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 AI Pacific cod stock assessment.

Changes in the Input Data

1) Catch data for 1991-2013 were updated, and preliminary catch data for 2014 were incorporated.
2) Commercial fishery size composition data for 2013 were updated, and preliminary size composition data from the 2014 commercial fisheries were incorporated.
3) All fishery data (catch and size composition) from years prior to 1991 were removed.
4) The numeric abundance estimate from the 2014 AI bottom trawl survey was incorporated (the 2014 estimate of 20.8 million fish was up about 8% from the 2012 estimate).
5) Age composition data from the 2010 AI bottom trawl survey were incorporated.

Changes in the Assessment Methodology

Although harvest specifications for AI Pacific cod, which began in 2014, have been based on Tier 5 methods, age-structured models of this stock have been explored in the preliminary and final 2012 BSAI Pacific cod assessments (Thompson and Lauth 2012), the preliminary and final 2013 AI Pacific cod assessments (Thompson and Palsson 2013), and this year's preliminary assessment (Appendix 2A.1). Three age-structured models were presented in this year's preliminary assessment. After reviewing this year's preliminary assessment, the Plan Team and SSC requested three models for inclusion in the final assessment: Model 1 is the Tier 5 random effects model accepted for use by the Team and SSC last year. Model 2 is identical to age-structured Model 1 from the preliminary assessment. Model 3 is also identical to age-structured Model 1 from the preliminary assessment, except that the prior distributions for survey selectivity parameters are tightened so that the resulting selectivity curve is less dome-shaped.

Tier 5 management based on the random effects model is the authors' recommendation for setting 2015-2016 harvest specifications.

Summary of Results

The principal results of the present assessment, based on the current 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: 2014	2015	As estimated or *recommended this* year for: 2015	2016
M (natural mortality rate)	0.34	0.34	0.34	0.34
Tier	5	5	5	5
Biomass (t)	59,000	59,000	68,900	68,900
F_{OFL}	0.34	0.34	0.34	0.34
$maxF_{ABC}$	0.26	0.26	0.26	0.26
F_{ABC}	0.26	0.26	0.26	0.26
OFL (t)	20,100	20,100	23,400	23,400
maxABC (t)	15,100	15,100	17,600	17,600
ABC (t)	15,100	15,100	17,600	17,600
Status	As determined *last* year for: 2012	2013	As determined *this* year for: 2013	2014
Overfishing	No	n/a	No	n/a

Responses to SSC and Plan Team Comments on Assessments in General

JPT1 (9/13 minutes): *"The Teams recommended that SAFE chapter authors continue to include 'other' removals as an appendix. Optionally, authors could also calculate the impact of these removals on reference points and specifications, but are not required to include such calculations in final recommendations for OFL and ABC."* "Other" removals are presented in Appendix 2A.2.

JPT2 (9/13 minutes): *"In conformity with the main recommendations of the working group, the Teams recommended the following:*

1. *Assessment authors should routinely do retrospective analyses extending back 10 years, plot spawning biomass estimates and error bars, plot relative differences, and report Mohn's rho (revised).*
2. *If a model exhibits a retrospective pattern, try to investigate possible causes.*
3. *Communicate the uncertainty implied by retrospective variability in biomass estimates.*
4. *For the time being, do not disqualify a model on the grounds of poor retrospective performance alone.*
5. *Do consider retrospective performance as one factor in model selection."*

This comment is addressed in the "Results" section, under "Model Evaluation" and also in a new subsection entitled "Retrospective Analysis," located under "Time Series Results."

JPT3 (9/13 minutes): *"The Teams recommended that each stock assessment model incorporate the best possible estimate of the current year's removals. The Teams plan to inventory how their respective authors address and calculate total current year removals. Following analysis of this inventory, the Teams will provide advice to authors on the appropriate methodology for calculating current year removals to ensure consistency across assessments and FMPs."* This comment is addressed under the

"Standard Harvest Scenarios, Projection Methodology, and Projection Results" subsection of the "Results" section.

SSC1 (10/13 minutes): *"We agree with the recommendations of the Plan Team that retrospective analyses extending back 10 years and including Mohn's revised ρ, should routinely be presented in the assessments, and that retrospective patterns should be taken into consideration when selecting a model and when communicating uncertainties associated with biomass estimates. The SSC also notes that a strong retrospective bias should be one of the criteria considered when setting ABCs and could provide justification for recommending a higher or lower ABC."* See response to comment JPT2. Consideration of retrospective bias in the context of ABC is addressed in the "Harvest Recommendations" subsection of the "Results" section.

SSC2 (12/13): *"During public testimony, it was proposed that assessment authors should consider projecting the reference points for the future two years (e.g., 2014 and 2015) on the phase diagrams. It was suggested that this forecast would be useful to the public. The SSC agrees. The SSC appreciated this suggestion and asks the assessment authors to do so in the next assessment."* Figure 2A.17 includes projected values for the next two years.

JPT4 (9/14): Regarding catch projections, *"the Teams recommend that authors choose a method that appears to be appropriate for their stock, and this method be clearly documented. The Teams recommend authors establish their best available estimate of catch in the current year and the next two years. The Teams recommend that authors should also document how those projected catches were determined in the Harvest Recommendations section (ideally Scenario 2)."* See response to comment JPT3. Estimation of projected catches is addressed in the same subsection, and those estimated catches are used in Scenario 2.

SSC3 (10/14): Regarding comment JPT4, *"The SSC supports these recommendations."* See response to comments JPT3 and JPT4.

Responses to SSC and Plan Team Comments Specific to this Assessment

Eleven comments specific to this assessment were addressed in the preliminary assessment. In the interest of efficiency, they are not repeated in this section. BSAI Plan Team (BPT) and SSC comments that were developed following completion of the preliminary assessment are shown below.

BPT1 (9/14): *"For November, the Team recommends that Grant supply three candidate models, all based on data from 1991 onward, which means that there is no need to estimate a recruitment offset (because the data do not span an environmental regime shift):*

1. *Model 1 from this meeting (same as Model 2 when the recruitment offset is disregarded).*
2. *A variant of Model 1 with the priors tightened enough that the survey selectivity schedule is smoother and more like a logistic curve.*
3. *Tier 5."*

All of the Team's requested models are included in this assessment, although re-numbered so that last year's model (Tier 5 random effects) is designated Model 1.

SSC4 (10/14): *"The SSC agrees with the Plan Team and recommendations including limiting the data to post-1990 and three candidate models be brought forward to the November plan team meeting."* See response to Comment BPT1. Data are limited to the post-1990 period (see discussion under "Catch Size Composition" in the "Fishery" subsection of the "Data" section).

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 63° N latitude. 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 since 1977, last year separate 2014-2015 harvest specifications were set for the two areas.

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 or AI areas.

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.

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% (Gregory et al. in prep.); 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, *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), 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 trawl, longline, pot, and jig components (although catches by jig gear are very small in comparison to the other three main gear types, with an average annual catch of less than 30 t since 1992). The breakdown of catch by gear during the most recent complete five-year period (2009-2013) is as follows: trawl gear accounted for an average of 75% of the catch, longline gear accounted for an average of 23%, and pot gear accounted for an average of 2%.

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 NMFS 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 been 84%, 16%, and 0%, respectively (bearing in mind that 2014 data are not yet complete).

Catches of Pacific cod taken in the AI for the periods 1964-1980, 1981-1990, and 1991-2014 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 1994-2014 by NMFS 3-digit statistical area (area breakdowns not available prior to 1994), both in absolute terms and as proportions of the yearly totals.

Effort and CPUE

Figure 2A.1 shows, subject to confidentiality restrictions, the approximate locations in which trawl hauls or longline sets sampled during 2013 and 2014 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. Both CPUE time series appear to be decreasing overall, although the negative slope of the regression for trawl gear is not statistically significant at the 5% level (P=0.06).

Discards

The catches shown in Tables 2A.1b and 2A.1c include estimated discards. Discard rates of Pacific cod in the AI Pacific cod fisheries are shown for each year 1991-2014 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 7.5%. Since then, they have averaged about 1.0%.

Management History

The history of acceptable biological catch (ABC), overfishing level (OFL), and total allowable catch (TAC) levels is summarized and compared with the time series of aggregate (i.e., all-gear, combined area) commercial catches in Table 2A.3. Note that, with the exception of 2014, this time series pertains to the combined BSAI region, so the catch time series differs from that shown in Table 2.1, which pertains to the AI only.

From 1980 through 2013, TAC averaged about 83% of ABC (ABC was not specified prior to 1980), and from 1980 through 2013 aggregate commercial catch averaged about 92% of TAC. In 10 of these 34 years, TAC equaled ABC exactly, and in 8 of these 34 years (24%), catch exceeded TAC (by an average of 3%). However, three of those overages occurred in 2007, 2008, and 2010, when TAC was reduced by 3% to account for a small, State-managed fishery inside State of Alaska waters within the AI subarea (similar reductions have been made in all years since 2006); thus, while the combined Federal and State catch exceeded the Federal TAC in 2007, 2008, and 2010 by 2% or less, the overall target catch (Federal TAC plus State GHL) was *not* exceeded.

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

Changes in ABC over time are typically attributable to three factors: 1) changes in resource abundance, 2) changes in management strategy, and 3) changes in the stock assessment model. 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.

Beginning with the 2014 fishery, the Board of Fisheries for the State of Alaska established a guideline harvest level (GHL) in State waters between 164 and 167 degrees west longitude in the EBS subarea (this supplemented a GHL that had been set aside for the Aleutian Islands subarea since 2006). The State's procedure for setting GHLs for the two subareas is to sum the subarea ABCs, then set a GHL in each subarea equal to 3% of the total.

The final rule for the 2015 Steller sea lion protection measures is anticipated to remove the prohibition of retention for Pacific cod in Area 543 (Western AI). A harvest limit for Area 543 will be 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 the "Harvest Recommendations" subsection of the "Results" section).

Table 2A.4 lists all amendments to the BSAI Groundfish FMP that reference Pacific cod explicitly.

DATA

This section describes data used in the models presented in this stock assessment, of which one is of the Tier 5 variety, and two are of the Tier 3 (age-structured) variety. This section does not attempt to summarize all available data pertaining to Pacific cod in the AI.

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

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 file for the two Tier 3 models:

Source	Type	Years
Fishery	Catch biomass	1991-2014
Fishery	Size composition	1991-2014
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	2010, 2012

As indicated in both of the above tables, the data time series used in the models for this year's assessment all begin no earlier than 1991. Beginning with last year's AI assessments, the SSC recommended that survey data prior to 1991 not be included in any of the models, due to lack of standardization between the gears and vessels used in the pre-1990 portion of the time series. For this year's AI Pacific cod assessment, the exclusion was extended to include fishery data as well as survey data. This is discussed further below, under "Catch Size Composition" in the "Fishery" subsection.

Fishery

Catch Biomass

The catch data used in the model consist of the totals for 1977-2014 shown in Tables 2A.1. Catches for the August-December portion of 2014 were estimated by the method described under Scenario 2 in the "Harvest recommendations" subsection of the "Results" section. With this one exception, the catches shown in Table 2.5 consist of "official" data from the NMFS Alaska Region. However, other removals of Pacific cod are known to have occurred over the years, including removals due to subsistence fishing, scientific research, and fisheries managed under other FMPs. Estimates of such other removals are shown in Appendix 2A.2.

Catch Size Composition

Fishery size compositions with at least 400 observations are presently available for nearly every year from 1977 through the first part of 2014 (the exceptions are the periods 1980-1981 and 1986-1989).

The data from the pre-1991 portion of the time series consistently show a much smaller proportion of large fish than the post-1990 portion. Figure 2A.3 shows cumulative distribution functions of the average (across years) size compositions, binned in 10-cm intervals, together with 95% confidence intervals (the confidence intervals were generated by both parametric and non-parametric bootstraps; because the results were nearly identical, only the non-parametric bootstrap results are shown). Not only are the curves representing the means very different, the confidence intervals do not come close to overlapping anywhere within the 40-90 cm range.

Some possible reasons for the difference are: 1) the samples collected during one or both time periods were not representative, 2) fishery selectivity at age was dramatically different between the two periods, 3) recruitment was consistently higher during the earlier period, and 4) fishing mortality was consistently higher during the earlier time period.

The first hypothesis in the above list has not yet been explored. However, Model 2 in last year's assessment allowed for all three of the other hypotheses, and last year's Model 1 allowed for the last two. The results of those models did not corroborate either the selectivity hypothesis or the recruitment hypothesis. Fishery selectivity at age in last year's Model 2 was, on average, about the same between the two time periods; and recruitment was, on average, either about the same during the two periods (last year's Model 1) or much higher during the later time period (last year's Model 2).

Both of last year's age-structured models did estimate, though, that fishing mortality was consistently much higher during the earlier time period. However, this finding was viewed with skepticism by the authors, in part because both models also estimated that biomass was very low during the first part of the time series, which, taken together with the estimates of very high fishing mortality during that period, implies that fishermen were expending very large amounts of effort in pursuit of very few fish, which did not seem to fit with the history of the fishery's development. Moreover, the survey biomass index has declined fairly consistently during the post-1990 period (see next subsection), which the models could not reconcile with a decreasing fishing mortality trend and a level or increasing recruitment trend.

Given the inability of last year's models to reconcile the pre-1991 fishery size composition data with the post-1990 data, the models presented in this year's preliminary assessment (Appendix 2A.1) omitted the pre-1991 fishery size composition data and, given the resulting lack of any ability to estimate fishery selectivity for the pre-1991 period, the pre-1991 catch data were eliminated as well. After reviewing the preliminary assessment, both the Plan Team and SSC recommended omitting all pre-1991 data for this year's final assessment (see Comments BPT1 and SSC4).

For use in the age-structured models, size composition data are grouped into 1-cm bins ranging from 4 to 120 cm, as shown in Table 2A.5.

The actual sample sizes for the fishery size composition data are shown below:

Year:	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
N:	22653	102653	46775	29716	30870	42610	23762	74286	34027	52435	57750	23442
Year:	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
N:	23690	23990	20754	20446	27543	26282	21954	34329	8879	11789	8590	4265

Survey

Biomass and Numerical Abundance

The time series of trawl survey biomass and numerical abundance are shown for Areas 541-543 (Eastern, Central, and Western AI, respectively), together with their respective coefficients of variation, in Table 2A.6. These estimates pertain to the Aleutian *management* area, and so are smaller than the estimates pertaining to the Aleutian *survey* area that have been reported in BSAI Pacific cod stock assessments prior to 2013.

Both the biomass and numerical abundance data indicate very consistent declines throughout the time series. Simple linear regressions on both time series estimate negative slope coefficients that are statistically significant at the 1% level.

As in recent assessments of Pacific cod in the EBS, the Tier 3 models developed here use survey estimates of population size measured in units of individual fish rather than biomass. The Tier 5 model, on the other hand, uses survey biomass.

Survey Size Composition

Table 2A.7 shows the total number of fish measured at each 1 cm interval from 4-120+ cm, by year, in the survey.

The actual sample sizes for the survey size composition data are shown below:

Year:	1991	1994	1997	2000	2002	2004	2006	2010	2012	2014
N:	7125	7497	4635	5178	3914	3721	2784	3521	3278	4549

Survey Age Composition

Age data from the 2010 AI trawl survey became available in time for use in this year's final assessment, supplementing the single year (2012) of age data available for last year's assessment. Actual sample sizes and the proportions of fish in ages 0 through 12+ are shown for each year below:

Year	N	0	1	2	3	4	5
2010	673	0.0000	0.0071	0.0659	0.2130	0.3360	0.2698
2012	599	0.0000	0.0721	0.0893	0.0901	0.2515	0.2834

Year	6	7	8	9	10	11	12+
2010	0.0609	0.0236	0.0074	0.0122	0.0021	0.0012	0.0009
2012	0.1544	0.0412	0.0120	0.0021	0.0026	0.0013	0.0000

ANALYTIC APPROACH

Tier 5 Model Structure

Model 1 is the 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 was accepted by the Plan Team and SSC in 2013 for the purpose of setting AI Pacific cod harvest specifications. The model is programmed using the ADMB software package (Fournier et al. 2012).

This is a very simple, state-space model of the "random walk" variety. The only parameter in the model is the log of the log-scale process error standard deviation. When used to implement the Tier 5 harvest control rules, the model also requires an estimate of the natural mortality rate.

The Tier 5 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.

Tier 3 Model Structures: General

Two Tier 3 models are presented in this assessment: Model 2 is identical to age-structured Model 1 from the preliminary assessment (Appendix 2A.1). Model 3 is also identical to age-structured Model 1 from the preliminary assessment, except "with the priors tightened enough that the survey selectivity schedule is smoother and more like a logistic curve" (Comment BPT1). Specifically, the standard deviation of the selectivity prior distributions (constant across age) was reduced until survey selectivity at age 20 was mid-way between the value estimated by Model 1 and unity.

The two Tier 3 models were developed using the Stock Synthesis (SS) program (Methot and Wetzel 2013). Version 3.24s (compiled on 07/24/13) of SS was used to run the models in this assessment. SS is programmed using the ADMB software package (Fournier et al. 2012). The current SS user manual is available at:
https://drive.google.com/a/noaa.gov/?tab=mo#folders/0Bz1UsDoLaOMLN2FiOTI3MWQtZDQwOS00YWZkLThmNmEtMTk2NTA2M2FjYWVh

The Tier 3 models bear some similarities to the model that has been accepted for use in management of the EBS Pacific cod stock since 2011 (Thompson 2013). Some of the main differences between the Tier Tier 3 AI models and the 2011-2013 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. Initial abundances were estimated for the first ten age groups instead of the first three.
6. 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. Selectivity-at-age pattern #17 in SS has one parameter for each age in the model. Except for age 0, the parameter for any given age represents the logarithm of the ratio of selectivity at that age to selectivity at the previous age (i.e., the backward first difference on the log scale). Age 0 fish are often expected to have a selectivity of zero, which can be achieved in this selectivity pattern by setting the parameter for age 0 equal to -1000, as was done for all three models presented here. As with other parameters in SS, each parameter in this selectivity pattern is associated with a prior distribution (see "Loop #1" under "Tier 3 Model Structures: Iterative Tuning Procedures," below).
7. The logarithm of survey catchability, ln(Q), was treated as a free parameter, with a normal prior distribution whose parameters were derived by averaging those used in other age-structured assessments of AI groundfish (similar to Model 2 in last year's preliminary and final AI assessments).
8. 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.
9. 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) where the sigma term was tuned according to the method described Thompson and Lauth (2012, Annex 2.1.1).

In most substantive respects, the two Tier 3 AI models are very similar to Model 2 in this year's EBS Pacific cod assessment.

Except for the ln(*Q*) parameter and the selectivity and *dev* parameters in both models, all parameters were estimated with uniform prior distributions.

Development of the final versions of both models included calculation of the Hessian matrix. These models also passed a "jitter" test of 50 runs with a jitter parameter (equal to half the standard deviation of the logit-scale distribution from which initial values are drawn) of 0.10 (or 0.01, in the event that too few runs converged when the jitter parameter was set at 0.10). 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 became the new base run, and 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.

Tier 3 Model Structures: Iterative Tuning Procedures

The quantities governing age-to-age and year-to-year changes in selectivity (both fishery and survey) were tuned iteratively during the development of Model 2 during this year's preliminary assessment (Appendix 2A.1, where it was labeled Model 1). Because this type of iterative tuning is time-consuming, it was not possible to redo the analysis for the final assessment; instead, the values resulting from the tuning procedure in the preliminary assessment were retained here, with the exception of the standard deviation for the prior distributions associated with the survey selectivity parameters in Model 3 (see also Comment SSC4 in this year's EBS Pacific cod assessment).

Three main loops were involved in the iterative tuning procedure:

1. Tuning the means of the prior distributions for the selectivity parameters.
2. Estimating "unconstrained" values of the standard deviations of the selectivity *dev*s.
3. Estimating "iterated" values of the standard deviations for the selectivity *dev*s.

Following the iterative procedure, the model was run with final estimates of the standard deviations for the selectivity *dev*s, which were estimated from a formula involving the results of loops #2 and #3.

The loops are described in more detail below.

Loop #1: tuning the parameters of the prior distributions for the selectivity parameters

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

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

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. The converged set of prior means (on the transformed scale, not the selectivity scale) was as follows (ages 7+ all had prior means of 0 for both the fishery and the survey):

Age:	1	2	3	4	5	6
Fishery:	3.290	3.280	3.049	1.380	0.117	0.005
Survey:	5.295	0.846	0.004	0.000	0.000	0.000

The converged prior standard deviations were 0.342 for the fishery and 0.319 for the survey (both constant across age). For Model 3 in the final assessment, the prior standard deviation for the survey was reduced until survey selectivity at age 20 was mid-way between the value estimated by Model 2 and unity. This was achieved by setting the prior standard deviation equal to 0.078.

Loop #2: Estimating "unconstrained" values of the standard deviations of the selectivity devs

Loops #2 and #3 were designed to produce the quantities needed in order to use the method of Thompson and Lauth (2012, Annex 2.1.1) for estimating the standard deviation of a *dev* vector. The purpose of Loop #2 was to determine the value of the selectivity *dev* vector (for either the fishery or the survey) that would be obtained if the *dev*s were completely unconstrained by their respective σs. 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 focus on one fleet (fishery or survey) at a time; 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.

Loop #3: Estimating "iterated" values of the standard deviations for the selectivity devs

Again proceeding one fleet (fishery or survey) at a time, this loop began with age-specific σs set at the unconstrained values estimated in Loop #2. The standard deviations of the estimated *dev*s then became the age-specific σs for the next run, and the process was repeated until the σs converged.

It is common for some ages to be "tuned" out during Loop #3 (i.e., the σs converge on zero). In the present case, all ages were tuned out except the following (these are final values of σ, after application of the algorithm described by Thompson and Lauth (2012, Annex 2.1.1), shown in parentheses):

Fishery: age 4 (0.092), age 6 (0.237)
Survey: age 2 (0.194), age 3 (0.078), age 7 (0.442).

Parameters Estimated Outside the Assessment Model

Natural Mortality (Tier 3 and Tier 5)

A value of 0.34 has been 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

All of the models in this assessment (both Tier 3 and Tier 5) fix *M* at the value of 0.34 used for BSAI Pacific cod since 2007.

Variability in Estimated Age (Tier 3 Only)

Variability in estimated age in SS is based on the standard deviation of estimated age between "reader" and "tester" age determinations. The same weighted least squares regression that has been used in the past several assessments of EBS Pacific cod was used here to estimate a proportional relationship between standard deviation and age. The regression for the small reader-tester sample (n=581) of AI Pacific cod age data yielded an estimated slope of 0.08550 (i.e, the standard deviation of estimated age was modeled as 0.0898 × age) and a weighted R^2 of 0.69. This regression corresponds to a standard deviation at age 1 of 0.090 and a standard deviation at age 20 of 1.796. These parameter estimates, which are very close to those estimated for the EBS stock, were used for the Tier 3 models in the present assessment.

Weight at Length (Tier 3 Only)

In both Tier 3 models, weight (kg) at length (cm) was assumed to follow the usual form weight=A×length^B and to be constant across the time series, with A and B estimated at 5.683×10^{-6} and 3.18, respectively, based on 8,126 samples collected from the AI fishery between 1974 and 2011.

Maturity (Tier 3 Only)

A detailed history and evaluation of parameter values used to describe the maturity schedule for BSAI Pacific cod was presented in the 2005 assessment (Thompson and Dorn 2005). A length-based maturity schedule was used for many years. The parameter values used for this schedule in the 2005 and 2006 assessments were set on the basis of a study by Stark (2007) at the following values: length at 50% maturity = 58 cm and slope of linearized logistic equation = –0.132. However, in 2007, changes in SS allowed for use of either a length-based or an age-based maturity schedule. Beginning with the 2007 assessment, the accepted model has used an age-based schedule with intercept = 4.88 years and slope = –0.965 (Stark 2007). The use of an age-based rather than a length-based schedule follows a recommendation from the maturity study's author (James Stark, Alaska Fisheries Science Center, personal communication). The age-based parameters from the EBS Pacific cod assessment were retained for the Tier 3 models in the present assessment.

Catchability (Tier 3 Only)

As noted above, *Q* was estimated internally in both Tier 3 models, using a prior distribution based on a meta-analysis of prior distributions for *Q* in other AI groundfish stock assessments. The prior distribution was assumed to be normal (*Q* is estimate on a log scale in SS), with mean 0 and standard deviation 0.11.

Parameters Estimated Inside the Assessment Model (Tier 3 Only)

Parameters estimated inside SS for the models used in this assessment include:

1. all three von Bertalanffy growth parameters
2. standard deviation of length at ages 1 and 20
3. mean ageing bias at ages 1 and 20
4. log mean recruitment
5. standard deviation of log recruitment
6. *dev*s for log-scale initial (i.e., 1991) abundance at ages 1 through 10
7. annual log-scale recruitment *dev*s for 1991-2011
8. initial (equilibrium) fishing mortality
9. log survey catchability
10. base values of fishery selectivity parameters for ages 1 through 20
11. base values of survey selectivity parameters for ages 1 through 20
12. annual *dev*s for the fishery selectivity parameters corresponding to ages 4 and 6
13. annual *dev*s for the survey selectivity parameters corresponding to ages 2, 3, and 7

Uniform prior distributions are used for all parameters, except that *dev* vectors are constrained by input standard deviations ("sigma"), which are somewhat analogous to a joint prior distribution.

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

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

Objective Function (Tier 5)

Model 1 incorporates both process error and observation error in the likelihood. Both are assumed to be lognormal. As a random effects model, the states (i.e, the individual points in the biomass time series) are "integrated out," leaving a marginal likelihood that is a function of just the one parameter (the log of the log-scale process error standard deviation).

Objective Function (Tier 3)

The Tier 3 models in this assessment include objective function components for initial (equilibrium) catch, trawl survey relative abundance, fishery and survey size composition, survey age composition, recruitment, prior distributions, "softbounds" (equivalent to an extremely weak prior distribution used to keep parameters from hitting bounds), and parameter deviations.

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

Use of Size Composition Data in Parameter Estimation

Size composition data are assumed to be drawn from a multinomial distribution specific to a particular fleet (fishery or survey) and year. In the parameter estimation process, SS weights a given size composition observation according to the emphasis associated with the respective likelihood component and the sample size specified for the multinomial distribution from which the data are assumed to be drawn. The steps used to scale the sample sizes here were similar to those used in the EBS Pacific cod assessment (Thompson 2013): 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).

The resulting input sample sizes for *fishery* length composition data are shown below:

Year:	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
N:	133	604	275	175	182	251	140	437	425	656	722	293

Year:	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
N:	296	300	259	256	344	329	274	429	111	147	107	53

The resulting input sample sizes for *survey* length composition data are shown below:

Year:	1991	1994	1997	2000	2002	2004	2006	2010	2012	2014
N:	463	487	301	336	254	242	181	229	213	295

Use of Age Composition Data in Parameter Estimation

Like the size composition data, the age composition data are assumed to be drawn from a multinomial distribution specific to a particular year and gear. To date, only two years of age composition data are available, namely the 2010 and 2012 surveys. As in the EBS Pacific cod assessment, the average input sample size for the age composition data was fixed at 300. The actual sample sizes of 673 and 599 for 2010 and 2012 thus translate into input sample sizes of 317 and 283, respectively.

Use of Survey Relative Abundance Data in Parameter Estimation

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

Use of Recruitment Deviation "Data" in Parameter Estimation

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

RESULTS

Model Evaluation

The models used in this assessment are described under "Analytic Approach" above.

Goodness of Fit (Tier 5)

Statistics related to Model 1's goodness of fit with respect to the survey biomass data are shown below:

Statistic	Value
Correlation (observed:expected)	0.98
Root mean squared error	0.11
Mean normalized residual	0.06
Standard deviation of normalized residuals	0.63

The above values are similar to those from last year's assessment.

Figure 2A.4 shows the fit of Model 1 to the trawl survey biomass data (note that the Tier 3 models use numbers of fish as the survey index, while Model 1 uses biomass).

Goodness of Fit (Tier 3)

The values for the objective function components for Models 2 and 3 are directly comparable, because the two models have identical numbers of parameters:

Parameter counts	Model 2	Model 3
Unconstrained parameters	10	10
Parameters with priors	41	41
Constrained deviations	152	152
Total	203	203

Objective function values are shown for Models 2 and 3 below (lower values are better, all else being equal; objective function components with a value less than 0.001 for all models are omitted for brevity; color scale extends from red (minimum) to green (maximum)):

Objective function component	Model 2	Model 3
Equilibrium catch	0.001	0.002
Survey abundance	-11.619	-9.270
Fishery size composition	102.218	101.117
Survey size composition	211.073	208.984
Age composition	11.519	15.943
Recruitment	-4.511	-0.174
Priors	17.680	20.262
"Softbounds"	0.001	0.001
Parameter *devs*	12.039	20.438
Total	338.400	357.302

Model 3 has a better (lower) value for the two size composition components and a negligibly better value for the "softbounds" component, but Model 2 has a better value for all other components and a much better value for the overall objective function.

The table below shows the number of size composition records (Nrec) that are available for the fishery and survey, and it also shows how the output "effective" sample sizes (Neff, McAllister and Ianelli 1997) of the Tier 3 models compare to the input sample sizes (Ninp) for these data. Two sets of ratios are provided, with the arithmetic mean input sample size used as the denominator for both sets. The *arithmetic* mean effective sample size is used as the numerator for the first set, and the *harmonic* mean effective sample size is used for the second (values greater than unity are preferred in both measures, all else being equal).

			Mean(Neff)/mean(Ninp)		Harm(Neff)/mean(Ninp)	
Fleet	Nrec	Mean(Ninp)	Model 2	Model 3	Model 2	Model 3
Fishery	24	300	14.62	15.19	8.77	8.01
Survey	10	300	3.50	3.55	2.29	2.31

Both Tier 3 models give ratios much greater than unity for all cases, with Model 3's ratios greater than those of Model 2 in three out of four cases.

Figures 2A.5 and 2A.6 show the Tier 3 models' fits to the fishery size composition and survey size composition data, respectively.

The table below shows the Tier 3 models' ratios of effective sample size to input sample size for the two years of age composition data:

			Mean(Neff)/mean(Ninp)		Harm(Neff)/mean(Ninp)	
Fleet	Nrec	Mean(Ninp)	Model 2	Model 3	Model 2	Model 3
Survey	2	300	1.05	0.69	0.79	0.52

Model 2 gives a ratio greater than 1.0 when the arithmetic mean is used in the numerator, but otherwise all of the ratios are less than unity.

Figure 2A.7 shows the Tier 3 models' fits to the one available year of survey age composition data.

The table below shows four statistics related to the Tier 3 models' goodness of fit with respect to the survey abundance data (color scale extends from red (minimum) to green (maximum)). Relative values of the four statistics can be interpreted as follows: correlation—higher values indicate a better fit, root mean squared error— values closer to the average log-scale standard error in the data (0.18) indicate a fit more consistent with the sampling variability in the data, mean normalized residual—values closer to zero indicate a better fit, standard deviation of normalized residuals—values closer to unity indicate a fit more consistent with the sampling variability in the data.

Statistic	Model 2	Model 3
Correlation (observed:expected)	0.95	0.96
Root mean squared error	0.17	0.21
Mean normalized residual	-0.56	-0.79
Standard deviation of normalized residuals	0.98	1.07

Model 2 fits these data slightly better than Model 3 in terms of all of the above measures except correlation, although the differences between models is fairly small for all measures.

Figure 2A.8 shows the fits of the Tier 3 models to the trawl survey abundance data. Model 3's estimates are higher (although sometimes just slightly) than the observed values in all years prior to 2012. Model 2 has a slightly better residual pattern than Model 3, although, as the above text table indicates, it is not ideal, either. The point estimates from both of the Tier 3 models fall within the 95% confidence intervals of the observations in 9 of the 10 years.

Parameter Estimates (Tier 5)

Model 1 has a single internally estimated parameter, the log of the log-scale process error standard deviation. The point estimate and standard deviation of this parameter were -1.762 and 0.671, respectively. Exponentiating the point estimate gives a log-scale process error standard deviation of 0.172.

Parameter Estimates (Tier 3)

Table 2A.8 displays some of the more important constants and all of the parameters (except fishing mortality rates) estimated internally in either of the Tier 3 models, along with the standard deviations of those estimates. Table 2A.8a shows selected constants. Table 2A.8b shows growth, ageing bias, recruitment (except annual *dev*s), initial fishing mortality, log catchability, and initial age composition parameters; Table 2A.8c shows annual log-scale recruitment *dev*s (these are plotted in Figure 2A.9); Table 2A.8d shows baseline selectivity parameters; Table 2A.8e shows fishery selectivity *dev*s; and Table 2A.8f shows survey selectivity *dev*s.

The estimates of log catchability in Table 2A.8b translate into Q values of 0.647 and 0.566 for Models 2 and 3, respectively.

Table 2A.9 shows estimates of fishing mortality. Two measures of annual fishing mortality are shown for each model. The first is an "average" fishing mortality rate across ages 8-18. This age range was determined in the 2013 assessment as the set of ages for which fishery selectivity was at least 90% on average across years (ages 19-20 also met this criterion, but SS generates a warning if the last two age groups are included in the average). The second measure of fishing mortality ("Apical F") is the rate corresponding to the length of full selection.

Other Derived Quantities

Figure 2A.10 shows the time series of spawning biomass relative to $B_{100\%}$ as estimated by the Tier 3 models.

Figure 2A.11 shows the time series of total (age 0+) biomass as estimated by the Tier 3 models, with the survey biomass time series included for comparison. Models 2 and 3 estimate very similar time series. Both are consistently much higher than the survey biomass time series, by factors of about 3.3 (on average) in both cases.

Figure 2A.12 shows trawl survey selectivity as estimated by the Tier 3 models. Selectivity for Model 2 is sharply peaked at age 4, with a secondary mode at age 7 in some years. In Model 2, average (across years) selectivity is less than 0.2 for all ages greater than 11, with selectivity dropping to an average value of 0.09 at age 20. Selectivity for Model 3 also peaks at age 4, but declines much less steeply than in Model 2. In Model 3, average selectivity is greater than 0.5 at all ages beyond age 4. As noted previously, the prior distributions for the selectivity parameters in Model 3 were tuned so that selectivity at age 20 would be mid-way between selectivity at age 20 in Model 2 and unity. This criterion turned out to be fairly effective in increasing Model 3 selectivity by an average of about 50% (relative to Model 2) at all ages greater than 4.

Figure 2A.13 shows fishery selectivity as estimated by the Tier 3 models. The profiles for the two models are broadly similar through the peak at age 11, but Model 2 selectivity declines by a greater amount than Model 3 selectivity at ages greater than 11.

Per request of the SSC (see Comment SSC4 in Appendix 2A.1), Figure 2A.14 shows likelihood profiles with respect to M for each Tier 3 model. The value of survey catchability is also shown. Both models assume a value of 0.34 for M, but the likelihood profiles indicate that a much lower value of M would minimize the objective function (0.11 in Model 2 and 0.18 in Model 3).

Table 2A.10 contains selected management reference points. For Models 2 and 3, the values in the first upper portion of this table (everything above the probabilities shown in the last seven rows) come from the standard projection model, based on parameter estimates from the respective SS model. The last seven rows (Models 2 and 3 only) come directly from SS rather than the standard projection model. The entries in these rows show the probability that the maximum permissible ABC in each of the next two years will exceed the corresponding true-but-unknown OFL and the probability that the stock will fall below $B_{20\%}$ in each of the next five years.

Evaluation Criteria

The following criteria were considered in evaluating the model:

1. Does the model contain new features that merit further evaluation before being adopted?
2. Would use of the model for setting 2015-2016 harvest specifications pose a significant risk to the stock?

In the context of the first criterion, one new feature of Models 2 and 3 that stands out is their use of SS selectivity pattern #17, which treats selectivity as a random walk with respect to age. Although this pattern has several benefits (see “Discussion” section in Appendix 2A.1), some aspects could benefit from further evaluation, specifically:

- Selectivity pattern #17 involves internal rescaling so that selectivity reaches a peak value of unity at some integer age. Restricting peak selectivity to occur at an integer age means that the function is not entirely differentiable, which is potentially problematic in ADMB.
- Although a substantial improvement in goodness of fit can sometimes be achieved by allowing annual *dev*s at the age of peak selectivity, this is sometimes accompanied by a large final gradient in the objective function (most likely related to the item in the previous bullet), which is usually considered to be symptomatic of a problem with the model.
- In some situations, a substantial improvement in goodness of fit can be achieved by estimating selectivity at unrealistically low values for all ages except for a few that are very close to the age-plus group.

