985), Livingston (1989, 1991), Lang et al. (2003), Westrheim (1996), and Yang (2004). The composition of Pacific cod prey varies to some extent by time and area. In terms of percent occurrence, some of the most important items in the diet of Pacific cod in the BSAI and GOA have been polychaetes, amphipods, and crangonid shrimp. In terms of numbers of individual organisms consumed, some of the most important dietary items have been euphausids, miscellaneous fishes, and amphipods. In terms of weight of organisms consumed, some of the most important dietary items have been walleye pollock, fishery offal, yellowfin sole, and crustaceans. Small Pacific cod feed mostly on invertebrates, while large Pacific cod are mainly piscivorous. Predators of Pacific cod include Pacific cod, halibut, salmon shark, northern fur seals, Steller sea lions, harbor porpoises, various whale species, and tufted puffin. Major trends in the most important prey or predator species could be expected to affect the dynamics of Pacific cod to some extent.

Fishery Effects on the Ecosystem

Potentially, fisheries for Pacific cod can have effects on other species in the ecosystem through a variety of mechanisms, for example by relieving predation pressure on shared prey species (i.e., species which serve as prey for both Pacific cod and other species), by reducing prey availability for predators of Pacific cod, by altering habitat, by imposing bycatch mortality, or by "ghost fishing" caused by lost fishing gear.

Incidental Catch Taken in the Pacific Cod Fisheries

Incidental catches taken in the Pacific cod fisheries, expressed as proportions of total incidental EBS catches (i.e., across all targets) for the respective species, are summarized in Tables 2.38-2.41. Catches for 2016 in each of these tables are incomplete. Table 2.38 shows incidental catch of FMP species taken from 1991-2016 by each of the three main gear types. Table 2.39 shows incidental catch of certain species of squid and members of the former "other species" complex taken from 2003-2016, aggregated across gear types. Table 2.40 shows incidental catch of prohibited species taken from 1991-2016, aggregated across gear types. Note that all entries for 2003 are marked "n/a" in Table 2.40, due to an error in the database that was discovered too late to be corrected in time for this assessment. Table 2.41 shows incidental catch of non-target species groups taken from 2004-2016, aggregated across gear types (Table 2.41 starts in 2004 rather than 2003 for the same reason that the entries for 2003 are marked "n/a" in Table 2.40).

Steller Sea Lions

Sinclair and Zeppelin (2002) showed that Pacific cod was one of the four most important prey items of Steller sea lions in terms of frequency of occurrence averaged over years, seasons, and sites, and was especially important in winter. Pitcher (1981) and Calkins (1998) also showed Pacific cod to be an important winter prey item in the GOA and BSAI, respectively. Furthermore, the size ranges of Pacific cod harvested by the fisheries and consumed by Steller sea lions overlap, and the fishery has operated to some extent in the same areas used by Steller sea lion as foraging grounds (Livingston (ed.), 2002).

One of the main research emphases of the AFSC Fisheries Interaction Team (now disbanded) was to determine the effectiveness of management measures designed to mitigate the impacts of the Pacific cod fisheries (among others) on Steller sea lions. A study conducted in 2002-2005 using pot fishing gear demonstrated that the local concentration of cod in the Unimak Pass area is very dynamic, so that fishery removals did not create a measurable decline in fish abundance (Conners and Munro 2008). A preliminary tagging study in 2003–2004 showed some cod remaining in the vicinity of the release area in the southeast Bering Sea for several months, while other fish moved distances of 150 km or more north-northwest along the shelf, some within a matter of two weeks (Rand et al. 2015).

Seabirds

The following is a summary of information provided by Livingston (ed., 2002): In both the BSAI and GOA, the northern fulmar (*Fulmarus glacialis*) comprises the majority of seabird bycatch, which occurs primarily in the longline fisheries, including the hook and line fishery for Pacific cod. Shearwater (*Puffinus* spp.) distribution overlaps with the Pacific cod longline fishery in the Bering Sea, and with trawl fisheries in general in both the Bering Sea and GOA. Black-footed albatross (*Phoebastria nigripes*) is taken in much greater numbers in the GOA longline fisheries than the Bering Sea longline fisheries, but is not taken in the trawl fisheries. The distribution of Laysan albatross (*Phoebastria immutabilis*) appears to overlap with the longline fisheries in the central and western Aleutians. The distribution of short-tailed albatross (*Phoebastria albatrus*) also overlaps with the Pacific cod longline fishery along the Aleutian chain, although the majority of the bycatch has taken place along the northern portion of the Bering Sea shelf edge (in contrast, only two takes have been recorded in the GOA). Some success has been obtained in devising measures to mitigate fishery-seabird interactions. For example, on vessels larger than 60 ft. LOA, paired streamer lines of specified performance and material standards have been found to reduce seabird incidental take significantly.

Fishery Usage of Habitat

The following is a summary of information provided by Livingston (ed., 2002): The longline and trawl fisheries for Pacific cod each comprise an important component of the combined fisheries associated with the respective gear type in each of the three major management regions (BS, AI, and GOA). Looking at each gear type in each region as a whole (i.e., aggregating across all target species) during the period 1998-2001, the total number of observed hauls/sets was as follows:

Gear	BS	AI	GOA
Trawl	240,347	43,585	68,436
Longline	65,286	13,462	7,139

In the BS, both longline and trawl effort was concentrated north of False Pass (Unimak Island) and along the shelf edge represented by the boundary of areas 513, 517 (in addition, longline effort was concentrated along the shelf edge represented by the boundary of areas 521-533). In the AI, both longline and trawl effort were dispersed over a wide area along the shelf edge. The catcher vessel longline fishery in the AI occurred primarily over mud bottoms. Longline catcher-processors in the AI tended to fish more over rocky bottoms. In the GOA, fishing effort was also dispersed over a wide area along the shelf, though pockets of trawl effort were located near Chirikof, Cape Barnabus, Cape Chiniak and Marmot Flats. The GOA longline fishery for Pacific cod generally took place over gravel, cobble, mud, sand, and rocky bottoms, in depths of 25 fathoms to 140 fathoms.

Impacts of the Pacific cod fisheries on essential fish habitat were further analyzed in an environmental impact statement by NMFS (2005), followed by a 5-year review in 2010 (NMFS 2010). A second 5-year review is currently in progress.

DATA GAPS AND RESEARCH PRIORITIES

Significant improvements in the quality of this assessment could be made if future research were directed toward closing certain data gaps. At this point, the most critical needs pertain to trawl survey catchability and selectivity, specifically: 1) to understand the factors determining these characteristics, 2) to understand whether/how these characteristics change over time, and 3) to obtain accurate estimates of these characteristics. Additional surveys of the NBS may prove helpful in this regard. Ageing also continues to be an issue, as the assessment models consistently estimate a positive ageing bias. Longer-term research needs include improved understanding of: 1) the ecology of Pacific cod in the EBS, including spatial dynamics, trophic and other interspecific relationships, and the relationship between climate and recruitment; 2) ecology of species taken as bycatch in the Pacific cod fisheries, including estimation of biomass, carrying capacity, and resilience; and 3) ecology of species that interact with Pacific cod, including estimation of interaction strengths, biomass, carrying capacity, and resilience.

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Ongoing contributions: Rick Methot developed the SS software used to conduct the Pacific cod assessments over the last many years. NMFS Alaska Region provided the official catch time series. Numerous AFSC personnel and countless fishery observers collected nearly all of the raw data that were used in this assessment.

Reviewers: Carey McGilliard and the BSAI Groundfish Plan Team provided reviews of this assessment.

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TABLES

Table 2.1a—Summary of 1964-1980 catches (t) of Pacific cod in the EBS by fleet sector. “For.” = foreign, “JV” = joint venture processing, “Dom.” = domestic annual processing. Catches by gear are not available for these years. Catches may not always include discards.

Year	For.	JV	Dom.	Total
1964	13,408	0	0	13,408
1965	14,719	0	0	14,719
1966	18,200	0	0	18,200
1967	32,064	0	0	32,064
1968	57,902	0	0	57,902
1969	50,351	0	0	50,351
1970	70,094	0	0	70,094
1971	43,054	0	0	43,054
1972	42,905	0	0	42,905
1973	53,386	0	0	53,386
1974	62,462	0	0	62,462
1975	51,551	0	0	51,551
1976	50,481	0	0	50,481
1977	33,335	0	0	33,335
1978	42,512	0	31	42,543
1979	32,981	0	780	33,761
1980	35,058	8,370	2,433	45,861

Table 2.1b—Summary of 1981-1990 catches (t) of Pacific cod in the EBS by fleet sector, and gear type. All catches include discards. “LLine” = longline, “Subt.” = sector subtotal. Breakdown of domestic annual processing by gear is not available prior to 1988.

	Foreign			Joint Venture		Domestic Annual Processing				
Year	Trawl	LLine	Subt.	Trawl	Subt.	Trawl	LLine	Pot	Subt.	Total
1981	30,347	5,851	36,198	7,410	7,410	n/a	n/a	n/a	12,899	56,507
1982	23,037	3,142	26,179	9,312	9,312	n/a	n/a	n/a	25,613	61,104
1983	32,790	6,445	39,235	9,662	9,662	n/a	n/a	n/a	45,904	94,801
1984	30,592	26,642	57,234	24,382	24,382	n/a	n/a	n/a	43,487	125,103
1985	19,596	36,742	56,338	35,634	35,634	n/a	n/a	n/a	51,475	143,447
1986	13,292	26,563	39,855	57,827	57,827	n/a	n/a	n/a	37,923	135,605
1987	7,718	47,028	54,746	47,722	47,722	n/a	n/a	n/a	47,435	149,903
1988	0	0	0	106,592	106,592	93,706	2,474	299	96,479	203,071
1989	0	0	0	44,612	44,612	119,631	13,935	145	133,711	178,323
1990	0	0	0	8,078	8,078	115,493	47,114	1,382	163,989	172,067

Table 2.1c—Summary of 1991-2016 catches (t) of Pacific cod in the EBS by gear type. The small catches taken by "other" gear types have been merged proportionally with the catches of the gear types shown. Pot catches for 2014-2016 include the State-managed fishery. Catches for 2016 are through September 25.

Year	Trawl	Longline	Pot	Total
1991	129,393	77,505	3,343	210,241
1992	77,276	79,420	7,514	164,210
1993	81,792	49,296	2,098	133,186
1994	85,294	78,898	8,071	172,263
1995	111,250	97,923	19,326	228,498
1996	92,029	88,996	28,042	209,067
1997	93,995	117,097	21,509	232,601
1998	60,855	84,426	13,249	158,529
1999	51,939	81,520	12,408	145,867
2000	53,841	81,678	15,856	151,376
2001	35,670	90,394	16,478	142,542
2002	51,118	100,371	15,067	166,555
2003	46,717	108,764	19,957	175,438
2004	57,866	108,618	17,264	183,748
2005	52,638	113,190	17,112	182,940
2006	53,236	96,613	18,969	168,818
2007	45,700	77,181	17,248	140,129
2008	33,497	88,936	17,368	139,802
2009	36,959	96,606	13,609	147,174
2010	41,298	81,848	19,723	142,869
2011	64,086	117,066	28,063	209,215
2012	75,534	128,513	28,737	232,784
2013	81,615	124,814	30,261	236,691
2014	72,260	127,311	39,193	238,763
2015	66,677	128,218	37,938	232,832
2016	69,786	98,691	39,314	207,791

Table 2.2—Discards (t) and discard rates (%) of Pacific cod in the Pacific cod fishery, by area, gear, and year for the period 1991-2016 (2016 data are current through September 25). The small amounts of discards taken by other gear types have been merged proportionally into the gear types shown. Note that Amendment 49, which mandated increased retention and utilization, was implemented in 1998.

	Discard amount (t)				Discard rate (%)			
Year	Trawl	Longline	Pot	Total	Trawl	Longline	Pot	All
1991	1,278	1,493	4	2,774	4.11	2.62	0.26	3.10
1992	3,314	1,768	59	5,141	8.68	2.23	0.78	4.12
1993	5,449	2,234	25	7,708	12.89	4.54	1.21	8.24
1994	4,599	2,917	161	7,677	9.98	3.71	2.01	5.79
1995	7,987	3,669	222	11,877	12.24	3.77	1.15	6.54
1996	2,971	2,833	391	6,194	5.12	3.19	1.39	3.54
1997	3,327	3,183	79	6,590	5.42	2.72	0.37	3.30
1998	102	2,456	52	2,610	0.27	2.92	0.39	1.94
1999	353	1,285	52	1,691	0.95	1.58	0.42	1.29
2000	207	2,267	71	2,546	0.56	2.78	0.45	1.90
2001	142	1,531	52	1,726	0.76	1.70	0.32	1.38
2002	557	2,066	91	2,715	1.73	2.06	0.61	1.84
2003	240	1,771	159	2,170	0.79	1.63	0.80	1.36
2004	158	1,814	48	2,019	0.41	1.67	0.28	1.23
2005	86	2,599	61	2,747	0.26	2.30	0.36	1.68
2006	193	1,528	63	1,784	0.54	1.58	0.33	1.18
2007	238	1,373	45	1,656	0.74	1.78	0.26	1.31
2008	13	1,280	156	1,449	0.09	1.44	0.90	1.20
2009	126	1,503	16	1,645	1.02	1.56	0.12	1.34
2010	154	1,402	19	1,575	1.08	1.72	0.10	1.36
2011	121	1,860	32	2,013	0.42	1.59	0.11	1.16
2012	136	1,759	40	1,934	0.38	1.37	0.14	1.01
2013	220	3,066	90	3,376	0.58	2.46	0.30	1.75
2014	192	2,893	155	3,240	0.50	2.28	0.40	1.58
2015	141	2,374	104	2,618	0.43	1.85	0.27	1.32
2016	117	2,029	60	2,206	0.29	2.06	0.15	1.24

Table 2.3—History of BSAI (1977-2013) and EBS (2014-2016) Pacific cod catch, TAC, ABC, and OFL (t). Catch for 2016 is through September 25. Note that specifications through 2013 were for the combined BSAI region, so BSAI catch is shown rather than the EBS catches from Table 2.1 for the period 1977-2013. Source for historical specifications: NPFMC staff.

Year	Catch	TAC	ABC	OFL
1977	36,597	58,000	-	-
1978	45,838	70,500	-	-
1979	39,354	70,500	-	-
1980	51,649	70,700	148,000	-
1981	63,941	78,700	160,000	-
1982	69,501	78,700	168,000	-
1983	103,231	120,000	298,200	-
1984	133,084	210,000	291,300	-
1985	150,384	220,000	347,400	-
1986	142,511	229,000	249,300	-
1987	163,110	280,000	400,000	-
1988	208,236	200,000	385,300	-
1989	182,865	230,681	370,600	-
1990	179,608	227,000	417,000	-
1991	210,241	229,000	229,000	-
1992	164,210	182,000	182,000	188,000
1993	133,186	164,500	164,500	192,000
1994	172,263	191,000	191,000	228,000
1995	228,498	250,000	328,000	390,000
1996	209,067	270,000	305,000	420,000
1997	232,601	270,000	306,000	418,000
1998	158,529	210,000	210,000	336,000
1999	145,867	177,000	177,000	264,000
2000	151,376	193,000	193,000	240,000
2001	142,542	188,000	188,000	248,000
2002	166,555	200,000	223,000	294,000
2003	175,438	207,500	223,000	324,000
2004	183,748	215,500	223,000	350,000
2005	182,940	206,000	206,000	265,000
2006	168,818	194,000	194,000	230,000
2007	140,129	170,720	176,000	207,000
2008	139,802	170,720	176,000	207,000
2009	147,174	176,540	182,000	212,000
2010	142,869	168,780	174,000	205,000
2011	209,215	227,950	235,000	272,000
2012	232,784	261,000	314,000	369,000
2013	236,691	260,000	307,000	359,000
2014	238,763	246,897	255,000	299,000
2015	232,832	240,000	255,000	346,000
2016	207,791	238,680	255,000	390,000

Table 2.4. Amendments to the BSAI Fishery Management Plan (FMP) that reference Pacific cod explicitly (excerpted from Appendix A of the FMP).

Amendment 2, implemented January 12, 1982:

For Pacific cod, decreased maximum sustainable yield to 55,000 t from 58,700 t, increased equilibrium yield to 160,000 t from 58,700 t, increased acceptable biological catch to 160,000 t from 58,700 t, increased optimum yield to 78,700 t from 58,700 t, increased reserves to 3,935 t from 2,935 t, increased domestic annual processing (DAP) to 26,000 t from 7,000 t, and increased DAH to 43,265 t from 24,265 t.

Amendment 4, implemented May 9, 1983, supersedes Amendment 2:

For Pacific Cod, increased equilibrium yield and acceptable biological catch to 168,000 t from 160,000 t, increased optimum yield to 120,000 t from 78,700 t, increased reserves to 6,000 t from 3,935 t, and increased TALFF to 70,735 t from 31,500 t.

Amendment 10, implemented March 16, 1987:

Established Bycatch Limitation Zones for domestic and foreign fisheries for yellowfin sole and other flatfish (including rock sole); an area closed to all trawling within Zone 1; red king crab, C. bairdi Tanner crab, and Pacific halibut PSC limits for DAH yellowfin sole and other flatfish fisheries; a C. bairdi PSC limit for foreign fisheries; and a red king crab PSC limit and scientific data collection requirement for U.S. vessels fishing for Pacific cod in Zone 1 waters shallower than 25 fathoms.

Amendment 24, implemented February 28, 1994, and effective through December 31, 1996:

1. Established the following gear allocations of BSAI Pacific cod TAC as follows: 2 percent to vessels using jig gear; 44.1 percent to vessels using hook-and-line or pot gear, and 53.9 percent to vessels using trawl gear.
2. Authorized the seasonal apportionment of the amount of Pacific cod allocated to gear groups. Criteria for seasonal apportionments and the seasons authorized to receive separate apportionments will be set forth in regulations.

Amendment 46, implemented January 1, 1997, superseded Amendment 24:

Replaced the three year Pacific cod allocation established with Amendment 24, with the following gear allocations in BSAI Pacific cod: 2 percent to vessels using jig gear; 51 percent to vessels using hook-and-line or pot gear; and 47 percent to vessels using trawl gear. The trawl apportionment will be divided 50 percent to catcher vessels and 50 percent to catcher processors. These allocations as well as the seasonal apportionment authority established in Amendment 24 will remain in effect until amended.

Amendment 49, implemented January 3, 1998:

Implemented an Increased Retention/Increased Utilization Program for pollock and Pacific cod beginning January 1, 1998 and rock sole and yellowfin sole beginning January 1, 2003.

Amendment 64, implemented September 1, 2000, revised Amendment 46:

Allocated the Pacific cod Total Allowable Catch to the jig gear (2 percent), fixed gear (51 percent), and trawl gear (47 percent) sectors.

Amendment 67, implemented May 15, 2002, revised Amendment 39:

Established participation and harvest requirements to qualify for a BSAI Pacific cod fishery endorsement for fixed gear vessels.

Amendment 77, implemented January 1, 2004, revised Amendment 64:

Implemented a Pacific cod fixed gear allocation between hook and line catcher processors (80 percent), hook and line catcher vessels (0.3 percent), pot catcher processors (3.3 percent), pot catcher vessels (15 percent), and catcher vessels (pot or hook and line) less than 60 feet (1.4 percent).

Amendment 80, implemented on July 26, 2007, superseded Amendments 49 and 75:

1. Allocates non-pollock groundfish in the BSAI among trawl sectors
2. Creates a limited access privilege program to facilitate the formation of harvesting cooperative in the non-American Fisheries Act trawl catcher/processor sector.

Amendment 85, partially implemented on March 5, 2007, superseded Amendments 46 and 77:

Implemented a gear allocation among all non-CDQ fishery sectors participating in the directed fishery for Pacific cod. After deduction of the CDQ allocation, the Pacific cod TAC is apportioned to vessels using jig gear (1.4 percent); catcher processors using trawl gear listed in Section 208(e)(1)-(20) of the AFA (2.3 percent); catcher processors using trawl gear as defined in Section 219(a)(7) of the Consolidated Appropriations Act, 2005 (Public Law 108-447) (13.4 percent); catcher vessels using trawl gear (22.1 percent); catcher processors using hook-and-line gear (48.7 percent); catcher vessels ≥60’ LOA using hook-and-line gear (0.2 percent); catcher processors using pot gear (1.5 percent); catcher vessels ≥60’ LOA using pot gear (8.4 percent); and catcher vessels <60’ LOA that use either hook-and-line gear or pot gear (2.0 percent).

Amendment 99, implemented on January 6, 2014 (effective February 6, 2014):

Allows holders of license limitation program (LLP) licenses endorsed to catch and process Pacific cod in the Bering Sea/Aleutian Islands hook-and-line fisheries to use their LLP license on larger newly built or existing vessels by:

1. Increasing the maximum vessel length limits of the LLP license, and
2. Waiving vessel length, weight, and horsepower limits of the American Fisheries Act.

Amendment 103, implemented November 14, 2014:

Revise the Pribilof Islands Habitat Conservation Zone to close to fishing for Pacific cod with pot gear (in addition to the closure to all trawling).

Table 2.5 (p. 1 of 4)— EBS catch (t) of Pacific cod by year, gear, and season for the years 1977-2016 as configured in Model 11.5. Because direct estimates of gear- and period-specific catches are not available for the years 1977-1980, the figures shown here are estimates derived by distributing each year's total catch according to the average proportion observed for each gear/period combination during the years 1981-1988. The small amounts of catch from "other" gear types have been merged into the gear types listed below proportionally.

		Trawl fishery			Longline fishery			Pot fishery		
Year	Season	Jan-Apr	May-Jul	Aug-Dec	Jan-Apr	May-Jul	Aug-Dec	Jan-Apr	May-Jul	Aug-Dec
1977	Jan-Feb	5974	0	0	740	0	0	0	0	0
1977	Mar-Apr	5974	0	0	740	0	0	0	0	0
1977	May-Jul	0	7080	0	0	544	0	0	0	0
1977	Aug-Oct	0	0	5475	0	0	1733	0	0	0
1977	Nov-Dec	0	0	3429	0	0	1646	0	0	0
1978	Jan-Feb	7884	0	0	977	0	0	0	0	0
1978	Mar-Apr	7884	0	0	977	0	0	0	0	0
1978	May-Jul	0	9343	0	0	717	0	0	0	0
1978	Aug-Oct	0	0	7226	0	0	2286	0	0	0
1978	Nov-Dec	0	0	4526	0	0	2172	0	0	0
1979	Jan-Feb	6452	0	0	800	0	0	0	0	0
1979	Mar-Apr	6452	0	0	800	0	0	0	0	0
1979	May-Jul	0	7646	0	0	587	0	0	0	0
1979	Aug-Oct	0	0	5914	0	0	1871	0	0	0
1979	Nov-Dec	0	0	3704	0	0	1778	0	0	0
1980	Jan-Feb	7355	0	0	912	0	0	0	0	0
1980	Mar-Apr	7355	0	0	912	0	0	0	0	0
1980	May-Jul	0	8716	0	0	669	0	0	0	0
1980	Aug-Oct	0	0	6741	0	0	2133	0	0	0
1980	Nov-Dec	0	0	4222	0	0	2027	0	0	0
1981	Jan-Feb	6027	0	0	514	0	0	0	0	0
1981	Mar-Apr	6027	0	0	514	0	0	0	0	0
1981	May-Jul	0	12405	0	0	673	0	0	0	0
1981	Aug-Oct	0	0	15439	0	0	2179	0	0	0
1981	Nov-Dec	0	0	10743	0	0	1971	0	0	0
1982	Jan-Feb	8697	0	0	145	0	0	0	0	0
1982	Mar-Apr	8697	0	0	145	0	0	0	0	0
1982	May-Jul	0	16449	0	0	389	0	0	0	0
1982	Aug-Oct	0	0	14224	0	0	1312	0	0	0
1982	Nov-Dec	0	0	8174	0	0	1154	0	0	0
1983	Jan-Feb	16303	0	0	1176	0	0	0	0	0
1983	Mar-Apr	16303	0	0	1176	0	0	0	0	0
1983	May-Jul	0	24351	0	0	1087	0	0	0	0
1983	Aug-Oct	0	0	19453	0	0	1627	0	0	0
1983	Nov-Dec	0	0	11353	0	0	1378	0	0	0
1984	Jan-Feb	19295	0	0	2005	0	0	0	0	0
1984	Mar-Apr	19295	0	0	2005	0	0	0	0	0
1984	May-Jul	0	26290	0	0	2421	0	0	0	0
1984	Aug-Oct	0	0	20844	0	0	10463	0	0	0
1984	Nov-Dec	0	0	12523	0	0	9754	0	0	0
1985	Jan-Feb	22269	0	0	5481	0	0	0	0	0
1985	Mar-Apr	22269	0	0	5481	0	0	0	0	0
1985	May-Jul	0	30250	0	0	3881	0	0	0	0
1985	Aug-Oct	0	0	20713	0	0	11260	0	0	0
1985	Nov-Dec	0	0	11155	0	0	10690	0	0	0

Table 2.5 (p. 2 of 4)— EBS catch (t) of Pacific cod by year, gear, and season for the years 1977-2015 as configured in Model 11.5.

		Trawl fishery			Longline fishery			Pot fishery		
Year	Season	Jan-Apr	May-Jul	Aug-Dec	Jan-Apr	May-Jul	Aug-Dec	Jan-Apr	May-Jul	Aug-Dec
1986	Jan-Feb	23914	0	0	3558	0	0	0	0	0
1986	Mar-Apr	23914	0	0	3558	0	0	0	0	0
1986	May-Jul	0	29689	0	0	2071	0	0	0	0
1986	Aug-Oct	0	0	20057	0	0	8785	0	0	0
1986	Nov-Dec	0	0	11191	0	0	8639	0	0	0
1987	Jan-Feb	25765	0	0	8379	0	0	0	0	0
1987	Mar-Apr	25765	0	0	8379	0	0	0	0	0
1987	May-Jul	0	23285	0	0	4671	0	0	0	0
1987	Aug-Oct	0	0	15932	0	0	13617	0	0	0
1987	Nov-Dec	0	0	10731	0	0	13376	0	0	0
1988	Jan-Feb	50988	0	0	214	0	0	0	0	0
1988	Mar-Apr	50988	0	0	214	0	0	0	0	0
1988	May-Jul	0	42602	0	0	571	0	0	0	0
1988	Aug-Oct	0	0	32137	0	0	1005	0	0	0
1988	Nov-Dec	0	0	23583	0	0	773	0	0	0
1989	Jan-Feb	50984	0	0	1524	0	0	13	0	0
1989	Mar-Apr	50984	0	0	1524	0	0	13	0	0
1989	May-Jul	0	36816	0	0	4074	0	0	49	0
1989	Aug-Oct	0	0	15561	0	0	4235	0	0	46
1989	Nov-Dec	0	0	9899	0	0	2579	0	0	25
1990	Jan-Feb	40658	0	0	5268	0	0	0	0	0
1990	Mar-Apr	40658	0	0	5268	0	0	0	0	0
1990	May-Jul	0	27930	0	0	13730	0	0	657	0
1990	Aug-Oct	0	0	9063	0	0	14197	0	0	526
1990	Nov-Dec	0	0	5262	0	0	8650	0	0	198
1991	Jan-Feb	34996	0	0	8229	0	0	20	0	0
1991	Mar-Apr	65276	0	0	12317	0	0	522	0	0
1991	May-Jul	0	16403	0	0	20115	0	0	410	0
1991	Aug-Oct	0	0	12271	0	0	21276	0	0	2306
1991	Nov-Dec	0	0	6420	0	0	9312	0	0	369
1992	Jan-Feb	23310	0	0	13660	0	0	13	0	0
1992	Mar-Apr	31836	0	0	22121	0	0	833	0	0
1992	May-Jul	0	11784	0	0	27051	0	0	5321	0
1992	Aug-Oct	0	0	8182	0	0	16319	0	0	1992
1992	Nov-Dec	0	0	1788	0	0	0	0	0	0
1993	Jan-Feb	27998	0	0	22396	0	0	24	0	0
1993	Mar-Apr	35294	0	0	21434	0	0	1597	0	0
1993	May-Jul	0	5552	0	0	4744	0	0	2093	0
1993	Aug-Oct	0	0	6944	0	0	3002	0	0	0
1993	Nov-Dec	0	0	1544	0	0	564	0	0	0
1994	Jan-Feb	13856	0	0	22458	0	0	0	0	0
1994	Mar-Apr	43634	0	0	29089	0	0	4159	0	0
1994	May-Jul	0	4453	0	0	6210	0	0	1792	0
1994	Aug-Oct	0	0	20070	0	0	20718	0	0	3133
1994	Nov-Dec	0	0	2691	0	0	0	0	0	0
1995	Jan-Feb	31939	0	0	29936	0	0	23	0	0
1995	Mar-Apr	58159	0	0	34516	0	0	7715	0	0
1995	May-Jul	0	1145	0	0	4161	0	0	7342	0
1995	Aug-Oct	0	0	19770	0	0	21305	0	0	2927
1995	Nov-Dec	0	0	119	0	0	8802	0	0	640

Table 2.5 (p. 3 of 4)— EBS catch (t) of Pacific cod by year, gear, and season for the years 1977-2015 as configured in Model 11.5.

		Trawl fishery			Longline fishery			Pot fishery		
Year	Season	Jan-Apr	May-Jul	Aug-Dec	Jan-Apr	May-Jul	Aug-Dec	Jan-Apr	May-Jul	Aug-Dec
1996	Jan-Feb	21151	0	0	28835	0	0	25	0	0
1996	Mar-Apr	50436	0	0	29471	0	0	12571	0	0
1996	May-Jul	0	6797	0	0	4179	0	0	11600	0
1996	Aug-Oct	0	0	10543	0	0	23629	0	0	4347
1996	Nov-Dec	0	0	1475	0	0	3278	0	0	728
1997	Jan-Feb	25713	0	0	31971	0	0	30	0	0
1997	Mar-Apr	52321	0	0	30578	0	0	9639	0	0
1997	May-Jul	0	5174	0	0	8145	0	0	7352	0
1997	Aug-Oct	0	0	9321	0	0	21323	0	0	3780
1997	Nov-Dec	0	0	2366	0	0	24250	0	0	637
1998	Jan-Feb	15535	0	0	29256	0	0	1719	0	0
1998	Mar-Apr	27765	0	0	19060	0	0	5613	0	0
1998	May-Jul	0	4940	0	0	3709	0	0	5321	0
1998	Aug-Oct	0	0	12586	0	0	16155	0	0	1890
1998	Nov-Dec	0	0	1330	0	0	13196	0	0	454
1999	Jan-Feb	17660	0	0	30548	0	0	1900	0	0
1999	Mar-Apr	24661	0	0	20876	0	0	4937	0	0
1999	May-Jul	0	3028	0	0	3283	0	0	5420	0
1999	Aug-Oct	0	0	5658	0	0	20571	0	0	2054
1999	Nov-Dec	0	0	229	0	0	4986	0	0	56
2000	Jan-Feb	18935	0	0	30652	0	0	11647	0	0
2000	Mar-Apr	23194	0	0	8195	0	0	4105	0	0
2000	May-Jul	0	3800	0	0	1394	0	0	1077	0
2000	Aug-Oct	0	0	6199	0	0	22107	0	0	1667
2000	Nov-Dec	0	0	590	0	0	17816	0	0	0
2001	Jan-Feb	7962	0	0	18208	0	0	2206	0	0
2001	Mar-Apr	13895	0	0	16568	0	0	11279	0	0
2001	May-Jul	0	3500	0	0	3882	0	0	1005	0
2001	Aug-Oct	0	0	8904	0	0	30967	0	0	2970
2001	Nov-Dec	0	0	803	0	0	19752	0	0	641
2002	Jan-Feb	13410	0	0	35198	0	0	1845	0	0
2002	Mar-Apr	21130	0	0	14486	0	0	8407	0	0
2002	May-Jul	0	8163	0	0	1903	0	0	531	0
2002	Aug-Oct	0	0	8594	0	0	34463	0	0	2997
2002	Nov-Dec	0	0	291	0	0	14335	0	0	803
2003	Jan-Feb	15389	0	0	35435	0	0	11705	0	0
2003	Mar-Apr	16452	0	0	17100	0	0	1651	0	0
2003	May-Jul	0	6752	0	0	2748	0	0	454	0
2003	Aug-Oct	0	0	7793	0	0	35120	0	0	5141
2003	Nov-Dec	0	0	264	0	0	18004	0	0	1429
2004	Jan-Feb	21886	0	0	37436	0	0	9023	0	0
2004	Mar-Apr	17432	0	0	16627	0	0	2854	0	0
2004	May-Jul	0	9773	0	0	2919	0	0	946	0
2004	Aug-Oct	0	0	8766	0	0	31394	0	0	3841
2004	Nov-Dec	0	0	75	0	0	20181	0	0	596
2005	Jan-Feb	27361	0	0	46935	0	0	9033	0	0
2005	Mar-Apr	15119	0	0	6612	0	0	3114	0	0
2005	May-Jul	0	7410	0	0	3290	0	0	0	0
2005	Aug-Oct	0	0	2892	0	0	35350	0	0	4550
2005	Nov-Dec	0	0	113	0	0	20756	0	0	407

Table 2.5 (p. 4 of 4)— EBS catch (t) of Pacific cod by year, gear, and season for the years 1977-2015 as configured in Model 11.5. Aug-Oct and Nov-Dec catches for 2016 are extrapolated.

		Trawl fishery			Longline fishery			Pot fishery		
Year	Season	Jan-Apr	May-Jul	Aug-Dec	Jan-Apr	May-Jul	Aug-Dec	Jan-Apr	May-Jul	Aug-Dec
2006	Jan-Feb	28611	0	0	45149	0	0	10608	0	0
2006	Mar-Apr	13901	0	0	6017	0	0	3297	0	0
2006	May-Jul	0	6347	0	0	1905	0	0	364	0
2006	Aug-Oct	0	0	4357	0	0	42493	0	0	3887
2006	Nov-Dec	0	0	70	0	0	1013	0	0	799
2007	Jan-Feb	15947	0	0	42943	0	0	10702	0	0
2007	Mar-Apr	16302	0	0	1917	0	0	1139	0	0
2007	May-Jul	0	10225	0	0	1213	0	0	479	0
2007	Aug-Oct	0	0	3190	0	0	30304	0	0	4922
2007	Nov-Dec	0	0	67	0	0	777	0	0	0
2008	Jan-Feb	15579	0	0	41627	0	0	8850	0	0
2008	Mar-Apr	7093	0	0	3657	0	0	1951	0	0
2008	May-Jul	0	3868	0	0	2665	0	0	225	0
2008	Aug-Oct	0	0	6306	0	0	33019	0	0	6218
2008	Nov-Dec	0	0	655	0	0	7966	0	0	124
2009	Jan-Feb	12194	0	0	44713	0	0	9395	0	0
2009	Mar-Apr	9602	0	0	3726	0	0	1722	0	0
2009	May-Jul	0	4174	0	0	2239	0	0	257	0
2009	Aug-Oct	0	0	10491	0	0	35381	0	0	1301
2009	Nov-Dec	0	0	403	0	0	10494	0	0	1081
2010	Jan-Feb	16351	0	0	40595	0	0	10695	0	0
2010	Mar-Apr	8148	0	0	2050	0	0	1726	0	0
2010	May-Jul	0	3982	0	0	2904	0	0	268	0
2010	Aug-Oct	0	0	9602	0	0	25115	0	0	5432
2010	Nov-Dec	0	0	1601	0	0	12616	0	0	1786
2011	Jan-Feb	21215	0	0	29312	0	0	15345	0	0
2011	Mar-Apr	20797	0	0	26006	0	0	2297	0	0
2011	May-Jul	0	7275	0	0	14044	0	0	594	0
2011	Aug-Oct	0	0	13355	0	0	31048	0	0	8954
2011	Nov-Dec	0	0	1728	0	0	17245	0	0	0
2012	Jan-Feb	39141	0	0	33808	0	0	19238	0	0
2012	Mar-Apr	14802	0	0	24489	0	0	2295	0	0
2012	May-Jul	0	8667	0	0	21241	0	0	794	0
2012	Aug-Oct	0	0	11670	0	0	27629	0	0	6232
2012	Nov-Dec	0	0	1058	0	0	20888	0	0	832
2013	Jan-Feb	35433	0	0	38744	0	0	19229	0	0
2013	Mar-Apr	16948	0	0	21974	0	0	3277	0	0
2013	May-Jul	0	5981	0	0	13880	0	0	0	0
2013	Aug-Oct	0	0	20904	0	0	26573	0	0	5892
2013	Nov-Dec	0	0	1608	0	0	22682	0	0	3567
2014	Jan-Feb	31400	0	0	32550	0	0	21523	0	0
2014	Mar-Apr	22055	0	0	26084	0	0	7124	0	0
2014	May-Jul	0	7069	0	0	21204	0	0	154	0
2014	Aug-Oct	0	0	11014	0	0	25890	0	0	6093
2014	Nov-Dec	0	0	990	0	0	22085	0	0	3528
2015	Jan-Feb	22015.6	0	0	27883.1	0	0	20031.6	0	0
2015	Mar-Apr	25510	0	0	27187.3	0	0	7904	0	0
2015	May-Jul	0	7883.76	0	0	20844	0	0	160.726	0
2015	Aug-Oct	0	0	10615	0	0	30960	0	0	6771
2015	Nov-Dec	0	0	626	0	0	21221	0	0	3218

Table 2.6 (page 1 of 3)— Fishery CPUE as configured in Model 11.5. Units are kg/minute for trawl gear, kg/hook for longline gear, and kg/pot for pot gear.

Jan-Apr trawl fishery				May-Jul trawl fishery				Aug-Dec trawl fishery			
Year	Season	CPUE	Sigma	Year	Season	CPUE	Sigma	Year	Season	CPUE	Sigma
1991	Jan-Feb	55.864	0.091	1991	May-Jul	36.761	0.203	1991	Aug-Oct	71.702	0.603
1992	Jan-Feb	60.427	0.161	1992	May-Jul	38.568	0.291	1992	Aug-Oct	57.517	0.773
1993	Jan-Feb	62.047	0.157	1993	May-Jul	39.902	0.469	1993	Aug-Oct	113.970	0.503
1994	Jan-Feb	51.965	0.222	1994	May-Jul	26.767	0.248	1994	Aug-Oct	56.308	0.390
1995	Jan-Feb	88.482	0.122	1995	May-Jul	59.393	1.669	1995	Aug-Oct	60.164	0.323
1996	Jan-Feb	48.331	0.132	1996	May-Jul	29.174	0.314	1996	Aug-Oct	34.896	0.291
1997	Jan-Feb	75.605	0.122	1997	May-Jul	24.880	0.259	1997	Aug-Oct	62.619	0.567
1998	Jan-Feb	59.920	0.159	1998	May-Jul	26.245	0.303	1998	Aug-Oct	38.995	0.305
1999	Jan-Feb	42.399	0.119	1999	May-Jul	15.672	0.426	1999	Aug-Oct	20.611	0.367
2000	Jan-Feb	34.522	0.123	2000	May-Jul	32.694	0.293	2000	Aug-Oct	15.070	0.528
2001	Jan-Feb	25.452	0.166	2001	May-Jul	60.120	0.298	2001	Aug-Oct	16.662	0.249
2002	Jan-Feb	35.892	0.141	2002	May-Jul	39.985	0.209	2002	Aug-Oct	15.141	0.196
2003	Jan-Feb	24.642	0.169	2003	May-Jul	49.493	0.210	2003	Aug-Oct	19.171	0.156
2004	Jan-Feb	62.609	0.138	2004	May-Jul	34.588	0.163	2004	Aug-Oct	21.519	0.154
2005	Jan-Feb	43.993	0.116	2005	May-Jul	24.100	0.172	2005	Aug-Oct	15.932	0.834
2006	Jan-Feb	36.397	0.107	2006	May-Jul	30.653	0.186	2006	Aug-Oct	26.772	0.376
2007	Jan-Feb	30.849	0.095	2007	May-Jul	39.485	0.114	2007	Aug-Oct	18.147	0.681
2008	Jan-Feb	24.385	0.152	2008	May-Jul	40.650	0.251	2008	Aug-Oct	60.047	0.336
2009	Jan-Feb	37.853	0.171	2009	May-Jul	33.932	0.292	2009	Aug-Oct	54.154	0.226
2010	Jan-Feb	41.949	0.137	2010	May-Jul	32.031	0.336	2010	Aug-Oct	73.484	0.198
2011	Jan-Feb	50.737	0.110	2011	May-Jul	49.228	0.259	2011	Aug-Oct	56.918	0.202
2012	Jan-Feb	97.338	0.099	2012	May-Jul	117.192	0.247	2012	Aug-Oct	52.247	0.255
2013	Jan-Feb	67.061	0.081	2013	May-Jul	39.218	0.291	2013	Aug-Oct	82.463	0.140
2014	Jan-Feb	57.039	0.087	2014	May-Jul	53.157	0.224	2014	Aug-Oct	56.967	0.283
2015	Jan-Feb	49.877	0.112	2015	May-Jul	52.999	0.215	2015	Aug-Oct	86.387	0.266
2016	Jan-Feb	66.897	0.092	2016	May-Jul	31.841	0.306	2016	Aug-Oct	26.146	0.546
1991	Mar-Apr	61.454	0.059					1993	Nov-Dec	32.678	0.914
1992	Mar-Apr	48.269	0.069					1996	Nov-Dec	29.543	0.482
1993	Mar-Apr	48.840	0.073					1997	Nov-Dec	31.309	1.093
1994	Mar-Apr	52.428	0.053					1998	Nov-Dec	16.891	0.646
1995	Mar-Apr	55.463	0.061					1999	Nov-Dec	12.994	0.964
1996	Mar-Apr	33.954	0.051					2009	Nov-Dec	28.369	1.180
1997	Mar-Apr	45.985	0.062					2010	Nov-Dec	40.079	0.681
1998	Mar-Apr	31.809	0.072					2011	Nov-Dec	20.796	1.180
1999	Mar-Apr	35.675	0.086					2012	Nov-Dec	52.570	1.293
2000	Mar-Apr	31.397	0.085					2013	Nov-Dec	17.174	1.669
2001	Mar-Apr	21.213	0.106					2014	Nov-Dec	24.191	1.180
2002	Mar-Apr	26.640	0.103								
2003	Mar-Apr	28.131	0.095								
2004	Mar-Apr	42.816	0.116								
2005	Mar-Apr	48.932	0.114								
2006	Mar-Apr	56.188	0.141								
2007	Mar-Apr	45.097	0.092								
2008	Mar-Apr	40.343	0.196								
2009	Mar-Apr	55.557	0.183								
2010	Mar-Apr	55.766	0.266								
2011	Mar-Apr	76.788	0.148								
2012	Mar-Apr	76.796	0.154								
2013	Mar-Apr	64.027	0.138								
2014	Mar-Apr	61.816	0.101								
2015	Mar-Apr	72.289	0.100								
2016	Mar-Apr	85.530	0.129								

Table 2.6 (page 2 of 3)— Fishery CPUE as configured in Model 11.5. Units are kg/minute for trawl gear, kg/hook for longline gear, and kg/pot for pot gear.

Jan-Apr longline fishery			
Year	Season	CPUE	Sigma
1991	Jan-Feb	1.124	0.156
1992	Jan-Feb	0.873	0.088
1993	Jan-Feb	0.654	0.066
1994	Jan-Feb	0.728	0.068
1995	Jan-Feb	0.895	0.069
1996	Jan-Feb	0.878	0.069
1997	Jan-Feb	0.989	0.072
1998	Jan-Feb	0.888	0.074
1999	Jan-Feb	0.743	0.067
2000	Jan-Feb	0.730	0.069
2001	Jan-Feb	0.586	0.079
2002	Jan-Feb	0.680	0.062
2003	Jan-Feb	0.517	0.053
2004	Jan-Feb	0.562	0.060
2005	Jan-Feb	0.626	0.055
2006	Jan-Feb	0.747	0.062
2007	Jan-Feb	0.734	0.045
2008	Jan-Feb	0.794	0.068
2009	Jan-Feb	0.893	0.069
2010	Jan-Feb	0.781	0.067
2011	Jan-Feb	0.716	0.083
2012	Jan-Feb	0.774	0.081
2013	Jan-Feb	0.736	0.062
2014	Jan-Feb	0.599	0.068
2015	Jan-Feb	0.576	0.072
2016	Jan-Feb	0.665	0.073
1991	Mar-Apr	0.993	0.110
1992	Mar-Apr	0.858	0.071
1993	Mar-Apr	0.669	0.061
1994	Mar-Apr	0.735	0.060
1995	Mar-Apr	0.841	0.062
1996	Mar-Apr	0.756	0.067
1997	Mar-Apr	0.829	0.078
1998	Mar-Apr	0.619	0.075
1999	Mar-Apr	0.617	0.067
2000	Mar-Apr	0.617	0.097
2001	Mar-Apr	0.539	0.073
2002	Mar-Apr	0.676	0.082
2003	Mar-Apr	0.530	0.068
2004	Mar-Apr	0.579	0.076
2005	Mar-Apr	0.678	0.113
2006	Mar-Apr	0.796	0.112
2007	Mar-Apr	0.693	0.155
2008	Mar-Apr	0.774	0.145
2009	Mar-Apr	1.159	0.172
2010	Mar-Apr	0.829	0.195
2011	Mar-Apr	0.703	0.072
2012	Mar-Apr	0.597	0.082
2013	Mar-Apr	0.659	0.083
2014	Mar-Apr	0.523	0.071
2015	Mar-Apr	0.571	0.073
2016	Mar-Apr	0.562	0.085

May-Jul longline fishery			
Year	Season	CPUE	Sigma
1991	May-Jul	0.771	0.075
1992	May-Jul	0.530	0.052
1993	May-Jul	0.551	0.176
1994	May-Jul	0.713	0.133
1995	May-Jul	0.760	0.179
1996	May-Jul	0.669	0.178
1997	May-Jul	0.657	0.120
1998	May-Jul	0.496	0.184
1999	May-Jul	0.637	0.143
2000	May-Jul	0.610	0.169
2001	May-Jul	0.514	0.107
2002	May-Jul	0.405	0.137
2003	May-Jul	0.376	0.109
2004	May-Jul	0.367	0.115
2005	May-Jul	0.385	0.106
2006	May-Jul	0.366	0.162
2007	May-Jul	0.406	0.142
2008	May-Jul	0.366	0.140
2009	May-Jul	0.384	0.151
2010	May-Jul	0.419	0.156
2011	May-Jul	0.374	0.088
2012	May-Jul	0.429	0.080
2013	May-Jul	0.424	0.091
2014	May-Jul	0.356	0.064
2015	May-Jul	0.459	0.079
2016	May-Jul	0.440	0.080

Aug-Dec longline fishery			
Year	Season	CPUE	Sigma
1991	Aug-Oct	0.595	0.062
1992	Aug-Oct	0.512	0.069
1994	Aug-Oct	0.576	0.068
1995	Aug-Oct	0.587	0.070
1996	Aug-Oct	0.542	0.060
1997	Aug-Oct	0.580	0.064
1998	Aug-Oct	0.398	0.064
1999	Aug-Oct	0.481	0.061
2000	Aug-Oct	0.404	0.053
2001	Aug-Oct	0.398	0.052
2002	Aug-Oct	0.372	0.046
2003	Aug-Oct	0.342	0.044
2004	Aug-Oct	0.312	0.048
2005	Aug-Oct	0.330	0.045
2006	Aug-Oct	0.391	0.047
2007	Aug-Oct	0.402	0.038
2008	Aug-Oct	0.307	0.048
2009	Aug-Oct	0.348	0.049
2010	Aug-Oct	0.352	0.060
2011	Aug-Oct	0.369	0.059
2012	Aug-Oct	0.321	0.060
2013	Aug-Oct	0.355	0.057
2014	Aug-Oct	0.360	0.058
2015	Aug-Oct	0.372	0.055
2016	Aug-Oct	0.419	0.123
1991	Nov-Dec	0.551	0.093
1995	Nov-Dec	0.648	0.110
1996	Nov-Dec	0.590	0.277
1997	Nov-Dec	0.577	0.073
1998	Nov-Dec	0.501	0.072
1999	Nov-Dec	0.541	0.120
2000	Nov-Dec	0.416	0.067
2001	Nov-Dec	0.432	0.065
2002	Nov-Dec	0.394	0.072
2003	Nov-Dec	0.365	0.060
2004	Nov-Dec	0.441	0.065
2005	Nov-Dec	0.385	0.064
2006	Nov-Dec	0.433	0.214
2007	Nov-Dec	0.449	0.332
2008	Nov-Dec	0.449	0.087
2009	Nov-Dec	0.428	0.090
2010	Nov-Dec	0.447	0.087
2011	Nov-Dec	0.447	0.086
2012	Nov-Dec	0.476	0.077
2013	Nov-Dec	0.479	0.071
2014	Nov-Dec	0.439	0.067
2015	Nov-Dec	0.463	0.076

Table 2.6 (page 3 of 3)— Fishery CPUE as configured in Model 11.5. Units are kg/minute for trawl gear, kg/hook for longline gear, and kg/pot for pot gear.

Jan-Apr pot fishery			
Year	Season	CPUE	Sigma
2000	Jan-Feb	56.553	0.152
2001	Jan-Feb	72.207	0.503
2002	Jan-Feb	81.893	0.264
2003	Jan-Feb	73.858	0.139
2004	Jan-Feb	78.980	0.170
2005	Jan-Feb	85.328	0.168
2006	Jan-Feb	83.292	0.154
2007	Jan-Feb	64.671	0.109
2008	Jan-Feb	81.642	0.208
2009	Jan-Feb	92.345	0.189
2010	Jan-Feb	88.535	0.167
2011	Jan-Feb	130.718	0.153
2012	Jan-Feb	138.710	0.148
2013	Jan-Feb	128.974	0.143
2014	Jan-Feb	105.380	0.145
2015	Jan-Feb	105.052	0.129
2016	Jan-Feb	97.702	0.122
1992	Mar-Apr	86.412	0.422
1993	Mar-Apr	84.191	0.136
1994	Mar-Apr	89.313	0.107
1995	Mar-Apr	91.679	0.094
1996	Mar-Apr	73.485	0.077
1997	Mar-Apr	93.226	0.120
1998	Mar-Apr	77.558	0.184
1999	Mar-Apr	67.604	0.195
2000	Mar-Apr	45.310	0.163
2001	Mar-Apr	69.247	0.137
2002	Mar-Apr	61.628	0.176
2004	Mar-Apr	65.936	0.390
2006	Mar-Apr	116.202	0.422
2014	Mar-Apr	183.575	0.353
2015	Mar-Apr	133.103	0.173
2016	Mar-Apr	118.028	0.244

May-Jul pot fishery			
Year	Season	CPUE	Sigma
1991	May-Jul	64.037	0.251
1992	May-Jul	66.730	0.077
1993	May-Jul	90.669	0.228
1994	May-Jul	75.421	0.173
1995	May-Jul	72.065	0.098
1996	May-Jul	55.819	0.089
1997	May-Jul	46.843	0.114
1998	May-Jul	49.999	0.129
1999	May-Jul	47.466	0.124

Aug-Dec pot fishery			
Year	Season	CPUE	Sigma
1991	Aug-Oct	88.556	0.132
1992	Aug-Oct	30.252	0.113
1994	Aug-Oct	97.172	0.151
1995	Aug-Oct	57.783	0.153
1996	Aug-Oct	49.758	0.136
1997	Aug-Oct	47.938	0.167
1998	Aug-Oct	32.057	0.281
1999	Aug-Oct	37.675	0.213
2001	Aug-Oct	46.493	0.169
2002	Aug-Oct	42.331	0.189
2003	Aug-Oct	57.632	0.174
2004	Aug-Oct	48.802	0.210
2005	Aug-Oct	45.872	0.192
2006	Aug-Oct	55.342	0.185
2007	Aug-Oct	65.356	0.151
2008	Aug-Oct	57.252	0.164
2009	Aug-Oct	72.836	0.266
2010	Aug-Oct	82.936	0.210
2011	Aug-Oct	81.445	0.148
2012	Aug-Oct	64.934	0.130
2013	Aug-Oct	87.471	0.128
2014	Aug-Oct	77.822	0.162
2015	Aug-Oct	82.978	0.113
1991	Nov-Dec	91.633	0.262
1995	Nov-Dec	53.251	0.188
1996	Nov-Dec	46.456	0.422
1997	Nov-Dec	41.829	0.413
1998	Nov-Dec	41.138	0.802
2001	Nov-Dec	40.740	0.631
2002	Nov-Dec	55.955	0.417
2003	Nov-Dec	60.093	0.334
2004	Nov-Dec	66.375	0.451
2006	Nov-Dec	37.187	0.422
2010	Nov-Dec	104.985	0.373
2013	Nov-Dec	90.404	0.213
2014	Nov-Dec	69.205	0.210
2015	Nov-Dec	71.605	0.220

Table 2.7— Total biomass and abundance, with standard deviations, as estimated by EBS shelf bottom trawl surveys, 1982-2016. For biomass, lower and upper 95% confidence intervals are also shown.

	Biomass (t)				Abundance (1000s of fish)	
Year	Estimate	Std. error	L95% CI	U95% CI	Estimate	Std. error
1982	1,013,061	73,621	867,292	1,158,831	583,781	38,064
1983	1,187,096	120,958	942,640	1,431,553	752,456	80,566
1984	1,013,558	62,513	889,782	1,137,334	651,058	47,126
1985	1,001,112	55,845	890,540	1,111,684	841,108	113,438
1986	1,118,006	69,626	980,146	1,255,866	838,217	83,855
1987	1,027,518	63,670	901,452	1,153,584	677,054	44,120
1988	960,962	76,961	808,579	1,113,344	507,560	35,581
1989	833,473	62,713	709,300	957,645	292,247	19,986
1990	691,256	51,455	589,376	793,136	423,835	36,466
1991	514,407	38,039	439,090	589,725	488,892	51,108
1992	529,049	44,616	440,708	617,390	577,560	68,603
1993	663,308	53,143	558,085	768,531	810,608	99,259
1994	1,360,790	247,737	865,316	1,856,263	1,232,175	152,212
1995	1,002,961	91,622	821,550	1,184,372	757,910	75,473
1996	889,366	87,521	716,076	1,062,657	607,198	88,384
1997	604,439	68,120	468,199	740,678	485,643	70,802
1998	534,150	42,937	449,135	619,165	514,339	46,852
1999	569,765	49,471	471,811	667,718	488,337	45,289
2000	531,171	43,160	445,714	616,627	483,808	44,188
2001	811,816	73,211	665,394	958,239	960,917	91,898
2002	584,565	63,820	456,926	712,205	536,342	53,802
2003	590,973	62,121	466,732	715,214	498,873	62,220
2004	562,309	33,739	495,505	629,113	397,948	34,332
2005	606,050	43,056	520,799	691,301	450,705	63,363
2006	517,698	28,341	461,583	573,813	394,024	23,785
2007	423,704	34,811	354,081	493,326	733,402	195,956
2008	403,125	26,822	350,018	456,232	476,697	49,413
2009	421,291	34,969	352,053	490,530	716,637	62,705
2010	860,210	102,307	657,642	1,062,778	887,836	117,022
2011	896,039	66,843	763,690	1,028,388	836,822	79,207
2012	890,665	100,473	689,718	1,091,612	987,973	91,589
2013	791,958	73,952	644,054	939,862	750,889	124,917
2014	1,079,712	153,299	769,895	1,389,528	1,122,144	143,618
2015	1,102,261	150,981	800,299	1,404,223	982,470	113,501
2016	944,621	76,948	790,725	1,098,516	640,359	61,639

Table 2.8 (page 1 of 4)—Trawl survey size composition, by year and cm (sample size in column 2).

Year	Nact	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
1982	10548	0	0	0	0	0	1	8	9	19	26	52	59	109	66	51	52	46	19	8	9	2	8	18	25	40	67	87	123	193	221
1983	13149	0	0	0	0	0	7	96	290	455	458	484	461	433	394	252	250	120	74	44	29	9	5	18	34	46	56	100	125	146	173
1984	12145	0	0	0	0	0	6	25	36	55	43	27	25	26	30	46	32	64	72	90	125	231	312	379	460	574	600	647	569	477	394
1985	16880	0	0	0	0	0	4	56	102	179	145	216	287	304	372	503	507	526	647	559	555	321	212	130	91	100	106	159	220	216	272
1986	15378	0	0	0	0	1	23	38	93	133	130	202	175	177	150	93	34	27	20	22	72	114	218	360	449	697	629	616	638	653	580
1987	10599	0	0	0	0	0	0	14	4	7	24	38	60	81	108	121	121	153	124	80	61	47	63	76	117	124	200	274	302	325	291
1988	9991	0	0	0	0	0	0	1	8	7	28	13	27	26	23	42	27	18	26	35	48	68	77	88	86	109	83	124	122	137	179
1989	10001	0	0	0	0	0	3	3	19	47	37	70	86	108	105	101	66	39	19	21	30	4	15	16	35	13	34	30	24	33	37
1990	5630	0	0	0	0	0	26	71	104	154	150	185	236	259	205	149	117	89	57	35	41	42	33	47	76	77	95	103	97	92	118
1991	7220	0	0	0	0	0	6	31	94	112	140	137	163	133	136	128	107	135	86	72	72	78	100	97	166	192	265	285	325	289	372
1992	9599	0	0	0	0	0	0	1	17	81	183	191	175	150	198	221	233	247	215	227	111	119	135	182	264	288	302	349	373	348	310
1993	10402	0	0	0	0	1	2	29	81	191	423	293	403	354	321	318	343	311	321	215	134	97	61	55	66	85	94	173	206	230	290
1994	13924	0	0	0	0	0	3	10	5	27	42	76	91	100	100	116	136	111	103	91	131	120	171	154	205	321	430	552	639	732	767
1995	9208	0	0	0	0	0	3	12	15	13	19	41	37	42	56	59	81	68	34	24	19	37	47	89	108	158	194	228	218	245	225
1996	9349	0	0	0	0	0	1	2	11	9	23	33	48	64	53	66	69	64	54	36	20	22	23	58	65	129	163	194	229	275	237
1997	9177	0	0	0	0	0	8	17	65	114	167	193	192	196	212	284	226	218	226	178	105	58	41	41	34	70	109	103	154	223	231
1998	9572	0	0	0	0	0	1	4	23	53	84	117	104	136	91	45	22	6	4	17	25	57	72	182	276	381	494	599	628	614	513
1999	11695	0	0	0	0	0	1	15	53	100	109	122	94	113	78	42	30	41	49	39	53	109	110	196	228	222	310	268	295	308	240
2000	12547	0	0	0	4	10	23	51	99	137	298	478	582	442	278	274	141	87	33	9	12	25	39	77	119	170	197	220	258	305	222
2001	19748	0	0	0	0	5	6	27	63	127	204	312	449	658	710	766	678	662	440	349	219	136	112	160	226	314	365	507	657	832	826
2002	12237	0	0	0	0	1	3	6	21	43	63	80	101	159	112	166	111	71	51	35	17	42	63	106	160	240	268	434	474	555	553
2003	12353	0	0	1	0	1	3	5	11	56	92	138	205	232	206	249	254	282	252	237	199	218	154	120	66	57	59	79	57	115	144
2004	10811	0	2	0	0	0	1	4	20	45	86	152	106	194	187	215	211	135	144	111	65	56	72	92	104	188	196	219	238	273	301
2005	11288	0	0	0	0	0	0	1	4	22	43	87	138	201	248	304	284	301	290	362	362	387	376	289	210	137	135	141	115	158	178
2006	12131	0	1	0	4	7	40	101	336	405	427	453	401	343	330	359	280	243	146	105	65	54	56	55	64	86	115	168	189	246	243
2007	12809	0	0	0	0	7	7	129	481	1163	1425	1398	1141	730	715	511	326	400	230	121	122	42	44	65	86	124	117	154	122	140	147
2008	12985	0	0	1	0	0	6	54	169	350	380	390	350	312	227	151	75	40	21	40	70	162	307	479	550	707	745	719	682	559	461
2009	16679	1	0	0	7	36	106	401	971	1058	1087	878	744	650	485	460	318	219	114	35	28	33	82	93	173	253	336	396	467	436	339
2010	7564	0	0	0	0	0	1	5	18	24	29	50	50	56	46	31	15	17	9	13	31	60	126	193	241	355	431	417	394	394	323
2011	20739	0	0	0	0	0	8	20	76	142	257	306	385	413	597	627	905	886	851	536	286	109	34	37	55	48	56	72	121	136	188
2012	13076	0	0	6	0	0	74	379	686	732	563	424	417	310	410	396	208	129	48	31	10	28	37	59	84	178	259	269	358	352	390
2013	18691	0	0	0	0	1	9	50	116	146	207	222	283	239	177	127	35	22	63	86	268	398	653	785	982	1078	840	908	652	658	415
2014	17944	0	0	0	1	0	1	9	90	117	239	340	466	519	657	498	608	490	520	308	218	111	103	91	72	96	221	247	419	331	484
2015	19316	0	0	0	0	0	0	11	42	42	85	77	52	47	57	57	60	74	85	69	77	76	78	81	122	177	277	385	524	722	906
2016	17170	0	0	0	0	1	0	5	17	27	54	61	40	22	52	66	99	152	228	277	261	229	154	109	58	35	40	68	87	105	131

Table 2.8 (page 2 of 4)—Trawl survey size composition, by year and cm.

Year	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
1982	240	305	317	237	197	144	146	126	137	180	203	282	302	272	328	329	280	284	270	254	239	278	258	267	225	260	264	261	225	227
1983	165	213	145	127	107	61	62	86	94	143	157	212	269	301	288	298	316	254	248	246	225	298	277	258	262	245	262	245	201	224
1984	345	295	220	155	107	102	88	59	94	75	91	94	96	108	134	106	109	95	109	142	129	156	167	197	198	154	215	169	200	202
1985	300	309	312	288	343	351	389	413	514	500	514	482	470	359	323	244	192	168	128	96	93	103	101	104	85	87	90	85	148	110
1986	557	448	402	349	332	220	194	138	126	136	163	185	216	205	246	218	248	269	258	275	288	299	226	252	251	175	171	120	146	111
1987	280	207	235	201	172	186	221	210	293	327	330	330	322	323	252	251	266	157	159	133	120	146	140	98	123	92	139	136	123	131
1988	190	269	216	195	211	141	184	165	239	222	197	319	277	294	277	247	308	266	229	250	250	260	220	214	227	194	199	166	207	165
1989	70	33	107	109	134	115	125	101	115	115	139	176	165	176	183	176	200	253	236	260	247	234	326	293	219	222	197	290	186	228
1990	124	80	113	96	67	57	67	51	47	38	38	31	35	48	39	41	25	51	31	62	53	66	58	74	72	75	85	89	89	78
1991	308	251	261	195	173	143	118	84	68	64	61	51	61	53	61	74	49	61	42	71	89	58	75	40	34	42	41	34	52	44
1992	304	241	215	176	149	125	180	146	216	188	220	242	186	186	160	143	154	119	107	89	78	57	63	29	42	51	50	66	45	35
1993	315	239	246	227	196	153	161	182	183	221	221	234	270	207	185	193	159	151	129	113	118	108	88	64	66	79	66	57	58	52
1994	673	643	472	362	288	196	115	133	114	221	188	164	233	256	264	299	172	189	230	188	181	175	219	251	252	162	219	153	204	163
1995	198	155	217	249	239	314	378	371	417	421	394	342	335	293	199	189	153	142	114	98	108	95	88	93	86	72	93	99	104	100
1996	251	191	200	168	157	168	154	176	214	238	288	261	292	320	301	297	323	272	282	282	244	254	206	167	152	132	141	99	94	86
1997	222	174	159	155	138	145	136	125	127	135	135	171	194	228	152	172	134	150	180	187	160	167	124	213	164	173	123	130	107	111
1998	537	346	260	228	166	147	134	101	119	117	134	127	169	119	115	133	112	94	89	82	82	72	61	79	89	75	66	77	87	85
1999	227	197	191	240	290	308	382	486	509	584	558	505	395	408	311	233	199	165	142	144	117	117	93	104	92	85	71	117	86	94
2000	197	184	188	174	199	223	256	267	303	306	347	308	355	321	391	342	351	262	315	239	256	194	202	183	159	159	149	112	101	90
2001	921	806	700	512	409	301	218	189	176	152	157	186	229	280	230	266	250	230	262	273	257	235	219	225	189	208	184	149	197	131
2002	520	381	400	312	295	250	289	259	407	359	453	393	389	278	330	188	227	183	166	137	162	129	155	89	109	121	125	101	111	107
2003	316	216	319	240	274	291	318	361	342	389	456	425	461	415	390	277	276	234	246	260	198	185	166	148	124	144	138	116	96	70
2004	317	310	335	313	325	254	242	211	208	188	181	155	148	151	174	170	205	198	162	182	171	186	167	189	143	156	167	148	143	139
2005	197	197	207	231	288	252	204	194	203	207	216	167	205	168	193	131	171	126	144	129	135	111	111	101	98	100	117	84	118	82
2006	264	245	303	263	298	252	244	209	200	161	171	145	151	127	157	147	191	169	175	145	174	137	182	105	128	90	97	105	95	106
2007	124	114	92	93	76	60	73	77	74	68	82	76	85	79	80	60	75	74	82	68	72	59	54	48	52	47	61	50	60	49
2008	341	282	200	161	151	133	130	117	143	129	138	138	139	113	135	121	124	127	134	114	108	101	112	91	113	103	113	91	81	81
2009	306	221	214	215	225	302	304	362	380	379	347	334	280	289	247	181	147	144	117	103	93	82	75	78	85	88	72	85	77	53
2010	269	183	165	106	95	64	75	78	124	132	232	154	165	160	157	124	135	106	147	114	156	151	140	95	140	112	101	71	90	58
2011	164	232	229	272	287	403	457	673	801	859	925	872	790	634	511	347	349	278	265	185	230	225	265	184	276	241	301	228	294	184
2012	279	309	190	158	98	81	61	46	63	59	85	81	130	111	196	188	239	285	379	323	408	309	316	218	198	168	164	97	120	86
2013	310	240	180	174	145	126	184	153	230	292	361	431	519	407	386	349	325	258	259	195	210	136	192	142	214	193	234	192	212	203
2014	460	498	349	311	184	190	145	203	282	444	458	655	675	608	559	492	425	285	216	203	206	182	165	192	249	247	198	191	203	135
2015	1055	1114	987	939	766	575	498	286	267	200	377	373	500	474	469	426	454	320	352	347	318	337	389	337	433	331	300	219	245	158
2016	180	164	230	251	299	283	333	388	471	577	611	812	892	863	883	761	685	538	409	422	295	293	277	267	248	264	247	226	232	228

Table 2.8 (page 3 of 4)—Trawl survey size composition, by year and cm.

Year	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
1982	202	193	190	198	122	172	124	132	73	73	72	64	45	34	37	30	20	27	24	12	8	7	9	3	6	4	1	2	3	0	2	0	1	2	1
1983	196	200	191	166	188	176	145	181	126	122	78	81	79	68	59	39	48	32	29	24	18	12	1	7	8	3	11	1	1	2	4	0	3	0	1
1984	188	161	197	183	181	171	153	145	83	119	98	104	75	82	56	68	46	40	32	33	27	22	28	12	16	19	12	9	4	7	6	0	4	3	2
1985	110	113	171	123	134	146	147	135	135	120	138	107	135	99	95	59	75	59	50	48	21	37	22	22	16	14	10	8	7	8	4	1	3	7	2
1986	81	99	76	84	70	87	105	99	89	70	90	86	69	81	71	62	84	56	53	43	29	26	35	18	21	18	30	10	16	13	5	4	6	2	7
1987	121	132	124	133	132	110	116	94	60	91	53	56	55	23	43	33	33	44	28	29	29	29	9	7	15	9	10	13	6	10	10	2	4	6	3
1988	116	124	99	138	106	106	81	116	84	84	56	79	71	48	41	55	71	62	53	31	30	11	27	15	6	15	2	15	2	6	6	6	5	1	4
1989	242	184	167	241	213	136	201	105	184	198	167	154	143	107	151	107	63	53	85	61	74	88	43	60	41	14	43	30	19	24	28	32	14	10	21
1990	78	54	80	55	60	34	64	43	53	52	53	49	33	38	38	25	37	39	10	24	19	23	19	10	11	18	11	6	5	5	7	11	10	3	1
1991	43	26	45	41	47	46	48	32	31	25	40	32	27	14	16	19	21	33	24	21	12	13	8	13	7	8	6	3	5	4	1	6	8	3	2
1992	25	31	30	47	35	32	24	14	21	22	21	15	24	15	18	24	28	14	17	14	11	13	14	7	10	7	13	5	7	7	4	7	8	3	9
1993	36	66	37	37	61	28	28	14	15	15	14	16	12	12	11	12	12	11	9	5	12	10	4	7	8	8	4	3	4	7	3	7	5	5	4
1994	180	160	126	84	133	62	102	49	67	30	40	20	30	13	21	9	9	10	12	5	9	8	9	7	4	6	35	13	9	3	1	3	6	4	2
1995	87	70	54	60	72	71	69	50	54	45	36	28	22	37	20	25	21	20	18	12	13	10	7	8	7	7	4	11	3	4	4	10	1	3	2
1996	79	57	60	60	56	56	45	56	62	32	44	36	28	29	35	22	21	24	25	15	25	10	13	22	17	9	3	3	7	10	3	5	5	3	2
1997	115	101	99	92	80	69	56	61	53	29	18	31	20	28	16	11	10	9	12	17	12	10	8	9	9	4	3	8	7	2	6	3	2	4	0
1998	74	65	97	58	63	47	46	52	55	37	52	29	36	21	21	25	13	16	9	15	11	8	10	7	4	3	5	5	10	3	6	3	1	2	2
1999	80	95	63	70	49	62	70	49	45	51	37	28	28	23	26	27	24	19	13	17	15	12	11	17	16	6	16	6	5	5	5	2	5	6	6
2000	85	54	65	58	52	36	50	33	38	31	34	29	22	12	14	22	22	12	18	19	8	9	5	9	26	7	7	7	4	4	10	2	8	5	3
2001	155	151	106	83	106	67	78	57	51	33	38	26	20	27	20	31	17	17	12	11	13	5	10	6	6	5	7	5	4	2	4	6	1	2	0
2002	99	56	106	72	64	66	58	47	35	35	32	24	31	24	13	10	20	14	6	6	2	7	2	4	5	2	2	4	5	5	1	3	2	3	6
2003	95	64	72	69	66	67	76	47	56	40	40	36	35	26	28	16	18	21	22	11	14	7	9	6	7	5	4	4	3	2	1	0	1	1	0
2004	120	103	101	86	105	82	64	73	59	58	34	50	45	43	46	32	27	24	23	16	22	11	26	12	19	15	13	6	4	8	4	3	4	4	2
2005	127	104	112	101	101	77	83	74	70	59	72	51	72	54	65	49	44	40	40	32	25	17	28	20	23	14	10	14	10	8	4	9	5	3	4
2006	90	88	98	61	96	51	71	60	58	64	67	57	59	42	57	44	58	50	51	37	42	39	34	20	35	16	23	15	18	10	10	6	11	9	1
2007	49	45	46	32	43	40	31	24	32	23	38	21	19	14	12	17	17	18	10	10	9	25	11	8	9	15	10	13	8	3	8	4	6	2	3
2008	88	62	71	64	71	44	53	35	39	23	43	19	23	21	23	13	16	12	16	14	12	8	20	11	10	8	12	5	10	10	10	9	3	8	9
2009	65	71	52	38	48	30	40	29	21	24	13	17	14	15	14	4	13	6	8	4	4	7	6	6	3	4	5	1	1	1	2	3	5	2	3
2010	67	40	42	29	22	16	19	17	9	6	7	8	10	3	7	2	2	4	2	2	1	3	4	0	2	1	2	1	1	2	0	0	2	1	0
2011	249	172	205	152	159	115	126	61	78	51	50	27	25	21	15	14	18	7	14	10	7	3	4	4	4	4	1	5	3	4	7	2	1	0	1
2012	104	78	79	63	66	46	72	37	47	24	29	21	20	19	18	6	10	4	7	6	6	4	4	4	1	1	2	2	1	3	3	2	0	0	1
2013	234	213	193	163	141	136	109	104	92	51	63	44	31	44	29	31	8	29	12	24	12	10	7	7	4	3	5	4	4	5	1	2	0	1	0
2014	140	110	106	62	62	52	66	56	53	66	49	43	40	29	28	20	15	16	8	8	8	4	4	6	3	1	6	2	3	2	0	0	3	1	2
2015	168	113	107	111	98	81	65	61	62	57	45	55	43	35	24	24	20	23	14	7	12	7	17	9	6	3	4	1	2	2	0	2	1	1	1
2016	212	225	245	190	172	158	168	135	95	85	69	51	46	47	36	24	24	35	16	19	21	16	10	9	8	8	5	6	5	3	2	3	2	2	2

Table 2.8 (page 4 of 4)—Trawl survey size composition, by year and cm.

