Chapter 2A: Assessment of the Pacific Cod Stock in the Aleutian Islands

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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 Aleutian Islands (AI) Pacific cod stock assessment.

Changes in the Input Data

1) Catch data for 1991-2015 were updated, and preliminary catch data for 2016 were included.
2) The biomass estimate from the 2016 AI bottom trawl survey was incorporated (the 2016 estimate of 84,409 t was up about 15% from the 2014 estimate).

Changes in the Assessment Methodology

Although harvest specifications for AI Pacific cod have been based on Tier 5 methods ever the AI and EBS stocks began to be managed separately (in 2014), age-structured models of this stock have been explored in both versions (preliminary and final) of every assessment from 2012 (Thompson and Lauth 2012) up through this year's preliminary assessment. One Tier 5 model and five age-structured models were presented in this year's preliminary assessment (Appendix 2A.1). After reviewing this year's preliminary assessment, the Plan Team and SSC recommended that no age-structured models be included in this year's final assessment of the AI Pacific cod stock, so that more time would be available for development of new age-structured models of the EBS Pacific cod stock. Thus, this year's final assessment includes no changes in assessment methodology.

Summary of Results

The principal results of the present assessment, based on the authors' 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	5	5	5	5
Biomass (t)	68,900	68,900	79,600	79,600
F_{OFL}	0.34	0.34	0.36	0.36
$maxF_{ABC}$	0.26	0.26	0.27	0.27
F_{ABC}	0.26	0.26	0.27	0.27
OFL (t)	23,400	23,400	28,700	28,700
maxABC (t)	17,600	17,600	21,500	21,500
ABC (t)	17,600	17,600	21,500	21,500
Status	As determined *last* year for: 2014	2015	As determined *this* year for: 2015	2016
Overfishing	No	n/a	No	n/a

Responses to SSC and Plan Team Comments on Assessments in General

Four comments on assessments in general were addressed in the preliminary assessment (Appendix 2A.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):

SSC8 (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.

SSC9 (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.

SSC10 (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

Three comments specific to this assessment, one of which contained several parts, were addressed in the preliminary assessment (Appendix 2A.1). In the interest of efficiency, they are not repeated in this section. One other comment from the 12/15 SSC meeting was deferred until this year's final assessment:

SSC5 (12/15 minutes): *"One additional recommendation from the SSC is to examine weights-at-age of Pacific cod by area."* Weights at age are presented by area in the "Data" section.

BSAI Plan Team (BPT) and SSC comments that were developed following completion of the preliminary assessment are shown below.

BPT1 (9/16 minutes): *"The Team recommends staying with the status quo model (Model 13.4), allow the SSC to comment on this draft document, and to focus more on developing and improving models for the Bering Sea stock. However, Model 16.1 is the Team's preferred age-structured model, and the Team appreciates the progress made. However, the Team sees a benefit of spending more time on developing age-structured models and methods using the EBS stock."* Other than the models from the preliminary assessment described in Appendix 2A.1, Model 13.4 is the only model presented here. Limiting the number of AI models in this way made it possible for the EBS assessment to contain all six models that were requested for that stock (see comment SSC11).

BPT2 (9/16 minutes): *"The Plan Team has concerns regarding the form of the selectivity and the new data sources. We feel that these issues cannot be fully examined by November, but the Team recommends that they be addressed in the next cycle (2017)."* This comment will be forwarded to the Joint Team Subcommittee on Pacific Cod Models for consideration at next year's meeting (see comment SSC13).

SSC11 (10/16 minutes): *"While the SSC strongly encourages further development of the model, we endorse the Plan Team recommendation to focus on the EBS models for this assessment cycle and not bring forward an age-structured model for AI Pacific Cod stock at this time."* Other than the models from the preliminary assessment described in Appendix 2A.1, Model 13.4 is the only model presented here (see comment BPT1).

SSC12 (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."* Multi-model inference was not feasible for this assessment, given that only one model is presented (see comments BPT1 and SSC11).

SSC13 (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.

SSC14 (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 the only model requested for this assessment is not age-structured, this recommendation will be forwarded to the Joint Team Subcommittee on Pacific Cod Models for consideration at next year's meeting (see comment SSC13).

SSC15 (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."* This recommendation will be forwarded to the Joint Team Subcommittee on Pacific Cod Models for consideration at next year's meeting (see comment SSC13).

SSC16 (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 SSC13).

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, Japanese vessels began harvesting Pacific cod in the AI. However, these catches were not particularly large, and by the time that the Magnuson Fishery Conservation and Management Act went into effect in 1977, foreign catches of Pacific cod in the AI had never exceeded 4,200 t. Joint venture fisheries began operations in the AI in 1981, and peaked in 1987, with catches totaling over 10,000 t. Foreign fishing for AI Pacific cod ended in 1986, followed by an end to joint venture fishing in 1990. Domestic fishing for AI Pacific cod began in 1981, with a peak catch of over 43,000 t in 1992.

Presently, the Pacific cod stock is exploited by a multiple-gear fishery, including primarily trawl and longline components. Pot gear also accounted for some of the catch through 2014 (averaging 8% of the total from 1991-2014), but there have not been any catches by pot gear since then. Jig gear also contributes some of the catch, although the amounts are very small in comparison to the other three main gear types, with an average annual catch of less than 24 t since 1991. The breakdown of catch by gear during the most recent complete year (2015) is as follows: trawl gear accounted for 66% of the catch, and longline gear accounted for 34%.

Historically, Pacific cod were caught throughout the AI. For the last five years prior to enactment of additional Steller sea lion (*Eumetopias jubatus*) protective regulations in 2011, the proportions of Pacific cod catch in statistical areas 541 (Eastern AI), 542 (Central AI), and 543 (Western AI) averaged 58%, 19%, and 23%, respectively. For the period 2011-2014, the average distribution has was 84%, 16%, and 0%, respectively. In 2015, area 543 was reopened to limited fishing for Pacific cod (see “Management History” below). The average catch distribution for 2015-2016 (through October 23, 2016) was 54%, 19%, and 27%, respectively.

Catches of Pacific cod taken in the AI for the periods 1964-1980, 1981-1990, and 1991-2016 are shown in Tables 2A.1a, 2A.1b, and 2A.1c, respectively. The catches in Tables 2A.1a and 2A.1b are broken down by fleet sector (foreign, joint venture, domestic annual processing). The catches in Table 2A.1b are also broken down by gear to the extent possible. The catches in Table 2A.1c are broken down by gear. Table 2A.1d breaks down catches from 1994-2016 by 3-digit statistical area (area breakdowns not available prior to 1994), both in absolute terms and as proportions of the yearly totals.

Appendix 2A.2 contains an economic performance report on the BSAI Pacific cod fishery.

Effort and CPUE

Figure 2A.1 shows, subject to confidentiality restrictions, the approximate locations in which trawl hauls or longline 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.

Gear-specific time series of fishery catch per unit effort (CPUE) are plotted, along with linear regression lines, in Figure 2A.2. Neither long-term trend is statistically significant at the 5% level.

Discards

The catches shown in Tables 2A.1b and 2A.1c include estimated discards. Discard amounts and rates of Pacific cod in the AI Pacific cod fisheries are shown for each year 1991-2016 in Table 2A.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 5.6%. Since then, they have averaged about 1.0%.

Management History

Table 2A.3 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.

History with Respect to the EBS Stock

Prior to 2014, the AI and EBS Pacific cod stocks were managed jointly, with a single TAC, ABC, and OFL. Beginning with the 2014 fishery, the two stocks have since been managed separately.

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 2A.4. 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 2A.1, which pertains to the AI only. Total catch has been less than OFL in every year since 1993.

ABCs were first specified in 1980. Prior to separate management of the AI and EBS stocks in 2014, TAC averaged about 83% of ABC, and aggregate commercial catch averaged about 92% of TAC (since 1980). In 10 of the 34 years between 1980 and 2013, TAC equaled ABC exactly.

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. Because ABC for all years through 2013 were based on the EBS assessment model (with an expansion factor for the AI), readers are referred to Chapter 2 for a history of changes in that model. During the period of separate AI and EBS management, the assessment of the AI stock has been based on a simple, random effects (Tier 5) model.

History with Respect to the State Fishery

Beginning with the 2006 fishery, the State of Alaska managed a fishery for AI Pacific cod inside State waters, with a guideline harvest level (GHL) equal to 3% of the BSAI ABC. Beginning with the 2014 fishery, this practice was modified by establishing two separate GHL fisheries, one for the AI and one for the EBS. The table below shows the formulas that have been used to set the State GHL for the AI:

Year	Formula
2014	0.03 × (EBS ABC + AI ABC)
2015	0.03 × (EBS ABC + AI ABC)
2016	0.27 × AI ABC

During the period in which a State fishery has existed: 1) TAC has been reduced so that the sum of the TAC and GHL would not exceed the ABC, 2) catch in the Federal fishery has been kept below TAC, and 3) total catch (Federal+State) has been kept below ABC.

History with Respect to Steller Sea Lion Protection Measures

The National Marine Fisheries Service (NMFS) listed the western distinct population segment of Steller sea lions as endangered under the ESA in 1997. Since then, protection measures designed to protect potential Steller sea lion prey from the potential effects of groundfish fishing have been revised several times. One such revision was implemented in 2011, remaining in effect through 2014. This revision prohibited the retention of Pacific cod in Area 543. The latest revision, implemented in 2015, replaced this prohibition with a "harvest limit" for Area 543 determined by subtracting the State GHL from the AI Pacific cod ABC, then multiplying the result by the proportion of the AI Pacific cod biomass in Area 543 (see "Area Allocation of ABC," under "Harvest Recommendations," in the "Results" section).

DATA

This section describes data used in the model presented in this stock assessment, plus a response to a request by the SSC for a presentation of weight at age by subarea (comment SSC5). This section does not attempt to summarize all available data pertaining to Pacific cod in the AI.

Trawl Survey Biomass

The time series of NMFS bottom trawl survey biomass is shown for Areas 541-543 (Eastern, Central, and Western AI, respectively), together with their respective coefficients of variation, in Table 2A.5. These estimates pertain to the Aleutian *management* area, and so are smaller than the estimates pertaining to the Aleutian *survey* area that were reported in BSAI Pacific cod stock assessments prior to 2013.

The biomass data indicate a consistent decline throughout the time series. Simple linear regression on the time series estimates a negative slope coefficient that is statistically significant at the 1% level.

Trawl Survey Weight at Age by Area

A time series of mean weight at age by area was computed by estimating an area-specific (but time-invariant) weight-at-length relationship from the entire set of weight and length measurements from the trawl survey (n = 2572, 3060, and 3475 for the WAI, CAI, and EAI, respectively), and applying it to the time series of mean lengths at age from the survey. The α and β parameters of the weight-at-length relationship $W = \exp(\alpha + \beta \cdot \ln(L))$, with length measured in cm and weight in grams were:

Area	α	β
WAI	-12.350	3.238
CAI	-12.246	3.215
EAI	-12.070	3.165

The time series of weight at age by area is shown in Table 2A.6. The mean weight at each age and area is scaled relative to the average (across areas) in Figure 2A.3 (i.e., at any given age, the three curves have an average value of unity). For ages 5 and above, mean weights at age are highest in the WAI and lowest in the EAI. Below age 5, the relationship is variable.

ANALYTIC APPROACH

Model Structure (General)

The history of models used in previous AI Pacific cod assessments is described in Appendix 2A.3.

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 13.4 is one of four models introduced in 2013, the first year that the SSC accepted a model for separate management of the AI stock), while names of models constituting *minor* changes get linked to the model that they modify (e.g., Model 13.4a would refer to a model that constituted a minor change from Model 13.4).

Model 13.4 is the Tier 5 random effects model recommended by the Survey Averaging Working Group (http://www.afsc.noaa.gov/REFM/stocks/Plan_Team/2013/Sept/SAWG_2013_draft.pdf), which has been accepted by the Plan Team and SSC since the 2013 assessment for the purpose of setting AI Pacific cod harvest specifications. The Tier 5 random effects model is programmed using the ADMB software package (Fournier et al. 2012).

The Tier 5 random effects model is a very simple, state-space model of the "random walk" variety. The only parameter in Model 13.4 is the log of the log-scale process error standard deviation.

When used to implement the Tier 5 harvest control rules, the Tier 5 models also require an estimate of the natural mortality rate.

The Tier 5 random effects model assumes that the observation error variances are equal to the sampling variances estimated from the haul-by-haul survey data. The log-scale process errors and observations are both assumed to be normally distributed.

Parameters Estimates

Natural Mortality

A value of 0.34 was used for the natural mortality rate *M* in all BSAI Pacific cod stock assessments since 2007 (Thompson et al. 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

However, the author's recommended model in this year's EBS Pacific cod assessment estimates *M* at a value of 0.36. To be consistent with the EBS assessment, a natural mortality rate of 0.36 is assumed in this assessment as well.

RESULTS

Model Output

Model 13.4 estimates the log-scale process error standard deviation at a value of 0.17 with a coefficient of variation equal to 0.37.

The time series of biomass estimated by the model, with 95% confidence intervals, is shown in Table 2A.7, along with the corresponding estimates from last year's assessment.

The model's fit to the survey biomass time series is shown in Figure 2A.4. The root-mean-squared error is 0.103, compared to an average log-scale standard error of 0.182. The mean normalized residual is 0.056, the standard deviation of normalized residuals is 0.625, and the correlation between the survey biomass data and the model's estimates is 0.975.

Harvest Recommendations

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.

The following formulae apply under Tier 5:

$$F_{OFL} = M$$

$$F_{ABC} \leq 0.75 \times M$$

The estimates needed for harvest specifications are as follow:

Quantity	2017	2018
Biomass (t)	79,600	79,600
M	0.36	0.36

The 95% confidence interval for the above biomass estimate extends from 58,500-108,000 t.

Specification of OFL and Maximum Permissible ABC

Estimates of OFL, maximum permissible ABC, and the associated fishing mortality rates for 2017 and 2018 are shown below:

Quantity	2017	2018
OFL (t)	28,700	28,700
maxABC (t)	21,500	21,500
F_{OFL}	0.36	0.36
$maxF_{ABC}$	0.27	0.27

Under the estimate of M used in previous assessments (0.34), OFL would be reduced to 27,100 t, maxABC would be reduced to 20,300 t, F_{OFL} would be reduced to 0.34, and $maxF_{ABC}$ would be reduced to 0.26 (both years, for all quantities).

ABC Recommendation

The authors' recommended ABCs for 2017 and 2018 are the maximum permissible values: 21,500 t in both years.

Area Allocation of Harvests

As noted in the "Management History" subsection of the "Fishery" section, the current Steller sea lion protection measures require an estimate of the proportion of the AI Pacific cod stock residing in Area 543, which will be used to set the harvest limit in 543 after subtraction of the State GHL from the overall AI ABC. The Area 543 proportion could be computed on the basis of the survey observations themselves, or by running Model 13.4 for Area 543 and then computing the ratios of the resulting estimates to those of Model 13.4. More specifically, some possible estimators of this proportion are: 1) the 1991-2016 average proportion from the raw survey data (26.2%), 2) the most recent proportion from the raw survey data (23.4%), 3) the 1991-2016 average proportion from Model 13.4 (25.5%), and 4) the most recent proportion from Model 13.4 (25.6%). All of these estimates are quite close to one another, with an average value of 25.2%. If Model 13.4 is used to set the 2017 ABC based on the model's most recent estimate of biomass, it seems reasonable to estimate the biomass proportion in Area 543 accordingly, by using the most recent estimate from Model 13.4 (25.6%).

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 AI catch estimate for the most recent complete year (2015) is 9,225 t. This is less than the 2015 AI OFL of 23,400 t. Therefore, the AI Pacific cod stock is not being subjected to overfishing.

Is the stock overfished? Because this stock is managed under Tier 5, no determination can be made with respect to overfished status.

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). Because the data time series in the models presented in this assessment do not begin until 1991, the 1977 regime shift should not be a factor in any of the quantities presented here, although it may indeed have had an impact on the stock.

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 2A.8-2A.11. Catches for 2016 in each of these tables are incomplete. Table 2A.8 shows incidental catch of FMP species taken from 1991-2016 by trawl gear and fixed gear. Table 2A.9 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 2A.10 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 2A.10, due to an error in the database that was discovered too late to be corrected in time for this assessment. Table 2A.11 shows incidental catch of non-target species groups taken from 2004-2016, aggregated across gear types (Table 2A.11 starts in 2004 rather than 2003 for the same reason that the entries for 2003 are marked “n/a” in Table 2A.10).

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 operates to some extent in the same geographic 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 fixed gear 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 (EBS, 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 sets was as follows:

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

In the EBS, 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. Ageing also continues to be an issue, as the assessment models that have been explored to date consistently estimate a positive ageing bias. Longer-term research needs include improved understanding of: 1) the ecology of Pacific cod in the AI, 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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TABLES

Table 2A.1a—Summary of 1964-1980 catches (t) of Pacific cod in the AI 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.

	Aleutian Islands			
Year	For.	JV	Dom.	Total
1964	241	0	0	241
1965	451	0	0	451
1966	154	0	0	154
1967	293	0	0	293
1968	289	0	0	289
1969	220	0	0	220
1970	283	0	0	283
1971	2,078	0	0	2,078
1972	435	0	0	435
1973	977	0	0	977
1974	1,379	0	0	1,379
1975	2,838	0	0	2,838
1976	4,190	0	0	4,190
1977	3,262	0	0	3,262
1978	3,295	0	0	3,295
1979	5,593	0	0	5,593
1980	5,788	0	0	5,788

Table 2A.1b—Summary of 1981-1990 catches (t) of Pacific cod in the AI by area, 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	LL+pot	Subt.	Total
1981	2,680	235	2,915	1,749	1,749	n/a	n/a	2,770	7,434
1982	1,520	476	1,996	4,280	4,280	n/a	n/a	2,121	8,397
1983	1,869	402	2,271	4,700	4,700	n/a	n/a	1,459	8,430
1984	473	804	1,277	6,390	6,390	n/a	n/a	314	7,981
1985	10	829	839	5,638	5,638	n/a	n/a	460	6,937
1986	5	0	5	6,115	6,115	n/a	n/a	786	6,906
1987	0	0	0	10,435	10,435	n/a	n/a	2,772	13,207
1988	0	0	0	3,300	3,300	1,698	167	1,865	5,165
1989	0	0	0	6	6	4,233	303	4,536	4,542
1990	0	0	0	0	0	6,932	609	7,541	7,541

Table 2A.1c—Summary of 1991-2016 catches (t) of Pacific cod in the AI. To avoid confidentiality problems, longline and pot catches have been combined. The small catches taken by "other" gear types have been merged proportionally with the catches of the gear types shown. Catches for 2016 are through October 23.

	Federal			State	
Year	Trawl	LL+pot	Subtotal	Subtotal	Total
1991	3,414	6,383	9,798		9,798
1992	14,587	28,481	43,068		43,068
1993	17,328	16,876	34,205		34,205
1994	14,383	7,156	21,539		21,539
1995	10,574	5,960	16,534		16,534
1996	21,179	10,430	31,609		31,609
1997	17,411	7,753	25,164		25,164
1998	20,531	14,196	34,726		34,726
1999	16,478	11,653	28,130		28,130
2000	20,379	19,306	39,685		39,685
2001	15,836	18,372	34,207		34,207
2002	27,929	2,872	30,801		30,801
2003	31,478	978	32,457		32,457
2004	25,770	3,103	28,873		28,873
2005	19,624	3,069	22,694		22,694
2006	16,956	3,535	20,490	3,721	24,211
2007	25,714	4,495	30,208	4,146	34,355
2008	19,404	7,506	26,910	4,319	31,229
2009	20,277	6,245	26,522	2,060	28,582
2010	16,759	8,277	25,036	3,967	29,003
2011	9,359	1,233	10,592	266	10,858
2012	9,786	3,201	12,988	5,232	18,220
2013	7,001	1,789	8,790	4,793	13,583
2014	5,715	426	6,141	4,451	10,592
2015	5,968	3,096	9,064	161	9,225
2016	10,594	1,690	12,284	882	13,165

Table 2A.1d—Summary of 1994-2016 catches (t) of Pacific cod in the AI, by NMFS 3-digit statistical area (area breakdowns not available prior to 1994). Catches for 2016 are through October 13.

	Amount			Proportion		
Year	Western	Central	Eastern	Western	Central	Eastern
1994	2,059	7,441	12,039	0.096	0.345	0.559
1995	1,713	5,086	9,735	0.104	0.308	0.589
1996	4,023	4,509	23,077	0.127	0.143	0.730
1997	894	4,440	19,830	0.036	0.176	0.788
1998	3,487	9,299	21,940	0.100	0.268	0.632
1999	2,322	5,276	20,532	0.083	0.188	0.730
2000	9,073	8,799	21,812	0.229	0.222	0.550
2001	12,767	7,358	14,082	0.373	0.215	0.412
2002	2,259	7,133	21,408	0.073	0.232	0.695
2003	2,997	6,707	22,752	0.092	0.207	0.701
2004	3,649	6,833	18,391	0.126	0.237	0.637
2005	4,239	3,582	14,873	0.187	0.158	0.655
2006	4,570	4,675	14,967	0.189	0.193	0.618
2007	4,974	4,692	24,689	0.145	0.137	0.719
2008	7,319	5,555	18,355	0.234	0.178	0.588
2009	7,929	6,899	13,754	0.277	0.241	0.481
2010	8,213	6,291	14,499	0.283	0.217	0.500
2011	24	1,768	9,066	0.002	0.163	0.835
2012	29	2,816	15,374	0.002	0.155	0.844
2013	50	2,882	10,651	0.004	0.212	0.784
2014	30	1,043	9,518	0.003	0.099	0.899
2015	3,170	2,367	3,688	0.344	0.257	0.400
2016	2,550	1,607	9,008	0.194	0.122	0.684

Table 2A.2—Discards (t) and discard rates of Pacific cod in the AI Pacific cod fishery for the period 1991-2016 (2016 data are current through October 23). Note that Amendment 49, which mandated increased retention and utilization, was implemented in 1998.

Year	Discards	Total	Rate
1991	105	5,385	0.020
1992	1,085	38,788	0.028
1993	3,527	29,193	0.121
1994	1,302	14,295	0.091
1995	460	10,822	0.042
1996	859	22,436	0.038
1997	1,220	22,804	0.053
1998	613	30,836	0.020
1999	420	25,471	0.016
2000	605	37,308	0.016
2001	455	31,920	0.014
2002	604	29,369	0.021
2003	216	30,182	0.007
2004	238	26,538	0.009
2005	139	20,215	0.007
2006	214	22,470	0.010
2007	483	32,422	0.015
2008	143	29,901	0.005
2009	149	26,437	0.006
2010	192	27,242	0.007
2011	45	9,094	0.005
2012	84	16,789	0.005
2013	125	11,951	0.011
2014	27	9,233	0.003
2015	41	6,313	0.007
2016	48	10,080	0.005

Table 2A.3. 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 2A.4—History of **BSAI** Pacific cod catch, TAC, ABC, and OFL (t) through 2013, and **AI** catch and specifications for 2014-2016. Catch for 2016 is through September 27. Note that specifications through 2013 were for the combined BSAI region, so BSAI catch is shown rather than the AI catches from Table 2A.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	220,038	229,000	229,000	-
1992	207,278	182,000	182,000	188,000
1993	167,391	164,500	164,500	192,000
1994	193,802	191,000	191,000	228,000
1995	245,033	250,000	328,000	390,000
1996	240,676	270,000	305,000	420,000
1997	257,765	270,000	306,000	418,000
1998	193,256	210,000	210,000	336,000
1999	173,998	177,000	177,000	264,000
2000	191,060	193,000	193,000	240,000
2001	176,749	188,000	188,000	248,000
2002	197,356	200,000	223,000	294,000
2003	207,907	207,500	223,000	324,000
2004	212,618	215,500	223,000	350,000
2005	205,635	206,000	206,000	265,000
2006	193,025	194,000	194,000	230,000
2007	174,486	170,720	176,000	207,000
2008	171,277	170,720	176,000	207,000
2009	175,756	176,540	182,000	212,000
2010	171,875	168,780	174,000	205,000
2011	220,109	227,950	235,000	272,000
2012	251,055	261,000	314,000	369,000
2013	250,274	260,000	307,000	359,000
2014	10,592	6,997	15,100	20,100
2015	9,225	9,422	17,600	23,400
2016	13,165	12,839	17,600	23,400

Table 2A.5— Total biomass (absolute and relative), with coefficients of variation, as estimated by AI shelf bottom trawl surveys, 1991-2016.