A second new feature that may merit further investigation is the absence of the pre-1991 fishery data in Models 2 and 3. While removing these data resulted in much better fits to the remaining data, there is some possibility that the resulting estimates of reference points such as $B_{40\%}$ may be biased. This would be the case if mean recruitment in the pre-1991 portion of the time series were substantially different from mean recruitment in the post-1990 period. As noted previously, it might be possible to reconcile the difference in size compositions between the two parts of the time series (Figure 2A.3) with the other data in the model if fishery selectivity were sufficiently different between the two periods. Unfortunately, although one of last year's age-structured models allowed for time-varying fishery selectivity, it failed to find substantial differences between the two periods. However, the method used for determining the appropriate amount of time variability (Thompson and Lauth 2012, Annex 2.1.1) can tend to underestimate this amount under certain conditions. An alternative for future exploration might be to specify period-specific fisheries, and then allow for an appropriate amount of time-variability within each period. If this is successful, then perhaps the pre-1991 fishery data could be restored.

With regard to the second criterion, a formal risk analysis has not been undertaken in this assessment, but one feature of Models 2 and 3 that merits attention in this context is the difference between these models' estimates of total biomass and the biomass estimated by the survey (Figure 2A.11). As noted above, the ratio of model biomass to survey biomass has an average (across the time series) value of about 3.3 for both models. While it is not inconceivable that the survey misses so many fish, it does not seem wise to accept such an enormous discrepancy without first examining other hypotheses more fully.

On the basis of the above, Model 1 is recommended for use in setting final harvest specifications for 2015 and preliminary harvest specifications for 2016, with two caveats: First, it should be noted that use of trawl survey data for a Tier 5 assessment was criticized in the 2013 CIE review of assessments for non-target species, primarily because catchability (and selectivity for recruited ages) may not equal unity. Second, it is important to understand that the design of the AI trawl survey is not entirely random. The sampling frame for the AI survey is the list of stations that were successfully sampled from all previous surveys dating back to 1980. The 1980 survey was a systematic survey with sampling stations set approximately every 20 nautical miles. Over time more stations were added, but the systematic nature of the survey is still evident. As such, the survey design is a stratified random survey of previously and successfully towed stations that were originally based on a systematic design. This approach was taken because experience showed that much of the AI area is untrawlable. However, area swept estimates of density are still expanded over all habitat regardless of whether it is deemed trawlable or not.

Final Parameter Estimates and Associated Schedules

For typical stock assessments, this subsection of the chapter would summarize the parameter estimates and associated schedules associated with the final model. However, given the ongoing interest in development of age-structured models for AI Pacific cod, an attempt will be made to present information for *all* of the models, thereby giving the Plan Team and SSC maximum flexibility in developing their own recommended harvest specifications.

As noted previously, estimates of all statistically estimated parameters in the Tier 3 models are shown in Table 2A.8. Estimates of fishing mortality rates from the Tier 3 models are shown in Table 2A.9. Estimates of the only statistically estimated parameter in the Tier 5 mode is shown in the main text, under "Parameter Estimates (Tier 5)."

Schedules of selectivity at length for the fishery from the Tier 3 models are shown in Table 2A.11, and schedules of selectivity at age for the trawl surveys from the Tier 3 models are shown in Table 2A.12. The survey selectivity schedule and the fishery selectivity schedule for the Tier 3 models are plotted in Figures 2A.12 and 2A.13, respectively.

Schedules of length at age and weight at age for the population, fishery, and survey are shown in Table 2A.13.

Time Series Results

As in the previous subsection, results for all three models (Tiers 3 and 5) will be presented here to the extent possible.

Definitions

The biomass estimates presented here will be defined in three ways for the Tier 3 models: 1) age 0+ biomass, consisting of the biomass of all fish aged 0 years or greater in January of a given year; 2) age 3+ biomass, consisting of the biomass of all fish aged 3 years or greater in January of a given year; and 3) spawning biomass, consisting of the biomass of all spawning females in a given year. For the Tier 5 models, biomass will be defined as the model estimate of survey biomass (as distinguished from observed survey biomass).

For the remaining quantities (recruitment and fishing mortality), Tier 5 estimates do not exist, so only Tier 3 estimates will be given. The recruitment estimates presented here will be defined as numbers of age 0 fish in a given year. To supplement the full-selection fishing mortality rates already shown in Table 2A.9, an alternative "effective" fishing mortality rate will be provided here, defined for each age and year as $-\ln(N_{a+1,t+1}/N_{a,t})-M$, where N = number of fish, a = age measured in years, t = time measured in years, and M = instantaneous natural mortality rate. In addition, the ratio of full-selection fishing mortality to $F_{35\%}$ will be shown.

Biomass

Table 2A.14a shows the time series of age 0+, age 3+, and female spawning biomass for the years 1977-2014 as estimated by the Tier 3 models (projections through 2015 are also shown for this year's assessment). The estimated spawning biomass time series are accompanied by their respective standard deviations. Table 2A.14b shows the time series of survey biomass with 95% confidence intervals as estimated last year and this year by Model 1 (because this is a random walk model, projected biomass for 2015 is the same as estimated biomass for 2014).

As noted previously, the time series of total (age 0+) biomass as estimated by the Tier 3 models are shown, together with the observed time series of trawl survey biomass, in Figure 2A.11, and the time series of survey biomass as estimated by the Tier 5 model is shown in Figure 2A.4. The time series of female spawning biomass as estimated by the Tier 3 models are shown, together with the observed time series of trawl survey biomass, in Figure 2A.15.

Recruitment and Numbers at Age

Table 2A.15 shows the time series of age 0 recruitment (1000s of fish) for the years 1977-2013 as estimated by the Tier 3 models. Both estimated time series are accompanied by their respective standard deviations.

For the time series as a whole, both Tier 3 models estimate that 1996 was the largest cohort. Of the last ten cohorts, Model 2 estimates that only the 2007 year class was above average, and Model 3 estimates that none were above average. The recruitment time series for Models 2 and 3 had autocorrelation coefficients of 0.29 and 0.25, respectively.

Tier 3 model estimates of recruitment for the entire time series (1977-2013) are shown in Figure 2A.16, along with their respective 95% confidence intervals.

The time series of numbers at age as estimated by the Tier 3 models are shown in Table 2A.16.

Fishing Mortality

Table 2A.17 shows "effective" fishing mortality by age and year for ages 1-19 and years 1977-2014 as estimated by the Tier 3 models.

For each of the Tier 3 models, Figure 2A.17 plots the estimated trajectory of relative fishing mortality and relative female spawning biomass from 1977 through 2016 based on full-selection fishing mortality, overlaid with the current harvest control rules (projected values for 2015 and 2016 are from Scenario 2 under "Harvest Recommendations," below). It should be noted that, except for the projection years, this trajectory is based on SS output, which may not match the estimates obtained by the standard projection program exactly.

Retrospective Analysis

Figure 2A.18 shows the retrospective behavior of Models 2 and 3 with respect to female spawning biomass over the years 2004-2014. This figure was obtained by conducting ten additional model runs, dropping the 2014 data to create the run labeled "2013," dropping the 2013-2014 data to create the run labeled "2012," and so forth (the run labeled "2014" is this year's model run). In an attempt to quantify the results of this type of retrospective analysis, Mohn (1999) introduced a statistic labeled ρ, which has since been redefined to represent the average relative bias in terminal year estimates of a given quantity (in this case, female spawning biomass) across retrospective runs. For Model 2, $\rho = -0.384$, indicating that Model 2 tends to underestimate spawning biomass in the current year by nearly 40%. Model 3 produced a similar ρ value of -0.431. Both of these ρ values are higher (in absolute terms) than 18 of the 20 examples of BSAI and GOA groundfish stocks reported in the 2013 report of the Retrospective Working Group. Not only are the retrospective biases of Model 2 and 3 high and negative on average, they are negative in all runs shown in Figure 2A.18.

Determining the cause of a retrospective bias can be difficult. One oft-considered possibility is that certain parameters are constrained in the model to be constant over time, whereas the model would behave better if those parameters were allowed to vary over time. Examining the correlation between estimated parameter values and the number of "peels" (i.e., the number of data years dropped in each sequential run) in a retrospective analysis has been suggested as an appropriate diagnostic tool. For all estimated parameters in Models 2 and 3 (except those that get eliminated from the model during the peeling process, leaving a total of 119), correlation coefficients with respect to number of peels were computed.

The results are shown in Figure 2A.18, in the form of a cumulative distribution function. For example, 38 and 28 parameters (32% and 24% of the total) in Models 2 and 3, respectively, had a correlation (in absolute value) of at least 0.90 with respect to number of peels.

For Model 2, the parameters with correlations of at least 0.90 in absolute value were:

Length at age 1 (cm)
Asymptotic length (cm)
Brody growth coefficient
ln(catchability)
Initial age 6 ln(abundance) dev
Initial age 8 ln(abundance) dev
Initial age 9 ln(abundance) dev
Initial age 10 ln(abundance) dev
Recruitment dev for 1994
Recruitment dev for 1997
Recruitment dev for 1998
Recruitment dev for 1999
Fishery selparm age 2
Fishery selparm age 3
Fishery selparm age 13
Fishery selparm age 14
Fishery selparm age 15
Fishery selparm age 16
Fishery selparm age 17
Fishery selparm age 18
Fishery selparm age 19
Fishery selparm age 20
Survey selparm age 3
Survey selparm age 11
Survey selparm age 12
Survey selparm age 13
Survey selparm age 14
Survey selparm age 15
Survey selparm age 16
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Survey selparm age 19
Survey selparm age 20
Fishery seldev age 4 year 1995
Fishery seldev age 4 year 2003
Survey seldev age 6 year 1995
Survey seldev age 3 year 2002
Survey seldev age 3 year 2004

For Model 3, the parameters with correlations of at least 0.90 in absolute value were:

Length at age 1 (cm)
ln(catchability)
ln(mean recruitment)
Initial age 5 ln(abundance) dev
Initial age 8 ln(abundance) dev
Initial age 9 ln(abundance) dev
Initial age 10 ln(abundance) dev
Recruitment dev for 1994
Recruitment dev for 1997
Recruitment dev for 1998
Recruitment dev for 1999
Fishery selparm age 2
Fishery selparm age 3
Fishery selparm age 14
Fishery selparm age 15
Fishery selparm age 16
Fishery selparm age 17
Fishery selparm age 18
Fishery selparm age 19
Fishery selparm age 20
Survey selparm age 3
Survey selparm age 5
Fishery seldev age 4 year 1994
Fishery seldev age 6 year 1992
Fishery seldev age 6 year 2003
Survey seldev age 2 year 1991
Survey seldev age 7 year 1997
Survey seldev age 7 year 2000

Most of the parameters in the above lists already pertain to a specific year in the time series, so it is not clear that adding time variability to an existing estimated parameter will solve the problem. The non-time-varying parameters are the growth parameters, catchability, and mean recruitment. Adding time-variabililty to one or more of these parameters may help to address the retrospective bias. For example, Model 2 in this year's EBS Pacific cod assessment included time-varying catchability, and its value of rho was only -0.049. However, there was not sufficient time to investigate such modifications in the present assessment.

It should be noted that only one model run was conducted for each peel in the retrospective analysis (i.e., no "jitter" analysis was conducted), meaning it is possible that some of the retrospective runs may not have converged to the true minimum of the objective function.

Harvest Recommendations

As in the previous two subsections, results for all three models (Tiers 3 and 5) will be presented here to the extent possible.

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.

Tier 3 of the Amendment 56 control rules uses the following reference points: $B_{40\%}$, equal to 40% of the equilibrium spawning biomass that would be obtained in the absence of fishing; $F_{35\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 35% of the level that would be obtained in the absence of fishing; and $F_{40\%}$, equal to the fishing mortality rate that reduces the equilibrium level of spawning per recruit to 40% of the level that would be obtained in the absence of fishing. The only parameter used in the Tier 5 reference points is *M*.

If the SSC determines that the estimates of 2015-16 spawning biomass and the Tier 3 reference points from either of the Tier 3 models are all reliable, then AI Pacific cod will be managed under Tier 3. If the SSC determines that neither of the Tier 3 models produces reliable estimates of all of these quantities, then AI Pacific cod will continue to be managed under Tier 5.

The following formulae apply under Tier 3:

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

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

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

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

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

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

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

$F_{OFL} = 0$

$F_{ABC} = 0$

The following formulae apply under Tier 5:

$F_{OFL} = M$

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

Estimates of projected biomass and all Tier 3 and Tier 5 reference points are shown for the respective models in Table 2A.10. For the authors' recommended model (Tier 5, Model 1), the estimates are as follow:

Quantity	2015	2016
Biomass (t)	68,900	68,900
M	0.34	0.34

The 95% confidence interval for the above Tier 5 biomass estimate extends from 50,100-93,800 t.

Specification of OFL and Maximum Permissible ABC

As shown in Table 2A.10, of the two Tier 3 models, Model 2 projects that female spawning biomass will be above $B_{40\%}$ in both 2015 (Tier 3a) but below in 2016 (Tier 3b), while Model 3 projects that it will be below in both years (Tier 3b). Tier 5 has no sub-tiers.

Estimates of OFL, maximum permissible ABC, and the associated fishing mortality rates for 2015 and 2016 are shown for the respective models in Table 2A.10. For the authors' recommended model (Tier 5, Model 1), the estimates are as follow:

Quantity	2015	2016
OFL (t)	23,400	23,400
maxABC (t)	17,900	17,900
F_{OFL}	0.34	0.34
$maxF_{ABC}$	0.26	0.26

The age 0+ biomass projections for 2015 and 2016 from the Tier 3 models (using SS rather than the standard projection model) are 170,000 t and 151,000 t, respectively (Model 2); and 151,000 t and 132,000 t, respectively (Model 3).

Standard Harvest Scenarios, Projection Methodology, and Projection Results (Tier 3 Only)

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

For each scenario, the projections begin with an estimated vector of numbers at age for January 1, 2015. This requires an appropriate estimate of total catch for 2014. Because each year's stock assessment is finalized before complete (i.e., year-long) catch data are available for that year, it is necessary to extrapolate the available catch data through the end of the year.

Twelve estimators were evaluated to determine the best method of estimating total current-year catch as a function of previous intra-annual fishery performance, which parallel the set of estimators used in this year's EBS Pacific cod assessment. Typically, current-year catch data are available through the beginning of October. In the seasonal structure used by the base model for the EBS stock, the last two "catch seasons" span the months August-October and November-December, meaning that current-year catch data are missing for part of season 4 and all of season 5. All 12 estimators therefore involved extrapolating the catch for seasons 1-3 through the end of the year. The estimators consisted of two groups of six each. One group was based on the average *absolute* amounts of catch taken in some number of previous years during seasons 4-5, and the other was based on the average *relative* amounts of catch taken in some number of previous years during seasons 4-5. For both groups, averages were taken over a range of previous years spanning 1 to 6. The results of this analysis are shown in Figure 2A.20. Although it may be difficult to identify the best estimator by eye, it turned out that all of the "relative" estimators performed better than any of the "absolute" estimators (the opposite was the case in the EBS assessment), and the best "relative" estimator was based on the average January-July catch proportion from the preceding 5 years.

Because management of the Pacific cod fisheries has a very strong track record of keeping catch below ABC, however, this estimator was used only in the event that it did not result in a current-year catch greater than current-year ABC. In the case of the 2014 fishery, the estimator resulted in a catch of 11,852 t, which is less than the 2014 ABC of 15,100 t, so final 2014 catch was estimated at a value of 11,852 t.

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

For the first two projection years under Scenario 2, total catch was computed based on two factors: 1) the relationship between previous ABCs and previous catches, and 2) the fact that neither BSAI or AI Pacific cod catch has ever exceeded BSAI or AI Pacific cod ABC in the last 20 years. Computation of an appropriate estimator is complicated by the fact that, prior to 2014, the Pacific cod ABC applied to the EBS and AI combined, but, as in 2014, future ABCs are anticipated to apply to the AI only. To adjust for this, a series of "pseudo-ABCs" was computed for the years 1995-2013 by multiplying each BSAI ABC by the corresponding ratio of AI catch to BSAI catch. Catch for the AI was then regressed against the AI pseudo-ABC, giving an intercept of about -900 t and a slope of about 0.95. This regression implies that catch will be less than ABC for all values of ABC. The data, the catch=ABC line, the regression line, and the estimator are shown in Figure 2A.21.

Five of the seven standard scenarios are sometimes used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TACs for 2015 and 2016, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

> *Scenario 1*: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
>
> *Scenario 2*: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2015 recommended in the assessment to the *max* F_{ABC} for 2015. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)
>
> *Scenario 3*: In all future years, F is set equal to the 2009-2013 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
>
> *Scenario 4*: In all future years, the upper bound on F_{ABC} is set at $F_{60\%}$. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)
>
> *Scenario 5*: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

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

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is 1) above its MSY level in 2014 or 2) above 1/2 of its MSY level in 2014 and expected to be above its MSY level in 2024 under this scenario, then the stock is not overfished.)

Scenario 7: In 2015 and 2016, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is 1) above its MSY level in 2016 or 2) above 1/2 of its MSY level in 2016 and expected to be above its MSY level in 2026 under this scenario, then the stock is not approaching an overfished condition.)

Projections corresponding to the standard scenarios are shown for the Tier 3 models in Tables 2A.18-2A.24. Each of these tables consists of two pages, with the first corresponding to Model 2 and the second corresponding to Model 3.

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2015, it does not provide the best estimate of OFL for 2016, because the mean 2016 catch under Scenario 6 is predicated on the 2015 catch being equal to the 2015 OFL, whereas the actual 2015 catch will likely be less than the 2015 OFL. Table 2A.10 contains the appropriate one- and two-year ahead projections for both ABC and OFL under Model 1.

ABC Recommendation

The authors' recommended ABCs for 2015 and 2016 are the maximum permissible values from the Tier 5 random effects model: 17,600 t in both years.

Area Allocation of Harvests

As noted in the "Management History" subsection of the "Fishery" section, the anticipated final rule for the 2015 Steller sea lion protection measures requires 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 the Tier 5 random effects model for Area 543 and then computing the ratios of the resulting estimates to those of Model 1. More specifically, some possible estimators of this proportion are: 1) the 1991-2014 average proportion from the survey (26.5%), 2) the most recent proportion from the survey (24.6%), 3) the 1991-2014 average proportion from the random effects model (25.6%), and 4) the most recent proportion from the random effects model (26.3%). All of these estimates are quite close to one another, with an average value of 25.7%. If the random effects model is used to set the 2015 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 the random effects model (26.3%).

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 BSAI catch estimate for the most recent complete year (2013) is 250,274 t. This is less than the 2013 BSAI OFL of 359,000 t. Therefore, the combined BSAI stock is not being subjected to overfishing.

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

Is the stock currently overfished? This depends on the stock's estimated spawning biomass in 2014:

a. If spawning biomass for 2014 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b. If spawning biomass for 2014 is estimated to be above $B_{35\%}$, the stock is above its MSST.
c. If spawning biomass for 2014 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 2.33). If the mean spawning biomass for 2024 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario #7 (Table 2.25):

a. If the mean spawning biomass for 2016 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.
b. If the mean spawning biomass for 2016 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c. If the mean spawning biomass for 2016 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2026. If the mean spawning biomass for 2026 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

Based on the above criteria and Tables 2A.23 and 2A.24, if either of the Tier 3 models is accepted for use in status determination, the stock is not overfished and is not approaching an overfished condition.

ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on the Stock

A primary ecosystem phenomenon affecting the Pacific cod stock seems to be the occurrence of periodic "regime shifts," in which central tendencies of key variables in the physical environment change on a scale spanning several years to a few decades (Zador, 2011). One well-documented example of such a regime shift occurred in 1977, and shifts occurring in 1989 and 1999 have also been suggested (e.g., Hare and Mantua 2000). 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 are summarized in Tables 2A.25-2A.28. Catches for 2014 in each of these tables are incomplete. Table 2A.25 shows incidental catch of FMP species, other than squid and the members of the former "other species" complex, taken from 1991-2014 by trawl gear and longline gear (incidental catch of these species by pot gear in the AI Pacific cod fishery is typically negligible). Table 2A.26 shows incidental catch of squid and the members of the former "other species" complex taken from 2003-2014, aggregated across gear types. Table 2A.27 shows incidental catch of prohibited species taken from 1991-2014, plus mortality estimates for halibut, aggregated across gear types. Table 2A.28 shows incidental catch of non-target species groups taken from 2003-2014, aggregated across gear types.

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).

The Fisheries Interaction Team of the Alaska Fisheries Science Center has been engaged in research to determine the effectiveness of recent management measures designed to mitigate the impacts of the Pacific cod fisheries (among others) on Steller sea lions. Results from studies conducted in 2002-2003 were summarized by Conners et al. (2004). These studies included a tagging feasibility study, which may evolve into an ongoing research effort capable of providing information on the extent and rate to which Pacific cod move in and out of various portions of Steller sea lion critical habitat. Nearly 6,000 cod with spaghetti tags were released, of which approximately 1,000 had been returned as of September, 2003.

Seabirds

The following is a summary of information provided by Livingston (ed., 2002): In both the BSAI and GOA, the northern fulmar (*Fulmarus glacialis*) comprises the majority of seabird bycatch, which occurs primarily in the longline fisheries, including the hook and line fishery for Pacific cod (Tables 2.33b and 2.36b). 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 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 1991-2014 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 2014 are through October 13.

	Federal			State	
Year	Trawl	Long.+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	977	32,456		32,456
2004	25,770	3,103	28,873		28,873
2005	19,624	3,075	22,699		22,699
2006	16,963	3,535	20,498	3,714	24,211
2007	25,714	4,497	30,211	4,146	34,357
2008	19,404	7,507	26,910	4,319	31,229
2009	20,277	6,245	26,522	2,060	28,582
2010	16,757	8,277	25,034	3,967	29,001
2011	9,359	1,233	10,592	266	10,858
2012	9,789	3,201	12,991	5,232	18,223
2013	6,966	1,812	8,778	4,793	13,572
2014	5,656	429	6,085	4,451	10,536

Table 2A.1d—Summary of 1994-2014 catches (t) of Pacific cod in the AI, by NMFS 3-digit statistical area (area breakdowns not available prior to 1994). Catches for 2014 are through October 20.

	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	6,713	22,746	0.092	0.207	0.701
2004	3,657	6,825	18,391	0.127	0.236	0.637
2005	4,268	3,552	14,879	0.188	0.157	0.655
2006	4,583	4,662	14,967	0.189	0.193	0.618
2007	5,008	4,660	24,688	0.146	0.136	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	14,497	0.283	0.217	0.500
2011	24	1,768	9,066	0.002	0.163	0.835
2012	29	2,816	15,377	0.002	0.155	0.844
2013	53	2,875	10,644	0.004	0.212	0.784
2014	30	1,041	9,485	0.003	0.099	0.899

Table 2A.2—Discards (t) of Pacific cod in the AI Pacific cod fishery, by gear and year for the period 1991-2014 (2014 data are current through October 20). To avoid confidentiality problems, longline and pot catches have been combined. The small amounts of discards taken by other gear types have been merged proportionally into the gear types shown. Note that Amendment 49, which mandated increased retention and utilization, was implemented in 1998. Note also that the version of this table in the 2012 and 2013 assessments inadvertently included discards of Pacific cod in *all* fisheries, not just the Pacific cod fishery.

Year	Trawl	Long.+pot	Total
1991	21	84	105
1992	633	452	1,085
1993	1,371	2,156	3,527
1994	1,091	211	1,302
1995	115	345	460
1996	343	516	859
1997	580	639	1,220
1998	140	473	613
1999	225	196	420
2000	138	466	605
2001	213	243	455
2002	526	79	604
2003	187	29	216
2004	181	57	238
2005	101	38	139
2006	100	113	214
2007	352	131	483
2008	30	113	143
2009	33	115	149
2010	38	154	192
2011	20	24	45
2012	14	70	84
2013	87	38	126
2014	22	5	27

Table 2A.3—History of **BSAI** Pacific cod catch, TAC, ABC, and OFL (t). Catch for 2013 is through October 12. 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	6,085	6,997	15,100	20,100

Table 2A.4—Amendments to the BSAI Fishery Management Plan (FMP) that reference Pacific cod explicitly (excerpted from Appendix A of the FMP).

Amendment 2, implemented January 12, 1982:

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

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

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

Amendment 10, implemented March 16, 1987:

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

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

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

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

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

Amendment 49, implemented January 3, 1998:

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

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

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

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

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

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

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

Amendment 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).

Table 2A.5 (page 1 of 3)—Fishery size composition, by year and cm.

Year	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	1	0	0	0
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	1	5
1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
1997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1999	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2000	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2001	0	4	5	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
2003	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
2004	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
2005	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
2007	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Year	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
1991	0	0	0	2	0	0	1	2	8	2	4	9	13	11	15	7	9	21	28	39
1992	0	0	0	0	0	0	0	3	4	4	9	21	27	46	40	62	116	153	226	310
1993	0	0	0	0	1	4	7	11	9	12	17	20	30	29	33	39	45	67	76	113
1994	0	0	0	0	1	2	4	7	5	3	8	3	14	8	19	19	26	33	52	73
1995	14	22	34	38	59	51	49	54	66	56	51	33	22	19	11	12	11	23	20	30
1996	0	2	0	2	5	15	6	9	8	14	18	15	12	29	39	39	50	63	108	136
1997	0	0	0	0	2	2	0	7	4	5	9	12	6	9	17	22	17	25	25	32
1998	1	1	4	1	8	9	25	28	43	51	47	88	92	94	87	122	183	200	212	296
1999	0	1	1	3	0	1	3	3	7	6	8	25	21	19	30	32	38	62	75	131
2000	0	1	0	0	0	4	6	5	6	13	7	6	7	20	30	52	62	98	140	169
2001	0	0	0	1	3	10	5	11	12	15	15	23	34	64	72	93	130	163	211	230
2002	0	1	0	1	2	5	3	9	11	12	8	24	22	33	37	48	71	65	68	65
2003	0	1	0	0	1	3	5	5	12	16	22	15	21	25	21	17	33	50	53	64
2004	1	0	1	1	2	2	5	5	14	22	17	44	43	49	69	71	81	94	81	86
2005	0	0	0	0	3	2	1	1	2	5	2	6	12	4	7	11	16	20	30	30
2006	0	1	0	1	0	0	1	3	4	0	4	3	5	0	3	6	14	11	31	33
2007	3	0	1	0	5	3	5	7	12	12	12	20	15	19	17	20	27	31	31	50
2008	0	1	1	2	0	1	3	0	3	2	7	5	10	9	19	21	43	41	47	67
2009	0	0	0	3	0	0	1	4	3	4	10	14	15	20	20	39	52	53	67	86
2010	1	0	0	2	0	0	2	1	0	6	12	14	13	22	40	45	72	87	120	143
2011	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	1	2	3	15
2012	0	0	0	0	0	0	0	0	2	2	1	3	2	4	5	1	12	4	2	7
2013	0	0	0	0	0	0	0	0	0	1	1	1	2	1	2	1	3	6	10	10
2014	0	0	0	0	0	0	0	1	0	0	0	0	3	1	0	2	0	4	2	6

Table 2A.5 (page 2 of 3)—Fishery size composition, by year and cm.

Year	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
1991	24	36	56	63	62	76	62	92	103	141	140	186	214	255	252	312	285	324	359	360
1992	463	550	587	621	705	792	820	872	826	886	898	962	990	1025	1183	1297	1328	1454	1522	1752
1993	121	218	240	274	321	433	573	674	751	827	861	957	985	937	846	857	793	754	764	775
1994	101	83	139	160	161	223	233	257	291	297	333	359	389	466	512	572	632	654	720	750
1995	26	29	33	55	83	81	83	107	137	181	186	195	254	269	308	318	385	404	430	451
1996	168	197	268	249	296	334	335	362	416	423	508	453	502	583	534	558	572	685	800	926
1997	43	56	83	78	110	103	165	147	191	227	248	298	348	351	329	366	440	426	397	371
1998	359	455	483	523	639	629	793	723	718	804	822	798	867	808	882	931	1092	1143	1176	1298
1999	118	173	183	215	305	292	317	366	374	380	400	436	471	464	541	516	516	595	592	646
2000	170	246	286	291	362	375	367	462	488	559	582	658	752	825	841	855	875	946	971	968
2001	296	321	347	424	466	495	563	643	741	772	762	851	951	948	1041	1078	1195	1312	1324	1493
2002	74	89	102	110	122	152	164	179	156	147	154	174	165	139	172	164	198	218	224	255
2003	62	110	105	141	140	164	199	228	232	229	229	253	271	290	239	239	311	279	274	304
2004	84	82	112	116	145	174	186	237	264	307	320	362	381	348	398	371	367	405	399	439
2005	51	51	79	67	79	87	118	127	145	154	193	172	229	253	249	258	297	309	334	340
2006	41	49	70	108	121	137	154	163	199	186	215	211	261	298	315	314	395	395	378	388
2007	30	65	56	64	71	92	112	153	197	201	229	271	331	352	409	468	483	491	496	544
2008	88	96	128	172	209	235	299	308	341	323	316	338	300	310	331	301	308	335	316	358
2009	65	90	78	100	104	121	133	154	167	167	190	234	318	324	359	337	407	414	482	485
2010	184	226	232	307	370	399	444	490	459	519	530	496	490	499	504	531	502	493	509	531
2011	16	18	31	37	47	61	49	72	72	94	102	93	118	132	150	145	187	168	191	212
2012	5	11	10	15	19	32	28	26	51	45	56	76	100	115	126	174	168	214	256	292
2013	13	17	26	37	51	42	55	48	44	53	62	64	48	41	64	65	94	87	85	116
2014	1	7	6	10	20	21	31	27	31	50	42	42	46	51	57	39	55	55	54	70

Year	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83
1991	380	428	463	565	575	544	698	648	732	801	852	829	852	827	753	829	856	703	774	707
1992	1800	2141	2134	2337	2558	2797	2940	2871	3149	3267	3427	3578	3478	3549	3297	3289	3169	2878	2726	2644
1993	783	828	829	856	775	903	891	866	922	938	992	1035	972	1105	1007	1162	1105	1184	1208	1162
1994	762	853	800	865	828	881	827	808	780	804	766	730	617	655	598	545	550	520	535	498
1995	554	556	590	642	635	686	782	748	735	733	782	890	778	857	837	864	880	821	776	736
1996	914	1040	1158	1030	1056	965	1062	977	992	1071	1042	1125	1010	933	926	931	1037	954	1006	982
1997	363	352	349	317	362	371	351	355	402	383	407	489	458	445	513	582	608	572	548	531
1998	1407	1664	1689	1616	1766	1826	2306	1998	1888	1881	1781	2067	1667	1564	1513	1483	1604	1368	1262	1249
1999	621	616	628	560	717	715	702	664	735	783	829	797	773	808	906	800	836	826	820	808
2000	972	991	977	1054	1028	1040	1124	1002	1133	1112	1053	1053	1012	1050	990	1002	1053	972	1084	988
2001	1383	1452	1495	1607	1693	1659	1697	1651	1631	1558	1564	1361	1349	1263	1122	1076	973	962	898	924
2002	279	324	370	451	447	481	571	637	744	718	738	768	809	790	814	779	757	702	726	671
2003	277	272	357	337	307	366	408	415	372	398	349	420	418	432	469	500	547	580	593	688
2004	416	437	460	483	496	481	530	552	515	491	578	510	552	591	523	537	544	518	532	537
2005	340	366	319	362	408	405	464	454	460	518	534	561	559	561	563	637	685	632	623	598
2006	440	429	364	392	449	361	377	368	389	394	447	411	435	411	479	477	500	457	503	472
2007	461	498	466	532	488	493	456	453	428	440	473	458	491	472	519	502	523	532	531	539
2008	408	460	438	427	481	493	521	515	473	524	498	468	471	437	429	403	422	438	425	372
2009	491	452	486	447	486	404	475	406	414	453	434	457	413	451	413	390	379	400	359	363
2010	577	618	531	583	634	668	821	620	695	775	809	822	825	759	764	763	770	687	618	605
2011	210	210	208	228	195	214	217	155	162	147	145	172	135	179	155	161	221	182	184	201
2012	330	327	307	315	351	386	407	384	427	374	391	345	376	343	354	293	297	261	272	208
2013	103	129	158	147	172	187	171	200	231	204	198	196	209	254	227	259	248	217	247	234
2014	61	63	51	56	77	68	72	90	74	56	74	74	81	74	70	87	92	109	95	95

Table 2A.5 (page 3 of 3)—Fishery size composition, by year and cm.

Year	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
1991	642	619	600	515	463	393	311	263	259	212	174	171	115	133	103	72	60	28	42	29
1992	2441	2466	2071	1887	1768	1679	1534	1265	1227	1047	982	879	750	690	635	592	406	314	270	237
1993	1165	1170	1104	1048	955	913	780	728	713	609	548	567	498	423	407	364	298	279	252	213
1994	533	480	480	516	499	564	573	423	391	388	344	395	293	255	276	271	269	178	143	145
1995	741	736	683	646	580	525	629	499	552	620	709	623	496	383	334	330	403	236	263	253
1996	936	903	876	791	761	750	747	524	607	522	564	459	427	428	376	392	409	299	273	267
1997	511	563	509	484	523	492	611	491	480	528	476	465	408	429	394	335	361	287	264	239
1998	1122	1276	1163	1043	1227	1098	1286	1038	910	1028	1066	1076	969	903	924	846	964	726	640	618
1999	775	747	738	655	640	581	569	514	473	413	382	354	362	330	357	328	360	300	287	249
2000	1066	1006	1139	991	1064	1102	1210	1008	1027	906	890	760	769	636	624	566	574	520	468	458
2001	834	722	678	662	653	677	655	611	543	546	525	509	534	481	460	492	527	408	371	384
2002	648	603	574	496	495	412	377	322	328	309	280	257	237	197	182	143	224	165	153	142
2003	669	748	731	710	685	675	699	604	560	556	485	430	406	362	319	282	320	201	213	160
2004	472	439	415	408	366	351	394	347	359	361	329	327	313	321	317	233	269	245	216	178
2005	485	516	466	445	387	421	408	336	311	340	296	261	240	238	202	205	188	182	158	155
2006	478	461	525	468	492	457	442	406	366	362	325	279	249	233	210	190	197	168	170	131
2007	596	559	634	593	662	659	689	640	611	662	585	606	544	550	518	474	418	363	357	315
2008	447	431	449	433	445	485	480	470	484	516	454	518	505	497	503	445	515	470	412	459
2009	346	322	322	279	322	301	304	342	336	318	342	341	309	314	320	323	343	286	318	326
2010	580	480	457	502	427	433	429	388	383	396	354	340	398	392	353	383	436	364	446	458
2011	210	216	213	198	182	179	157	164	152	153	125	116	123	113	97	97	87	80	72	55
2012	186	188	202	156	171	128	165	145	159	118	140	128	131	107	97	102	104	84	99	81
2013	228	227	223	225	202	210	196	164	176	152	153	112	124	126	107	104	103	108	89	86
2014	127	99	111	113	97	127	115	94	111	117	119	96	85	82	75	60	51	51	43	40

Year	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120+
1991	22	16	9	5	2	1	2	0	0	1	1	1	0	0	0	0	0
1992	211	147	128	115	82	59	67	49	26	16	14	5	3	0	6	1	1
1993	172	142	120	70	78	41	40	29	20	14	7	3	4	2	1	0	1
1994	107	81	59	40	34	27	44	18	11	16	5	9	5	4	3	1	1
1995	218	203	113	90	82	66	112	40	47	26	11	25	9	3	0	1	2
1996	239	247	191	166	120	98	123	50	55	18	18	6	4	5	1	0	5
1997	210	196	145	137	120	99	77	51	37	28	22	26	14	4	6	2	9
1998	586	619	419	331	299	250	244	134	99	74	50	48	24	14	4	9	24
1999	260	223	188	144	124	88	86	49	42	33	24	12	2	6	2	5	13
2000	406	384	343	338	244	177	194	126	93	46	27	29	17	8	3	3	14
2001	306	294	254	224	218	167	193	81	86	54	33	42	16	14	12	16	21
2002	140	111	102	81	64	53	46	27	29	12	5	1	4	1	1	1	0
2003	153	108	98	84	73	49	48	25	29	13	6	4	6	0	5	2	2
2004	193	128	117	98	78	72	64	30	29	16	10	4	4	1	5	3	2
2005	136	126	100	92	70	46	46	26	24	17	9	5	6	3	1	4	9
2006	130	115	94	94	79	65	57	34	26	25	15	12	1	2	4	2	6
2007	263	209	196	171	145	113	86	50	36	28	19	11	10	3	3	2	0
2008	357	328	287	231	209	169	156	89	63	35	21	18	15	10	7	5	67
2009	280	273	261	251	222	151	130	95	74	40	30	24	9	3	0	2	2
2010	387	391	343	316	306	257	218	148	117	62	51	47	20	13	4	1	8
2011	72	58	55	42	41	27	24	26	12	10	3	6	4	3	1	2	4
2012	74	73	61	37	48	37	38	25	27	12	15	12	6	6	3	4	8
2013	65	56	45	51	39	27	18	16	4	6	4	0	2	0	0	1	0
2014	37	28	38	24	18	16	12	10	9	3	3	0	0	1	0	0	0

Table 2A.6— Total biomass and abundance (absolute and relative), with coefficients of variation, as estimated by AI shelf bottom trawl surveys, 1991-2014.