Year	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120+
1982	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	4	2	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1986	2	4	3	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	1	1	3	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	8	3	1	3	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
1989	11	10	22	1	22	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1990	1	5	0	6	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	3	0	0	0	6	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	1	4	3	3	3	3	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0
1993	4	1	2	2	1	8	2	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0
1994	1	2	9	6	3	1	7	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
1995	3	5	1	3	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
1996	2	4	1	2	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
1997	1	2	0	0	1	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
1998	1	1	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	3	2	1	0	2	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2000	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	5	1	1	0	2	1	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2002	1	1	0	0	1	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
2003	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2004	2	0	1	0	5	0	1	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0
2005	0	4	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2006	7	5	3	2	3	2	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0
2007	2	3	2	8	1	2	1	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0
2008	2	4	3	7	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
2009	1	2	1	1	0	1	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2010	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	0	2	2	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	2	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2014	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2015	2	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2016	0	1	3	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2.9—Age compositions observed by the EBS shelf bottom trawl survey, 1994-2015. “Nact” = actual sample size (these get rescaled so that the average across all age compositions equals 300).

Year	Nact	0	1	2	3	4	5	6	7	8	9	10	11	12+
1994	715	0.000005	0.088672	0.382767	0.171412	0.122294	0.118182	0.080798	0.020837	0.007176	0.004734	0.001400	0.000877	0.000847
1995	571	0.000011	0.052455	0.264340	0.420604	0.099263	0.078477	0.049525	0.016434	0.009218	0.006001	0.001592	0.000861	0.001218
1996	711	0.000009	0.056039	0.207937	0.202719	0.292993	0.135159	0.057671	0.028893	0.010285	0.004356	0.001891	0.001134	0.000913
1997	719	0.000000	0.255019	0.168807	0.183404	0.156924	0.119989	0.077764	0.022284	0.010205	0.003092	0.001292	0.000837	0.000384
1998	635	0.000004	0.076678	0.440954	0.203769	0.112415	0.056560	0.059534	0.028349	0.015990	0.004092	0.000810	0.000620	0.000225
1999	860	0.000003	0.079333	0.199608	0.302578	0.231813	0.080458	0.057700	0.027426	0.012165	0.005398	0.001337	0.001540	0.000641
2000	860	0.000016	0.234045	0.126952	0.150320	0.241908	0.147327	0.061410	0.013983	0.013878	0.005623	0.002827	0.001265	0.000446
2001	920	0.000010	0.289356	0.235498	0.193613	0.090842	0.083317	0.068087	0.026483	0.007913	0.002233	0.001513	0.000830	0.000305
2002	870	0.000057	0.079969	0.187981	0.317798	0.233323	0.071814	0.058708	0.033935	0.010407	0.003866	0.001138	0.000496	0.000508
2003	1263	0.000010	0.175004	0.156251	0.250572	0.209411	0.118871	0.041031	0.030074	0.013595	0.003643	0.000534	0.000536	0.000467
2004	995	0.000016	0.143715	0.165800	0.270793	0.128216	0.127925	0.090590	0.039844	0.019027	0.008659	0.002185	0.002584	0.000645
2005	1279	0.000000	0.183283	0.244428	0.209260	0.121129	0.065286	0.079441	0.054992	0.023756	0.010480	0.003625	0.003628	0.000691
2006	1300	0.000000	0.324413	0.142773	0.164963	0.121408	0.092865	0.063362	0.046415	0.028492	0.009924	0.003059	0.001347	0.000979
2007	1441	0.000000	0.700419	0.095563	0.067128	0.041366	0.045974	0.017598	0.014302	0.008393	0.005034	0.001740	0.001509	0.000972
2008	1213	0.000144	0.213306	0.445262	0.144892	0.082666	0.048588	0.032949	0.010242	0.010253	0.005786	0.002760	0.001363	0.001791
2009	1412	0.000675	0.454268	0.189424	0.230908	0.064146	0.028780	0.014629	0.009463	0.003920	0.002059	0.000825	0.000575	0.000328
2010	1292	0.000000	0.046504	0.479394	0.179317	0.203241	0.064417	0.014561	0.007700	0.002561	0.001271	0.000380	0.000517	0.000138
2011	1253	0.000030	0.290446	0.073000	0.388141	0.111090	0.095573	0.027843	0.006911	0.003347	0.001640	0.000971	0.000559	0.000448
2012	1301	0.000045	0.365988	0.234280	0.058292	0.237219	0.061719	0.030655	0.007422	0.002046	0.001548	0.000467	0.000156	0.000162
2013	1418	0.000000	0.107227	0.426997	0.178038	0.108369	0.112914	0.050391	0.010939	0.003598	0.000810	0.000197	0.000291	0.000230
2014	1223	0.000048	0.278522	0.185139	0.236592	0.201442	0.048010	0.035751	0.010180	0.002252	0.000916	0.000709	0.000144	0.000295
2015	856	0.000000	0.068339	0.400726	0.219958	0.185469	0.088264	0.020851	0.013564	0.001652	0.000615	0.000264	0.000134	0.000164

Table 2.10—Mean size (cm) at age from age-length key applied to respective size compositions, and sample sizes. Mean lengths for samples of size zero result from application of area-specific long-term average age-length keys. These data are used in Model 11.5 only.

Average length (cm) at age:

Year	0	1	2	3	4	5	6	7	8	9	10	11	12+
1994	11.00	19.02	31.77	39.93	49.49	58.15	64.18	70.91	81.58	86.82	94.76	90.32	95.75
1995	11.00	17.36	32.35	43.22	53.13	62.11	69.90	74.72	81.81	85.01	92.00	91.34	95.51
1996	11.00	17.67	31.64	41.44	50.30	57.76	67.26	75.94	82.19	88.56	90.26	90.32	95.78
1997	0.00	17.22	31.87	42.02	51.78	59.84	64.98	72.43	79.32	86.65	91.96	92.31	93.81
1998	11.00	15.52	30.77	37.87	49.37	59.07	66.40	70.45	77.63	89.24	89.18	92.04	91.13
1999	11.00	15.83	29.66	40.34	46.26	56.80	65.53	71.51	79.82	82.59	92.01	90.47	96.05
2000	11.00	15.26	30.33	38.99	47.70	53.76	59.87	73.39	74.57	79.79	82.41	81.72	94.11
2001	11.00	17.89	31.36	36.70	48.31	55.35	62.03	66.01	76.95	82.27	78.58	89.10	92.23
2002	11.00	16.54	30.08	36.95	46.92	55.84	62.72	68.82	72.00	79.77	92.23	89.97	94.65
2003	11.00	18.00	29.81	40.87	48.29	56.52	65.36	70.44	75.30	81.52	84.94	84.17	79.15
2004	11.00	17.24	30.21	37.98	49.00	57.04	64.11	71.15	75.61	83.31	88.13	86.20	94.39
2005	0.00	18.59	26.70	39.16	48.56	57.03	64.12	72.34	78.60	81.76	88.33	87.14	93.66
2006	0.00	15.33	30.89	38.55	47.57	55.93	65.02	73.82	82.42	85.67	88.74	94.13	96.82
2007	0.00	15.06	31.03	41.18	50.61	59.35	66.64	74.75	81.58	84.28	94.22	87.83	91.35
2008	11.00	15.37	29.77	41.31	53.38	60.88	66.05	72.84	79.09	84.33	89.80	95.07	91.31
2009	11.00	14.14	31.10	42.51	51.63	59.79	65.93	71.91	75.60	83.69	90.02	88.82	90.16
2010	0.00	15.55	30.51	43.47	53.84	59.23	66.33	70.81	81.50	81.92	89.97	84.17	99.36
2011	11.00	18.19	33.07	43.94	53.86	62.52	67.87	73.11	77.22	85.25	85.84	83.83	95.47
2012	11.00	14.02	32.06	44.55	53.52	61.30	68.51	73.17	81.31	83.57	91.96	93.52	96.88
2013	0.00	16.27	28.90	43.88	50.64	61.98	66.60	74.93	77.31	83.71	88.35	87.26	95.00
2014	11.00	17.65	31.84	44.08	51.56	61.06	67.36	71.05	79.98	86.87	86.10	93.74	89.19
2015	0.00	20.66	34.62	43.60	54.73	61.61	72.31	74.48	81.88	80.65	94.37	97.02	95.99

Number of samples at age (0 indicates mean length inferred from long-term average age-length key):

Year	0	1	2	3	4	5	6	7	8	9	10	11	12+
1994	0	40	213	143	109	89	73	26	12	7	1	2	0
1995	0	23	138	194	89	55	38	14	9	6	1	1	3
1996	0	34	143	138	183	101	65	37	5	2	0	1	2
1997	0	94	92	109	125	120	110	38	21	5	3	2	0
1998	0	56	145	97	94	73	88	47	28	6	0	1	0
1999	0	81	162	188	155	100	70	43	16	8	0	1	0
2000	0	111	100	130	202	175	82	21	19	6	6	1	0
2001	0	163	155	153	132	123	117	42	15	6	4	5	2
2002	1	72	153	201	186	80	87	61	14	6	2	0	1
2003	0	163	197	191	189	191	129	110	66	17	1	4	2
2004	0	141	133	197	128	150	129	59	32	17	4	4	0
2005	0	141	218	238	171	112	146	120	73	29	18	10	2
2006	0	205	176	179	168	155	140	133	93	36	10	4	1
2007	0	252	203	189	154	207	104	119	75	62	21	12	13
2008	0	141	262	244	188	134	97	45	45	28	13	8	8
2009	0	222	259	325	186	133	100	81	47	23	13	12	9
2010	0	105	344	229	296	144	70	48	30	13	5	7	0
2011	0	185	148	315	178	218	107	40	20	12	11	8	10
2012	0	162	289	129	284	161	150	55	30	20	11	3	4
2013	0	133	289	264	171	271	163	81	25	10	3	4	3
2014	0	156	152	234	283	134	165	57	23	9	8	0	2
2015	0	98	147	145	156	136	79	69	15	5	3	0	2

Table 2.11—Mean weight at age (kg) as estimated by the trawl survey (no weight data prior to 1998).

Year	0	1	2	3	4	5	6	7	8	9	10	11	12+
1998	0.000	0.031	0.286	0.563	1.339	2.404	3.522	4.273	5.865	9.246	9.227	10.228	9.924
1999	0.000	0.027	0.193	0.510	0.787	1.505	2.365	3.118	4.412	4.914	6.915	6.555	8.030
2000	0.000	0.026	0.249	0.570	1.107	1.641	2.339	4.575	4.821	6.023	6.700	6.516	10.401
2001	0.000	0.047	0.290	0.482	1.174	1.823	2.634	3.222	5.291	6.566	5.660	8.499	9.524
2002	0.000	0.039	0.256	0.488	1.030	1.776	2.555	3.418	3.937	5.425	8.546	7.907	9.317
2003	0.000	0.050	0.257	0.716	1.232	2.055	3.296	4.206	5.225	6.765	7.729	7.504	6.330
2004	0.000	0.043	0.266	0.557	1.270	2.074	3.026	4.237	5.157	7.056	8.461	7.877	10.590
2005	0.000	0.054	0.175	0.608	1.224	2.066	3.027	4.483	5.872	6.678	8.587	8.218	10.462
2006	0.000	0.028	0.277	0.570	1.129	1.912	3.122	4.720	6.757	7.663	8.592	10.412	11.595
2007	0.000	0.022	0.247	0.638	1.271	2.166	3.193	4.688	6.281	7.006	10.171	8.042	9.198
2008	0.000	0.029	0.247	0.715	1.640	2.512	3.272	4.493	5.868	7.224	8.857	10.654	9.452
2009	0.000	0.022	0.276	0.760	1.426	2.294	3.148	4.171	4.905	6.817	8.632	8.266	8.762
2010	0.000	0.030	0.267	0.838	1.677	2.284	3.294	4.071	6.418	6.526	8.841	7.123	12.192
2011	0.000	0.049	0.348	0.879	1.709	2.780	3.635	4.634	5.540	7.652	7.826	7.243	11.133
2012	0.000	0.021	0.304	0.878	1.590	2.465	3.531	4.368	6.143	6.712	9.143	9.655	10.827
2013	0.000	0.035	0.222	0.859	1.367	2.629	3.320	4.862	5.381	6.961	8.288	7.962	10.518
2014	0.000	0.046	0.308	0.881	1.461	2.522	3.466	4.116	6.035	7.880	7.659	10.079	8.658
2015	0.000	0.075	0.392	0.819	1.695	2.475	4.134	4.543	6.153	5.862	9.689	10.590	10.376
Ave:	0.000	0.037	0.271	0.680	1.335	2.189	3.171	4.279	5.676	6.982	8.523	8.612	9.973

Table 2.12— Relative population numbers, with standard deviations and 95% confidence intervals, as estimated by NMFS longline surveys, 1997-2015.

	Relative population number			
Year	Estimate	Std. error	L95% CI	U95% CI
1997	204,250	20,290	163,671	244,830
1999	139,390	14,690	110,009	168,770
2001	168,872	22,719	123,435	214,310
2003	203,096	25,236	152,624	253,568
2005	109,534	23,052	63,430	155,638
2007	119,105	16,525	86,055	152,155
2009	95,553	21,171	53,211	137,895
2011	143,786	26,141	91,504	196,069
2013	171,225	41,944	87,337	255,113
2015	157,996	30,499	96,998	218,994

Table 2.13—NMFS longline survey size composition, by year and cm (sample size in column 2 of top panel). No fish smaller than 37 cm have been observed in this survey.

Year	Nact	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65
1997	9671	0	0	0	0	0	3	1	4	1	8	12	18	38	47	79	109	136	149	201	198	187	177	234	221	275	311	393	411	526
1999	9860	4	0	1	5	5	4	35	38	92	121	194	221	289	269	188	259	224	199	270	253	280	270	308	302	472	405	449	452	530
2001	10313	0	0	3	1	2	3	7	10	14	24	34	36	80	89	94	153	169	212	247	313	294	305	371	386	398	445	426	525	542
2003	9984	1	0	1	0	5	11	16	30	51	82	120	175	268	280	390	384	460	481	460	542	449	378	423	467	501	454	539	461	466
2005	6506	0	0	0	3	3	0	10	10	10	15	12	46	38	68	107	125	177	159	191	171	193	205	214	237	247	300	265	331	307
2007	6964	0	0	0	1	2	4	9	19	36	56	68	99	102	104	158	132	136	127	129	169	164	236	227	273	257	277	352	266	284
2009	7135	1	2	1	6	11	23	40	73	108	193	255	240	291	315	273	251	182	223	185	191	222	198	211	257	295	274	256	267	335
2011	8137	3	0	1	4	5	10	46	42	78	101	104	148	127	116	111	143	155	155	202	212	292	356	382	477	527	565	491	487	465
2013	8003	0	0	0	0	2	1	1	3	4	14	23	75	79	111	142	166	180	196	169	163	169	187	220	229	287	359	463	469	536
2015	9453	0	0	0	0	1	2	1	5	12	26	30	90	93	149	205	238	324	412	482	539	596	626	590	526	428	425	386	365	350

Year	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
1997	495	608	621	696	534	565	468	462	310	281	204	161	117	97	66	50	36	19	18	17	15	13	7	8	16	8	4	4	5	6
1999	441	422	367	361	337	305	258	224	161	203	121	99	82	53	47	33	31	18	35	11	8	3	28	9	29	2	3	2	5	1
2001	497	568	593	541	490	409	436	292	291	185	146	154	120	100	47	62	48	38	24	28	8	14	4	10	5	8	1	2	1	0
2003	345	297	231	167	175	148	160	148	74	39	116	19	29	25	27	9	19	12	8	3	7	8	5	4	2	4	2	1	2	1
2005	314	329	260	247	260	247	224	168	191	130	109	124	57	72	66	58	40	28	28	16	15	20	6	14	11	7	4	6	3	3
2007	300	279	220	248	227	139	204	161	172	140	94	121	107	98	90	72	68	74	46	49	54	35	39	41	22	20	16	19	17	20
2009	241	209	137	156	109	144	131	142	123	91	67	57	73	31	44	21	10	26	15	11	10	5	10	7	10	2	17	11	9	1
2011	462	406	307	230	187	169	135	74	62	63	40	30	16	13	12	8	12	12	11	4	3	5	13	10	3	10	6	2	4	9
2013	508	548	540	482	383	342	259	184	154	87	85	61	26	32	20	10	3	8	1	5	3	2	2	1	1	0	0	0	1	1
2015	306	244	256	235	248	194	156	142	133	117	85	55	68	54	46	50	29	21	20	16	13	14	7	9	6	5	6	2	4	1

Year	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120+
1997	6	2	2	3	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1999	2	1	2	0	3	2	1	2	6	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2001	3	2	0	0	2	1	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
2003	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2005	1	0	1	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	15	14	11	17	9	4	4	3	2	3	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0
2009	2	2	9	6	4	5	2	0	3	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2011	6	1	1	1	1	0	2	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2015	0	1	1	1	3	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2.14a—Key features shared by Models 11.5 and 16.1.

Features common to both models
Time-invariant natural mortality, survey catchability, and mean length at age
Parameters governing width of length-at-age distribution (for a given mean) estimated internally
Ageing bias parameters estimated internally
Survey size composition data used in all years, including years with age composition data

Table 2.14b—Key features that differ between Models 11.5 and 16.1. "Internal" means that the parameter was estimated inside the assessment model; "external" means that the parameter was estimated outside the assessment model.

Features that differ between models	Model 11.5	Model 16.1
Seasons per year	5 (for catch), 3 (for fishery selectivity)	1
Number of initial age groups estimated	3	20
Natural mortality rate estimation	External (Jensen 1996)	Internal
Trawl survey catchability estimation	External (based on Nichol et al. 2007, 2009 assessment)	Internal
Mean length at age functional form	Von Bertalanffy (3 parameters, internal)	Richards (4 parameters, internal)
Mean length at age data	Included, but not used for estimation	Not included
Fishery CPUE data	Included, but not used for estimation	Not included
Weight at age	Internal length at age, external weight at length (seasonal)	External
SD of log age 0 recruitment (σR)	External (based on 2009 assessment)	Internal
"Fballpark" (like a weak prior on F)	Used	Not used
Selectivity functional form	Double normal (fishery and trawl survey)	Logistic (fishery and trawl survey)
Selectivity basis	Length (fishery), age (trawl survey)	Age (fishery and trawl survey)
Selectivity structure	Gear (3) and season (3)	None
Time-varying fishery selectivity	Estimated independently for 2 to 7 "blocks" of years	None
Time-varying survey selectivity	Annual *dev* s for the *ascending_width* parameter	None

Table 2.15—Annual offsets to the base values of the α and β weight-at-length parameters.

Year:	1977	1978	1979	1980	1981	1982	1983	1984
α offset:	2.07E-06	-2.45E-06	1.34E-06	-2.64E-07	6.80E-07	2.67E-06	3.22E-07	1.14E-05
β offset:	-7.16E-02	1.40E-01	-4.80E-02	7.43E-03	-3.27E-02	-8.56E-02	-3.78E-03	-2.77E-01

Year:	1985	1986	1987	1988	1989	1990	1991	1992
α offset:	-1.02E-06	-2.25E-06	-2.20E-07	-2.17E-06	-1.26E-06	1.17E-06	1.64E-06	2.12E-07
β offset:	5.76E-02	1.30E-01	1.61E-02	1.33E-01	8.09E-02	-3.03E-02	-6.19E-02	-1.79E-02

Year:	1993	1994	1995	1996	1997	1998	1999	2000
α offset:	2.62E-06	4.70E-07	-9.75E-07	7.50E-06	1.10E-06	1.58E-06	1.83E-06	2.07E-06
β offset:	-7.33E-02	-1.78E-02	4.83E-02	-2.00E-01	-5.35E-02	-7.12E-02	-6.93E-02	-6.46E-02

Year:	2001	2002	2003	2004	2005	2006	2007	2008
α offset:	3.93E-06	1.36E-06	-3.40E-07	2.02E-06	-9.51E-09	9.20E-07	4.56E-07	4.16E-06
β offset:	-1.23E-01	-4.93E-02	1.51E-02	-7.27E-02	4.11E-03	-3.40E-02	-1.27E-02	-1.30E-01

Year:	2009	2010	2011	2012	2013	2014	2015
α offset:	-7.18E-07	1.10E-06	5.78E-07	2.85E-06	-7.54E-07	-1.92E-06	-2.15E-06
β offset:	3.71E-02	-4.36E-02	-2.88E-02	-1.06E-01	2.96E-02	9.14E-02	1.01E-01

Table 2.16—Begin-year mean weights at age, interpolated from the survey mean weights at age shown in Table 2.11.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12+
1999	0	0.013	0.112	0.398	0.675	1.422	2.384	3.320	4.342	5.390	8.080	7.891	9.129
2000	0	0.013	0.138	0.381	0.808	1.214	1.922	3.470	3.970	5.217	5.807	6.715	8.478
2001	0	0.024	0.158	0.366	0.872	1.465	2.138	2.780	4.933	5.694	5.842	7.600	8.020
2002	0	0.020	0.152	0.389	0.756	1.475	2.189	3.026	3.579	5.358	7.556	6.784	8.908
2003	0	0.025	0.148	0.486	0.860	1.543	2.536	3.380	4.321	5.351	6.577	8.025	7.118
2004	0	0.022	0.158	0.407	0.993	1.653	2.541	3.767	4.681	6.140	7.613	7.803	9.047
2005	0	0.027	0.109	0.437	0.891	1.668	2.550	3.754	5.055	5.918	7.821	8.340	9.170
2006	0	0.014	0.165	0.372	0.869	1.568	2.594	3.874	5.620	6.768	7.635	9.500	9.907
2007	0	0.011	0.138	0.458	0.921	1.648	2.553	3.905	5.501	6.881	8.917	8.317	9.805
2008	0	0.014	0.135	0.481	1.139	1.892	2.719	3.843	5.278	6.753	7.932	10.413	8.747
2009	0	0.011	0.153	0.503	1.071	1.967	2.830	3.721	4.699	6.343	7.928	8.562	9.708
2010	0	0.015	0.144	0.557	1.218	1.855	2.794	3.610	5.294	5.715	7.829	7.878	10.229
2011	0	0.025	0.189	0.573	1.273	2.228	2.959	3.964	4.806	7.035	7.176	8.042	9.128
2012	0	0.010	0.176	0.613	1.234	2.087	3.155	4.002	5.389	6.126	8.398	8.741	9.035
2013	0	0.017	0.122	0.581	1.123	2.110	2.892	4.197	4.874	6.552	7.500	8.553	10.087
2014	0	0.023	0.171	0.551	1.160	1.945	3.047	3.718	5.449	6.630	7.310	9.183	8.310
2015	0	0.038	0.219	0.563	1.288	1.968	3.328	4.004	5.134	5.949	8.784	9.124	10.227
Ave:	0	0.019	0.152	0.477	1.009	1.747	2.655	3.667	4.878	6.107	7.571	8.322	9.121

Table 2.17—Input multinomial sample sizes for length composition data as specified in the stock assessment models (S1…S5 = seasons 1-5, Srv. = shelf trawl survey). Sample sizes for the NMFS longline survey length composition data in Model 16.7 are shown in the main text.

	Model 11.5																M16.x	
	Trawl fishery					Longline fishery					Pot fishery					Srv.	Fish.	Srv.
Year	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5			
1977			10	13													2	
1978				34		8	23		41	17							12	
1979			16		6	73	24	31	12	19							17	
1980	23	63				8	6	29	13	18							15	
1981			50		15	7	5	26		11							11	
1982		25	20	5	13		12	16	34	19						238	13	250
1983	19	70	27	11	149	82	86	47	53	58						297	56	312
1984	77	97	90	22	34	67	90	81	189	726						274	138	288
1985	73	243	10	16	6	311	67	7	372	1070						381	204	400
1986	84	199	78	45		227	28	97	200	940			11	13		347	178	365
1987	253	176	102	152	80	687	199	100	613	1257			5	15		239	339	251
1988	720	317	34	6	34	12										226	105	237
1989	619		67		12				37					9		226	70	237
1990	220	562	273	5		14	81	616	620	304			7	71		127	260	134
1991	426	1018	53			165	245	555	913	285			17	118	13	163	357	171
1992	106	729	55			392	723	1029	535		6	10	244	115		217	369	228
1993	165	902				487	718	83				91	36			235	232	247
1994	109	1343	82			591	853	180	438			203	105	68		314	372	330
1995	88	890		8		600	770	100	492	216	7	268	338	95	61	208	368	218
1996	66	1287	95	40	14	738	737	103	742	37		433	456	177	20	211	463	222
1997	126	1098	29			751	796	265	829	708		269	343	126	23	207	502	218
1998	75	939	31	38	5	644	574	111	987	858		211	240	50		216	446	227
1999	238	565	12	15		740	789	239	976	246		118	292	83		264	404	277
2000	198	527	36			684	395	130	1265	830	304	168				283	425	298
2001	74	305	41	52		557	670	327	1420	855	27	291	19	138	9	446	448	469
2002	161	316	90	121		980	549	210	1714	699	80	162	16	125	16	276	491	290
2003	121	414	100	149		1277	802	322	1896	1006	264	13		135	39	279	612	293
2004	146	255	134	85		1043	668	278	1662	832	158	34	14	116	18	244	497	257
2005	205	272	112			1216	299	315	1659	818	143	22		136		255	487	268
2006	278	157	82	13		960	294	151	1659	81	200	49	11	138	29	274	384	288
2007	188	211	145			882	75	89	1218	56	210	23		100		289	299	304
2008	165	92	32	21		805	190	207	1551	462	120	26		123		293	355	308
2009	85	57	27	66		721	116	163	1483	431	122	21		52	15	377	315	396
2010	163	37	17	58		775	75	148	960	434	142			114	37	171	277	179
2011	242	138	36	84		492	667	419	1019	441	164			168		468	363	492
2012	328	125	45	27		573	542	556	1021	580	203	28		238		295	400	310
2013	465	168	30	123		890	507	421	1092	692	127	9		195	78	422	503	443
2014	435	348	58	51		760	689	853	996	768	146	21		114	61	405	497	426
2015	241	327	49	40		673	654	550	1171	623	193	66	16	221	47	436	456	458
2016	369	193	30	10		658	495	550	228		169	36				388	257	407

Table 2.18—Objective function components and parameter counts.

Component	M11.5	M16.1	M16.6	M16.7	M16.8	M16.9
Catch	0.00	0.00	0.00	0.00	0.00	0.00
Equilibrium catch	0.01	0.00	0.00	0.00	0.00	0.00
Survey abundance index	-3.95	-23.52	-25.21	-34.29	-41.36	-18.72
Size composition	5242.98	1378.92	1372.94	1636.85	1218.48	1187.99
Age composition	153.94	243.81	241.40	252.32	127.95	238.82
Recruitment	21.18	3.38	4.25	4.78	0.72	0.89
"Softbounds"	0.02	0.01	0.01	0.01	0.00	0.00
Deviations	20.71	0.00	0.00	0.00	0.00	0.01
"F ballpark"	0.00	n/a	n/a	n/a	n/a	n/a
TOTAL	5434.88	1602.60	1593.39	1859.67	1305.79	1408.97

Size composition	M11.5	M16.1	M16.6	M16.7	M16.8	M16.9
Jan-Apr trawl fishery	1134.15	n/a	n/a	n/a	n/a	n/a
May-Jul trawl fishery	213.12	n/a	n/a	n/a	n/a	n/a
Aug-Dec trawl fishery	257.56	n/a	n/a	n/a	n/a	n/a
Jan-Apr longl. fishery	795.94	n/a	n/a	n/a	n/a	n/a
May-Jul longl. fishery	264.57	n/a	n/a	n/a	n/a	n/a
Aug-Dec longl. fishery	1129.12	n/a	n/a	n/a	n/a	n/a
Jan-Apr pot fishery	149.33	n/a	n/a	n/a	n/a	n/a
May-Jul pot fishery	70.47	n/a	n/a	n/a	n/a	n/a
Aug-Dec pot fishery	262.89	n/a	n/a	n/a	n/a	n/a
Fishery	n/a	366.40	364.60	365.10	338.72	192.69
Trawl survey	965.82	1012.52	1008.34	1020.80	879.76	995.30
NMFS LL survey	n/a	n/a	n/a	250.94	n/a	n/a

Survey abundance index	M11.5	M16.1	M16.6	M16.7	M16.8	M16.9
Trawl survey	-3.95	-23.52	-25.21	-25.15	-41.36	-18.72
NMFS LL survey	n/a	n/a	n/a	-9.15	n/a	n/a

Parameter type	M11.5	M16.1	M16.6	M16.7	M16.8	M16.9
True parameters:	115	18	18	21	17	18
Constrained *dev* s:	75	59	59	59	92	139
Total:	190	77	77	80	109	157

Table 2.19—Log-scale standard errors of the data (σave), root mean squared errors (RMSE), mean normalized residuals (MNR), standard deviations of normalized residuals (SDNR), and observed:expected correlations (Corr.) for fishery CPUE and survey relative abundance time series. Fishery CPUE data are not used in fitting Model 11.5 and are not included at all in Models 16.x; fishery CPUE results are shown for comparison only.

Model	Fleet	σave	RMSE	MNR	SDNR	Corr.
11.5	Jan-Apr trawl fishery	0.08	0.48	0.57	4.02	0.17
11.5	May-Jul trawl fishery	0.25	0.42	-0.16	1.70	0.19
11.5	Aug-Dec trawl fishery	0.57	0.69	0.17	2.31	0.12
11.5	Jan-Apr longline fishery	0.08	0.39	0.23	4.68	-0.18
11.5	May-Jul longline fishery	0.20	0.29	0.35	2.61	0.46
11.5	Aug-Dec longline fishery	0.12	0.27	0.12	4.12	0.30
11.5	Jan-Apr pot fishery	0.12	0.35	0.18	2.05	0.23
11.5	May-Jul pot fishery	0.14	0.21	0.04	1.47	0.23
11.5	Aug-Dec pot fishery	0.32	0.39	0.01	2.06	0.14
11.5	Shelf trawl survey	0.11	0.23	1.04	1.82	0.78
16.1	Shelf trawl survey	0.11	0.19	0.07	1.79	0.79
16.6	Shelf trawl survey	0.11	0.19	0.10	1.76	0.79
16.7	Shelf trawl survey	0.11	0.18	0.11	1.76	0.80
16.8	Shelf trawl survey	0.11	0.16	0.11	1.47	0.85
16.9	Shelf trawl survey	0.11	0.20	0.08	1.86	0.78
16.7	NMFS longline survey	0.16	0.25	-0.27	1.42	0.60

Table 2.20—Ratios of effective sample size to input sample size for each fishery and survey size composition time series. Nrec = number of records, Ninp = input sample size, Neff = effective sample size, A(·) = arithmetic mean, H(·) = harmonic mean. Note that the arithmetic mean input sample size for the trawl survey size composition data in Model 11.5 (285) differs from that of the other models (300).

				Ratios		
Model	Fleet	Nrec	A(Ninp)	A(Neff/Ninp)	A(Neff)/A(Ninp)	H(Neff)/A(Ninp)
11.5	Jan-Apr trawl fish.	70	312	4.97	3.02	1.71
11.5	May-Jul trawl fish.	36	61	9.24	7.49	3.34
11.5	Aug-Dec trawl fish.	39	43	12.67	6.07	3.36
11.5	Jan-Apr longl. fish.	74	474	8.36	3.99	1.20
11.5	May-Jul longl. fish.	36	261	9.35	5.00	2.91
11.5	Aug-Dec longl. fish.	69	674	6.34	3.11	0.91
11.5	Jan-Apr pot fish.	42	128	13.89	10.10	3.87
11.5	May-Jul pot fish.	17	128	17.97	7.81	1.86
11.5	Aug-Dec pot fish.	41	86	10.12	7.41	2.89
16.1	Fishery	40	300	8.68	5.83	1.88
16.6	Fishery	40	300	8.73	5.87	1.90
16.7	Fishery	40	300	10.25	8.47	1.89
16.8	Fishery	40	300	10.12	8.24	1.91
16.9	Fishery	40	300	16.43	8.82	3.48
11.5	Trawl survey	35	285	1.95	1.65	1.02
16.1	Trawl survey	35	300	1.82	1.56	1.00
16.6	Trawl survey	35	300	1.83	1.56	1.01
16.7	Trawl survey	35	300	1.84	1.57	1.00
16.8	Trawl survey	35	300	2.26	1.90	1.15
16.9	Trawl survey	35	300	1.87	1.59	1.03
16.7	NMFS LL survey	10	300	1.79	1.59	1.01

Table 2.21—Input sample size, effective sample size, and ratio thereof for each year of age composition data from the bottom trawl survey. Last two rows show arithmetic and harmonic means. Color scale extends from red (low) to green (high) in each row.

		Effective N						Ratio					
Year	Input N	M11.5	M16.1	M16.6	M16.7	M16.8	M16.9	M11.5	M16.1	M16.6	M16.7	M16.8	M16.9
1994	204	428	186	209	233	237	163	2.10	0.91	0.49	1.26	1.13	0.70
1995	163	37	29	29	24	54	31	0.23	0.18	0.79	0.82	1.85	1.29
1996	203	365	68	79	60	598	83	1.80	0.34	0.22	0.87	7.55	1.39
1997	205	154	51	54	62	194	45	0.75	0.25	0.35	1.23	3.61	0.72
1998	181	1245	93	83	103	1229	97	6.88	0.51	0.07	1.11	14.77	0.94
1999	246	124	61	55	50	94	68	0.50	0.25	0.45	0.83	1.70	1.35
2000	246	114	62	53	42	60	82	0.46	0.25	0.46	0.67	1.15	1.96
2001	263	103	37	39	38	74	37	0.39	0.14	0.37	1.03	1.91	0.97
2002	248	88	40	38	39	96	40	0.35	0.16	0.43	0.98	2.53	1.04
2003	361	280	824	986	935	224	707	0.78	2.28	3.52	1.13	0.23	0.76
2004	284	31	34	34	34	50	35	0.11	0.12	1.11	0.97	1.46	1.04
2005	365	365	183	182	170	321	169	1.00	0.50	0.50	0.93	1.76	0.99
2006	371	141	51	52	57	404	55	0.38	0.14	0.37	1.11	7.82	0.97
2007	412	58	11	11	10	74	12	0.14	0.03	0.19	0.93	6.72	1.17
2008	346	261	135	136	153	838	127	0.75	0.39	0.52	1.13	6.18	0.83
2009	403	96	162	139	130	395	165	0.24	0.40	1.46	0.81	2.84	1.27
2010	369	101	210	260	241	171	285	0.27	0.57	2.57	1.15	0.66	1.18
2011	358	144	121	117	110	106	110	0.40	0.34	0.81	0.90	0.90	1.00
2012	372	92	76	78	69	97	91	0.25	0.20	0.85	0.91	1.24	1.32
2013	405	113	127	125	112	137	135	0.28	0.31	1.10	0.88	1.10	1.21
2014	349	416	290	311	370	323	259	1.19	0.83	0.75	1.27	1.04	0.70
2015	244	312	201	206	222	415	202	1.28	0.82	0.66	1.11	2.01	0.91
Mean	300	230	139	149	148	282	136	0.93	0.45	0.82	1.00	3.19	1.08
Harm.	277	112	59	59	56	132	62	0.38	0.19	0.40	0.98	1.33	1.01

Table 2.22a—Biological parameters, ageing bias, recruitment parameters (except annual *devs*), initial fishing mortality, and log catchability estimated by at least one of the stock assessment models ("-" in the SD column means that the parameter value was assumed rather than estimated (specifically, natural mortality, σ(recruitment), and ln(trawl survey catchability), all in Model 11.5), and "n/a" means that the parameter was not used in the respective model).

	Model 11.5		Model 16.1		Model 16.6		Model 16.7		Model 16.8		Model 16.9	
Parameter	Est.	SD	Est.	SD	Est.	SD	Est.	SD	Est.	SD	Est.	SD
Natural mortality	0.340	_	0.378	0.012	0.363	0.013	0.344	0.012	0.375	0.012	0.376	0.012
Length at age 1 (cm)	14.352	0.106	16.399	0.088	16.401	0.088	16.449	0.088	16.360	0.088	16.381	0.088
Asymptotic length (cm)	92.747	0.494	98.412	1.826	99.387	1.901	101.132	1.814	100.396	1.984	97.914	1.778
Brody growth coefficient	0.239	0.002	0.200	0.012	0.197	0.012	0.200	0.011	0.195	0.012	0.195	0.012
Richards growth coefficient	n/a	n/a	1.054	0.048	1.050	0.048	1.014	0.043	1.050	0.048	1.077	0.050
SD of length at age 1 (cm)	3.605	0.067	3.424	0.058	3.425	0.058	3.479	0.057	3.422	0.058	3.403	0.058
SD of length at age 20 (cm)	9.616	0.154	9.663	0.275	9.717	0.282	8.851	0.219	9.551	0.296	9.984	0.289
Ageing bias at age 1 (years)	0.336	0.013	0.325	0.012	0.321	0.013	0.308	0.014	0.323	0.013	0.328	0.012
Ageing bias at age 20 (years)	0.322	0.145	0.323	0.153	0.351	0.154	0.527	0.154	0.351	0.160	0.313	0.150
ln(mean post-1976 recruitment)	13.171	0.019	13.620	0.104	13.220	0.104	13.011	0.094	13.555	0.094	13.593	0.103
σ(recruitment)	0.570	_	0.631	0.066	0.638	0.066	0.638	0.066	0.602	0.065	0.610	0.061
ln(pre-1977 recruitment offset)	-1.137	0.130	-1.047	0.226	-1.099	0.216	-1.172	0.198	-1.098	0.220	-0.748	0.203
Initial F (Jan-Apr trawl fishery)	0.664	0.141	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Initial F (fishery)	n/a	n/a	0.127	0.045	0.155	0.056	0.188	0.071	0.149	0.056	0.073	0.021
ln(trawl survey catchability)	-0.261	_	-0.487	0.062	-0.133	0.065	0.033	0.056	-0.408	0.056	-0.496	0.061
ln(NMFS LL survey catchability)	n/a	n/a	n/a	n/a	n/a	n/a	0.410	0.071	n/a	n/a	n/a	n/a

Table 2.22b—Initial age composition *dev*s estimated by the stock assessment models.

	Model 11.5		Model 16.1		Model 16.6		Model 16.7		Model 16.8		Model 16.9	
Parameter	Est.	SD	Est.	SD	Est.	SD	Est.	SD	Est.	SD	Est.	SD
Initial age 20 ln(abundance) dev	n/a	n/a	-0.006	0.630	-0.005	0.636	-0.004	0.636	-0.004	0.600	-0.008	0.608
Initial age 19 ln(abundance) dev	n/a	n/a	-0.004	0.630	-0.003	0.637	-0.003	0.637	-0.003	0.601	-0.005	0.609
Initial age 18 ln(abundance) dev	n/a	n/a	-0.006	0.629	-0.006	0.636	-0.005	0.636	-0.005	0.600	-0.007	0.608
Initial age 17 ln(abundance) dev	n/a	n/a	-0.010	0.628	-0.009	0.635	-0.009	0.635	-0.008	0.599	-0.012	0.607
Initial age 16 ln(abundance) dev	n/a	n/a	-0.016	0.626	-0.016	0.633	-0.014	0.633	-0.013	0.598	-0.018	0.605
Initial age 15 ln(abundance) dev	n/a	n/a	-0.027	0.623	-0.025	0.630	-0.024	0.630	-0.022	0.595	-0.027	0.602
Initial age 14 ln(abundance) dev	n/a	n/a	-0.043	0.619	-0.041	0.626	-0.039	0.626	-0.036	0.591	-0.042	0.598
Initial age 13 ln(abundance) dev	n/a	n/a	-0.069	0.612	-0.066	0.619	-0.063	0.620	-0.060	0.586	-0.063	0.592
Initial age 12 ln(abundance) dev	n/a	n/a	-0.109	0.602	-0.103	0.610	-0.101	0.611	-0.096	0.577	-0.093	0.585
Initial age 11 ln(abundance) dev	n/a	n/a	-0.163	0.589	-0.157	0.597	-0.155	0.600	-0.147	0.566	-0.134	0.575
Initial age 10 ln(abundance) dev	n/a	n/a	-0.239	0.574	-0.232	0.582	-0.232	0.585	-0.220	0.552	-0.188	0.563
Initial age 9 ln(abundance) dev	n/a	n/a	-0.332	0.556	-0.328	0.563	-0.332	0.567	-0.312	0.535	-0.253	0.549
Initial age 8 ln(abundance) dev	n/a	n/a	-0.437	0.537	-0.442	0.543	-0.451	0.547	-0.418	0.517	-0.323	0.536
Initial age 7 ln(abundance) dev	n/a	n/a	-0.542	0.519	-0.560	0.523	-0.578	0.525	-0.526	0.499	-0.386	0.524
Initial age 6 ln(abundance) dev	n/a	n/a	-0.616	0.504	-0.650	0.505	-0.680	0.503	-0.609	0.483	-0.412	0.517
Initial age 5 ln(abundance) dev	n/a	n/a	-0.580	0.497	-0.628	0.495	-0.678	0.488	-0.588	0.473	-0.345	0.518
Initial age 4 ln(abundance) dev	n/a	n/a	-0.194	0.481	-0.246	0.478	-0.309	0.471	-0.227	0.459	-0.064	0.523
Initial age 3 ln(abundance) dev	1.305	0.187	-0.068	0.471	-0.092	0.463	-0.021	0.435	-0.075	0.447	0.052	0.481
Initial age 2 ln(abundance) dev	-0.699	0.418	-0.118	0.521	-0.153	0.516	-0.220	0.498	-0.137	0.493	-0.253	0.538
Initial age 1 ln(abundance) dev	1.399	0.210	0.771	0.524	0.744	0.513	0.790	0.451	0.725	0.498	0.133	0.543

Table 2.22c—Annual log-scale recruitment *devs* estimated by the stock assessment models. Color scale extends from red (low) to green (high) in each column.

	Model 11.5		Model 16.1		Model 16.6		Model 16.7		Model 16.8		Model 16.9	
Year	Est.	SD	Est.	SD	Est.	SD	Est.	SD	Est.	SD	Est.	SD
1977	1.363	0.108	1.002	0.217	0.935	0.212	0.723	0.200	0.906	0.207	1.081	0.214
1978	0.483	0.207	0.505	0.263	0.483	0.253	0.446	0.206	0.468	0.239	0.587	0.286
1979	0.713	0.106	0.496	0.147	0.481	0.144	0.442	0.125	0.469	0.136	0.600	0.156
1980	-0.329	0.130	-0.287	0.139	-0.284	0.137	-0.247	0.121	-0.368	0.141	-0.394	0.162
1981	-0.863	0.141	-0.883	0.142	-0.883	0.142	-0.854	0.132	-0.725	0.152	-0.913	0.148
1982	0.981	0.041	0.784	0.051	0.782	0.051	0.740	0.050	0.740	0.059	0.845	0.054
1983	-0.509	0.110	-0.584	0.126	-0.580	0.125	-0.529	0.115	-0.338	0.123	-0.582	0.133
1984	0.777	0.045	0.758	0.051	0.766	0.050	0.741	0.049	0.690	0.062	0.785	0.054
1985	-0.053	0.070	-0.222	0.090	-0.202	0.090	-0.145	0.083	-0.118	0.098	-0.138	0.093
1986	-0.749	0.092	-0.647	0.103	-0.614	0.102	-0.556	0.095	-0.702	0.116	-0.575	0.110
1987	-1.094	0.105	-1.528	0.181	-1.487	0.179	-1.371	0.161	-1.567	0.203	-1.645	0.201
1988	-0.202	0.056	-0.500	0.098	-0.483	0.097	-0.480	0.092	-0.170	0.096	-0.584	0.109
1989	0.534	0.040	0.534	0.059	0.530	0.058	0.496	0.055	0.442	0.069	0.544	0.063
1990	0.340	0.044	0.342	0.067	0.331	0.065	0.360	0.060	0.431	0.070	0.323	0.071
1991	-0.282	0.060	-0.053	0.079	-0.078	0.078	-0.025	0.072	-0.176	0.098	-0.081	0.085
1992	0.623	0.032	0.763	0.043	0.725	0.041	0.732	0.038	0.694	0.047	0.824	0.045
1993	-0.409	0.057	-0.149	0.068	-0.199	0.067	-0.288	0.064	-0.083	0.073	-0.136	0.072
1994	-0.330	0.050	-0.258	0.071	-0.341	0.069	-0.253	0.060	-0.268	0.077	-0.246	0.075
1995	-0.256	0.053	-0.340	0.078	-0.439	0.077	-0.360	0.064	-0.206	0.081	-0.370	0.083
1996	0.641	0.032	0.665	0.041	0.574	0.040	0.551	0.037	0.656	0.046	0.721	0.043
1997	-0.243	0.050	-0.117	0.064	-0.180	0.063	-0.252	0.060	-0.032	0.068	-0.114	0.068
1998	-0.273	0.048	-0.222	0.068	-0.254	0.067	-0.167	0.059	-0.100	0.075	-0.289	0.073
1999	0.376	0.031	0.483	0.042	0.482	0.041	0.519	0.037	0.614	0.046	0.464	0.045
2000	-0.104	0.036	0.191	0.045	0.213	0.044	0.249	0.042	0.018	0.060	0.159	0.048
2001	-0.877	0.056	-0.646	0.068	-0.601	0.067	-0.566	0.063	-0.438	0.071	-0.695	0.071
2002	-0.345	0.038	-0.356	0.053	-0.302	0.052	-0.266	0.048	-0.393	0.065	-0.392	0.055
2003	-0.590	0.045	-0.538	0.056	-0.474	0.055	-0.479	0.052	-0.388	0.063	-0.568	0.058
2004	-0.718	0.049	-0.715	0.060	-0.651	0.060	-0.637	0.057	-0.707	0.079	-0.788	0.063
2005	-0.602	0.046	-0.410	0.054	-0.347	0.054	-0.305	0.049	-0.575	0.082	-0.442	0.055
2006	0.650	0.026	0.755	0.035	0.822	0.034	0.788	0.031	0.604	0.040	0.766	0.039
2007	-0.533	0.059	-0.065	0.057	-0.004	0.056	-0.021	0.051	-0.109	0.072	-0.060	0.060
2008	1.101	0.028	1.106	0.036	1.150	0.033	1.116	0.030	1.005	0.041	1.110	0.040
2009	-0.649	0.097	-0.939	0.113	-0.894	0.111	-0.862	0.103	-0.841	0.129	-1.042	0.119
2010	0.604	0.045	0.631	0.050	0.644	0.048	0.614	0.044	0.467	0.061	0.630	0.052
2011	0.993	0.046	1.046	0.050	1.038	0.049	0.957	0.046	0.820	0.058	1.106	0.051
2012	0.223	0.074	0.171	0.073	0.162	0.073	0.123	0.070	0.211	0.085	0.213	0.075
2013	1.117	0.064	0.998	0.061	0.982	0.061	0.927	0.059	0.856	0.075	1.025	0.061
2014	-0.884	0.152	-0.966	0.143	-0.983	0.143	-1.025	0.141	-1.001	0.188	-0.942	0.144
2015	-0.622	0.201	-0.804	0.197	-0.820	0.198	-0.836	0.193	-0.786	0.287	-0.789	0.198

Table 2.22d—Fishery selectivity parameters estimated by Model 11.5.

Parameter	Est.	SD
P3_May-Jul_Trawl	5.635	0.103
P2_Jan-Apr_Longline	-6.912	14.211
P4_Jan-Apr_Longline	5.032	0.137
P3_May-Jul_Longline	5.082	0.043
P2_Aug-Dec_Longline	-2.095	0.267
P4_Aug-Dec_Longline	4.952	0.347
P2_Jan-Apr_Pot	-9.392	15.244
P3_Jan-Apr_Pot	5.033	0.046
P4_Jan-Apr_Pot	4.351	0.283
P3_May-Jul_Pot	4.920	0.084
P1_Jan-Apr_Trawl_1977	68.881	3.174
P1_Jan-Apr_Trawl_1985	75.859	1.714
P1_Jan-Apr_Trawl_1990	68.955	1.108
P1_Jan-Apr_Trawl_1995	73.966	0.960
P1_Jan-Apr_Trawl_2000	78.219	1.231
P1_Jan-Apr_Trawl_2005	78.243	0.708
P3_Jan-Apr_Trawl_1977	6.173	0.179
P3_Jan-Apr_Trawl_1985	6.604	0.079
P3_Jan-Apr_Trawl_1990	6.094	0.059
P3_Jan-Apr_Trawl_1995	6.299	0.047
P3_Jan-Apr_Trawl_2000	6.304	0.062
P3_Jan-Apr_Trawl_2005	6.022	0.037
P1_May-Jul_Trawl_1977	50.183	1.717
P1_May-Jul_Trawl_1985	51.339	1.748
P1_May-Jul_Trawl_1990	62.003	1.546
P1_May-Jul_Trawl_2000	53.046	1.523
P1_May-Jul_Trawl_2005	58.497	1.421
P1_Aug-Dec_Trawl_1977	62.702	4.089
P1_Aug-Dec_Trawl_1980	81.845	5.841
P1_Aug-Dec_Trawl_1985	85.878	5.340
P1_Aug-Dec_Trawl_1990	75.459	33.666
P1_Aug-Dec_Trawl_1995	102.473	_
P1_Aug-Dec_Trawl_2000	56.927	1.470
P3_Aug-Dec_Trawl_1977	5.556	0.332
P3_Aug-Dec_Trawl_1980	6.664	0.237
P3_Aug-Dec_Trawl_1985	6.593	0.234
P3_Aug-Dec_Trawl_1990	6.318	1.927
P3_Aug-Dec_Trawl_1995	7.021	0.090
P3_Aug-Dec_Trawl_2000	5.257	0.149
P1_Jan-Apr_Longline_1977	59.291	2.087
P1_Jan-Apr_Longline_1980	72.266	2.556
P1_Jan-Apr_Longline_1985	74.994	0.927
P1_Jan-Apr_Longline_1990	66.279	0.478
P1_Jan-Apr_Longline_1995	65.878	0.427
P1_Jan-Apr_Longline_2000	63.750	0.442
P1_Jan-Apr_Longline_2005	67.679	0.334
P3_Jan-Apr_Longline_1977	5.168	0.211
P3_Jan-Apr_Longline_1980	5.907	0.184
P3_Jan-Apr_Longline_1985	5.852	0.069
P3_Jan-Apr_Longline_1990	5.242	0.046
P3_Jan-Apr_Longline_1995	5.318	0.040

Parameter	Est.	SD
P3_Jan-Apr_Longline_2000	5.383	0.041
P3_Jan-Apr_Longline_2005	5.324	0.027
P6_Jan-Apr_Longline_1977	-1.259	0.799
P6_Jan-Apr_Longline_1980	0.518	1.096
P6_Jan-Apr_Longline_1985	-1.072	0.422
P6_Jan-Apr_Longline_1990	-0.464	0.137
P6_Jan-Apr_Longline_1995	-0.636	0.139
P6_Jan-Apr_Longline_2000	-1.144	0.144
P6_Jan-Apr_Longline_2005	-0.810	0.139
P1_May-Jul_Longline_1977	64.073	2.218
P1_May-Jul_Longline_1980	62.984	1.372
P1_May-Jul_Longline_1985	63.802	1.139
P1_May-Jul_Longline_1990	64.180	0.478
P1_May-Jul_Longline_2000	60.315	0.550
P1_May-Jul_Longline_2005	65.578	0.479
P1_Aug-Dec_Longline_1977	60.968	2.260
P1_Aug-Dec_Longline_1980	69.217	1.678
P1_Aug-Dec_Longline_1985	64.151	0.785
P1_Aug-Dec_Longline_1990	67.114	0.726
P1_Aug-Dec_Longline_1995	69.475	0.714
P1_Aug-Dec_Longline_2000	63.592	0.434
P1_Aug-Dec_Longline_2005	63.965	0.327
P3_Aug-Dec_Longline_1977	4.570	0.325
P3_Aug-Dec_Longline_1980	5.380	0.143
P3_Aug-Dec_Longline_1985	4.845	0.092
P3_Aug-Dec_Longline_1990	5.035	0.077
P3_Aug-Dec_Longline_1995	5.507	0.054
P3_Aug-Dec_Longline_2000	5.182	0.042
P3_Aug-Dec_Longline_2005	4.990	0.032
P6_Aug-Dec_Longline_1977	-2.381	1.919
P6_Aug-Dec_Longline_1980	0.823	0.853
P6_Aug-Dec_Longline_1985	0.294	0.243
P6_Aug-Dec_Longline_1990	2.687	1.114
P6_Aug-Dec_Longline_1995	9.566	11.507
P6_Aug-Dec_Longline_2000	-0.275	0.181
P6_Aug-Dec_Longline_2005	4.631	5.905
P1_Jan-Apr_Pot_1977	69.059	0.918
P1_Jan-Apr_Pot_1995	68.684	0.535
P1_Jan-Apr_Pot_2000	68.328	0.506
P1_Jan-Apr_Pot_2005	69.474	0.486
P6_Jan-Apr_Pot_1977	0.200	0.551
P6_Jan-Apr_Pot_1995	-0.202	0.252
P6_Jan-Apr_Pot_2000	-0.543	0.233
P6_Jan-Apr_Pot_2005	0.190	0.223
P1_May-Jul_Pot_1977	67.256	0.874
P1_May-Jul_Pot_1995	65.879	0.735
P1_Aug-Dec_Pot_1977	68.524	1.203
P1_Aug-Dec_Pot_2000	62.702	0.651
P3_Aug-Dec_Pot_1977	5.194	0.121
P3_Aug-Dec_Pot_2000	4.559	0.091

Table 2.22e—Survey selectivity parameters as estimated by Model 11.5. Color scale extends from red (low) to green (high).

Parameter	Estimate	St. dev.
P1	1.265	0.052
P2	-2.682	0.346
P3	-2.384	0.427
P4	2.522	0.384
P5	-9.992	_
P6	-1.002	0.312
P3_dev_1982	-0.040	0.033
P3_dev_1983	-0.032	0.018
P3_dev_1984	-0.075	0.028
P3_dev_1985	0.013	0.022
P3_dev_1986	-0.039	0.024
P3_dev_1987	0.026	0.038
P3_dev_1988	-0.070	0.032
P3_dev_1989	-0.112	0.019
P3_dev_1990	-0.023	0.022
P3_dev_1991	-0.033	0.023
P3_dev_1992	0.092	0.040
P3_dev_1993	0.054	0.029
P3_dev_1994	-0.032	0.022
P3_dev_1995	-0.084	0.021
P3_dev_1996	-0.106	0.019
P3_dev_1997	-0.055	0.016
P3_dev_1998	-0.069	0.020
P3_dev_1999	-0.072	0.018
P3_dev_2000	-0.027	0.017
P3_dev_2001	0.168	0.037
P3_dev_2002	-0.012	0.024
P3_dev_2003	0.009	0.020
P3_dev_2004	-0.009	0.021
P3_dev_2005	0.057	0.028
P3_dev_2006	0.175	0.037
P3_dev_2007	0.211	0.036
P3_dev_2008	0.124	0.037
P3_dev_2009	0.009	0.017
P3_dev_2010	-0.046	0.024
P3_dev_2011	0.031	0.020
P3_dev_2012	0.041	0.021
P3_dev_2013	-0.039	0.018
P3_dev_2014	-0.017	0.017

Table 2.22f—Main selectivity parameters estimated by Models 16.x.

	Model 16.1		Model 16.6		Model 16.7		Model 16.8		Model 16.9	
Parameter	Est.	SD	Est.	SD	Est.	SD	Est.	SD	Est.	SD
Fishery A50%	4.319	0.046	4.324	0.046	4.303	0.040	4.327	0.047	4.496	64.179
Fishery A95%-A50%	1.156	0.032	1.158	0.032	1.193	0.029	1.164	0.032	1.264	12.234
Trawl survey A50%	1.010	0.006	1.006	0.006	1.001	0.006	1.001	0.002	1.008	0.006
Trawl survey A95%-A50%	0.289	0.050	0.289	0.050	0.289	0.050	0.010	_	0.289	0.051
NMFS LL survey A50%	n/a	n/a	n/a	n/a	4.009	0.078	n/a	n/a	n/a	n/a
NMFS LL survey A95%-A50%	n/a	n/a	n/a	n/a	0.190	1.656	n/a	n/a	n/a	n/a

Table 2.22g—Selectivity *dev*s as estimated by Models 16.8 and 16.9. Color scale extends from red (low) to green (high). Standard deviations in Model 16.9 reflect logit-transformed parameters and wide bounds.

	Model 16.8		Model 16.9			
	Survey A50% dev		Fishery A50% dev		Fishery A95%-A50% dev	
Year	Est.	SD	Est.	SD	Est.	SD
1977	n/a	n/a	-0.296	13.003	-1.211	24.658
1978	n/a	n/a	-0.199	12.968	-0.635	13.206
1979	n/a	n/a	-0.328	12.969	-1.407	20.606
1980	n/a	n/a	-0.290	13.011	-1.292	22.732
1981	n/a	n/a	-0.472	12.981	-0.811	13.624
1982	0.0015	0.0012	0.262	12.970	1.256	14.080
1983	0.0001	0.0009	0.225	12.968	3.732	36.191
1984	0.0027	0.0011	0.106	12.968	4.926	32.618
1985	-0.0004	0.0010	-0.176	12.968	-0.691	13.157
1986	0.0008	0.0010	-0.012	12.968	0.331	13.151
1987	-0.0004	0.0012	0.031	12.968	0.265	13.150
1988	0.0014	0.0015	-0.110	12.968	1.694	14.847
1989	0.0033	0.0010	0.068	12.968	4.489	33.790
1990	0.0003	0.0010	0.232	12.968	4.856	32.791
1991	0.0010	0.0010	-0.031	12.968	0.157	13.152
1992	-0.0023	0.0014	-0.130	12.968	-0.437	13.148
1993	-0.0013	0.0010	-0.062	12.968	0.054	13.149
1994	0.0014	0.0010	0.016	12.968	0.211	13.148
1995	0.0022	0.0010	-0.069	12.968	-0.138	13.149
1996	0.0028	0.0010	0.072	12.968	0.207	13.149
1997	0.0010	0.0009	0.118	12.968	0.608	13.150
1998	0.0021	0.0010	0.025	12.968	0.176	13.149
1999	0.0020	0.0009	-0.098	12.968	-0.223	13.148
2000	0.0009	0.0009	-0.045	12.968	-0.639	13.159
2001	-0.0066	0.0048	-0.038	12.968	-0.280	13.149
2002	0.0010	0.0010	-0.133	12.968	-0.417	13.148
2003	-0.0013	0.0010	-0.089	12.968	-0.570	13.149
2004	0.0003	0.0009	-0.092	12.972	-1.299	22.665
2005	-0.0022	0.0012	-0.048	12.968	-0.231	13.149
2006	-0.0073	0.0076	-0.051	12.968	-0.457	13.150
2007	-0.0358	2.2942	0.037	12.968	-0.144	13.149
2008	-0.0010	0.0010	-0.041	12.968	-0.359	13.148
2009	-0.0010	0.0009	-0.103	12.968	-0.963	13.159
2010	0.0005	0.0011	-0.070	12.996	-1.430	20.052
2011	-0.0014	0.0009	0.082	12.968	-0.009	13.149
2012	-0.0017	0.0010	-0.076	12.989	-1.402	20.778
2013	0.0011	0.0009	-0.122	12.968	-0.441	13.149
2014	-0.0004	0.0009	-0.070	12.968	-0.595	13.148
2015	n/a	n/a	-0.079	12.983	-1.418	20.406
2016	n/a	n/a	0.004	12.968	-0.192	13.150

Table 2.23a—Annual fishing mortality rates as estimated by the models. Color scale extends from red (low) to green (high) in each **column**.

	Model 11.5		Model 16.1		Model 16.6		Model 16.7		Model 16.8		Model 16.9	
Year	Est.	SD	Est.	SD	Est.	SD	Est.	SD	Est.	SD	Est.	SD
1977	0.081	0.014	0.189	0.069	0.244	0.090	0.307	0.112	0.219	0.084	0.088	0.026
1978	0.091	0.015	0.247	0.092	0.313	0.120	0.403	0.153	0.291	0.114	0.115	0.034
1979	0.064	0.009	0.190	0.069	0.245	0.091	0.315	0.115	0.226	0.086	0.083	0.022
1980	0.055	0.008	0.216	0.068	0.274	0.087	0.348	0.104	0.256	0.084	0.104	0.028
1981	0.051	0.007	0.151	0.030	0.178	0.034	0.227	0.040	0.178	0.036	0.056	0.013
1982	0.040	0.004	0.088	0.011	0.096	0.012	0.124	0.015	0.103	0.013	0.171	0.1
1983	0.056	0.005	0.104	0.011	0.111	0.011	0.139	0.013	0.119	0.012	0.159	0.05
1984	0.075	0.005	0.124	0.011	0.151	0.013	0.185	0.015	0.141	0.012	0.138	0.019
1985	0.096	0.005	0.151	0.013	0.168	0.014	0.202	0.015	0.171	0.014	0.131	0.011
1986	0.093	0.005	0.151	0.012	0.170	0.013	0.200	0.014	0.171	0.013	0.141	0.012
1987	0.108	0.005	0.159	0.011	0.181	0.012	0.212	0.013	0.178	0.012	0.160	0.015
1988	0.144	0.007	0.229	0.015	0.242	0.016	0.280	0.016	0.251	0.016	0.195	0.022
1989	0.134	0.006	0.201	0.013	0.205	0.012	0.235	0.013	0.220	0.013	0.215	0.027
1990	0.144	0.006	0.218	0.013	0.229	0.013	0.260	0.013	0.237	0.014	0.272	0.026
1991	0.223	0.009	0.347	0.022	0.404	0.023	0.458	0.023	0.381	0.023	0.315	0.025
1992	0.223	0.009	0.378	0.028	0.487	0.035	0.560	0.036	0.414	0.030	0.313	0.023
1993	0.187	0.008	0.334	0.025	0.373	0.028	0.432	0.028	0.349	0.026	0.285	0.029
1994	0.221	0.016	0.357	0.024	0.402	0.026	0.467	0.026	0.377	0.024	0.379	0.042
1995	0.325	0.012	0.461	0.030	0.509	0.032	0.591	0.032	0.484	0.029	0.423	0.036
1996	0.296	0.011	0.418	0.028	0.470	0.031	0.543	0.030	0.458	0.029	0.516	0.054
1997	0.338	0.013	0.425	0.027	0.518	0.034	0.616	0.033	0.480	0.030	0.586	0.084
1998	0.265	0.011	0.285	0.019	0.416	0.029	0.514	0.031	0.323	0.020	0.290	0.029
1999	0.253	0.011	0.449	0.031	0.425	0.031	0.522	0.034	0.511	0.034	0.389	0.031
2000	0.241	0.009	0.422	0.030	0.408	0.031	0.491	0.032	0.471	0.033	0.408	0.037
2001	0.207	0.007	0.340	0.022	0.326	0.022	0.395	0.023	0.372	0.024	0.311	0.031
2002	0.250	0.008	0.441	0.028	0.392	0.025	0.479	0.027	0.472	0.030	0.363	0.025
2003	0.268	0.008	0.414	0.026	0.423	0.027	0.502	0.028	0.420	0.026	0.359	0.024
2004	0.293	0.009	0.401	0.024	0.401	0.023	0.465	0.023	0.398	0.022	0.365	0.021
2005	0.325	0.010	0.416	0.024	0.410	0.022	0.475	0.022	0.422	0.023	0.409	0.029
2006	0.364	0.013	0.449	0.029	0.469	0.027	0.548	0.026	0.450	0.027	0.454	0.03
2007	0.354	0.013	0.429	0.030	0.455	0.028	0.540	0.027	0.429	0.028	0.500	0.047
2008	0.399	0.015	0.483	0.037	0.561	0.038	0.685	0.038	0.471	0.032	0.510	0.047
2009	0.447	0.019	0.652	0.058	0.688	0.056	0.859	0.058	0.660	0.053	0.646	0.066
2010	0.369	0.016	0.467	0.043	0.525	0.043	0.639	0.043	0.535	0.044	0.810	0.107
2011	0.435	0.020	0.418	0.035	0.533	0.041	0.662	0.041	0.514	0.037	0.668	0.232
2012	0.398	0.019	0.403	0.036	0.496	0.040	0.620	0.041	0.506	0.039	0.484	0.052
2013	0.343	0.017	0.318	0.028	0.404	0.033	0.518	0.034	0.405	0.031	0.282	0.028
2014	0.325	0.018	0.351	0.034	0.453	0.042	0.597	0.047	0.467	0.041	0.345	0.038
2015	0.269	0.016	0.281	0.027	0.391	0.038	0.517	0.044	0.388	0.036	0.303	0.034
2016	0.260	0.017	0.289	0.029	0.343	0.034	0.462	0.043	0.416	0.042	0.300	0.052

Table 2.23b— Model 11.5 estimates of seasonal full-selection fishing mortality rates, on an annual time scale. Sea1=Jan-Feb, Sea2=Mar-Apr, Sea3=May-Jul, Sea4=Aug-Oct, Sea5=Nov-Dec.

	Trawl fishery					Longline fishery					Pot fishery				
Year	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5	Sea1	Sea2	Sea3	Sea4	Sea5
1977	0.086	0.089	0.055	0.049	0.042	0.017	0.017	0.006	0.024	0.032	0	0	0	0	0
1978	0.098	0.101	0.066	0.056	0.050	0.017	0.017	0.006	0.025	0.034	0	0	0	0	0
1979	0.070	0.072	0.043	0.039	0.033	0.013	0.013	0.005	0.019	0.025	0	0	0	0	0
1980	0.062	0.062	0.031	0.041	0.034	0.010	0.010	0.004	0.013	0.017	0	0	0	0	0
1981	0.034	0.033	0.033	0.064	0.060	0.004	0.004	0.002	0.009	0.010	0	0	0	0	0
1982	0.035	0.035	0.036	0.045	0.036	0.001	0.001	0.001	0.004	0.005	0	0	0	0	0
1983	0.055	0.057	0.051	0.053	0.044	0.005	0.005	0.003	0.004	0.005	0	0	0	0	0
1984	0.062	0.066	0.057	0.056	0.049	0.007	0.008	0.006	0.027	0.038	0	0	0	0	0
1985	0.079	0.084	0.067	0.065	0.051	0.024	0.026	0.010	0.034	0.048	0	0	0	0	0
1986	0.088	0.094	0.067	0.065	0.053	0.017	0.019	0.005	0.027	0.039	0	0	0	0	0
1987	0.097	0.103	0.053	0.053	0.052	0.043	0.046	0.013	0.043	0.061	0	0	0	0	0
1988	0.196	0.211	0.103	0.113	0.120	0.001	0.001	0.002	0.003	0.004	0	0	0	0	0
1989	0.209	0.227	0.100	0.059	0.054	0.008	0.009	0.012	0.015	0.013	0.000	0.000	0.000	0.000	0.000
1990	0.178	0.195	0.093	0.033	0.029	0.032	0.035	0.048	0.052	0.047	0.000	0.000	0.002	0.002	0.001
1991	0.182	0.382	0.068	0.056	0.044	0.063	0.106	0.088	0.100	0.066	0.000	0.004	0.002	0.011	0.003
1992	0.150	0.225	0.056	0.044	0.014	0.135	0.241	0.143	0.093	0.000	0.000	0.009	0.030	0.011	0.000
1993	0.191	0.260	0.026	0.036	0.011	0.228	0.232	0.025	0.016	0.004	0.000	0.018	0.013	0.000	0.000
1994	0.088	0.297	0.020	0.100	0.019	0.194	0.267	0.030	0.105	0.000	0.000	0.041	0.010	0.016	0.000
1995	0.216	0.435	0.005	0.199	0.002	0.248	0.317	0.021	0.110	0.065	0.000	0.078	0.040	0.015	0.005
1996	0.146	0.381	0.031	0.109	0.022	0.243	0.270	0.021	0.122	0.024	0.000	0.130	0.063	0.023	0.005
1997	0.183	0.413	0.026	0.101	0.037	0.273	0.291	0.044	0.118	0.196	0.000	0.101	0.042	0.021	0.005
1998	0.124	0.242	0.027	0.143	0.022	0.290	0.209	0.022	0.098	0.116	0.018	0.066	0.033	0.012	0.004
1999	0.149	0.227	0.017	0.067	0.004	0.334	0.249	0.021	0.129	0.044	0.023	0.065	0.036	0.013	0.001
2000	0.175	0.230	0.017	0.027	0.004	0.314	0.088	0.007	0.128	0.147	0.142	0.053	0.007	0.009	0.000
2001	0.068	0.125	0.015	0.039	0.005	0.167	0.162	0.019	0.174	0.162	0.023	0.124	0.006	0.015	0.005
2002	0.112	0.191	0.035	0.038	0.002	0.338	0.152	0.010	0.203	0.122	0.019	0.096	0.003	0.016	0.006
2003	0.132	0.152	0.030	0.035	0.002	0.351	0.182	0.014	0.207	0.154	0.130	0.020	0.003	0.027	0.011
2004	0.193	0.168	0.048	0.044	0.001	0.378	0.184	0.016	0.201	0.192	0.101	0.035	0.006	0.022	0.005
2005	0.283	0.174	0.044	0.017	0.001	0.536	0.085	0.022	0.232	0.203	0.104	0.040	0.000	0.030	0.004
2006	0.350	0.193	0.044	0.030	0.001	0.632	0.095	0.016	0.337	0.012	0.149	0.053	0.003	0.031	0.009
2007	0.231	0.267	0.083	0.026	0.001	0.709	0.035	0.012	0.278	0.010	0.179	0.021	0.005	0.046	0.000
2008	0.262	0.134	0.035	0.055	0.008	0.783	0.077	0.029	0.343	0.122	0.170	0.042	0.003	0.066	0.002
2009	0.237	0.208	0.035	0.080	0.004	0.944	0.086	0.026	0.366	0.150	0.209	0.043	0.003	0.014	0.016
2010	0.309	0.162	0.027	0.060	0.014	0.724	0.037	0.028	0.204	0.142	0.221	0.037	0.003	0.045	0.021
2011	0.320	0.333	0.040	0.067	0.012	0.391	0.368	0.113	0.213	0.160	0.234	0.037	0.005	0.064	0.000
2012	0.490	0.195	0.040	0.051	0.007	0.365	0.274	0.133	0.149	0.158	0.245	0.030	0.005	0.034	0.006
2013	0.363	0.184	0.026	0.086	0.009	0.345	0.210	0.077	0.133	0.162	0.192	0.035	0.000	0.030	0.026
2014	0.287	0.216	0.027	0.039	0.005	0.279	0.240	0.110	0.117	0.138	0.203	0.073	0.001	0.028	0.023
2015	0.176	0.214	0.026	0.033	0.003	0.207	0.211	0.090	0.117	0.112	0.168	0.069	0.001	0.026	0.017
2016	0.238	0.160	0.024	0.029	0.002	0.221	0.158	0.085	0.105	0.101	0.132	0.132	0.000	0.023	0.016

Table 2.24—Summary of key management reference points from the standard projection algorithm (last seven rows are from SS). All biomass figures are in t. Color scale: red = row minimum, green = row maximum.

Quantity	M11.5	M16.1	M16.6	M16.7	M16.8	M16.9
B100%	788,000	668,000	620,000	609,000	631,000	681,000
B40%	315,000	267,000	248,000	243,000	252,000	272,000
B35%	276,000	234,000	217,000	213,000	221,000	238,000
B(2017)	440,000	380,000	327,000	242,000	268,000	393,000
B(2018)	462,000	393,000	340,000	267,000	289,000	408,000
B(2017)/B100%	0.56	0.57	0.53	0.40	0.42	0.58
B(2018)/B100%	0.59	0.59	0.55	0.44	0.46	0.60
F40%	0.28	0.29	0.31	0.29	0.29	0.32
F35%	0.34	0.36	0.38	0.35	0.35	0.38
maxFABC(2017)	0.28	0.29	0.31	0.29	0.29	0.32
maxFABC(2018)	0.28	0.29	0.31	0.29	0.29	0.32
maxABC(2017)	338,000	265,000	239,000	170,000	191,000	276,000
maxABC(2018)	325,000	280,000	255,000	192,000	211,000	302,000
FOFL(2017)	0.34	0.36	0.38	0.35	0.35	0.38
FOFL(2018)	0.34	0.36	0.38	0.35	0.35	0.38
OFL(2017)	396,000	314,000	284,000	200,000	226,000	327,000
OFL(2018)	381,000	331,000	302,000	228,000	249,000	357,000
Pr(maxABC(2017)>truOFL(2017))	0.01	0.08	0.08	0.08	0.08	0.09
Pr(maxABC(2018)>truOFL(2018))	0.03	0.10	0.10	0.08	0.10	0.10
Pr(B(2017)<B20%)	0.00	0.00	0.00	0.00	0.00	0.00
Pr(B(2018)<B20%)	0.00	0.00	0.00	0.00	0.00	0.00
Pr(B(2019)<B20%)	0.00	0.00	0.00	0.00	0.00	0.00
Pr(B(2020)<B20%)	0.00	0.00	0.00	0.00	0.00	0.00
Pr(B(2021)<B20%)	0.00	0.00	0.00	0.00	0.00	0.00

Legend:
B100% = equilibrium unfished spawning biomass
B40% = 40% of B100% (the inflection point of the harvest control rules in Tier 3)
B35% = 35% of B100% (the BMSY proxy for Tier 3)
B(year) = projected spawning biomass for year
B(year)/B100% = ratio of spawning biomass to B100%
F40% = fishing mortality that reduces equilibrium spawning per recruit to 40% of unfished
F35% = fishing mortality that reduces equilibrium spawning per recruit to 35% of unfished
maxFABC(year) = maximum permissible ABC fishing mortality rate under Tier 3
maxABC(year) = maximum permissible ABC under Tier 3
FOFL(year) = OFL fishing mortality rate under Tier 3
OFL(year) = OFL under Tier 3
Pr(maxABC(year)>truOFL(year)) = probability that maxABC is greater than the "true" OFL
Pr(B(year)<B20%) = probability that spawning biomass is less than 20% of unfished

Table 2.25—Schedules of length (cm) at age and selectivity at age as defined by parameter estimates from Model 16.6.