	Biomass (t)			
Year	Western	Central	Eastern	All
1991	75,514	39,729	64,926	180,170
1994	23,797	51,538	78,081	153,416
1997	14,357	30,252	28,239	72,848
2000	44,261	36,456	47,117	127,834
2002	23,623	24,687	25,241	73,551
2004	9,637	20,731	51,851	82,219
2006	19,480	22,033	43,348	84,861
2010	21,341	11,207	23,277	55,826
2012	13,514	14,804	30,592	58,911
2014	18,088	8,488	47,032	73,608
2016	19,775	19,496	45,138	84,409

	Biomass proportions			
Year	Western	Central	Eastern	All
1991	0.419	0.221	0.360	1.000
1994	0.155	0.336	0.509	1.000
1997	0.197	0.415	0.388	1.000
2000	0.346	0.285	0.369	1.000
2002	0.321	0.336	0.343	1.000
2004	0.117	0.252	0.631	1.000
2006	0.230	0.260	0.511	1.000
2010	0.382	0.201	0.417	1.000
2012	0.229	0.251	0.519	1.000
2014	0.246	0.115	0.639	1.000
2016	0.234	0.231	0.535	1.000

	Biomass coefficient of variation			
Year	Western	Central	Eastern	All
1991	0.092	0.112	0.370	0.141
1994	0.292	0.390	0.301	0.206
1997	0.261	0.208	0.230	0.134
2000	0.423	0.270	0.222	0.185
2002	0.245	0.264	0.329	0.164
2004	0.169	0.207	0.304	0.200
2006	0.233	0.188	0.545	0.288
2010	0.409	0.257	0.223	0.189
2012	0.264	0.203	0.241	0.148
2014	0.236	0.276	0.275	0.187
2016	0.375	0.496	0.212	0.184

Table 2A.6—Mean weight (kg) at age by area, as estimated by the trawl survey.

Western:

Year	1	2	3	4	5	6	7	8	9	10	11	12
1991	0.31	0.51	1.51	3.05	4.22	5.70	7.16	6.43	8.12	8.56		
2000	0.04	0.41	1.35	2.28	3.03	4.87	7.35	11.48	12.70	14.28		
2002	0.05	0.38	1.17	2.11	4.27	6.05	7.60	9.31	13.38	10.30	14.71	
2004	0.08	0.75	1.15	1.69	3.55	6.03	9.41	11.11	13.54	14.33		
2006	0.05	0.63	1.29	1.98	3.74	5.41	8.71	12.18	12.91	13.60	15.76	
2010	0.06	0.32	1.41	1.99	3.64	5.19	7.01	10.38	13.10	15.12	12.93	17.09
2012	0.06	0.55	1.20	1.91	2.97	5.54	8.18	8.82	13.07	14.17	13.79	
2014	0.07	0.53	1.45	2.30	3.17	5.60	6.37	8.05	10.91	9.83		
Mean:	0.08	0.50	1.31	2.14	3.55	5.54	7.68	9.60	12.12	12.36	14.27	17.09

Central:

Year	1	2	3	4	5	6	7	8	9	10	11	12
1991	0.22	0.49	1.14	2.65	4.08	5.87	6.92	6.73	8.08	9.48		
2000	0.06	0.30	1.32	2.35	3.31	5.21	6.88	10.84	9.54	16.20		
2002	0.09	0.52	1.06	2.14	4.30	6.34	7.87	9.16	10.67	11.77	12.63	
2004	0.07	0.59	1.15	2.21	3.81	5.65	8.21	11.26	12.37	12.13		
2006	0.10	0.58	1.26	1.89	4.14	5.83	7.36	9.87	12.47	13.74	12.52	
2010		0.41	1.02	1.53	3.55	4.62	6.51	8.68	11.99	14.33	12.92	17.05
2012	0.07	0.49	1.11	2.29	3.48	4.56	6.94	8.43	11.33	10.50		
2014	0.09	0.51	1.49	2.39	3.65	5.37	5.89	7.55	11.04	9.96	16.06	
Mean:	0.09	0.48	1.19	2.16	3.78	5.41	7.05	8.99	10.87	12.13	13.48	17.05

Eastern:

Year	1	2	3	4	5	6	7	8	9	10	11	12
1991	0.46	0.45	1.13	2.73	3.94	5.05	6.13	5.99	7.52	8.01	16.09	
2000	0.05	0.45	1.08	2.11	3.37	4.96	5.82	7.81	6.80	12.03		
2002	0.09	0.46	1.06	2.05	3.69	5.25	6.60	7.35	9.57	7.55	10.07	
2004	0.08	0.58	1.29	2.48	3.81	5.26	7.16	8.52	9.59	11.32		
2006	0.09	0.59	1.45	2.14	4.26	5.96	7.80	10.26	10.09	7.34	11.49	
2010	0.10	0.45	1.31	1.92	2.94	3.60	5.49	4.68	8.06			
2012	0.07	0.62	1.26	2.40	3.41	4.09	5.67	7.08	11.06			
2014	0.05	0.48	1.55	2.37	3.50	5.42	5.97	6.72	9.22	9.53		
Mean:	0.10	0.51	1.26	2.27	3.60	4.91	6.30	7.18	8.92	9.18	12.38	

Table 2A.7—Comparison of biomass (t) estimated by Model 13.4 in this year's and last year's assessments, with lower and upper 95% confidence bounds.

	Last year's assessment			This year's assessment		
Year	Mean	L95%CI	U95%CI	Mean	L95%CI	U95%CI
1991	171,637	131,586	223,879	171,063	131,250	222,952
1992	158,994	110,631	228,499	158,448	111,091	225,993
1993	147,282	101,221	214,304	146,763	101,715	211,762
1994	136,433	99,759	186,588	135,940	99,846	185,083
1995	115,818	80,527	166,577	115,740	81,146	165,082
1996	98,318	69,377	139,333	98,541	70,100	138,522
1997	83,463	64,498	108,004	83,898	65,034	108,235
1998	89,714	63,684	126,385	89,858	64,296	125,581
1999	96,434	67,642	137,482	96,241	68,098	136,015
2000	103,657	76,612	140,250	103,077	76,655	138,607
2001	91,773	66,335	126,968	91,613	66,687	125,855
2002	81,252	62,827	105,080	81,424	63,142	104,999
2003	80,844	58,305	112,097	80,916	58,753	111,438
2004	80,439	60,311	107,284	80,411	60,488	106,895
2005	78,661	54,753	113,007	78,602	55,126	112,074
2006	76,921	53,841	109,895	76,833	54,117	109,084
2007	72,373	47,738	109,719	72,422	48,243	108,718
2008	68,093	44,469	104,268	68,263	45,047	103,446
2009	64,067	43,355	94,673	64,344	43,905	94,297
2010	60,278	44,959	80,818	60,650	45,318	81,169
2011	60,701	43,837	84,052	61,233	44,463	84,327
2012	61,126	48,014	77,817	61,822	48,618	78,611
2013	64,887	46,763	90,035	66,577	48,817	90,799
2014	68,880	50,604	93,757	71,699	54,757	93,882
2015				75,524	54,100	105,432
2016				79,553	58,520	108,145

Table 2A.8a (page 1 of 2)— Incidental catch (t) of FMP species taken in the AI trawl fishery for Pacific cod, expressed as a proportion of the incidental catch of that species taken in all FMP AI fisheries, 1991-2016 (2016 data current through October 23). 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	
Arrowtooth Flounder	0.00	0.08	0.08	0.05	0.01	0.06	0.05	0.14	0.14	0.15	0.13	0.27	0.30
Atka Mackerel	0.01	0.23	0.18	0.02	0.01	0.03	0.01	0.07	0.09	0.06	0.07	0.01	0.06
Flathead Sole					0.45	0.42	0.68	0.88	0.95	0.91	0.73	0.96	0.82
Flounder	conf	0.61	0.46	0.37									
Greenland Turbot	0.00	0.00	0.00	0.01	conf	conf	conf	0.17	0.01	0.03	0.02	0.02	0.04
Kamchatka Flounder													
Northern Rockfish												0.03	0.04
Octopus													
Other Flatfish						0.01	0.05	0.81	0.62	0.71	0.27	0.63	0.47
Other Rockfish	0.00	0.08	0.04	0.04	0.04	0.05	0.42	0.20	0.07	0.07	0.03	0.06	0.06
Other Species													0.25
Pacific Cod	0.04	0.28	0.23	0.31	0.04	0.11	0.27	0.22	0.44	0.20	0.45	0.72	0.56
Pacific Ocean Perch	0.01	0.08	0.07	0.04	0.01	0.02	0.03	0.16	0.03	0.11	0.05	0.03	0.07
Pollock	0.00	0.02	0.03	0.07	0.01	0.01	0.12	0.75	0.82	0.80	0.55	0.89	0.58
Rock Sole	0.03	0.73	0.56	0.58	0.56	0.52	0.76	0.89	0.94	0.96	0.86	0.94	0.88
Rougheye Rockfish													
Sablefish		conf	conf	conf		conf	conf	0.19	conf	conf	conf	0.02	0.06
Sculpin													
Shark													
Sharpchin/Northern Rockfish		0.14	0.05	0.03	0.01	0.03	0.05	0.05	0.04	0.06	0.03		
Short/Rough/Sharp/North	0.09	conf											
Shortraker Rockfish													
Shortraker/Rougheye Rockfish		0.01	0.02	0.00	conf	0.01	0.01	0.01	0.01	0.00	0.02	0.00	0.06
Skate													
Squid	conf	0.01	0.02	0.00	conf	conf	0.02	0.05	0.02	0.05	0.16	0.05	0.10
Yellowfin Sole				conf		conf		conf	conf	conf	conf	conf	0.71

Table 2A.8a (page 2 of 2)—Incidental catch (t) of FMP species taken in the AI trawl fishery for Pacific cod, expressed as a proportion of the incidental catch of that species taken in all FMP AI fisheries, 1991-2016 (2016 data current through October 23). 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	0.22	1.00	conf	conf		conf	conf	conf		conf
Arrowtooth Flounder	0.29	0.26	0.19	0.27	0.09	0.05	0.03	0.07	0.12	0.07	0.03	conf	0.07
Atka Mackerel	0.04	0.07	0.14	0.02	0.01	0.01	0.00	0.00	0.00	conf	conf	conf	conf
Flathead Sole	0.91	0.73	0.84	0.77	0.70	0.52	0.65	0.52	0.85	0.78	0.60	conf	0.85
Flounder													
Greenland Turbot	0.04	0.04	conf	0.09	0.00	0.00	conf		conf	conf			
Kamchatka Flounder								0.02	0.02	0.00	conf	conf	0.00
Northern Rockfish	0.03	0.06	0.04	0.03	0.03	0.03	0.03	0.02	0.01	0.06	0.17	conf	0.12
Octopus								conf	0.17	conf	conf	conf	conf
Other Flatfish	0.28	0.45	0.51	0.39	0.81	0.07	0.09	0.01	0.28	0.40	0.24	conf	0.09
Other Rockfish	0.06	0.07	0.03	0.04	0.07	0.04	0.03	0.01	0.03	0.02	0.01	conf	0.02
Other Species	0.18	0.14	0.15	0.19	0.07	0.08	0.04						
Pacific Cod	0.57	0.21	0.32	0.64	0.15	0.16	0.18	0.25	0.12	0.29	0.17	conf	0.35
Pacific Ocean Perch	0.05	0.07	0.04	0.03	0.09	0.01	0.01	0.00	0.01	0.00	0.00	conf	0.02
Pollock	0.44	0.82	0.89	0.58	0.47	0.06	0.03	0.01	0.65	0.16	0.04	conf	0.12
Rock Sole	0.85	0.86	0.85	0.75	0.91	0.84	0.86	0.74	0.88	0.83	0.80	conf	0.80
Rougheye Rockfish	0.00	0.11	0.02	0.01	0.00	conf	0.01	0.04	conf	conf			
Sablefish	0.01	0.01	0.03	0.02		conf			conf		conf		
Sculpin								0.06	0.06	0.04	0.02	conf	0.05
Shark								conf			conf	conf	conf
Sharpchin/Northern Rockfish													
Short/Rough/Sharp/North													
Shortraker Rockfish	0.00	conf	0.00	0.00	conf		conf		conf	conf			conf
Shortraker/Rougheye Rockfish													
Skate								0.02	0.03	0.02	0.01	conf	0.02
Squid	0.11	0.07	0.07	0.02	0.00	0.00	0.00	conf	0.00	0.00	conf	conf	conf
Yellowfin Sole	1.00	conf	0.79	0.05	0.41	conf	conf	conf	conf	conf	conf		

Table 2A.8b (page 1 of 2)— Incidental catch (t) of FMP species taken in the AI fixed gear fishery for Pacific cod, expressed as a proportion of the incidental catch of that species taken in all FMP AI fisheries, 1991-2016 (2016 data current through October 23). 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
Arrowtooth Flounder	0.01	0.14	0.05	0.03	0.02	0.02	0.05	0.12	0.09	0.24	0.23	0.04	0.01
Atka Mackerel	conf	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.05	0.03	0.01	0.00
Flathead Sole					0.03	0.11	0.05	0.10	0.01	0.06	0.17	0.01	0.00
Flounder	conf	0.08	0.07	0.02									
Greenland Turbot	0.09	0.05	0.03	0.01	0.00	0.02	0.03	0.05	0.15	0.04	0.04	0.02	0.00
Kamchatka Flounder													
Northern Rockfish												0.01	0.00
Octopus													
Other Flatfish					conf	0.01	0.30	0.06	0.09	0.20	0.48	0.02	
Other Rockfish	0.07	0.15	0.17	0.37	0.04	0.16	0.21	0.30	0.15	0.27	0.24	0.11	0.04
Other Species													0.11
Pacific Cod	0.16	0.20	0.37	0.06	0.11	0.16	0.30	0.74	0.38	0.67	0.52	0.11	0.09
Pacific Ocean Perch	conf	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Pollock	0.00	0.00	0.02	0.00	0.01	0.01	0.03	0.05	0.01	0.02	0.06	0.00	0.00
Rock Sole	0.01	0.02	0.02	0.03	0.02	0.05	0.02	0.03	0.00	0.01	0.02	0.00	0.00
Rougheye Rockfish													
Sablefish	0.30	0.19	0.26	0.03	0.02	0.34	0.21	0.17	0.04	0.13	0.32	0.06	0.08
Sculpin													
Shark													
Sharpchin/Northern Rockfish		0.03	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.02	0.02		
Short/Rough/Sharp/North	0.02	conf											
Shortraker Rockfish													
Shortraker/Rougheye Rockfish		0.62	0.34	0.19	0.06	0.23	0.19	0.77	0.49	0.54	0.49	0.18	0.14
Skate													
Slope Rockfish		conf											
Squid		conf				conf	conf	conf	conf		conf		
Yellowfin Sole		conf		conf	conf	conf	conf	conf	conf	conf	conf		

Table 2A.8b (page 2 of 2)— Incidental catch (t) of FMP species taken in the AI fixed gear fishery for Pacific cod, expressed as a proportion of the incidental catch of that species taken in all FMP AI fisheries, 1991-2016 (2016 data current through October 23). 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
Arrowtooth Flounder	0.03	0.08	0.05	0.06	0.14	0.05	0.04	0.03	0.04	0.01	conf	0.06	conf
Atka Mackerel	0.00	0.01	0.01	0.01	0.04	0.03	0.01	conf	0.01	0.03	conf	0.02	conf
Flathead Sole	0.01	0.01	0.03	0.12	0.21	0.23	0.16	conf	0.12	conf	conf	conf	conf
Flounder													
Greenland Turbot	0.02	conf	0.01	0.02	0.01	0.00	0.02	0.00	0.03	conf	conf	conf	
Kamchatka Flounder								conf	0.01	0.01	conf	0.01	conf
Northern Rockfish	0.01	0.01	0.00	0.01	0.03	0.04	0.06	conf	0.02	0.18	conf	0.07	conf
Octopus								0.79	0.50	0.89	conf	0.59	conf
Other Flatfish	0.38	conf	0.01	0.01	0.04	0.52	0.15	conf	conf	conf	conf	conf	
Other Rockfish	0.32	0.12	0.09	0.17	0.33	0.46	0.53	0.08	0.12	0.05	conf	0.28	conf
Other Species	0.28	0.36	0.28	0.26	0.30	0.41	0.52						
Pacific Cod	0.18	0.08	0.37	0.24	0.56	0.56	0.75	0.31	0.62	0.13	conf	0.38	conf
Pacific Ocean Perch	0.00	0.00	0.00	0.00	0.01	0.00	0.00	conf	0.00	conf	conf	0.00	conf
Pollock	0.01	0.00	0.01	0.00	0.01	0.01	0.05	0.02	0.01	0.00	conf	0.02	conf
Rock Sole	0.00	0.01	0.01	0.01	0.01	0.01	0.01	conf	0.01	0.00	conf	0.02	conf
Rougheye Rockfish	0.26	0.27	0.08	0.28	0.73	0.35	0.44	conf	0.52	0.25	conf	0.83	conf
Sablefish	0.00	conf	0.15	0.01	0.10	0.12	0.10	0.00	0.32	0.04	conf	conf	
Sculpin								0.17	0.39	0.41	conf	0.40	conf
Shark								0.02	0.12	conf	conf	0.22	conf
Sharpchin/Northern Rockfish													
Short/Rough/Sharp/North													
Shortraker Rockfish	0.06	0.22	0.08	0.06	0.18	0.09	0.66	0.02	0.10	0.18	conf	0.20	conf
Shortraker/Rougheye Rockfish													
Skate								0.18	0.36	0.17	conf	0.27	conf
Slope Rockfish													
Squid	conf												
Yellowfin Sole			conf	conf	conf	conf				conf	conf		

Table 2A.9— Incidental catch (t) of selected members of the former "Other Species" complex taken in the AI fisheries for Pacific cod (all gears), expressed as a proportion of the incidental catch of that species taken in all FMP AI fisheries, 1991-2016 (2016 data current through October 23). Color shading: red = row minimum, green = row maximum (minima and maxima computed across both panels of the table).

Species	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
octopus, North Pacific									1.00	conf	conf	conf	0.73
Pacific sleeper shark										conf		conf	0.00
shark, other													
shark, salmon										conf			
shark, spiny dogfish													0.71
skate, Alaskan													
skate, big													
skate, longnose													
skate, other									0.99	conf	conf	0.34	0.28
squid, majestic	conf	0.01	0.02	conf	conf	conf	0.02	0.05	0.02	0.05	0.16	0.05	0.10

Species	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
octopus, North Pacific	0.72	0.96	0.94	0.77	0.89	0.97	0.97	0.93	0.67	0.89	0.24	0.60	conf
Pacific sleeper shark	0.30	conf	conf	conf	conf	conf	0.08				conf	conf	
shark, other	conf												
shark, salmon						conf		conf				conf	conf
shark, spiny dogfish	0.96	1.00	0.75	0.87	0.55	0.84	0.95	0.94	0.66	conf	conf	0.79	conf
skate, Alaskan							0.69						
skate, big	1.00	conf	0.26	conf	conf	0.01	0.99						
skate, longnose	0.56	conf	conf		conf	1.00	conf						
skate, other	0.49	0.59	0.42	0.54	0.34	0.62	0.62	0.20	0.39	0.19	0.03	0.27	0.30
squid, majestic	0.11	0.07	0.07	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	conf	0.00

Table 2A.10—Incidental catch (herring and halibut in t, salmon and crab in number of individuals) of prohibited species taken in the AI fisheries for Pacific cod (all gears), expressed as a proportion of the incidental catch of that species taken in all FMP AI fisheries, 1991-2016 (2016 data current through October 23). 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	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Bairdi Tanner Crab	0.30	0.57	0.70	0.96	0.87	0.91	0.94	1.00	1.00	1.00	0.86	0.99	n/a
Blue King Crab													n/a
Chinook Salmon	0.01	0.02	0.15	0.03	0.23	0.17	0.46	0.71	0.90	1.00	0.46	0.68	n/a
Golden (Brown) King Crab													n/a
Halibut	0.52	0.81	0.42	0.44	0.46	0.57	0.53	0.82	0.57	0.48	0.74	0.30	n/a
Herring			conf							conf			n/a
Non-Chinook Salmon	conf	0.22			0.00	conf	0.07	0.03	conf	0.11	0.22	0.76	n/a
Opilio Tanner (Snow) Crab	0.40	0.30	0.51	0.02	0.01	0.19	0.25	0.52	0.30	0.26	conf	0.69	n/a
Other King Crab	0.08	0.24	0.04	0.05	0.04	0.10	0.00	0.06	0.23	0.07	0.13	0.03	n/a
Red King Crab	0.21	0.08	0.33	0.14	0.11	0.05	conf	0.83	conf	0.43	0.94	0.97	n/a

Species	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Bairdi Tanner Crab	1.00	0.98	0.99	1.00	1.00	1.00	0.98	0.50	1.00	0.98	0.98	0.00	0.00
Blue King Crab		0.30	1.00	1.00	0.78	0.92	1.00	1.00	1.00	1.00		0.00	
Chinook Salmon	0.73	0.80	0.86	0.72	0.80	0.82	0.76	0.55	0.65	0.94	0.62	0.44	0.57
Golden (Brown) King Crab	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Halibut	0.66	0.70	0.50	0.77	0.70	0.59	0.55	0.32	0.34	0.16	0.14	0.38	0.27
Herring		1.00	0.05	0.19	0.00	0.00	0.00		0.00	1.00	1.00		
Non-Chinook Salmon	0.43	0.11	0.28	0.56	0.17	0.17	0.02	0.36	0.00	0.02	0.00	0.00	0.01
Opilio Tanner (Snow) Crab	1.00	0.84	0.99	1.00	1.00	1.00	1.00	0.98	0.99	0.91	0.81	0.00	
Other King Crab													
Red King Crab	0.97	0.84	0.06	0.82	0.75	0.34	0.22	0.32	0.20	0.91	0.16	0.00	0.00

Table 2A.11a—Incidental catch (t) of non-target species groups—other than birds—taken in the AI trawl fisheries for Pacific cod, expressed as a proportion of the incidental catch of that species group taken in all FMP AI fisheries, 2004-2016 (2016 data are current through October 23). Color shading: red = row minimum, green = row maximum.