	Biomass (t)				Population (1000s)			
Year	Western	Central	Eastern	All	Western	Central	Eastern	All
1991	75,514	39,729	64,926	180,170	18,679	13,138	33,669	65,486
1994	23,797	51,538	78,081	153,416	4,491	12,425	37,284	54,201
1997	14,357	30,252	28,239	72,848	4,000	12,014	8,859	24,873
2000	44,261	36,456	47,117	127,834	13,899	10,661	18,819	43,379
2002	23,623	24,687	25,241	73,551	6,840	6,704	12,579	26,123
2004	9,637	20,731	51,851	82,219	3,220	5,755	13,040	22,016
2006	19,734	21,823	43,348	84,905	6,521	6,243	8,882	21,646
2010	21,341	11,207	23,277	55,826	5,323	5,169	9,577	20,068
2012	13,514	14,804	30,592	58,911	4,100	5,596	9,480	19,176
2014	18,088	8,488	47,032	73,608	5,090	2,705	12,994	20,789

	Biomass proportions				Population proportions			
Year	Western	Central	Eastern	All	Western	Central	Eastern	All
1991	0.419	0.221	0.360	1.000	0.285	0.201	0.514	1.000
1994	0.155	0.336	0.509	1.000	0.083	0.229	0.688	1.000
1997	0.197	0.415	0.388	1.000	0.161	0.483	0.356	1.000
2000	0.346	0.285	0.369	1.000	0.320	0.246	0.434	1.000
2002	0.321	0.336	0.343	1.000	0.262	0.257	0.482	1.000
2004	0.117	0.252	0.631	1.000	0.146	0.261	0.592	1.000
2006	0.232	0.257	0.511	1.000	0.301	0.288	0.410	1.000
2010	0.382	0.201	0.417	1.000	0.265	0.258	0.477	1.000
2012	0.229	0.251	0.519	1.000	0.214	0.292	0.494	1.000
2014	0.246	0.115	0.639	1.000	0.245	0.130	0.625	1.000

	Biomass coefficient of variation				Population coefficient of variation			
Year	Western	Central	Eastern	All	Western	Central	Eastern	All
1991	0.092	0.112	0.370	0.141	0.149	0.128	0.439	0.231
1994	0.292	0.390	0.301	0.206	0.245	0.202	0.444	0.310
1997	0.261	0.208	0.230	0.134	0.249	0.281	0.163	0.153
2000	0.423	0.270	0.222	0.185	0.544	0.305	0.291	0.228
2002	0.245	0.264	0.329	0.164	0.297	0.168	0.277	0.160
2004	0.169	0.207	0.304	0.200	0.166	0.173	0.241	0.152
2006	0.230	0.194	0.545	0.288	0.317	0.165	0.332	0.173
2010	0.409	0.257	0.223	0.189	0.338	0.173	0.216	0.144
2012	0.264	0.203	0.241	0.148	0.136	0.199	0.208	0.122
2014	0.236	0.276	0.275	0.187	0.153	0.216	0.220	0.145

Table 2A.7—Trawl survey size composition, by year and cm.

Year	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	11	1	0	1	3	2	4	9	26	81	114	147	216
1994	0	0	0	0	0	0	0	0	0	62	254	398	595	528	236	211	167	63	12	16	7	4	4	4	3	3	9	18	24
1997	0	0	0	0	0	0	0	0	0	0	0	0	3	12	5	19	35	87	81	111	102	82	42	19	2	12	7	15	27
2000	0	0	0	0	0	0	0	0	0	0	5	38	33	37	51	20	2	6	0	2	1	4	7	4	3	14	10	13	13
2002	0	0	0	0	0	1	0	0	0	0	6	6	12	16	25	9	13	12	13	5	19	9	9	21	22	28	22	37	45
2004	0	0	0	0	0	0	0	0	0	0	5	0	1	3	6	2	14	14	8	8	5	1	1	1	0	0	0	3	1
2006	0	0	0	0	0	0	0	0	0	5	11	13	42	71	69	57	22	21	18	16	23	13	3	2	1	2	0	1	6
2010	0	0	0	0	0	0	0	0	0	0	6	16	12	14	15	23	17	10	3	0	0	3	1	1	2	10	15	26	22
2012	0	0	0	0	0	0	0	0	0	0	1	5	19	24	50	44	50	31	24	8	9	5	1	0	3	2	2	11	7
2014	0	0	0	0	0	0	0	0	0	6	0	7	16	27	18	45	28	24	30	27	14	10	5	11	10	14	12	24	33

Year	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61
1991	249	293	322	299	242	224	150	139	85	92	54	80	52	64	72	73	68	54	76	63	58	68	60	98	94	82	115	116	110
1994	34	40	44	48	43	47	38	30	44	59	46	60	63	90	90	102	83	102	67	68	66	72	62	53	93	78	76	84	93
1997	32	36	51	61	60	60	58	45	32	31	34	34	25	35	47	52	59	82	70	73	79	96	103	106	127	150	125	172	165
2000	15	26	12	32	14	17	4	27	24	21	52	96	134	93	117	110	132	123	154	131	136	125	119	130	125	175	183	165	187
2002	99	92	103	134	142	119	93	85	63	52	62	56	59	62	77	81	87	63	62	76	68	94	69	97	72	74	61	64	41
2004	5	6	17	25	30	24	28	26	40	41	38	32	48	56	60	84	83	97	86	84	91	67	98	81	92	83	66	109	80
2006	1	5	3	8	13	11	20	12	19	14	9	21	27	38	39	44	62	63	69	75	57	61	49	49	56	29	45	37	35
2010	27	23	23	27	16	23	28	25	28	35	44	63	84	92	114	117	126	113	121	138	146	135	118	112	116	93	69	93	81
2012	32	23	18	32	55	38	18	41	29	31	20	26	30	34	31	32	42	44	64	58	49	70	56	66	62	86	90	88	86
2014	43	23	29	47	48	30	26	39	11	21	19	19	23	36	42	71	57	104	84	111	125	125	128	120	127	106	113	93	95

Year	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
1991	121	139	86	119	163	157	162	131	136	119	136	117	119	99	89	109	115	81	84	75	63	61	65	46	56	50	22	31	30
1994	95	123	118	124	102	125	114	128	108	118	124	111	133	77	79	86	78	50	71	47	72	62	52	72	46	59	44	54	93
1997	121	148	135	106	85	103	112	80	63	50	59	50	49	58	49	34	27	27	33	31	31	23	25	19	23	24	23	18	22
2000	156	151	154	148	168	115	112	97	84	86	77	86	70	82	88	59	46	49	42	28	27	36	19	27	18	26	22	15	12
2002	39	40	44	33	33	34	31	34	34	33	36	34	42	45	47	42	34	39	49	49	50	55	39	44	38	38	32	15	30
2004	60	89	102	90	89	101	92	83	84	83	88	61	82	68	72	65	62	48	38	55	52	40	35	40	37	38	11	18	21
2006	51	45	35	39	54	29	42	39	44	30	47	47	39	35	41	34	38	42	47	46	46	30	54	32	28	41	37	39	47
2010	65	45	54	56	56	69	78	58	47	43	35	35	31	33	33	24	23	13	9	23	19	19	12	4	16	12	10	15	9
2012	79	104	157	105	97	85	95	80	63	47	56	50	67	59	43	40	39	49	37	36	32	19	20	11	14	13	15	7	10
2014	103	76	99	117	81	84	77	87	113	84	87	86	62	71	74	85	46	59	55	42	46	42	39	44	37	38	39	40	56

Year	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119+
1991	43	30	20	11	14	6	12	4	12	4	1	5	0	3	3	1	6	0	1	0	0	0	0	0	1	0	0	0	0
1994	60	66	48	38	42	50	27	18	27	9	10	8	8	7	5	5	2	0	2	0	0	0	2	2	0	0	0	0	0
1997	31	26	9	25	8	20	13	16	20	9	10	22	7	3	10	8	1	3	3	2	0	0	0	0	0	0	0	0	0
2000	17	13	6	12	10	8	6	10	8	5	2	4	5	3	4	6	1	11	2	1	2	0	0	0	1	0	0	0	0
2002	29	10	21	16	12	9	7	8	4	5	3	6	13	1	6	2	2	2	0	1	0	3	0	0	1	0	0	0	0
2004	15	21	17	14	15	11	8	9	15	7	2	8	8	5	6	3	2	3	1	0	1	0	0	0	0	0	0	0	0
2006	28	17	17	13	28	19	15	10	14	13	5	9	4	15	3	3	6	8	3	0	1	3	2	1	0	1	0	0	0
2010	11	9	8	10	6	7	9	5	7	10	15	5	6	3	8	3	6	6	4	3	5	1	1	0	1	0	0	0	0
2012	8	7	9	5	16	9	5	4	5	6	6	5	4	7	1	1	1	1	1	0	1	0	0	0	0	1	0	0	0
2014	32	29	37	22	32	29	27	22	14	10	4	12	5	10	4	5	2	3	2	1	0	2	0	0	0	0	0	0	0

Table 2A.8a—Selected constants used in the SS control files for Models 2 and 3.

Parameter	Model 2	Model 3
Natural mortality rate	3.40E-01	3.40E-01
Weight-length α (proportionality)	5.68E-06	5.68E-06
Weight-length β (exponent)	3.18E+00	3.18E+00
Age at 50% maturity	4.88E+00	4.88E+00
Maturity slope	-9.65E-01	-9.65E-01
Std. dev. of ageing error at age 1	9.30E-02	9.30E-02
Std. dev. of ageing error at age 12	1.86E+00	1.86E+00
Stock-recruitment "steepness"	1.00E+00	1.00E+00

Table 2A.8b—Growth, ageing bias, recruitment (except annual *devs*), catchability, initial fishing mortality, and initial age composition parameters, as estimated internally by Models 2 and 3.

	Model 2		Model 3	
Parameter	Estimate	St. dev.	Estimate	St. dev.
Length at age 1 (cm)	1.80E+01	1.93E-01	1.80E+01	1.92E-01
Asymptotic length (cm)	1.10E+02	1.91E+00	1.07E+02	1.28E+00
Brody growth coefficient	2.17E-01	6.94E-03	2.26E-01	5.52E-03
SD of length at age 1 (cm)	3.16E+00	1.37E-01	3.16E+00	1.37E-01
SD of length at age 20 (cm)	8.11E+00	4.03E-01	8.02E+00	3.76E-01
Ageing bias at age 1 (years)	4.81E-01	3.14E-02	4.83E-01	3.04E-02
Ageing bias at age 20 (years)	1.14E+00	4.41E-01	9.46E-01	4.68E-01
ln(mean recruitment)	1.10E+01	8.13E-02	1.10E+01	7.57E-02
σ(recruitment)	4.94E-01	6.73E-02	5.47E-01	7.09E-02
Initial fishing mortality rate	4.24E-02	1.06E-02	4.74E-02	1.15E-02
ln(catchability)	-4.35E-01	8.67E-02	-5.69E-01	7.79E-02
Initial age 1 ln(abundance) dev	2.83E-01	1.74E-01	4.82E-01	1.72E-01
Initial age 2 ln(abundance) dev	-7.35E-01	3.91E-01	-6.76E-01	4.35E-01
Initial age 3 ln(abundance) dev	1.03E+00	1.48E-01	1.12E+00	1.50E-01
Initial age 4 ln(abundance) dev	-1.74E-01	1.84E-01	-1.32E-01	1.91E-01
Initial age 5 ln(abundance) dev	4.90E-01	1.69E-01	7.66E-01	1.76E-01
Initial age 6 ln(abundance) dev	1.13E+00	1.98E-01	1.09E+00	2.37E-01
Initial age 7 ln(abundance) dev	8.69E-01	3.27E-01	1.24E+00	2.71E-01
Initial age 8 ln(abundance) dev	7.77E-03	4.36E-01	2.93E-02	5.28E-01
Initial age 9 ln(abundance) dev	-4.99E-01	4.05E-01	-3.41E-01	4.64E-01
Initial age 10 ln(abundance) dev	-6.91E-01	3.93E-01	-5.64E-01	4.43E-01

Table 2A.8c—Annual log-scale recruitment *dev*s estimated by Models 2 and 3. Color scale extends from red (low) to green (high) in each **column**.

	Model 2		Model 3	
Year	Estimate	St. dev.	Estimate	St. dev.
1991	2.51E-01	1.40E-01	2.73E-01	1.40E-01
1992	-2.51E-01	2.21E-01	-3.18E-01	2.48E-01
1993	7.78E-01	1.24E-01	1.02E+00	1.18E-01
1994	-1.32E-01	1.51E-01	-1.44E-01	1.65E-01
1995	4.26E-01	1.58E-01	6.06E-01	1.72E-01
1996	8.85E-01	1.19E-01	1.07E+00	1.16E-01
1997	6.45E-01	1.12E-01	6.74E-01	1.16E-01
1998	6.20E-02	1.81E-01	1.02E-01	1.85E-01
1999	7.93E-01	1.17E-01	7.86E-01	1.20E-01
2000	6.62E-02	1.52E-01	-9.24E-02	1.37E-01
2001	-1.24E-01	1.29E-01	-1.28E-01	1.29E-01
2002	-5.25E-01	1.53E-01	-5.04E-01	1.61E-01
2003	-2.04E-01	1.33E-01	-2.12E-01	1.35E-01
2004	-5.33E-01	1.76E-01	-6.15E-01	1.80E-01
2005	-1.57E-01	1.51E-01	-1.69E-01	1.61E-01
2006	-1.87E-01	1.28E-01	-1.20E-01	1.27E-01
2007	2.45E-01	1.08E-01	1.27E-01	1.03E-01
2008	-1.22E-01	1.36E-01	1.01E-02	1.33E-01
2009	-7.19E-01	1.85E-01	-8.68E-01	1.88E-01
2010	-1.60E-01	1.74E-01	-2.87E-02	1.77E-01
2011	-4.91E-01	1.94E-01	-5.68E-01	1.89E-01
2012	-3.32E-01	3.51E-01	-4.79E-01	3.70E-01
2013	-2.13E-01	3.68E-01	-4.27E-01	3.77E-01

Table 2A.8d—Base selectivity parameters as estimated by Models 2 and 3.

		Model 2		Model 3	
Fleet	Age	Estimate	St. dev.	Estimate	St. dev.
Fishery	1	3.29E+00	3.42E-01	3.29E+00	3.42E-01
Fishery	2	3.41E+00	3.18E-01	3.41E+00	3.19E-01
Fishery	3	3.22E+00	1.86E-01	3.22E+00	1.87E-01
Fishery	4	1.23E+00	1.80E-01	1.22E+00	1.80E-01
Fishery	5	3.34E-01	1.13E-01	2.78E-01	1.20E-01
Fishery	6	1.49E-01	2.84E-01	1.64E-01	2.84E-01
Fishery	7	-1.01E-01	1.97E-01	-9.93E-02	1.94E-01
Fishery	8	6.94E-02	2.53E-01	-9.21E-03	2.48E-01
Fishery	9	1.71E-01	2.70E-01	8.16E-02	2.70E-01
Fishery	10	2.72E-01	2.90E-01	3.50E-01	2.85E-01
Fishery	11	4.68E-02	3.28E-01	2.15E-01	2.91E-01
Fishery	12	-3.03E-01	3.52E-01	-4.79E-02	3.18E-01
Fishery	13	-4.78E-01	3.18E-01	-2.58E-01	3.16E-01
Fishery	14	-3.56E-01	3.18E-01	-1.86E-01	3.23E-01
Fishery	15	-2.49E-01	3.23E-01	-1.43E-01	3.28E-01
Fishery	16	-2.09E-01	3.24E-01	-1.52E-01	3.27E-01
Fishery	17	-1.60E-01	3.27E-01	-1.37E-01	3.27E-01
Fishery	18	-1.19E-01	3.29E-01	-1.06E-01	3.29E-01
Fishery	19	-8.45E-02	3.32E-01	-7.21E-02	3.32E-01
Fishery	20	-6.52E-02	3.34E-01	-5.70E-02	3.34E-01
Survey	1	5.29E+00	3.19E-01	5.29E+00	7.80E-02
Survey	2	9.46E-01	2.67E-01	8.58E-01	7.71E-02
Survey	3	6.55E-01	2.10E-01	1.01E-01	7.50E-02
Survey	4	4.47E-01	1.06E-01	1.43E-01	6.12E-02
Survey	5	-4.33E-01	1.26E-01	-1.40E-01	6.10E-02
Survey	6	-2.68E-01	2.18E-01	-6.60E-02	7.15E-02
Survey	7	1.23E-02	3.11E-01	-1.75E-03	7.79E-02
Survey	8	-3.14E-01	2.36E-01	-8.03E-03	7.68E-02
Survey	9	-3.03E-01	2.69E-01	-2.38E-02	7.64E-02
Survey	10	-1.79E-01	2.89E-01	-2.98E-02	7.64E-02
Survey	11	-1.92E-01	2.98E-01	-2.82E-02	7.68E-02
Survey	12	-2.00E-01	3.03E-01	-2.45E-02	7.71E-02
Survey	13	-1.65E-01	3.04E-01	-2.13E-02	7.73E-02
Survey	14	-1.26E-01	3.07E-01	-1.65E-02	7.75E-02
Survey	15	-1.03E-01	3.09E-01	-1.30E-02	7.76E-02
Survey	16	-7.81E-02	3.10E-01	-9.66E-03	7.77E-02
Survey	17	-5.32E-02	3.13E-01	-7.09E-03	7.78E-02
Survey	18	-3.69E-02	3.14E-01	-4.86E-03	7.78E-02
Survey	19	-2.59E-02	3.16E-01	-3.54E-03	7.79E-02
Survey	20	-1.86E-02	3.16E-01	-2.51E-03	7.79E-02

Table 2A.8e—Fishery selectivity *dev*s as estimated by Models 2 and 3.

			Model 2		Model 3			Model 2		Model 3	
Fleet	Year	Age	Estimate	St. dev.	Estimate	St. dev.	Age	Estimate	St. dev.	Estimate	St. dev.
Fishery	1991	4	-4.21E-04	5.37E-02	-5.83E-03	5.54E-02	6	5.37E-02	4.05E-02	5.96E-02	4.08E-02
Fishery	1992	4	7.77E-02	3.19E-02	7.05E-02	3.19E-02	6	-4.16E-02	3.50E-02	-3.54E-02	3.48E-02
Fishery	1993	4	-7.31E-02	3.59E-02	-6.76E-02	3.66E-02	6	3.43E-02	3.81E-02	3.60E-02	3.85E-02
Fishery	1994	4	-9.90E-03	3.90E-02	-1.44E-02	3.95E-02	6	-2.47E-02	3.77E-02	-1.89E-02	3.78E-02
Fishery	1995	4	-8.12E-03	4.65E-02	-1.76E-02	4.68E-02	6	1.64E-02	3.87E-02	1.91E-02	3.87E-02
Fishery	1996	4	7.04E-02	3.51E-02	9.45E-02	3.55E-02	6	-6.62E-02	3.69E-02	-7.67E-02	3.75E-02
Fishery	1997	4	-2.94E-02	4.99E-02	-3.84E-02	5.15E-02	6	5.94E-02	3.91E-02	6.91E-02	3.92E-02
Fishery	1998	4	-1.50E-02	2.93E-02	-1.14E-02	3.01E-02	6	1.16E-03	3.33E-02	5.64E-03	3.32E-02
Fishery	1999	4	3.30E-02	3.11E-02	3.36E-02	3.21E-02	6	1.98E-02	3.52E-02	2.67E-02	3.60E-02
Fishery	2000	4	-1.35E-02	2.75E-02	-2.70E-02	2.76E-02	6	8.15E-02	3.40E-02	8.64E-02	3.42E-02
Fishery	2001	4	-6.62E-02	2.89E-02	-7.42E-02	2.95E-02	6	1.15E-02	3.28E-02	6.25E-03	3.27E-02
Fishery	2002	4	6.27E-03	3.61E-02	-2.13E-03	3.66E-02	6	6.81E-02	3.81E-02	6.22E-02	3.89E-02
Fishery	2003	4	-1.17E-01	3.67E-02	-1.28E-01	3.65E-02	6	1.20E-01	3.76E-02	1.08E-01	3.78E-02
Fishery	2004	4	-1.02E-01	3.10E-02	-9.50E-02	3.10E-02	6	2.94E-02	3.55E-02	1.27E-02	3.53E-02
Fishery	2005	4	-1.93E-02	4.07E-02	-6.04E-03	4.14E-02	6	-5.30E-03	3.63E-02	-1.34E-02	3.67E-02
Fishery	2006	4	2.74E-02	3.72E-02	3.24E-02	3.74E-02	6	-5.30E-02	3.57E-02	-5.31E-02	3.58E-02
Fishery	2007	4	3.37E-02	4.02E-02	2.96E-02	4.06E-02	6	-7.79E-03	3.53E-02	-5.31E-03	3.53E-02
Fishery	2008	4	-1.75E-02	3.32E-02	-1.27E-02	3.37E-02	6	1.79E-02	3.54E-02	1.81E-02	3.53E-02
Fishery	2009	4	3.42E-02	3.53E-02	4.45E-02	3.58E-02	6	1.60E-02	3.62E-02	1.99E-02	3.66E-02
Fishery	2010	4	-1.43E-02	2.82E-02	-2.43E-02	2.82E-02	6	5.92E-02	3.63E-02	7.29E-02	3.64E-02
Fishery	2011	4	2.03E-02	5.16E-02	3.29E-02	5.07E-02	6	8.84E-02	4.01E-02	9.28E-02	4.04E-02
Fishery	2012	4	7.67E-02	5.70E-02	7.09E-02	5.86E-02	6	4.31E-02	3.91E-02	6.10E-02	3.97E-02
Fishery	2013	4	9.38E-03	5.29E-02	1.48E-02	5.26E-02	6	8.77E-02	4.56E-02	1.06E-01	4.66E-02
Fishery	2014	4	-7.95E-03	6.73E-02	-1.62E-02	6.94E-02	6	8.47E-02	5.12E-02	1.04E-01	5.19E-02

Table 2A.8f—Survey selectivity *dev*s as estimated by Models 2 and 3.

			Model 2		Model 3	
Fleet	Year	Age	Estimate	St. dev.	Estimate	St. dev.
Survey	1991	2	3.43E-01	8.46E-02	3.61E-01	8.13E-02
Survey	1994	2	-1.31E-01	4.25E-02	-8.79E-02	3.58E-02
Survey	1997	2	-2.65E-03	4.09E-02	1.06E-02	3.30E-02
Survey	2000	2	2.99E-02	5.05E-02	4.11E-02	4.40E-02
Survey	2002	2	1.37E-01	5.00E-02	1.77E-01	4.15E-02
Survey	2004	2	8.26E-02	6.35E-02	9.58E-02	5.87E-02
Survey	2006	2	-1.37E-01	5.22E-02	-1.11E-01	4.56E-02
Survey	2010	2	1.17E-02	5.24E-02	-4.94E-03	4.59E-02
Survey	2012	2	-1.04E-01	4.54E-02	-1.11E-01	3.72E-02
Survey	2014	2	n/a	n/a	n/a	n/a
Survey	1991	3	-5.39E-02	2.71E-02	6.40E-03	2.07E-02
Survey	1994	3	3.07E-03	3.55E-02	4.83E-02	3.32E-02
Survey	1997	3	4.87E-02	3.03E-02	1.23E-01	2.60E-02
Survey	2000	3	9.76E-02	3.66E-02	1.52E-01	3.31E-02
Survey	2002	3	-1.22E-01	2.98E-02	-9.23E-02	1.92E-02
Survey	2004	3	7.15E-02	3.74E-02	1.35E-01	3.35E-02
Survey	2006	3	1.08E-01	4.23E-02	1.55E-01	3.88E-02
Survey	2010	3	7.94E-02	3.02E-02	1.61E-01	2.40E-02
Survey	2012	3	8.85E-02	3.33E-02	1.65E-01	2.82E-02
Survey	2014	3	6.73E-02	4.15E-02	1.17E-01	4.06E-02
Survey	1991	7	4.85E-02	5.40E-02	-4.99E-02	4.36E-02
Survey	1994	7	7.39E-02	4.34E-02	8.09E-04	2.46E-02
Survey	1997	7	-7.70E-03	4.72E-02	-8.91E-02	2.97E-02
Survey	2000	7	-5.34E-03	4.94E-02	-8.56E-02	3.50E-02
Survey	2002	7	1.37E-01	4.08E-02	1.22E-02	3.54E-02
Survey	2004	7	-2.13E-02	4.81E-02	-1.10E-01	3.34E-02
Survey	2006	7	3.76E-02	4.48E-02	-2.86E-02	2.69E-02
Survey	2010	7	-2.36E-02	4.85E-02	-9.54E-02	3.22E-02
Survey	2012	7	-5.98E-02	5.34E-02	-1.26E-01	4.10E-02
Survey	2014	7	5.78E-02	4.64E-02	9.52E-03	3.00E-02

Table 2A.9— Annual fishing mortality rates as estimated by Models 2 and 3. "F averaged over 8-18" represents an average rate across the specified age range; "Apical F" represents the fishing mortality rate at the length of peak selectivity. Color scale extends from red (low) to green (high) in each **column**.

	Model 2				Model 3			
	F averaged over 8-18		Apical F		F averaged over 8-18		Apical F	
Year	Estimate	St. dev.	Estimate	St. dev.	Estimate	St. dev.	Estimate	St. dev.
1991	3.781E-02	6.937E-03	5.620E-02	1.541E-02	3.744E-02	6.964E-03	5.436E-02	1.600E-02
1992	1.214E-01	2.050E-02	1.907E-01	5.417E-02	1.216E-01	2.156E-02	1.900E-01	5.715E-02
1993	1.149E-01	2.112E-02	1.815E-01	5.338E-02	1.038E-01	1.794E-02	1.797E-01	5.646E-02
1994	6.267E-02	1.160E-02	9.476E-02	3.013E-02	5.794E-02	1.028E-02	9.884E-02	3.207E-02
1995	5.820E-02	9.693E-03	7.996E-02	2.342E-02	5.304E-02	8.234E-03	8.241E-02	2.396E-02
1996	1.073E-01	1.851E-02	1.432E-01	2.913E-02	9.941E-02	1.632E-02	1.457E-01	3.034E-02
1997	1.061E-01	1.670E-02	1.482E-01	3.817E-02	1.008E-01	1.463E-02	1.484E-01	3.965E-02
1998	1.395E-01	2.260E-02	1.992E-01	5.594E-02	1.315E-01	1.931E-02	1.995E-01	5.693E-02
1999	1.251E-01	2.001E-02	1.750E-01	4.821E-02	1.168E-01	1.699E-02	1.715E-01	4.848E-02
2000	2.132E-01	3.647E-02	2.967E-01	7.450E-02	2.041E-01	3.279E-02	2.850E-01	7.512E-02
2001	1.356E-01	2.258E-02	2.046E-01	5.577E-02	1.223E-01	1.821E-02	1.920E-01	5.536E-02
2002	1.434E-01	2.427E-02	2.135E-01	5.862E-02	1.297E-01	1.935E-02	2.039E-01	5.848E-02
2003	1.598E-01	2.690E-02	2.345E-01	6.310E-02	1.469E-01	2.190E-02	2.290E-01	6.395E-02
2004	1.238E-01	2.028E-02	1.842E-01	4.968E-02	1.140E-01	1.581E-02	1.852E-01	4.975E-02
2005	9.600E-02	1.357E-02	1.386E-01	3.912E-02	9.436E-02	1.118E-02	1.506E-01	4.060E-02
2006	1.094E-01	1.538E-02	1.484E-01	4.017E-02	1.125E-01	1.361E-02	1.663E-01	4.145E-02
2007	1.906E-01	2.369E-02	2.683E-01	7.009E-02	2.016E-01	2.103E-02	3.038E-01	7.200E-02
2008	2.224E-01	3.035E-02	3.095E-01	8.450E-02	2.420E-01	2.839E-02	3.587E-01	9.023E-02
2009	2.447E-01	3.854E-02	3.338E-01	9.320E-02	2.774E-01	3.803E-02	3.975E-01	1.037E-01
2010	3.164E-01	5.978E-02	4.391E-01	1.188E-01	3.826E-01	6.492E-02	5.417E-01	1.425E-01
2011	1.223E-01	2.516E-02	1.820E-01	5.336E-02	1.488E-01	2.851E-02	2.230E-01	6.608E-02
2012	1.701E-01	3.651E-02	2.586E-01	7.863E-02	2.129E-01	4.218E-02	3.276E-01	9.737E-02
2013	1.296E-01	2.617E-02	1.984E-01	6.026E-02	1.577E-01	3.060E-02	2.547E-01	7.503E-02
2014	1.122E-01	2.222E-02	1.682E-01	5.087E-02	1.262E-01	2.389E-02	2.086E-01	6.048E-02

Table 2A.10—Summary of key management reference points. Values for Models 2 and 3 come from the standard projection algorithm (except the last seven rows, which come from SS). All biomass figures are in t. Color scale extends from red (low) to green (high) in each **row**.

Quantity	Model 1	Model 2	Model 3
B100%	n/a	127,000	121,000
B40%	n/a	50,800	48,400
B35%	n/a	44,500	42,400
B(2015)	68,900	52,800	46,600
B(2016)	68,900	45,700	40,900
B(2015)/B100%	n/a	0.42	0.38
B(2016)/B100%	n/a	0.36	0.34
F40%	n/a	0.54	0.63
F35%	n/a	0.66	0.79
maxFABC(2015)	0.26	0.54	0.61
maxFABC(2016)	0.26	0.48	0.53
maxABC(2015)	17,600	33,400	29,300
maxABC(2016)	17,600	26,300	23,500
FOFL(2015)	0.34	0.66	0.76
FOFL(2016)	0.34	0.59	0.66
OFL(2015)	23,400	40,000	34,900
OFL(2016)	23,400	32,600	29,200
Pr(maxABC(2015)>truOFL(2015))	n/a	0.13	0.12
Pr(maxABC(2016)>truOFL(2016))	n/a	0.38	0.38
Pr(B(2015)<B20%)	n/a	0.00	0.00
Pr(B(2016)<B20%)	n/a	0.00	0.00
Pr(B(2017)<B20%)	n/a	0.00	0.00
Pr(B(2018)<B20%)	n/a	0.00	0.00
Pr(B(2019)<B20%)	n/a	0.00	0.00

Legend:
B100% = equilibrium unfished spawning biomass
B40% = 40% of B100% (the inflection point of the harvest control rules in Tier 3)
B35% = 35% of B100% (the BMSY proxy for Tier 3)
B(year) = projected survey biomass (Model 1) or spawning biomass (Models 2 and 3) for year
B(year)/B100% = ratio of spawning biomass to B100%
F40% = fishing mortality that reduces equilibrium spawning per recruit to 40% of unfished
F35% = fishing mortality that reduces equilibrium spawning per recruit to 35% of unfished
maxFABC(year) = maximum permissible ABC fishing mortality rate under Tier 3
maxABC(year) = maximum permissible ABC under Tier 3
FOFL(year) = OFL fishing mortality rate under Tier 3
OFL(year) = OFL under Tier 3
Pr(maxABC(year)>truOFL(year)) = probability that maxABC is greater than the "true" OFL
Pr(B(year)<B20%) = probability that spawning biomass is less than 20% of unfished

Table 2A.11a—Fishery selectivity as estimated by Model 2.

	Age																				
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1991	0.000	0.000	0.003	0.067	0.228	0.319	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
1992	0.000	0.000	0.003	0.081	0.592	0.827	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
1993	0.000	0.000	0.007	0.167	0.277	0.387	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
1994	0.000	0.000	0.006	0.160	0.500	0.698	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
1995	0.000	0.000	0.004	0.105	0.331	0.463	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
1996	0.000	0.000	0.004	0.105	0.716	1.000	0.599	0.542	0.581	0.689	0.903	0.947	0.699	0.434	0.304	0.237	0.192	0.164	0.145	0.134	0.125
1997	0.000	0.000	0.003	0.084	0.216	0.302	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
1998	0.000	0.000	0.005	0.130	0.386	0.539	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
1999	0.000	0.000	0.003	0.067	0.320	0.447	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2000	0.000	0.000	0.002	0.058	0.173	0.242	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2001	0.000	0.000	0.008	0.195	0.348	0.486	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2002	0.000	0.000	0.002	0.054	0.198	0.276	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2003	0.000	0.000	0.004	0.110	0.118	0.165	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2004	0.000	0.000	0.009	0.233	0.291	0.407	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2005	0.000	0.000	0.006	0.145	0.412	0.575	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2006	0.000	0.000	0.006	0.148	0.663	0.926	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2007	0.000	0.000	0.004	0.088	0.422	0.589	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2008	0.000	0.000	0.004	0.113	0.326	0.456	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2009	0.000	0.000	0.003	0.069	0.333	0.465	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2010	0.000	0.000	0.003	0.073	0.216	0.302	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2011	0.000	0.000	0.002	0.039	0.162	0.226	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2012	0.000	0.000	0.001	0.035	0.254	0.355	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2013	0.000	0.000	0.002	0.043	0.163	0.228	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132
2014	0.000	0.000	0.002	0.053	0.168	0.235	0.633	0.572	0.613	0.727	0.954	1.000	0.739	0.458	0.321	0.250	0.203	0.173	0.154	0.141	0.132

Table 2A.11b—Fishery selectivity as estimated by Model 3.

	Age																				
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1991	0.000	0.000	0.003	0.065	0.207	0.274	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
1992	0.000	0.000	0.003	0.080	0.535	0.707	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
1993	0.000	0.000	0.006	0.152	0.262	0.346	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
1994	0.000	0.000	0.006	0.155	0.454	0.599	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
1995	0.000	0.000	0.004	0.109	0.310	0.410	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
1996	0.000	0.000	0.004	0.090	0.757	1.000	0.547	0.495	0.491	0.533	0.756	0.937	0.893	0.690	0.573	0.496	0.426	0.372	0.334	0.311	0.294
1997	0.000	0.000	0.003	0.082	0.189	0.249	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
1998	0.000	0.000	0.005	0.118	0.355	0.469	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
1999	0.000	0.000	0.002	0.061	0.288	0.380	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2000	0.000	0.000	0.002	0.062	0.159	0.210	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2001	0.000	0.000	0.009	0.218	0.353	0.466	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2002	0.000	0.000	0.002	0.061	0.202	0.267	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2003	0.000	0.000	0.005	0.136	0.128	0.169	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2004	0.000	0.000	0.010	0.252	0.331	0.437	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2005	0.000	0.000	0.005	0.135	0.430	0.567	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2006	0.000	0.000	0.005	0.138	0.639	0.843	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2007	0.000	0.000	0.004	0.088	0.396	0.523	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2008	0.000	0.000	0.004	0.105	0.313	0.414	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2009	0.000	0.000	0.002	0.059	0.308	0.406	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2010	0.000	0.000	0.003	0.068	0.182	0.240	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2011	0.000	0.000	0.001	0.032	0.149	0.197	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2012	0.000	0.000	0.001	0.030	0.204	0.270	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2013	0.000	0.000	0.001	0.034	0.131	0.173	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314
2014	0.000	0.000	0.002	0.047	0.134	0.177	0.584	0.529	0.524	0.569	0.807	1.000	0.953	0.736	0.611	0.530	0.455	0.397	0.357	0.332	0.314

Table 2A.12—Survey selectivity as estimated by Models 2 and 3.