	Begin-year length		Mid-year length		Selectivity	
Age	Mean	SD	Mean	SD	Fishery	Survey
0	0.001	3.425	5.468	3.425	0.000	0.000
1	10.934	3.425	16.401	3.425	0.000	0.486
2	24.577	4.045	31.866	4.598	0.003	1.000
3	38.398	5.093	44.268	5.538	0.033	1.000
4	49.552	5.939	54.316	6.300	0.305	1.000
5	58.614	6.626	62.495	6.920	0.848	1.000
6	66.001	7.186	69.169	7.426	0.986	1.000
7	72.033	7.643	74.623	7.839	0.999	1.000
8	76.966	8.017	79.086	8.178	1.000	1.000
9	81.004	8.323	82.739	8.455	1.000	1.000
10	84.311	8.574	85.733	8.682	1.000	1.000
11	87.020	8.779	88.186	8.868	1.000	1.000
12	89.241	8.948	90.197	9.020	1.000	1.000
13	91.063	9.086	91.847	9.145	1.000	1.000
14	92.556	9.199	93.199	9.248	1.000	1.000
15	93.782	9.292	94.309	9.332	1.000	1.000
16	94.787	9.368	95.220	9.401	1.000	1.000
17	95.612	9.431	95.967	9.458	1.000	1.000
18	96.288	9.482	96.580	9.504	1.000	1.000
19	96.844	9.524	97.083	9.542	1.000	1.000
20	97.738	9.717	97.893	9.717	1.000	1.000

Table 2.26—Begin-year weight at age as defined by input weight-at-length parameters and length-at-age parameters estimated by Model 16.6.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1977	0.00	0.02	0.18	0.69	1.52	2.55	3.68	4.82	5.91	6.93	7.84	8.65	9.35	9.95	10.46	10.90	11.26	11.56	11.82	12.03	12.38
1978	0.00	0.01	0.15	0.63	1.45	2.51	3.72	4.96	6.17	7.31	8.34	9.26	10.06	10.76	11.35	11.85	12.27	12.63	12.92	13.17	13.58
1979	0.00	0.02	0.17	0.68	1.51	2.54	3.67	4.82	5.93	6.95	7.88	8.69	9.40	10.01	10.53	10.97	11.34	11.65	11.91	12.12	12.47
1980	0.00	0.01	0.16	0.65	1.45	2.46	3.58	4.72	5.82	6.85	7.77	8.59	9.31	9.92	10.45	10.89	11.27	11.58	11.84	12.05	12.41
1981	0.00	0.02	0.17	0.66	1.45	2.45	3.55	4.67	5.74	6.74	7.64	8.44	9.13	9.73	10.24	10.66	11.03	11.33	11.58	11.79	12.13
1982	0.00	0.02	0.18	0.71	1.55	2.59	3.74	4.89	5.99	7.02	7.94	8.75	9.46	10.06	10.58	11.01	11.38	11.69	11.94	12.15	12.50
1983	0.00	0.02	0.17	0.69	1.53	2.60	3.78	4.99	6.15	7.23	8.20	9.06	9.81	10.46	11.01	11.48	11.87	12.20	12.47	12.70	13.07
1984	0.00	0.02	0.20	0.72	1.49	2.42	3.41	4.39	5.32	6.17	6.92	7.59	8.16	8.65	9.07	9.42	9.71	9.96	10.16	10.33	10.61
1985	0.00	0.01	0.16	0.67	1.51	2.59	3.80	5.03	6.23	7.34	8.35	9.25	10.03	10.70	11.28	11.77	12.18	12.52	12.80	13.04	13.43
1986	0.00	0.01	0.15	0.64	1.48	2.57	3.80	5.06	6.30	7.45	8.50	9.43	10.25	10.96	11.56	12.07	12.50	12.86	13.15	13.40	13.82
1987	0.00	0.02	0.17	0.67	1.51	2.57	3.74	4.94	6.10	7.17	8.15	9.01	9.76	10.41	10.96	11.43	11.82	12.15	12.42	12.65	13.03
1988	0.00	0.01	0.16	0.66	1.53	2.66	3.92	5.23	6.51	7.70	8.79	9.75	10.60	11.33	11.95	12.48	12.92	13.29	13.60	13.86	14.29
1989	0.00	0.01	0.17	0.69	1.57	2.70	3.97	5.27	6.53	7.71	8.78	9.73	10.56	11.27	11.88	12.40	12.83	13.20	13.50	13.75	14.17
1990	0.00	0.02	0.18	0.71	1.58	2.66	3.86	5.08	6.25	7.33	8.31	9.18	9.94	10.59	11.14	11.61	12.00	12.33	12.60	12.83	13.21
1991	0.00	0.02	0.17	0.68	1.49	2.51	3.62	4.74	5.83	6.83	7.73	8.53	9.22	9.82	10.33	10.76	11.12	11.42	11.67	11.88	12.22
1992	0.00	0.02	0.16	0.64	1.42	2.41	3.50	4.61	5.67	6.66	7.56	8.35	9.04	9.63	10.13	10.56	10.92	11.22	11.47	11.68	12.02
1993	0.00	0.02	0.19	0.74	1.62	2.71	3.91	5.12	6.28	7.36	8.33	9.19	9.93	10.57	11.12	11.58	11.96	12.29	12.55	12.78	13.15
1994	0.00	0.02	0.17	0.67	1.49	2.52	3.66	4.81	5.93	6.96	7.90	8.72	9.44	10.06	10.59	11.04	11.41	11.72	11.99	12.20	12.56
1995	0.00	0.01	0.16	0.65	1.47	2.52	3.69	4.88	6.04	7.12	8.09	8.96	9.72	10.37	10.92	11.39	11.79	12.12	12.39	12.62	13.00
1996	0.00	0.02	0.20	0.74	1.56	2.56	3.64	4.72	5.75	6.69	7.53	8.27	8.92	9.47	9.94	10.33	10.66	10.94	11.17	11.36	11.67
1997	0.00	0.02	0.17	0.65	1.43	2.40	3.47	4.55	5.59	6.56	7.43	8.20	8.87	9.44	9.93	10.35	10.69	10.98	11.22	11.43	11.76
1998	0.00	0.02	0.17	0.65	1.42	2.39	3.45	4.52	5.54	6.49	7.35	8.10	8.76	9.33	9.81	10.21	10.55	10.84	11.08	11.27	11.60
1999	0.00	0.02	0.17	0.68	1.48	2.49	3.60	4.71	5.79	6.78	7.67	8.46	9.15	9.74	10.24	10.67	11.02	11.32	11.57	11.77	12.11
2000	0.00	0.02	0.18	0.71	1.56	2.62	3.79	4.96	6.09	7.14	8.08	8.92	9.64	10.27	10.80	11.24	11.62	11.93	12.20	12.41	12.77
2001	0.00	0.02	0.19	0.71	1.54	2.56	3.67	4.79	5.86	6.85	7.74	8.52	9.20	9.78	10.28	10.70	11.05	11.34	11.58	11.79	12.12
2002	0.00	0.02	0.17	0.68	1.50	2.53	3.66	4.81	5.91	6.93	7.85	8.67	9.38	9.98	10.50	10.94	11.31	11.62	11.87	12.08	12.44
2003	0.00	0.02	0.16	0.66	1.47	2.50	3.64	4.81	5.93	6.98	7.93	8.77	9.50	10.13	10.67	11.12	11.50	11.82	12.09	12.31	12.68
2004	0.00	0.02	0.18	0.69	1.50	2.52	3.64	4.76	5.85	6.85	7.75	8.55	9.24	9.84	10.34	10.77	11.13	11.43	11.68	11.89	12.23
2005	0.00	0.02	0.17	0.67	1.49	2.54	3.69	4.87	6.01	7.07	8.02	8.87	9.60	10.24	10.78	11.24	11.62	11.94	12.21	12.43	12.80
2006	0.00	0.02	0.17	0.68	1.50	2.53	3.67	4.82	5.93	6.96	7.89	8.71	9.42	10.04	10.56	11.00	11.38	11.69	11.95	12.16	12.52
2007	0.00	0.02	0.17	0.68	1.51	2.57	3.73	4.91	6.04	7.10	8.06	8.90	9.64	10.27	10.81	11.27	11.65	11.97	12.24	12.46	12.83
2008	0.00	0.02	0.19	0.71	1.53	2.55	3.65	4.76	5.82	6.79	7.67	8.44	9.11	9.69	10.18	10.60	10.94	11.23	11.47	11.67	12.00
2009	0.00	0.01	0.16	0.66	1.49	2.54	3.71	4.91	6.07	7.15	8.12	8.99	9.74	10.40	10.95	11.42	11.81	12.14	12.42	12.65	13.03
2010	0.00	0.02	0.17	0.67	1.48	2.50	3.62	4.75	5.84	6.85	7.76	8.57	9.27	9.87	10.38	10.82	11.18	11.49	11.74	11.95	12.30
2011	0.00	0.02	0.17	0.66	1.45	2.45	3.55	4.67	5.75	6.75	7.65	8.45	9.14	9.74	10.25	10.68	11.04	11.34	11.59	11.80	12.15
2012	0.00	0.02	0.18	0.67	1.46	2.44	3.50	4.58	5.61	6.55	7.41	8.16	8.82	9.38	9.86	10.26	10.60	10.88	11.12	11.31	11.64
2013	0.00	0.01	0.16	0.64	1.43	2.45	3.57	4.72	5.83	6.86	7.80	8.63	9.35	9.97	10.51	10.96	11.33	11.65	11.91	12.13	12.49
2014	0.00	0.01	0.15	0.61	1.39	2.40	3.53	4.69	5.81	6.86	7.82	8.67	9.41	10.05	10.59	11.06	11.44	11.77	12.04	12.26	12.64
2015	0.00	0.01	0.14	0.59	1.36	2.34	3.45	4.59	5.69	6.73	7.67	8.50	9.23	9.86	10.40	10.85	11.23	11.55	11.82	12.04	12.41
2016	0.00	0.02	0.16	0.66	1.47	2.50	3.64	4.79	5.91	6.95	7.89	8.72	9.44	10.07	10.60	11.05	11.42	11.74	12.00	12.22	12.58

Table 2.27—Time series of EBS Pacific cod age 0+ biomass, age 3+ biomass, female spawning biomass (t), and standard deviation of spawning biomass ("SB SD") as estimated by the final models in last year's and this year's assessments. Spawning biomasses listed for 2016 under last year's assessment and for 2017 under this year's assessment represent output from the standard projection model.

	Last year's assessment				This year's assessment			
Year	Age 0+	Age 3+	Spawn.	SB SD	Age 0+	Age 3+	Spawn.	SB SD
1977	580,639	572,253	163,291	31,819	238,614	223,326	70,865	24,355
1978	662,973	613,704	180,863	31,815	256,462	223,849	69,420	24,426
1979	837,745	721,585	209,322	32,738	370,312	265,037	70,557	23,663
1980	1,208,950	1,156,370	265,060	34,971	570,378	505,965	92,073	24,019
1981	1,629,440	1,569,570	369,954	38,337	827,796	765,577	145,981	25,966
1982	1,972,970	1,951,710	518,100	42,278	1,106,220	1,073,460	247,693	31,990
1983	2,151,420	2,131,750	658,400	44,272	1,237,100	1,210,540	350,393	36,843
1984	2,163,410	2,085,600	730,720	42,467	1,190,670	1,090,430	371,180	33,482
1985	2,139,140	2,115,600	726,420	37,989	1,276,680	1,246,900	420,649	35,009
1986	2,086,050	2,021,450	689,270	32,820	1,269,260	1,194,720	406,577	31,529
1987	2,063,010	2,035,030	663,430	28,260	1,291,840	1,259,500	395,026	27,811
1988	1,990,860	1,976,770	640,555	24,608	1,315,560	1,296,100	417,063	26,771
1989	1,792,190	1,780,400	601,150	21,610	1,200,380	1,189,160	402,900	24,351
1990	1,564,990	1,536,690	552,990	18,953	1,016,270	982,785	365,345	20,398
1991	1,367,790	1,314,930	477,333	16,285	833,926	762,154	292,052	15,778
1992	1,232,480	1,190,500	384,888	13,820	719,402	665,888	207,754	12,834
1993	1,222,170	1,195,220	337,244	12,072	830,487	780,122	192,784	12,988
1994	1,269,250	1,214,270	350,966	11,363	859,959	780,070	200,617	12,101
1995	1,295,990	1,275,180	353,929	11,328	913,253	881,497	222,817	12,672
1996	1,236,950	1,214,240	347,596	11,460	912,478	876,930	223,066	13,106
1997	1,156,000	1,128,240	336,292	11,391	785,469	753,258	214,083	12,595
1998	1,051,930	995,227	307,581	11,089	685,519	616,558	188,334	12,288
1999	1,072,690	1,048,190	292,121	10,714	717,289	681,281	182,377	12,549
2000	1,110,350	1,084,210	291,681	10,439	777,932	737,965	189,306	13,136
2001	1,126,320	1,081,630	318,496	10,281	792,518	719,162	196,919	12,876
2002	1,148,480	1,121,510	324,413	9,812	826,840	777,016	210,966	12,865
2003	1,124,710	1,110,720	316,221	9,043	825,474	802,516	211,567	12,515
2004	1,046,300	1,024,300	304,265	8,256	801,338	769,480	215,587	11,985
2005	929,101	911,637	272,196	7,602	727,157	701,947	213,810	11,370
2006	806,650	790,942	230,281	7,023	629,130	605,741	189,101	10,217
2007	703,317	681,507	196,128	6,482	556,424	518,554	160,504	9,330
2008	667,841	609,888	171,337	6,100	566,147	466,989	137,495	8,453
2009	723,102	696,689	156,561	6,034	635,332	585,479	127,669	8,726
2010	841,372	750,699	168,038	6,599	785,604	665,880	139,011	9,933
2011	1,057,930	1,037,380	213,789	8,274	949,486	925,047	185,652	12,560
2012	1,197,200	1,135,900	254,174	11,074	1,033,000	944,495	224,467	15,964
2013	1,324,910	1,241,520	304,236	14,942	1,080,380	978,122	258,446	19,443
2014	1,494,390	1,445,130	348,402	19,718	1,136,650	1,088,360	273,303	22,390
2015	1,666,970	1,585,980	401,573	25,678	1,185,890	1,101,870	284,191	25,368
2016	1,831,620	1,817,980	466,000	30,739	1,324,040	1,308,360	337,455	31,215
2017					1,255,550	1,233,720	326,592	35,425

Table 2.28—Time series of age 0 recruitment (1000s of fish), with standard deviations, as estimated by the final models in last year's and this year's assessments.

	Last year's values		This year's values	
Year	Recruits	Std. dev.	Recruits	Std. dev.
1977	1,756,770	193,401	1,144,750	291,512
1978	735,150	154,302	728,494	206,031
1979	911,872	95,777	727,199	136,045
1980	316,193	42,086	338,565	59,776
1981	186,119	27,168	185,901	34,070
1982	1,199,810	47,679	982,656	119,243
1983	270,491	30,591	251,708	42,442
1984	975,814	42,279	966,891	112,849
1985	420,228	29,856	367,518	50,174
1986	206,951	19,138	243,353	34,115
1987	148,111	15,608	101,666	20,766
1988	367,125	20,676	277,455	37,886
1989	769,057	30,920	763,595	86,361
1990	627,254	27,833	625,925	71,589
1991	338,528	20,762	415,703	51,114
1992	836,942	26,123	928,333	95,226
1993	295,068	16,994	368,560	43,036
1994	322,162	16,048	319,622	37,706
1995	349,179	18,802	289,947	35,339
1996	858,353	26,888	798,434	85,113
1997	350,987	17,271	375,721	43,067
1998	343,807	16,119	348,699	38,932
1999	662,988	19,273	727,777	72,993
2000	406,171	13,814	556,135	56,753
2001	187,567	10,495	246,470	27,034
2002	320,855	11,944	332,437	34,816
2003	252,583	11,704	279,904	29,449
2004	221,685	11,169	234,562	25,592
2005	252,378	12,323	317,928	34,223
2006	886,192	27,543	1,023,420	106,295
2007	271,215	17,279	447,919	51,147
2008	1,405,850	53,534	1,420,070	153,244
2009	237,580	24,864	183,956	27,608
2010	837,777	48,260	856,424	96,804
2011	1,248,580	78,359	1,269,710	147,292
2012	646,490	59,830	528,928	66,385
2013	1,261,180	112,053	1,200,650	141,608
2014	159,532	40,506	168,227	29,891
2015			197,947	44,945
Average	574,858		552,389	

Table 2.29—Numbers (1000s) at age as estimated by Model 16.6.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1977	1144750	219490	62271	46037	27320	12376	7388	4826	3235	2159	1417	909	572	354	216	131	79	47	28	17	25
1978	728494	796658	152741	43308	31778	17648	7002	4041	2631	1763	1177	772	496	312	193	118	71	43	26	15	23
1979	727199	506976	554378	106206	29825	20099	9415	3577	2056	1338	897	599	393	252	159	98	60	36	22	13	19
1980	338565	506075	352800	385551	73311	19264	11367	5147	1950	1120	729	489	326	214	137	86	53	33	20	12	18
1981	185901	235616	352171	245341	265873	46930	10628	6038	2725	1032	593	386	259	173	113	73	46	28	17	10	16
1982	982656	129373	163965	244967	169727	175244	28081	6205	3517	1587	601	345	225	151	101	66	42	27	16	10	15
1983	251708	683856	90032	114078	169935	114715	112439	17780	3924	2224	1003	380	218	142	95	64	42	27	17	10	16
1984	966891	175170	475902	62637	79097	114337	72682	70159	11079	2445	1386	625	237	136	89	59	40	26	17	10	16
1985	367518	672884	121902	331058	43372	52569	70011	43586	41992	6630	1463	829	374	142	81	53	36	24	16	10	16
1986	243353	255765	468261	84796	229106	28679	31735	41296	25654	24712	3901	861	488	220	83	48	31	21	14	9	15
1987	101666	169355	177987	325726	58679	151402	17284	18684	24260	15068	14514	2292	506	287	129	49	28	18	12	8	14
1988	277455	70752	117854	123805	225313	38638	90344	10059	10848	14082	8747	8425	1330	294	166	75	28	16	11	7	13
1989	763595	193088	49236	81964	85466	145639	21899	49519	5496	5926	7693	4778	4602	727	160	91	41	16	9	6	11
1990	625925	531405	134369	34245	56653	55880	85212	12456	28092	3117	3361	4363	2710	2610	412	91	52	23	9	5	10
1991	415703	435596	369801	93453	23651	36763	32017	47300	6894	15544	1725	1860	2414	1499	1444	228	50	29	13	5	8
1992	928333	289297	303117	257073	64166	14553	18170	14966	21996	3204	7225	802	864	1122	697	671	106	23	13	6	6
1993	368560	646047	201309	210669	176017	38487	6699	7820	6401	9403	1370	3088	343	369	480	298	287	45	10	6	5
1994	319622	256489	449566	139955	144795	109318	19519	3227	3749	3067	4506	656	1480	164	177	230	143	138	22	5	5
1995	289947	222432	178483	312524	96099	89137	54097	9137	1503	1745	1428	2097	306	689	76	82	107	66	64	10	5
1996	798434	201780	154780	124040	213832	57267	40298	22797	3825	629	730	597	878	128	288	32	34	45	28	27	6
1997	375721	555647	140410	107578	84979	128936	26753	17642	9920	1664	274	318	260	382	56	125	14	15	19	12	14
1998	348699	261472	386647	97578	73582	50492	57819	11168	7316	4112	690	113	132	108	158	23	52	6	6	8	11
1999	727777	242668	181949	268775	66971	45107	24695	26699	5130	3359	1888	317	52	60	49	73	11	24	3	3	9
2000	556135	506476	168864	126478	184416	40947	21902	11308	12159	2335	1529	859	144	24	28	23	33	5	11	1	5
2001	246470	387027	352439	117387	86828	113316	20158	10191	5234	5626	1080	707	398	67	11	13	10	15	2	5	3
2002	332437	171524	269323	245055	80807	54700	59791	10167	5119	2628	2825	542	355	200	33	6	6	5	8	1	4
2003	279904	231350	119358	187231	168325	49904	27309	28278	4785	2408	1236	1329	255	167	94	16	3	3	2	4	2
2004	234562	194791	160988	82970	128474	102979	24272	12529	12904	2182	1098	564	606	116	76	43	7	1	1	1	3
2005	317928	163237	135549	111914	56974	79122	51019	11377	5843	6015	1017	512	263	282	54	36	20	3	1	1	2
2006	1023420	221253	113591	94228	76826	34990	38897	23700	5258	2699	2778	470	236	121	130	25	16	9	2	0	1
2007	447919	712218	153961	78951	64558	46345	16366	17053	10328	2290	1176	1210	205	103	53	57	11	7	4	1	1
2008	1420070	311717	495604	107013	54116	39109	21934	7274	7535	4562	1011	519	534	90	45	23	25	5	3	2	1
2009	183956	988255	216906	344380	73092	31740	16917	8780	2891	2993	1812	402	206	212	36	18	9	10	2	1	1
2010	856424	128019	687652	150670	234223	41241	12327	5975	3074	1011	1047	634	141	72	74	13	6	3	3	1	1
2011	1269710	596003	89082	477875	103032	138870	18384	5110	2460	1265	416	431	261	58	30	31	5	3	1	1	1
2012	528928	883616	414728	61905	326699	60941	61490	7562	2088	1005	516	170	176	106	24	12	12	2	1	1	1
2013	1200650	368092	614867	288232	42373	195419	27841	26230	3205	884	426	219	72	75	45	10	5	5	1	0	1
2014	168227	835560	256143	427434	197899	26067	96518	13004	12188	1489	411	198	102	33	35	21	5	2	2	0	0
2015	197947	117073	581433	178038	292994	119937	12351	42954	5754	5390	658	182	87	45	15	15	9	2	1	1	0
2016	551005	137756	81467	404206	122293	180956	59890	5843	20218	2707	2536	310	85	41	21	7	7	4	1	0	1

Table 2.30—Model 16.6 estimates of “effective” fishing mortality (= -ln($N_{a+1,t+1}/N_{a,t}$)-M) at age and year.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1977	0.000	0.001	0.008	0.075	0.207	0.241	0.244	0.244	0.244	0.244	0.244	0.244	0.244	0.244	0.244	0.244	0.244	0.244	0.244
1978	0.000	0.001	0.010	0.096	0.266	0.309	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313	0.313
1979	0.000	0.001	0.008	0.075	0.207	0.241	0.244	0.245	0.245	0.245	0.245	0.245	0.245	0.245	0.245	0.245	0.245	0.245	0.245
1980	0.000	0.001	0.009	0.084	0.232	0.270	0.274	0.274	0.274	0.274	0.274	0.274	0.274	0.274	0.274	0.274	0.274	0.274	0.274
1981	0.000	0.000	0.006	0.054	0.151	0.176	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178	0.178
1982	0.000	0.000	0.003	0.029	0.081	0.095	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096
1983	0.000	0.000	0.004	0.034	0.094	0.109	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111
1984	0.000	0.000	0.005	0.046	0.128	0.149	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151	0.151
1985	0.000	0.000	0.006	0.051	0.142	0.165	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168
1986	0.000	0.000	0.006	0.052	0.144	0.167	0.169	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170	0.170
1987	0.000	0.000	0.006	0.055	0.154	0.179	0.181	0.181	0.181	0.181	0.181	0.181	0.181	0.181	0.181	0.181	0.181	0.181	0.181
1988	0.000	0.001	0.008	0.074	0.205	0.239	0.242	0.242	0.242	0.242	0.242	0.242	0.242	0.242	0.242	0.242	0.242	0.242	0.242
1989	0.000	0.001	0.007	0.062	0.173	0.202	0.204	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.205
1990	0.000	0.001	0.008	0.070	0.194	0.226	0.229	0.229	0.229	0.229	0.229	0.229	0.229	0.229	0.229	0.229	0.229	0.229	0.229
1991	0.000	0.001	0.013	0.123	0.342	0.398	0.403	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404
1992	0.000	0.001	0.016	0.149	0.413	0.481	0.487	0.487	0.487	0.487	0.487	0.487	0.487	0.487	0.487	0.487	0.487	0.487	0.487
1993	0.000	0.001	0.012	0.114	0.316	0.368	0.373	0.373	0.373	0.373	0.373	0.373	0.373	0.373	0.373	0.373	0.373	0.373	0.373
1994	0.000	0.001	0.013	0.123	0.341	0.397	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402	0.402
1995	0.000	0.001	0.017	0.155	0.431	0.502	0.508	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509	0.509
1996	0.000	0.001	0.016	0.143	0.399	0.464	0.470	0.470	0.470	0.470	0.470	0.470	0.470	0.470	0.470	0.470	0.470	0.470	0.470
1997	0.000	0.001	0.017	0.158	0.439	0.511	0.518	0.518	0.518	0.518	0.518	0.518	0.518	0.518	0.518	0.518	0.518	0.518	0.518
1998	0.000	0.001	0.014	0.127	0.353	0.410	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416	0.416
1999	0.000	0.001	0.014	0.129	0.360	0.419	0.424	0.424	0.425	0.425	0.425	0.425	0.425	0.425	0.425	0.425	0.425	0.425	0.425
2000	0.000	0.001	0.014	0.125	0.346	0.403	0.408	0.408	0.408	0.408	0.408	0.408	0.408	0.408	0.408	0.408	0.408	0.408	0.408
2001	0.000	0.001	0.011	0.100	0.277	0.322	0.326	0.326	0.326	0.326	0.326	0.326	0.326	0.326	0.326	0.326	0.326	0.326	0.326
2002	0.000	0.001	0.013	0.119	0.332	0.386	0.391	0.392	0.392	0.392	0.392	0.392	0.392	0.392	0.392	0.392	0.392	0.392	0.392
2003	0.000	0.001	0.014	0.129	0.358	0.417	0.422	0.422	0.423	0.423	0.423	0.423	0.423	0.423	0.423	0.423	0.423	0.423	0.423
2004	0.000	0.001	0.013	0.122	0.340	0.395	0.400	0.401	0.401	0.401	0.401	0.401	0.401	0.401	0.401	0.401	0.401	0.401	0.401
2005	0.000	0.001	0.014	0.125	0.348	0.404	0.409	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410
2006	0.000	0.001	0.016	0.143	0.397	0.462	0.468	0.469	0.469	0.469	0.469	0.469	0.469	0.469	0.469	0.469	0.469	0.469	0.469
2007	0.000	0.001	0.015	0.139	0.386	0.448	0.454	0.455	0.455	0.455	0.455	0.455	0.455	0.455	0.455	0.455	0.455	0.455	0.455
2008	0.000	0.002	0.019	0.171	0.476	0.553	0.560	0.561	0.561	0.561	0.561	0.561	0.561	0.561	0.561	0.561	0.561	0.561	0.561
2009	0.000	0.002	0.023	0.210	0.583	0.678	0.687	0.688	0.688	0.688	0.688	0.688	0.688	0.688	0.688	0.688	0.688	0.688	0.688
2010	0.000	0.001	0.018	0.160	0.445	0.518	0.525	0.525	0.525	0.525	0.525	0.525	0.525	0.525	0.525	0.525	0.525	0.525	0.525
2011	0.000	0.001	0.018	0.163	0.452	0.526	0.533	0.533	0.533	0.533	0.533	0.533	0.533	0.533	0.533	0.533	0.533	0.533	0.533
2012	0.000	0.001	0.017	0.151	0.421	0.489	0.496	0.496	0.496	0.496	0.496	0.496	0.496	0.496	0.496	0.496	0.496	0.496	0.496
2013	0.000	0.001	0.014	0.123	0.343	0.399	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404
2014	0.000	0.001	0.015	0.138	0.384	0.447	0.453	0.453	0.453	0.453	0.453	0.453	0.453	0.453	0.453	0.453	0.453	0.453	0.453
2015	0.000	0.001	0.013	0.119	0.332	0.386	0.391	0.391	0.391	0.391	0.391	0.391	0.391	0.391	0.391	0.391	0.391	0.391	0.391
2016	0.000	0.001	0.011	0.105	0.291	0.338	0.343	0.343	0.343	0.343	0.343	0.343	0.343	0.343	0.343	0.343	0.343	0.343	0.343

Table 2.31—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in 2017-2029 (Scenario 1), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	239,000	239,000	239,000	239,000	0
2018	246,000	246,000	246,000	246,000	0
2019	195,000	195,000	195,000	195,000	1
2020	157,000	158,000	158,000	158,000	166
2021	141,000	144,000	145,000	153,000	4,118
2022	131,000	148,000	153,000	187,000	18,899
2023	108,000	151,000	160,000	236,000	42,541
2024	94,000	157,000	163,000	262,000	52,774
2025	87,000	161,000	166,000	258,000	56,866
2026	85,100	165,000	170,000	272,000	59,397
2027	85,300	166,000	170,000	272,000	59,395
2028	84,600	165,000	170,000	270,000	58,033
2029	87,600	165,000	169,000	268,000	56,955

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	324,000	324,000	324,000	324,000	0
2018	325,000	325,000	325,000	325,000	0
2019	289,000	289,000	289,000	289,000	45
2020	247,000	248,000	248,000	250,000	847
2021	224,000	228,000	230,000	240,000	5,514
2022	213,000	228,000	232,000	266,000	17,850
2023	199,000	231,000	239,000	306,000	35,836
2024	188,000	236,000	245,000	345,000	49,193
2025	180,000	239,000	250,000	353,000	56,361
2026	178,000	240,000	254,000	361,000	60,190
2027	179,000	242,000	255,000	369,000	61,330
2028	178,000	242,000	255,000	373,000	60,156
2029	181,000	243,000	254,000	371,000	58,630

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	0.31	0.31	0.31	0.31	0.00
2018	0.31	0.31	0.31	0.31	0.00
2019	0.31	0.31	0.31	0.31	0.00
2020	0.31	0.31	0.31	0.31	0.00
2021	0.28	0.28	0.29	0.30	0.01
2022	0.26	0.28	0.29	0.31	0.02
2023	0.25	0.29	0.29	0.31	0.02
2024	0.23	0.29	0.28	0.31	0.03
2025	0.22	0.30	0.28	0.31	0.03
2026	0.22	0.30	0.28	0.31	0.03
2027	0.22	0.30	0.29	0.31	0.03
2028	0.22	0.30	0.29	0.31	0.03
2029	0.22	0.30	0.29	0.31	0.03

Table 2.32—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that catches in 2017-2018 are less than ABC by amounts predicted from past performance, but that $F = max\ F_{ABC}$ in 2019-2029 (Scenario 2), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	203,000	203,000	203,000	203,000	0
2018	212,000	212,000	212,000	212,000	0
2019	210,000	210,000	210,000	210,000	1
2020	167,000	168,000	168,000	168,000	49
2021	152,000	155,000	156,000	164,000	3,633
2022	135,000	152,000	157,000	190,000	18,453
2023	109,000	152,000	161,000	237,000	42,525
2024	94,200	158,000	163,000	262,000	52,881
2025	86,900	161,000	166,000	259,000	56,949
2026	85,000	165,000	170,000	273,000	59,441
2027	85,200	166,000	170,000	272,000	59,414
2028	84,600	165,000	170,000	270,000	58,039
2029	87,600	165,000	169,000	268,000	56,957

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	327,000	327,000	327,000	327,000	0
2018	340,000	340,000	340,000	340,000	0
2019	313,000	313,000	313,000	313,000	45
2020	264,000	265,000	265,000	266,000	854
2021	234,000	238,000	240,000	250,000	5,585
2022	217,000	232,000	236,000	271,000	18,113
2023	201,000	232,000	241,000	309,000	36,201
2024	188,000	236,000	246,000	347,000	49,478
2025	180,000	238,000	250,000	354,000	56,520
2026	178,000	240,000	254,000	361,000	60,259
2027	179,000	242,000	255,000	369,000	61,354
2028	178,000	242,000	255,000	373,000	60,162
2029	181,000	243,000	254,000	371,000	58,630

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	0.26	0.26	0.26	0.26	0.00
2018	0.25	0.25	0.25	0.25	0.00
2019	0.31	0.31	0.31	0.31	0.00
2020	0.31	0.31	0.31	0.31	0.00
2021	0.29	0.30	0.30	0.31	0.01
2022	0.27	0.29	0.29	0.31	0.01
2023	0.25	0.29	0.29	0.31	0.02
2024	0.23	0.29	0.28	0.31	0.03
2025	0.22	0.30	0.28	0.31	0.03
2026	0.22	0.30	0.28	0.31	0.03
2027	0.22	0.30	0.29	0.31	0.03
2028	0.22	0.30	0.29	0.31	0.03
2029	0.22	0.30	0.29	0.31	0.03

Table 2.33—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that the upper bound on F_{ABC} is set the most recent five-year average fishing mortality rate in 2017-2029 (Scenario 3), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	312,000	312,000	312,000	312,000	0
2018	298,000	298,000	298,000	298,000	0
2019	217,000	217,000	217,000	217,000	1
2020	169,000	169,000	169,000	169,000	67
2021	168,000	169,000	169,000	172,000	1,593
2022	159,000	173,000	178,000	211,000	18,085
2023	132,000	173,000	184,000	272,000	46,616
2024	119,000	176,000	187,000	298,000	56,860
2025	112,000	179,000	190,000	293,000	60,389
2026	110,000	180,000	192,000	308,000	63,334
2027	110,000	182,000	192,000	308,000	62,855
2028	110,000	182,000	191,000	307,000	60,791
2029	111,000	180,000	190,000	301,000	59,621

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	319,000	319,000	319,000	319,000	0
2018	295,000	295,000	295,000	295,000	0
2019	243,000	243,000	243,000	243,000	45
2020	197,000	198,000	198,000	200,000	854
2021	176,000	181,000	182,000	193,000	5,754
2022	163,000	179,000	184,000	220,000	19,144
2023	145,000	180,000	189,000	259,000	37,552
2024	132,000	185,000	193,000	290,000	49,457
2025	122,000	187,000	196,000	291,000	55,061
2026	120,000	189,000	198,000	303,000	57,808
2027	121,000	190,000	199,000	303,000	58,061
2028	122,000	189,000	198,000	307,000	56,577
2029	122,000	188,000	197,000	304,000	55,334

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	0.42	0.42	0.42	0.42	0.00
2018	0.42	0.42	0.42	0.42	0.00
2019	0.42	0.42	0.42	0.42	0.00
2020	0.42	0.42	0.42	0.42	0.00
2021	0.42	0.42	0.42	0.42	0.00
2022	0.42	0.42	0.42	0.42	0.00
2023	0.42	0.42	0.42	0.42	0.00
2024	0.42	0.42	0.42	0.42	0.00
2025	0.42	0.42	0.42	0.42	0.00
2026	0.42	0.42	0.42	0.42	0.00
2027	0.42	0.42	0.42	0.42	0.00
2028	0.42	0.42	0.42	0.42	0.00
2029	0.42	0.42	0.42	0.42	0.00

Table 2.34—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that the upper bound on F_{ABC} is set at $F_{60\%}$ in 2017-2029 (Scenario 4), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	120,000	120,000	120,000	120,000	0
2018	138,000	138,000	138,000	138,000	0
2019	124,000	124,000	124,000	124,000	0
2020	109,000	109,000	109,000	109,000	23
2021	108,000	108,000	108,000	109,000	555
2022	104,000	109,000	111,000	123,000	6,578
2023	92,500	109,000	114,000	151,000	19,329
2024	84,800	110,000	116,000	168,000	26,226
2025	79,600	113,000	118,000	171,000	29,776
2026	76,500	115,000	120,000	173,000	32,245
2027	76,300	116,000	121,000	180,000	33,101
2028	75,800	116,000	121,000	179,000	32,658
2029	76,700	116,000	121,000	179,000	32,006

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	332,000	332,000	332,000	332,000	0
2018	375,000	375,000	375,000	375,000	0
2019	377,000	377,000	377,000	377,000	45
2020	354,000	355,000	355,000	356,000	854
2021	333,000	337,000	339,000	349,000	5,767
2022	315,000	331,000	336,000	374,000	19,573
2023	294,000	331,000	341,000	421,000	41,776
2024	272,000	337,000	348,000	475,000	62,665
2025	255,000	342,000	355,000	499,000	77,093
2026	244,000	346,000	360,000	506,000	85,916
2027	241,000	351,000	364,000	526,000	90,325
2028	239,000	353,000	365,000	533,000	90,966
2029	237,000	353,000	365,000	532,000	89,731

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	0.15	0.15	0.15	0.15	0.00
2018	0.15	0.15	0.15	0.15	0.00
2019	0.15	0.15	0.15	0.15	0.00
2020	0.15	0.15	0.15	0.15	0.00
2021	0.15	0.15	0.15	0.15	0.00
2022	0.15	0.15	0.15	0.15	0.00
2023	0.15	0.15	0.15	0.15	0.00
2024	0.15	0.15	0.15	0.15	0.00
2025	0.15	0.15	0.15	0.15	0.00
2026	0.15	0.15	0.15	0.15	0.00
2027	0.15	0.15	0.15	0.15	0.00
2028	0.15	0.15	0.15	0.15	0.00
2029	0.15	0.15	0.15	0.15	0.00

Table 2.35—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that F = 0 in 2017-2029 (Scenario 5), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	0	0	0	0	0
2018	0	0	0	0	0
2019	0	0	0	0	0
2020	0	0	0	0	0
2021	0	0	0	0	0
2022	0	0	0	0	0
2023	0	0	0	0	0
2024	0	0	0	0	0
2025	0	0	0	0	0
2026	0	0	0	0	0
2027	0	0	0	0	0
2028	0	0	0	0	0
2029	0	0	0	0	0

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	339,000	339,000	339,000	339,000	0
2018	427,000	427,000	427,000	427,000	0
2019	481,000	481,000	481,000	481,000	45
2020	498,000	499,000	499,000	500,000	854
2021	499,000	504,000	505,000	516,000	5,774
2022	495,000	512,000	517,000	555,000	19,804
2023	483,000	522,000	533,000	618,000	44,282
2024	464,000	535,000	550,000	694,000	72,096
2025	444,000	550,000	565,000	750,000	95,588
2026	427,000	561,000	578,000	782,000	112,729
2027	420,000	569,000	588,000	805,000	123,962
2028	416,000	579,000	595,000	826,000	129,665
2029	414,000	586,000	600,000	841,000	131,269

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	0.00	0.00	0.00	0.00	0.00
2018	0.00	0.00	0.00	0.00	0.00
2019	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00
2021	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00
2023	0.00	0.00	0.00	0.00	0.00
2024	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00
2026	0.00	0.00	0.00	0.00	0.00
2027	0.00	0.00	0.00	0.00	0.00
2028	0.00	0.00	0.00	0.00	0.00
2029	0.00	0.00	0.00	0.00	0.00

Table 2.36—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = F_{OFL}$ in 2017-2029 (Scenario 6), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	284,000	284,000	284,000	284,000	0
2018	279,000	279,000	279,000	279,000	0
2019	210,000	210,000	210,000	210,000	1
2020	147,000	147,000	147,000	148,000	561
2021	139,000	143,000	144,000	152,000	4,582
2022	134,000	153,000	159,000	210,000	23,811
2023	110,000	157,000	170,000	264,000	51,301
2024	96,600	165,000	175,000	288,000	61,456
2025	90,500	167,000	178,000	284,000	65,178
2026	88,300	169,000	180,000	298,000	67,581
2027	89,000	170,000	180,000	298,000	67,273
2028	88,200	170,000	179,000	295,000	65,668
2029	90,900	169,000	178,000	294,000	64,586

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	321,000	321,000	321,000	321,000	0
2018	306,000	306,000	306,000	306,000	0
2019	260,000	260,000	260,000	260,000	45
2020	217,000	218,000	218,000	219,000	813
2021	202,000	206,000	207,000	217,000	5,336
2022	194,000	209,000	213,000	246,000	17,334
2023	183,000	214,000	221,000	286,000	33,613
2024	173,000	219,000	227,000	315,000	44,371
2025	166,000	220,000	230,000	319,000	49,640
2026	165,000	222,000	232,000	328,000	52,446
2027	165,000	222,000	232,000	331,000	52,936
2028	164,000	222,000	231,000	331,000	51,467
2029	167,000	221,000	231,000	330,000	50,099

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	0.38	0.38	0.38	0.38	0.00
2018	0.38	0.38	0.38	0.38	0.00
2019	0.38	0.38	0.38	0.38	0.00
2020	0.33	0.33	0.33	0.33	0.00
2021	0.30	0.31	0.31	0.33	0.01
2022	0.29	0.32	0.32	0.38	0.02
2023	0.27	0.32	0.33	0.38	0.04
2024	0.26	0.33	0.33	0.38	0.04
2025	0.25	0.33	0.33	0.38	0.05
2026	0.24	0.34	0.33	0.38	0.05
2027	0.25	0.34	0.33	0.38	0.05
2028	0.24	0.34	0.33	0.38	0.05
2029	0.25	0.33	0.33	0.38	0.05

Table 2.37—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in each year 2017-2018 and $F = F_{OFL}$ thereafter (Scenario 7), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	239,000	239,000	239,000	239,000	0
2018	246,000	246,000	246,000	246,000	0
2019	231,000	231,000	231,000	231,000	1
2020	168,000	168,000	168,000	169,000	587
2021	147,000	151,000	152,000	160,000	4,651
2022	136,000	155,000	161,000	211,000	23,682
2023	111,000	158,000	171,000	264,000	51,246
2024	96,400	165,000	174,000	288,000	61,482
2025	90,300	167,000	178,000	284,000	65,207
2026	88,200	169,000	180,000	297,000	67,595
2027	89,000	170,000	180,000	298,000	67,276
2028	88,200	170,000	179,000	295,000	65,668
2029	90,900	169,000	178,000	294,000	64,585

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	324,000	324,000	324,000	324,000	0
2018	325,000	325,000	325,000	325,000	0
2019	286,000	286,000	286,000	286,000	45
2020	233,000	234,000	234,000	235,000	810
2021	208,000	212,000	213,000	224,000	5,319
2022	197,000	211,000	215,000	248,000	17,314
2023	183,000	214,000	222,000	286,000	33,641
2024	173,000	219,000	226,000	315,000	44,407
2025	166,000	220,000	230,000	319,000	49,657
2026	164,000	222,000	232,000	328,000	52,447
2027	165,000	222,000	232,000	330,000	52,932
2028	164,000	222,000	231,000	331,000	51,463
2029	167,000	221,000	231,000	330,000	50,096

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	0.31	0.31	0.31	0.31	0.00
2018	0.31	0.31	0.31	0.31	0.00
2019	0.38	0.38	0.38	0.38	0.00
2020	0.35	0.35	0.36	0.36	0.00
2021	0.31	0.32	0.32	0.34	0.01
2022	0.30	0.32	0.32	0.38	0.02
2023	0.27	0.32	0.33	0.38	0.04
2024	0.26	0.33	0.33	0.38	0.04
2025	0.25	0.33	0.33	0.38	0.05
2026	0.24	0.34	0.33	0.38	0.05
2027	0.25	0.34	0.33	0.38	0.05
2028	0.24	0.34	0.33	0.38	0.05
2029	0.25	0.33	0.33	0.38	0.05

Table 2.38a (page 1 of 2)—Incidental catch (t) of FMP species taken in the EBS trawl fishery for Pacific cod, expressed as a proportion of the incidental catch of that species taken in all FMP EBS fisheries, 1991-2016 (2016 data current through October 9). Color shading: red = row minimum, green = row maximum (minima and maxima computed across both pages of the table).

Species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Alaska Plaice												0.03	0.03
Arrowtooth Flounder	0.06	0.24	0.21	0.16	0.20	0.26	0.24	0.11	0.12	0.11	0.19	0.38	0.43
Atka Mackerel	0.12	0.20	0.01	0.02	0.01	0.11	0.22	0.82	0.11	0.19	0.27	0.35	0.75
Flathead Sole					0.32	0.30	0.29	0.16	0.21	0.19	0.11	0.22	0.23
Flounder	0.02	0.07	0.13	0.14									
Greenland Turbot	0.02	0.03	0.04	0.02	0.06	0.06	0.02	0.09	0.01	0.05	0.03	0.04	0.11
Kamchatka Flounder													
Northern Rockfish												0.40	0.24
Octopus													
Other Flatfish					0.06	0.07	0.06	0.04	0.03	0.05	0.05	0.14	0.33
Other Rockfish	0.04	0.28	0.23	0.05	0.14	0.11	0.07	0.35	0.14	0.19	0.02	0.11	0.28
Other Species													0.12
Pacific Cod	0.08	0.14	0.17	0.16	0.20	0.12	0.17	0.03	0.12	0.06	0.06	0.16	0.09
Pacific Ocean Perch	0.21	0.24	0.27	0.23	0.29	0.19	0.39	0.27	0.14	0.53	0.04	0.02	0.04
Pollock	0.05	0.12	0.24	0.20	0.21	0.25	0.30	0.23	0.45	0.30	0.18	0.27	0.38
Rock Sole	0.04	0.08	0.12	0.18	0.34	0.31	0.30	0.22	0.31	0.19	0.27	0.22	0.27
Rougheye Rockfish													
Sablefish	0.01	0.01	conf	0.01	0.00	0.04	0.00	0.03	0.06	0.08	0.04	0.10	0.19
Sculpin													
Shark													
Sharpchin/Northern Rockfish		0.29	0.30								0.12		
Short/Rough/Sharp/North Rockfish	0.26	0.58	0.18	0.12	0.17	0.13	0.45	0.27	0.16	0.28	0.46		
Shortraker Rockfish													
Shortraker/Rougheye Rockfish		0.02	conf								conf	0.05	0.05
Skate													
Squid	0.01	0.03	0.00	0.28	0.00	conf	0.00	0.01	0.00	0.00	0.01	0.00	0.02
Yellowfin Sole	0.00	0.01	0.03	0.04	0.01	0.05	0.02	0.02	0.03	0.07	0.05	0.09	0.06

Table 2.38a (page 2 of 2)—Incidental catch (t) of FMP species taken in the EBS trawl fishery for Pacific cod, expressed as a proportion of the incidental catch of that species taken in all FMP EBS fisheries, 1991-2016 (2016 data current through October 9). Color shading: red = row minimum, green = row maximum (minima and maxima computed across both pages of the table).

Species/group	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Alaska Plaice	0.05	0.04	0.02	0.03	0.00	0.01	0.00	0.01	0.01	0.05	0.02	0.00	0.00
Arrowtooth Flounder	0.52	0.41	0.45	0.23	0.08	0.08	0.07	0.06	0.07	0.07	0.08	0.08	0.09
Atka Mackerel	0.76	0.36	0.24	0.17	0.10	0.40	0.39	0.35	0.27	0.06	0.09	0.03	0.90
Flathead Sole	0.33	0.23	0.41	0.39	0.11	0.07	0.06	0.09	0.08	0.08	0.08	0.08	0.08
Flounder													
Greenland Turbot	0.17	0.05	0.11	0.21	0.01	0.00	0.03	0.00	0.02	0.01	0.01	0.00	0.00
Kamchatka Flounder								0.01	0.01	0.02	0.04	0.02	0.03
Northern Rockfish	0.59	0.31	0.28	0.08	0.05	0.03	0.20	0.06	0.11	0.01	0.01	0.00	conf
Octopus								0.03	0.01	0.02	0.02	0.01	0.00
Other Flatfish	0.49	0.35	0.20	0.07	0.03	0.03	0.04	0.03	0.03	0.03	0.01	0.07	0.11
Other Rockfish	0.33	0.32	0.24	0.06	0.06	0.02	0.04	0.03	0.32	0.03	0.03	0.07	0.05
Other Species	0.12	0.07	0.11	0.17	0.04	0.03	0.03						
Pacific Cod	0.07	0.03	0.08	0.12	0.01	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.04
Pacific Ocean Perch	0.26	0.22	0.08	0.04	0.01	0.01	0.00	0.01	0.07	0.00	conf	0.00	0.00
Pollock	0.39	0.36	0.53	0.75	0.43	0.37	0.32	0.42	0.29	0.22	0.17	0.05	0.10
Rock Sole	0.30	0.37	0.35	0.27	0.14	0.07	0.12	0.18	0.16	0.07	0.21	0.30	0.25
Rougheye Rockfish	0.12	0.05			conf		conf						conf
Sablefish	0.32	0.09	0.00	0.00	0.00	conf	conf	conf	conf	0.02		0.01	0.00
Sculpin								0.07	0.07	0.07	0.07	0.07	0.13
Shark										0.00	0.00	0.01	conf
Sharpchin/Northern Rockfish													
Short/Rough/Sharp/North Rockfish													
Shortraker Rockfish	conf		conf	conf		conf				conf			conf
Shortraker/Rougheye Rockfish													
Skate								0.01	0.01	0.01	0.01	0.01	0.01
Squid	0.01	0.00	conf	0.00	conf		0.00	0.00	0.00	0.00	0.00	0.00	conf
Yellowfin Sole	0.11	0.11	0.08	0.03	0.01	0.00	0.01	0.01	0.01	0.06	0.02	0.00	0.00

Table 2.38b (page 1 of 2)—Incidental catch (t) of FMP species taken in the EBS longline fishery for Pacific cod, expressed as a proportion of the incidental catch of that species taken in all FMP EBS fisheries, 1991-2016 (2016 data current through October 9). Color shading: red = row minimum, green = row maximum (minima and maxima computed across both pages of the table).

Species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Alaska Plaice												0.00	0.00
Arrowtooth Flounder	0.11	0.15	0.08	0.10	0.20	0.15	0.23	0.11	0.08	0.14	0.14	0.11	0.11
Atka Mackerel	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00
Flathead Sole		conf			0.03	0.03	0.03	0.05	0.06	0.06	0.08	0.09	0.09
Flounder	0.01	0.01	0.01	0.01									
Greenland Turbot	0.10	0.20	0.05	0.09	0.14	0.19	0.19	0.07	0.04	0.12	0.05	0.08	0.17
Kamchatka Flounder													
Northern Rockfish												0.08	0.09
Octopus													
Other Flatfish					0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.06	0.04
Other Rockfish	0.03	0.12	0.14	0.08	0.06	0.20	0.11	0.08	0.20	0.12	0.35	0.25	0.11
Other Species													0.56
Pacific Cod	0.09	0.08	0.07	0.10	0.09	0.11	0.16	0.70	0.42	0.69	0.62	0.58	0.65
Pacific Ocean Perch	0.00	0.01	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pollock	0.01	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.02	0.05	0.06	0.04	0.05
Rock Sole	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rougheye Rockfish													
Sablefish	0.05	0.73	0.07	0.08	0.12	0.13	0.12	0.08	0.08	0.39	0.32	0.20	0.30
Sculpin													
Shark													
Sharpchin/Northern Rockfish		0.01	0.01								0.05		
Short/Rough/Sharp/North Rockfish	0.03	0.05	0.04	0.11	0.18	0.18	0.05	0.14	0.03	0.19	0.05		
Shortraker Rockfish													
Shortraker/Rougheye Rockfish		0.10	0.19								0.74	0.19	0.20
Skate													
Squid										0.00		conf	conf
Yellowfin Sole	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.07	0.05	0.05

Table 2.38b (page 2 of 2)—Incidental catch (t) of FMP species taken in the EBS longline fishery for Pacific cod, expressed as a proportion of the incidental catch of that species taken in all FMP EBS fisheries, 1991-2016 (2016 data current through October 9). Color shading: red = row minimum, green = row maximum (minima and maxima computed across both pages of the table).

Species/group	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Alaska Plaice	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arrowtooth Flounder	0.09	0.14	0.12	0.16	0.18	0.20	0.16	0.22	0.28	0.14	0.21	0.33	0.19
Atka Mackerel	0.01	0.00	0.00	0.01	0.01	0.01	0.02	0.01	0.01	0.13	0.17	0.02	0.05
Flathead Sole	0.11	0.14	0.11	0.06	0.14	0.12	0.14	0.18	0.17	0.24	0.39	0.39	0.33
Flounder													
Greenland Turbot	0.11	0.12	0.13	0.15	0.11	0.15	0.16	0.16	0.11	0.01	0.02	0.13	0.28
Kamchatka Flounder								0.14	0.11	0.07	0.09	0.13	0.15
Northern Rockfish	0.05	0.08	0.04	0.11	0.30	0.56	0.68	0.39	0.16	0.38	0.43	0.48	0.31
Octopus								0.05	0.12	0.11	0.06	0.08	0.15
Other Flatfish	0.06	0.09	0.07	0.01	0.01	0.06	0.07	0.02	0.03	0.01	0.01	0.04	0.02
Other Rockfish	0.23	0.26	0.24	0.24	0.19	0.16	0.61	0.38	0.21	0.37	0.50	0.51	0.21
Other Species	0.65	0.68	0.56	0.44	0.51	0.51	0.53						
Pacific Cod	0.75	0.82	0.63	0.68	0.63	0.73	0.51	0.78	0.66	0.63	0.76	0.78	0.81
Pacific Ocean Perch	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00
Pollock	0.03	0.03	0.03	0.03	0.11	0.10	0.22	0.17	0.09	0.11	0.04	0.06	0.06
Rock Sole	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.03	0.05	0.02
Rougheye Rockfish	0.14	0.33	0.68	0.48	0.39	0.31	0.18	0.27	0.19	0.17	0.24	0.45	0.37
Sablefish	0.16	0.22	0.21	0.16	0.03	0.04	0.04	0.19	0.02	0.10	0.07	0.26	0.70
Sculpin								0.25	0.25	0.17	0.31	0.38	0.33
Shark								0.31	0.33	0.40	0.41	0.44	0.33
Sharpchin/Northern Rockfish													
Short/Rough/Sharp/North Rockfish													
Shortraker Rockfish	0.12	0.31	0.20	0.63	0.12	0.64	0.33	0.29	0.22	0.09	0.08	0.24	0.13
Shortraker/Rougheye Rockfish													
Skate								0.76	0.76	0.78	0.82	0.89	0.91
Squid	conf	conf			conf	conf	conf	0.00		0.00	0.00	0.00	
Yellowfin Sole	0.04	0.07	0.05	0.02	0.06	0.09	0.03	0.14	0.20	0.23	0.39	0.47	0.35

Table 2.38c (page 1 of 2)—Incidental catch (t) of FMP species taken in the EBS pot fishery for Pacific cod, expressed as a proportion of the incidental catch of that species taken in all FMP EBS fisheries, 1991-2016 (2016 data current through October 9). Color shading: red = row minimum, green = row maximum (minima and maxima computed across both pages of the table).

Species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Alaska Plaice												conf	conf
Arrowtooth Flounder	0.00	0.00	conf	conf	0.00	0.00	0.00	0.00	conf	conf	conf	0.02	0.00
Atka Mackerel	0.00	0.03	conf	0.05	0.23	0.11	0.29	0.03	conf	conf	conf	conf	0.06
Flathead Sole					conf	0.00	conf	conf	0.00	conf	conf	conf	0.00
Flounder	conf	0.00	conf	conf									
Greenland Turbot	conf	conf		conf	0.00	0.00	conf	conf	conf		conf	conf	0.00
Kamchatka Flounder													
Northern Rockfish												conf	0.02
Octopus													
Other Flatfish					conf	0.00	0.00	conf	conf	conf	conf	conf	0.00
Other Rockfish	0.00	0.00	conf	0.01	0.02	0.04	0.06	0.03	conf	conf	conf	conf	0.07
Other Species													0.02
Pacific Cod	0.00	0.00	0.00	0.01	0.01	0.02	0.00	0.01	0.02	0.02	0.02	0.03	0.06
Pacific Ocean Perch	conf	conf	conf	conf	0.00	0.00	conf	conf	conf	conf	conf	conf	0.00
Pollock	0.00	0.00	conf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	conf	0.00	0.00
Rock Sole	0.00	0.00	conf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	conf	conf	0.00
Rougheye Rockfish													
Sablefish	conf	conf		conf	conf	conf	conf	conf	conf		conf	conf	0.00
Sculpin													
Shark													
Sharpchin/Northern Rockfish		conf	conf								conf		
Short/Rough/Sharp/North Rockfish	0.00			conf	0.01	0.00	0.00	conf	conf	conf	conf		
Shortraker Rockfish													
Shortraker/Rougheye Rockfish		conf	conf								conf	conf	0.00
Skate													
Squid					conf	conf			conf		conf	conf	
Yellowfin Sole	0.00	0.00	conf	conf	0.00	0.01	0.00	0.00	0.00	0.00	conf	0.00	0.01

Table 2.38c (page 2 of 2)—Incidental catch (t) of FMP species taken in the EBS pot fishery for Pacific cod, expressed as a proportion of the incidental catch of that species taken in all FMP EBS fisheries, 1991-2016 (2016 data current through October 9). Color shading: red = row minimum, green = row maximum (minima and maxima computed across both pages of the table).

Species/group	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Alaska Plaice	conf	conf	conf	conf					0.00	conf	conf	conf	conf
Arrowtooth Flounder	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Atka Mackerel	0.03	0.17	0.29	0.11	0.68	0.03	0.56	0.11	0.05	0.19	0.36	0.06	0.02
Flathead Sole	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Flounder													
Greenland Turbot		conf	0.00	conf	conf	conf		0.00			conf	conf	
Kamchatka Flounder								0.00	0.00	0.00	conf	0.00	
Northern Rockfish	0.01	0.02	0.01	0.02	0.11	0.06	0.02	0.02	0.01	0.00	0.01	0.01	0.00
Octopus								0.88	0.81	0.85	0.90	0.85	0.74
Other Flatfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other Rockfish	0.04	0.10	0.12	0.01	0.02	0.00	0.02	0.04	0.02	0.11	0.05	0.05	0.03
Other Species	0.01	0.01	0.02	0.01	0.02	0.01	0.01						
Pacific Cod	0.02	0.02	0.03	0.02	0.08	0.01	0.01	0.01	0.01	0.02	0.04	0.03	0.02
Pacific Ocean Perch	0.00	0.00	0.00	conf	0.00	0.00	0.00	0.00	0.00	0.00		0.00	
Pollock	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rock Sole	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rougheye Rockfish	0.00	0.01											
Sablefish	0.01	0.00	0.08					conf		0.00			
Sculpin								0.03	0.02	0.06	0.07	0.06	0.05
Shark								conf	0.00				
Sharpchin/Northern Rockfish													
Short/Rough/Sharp/North Rockfish													
Shortraker Rockfish							0.00				conf		
Shortraker/Rougheye Rockfish													
Skate								0.00	conf		0.00	conf	conf
Squid		conf		conf			conf				conf		conf
Yellowfin Sole	0.01	0.01	0.01	0.02	0.02	0.01	0.00	0.01	0.01	0.05	0.08	0.08	0.03

Table 2.39—Incidental catch (t) of selected members of the former "Other Species" complex taken in the EBS fisheries for Pacific cod (all gears), expressed as a proportion of the incidental catch of that species taken in all FMP EBS fisheries, 1991-2016 (2016 data current through September 25). Color shading: red = row minimum, green = row maximum (minima and maxima computed across both panels of the table).

Species Common Name	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
octopus, North Pacific									conf	conf	conf	0.73	0.81
shark, other												conf	0.66
shark, Pacific sleeper									conf	conf	0.05	0.09	0.50
shark, salmon									conf				conf
shark, spiny dogfish										0.91	0.42	0.92	0.99
skate, Alaska													
skate, big													
skate, longnose												conf	0.71
skate, other									0.16	0.04	conf	0.43	0.81
squid, majestic	0.01	0.03	0.00	0.28	0.00	conf	0.00	0.01	0.00	0.00	0.01	0.00	0.02

Species Common Name	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
octopus, North Pacific	0.82	0.88	0.94	0.89	0.90	0.66	0.84	0.97	0.94	0.98	0.97	0.93	0.89
shark, other	0.35	0.52	0.01	0.16	0.42	0.72	0.48	0.75	0.41	0.79	0.79	0.61	conf
shark, Pacific sleeper	0.56	0.60	0.41	0.20	0.17	0.30	0.59	0.50	0.22	0.39	0.61	0.61	0.51
shark, salmon	conf	0.07	0.02							0.01		conf	
shark, spiny dogfish	0.97	0.98	0.97	0.83	0.63	0.95	0.93	0.93	0.98	0.80	0.83	0.89	0.87
skate, Alaska							0.26						
skate, big	0.84	0.72	0.92	0.73	0.71	0.51	0.73						
skate, longnose	0.55	0.97	0.67	0.37	1.00	0.67	0.49						
skate, other	0.85	0.85	0.78	0.75	0.70	0.67	0.93	0.78	0.77	0.79	0.83	0.90	0.93
squid, majestic	0.01	0.00	conf	0.00	conf	conf	0.00	0.00	0.00	0.00	0.00	0.00	conf

Table 2.40—Incidental catch (herring and halibut in t, salmon and crab in number of individuals) of prohibited species taken in the EBS fisheries for Pacific cod (all gears), expressed as a proportion of the incidental catch of that species taken in all FMP EBS fisheries, 1991-2016 (2016 data current through October 2). Color shading: red = row minimum, green = row maximum (minima and maxima computed across both panels of the table). Note that all entries for 2003 are marked "n/a", due to an error in the database that was discovered too late to be corrected in time for this assessment.

Species Group Name	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Bairdi Tanner Crab	0.20	0.10	0.07	0.13	0.14	0.22	0.15	0.10	0.17	0.16	0.14	0.29	n/a
Blue King Crab													n/a
Chinook Salmon	0.09	0.12	0.13	0.18	0.34	0.09	0.09	0.04	0.14	0.20	0.08	0.04	n/a
Golden (Brown) King Crab													n/a
Halibut	0.52	0.64	0.49	0.67	0.71	0.74	0.71	0.68	0.66	0.69	0.63	0.69	n/a
Herring	conf	0.01	0.03	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.02	0.02	n/a
Non-Chinook Salmon	0.00	0.00	0.00	0.01	0.04	0.00	0.01	0.01	0.00	0.00	0.03	0.01	n/a
Opilio Tanner (Snow) Crab	0.02	0.02	0.02	0.04	0.05	0.10	0.17	0.17	0.33	0.12	0.12	0.34	n/a
Other King Crab	0.02	0.12	0.01	0.08	0.16	0.66	0.54	0.73	0.35	0.33	0.58	0.69	n/a
Red King Crab	0.31	0.07	0.01	0.01	0.17	0.78	0.36	0.23	0.18	0.38	0.26	0.32	n/a

Species Group Name	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Bairdi Tanner Crab	0.30	0.19	0.40	0.57	0.66	0.53	0.45	0.27	0.22	0.26	0.50	0.61	0.69
Blue King Crab	0.94	0.95	0.70	1.00	0.87	0.89	1.00	0.56	0.77	0.32	0.57	0.81	0.94
Chinook Salmon	0.08	0.04	0.03	0.04	0.03	0.01	0.04	0.00	0.05	0.04	0.05	0.05	0.09
Golden (Brown) King Crab	0.00	0.21	0.01	0.00	0.00	0.01	0.02	0.00	0.02	0.03	0.03	0.02	0.01
Halibut	0.73	0.72	0.68	0.64	0.66	0.63	0.65	0.68	0.69	0.67	0.63	0.66	0.60
Herring	0.01	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Non-Chinook Salmon	0.01	0.00	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Opilio Tanner (Snow) Crab	0.14	0.08	0.34	0.53	0.47	0.52	0.31	0.20	0.08	0.06	0.19	0.23	0.23
Other King Crab													
Red King Crab	0.14	0.16	0.14	0.32	0.29	0.10	0.06	0.35	0.26	0.76	0.82	0.90	0.44

Table 2.41a (page 1 of 2)—Incidental catch (t) of non-target species groups—other than birds—taken in the EBS fisheries for Pacific cod (all gears), expressed as a proportion of the incidental catch of that species group taken in all FMP EBS fisheries, 2004-2016 (2016 data are current through September 25). Color shading: red = row minimum, green = row maximum.

Species Group Name	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Benthic urochordata	0.00	0.01	0.01	0.00	0.00	0.01	0.04	0.20	0.28	0.20	0.29	0.27	0.06
Bivalves	0.84	0.72	0.77	0.61	0.85	0.85	0.47	0.82	0.92	0.88	0.79	0.81	0.67
Brittle star unidentified	0.02	0.01	0.02	0.04	0.01	0.05	0.01	0.07	0.06	0.09	0.04	0.08	0.05
Capelin	0.02			0.00	0.00		0.00	0.00	0.00	0.10	0.02	0.00	
Corals Bryozoans - Corals Bryozoans Unidentified	0.46	0.40	0.09	0.86	0.15	0.85	0.24	0.50	0.92	0.25	0.46	0.60	0.36
Corals Bryozoans - Red Tree Coral	0.62	0.44	0.01	0.96	0.12	0.33							
Dark Rockfish					0.98	0.96	0.96	0.98	0.79	0.98	0.25	0.77	0.23
Eelpouts	0.36	0.46	0.29	0.11	0.09	0.04	0.05	0.05	0.14	0.16	0.28	0.58	0.47
Eulachon	0.01	0.00	0.00	0.00	0.00		conf	0.00	0.00				
Giant Grenadier	0.07	0.12	0.05	0.07	0.10	0.07	0.12	0.28	0.21	0.12	0.19	0.04	0.10
Greenlings	0.64	0.56	0.62	0.20	0.73	0.74	0.78	0.64	0.77	1.00	0.84	0.69	0.66
Grenadier - Pacific Grenadier	0.70	0.00					0.05						
Grenadier - Ratail Grenadier Unidentified	0.11	0.15	0.09	0.23	0.40	0.08	0.19	0.04	0.04	0.76	0.06	0.61	0.07
Gunnels	1.00	1.00		0.03									
Hermit crab unidentified	0.05	0.01	0.04	0.03	0.02	0.06	0.02	0.03	0.06	0.08	0.06	0.15	0.13
Invertebrate unidentified	0.01	0.01	0.08	0.22	0.02	0.24	0.41	0.38	0.21	0.25	0.30	0.27	0.47
Lanternfishes (myctophidae)	conf												
Large Sculpins - Bigmouth Sculpin					0.35	0.46	0.46	0.56	0.58	0.54	0.66	0.68	0.83
Large Sculpins - Brown Irish Lord					1.00	1.00							
Large Sculpins - Great Sculpin					0.18	0.16	0.16	0.28	0.23	0.23	0.35	0.39	0.37
Large Sculpins - Hemilepidotus Unidentified					0.93	0.99	1.00	0.99	0.99	0.98	0.98	0.98	0.97
Large Sculpins - Myoxocephalus Unidentified					0.23	0.60	0.93	0.73	0.96	0.79	0.81	0.89	0.90
Large Sculpins - Plain Sculpin					0.01	0.01	0.02	0.02	0.03	0.06	0.07	0.07	0.06
Large Sculpins - Red Irish Lord					0.11	0.63	0.90	0.86	1.00	0.07	0.26	0.25	0.17
Large Sculpins - Warty Sculpin					0.22	0.15	0.32	0.21	0.09	0.12	0.12	0.06	0.09
Large Sculpins - Yellow Irish Lord					0.51	0.33	0.52	0.42	0.64	0.48	0.43	0.56	0.55
Large Sculpins	0.60	0.48	0.44	0.36									
Misc crabs	0.11	0.15	0.42	0.38	0.17	0.12	0.21	0.12	0.16	0.21	0.23	0.20	0.18
Misc crustaceans	0.20	0.53	0.14	0.18	0.03	0.02	0.05	0.04	0.03	0.10	0.08	0.05	0.13
Misc fish	0.42	0.37	0.28	0.17	0.14	0.18	0.20	0.24	0.33	0.24	0.52	0.44	0.53
Misc inverts (worms etc)	0.02	0.01	0.06	0.32	0.01	0.02	0.00	0.01	0.00	conf	0.02	0.03	
Other Sculpins	0.64	0.55	0.60	0.40	0.70	0.58	0.69	0.57	0.75	0.30	0.50	0.42	0.46
Other osmerids	0.06	0.00	0.01	0.00		0.00	0.00	0.00	conf	0.00		0.00	

Table 2.41a (page 2 of 2)—Incidental catch (t) of non-target species groups—other than birds—taken in the EBS fisheries for Pacific cod (all gears), expressed as a proportion of the incidental catch of that species group taken in all FMP EBS fisheries, 2004-2016 (2016 data are current through September 25). Color shading: red = row minimum, green = row maximum.

Species Group Name	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Pacific Sand lance	0.31	0.56	0.03	0.12	0.21		0.01	0.01	conf		conf	0.09	0.09
Pacific Sandfish							0.28				0.07	0.19	0.32
Pandalid shrimp	0.18	0.01	0.02	0.10	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polychaete unidentified	0.01	0.71	0.00	0.01	0.00	0.10	0.04	0.08	0.37	0.04	0.28	0.43	0.39
Scypho jellies	0.08	0.05	0.02	0.03	0.01	0.01	0.01	0.02	0.02	0.05	0.01	0.02	0.01
Sea anemone unidentified	0.62	0.86	0.79	0.36	0.51	0.74	0.62	0.76	0.86	0.76	0.81	0.86	0.85
Sea pens whips	0.90	0.93	0.86	0.60	0.86	0.93	0.87	0.90	0.91	0.96	0.96	0.96	0.96
Sea star	0.14	0.16	0.12	0.09	0.07	0.15	0.11	0.09	0.20	0.15	0.22	0.20	0.22
Snails	0.07	0.11	0.07	0.10	0.09	0.25	0.17	0.17	0.25	0.31	0.43	0.46	0.69
Sponge unidentified	0.09	0.06	0.15	0.08	0.08	0.07	0.03	0.06	0.15	0.09	0.09	0.17	0.19
Stichaeidae	0.06	0.11	0.06	0.01	0.04	0.00	conf					0.03	
Urchins dollars cucumbers	0.48	0.48	0.40	0.24	0.18	0.08	0.15	0.35	0.41	0.26	0.37	0.48	0.52

Table 2.41b—Incidental catch (t) of bird species groups taken in the EBS fisheries for Pacific cod (all gears), expressed as a proportion of the incidental catch of that species group taken in all FMP EBS fisheries, 2004-2016 (2016 data are current through September 25).

Species Group Name	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Auklets									1.00		0.33	1.00	1.00
Black-footed Albatross	1.00	1.00	0.95	1.00	1.00	1.00	1.00						
Cormorant			1.00										
Gull	1.00	1.00	0.97	0.60	0.99	0.90	0.89	1.00	1.00	0.96	1.00	1.00	0.96
Kittiwake	0.31	0.44				0.34		1.00	1.00	1.00	1.00	1.00	1.00
Laysan Albatross	0.76	0.37	0.01	0.00	0.68	0.00	0.31	0.94	0.71	0.20	0.75	0.17	0.67
Murre	0.41	0.01	0.65	0.73	1.00	1.00			1.00				0.22
Northern Fulmar	0.91	0.86	0.57	0.74	0.75	0.86	0.85	0.86	0.79	0.87	0.82	0.84	0.93
Other Alcid	1.00												
Other													
Puffin							1.00						
Shearwaters	0.99	0.37	0.95	0.94	0.99	0.87	0.85	0.72	0.90	0.69	0.36	0.66	0.93
Short-tailed Albatross							1.00	1.00			0.32		
Storm Petrels			0.33										
Unidentified Albatross			1.00								0.92		
Unidentified	0.96	0.98	0.97	0.96	1.00	0.92	0.94	1.00	0.95	0.94	1.00	0.94	0.99

FIGURES

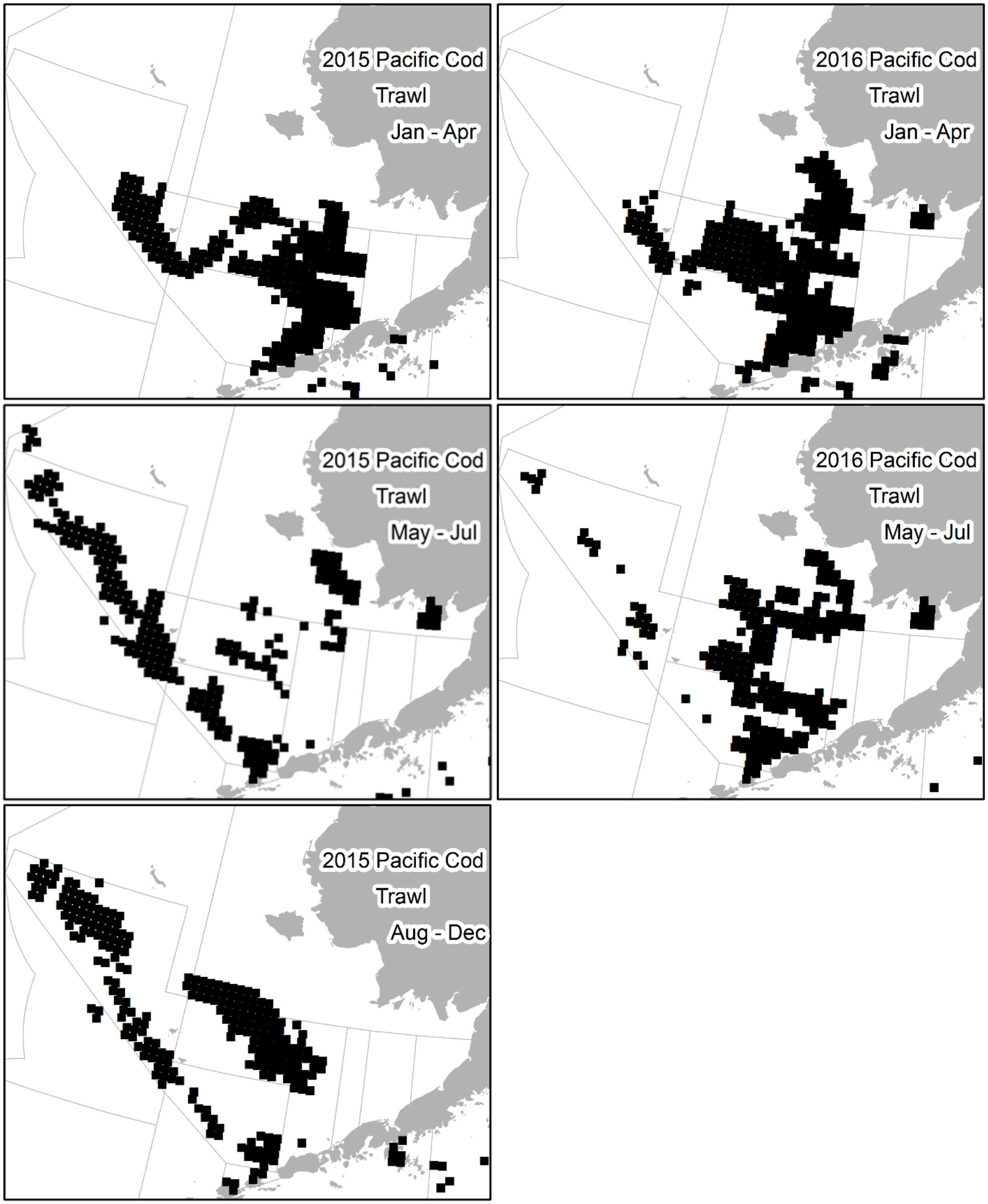


Figure 2.1a. EBS maps showing each 400 square km cell with trawl hauls containing Pacific cod from at least 3 distinct vessels by season in 2015-2016, overlaid against NMFS 3-digit statistical areas.