Species Group	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Benthic urochordata	0.15	0.31	0.13	0.05	conf	conf	conf		0.00	0.14	conf	conf	conf
Bivalves	0.91	0.78	0.99	0.94	0.93	0.59	0.09	0.32	0.26	0.04	conf	conf	conf
Brittle star unidentified	0.05	conf	0.21	0.65			0.00	conf	0.00	0.00	conf	conf	
Capelin				conf	conf				conf	0.10	1.00		
Corals Bryozoans - Corals Bryozoans Unidentified	0.33	0.23	0.31	0.41	0.25	0.14	0.04	0.00	0.00	0.02	conf	conf	0.04
Corals Bryozoans - Red Tree Coral	0.01	0.51		0.91									
Dark Rockfish					conf		conf						
Eelpouts	0.50	conf	0.02	0.06		0.01			0.01	0.00	conf	conf	
Eulachon		conf	0.01	conf	conf				1.00				
Giant Grenadier										conf			
Greenlings	0.05	conf	0.06	0.13	0.10	0.01	conf	conf	0.22		conf		
Grenadier - Ratail Grenadier Unidentified	conf	conf											
Hermit crab unidentified	0.98	0.08	0.64	0.66	0.12	0.21	0.03	conf	0.42	0.11	conf		conf
Invertebrate unidentified	0.00	0.02	0.62	0.15	0.04	0.01	conf	0.01	0.00	0.00	conf		conf
Lanternfishes (myctophidae)												conf	
Large Sculpins - Bigmouth Sculpin					0.08	0.10	0.04	0.04	0.03	0.05	0.00	conf	0.06
Large Sculpins - Great Sculpin					0.60	0.68	0.55	0.77	0.75	0.36	0.05	conf	0.66
Large Sculpins - Hemilepidotus Unidentified					0.00		0.00		0.00	0.00	conf		
Large Sculpins - Myoxocephalus Unidentified					0.09				0.01	0.13	conf		conf
Large Sculpins - Plain Sculpin					conf				0.73	0.78	conf		
Large Sculpins - Red Irish Lord									0.04		conf		
Large Sculpins - Warty Sculpin					conf	conf			0.15	0.08	conf		
Large Sculpins - Yellow Irish Lord					0.14	0.09	0.04	0.08	0.07	0.04	0.03	conf	0.10
Large Sculpins	0.22	0.17	0.25	0.24									
Misc crabs	0.57	0.51	0.46	0.10	0.17	0.07	0.02	0.04	0.03	0.01	conf	conf	conf
Misc crustaceans	0.29	0.98	0.93	0.33	conf	conf	0.16	conf	0.00	0.00	conf	conf	
Misc fish	0.10	0.11	0.06	0.09	0.04	0.07	0.06	0.04	0.02	0.03	0.03	conf	0.01
Misc inverts (worms etc)	conf	conf	0.94	conf					conf	0.00	conf		
Other osmerids			0.00	conf					conf	1.00			
Other Sculpins	0.01	0.04	0.07	0.05	0.01	0.03	0.00	0.01	0.00	0.01	0.01	conf	conf
Pacific Sand lance		conf	1.00	conf	conf		conf					conf	
Pandalid shrimp	0.01	0.03	0.00	0.06	0.00	conf	0.00	conf	0.00	0.00	conf	conf	conf
Polychaete unidentified	conf	conf		0.15	conf	conf				1.00	conf		
Scypho jellies	0.47	conf	0.11	0.04	0.01	conf	0.20	conf	0.06	0.17	conf	conf	0.05
Sea anemone unidentified	0.31	0.21	0.19	0.10	0.06	0.01	conf	conf	0.01	0.00	conf	conf	conf
Sea pens whips	0.90	0.04	0.07	0.13	conf	0.02	conf	conf					
Sea star	0.26	0.14	0.24	0.14	0.04	0.02	0.01	0.02	0.02	0.03	0.01	conf	0.02
Snails	0.49	0.15	0.27	0.25	0.05	0.06	0.03	conf	0.01	0.01	conf	conf	conf
Sponge unidentified	0.12	0.28	0.21	0.08	0.02	0.04	0.01	0.02	0.01	0.00	0.00	conf	0.02
Stichaeidae		conf	0.09	conf		conf							
Urchins dollars cucumbers	0.43	0.14	0.16	0.32	0.04	0.15	0.01	0.00	0.01	0.01	0.01	conf	0.01

Table 2A.11b—Incidental catch (t) of non-target species groups—other than birds—taken in the AI fixed gear fisheries for Pacific cod, expressed as a proportion of the incidental catch of that species group taken in all FMP AI fisheries, 2004-2016 (2016 data are current through October 23). Color shading: red = row minimum, green = row maximum.

Species Group	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Benthic urochordata	conf	0.08	0.01	0.01	0.03	0.01	0.07	0.01	0.03	conf	0.00	conf	conf
Bivalves	0.02	0.20	0.01	0.04	0.03	0.19	0.71	0.22	0.50	0.09	0.09	0.19	conf
Brittle star unidentified	0.00	0.02	0.19	0.00	0.20	0.01	0.03	0.00	0.00	0.04	0.00	conf	
Corals Bryozoans - Corals Bryozoans Unidentified	0.04	0.01	0.02	0.07	0.02	0.24	0.30	0.08	0.09	0.06	conf	0.07	conf
Corals Bryozoans - Red Tree Coral	conf		0.01		0.14	0.88							
Dark Rockfish					0.64	0.53	0.56	0.13	0.09	0.21	0.01	0.19	
Eelpouts	conf	0.08	0.02	0.09	0.02	0.00	0.02	0.01	0.00	conf		conf	
Giant Grenadier	conf	0.00	0.07	0.02	0.02	0.00	0.06	0.01	0.01	conf	conf	conf	
Greenlings	0.15	0.03	0.82	0.11	0.54	0.38	0.55	0.72	0.24		0.38	1.00	conf
Grenadier - Pacific Grenadier	conf	1.00					conf						
Grenadier - Ratail Grenadier Unidentified	0.01	0.00	0.03	0.22	0.01	0.01	0.27	0.00	0.01	conf			
Gunnels	conf	0.01		0.51									
Hermit crab unidentified	0.00	0.02	0.05	0.15	0.74	0.64	0.41	0.10	0.12	0.27	0.10	conf	
Invertebrate unidentified	0.12	0.03	0.00	0.02	0.05	0.00	0.20	0.03	0.00	0.00	conf	conf	conf
Large Sculpins - Bigmouth Sculpin					0.04	0.04	0.09	0.01	0.02	0.00	0.00	conf	conf
Large Sculpins - Brown Irish Lord					1.00	1.00							
Large Sculpins - Great Sculpin					0.33	0.27	0.17	0.09	0.20	0.57	0.64	0.01	conf
Large Sculpins - Hemilepidotus Unidentified					0.97	0.98	0.99	0.92	0.98	0.98	0.76	0.87	conf
Large Sculpins - Myoxocephalus Unidentified					0.79	1.00	0.72	0.99	0.98	0.45	0.66	conf	conf
Large Sculpins - Plain Sculpin					0.98	0.97	0.52	1.00	0.27	0.22	0.29		
Large Sculpins - Red Irish Lord					0.12	0.32	0.10	0.31	0.02	0.48	0.02	conf	
Large Sculpins - Warty Sculpin					0.96	0.92	0.03	1.00	0.85	0.84	0.55	conf	
Large Sculpins - Yellow Irish Lord					0.20	0.10	0.22	0.05	0.15	0.15	0.12	0.06	conf
Large Sculpins	0.18	0.22	0.19	0.21									
Misc crabs	0.01	0.01	0.03	0.55	0.31	0.40	0.55	0.04	0.33	0.69	0.50	conf	conf
Misc crustaceans	conf	0.00	0.00	0.01	0.01	0.00	0.22	conf	conf		conf	conf	
Misc fish	0.02	0.00	0.00	0.00	0.02	0.01	0.04	0.01	0.02	0.02	0.01	0.00	conf
Misc inverts (worms etc)	conf	0.83	0.00	0.01	0.00	0.00							
Other osmerids		0.06											
Other Sculpins	0.40	0.04	0.24	0.12	0.10	0.24	0.48	0.03	0.07	0.06	0.03	0.08	conf
Pacific Sandfish											1.00		
Pandalid shrimp							conf						
Polychaete unidentified	conf	0.56	1.00	0.00	0.00	0.05	conf	conf	conf				
Scypho jellies	conf	0.00	0.08	0.02	0.21	0.11	0.15	0.20	0.77	0.80	0.61		
Sea anemone unidentified	0.23	0.72	0.60	0.28	0.27	0.46	0.39	0.07	0.13	0.03	0.01	0.04	conf
Sea pens whips	conf	0.92	0.89	0.72	0.36	0.62	0.94	0.93	1.00	conf		0.35	conf
Sea star	0.46	0.35	0.33	0.43	0.58	0.50	0.65	0.09	0.31	0.19	0.19	0.13	conf
Snails	0.03	0.11	0.34	0.23	0.58	0.69	0.35	0.45	0.27	0.28	0.10	0.05	conf
Sponge unidentified	0.03	0.05	0.01	0.02	0.01	0.07	0.09	0.01	0.04	0.01	0.00	0.02	conf
Urchins dollars cucumbers	0.10	0.02	0.11	0.10	0.08	0.03	0.10	0.01	0.03	0.01	0.01	0.02	conf

Table 2A.11c— Incidental catch (t) of bird species groups taken in the AI fisheries for Pacific cod, expressed as a proportion of the incidental catch of that species group taken in all FMP AI fisheries, 2004-2016 (2016 data are current through September 25).

Trawl gear:

Species	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Birds - Gull				0.19									
Birds - Laysan Albatross		conf				conf							
Birds - Northern Fulmar	0.04	0.64	0.10		0.49	conf	0.37						conf
Birds - Unidentified Albatross			1.00										
Birds - Unidentified			0.95										

Fixed gear:

Species	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Birds - Auklets									1.00		1.00		
Birds - Black-footed Albatross	conf	1.00	0.00	1.00	1.00	1.00	conf						
Birds - Cormorant			1.00										
Birds - Gull	0.25	0.60	0.45	0.41	1.00	0.59	0.54	0.08	0.07	conf		conf	
Birds - Kittiwake	conf	1.00				0.84		1.00	1.00	conf			
Birds - Laysan Albatross	conf	0.17	0.44	0.25	0.40	0.11	0.30	0.00	0.00	conf		conf	
Birds - Murre	conf	0.34	0.47	0.98	1.00	1.00			1.00				
Birds - Northern Fulmar	0.23	0.25	0.72	0.83	0.27	0.29	0.22	0.10	0.46	0.25	0.03	conf	
Birds - Other Alcid	conf												
Birds - Puffin							conf						
Birds - Shearwaters	1.00	0.89	0.00	0.07	1.00	0.21	conf	0.26	0.26	conf			
Birds - Short-tailed Albatross							conf	1.00					
Birds - Storm Petrels			1.00										
Birds - Unidentified	1.00	1.00	0.00	0.27	1.00	0.10	0.62	1.00	1.00	conf			

FIGURES

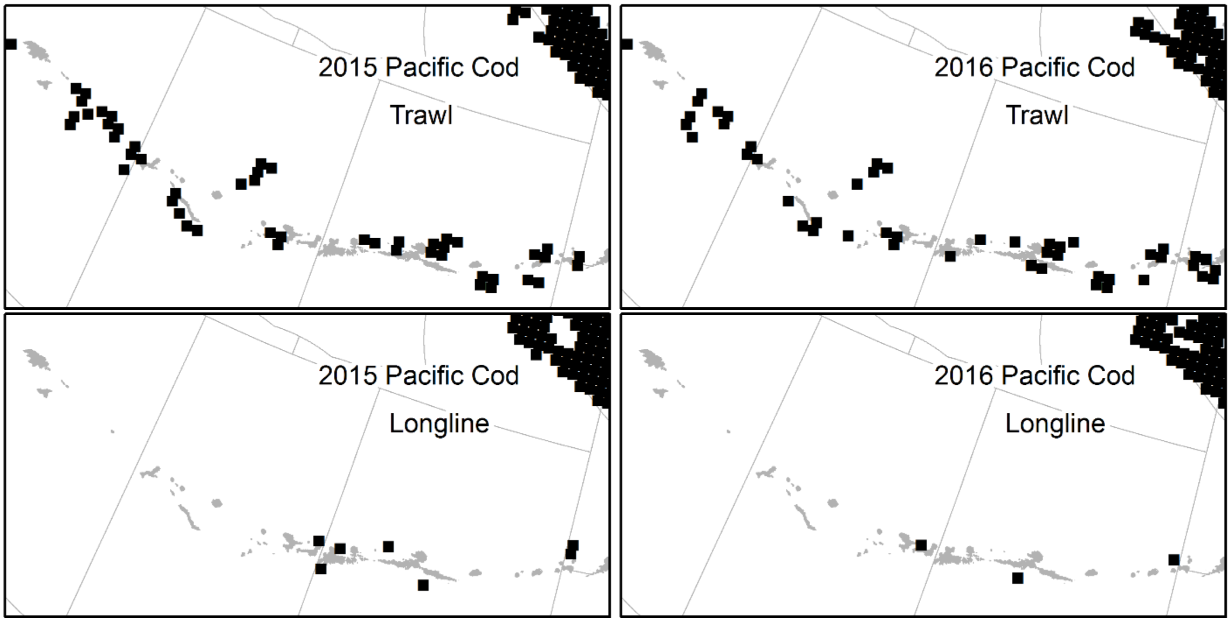

Figure 2A.1--AI maps showing each 400 square km cell with trawl hauls or longline sets containing Pacific cod from at least 3 distinct vessels in 2015-6, overlaid against NMFS 3-digit statistical areas.

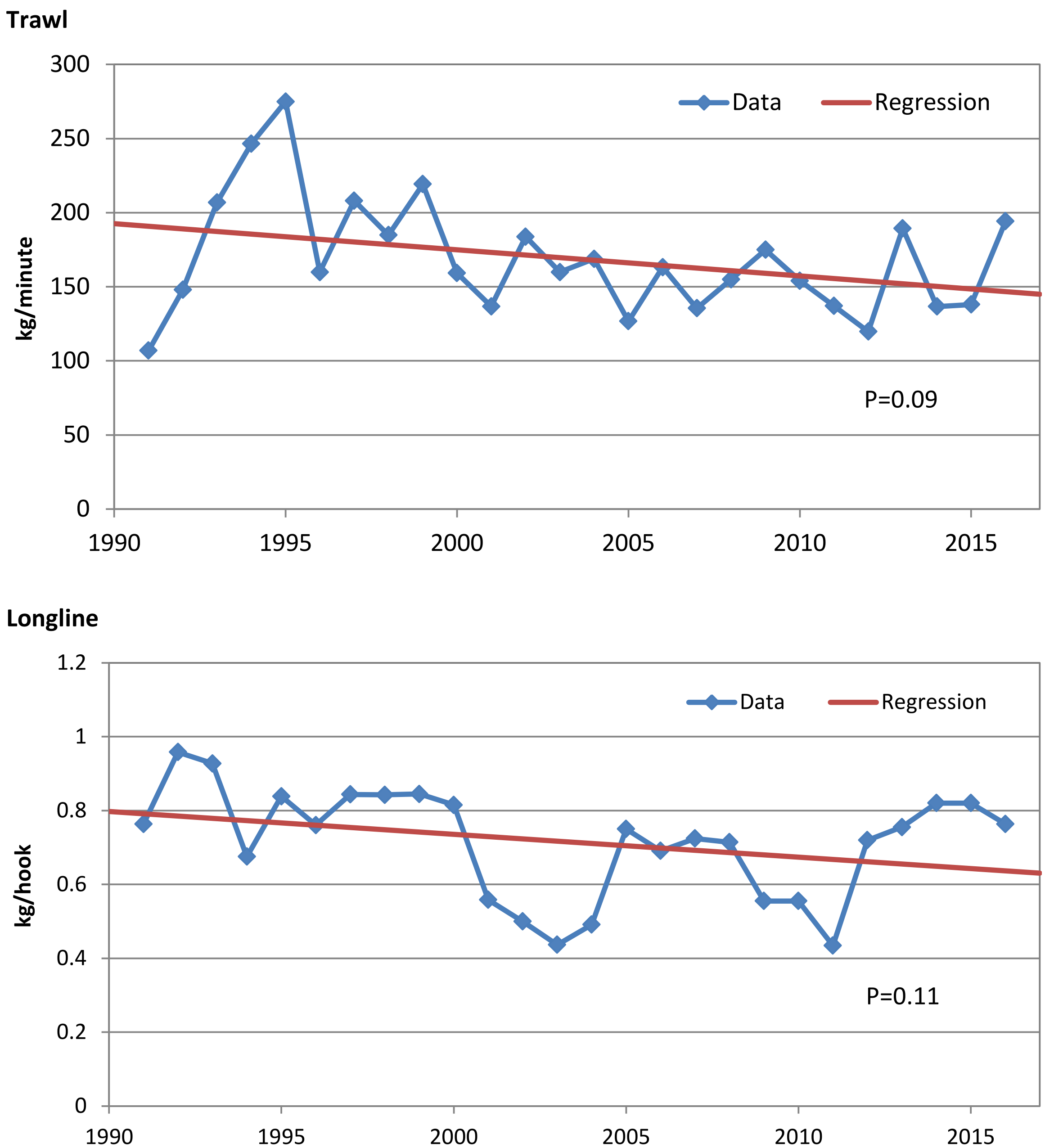

Figure 2A.2—Catch per unit effort for the trawl and longline fisheries, 1991-2016 (2016 data are partial).

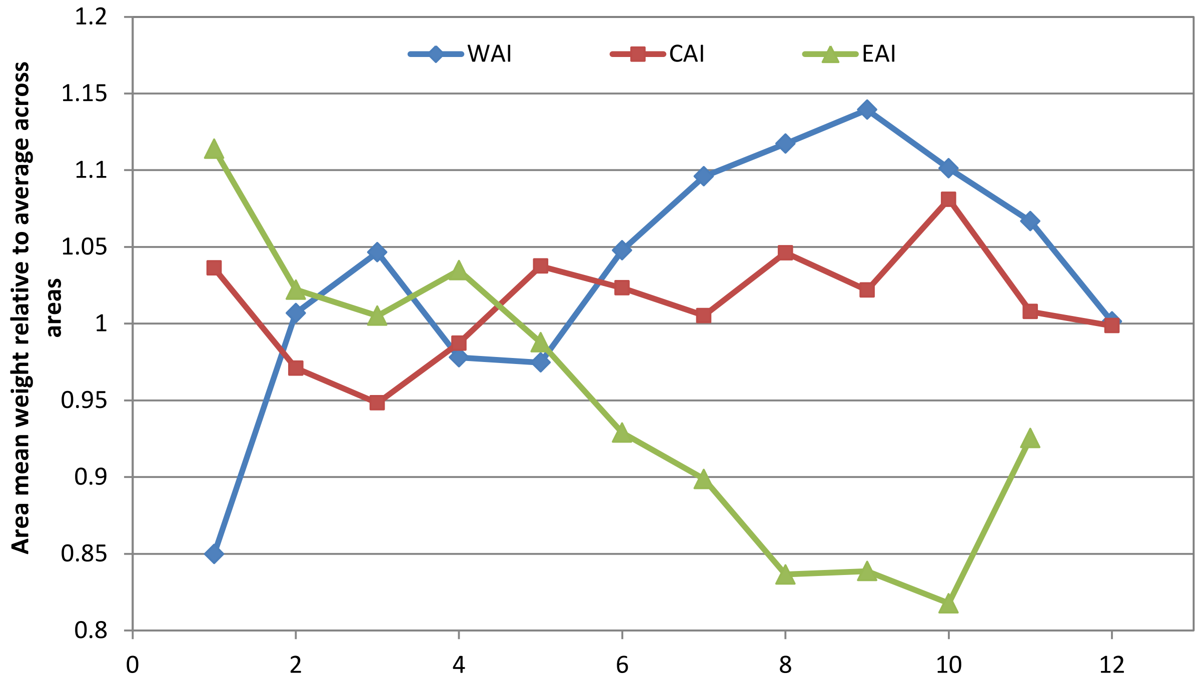

Figure 2A.3—Weight at age by age and area, expressed relative to age-specific average across areas.

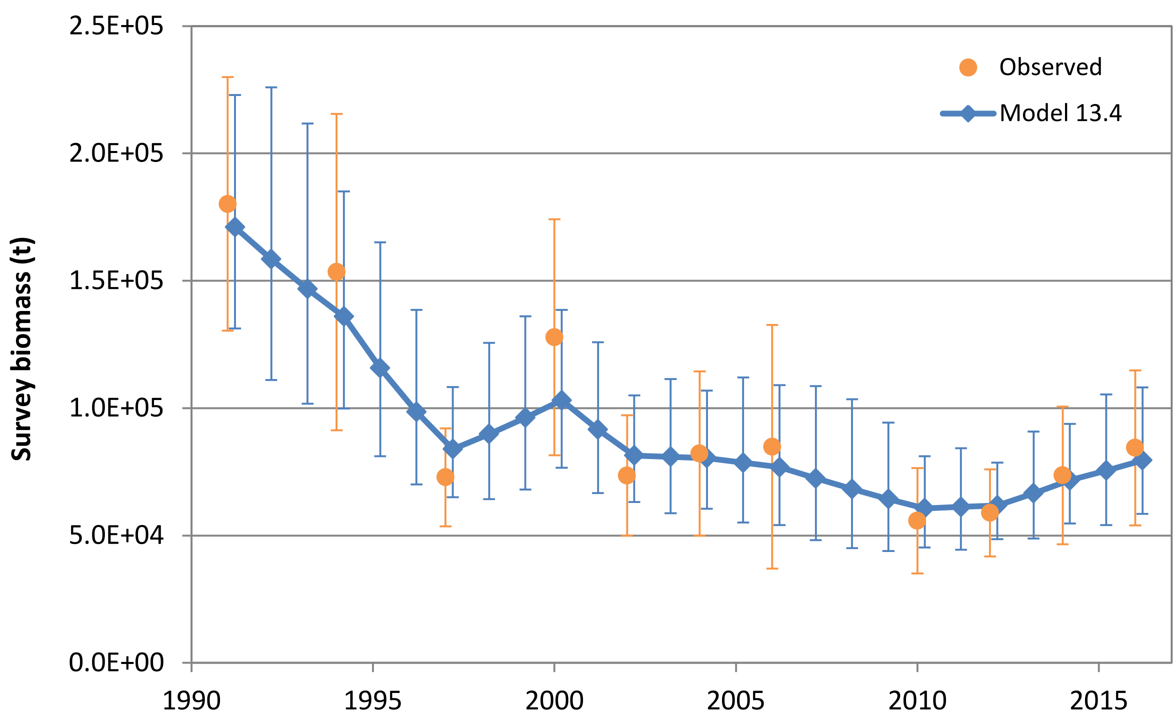

Figure 2A.4—Fit of Model 13.4 to survey biomass time series, with 95% confidence intervals for the observations and the estimates.

APPENDIX 2A.1: PRELIMINARY ASSESSMENT OF THE PACIFIC COD STOCK IN THE ALEUTIAN ISLANDS

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Introduction

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

Responses to SSC and Plan Team comments on assessments in general

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

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

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

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

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

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

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

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

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

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

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

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

SSC7 (6/16 minutes): "*The SSC agrees with CIE recommendations to use all reasonable data sources that are available, although the use of the longline survey data in the model has been attempted in the past with little success. As the author noted, survey indices were generally negatively correlated with model-estimated biomass in past assessments. The use of 'extra SD' in the proposed models for both regions is a reasonable approach to deal with this issue.*" Internally estimated increments to the log-scale standard errors for the IPHC and NMFS longline survey indices are reported in Table 2A.1.7.

Data

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

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

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

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

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

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

Relative abundance data from the IPHC and NMFS longline surveys are shown in Table 2A.1.1, and size composition data from those two surveys are shown in Table 2A.1.2.

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

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

Model structures

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

Developing the models requested by the Joint Team Subcommittee

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

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

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

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

These issues were addressed as follows:

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

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

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

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

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

and

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

where

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Model 15.7 Structure: Main Features

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

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

Model 15.7 Structure: Iterative Tuning

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

Iterative Tuning of Prior Distributions for Selectivity Parameters

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

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

Iterative Tuning of Time-Varying Selectivity Parameters

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

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

The iteration was conducted separately for the fishery and survey.

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

Results

Overview

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

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

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

Goodness of fit

Objective function values and parameter counts are shown for each model in Table 2A.1.3a, and multipliers used to adjust multinomial sample sizes are shown in Table 2A.1.3b. Objective function values are not directly comparable across models, because different data files are used for some models, different constraints are imposed, and the number and types of parameters vary considerably.

Figure 2A.1.1a shows the fits of all six models to the trawl survey abundance data; Figure 2A.1.1b shows the fits of Models 16.2, and 16.4 to the IPHC longline survey abundance data; and Figure 2A.1.1c shows the fits of Models 16.3 and 16.4 to the NMFS longline survey abundance data.

Table 2A.1.4 shows goodness of fit for the survey abundance data (Models 16.1-16.5). Four measures are shown: root mean squared error (for comparison, the average log-scale standard error "σave" is also shown), mean normalized residual, standard deviation of normalized residuals, and correlation (observed:estimated). For the trawl survey data, Model 16.2 gives a root mean squared error close to σave, while all of the others give higher RMSEs. Models 16.2-16.5 all give mean normalized residuals in the +/– 0.1 range. Models 16.1-16.5 all give standard deviation of normalized residuals greater than unity. Models 16.2-16.4 give correlations greater close to 0.90 or better. The two models that use the IPHC longline survey data both give mean normalized residuals close to zero, standard deviation of normalized residuals close to unity (note that these models inflate the input σ values by an internally estimated amount, and the resulting estimates of σave are fairly high, in the 0.42-0.42 range), and correlations in the 0.46-0.54 range. The two models that use the NMFS longline survey data perform similarly to those that use the IPHC data.