Model 2

	Age																				
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1991	0.000	0.009	0.569	0.639	1.000	0.649	0.496	0.816	0.596	0.440	0.368	0.304	0.249	0.211	0.186	0.168	0.155	0.147	0.142	0.138	0.136
1994	0.000	0.440	0.306	0.608	0.951	0.617	0.472	1.000	0.731	0.540	0.451	0.372	0.305	0.259	0.228	0.206	0.190	0.180	0.174	0.170	0.166
1997	0.000	0.082	0.205	0.639	1.000	0.649	0.496	0.465	0.340	0.251	0.210	0.173	0.142	0.120	0.106	0.096	0.089	0.084	0.081	0.079	0.077
2000	0.000	0.037	0.127	0.639	1.000	0.649	0.496	0.476	0.348	0.257	0.215	0.177	0.145	0.123	0.109	0.098	0.091	0.086	0.083	0.081	0.079
2002	0.000	0.059	0.577	0.328	0.513	0.333	0.254	1.000	0.731	0.540	0.451	0.372	0.305	0.259	0.228	0.206	0.190	0.180	0.174	0.170	0.166
2004	0.000	0.028	0.164	0.639	1.000	0.649	0.496	0.406	0.297	0.219	0.183	0.151	0.124	0.105	0.093	0.084	0.077	0.073	0.071	0.069	0.068
2006	0.000	0.175	0.115	0.639	1.000	0.649	0.496	0.732	0.535	0.395	0.330	0.272	0.223	0.189	0.167	0.151	0.139	0.132	0.127	0.124	0.122
2010	0.000	0.052	0.151	0.639	1.000	0.649	0.496	0.397	0.290	0.214	0.179	0.148	0.121	0.103	0.091	0.082	0.076	0.072	0.069	0.067	0.066
2012	0.000	0.152	0.139	0.639	1.000	0.649	0.496	0.276	0.202	0.149	0.125	0.103	0.084	0.071	0.063	0.057	0.053	0.050	0.048	0.047	0.046
2014	0.000	0.066	0.171	0.639	1.000	0.649	0.496	0.895	0.654	0.483	0.404	0.333	0.273	0.231	0.204	0.184	0.170	0.162	0.156	0.152	0.149

Model 3

	Age																				
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1991	0.000	0.011	0.735	0.866	1.000	0.870	0.814	0.494	0.490	0.478	0.464	0.451	0.440	0.431	0.424	0.419	0.415	0.412	0.410	0.408	0.407
1994	0.000	0.492	0.483	0.866	1.000	0.870	0.814	0.819	0.813	0.794	0.770	0.749	0.731	0.715	0.704	0.695	0.688	0.683	0.680	0.677	0.676
1997	0.000	0.088	0.230	0.866	1.000	0.870	0.814	0.334	0.332	0.324	0.314	0.306	0.298	0.292	0.287	0.283	0.281	0.279	0.277	0.276	0.276
2000	0.000	0.049	0.174	0.866	1.000	0.870	0.814	0.346	0.343	0.335	0.325	0.316	0.309	0.302	0.297	0.293	0.291	0.289	0.287	0.286	0.285
2002	0.000	0.077	1.000	0.440	0.508	0.442	0.414	0.466	0.463	0.452	0.439	0.426	0.416	0.407	0.401	0.395	0.392	0.389	0.387	0.386	0.385
2004	0.000	0.034	0.206	0.866	1.000	0.870	0.814	0.272	0.270	0.263	0.256	0.249	0.242	0.237	0.233	0.230	0.228	0.227	0.226	0.225	0.224
2006	0.000	0.217	0.169	0.866	1.000	0.870	0.814	0.611	0.606	0.592	0.574	0.558	0.545	0.533	0.525	0.518	0.513	0.509	0.507	0.505	0.504
2010	0.000	0.071	0.159	0.866	1.000	0.870	0.814	0.314	0.311	0.304	0.295	0.287	0.280	0.274	0.270	0.266	0.264	0.262	0.260	0.260	0.259
2012	0.000	0.196	0.153	0.866	1.000	0.870	0.814	0.232	0.230	0.224	0.218	0.212	0.207	0.202	0.199	0.196	0.195	0.193	0.192	0.192	0.191
2014	0.000	0.104	0.245	0.866	1.000	0.870	0.814	0.894	0.887	0.866	0.840	0.817	0.797	0.780	0.768	0.758	0.751	0.745	0.742	0.739	0.737

Table 2A.13—Schedules of population length (cm) and weight (kg) by age as estimated by Models 2 and 3. Lengths and weights correspond to mid-point of the year.

	Population				Fishery				Survey			
	Length		Weight		Length		Weight		Length		Weight	
Age	Model 2	Model 3	Model 2	Model 3	Model 2	Model 3	Model 2	Model 3	Model 2	Model 3	Model 2	Model 3
0	6.34	6.34	0.00	0.00	6.40	6.39	0.00	0.00	6.40	6.39	0.00	0.00
1	18.02	18.01	0.06	0.06	18.02	18.01	0.06	0.06	18.02	18.01	0.06	0.06
2	35.97	36.09	0.53	0.53	35.97	36.09	0.53	0.53	35.97	36.09	0.53	0.53
3	50.42	50.52	1.52	1.53	50.42	50.52	1.52	1.53	50.42	50.52	1.52	1.53
4	62.06	62.02	2.93	2.93	62.06	62.02	2.93	2.93	62.06	62.02	2.93	2.93
5	71.43	71.20	4.58	4.53	71.43	71.20	4.58	4.53	71.43	71.20	4.58	4.53
6	78.97	78.53	6.29	6.18	78.97	78.53	6.29	6.18	78.97	78.53	6.29	6.18
7	85.04	84.37	7.95	7.75	85.04	84.37	7.95	7.75	85.04	84.37	7.95	7.75
8	89.92	89.02	9.48	9.19	89.92	89.02	9.48	9.19	89.92	89.02	9.48	9.19
9	93.85	92.74	10.86	10.46	93.85	92.74	10.86	10.46	93.85	92.74	10.86	10.46
10	97.02	95.71	12.06	11.56	97.02	95.71	12.06	11.56	97.02	95.71	12.06	11.56
11	99.57	98.07	13.10	12.49	99.57	98.07	13.10	12.49	99.57	98.07	13.10	12.49
12	101.62	99.96	13.97	13.26	101.62	99.96	13.97	13.26	101.62	99.96	13.97	13.26
13	103.27	101.46	14.70	13.91	103.27	101.46	14.70	13.91	103.27	101.46	14.70	13.91
14	104.60	102.66	15.31	14.43	104.60	102.66	15.31	14.43	104.60	102.66	15.31	14.43
15	105.67	103.62	15.81	14.87	105.67	103.62	15.81	14.87	105.67	103.62	15.81	14.87
16	106.53	104.38	16.23	15.22	106.53	104.38	16.23	15.22	106.53	104.38	16.23	15.22
17	107.23	104.99	16.56	15.50	107.23	104.99	16.56	15.50	107.23	104.99	16.56	15.50
18	107.79	105.48	16.84	15.73	107.79	105.48	16.84	15.73	107.79	105.48	16.84	15.73
19	108.24	105.87	17.06	15.91	108.24	105.87	17.06	15.91	108.24	105.87	17.06	15.91
20	108.91	106.43	17.41	16.19	108.91	106.43	17.41	16.19	108.91	106.43	17.41	16.19

Table 2A.14a—Time series of age 0+ biomass, age 3+ biomass, female spawning biomass (t), and standard deviation of spawning biomass ("SB SD") as estimated by Models 2 and 3. Spawning biomass for 2015 represents output from the standard projection model.

	Model 2				Model 3			
Year	Age 0+	Age 3+	Spawn.	SB SD	Age 0+	Age 3+	Spawn.	SB SD
1991	410,220	391,878	132,484	16,598	437,490	418,181	140,115	17,078
1992	436,601	427,408	148,960	18,414	465,346	454,854	158,363	18,890
1993	420,158	411,589	146,101	18,928	448,803	440,501	156,045	19,338
1994	401,801	395,323	143,200	18,787	427,931	421,643	153,071	18,964
1995	389,415	375,267	143,175	18,249	412,706	395,717	152,402	18,117
1996	383,077	376,461	140,819	17,310	405,967	399,511	148,945	16,928
1997	361,938	350,604	130,739	16,160	385,137	372,210	137,938	15,631
1998	355,401	338,950	124,136	15,135	380,786	362,107	131,384	14,573
1999	352,256	339,628	116,927	14,365	380,902	368,513	124,999	13,843
2000	360,366	352,091	115,887	13,945	389,621	381,511	125,116	13,449
2001	355,770	341,284	114,326	13,849	381,739	368,134	124,470	13,289
2002	355,006	347,718	117,517	13,794	373,818	367,806	127,271	13,000
2003	348,363	342,437	118,801	13,410	357,565	351,935	126,307	12,243
2004	328,325	324,038	116,904	12,647	328,407	324,259	120,810	11,082
2005	301,279	295,778	113,341	11,629	294,329	289,163	113,274	9,767
2006	274,518	270,227	106,675	10,519	262,630	258,824	103,353	8,498
2007	244,891	238,956	95,467	9,479	229,701	224,071	90,132	7,418
2008	210,002	203,888	78,785	8,643	193,055	187,001	72,403	6,621
2009	187,201	178,617	65,395	8,085	169,302	161,884	58,529	6,142
2010	176,102	170,245	56,588	7,851	157,236	150,968	49,493	5,998
2011	167,437	163,768	51,289	7,975	148,450	145,271	44,027	6,195
2012	174,123	168,377	55,885	8,364	155,532	149,391	48,402	6,615
2013	170,629	166,288	57,280	8,706	153,114	149,322	49,705	6,993
2014	169,493	164,424	58,215	8,808	152,324	148,191	50,938	7,197
2015	169,768	163,894	52,817	8,764	151,184	146,489	46,601	7,303

Table 2A.14b—Time series of survey biomass (t) and 95% confidence intervals as estimated last year and this year under Model 1. Values for projection years (not shown) are equal to the last year in the series.

	Last year's assessment			This year's assessment		
Year	Mean	U95%CI	L95%CI	Mean	U95%CI	L95%CI
1991	172,531	225,071	132,255	171,637	223,879	131,586
1992	159,866	232,627	109,863	158,994	228,499	110,631
1993	148,130	218,510	100,419	147,282	214,304	101,221
1994	137,256	188,877	99,743	136,433	186,588	99,759
1995	115,954	169,205	79,462	115,818	166,577	80,527
1996	97,958	140,742	68,180	98,318	139,333	69,377
1997	82,755	107,292	63,829	83,463	108,004	64,498
1998	89,490	127,817	62,656	89,714	126,385	63,684
1999	96,773	140,031	66,879	96,434	137,482	67,642
2000	104,649	142,608	76,794	103,657	140,250	76,612
2001	92,040	128,873	65,734	91,773	126,968	66,335
2002	80,949	105,138	62,325	81,252	105,080	62,827
2003	80,706	113,231	57,524	80,844	112,097	58,305
2004	80,463	107,900	60,003	80,439	107,284	60,311
2005	78,706	114,554	54,076	78,661	113,007	54,753
2006	76,987	111,145	53,326	76,921	109,895	53,841
2007	72,158	111,310	46,778	72,373	109,719	47,738
2008	67,632	105,507	43,354	68,093	104,268	44,469
2009	63,390	95,090	42,258	64,067	94,673	43,355
2010	59,414	79,927	44,166	60,278	80,818	44,959
2011	59,222	83,284	42,112	60,701	84,052	43,837
2012	59,031	76,711	45,425	61,126	77,817	48,014
2013				64,887	90,035	46,763
2014				68,880	93,757	50,604

Table 2A.15—Time series of EBS Pacific cod age 0 recruitment (1000s of fish), with standard deviations, as estimated by Models 2 and 3. Color scale extends from red (low) to green (high) in each **column**.

	Model 2		Model 3	
Year	Recruits	Std. dev.	Recruits	Std. dev.
1991	68,961	10,694	66,564	9,949
1992	41,759	9,962	36,860	9,797
1993	116,830	15,089	140,502	16,759
1994	47,021	7,682	43,861	7,611
1995	82,148	14,284	92,857	16,909
1996	130,073	16,491	148,358	17,309
1997	102,302	12,249	99,436	11,339
1998	57,108	10,946	56,080	10,767
1999	118,571	14,024	111,239	12,070
2000	57,350	8,497	46,195	6,382
2001	47,428	6,357	44,582	5,587
2002	31,756	5,188	30,612	5,141
2003	43,763	6,409	40,982	5,779
2004	31,499	6,192	27,403	5,322
2005	45,879	7,832	42,803	7,412
2006	44,526	6,807	44,930	6,662
2007	68,602	9,645	57,500	7,354
2008	47,514	7,233	51,177	7,640
2009	26,146	5,458	21,277	4,404
2010	45,746	8,790	49,234	9,535
2011	32,838	7,133	28,707	5,967
2012	38,520	14,957	31,372	12,867
2013	43,383	17,555	33,069	13,807
Average	59,553		58,504	

Table 2A.16a—Numbers (1000s) at age at the beginning of the year as estimated by Model 2.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1991	68961	50690	76135	16267	22421	29867	16212	4748	1986	1137	751	1210	825	569	397	279	196	139	98	69	168
1992	41759	49084	36080	54183	11535	15755	20881	11136	3272	1366	777	507	814	563	395	278	196	138	98	69	167
1993	116830	29723	34936	25665	37975	7334	9579	13172	7107	2072	846	461	298	503	368	264	189	134	95	68	164
1994	47021	83156	21155	24837	17723	25704	4866	6078	8451	4526	1293	507	274	185	330	247	180	129	92	66	161
1995	82148	33468	59187	15048	17411	12032	17124	3262	4098	5676	3007	840	328	182	126	228	172	126	91	65	159
1996	130073	58470	23821	42113	10622	12069	8252	11587	2218	2777	3811	1983	552	220	125	88	159	120	88	64	158
1997	102302	92582	41617	16945	29528	6823	7444	5391	7632	1453	1791	2384	1232	356	147	85	60	110	84	61	155
1998	57108	72816	65896	29607	11912	20355	4644	4824	3525	4960	928	1107	1463	786	236	100	58	42	76	58	151
1999	118571	40648	51826	46854	20533	7851	13013	2914	3064	2220	3054	546	645	899	511	158	68	40	29	53	145
2000	57350	84395	28932	36871	32958	13818	5167	8291	1877	1959	1392	1840	326	404	590	344	108	46	27	20	137
2001	47428	40820	60069	20579	25799	22283	9154	3048	4980	1113	1124	746	973	187	251	382	227	72	31	19	108
2002	31756	33758	29053	42687	14074	17101	14359	5724	1930	3127	683	658	433	596	121	167	258	155	50	22	87
2003	43763	22603	24028	20670	30034	9603	11474	8928	3606	1205	1905	397	378	263	384	80	113	176	106	34	75
2004	31499	31149	16088	17085	14338	20793	6576	7040	5557	2223	723	1084	223	226	168	254	54	77	120	73	76
2005	45879	22420	22170	11431	11649	9673	13732	4165	4510	3533	1384	432	642	139	148	113	172	37	53	83	103
2006	44526	32656	15957	15767	7974	7831	6358	8953	2739	2948	2273	863	268	412	93	101	78	119	26	37	130
2007	68602	31693	23243	11348	10980	5144	4858	4119	5854	1780	1884	1404	529	171	274	63	69	54	83	18	117
2008	47514	48829	22557	16528	7888	6978	3126	2918	2515	3534	1042	1038	764	309	107	179	42	47	36	57	92
2009	26146	33819	34753	16033	11360	5075	4313	1829	1740	1481	2009	552	542	433	191	69	118	28	31	25	102
2010	45746	18610	24071	24714	11151	7236	3093	2485	1075	1009	827	1040	281	302	264	122	45	78	19	21	86
2011	32838	32561	13245	17111	17039	7218	4510	1667	1376	585	522	387	477	145	176	163	78	30	52	13	72
2012	38520	23373	23176	9425	12094	11776	4930	2861	1069	876	365	312	230	297	95	118	111	53	20	36	59
2013	43383	27417	16636	16490	6648	8061	7647	2979	1756	650	517	203	172	135	188	62	79	75	36	14	65
2014	60649	30879	19514	11837	11637	4581	5484	4801	1893	1107	400	304	118	105	88	125	42	54	52	25	55

Table 2A.16b—Numbers (1000s) at age at the beginning of the year as estimated by Model 3.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1991	66564	58377	78964	16016	27882	27124	22276	4576	2194	1219	755	1181	802	545	375	259	180	125	88	61	144
1992	36860	47378	41551	56197	11359	19624	19021	15360	3165	1518	841	514	796	542	373	258	179	125	87	61	143
1993	140502	26236	33722	29557	39397	7303	12212	12117	9888	2039	970	514	303	473	335	236	166	117	82	58	137
1994	43861	100005	18673	23976	20471	26751	4885	7826	7842	6405	1310	597	305	182	295	214	153	109	78	55	131
1995	92857	31219	71179	13283	16806	13931	17946	3282	5287	5300	4310	861	385	198	120	198	144	104	75	53	128
1996	148358	66093	22220	50645	9369	11660	9587	12173	2236	3604	3600	2870	565	253	133	81	135	99	72	52	126
1997	99436	105597	47042	15808	35580	5972	7174	6300	8061	1482	2374	2295	1782	353	163	87	54	90	67	49	121
1998	56080	70776	75160	33467	11116	24626	4096	4682	4146	5308	969	1499	1408	1101	225	106	57	36	60	45	115
1999	111239	39916	50374	53446	23267	7371	15963	2595	2999	2658	3373	587	874	829	677	142	68	37	24	40	107
2000	46195	79177	28411	35840	37643	15764	4915	10279	1687	1951	1716	2091	352	528	520	434	92	45	25	16	99
2001	44582	32880	56355	20208	25066	25607	10569	2962	6292	1034	1181	971	1119	191	305	311	265	58	28	16	75
2002	30612	31732	23402	40044	13792	16673	16666	6724	1905	4050	660	720	570	663	118	193	200	173	38	19	61
2003	40982	21788	22586	16648	28149	9421	11239	10531	4297	1218	2567	398	418	334	406	74	123	130	114	25	53
2004	27403	29170	15508	16056	11487	19456	6451	6998	6641	2713	761	1519	226	239	201	251	47	79	84	75	52
2005	42803	19504	20761	11017	10907	7690	12773	4121	4516	4289	1738	467	898	135	149	128	162	31	52	56	85
2006	44930	30466	13882	14765	7684	7277	5026	8325	2708	2971	2802	1095	286	554	86	96	84	108	21	35	95
2007	57500	31980	21684	9872	10271	4918	4502	3246	5427	1767	1924	1744	660	174	349	55	63	55	72	14	88
2008	51177	40927	22761	15418	6842	6482	2986	2683	1967	3294	1058	1072	916	352	99	206	33	39	35	46	66
2009	21277	36426	29129	16177	10567	4352	3977	1724	1580	1160	1912	564	533	463	192	56	121	20	24	22	71
2010	49234	15144	25926	20714	11247	6655	2635	2244	994	913	659	988	270	260	246	107	33	72	12	15	58
2011	28707	35043	10779	18426	14206	7255	4160	1367	1200	533	478	303	409	115	124	126	57	18	41	7	44
2012	31372	20433	24942	7670	13022	9781	4942	2599	865	760	334	284	173	235	69	77	80	37	12	27	34
2013	33069	22330	14543	17746	5405	8668	6373	2905	1556	518	449	183	146	90	132	40	46	49	23	7	39
2014	58856	23538	15894	10348	12523	3721	5903	3909	1807	969	319	260	101	81	53	80	25	29	31	15	31

Table 2A.17a—“Effective” fishing mortality (= -ln($N_{a+1,t+1}/N_{a,t}$)-M) at age and year, as estimated by Model 2.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1991	0.000	0.000	0.004	0.013	0.018	0.036	0.032	0.034	0.041	0.054	0.056	0.042	0.026	0.018	0.014	0.011	0.010	0.009	0.008
1992	0.000	0.001	0.015	0.113	0.158	0.121	0.109	0.117	0.139	0.182	0.191	0.141	0.087	0.061	0.048	0.039	0.033	0.029	0.026
1993	0.000	0.001	0.030	0.050	0.070	0.115	0.104	0.111	0.132	0.173	0.182	0.134	0.083	0.058	0.045	0.037	0.031	0.028	0.024
1994	0.000	0.001	0.015	0.047	0.066	0.060	0.054	0.058	0.069	0.090	0.095	0.070	0.043	0.030	0.024	0.019	0.016	0.015	0.013
1995	0.000	0.000	0.008	0.026	0.037	0.051	0.046	0.049	0.058	0.076	0.080	0.059	0.037	0.026	0.020	0.016	0.014	0.012	0.011
1996	0.000	0.001	0.015	0.103	0.143	0.086	0.078	0.083	0.099	0.129	0.136	0.100	0.062	0.044	0.034	0.028	0.023	0.021	0.018
1997	0.000	0.000	0.012	0.032	0.045	0.094	0.085	0.091	0.108	0.141	0.148	0.109	0.068	0.048	0.037	0.030	0.026	0.023	0.020
1998	0.000	0.001	0.026	0.077	0.107	0.126	0.114	0.122	0.145	0.190	0.199	0.147	0.091	0.064	0.050	0.040	0.034	0.031	0.027
1999	0.000	0.000	0.012	0.056	0.078	0.111	0.100	0.107	0.127	0.167	0.175	0.129	0.080	0.056	0.044	0.036	0.030	0.027	0.024
2000	0.000	0.001	0.017	0.051	0.072	0.188	0.170	0.182	0.216	0.283	0.297	0.219	0.136	0.095	0.074	0.060	0.051	0.046	0.040
2001	0.000	0.002	0.040	0.071	0.099	0.130	0.117	0.125	0.149	0.195	0.205	0.151	0.094	0.066	0.051	0.042	0.035	0.031	0.027
2002	0.000	0.000	0.012	0.042	0.059	0.135	0.122	0.131	0.155	0.204	0.214	0.158	0.098	0.069	0.053	0.043	0.037	0.033	0.029
2003	0.000	0.001	0.026	0.028	0.039	0.148	0.134	0.144	0.171	0.224	0.235	0.173	0.107	0.075	0.059	0.048	0.041	0.036	0.032
2004	0.000	0.002	0.043	0.054	0.075	0.117	0.105	0.113	0.134	0.176	0.184	0.136	0.084	0.059	0.046	0.037	0.032	0.028	0.025
2005	0.000	0.001	0.020	0.057	0.080	0.088	0.079	0.085	0.101	0.132	0.139	0.102	0.063	0.044	0.035	0.028	0.024	0.021	0.019
2006	0.000	0.001	0.022	0.098	0.137	0.094	0.085	0.091	0.108	0.142	0.148	0.110	0.068	0.048	0.037	0.030	0.026	0.023	0.020
2007	0.000	0.001	0.024	0.113	0.158	0.170	0.154	0.165	0.195	0.256	0.268	0.198	0.123	0.086	0.067	0.054	0.046	0.041	0.036
2008	0.000	0.001	0.035	0.101	0.141	0.196	0.177	0.190	0.225	0.295	0.310	0.229	0.142	0.099	0.077	0.063	0.054	0.048	0.042
2009	0.000	0.001	0.023	0.111	0.155	0.211	0.191	0.205	0.243	0.319	0.334	0.247	0.153	0.107	0.084	0.068	0.058	0.051	0.045
2010	0.000	0.001	0.032	0.095	0.133	0.278	0.251	0.269	0.319	0.419	0.439	0.324	0.201	0.141	0.110	0.089	0.076	0.067	0.059
2011	0.000	0.000	0.007	0.029	0.041	0.115	0.104	0.112	0.132	0.174	0.182	0.134	0.083	0.058	0.046	0.037	0.031	0.028	0.024
2012	0.000	0.000	0.009	0.066	0.092	0.164	0.148	0.159	0.188	0.247	0.259	0.191	0.118	0.083	0.065	0.052	0.045	0.040	0.035
2013	0.000	0.000	0.009	0.032	0.045	0.126	0.113	0.122	0.144	0.189	0.198	0.147	0.091	0.064	0.050	0.040	0.034	0.030	0.027
2014	0.000	0.000	0.009	0.028	0.039	0.106	0.096	0.103	0.122	0.160	0.168	0.124	0.077	0.054	0.042	0.034	0.029	0.026	0.023

Table 2A.17b—"Effective" fishing mortality (= -ln($N_{a+1,t+1}/N_{a,t}$)-M) at age and year, as estimated by Model 3.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1991	0.000	0.000	0.004	0.011	0.015	0.032	0.029	0.028	0.031	0.044	0.054	0.052	0.040	0.033	0.029	0.025	0.022	0.019	0.017
1992	0.000	0.001	0.015	0.102	0.134	0.111	0.100	0.100	0.108	0.153	0.190	0.181	0.140	0.116	0.101	0.086	0.075	0.068	0.061
1993	0.000	0.001	0.027	0.047	0.062	0.105	0.095	0.094	0.102	0.145	0.180	0.171	0.132	0.110	0.095	0.082	0.071	0.064	0.057
1994	0.000	0.001	0.015	0.045	0.059	0.058	0.052	0.052	0.056	0.080	0.099	0.094	0.073	0.060	0.052	0.045	0.039	0.035	0.032
1995	0.000	0.000	0.009	0.026	0.034	0.048	0.044	0.043	0.047	0.066	0.082	0.079	0.061	0.050	0.044	0.038	0.033	0.029	0.026
1996	0.000	0.001	0.013	0.110	0.146	0.080	0.072	0.072	0.078	0.110	0.137	0.130	0.101	0.083	0.072	0.062	0.054	0.049	0.044
1997	0.000	0.000	0.012	0.028	0.037	0.087	0.078	0.078	0.084	0.120	0.148	0.141	0.109	0.091	0.079	0.068	0.059	0.053	0.047
1998	0.000	0.001	0.024	0.071	0.094	0.117	0.106	0.105	0.113	0.161	0.200	0.190	0.147	0.122	0.106	0.091	0.079	0.071	0.064
1999	0.000	0.000	0.011	0.049	0.065	0.100	0.091	0.090	0.098	0.138	0.172	0.164	0.126	0.105	0.091	0.078	0.068	0.061	0.055
2000	0.000	0.001	0.018	0.045	0.060	0.166	0.151	0.149	0.162	0.230	0.285	0.272	0.210	0.174	0.151	0.130	0.113	0.102	0.090
2001	0.000	0.002	0.042	0.068	0.089	0.112	0.102	0.101	0.109	0.155	0.192	0.183	0.141	0.117	0.102	0.087	0.076	0.069	0.061
2002	0.000	0.000	0.012	0.041	0.054	0.119	0.108	0.107	0.116	0.164	0.204	0.194	0.150	0.125	0.108	0.093	0.081	0.073	0.065
2003	0.000	0.001	0.031	0.029	0.039	0.134	0.121	0.120	0.130	0.185	0.229	0.218	0.169	0.140	0.121	0.104	0.091	0.082	0.073
2004	0.000	0.002	0.047	0.061	0.081	0.108	0.098	0.097	0.105	0.149	0.185	0.177	0.136	0.113	0.098	0.084	0.073	0.066	0.060
2005	0.000	0.001	0.020	0.065	0.085	0.088	0.080	0.079	0.086	0.121	0.151	0.144	0.111	0.092	0.080	0.069	0.060	0.054	0.048
2006	0.000	0.001	0.023	0.106	0.140	0.097	0.088	0.087	0.095	0.134	0.166	0.159	0.122	0.102	0.088	0.076	0.066	0.059	0.053
2007	0.000	0.001	0.027	0.120	0.159	0.177	0.161	0.159	0.173	0.245	0.304	0.290	0.224	0.186	0.161	0.138	0.121	0.108	0.096
2008	0.000	0.002	0.038	0.112	0.148	0.209	0.190	0.188	0.204	0.289	0.359	0.342	0.264	0.219	0.190	0.163	0.142	0.128	0.115
2009	0.000	0.001	0.023	0.122	0.162	0.232	0.210	0.208	0.226	0.321	0.398	0.379	0.293	0.243	0.211	0.181	0.158	0.142	0.126
2010	0.000	0.001	0.037	0.098	0.130	0.316	0.287	0.284	0.308	0.437	0.542	0.516	0.399	0.331	0.287	0.247	0.215	0.193	0.172
2011	0.000	0.000	0.007	0.033	0.044	0.130	0.118	0.117	0.127	0.180	0.223	0.213	0.164	0.136	0.118	0.101	0.088	0.080	0.070
2012	0.000	0.000	0.010	0.067	0.088	0.191	0.173	0.172	0.186	0.264	0.328	0.312	0.241	0.200	0.174	0.149	0.130	0.117	0.105
2013	0.000	0.000	0.009	0.033	0.044	0.149	0.135	0.133	0.145	0.205	0.255	0.243	0.188	0.156	0.135	0.116	0.101	0.091	0.081
2014	0.000	0.000	0.010	0.028	0.037	0.122	0.110	0.109	0.119	0.168	0.209	0.199	0.154	0.128	0.111	0.095	0.083	0.074	0.067

Table 2A.18a—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in 2015-2027 (Scenario 1), with random variability in future recruitment, based on Model 2.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	33,400	33,400	33,400	33,400	0
2016	26,300	26,300	26,300	26,300	0
2017	21,800	21,800	21,800	21,800	2
2018	21,700	21,700	21,700	21,800	49
2019	23,300	24,000	24,100	25,300	628
2020	25,300	28,000	28,500	33,200	2,443
2021	25,200	30,500	30,800	36,800	3,672
2022	23,000	31,900	32,000	42,600	6,054
2023	22,500	32,900	32,800	43,600	6,756
2024	22,400	33,800	33,300	45,000	7,000
2025	22,400	33,600	33,700	46,100	7,200
2026	22,200	33,500	33,600	45,200	7,199
2027	22,500	33,800	33,400	45,300	7,060

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	52,600	52,600	52,600	52,600	0
2016	44,700	44,700	44,700	44,700	0
2017	40,800	40,800	40,800	40,800	4
2018	40,600	40,700	40,700	40,900	85
2019	42,400	43,100	43,200	44,300	609
2020	43,900	46,100	46,500	50,200	2,041
2021	43,300	48,200	48,800	56,900	4,224
2022	42,100	49,400	50,400	62,300	6,280
2023	41,400	50,100	51,300	64,300	7,374
2024	41,300	50,500	51,800	67,300	7,907
2025	40,900	50,500	52,000	67,700	8,137
2026	41,000	50,500	51,900	66,400	8,085
2027	41,200	50,600	51,800	66,600	7,875

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.54	0.54	0.54	0.54	0.00
2016	0.47	0.47	0.47	0.47	0.00
2017	0.43	0.43	0.43	0.43	0.00
2018	0.42	0.42	0.42	0.43	0.00
2019	0.44	0.45	0.45	0.46	0.01
2020	0.46	0.48	0.49	0.53	0.02
2021	0.45	0.51	0.50	0.54	0.03
2022	0.44	0.52	0.51	0.54	0.03
2023	0.43	0.53	0.51	0.54	0.04
2024	0.43	0.53	0.51	0.54	0.04
2025	0.43	0.53	0.51	0.54	0.04
2026	0.43	0.53	0.51	0.54	0.04
2027	0.43	0.53	0.51	0.54	0.04

Table 2A.18b—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in 2015-2027 (Scenario 1), with random variability in future recruitment, based on Model 3.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	29,300	29,300	29,300	29,300	0
2016	23,500	23,500	23,500	23,500	0
2017	18,900	18,900	18,900	18,900	2
2018	18,500	18,600	18,600	18,700	55
2019	19,700	20,400	20,500	21,800	706
2020	22,800	25,500	26,100	31,400	2,711
2021	23,300	28,600	29,100	35,900	4,010
2022	20,500	30,000	30,600	43,600	7,129
2023	19,900	31,300	31,400	44,500	7,851
2024	19,900	32,300	32,200	46,200	8,203
2025	19,800	32,300	32,700	47,700	8,435
2026	19,800	32,300	32,600	46,400	8,443
2027	20,100	32,400	32,400	46,900	8,296

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	46,400	46,400	46,400	46,400	0
2016	39,900	39,900	39,900	39,900	0
2017	36,100	36,100	36,100	36,100	5
2018	35,700	35,800	35,800	36,000	99
2019	37,600	38,300	38,500	39,800	708
2020	39,600	42,000	42,500	46,900	2,358
2021	39,400	44,600	45,500	54,700	4,849
2022	38,300	46,200	47,400	61,400	7,167
2023	37,400	47,200	48,600	63,300	8,350
2024	37,500	47,700	49,300	66,200	9,021
2025	37,300	47,800	49,600	67,700	9,349
2026	37,000	47,900	49,500	66,400	9,308
2027	37,600	48,000	49,400	66,700	9,029

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.61	0.61	0.61	0.61	0.00
2016	0.52	0.52	0.52	0.52	0.00
2017	0.46	0.46	0.46	0.46	0.00
2018	0.46	0.46	0.46	0.46	0.00
2019	0.48	0.49	0.50	0.51	0.01
2020	0.51	0.55	0.55	0.61	0.03
2021	0.51	0.58	0.58	0.63	0.04
2022	0.49	0.60	0.59	0.63	0.05
2023	0.48	0.62	0.59	0.63	0.05
2024	0.48	0.62	0.59	0.63	0.05
2025	0.48	0.62	0.59	0.63	0.05
2026	0.48	0.63	0.59	0.63	0.05
2027	0.48	0.63	0.59	0.63	0.05

Table 2A.19a—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the authors' best estimates of 2015-2016 catches given ABC = maxABC in 2015-2016, with $F = max$ F_{ABC} thereafter (Scenario 2), and with random variability in future recruitment, based on Model 2.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	30,900	30,900	30,900	30,900	0
2016	25,200	25,200	25,200	25,200	0
2017	23,100	23,100	23,100	23,100	2
2018	22,300	22,400	22,400	22,500	49
2019	23,600	24,200	24,400	25,500	631
2020	25,400	28,100	28,600	33,300	2,440
2021	25,200	30,500	30,800	36,800	3,669
2022	22,900	31,900	32,000	42,600	6,054
2023	22,500	32,900	32,800	43,600	6,757
2024	22,400	33,800	33,300	45,000	6,999
2025	22,400	33,600	33,700	46,100	7,199
2026	22,200	33,500	33,600	45,200	7,198
2027	22,500	33,800	33,400	45,300	7,060

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	52,800	52,800	52,800	52,800	0
2016	45,700	45,700	45,700	45,700	0
2017	41,900	41,900	41,900	41,900	4
2018	41,200	41,300	41,300	41,400	85
2019	42,700	43,300	43,400	44,500	609
2020	43,900	46,200	46,500	50,300	2,041
2021	43,300	48,200	48,900	56,900	4,224
2022	42,100	49,400	50,300	62,300	6,281
2023	41,400	50,100	51,200	64,300	7,374
2024	41,300	50,500	51,800	67,300	7,908
2025	40,900	50,500	52,000	67,700	8,138
2026	41,000	50,500	51,900	66,400	8,085
2027	41,200	50,600	51,800	66,600	7,876

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.49	0.49	0.49	0.49	0.00
2016	0.43	0.43	0.43	0.43	0.00
2017	0.44	0.44	0.44	0.44	0.00
2018	0.43	0.43	0.43	0.43	0.00
2019	0.45	0.45	0.45	0.47	0.01
2020	0.46	0.49	0.49	0.53	0.02
2021	0.45	0.51	0.50	0.54	0.03
2022	0.44	0.52	0.51	0.54	0.03
2023	0.43	0.53	0.51	0.54	0.04
2024	0.43	0.53	0.51	0.54	0.04
2025	0.43	0.53	0.51	0.54	0.04
2026	0.43	0.53	0.51	0.54	0.04
2027	0.43	0.53	0.51	0.54	0.04

Table 2A.19b—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the authors' best estimates of 2015-2016 catches given ABC = maxABC in 2015-2016, with $F = max\ F_{ABC}$ thereafter (Scenario 2), and with random variability in future recruitment, based on Model 3.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	27,000	27,000	27,000	27,000	0
2016	22,300	22,300	22,300	22,300	0
2017	20,100	20,100	20,100	20,100	2
2018	19,100	19,100	19,200	19,300	56
2019	20,000	20,600	20,800	22,100	709
2020	22,900	25,600	26,200	31,500	2,710
2021	23,300	28,600	29,100	35,900	4,009
2022	20,500	30,000	30,600	43,600	7,130
2023	19,900	31,300	31,400	44,500	7,852
2024	19,900	32,200	32,200	46,200	8,203
2025	19,800	32,300	32,700	47,700	8,435
2026	19,800	32,300	32,600	46,400	8,442
2027	20,100	32,400	32,400	46,900	8,296

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	46,600	46,600	46,600	46,600	0
2016	40,900	40,900	40,900	40,900	0
2017	37,200	37,300	37,300	37,300	5
2018	36,200	36,300	36,400	36,500	99
2019	37,900	38,600	38,700	40,000	708
2020	39,700	42,100	42,600	47,000	2,357
2021	39,400	44,600	45,500	54,700	4,848
2022	38,300	46,200	47,400	61,400	7,166
2023	37,400	47,200	48,600	63,300	8,349
2024	37,500	47,700	49,300	66,200	9,020
2025	37,300	47,800	49,600	67,700	9,348
2026	37,000	47,900	49,500	66,400	9,307
2027	37,600	48,000	49,400	66,700	9,029

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.55	0.55	0.55	0.55	0.00
2016	0.47	0.47	0.47	0.47	0.00
2017	0.48	0.48	0.48	0.48	0.00
2018	0.47	0.47	0.47	0.47	0.00
2019	0.49	0.50	0.50	0.52	0.01
2020	0.51	0.55	0.55	0.61	0.03
2021	0.51	0.58	0.58	0.63	0.04
2022	0.49	0.60	0.59	0.63	0.05
2023	0.48	0.62	0.59	0.63	0.05
2024	0.48	0.62	0.59	0.63	0.05
2025	0.48	0.62	0.59	0.63	0.05
2026	0.48	0.63	0.59	0.63	0.05
2027	0.48	0.63	0.59	0.63	0.05