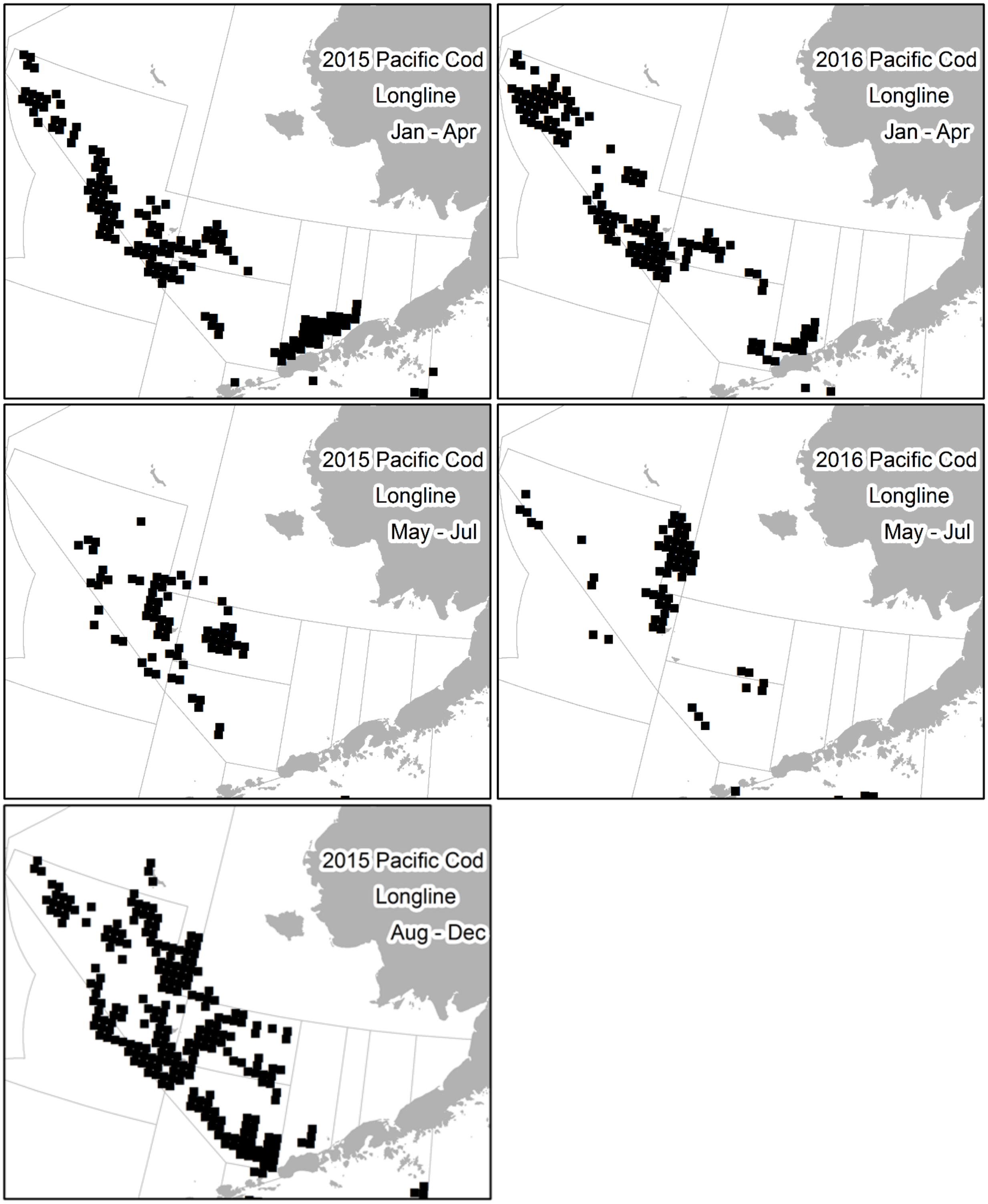


Figure 2.1b. EBS maps showing each 400 square km cell with longline sets containing Pacific cod from at least 3 distinct vessels by season in 2015-2016, overlaid against NMFS 3-digit statistical areas.

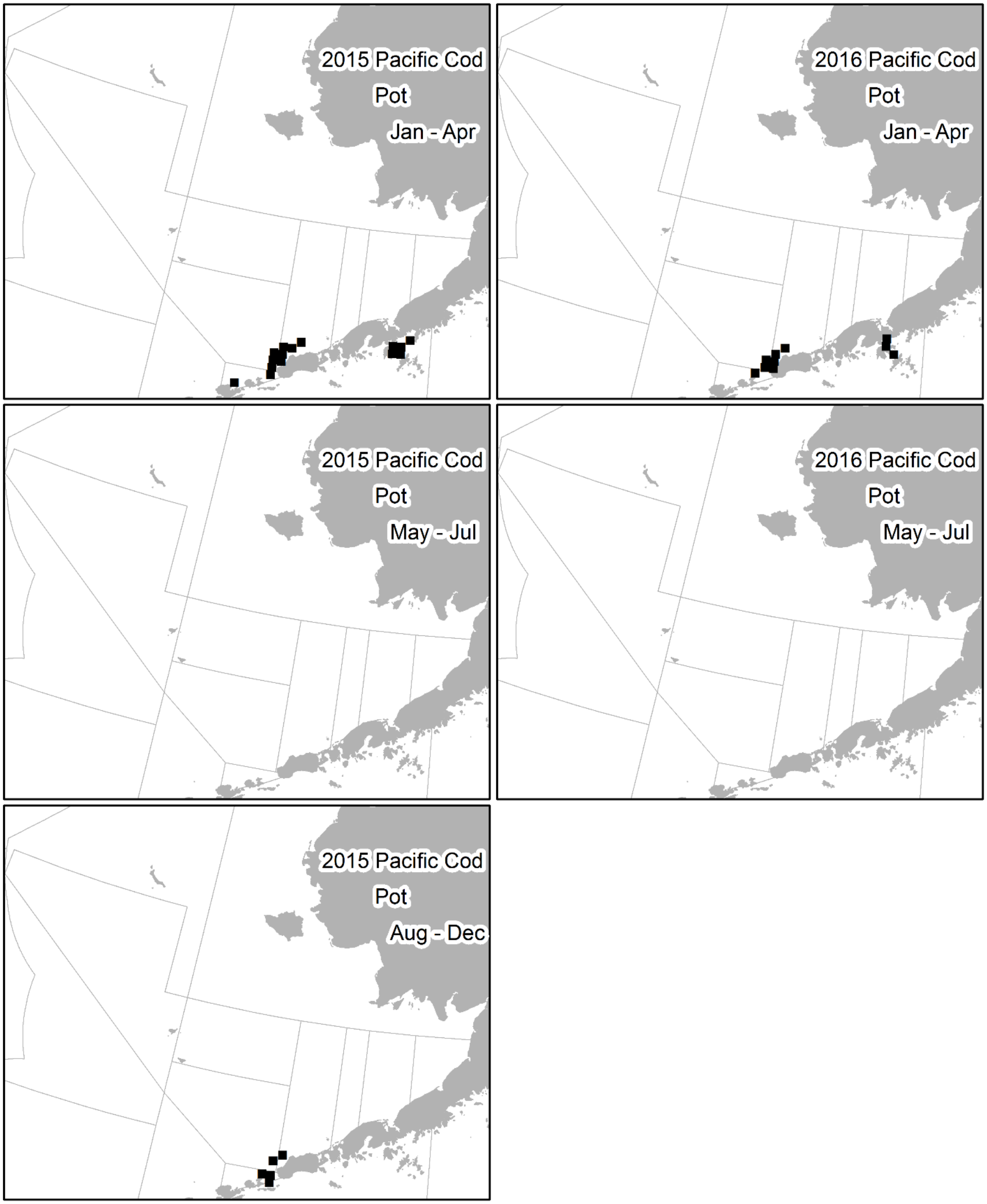


Figure 2.1c. EBS maps showing each 400 square km cell with pot sets containing Pacific cod from at least 3 distinct vessels by season in 2015-2016, overlaid against NMFS 3-digit statistical areas.

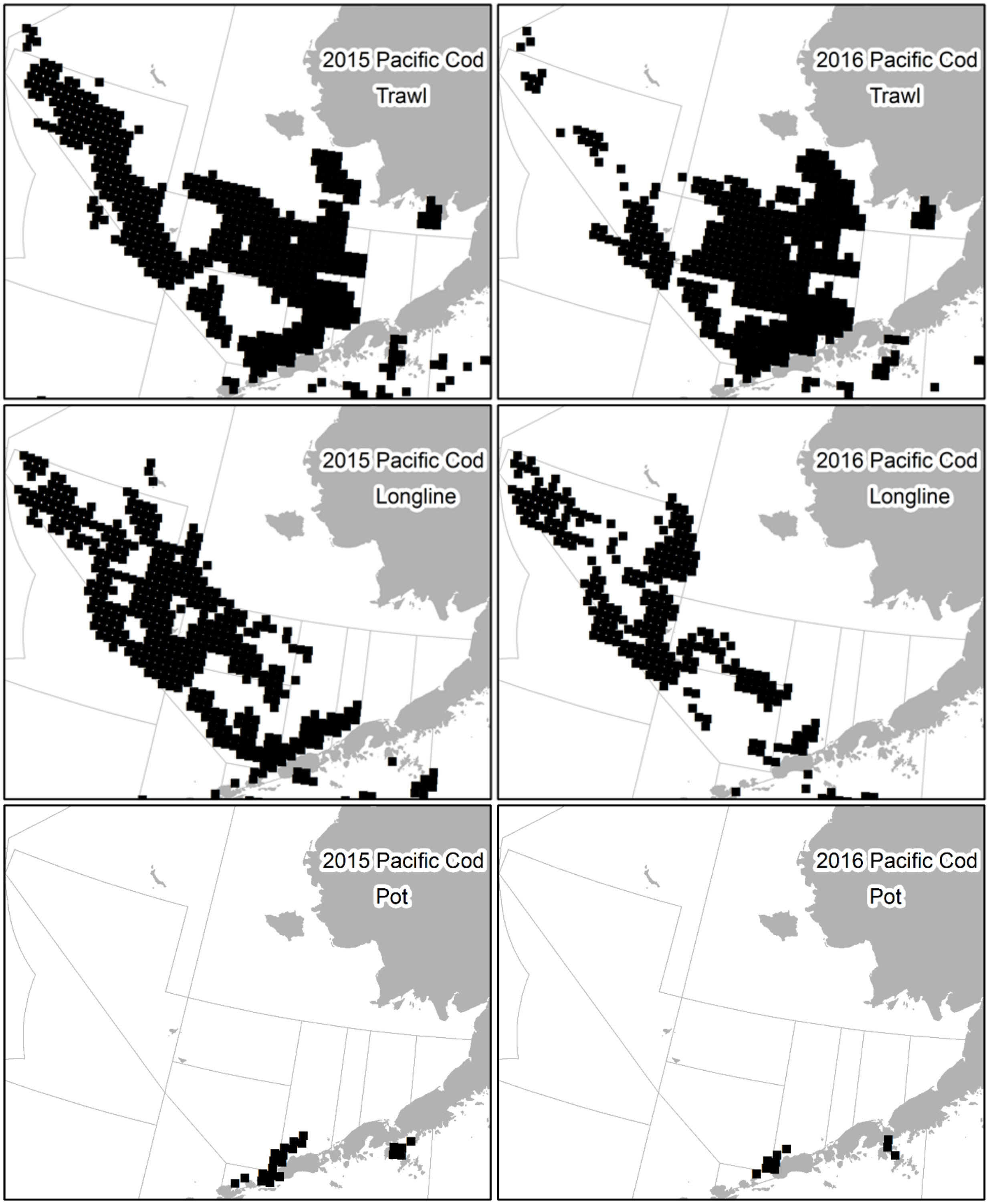


Figure 2.2. Maps showing each 400 square km cell with pot sets containing Pacific cod from at least 3 distinct vessels by season in 2015-2016, overlaid against NMFS 3-digit statistical areas.

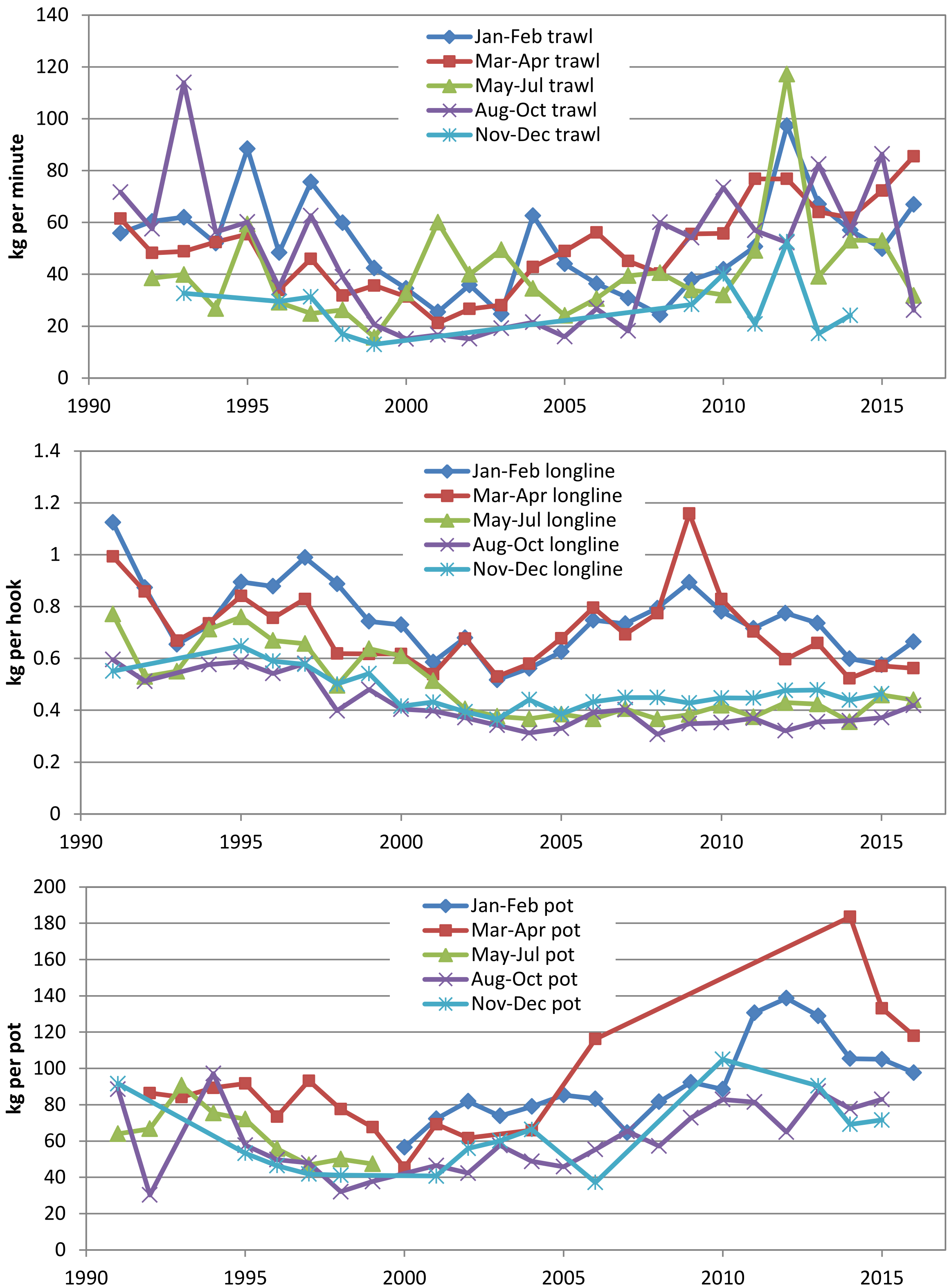


Figure 2.3—Time series of fishery catch per unit effort, by gear and season.

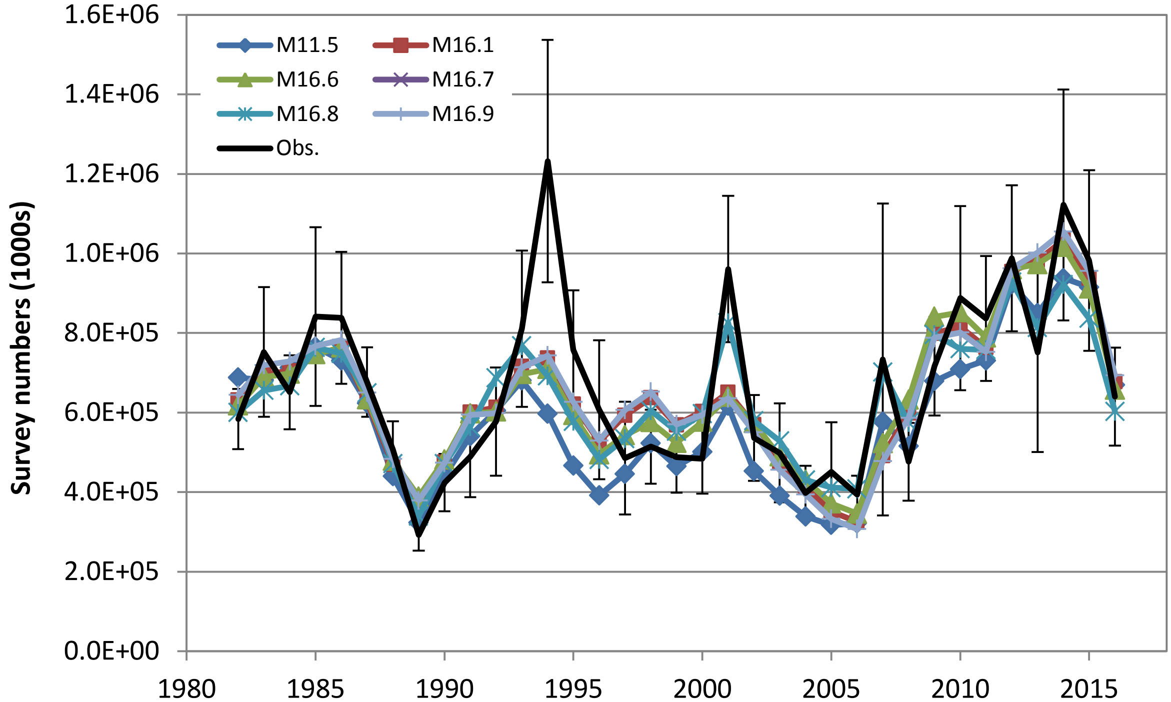


Figure 2.4a—Model fits to the trawl survey abundance time series, with 95% CI for the observations.

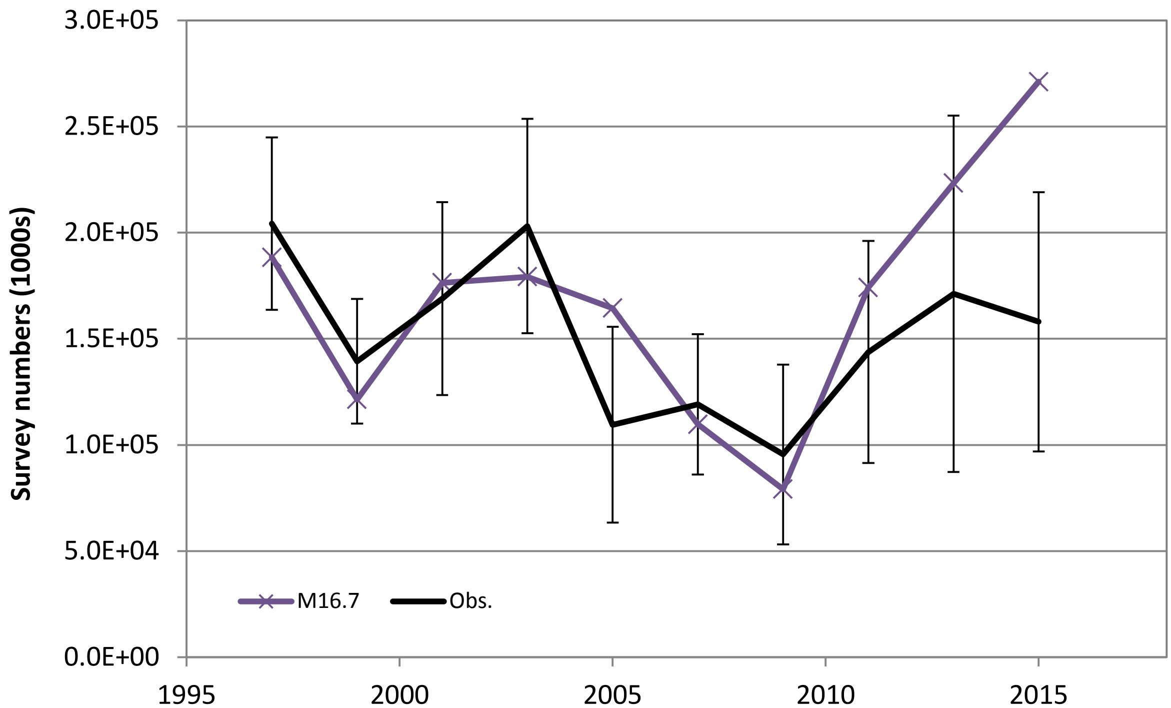


Figure 2.4b—Model 16.7 fits to the NMFS longline survey abundance time series, with 95% CI for the observations.

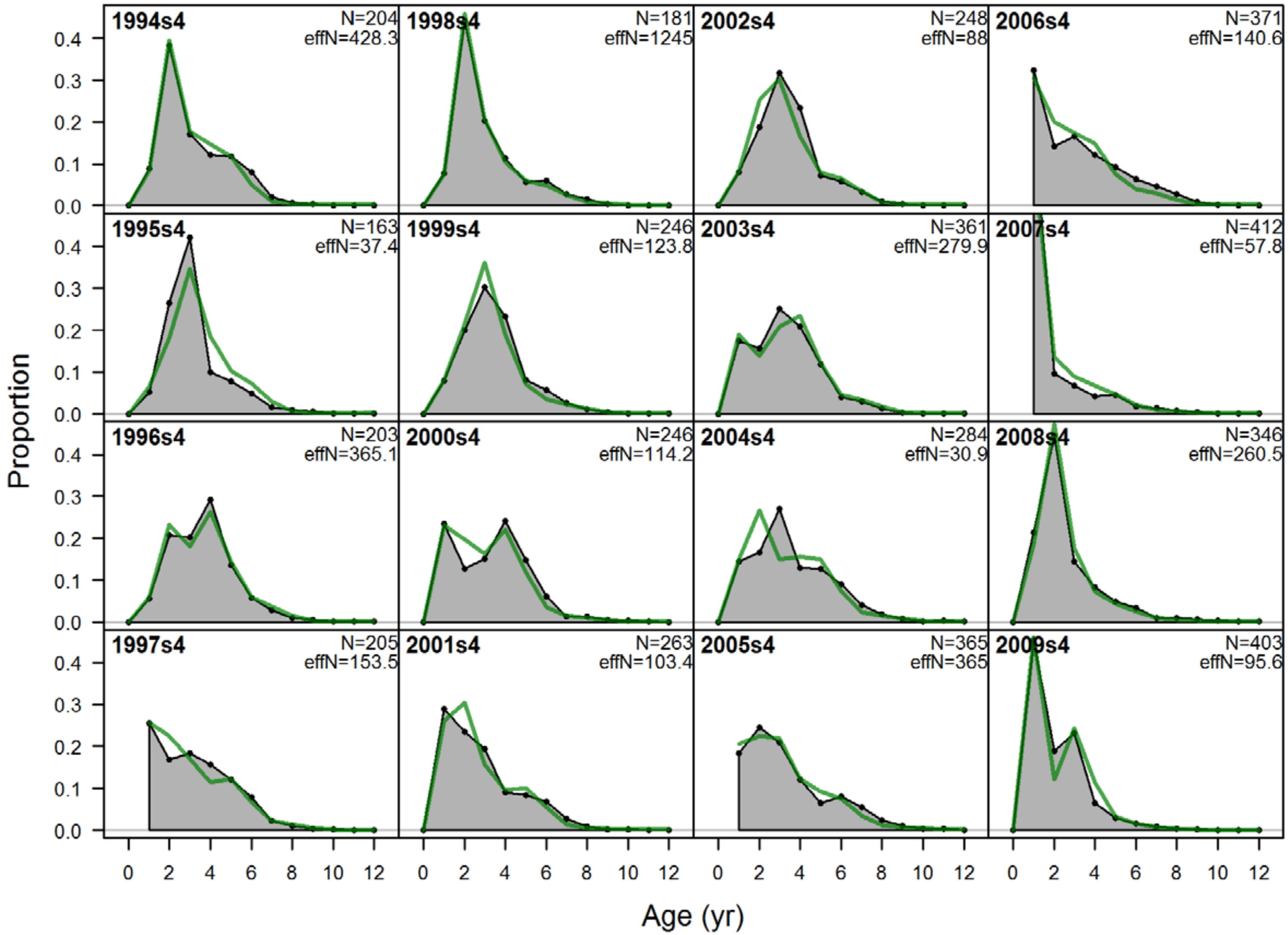


Figure 2.5a (page 1 of 2)—Fit to trawl survey age composition data obtained by Model 11.5 (grey = observed, green = estimated).

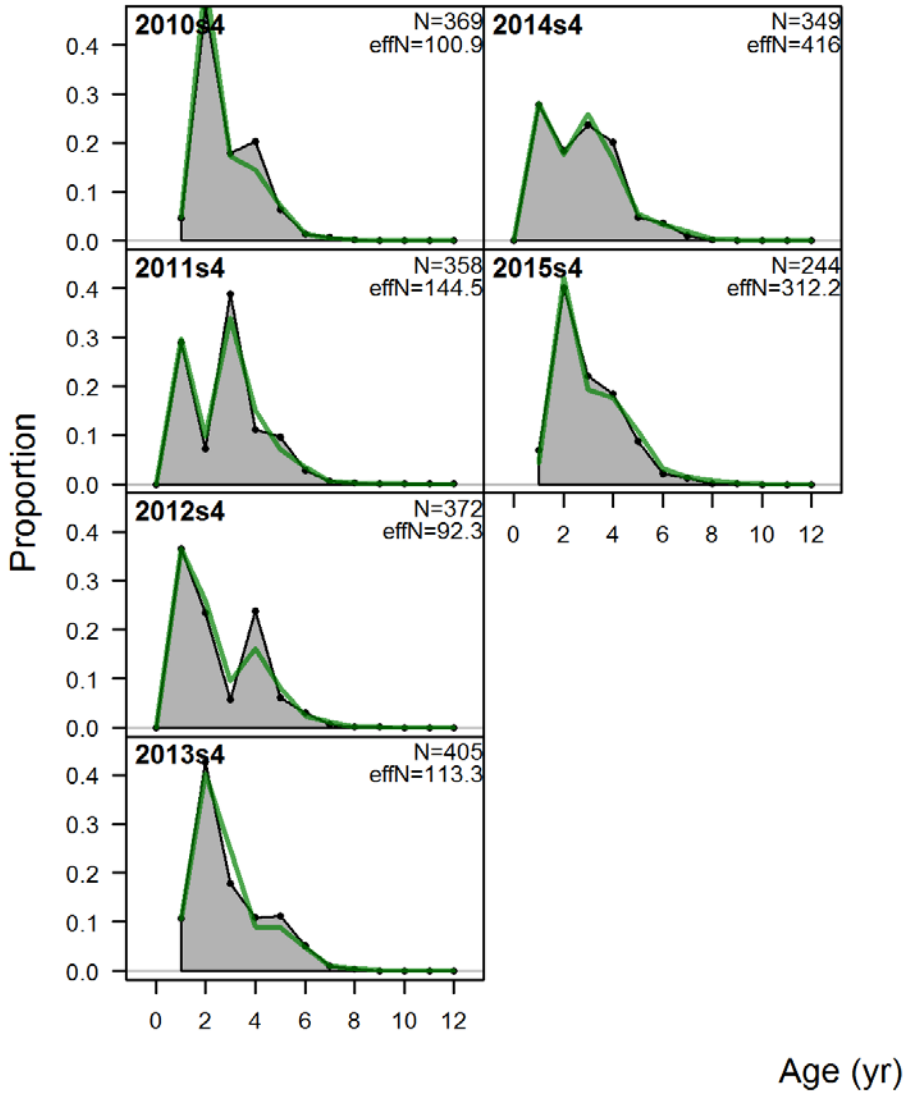


Figure 2.5a (page 2 of 2)—Fit to trawl survey age composition data obtained by Model 11.5 (grey = observed, green = estimated).

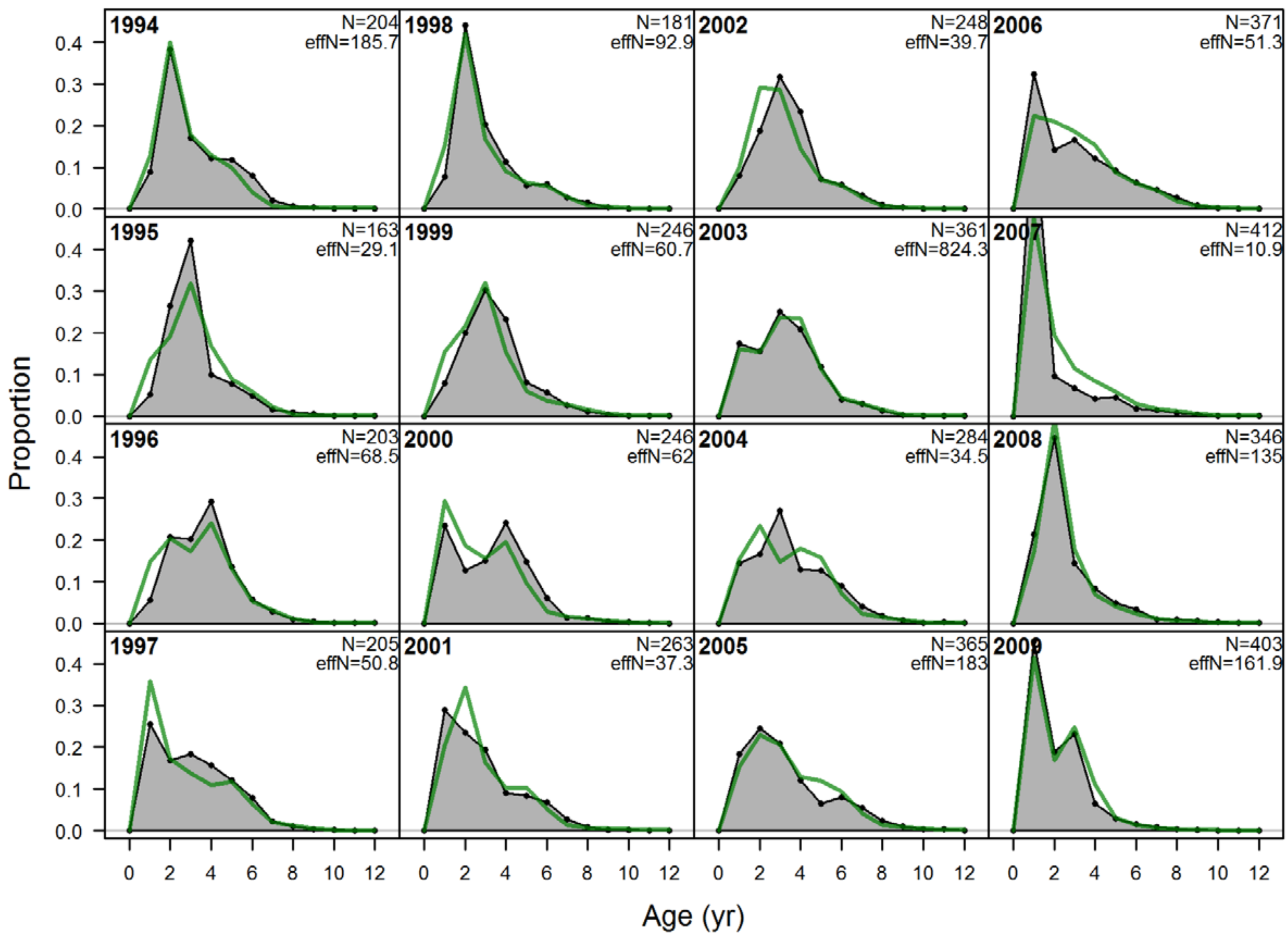


Figure 2.5b (page 1 of 2)—Fit to trawl survey age composition data obtained by Model 16.1 (grey = observed, green = estimated).

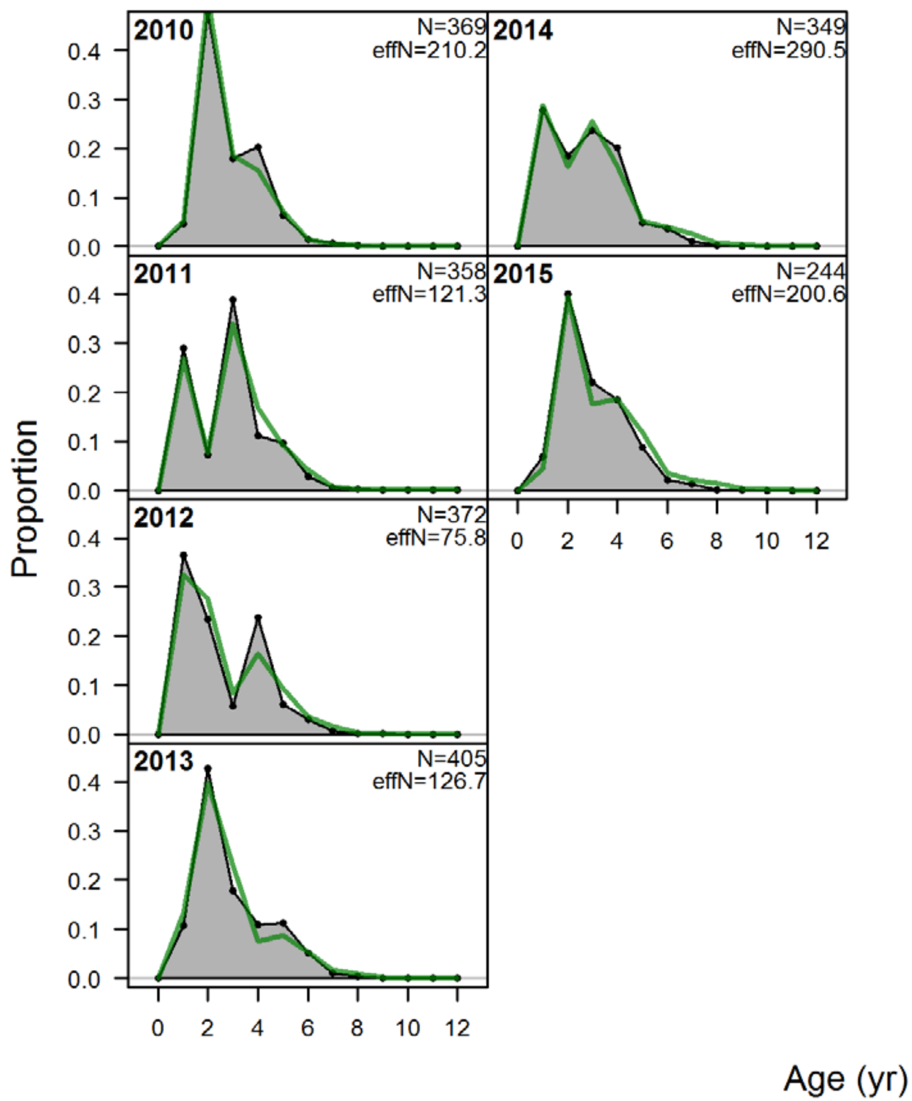


Figure 2.5b (page 2 of 2)—Fit to trawl survey age composition data obtained by Model 16.1 (grey = observed, green = estimated).

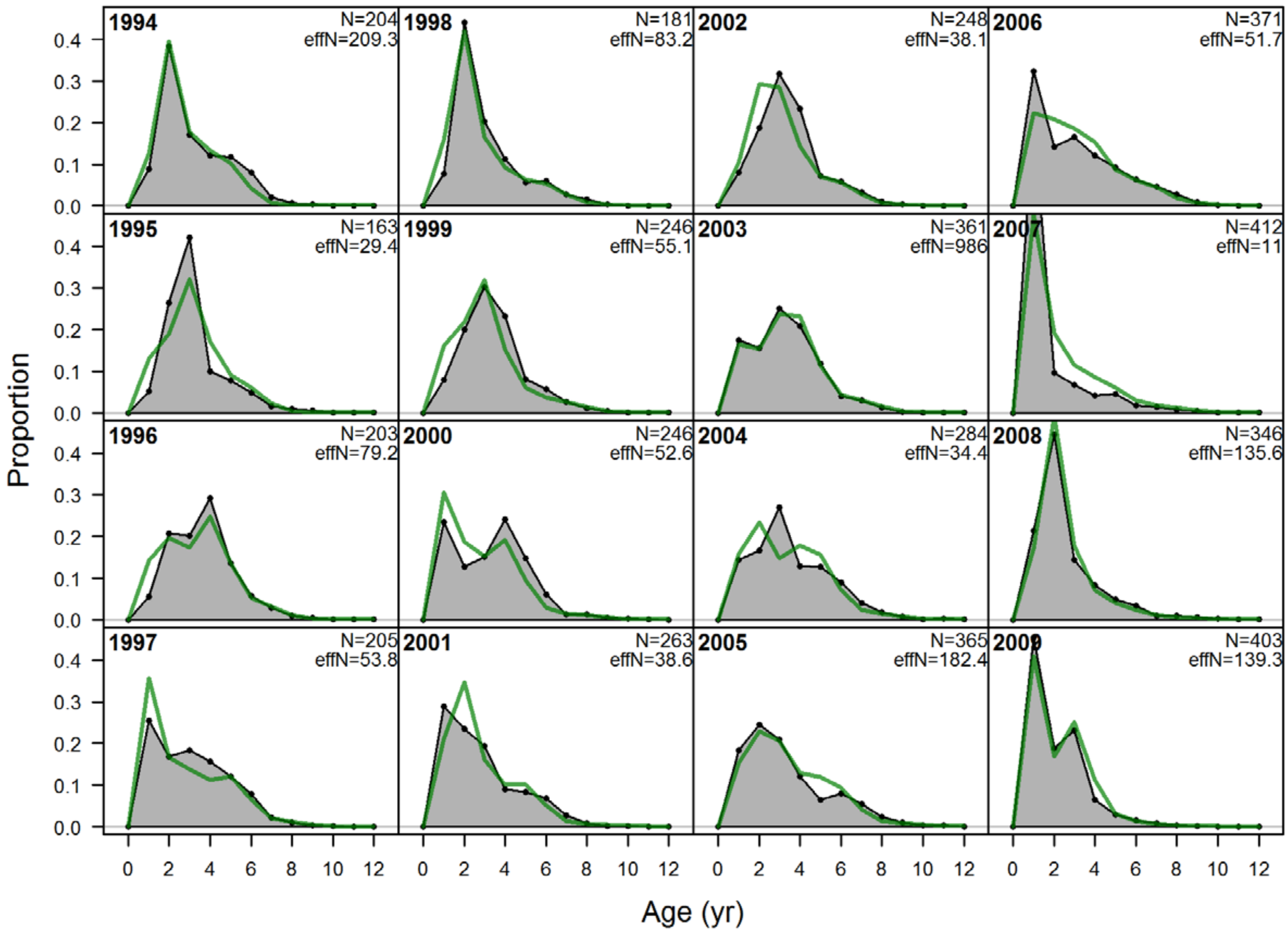


Figure 2.5c (page 1 of 2)—Fit to trawl survey age composition data obtained by Model 16.6 (grey = observed, green = estimated).

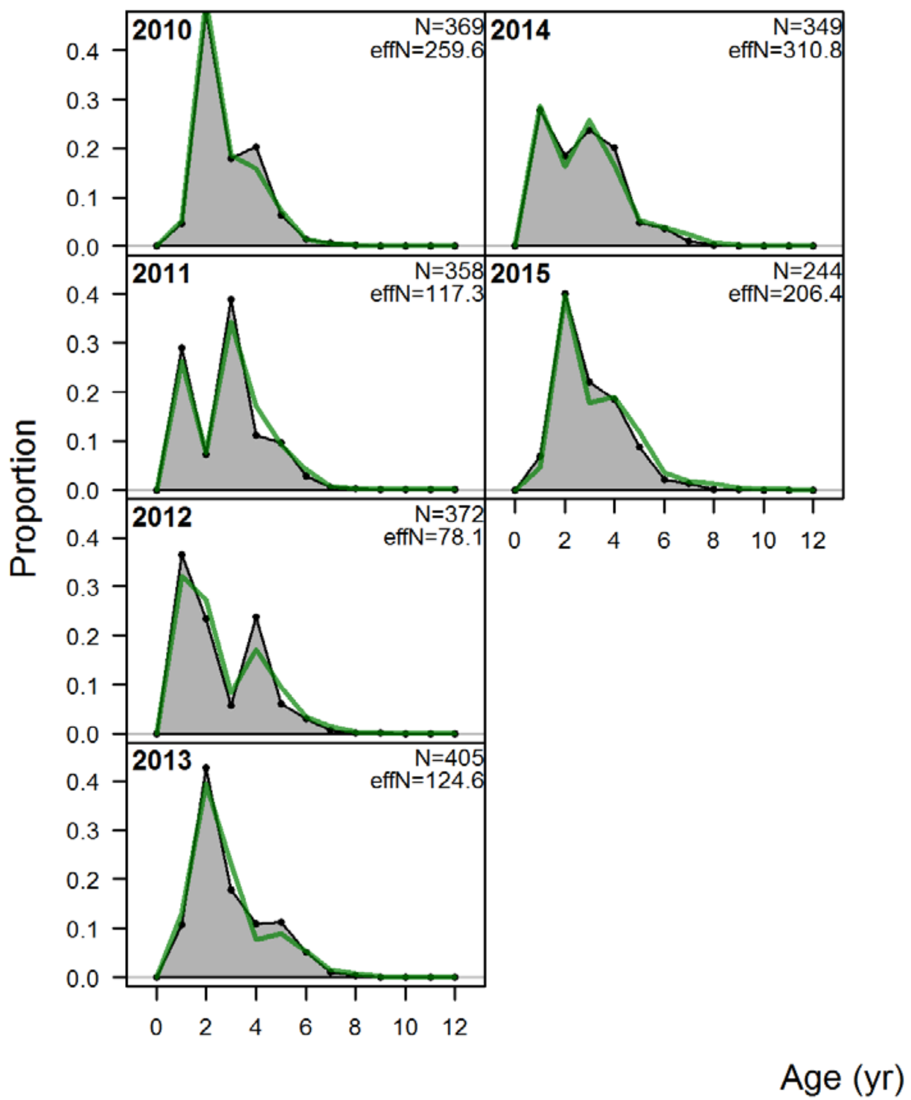


Figure 2.5c (page 2 of 2)—Fit to trawl survey age composition data obtained by Model 16.6 (grey = observed, green = estimated).

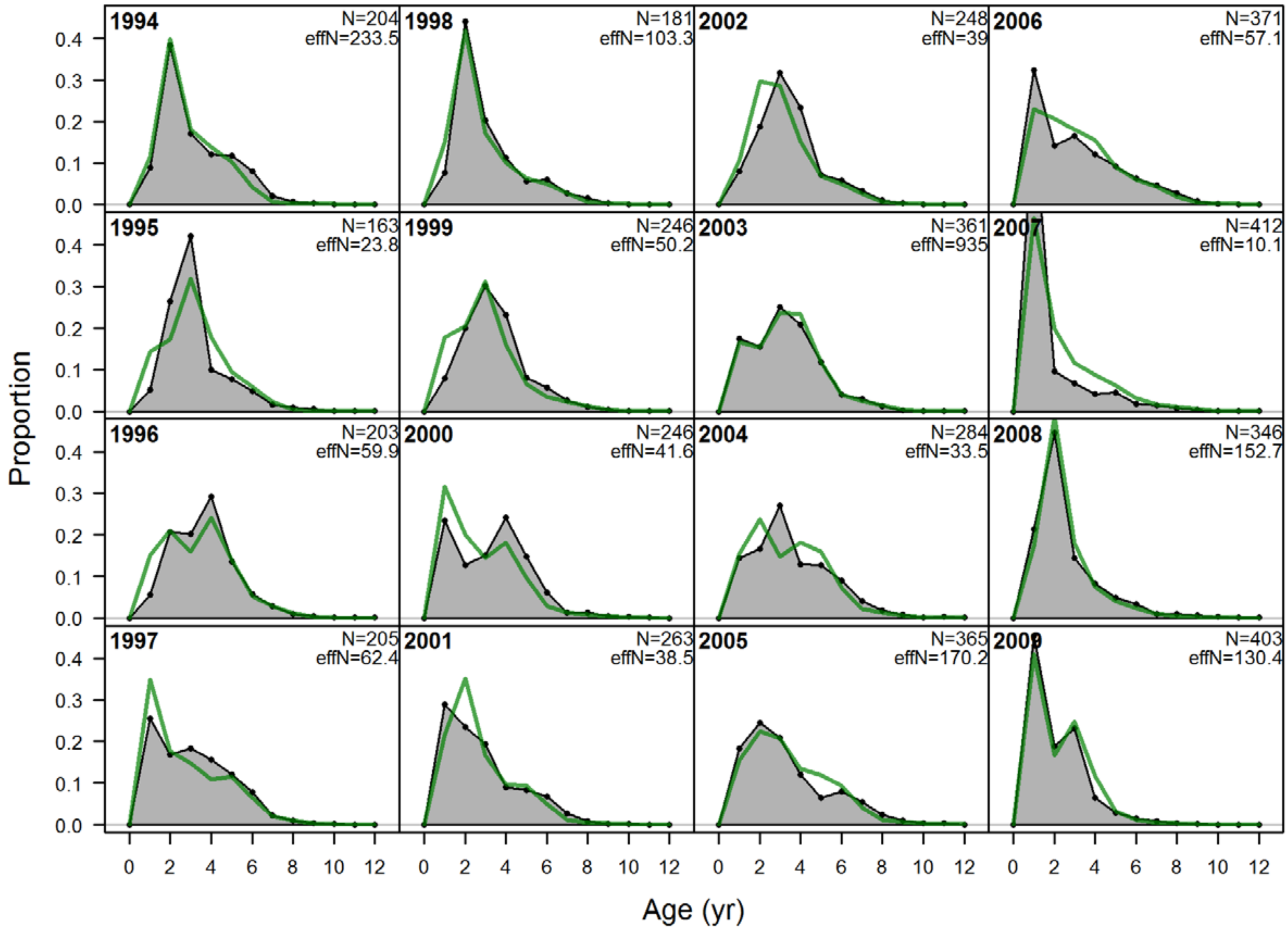


Figure 2.5d (page 1 of 2)—Fit to trawl survey age composition data obtained by Model 16.7 (grey = observed, green = estimated).

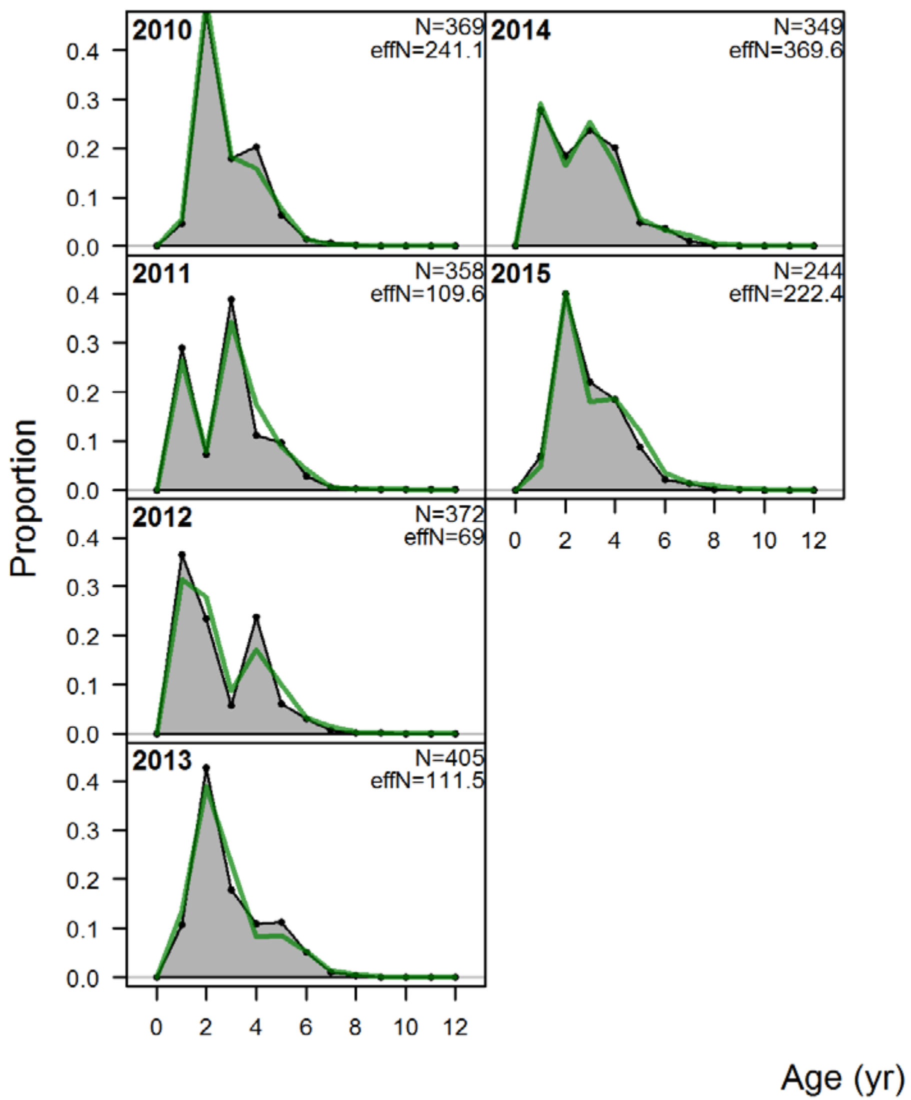


Figure 2.5d (page 2 of 2)—Fit to trawl survey age composition data obtained by Model 16.7 (grey = observed, green = estimated).

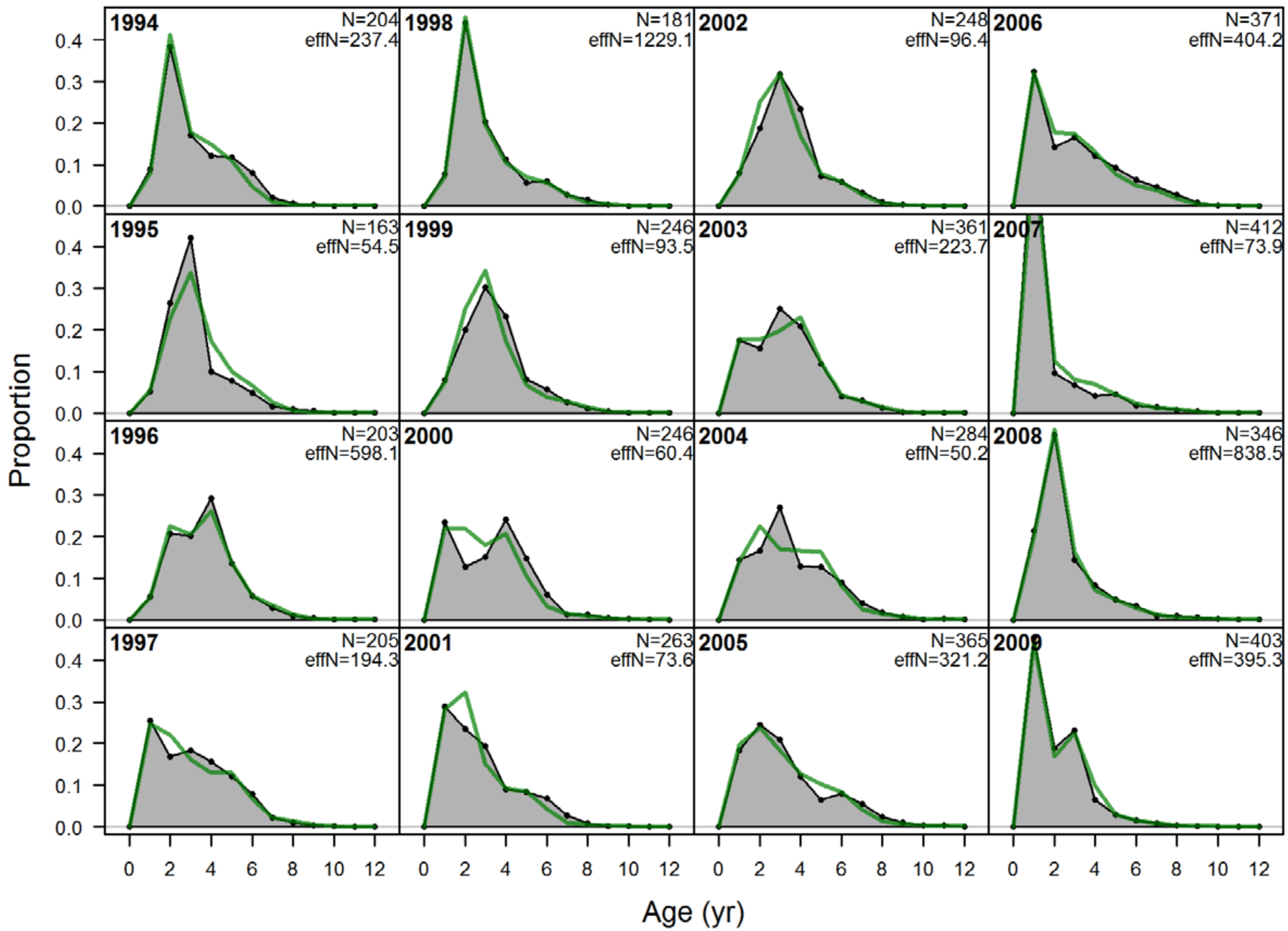


Figure 2.5e (page 1 of 2)—Fit to trawl survey age composition data obtained by Model 16.8 (grey = observed, green = estimated).

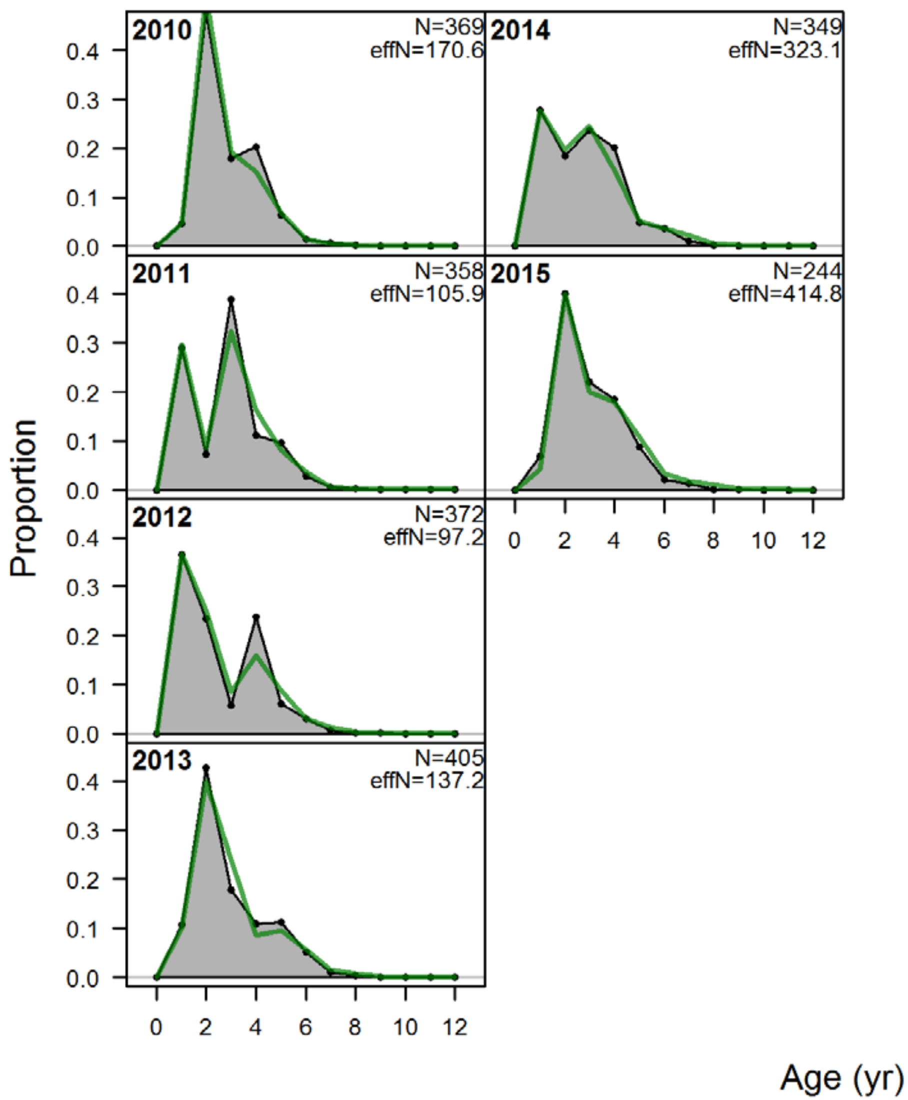


Figure 2.5e (page 2 of 2)—Fit to trawl survey age composition data obtained by Model 16.8 (grey = observed, green = estimated).

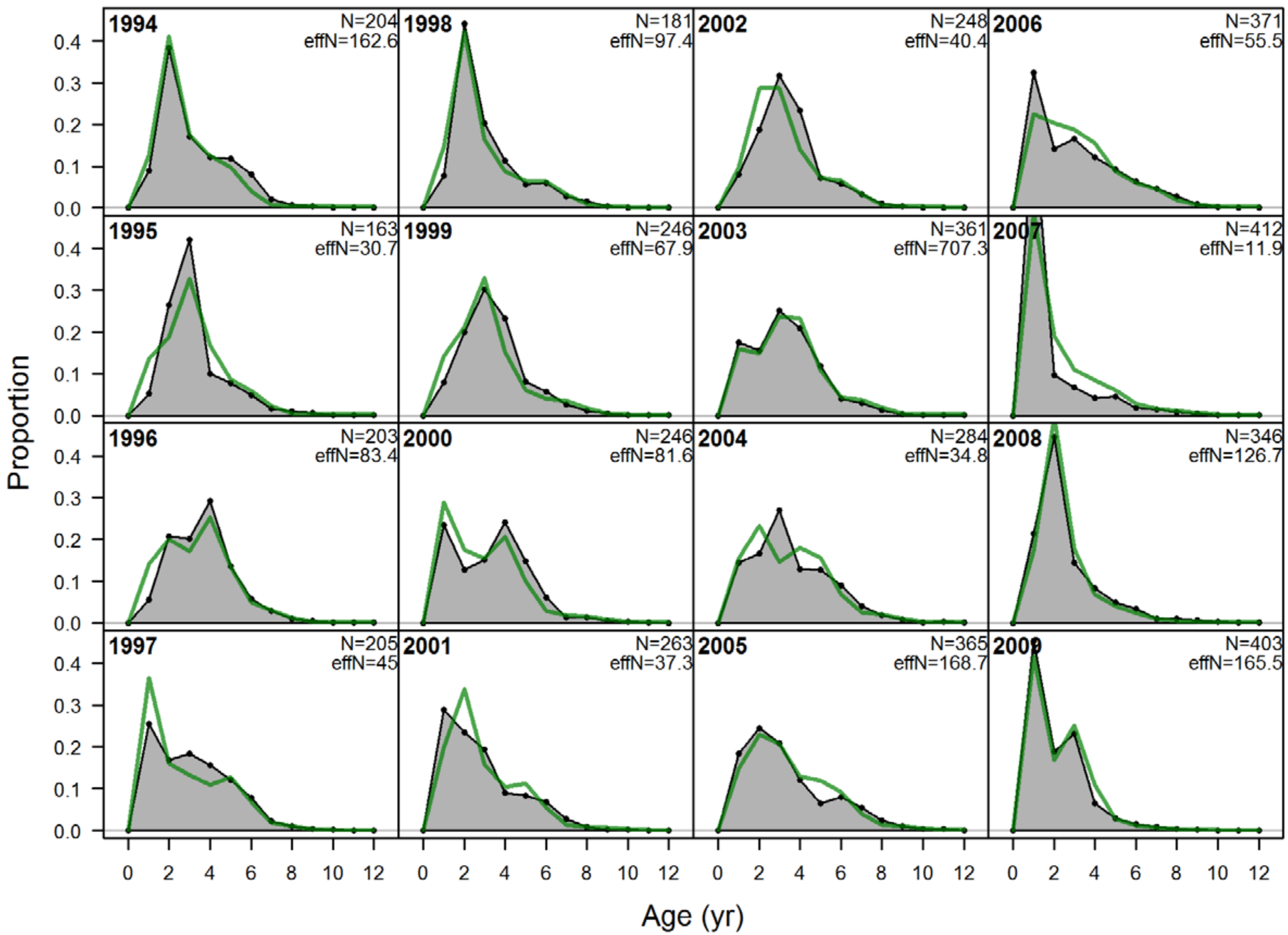


Figure 2.5f (page 1 of 2)—Fit to trawl survey age composition data obtained by Model 16.9 (grey = observed, green = estimated).

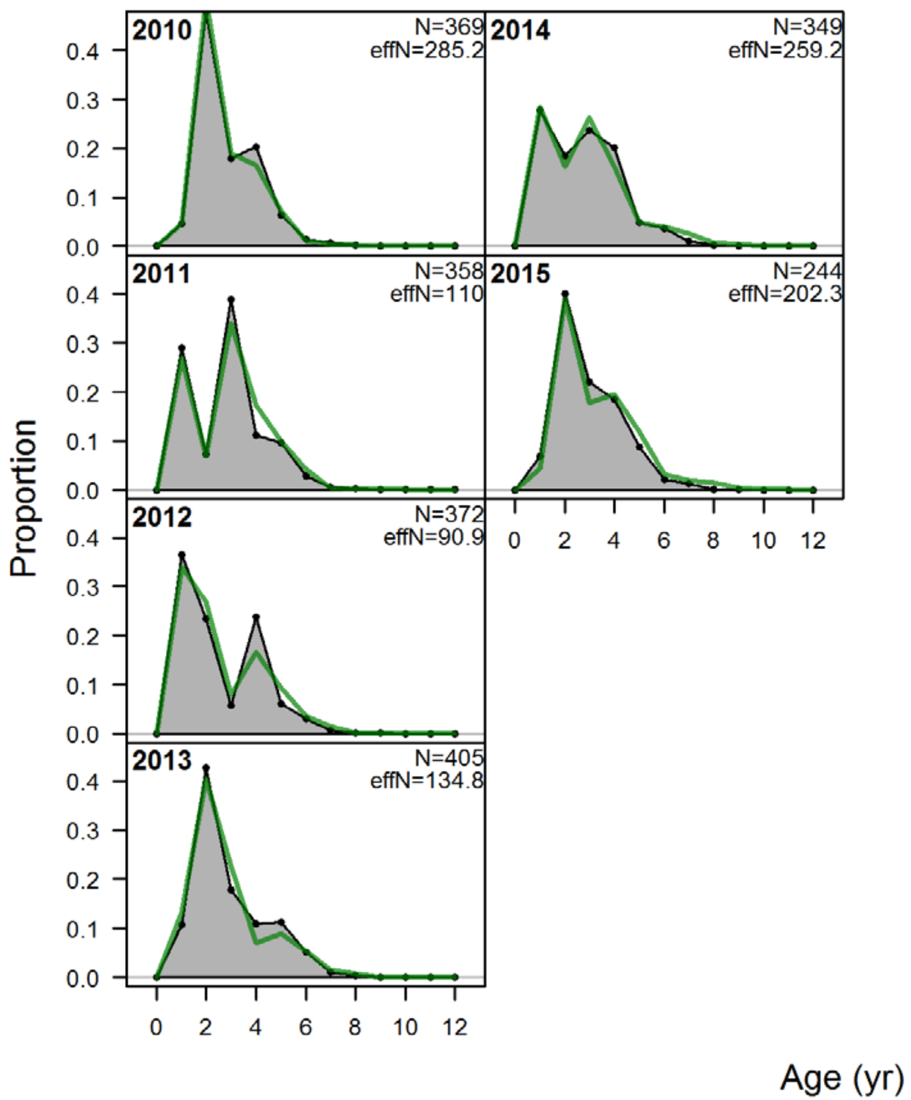


Figure 2.5f (page 2 of 2)—Fit to trawl survey age composition data obtained by Model 16.9 (grey = observed, green = estimated).

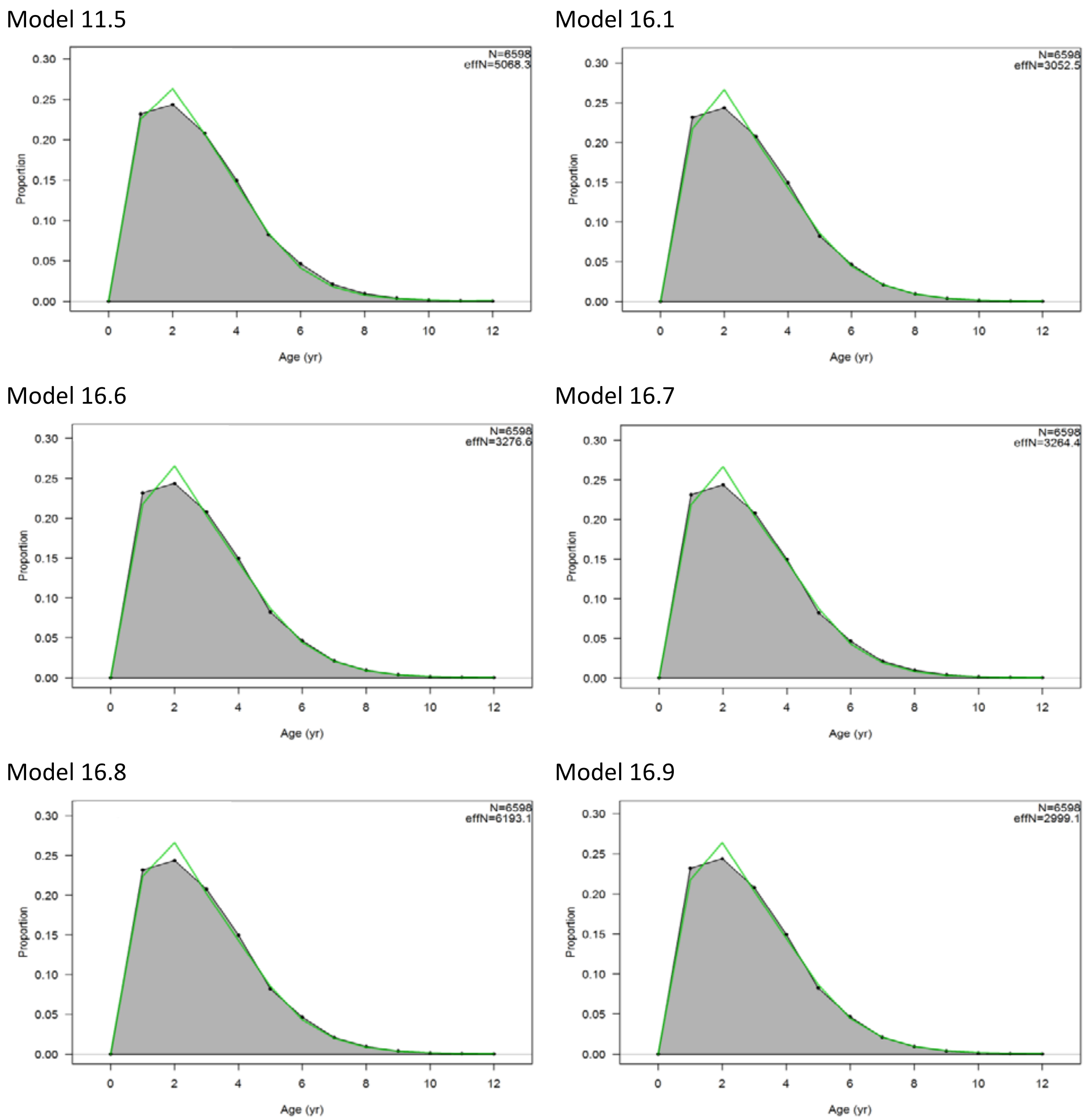


Figure 2.6—Time-aggregated fits to the trawl survey age composition data.