Sample size ratios for the size composition data (Models 16.1-16.5) are shown in Table 2A.1.5 (note that input sample sizes are the same for all models except for the trawl survey data in Model 16.5). These results can be summarized as follows:

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

Sample size ratios for the survey age composition data are shown in Table 2A.1.6 (Models 16.1-16.5). Measured either as the ratio of the arithmetic means or the ratio of the harmonic mean effective sample size to the arithmetic mean input sample size, all of the models give values of 0.50 or less.

Figure 2A.1.2 shows the fits to the survey *size* composition data, and Figure 2A.1.3 shows the fits to the survey *age* composition data (Models 16.1-16.5 in both cases).

Parameter estimates, time series, and retrospective analysis

Table 2A.1.7 lists key parameters estimated internally in at least one of the models, along with their standard deviations. Note that the natural mortality rate *M* was not estimated in any of the models, but was instead fixed at a value of 0.34, based on the assessment of Pacific cod in the eastern Bering Sea (Thompson 2015). The estimates of log catchability for the trawl survey shown in Table 2A.1.7 map into the following estimates of catchability on the natural scale, spanning the range 0.161 (Model 16.2) to 0.527 (Model 16.1):

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

Selectivity schedules are plotted for the fishery in Figure 2A.1.4, the trawl survey in Figure 2A.1.5a, the IPHC longline survey in Figure 2A.1.5b, and the NMFS longline survey in Figure 2A.1.5c.

Time series estimated by the models are shown for total biomass, female spawning biomass relative to $B_{100\%}$, age 0 recruitment, and fishing mortality relative to $F_{40\%}$ in Figures 2A.1.6, 2A.1.7, 2A.1.8, and 2A.1.9, respectively.

Figure 2A.1.10 shows 10-year retrospectives of spawning biomass for each of the models, including Model 13.4 (where survey biomass is used in place of spawning biomass). Mohn's ρ (revised) values for the models are shown below:

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

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Tables

Table 2A.1.1—Relative abundance data for the IPHC and NMFS longline surveys, with log-scale standard errors (σ). Note that the σ values shown here may be incremented by an amount estimated by any of the models that use these data (Models 16.2-16.5).

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

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

Table 2A.1.2—Size (cm) composition data from the NMFS and IPHC longline surveys. No fish were observed at lengths smaller than 21 cm (page 1 of 2).

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

Table 2A.1.2—Size (cm) composition data from the NMFS and IPHC longline surveys. No fish were observed at lengths smaller than 21 cm (page 2 of 2).

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

Table 2A.1.3a—Objective function values and parameter counts for Models 16.1-16.5.

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

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

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

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

Table 2A.1.3b—Multinomial sample size multipliers for Models 16.1-16.5

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

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

Table 2A.1.4—Various goodness-of-fit measures for survey abundance data. σave = mean log-scale standard error, RMSE = root mean squared error, MNR = mean normalized residual, SDNR = standard deviation of normalized residuals, Corr. = correlation (observed:estimated).

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

Table 2A.1.5—Statistics related to effective sample sizes (Neff) for length composition data. Nrec = no. records, A(·) = arithmetic mean, H(·) = harmonic mean, Ninp = input sample size.

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

Table 2A.1.6—Statistics related to effective sample size (Eff. N) for survey age composition data. "In. N" = input sample size, Mean = arithmetic mean, Harm. = harmonic mean, Ratio1 = arithmetic mean effective sample size divided by arithmetic mean input sample size, Ratio2 = harmonic mean effective sample size divided by arithmetic mean input sample size.

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

Table 2A.1.7—Estimates ("Est.") of key parameters and their standard deviations ("SD"). A blank indicates that the parameter (row) was not used in that model (column). The natural mortality rate *M* was not estimated in any of the models, but was instead fixed at a value of 0.34 borrowed from the assessment of Pacific cod in the eastern Bering Sea (Thompson 2015).

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

Figures

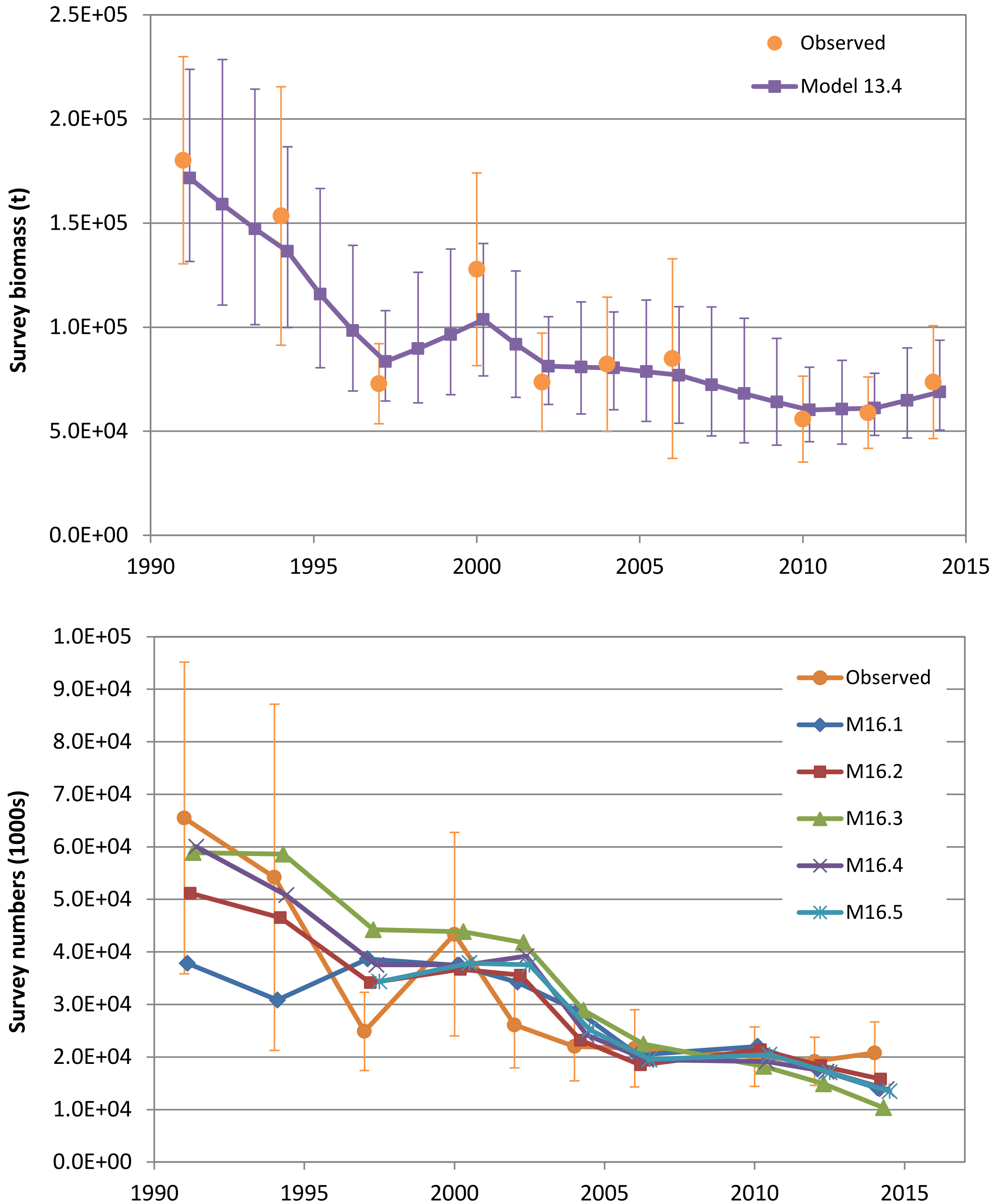


Figure 2A.1.1a—Model fits to the trawl survey indices. Upper panel: fit of Model 13.4 to trawl survey biomass; lower panel: fits of Models 16.1-16.5 to trawl survey abundance.

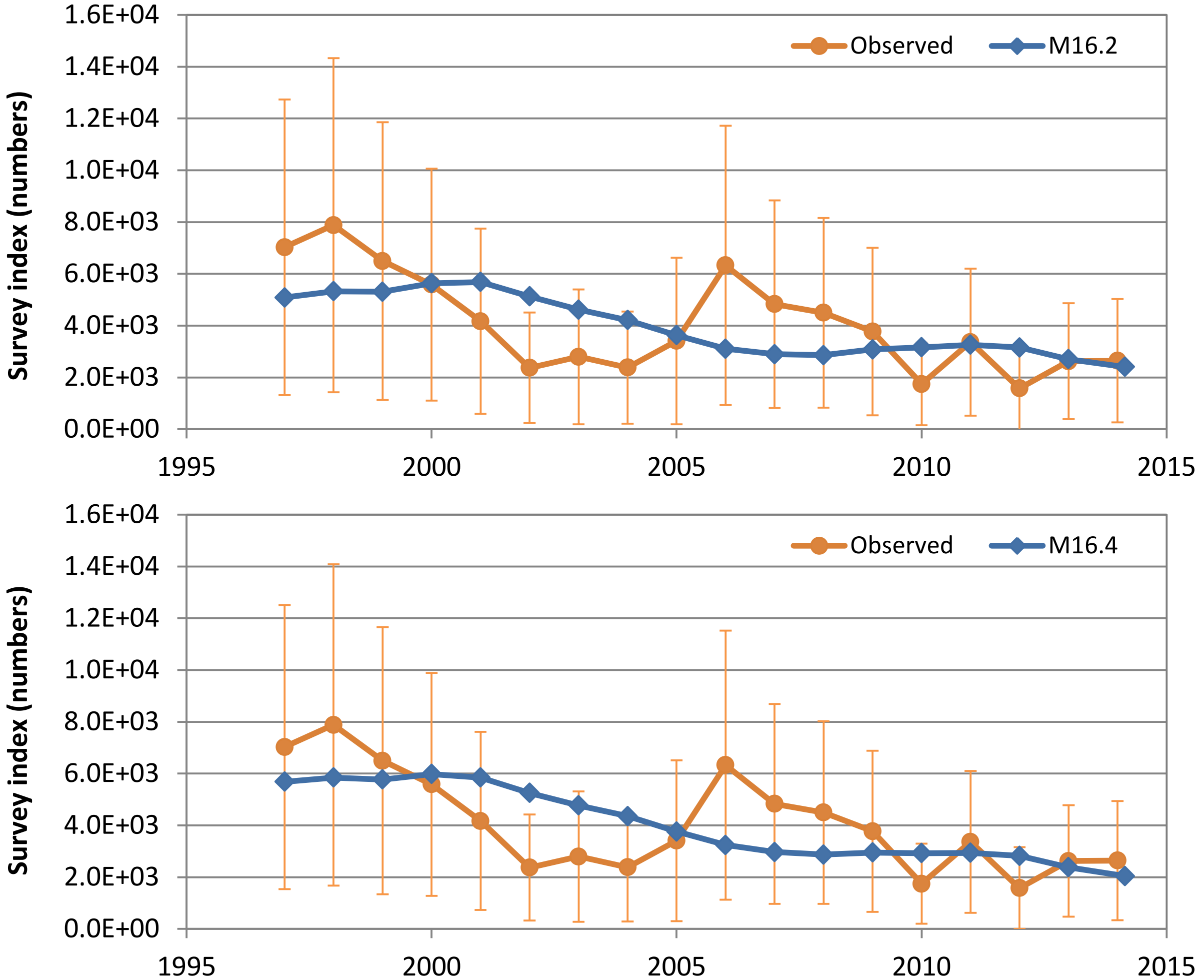


Figure 2A.1.1b—Model fits to the IPHC longline survey abundance time series (Models 16.2 and 16.4 only). Survey time series shows 95% confidence interval, which differs between models.

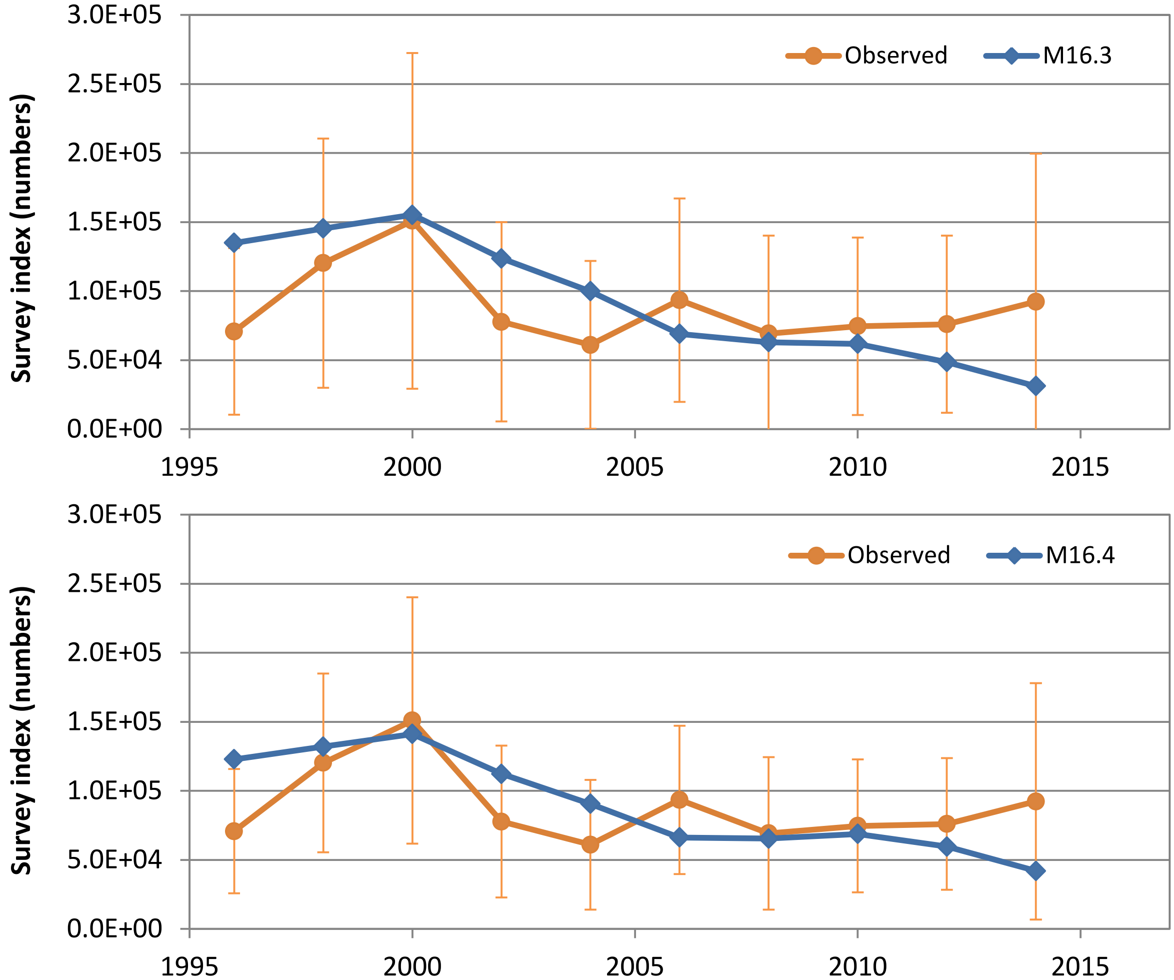


Figure 2A.1.1c—Model fits to the NMFS longline survey abundance time series (Models 16.3 and 16.4 only). Survey time series shows 95% confidence interval, which differs between models.

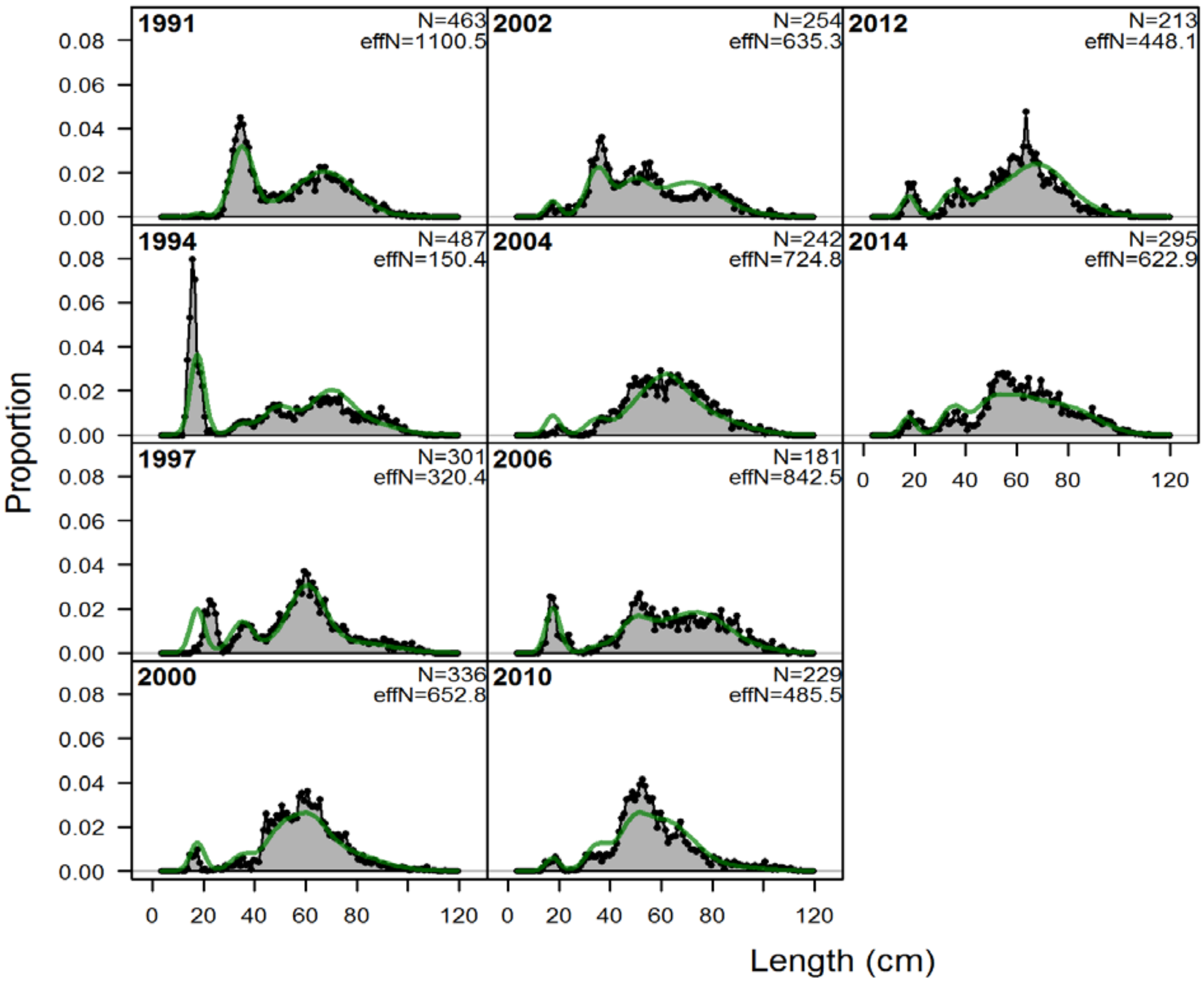


Figure 2A.1.2a—Model 16.1 fits to trawl survey size composition data.

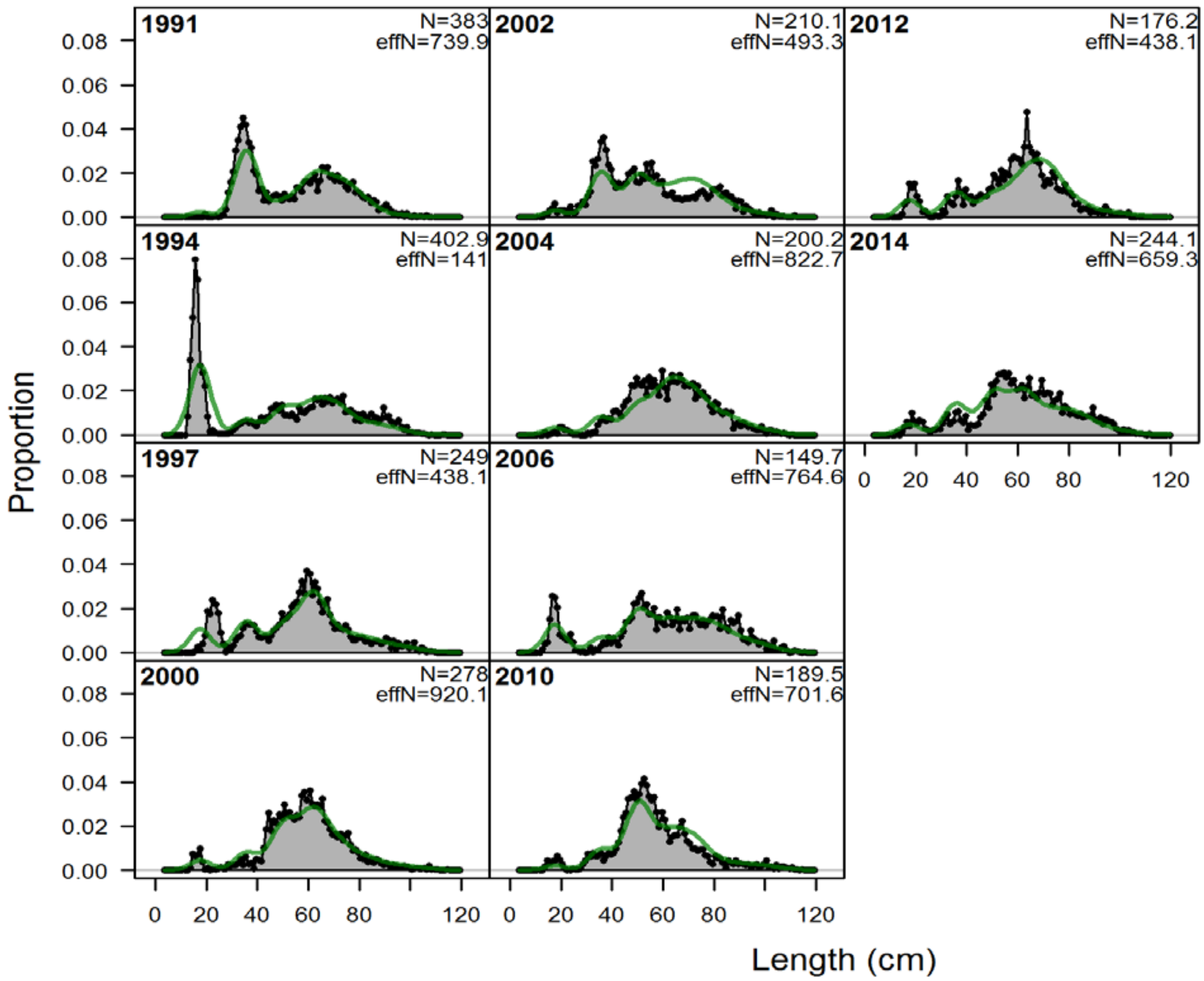


Figure 2A.1.2b—Model 16.2 fits to trawl survey size composition data.