Table 2A.20a—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that the upper bound on F_{ABC} is set the most recent five-year average fishing mortality rate in 2015-2027 (Scenario 3), with random variability in future recruitment, based on Model 2.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	13,400	13,400	13,400	13,400	0
2016	14,000	14,000	14,000	14,000	0
2017	13,800	13,800	13,800	13,800	0
2018	14,200	14,200	14,200	14,200	3
2019	14,600	14,700	14,700	15,000	136
2020	15,400	16,100	16,200	17,300	594
2021	15,900	17,200	17,400	19,300	1,049
2022	15,300	18,100	18,500	22,900	2,349
2023	15,400	19,000	19,400	24,300	2,839
2024	15,700	19,800	20,200	25,600	3,116
2025	16,000	20,300	20,700	27,000	3,348
2026	15,800	20,600	21,000	27,500	3,474
2027	15,900	20,700	21,000	27,000	3,464

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	54,300	54,300	54,300	54,300	0
2016	53,400	53,400	53,400	53,400	0
2017	53,000	53,000	53,000	53,000	4
2018	54,200	54,300	54,300	54,500	89
2019	57,000	57,700	57,800	59,000	650
2020	59,800	62,300	62,700	66,900	2,289
2021	60,900	66,800	67,600	77,300	5,099
2022	60,900	70,800	71,800	86,700	8,127
2023	60,500	74,000	75,100	93,500	10,322
2024	61,000	76,400	77,600	98,100	11,708
2025	61,100	77,700	79,200	103,000	12,480
2026	61,100	78,800	80,200	103,000	12,761
2027	61,700	79,600	80,700	104,000	12,694

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.20	0.20	0.20	0.20	0.00
2016	0.20	0.20	0.20	0.20	0.00
2017	0.20	0.20	0.20	0.20	0.00
2018	0.20	0.20	0.20	0.20	0.00
2019	0.20	0.20	0.20	0.20	0.00
2020	0.20	0.20	0.20	0.20	0.00
2021	0.20	0.20	0.20	0.20	0.00
2022	0.20	0.20	0.20	0.20	0.00
2023	0.20	0.20	0.20	0.20	0.00
2024	0.20	0.20	0.20	0.20	0.00
2025	0.20	0.20	0.20	0.20	0.00
2026	0.20	0.20	0.20	0.20	0.00
2027	0.20	0.20	0.20	0.20	0.00

Table 2A.20b—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that the upper bound on F_{ABC} is set the most recent five-year average fishing mortality rate in 2015-2027 (Scenario 3), with random variability in future recruitment, based on Model 3.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	12,500	12,500	12,500	12,500	0
2016	13,400	13,400	13,400	13,400	0
2017	12,900	12,900	12,900	12,900	0
2018	13,100	13,100	13,100	13,200	3
2019	13,300	13,500	13,500	13,800	167
2020	14,600	15,300	15,400	16,600	656
2021	15,400	16,600	16,800	19,000	1,102
2022	14,300	17,400	17,900	23,200	2,847
2023	14,300	18,300	18,800	25,100	3,412
2024	14,500	19,300	19,700	26,600	3,755
2025	15,100	19,900	20,500	27,700	3,996
2026	15,000	20,500	20,900	28,500	4,155
2027	15,200	20,700	21,100	28,400	4,148

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	47,800	47,800	47,800	47,800	0
2016	47,200	47,200	47,200	47,200	0
2017	46,200	46,200	46,200	46,200	5
2018	46,600	46,700	46,700	46,900	104
2019	48,900	49,700	49,800	51,300	755
2020	51,700	54,400	55,000	59,900	2,636
2021	53,000	59,300	60,300	71,300	5,828
2022	53,000	63,500	65,000	82,500	9,229
2023	52,700	67,400	68,800	90,400	11,635
2024	52,300	70,100	71,700	95,200	13,206
2025	53,500	71,900	73,700	100,000	14,127
2026	54,000	73,000	74,700	101,000	14,468
2027	54,200	73,800	75,300	101,000	14,341

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.24	0.24	0.24	0.24	0.00
2016	0.24	0.24	0.24	0.24	0.00
2017	0.24	0.24	0.24	0.24	0.00
2018	0.24	0.24	0.24	0.24	0.00
2019	0.24	0.24	0.24	0.24	0.00
2020	0.24	0.24	0.24	0.24	0.00
2021	0.24	0.24	0.24	0.24	0.00
2022	0.24	0.24	0.24	0.24	0.00
2023	0.24	0.24	0.24	0.24	0.00
2024	0.24	0.24	0.24	0.24	0.00
2025	0.24	0.24	0.24	0.24	0.00
2026	0.24	0.24	0.24	0.24	0.00
2027	0.24	0.24	0.24	0.24	0.00

Table 2A.21a—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that the upper bound on F_{ABC} is set at $F_{60\%}$ in 2015-2027 (Scenario 4), with random variability in future recruitment, based on Model 2.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	16,400	16,400	16,400	16,400	0
2016	16,700	16,700	16,700	16,700	0
2017	16,200	16,200	16,200	16,200	0
2018	16,400	16,400	16,400	16,400	3
2019	16,800	17,000	17,000	17,300	168
2020	17,800	18,600	18,700	20,000	730
2021	18,300	19,800	20,000	22,400	1,280
2022	17,400	20,800	21,200	26,500	2,816
2023	17,500	21,800	22,200	28,200	3,373
2024	17,800	22,700	23,000	29,400	3,673
2025	18,100	23,000	23,600	30,900	3,918
2026	17,900	23,300	23,800	31,300	4,033
2027	18,100	23,400	23,900	30,900	3,999

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	54,000	54,000	54,000	54,000	0
2016	52,000	52,000	52,000	52,000	0
2017	50,700	50,700	50,700	50,700	4
2018	51,300	51,400	51,400	51,600	89
2019	53,700	54,400	54,500	55,700	650
2020	56,100	58,600	59,000	63,200	2,281
2021	56,900	62,700	63,500	73,100	5,047
2022	56,500	66,200	67,200	81,800	7,970
2023	56,100	69,100	70,200	88,000	9,998
2024	56,400	71,100	72,200	92,000	11,232
2025	56,200	72,200	73,600	96,000	11,890
2026	56,300	73,100	74,300	96,500	12,093
2027	56,800	73,700	74,700	96,300	11,983

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.24	0.24	0.24	0.24	0.00
2016	0.24	0.24	0.24	0.24	0.00
2017	0.24	0.24	0.24	0.24	0.00
2018	0.24	0.24	0.24	0.24	0.00
2019	0.24	0.24	0.24	0.24	0.00
2020	0.24	0.24	0.24	0.24	0.00
2021	0.24	0.24	0.24	0.24	0.00
2022	0.24	0.24	0.24	0.24	0.00
2023	0.24	0.24	0.24	0.24	0.00
2024	0.24	0.24	0.24	0.24	0.00
2025	0.24	0.24	0.24	0.24	0.00
2026	0.24	0.24	0.24	0.24	0.00
2027	0.24	0.24	0.24	0.24	0.00

Table 2A.21b—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that the upper bound on F_{ABC} is set at $F_{60\%}$ in 2015-2027 (Scenario 4), with random variability in future recruitment, based on Model 3.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	14,500	14,500	14,500	14,500	0
2016	15,300	15,300	15,300	15,300	0
2017	14,600	14,600	14,600	14,600	0
2018	14,700	14,700	14,700	14,700	4
2019	14,800	14,900	15,000	15,300	196
2020	16,200	17,000	17,100	18,600	769
2021	17,000	18,400	18,600	21,200	1,285
2022	15,800	19,200	19,900	26,000	3,274
2023	15,600	20,300	20,800	28,000	3,894
2024	15,800	21,300	21,800	29,500	4,263
2025	16,500	22,000	22,700	31,000	4,518
2026	16,400	22,500	23,000	31,500	4,669
2027	16,600	22,700	23,200	31,400	4,639

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	47,600	47,600	47,600	47,600	0
2016	46,300	46,300	46,300	46,300	0
2017	44,600	44,600	44,600	44,600	5
2018	44,600	44,700	44,700	44,900	104
2019	46,700	47,400	47,600	49,000	755
2020	49,300	51,900	52,500	57,400	2,629
2021	50,300	56,500	57,500	68,500	5,784
2022	50,000	60,500	61,900	79,300	9,097
2023	49,700	64,100	65,400	86,200	11,358
2024	49,200	66,400	68,000	90,800	12,798
2025	50,400	67,900	69,700	95,100	13,619
2026	50,700	69,000	70,600	95,800	13,887
2027	51,200	69,600	71,000	95,800	13,721

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.28	0.28	0.28	0.28	0.00
2016	0.28	0.28	0.28	0.28	0.00
2017	0.28	0.28	0.28	0.28	0.00
2018	0.28	0.28	0.28	0.28	0.00
2019	0.28	0.28	0.28	0.28	0.00
2020	0.28	0.28	0.28	0.28	0.00
2021	0.28	0.28	0.28	0.28	0.00
2022	0.28	0.28	0.28	0.28	0.00
2023	0.28	0.28	0.28	0.28	0.00
2024	0.28	0.28	0.28	0.28	0.00
2025	0.28	0.28	0.28	0.28	0.00
2026	0.28	0.28	0.28	0.28	0.00
2027	0.28	0.28	0.28	0.28	0.00

Table 2A.22a—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that *F* = 0 in 2015-2027 (Scenario 5), with random variability in future recruitment, based on Model 2.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0	0	0	0	0
2016	0	0	0	0	0
2017	0	0	0	0	0
2018	0	0	0	0	0
2019	0	0	0	0	0
2020	0	0	0	0	0
2021	0	0	0	0	0
2022	0	0	0	0	0
2023	0	0	0	0	0
2024	0	0	0	0	0
2025	0	0	0	0	0
2026	0	0	0	0	0
2027	0	0	0	0	0

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	55,200	55,200	55,200	55,200	0
2016	59,700	59,700	59,700	59,700	0
2017	64,100	64,100	64,100	64,200	4
2018	69,400	69,500	69,500	69,600	89
2019	75,500	76,200	76,300	77,500	652
2020	81,200	83,800	84,200	88,500	2,324
2021	85,300	91,400	92,200	102,000	5,331
2022	87,700	98,200	99,500	116,000	8,846
2023	89,100	104,000	106,000	127,000	11,904
2024	90,600	109,000	111,000	136,000	14,166
2025	92,000	113,000	115,000	143,000	15,681
2026	93,000	116,000	118,000	148,000	16,556
2027	94,600	119,000	120,000	150,000	16,909

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.00	0.00	0.00	0.00	0.00
2016	0.00	0.00	0.00	0.00	0.00
2017	0.00	0.00	0.00	0.00	0.00
2018	0.00	0.00	0.00	0.00	0.00
2019	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00
2021	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00
2023	0.00	0.00	0.00	0.00	0.00
2024	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00
2026	0.00	0.00	0.00	0.00	0.00
2027	0.00	0.00	0.00	0.00	0.00

Table 2A.22b—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that *F* = 0 in 2015-2027 (Scenario 5), with random variability in future recruitment, based on Model 3.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0	0	0	0	0
2016	0	0	0	0	0
2017	0	0	0	0	0
2018	0	0	0	0	0
2019	0	0	0	0	0
2020	0	0	0	0	0
2021	0	0	0	0	0
2022	0	0	0	0	0
2023	0	0	0	0	0
2024	0	0	0	0	0
2025	0	0	0	0	0
2026	0	0	0	0	0
2027	0	0	0	0	0

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	48,700	48,700	48,700	48,700	0
2016	53,100	53,100	53,100	53,100	0
2017	56,700	56,700	56,700	56,800	5
2018	60,800	60,900	60,900	61,100	104
2019	66,100	66,800	67,000	68,400	757
2020	71,400	74,200	74,700	79,700	2,678
2021	75,300	81,900	82,900	94,400	6,086
2022	77,700	89,000	90,600	110,000	10,022
2023	78,900	95,700	97,400	123,000	13,436
2024	80,300	101,000	103,000	132,000	16,013
2025	82,000	106,000	107,000	141,000	17,794
2026	83,200	109,000	111,000	146,000	18,831
2027	84,300	111,000	113,000	148,000	19,205

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.00	0.00	0.00	0.00	0.00
2016	0.00	0.00	0.00	0.00	0.00
2017	0.00	0.00	0.00	0.00	0.00
2018	0.00	0.00	0.00	0.00	0.00
2019	0.00	0.00	0.00	0.00	0.00
2020	0.00	0.00	0.00	0.00	0.00
2021	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00
2023	0.00	0.00	0.00	0.00	0.00
2024	0.00	0.00	0.00	0.00	0.00
2025	0.00	0.00	0.00	0.00	0.00
2026	0.00	0.00	0.00	0.00	0.00
2027	0.00	0.00	0.00	0.00	0.00

Table 2A.23a—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = F_{OFL}$ in 2016-2027 (Scenario 6), with random variability in future recruitment, based on Model 2.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	40,000	40,000	40,000	40,000	0
2016	28,300	28,300	28,300	28,300	0
2017	22,700	22,700	22,700	22,700	2
2018	22,700	22,700	22,700	22,800	54
2019	24,600	25,400	25,500	26,800	710
2020	26,700	29,700	30,300	35,600	2,875
2021	26,400	32,200	33,000	41,800	4,709
2022	23,900	33,500	34,300	47,400	7,336
2023	23,400	34,400	34,900	47,900	7,980
2024	23,400	34,500	35,300	48,900	8,122
2025	23,200	34,500	35,400	49,700	8,300
2026	23,100	34,400	35,300	48,800	8,243
2027	23,300	34,200	35,100	48,900	8,082

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	52,000	52,000	52,000	52,000	0
2016	42,000	42,000	42,000	42,000	0
2017	37,700	37,700	37,700	37,800	4
2018	37,600	37,700	37,700	37,900	85
2019	39,500	40,200	40,300	41,400	604
2020	40,800	43,000	43,400	47,100	2,000
2021	40,100	44,800	45,500	53,200	4,007
2022	38,900	45,900	46,500	57,100	5,676
2023	38,200	46,300	47,000	58,400	6,422
2024	38,200	46,200	47,200	60,200	6,742
2025	37,700	46,100	47,300	60,400	6,860
2026	37,700	46,200	47,100	59,100	6,752
2027	38,000	46,100	47,000	59,000	6,556

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.66	0.66	0.66	0.66	0.00
2016	0.54	0.54	0.54	0.54	0.00
2017	0.48	0.48	0.48	0.48	0.00
2018	0.48	0.48	0.48	0.49	0.00
2019	0.51	0.52	0.52	0.53	0.01
2020	0.53	0.56	0.56	0.61	0.03
2021	0.52	0.58	0.59	0.66	0.05
2022	0.50	0.60	0.59	0.66	0.06
2023	0.49	0.60	0.60	0.66	0.06
2024	0.49	0.60	0.60	0.66	0.06
2025	0.48	0.60	0.60	0.66	0.06
2026	0.48	0.60	0.60	0.66	0.06
2027	0.49	0.60	0.59	0.66	0.06

Table 2A.23b—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = F_{OFL}$ in 2015-2027 (Scenario 6), with random variability in future recruitment, based on Model 3.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	34,900	34,900	34,900	34,900	0
2016	25,500	25,500	25,500	25,500	0
2017	19,700	19,700	19,700	19,700	3
2018	19,300	19,400	19,400	19,500	62
2019	20,800	21,600	21,800	23,200	802
2020	24,300	27,300	28,000	34,000	3,174
2021	24,600	30,400	31,300	41,000	5,044
2022	21,400	31,700	33,000	49,000	8,519
2023	20,700	32,800	33,600	49,000	9,165
2024	20,600	33,400	34,200	50,500	9,449
2025	20,800	33,100	34,500	51,400	9,660
2026	20,200	33,000	34,200	50,400	9,584
2027	20,600	32,900	34,000	50,900	9,413

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	45,900	45,900	45,900	45,900	0
2016	37,600	37,600	37,600	37,600	0
2017	33,400	33,400	33,400	33,400	5
2018	33,100	33,100	33,200	33,300	99
2019	35,100	35,800	35,900	37,200	703
2020	37,000	39,300	39,800	44,100	2,312
2021	36,500	41,600	42,400	51,300	4,623
2022	35,300	43,000	43,800	56,500	6,543
2023	34,400	43,500	44,600	57,200	7,360
2024	34,700	43,700	45,000	59,700	7,809
2025	34,500	43,500	45,000	60,100	8,008
2026	34,300	43,700	44,900	59,000	7,901
2027	34,700	43,600	44,700	59,400	7,639

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.75	0.75	0.75	0.75	0.00
2016	0.60	0.60	0.60	0.60	0.00
2017	0.53	0.53	0.53	0.53	0.00
2018	0.53	0.53	0.53	0.53	0.00
2019	0.56	0.57	0.57	0.60	0.01
2020	0.59	0.63	0.64	0.72	0.04
2021	0.59	0.67	0.68	0.79	0.06
2022	0.56	0.70	0.69	0.79	0.08
2023	0.55	0.70	0.70	0.79	0.08
2024	0.55	0.71	0.70	0.79	0.08
2025	0.55	0.71	0.70	0.79	0.08
2026	0.55	0.71	0.70	0.79	0.08
2027	0.55	0.71	0.70	0.79	0.08

Table 2A.24a—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in each year 2015-2016 and $F = F_{OFL}$ thereafter (Scenario 7), with random variability in future recruitment, based on Model 2.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	33,400	33,400	33,400	33,400	0
2016	26,300	26,300	26,300	26,300	0
2017	26,000	26,000	26,000	26,000	2
2018	24,100	24,200	24,200	24,300	56
2019	25,200	25,900	26,000	27,400	715
2020	26,800	29,900	30,400	35,800	2,875
2021	26,400	32,200	32,900	41,700	4,706
2022	23,800	33,500	34,300	47,400	7,335
2023	23,300	34,300	34,900	47,900	7,979
2024	23,400	34,500	35,200	48,900	8,121
2025	23,200	34,500	35,400	49,700	8,299
2026	23,100	34,400	35,300	48,800	8,242
2027	23,300	34,200	35,100	48,900	8,082

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	52,600	52,600	52,600	52,600	0
2016	44,700	44,700	44,700	44,700	0
2017	40,400	40,400	40,400	40,400	4
2018	38,800	38,900	38,900	39,100	85
2019	39,900	40,600	40,700	41,800	604
2020	40,900	43,100	43,500	47,200	1,998
2021	40,100	44,800	45,400	53,200	4,006
2022	38,900	45,900	46,500	57,100	5,675
2023	38,200	46,200	47,000	58,400	6,422
2024	38,200	46,200	47,200	60,200	6,742
2025	37,700	46,100	47,300	60,400	6,860
2026	37,700	46,200	47,100	59,100	6,753
2027	38,000	46,100	47,000	59,000	6,557

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.54	0.54	0.54	0.54	0.00
2016	0.47	0.47	0.47	0.47	0.00
2017	0.52	0.52	0.52	0.52	0.00
2018	0.50	0.50	0.50	0.50	0.00
2019	0.51	0.52	0.53	0.54	0.01
2020	0.53	0.56	0.56	0.61	0.03
2021	0.52	0.58	0.59	0.66	0.05
2022	0.50	0.60	0.59	0.66	0.06
2023	0.49	0.60	0.60	0.66	0.06
2024	0.49	0.60	0.60	0.66	0.06
2025	0.48	0.60	0.60	0.66	0.06
2026	0.48	0.60	0.60	0.66	0.06
2027	0.49	0.60	0.59	0.66	0.06

Table 2A.24b—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in each year 2015-2017 and $F = F_{OFL}$ thereafter (Scenario 7), with random variability in future recruitment, based on Model 3.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	29,300	29,300	29,300	29,300	0
2016	23,500	23,500	23,500	23,500	0
2017	22,700	22,700	22,700	22,700	3
2018	20,600	20,700	20,700	20,800	63
2019	21,300	22,100	22,300	23,700	809
2020	24,400	27,400	28,100	34,200	3,174
2021	24,600	30,400	31,300	41,000	5,042
2022	21,300	31,600	32,900	49,000	8,519
2023	20,600	32,700	33,600	48,900	9,166
2024	20,600	33,400	34,200	50,500	9,449
2025	20,800	33,100	34,400	51,400	9,659
2026	20,200	33,000	34,200	50,400	9,583
2027	20,600	32,900	34,000	50,900	9,413

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	46,400	46,400	46,400	46,400	0
2016	39,900	39,900	39,900	39,900	0
2017	35,800	35,800	35,800	35,800	5
2018	34,100	34,200	34,200	34,400	98
2019	35,500	36,100	36,300	37,600	702
2020	37,100	39,400	39,900	44,200	2,310
2021	36,500	41,500	42,400	51,300	4,621
2022	35,300	43,000	43,800	56,500	6,541
2023	34,400	43,500	44,500	57,200	7,358
2024	34,700	43,700	45,000	59,700	7,808
2025	34,500	43,500	45,000	60,100	8,007
2026	34,300	43,700	44,900	59,000	7,900
2027	34,700	43,600	44,700	59,400	7,639

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2015	0.61	0.61	0.61	0.61	0.00
2016	0.52	0.52	0.52	0.52	0.00
2017	0.57	0.57	0.57	0.57	0.00
2018	0.54	0.54	0.55	0.55	0.00
2019	0.57	0.58	0.58	0.60	0.01
2020	0.59	0.63	0.64	0.72	0.04
2021	0.58	0.67	0.68	0.79	0.06
2022	0.56	0.70	0.69	0.79	0.08
2023	0.55	0.70	0.70	0.79	0.08
2024	0.55	0.71	0.70	0.79	0.08
2025	0.55	0.71	0.70	0.79	0.08
2026	0.55	0.71	0.70	0.79	0.08
2027	0.55	0.71	0.70	0.79	0.08

Table 2.25a (page 1 of 2)—Incidental catch (t) of FMP species, other than squid and members of the former “other species” complex, taken in the Aleutian Islands trawl fishery for Pacific cod, 1991-2014 (2014 data current through October 20).

Trawl fishery

Species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Pollock	26	205	135	164	12	29	279	270	482	778	312	719
Pacific Cod	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sablefish								6				1
Yellowfin Sole												
Greenland Turbot	1	5	11	15				16	1	8	6	7
Arrowtooth Flounder	5	72	95	58	6	97	47	76	72	95	130	225
Kamchatka Flounder												
Rock Sole	19	161	178	116	185	204	193	380	540	456	462	1080
Flathead Sole					7	4	17	17	31	71	37	105
Alaska Plaice												
Other Flatfish						0	0	25	9	15	8	20
Flounder		26	27	19								
Pacific Ocean Perch	24	235	366	88	22	50	99	234	48	102	72	63
Northern Rockfish												117
Rougheye Rockfish												
Shortraker Rockfish												
Sharpchin/Northern Rockfish		195	313	132	37	157	88	158	191	274	182	
Shortraker/Rougheye Rockfish		28	9	2		1	2	3	1	3	4	1
Shortraker/Rougheye/Sharpchin/Northern Rockfish	13											
Other Rockfish	0	17	7	2	3	11	76	48	29	18	12	19
Atka Mackerel	164	2981	3176	239	124	579	94	567	499	260	842	378
Squid		0	2	0			1	1	0	0	2	0

Table 2.25a (page 2 of 2)—Incidental catch (t) of FMP species, other than squid and members of the former "other species" complex, taken in the Aleutian Islands trawl fishery for Pacific cod, 1991-2014 (2014 data current through October 20).

Trawl fishery

Species/group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Pollock	785	537	669	314	395	54	51	18	57	78	23	11
Pacific Cod	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sablefish	1	1	0	1	1							
Yellowfin Sole	0	9		3	0	0						
Greenland Turbot	8	6	5		7	1	1					
Arrowtooth Flounder	230	199	244	206	134	24	35	35	16	19	17	5
Kamchatka Flounder									3	2	2	
Rock Sole	802	699	437	449	585	258	432	427	196	217	146	101
Flathead Sole	39	34	24	33	22	10	14	17	3	9	5	2
Alaska Plaice					0	0						
Other Flatfish	8	10	6	11	9	13	3	2	0	7	3	8
Flounder												
Pacific Ocean Perch	185	160	180	134	96	105	32	5	2	43	33	1
Northern Rockfish	215	129	210	185	89	51	59	29	21	9	11	14
Rougheye Rockfish		1	3	1	0	0		0	1			
Shortraker Rockfish		3		2	0						0	
Sharpchin/Northern Rockfish												
Shortraker/Rougheye Rockfish	7											
Shortraker/Rougheye/Sharpchin/Northern Rockfish												
Other Rockfish	13	12	8	7	9	9	7	4	4	9	3	1
Atka Mackerel	1075	549	482	447	361	456	359	124	101	384		
Squid	3	2	1	1	0	0	0	0		0	0	

Table 2.25b (page 1 of 2)—Incidental catch (t) of FMP species, other than squid and members of the former “other species” complex, taken in the Aleutian Islands longline fishery for Pacific cod, 1991-2014 (2014 data current through October 20).

Longline fishery

Species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Pollock	7	15	41	5	19	9	41	35	12	44	72	5
Pacific Cod	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sablefish	94	71	56	66	10	67	32	12	14	24	37	62
Yellowfin Sole												
Greenland Turbot	71	78	57	32	13	14	24	30	30	30	26	6
Arrowtooth Flounder	32	137	61	37	15	21	44	59	49	152	214	35
Kamchatka Flounder												
Rock Sole	0	2	7	5	5	15	5	12	3	3	7	4
Flathead Sole					0	1	2	2	0	5	8	1
Alaska plaice												
Other Flatfish						0	1	2	1	4	13	1
Flounder		3	4	1								
Pacific Ocean Perch		120	2	1	0	1	0	0	0	9	3	0
Northern Rockfish												28
Rougheye Rockfish												
Shortraker Rockfish												
Sharpchin/Northern Rockfish		45	19	10	4	20	17	54	35	75	132	
Shortraker/Rougheye Rockfish		454	191	104	14	117	61	201	107	147	166	36
Shortraker/Rougheye/Sharpchin/Northern Rockfish	132											
Other Rockfish	34	163	36	33	4	21	36	92	61	68	97	30
Atka Mackerel		55	20	40	41	31	40	90	71	151	273	41
Squid												

Table 2.25b (page 2 of 2)—Incidental catch (t) of FMP species, other than squid and members of the former "other species" complex, taken in the Aleutian Islands longline fishery for Pacific cod, 1991-2014 (2014 data current through October 20).

Longline fishery

Species/group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Pollock	9	15	3	8	6	9	29	47	6	8	0	
Pacific Cod	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sablefish	14	2		37	22	23	3	30	6	15	1	
Yellowfin Sole												
Greenland Turbot	12	3		11	15	4	5	5	1	2		
Arrowtooth Flounder	14	18	34	36	66	42	45	65	8	10	2	
Kamchatka Flounder										4	3	
Rock Sole	1	2	4	3	3	2	2	3		2	0	
Flathead Sole	0	0	0	1	2	2	3	3		1		
Alaska Plaice												
Other Flatfish		10		0		0	16	2				
Flounder												
Pacific Ocean Perch	1	0	2	1	4	3	1	1		1		
Northern Rockfish	18	27	19	8	33	54	56	119		12	34	
Rougheye Rockfish		26	1	3	28	46	23	30		27	11	
Shortraker Rockfish		3	5	8	12	6	6	28	2	6	4	
Sharpchin/Northern Rockfish												
Shortraker/Rougheye Rockfish	12											
Shortraker/Rougheye/Sharpchin/Northern Rockfish												
Other Rockfish	12	55	12	20	50	45	77	81	14	20	15	
Atka Mackerel	14	12	19	9	25	47	89	93		19	23	
Squid												

Table 2A.26—Incidental catch (t) of squid and members of the former “other species” complex taken in the Aleutian Islands fisheries for Pacific cod, 2003-2014 (2014 data are current through October 8).

Species/group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Octopus	14	14	12	64	26	19	20	48	10	8	38	8
Sculpins, Large	107	294	207	307	378	375	402	523	99	366	298	88
Sculpins, Other	153	64	7	69	29	26	91	201	6	13	9	4
Shark, Other		0										
Shark, Pacific Sleeper	0	2	2	0	0	0	0	0				
Shark, Salmon							0		0			
Shark, Spiny Dogfish	0	0	0	1	0	3	1	1	0	0	0	0
Skate, Alaska								207	39	64	38	9
Skate, Aleutian									6	25	6	3
Skate, Big		0	0	5	0	0	0	0		2	0	0
Skate, Longnose		0	0	0		0	0	0		0	0	0
Skate, Other	200	486	405	411	647	576	748	602	116	251	148	22
Skate, Whiteblotched									2	4	8	3
Squid	3	2	1	1	0	0	0	0	0	0	0	0

Table 2A.27—Catches of prohibited species by Aleutian Islands fisheries for Pacific cod, 1991-2014 (2014 data are current through October 13). Herring and halibut catches (and halibut mortality totals) are in t, salmon and crab are in 1000s of individuals.

Species	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Bairdi Tanner Crab	2	2	1	1	1	7	3	1	6	48	5	14
Opilio Tanner (Snow) Crab	2	1	1	0	0	0	0	0	0	0	0	1
Red King Crab	0	0	0	0	0	0	0	1	0	1	1	8
Blue King Crab												
Golden (Brown) King Crab												
Other King Crab	2	5	1	2	0	1	0	1	7	1	1	1
Herring												
Chinook Salmon	0	0	0	0	1	0	1	1	0	1	0	2
Non-Chinook Salmon		0			0		0	0		0	0	0

Species	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Bairdi Tanner Crab	11	8	3	7	28	199	41	11	1	11	16	
Opilio Tanner (Snow) Crab	0	0	0	12	73	108	126	34	1	2	1	
Red King Crab	7	1	3	0	3	6	1	1	1	1	8	
Blue King Crab	0	0	0	0	9	0	0	18	0	0	0	
Golden (Brown) King Crab	0	0	0	0	1	2	1	0	1	0	0	
Other King Crab												
Herring	0	0	0	0	0	0	0	0	0	0	0	
Chinook Salmon	2	1	1	1	1	1	1	1	0	0	0	
Non-Chinook Salmon	0	0	0	0	1	0	0	0	0	0	0	

Halibut quantity	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Catch	313	1626	531	423	386	546	438	1023	457	643	1486	261
Mortality				62	48	122	75	190	86	111	172	50

Halibut quantity	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Catch	175	328	306	331	936	698	718	711	211	245	81	51
Mortality	58	60	79	82	148	89	102	74	35	56	24	19

Table 2A.28—Incidental catch (t) of non-target species groups by Aleutian Islands Pacific cod fisheries, 2003-2014 (2014 data are current through October 8), sorted in order of descending average.

Species/group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Ave.
Giant Grenadier	0	0	1	95	31	26	10	189	18	51	1	23	37
Misc fish	29	18	20	17	26	17	18	17	9	9	7	5	16
Grenadier	46	13	1	26	10	0	2	70	0	4	1		16
Sponge unidentified	25	23	26	28	19	4	15	9	3	7	2	1	13
Corals Bryozoans	25	13	12	12	16	11	11	10	6	4	4	1	10
Sea star	6	9	6	7	9	11	21	18	2	8	5	3	9
Invertebrate unidentified	0	1	0	14	2	4	0	10	0	0	0	0	3
Bivalves	15	1	1	3	2	1	0	0	0	0	0	0	2
Dark Rockfish						2	4	4	0	0	0	0	1
Scypho jellies	0	0	1	2	0	0	0	0	0	3	6	2	1
Snails	1	1	0	1	1	2	3	1	0	1	1	0	1
Greenlings	1	0	0	4	1	1	0	1	0	0	0	0	1
Urchins dollars cucumbers	1	1	0	1	1	0	1	0	0	0	0	0	1
Sea anemone unidentified	0	0	1	1	1	0	1	1	0	1	0	0	1
Sea pens whips	0	0	0	0	0	0	1	1	0	0	0		0
Eelpouts	0	1	0	0	0	0	0	0	0	0	0	0	0
Benthic urochordata	0	0	0	0	1	0	0	0	0	0	0	0	0
Misc crustaceans	0	0	0	0	0	0	0	0	0	0	0	0	0
Hermit crab unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0
Brittle star unidentified	0	0	0	0	1	0	0	0	0	0	0	0	0
Pandalid shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0
Polychaete unidentified	0	0	0	0	0	0	0	0	0	0	0	0	0
Pacific Sand lance	0		0	0	0	0		0					0
Eulachon			0	0	0	0				0			0
Misc inverts (worms etc)		0	0	0	0	0	0	0	0	0	0	0	0
Capelin					0	0				0	0	0	0
Stichaeidae	0		0	0	0		0						0
Other osmerids			0	0	0					0	0		0
Gunnels		0	0		0								0
Birds	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc crabs	1	1	0	1	2	1	1	1	0	0	2	1	1

FIGURES

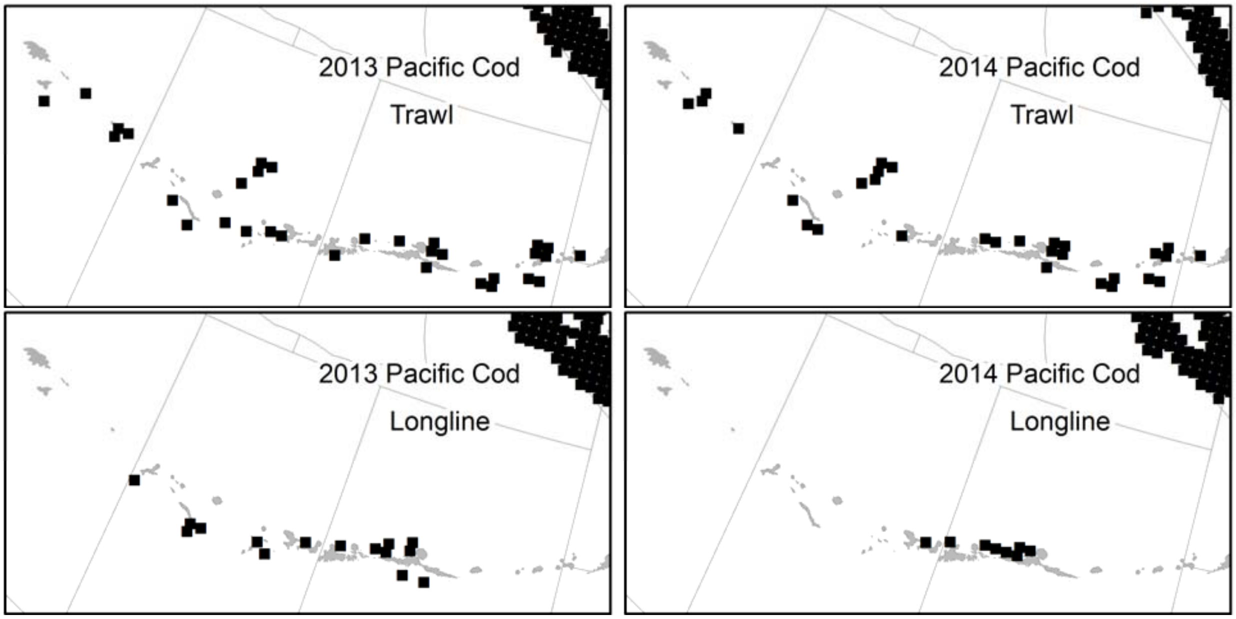


Figure 2A.1--AI maps showing each 400 square km cell with trawl hauls or longline sets containing Pacific cod from at least 3 distinct vessels in 2013-2014, overlaid against NMFS 3-digit statistical areas.