Model 11.5

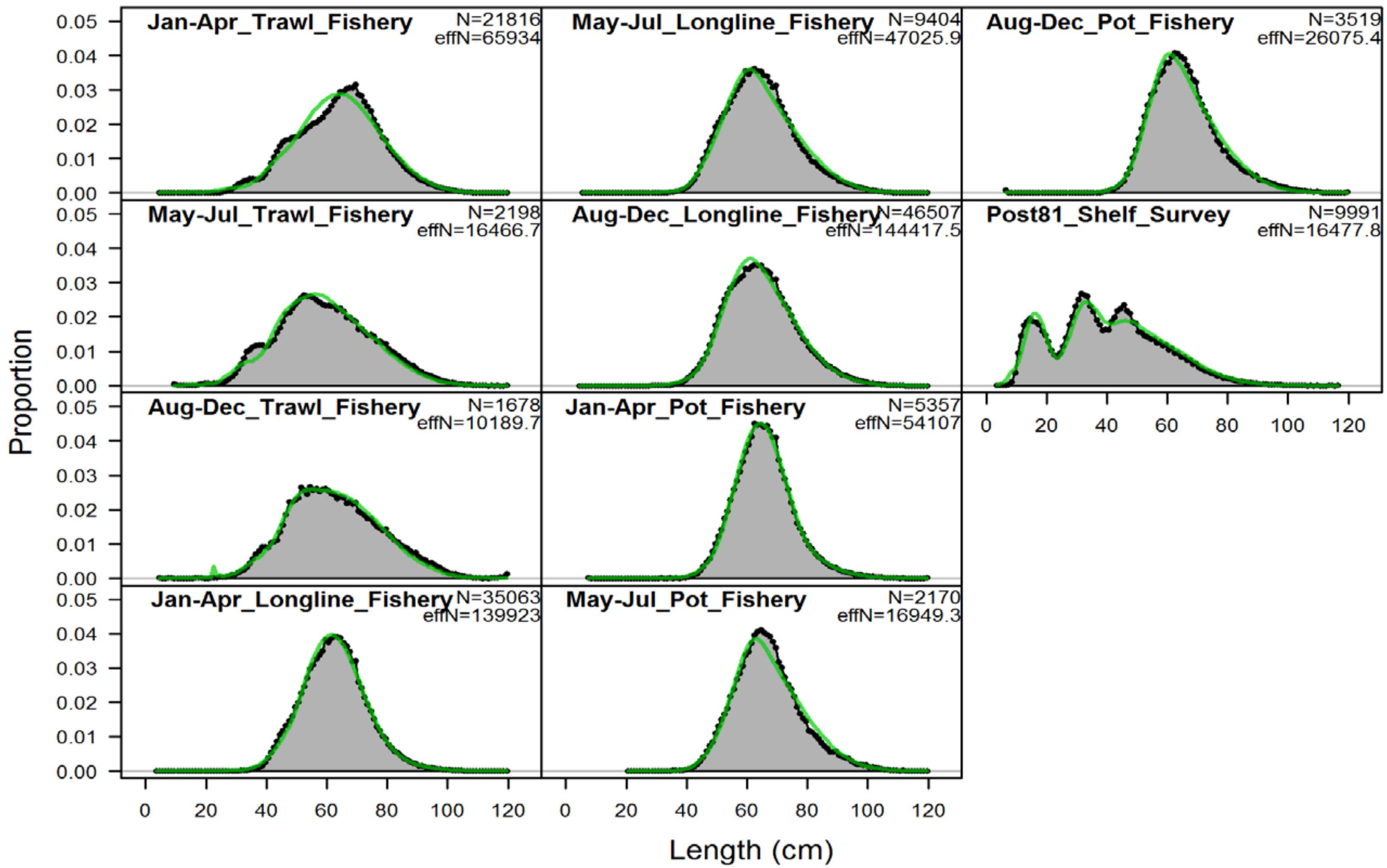
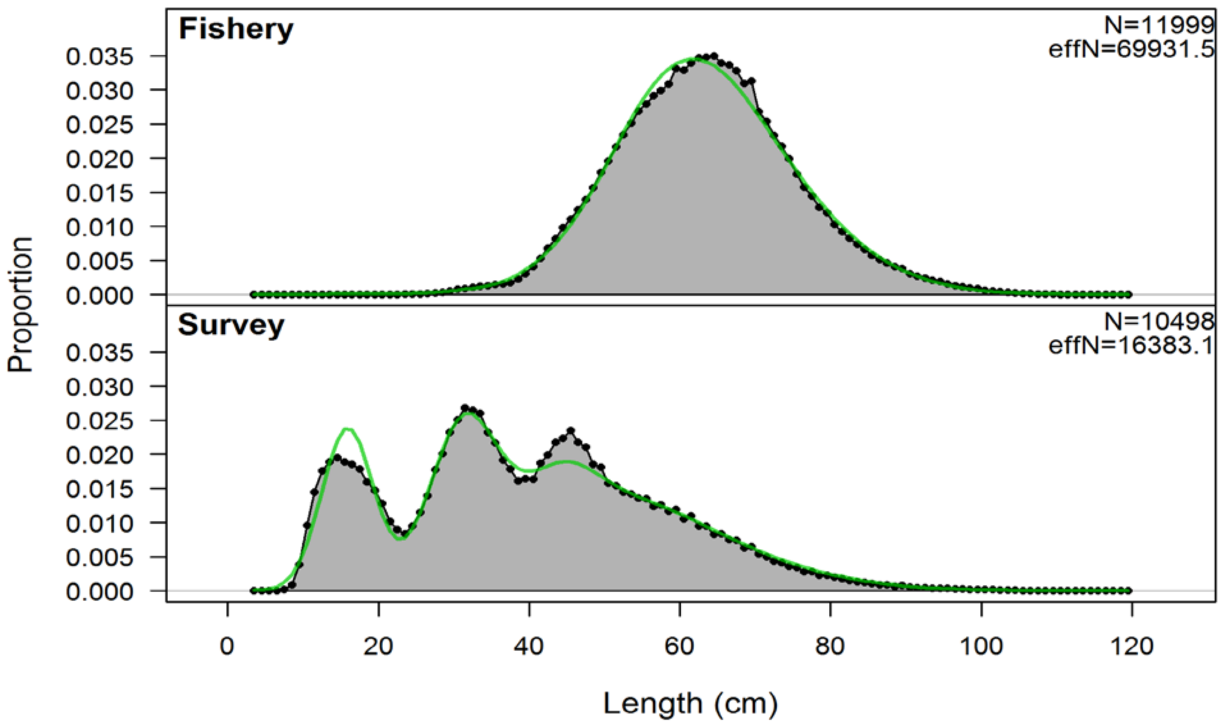


Figure 2.7a—Time-aggregated fits to the size composition data for Model 11.5.

Model 16.1



Model 16.6

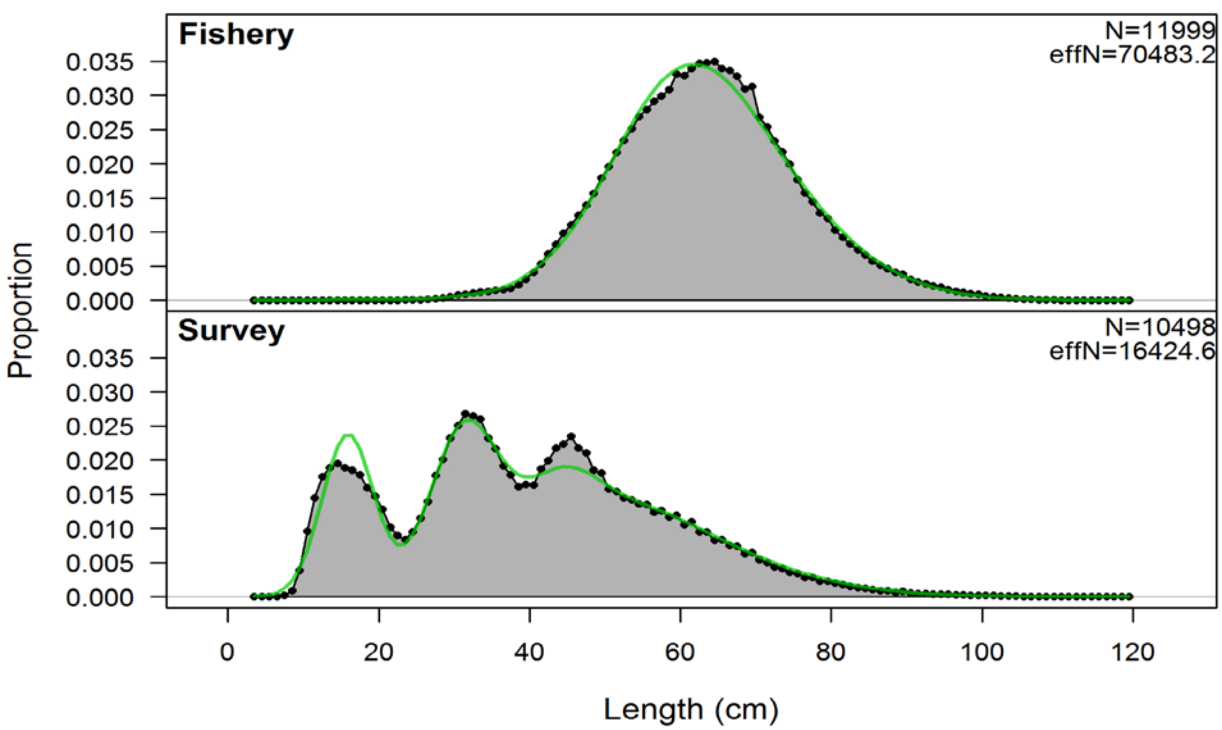


Figure 2.7b—Time-aggregated fits to the size composition data for Models 16.1 and 16.6.

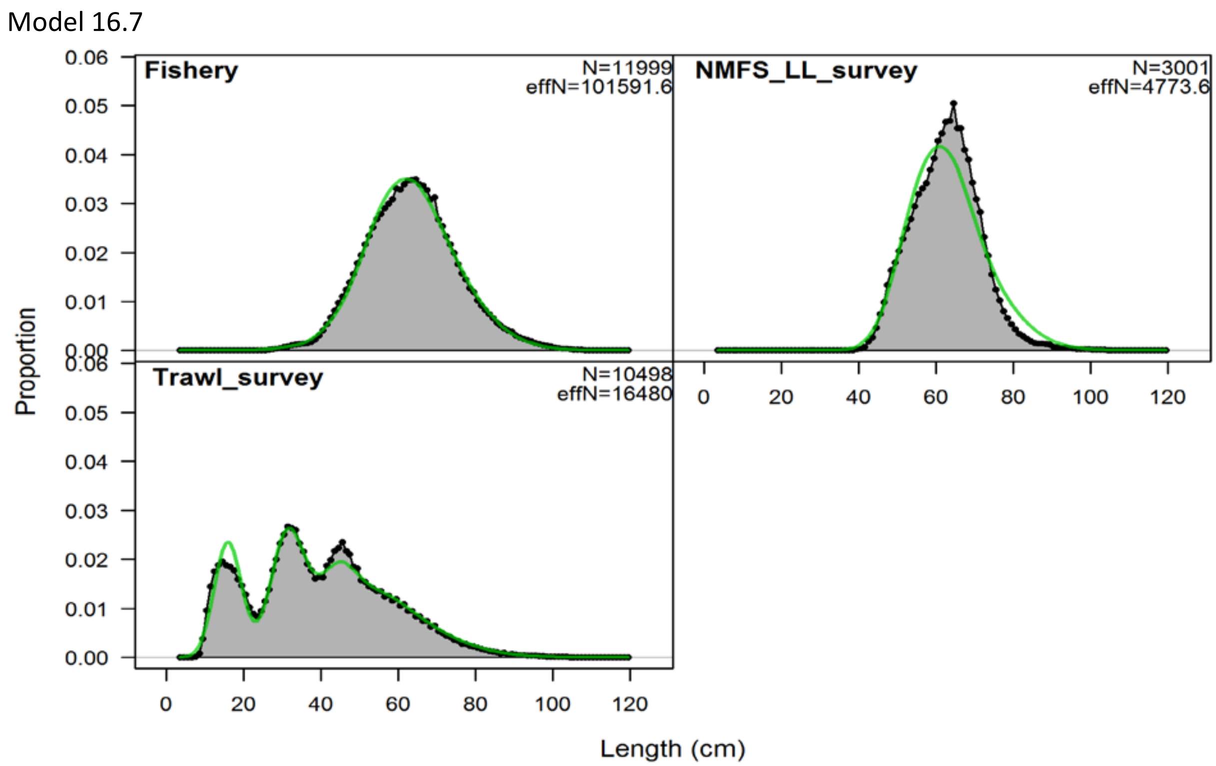
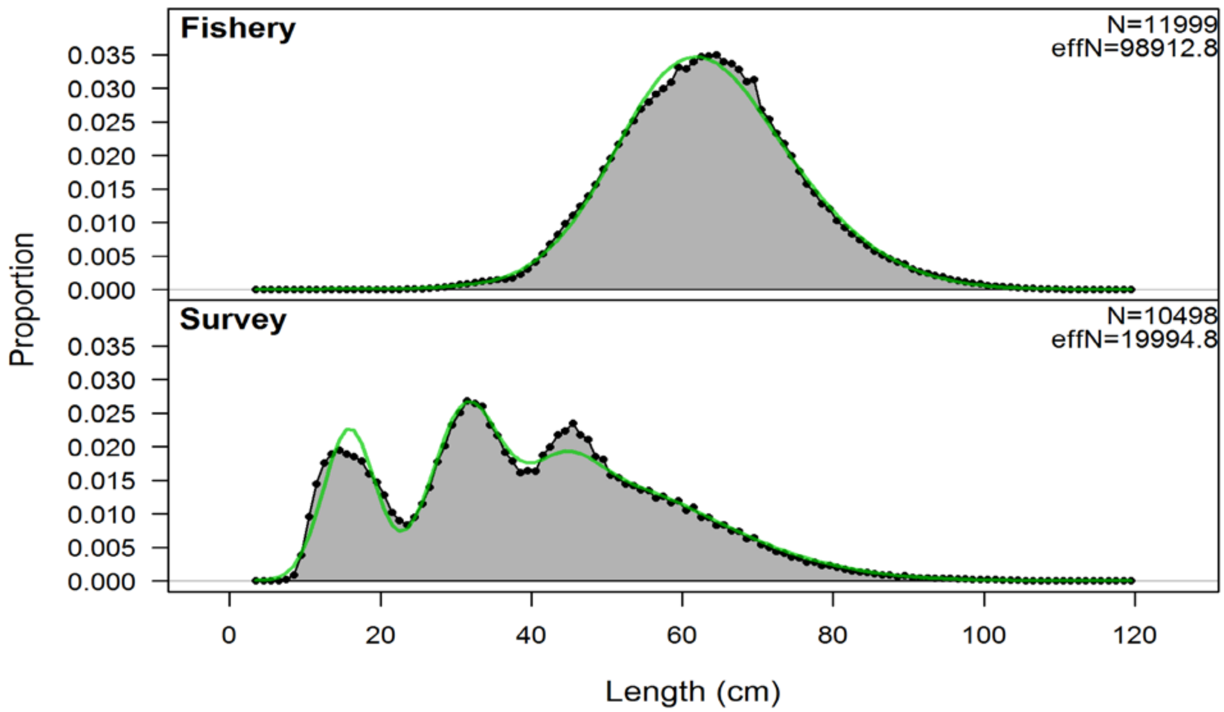


Figure 2.7c—Time-aggregated fits to the size composition data for Model 16.7.

Model 16.8



Model 16.9

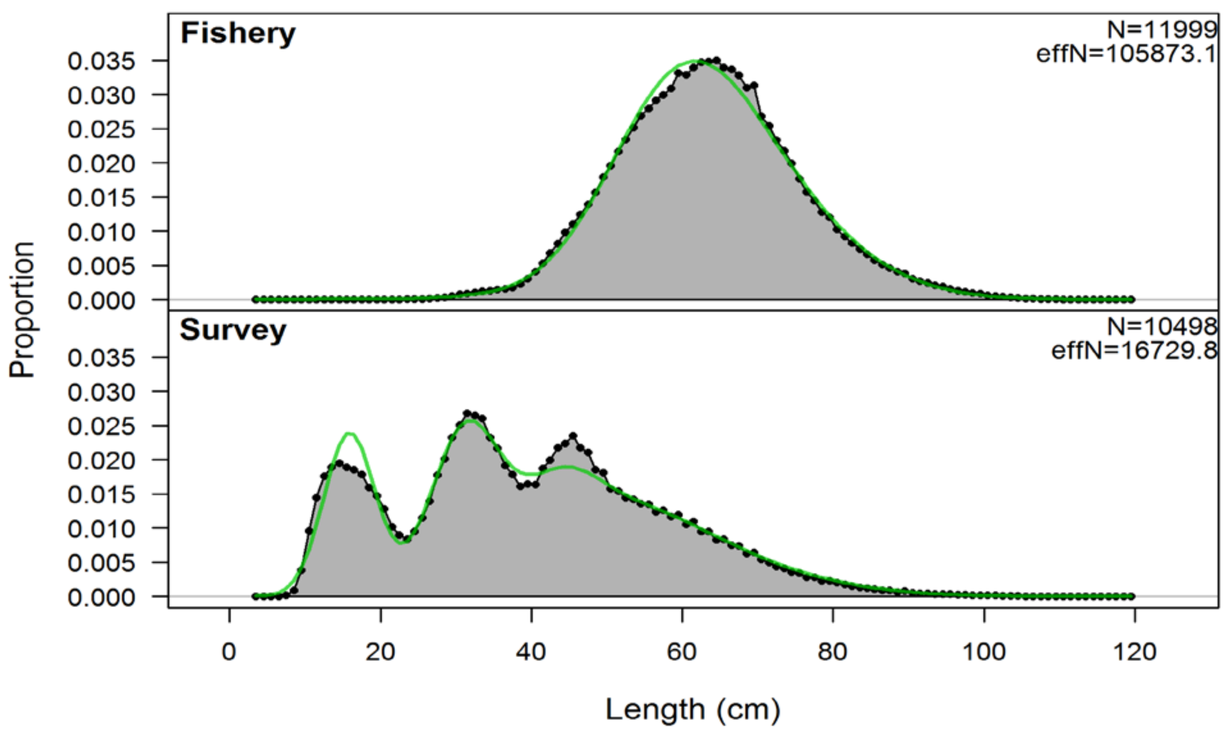


Figure 2.7d—Time-aggregated fits to the size composition data for Models 16.8 and 16.9.

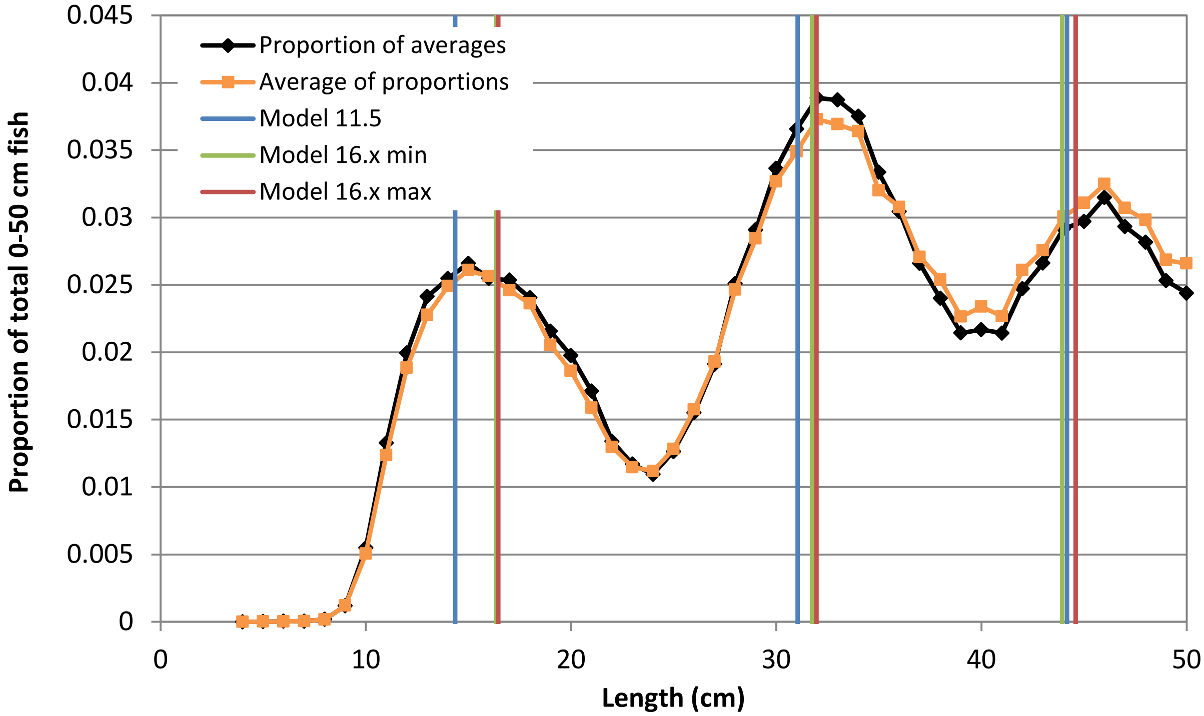


Figure 2.8—Estimates of mean size at ages 1-3 from Models 1 and 16.x, compared to long-term average survey size (0-50 cm) composition. The mean sizes at age 1-3 from the five models in the 16.x series are so similar that only the minimum and maximum (at each age) from these five models is shown.

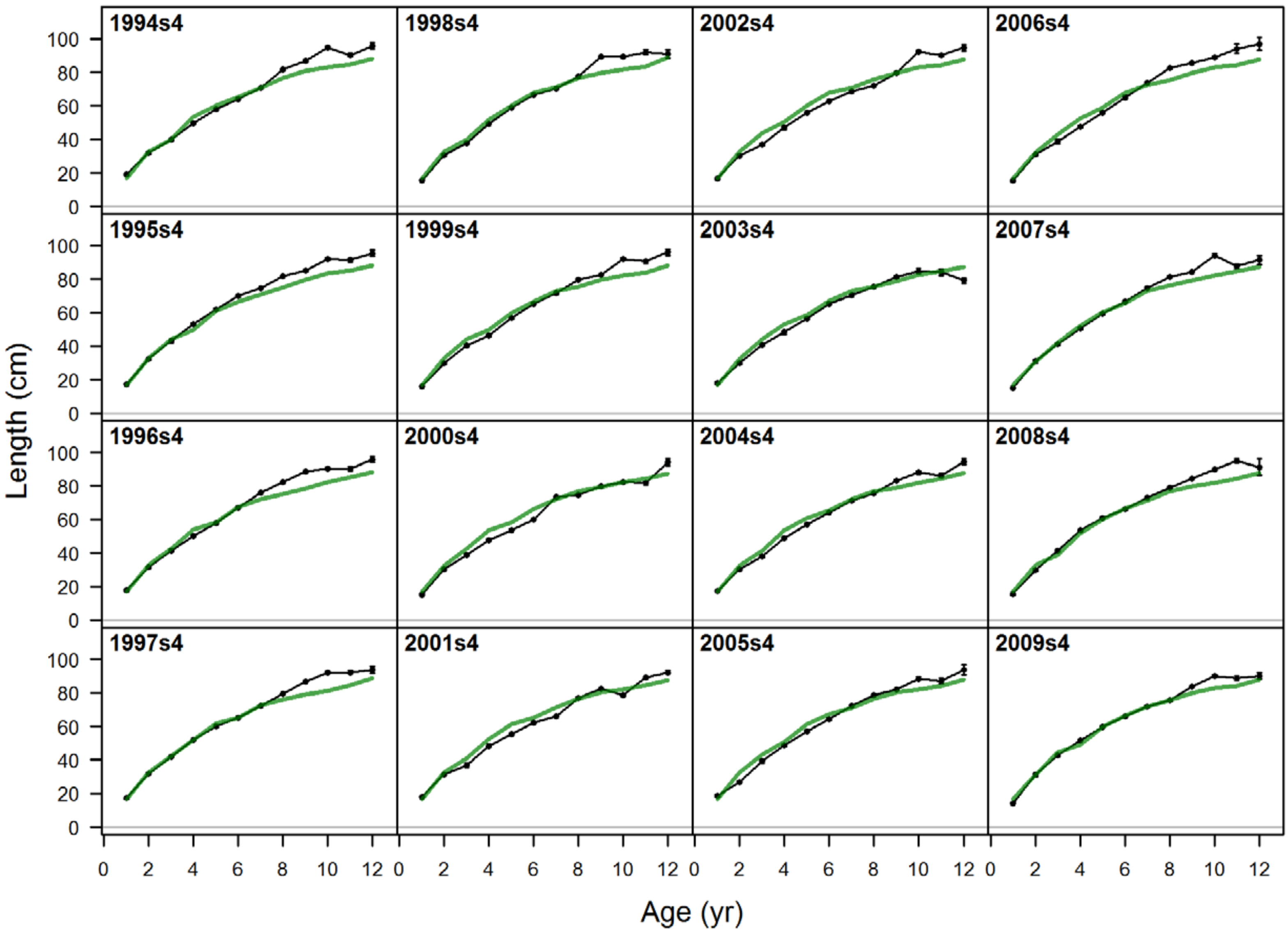


Figure 2.9 (page 1 of 2)—Fit to mean-size-at-age data from Model 11.5 (not used in Models 16.x). Black = observed, green = estimated.

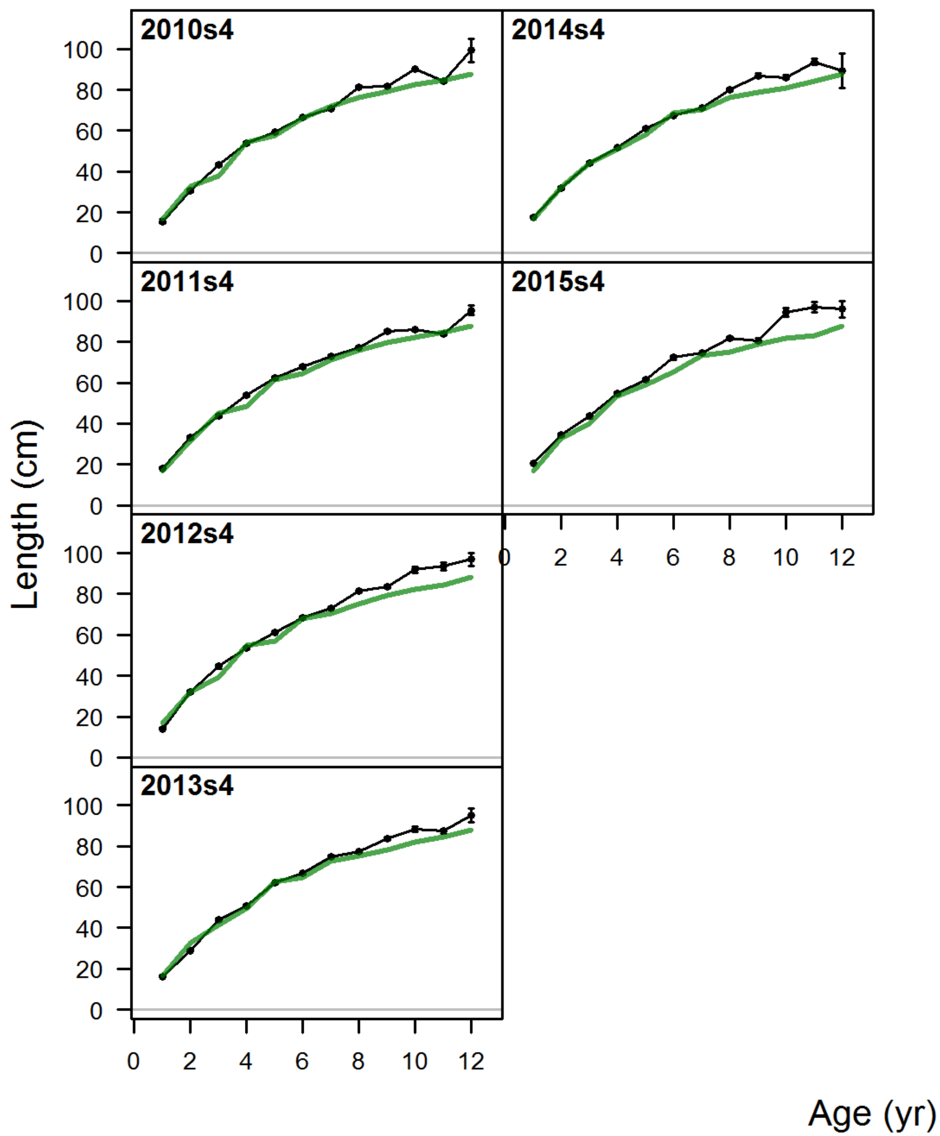


Figure 2.9 (page 2 of 2)—Fit to mean-size-at-age data from Model 11.5 (not used in Models 16.x). Black = observed, green = estimated.

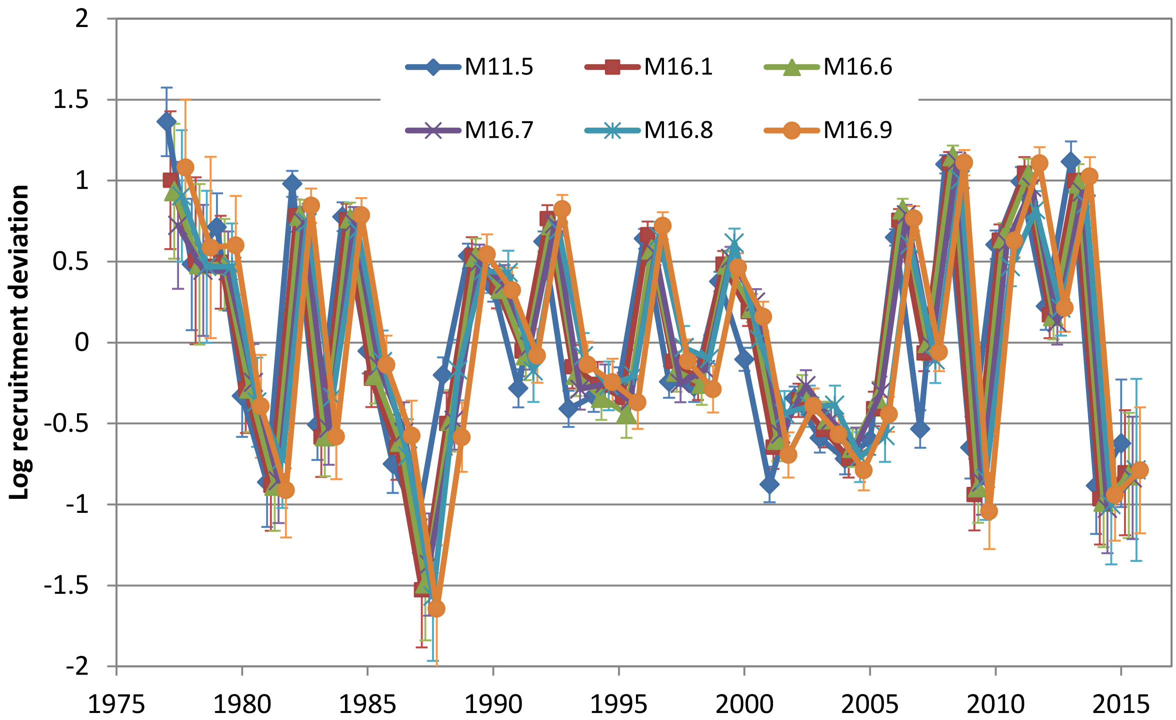


Figure 2.10—Time series of estimated log recruitment deviations as estimated by the models, with 95% confidence intervals.

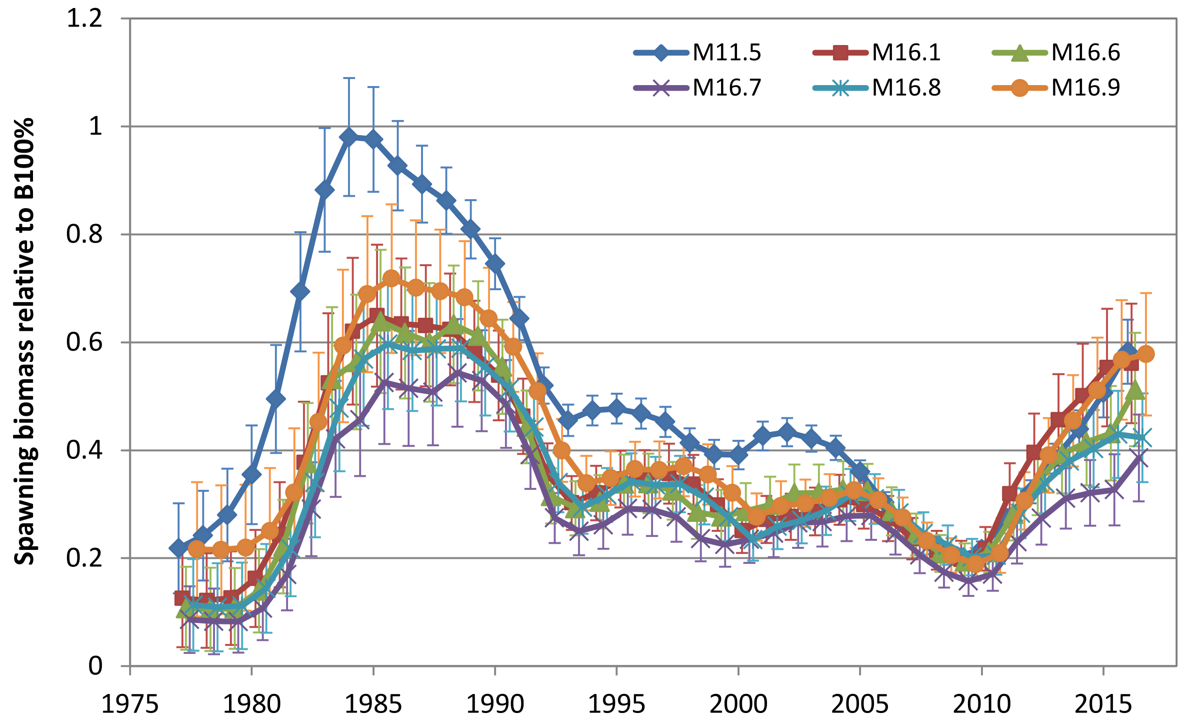


Figure 2.11a—Time series of spawning biomass relative to $B_{100\%}$ as estimated by the models.

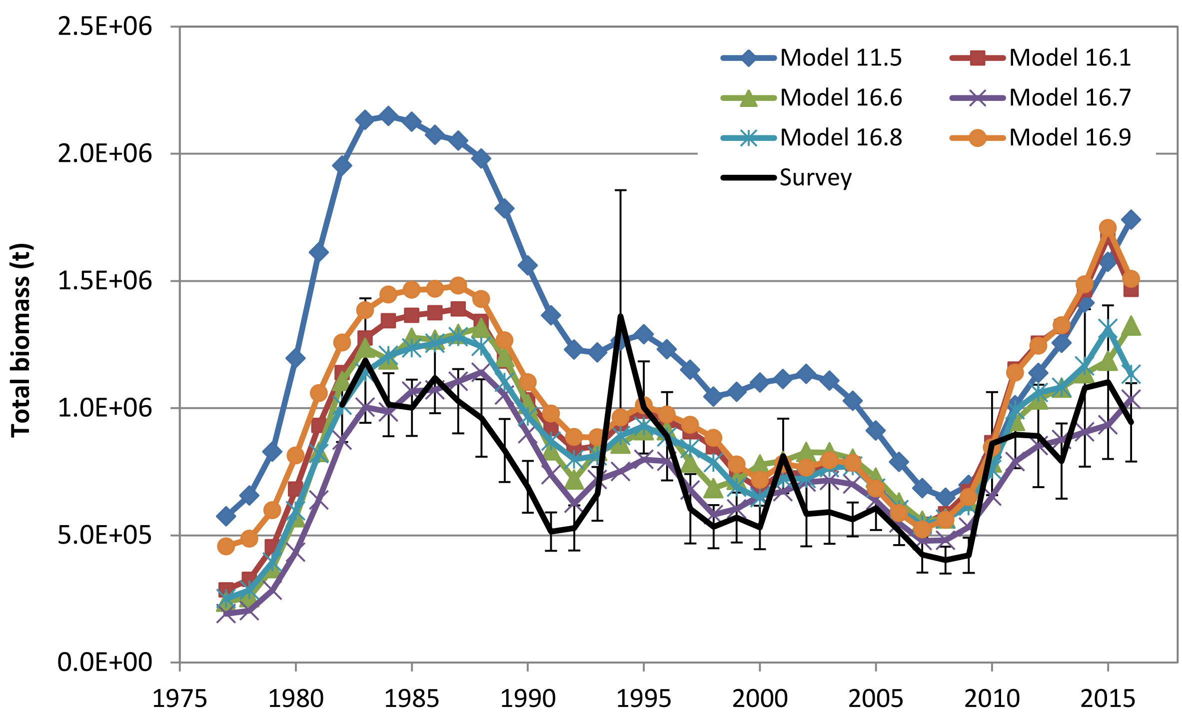


Figure 2.11b—Time series of total biomass (t) as estimated by the models, with survey biomass shown for comparison.

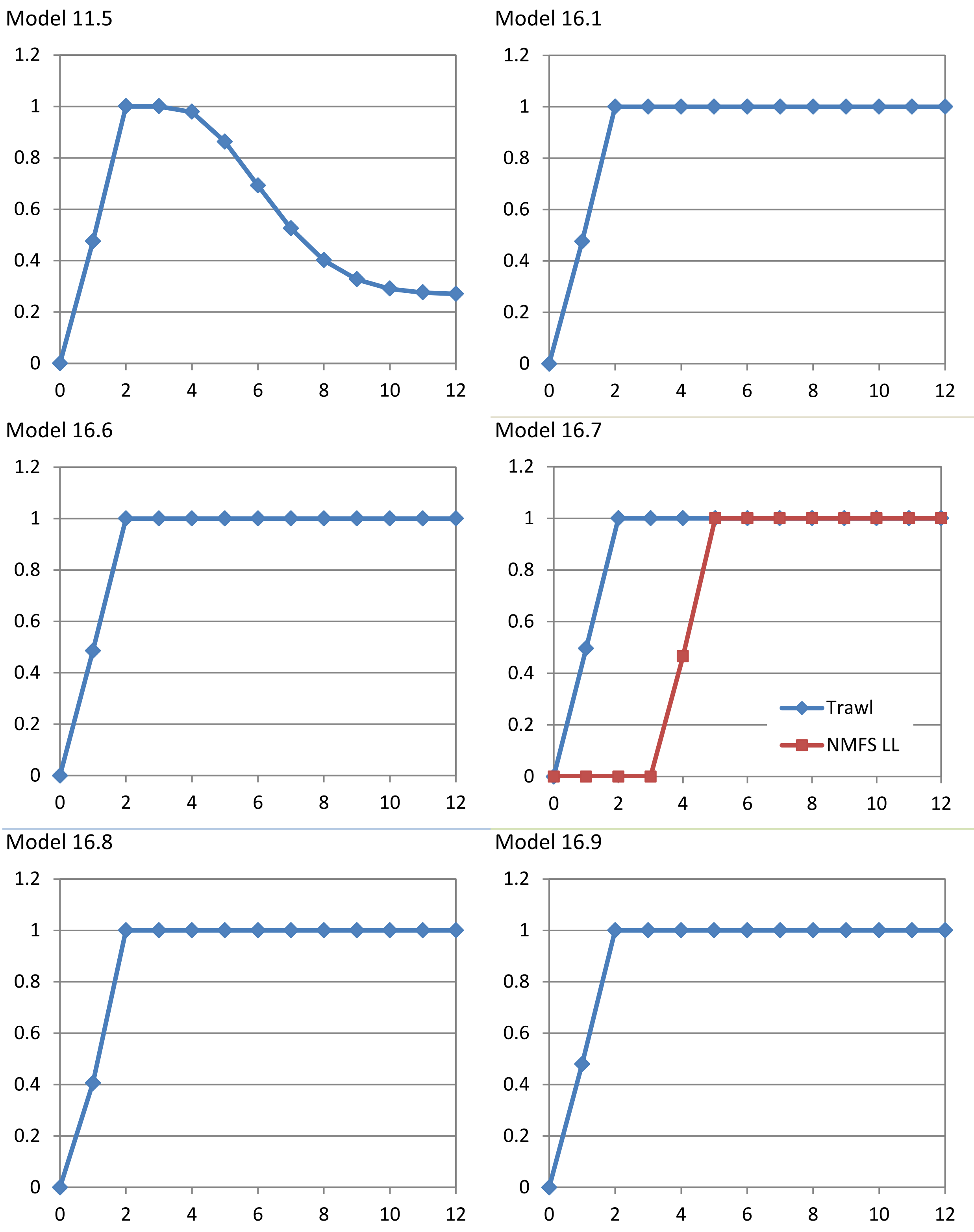
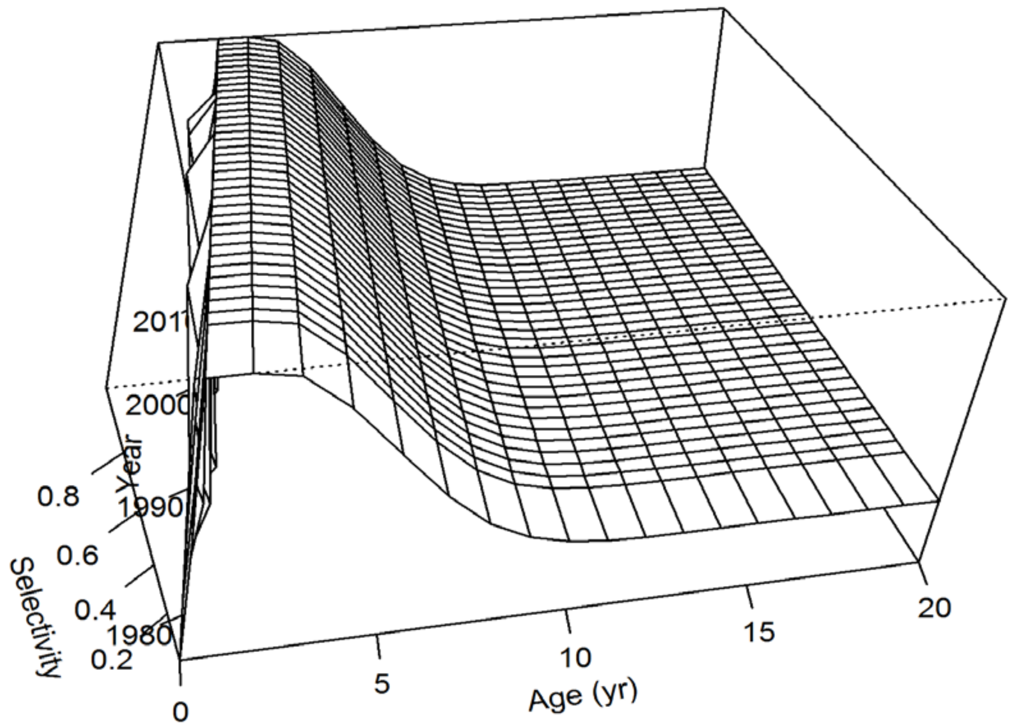


Figure 2.12a—Survey (trawl, unless indicated otherwise) selectivity at age as estimated by the models (base values shown for Models 11.5 and 16.8, which have annually varying selectivity).

Model 11.5



Model 16.8

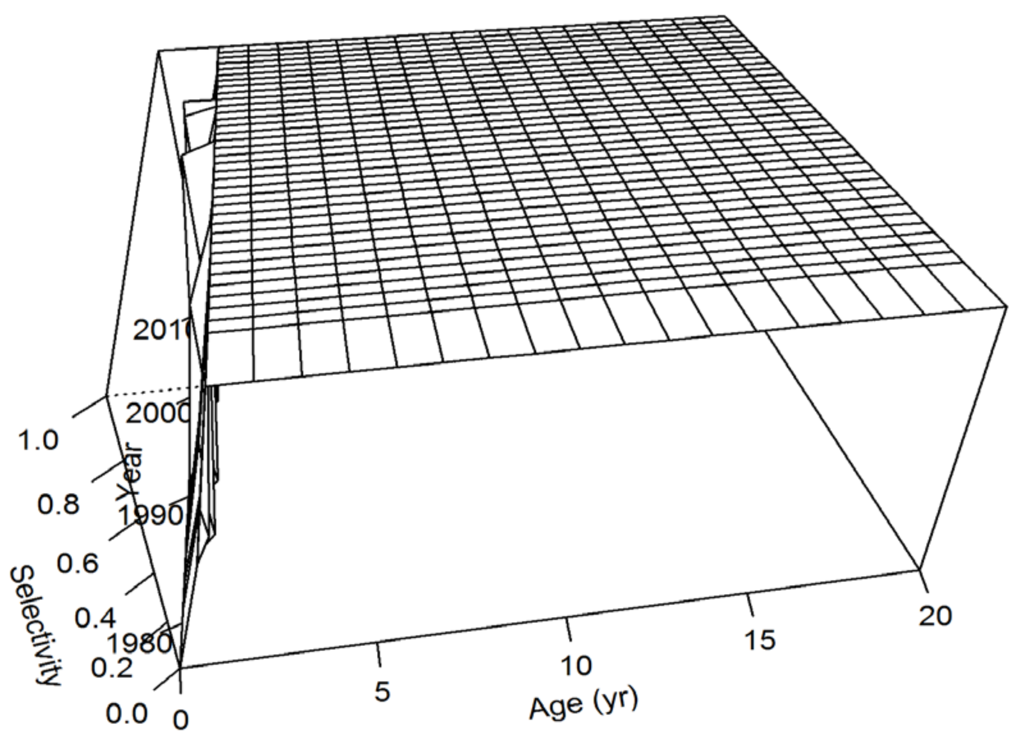


Figure 2.12b—Annually varying trawl survey selectivity for Models 11.5 and 16.8.

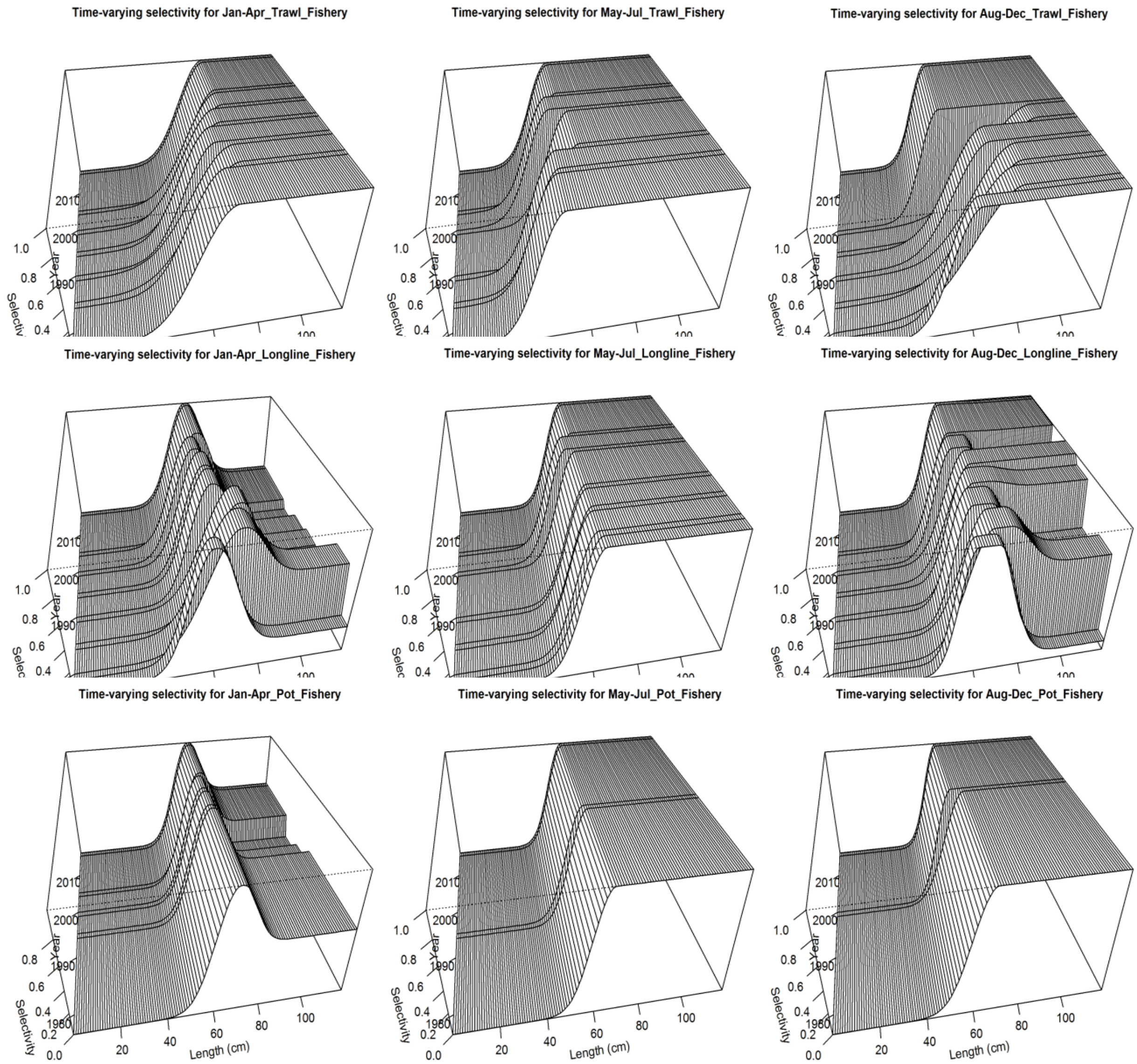


Figure 2.13a—Fishery selectivity at length (cm) as estimated by Model 11.5. Rows represent gear types (trawl, longline, and pot, respectively), and columns represent seasons (Jan-Apr, May-Jul, and Aug-Dec, respectively).

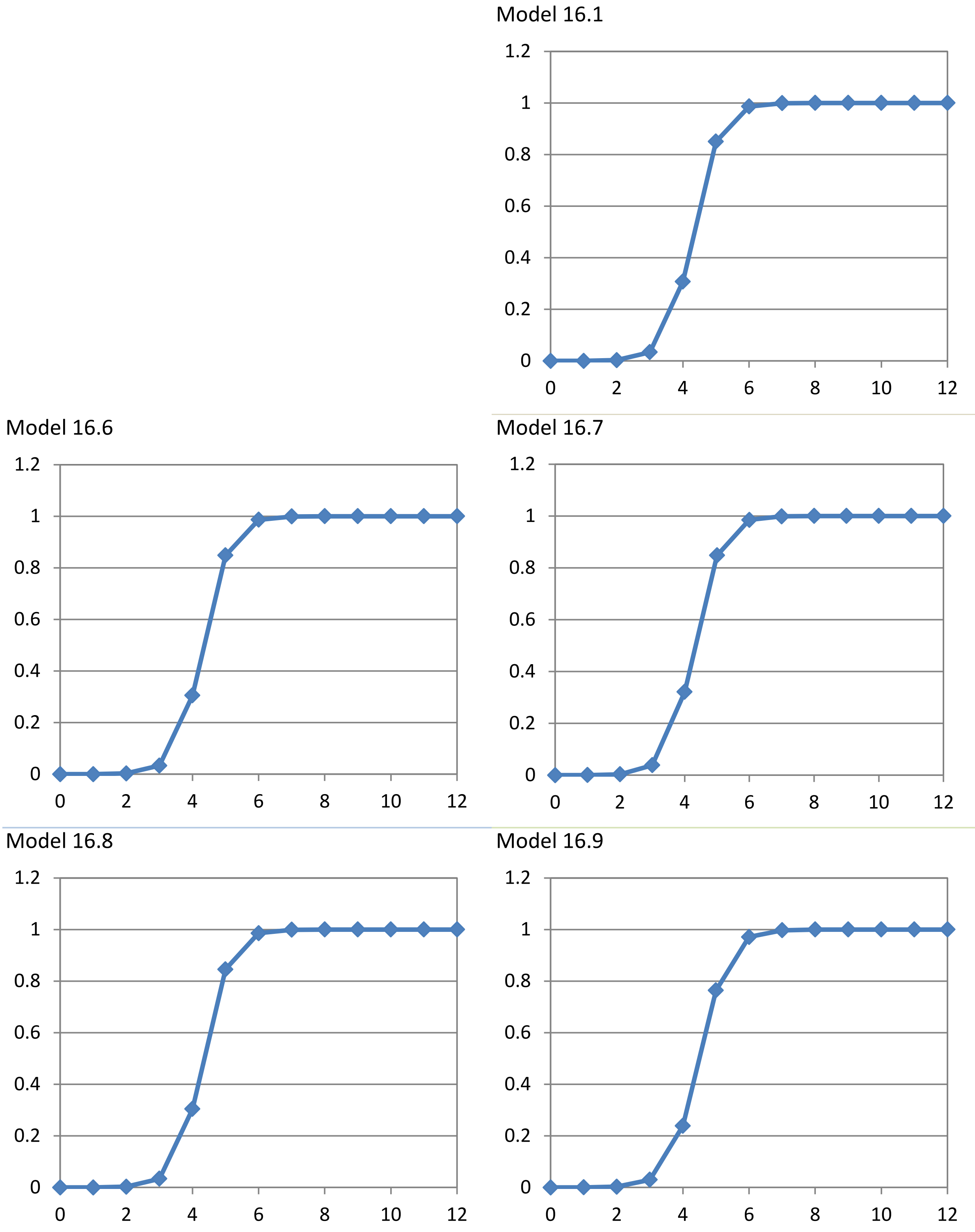


Figure 2.13b—Base fishery selectivity at age as estimated by models in the 16.x series (base values shown for Model 16.9, which has annually varying selectivity).

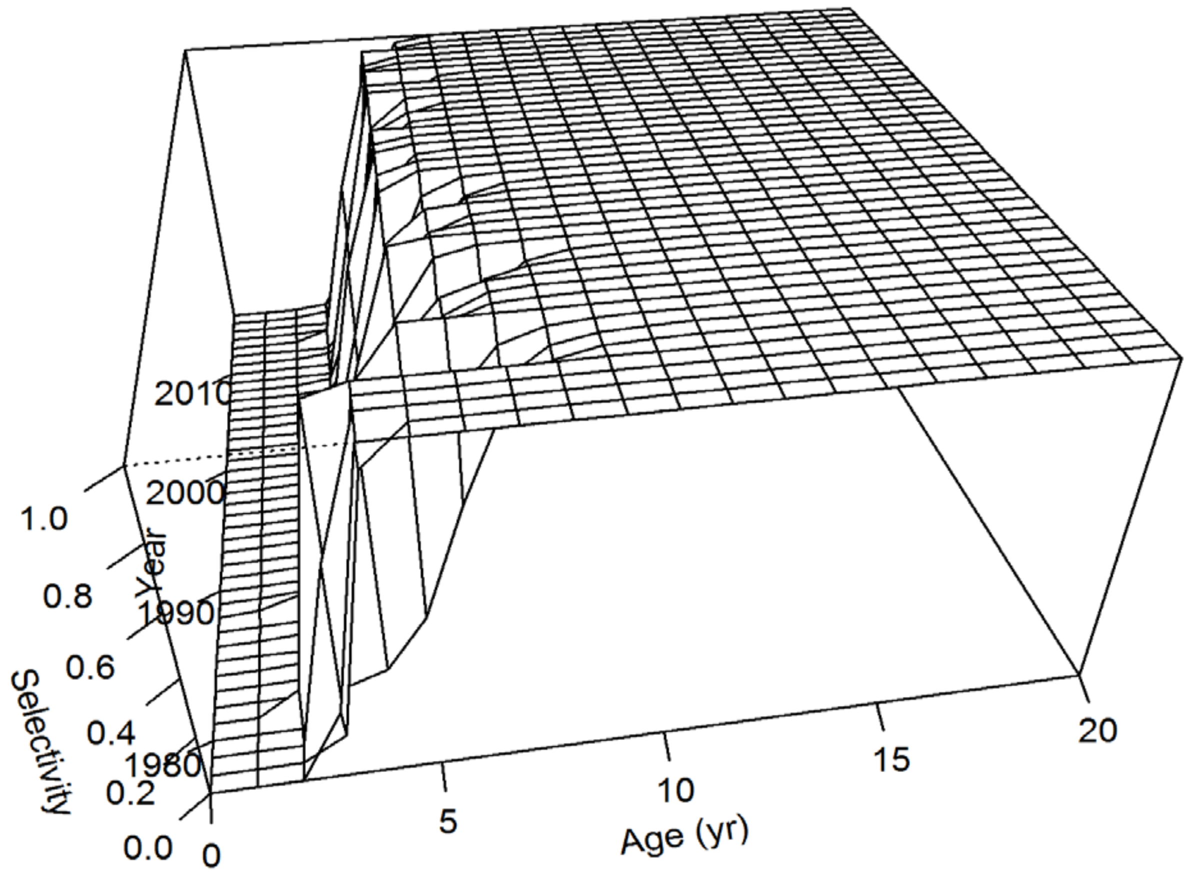


Figure 2.13c—Annually varying trawl survey selectivity for Model 16.9.

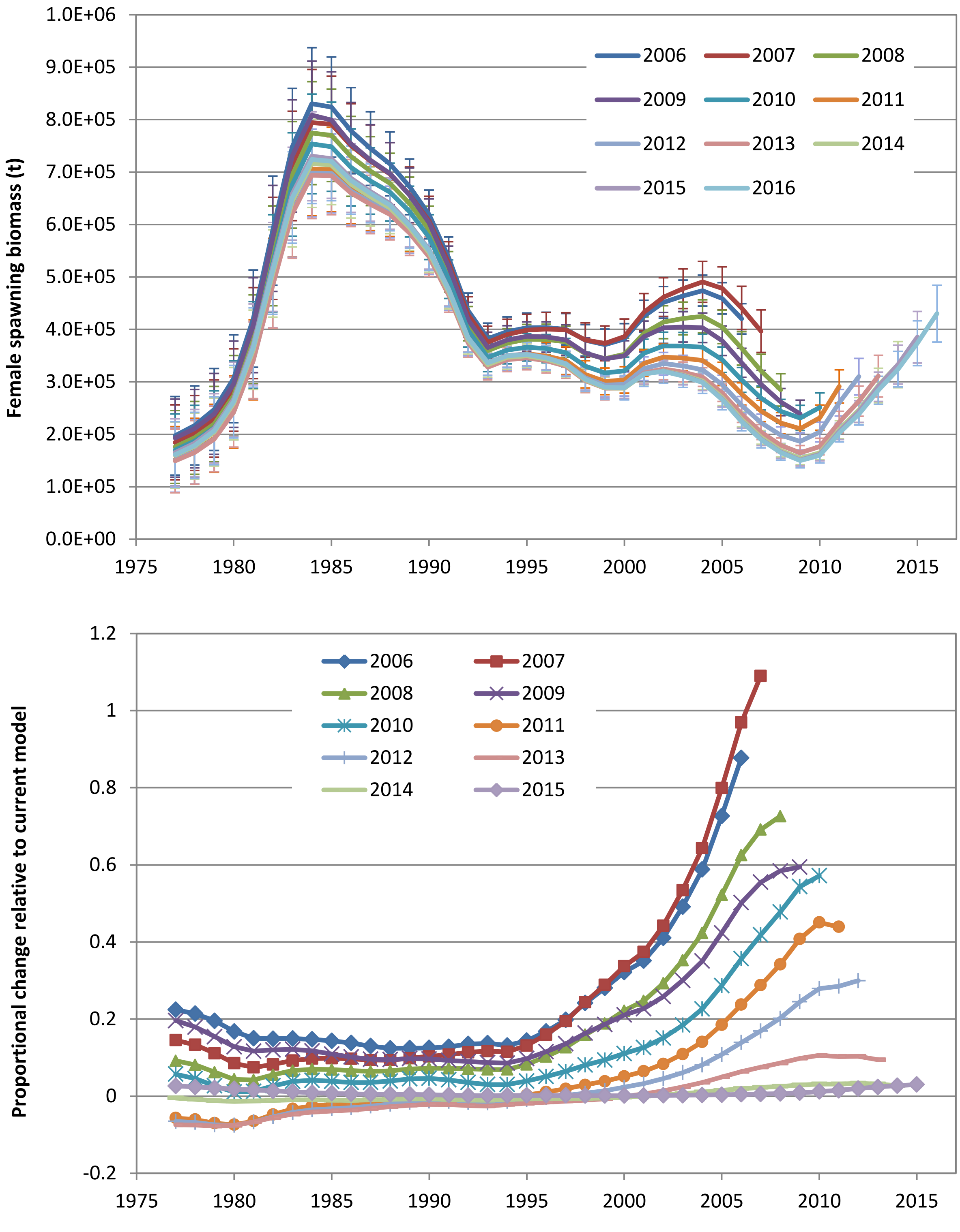
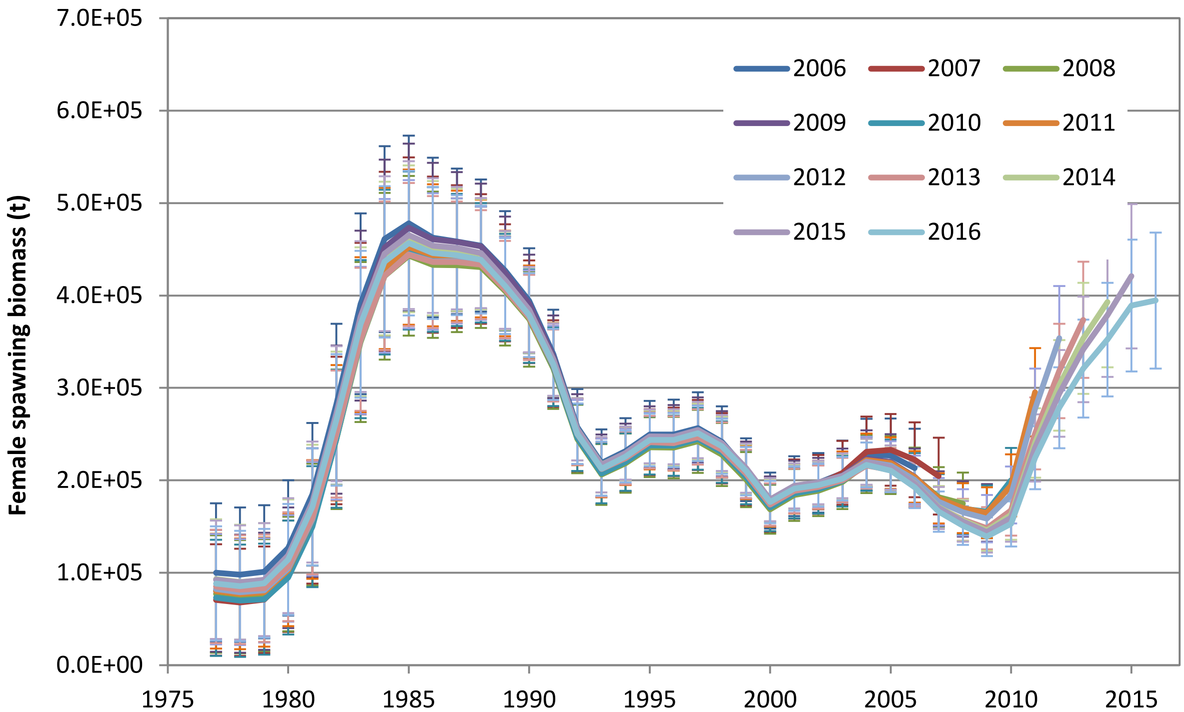


Figure 2.14a—Retrospective analysis of spawning biomass estimates from Model 11.5. Top panel: spawning biomass time series with 95% confidence intervals from the current version of Model 11.5 (2016) and 10 retrospective runs (2006-2015) obtained by dropping one year of data at a time. Bottom panel: change in spawning biomass relative to the current version of Model 11.5 for each of 10 retrospective runs. Mohn's $\rho = 0.475$.



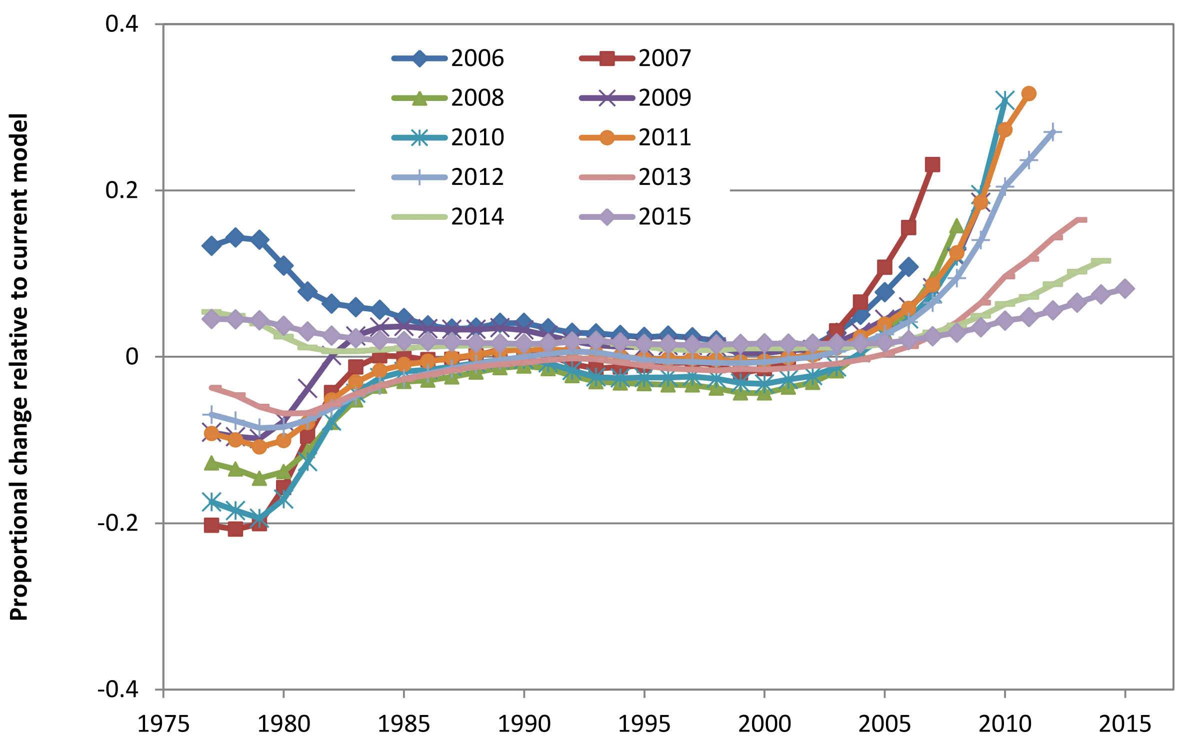
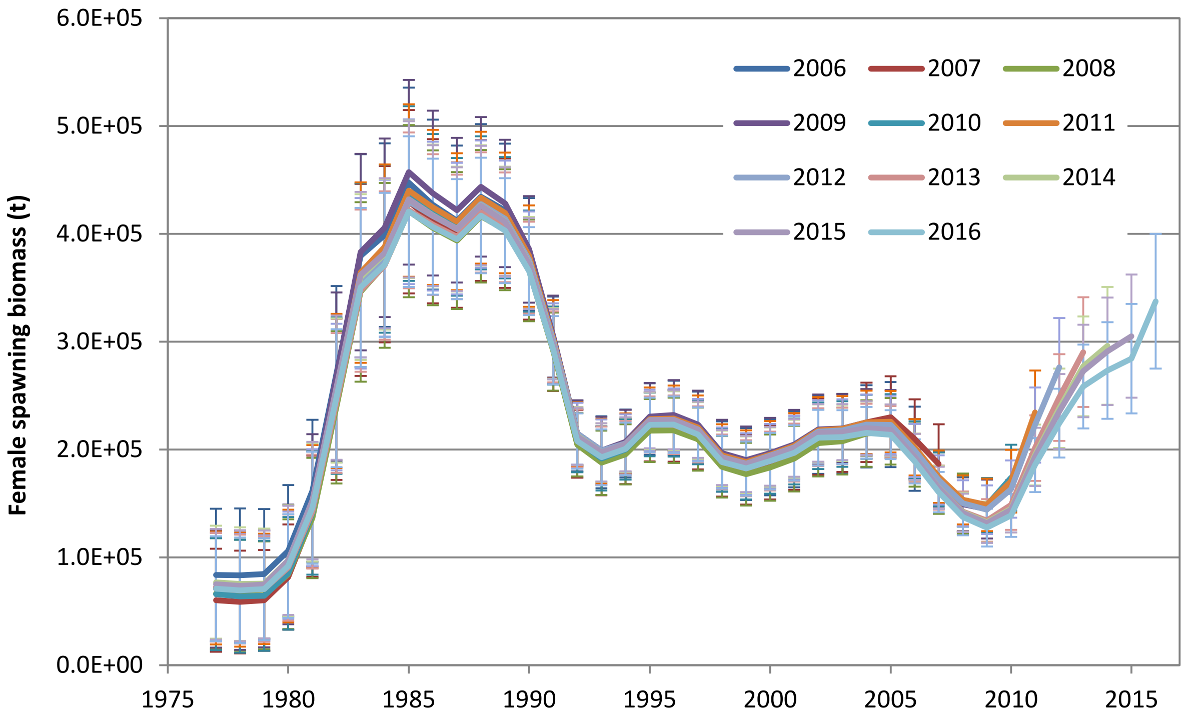


Figure 2.14b—Retrospective analysis of spawning biomass estimates from Model 16.1. Top panel: spawning biomass time series with 95% confidence intervals from the current version of Model 16.1 (2016) and 10 retrospective runs (2006-2015) obtained by dropping one year of data at a time. Bottom panel: change in spawning biomass relative to the current version of Model 16.1 for each of 10 retrospective runs. Mohn's $\rho = 0.194$.



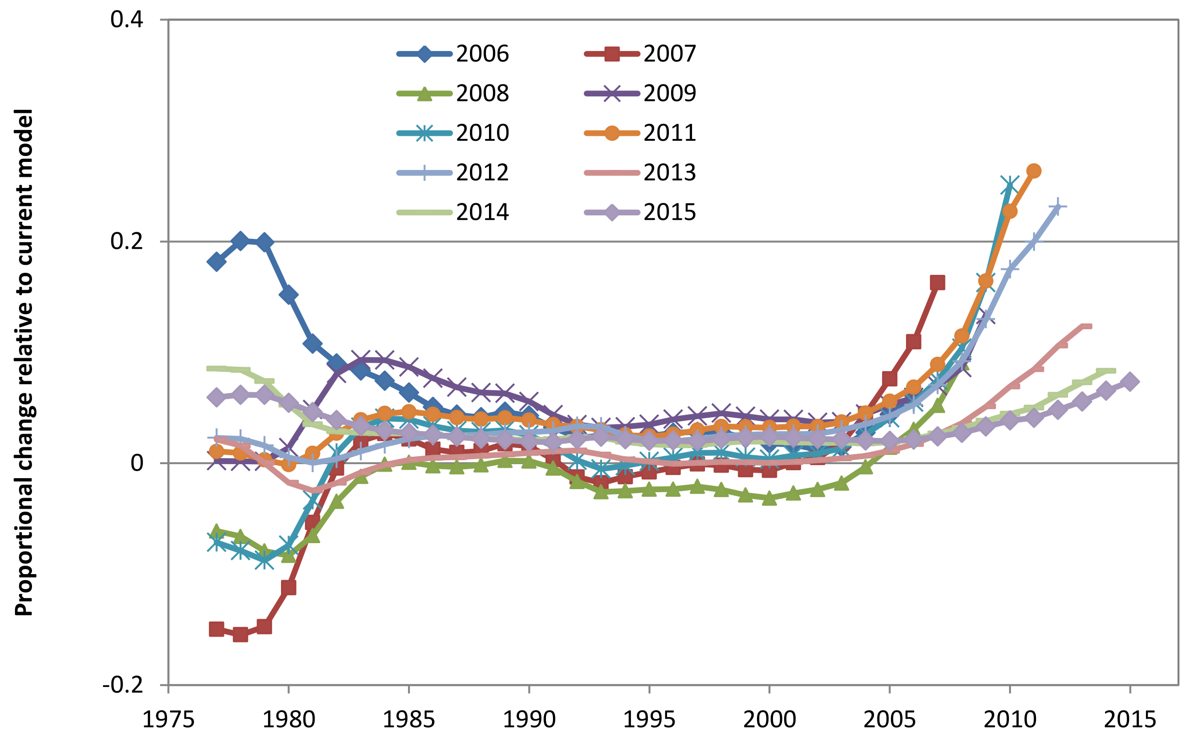


Figure 2.14c—Retrospective analysis of spawning biomass estimates from Model 16.6. Top panel: spawning biomass time series with 95% confidence intervals from the current version of Model 16.6 (2016) and 10 retrospective runs (2006-2015) obtained by dropping one year of data at a time. Bottom panel: change in spawning biomass relative to the current version of Model 16.6 for each of 10 retrospective runs. Mohn's $\rho = 0.147$.

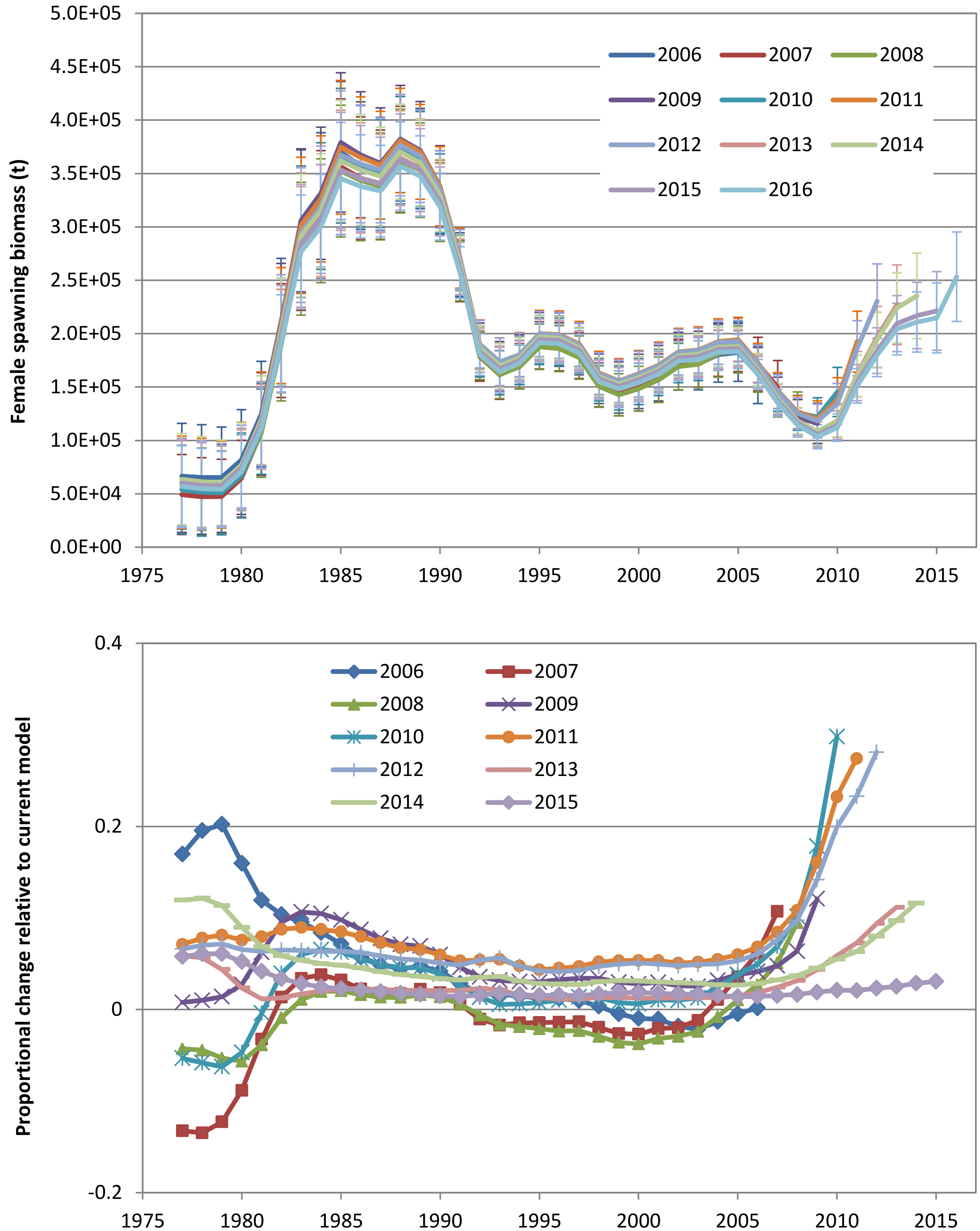


Figure 2.14d—Retrospective analysis of spawning biomass estimates from Model 16.7. Top panel: spawning biomass time series with 95% confidence intervals from the current version of Model 16.7 (2016) and 10 retrospective runs (2006-2015) obtained by dropping one year of data at a time. Bottom panel: change in spawning biomass relative to the current version of Model 16.7 for each of 10 retrospective runs. Mohn's $\rho = 0.144$.