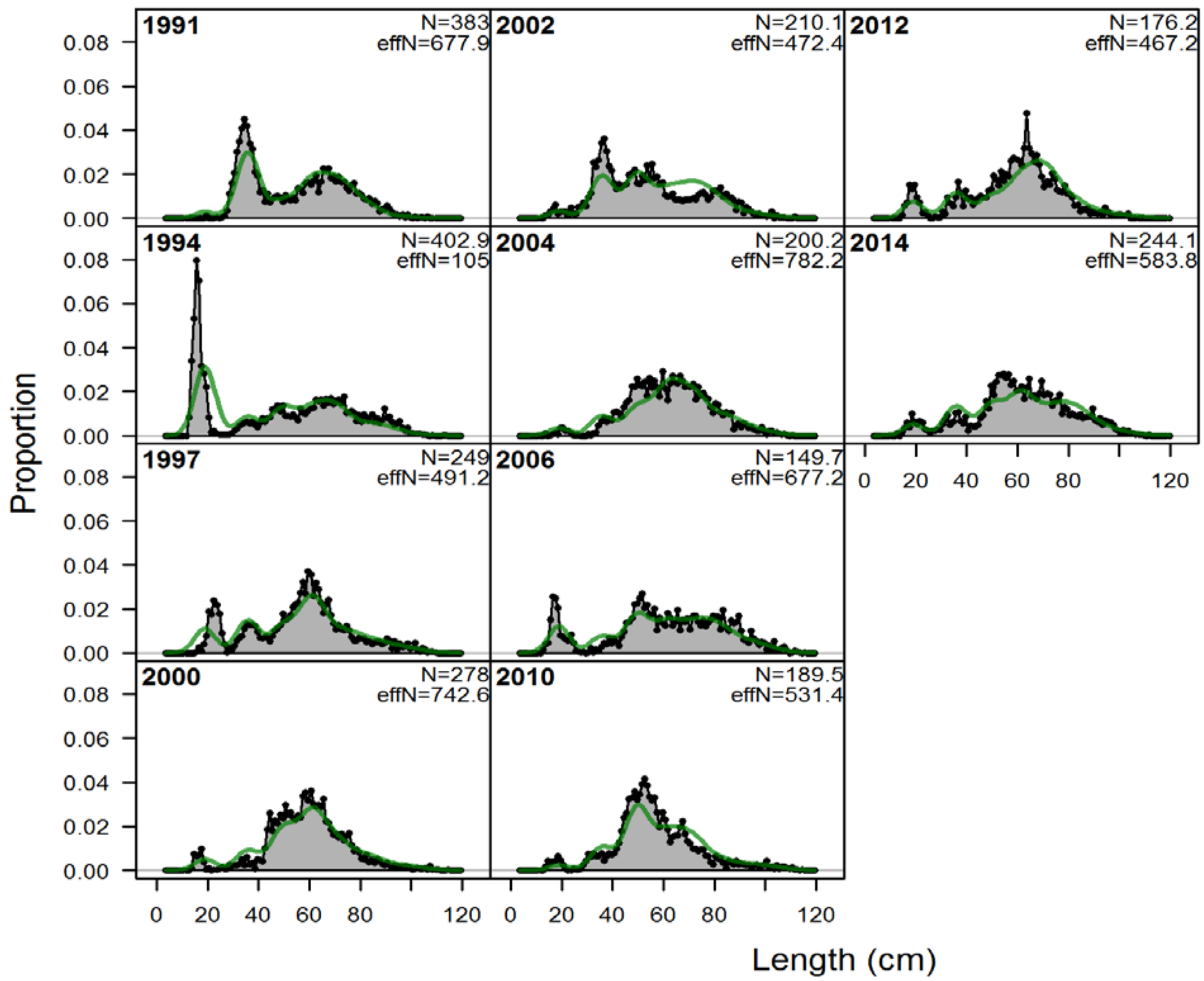


Figure 2A.1.2c—Model 16.3 fits to trawl survey size composition data.

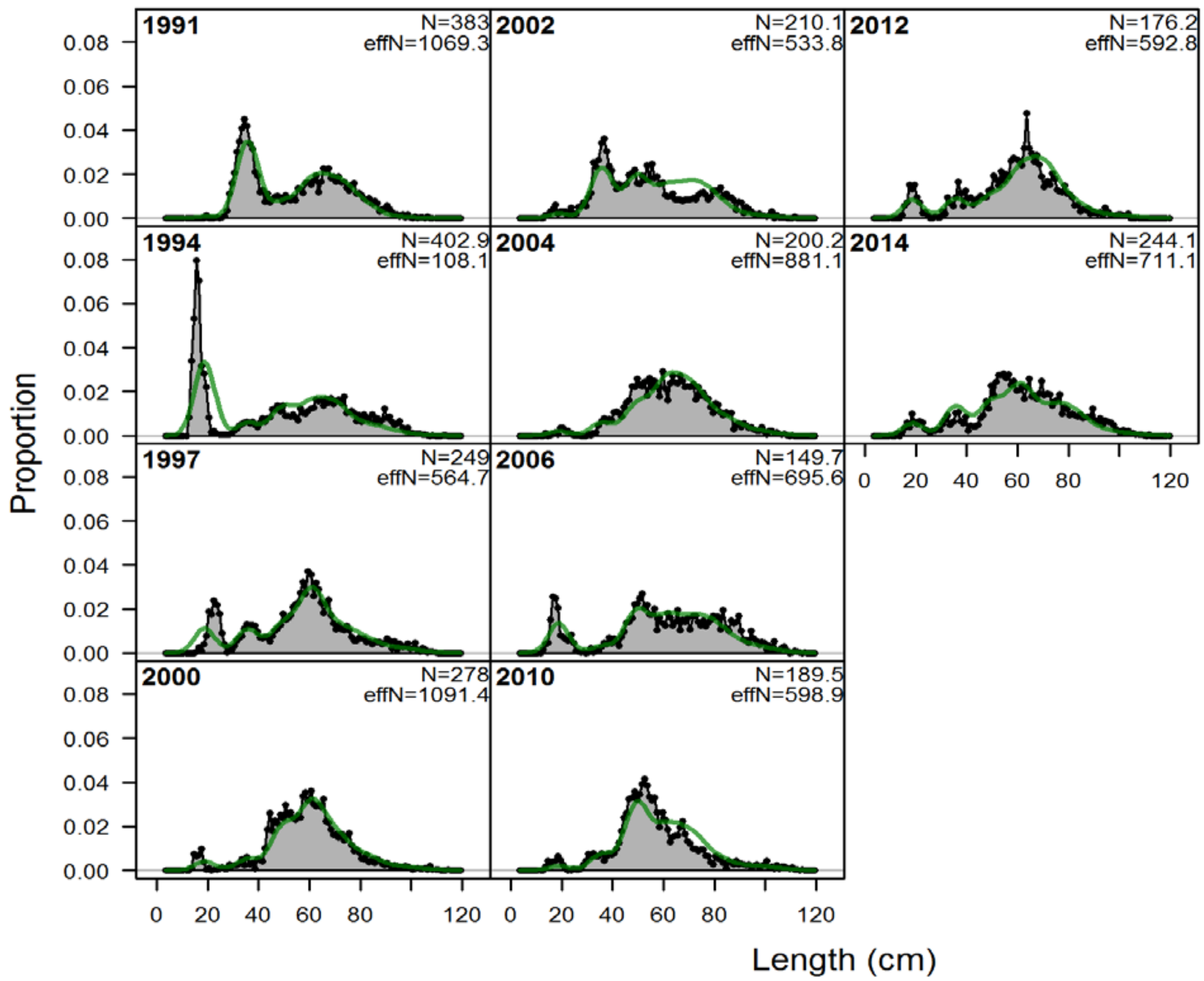


Figure 2A.1.2d—Model 16.4 fits to trawl survey size composition data.

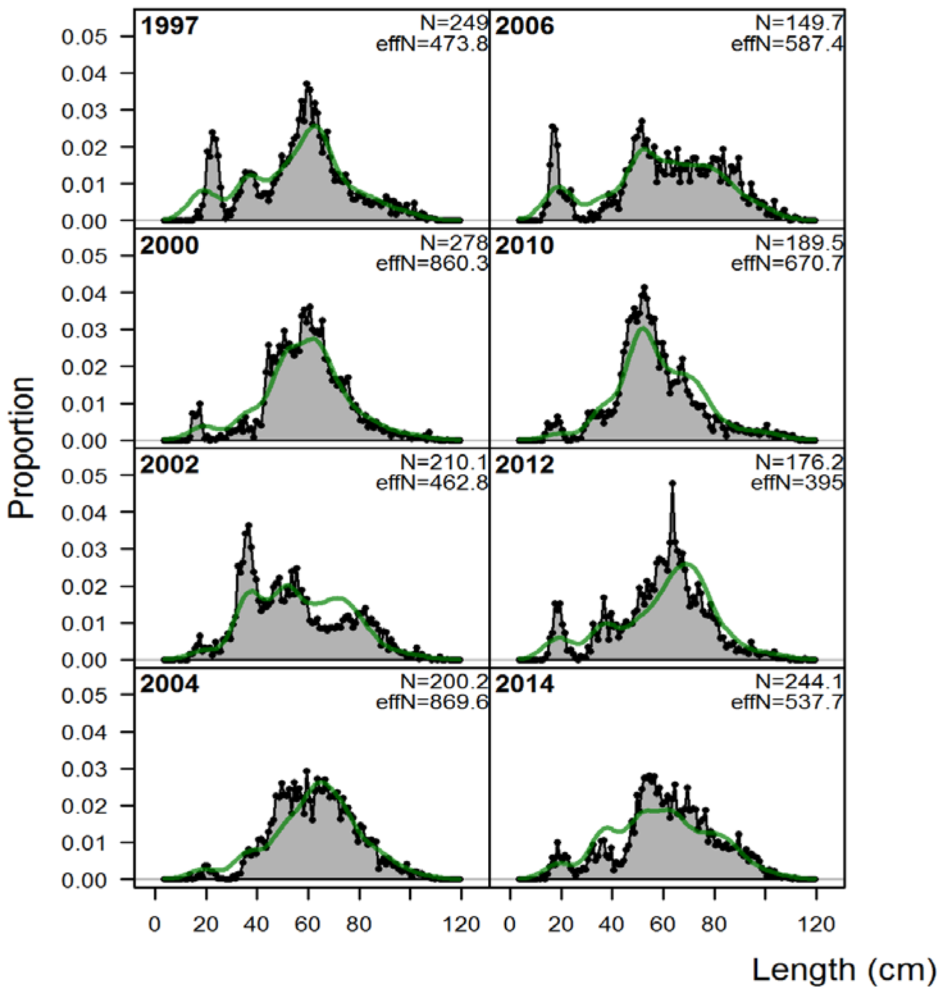


Figure 2A.1.2e—Model 16.5 fits to trawl survey size composition data.

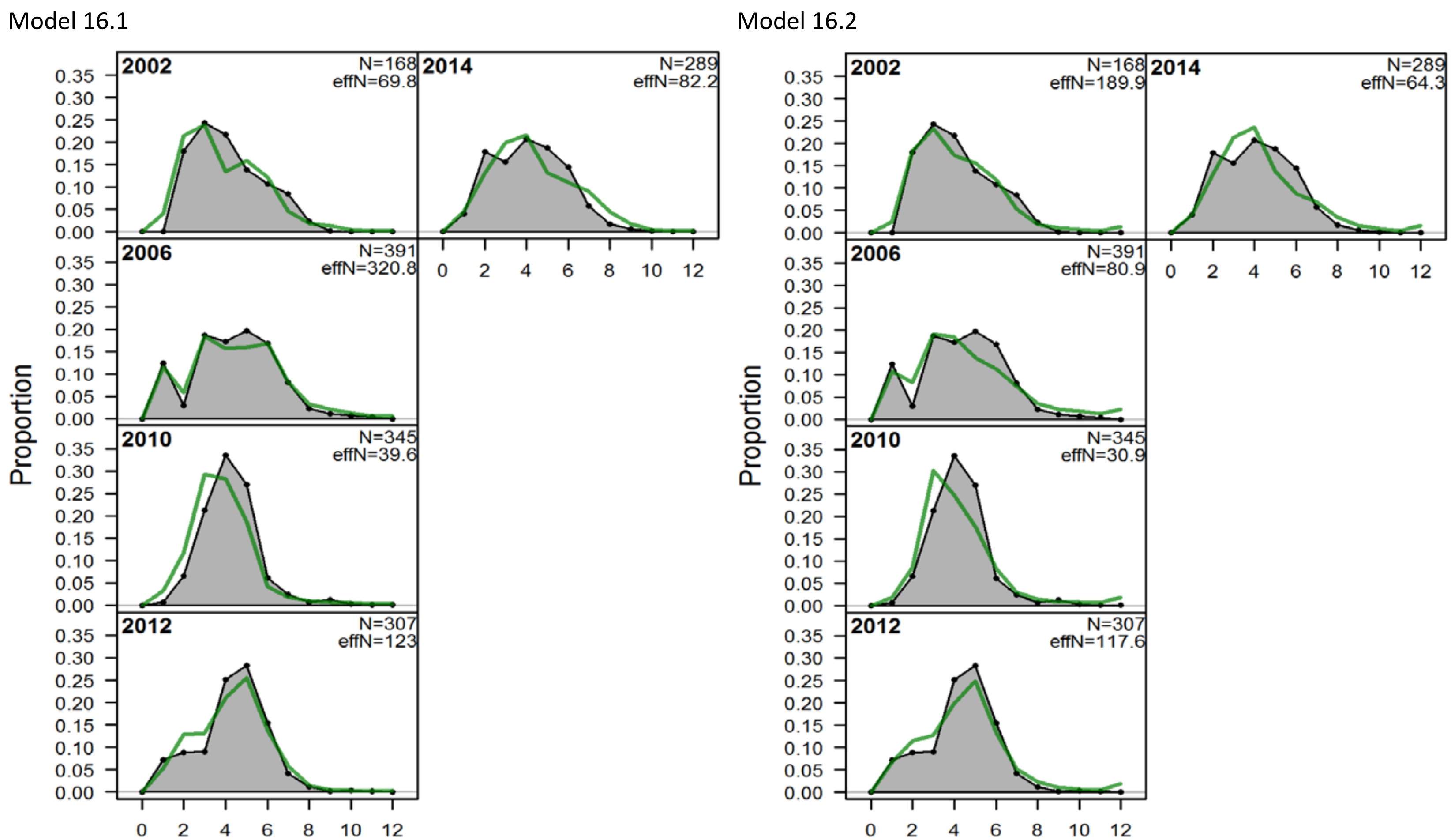


Figure 2A.1.3—Model fits to trawl survey age composition data (page 1 of 3).

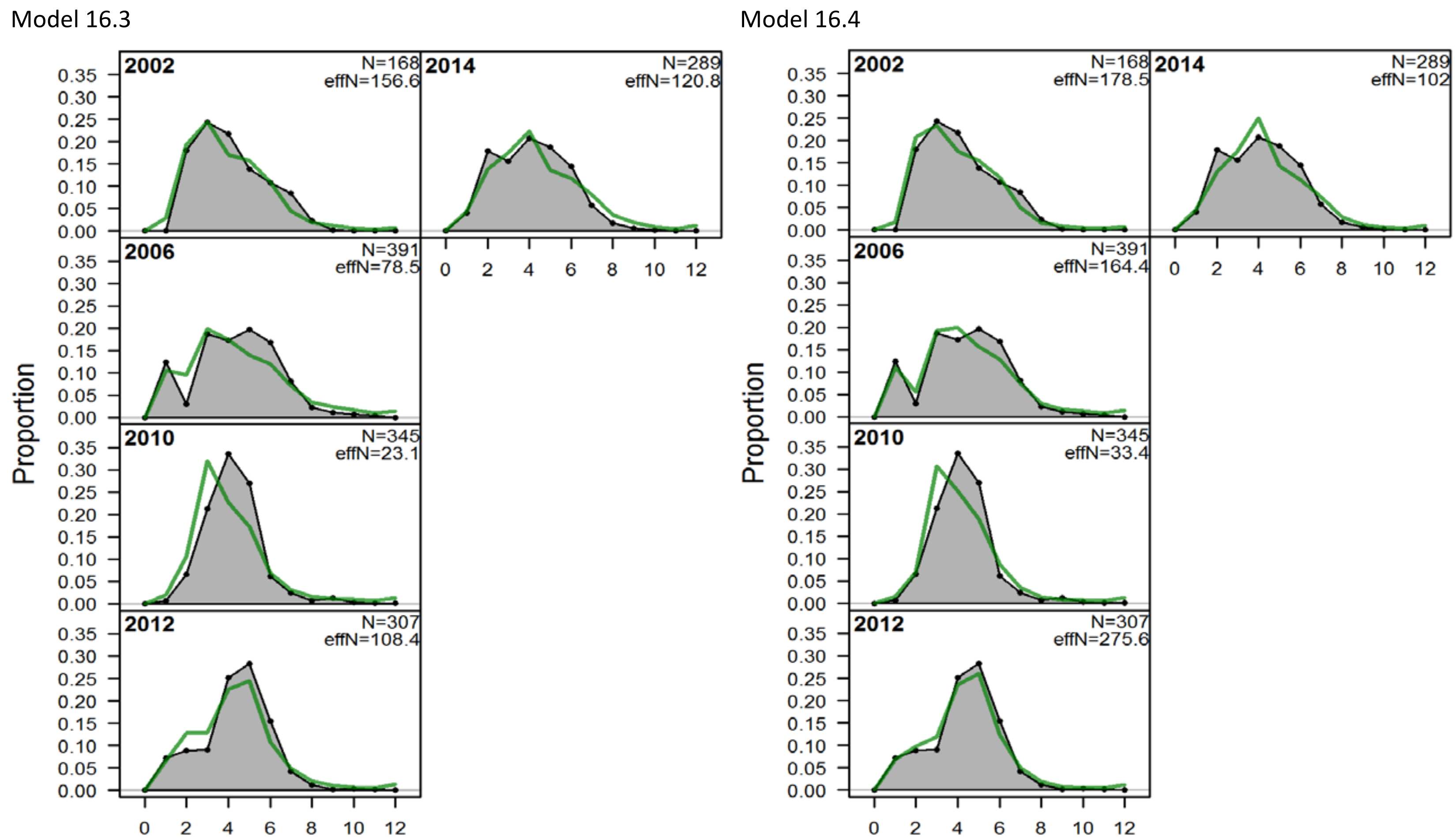


Figure 2A.1.3—Model fits to trawl survey age composition data (page 2 of 3).

Model 16.5

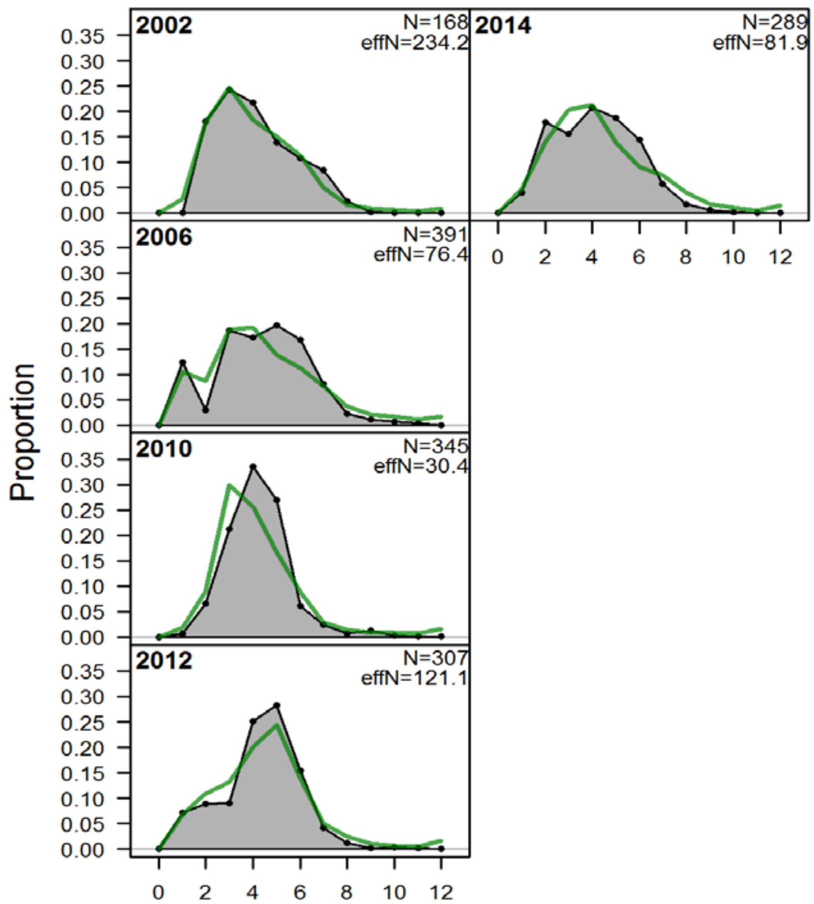


Figure 2A.1.3—Model fits to trawl survey age composition data (page 3 of 3).

Model 16.1

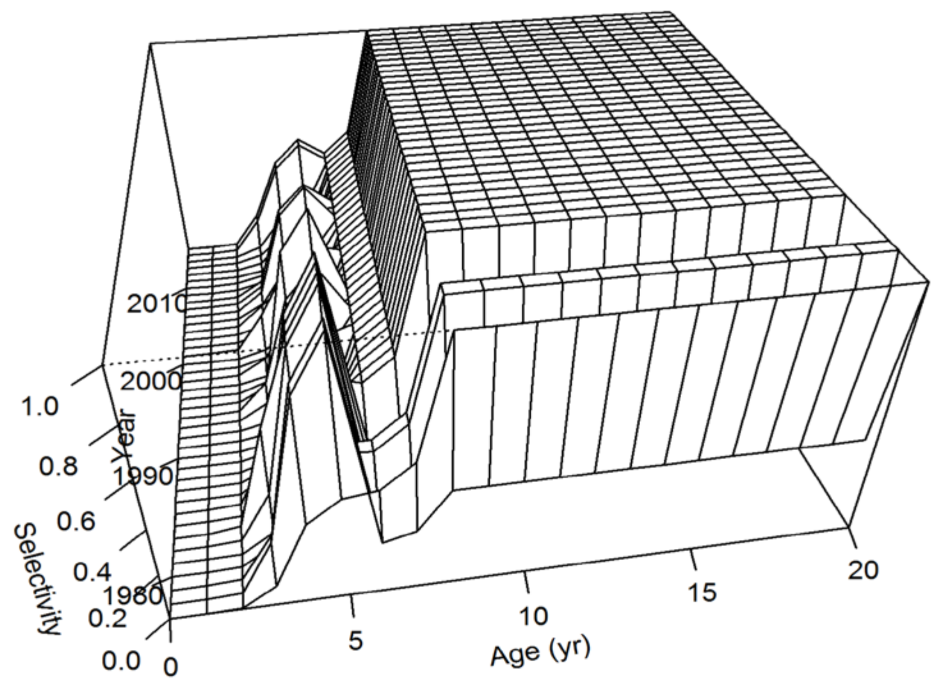
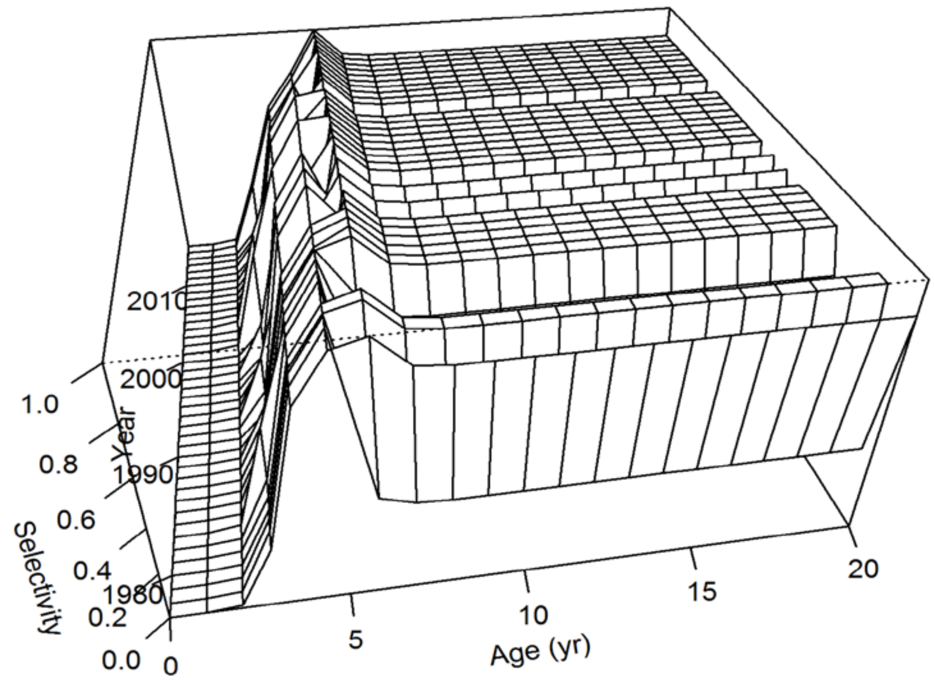


Figure 2A.1.4—Fishery selectivity (page 1 of 3).