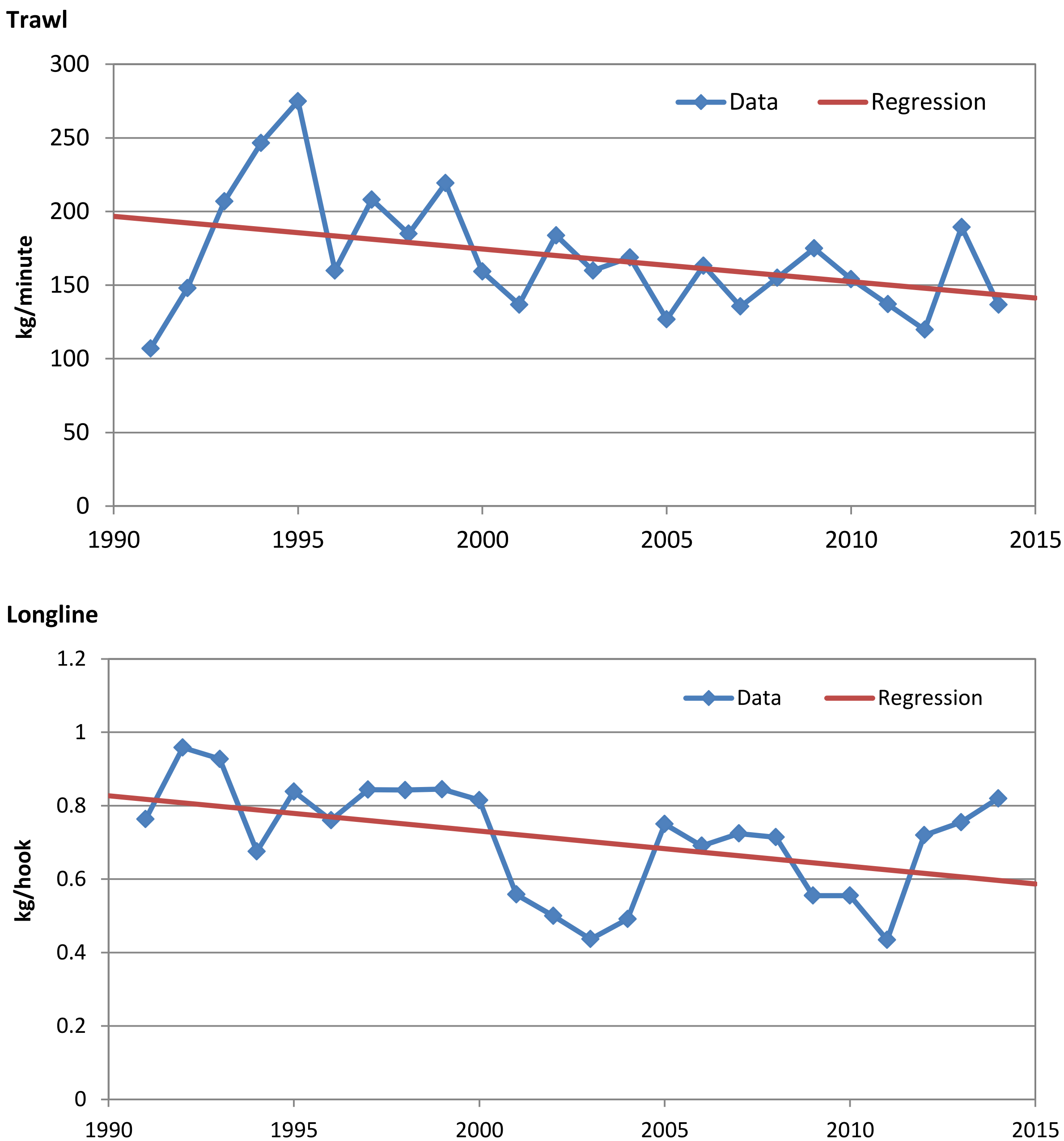


Figure 2A.2—Catch per unit effort for the trawl and longline fisheries, 1991-2014 (2014 data are partial).

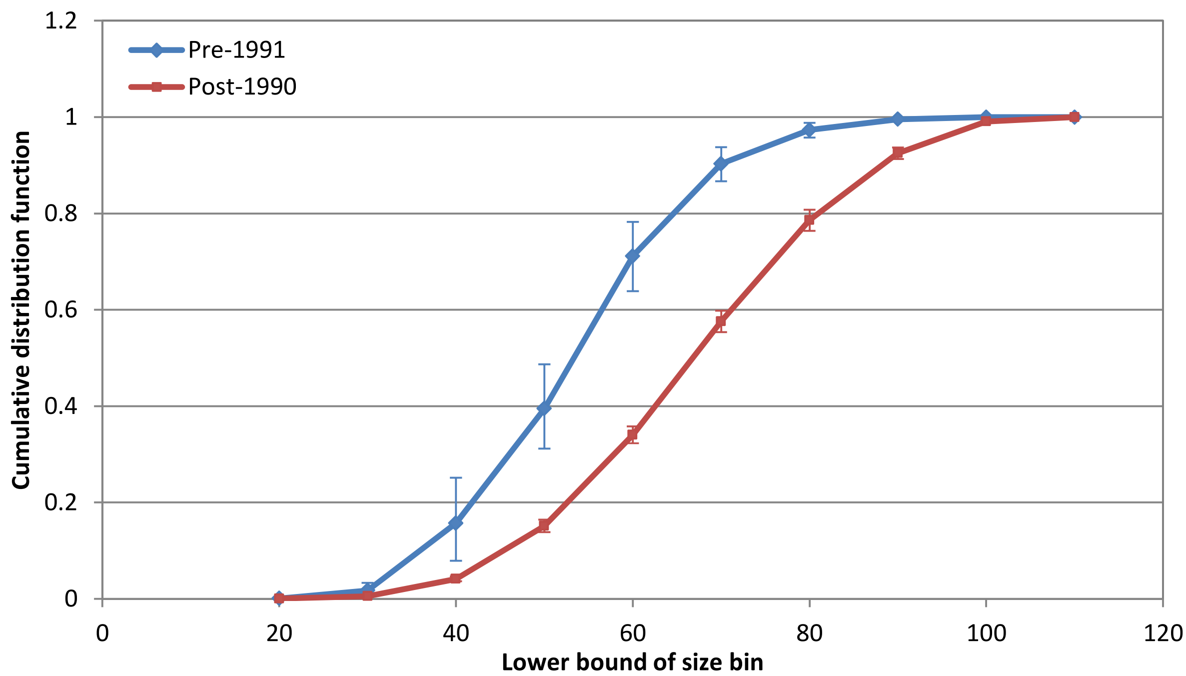


Figure 2A.3—Cumulative distribution functions of mean (across years) fishery size compositions during the 1977-1990 and 1991-2014 periods, with bootstrapped 95% confidence intervals.

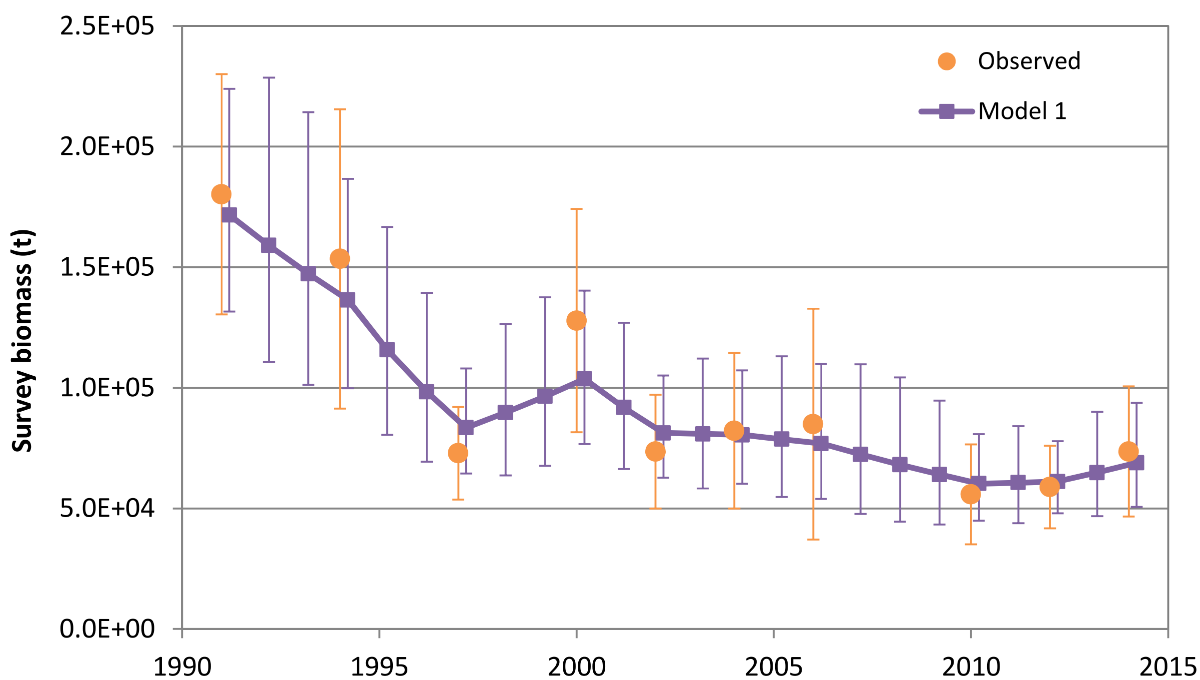


Figure 2A.4—Fit of Model 1 (Tier 5 random effects model) to survey biomass time series, with 95% confidence intervals for the observations and the estimates.

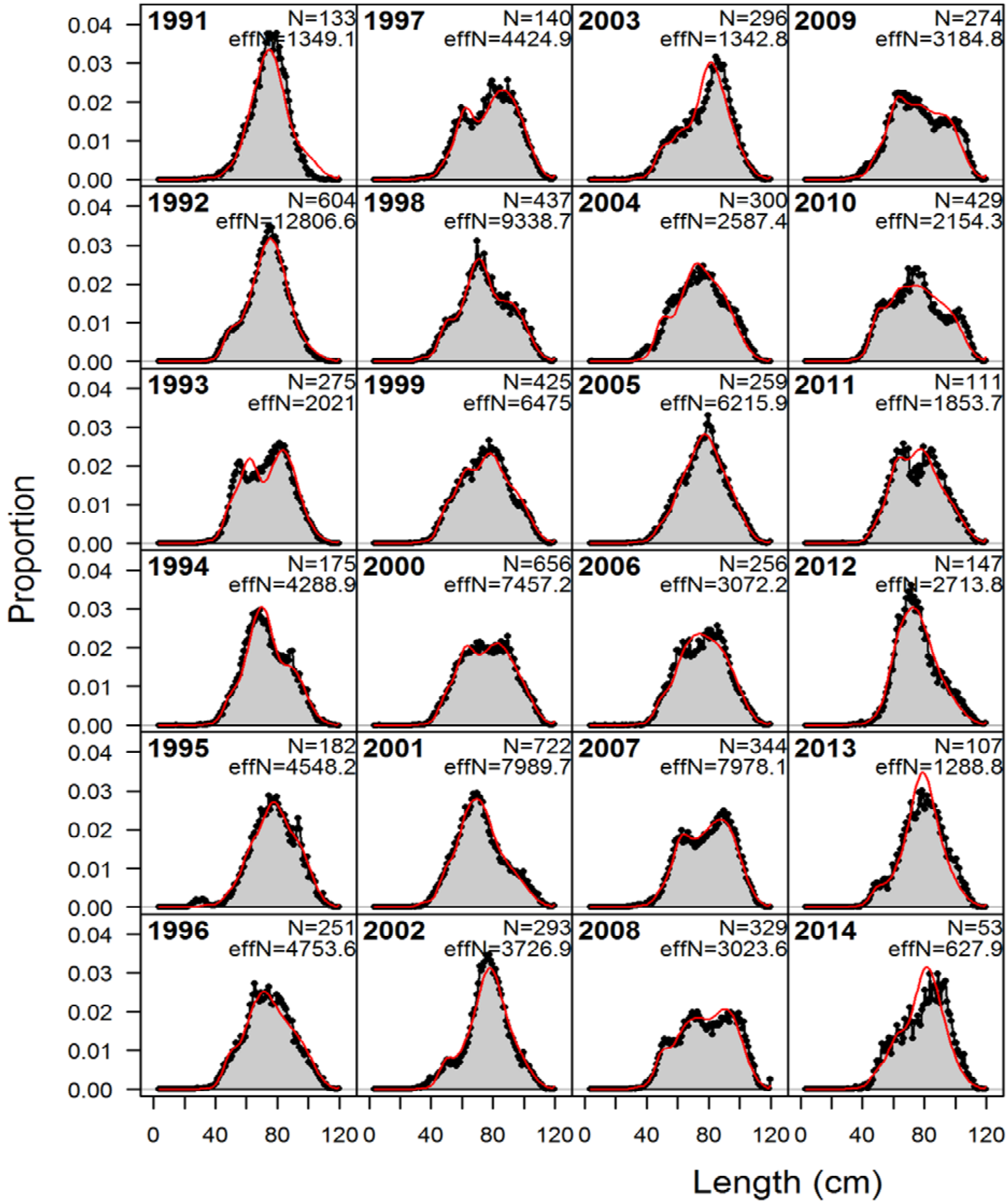


Figure 2A.5a—Fit to fishery size composition data obtained by Model 2 (grey = observed, red = estimated).

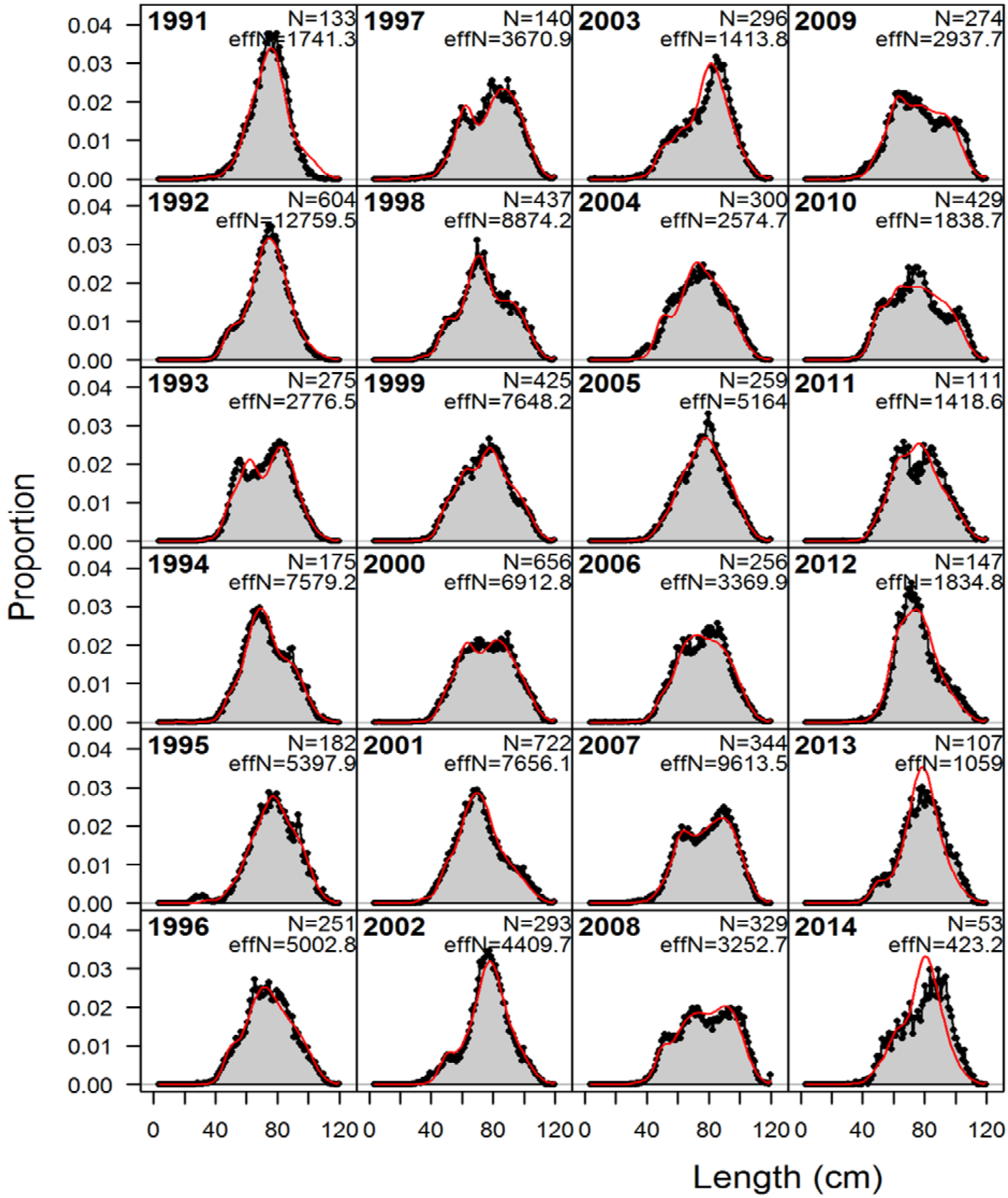


Figure 2A.5b—Fit to fishery size composition data obtained by Model 3 (grey = observed, red = estimated).

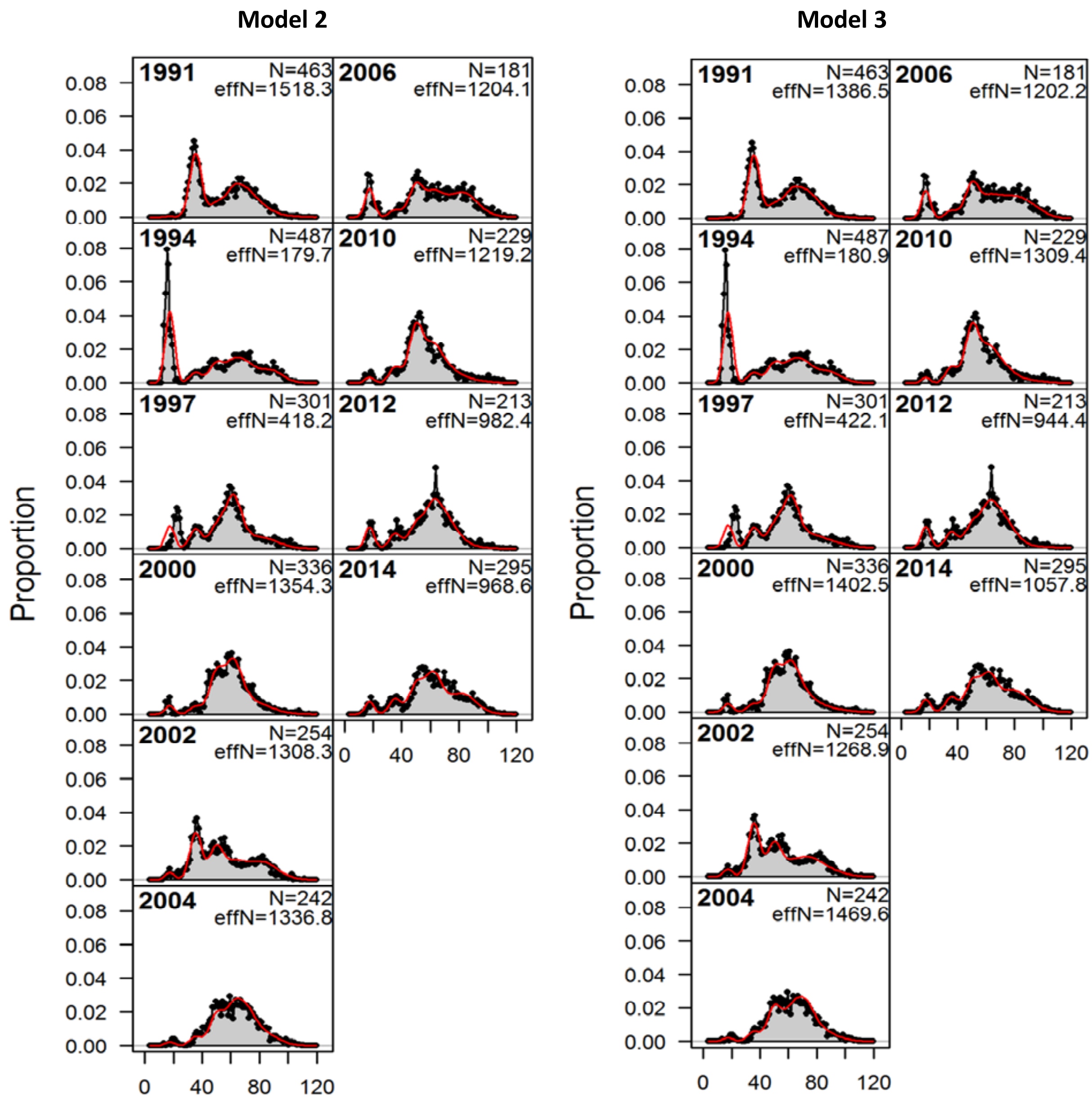


Figure 2A.6—Fits to survey size composition data obtained by Models 2 and 3 (grey = observed, red = estimated).

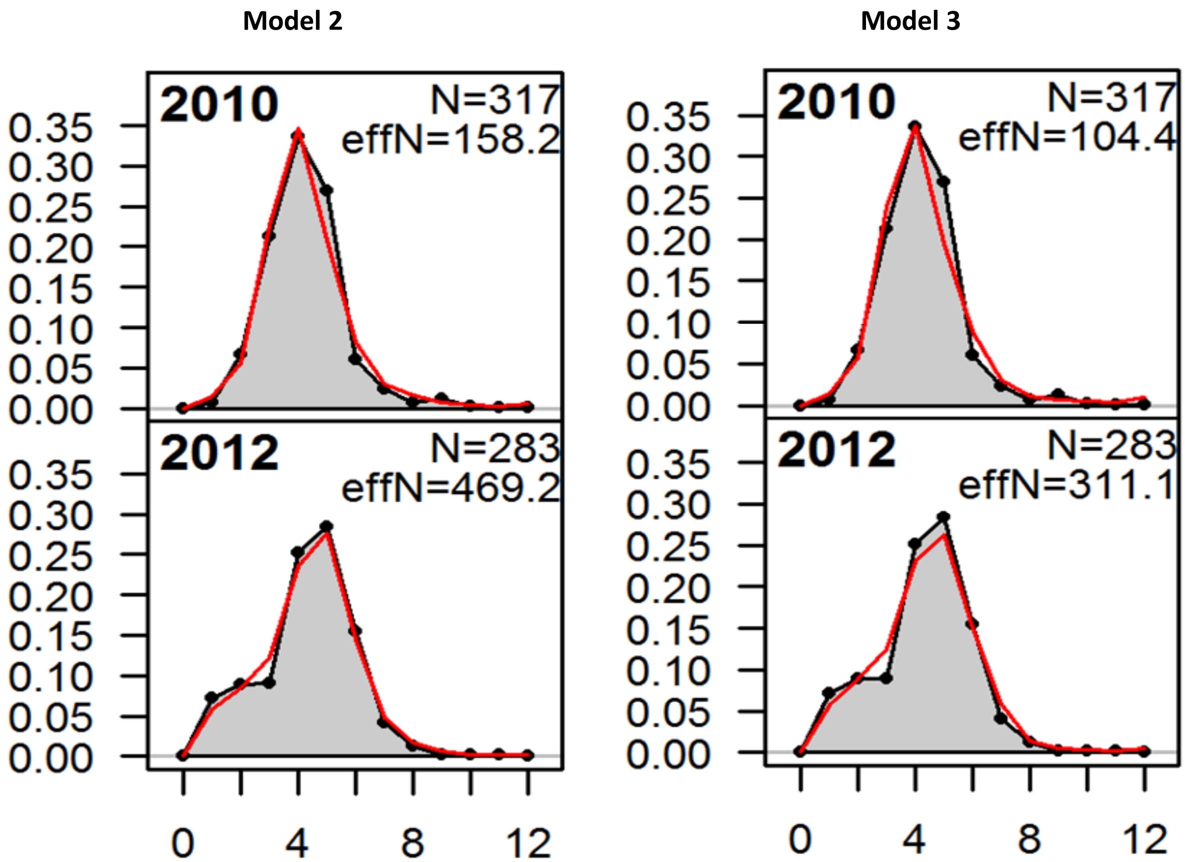


Figure 2A.7—Fits to age composition data obtained by Models 2 and 3 (grey = observed, red = estimated).

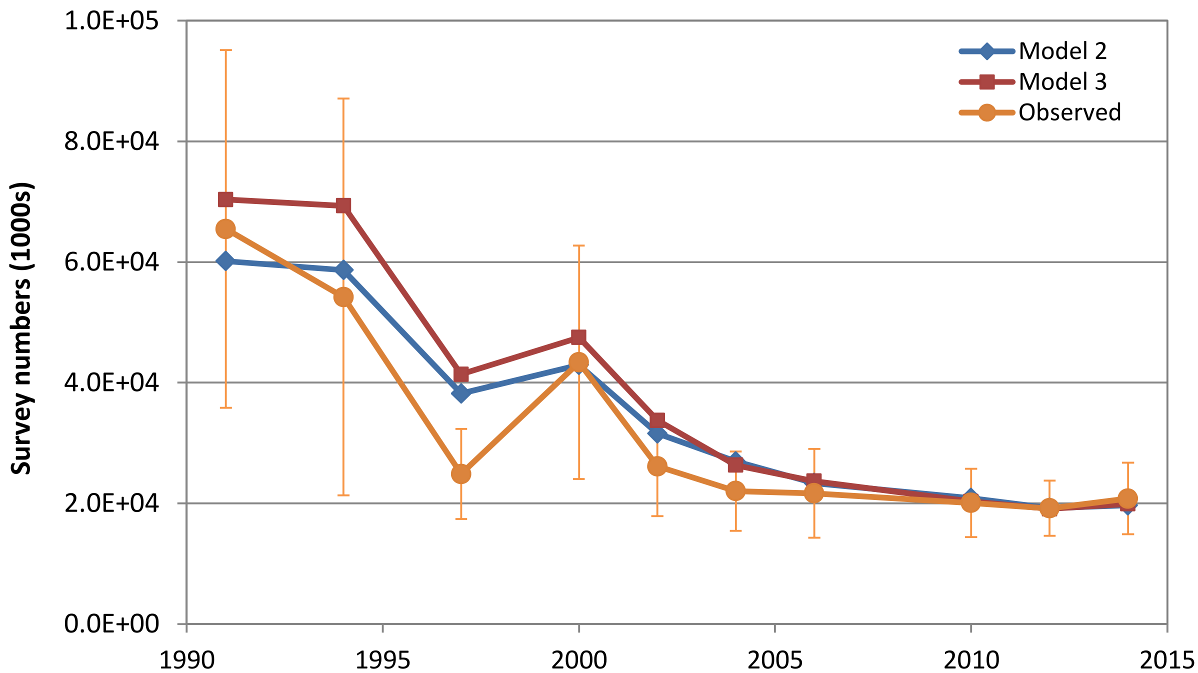


Figure 2A.8—Tier 3 model fits to the survey abundance time series, with 95% confidence intervals for the observations.

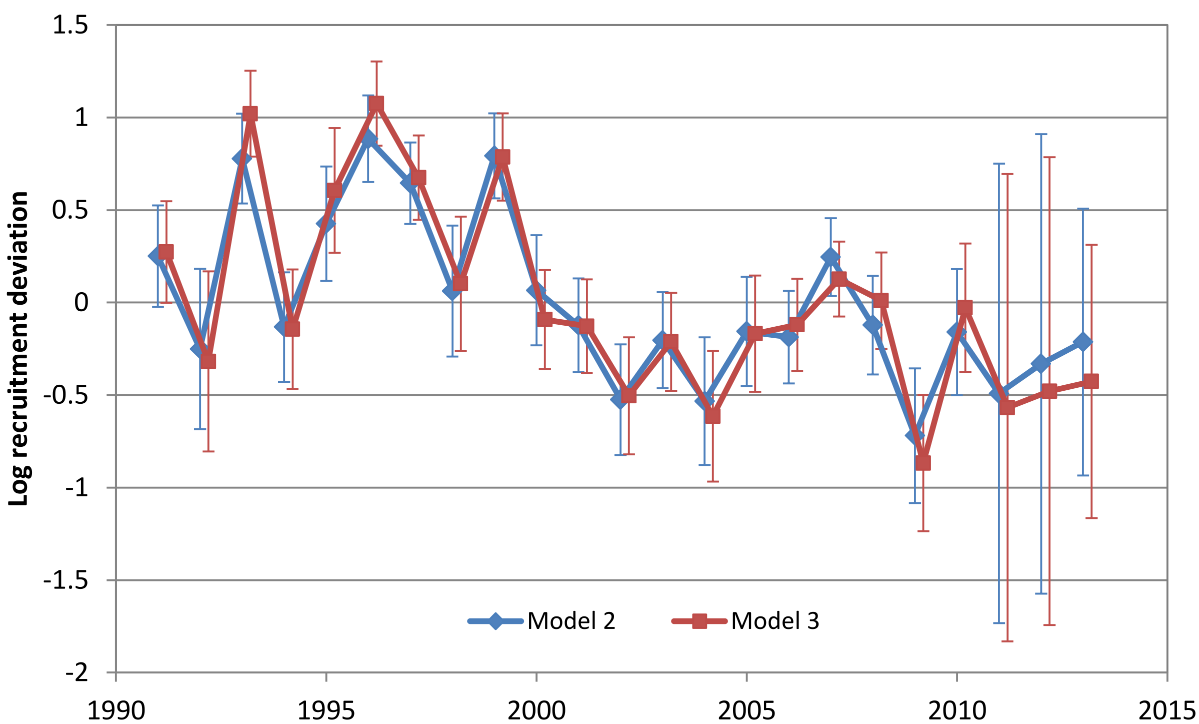


Figure 2A.9—Time series of estimated log recruitment deviations from Models 2 and 3, with 95% confidence intervals (horizontal axis values have been offset slightly to prevent over-plotting).

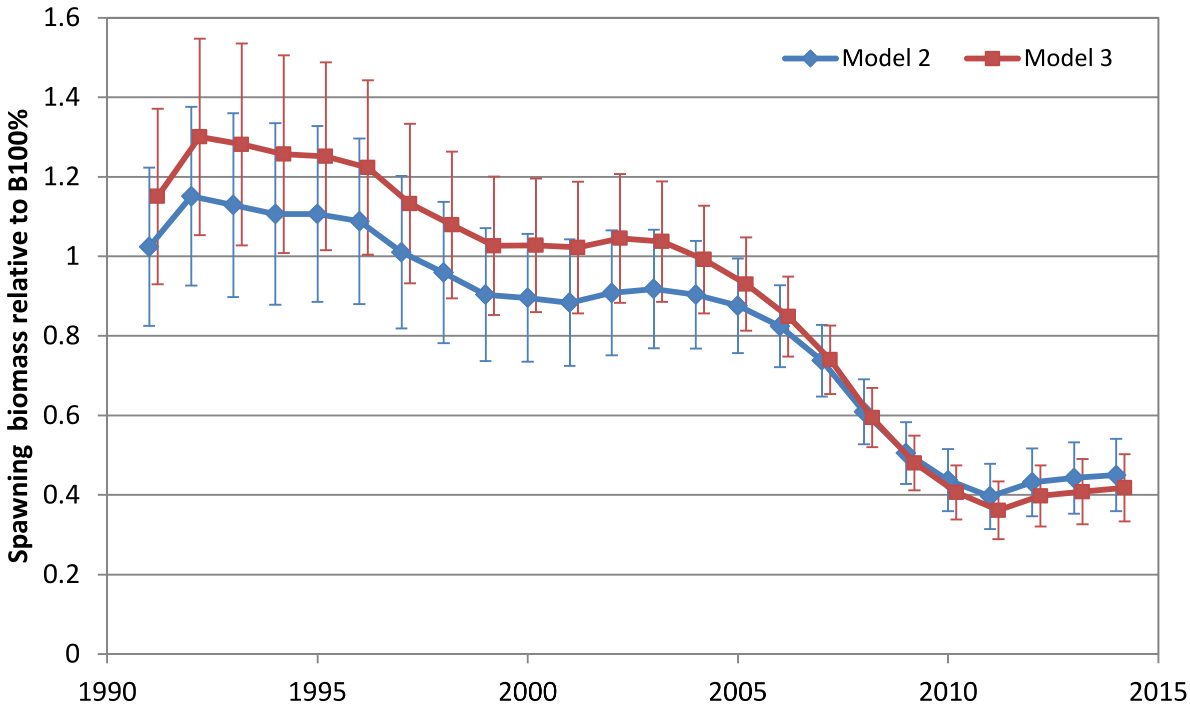


Figure 2A.10—Time series of spawning biomass relative to $B_{100\%}$ as estimated by Models 2 and 3.

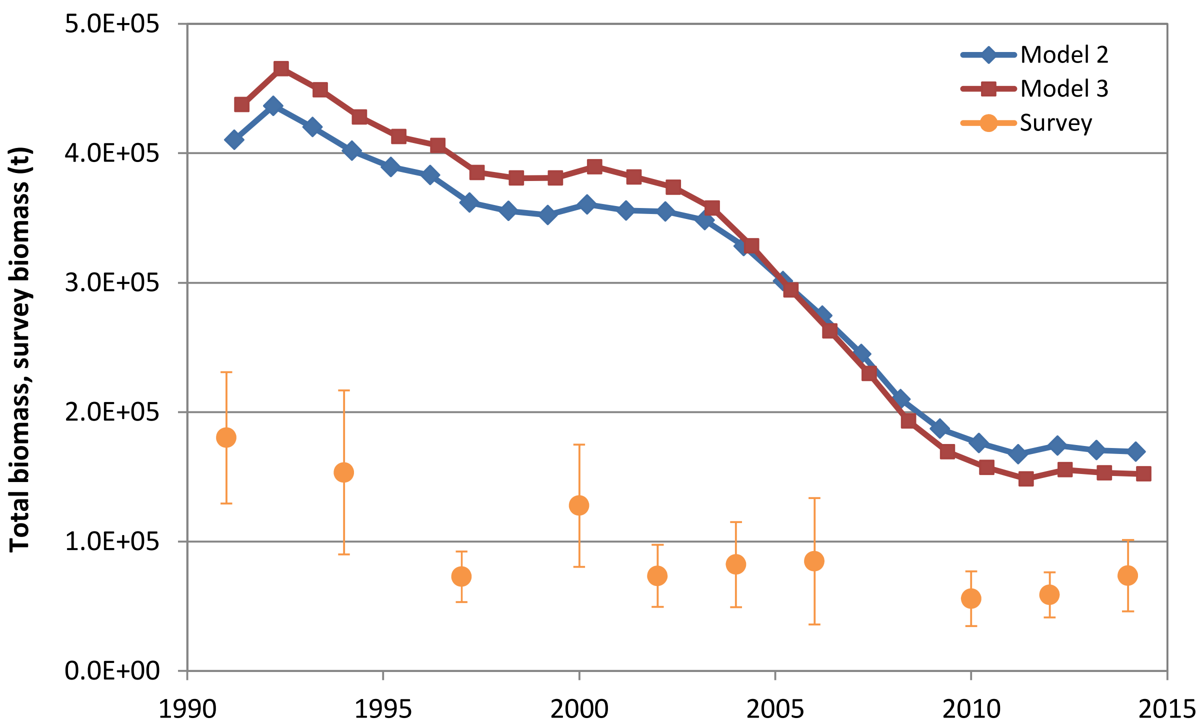
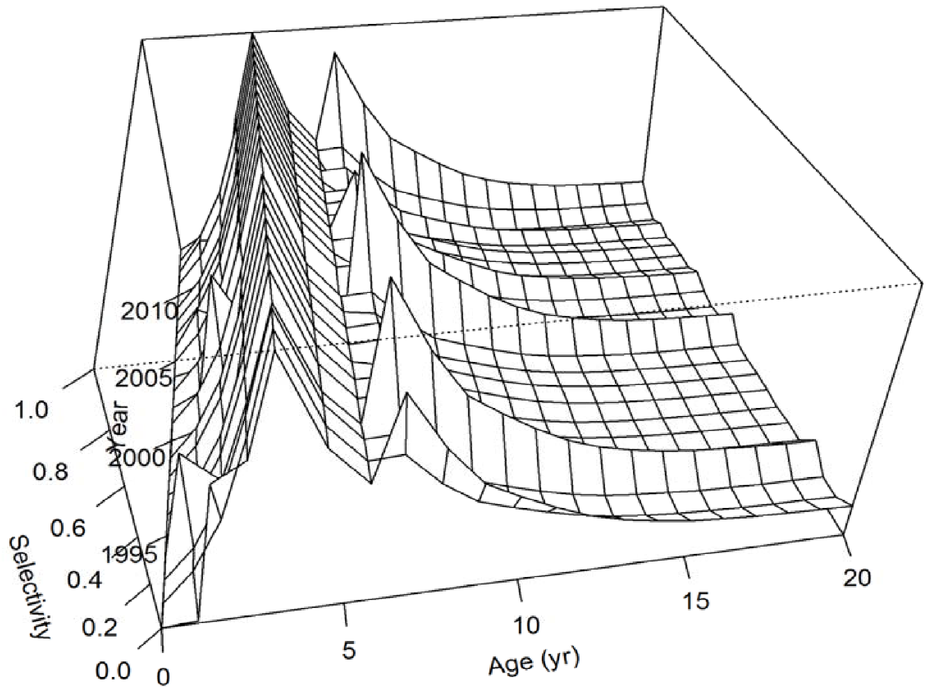


Figure 2A.11—Time series of total (age 0+) biomass as estimated by Models 1 and 2, together with survey biomass observations (horizontal axis values have been offset slightly to prevent over-plotting).