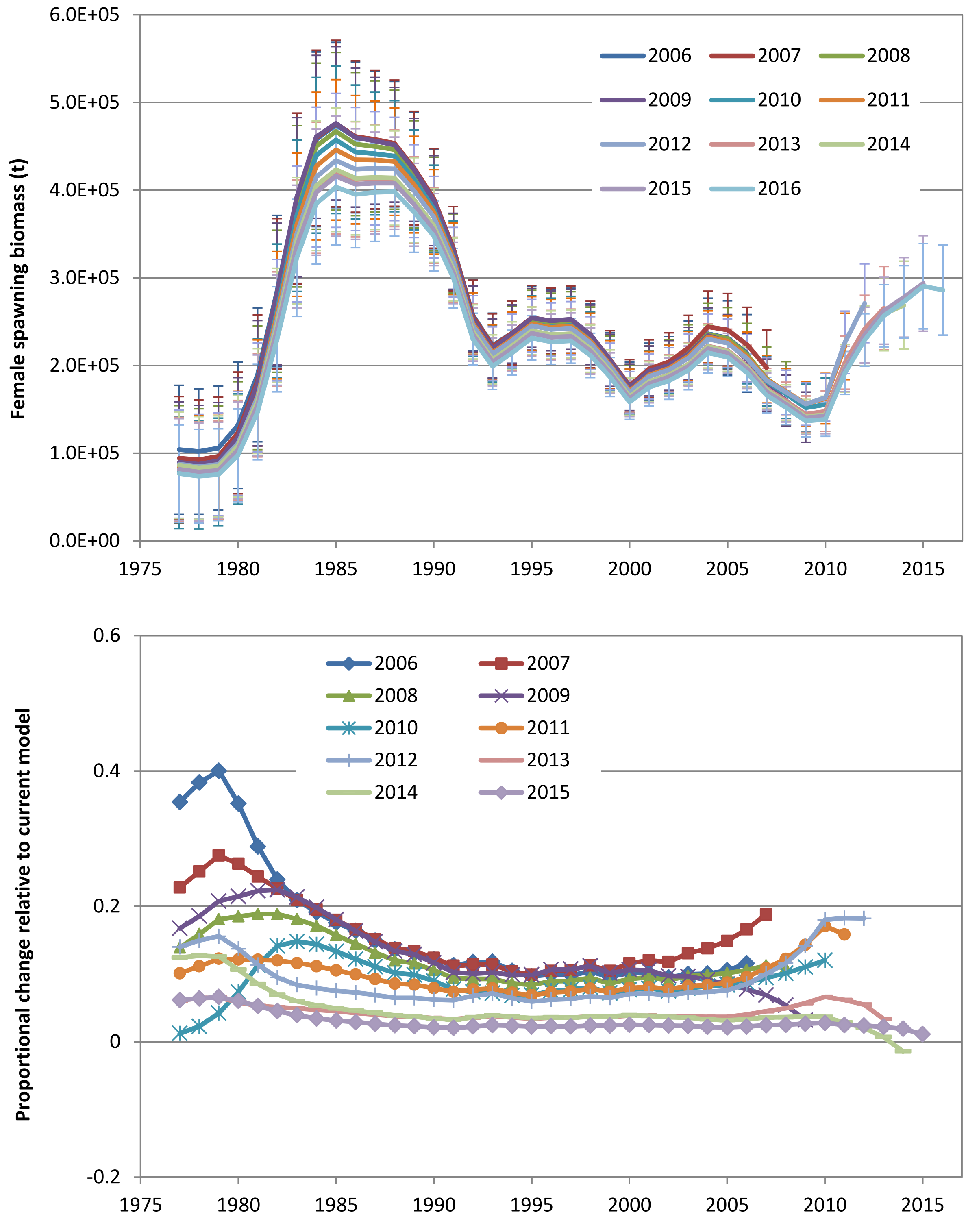


Figure 2.14e—Retrospective analysis of spawning biomass estimates from Model 16.8. Top panel: spawning biomass time series with 95% confidence intervals from the current version of Model 16.8 (2016) and 10 retrospective runs (2006-2015) obtained by dropping one year of data at a time. Bottom panel: change in spawning biomass relative to the current version of Model 16.8 for each of 10 retrospective runs. Mohn's $\rho = 0.094$.

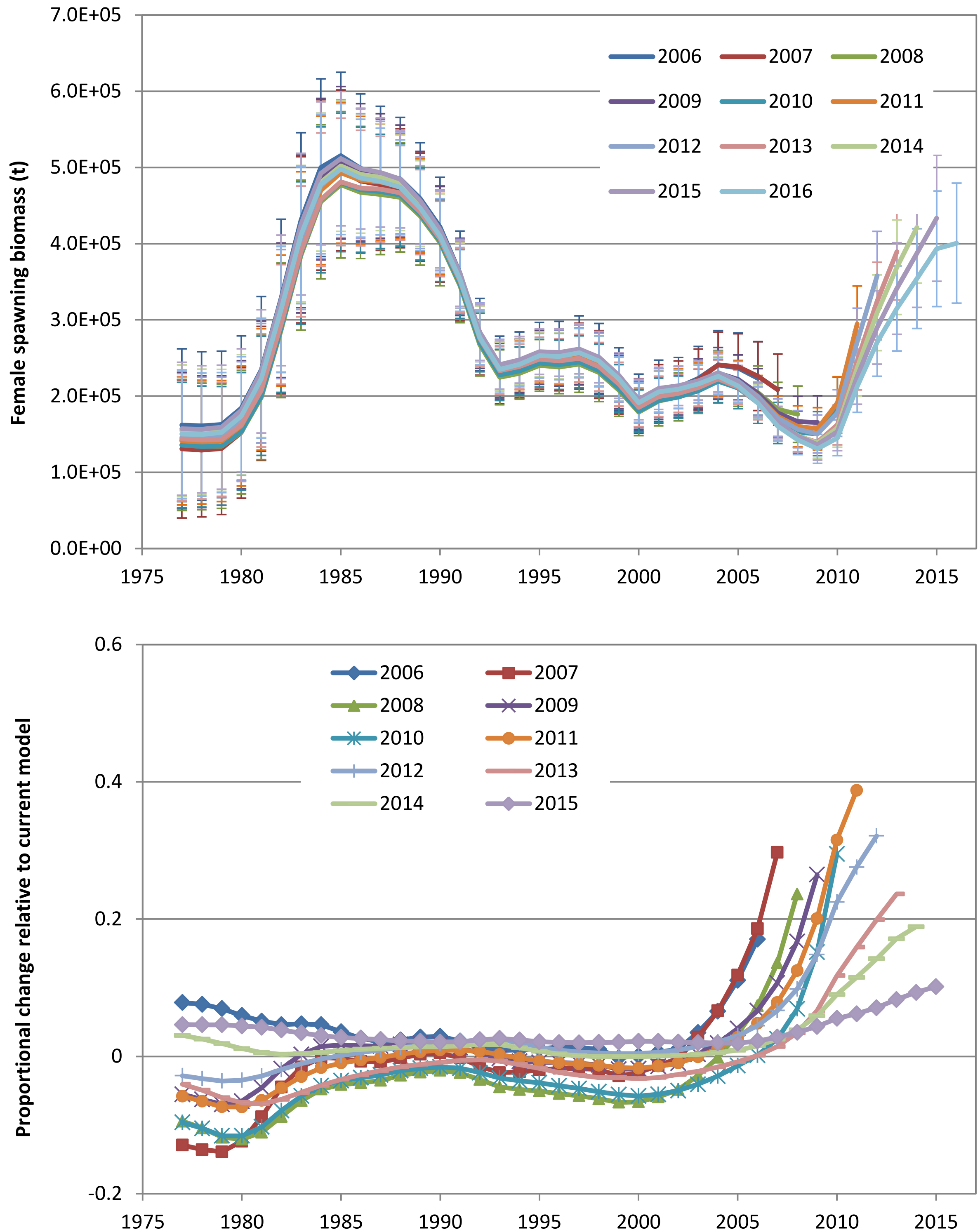


Figure 2.14f—Retrospective analysis of spawning biomass estimates from Model 16.9. Top panel: spawning biomass time series with 95% confidence intervals from the current version of Model 16.9 (2016) and 10 retrospective runs (2006-2015) obtained by dropping one year of data at a time. Bottom panel: change in spawning biomass relative to the current version of Model 16.9 for each of 10 retrospective runs. Mohn's $\rho = 0.250$.

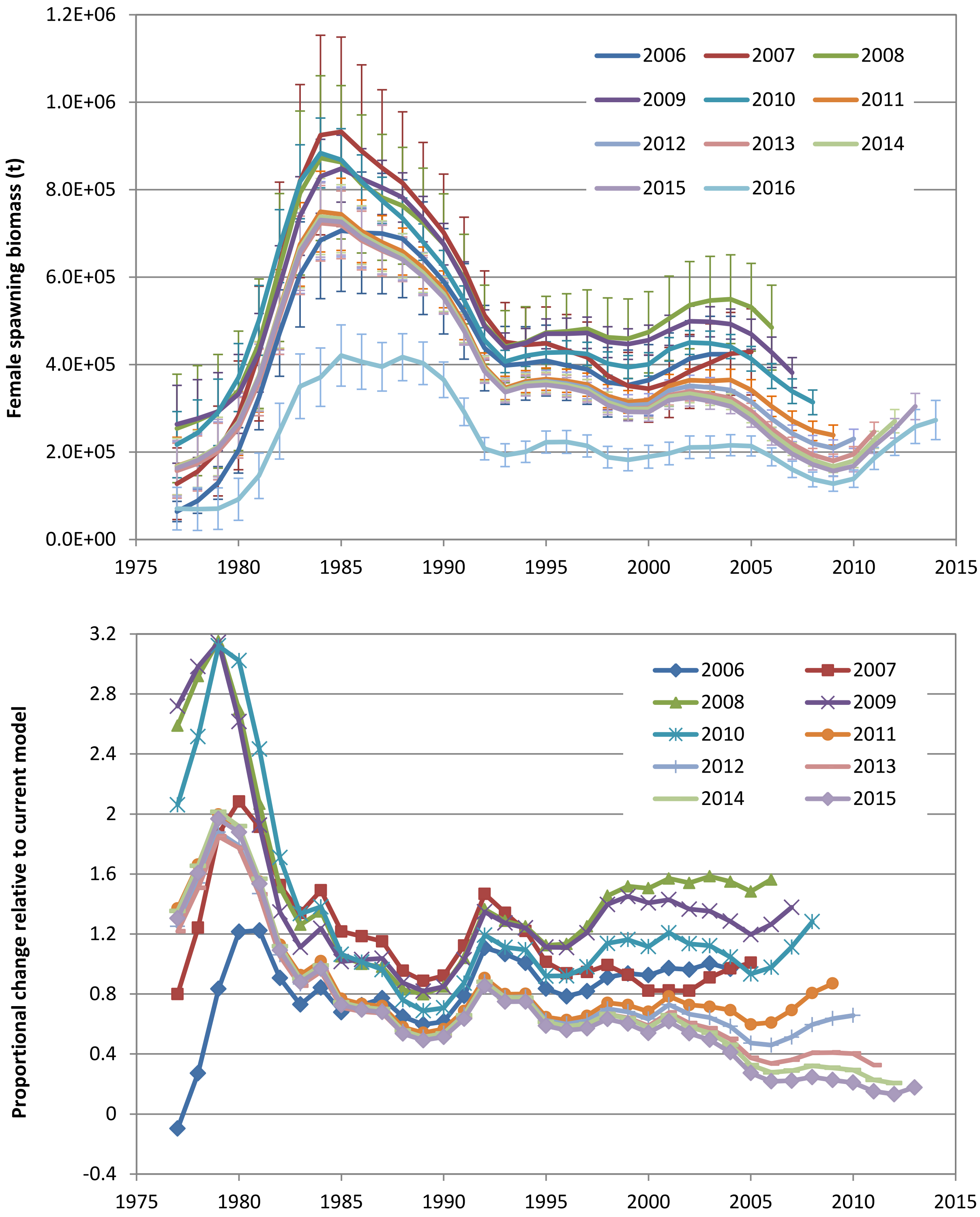


Figure 2.15—Between-assessment retrospective analysis of spawning biomass estimates. Top panel: spawning biomass time series with 95% confidence intervals from each of the final models in the assessments from 2006-2016 (assuming that Model 16.6 is adopted as the final model this year). Bottom panel: change in spawning biomass relative to this year's final model for the final model from each of the 10 previous assessments. Mohn's $\rho = 0.885$.

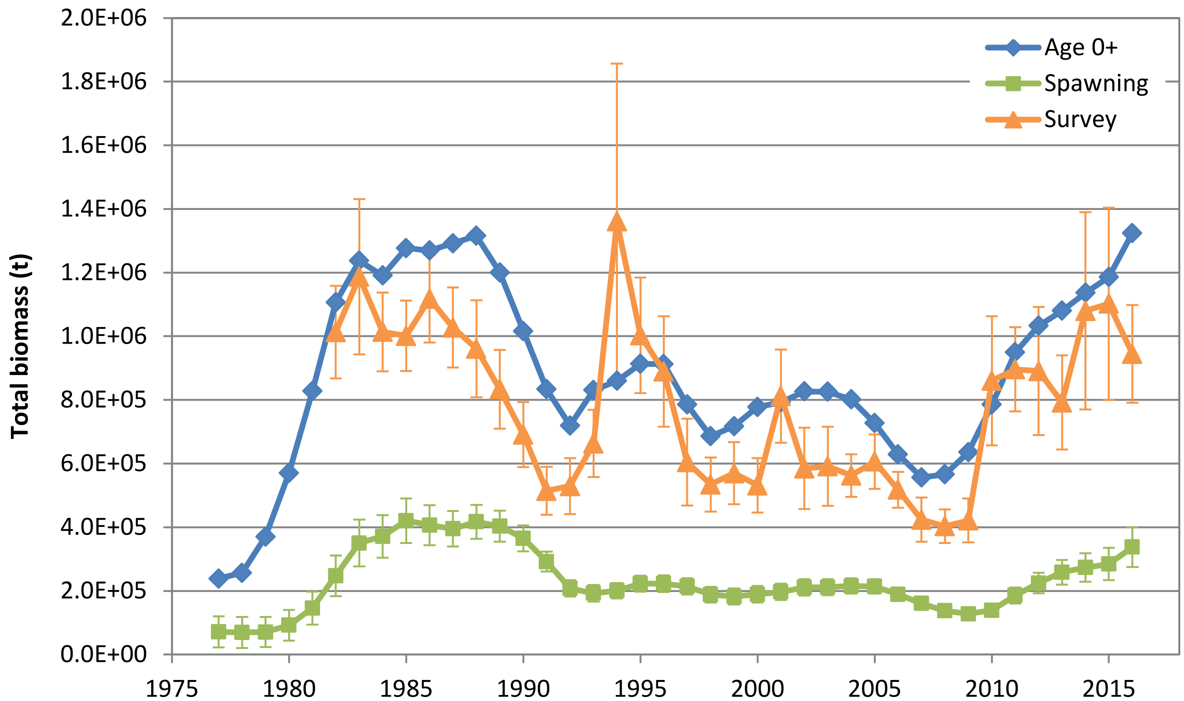


Figure 2.16—Time series of age 0+ and female spawning biomass as estimated by Model 16.6. Survey biomass is shown for comparison.

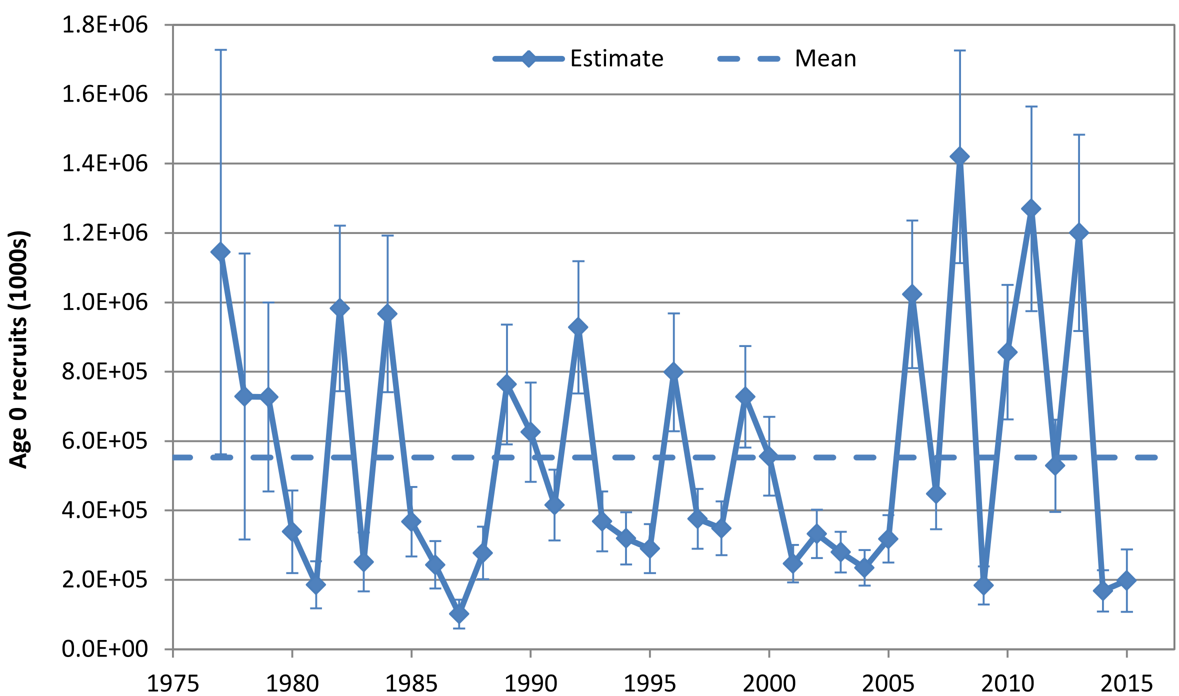


Figure 2.17—Time series of recruitment at age 0 as estimated Model 16.6.

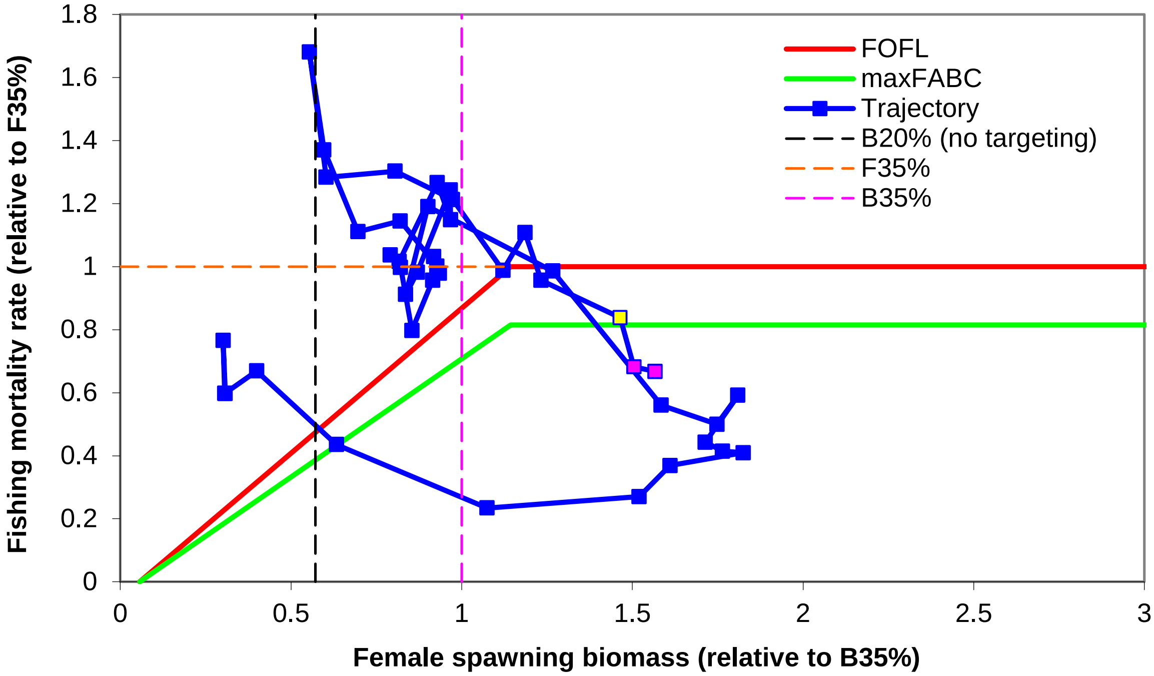


Figure 2.18—Trajectory of Pacific cod fishing mortality and female spawning biomass as estimated by Model 16.6, 1977-2018 (yellow square = current year, magenta squares = first two projection years).

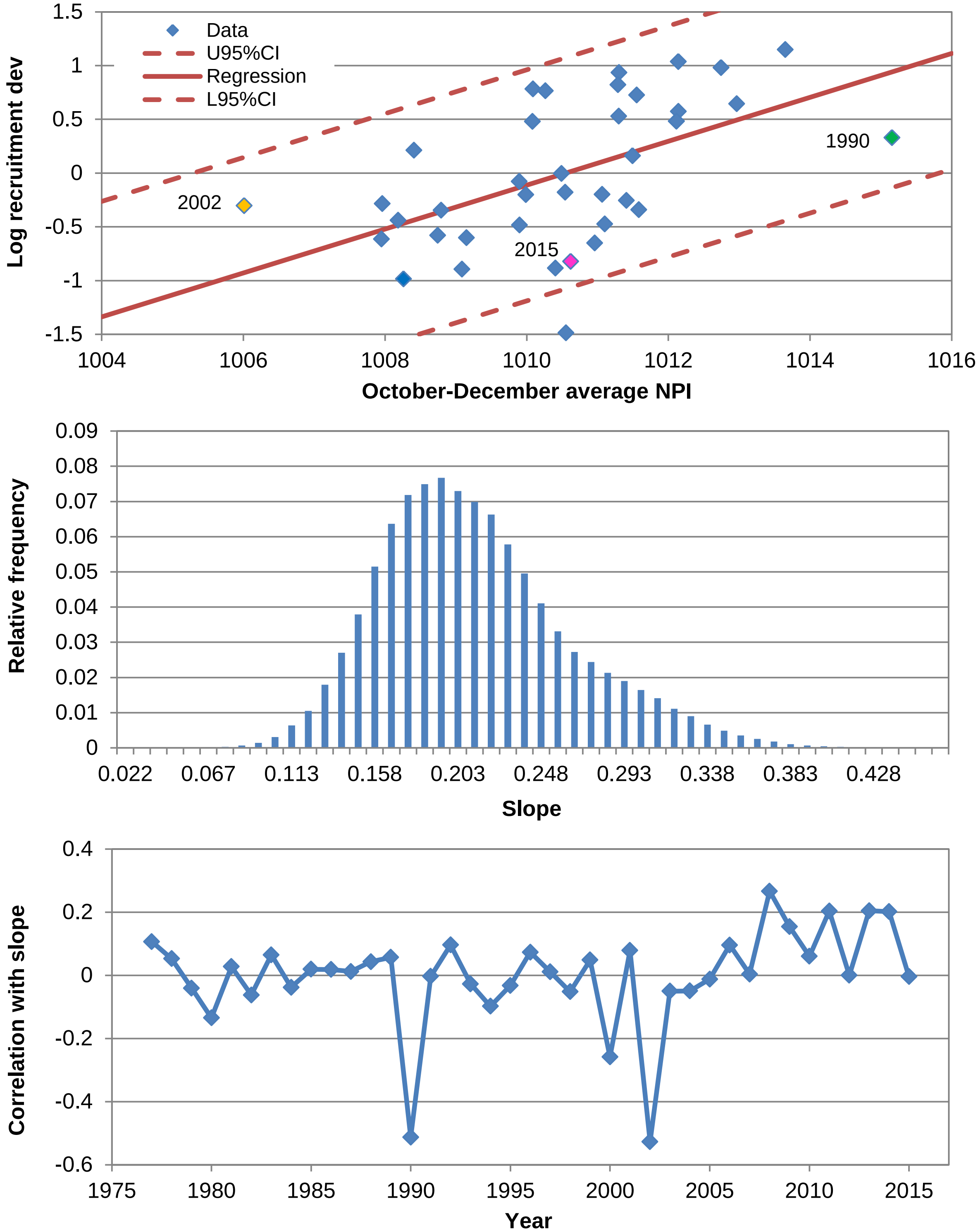


Figure 2.19—Environmental effects on recruitment. Upper panel: Estimated log recruitment *dev*s (age 0) versus same-year October-December average of the NPI, with regression line and 95% confidence interval. Middle panel: Distribution of the regression slope, as generated by a cross-validation analysis. Lower panel: Correlation between individual data points and regression slope. See text for details.

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:

6. 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).
7. 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.
8. The fishery age data come primarily from the longline fishery, and may not be representative of the overall fishery.
9. 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://www.st.nmfs.noaa.gov/Assets/science_program/SS_User_Manual_3.24s.pdf.

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):

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

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, 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:

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

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 15.6 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:

4. The model was re-run starting from the final parameter file from the best jitter run.
5. The resulting new control file, with the parameter estimates from the best jitter run incorporated as starting values, became the new base run.

6. 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:
    1. *beginning_of_peak_region* (where the curve first reaches a value of 1.0)
    2. *width_of_peak_region* (where the curve first departs from a value of 1.0)
    3. *ascending_width* (equal to twice the variance of the underlying normal distribution)
    4. *descending_width* (equal to twice the variance of the underlying normal distribution)
    5. *initial_selectivity* (at minimum length/age)
    6. *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.

<u>Iterative tuning of prior distributions for selectivity parameters</u>

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.

<u>Iterative tuning of time-varying catchability</u>

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.

<u>Iterative tuning of time-varying parameters other than catchability</u>

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.

Model	Sizecomp multinomial sample size multipliers			
	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

Model	Agecomp multinomial sample size multipliers			
	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

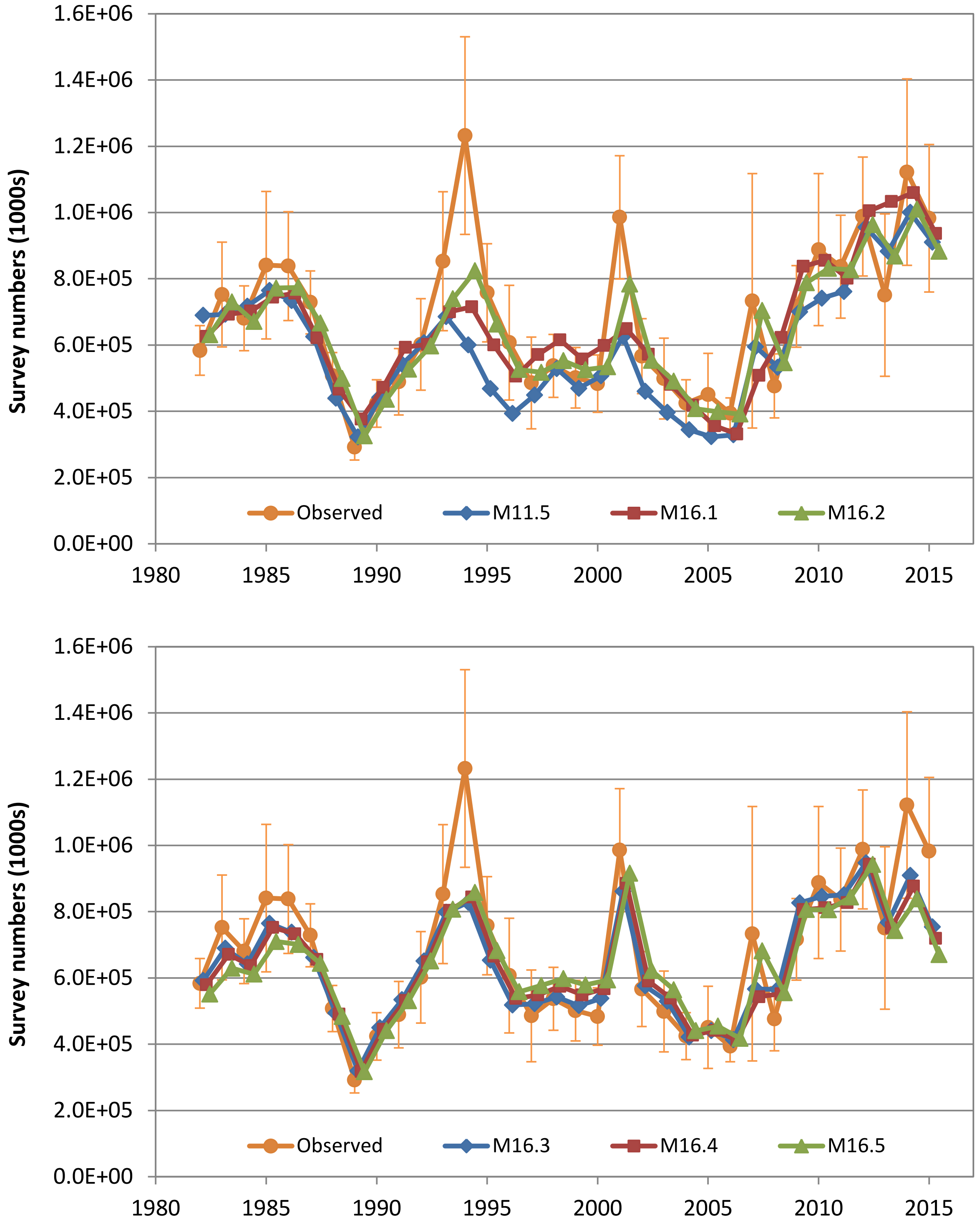


Figure 2.1.1a—Model fits to the trawl survey abundance time series. Upper panel: Models 11.5, 16.1, and 16.2. Lower panel: Models 16.3-16.5. Survey time series shows 95% confidence interval.

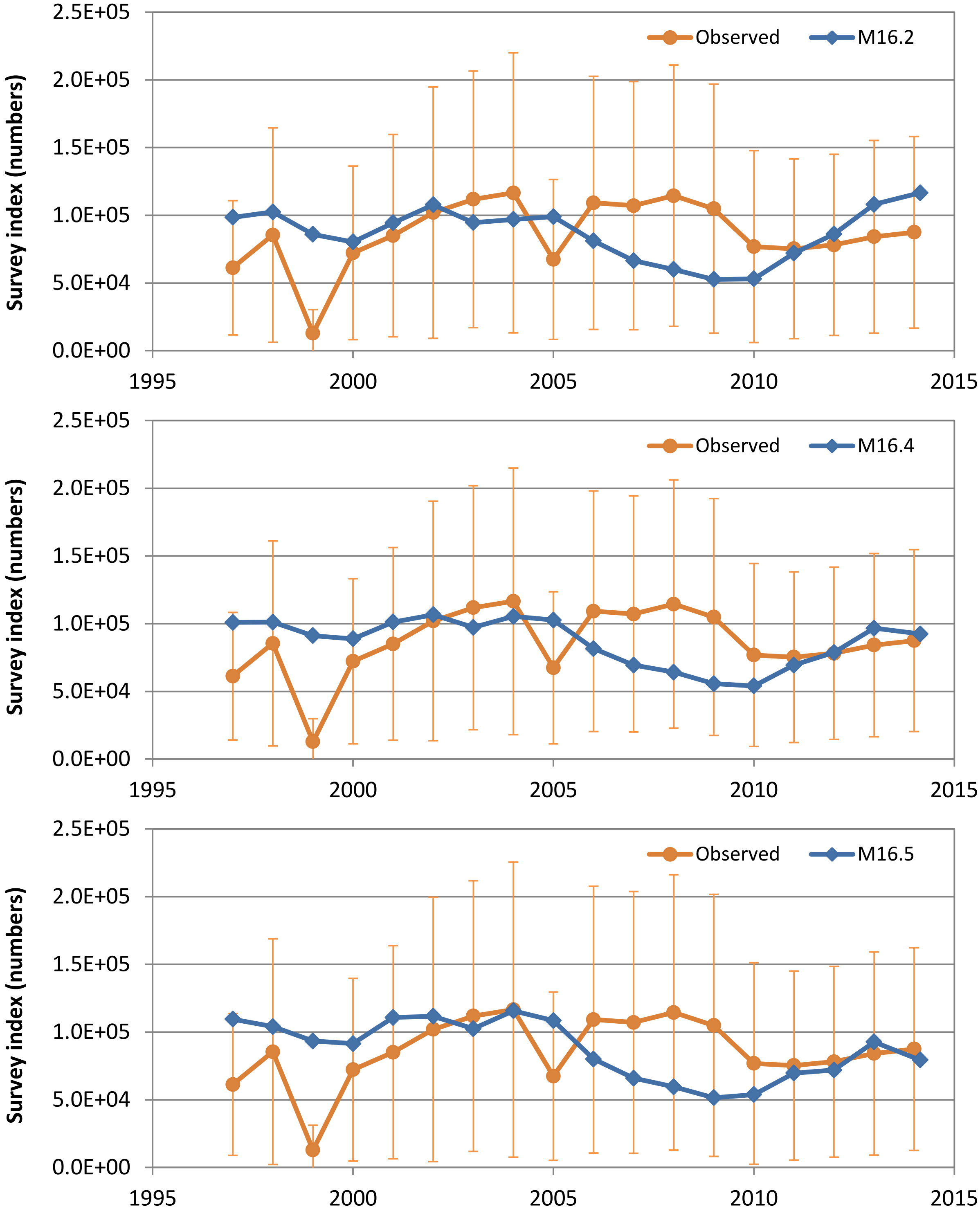


Figure 2.1.1b—Model fits to the IPHC longline survey abundance time series (Models 16.2, 16.4, and 16.5 only). Survey time series shows 95% confidence interval, which differs between models.

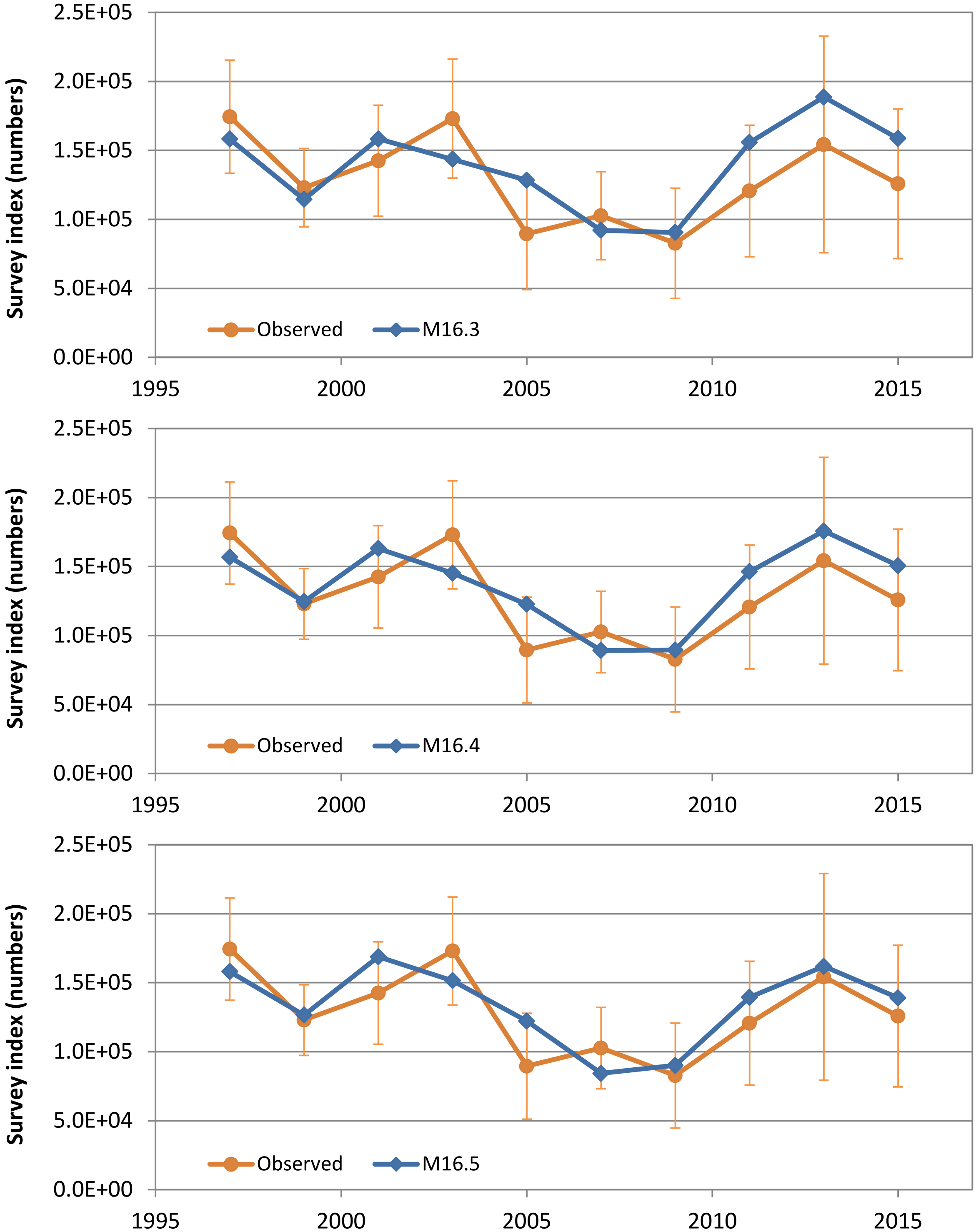


Figure 2.1.1c—Model fits to the NMFS longline survey abundance time series (Models 16.3, 16.4, and 16.5 only). Survey time series shows 95% confidence interval, which differs between models.

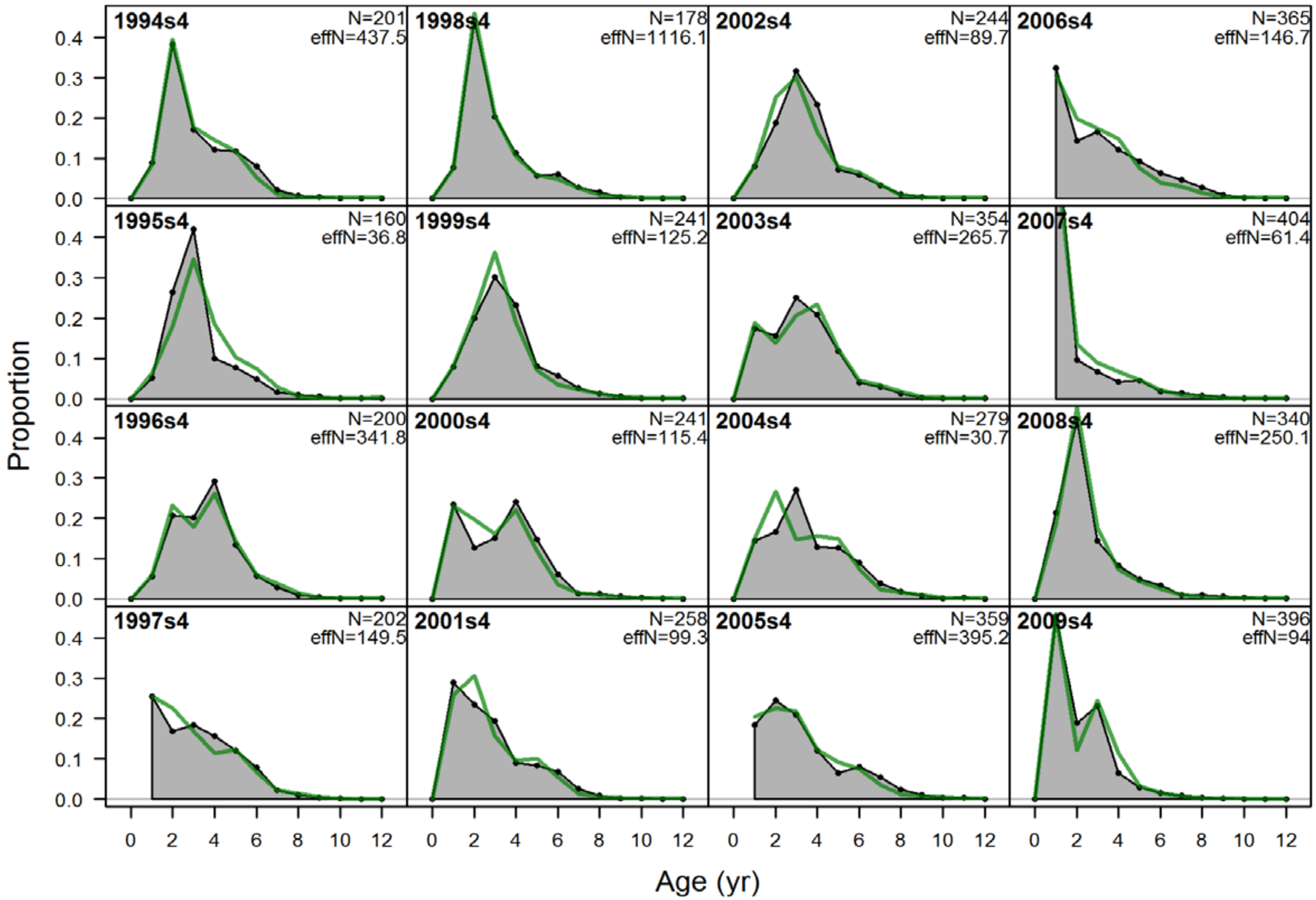


Figure 2.1.2a—Model 11.5 fits to trawl survey age composition data (page 1 of 2).

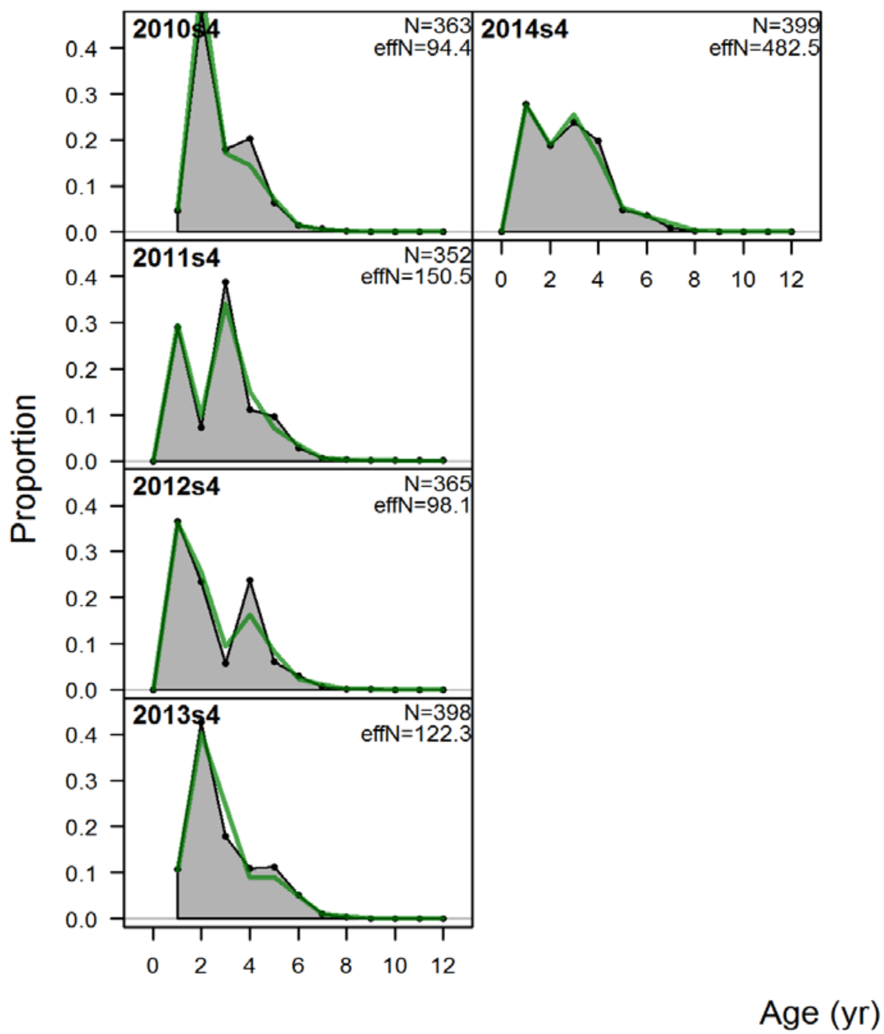


Figure 2.1.2a—Model 11.5 fits to trawl survey age composition data (page 2 of 2).

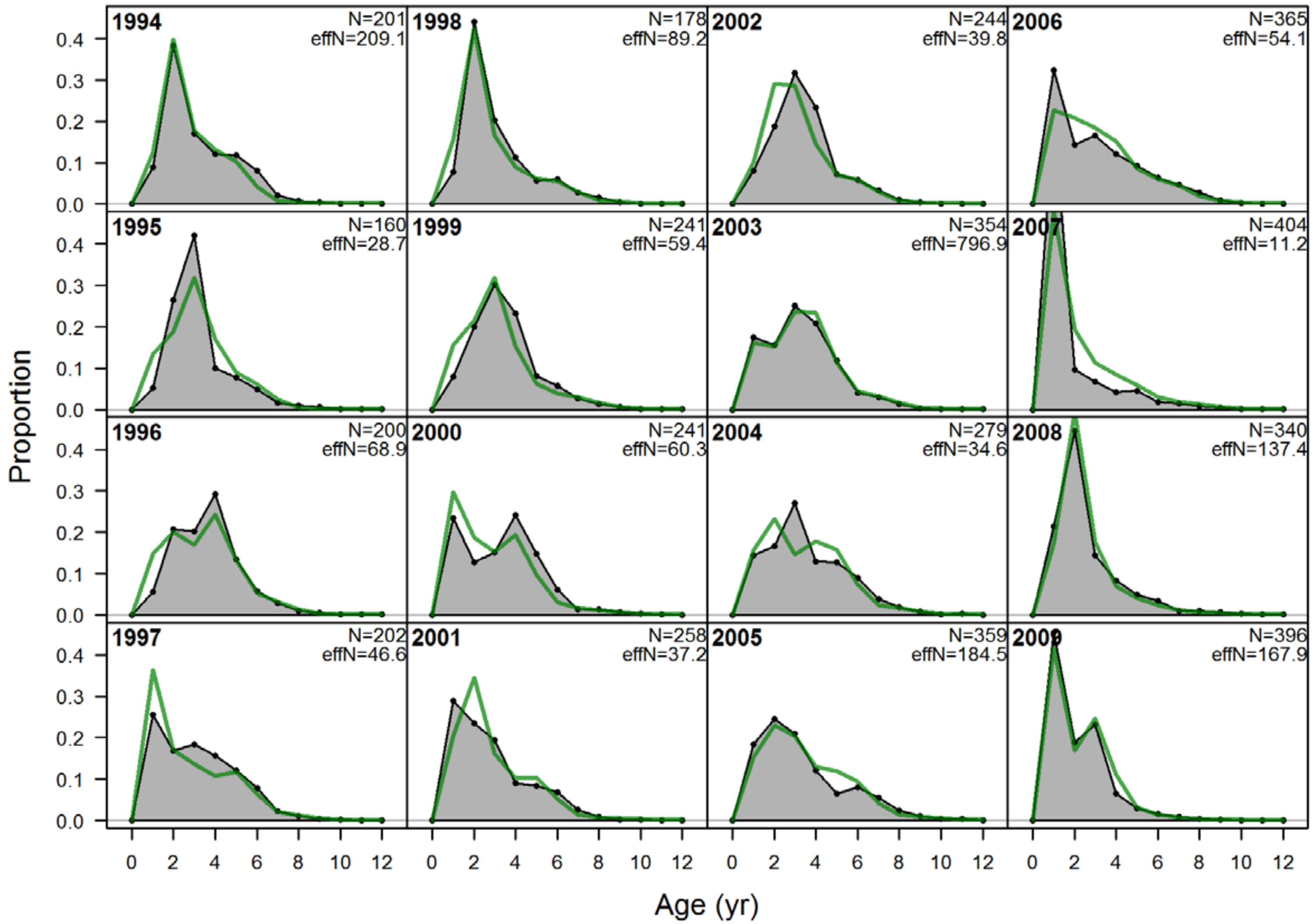


Figure 2.1.2b—Model 16.1 fits to trawl survey age composition data (page 1 of 2).

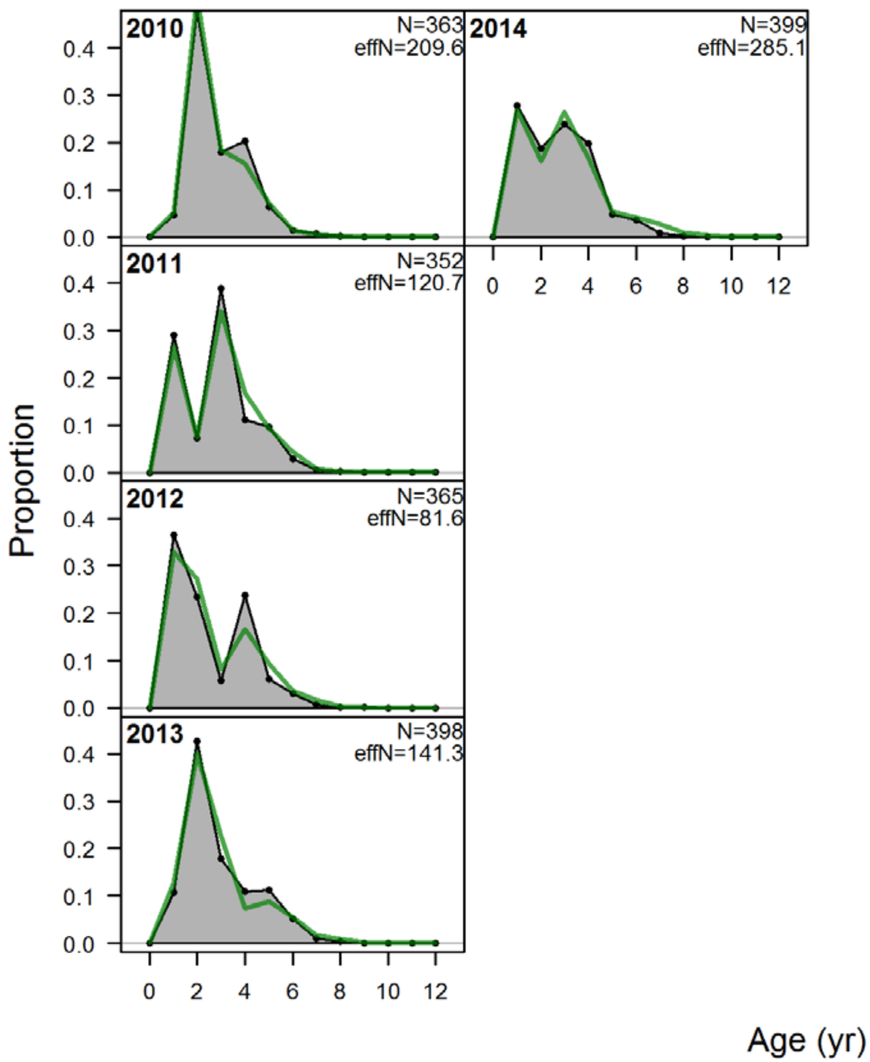


Figure 2.1.2b—Model 16.1 fits to trawl survey age composition data (page 2 of 2).

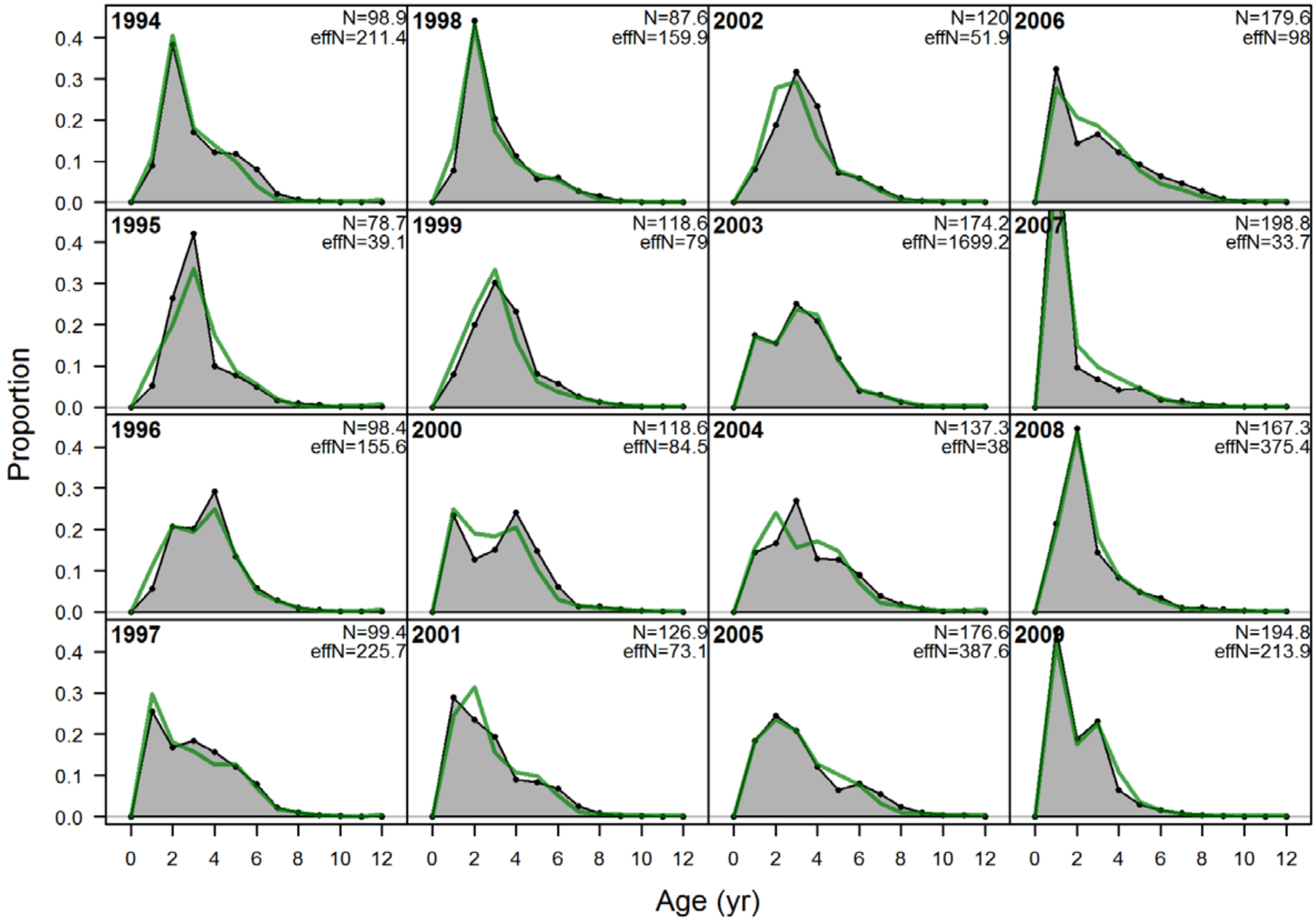


Figure 2.1.2c—Model 16.2 fits to trawl survey age composition data (page 1 of 2).

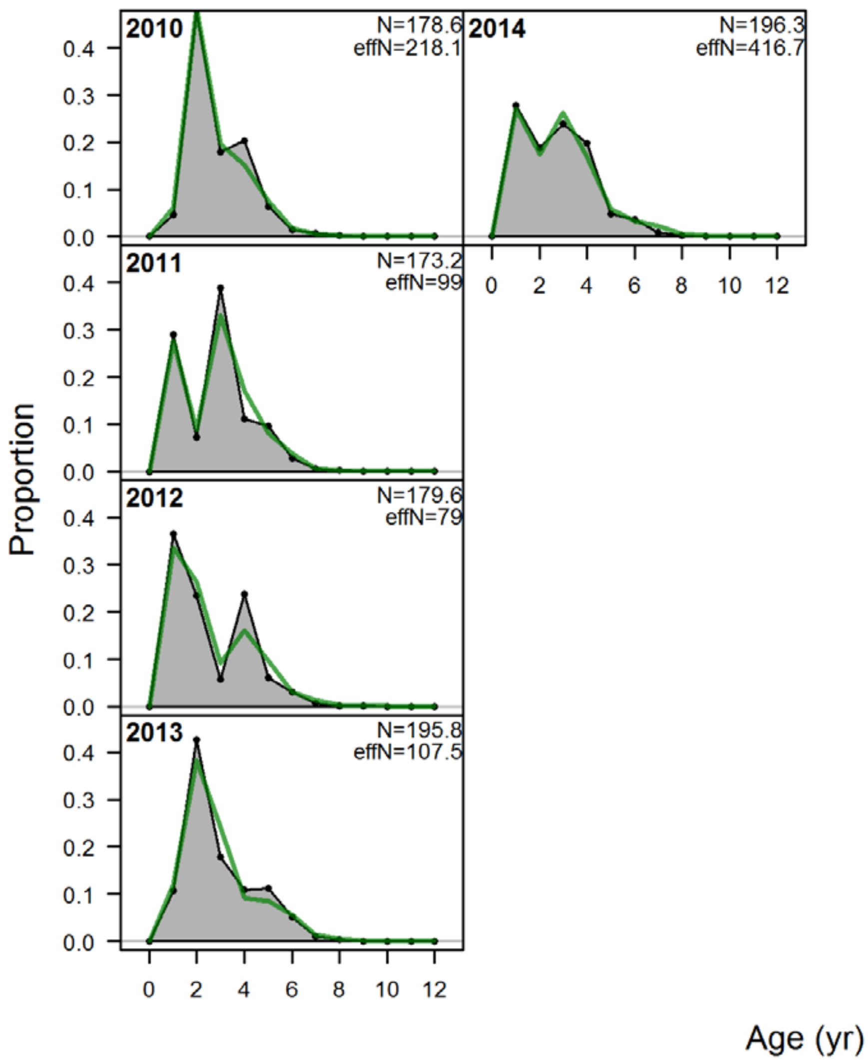


Figure 2.1.2c—Model 16.2 fits to trawl survey age composition data (page 2 of 2).

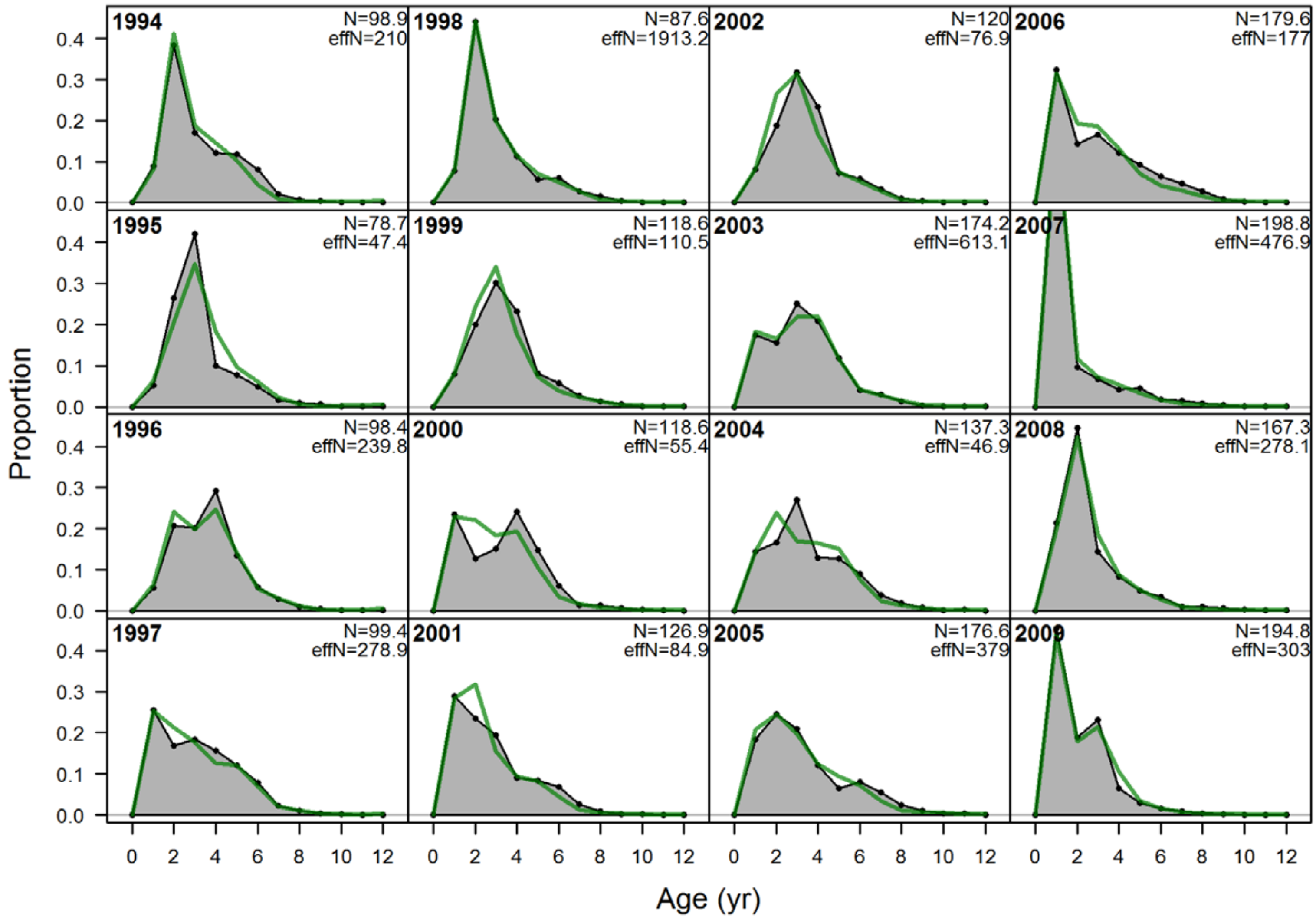


Figure 2.1.2d—Model 16.3 fits to trawl survey age composition data (page 1 of 2).

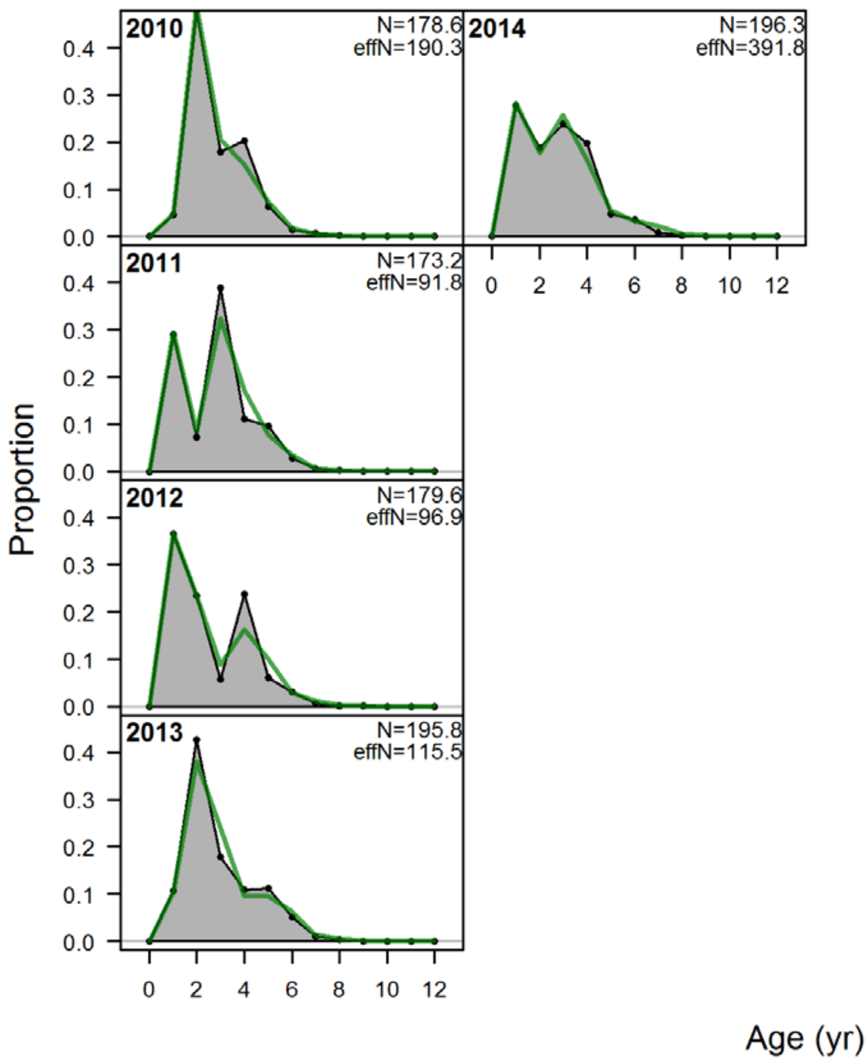


Figure 2.1.2d—Model 16.3 fits to trawl survey age composition data (page 2 of 2).

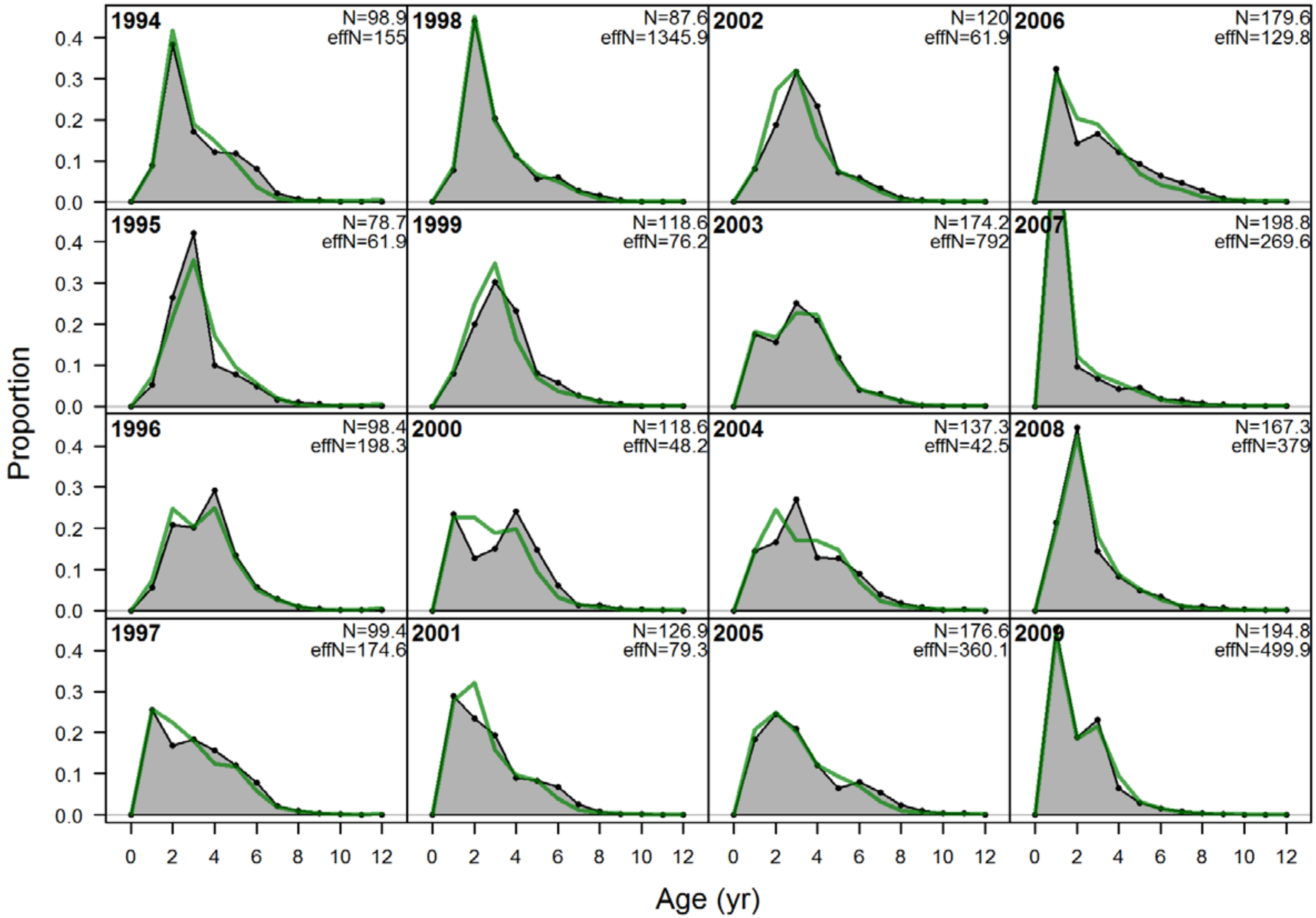


Figure 2.1.2e—Model 16.4 fits to trawl survey age composition data (page 1 of 2).

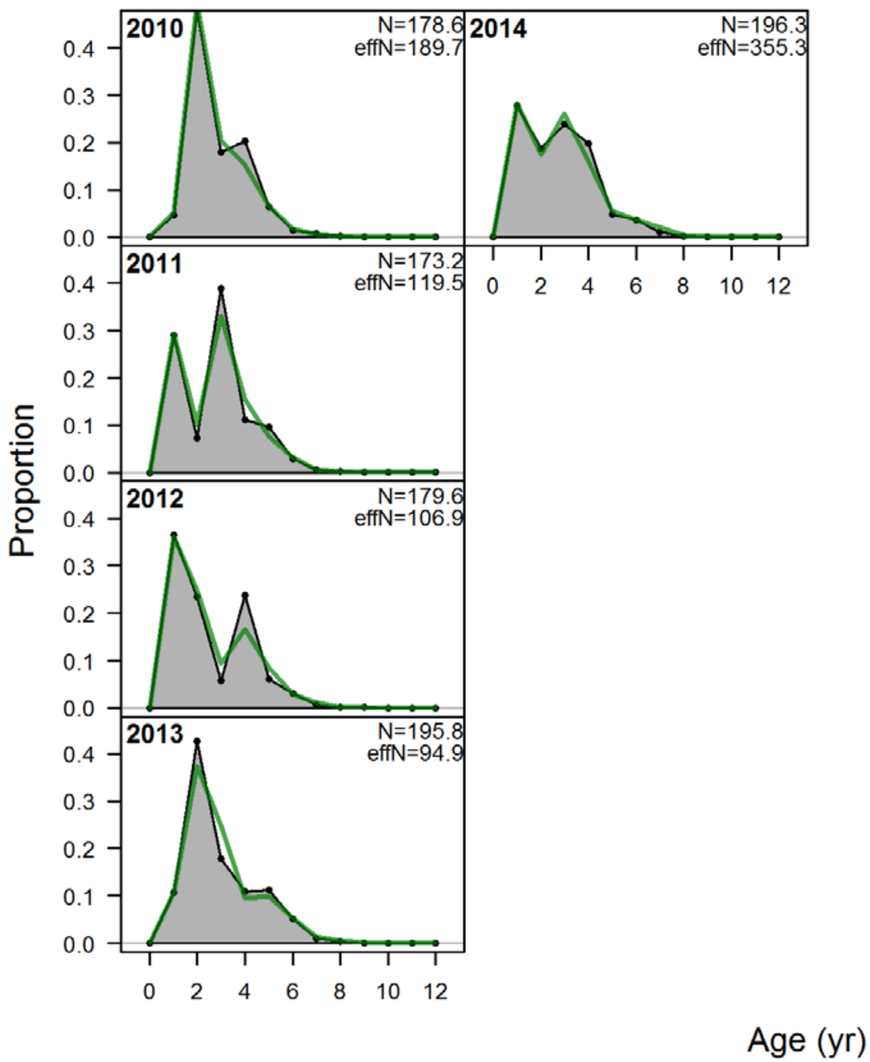


Figure 2.1.2e—Model 16.4 fits to trawl survey age composition data (page 2 of 2).