Model 16.2



Model 16.3

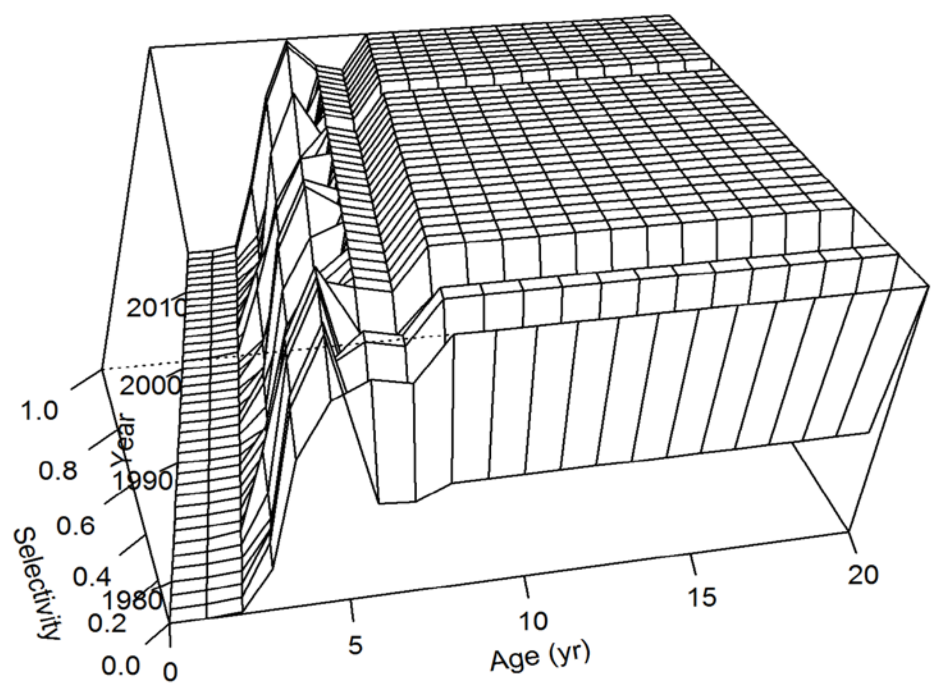
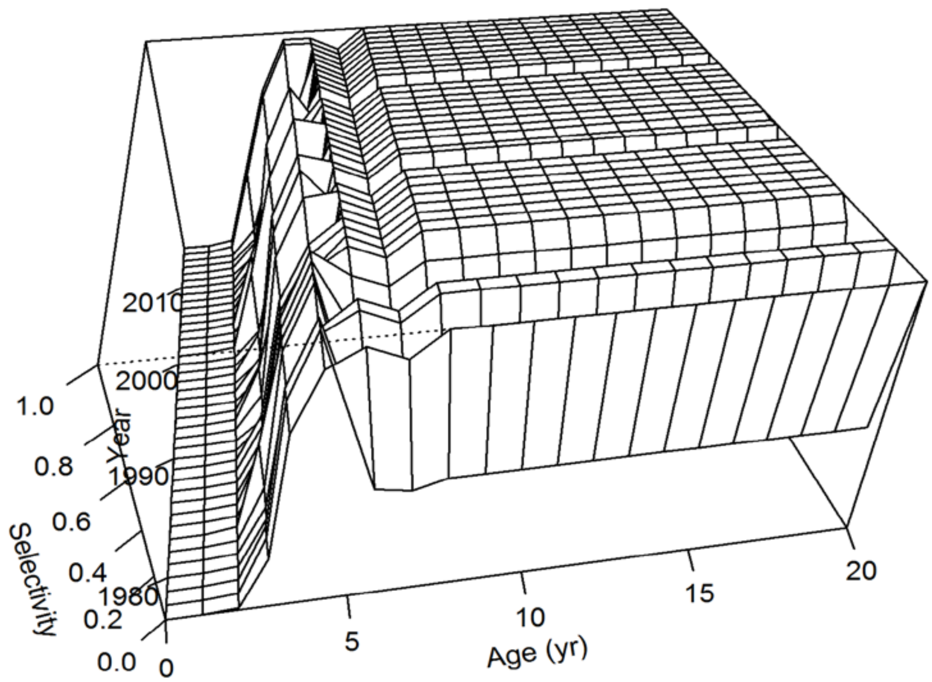


Figure 2A.1.4—Fishery selectivity (page 2 of 3).

Model 16.4



Model 16.5

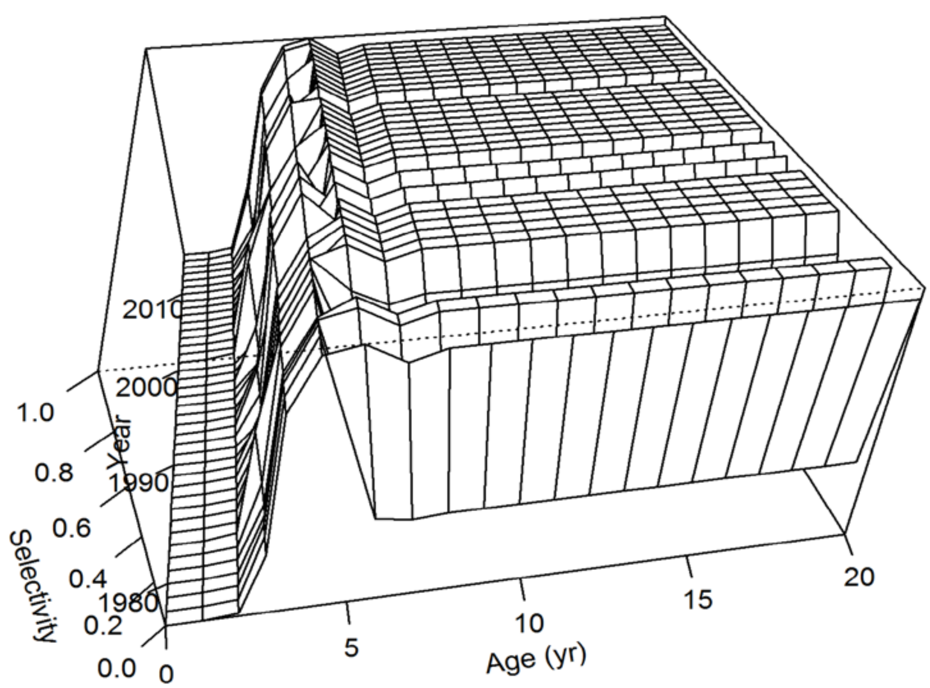


Figure 2A.1.4—Fishery selectivity (page 3 of 3).

Model 16.1

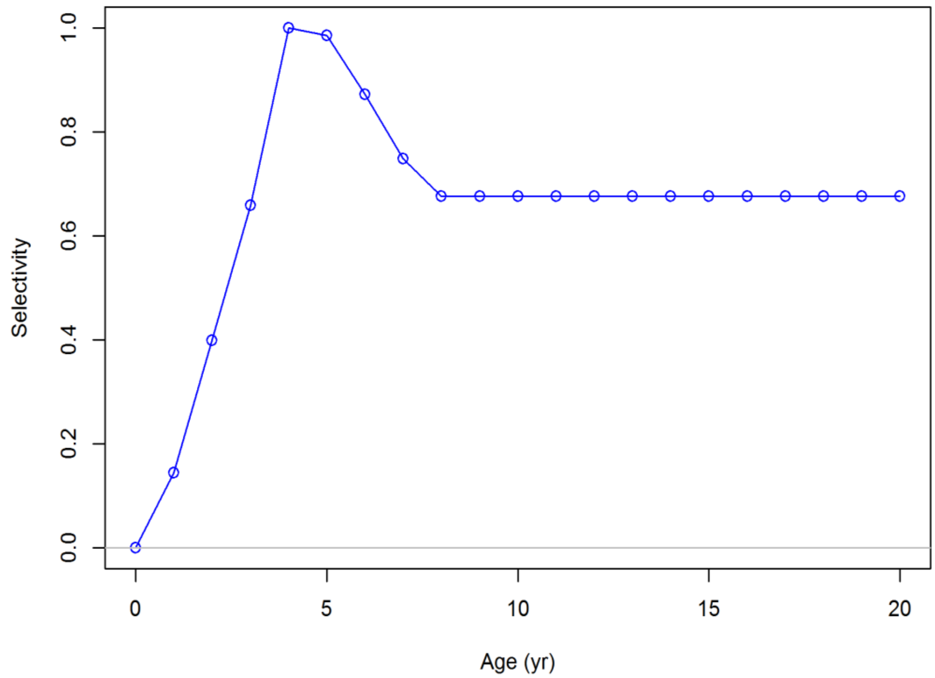
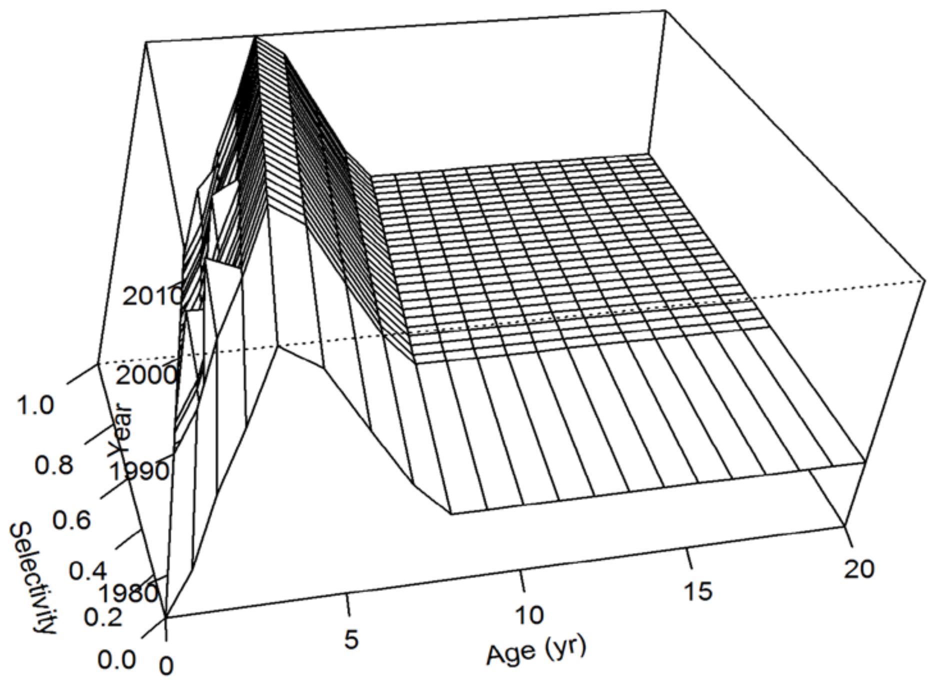


Figure 2A.1.5a—Trawl survey selectivity (page 1 of 3).

Model 16.2



Model 16.3

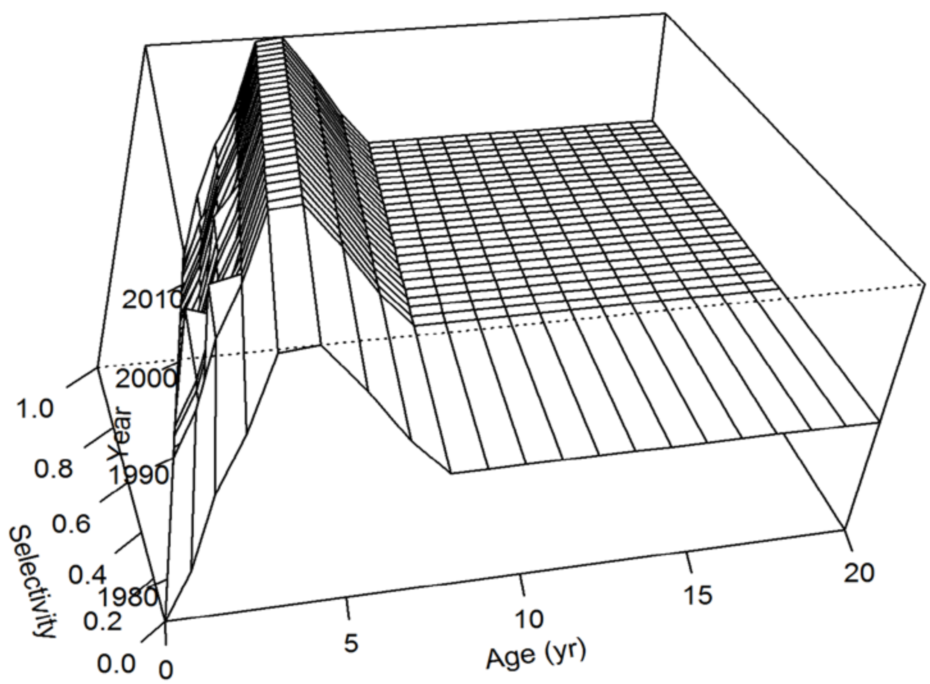
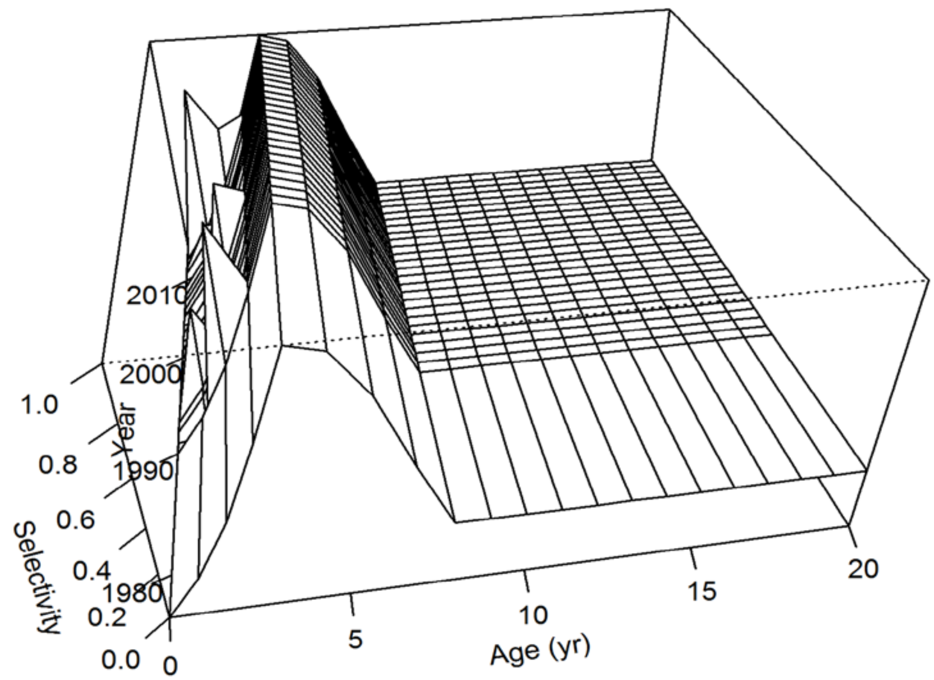


Figure 2A.1.5a—Trawl survey selectivity (page 2 of 3).

Model 16.4



Model 16.5

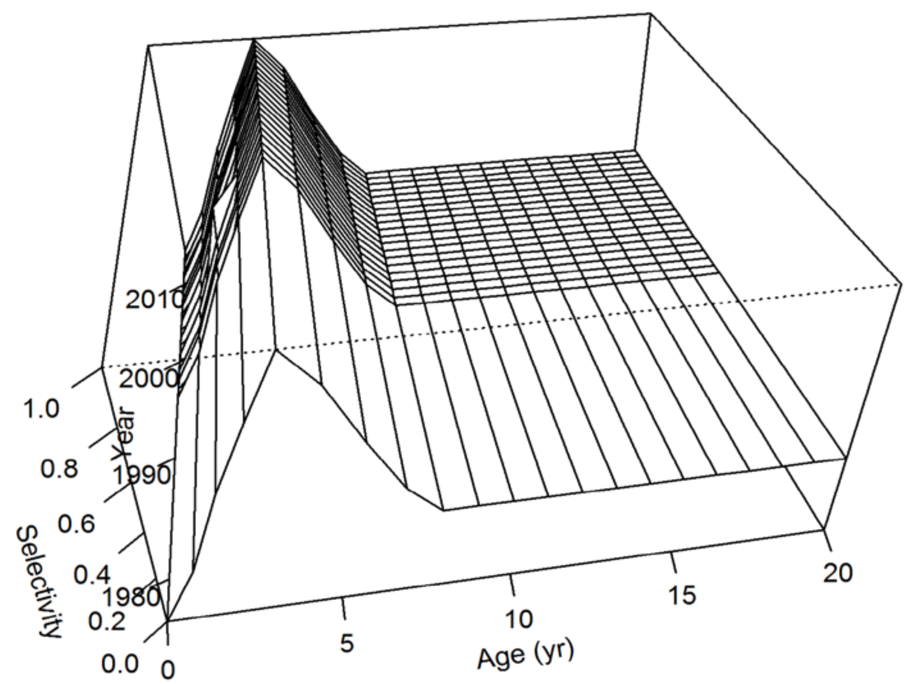
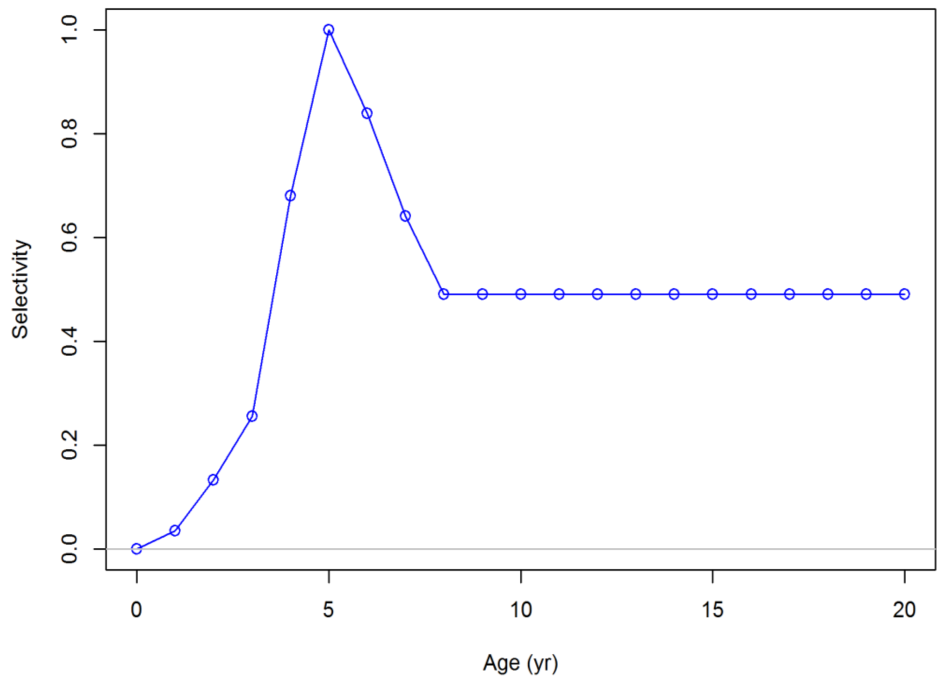


Figure 2A.1.5a—Trawl survey selectivity (page 3 of 3).

Model 16.2



Model 16.4

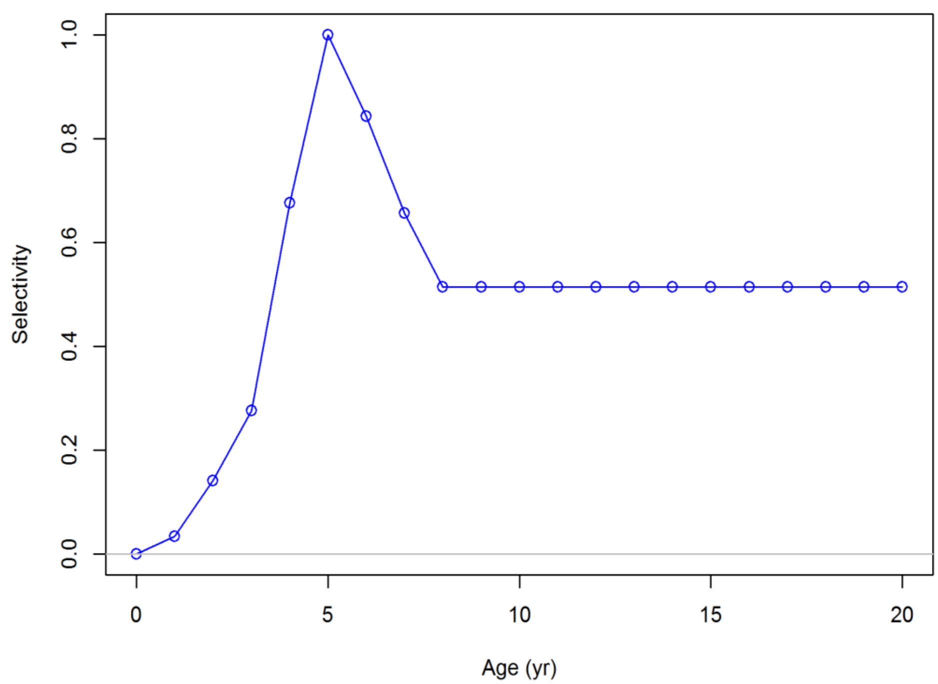
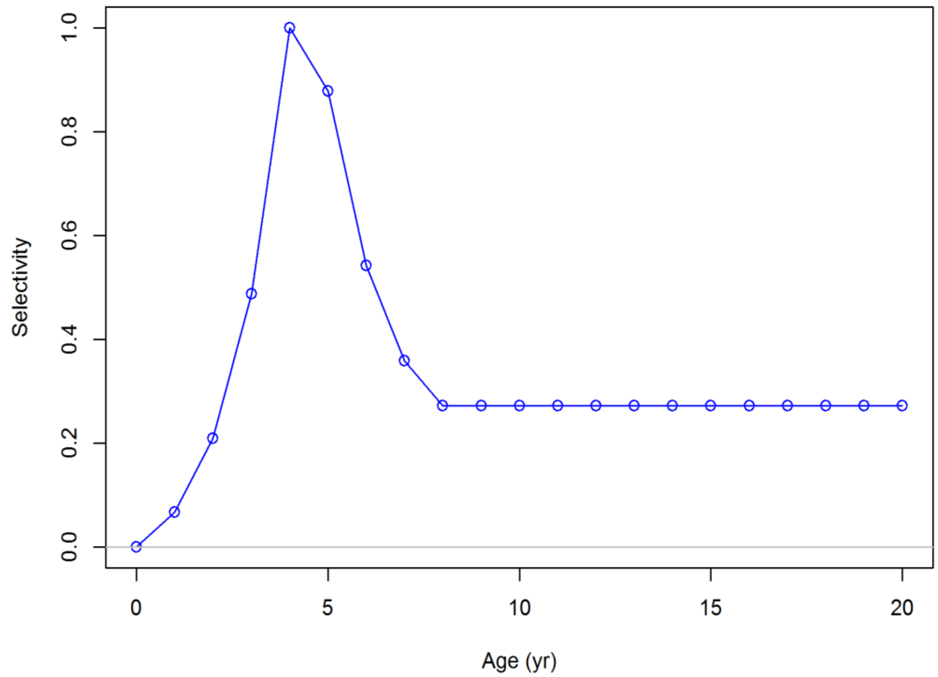


Figure 2A.1.5b—IPHC longline survey selectivity.

Model 16.3



Model 16.4

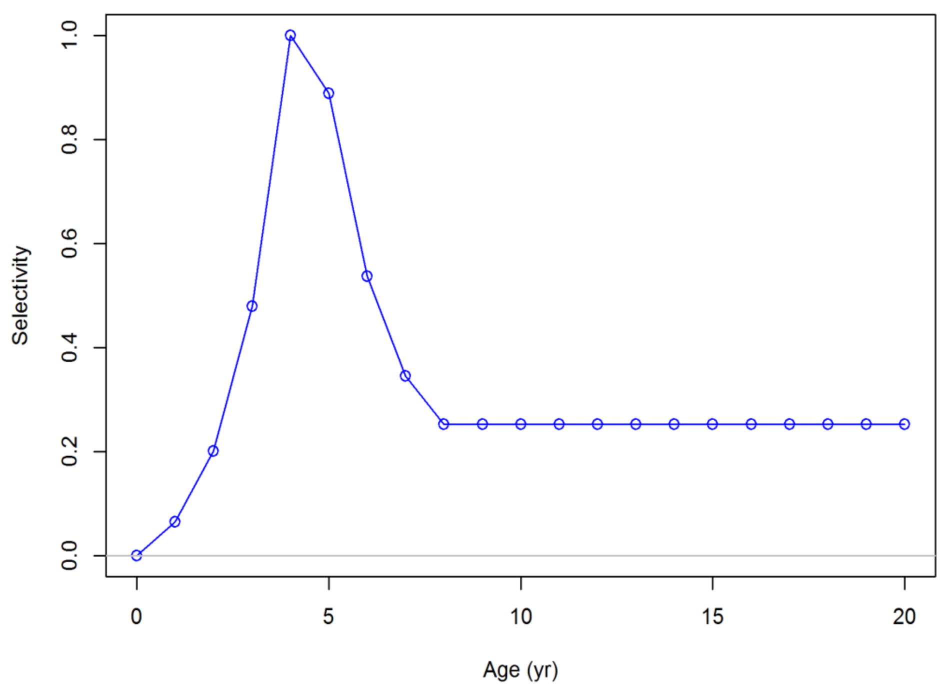


Figure 2A.1.5c—NMFS longline survey selectivity.