Model 2



Model 3

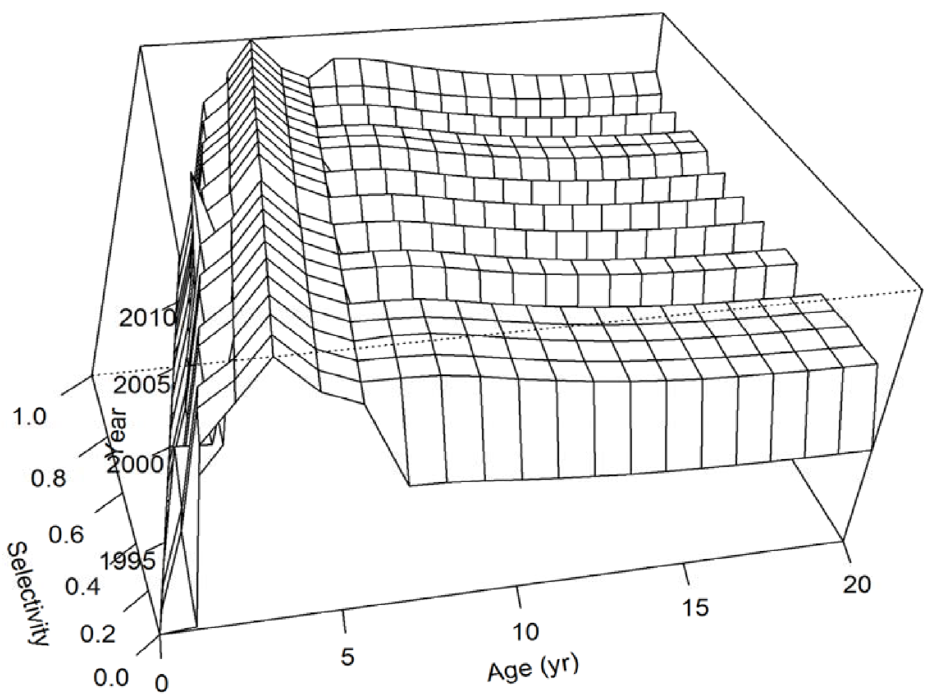
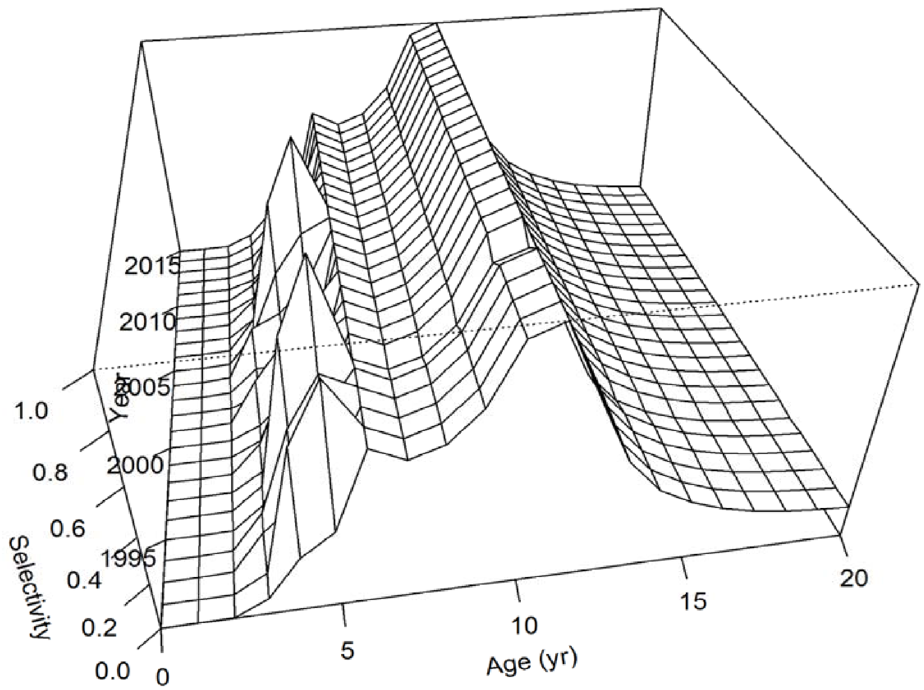


Figure 2A.12—Survey selectivity at age as estimated by Models 2 and 3.

Model 2



Model 3

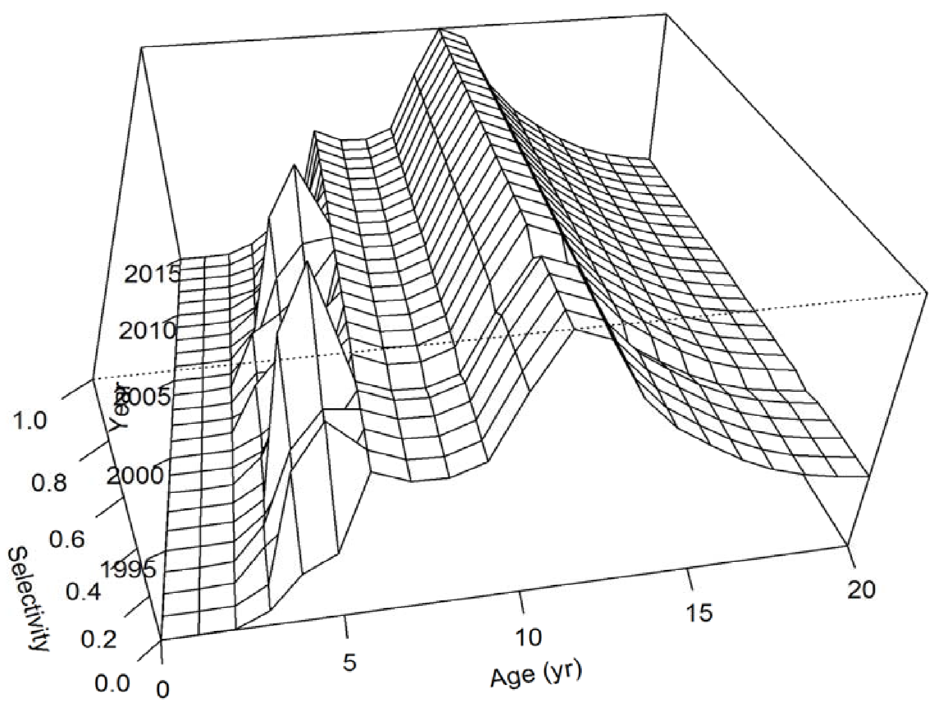
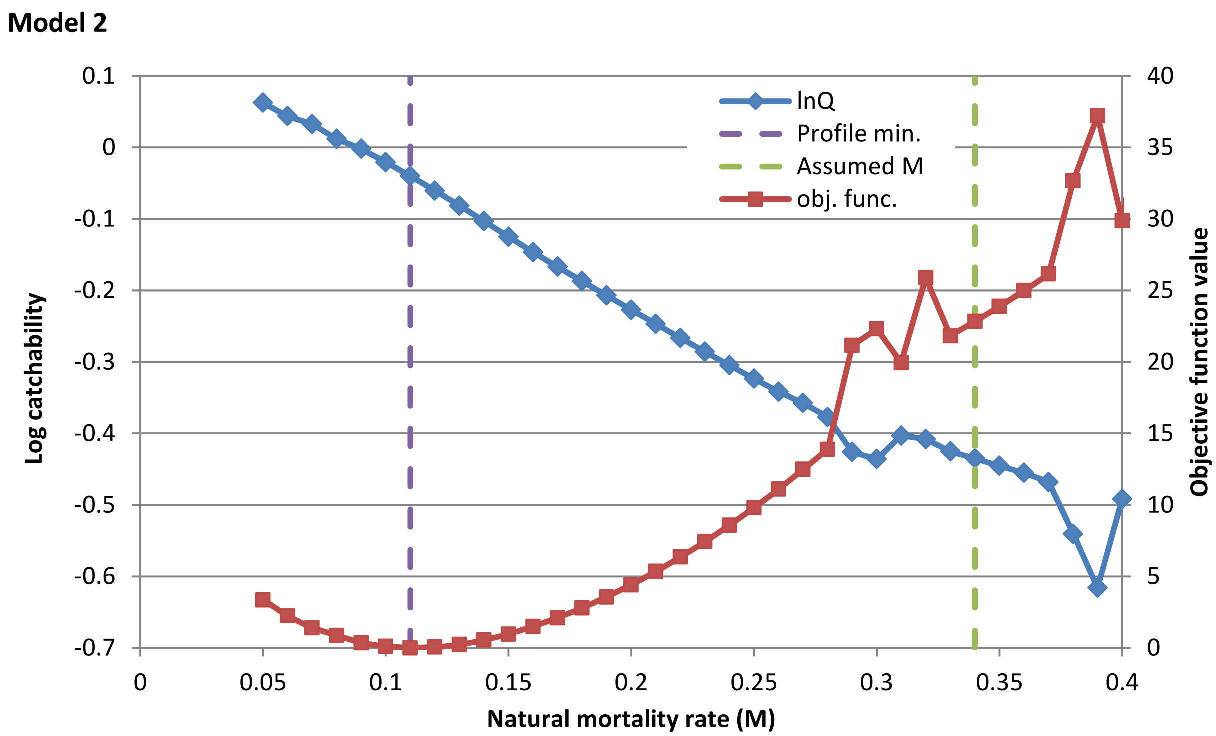


Figure 2A.13—Fishery selectivity at age as estimated by Models 2 and 3.



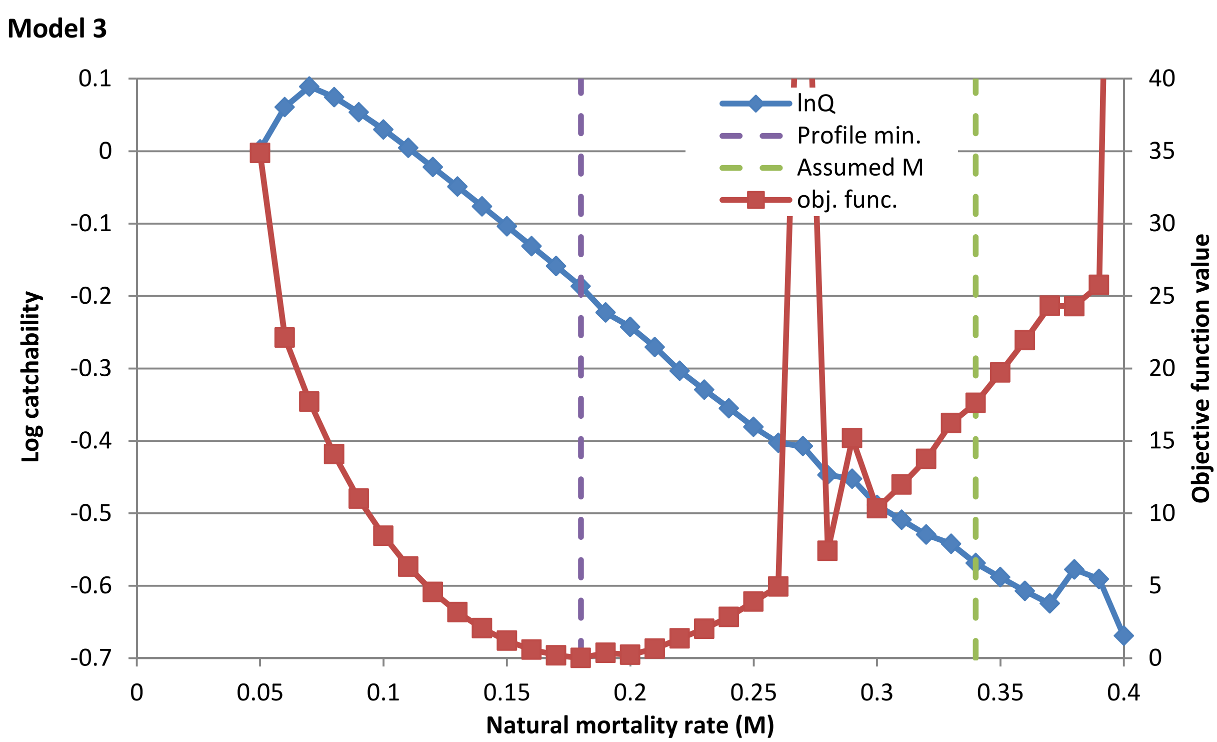


Figure 2A.14— Likelihood profiles with respect to the natural mortality rate for Models 2 and 3. Objective function minima occur at *M*=0.11 (Model 2) and *M*=0.18 (Model 3). The relationship between *M* and log *Q* is also shown. The jagged shapes for high values of *M* are likely due to lack of convergence in some runs.

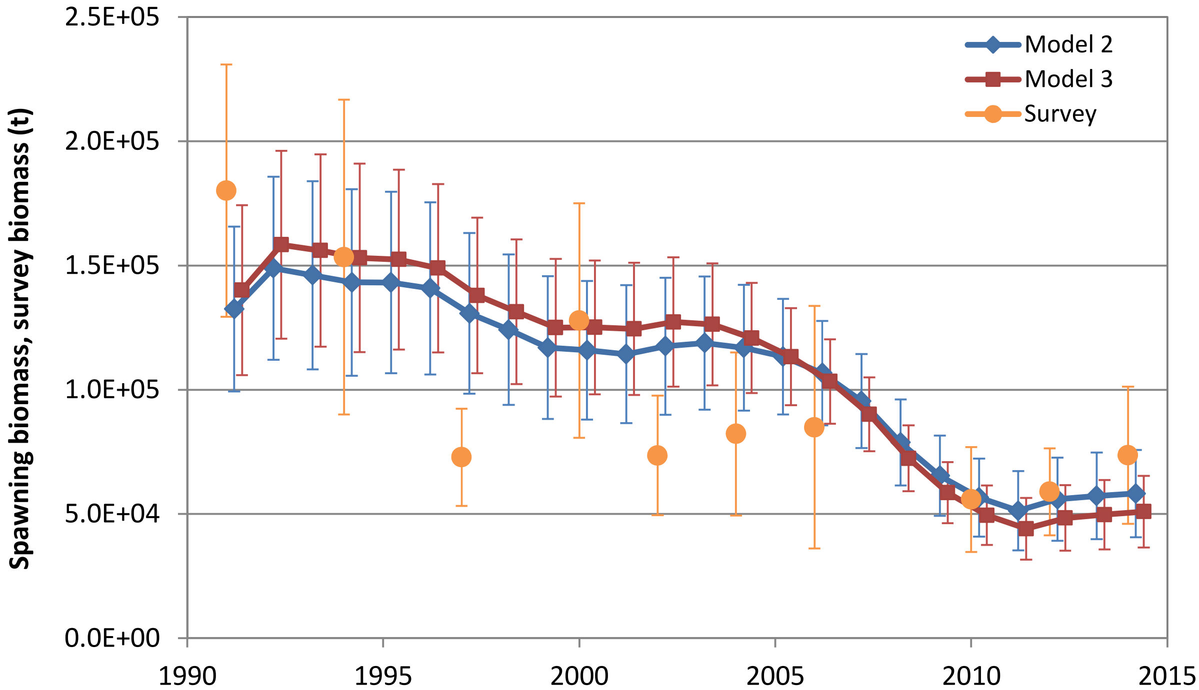


Figure 2A.15—Time series of female spawning biomass as estimated by Models 2 and 3, with 95% confidence intervals. Survey biomass is shown for comparison.

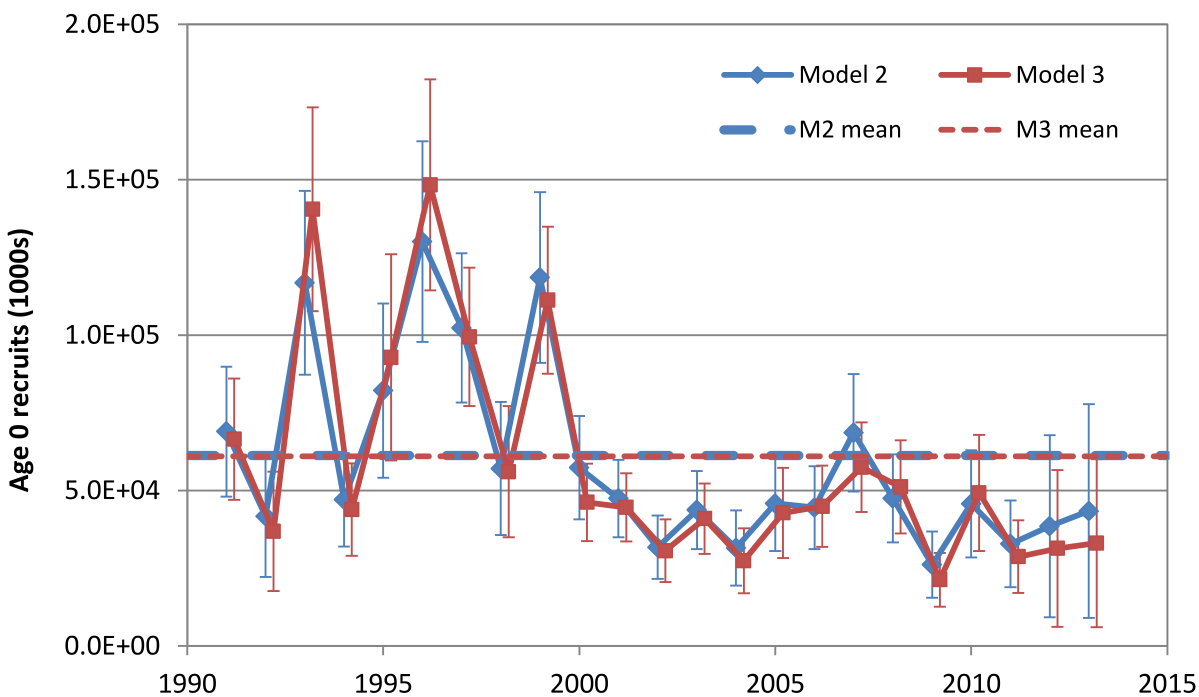
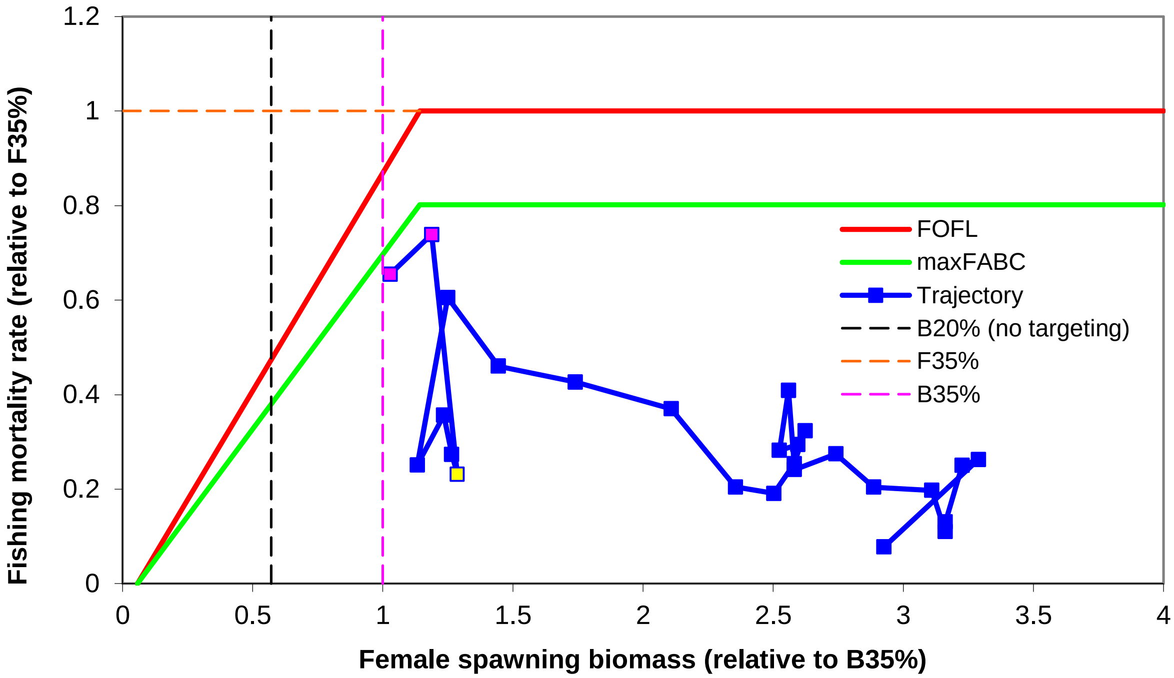


Figure 2A.16—Time series of recruitment at age 0 as estimated by the stock assessment model (horizontal axis values have been offset slightly to prevent over-plotting).

Model 2



Model 3

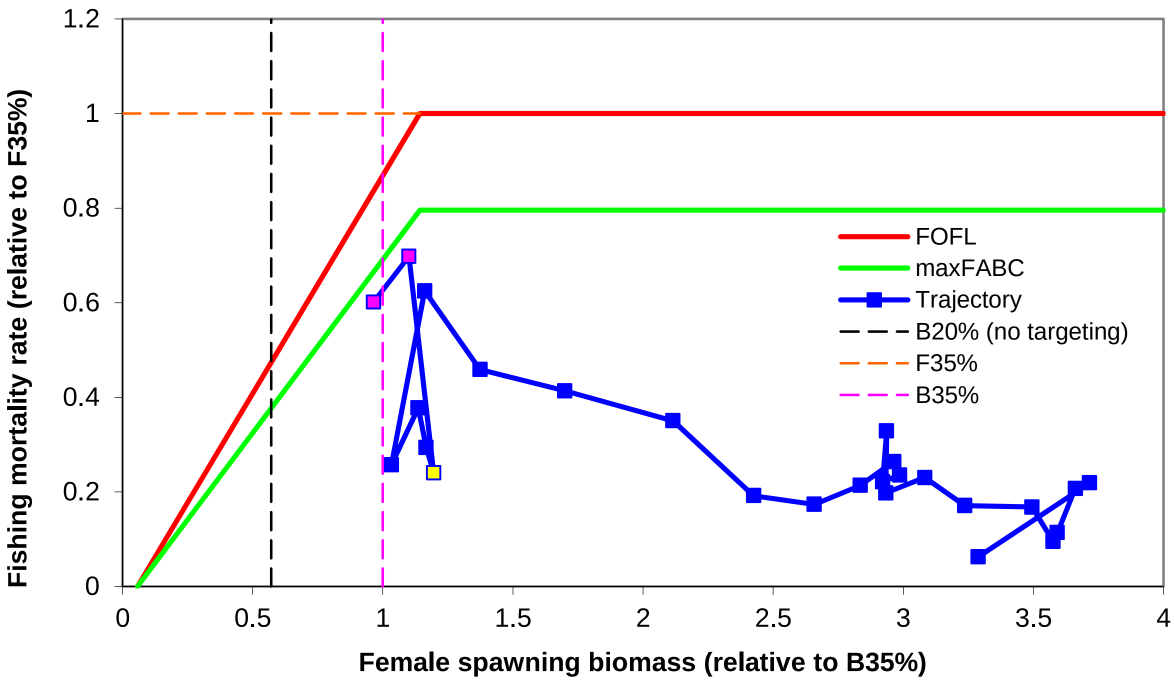
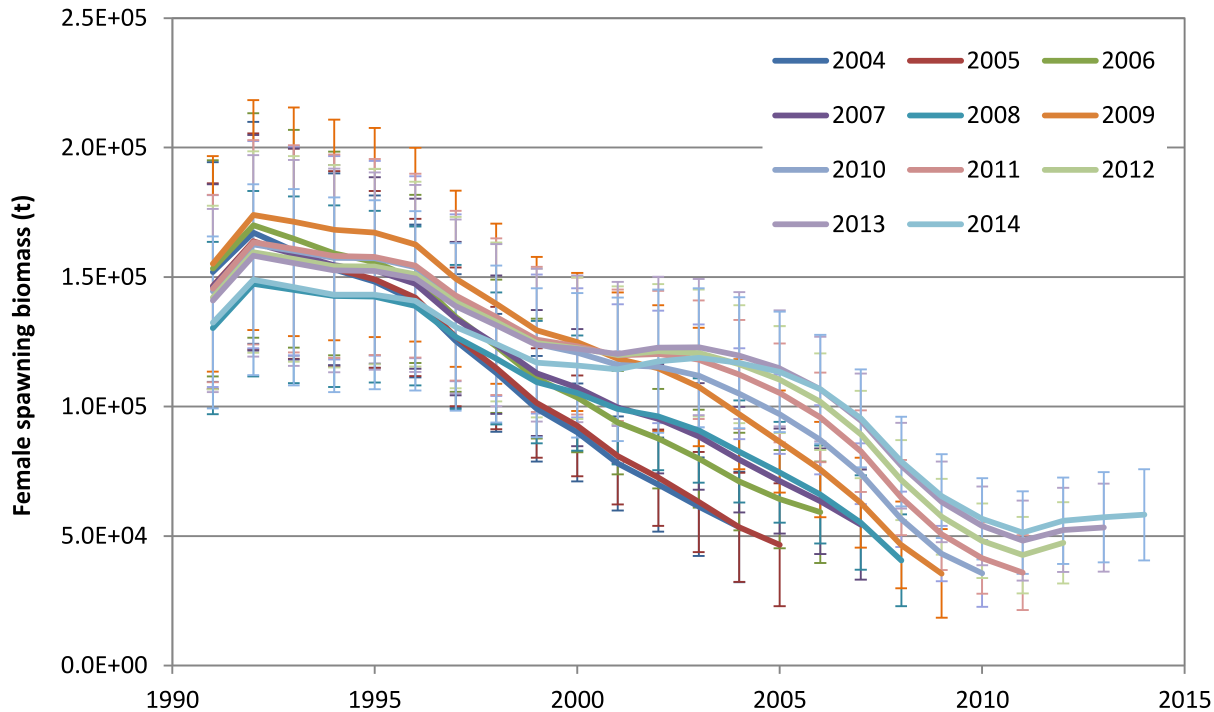


Figure 2A.17—Trajectory of AI Pacific cod fishing mortality and female spawning biomass as estimated by Models 2 and 3, 1991-present (yellow square = 2014, magenta squares = first two projection years).



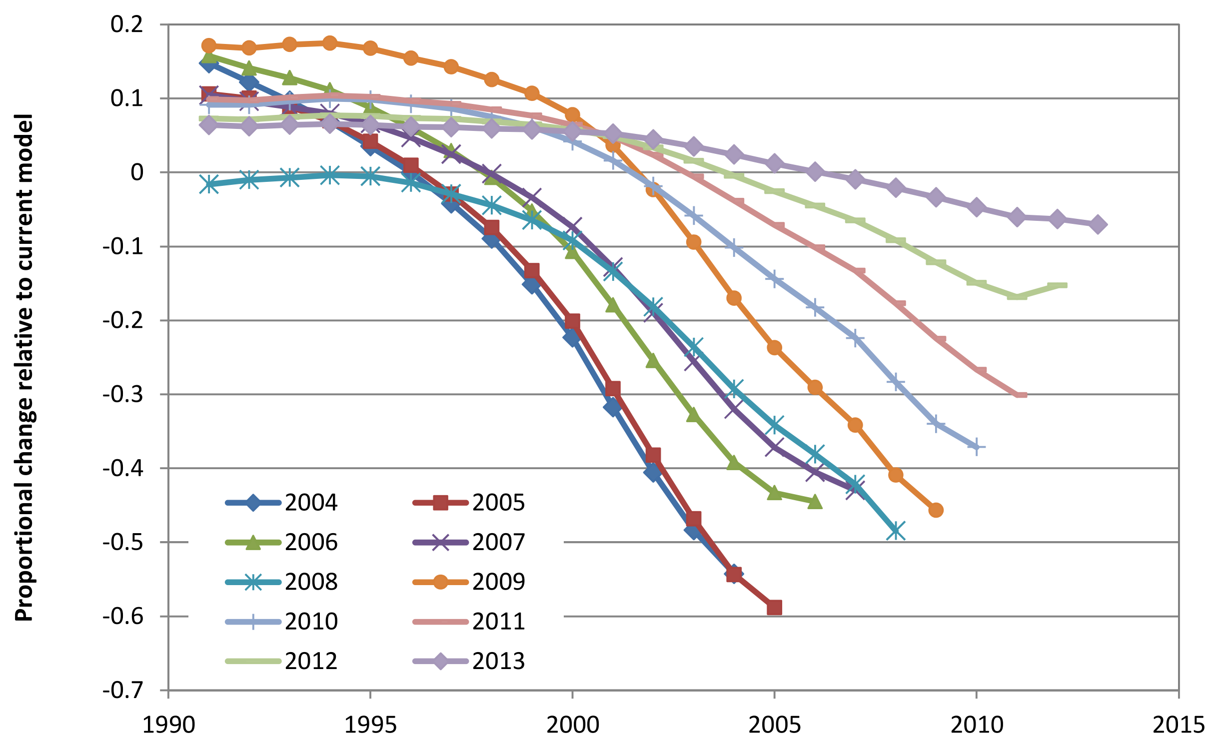
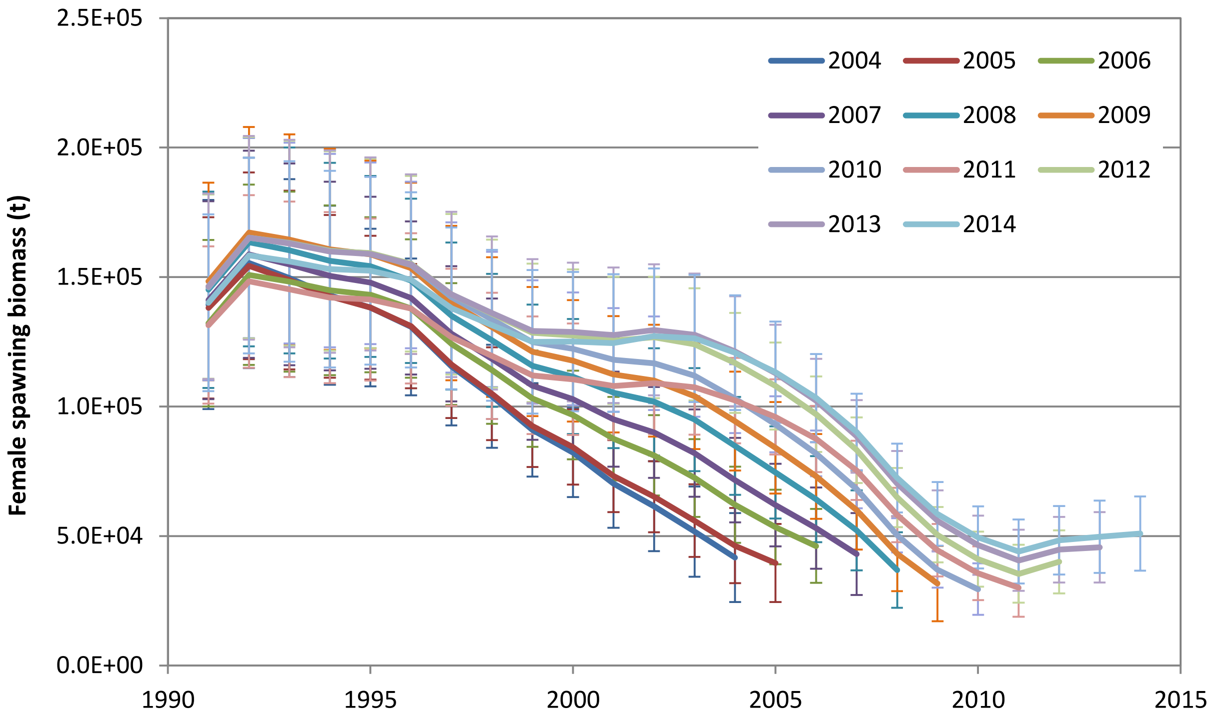


Figure 2A.18a—Retrospective analysis of spawning biomass estimates from Model 2. Top panel: spawning biomass time series with 95% confidence intervals from the current version of Model 2 (2014) and 10 retrospective runs (2004-2013) obtained by dropping one year of data at a time. Bottom panel: change in spawning biomass relative to the current version of Model 2 for each of 10 retrospective runs.



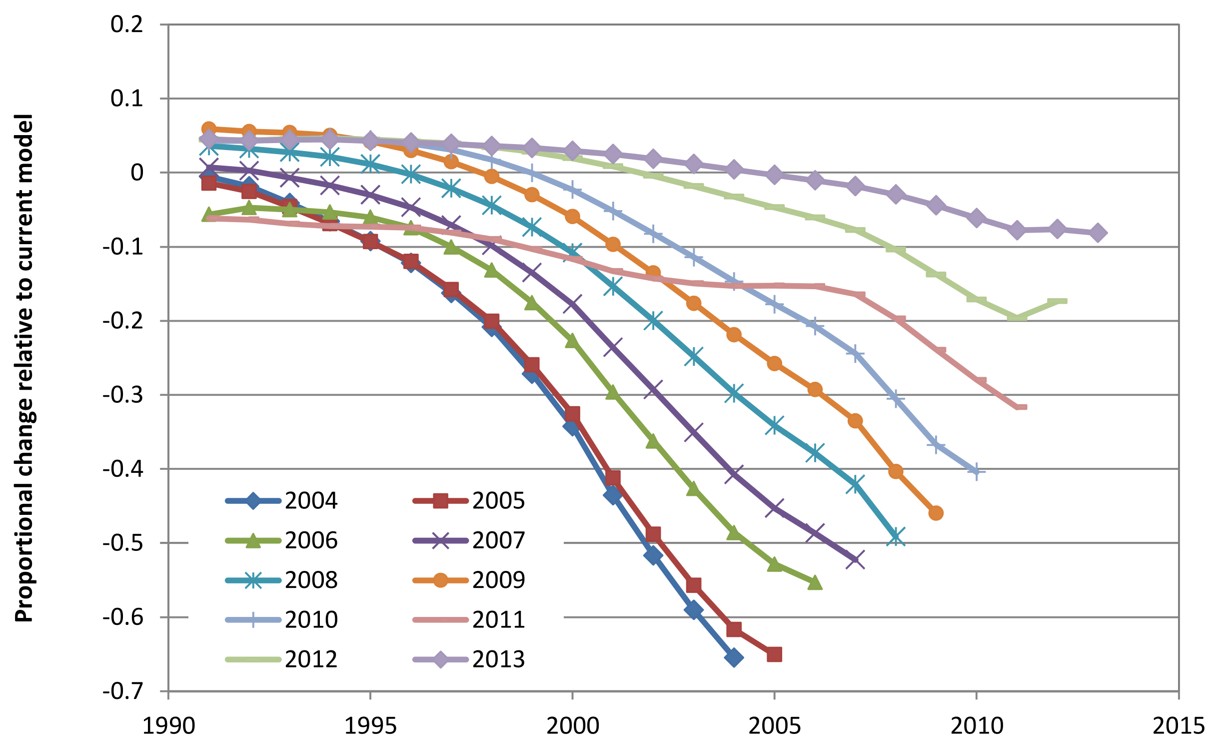


Figure 2A.18b—Retrospective analysis of spawning biomass estimates from Model 3. Top panel: spawning biomass time series with 95% confidence intervals from the current version of Model 3 (2014) and 10 retrospective runs (2004-2013) obtained by dropping one year of data at a time. Bottom panel: change in spawning biomass relative to the current version of Model 3 for each of 10 retrospective runs.

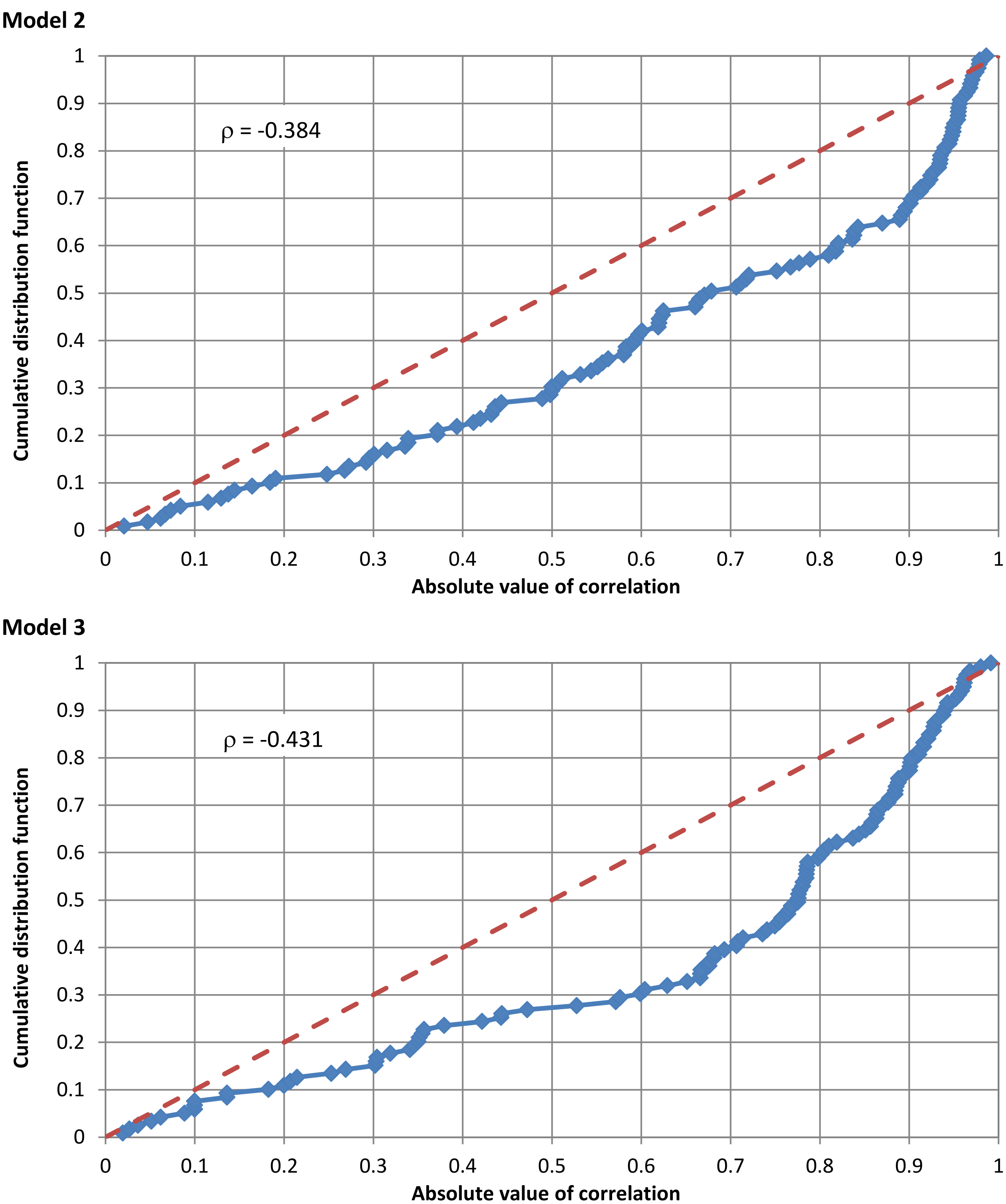


Figure 2A.19—Cumulative distribution function (cdf) of correlations (absolute value) between parameters and number of "peels" in retrospective runs in Models 2 and 3. The diagonal dashed line represents the cdf that would be obtained from a uniform distribution. The statistic ρ represents the average (across peels) relative bias in terminal year estimates of spawning biomass.