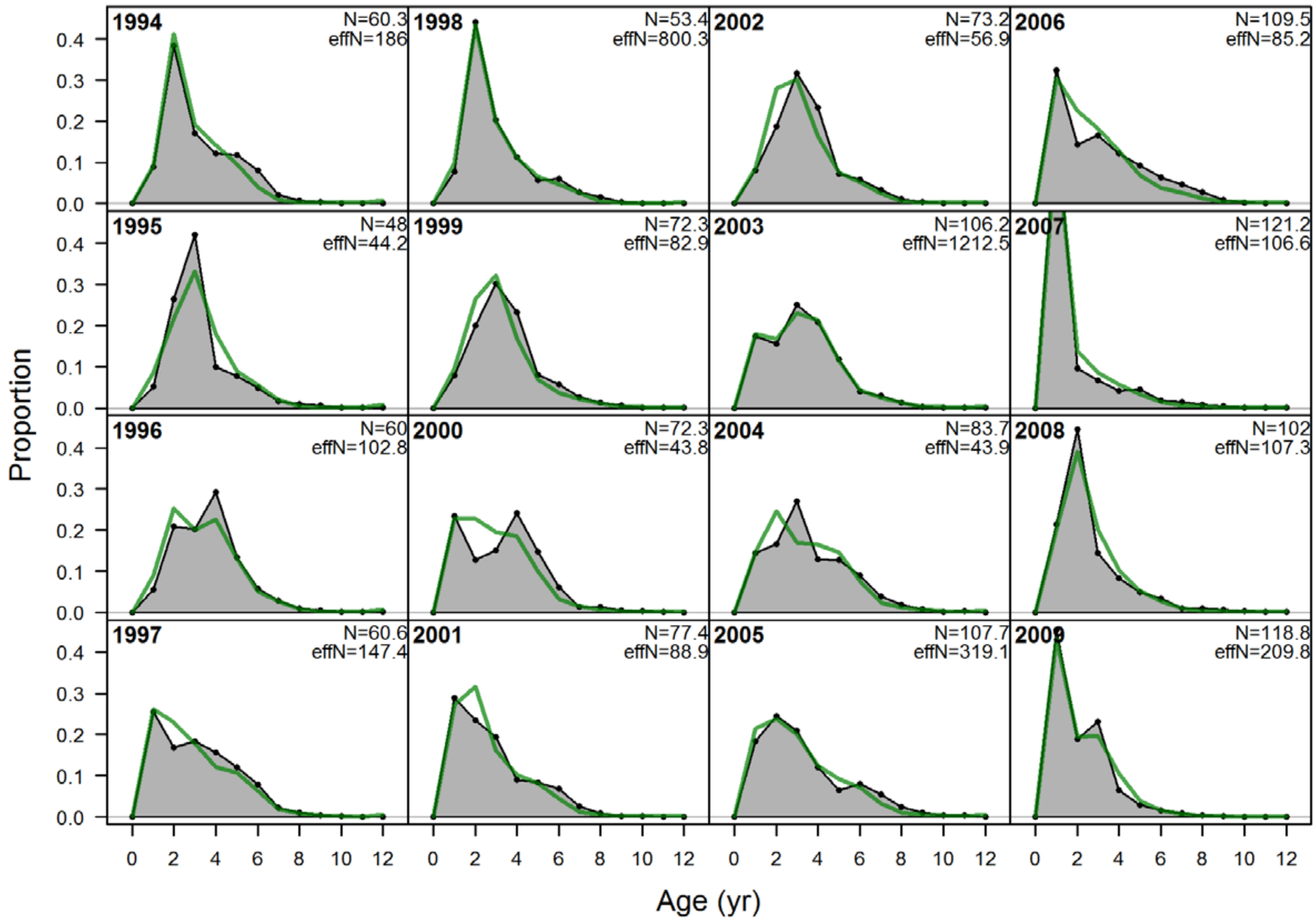


Figure 2.1.2f—Model 16.5 fits to trawl survey age composition data (page 1 of 2).

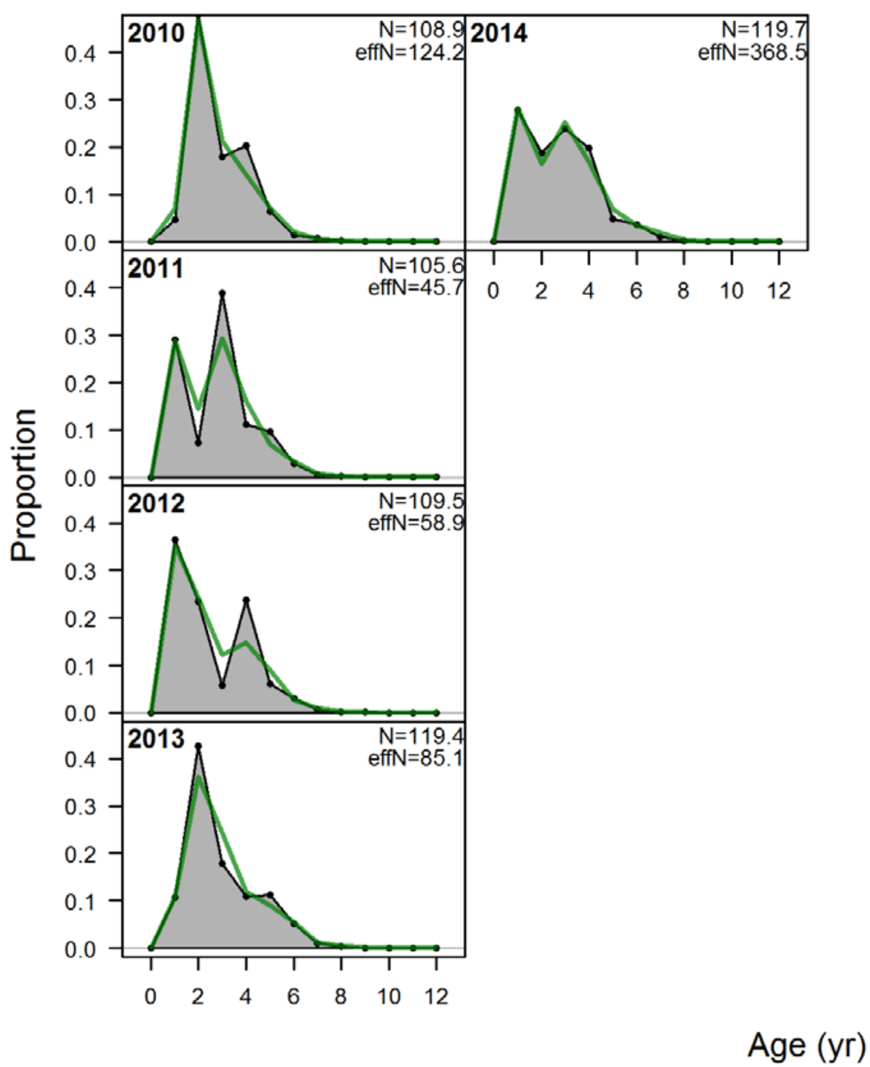


Figure 2.1.2f—Model 16.5 fits to trawl survey age composition data (page 2 of 2).

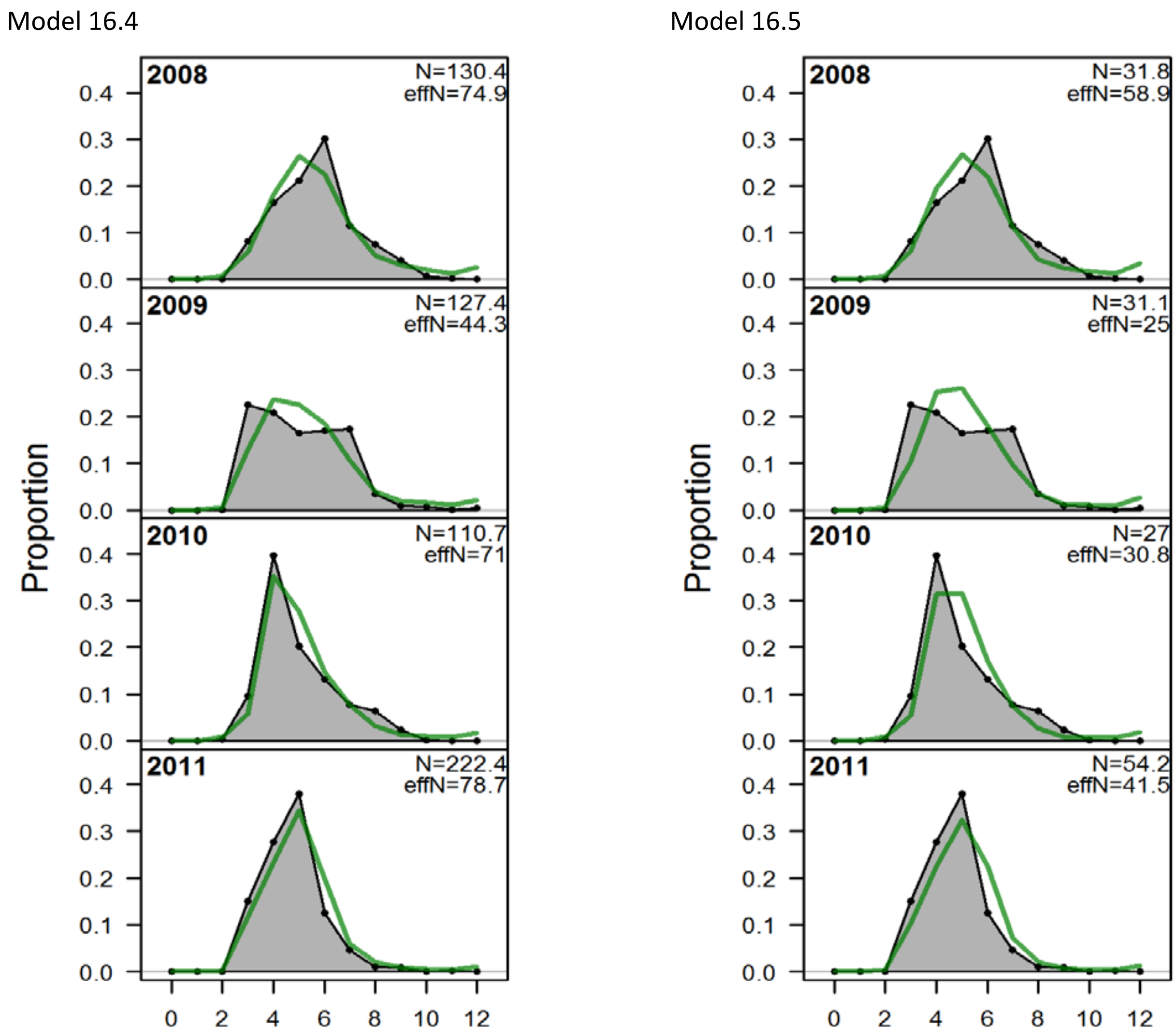


Figure 2.1.3—Model fits to fishery age composition data (Models 16.4 and 16.5 only).

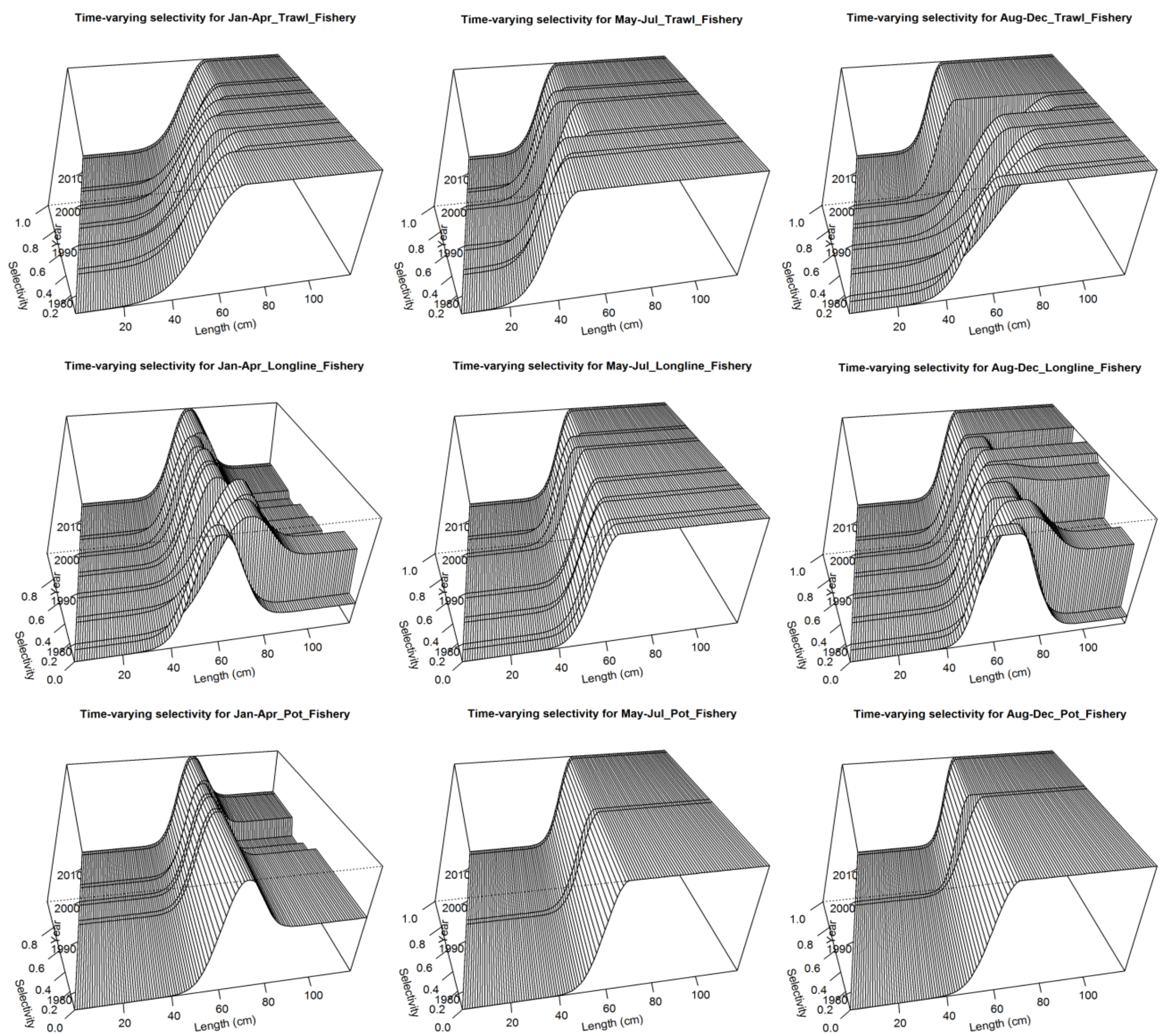


Figure 2.1.4a—Gear-and-season-specific fishery selectivity as estimated by Model 11.5.

Model 16.1

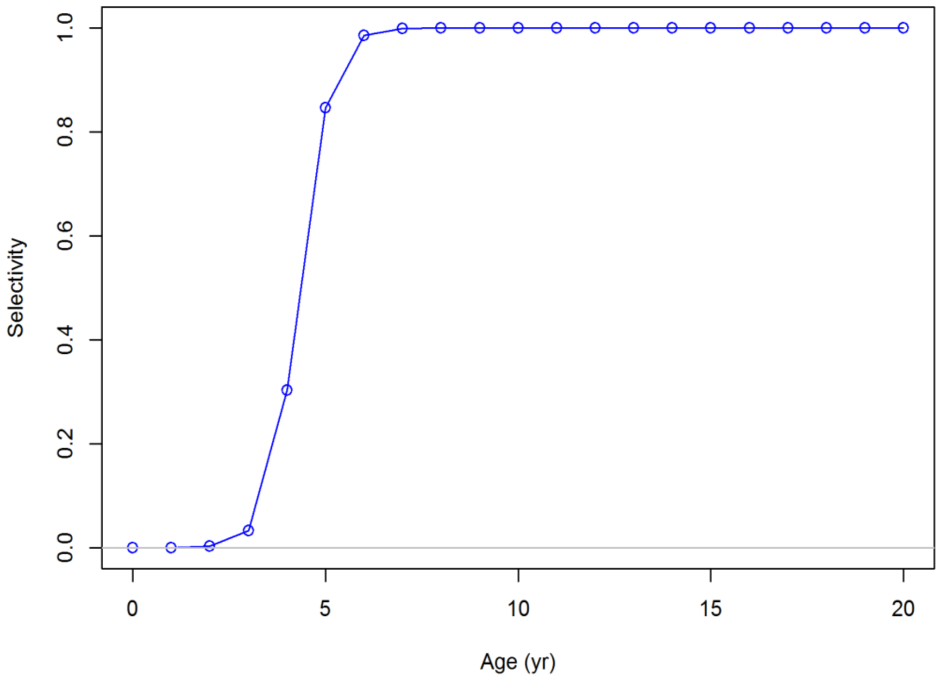
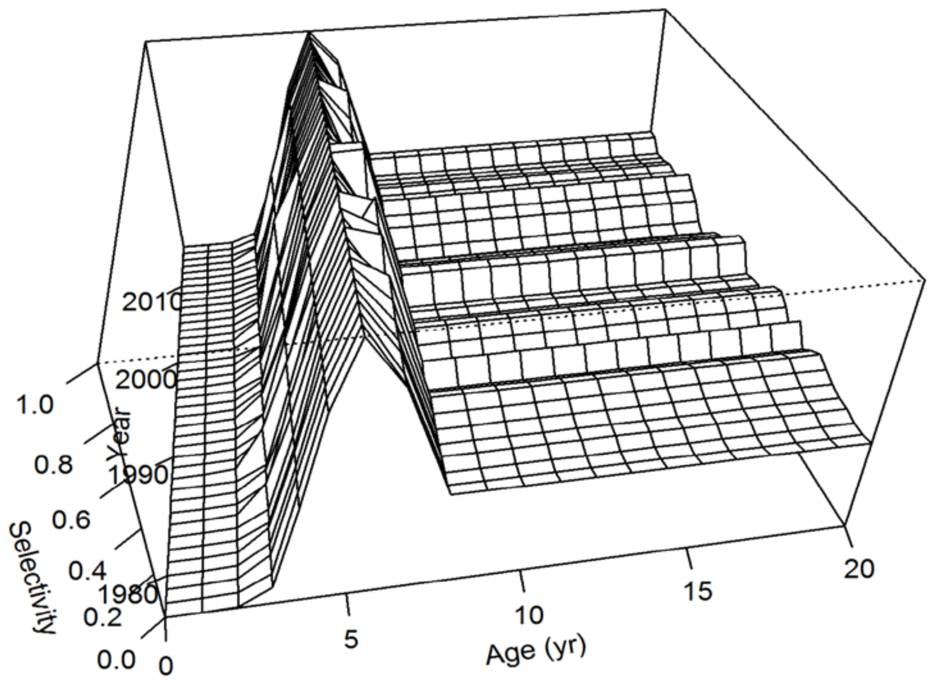


Figure 2.1.4b—Fishery selectivity as estimated by Model 16.1.

Model 16.2



Model 16.3

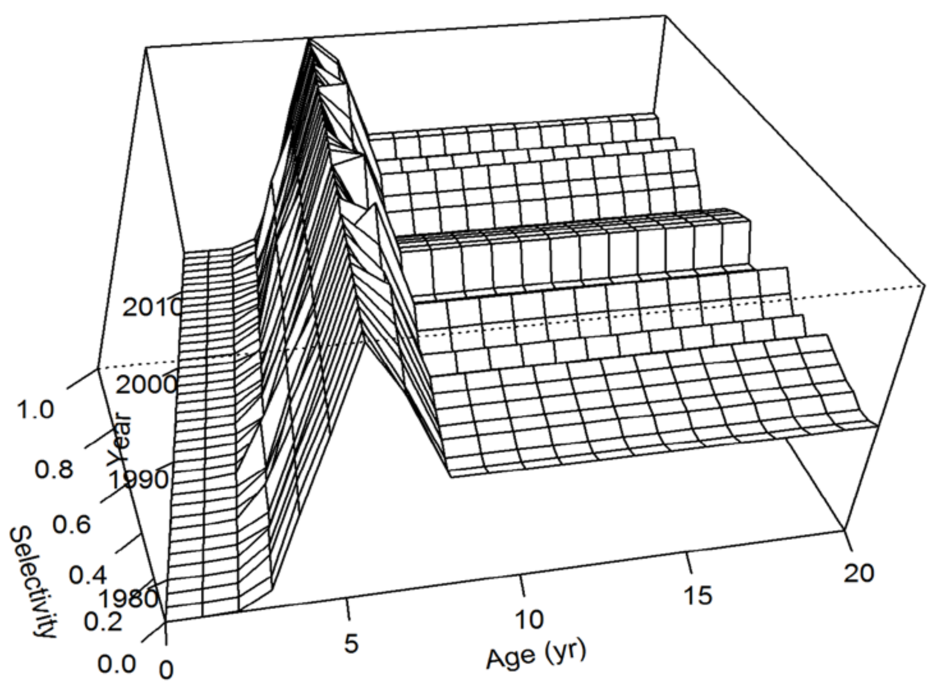
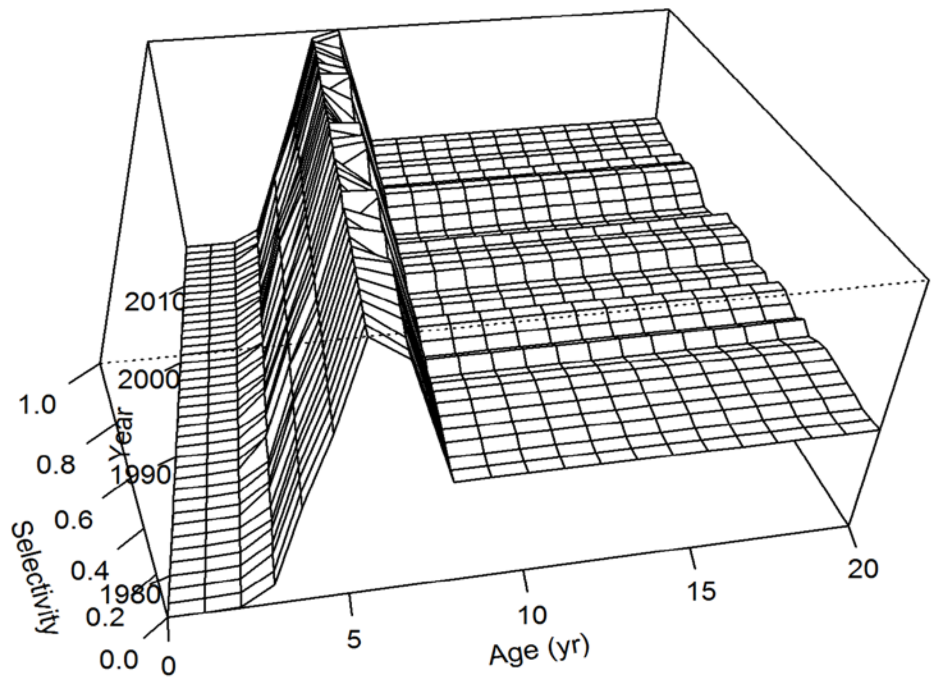


Figure 2.1.4c—Fishery selectivity as estimated by Models 16.2 and 16.3.

Model 16.4



Model 16.5

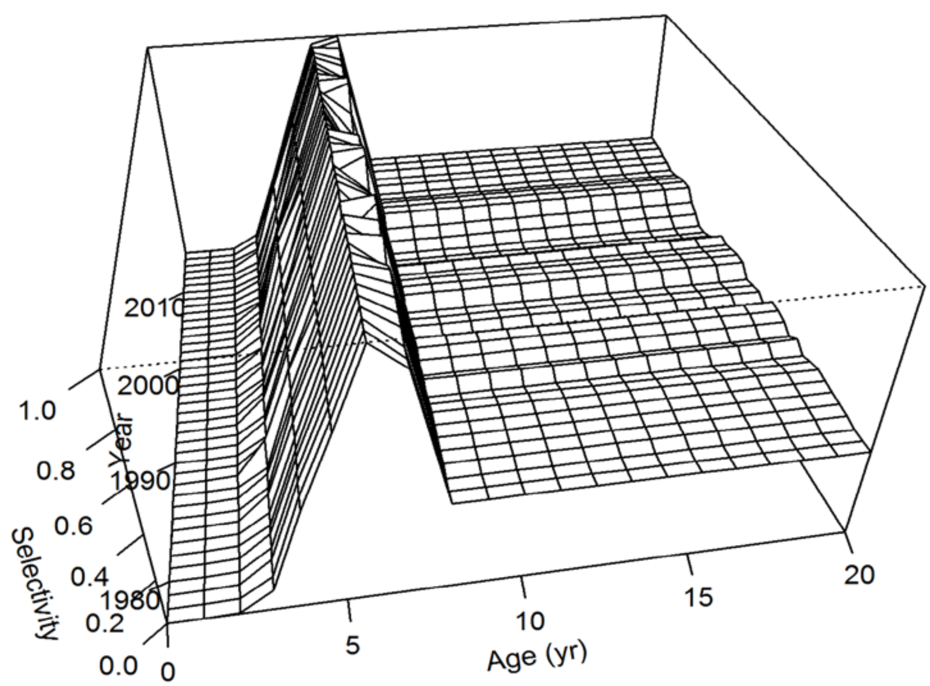
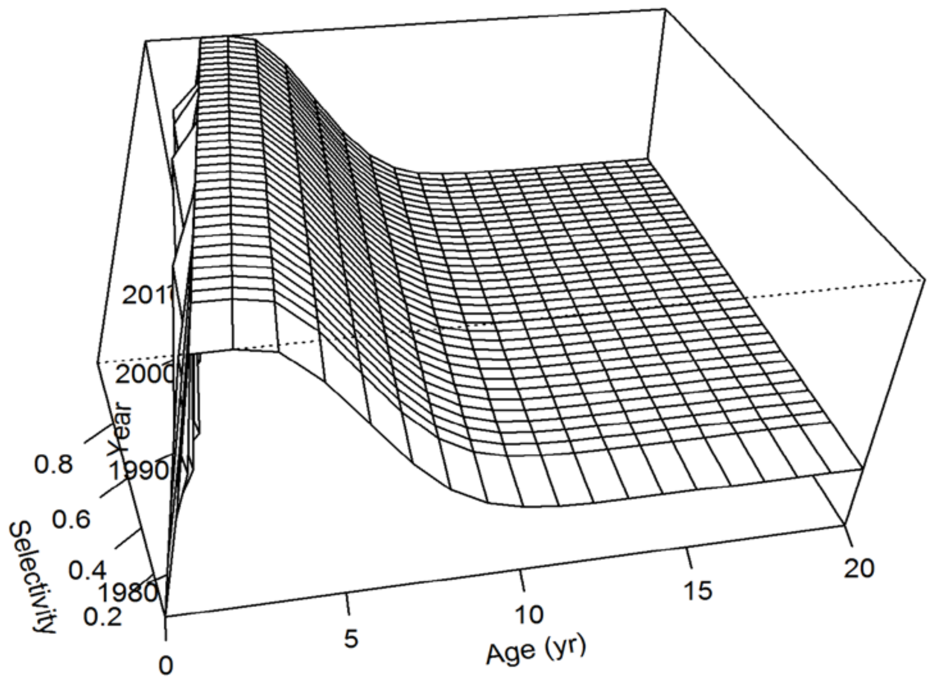


Figure 2.1.4d—Fishery selectivity as estimated by Models 16.4 and 16.5.

Model 11.5



Model 16.1

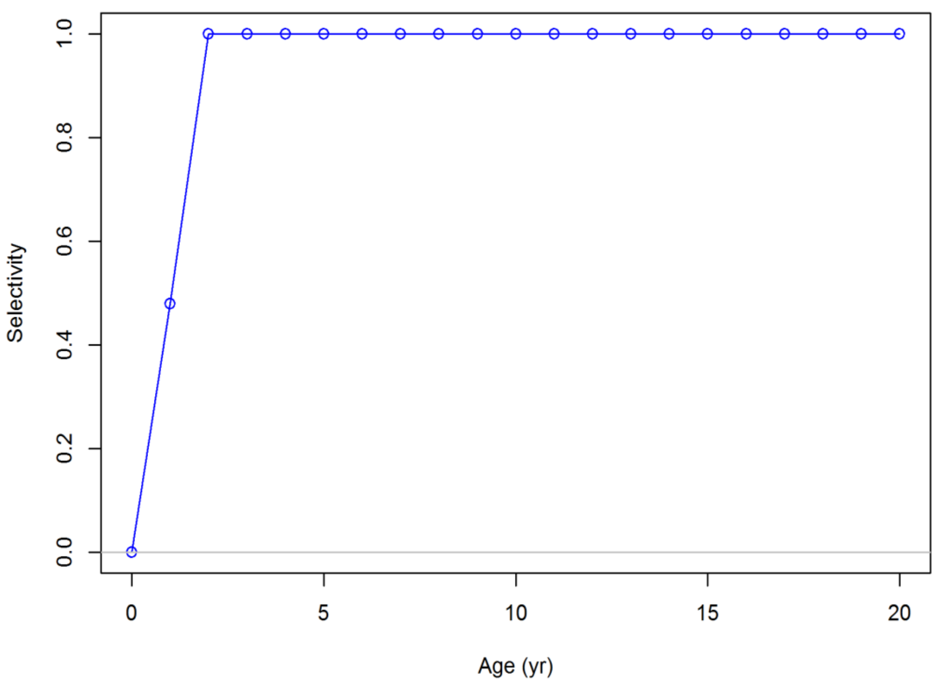
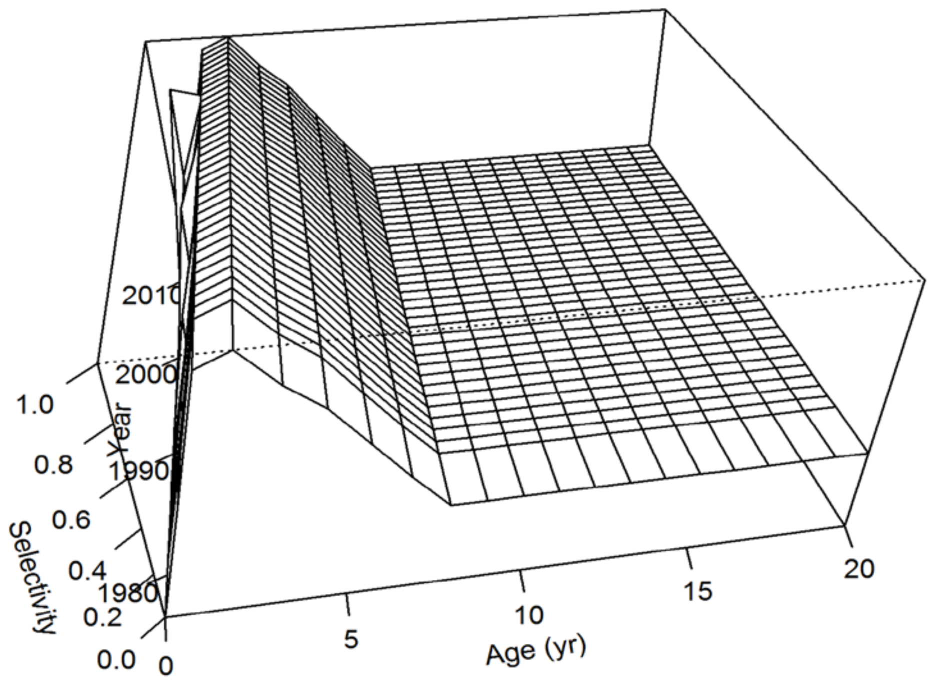


Figure 2.1.5a—Trawl survey selectivity (page 1 of 3).

Model 16.2



Model 16.3

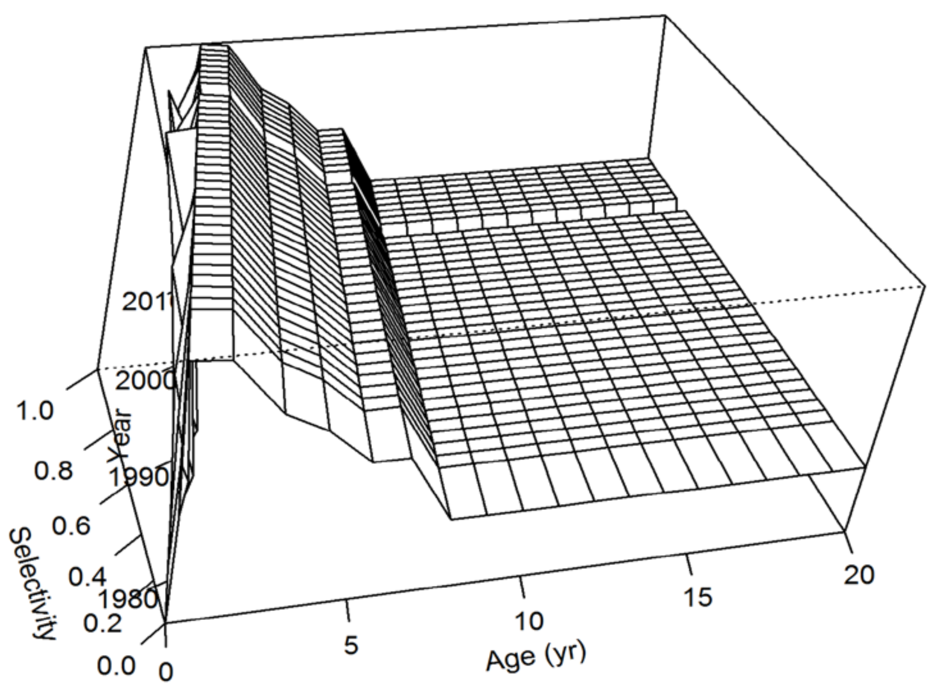
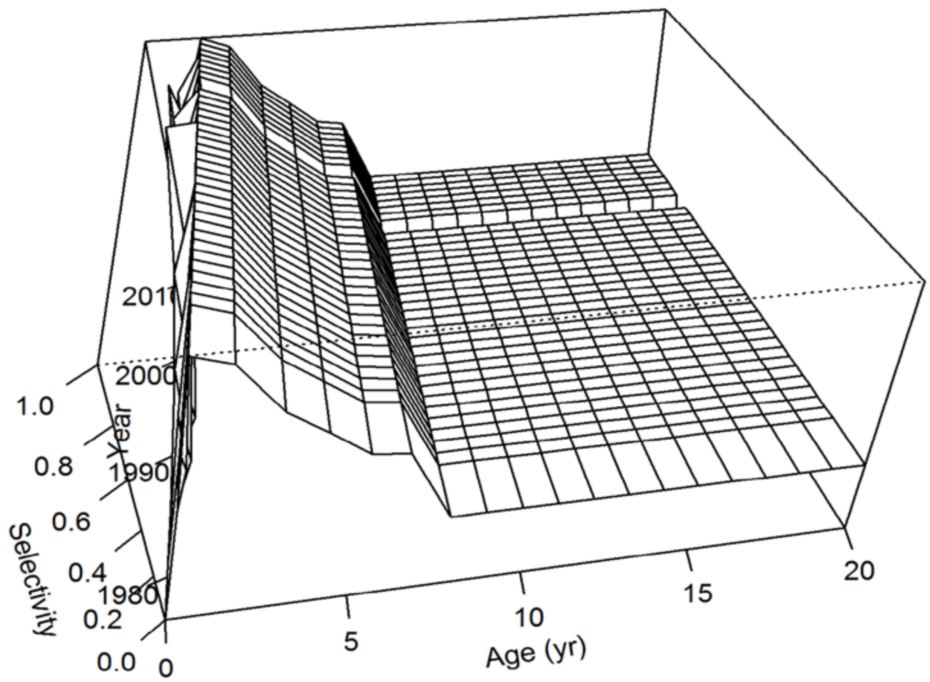


Figure 2.1.5a—Trawl survey selectivity (page 2 of 3).

Model 16.4



Model 16.5

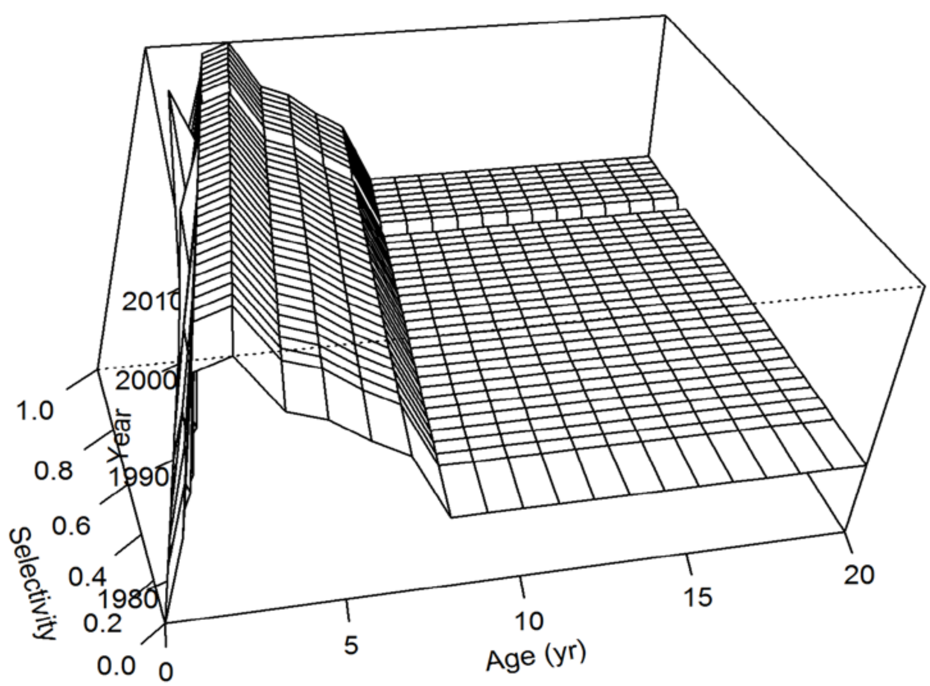
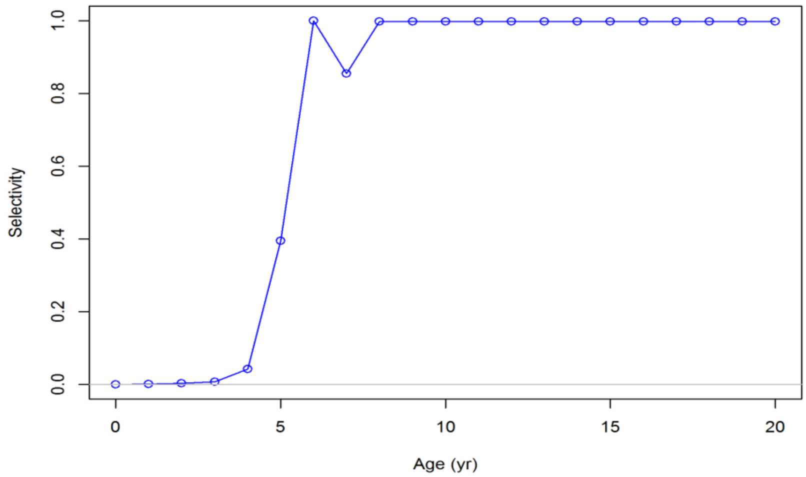
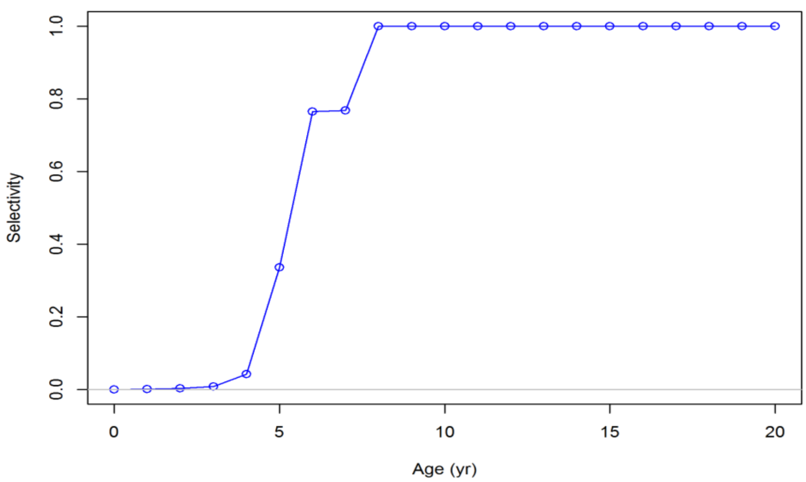


Figure 2.1.5a—Trawl survey selectivity (page 3 of 3).

Model 16.2



Model 16.4



Model 16.5

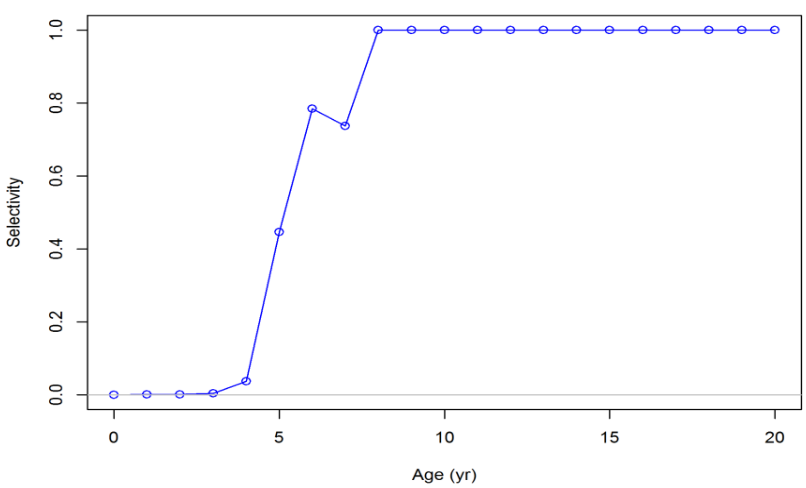
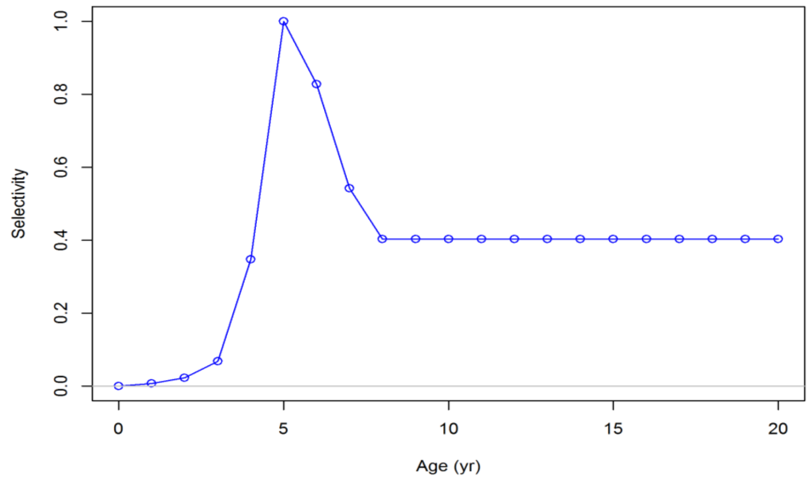
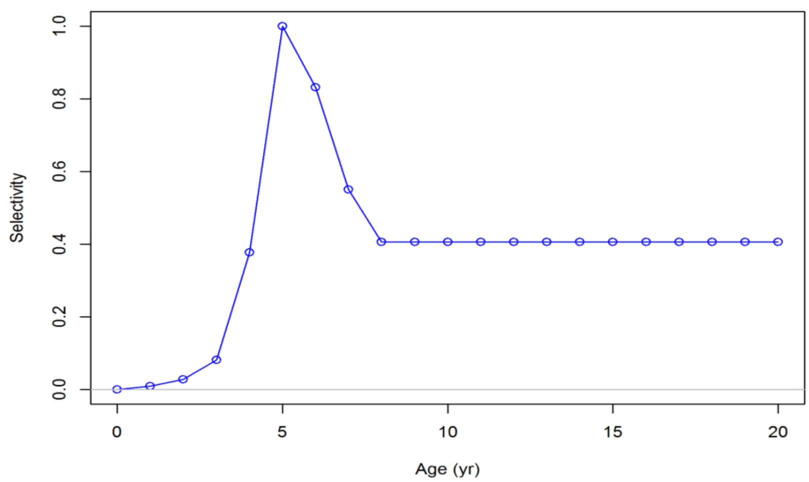


Figure 2.1.5b—IPHC longline survey selectivity.

Model 16.3



Model 16.4



Model 16.5

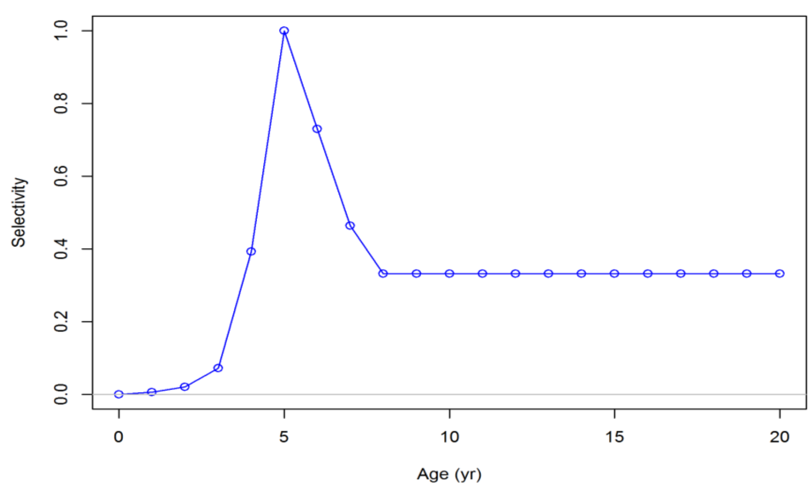


Figure 2.1.5c—NMFS longline survey selectivity.

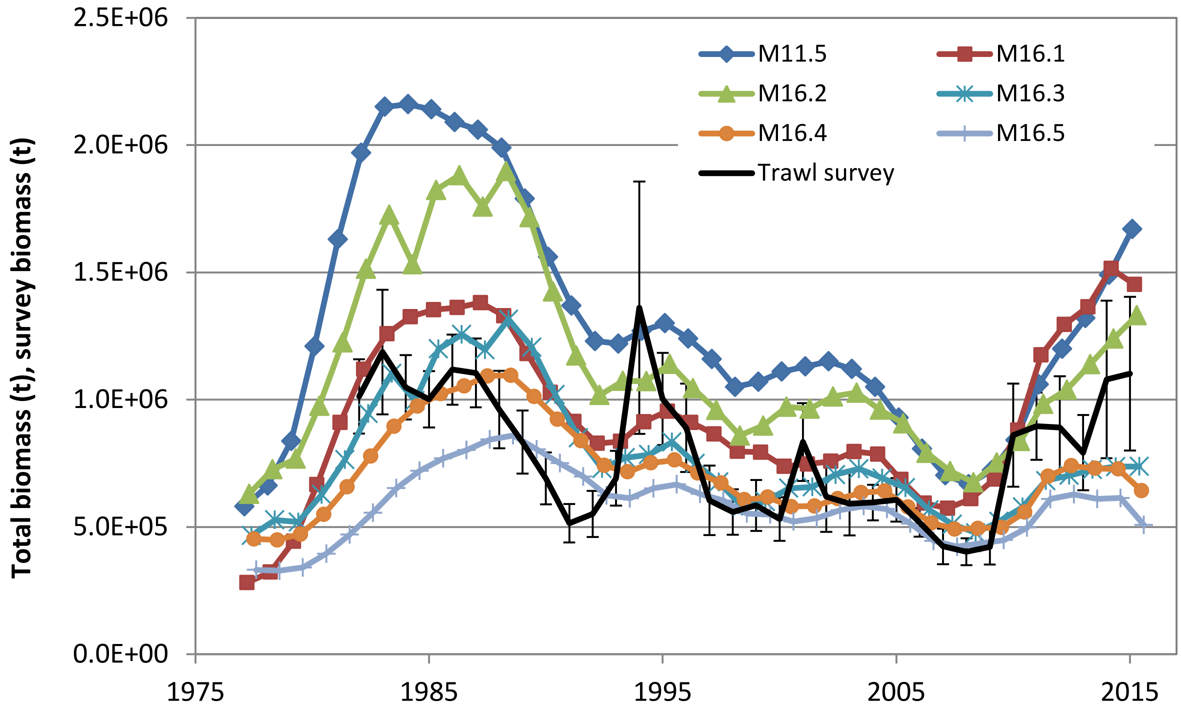


Figure 2.1.6—Total biomass time series as estimated by each of the models. Survey biomass (with 95% confidence interval) shown for comparison.

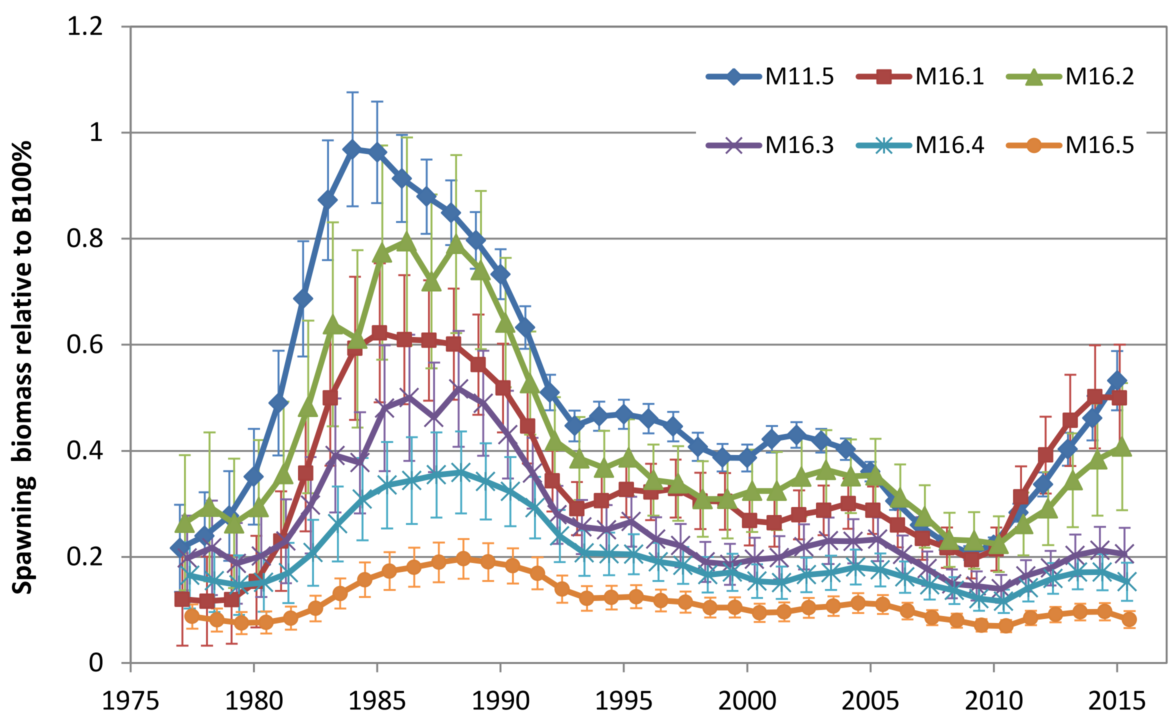


Figure 2.1.7—Time series of spawning biomass relative to $B_{100\%}$ for each of the models, with 95% confidence intervals.

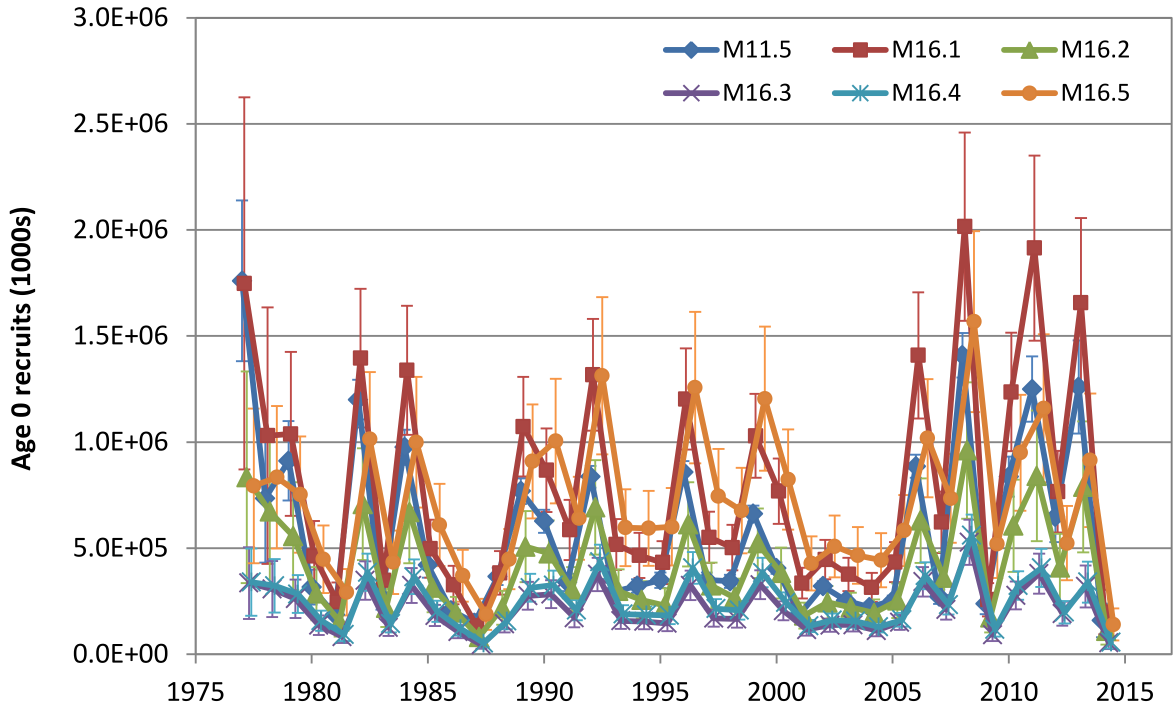


Figure 2.1.8—Age 0 recruitment (1000s of fish) for each model.

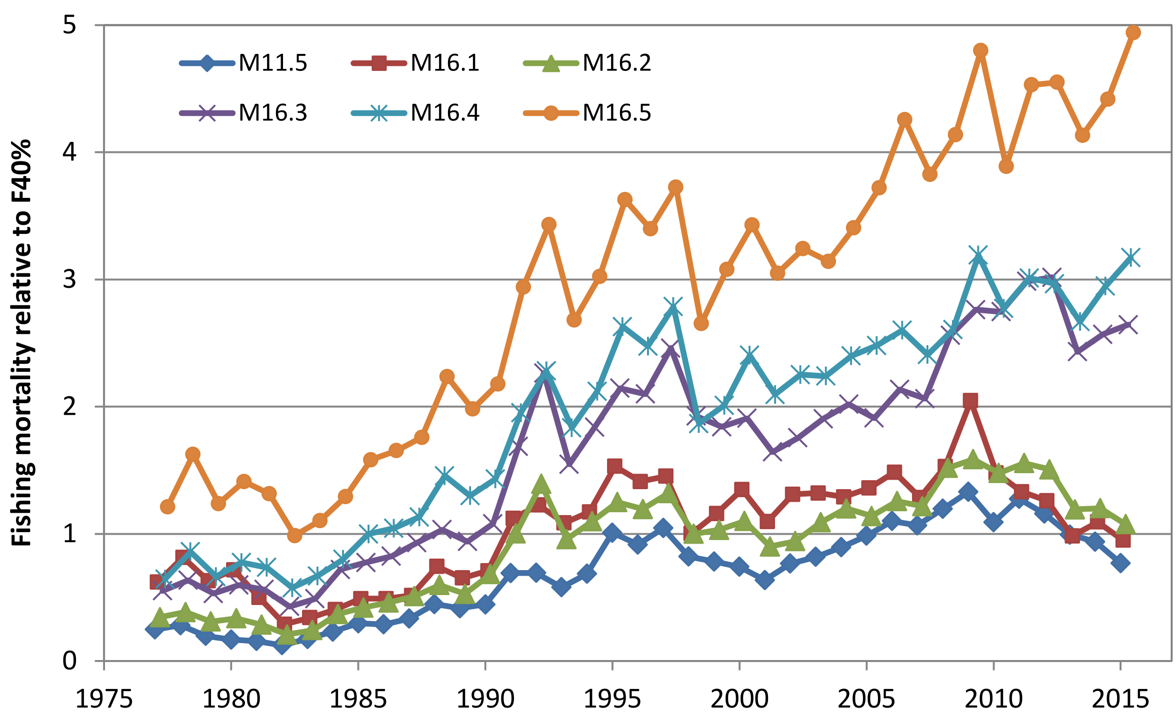


Figure 2.1.9—Time series of the ratio of full-selection fishing morality to $F_{40\%}$.

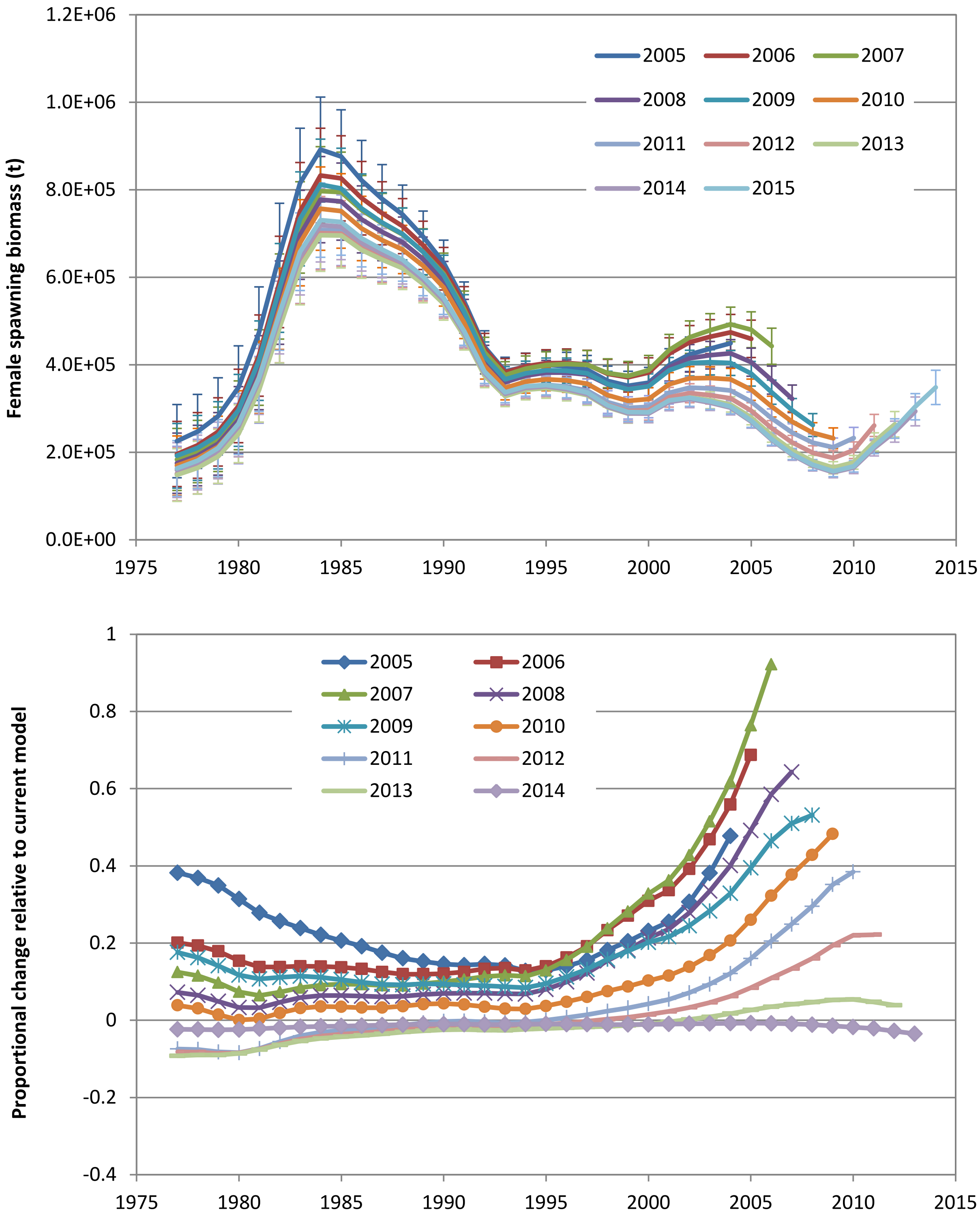
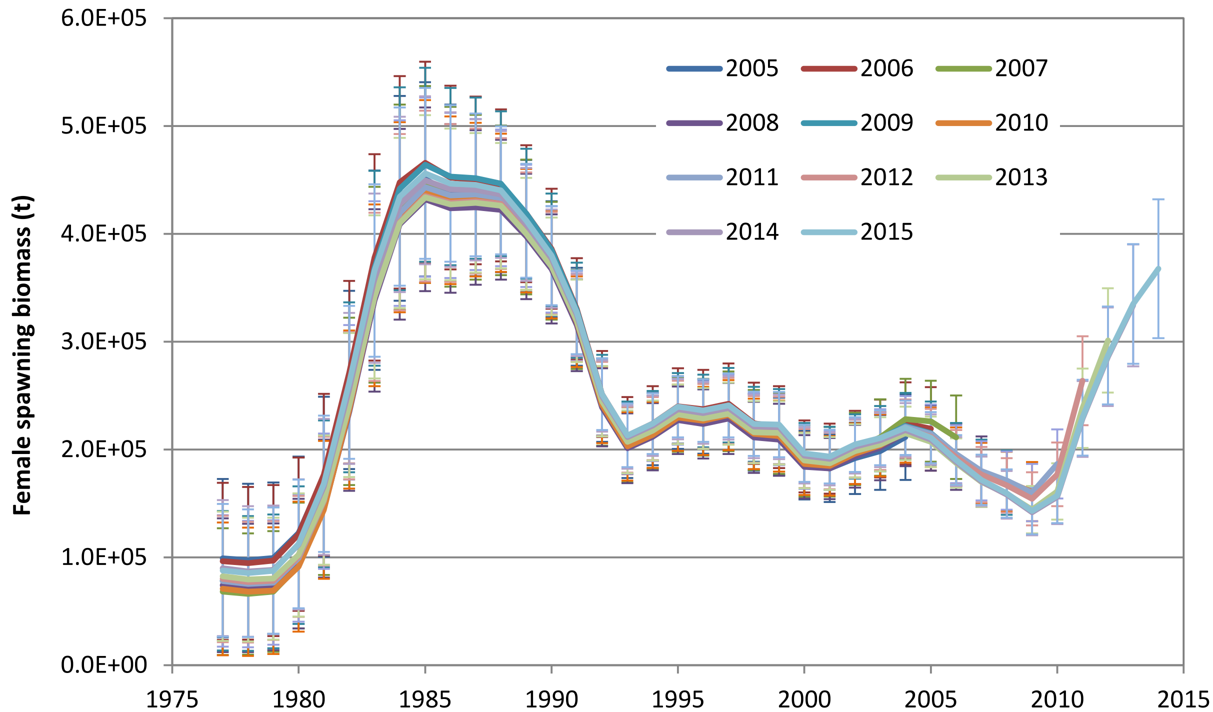


Figure 2.1.10a—Ten-year spawning biomass retrospective analysis of Model 11.5.



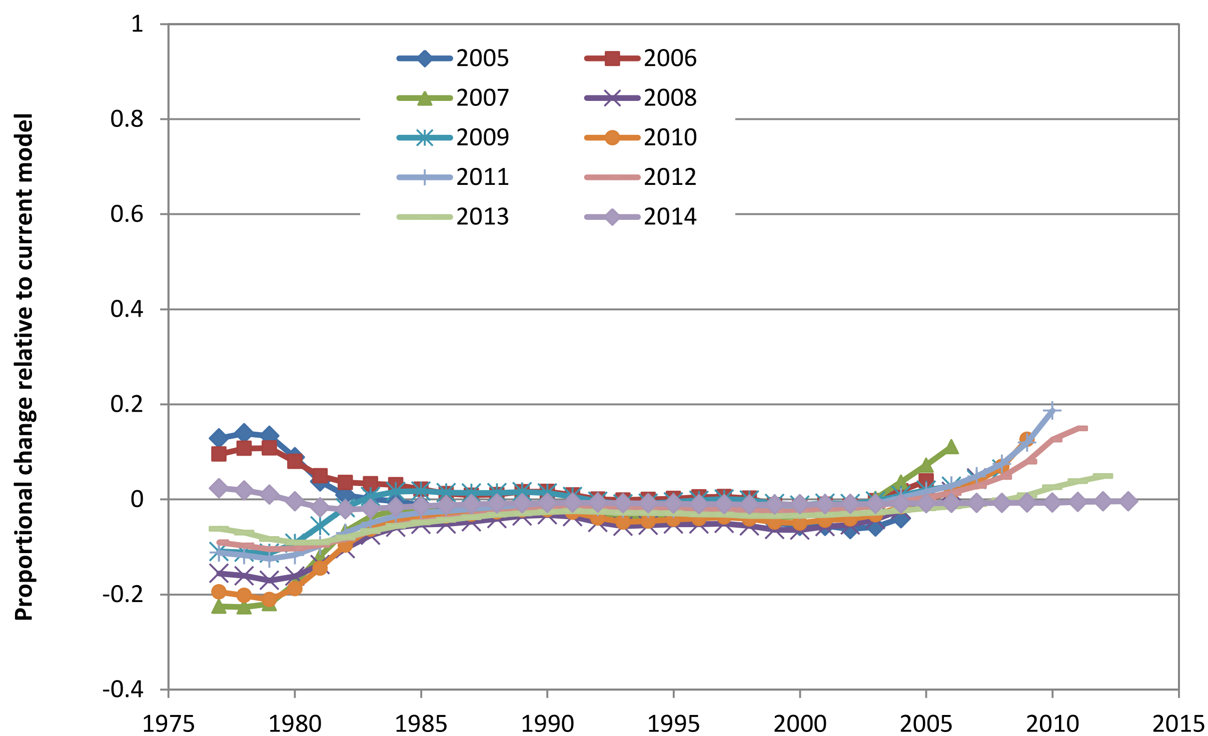


Figure 2.1.10b—Ten-year spawning biomass retrospective analysis of Model 16.1.

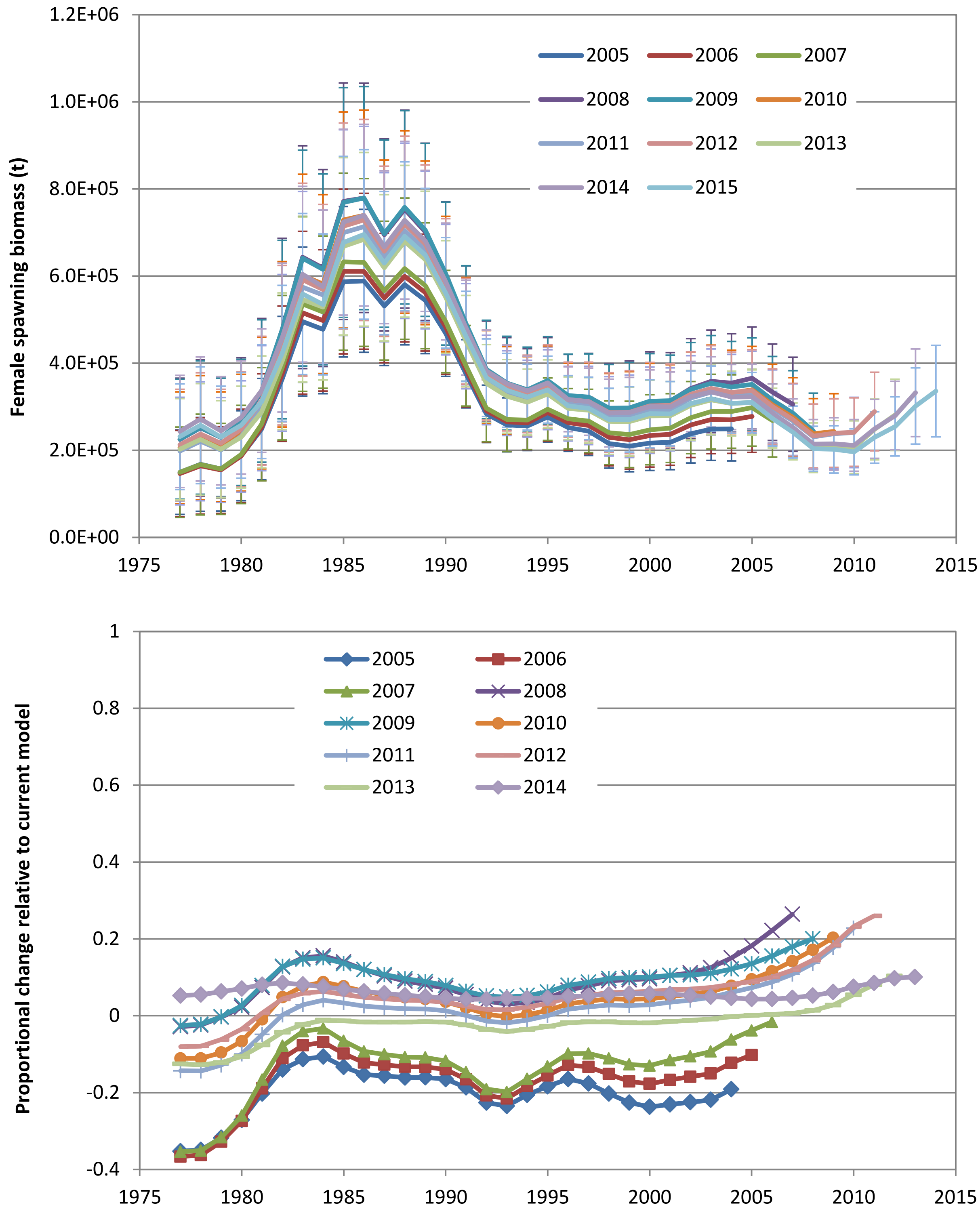


Figure 2.1.10c—Ten-year spawning biomass retrospective analysis of Model 16.2.

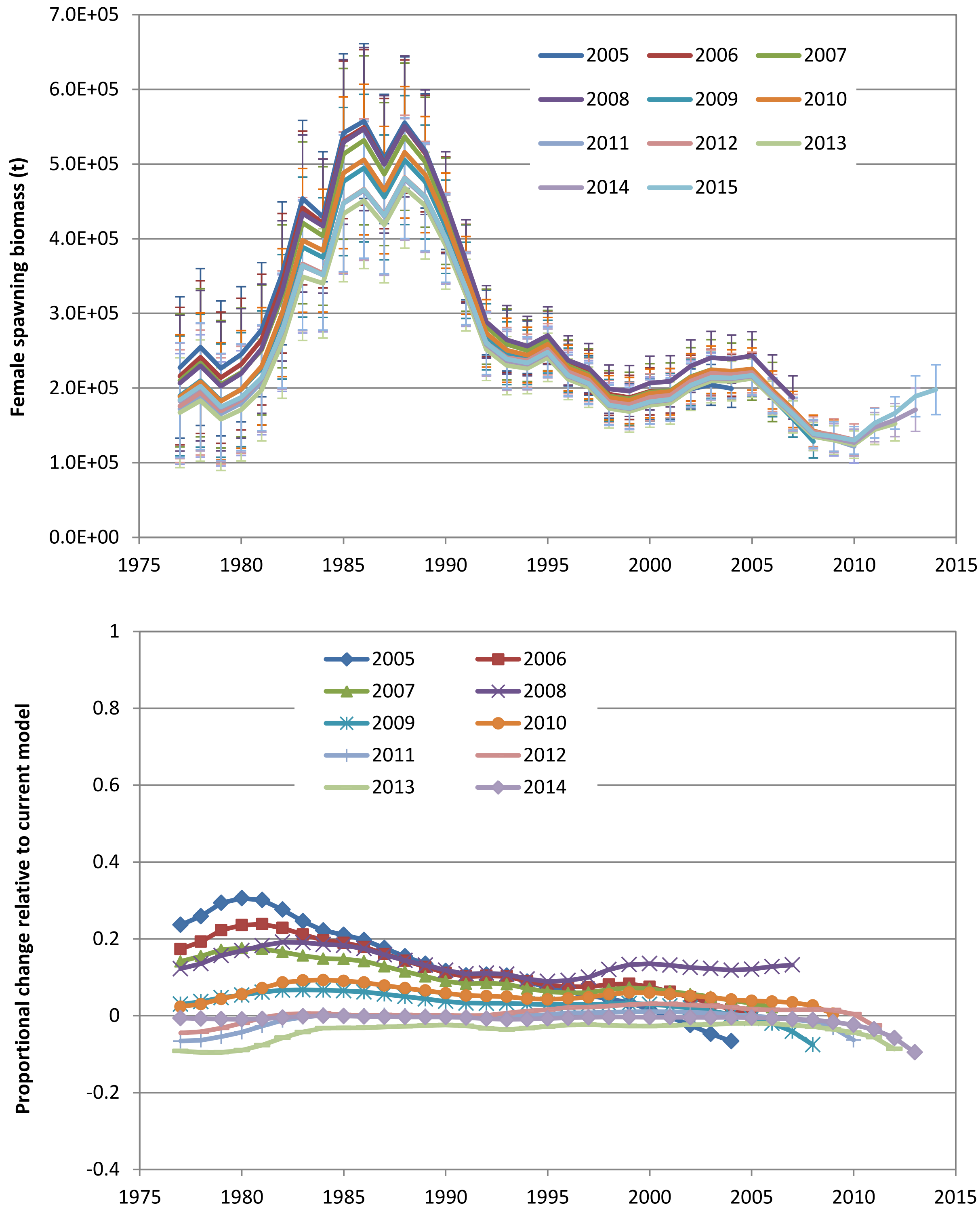


Figure 2.1.10d—Ten-year spawning biomass retrospective analysis of Model 16.3.