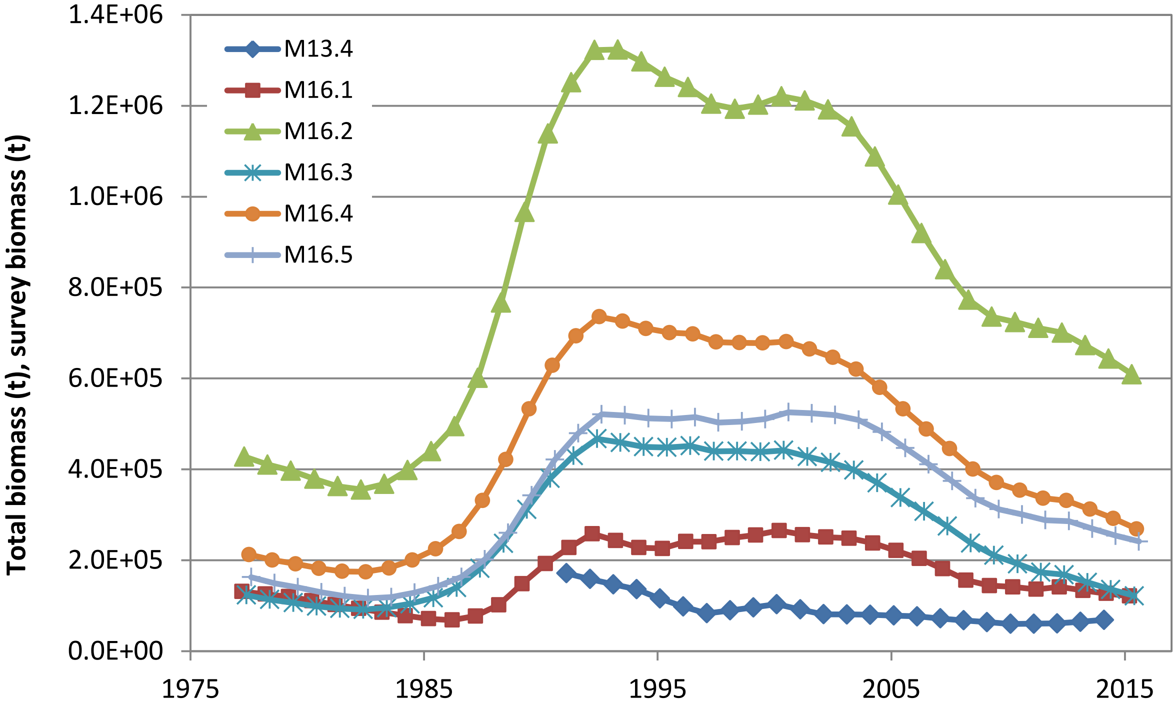


Figure 2A.1.6—Total biomass time series as estimated by each of the models.

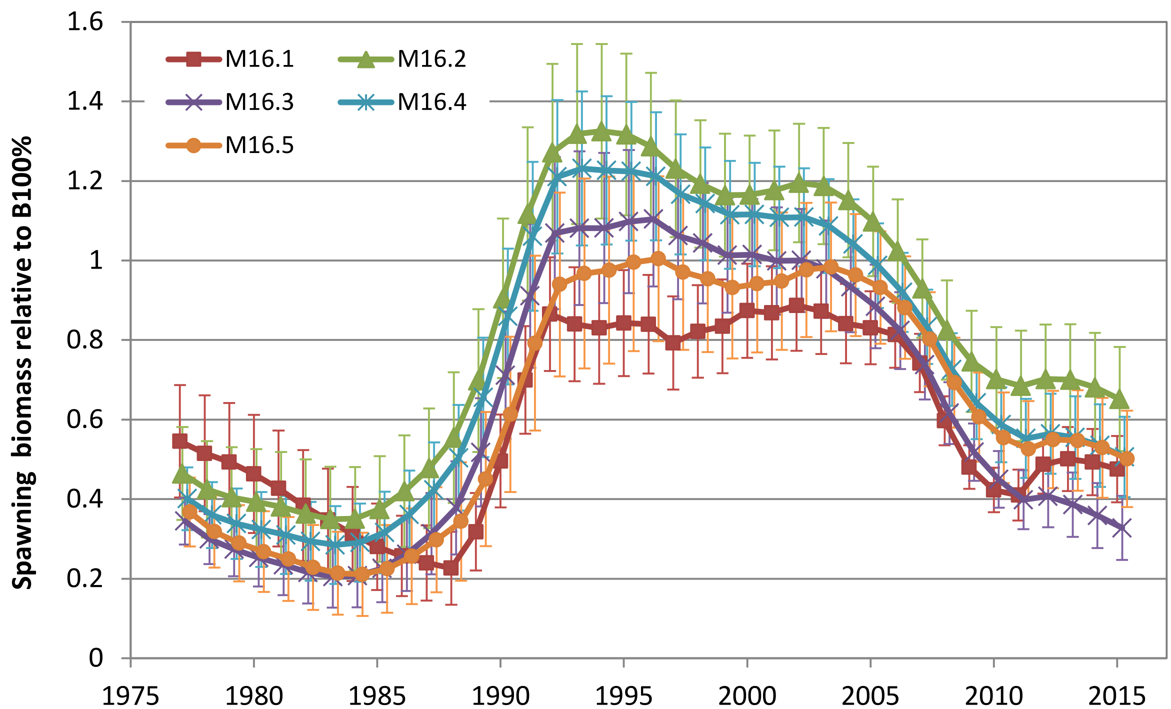


Figure 2A.1.7—Time series of spawning biomass relative to $B_{100\%}$ for each of the models, with 95% confidence intervals.

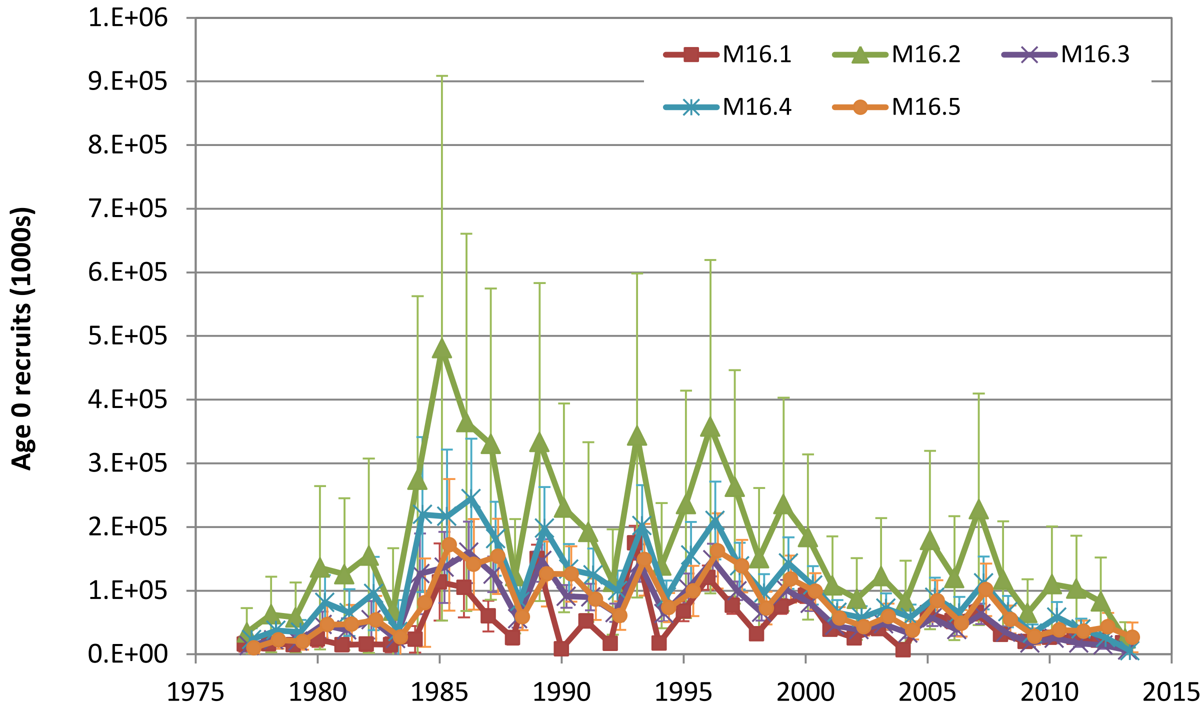


Figure 2A.1.8—Age 0 recruitment (1000s of fish) for each model.

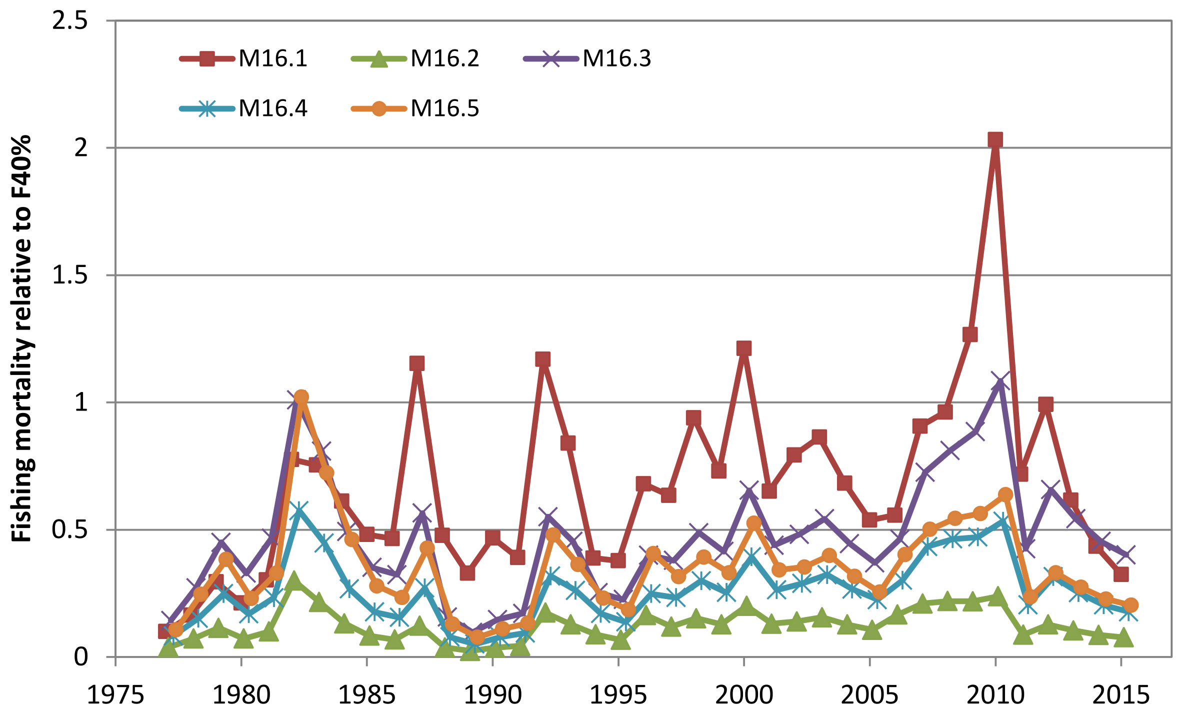


Figure 2A.1.9—Time series of the ratio of full-selection fishing morality to $F_{40\%}$.

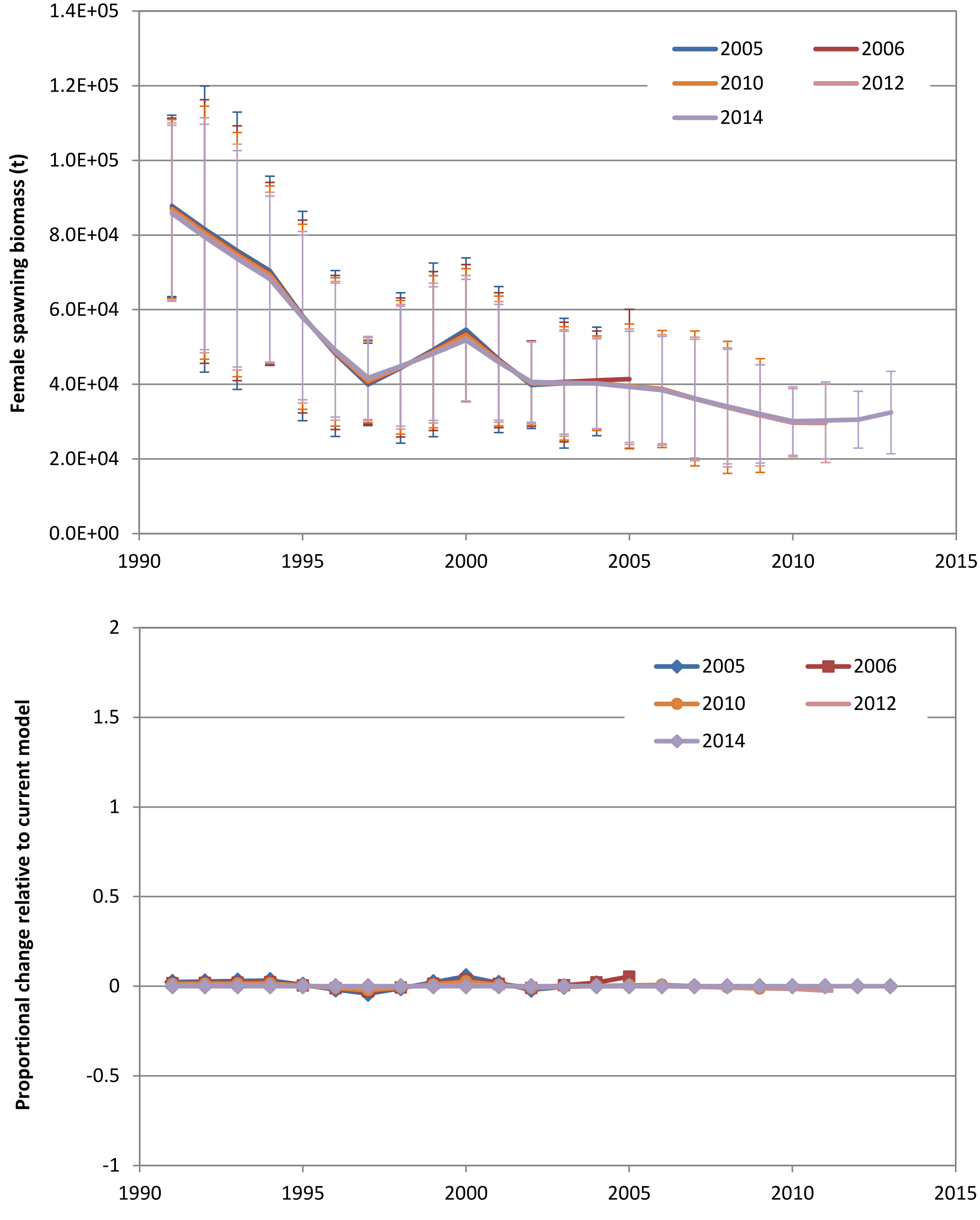


Figure 2A.1.10a—Ten-year survey biomass retrospective analysis of Model 13.4.

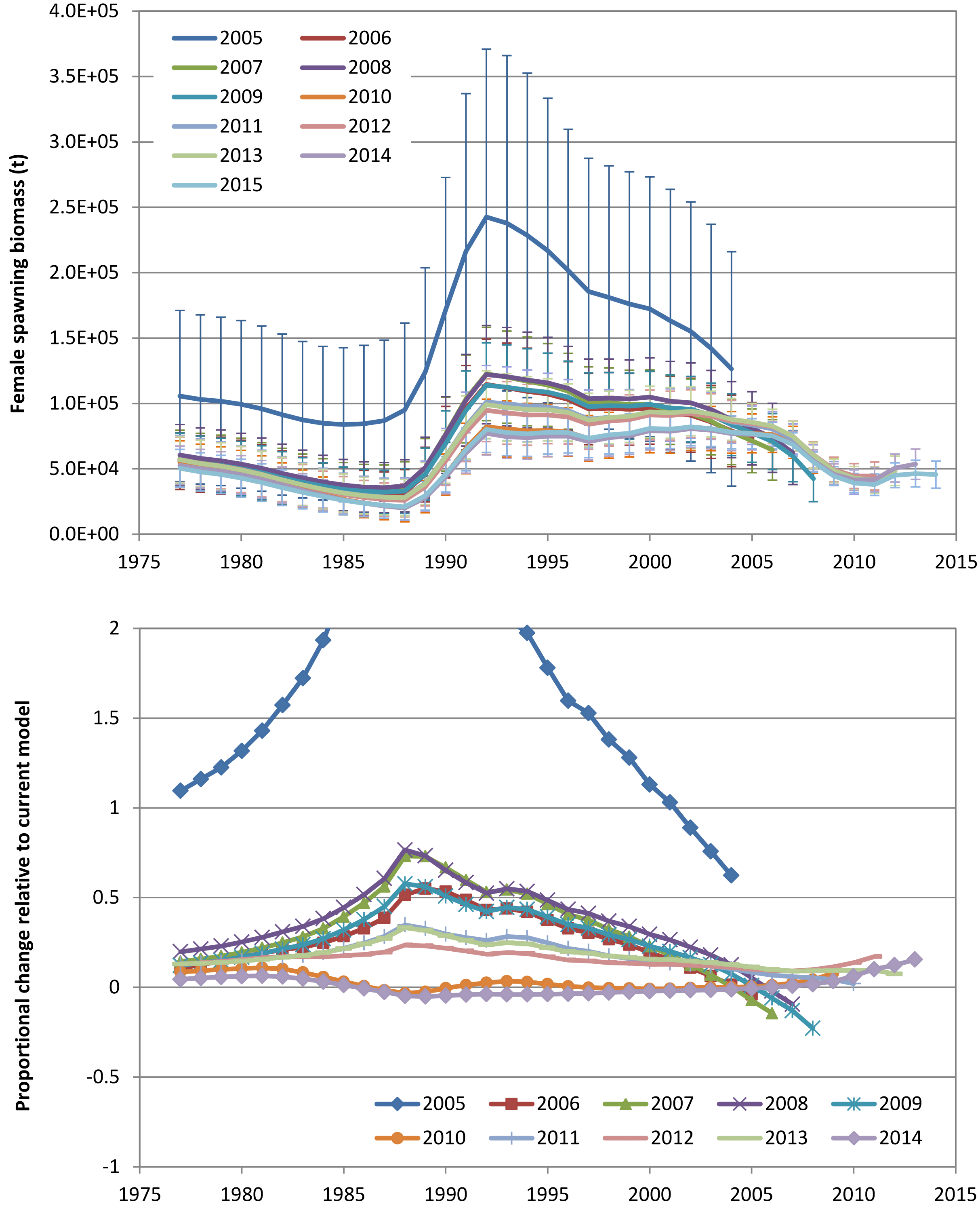


Figure 2A.1.10b—Ten-year spawning biomass retrospective analysis of Model 16.1.

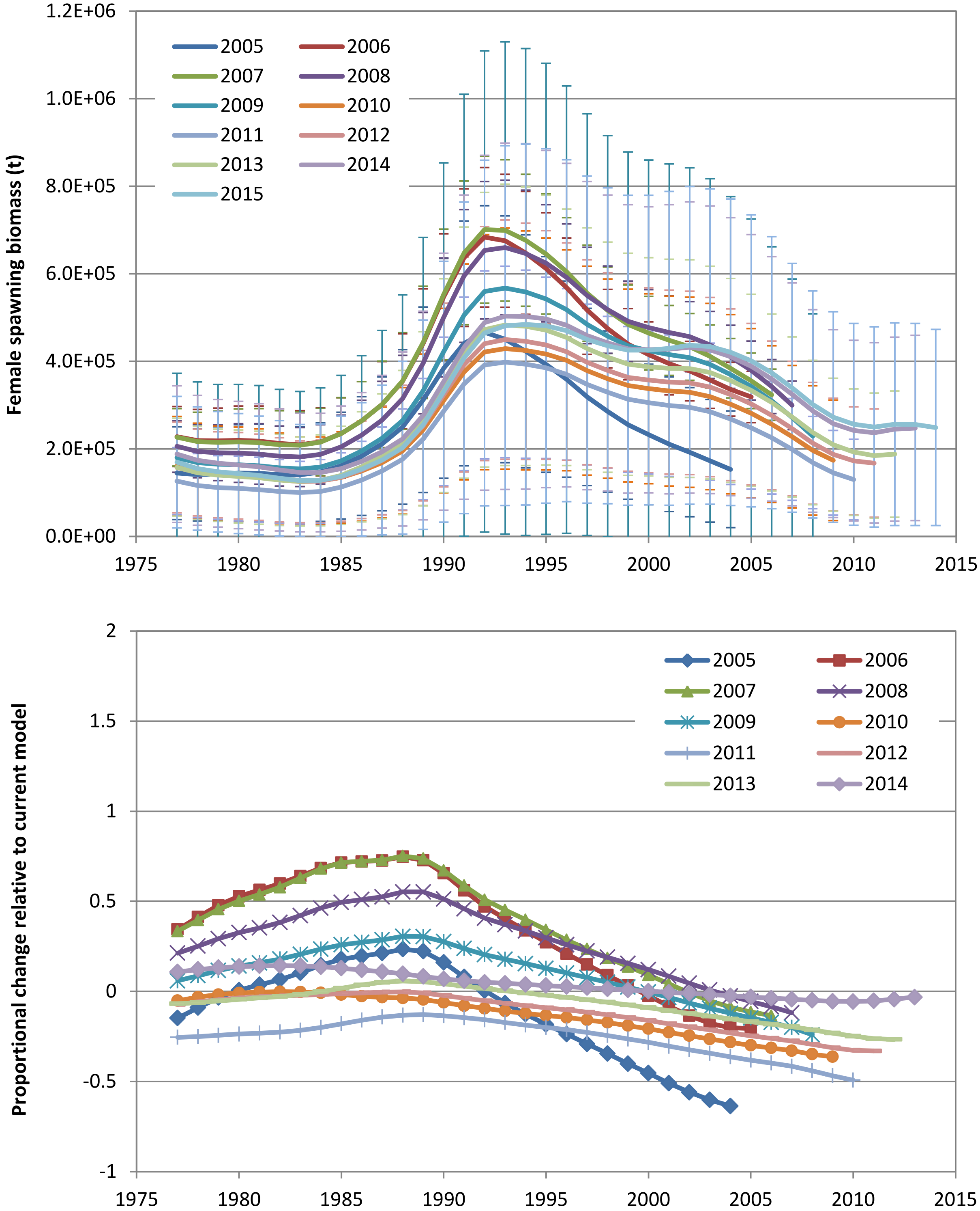


Figure 2A.1.10c—Ten-year spawning biomass retrospective analysis of Model 16.2.

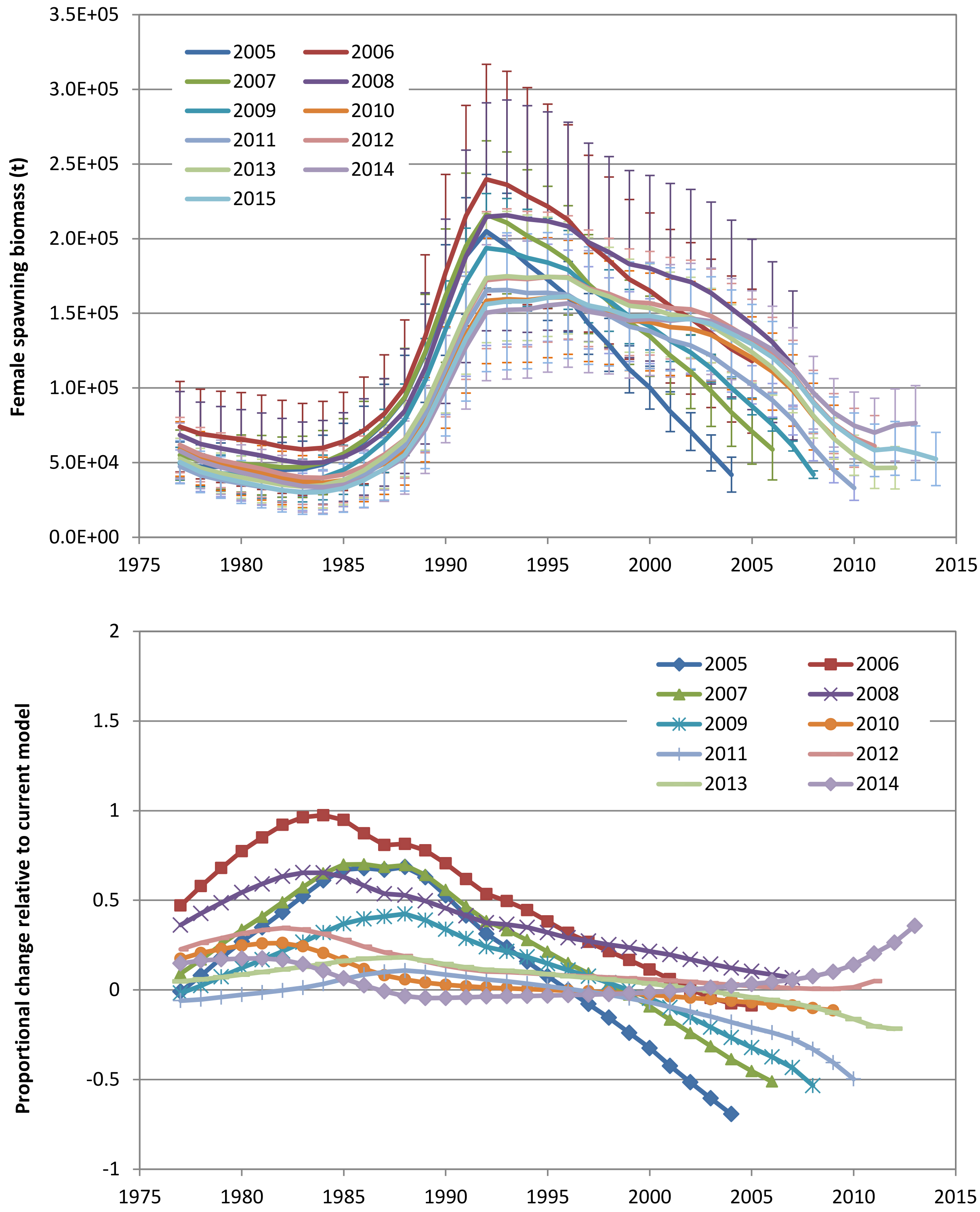
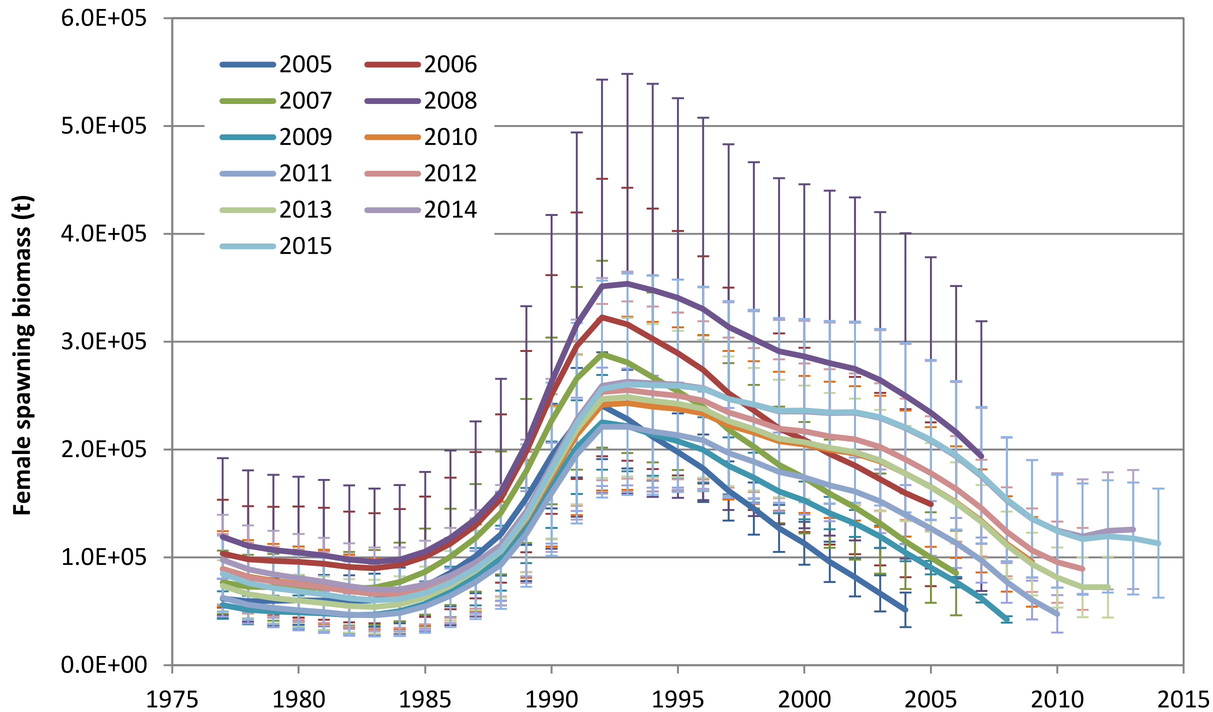


Figure 2A.1.10d—Ten-year spawning biomass retrospective analysis of Model 16.3.



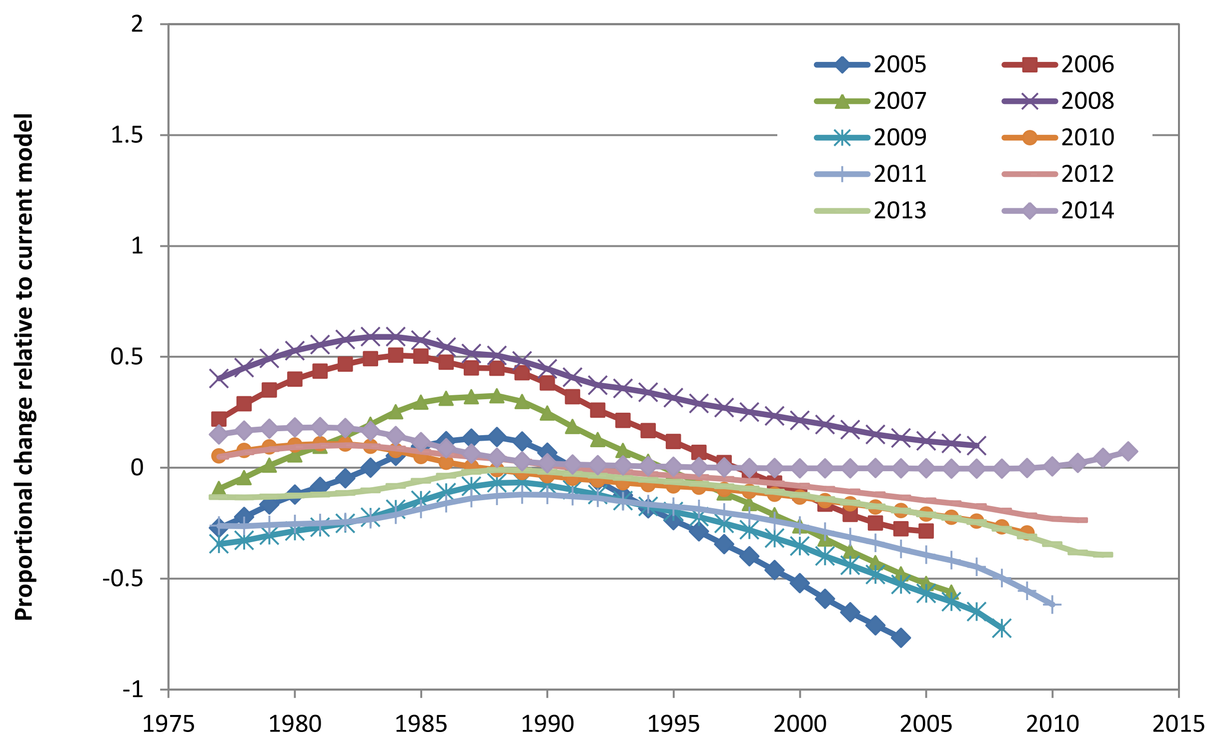
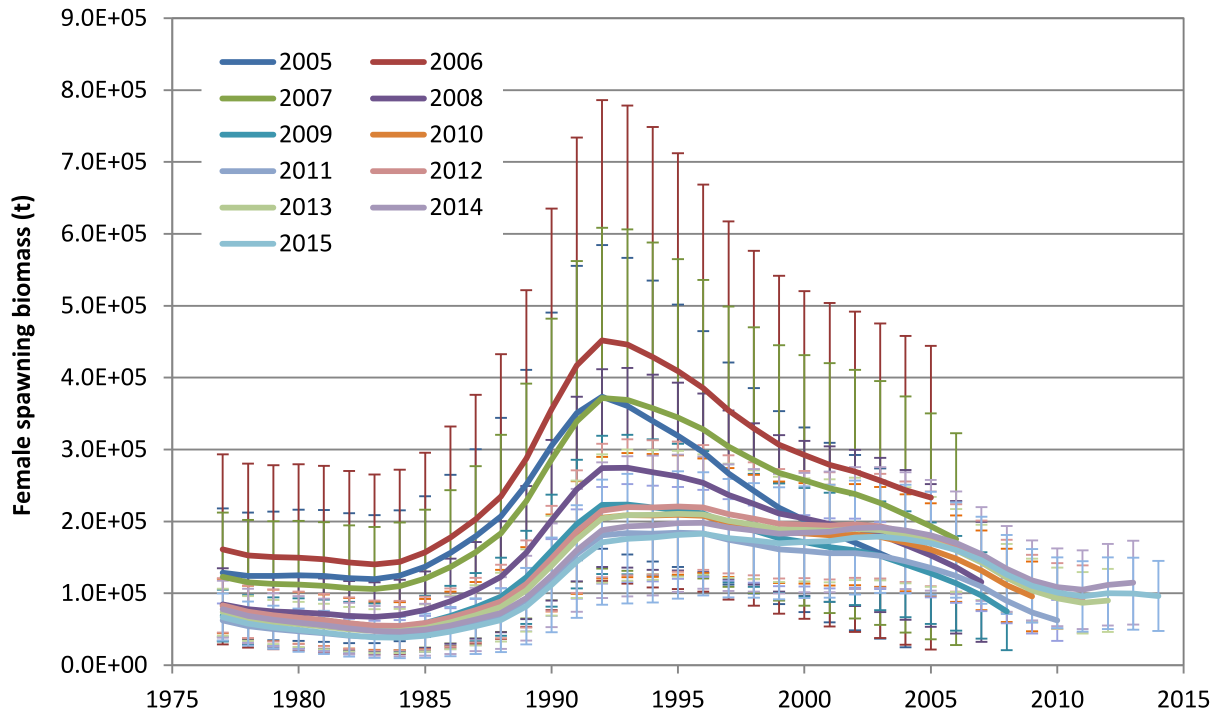


Figure 2A.1.10e—Ten-year spawning biomass retrospective analysis of Model 16.4.



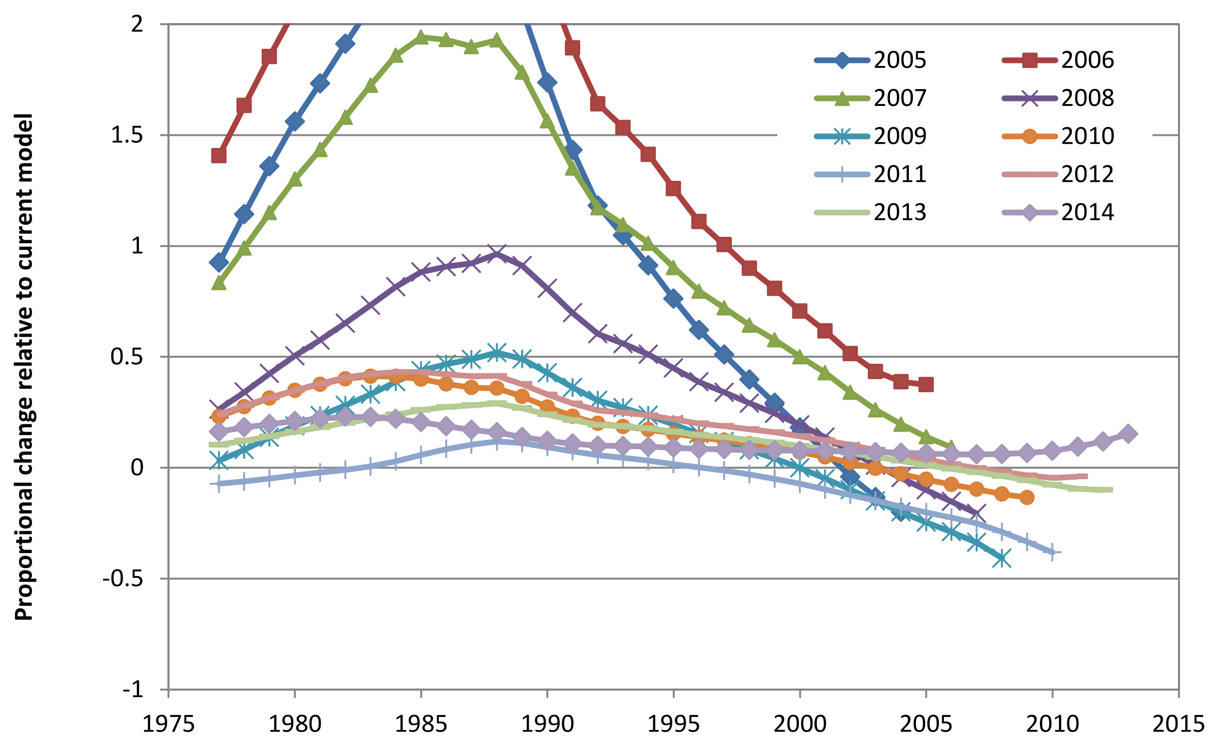


Figure 2A.1.10f—Ten-year spawning biomass retrospective analysis of Model 16.5.

APPENDIX 2A.2: BSAI PACIFIC COD ECONOMIC PERFORMANCE REPORT FOR 2015

Ben Fissel

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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 2A.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 2A.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 2A.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 2A.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 2A.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 2A.3: HISTORY OF PREVIOUS AI PACIFIC COD MODEL STRUCTURES DEVELOPED UNDER STOCK SYNTHESIS

For 2013 and beyond, the SSC's accepted model from the final assessment is shown in **bold red**.

Pre-2011

The AI Pacific cod stock was managed jointly with the EBS stock, with a single OFL and ABC. Prior to the 2004 assessment, results from the EBS model were inflated into BSAI-wide equivalents based on simple ratios of survey biomasses from the two regions.

Beginning with the 2004 assessment, the simple ratios were replaced by a random-walk Kalman filter.

2011

Preliminary assessment

A Tier 5 model based on the same Kalman filter approach that had been used to inflate EBS model results into BSAI-wide equivalents since 2004 was applied to the AI stock as a stand-alone model.

Final assessment

Because no new survey data had become available since the preliminary assessment, the Tier 5 Kalman filter model was not updated. The SSC did not accept the Tier 5 Kalman filter model, so the AI stock continued to be managed jointly with the EBS stock.

2012

Preliminary assessment

Two models were included:

- Model 1 was similar to the final 2011 EBS model except:
    - Only one season
    - Only one fishery
    - AI-specific weight-length parameters used
    - Length bins (1 cm each) extended out to 150 cm instead of 120 cm
    - Fishery selectivity forced asymptotic
    - Fishery selectivity constant over time
    - Survey samples age 1 fish at true age 1.5
    - Ageing bias not estimated (no age data available)
    - *Q* tuned to match the value from the archival tagging data relevant to the GOA/AI survey net
- Model 2 was identical to Model 1 except with time-varying *L1* and *Linf*
- Six other models considered in a factorial design in order to determine which growth parameters would be time-varying in Model 2, but only partial results presented

The SSC gave notice that it would not accept any model for this stock prior to the 2013 assessment.

Final assessment

Four models were included:

- Model 1 was identical to Model 1 from the preliminary assessment
- Model 2 was identical to Model 2 from the preliminary assessment
- Model 3 was identical to Model 1 except that input *N* values were multiplied by 1/3
- Model 4 was identical to Model 1 except:
    - Survey data from years prior to 1991 were omitted
    - Q was allowed to vary randomly around a base value
    - Survey selectivity was forced asymptotic
    - Fishery selectivity was allowed to be domed
    - Input N values for sizecomp data were estimated iteratively by setting the root-mean-squared-standardized-residual of the survey abundance time series equal to unity
    - All fishery selectivity parameters except *initial_selectivity* and the *ascending_width* survey selectivity parameters were allowed (initially) to vary randomly, with the input standard deviations estimated iteratively by matching the respective standard deviations of the estimated *dev*s
    - Input standard deviation for log-scale recruitment *dev*s was estimated internally (i.e., as a free parameter)

None of the models was accepted by the SSC, so the AI stock continued to be managed jointly with the EBS stock.

2013

Preliminary assessment

Three models were included:

- Model 1 was identical to Model 1 from the 2012 assessment except:
    - Fishery selectivity was not forced asymptotic
    - Selectivity was estimated as a random walk with respect to age instead of the double normal, with normal priors tuned so that the prior mean is consistent with logistic selectivity and the prior standard deviation is consistent with apparent departures from logistic selectivity
    - Potentially, length and age composition input sample sizes could be tuned so that the harmonic mean effective sample size is at least as large as the arithmetic mean input sample size (if it turned out that the initial average *N* of 300 already satisfied this criterion, no tuning was done)
    - Potentially, each selectivity parameter could be time-varying with annual additive *dev*s, where the sigma term is tuned to match the standard deviation of the estimated *dev*s (if this tuning resulted in a sigma that was essentially equal to zero, time variability was turned off)
- Model 2 was identical to Model 1 except that *Q* was estimated with an informative prior developed from a meta-analysis of other AI assessments
- Model 3 was identical to Model 1 except that both *M* and *Q* were estimated freely

Final assessment

Four models were included:

- Tier 3 Model 1 was identical to Model 1 from the preliminary assessment, except with *Q* fixed at 1.0
- Tier 3 Model 2 was identical to Tier 3 Model 1 except:
    - *Q* was estimated with the same prior as in Model 2 from the preliminary assessment
    - Survey selectivity was forced asymptotic

- Tier 5 Model 1 was the Kalman filter model that had been used since 2004 to estimate the expansion factor for converting results from the EBS model into BSAI equivalents
- **Tier 5 Model 2** was the random effects model recommended by the Survey Averaging Working Group

2014

Preliminary assessment

Three models were included:

- Model 1 was identical to Model 2 from the final 2013 assessment, except that survey selectivity was not forced to be asymptotic, each selectivity was allowed (potentially) to vary with time, a normal prior distribution for each selectivity parameter was tuned using the same method as Model 6 from the preliminary assessment 2014 EBS assessment, prior distributions and standard deviations for the annual selectivity deviations were estimated iteratively, and the 1976-1977 "recruitment offset" parameter was fixed at zero
- Model 2 was identical to Model 1, except that the recruitment offset was estimated freely
- Model 3 was identical to Model 2, except that survey selectivity first-differences were forced to equal zero after the age at which survey selectivity peaked in Model 2, and the lower bound on survey selectivity first-differences at all earlier ages was set at 0 (the combination of these two changes forced survey selectivity to increase monotonically until the age at which it peaked in Model 2, after which survey selectivity was constant at unity)

Final assessment

Three models were included:

- **Model 1** was identical to Tier 5 Model 2 from the final 2013 assessment
- Model 2 was identical to Model 1 from the preliminary assessment
- Model 3 was identical to Model 1 from the preliminary assessment, except that the prior distributions for survey selectivity parameters were tightened so that the resulting selectivity curve was less dome-shaped

2015

Preliminary assessment

New features or methods examined in the preliminary assessment included the following (these were based on experience with the preliminary assessment of the EBS Pacific cod stock):

1. The standard deviation of log-scale age 0 recruitment (σ_R) was estimated iteratively instead of being estimated internally.
2. Richards growth was assumed instead of von Bertalanffy growth (a special case of Richards).
3. 20 age groups were estimated in the initial numbers-at-age vector instead of 10.
4. Survey catchability was allowed to vary annually if the root-mean-squared-standardized residual exceeded unity (this resulted in time-varying Q for Model 5 but not for Model 3).
5. Selectivity at ages 8+ was constrained to equal selectivity at age 7 for the fishery, and selectivity at ages 9+ was constrained to equal selectivity at age 8 for the survey.
6. A superfluous selectivity parameter was fixed at the mean of the prior (in Models 3 and 4, the estimate of this parameter automatically went to the mean of the prior).

7. 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.
8. All iterative tunings were conducted simultaneously rather than sequentially.
9. The method of Thompson (in prep.) was used for iterative tuning of the sigma parameters for selectivity and recruitment.
10. Iterative tuning of the sigma parameter for time-varying catchability involved adjusting sigma until the root-mean-squared-standardized-residual for survey abundance equaled unity.

Four of the models spanned a 2×2 factorial design. The factors were:

- The new features or methods listed above (use or not use)
- Historic fishery time series data from 1977-1990 (use or not use)

Five models were included in all (there was no model numbered "1," per SSC request):

- Model 0 was identical to Model 1 from the final 2014 assessment (Tier 5 random effects)
- Model 2 used the new features/methods; did not use the historic fishery data
- Model 3 not use the new features/methods; did use the historic fishery data
- Model 4 did not use the new features/methods; did not use the historic fishery data
- Model 5 used the new features/methods; did not use the historic fishery data

Note that Model 4 was identical to Model 2 from the 2014 final assessment

Final assessment

Three models were included:

- Model 13.4 (new name for the Tier 5 random effects model)
- Model 15.6 was also a random effects model, but with the IPHC longline survey CPUE added as a second time series
- Model 15.7 was the same as Model 3 from the preliminary assessment (now renamed Model 15.3), but with both fishery and survey selectivity held constant (with respect to age) above age 8, as opposed to being free at all ages (1-20) in Model 15.3

APPENDIX 2A.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 AI Pacific cod from this dataset are shown in Table 2A.4.1.

Although many sources of removal are documented in Table 2A.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 of the combined BSAI Pacific cod stock (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 2A.4.1 for the last three complete years (2013-2015) is 29 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 2A.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
Aleutian Island Bottom Trawl Survey				13			13			13			
Aleutian Islands Cooperative Acoustic Survey													
Annual Longline Survey			19	19	19	19	19	19	19	19	19	19	19
Atka Tagging Survey													
Bait for Crab Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0
IPHC Annual Longline Survey													
Subsistence Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0

Activity	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Aleutian Island Bottom Trawl Survey		13			13			13			13		13
Aleutian Islands Cooperative Acoustic Survey													
Annual Longline Survey	19	19	19	19	19		17		27		25		19
Atka Tagging Survey											100	100	100
Bait for Crab Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0
IPHC Annual Longline Survey									15	15	15	15	15
Subsistence Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0

Activity	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Aleutian Island Bottom Trawl Survey		13		13				12		12		16	
Aleutian Islands Cooperative Acoustic Survey						1							
Annual Longline Survey		13		25		13		16		18		19	
Atka Tagging Survey	100	100		100	100				100	100			
Bait for Crab Fishery	0	0	0	0	0	0	0	0	0	0	0	1	0
IPHC Annual Longline Survey	15	15	15	15	15	15	15	9	23	9	13	15	21
Subsistence Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0