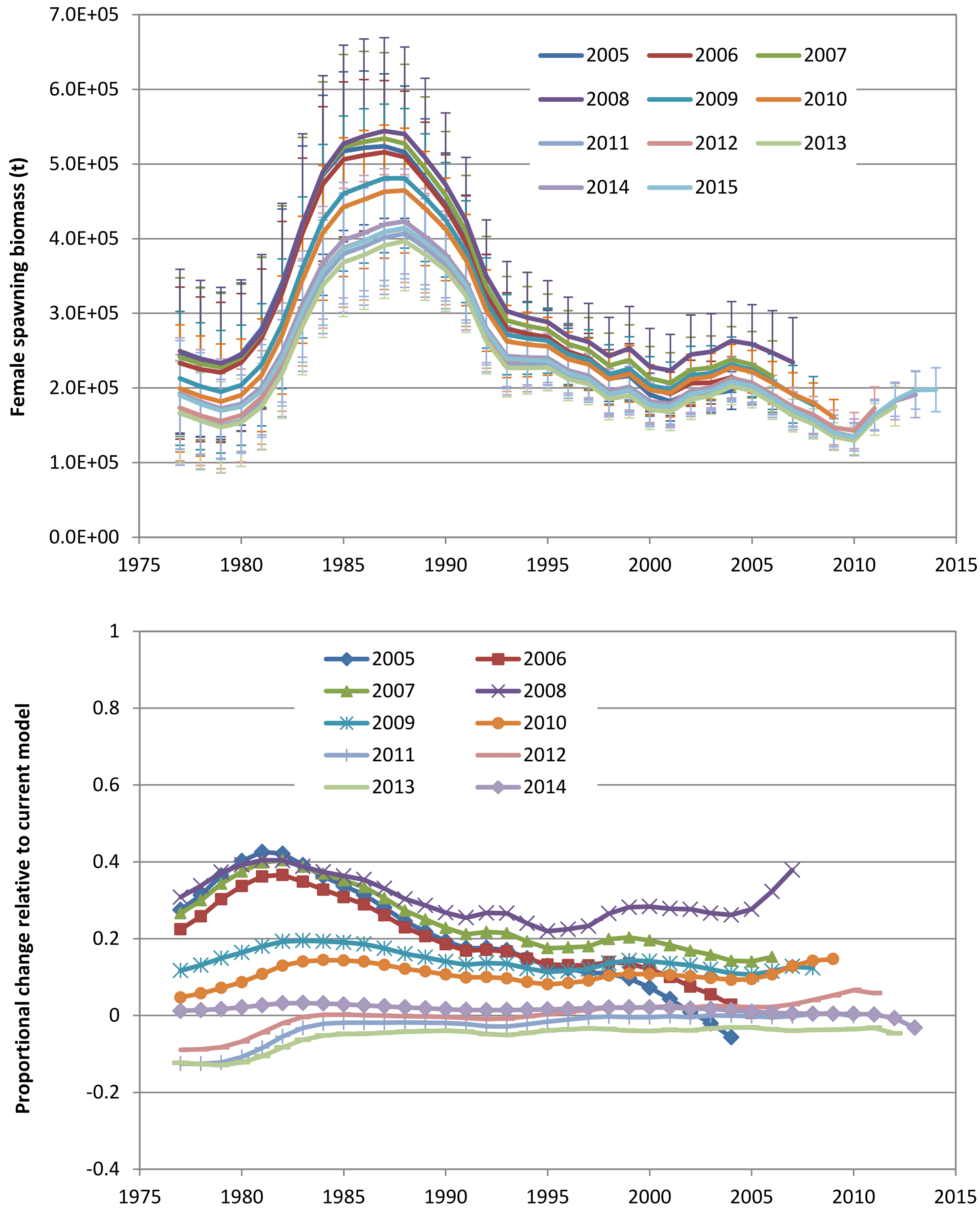


Figure 2.1.10e—Ten-year spawning biomass retrospective analysis of Model 16.4.

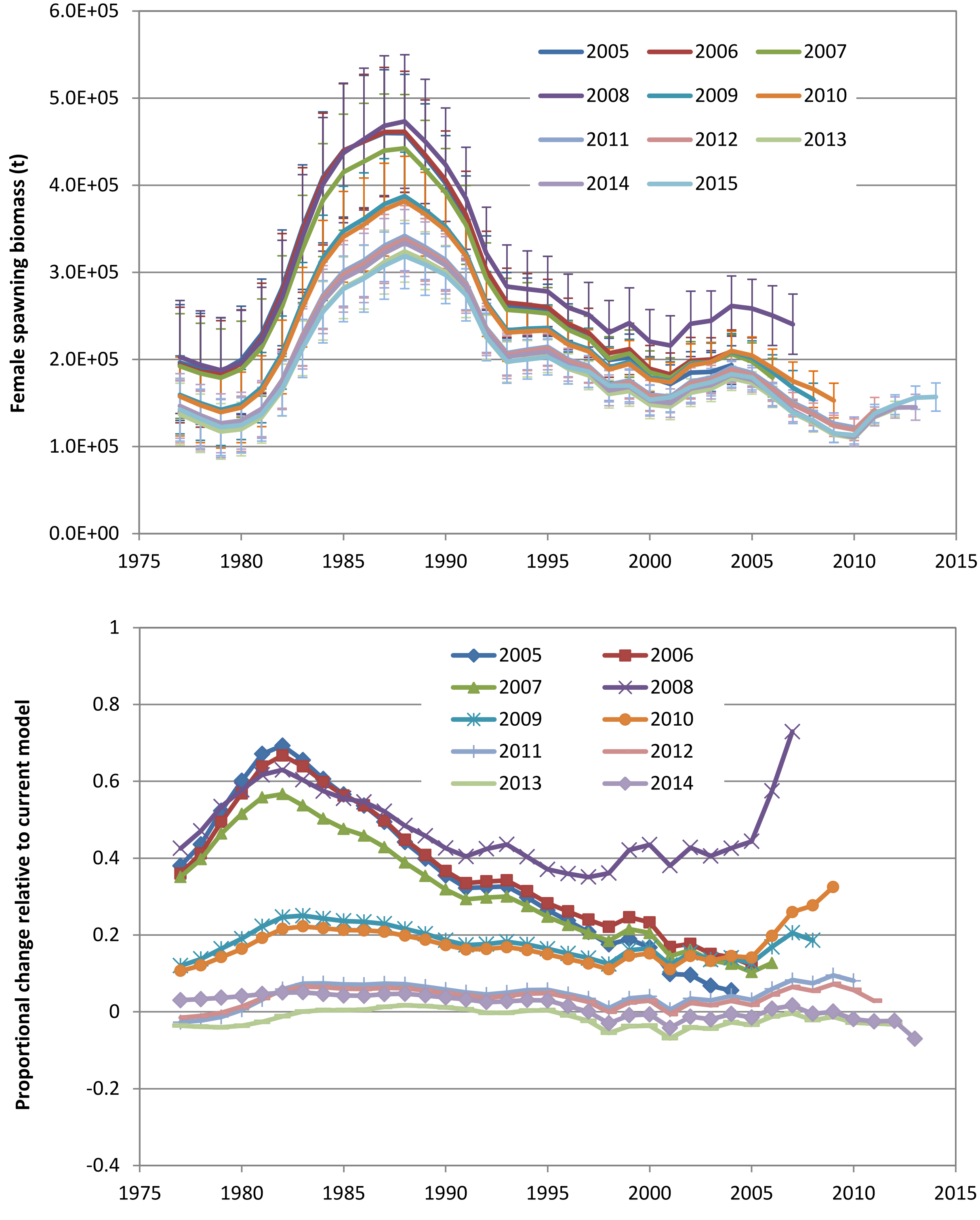


Figure 2.1.10f—Ten-year spawning biomass retrospective analysis of Model 16.5.

APPENDIX 2.2: BSAI PACIFIC COD ECONOMIC PERFORMANCE REPORT FOR 2015

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Pacific cod is the second largest species in terms of catch in the Bering Sea & Aleutian Island (BSAI) region. Pacific cod accounted for 13% of the BSAI's FMP groundfish harvest and 75% of the total Pacific cod harvest in Alaska. Retained catch of Pacific cod decreased 1% to 231 thousand t in 2015, and though down from its peak of 241 thousand t in 2012, is 35% higher than the 2006-2010 average (Table 2.2.1). The products made from BSAI Pacific cod had a first-wholesale value of $362 million in 2015, which was up from $354 million in 2014 and above the 2006-2010 average of $300 million (Table 2.2.2). The higher revenue in recent years is largely the result of increased catch and production levels as the average first-wholesale price of Pacific cod products have declined in recent.

Cod is an iconic fishery with a long history of production across much of the globe. Global catch was consistently over 2 million t through the 1980s, but began to taper off in the 1990s as cod stocks began to collapse in the northwest Atlantic Ocean. Over roughly the same period, the U.S. catch of Pacific cod (caught in Alaska) grew to approximately 250 thousand tons where it remained throughout the early to mid-2000s. European catch of Atlantic cod in the Barents Sea (conducted mostly by Russia, Norway, and Iceland) slowed and global catch hit a low in 2007 at 1.13 million t. U.S. Pacific cod's share of global catch was at a high at just over 20% in the early 2000s. Since 2007 global catch has grown to 1.85 million t in 2014 as catch in the Barents Sea has rebounded and U.S. catch has remained strong at over 300 thousand t since 2011. European Atlantic cod and U.S. Pacific cod remain the two major sources supplying the cod market over the past decade accounting for roughly 75% and 20%, respectively. Atlantic cod and Pacific cod are substitutes in the global market. Because of cod's long history global demand is present in a number of geographical regions, but Europe and the U.S. are the primary consumer markets for many Pacific cod products. The market for cod is also indirectly affected by activity in the pollock fisheries which experienced a similar period of decline in 2008-2010 before rebounding. Cod and pollock are commonly used to produce breaded fish portions. Alaska caught Pacific cod in the BSAI became certified by the Marine Stewardship Council (MSC) in 2010, a NGO based third-party sustainability certification, which some buyers seek.

The Pacific cod total allowable catch (TAC) is allocated to multiple sectors (fleets). CDQ entities receive 10% of the total BSAI quota. The largest sectoral allocation goes to the Freezer longline CPs which receive roughly 44% of the total BSAI cod quota (48.7% non-CDQ quota). While not an official catch share program, the Freezer longline CPs have formed a voluntary cooperative that allows them to form private contracts among members to distribute the sectoral allocation. The remaining large sectors are the trawl CPs, trawl CVs, the pot gear CVs and some smaller sideboard limits to cover the catch of Pacific cod while targeting other species. The CVs (collectively referred to as the inshore sector) make deliveries to shore-based processors, and catcher/processors process catch at-sea before going directly to the wholesale markets. Among the at-sea CPs, catch is distributed approximately three-quarters to the hook-and-line and one quarter to trawl. The inshore sector accounts for 25%-30% of the total BSAI Pacific cod catch of which approximately two-thirds is caught by the trawl and one-third by the pot gear sectors. The retained catch of the inshore sector decreased 3% increase to 61 thousand t. The value of these deliveries (shoreside ex-vessel value) totaled $29.4 million in 2015, which was down 21% from 2014, as ex-vessel prices also decreased 7% to an average of $0.249 per pound. Changes in ex-vessel prices over time generally reflect changes in the corresponding wholesale prices. Catch from the fixed gear vessels (which includes hook-and-line and pot gear) typically receive a slightly higher price from processors because they incur less damage when caught. The fixed gear price premium has varied over time but recently has been about $0.03 per pound.

The first-wholesale value of Pacific cod products was down 2% to $362.1 million in 2015, though revenues in recent years remain high as result of increased catch levels. The average price of Pacific cod products in 2015 increased 5% to $1.364 driven by an increase in the H&G price. Changes in global catch and production account for much the trends in the cod markets. In particular, the average first-wholesale prices peak at over $1.80 per pound in 2007-2008 and subsequent declined precipitously in 2009 to $1.20 per pound as markets priced in consecutive years of approximately 100 thousand t increases in the Barents Sea cod catch in 2009-2011; coupled with reduced demand from the recession. Average first-wholesale prices since have fluctuated between approximately $1.20 and $1.55 per pound. Head and gut (H&G) production is the focus of the BSAI processors but a significant amount of fillets are produced as well. H&G typically constitutes over 80% of value and fillets over 10% of value. Shoreside processors produce the majority of the fillets. Almost all of the at-sea sector's catch is processed into H&G. Other product types are not produced in significant quantities. At-sea head and gut prices tend to be about 20%-30% higher, in part because of the shorter period of time between catch and freezing, and in part because the at-sea sector is disproportionately caught by hook-and-line which yields a better price. Head & gut prices bottomed out at $1.049 in 2013, a year in which Barents Sea cod catch increased roughly 240 thousand t (an increase that is approximately the size of Alaska's cod total catch) but have since rebounded to $1.365. Fillet Prices have steady declined from over $3 in 2011 to $2.465 in 2015.

U.S. exports of cod have risen almost proportionally with increasing U.S. cod production. More than 90% of the exports are H&G, most of which goes to China for secondary processing and re-export. China's rise as a re-processor is fairly recent. Between 2001 and 2011 exports to China have increased nearly 10 fold. Japan and Europe (mostly Germany and the Netherlands) are also important export destinations. Approximately 30% of Alaska's cod production is estimated to remain in the U.S. In 2016 Norway and Russia maintained their Barents Sea TAC at 2015 levels despite recommendations by ICES to reduce the TAC by roughly 10%. Reports indicate that marginal reduction in the Barents Sea catch is planned to take effect in 2017, but it is sufficiently small that it may not impact prices much.

Table 2.2.1. Bering Sea & Aleutian Islands Pacific cod catch and ex-vessel data. Total and retained catch (thousand metric tons), number of vessel, catcher/processor (CP) hook-and-line H&L share of catch, CP trawl share of catch, shoreside pot gear share of catch, shoreside trawl share of catch, shoreside ex-vessel value (million US$), fixed gear and trawl price (US$ per pound), and shoreside number of vessel; 2006-2010 average and 2011-2015.

	Avg 06-10	2011	2012	2013	2014	2015
Total catch K mt	177.2	220.1	250.9	250.3	249.3	242
Retained Federal catch K mt	170.9	216.5	241.2	238.8	232.1	230.9
Vessels #	201.2	171	177	178	156	150
CP H&L share of BSAI catch	53%	53%	54%	51%	53%	56%
CP trawl share of BSAI catch	18%	15%	15%	18%	15%	15%
Shoreside fed total catch K mt	46.8	65	70	67	67	61
Shoreside catcher vessels #	61.2	54	55	50	47	49
CV pot gear share of BSAI catch	9%	11%	9%	9%	10%	9%
CV trawl share of BSAI catch	18%	18%	19%	17%	17%	16%
Shoreside ex-vessel value M $	$34.86	$34.04	$44.72	$34.04	$37.08	$29.40
Shoreside ex-vessel price lb $	$0.379	$0.275	$0.318	$0.244	$0.273	$0.249
Shoreside fixed gear ex-vessel price premium	$0.06	$0.06	$0.01	$0.01	$0.03	$0.03

Source: NMFS Alaska Region Blend and Catch-accounting System estimates; NMFS Alaska Region At-sea Production Reports; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN).

Table 2.2.2. Bering Sea & Aleutian Islands Pacific cod first-wholesale market data. First-wholesale production (thousand metric tons), value (million US$), price (US$ per pound); fillet and head and gut volume (thousand metric tons), value share, and price (US$ per pound); At-sea share of value and at-sea shoreside price difference (US$ per pound); 2006-2010 average and 2011-2015.

		Avg 06-10	2011	2012	2013	2014	2015
All products	**volume K mt**	85.74	107.39	122.75	121.70	123.51	120.40
All products	**Value M $**	$ 299.7	$ 366.0	$ 381.1	$ 303.7	$ 353.8	$ 362.1
All products	**price lb $**	$ 1.586	$ 1.546	$ 1.408	$ 1.132	$ 1.299	$ 1.364
Fillets	**volume K mt**	4.34	6.57	6.76	8.79	8.42	6.28
Fillets	**value share**	10.1%	12.1%	12.1%	18.1%	14.1%	9.4%
Fillets	**price lb $**	$ 3.182	$ 3.059	$ 3.100	$ 2.836	$ 2.683	$ 2.465
Head & Gut	**volume K mt**	70.41	88.78	104.24	97.76	100.56	100.76
Head & Gut	**value share**	82.0%	81.0%	82.4%	74.5%	78.8%	83.7%
Head & Gut	**price lb $**	$ 1.584	$ 1.514	$ 1.366	$ 1.049	$ 1.257	$ 1.365
At-sea	**value share**	74.5%	74.2%	70.8%	68.7%	69.0%	77.1%
At-sea	**price premium ($/lb)**	$ 0.00	$ -0.04	$ -0.13	$ -0.28	$ -0.01	$ -0.12

Source: NMFS Alaska Region Blend and Catch-accounting System estimates; NMFS Alaska Region At-sea Production Reports; and ADF&G Commercial Operators Annual Reports (COAR). Data compiled and provided by the Alaska Fisheries Information Network (AKFIN).

Table 2.2.3. Cod U.S. trade and global market data. Global production (thousand metric tons), U.S. share of global production, and Europe's share of global production; U.S. export volume (thousand metric tons), value (million US$), and price (US$ per pound); U.S. cod consumption (estimated), and share of domestic production remaining in the U.S. (estimated); and the share of U.S. export volume and value for head and gut (H&G), fillets, China, Japan, and Germany and Netherlands; 2006-2010 average and 2011-2016.

		Avg 06-10	2011	2012	2013	2014	2015	2016 (thru June)
Global cod catch K mt		1,209	1,505	1,600	1,828	1,850	-	-
U.S. P. cod share of global catch		19.0%	20.0%	20.4%	16.9%	17.6%	-	-
Europe share of global catch		71.8%	73.1%	73.2%	76.7%	76.0%	-	-
Pacific cod share of U.S. catch		96.7%	97.4%	98.6%	99.3%	99.3%	-	-
U.S. cod consumption K mt (est.)		80	88	98	105	115	108	-
Share of U.S. cod not exported		24%	24%	30%	31%	31%	26%	-
Export volume K mt		86.6	110.8	111.1	101.8	107.3	113.2	71.7
Export value M US$		$ 266.1	$ 371.3	$ 363.6	$ 308.0	$ 314.2	$ 334.9	$ 204.3
Export price lb US$		$ 1.393	$ 1.520	$ 1.485	$ 1.373	$ 1.328	$ 1.342	$ 1.293
Frozen (H&G)	volume share	71%	74%	80%	91%	92%	91%	94%
	value share	69%	75%	80%	89%	91%	90%	93%
Fillets	volume share	13%	9%	9%	4%	2%	3%	3%
	value share	16%	12%	11%	5%	4%	4%	4%
China	volume share	23%	39%	46%	51%	54%	53%	64%
	value share	21%	37%	43%	48%	51%	51%	61%
Japan	volume share	18%	20%	16%	13%	16%	13%	9%
	value share	18%	20%	16%	13%	16%	14%	9%
Netherlands & Germany	volume share	11%	10%	8%	8%	9%	8%	5%
	value share	13%	11%	9%	9%	10%	8%	5%

Notes: Pacific cod in this table is for all U.S. Unless noted, `cod' in this table refers to Atlantic and Pacific cod. Russia, Norway, and Iceland account for the majority of Europe's cod catch which is largely focused in the Barents Sea.
Source: FAO Fisheries & Aquaculture Dept. Statistics http://www.fao.org/fishery/statistics/en. NOAA Fisheries, Fisheries Statistics Division, Foreign Trade Division of the U.S. Census Bureau, http://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/index. U.S. Department of Agriculture http://www.ers.usda.gov/data-products/agricultural-exchange-rate-data-set.aspx.

APPENDIX 2.3: HISTORY OF PREVIOUS EBS PACIFIC COD MODEL STRUCTURES DEVELOPED UNDER STOCK SYNTHESIS

For 2005 and beyond, the SSC's accepted model from the final assessment is shown in **bold red**.

Pre-2005

Timeline

- Pre-1985: Simple projections of current survey numbers at age
- 1985: Projections based on 1979-1985 survey numbers at age
- 1986-1991: *ad hoc* separable age-structured FORTRAN model
- 1992: FORTRAN-based Stock Synthesis (SS), with age-based data
    - Strong 1989 cohort "disappears;" production ageing ceased
- 1993-2003: Models continued to be developed using SS, with length-based data only
- 2001: CIE review of code for proposed "ALASKA" (Age-, Length-, and Area-Structured Kalman Assessment) model and methodology for decision-theoretic estimation of OFL and ABC
    - Although review was favorable, use of ALASKA was postponed "temporarily"
- 2004: Models continued to be developed using SS, with length- *and* age-based data
    - New age data, based on revised ageing protocol
    - Agecomp data used in "marginal" form

Main features of the early Stock Synthesis EBS Pacific cod models

- Start year = 1977
- Three seasons (Jan-May, Jun-Aug, Sep-Dec)
- Four fisheries (Jan-May trawl, Jun-Dec trawl, longline, pot)
- *M* constant at 0.37
- *Q* constant at 1.00
- Efforts at internal estimation of *M*, *Q* unsuccessful
- Double-logistic selectivity for all fleets (fisheries and survey)
- No fleets constrained to exhibit asymptotic selectivity
- Sizecomp input sample size = square root of true sample size
- Survey index standard deviations set to values reported by RACE Division

2005

This assessment marked the first application of ADMB-based Stock Synthesis to EBS Pacific cod

Three models were included:

- Model 1 was identical to the 2004 final model (configured under FORTRAN-based SS), except for use of new maturity schedule developed by Stark
- **Model 2** was configured under ADMB-based SS, and was designed to be as close as possible to Model 1 given the limitations of the respective software packages, except:
    - Nonuniform priors used throughout
    - *M* fixed at 0.37, *Q* fixed at 1.00
- Model 3 was identical to Model 2 except that *M* and *Q* were estimated internally

Weight-length and length-age data examined for evidence of sexual dimorphism; none found.

2006

Nine models were included, consisting of 2005 final model and a 3-way factorial design of alternative models (the factorial models all differed from the 2005 final model in that they estimated trawl survey *Q* internally—in the 2005 final model, it was fixed at 1.0; and they estimated all selectivity parameters except for selectivity at the minimum size bin internally—in the 2005 final model, a few selectivity parameters were fixed externally):

- Model 0 was identical to 2005 final model
- Model A1 was identical to Model 0 except as noted above, with:
    - NMFS longline survey data omitted
    - Double logistic selectivity
    - Prior emphasis = 1.0
- Model A2 was identical to Model 0 except as noted above, with:
    - NMFS longline survey data omitted
    - Double logistic selectivity
    - Prior emphasis = 0.5
- **Model B1** was identical to Model 0 except as noted above, with:
    - NMFS longline survey data omitted
    - Double normal (four parameter) selectivity
    - Prior emphasis = 1.0
- Model B2 was identical to Model 0 except as noted above, with:
    - NMFS longline survey data omitted
    - Double normal (four parameter) selectivity
    - Prior emphasis = 0.5
- Model C1 was identical to Model 0 except as noted above, with:
    - NMFS longline survey data included
    - Double logistic selectivity
    - Prior emphasis = 1.0
- Model C2 was identical to Model 0 except as noted above, with:
    - NMFS longline survey data included
    - Double logistic selectivity
    - Prior emphasis = 0.5
- Model D1 was identical to Model 0 except as noted above, with:
    - NMFS longline survey data included
    - Double normal (four parameter) selectivity
    - Prior emphasis = 1.0
- Model D2 was identical to Model 0 except as noted above, with:
    - NMFS longline survey data included
    - Double normal (four parameter) selectivity
    - Prior emphasis = 0.5

2007

Technical workshop

SS introduced a six-parameter form of the double normal selectivity curve (the previous version used only four parameters). This functional form is constructed from two underlying and linearly rescaled normal distributions, with a horizontal line segment joining the two peaks. As configured in SS, the equation uses the following six parameters:

1. *beginning_of_peak_region* (where the curve first reaches a value of 1.0)
2. *width_of_peak_region* (where the curve first departs from a value of 1.0)
3. *ascending_width* (equal to twice the variance of the underlying normal distribution)
4. *descending_width* (equal to twice the variance of the underlying normal distribution)
5. *initial_selectivity* (at minimum length/age)
6. *final_selectivity* (at maximum length/age)

All but *beginning_of_peak_region* are transformed: The *ascending_width* and *descending_width* are log-transformed and the other three parameters are logit-transformed.

Model 0 was prepared ahead of workshop:

- *M* estimated internally
- Length-at-age parameters estimated internally
- Disequilibrium initial age structure
- Regime shift recruitment offset estimated internally
- Start year changed from 1964 to 1976
- New six-parameter double normal selectivity function used
- Prior distributions reflect 50% CV for most parameters

Twenty-one other models were prepared ahead of workshop, each of which was based on Model 0:

- Two models to examine inside/outside growth estimation:
    - Model 1 was identical to Model 0 except length-at-age parameters estimated outside the model
    - Model 2 was identical to Model 0 except standard deviation of length at age 12 estimated internally
- Two models to examine *M* conditional on *Q*, vice-versa:
    - Model 3 was identical to Model 0 except *M* fixed at 0.37 and *Q* free
    - Model 4 was identical to Model 0 except *Q* fixed at 0.75 and *M* free
- Six models to examine effects of prior distributions:
    - Model 5 was identical to Model 0 except 30% CV instead of 50%
    - Model 6 was identical to Model 0 except 40% CV instead of 50%
    - Model 7 was identical to Model 0 except emphasis = 0.2 instead of 1.0
    - Model 8 was identical to Model 0 except emphasis = 0.4 instead of 1.0
    - Model 9 was identical to Model 0 except emphasis = 0.6 instead of 1.0
    - Model 10 was identical to Model 0 except emphasis = 0.8 instead of 1.0
- Four models to examine effects of asymptotic selectivity:
    - Model 11 was identical to Model 0 except Jan-May trawl fishery selectivity forced asymptotic
    - Model 12 was identical to Model 0 except longline fishery selectivity forced asymptotic
    - Model 13 was identical to Model 0 except pot fishery selectivity forced asymptotic
    - Model 14 was identical to Model 0 except shelf trawl survey selectivity forced asymptotic
- One model to examine estimation of stock-recruit relationship:
    - Model 15 was identical to Model 0 except parameters of a Ricker stock-recruitment relationship estimated internally
- Six models to address EBS-specific comments from the public:
    - Model 16 was identical to Model 0 except input *N* determined by iterative re-weighting
    - Model 17 was identical to Model 0 except input *N* for mean-size-at-age data decreased by an order of magnitude
    - Model 18 was identical to Model 0 except standard error from the shelf trawl survey doubled

- Model 19 was identical to Model 0 except all age data removed
- Model 20 was identical to Model 0 except slope survey data removed
- Model 21 was identical to Model 0 except start year changed to 1982

An immense factorial grid of fixed $M \times Q$ models also prepared ahead of workshop, for which only partial results were presented

Eight models were developed during the workshop itself:

- Model 22 was identical to Model 0 except "old" (pre-Stark) maturity schedule used
- Model 23 was identical to Model 0 except priors turned off and separate *M* estimated for ages 1-2
- Model 24 was identical to Model 0 except priors turned off and longline fishery CPUE included as an index of abundance
- Model 25 was identical to Model 0 except priors turned off and Pcod bycatch from IPHC survey included as an index of abundance
- Model 26 was identical to Model 0 except priors turned off and either *Q* (=0.75) or *M* (=0.37) fixed
- Model 27 was identical to Model 0 except all priors turned off other than that for Jan-May trawl selectivity in largest size bin
- Model 28 was identical to Model 0 except survey selectivity forced asymptotic and *Q* fixed at 0.5
- Model 29 was identical to Model 0 except separate *M* estimated for ages 9+

Preliminary assessment

In general:

- Agecomp data presented as "age conditioned on length" (i.e., not marginals)
- Length-at-age SD a linear function of age
- Annual *dev*s for length at age 1, sigma=0.11
- Annual *dev*s for recruitment, sigma=0.6, 1973-2005
- Annual *dev*s for ascending selectivity, sigma=0.4
- All parameters estimated internally
- Except selectivity parameters pinned against bounds
- Uniform priors used exclusively
- Monotone selectivity for Jan-May trawl fishery
- All other selectivities new "double normal"

Four models were included, all of which were identical to the 2006 final model except as specified above and below:

- Model 1:
  - Estimated effect of 1976 regime shift on median recruitment
  - Added a large constant to fishery CPUE sigmas
- Model 2 was identical to Model 1 except age-dependent *M* estimated for ages 8+
- Model 3 was identical to Model 1 except that it did not add the large constant to longline CPUE sigmas
- Model 4 was identical to Model 1 except:
  - Effect of regime shift assumed to be zero
  - Did not add large constant to longline CPUE sigmas
  - Zero emphasis placed on initial catch and age composition
  - Iteratively re-weighted input sigmas and input *N*

Also attempted but not included:

- Simplified model with only a single fishery and no seasons

Final assessment

Four models were included:

- **Model 1** (comparisons to 2006 final model in parentheses):
    - o *M* fixed at 0.34 (*M* fixed at 0.37 in 2006)
    - o Length-at-age parameters estimated internally (fixed at point estimates from data in 2006)
    - o Start year set at 1977 (start year set at 1964 in 2006)
    - o Three age groups in initial state vector estimated (initial state vector assumed to be in equilibrium in 2006)
    - o 6-parameter double normal selectivity (4-parameter version used in 2006)
    - o Uniform priors used exclusively (informative normal priors used for many parameters in 2006)
    - o Fishery selectivities constant across all years (approximately decadal "time blocks" used in 2006)
    - o Ascending limb of survey selectivity varies annually with σ=0.2 (survey selectivity assumed to be constant in 2006)
    - o Survey selectivity based on age (length-based selectivity used in 2006)
    - o Some fishery selectivities forced asymptotic (all selectivities free in 2006)
    - o Fishery CPUE data included for comparison (not included in 2006)
    - o Age-based maturity schedule (length-based schedule used in 2006)
    - o All fisheries seasonally structured (trawl partially seasonal, other gears non-seasonal in 2006)
    - o Trawl survey abundance measured in numbers (abundance measured in biomass in 2006)
    - o Multinomial *N* based on rescaled bootstrap (sample size set equal to square root of actual *N* in 2006)
- Model 2 was identical to Model 1 except *M* fixed at 0.37
- Model 3 was identical to Model 1 except *M* estimated internally
- Model 4 was identical to Model 1 except:
    - o *M* estimated internally
    - o Survey selectivities forced to be asymptotic
    - o Age data ignored
    - o Start year set at 1982; 1977 regime shift ignored
    - o Length-based maturity used
    - o Length-based survey selectivity used
    - o Sigma=0.4 for annual deviations in selectivity parameters
    - o Initial catch ignored in estimating initial fishing mortality

2008

Preliminary assessment

Five models were included:

- Model 1 was identical to the 2007 final model
- Model 2 was identical to Model 1 except growth parameter *L2* estimated externally
- Model 3 was identical to Model 1 except exponential-logistic selectivity used instead of double normal

- Model 4 was identical to 2007 Model 4
- Model 5 was identical to Model 1 except:
  - o Fishery selectivity blocks (5 yr, 10 yr, 20 yr, or no blocks) chosen by AIC
  - o Lower bound of descending “width” = 5.0
  - o Regime-specific recruitment “dev” vectors
  - o “SigmaR” set equal (iteratively) to stdev(dev) from current regime
  - o Seasonal weight-length, based on fishery data
  - o Number of free initial ages chosen by AIC
  - o Size-at-age data used if modes ambiguous

Final assessment

Eight models were included:

- Model A1 was identical to Model 5 from September except lower bound on selectivity descending “width” parameter relaxed so as not to be constraining
- Model A2 was identical to Model A1, except without age data
- **Model B1** was identical to Model A1, except:
  - o “Asymptotic algorithm” used to determine which fisheries will be forced to exhibit asymptotic selectivity
  - o “Constant-parameters-across-blocks algorithm” used to determine which selectivity parameters can be held constant across blocks
- Model B2 was identical to Model B1, except without age data
- Model C1 was identical to Model B1, except with M estimated internally
- Model D2 was identical to Model B1, except:
  - o No age data
  - o Maturity modeled as function of length rather than age
  - o M estimated iteratively, based on mat. at len and len. at age
- Model E2 was identical to Model B1, except:
  - o No age data
  - o Post-1981 trawl survey selectivity forced to be asymptotic
  - o *M* estimated internally
- Model F2 was identical to Model 4 from the final assessment for 2007, except start year = 1977

2009

Preliminary assessment

Eight models were included, based on factorial design of the following:

- Selectivity functional form: double normal or exponential-logistic?
- Catchability: free or fixed at 1.0?
- Survey selectivity estimation: free or forced asymptotic?

Partial results were presented for a model with a prior distribution for *Q* based on archival tags (the prior had virtually no impact, which was why only partial results were presented)

Other features explored but not included in the above models:

- Fixing trawl survey catchability at the mean of the above normal prior distribution
- Allowing trawl survey catchability to vary as a random walk

- Fixing trawl survey catchability at a value of 1.00 for the pre-1982 portion of the time series, but allowing it to be estimated freely for the post-1981 portion of the time series
- Reducing the number of survey selectivity parameters subject to annual deviations
- Use of additive, rather than multiplicative, deviations for certain survey selectivity parameters
- Decreasing the value of the σ parameter used to constrain annual survey selectivity deviations
- Turning off annual deviations in survey selectivity parameters for the three most recent years
- Turning off all annual deviations in survey selectivity parameters
- Forcing trawl survey selectivity to peak at age 6.5, the approximate mid-point of the size range of 60-81 cm spanned by the results of Nichol et al. (2007)
- Imposing a beta prior distribution on the shape parameter of the exponential-logistic selectivity function in the trawl survey.

Final assessment

Fourteen models were included (all new since the preliminary assessment except for Model A1):

- Models without mean-size-at-age data:
  - Model A1 was identical to the 2008 final model, with the addition of new data, including the first available fishery agecomp data (from the 2008 Jan-May longline fishery)
  - Model A2 was identical to Model A1, except all agecomp data omitted
  - Model A3 was identical to Model A1, except 2008 Jan-May longline fishery agecomp data omitted
  - Model F2 was identical to Model F2 from the final assessment for 2008
- Models with mean-size-at-age data and agecomp data:
  - **Model B1** was identical to Model A1 except:
    - Survey selectivity held constant for most recent two years
    - Cohort-specific growth included
    - Input standard deviations of all “dev” vectors were set iteratively by matching the standard deviations of the set of estimated *dev*s
    - Standard deviation of length at age was estimated outside the model as a linear function of mean length at age
    - Selectivity at maximum size or age was treated as a controllable parameter
    - *Q* for the post-1981 trawl survey was fixed at the value that sets the average (weighted by numbers at length) of the product of *Q* and selectivity for the 60-81 cm size range equal to the point estimate of 0.47 obtained by Nichol et al. (2007)
    - Potential ageing bias was accounted for in the ageing error matrix by examining alternative bias values in increments of 0.1 for ages 2 and above (age-specific bias values were also examined, but did not improve the fit significantly).
  - Model C1 was identical to Model B1 except:
    - Input standard deviations for all “dev” vectors and the amount of ageing bias fixed at the values obtained iteratively in Model B1
    - *Catchability itself* (rather than the average product of catchability and selectivity for the 60-81 cm size range) set equal to 0.47
  - Model D1 was identical to Model B1 except:
    - Input standard deviations for all “dev” vectors and the amount of ageing bias fixed at the values obtained iteratively in Model B1
    - Selectivity at maximum size or age was removed from the set of controllable parameters (instead, selectivity at maximum size or age becomes a function of other selectivity parameters)
  - Model E1 was identical to Model B1 except:

        - Input standard deviations for all "dev" vectors and the amount of ageing bias fixed at the values obtained iteratively in Model B1
        - Selectivity at maximum size or age for all non-asymptotic fleets was set equal to a single value that was constant across fleets
    - Model G1 was identical to Model B1 except:
        - Input standard deviations for all "dev" vectors and the amount of ageing bias fixed at the values obtained iteratively in Model B1
        - Survey selectivity was held constant across all years (i.e., no selectivity *dev*s are estimated for any years)
- Models with mean-size-at-age data and without agecomp data:
    - Models B2, C2, D2, E2, and G2 were identical to their B1, C1, D1, E1, and G1 counterparts except that agecomp data were ignored and the corresponding sizecomp data were active.

2010

Preliminary assessment

Six models were included:

- Model 1 was identical to the 2009 final model
- Model 2 was identical to Model 1 except:
    - Input standard deviations for all "dev" vectors fixed at the values obtained iteratively in Model 1
    - IPHC survey data omitted
    - Fishery age data omitted
    - Traditional 3-or-5 cm size bins replaced with 1 cm size bins
    - Traditional 3-season structure replaced with new, 5-season structure
    - Spawn time changed from beginning of season 1 to beginning of season 2
- Model 3 was identical to Model 2 except:
    - Non-uniform prior distributions used for selectivity parameters and *Q*
- Model 4 was identical to Model 2 except:
    - All age data omitted
    - Maturity schedule was length-based rather than age-based
- Model 5 was identical to Model 4 except:
    - Parameters governing spread of lengths at age around mean length at age estimated internally
- Model 6 was identical to Model 5 except:
    - Cohort-specific growth replaced by annual variability in each of the three von Bertalanffy parameters

Final assessment

Three models were included:

- Model A was identical to Model 1 from the preliminary assessment
- **Model B** was identical Model 2 from the preliminary assessment, except cohort-specific growth replaced by constant growth
- Model C: same as Model 4 from the preliminary assessment, except cohort-specific growth replaced by constant growth

2011

CIE review

Exploratory model developed prior to review, which was the same as the 2010 final model, except:

- All sizecomp data turned on
- Nine season × gear fisheries consolidated into five seasonal fisheries
- Pre-1982 trawl survey data omitted
- Mean-size-at-age data omitted
- Fishery CPUE data omitted
- Average input *N* set to 100 for all fisheries and the survey
- First reference age for length-at-age relationship set at 0.833333
- Richards growth implemented
- Ageing bias estimated internally
- Selectivities modeled as random walks with age (constant for ages 8+)

Twelve new models were developed during the review itself:

- Model 1 was identical to the 2010 final model except:
  - Length at age 0 constrained to be positive
  - Richards growth implemented
- Model 2 was identical to the 2010 final model except length at age 0 constrained to be positive
- Model 3 was identical to the 2010 final model except:
  - All time blocks removed
  - All selectivity parameters freed except fishery selectivity at initial age
  - All selectivity parameters initialized at mid-point of bounds
- Model 4 was identical to the 2010 final model except:
  - All time blocks removed
  - Emphasis on fishery sizecomps set to 0.001
- Model 5 was identical to the 2010 final model except:
  - Richards growth implemented
  - Ageing bias estimated internally
- Model 6 was identical to Model 4 except time blocks included
- Model 7 was identical to the 2010 final model except *Q* estimated internally
- Model 8 was identical to the 2010 final model except *M* estimated internally with an informative prior
- Model 9 was identical to the 2010 final model except tail compression increased
- Model 10 was identical to the 2010 final model except mean-size-at-age data turned off
- Model 11 was the same the “exploratory” model except:
  - Pre-1982 trawl survey data included
  - All time blocks removed
  - Fishery CPUE data included (but not used for estimation)
  - Input *N* set as in the 2010 final model
  - First reference age for length-at-age relationship set at as in the 2010 final model
- Model 12 was identical to Model 11 except two iterations of survey variance and input *N* re-weighting added

Preliminary assessment

Seven models were included:

- Model 1 was identical to the 2010 final model
- Model 2a was identical to Model 1 except for use of spline-based selectivity
- Model 2b was identical to Model 1 except for omission of pre-1982 survey data
- Model 3 was identical to Model 2b except:
    - Ageing bias estimated internally rather than by trial and error
    - First reference age for length-at-age relationship (*amin*) set at 1.0
    - Standard deviation of length at age *amin* tuned iteratively to match the value predicted externally by regression
- Model 4 was identical to Model 2b except:
    - All agecomp data turned off
    - All sizecomp data turned on
    - First reference age for length-at-age relationship (*amin*) set at 1.0
    - Parameters governing standard deviation of length at age estimated internally
- Model A was identical to Model 2b except:
    - First reference age in the mean length-at-age relationship was set at 1.41667, to coincide with age 1 at the time of year when the survey takes place (in Models 1-2b, first reference age was set at 0; in Models 3-4, it was set at 1)
    - Richards growth equation was used (in Models 1-4, von Bertalanffy was used)
    - Ageing bias was estimated internally (as in Model 3; in Models 1-2 and 4, ageing bias was left at the values specified in the 2009 and 2010 assessments—although this was irrelevant for Model 4, which did not attempt to fit the age data)
    - σ_R was estimated internally (in Models 1-4, this parameter was left at the value used in the 2009 and 2010 assessments)
    - Fishery selectivity curves were defined for each of the five seasons, but were not stratified by gear type (in Models 1-4, seasons 1-2 and 4-5 were lumped into a pair of "super" seasons, and fisheries were also *gear*-specific)
    - Selectivity curve for the fishery that came closest to being asymptotic on its own (in this case, the season 4 fishery) was forced to be asymptotic by fixing both *width_of_peak_region* and *final_selectivity* at a value of 10.0 and *descending_width* at a value of 0.0 (in Models 1-4, the Jan-Apr trawl fishery was forced to exhibit asymptotic selectivity)
    - Survey selectivity was modeled as a function of length (in Models 1-4, survey selectivity was modeled as a function of age)
    - Number of estimated year class strengths in the initial numbers-at-age vector was set at 10 (in Models 1-4, only 3 elements were estimated)
    - The following parameters were tuned iteratively:
        - Standard deviation of length at the first reference age was tuned iteratively to match the value from the regression of standard deviation against length at age presented in the final assessment for 2010 (as in Model 3; in Models 1-2, this parameter was set at 0.01 because the first reference age was 0; in Model 4, it was estimated internally)
        - Base value for *Q* was tuned iteratively to set the average of the product of *Q* and survey selectivity across the 60-81 cm range equal to 0.47, corresponding to the Nichol et al. (2007) estimate (in Models 1-4, the base value was left at the value used in the 2009 and 2010 assessments)
        - *Q* was given annual (but not random walk) *dev*s, with σdev tuned iteratively to set the root-mean-squared-standardized-residual of the survey abundance estimates equal to 1.0 (in Models 1-4, *Q* was constant)
        - All estimated selectivity parameters were given annual random walk *dev*s with *σdev* tuned iteratively to match the standard deviation of the estimated *dev*s, except that the *dev*s for any selectivity parameter with a tuned σdev less than 0.005 were removed (in Models 1-4, certain fishery selectivity parameters were estimated independently in pre-specified blocks of years; the only time-varying selectivity parameter for the

survey was *ascending_width*, which had annual—but not random walk—*dev*s with σdev set at the value used in the 2009 and 2010 assessments)
    - Age composition "variance adjustment" multiplier was tuned iteratively to set the mean effective sample size equal to the mean input sample size (in Models 1-4, this multiplier was fixed at 1.0)
- Model 5 was identical to Model A except that it used the time series of selectivity parameters estimated (using random walk *dev*s) in Model A to identify appropriate breakpoints for defining block-specific selectivity parameters

Other model features explored but not included in any of the above:

- Annually varying Brody growth parameter
- Annually varying length at the first reference age
- Internal estimation of standard deviation of length at age
- Ordinary (not random walk) *dev*s for annually varying selectivity parameters
- One selectivity parameter for each age (up to some age-plus group) and fleet, either with ordinary or random walk *dev*s or constant
- Not forcing any fleet to exhibit asymptotic selectivity
- Internal estimation of survey catchability
- Iterative re-weighting of size composition likelihood components
- Internal estimation of the natural mortality rate
- Changing the SS parameter *comp_tail_compression* (the tails of each age or size composition record are compressed until the specified amount was reached; sometimes referred to as "dynamic binning")
- Changing the SS parameter *add_to_comp* (this amount was added to each element of each age or size composition vector—both observed and expected, which avoids taking the logarithm of zero and may also have robustness-related attributes)
- Internal estimation of ageing error variances

Final assessment

Five models were included:

- Model 1 was identical to the 2010 final model (and Model 1 from the preliminary assessment)
- Model 2b was identical to Model 2b from the preliminary assessment
- Model 3 was identical to Model 3 from the preliminary assessment
- Model 4 was identical to Model 4 from the preliminary assessment
- **Model 3b** was identical to Model 3 from the preliminary assessment except:
    - Parameters governing variability in length at age estimated internally
    - All sizecomp data turned on
    - Mean-size-at-age data turned off

2012

Preliminary assessment

Five primary and nine secondary models were included (names of secondary models have decimal points; full results presented for primary models only):

- Model 1 was identical to the 2011 final model
    - Model 1.1: Same as Model 1, except survey catchability estimated internally
    - Model 1.2: Same as Model 1, except ageing bias parameters fixed at GOA values

  - Model 1.3 Same as Model 1, except with revised weight-length representation
- Model 2 was identical to Model 1, except survey catchability re-tuned to match archival tag data
- Model 3 was identical to Model 1, except new fishery selectivity period beginning in 2008
- Model 4 was identical to Model 4 from the final assessment for 2011
  - Model Pre5.1: Same as Model 1.3, except for three minor changes to the data file
  - Model Pre5.2: Same as Model Pre5.1, except ages 1-10 in the initial vector estimated individually
  - Model Pre5.3: Same as Model Pre5.2, except Richards growth curve used
  - Model Pre5.4: Same as Model Pre5.3, except σ for recruitment *dev*s estimated internally as a free parameter
  - Model Pre5.5: Same as Model Pre5.4, except survey selectivity modeled as a function of length
  - Model Pre5.6: Same as Model Pre5.5, except fisheries defined by season only (not season-and-gear)
- Model 5: Same as Model Pre5.6, except four quantities estimated iteratively:
  - Survey catchability tuned to match archival tag data
  - Agecomp *N* tuned to set the mean ratio of effective *N* to input *N* equal to 1
  - Selectivity *dev* sigmas tuned according to the new method described in Annex 2.1.1 of the SAFE chapter

Final assessment

Four models were included:

- **Model 1** was identical to the 2011 final model
- Model 2 was identical to Model 1 except *Q* was estimated freely
- Model 3 was identical to Model 1 except:
  - Ageing bias was not estimated
  - All agecomp data are ignored
- Model 4 was identical to Model 5 from the the preliminary assessment

2013

Preliminary assessment

Four models were included:

- Model 1 was identical to the 2012 final model
- Model 2 was identical to Model 4 from the final 2012 assessment except *Q* estimated internally using a non-constraining uniform prior distribution
- Model 3 was identical to Model 4 from the final 2012 assessment except:
  - *Q* estimated internally using a prior distribution based on archival tagging data
  - Survey selectivity forced asymptotic
- Model 4 was identical to Model 4 from the final 2012 assessment

Final assessment

Due to a protracted government shutdown during the peak of the final assessment season, only one model was presented:

- The **unnumbered model** was identical to the 2012 final model

2014

Preliminary assessment

Six models were included:

- Model 1 was identical to the 2011-2013 final models
- Model 2 was the identical to Model 5 from the 2012 preliminary assessment (also identical to Model 4 in the 2012 final assessment and the 2013 preliminary assessment)
- Model 3 was identical to Model 2, except that survey catchability Q was fixed at 1.0
- Model 4 was identical to Model 2, except that Q was estimated with a uniform prior and with an internally estimated constant added to each year's log-scale survey abundance standard deviation
- Model 5 was identical to Model 2, except that Q was fixed at 1.0, survey selectivity was forced to be asymptotic, and the natural mortality rate M was estimated freely
- Model 6 was a substantially new model, with the following differences from Model 1:
    - Each year consisted of a single season instead of five
    - A single fishery was defined instead of nine season-and-gear-specific fisheries
    - The survey was assumed to sample age 1 fish at true age 1.5 instead of 1.41667
    - Initial abundances were estimated for the first ten age groups instead of the first three
    - The natural mortality rate was estimated internally
    - The base value of survey catchability was estimated internally
    - Length at age 1.5 was allowed to vary annually
    - Survey catchability was allowed to vary annually
    - Selectivity for both the fishery and the survey were allowed to vary annually
    - 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
    - Several quantities were tuned iteratively: prior distributions for selectivity parameters, catchability, and time-varying parameters other than catchability

Final assessment

Two models were included:

- **Model 1** was identical to the 2011-2013 final models
- Model 2 was identical to Model 2 from the preliminary assessment, except that the $L1$ growth parameter was not allowed to vary with time

2015

Preliminary assessment

Eight models were included.

Group A:

- Model 0 was the same as Model 1 from the 2014 final assessment.
- Model 7 was the same as Model 0, but with composition data weighted by Equation TA1.8 of Francis (2011).
- Model 8 was the same as Model 0, but with Richards growth (Model 0 used von Bertalanffy growth, which is a special case of Richards growth).

Subgroup B1:

- Model 2 was the same as Model 2 from the 2014 final assessment.
- Model 3 was the same as Model 2, but with composition data weighted by tuning the mean input sample size to the harmonic mean of the effective sample size, and with time-varying survey catchability (*Q*) turned off.
- Model 4 was the same as Model 2, but with 20 age groups estimated in the initial numbers-at-age vector (Model 2 estimated 10 age groups in the initial numbers-at-age vector).

For all models in Subgroup B1, selectivity prior distributions and the parameters governing time-variability in recruitment, selectivity, and survey catchability were *not* re-tuned. That is, they were left at the values estimated for Model 2 during the 2014 assessment, except that time variability in survey catchability was turned off in Model 3. Note that the tuning for Model 2 was performed during the 2014 *preliminary* assessment (where it was labeled Model 6), and was not updated during the final 2014 assessment.

Subgroup B2:

- Model 5 was based on Model 2, but had a number of differences (described below), one of which was that SS runs were accepted even if the gradient was large, so long as the estimated covariance matrix of the parameters appeared reasonable.
- Model 6 was the same as Model 5, except that SS runs were accepted only if the gradient was small. In the event that a large gradient was obtained, age-specific selectivity *dev* vectors were removed, one at a time, until the large gradient disappeared.

Except for some procedures related to iterative tuning (see next set paragraph), the differences between Model 5 and Model 2 were as follow:

- 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.
- 20 age groups were estimated in the initial numbers-at-age vector.
- Selectivity at ages 9+ was constrained to equal selectivity at age 8 for both the fishery and the survey.
- A superfluous selectivity parameter was fixed at the mean of the prior (in Model 2, the estimate of this parameter automatically went to the mean of the prior).
- 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).
- SS runs were accepted even if the gradient was large, so long as the estimated covariance matrix of the parameters appeared reasonable (i.e., all values were numeric, no values were unbelievably large).

Iterative tuning of prior distributions for selectivity parameters and time-varying catchability in Model 5 proceeded as in Model 2, except that all iterative tuning procedures were undertaken simultaneously, rather than in the phased approach used for Model 2. For time-varying recruitment and selectivity, the approach used in Model 2, which was based on the method of Thompson and Lauth (2012), was not retained in Model 5. For a univariate model, *if* the method of Thompson and Lauth (2012) returns a non-zero estimate of σ, there is reason to believe that this estimate will be unbiased. However, the method carries a fairly high probability of returning a "false negative;" that is, returning a zero estimate for σ when the true value is non-zero (Thompson in prep.). To reduce this bias toward under-parameterization, the following algorithm was used in Model 5 (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.

As noted above, the procedure used in Model 5 for iterative tuning of time-varying *Q* was the same as that used in Model 2. However, unlike Model 2, this procedure resulted in time-varying *Q* being "tuned out" in Model 5. Model 6, which also used this procedure, ended up retaining time-varying *Q*.

Final assessment

The final assessment included the same two models that were featured in the 2014 final assessment:

- **Model 11.5** was identical to the 2011-2014 final models
- Model 14.2 was identical to Model 2 from the 2014 final assessment

APPENDIX 2.4: SUPPLEMENTAL CATCH DATA

NMFS Alaska Region has made substantial progress in developing a database documenting many of the removals of FMP species that have resulted from activities outside of fisheries prosecuted under the BSAI Groundfish FMP, including removals resulting from scientific research, subsistence fishing, personal use, recreational fishing, exempted fishing permit activities, and commercial fisheries other than those managed under the BSAI groundfish FMP. Estimates for EBS Pacific cod from this dataset are shown in Table 2.4.1.

Although many sources of removal are documented in Table 2.4.1, the time series is highly incomplete for many of these. Cells shaded gray represent data contained in the NMFS database. Other entries represent extrapolations for years in which the respective activity was known or presumed to have taken place, where each extrapolated value consists of the time series average of the official data for the corresponding activity. In the case of surveys, years with missing values were identified from the literature or by contacting individuals knowledgeable about the survey (the NMFS database contains names of contact persons for most activities); in the case of fisheries, it was assumed that the activity occurred every year.

In the 2012 analysis (Attachment 2.4 of Thompson and Lauth 2012), the supplemental catch data were used to provide estimates of potential impacts of these data in the event that they were included in the catch time series used in the assessment model. The results of that analysis indicated that $F_{40\%}$ increased by about 0.01 and that the one-year-ahead catch corresponding to harvesting at $F_{40\%}$ decreased by about 4,000 t. Note that this is a separate issue from the effects of taking other removals “off the top” when specifying an ABC for the groundfish fishery; the former accounts for the impact on reference points, while the latter accounts for the fact that “other” removals will continue to occur.

The average of the total removals in Table 2.4.1 for the last three complete years (2013-2015) is 8,878 t.

It should be emphasized that these calculations are provided purely for purposes of comparison and discussion, as NMFS and the Council continue to refine policy pertaining to treatment of removals from sources other than the directed groundfish fishery.

Reference

Thompson, G. G., and R. R. Lauth. 2012. Assessment of the Pacific cod stock in the Eastern Bering Sea and Aleutian Islands Area. *In* Plan Team for Groundfish Fisheries of the Bering Sea/Aleutian Islands (compiler), Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, p. 245-544. North Pacific Fishery Management Council, 605 W. 4th Avenue Suite 306, Anchorage, AK 99501.

Table 2.4.1—Total removals of Pacific cod (t) from activities not related to directed fishing. Cells shaded gray represent data contained in the NMFS database. Other entries represent extrapolations for years in which the respective activity was known or presumed to have taken place.

Activity	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Aleutian Island Bottom Trawl Survey				2			2			2					2			2	
Annual Longline Survey						28	28	28	28	28	28	28	28	28	28	28	28	28	
Bait for Crab Fishery	6547	6547	6547	6547	6547	6547	6547	6547	6547	6547	6547	6547	6547	6547	6547	6547	6547	6547	6547
Bering Sea Acoustic Survey			0			0			0			0			0			0	
Bering Sea Slope Survey			1		1	1			1			1			1				
Eastern Bering Sea Bottom Trawl Survey	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Gulf of Alaska Bottom Trawl Survey								0			0			0			0		
IPHC Annual Longline Survey																			
Large-Mesh Trawl Survey														1	1			1	1
Northern Bering Sea Bottom Trawl Survey			1		1	1			1			1			1				
Pollock EFP 11-01																			
Pribilof Islands Crab Survey																			
St. Mathews Crab Survey																			9
Subsistence Fishery	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	0	2	5	2
Summer EBS Survey with Russia																		0	

Activity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Aleutian Island Bottom Trawl Survey		2			2		2		2		2				2		1		2	
Annual Longline Survey		38		30		28		30		23		25		20		24		27		32
Bait for Crab Fishery	6547	6547	6547	6547	6547	6547	6547	6547	6547	6547	6547	6547	6547	6547	1737	4544	6697	6618	9452	10233
Bering Sea Acoustic Survey	0	0		0	0		0		0		0	0	0	0	0		0			
Bering Sea Slope Survey					1		1		1				1		2		1	1	1	
Eastern Bering Sea Bottom Trawl Survey	40	40	40	40	40	40	40	40	40	40	40	40	40	40	38	42	52	33	39	39
Gulf of Alaska Bottom Trawl Survey	0			0		0		0		0		0		0		0		0		0
IPHC Annual Longline Survey			35	35	35	35	35	35	35	35	35	35	35	35	32	20	17	29	52	59
Large-Mesh Trawl Survey				1	1			1	1	1	1	1	1	1	1	1	2	1	1	1
Northern Bering Sea Bottom Trawl Survey															1					
Pollock EFP 11-01																11	307			
Pribilof Islands Crab Survey								5		5			5			5				
St. Mathews Crab Survey			9			9			9			9			9			9		
Subsistence Fishery	2	2	1	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Summer EBS Survey with Russia							0		0			0	0	0	0		0			

APPENDIX 2.5: PARALLEL RESULTS FOR THE "HARVEST RECOMMENDATIONS" SECTION, BASED ON MODEL 11.5

The results presented in the "Harvest Recommendations" section of the main text are based on Model 16.6. Because the structure of this model differs substantively from Model 11.5 (the model accepted for the last five years by the SSC), a set of parallel results for the items in that section, based on Model 11.5, is provided here.

Amendment 56 Reference Points

For a stock exploited by multiple gear types, estimation of $F_{35\%}$ and $F_{40\%}$ requires an assumption regarding the apportionment of fishing mortality among those gear types. For this assessment, the apportionment was based on Model 11.5's estimates of fishing mortality by gear for the five most recent complete years of data (2011-2015). The average fishing mortality rates for those years implied that total fishing mortality was divided among the three main gear types according to the following percentages: trawl 32.6%, longline 51.8%, and pot 15.6%. This apportionment results in estimates of $F_{35\%}$ and $F_{40\%}$ equal to 0.34 and 0.28, respectively. Model 11.5's estimates of $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are 788,000 t, 315,000 t, and 276,000 t, respectively.

Specification of OFL and Maximum Permissible ABC

Given the assumptions of Scenario 2 (below), female spawning biomass for 2017 and 2018 is estimated by Model 11.5 to be well above the $B_{40\%}$ value of 315,000 t, thereby placing Pacific cod in sub-tier "a" of Tier 3 for both 2017 and 2018. Given this, Model 11.5 estimates OFL, maximum permissible ABC, and the associated fishing mortality rates for 2017 and 2018 as follows:

Year	Overfishing Level	Maximum Permissible ABC
2017	OFL = 396,000 t	maxABC = 338,000 t
2018	OFL = 381,000 t	maxABC = 325,000 t
2017	*FOFL* = 0.34	*maxFABC* = 0.28
2018	*FOFL* = 0.34	*maxFABC* = 0.28

The age 0+ biomass projections for 2017 and 2018 from Model 11.5 (using SS rather than the standard projection model) are 1,760,000 t and 1,580,000 t. For comparison, the age 3+ biomass projections for 2017 and 2018 from Model 11.5 (again using SS) are 1,750,000 t and 1,540,000 t.

Standard Harvest Scenarios, Projection Methodology, and Projection Results

The standard harvest scenarios and projection methodology were the same as described for Model 16.6 in the main text. Projections corresponding to the standard scenarios are shown for Model 11.5 in Tables 2.5.30-2.5.36 (table numbering is kept the same as in the main text, so as to facilitate comparisons).

Status Determination

Methodology for status determination is as described in the main text. The status with respect to overfishing is independent of model choice for next year's specifications, as it depends entirely on the previous year's catch and OFL.

Based on the criteria described in the main text Tables 2.5.35 and 2.5.36, the stock is not overfished and is not approaching an overfished condition.

Table 2.5.30—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in 2017-2029 (Scenario 1), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	338,000	338,000	338,000	338,000	0
2018	312,000	312,000	312,000	312,000	0
2019	267,000	267,000	267,000	267,000	4
2020	232,000	233,000	233,000	236,000	1,264
2021	196,000	209,000	214,000	245,000	16,419
2022	163,000	197,000	207,000	279,000	38,109
2023	140,000	202,000	212,000	321,000	56,840
2024	125,000	213,000	219,000	338,000	67,951
2025	117,000	219,000	225,000	345,000	73,411
2026	118,000	225,000	228,000	356,000	75,089
2027	118,000	229,000	230,000	358,000	74,578
2028	121,000	227,000	230,000	357,000	73,106
2029	121,000	229,000	230,000	358,000	72,325

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	431,000	431,000	431,000	431,000	0
2018	432,000	432,000	432,000	432,000	0
2019	394,000	394,000	394,000	394,000	44
2020	340,000	341,000	341,000	343,000	983
2021	299,000	304,000	306,000	318,000	6,532
2022	273,000	290,000	295,000	335,000	20,644
2023	254,000	289,000	299,000	375,000	40,654
2024	239,000	295,000	307,000	423,000	57,415
2025	230,000	301,000	314,000	440,000	67,371
2026	228,000	303,000	320,000	447,000	72,770
2027	230,000	309,000	323,000	461,000	74,884
2028	231,000	308,000	324,000	465,000	74,125
2029	233,000	308,000	324,000	467,000	72,460

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	0.28	0.28	0.28	0.28	0.00
2018	0.28	0.28	0.28	0.28	0.00
2019	0.28	0.28	0.28	0.28	0.00
2020	0.28	0.28	0.28	0.28	0.00
2021	0.27	0.27	0.27	0.28	0.00
2022	0.24	0.26	0.26	0.28	0.01
2023	0.22	0.26	0.26	0.28	0.02
2024	0.21	0.26	0.26	0.28	0.03
2025	0.20	0.27	0.26	0.28	0.03
2026	0.20	0.27	0.26	0.28	0.03
2027	0.20	0.28	0.26	0.28	0.03
2028	0.20	0.27	0.26	0.28	0.03
2029	0.20	0.27	0.26	0.28	0.03

Table 2.5.31—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that catch in 2017 is less than ABC by an amount predicted from past performance, but that $F = max\ F_{ABC}$ in 2018-2029 (Scenario 2), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	262,000	262,000	262,000	262,000	0
2018	254,000	254,000	254,000	254,000	0
2019	290,000	290,000	290,000	290,000	4
2020	247,000	248,000	249,000	251,000	1,264
2021	216,000	226,000	230,000	255,000	13,599
2022	172,000	208,000	217,000	284,000	37,344
2023	144,000	206,000	216,000	325,000	56,664
2024	126,000	215,000	220,000	339,000	68,040
2025	118,000	220,000	225,000	347,000	73,534
2026	118,000	225,000	228,000	357,000	75,186
2027	118,000	229,000	230,000	358,000	74,636
2028	121,000	227,000	230,000	357,000	73,137
2029	121,000	229,000	230,000	358,000	72,339

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	440,000	440,000	440,000	440,000	0
2018	462,000	462,000	462,000	462,000	0
2019	432,000	432,000	432,000	432,000	44
2020	368,000	368,000	369,000	370,000	983
2021	316,000	322,000	323,000	336,000	6,919
2022	282,000	299,000	305,000	346,000	21,591
2023	258,000	293,000	303,000	382,000	41,660
2024	241,000	297,000	309,000	427,000	58,213
2025	230,000	301,000	315,000	443,000	67,870
2026	228,000	303,000	320,000	447,000	73,029
2027	230,000	309,000	323,000	461,000	75,002
2028	231,000	308,000	324,000	465,000	74,173
2029	233,000	308,000	324,000	467,000	72,477

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	0.21	0.21	0.21	0.21	0.00
2018	0.22	0.22	0.22	0.22	0.00
2019	0.28	0.28	0.28	0.28	0.00
2020	0.28	0.28	0.28	0.28	0.00
2021	0.28	0.28	0.28	0.28	0.00
2022	0.25	0.27	0.27	0.28	0.01
2023	0.23	0.26	0.26	0.28	0.02
2024	0.21	0.26	0.26	0.28	0.03
2025	0.20	0.27	0.26	0.28	0.03
2026	0.20	0.27	0.26	0.28	0.03
2027	0.20	0.28	0.26	0.28	0.03
2028	0.20	0.27	0.26	0.28	0.03
2029	0.20	0.27	0.26	0.28	0.03

Table 2.5.32—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that the upper bound on F_{ABC} is set the most recent five-year average fishing mortality rate in 2017-2029 (Scenario 3), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	365,000	365,000	365,000	365,000	0
2018	331,000	331,000	331,000	331,000	0
2019	280,000	280,000	280,000	280,000	4
2020	241,000	242,000	242,000	245,000	1,374
2021	213,000	224,000	228,000	255,000	14,739
2022	191,000	220,000	228,000	291,000	33,585
2023	172,000	223,000	233,000	336,000	50,865
2024	159,000	228,000	238,000	352,000	61,363
2025	151,000	231,000	242,000	359,000	66,900
2026	150,000	234,000	245,000	371,000	69,070
2027	150,000	236,000	245,000	370,000	68,639
2028	152,000	234,000	245,000	370,000	66,993
2029	151,000	235,000	244,000	369,000	66,159

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	428,000	428,000	428,000	428,000	0
2018	422,000	422,000	422,000	422,000	0
2019	379,000	379,000	379,000	379,000	44
2020	322,000	323,000	323,000	325,000	983
2021	280,000	285,000	287,000	300,000	6,898
2022	250,000	269,000	274,000	317,000	22,179
2023	224,000	264,000	274,000	356,000	43,704
2024	203,000	268,000	279,000	402,000	61,599
2025	189,000	273,000	284,000	416,000	72,182
2026	184,000	275,000	289,000	423,000	77,726
2027	183,000	280,000	291,000	432,000	79,663
2028	184,000	280,000	292,000	438,000	78,782
2029	183,000	280,000	291,000	438,000	77,148

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	0.31	0.31	0.31	0.31	0.00
2018	0.31	0.31	0.31	0.31	0.00
2019	0.31	0.31	0.31	0.31	0.00
2020	0.31	0.31	0.31	0.31	0.00
2021	0.31	0.31	0.31	0.31	0.00
2022	0.31	0.31	0.31	0.31	0.00
2023	0.31	0.31	0.31	0.31	0.00
2024	0.31	0.31	0.31	0.31	0.00
2025	0.31	0.31	0.31	0.31	0.00
2026	0.31	0.31	0.31	0.31	0.00
2027	0.31	0.31	0.31	0.31	0.00
2028	0.31	0.31	0.31	0.31	0.00
2029	0.31	0.31	0.31	0.31	0.00

Table 2.5.33—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that the upper bound on F_{ABC} is set at $F_{60\%}$ in 2017-2029 (Scenario 4), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	176,000	176,000	176,000	176,000	0
2018	178,000	178,000	178,000	178,000	0
2019	166,000	166,000	166,000	166,000	2
2020	153,000	153,000	153,000	155,000	630
2021	141,000	146,000	148,000	161,000	6,890
2022	130,000	144,000	148,000	179,000	16,420
2023	120,000	146,000	151,000	205,000	26,408
2024	112,000	150,000	155,000	219,000	33,680
2025	106,000	152,000	158,000	224,000	38,191
2026	105,000	153,000	160,000	235,000	40,514
2027	103,000	155,000	161,000	235,000	41,165
2028	105,000	156,000	161,000	237,000	40,672
2029	104,000	157,000	162,000	236,000	40,161

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	450,000	450,000	450,000	450,000	0
2018	498,000	498,000	498,000	498,000	0
2019	500,000	500,000	500,000	500,000	44
2020	468,000	469,000	469,000	471,000	985
2021	432,000	437,000	439,000	452,000	7,036
2022	401,000	421,000	427,000	473,000	23,733
2023	371,000	416,000	428,000	524,000	50,269
2024	343,000	421,000	436,000	591,000	76,480
2025	322,000	428,000	444,000	624,000	95,296
2026	308,000	436,000	452,000	640,000	106,998
2027	306,000	442,000	458,000	665,000	113,140
2028	304,000	445,000	461,000	669,000	114,582
2029	301,000	448,000	463,000	672,000	113,442

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	0.14	0.14	0.14	0.14	0.00
2018	0.14	0.14	0.14	0.14	0.00
2019	0.14	0.14	0.14	0.14	0.00
2020	0.14	0.14	0.14	0.14	0.00
2021	0.14	0.14	0.14	0.14	0.00
2022	0.14	0.14	0.14	0.14	0.00
2023	0.14	0.14	0.14	0.14	0.00
2024	0.14	0.14	0.14	0.14	0.00
2025	0.14	0.14	0.14	0.14	0.00
2026	0.14	0.14	0.14	0.14	0.00
2027	0.14	0.14	0.14	0.14	0.00
2028	0.14	0.14	0.14	0.14	0.00
2029	0.14	0.14	0.14	0.14	0.00

Table 2.5.34—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that *F* = 0 in 2017-2029 (Scenario 5), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	0	0	0	0	0
2018	0	0	0	0	0
2019	0	0	0	0	0
2020	0	0	0	0	0
2021	0	0	0	0	0
2022	0	0	0	0	0
2023	0	0	0	0	0
2024	0	0	0	0	0
2025	0	0	0	0	0
2026	0	0	0	0	0
2027	0	0	0	0	0
2028	0	0	0	0	0
2029	0	0	0	0	0

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	469,000	469,000	469,000	469,000	0
2018	574,000	574,000	574,000	574,000	0
2019	634,000	634,000	634,000	634,000	44
2020	648,000	649,000	649,000	651,000	987
2021	640,000	645,000	647,000	661,000	7,154
2022	625,000	646,000	652,000	700,000	25,135
2023	603,000	652,000	666,000	775,000	56,696
2024	576,000	668,000	686,000	873,000	92,585
2025	552,000	686,000	706,000	945,000	122,848
2026	530,000	702,000	724,000	988,000	144,846
2027	524,000	715,000	739,000	1,020,000	159,213
2028	520,000	727,000	750,000	1,050,000	166,537
2029	522,000	738,000	757,000	1,060,000	168,671

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	0.00	0.00	0.00	0.00	0.00
2018	0.00	0.00	0.00	0.00	0.00
2019	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00
2021	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00
2023	0.00	0.00	0.00	0.00	0.00
2024	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00
2026	0.00	0.00	0.00	0.00	0.00
2027	0.00	0.00	0.00	0.00	0.00
2028	0.00	0.00	0.00	0.00	0.00
2029	0.00	0.00	0.00	0.00	0.00

Table 2.5.35—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = F_{OFL}$ in 2017-2029 (Scenario 6), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	396,000	396,000	396,000	396,000	0
2018	353,000	353,000	353,000	353,000	0
2019	293,000	293,000	293,000	293,000	5
2020	241,000	243,000	243,000	247,000	2,131
2021	189,000	203,000	208,000	243,000	18,956
2022	162,000	198,000	211,000	301,000	45,354
2023	142,000	209,000	223,000	358,000	67,524
2024	128,000	222,000	234,000	373,000	79,141
2025	121,000	228,000	241,000	382,000	84,426
2026	122,000	232,000	244,000	393,000	85,613
2027	123,000	235,000	245,000	391,000	84,663
2028	124,000	234,000	244,000	396,000	83,011
2029	127,000	237,000	244,000	391,000	82,306

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	424,000	424,000	424,000	424,000	0
2018	410,000	410,000	410,000	410,000	0
2019	361,000	361,000	361,000	361,000	44
2020	304,000	304,000	304,000	306,000	887
2021	267,000	272,000	273,000	285,000	6,143
2022	248,000	264,000	269,000	306,000	19,393
2023	233,000	267,000	275,000	348,000	37,300
2024	221,000	275,000	283,000	385,000	51,225
2025	214,000	280,000	290,000	395,000	58,871
2026	213,000	282,000	294,000	408,000	62,832
2027	215,000	284,000	296,000	412,000	64,070
2028	215,000	284,000	296,000	419,000	62,861
2029	216,000	284,000	295,000	418,000	61,231

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	0.34	0.34	0.34	0.34	0.00
2018	0.34	0.34	0.34	0.34	0.00
2019	0.34	0.34	0.34	0.34	0.00
2020	0.32	0.32	0.32	0.33	0.00
2021	0.28	0.29	0.29	0.30	0.01
2022	0.26	0.28	0.28	0.33	0.02
2023	0.24	0.28	0.29	0.34	0.03
2024	0.23	0.29	0.29	0.34	0.04
2025	0.22	0.30	0.29	0.34	0.04
2026	0.22	0.30	0.29	0.34	0.04
2027	0.22	0.30	0.29	0.34	0.04
2028	0.22	0.30	0.30	0.34	0.04
2029	0.22	0.30	0.29	0.34	0.04

Table 2.5.36—Projections for EBS Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in each year 2017-2018 and $F = F_{OFL}$ thereafter (Scenario 7), with random variability in future recruitment.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	338,000	338,000	338,000	338,000	0
2018	312,000	312,000	312,000	312,000	0
2019	313,000	313,000	313,000	313,000	5
2020	263,000	264,000	264,000	267,000	1,505
2021	201,000	215,000	220,000	257,000	19,688
2022	166,000	203,000	215,000	307,000	45,333
2023	143,000	210,000	224,000	358,000	67,298
2024	129,000	221,000	234,000	372,000	79,034
2025	121,000	228,000	240,000	382,000	84,413
2026	122,000	232,000	244,000	393,000	85,629
2027	123,000	235,000	245,000	391,000	84,676
2028	124,000	234,000	244,000	396,000	83,017
2029	127,000	237,000	244,000	391,000	82,308

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	431,000	431,000	431,000	431,000	0
2018	432,000	432,000	432,000	432,000	0
2019	388,000	388,000	388,000	388,000	44
2020	321,000	322,000	322,000	324,000	983
2021	276,000	281,000	283,000	295,000	6,288
2022	252,000	268,000	273,000	310,000	19,442
2023	234,000	268,000	277,000	349,000	37,311
2024	222,000	275,000	284,000	386,000	51,224
2025	214,000	280,000	290,000	396,000	58,865
2026	213,000	282,000	294,000	408,000	62,822
2027	214,000	284,000	296,000	412,000	64,058
2028	215,000	284,000	296,000	419,000	62,850
2029	216,000	284,000	295,000	418,000	61,222

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2017	0.28	0.28	0.28	0.28	0.00
2018	0.28	0.28	0.28	0.28	0.00
2019	0.34	0.34	0.34	0.34	0.00
2020	0.34	0.34	0.34	0.34	0.00
2021	0.29	0.30	0.30	0.31	0.01
2022	0.26	0.28	0.29	0.33	0.02
2023	0.24	0.28	0.29	0.34	0.03
2024	0.23	0.29	0.29	0.34	0.04
2025	0.22	0.30	0.29	0.34	0.04
2026	0.22	0.30	0.29	0.34	0.04
2027	0.22	0.30	0.29	0.34	0.04
2028	0.22	0.30	0.29	0.34	0.04
2029	0.22	0.30	0.29	0.34	0.04