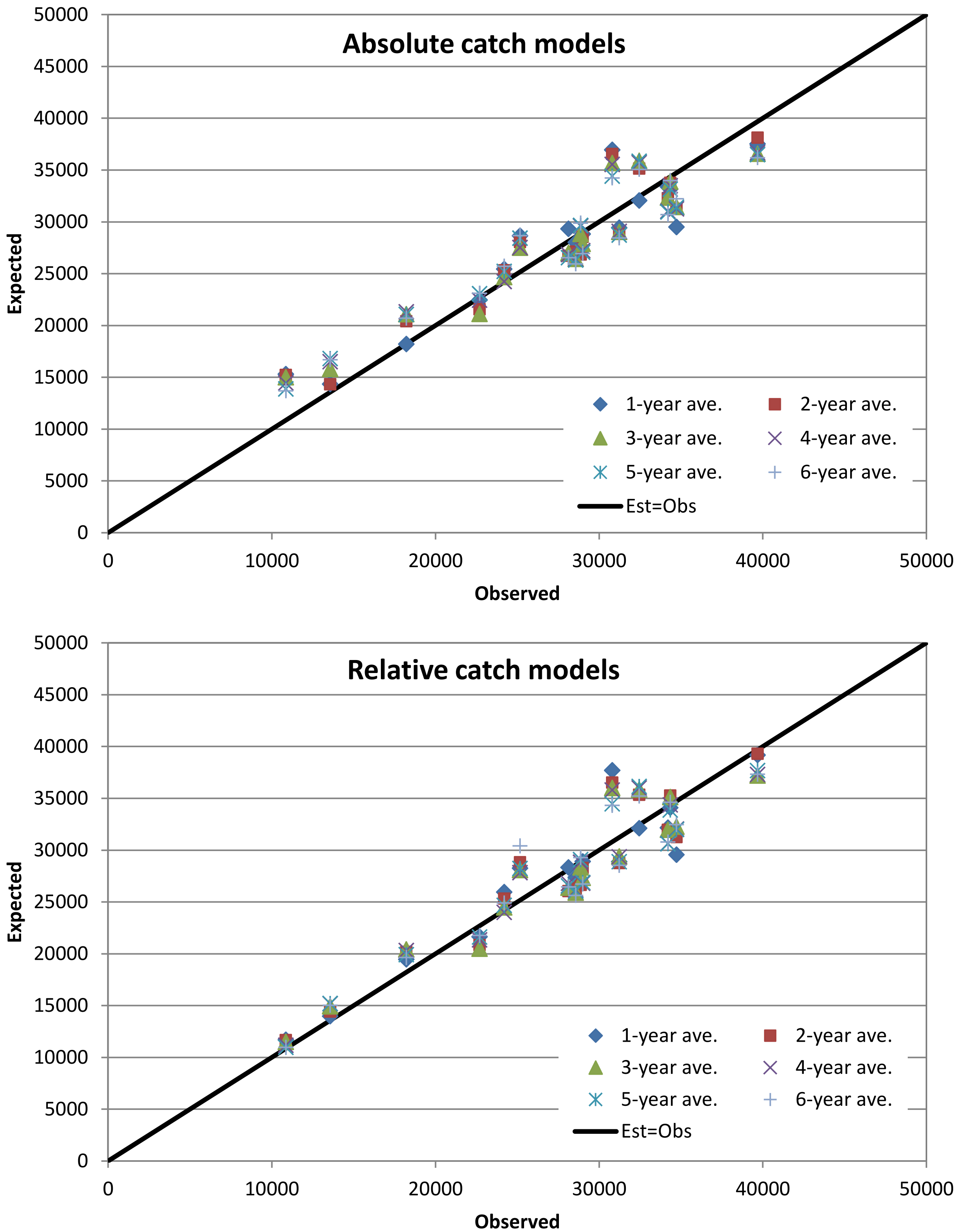


Figure 2A.20—Estimators of current-year catch as a function of either absolute or relative August-December catch in some number (1-6) of previous years. Estimators with symbols closer to the diagonal line are better than others.

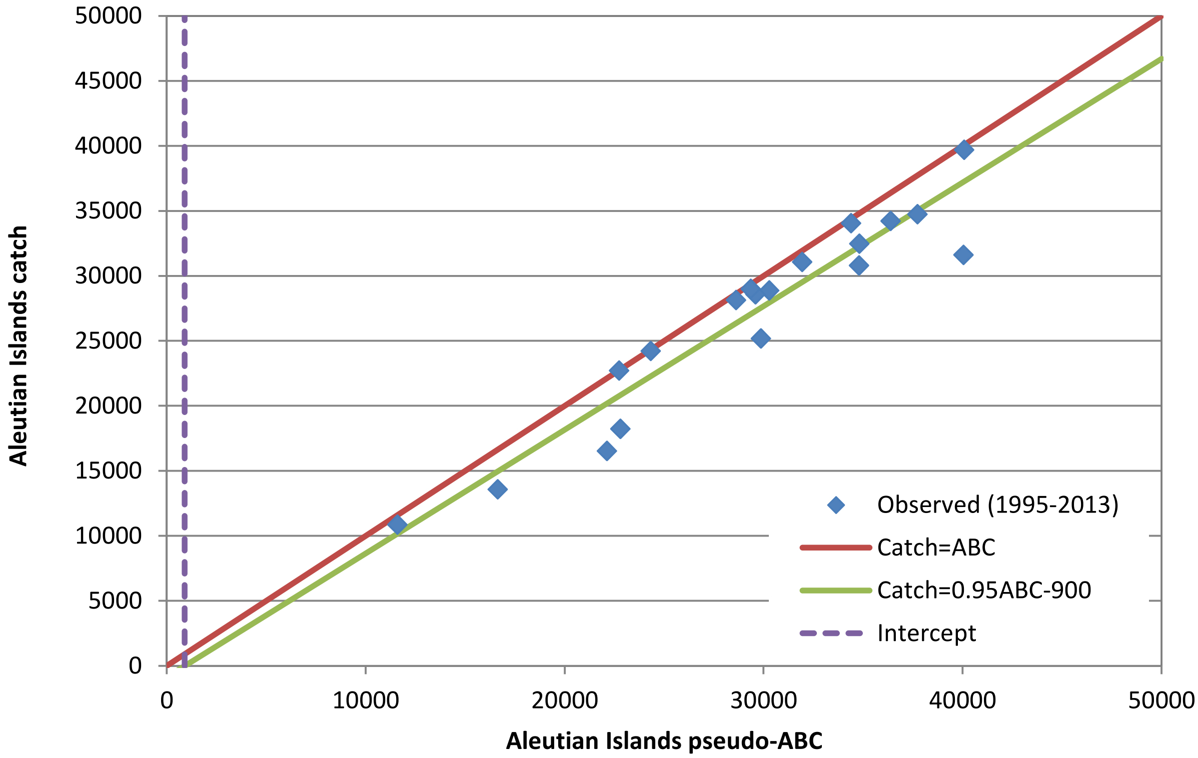


Figure 2A.21—Estimation of catch as a function of ABC. Because Pacific cod ABCs through 2013 were specified for the entire BSAI region, "pseudo-ABCs" are shown here, computed by multiplying the overall ABC by the proportion of BSAI catch taken in the AI. The estimator represented by the green line was used to project 2015 and 2016 catch for Models 2 and 3.

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 BSAI Plan Team, the joint BSAI and GOA Plan Teams, and the SSC regarding the need to develop an age-structured model of the Pacific cod (*Gadus macrocephalus*) stock in the Aleutian Islands (AI). The age-structured models presented in last year's stock assessment (Thompson and Palsson 2013) were not accepted for use by the BSAI Plan Team or SSC.

Responses to SSC and Plan Team Comments on Assessments in General

Because last year's SSC and Plan Team comments pertaining to assessments in general all dealt with features of the final SAFE chapters, they will be addressed in this year's final assessment.

Responses to SSC and Plan Team Comments Specific to Aleutian Islands Pacific Cod

Note: In previous years, the full Joint Plan Teams have met in the spring to consider recommendations for models to be included in that year's Pacific cod assessments. In 2014, this task was delegated to a Joint Team Subcommittee (JTS) on Pacific Cod Models. All comments specific to AI Pacific cod from the September 2013 BPT and October 2013 SSC meetings were addressed in the 2013 final assessment.

BPT1 (11/13 minutes): *"For continued development of a Tier 3 assessment, the Team recommended:*

a. *forcing the regime change recruitment offset to zero*
b. *examining the usefulness of IPHC longline survey data, and*
c. *continuing to monitor commercial CPUE."*

Subsequent conversation with Team members clarified that only item (a) in the above list was a model proposal; the other two items were comments not directly related to development of a new model. For item (a), see comment JTS1. No progress has been made on items (b) or (c).

SSC1 (12/13 minutes): *"The SSC encourages further work on the age-structured models. Some of the issues are very similar to those in the Bering Sea, in particular the appropriate shape of the selectivity function. The SSC notes that selectivity was modeled differently in the AI model using an empirical and more flexible approach, although the model with asymptotic selectivity (and estimated Q) produced a better fit."* Further work on the age-structured models is described in this preliminary assessment. The empirical and more flexible approach described in this comment was retained, with some modification, in this preliminary assessment. One of the models described here imposes asymptotic selectivity, and all three models estimated survey catchability (Q) internally. See also response to comment JTS1.

SSC2 (12/13 minutes): *"At this still early stage of model development, the SSC does not want to be overly prescriptive, but suggests bringing forward models that:*

a. focus on exploring the effects of different shapes of selectivity-at-age,
b. including a model with asymptotic selectivity."

Different shapes of the selectivity-at-age schedule are explored in the models presented in this preliminary assessment, and a model with forced asymptotic selectivity is included. See also response to comment JTS1.

JTS1 (3/14 minutes): *"For the AI, the subcommittee recommended that the following models be developed for this year's preliminary assessment:*

- *Model 1: A new model (author's choice) with the regime change recruitment offset fixed at 0.0*
- *Model 2: A new model (author's choice) with alternative selectivity specification(s)*
- *Model 3: A new model (author's choice) with forced asymptotic selectivity*

The subcommittee noted that the above list includes both of the model proposals contained in the SSC's December 2013 minutes. The subcommittee also suggested that obtaining a much larger supply of age data from the AI is more important than development of additional models at this point." This preliminary assessment includes all of the models requested in this comment. Additional age data are expected to be available in time for use in this year's final assessment.

SSC3 (4/14 minutes): *"The process for developing and refining appropriate models for Pacific cod still needs to mature and the SSC recommends that the assessment authors continue to work with the subcommittee to refine this process."* The authors will continue to work with the subcommittee to refine the process of developing appropriate models for Pacific cod. The next meeting of the subcommittee is anticipated to take place in the spring of 2015.

SSC4 (4/14 minutes): *"For 2014, the SSC recommends as an alternative model the use of the time-varying, non-parametric selectivity function described above"* (the reference to "above" in this comment pertains to a recommendation for modeling selectivity as a random walk with respect to age in the GOA Pacific cod assessment). Given the lack of any language to the contrary, it will be assumed that the SSC accepts the list of models recommended by the JTS, with the understanding that random walk selectivity is included in the "alternative selectivity specification(s)" requested for Model 2 in comment JTS1.

SSC5 (4/14 minutes): *"Additionally, profiling over the natural mortality rate should be conducted to gain a better understanding of the relationship between global scaling (Q and its associated priors) and natural mortality rate. The mode of the M-profile should not be used as a basis for setting the natural mortality rate in the model as it is conditional on other structural assumptions in the model."* Likelihood profiles with respect to the natural mortality rate are included for all models in this preliminary assessment. The mode is not used for setting the natural mortality rate in any of the models.

SSC6 (4/14 minutes): *"Lastly, the SSC recommends that as an overarching goal for these three areas, a common model structure be explored and based on the biology of Pacific cod and not devolve over time to address area-specific outliers or retrospective biases"* (the "three areas" referred to in this comment are the EBS, AI, and GOA). The model structures for all three areas already share several features in common. As further steps toward developing a common model structure, all models in this preliminary assessment of the AI stock and Model 6 in the preliminary assessment of the EBS stock use the same fleet structure and the same approach to selectivity.

SSC7 (4/14 minutes): *"The SSC clarified its intent regarding the use of the base model ('base' being used here to identify the model accepted by the SSC in the previous year) for 'several' years. While the SSC cannot be prescriptive about the exact length of time this would be, the idea is to continue the use of the model until there is general agreement by the stock assessment authors, the Plan Team, and the SSC on discontinuing its use."* This comment was directed primarily toward the EBS and GOA Pacific cod assessments, where age-structured models have been in use for several years. In the case of the AI Pacific cod stock, no age-structured model has yet been accepted for use. The existing management approach is based on Tier 5, applying a random effects model to the survey biomass time series in order to obtain the best estimate of current biomass. The authors understand that this approach will continue to be used until such time as the SSC adopts a different approach.

SSC8 (4/14 minutes): *"The SSC discussed the use of model averaging to ameliorate some of the problems of choosing among competing models with substantially different estimates. Essentially, the SSC agrees with the analyst that this approach should not be used until progress is made regarding issues about the selection of the competing models and averaging over models with nonlinearities in population and fishery processes."* Model averaging is not used in this preliminary assessment.

SSC9 (4/14 minutes): *"The SSC also discussed the nomenclature used to specify models in a historical context (when introduced and the model designator). While the SSC understands that this was useful for the historical presentation, it also notes that the nomenclature is confusing and probably not useful for the assessment in a given year. Furthermore, the use of "base model" to denote any model that is proposed seems overly inclusive and perhaps should be restricted to the chosen model in a previous assessment year."* Use of the term "base model" will henceforth be restricted to denoting the chosen model in a previous assessment year.

Data

The data file used for all three models presented here is identical to that used in last year's final assessment, with two exceptions:

1. Data prior to 1991 were removed, because last year's models had difficulty giving reasonable estimates of biomass and fishing mortality during the early years of the time series. Note that survey data from prior to 1991 had already been removed from last year's file.
2. Weighting of size composition data was adjusted so that the average (across years) was 300 for the fishery and 300 for the survey (in last year's assessment, the weighting achieved an average of 300 for the fishery and survey combined; the new adjustment results in more weight being given to the survey than before).

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

Source	Type	Years
Fishery	Catch biomass	1991-2012
Fishery	Catch size composition	1991-2012
AI bottom trawl survey	Numerical abundance	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012
AI bottom trawl survey	Size composition	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012

Analytic Approach

Model Structure

Per request of the Joint Team Subcommittee on Pacific Cod Models and the SSC, the following three models are presented in this preliminary assessment, all of which are estimated using Stock Synthesis (SS, Methot and Wetzel 2013):

- Model 1: A new model (author's choice) with the regime change recruitment offset fixed at 0.0
- Model 2: A new model (author's choice) with alternative selectivity specification(s)
- Model 3: A new model (author's choice) with forced asymptotic selectivity

All three are based on the models from last year's final AI assessment, which in turn were based on the accepted EBS model for 2012 (Thompson and Lauth 2012). Some of the main differences between last year's AI models and the 2012 EBS model were 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. Initial abundances were estimated for the first ten age groups instead of the first three.
6. 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. Selectivity-at-age pattern #17 in SS has one parameter for each age in the model. Except for age 0, the parameter for any given age represents the logarithm of the ratio of selectivity at that age to selectivity at the previous age (i.e., the backward first difference on the log scale). Age 0 fish are often expected to have a selectivity of zero, which can be achieved in this selectivity pattern by setting the parameter for age 0 equal to -1000, as was done for all three models presented here. As with other parameters in SS, each parameter in this selectivity pattern is associated with a prior distribution (see "Loop #1" under "Iterative Tuning Procedures Used for Model 2," below).

The three models presented in this preliminary assessment all include the following features, which represent additional departures from the 2012 EBS model:

1. The logarithm of survey catchability, ln(Q), was treated as a free parameter, with a normal prior distribution whose parameters were derived by averaging those used in other age-structured assessments of AI groundfish (similar to Model 2 in last year's preliminary and final assessments).
2. 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.
3. 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) where the sigma term was tuned according to the method described Thompson and Lauth (2012, Annex 2.1.1).

Except for the ln(Q) parameter and the selectivity and *dev* parameters in all models, all parameters were estimated with uniform prior distributions.

Model nomenclature follows that suggested in comment JTS1. Chronologically, model development proceeded as follows:

- Model 2 was developed first, with no constraint on the shape of the selectivity schedule other than that imposed by the prior distributions. For the vector of numbers at age in the initial year, SS allows the user to specify how many age groups to estimate as individual parameters, with the understanding that the remaining age groups are in equilibrium under an initial catch and mean recruitment level. The mean recruitment used to compute the equilibrium portion of the initial vector can be forced to equal the mean recruitment used for the remainder of the time series, or it can be allowed to differ, which is done by estimating a "recruitment offset" parameter. As in the EBS model, the recruitment offset parameter was estimated freely in Model 2.
- Model 1 was based on Model 2. The only change from Model 2 was that the recruitment offset parameter was fixed at a value of 0 in Model 1.
- Model 3 was also based on Model 2. The only changes from Model 2 were 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).

Development of the final versions of all models included calculation of the Hessian matrix. These models also passed a "jitter" test of 50 runs with a jitter parameter (equal to half the standard deviation of the logit-scale distribution from which initial values are drawn) of 0.01. 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 became the new base run, and 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.

Except for the ln(*Q*) parameter and the selectivity and *dev* parameters in all models, all parameters were estimated with uniform prior distributions. Bounds were non-constraining in all cases.

The software used to run all models was SS V3.24s, as compiled on 7/24/2013 (Methot 2013). Stock Synthesis is programmed using the ADMB software package (Fournier et al. 2012).

Iterative Tuning Procedures Used for Model 2

Because this preliminary assessment is only an exploration of alternative models, and in the interest of time, the following procedures were applied to Model 2 only (i.e., Models 1 and 3 used the tuned quantities from Model 2, rather than retuning these quantities individually for Models 1 and 3).

Three main loops were involved in the iterative tuning procedure:

4. Tuning the means of the prior distributions for the selectivity parameters.
5. Estimating "unconstrained" values of the standard deviations of the selectivity *dev*s.
6. Estimating "iterated" values of the standard deviations for the selectivity *dev*s.

Following the iterative procedure, the model was run with final estimates of the standard deviations for the selectivity *dev*s, which were estimated from a formula involving the results of loops #2 and #3.

The loops are described in more detail below.

Loop #1: tuning the parameters of the prior distributions for the selectivity parameters

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

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

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. The converged set of prior means (on the transformed scale, not the selectivity scale) was as follows (ages 7+ all had prior means of 0 for both the fishery and the survey):

Age:	1	2	3	4	5	6
Fishery:	3.290	3.280	3.049	1.380	0.117	0.005
Survey:	5.295	0.846	0.004	0.000	0.000	0.000

The converged prior standard deviations were 0.342 for the fishery and 0.319 for the survey (both constant across age).

Loop #2: Estimating "unconstrained" values of the standard deviations of the selectivity devs

Loops #2 and #3 were designed to produce the quantities needed to use the method of Thompson and Lauth (2012, Annex 2.1.1) for estimating the standard deviation of a *dev* vector. The purpose of Loop #2 was to determine the value of the selectivity *dev* vector (for either the fishery or the survey) that would be obtained if the *dev*s were completely unconstrained by their respective σs. 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 focus on one fleet (fishery or survey) at a time; 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.

Loop #3: Estimating "iterated" values of the standard deviations for the selectivity devs

Again proceeding one fleet (fishery or survey) at a time, this loop began with age-specific σs set at the unconstrained values estimated in Loop #2. The standard deviations of the estimated *dev*s then became the age-specific σs for the next run, and the process was repeated until the σs converged.

It is common for some ages to be "tuned" out during Loop #3 (i.e., the σs converge on zero). For Model 2, all ages were tuned out except the following (these are final values of σ, after application of the algorithm described by Thompson and Lauth (2013, Annex 2.1.1), shown in parentheses):

Fishery: age 4 (0.092), age 6 (0.237)
Survey: age 2 (0.194), age 3 (0.078), age 7 (0.442).

Because survey selectivity for Model 2 peaked at age 4, survey selectivity *dev*s were turned off for age 7 in Model 3 (because it required asymptotic selectivity).

Parameters Estimated Outside the Assessment Model

Some parameters were fixed externally at values borrowed from the EBS Pacific cod model:

1. The natural mortality rate was fixed at 0.34.
2. The parameters of the logistic maturity-at-age relationship were set at values of 4.88 years (age at 50% maturity) and –0.965 (slope) in all models.

In all three models, weight (kg) at length (cm) was assumed to follow the usual form weight=A×length^B and to be constant across the time series, with A and B estimated at 5.683×10^{-6} and 3.18, respectively, based on 8,126 samples collected from the AI fishery between 1974 and 2011.

Parameters Estimated Inside the Assessment Model

Parameters estimated inside SS for all models include the von Bertalanffy growth parameters; standard deviation of length at ages 1 and 20; ageing bias at ages 1 and 20; log mean recruitment since the beginning of the time series; offset for log mean recruitment prior to the beginning of the time series (Models 2 and 3 only); *dev*s for log-scale initial (i.e., 1991) abundance at ages 1 through 10; annual log-scale recruitment *dev*s for 1991-2011; initial (equilibrium) fishing mortality; base values for all fishery and survey selectivity parameters; and annual *dev*s for the selectivity parameters corresponding to ages 4 and 6 in the fishery, and ages 2, 3, and 7 (Models 1 and 2 only for age 7) in the survey.

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

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

Likelihood Components

All three models include likelihood components for initial (equilibrium) catch, trawl survey relative abundance, fishery and survey size composition, survey age composition, recruitment, prior distributions, "softbounds" (equivalent to an extremely weak prior distribution used to keep parameters from hitting bounds), and parameter deviations.

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

Results

Overview

The following table summarizes the status of the stock as estimated by the three models ("Value" is the point estimate, "SD" is the standard deviation to the point estimate, "FSB 2014" is female spawning biomass in 2014 (t), and "Bratio 2014" is the ratio of FSB 2014 to $B_{100\%}$:

	Model 1		Model 2		Model 3	
Quantity	Value	SD	Value	SD	Value	SD
FSB 2014	52,229	8,748	51,751	8,753	31,922	4,996
Bratio 2014	0.395	0.047	0.387	0.049	0.254	0.046

For these two quantities, the estimates from Models 1 and 2 are fairly similar, with the estimates from Model 3 being substantially lower.

Goodness of Fit

Objective function values are shown for each model below (lower values are better, all else being equal; objective function components with a value less than 0.0005 for all models are omitted for brevity; color scale extends from red (minimum) to green (maximum); note that the parameter counts include constrained deviations):

Component	Model 1	Model 2	Model 3
Survey index	-8.838	-9.129	-1.972
Size composition (fishery)	93.943	92.256	108.043
Size composition (survey)	190.720	190.479	217.886
Age composition	2.967	2.849	5.462
Recruitment	-0.303	2.171	21.367
Priors	17.463	16.606	17.808
"Softbounds"	0.001	0.001	0.006
Parameter devs	11.621	11.557	19.990
Total	307.574	306.789	388.591
Number of parameters	196	197	158
AIC	1007.148	1007.578	1093.182

Model 1 has one fewer parameter than Model 2 (the initial recruitment offset), and Model 3 has 39 fewer parameters than Model 2 (all selectivity parameters, although most of them are constrained deviations, and so should not be counted as full parameters).

Figure 2A.1.1 shows the fits of the three models to the trawl survey abundance data. All three models estimate a 2012 survey biomass close to the observed value. Models 1 and 2 tend to overestimate the survey abundance, although usually not by much. Model 3 has the best mix of positive and negative residuals, but does not perform as well as the other models by most other measures, as shown below (for comparison to the root mean squared residual, the average log-scale standard error in the data is 0.184; color scale extends from red (minimum) to green (maximum)):

Quantity	Model 1	Model 2	Model 3
Correlation (observed:expected)	0.959	0.954	0.695
Root mean squared residual	0.190	0.184	0.303
Mean standardized residual	-0.701	-0.656	-0.582
Root mean squared standardized residual	1.225	1.198	1.740

Models 1 and 2 do better than Model 3 by all of the above measures except mean standardized residual.

Figure 2A.1.2 shows the models' fits to the fishery size composition data, and Figure 2A.1.3 shows the models' fits to the survey size composition data. Effective sample sizes and negative log likelihoods for the size composition data are shown in Table 2A.1.1. All three models give effective sample sizes far above the mean input sample sizes for both the fishery and the survey. The performances of Models 1 and 2 are very similar, giving slightly higher effective sample sizes and slightly lower (better) negative log likelihoods than Model 1.

Figure 2A.1.4 shows the models' fits to the single available year of survey age composition data. Effective sample sizes and negative log likelihoods are shown below. Models 1 and 2 both give effective sample sizes far above the input sample size, while the effective sample size given by Model 1 is slightly below the input sample size. Again, Models 1 and 2 give slightly lower (better) negative log likelihoods than Model 1.

			Effective sample size			Negative log likelihood		
Fleet	Year	N	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Survey	2012	300	730	769	286	2.967	2.849	5.462

Parameters, Schedules, and Time Series Estimates

Table 2A.1.2 lists the constants and parameters listed in the SS control files for the three models, along with standard deviations ("SD") for all estimated parameters. Constants are listed in Table 2A.1.2a, main parameters (except selectivity) are listed in Table 2A.1.2b, base selectivity parameters are listed in Table 2A.1.2c, deviations (*dev*s) for fishery selectivity parameters are listed in Table 2A.1.2d, and deviations for survey selectivity parameters are listed in Table 2A.1.2e. Quantities with "n/a" listed under "SD" were fixed rather than estimated.

Selectivity schedules (fishery and survey) for Models 1, 2, and 3 are shown in Figures 2A.1.5a, 2A.1.5b, and 2A.1.5c, respectively. The schedules for Models 1 and 2 are very similar. The main difference between Model 3's selectivity schedules and those of Models 1 and 2 is the asymptotic nature of Model 3's survey selectivity (which was a design feature of Model 3).

Time series estimated by the three models are shown for female spawning biomass, relative (to $B_{100\%}$) female spawning biomass, and age 0 recruitment in Figures 2A.1.6, 2A.1.7, and 2A.1.8, respectively. Figures 2A.1.6 and 2A.1.7 are very similar except for scale. In these two figures, the values estimated by Model 1 are higher than those estimated by Model 2 for the early portion of the time series, but the two models converge by the end of the time series; both Models 1 and 2 estimate values that are higher than those estimated by Model 3 throughout the time series. In Figure 2A.1.8, the recruitments estimated by Models 1 and 2 are very similar, and again are consistently higher than those estimated by Model 3 throughout the time series.

Discussion

The structural differences between the three models presented in this preliminary assessment are simple: Models 2 and 3 estimate a recruitment offset which allows the average recruitment in the years preceding the start of the time series to differ from the average recruitment during the time series, whereas Model 1 forces the average recruitment to be the same during both periods. Models 1 and 2 allow survey selectivity to vary freely, except to the extent that they are constrained by their respective prior distributions, whereas Model 3 forces survey selectivity to be asymptotic.

In general, the differences between the estimates produced by Models 1 and 2 are small. However, some of the differences between Models 1 and 2 and Model 3 are substantial. For example, as reported in the "Overview" subsection of the "Results" section, Model 3's estimates of female spawning biomass in 2014 are 38-39% lower than those obtained by Models 1 and 2. The estimates of ln(Q), on the other hand, are fairly similar for all three models, with a range of -0.485 to -0.453, corresponding to a Q range of 0.616 to 0.636. These values imply that the survey misses at least 36-38% of even the most-selected age group.

Although the natural mortality rate M is not estimated internally in any of the models, Figure 2A.1.9 shows the likelihood profiles with respect to M for each of the models. If M were estimated internally, Models 1 and 2 would give an estimate (0.11) much lower than the value (0.34) that has been used in the EBS Pacific cod assessment for the last several years. This may indicate structural deficiencies in Models 1 and 2.

The three models presented here generally provide good-to-excellent fits to all three types of data (survey abundance index, size compostion, and age composition).

For all three models, data prior to 1991 were removed, because last year's models had difficulty giving reasonable estimates of biomass and fishing mortality during the early years of the time series (note that survey data from prior to 1991 had already been removed from last year's file). Although the problematic estimates are now gone, it may be worth considering further whether removal of all pre-1991 data is an appropriate way to address the issue.

Additional age data from the AI bottom trawl survey are expected to become available in time for use in this year's final assessment. Given that only a single year of age data was available for this preliminary assessment, it is possible that these additional data will affect the results of the models substantially.

Last year's preliminary assessment provided the first exploration of SS selectivity-at-age pattern #17 (random walk with age) for Pacific cod, and use of this pattern has been retained here. Some advantages of pattern #17 are the following:

1. Pattern #17 allows for use of prior distributions that are consistent with a logistic functional form without actually forcing the resulting selectivity schedule to be logistic.
2. Pattern #17 provides an alternative to the somewhat complicated parameterization of the double normal selectivity curve (which has been used in the EBS Pacific cod models for the last several years), in which the effects of some parameters are conditional on the values of other parameters, thus making it difficult to specify appropriate prior distributions.
3. The iterative tuning procedure used here for the means of the prior distributions provides a way to specify these quantities objectively and uniquely for each age.
4. Estimation of individual selectivities at age avoids the problem of mis-specifying a functional form *a priori*, which can have significant consequences (e.g., Kimura 1990, Clark 1999).

This preliminary assessment also emphasized the potential time variability of both fishery and survey selectivity. Although a scientific consensus on how (or whether) to address this phenomenon has yet to be achieved, some of the presentations at the 2013 CAPAM selectivity workshop (Crone et al., 2013) seemed to favor allowing selectivity to vary over time.

It should be emphasized that iterative tuning of the selectivity prior distributions and the sigma parameters for time-varying selectivity was applied only to Model 2, with Models 1 and 3 simply "borrowing" the resulting tuned quantities. If these iterative tuning procedures were also applied to Models 1 and 3, the performance of the latter models would likely change somewhat.

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Table 2A.1.1—Effective sample sizes for size composition fits.

			Effective sample size			Negative log likelihood		
Fleet	Year	N	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Fishery	1991	129	1540	1704	1710	6.121	5.852	6.334
Fishery	1992	586	13269	14622	17131	4.592	4.276	3.910
Fishery	1993	267	2034	2054	2285	4.759	4.669	4.272
Fishery	1994	170	4838	4675	2276	1.352	1.355	2.465
Fishery	1995	176	4794	4694	3894	5.416	5.408	4.957
Fishery	1996	243	5221	5342	5157	2.210	2.169	2.715
Fishery	1997	136	4350	4430	2109	1.281	1.258	2.394
Fishery	1998	424	9331	9337	7858	2.282	2.271	3.069
Fishery	1999	412	6641	6893	14991	3.063	2.971	2.479
Fishery	2000	636	6923	6938	4411	4.887	4.857	7.319
Fishery	2001	700	7972	7825	5376	6.902	7.033	11.226
Fishery	2002	284	3956	3905	4415	4.884	4.878	3.523
Fishery	2003	287	1280	1305	2458	6.308	6.198	4.443
Fishery	2004	291	2654	2688	2895	7.364	7.301	6.670
Fishery	2005	252	6135	6038	2856	1.550	1.556	2.742
Fishery	2006	248	3320	3287	1976	2.707	2.733	4.153
Fishery	2007	334	8089	8716	4439	2.621	2.572	4.078
Fishery	2008	319	3038	3161	1962	4.938	4.778	6.956
Fishery	2009	266	3213	3281	1882	5.297	5.198	7.216
Fishery	2010	416	2566	2553	2116	8.116	8.057	9.597
Fishery	2011	108	1886	2008	2364	1.915	1.835	1.767
Fishery	2012	143	2609	2730	2146	2.204	2.085	2.874
Fishery	2013	76	715	776	951	3.173	2.944	2.887
Fishery	Ave/sum	300	4625	4737	4246	93.943	92.256	108.043
Survey	1991	462	1620	1637	1145	12.828	12.835	18.038
Survey	1994	486	187	188	187	57.723	57.567	56.682
Survey	1997	300	413	413	381	54.466	54.430	58.205
Survey	2000	336	1395	1400	1025	14.436	14.411	19.027
Survey	2002	254	1294	1292	816	10.687	10.657	12.388
Survey	2004	241	1433	1430	1196	10.675	10.665	13.098
Survey	2006	181	1233	1235	895	9.664	9.638	12.268
Survey	2010	228	1768	1754	827	7.548	7.584	13.074
Survey	2012	213	958	948	573	12.694	12.692	15.106
Survey	Ave/sum	300	1144	1144	783	190.720	190.479	217.886

Table 2A.1.2a—Constants (not estimated internally) in the SS control file.

Parameter	Model 1	Model 2	Model 3
Natural mortality rate	3.40E-01	3.40E-01	3.40E-01
Weight-length a (proportionality)	5.68E-06	5.68E-06	5.68E-06
Weight-length b (exponent)	3.18E+00	3.18E+00	3.18E+00
Age at 50% maturity	4.88E+00	4.88E+00	4.88E+00
Maturity slope	-9.65E-01	-9.65E-01	-9.65E-01
Std. dev. of ageing error at age 1	9.30E-02	9.30E-02	9.30E-02
Std. dev. of ageing error at age 12	1.86E+00	1.86E+00	1.86E+00
Stock-recruitment "steepness"	1.00E+00	1.00E+00	1.00E+00

Table 2A.1.2b—Main parameters (except selectivity) parameters estimated by the models.

	Model 1		Model 2		Model 3	
Parameter	Value	SD	Value	SD	Value	SD
Length at age 1 (cm)	1.79E+01	1.98E-01	1.79E+01	1.98E-01	1.79E+01	1.91E-01
Asymptotic length (cm)	1.09E+02	1.78E+00	1.09E+02	1.77E+00	1.11E+02	1.96E+00
Brody growth coefficient	2.19E-01	6.74E-03	2.19E-01	6.73E-03	2.18E-01	6.78E-03
SD of length at age 1 (cm)	3.15E+00	1.41E-01	3.14E+00	1.41E-01	2.97E+00	1.35E-01
SD of length at age 20 (cm)	7.98E+00	4.05E-01	8.02E+00	4.07E-01	9.81E+00	4.92E-01
Ageing bias at age 1 (years)	2.99E-01	1.74E-01	3.01E-01	1.79E-01	4.20E-01	7.58E-02
Ageing bias at age 20 (years)	1.47E+00	1.09E+00	1.40E+00	1.11E+00	-1.72E-01	6.10E-01
ln(mean post-1990 recruitment)	1.10E+01	8.40E-02	1.11E+01	8.81E-02	1.10E+01	1.36E-01
σ(recruitment)	5.56E-01	7.60E-02	5.99E-01	9.27E-02	9.56E-01	1.43E-01
ln(pre-1991 recruitment offset)	0.00E+00	n/a	-2.37E-01	2.03E-01	-1.29E+00	3.14E-01
Initial fishing mortality rate	5.82E-03	1.36E-03	7.67E-03	2.51E-03	3.07E-02	9.26E-03
ln(catchability)	-4.68E-01	8.59E-02	-4.53E-01	8.69E-02	-4.85E-01	8.20E-02
Initial age 1 ln(abundance) dev	3.69E-01	1.80E-01	5.55E-01	2.49E-01	1.30E+00	3.77E-01
Initial age 2 ln(abundance) dev	1.13E+00	1.53E-01	1.33E+00	2.36E-01	2.46E+00	3.18E-01
Initial age 3 ln(abundance) dev	-1.41E-01	1.91E-01	3.20E-02	2.49E-01	6.92E-01	3.68E-01
Initial age 4 ln(abundance) dev	5.98E-01	1.76E-01	7.80E-01	2.43E-01	1.91E+00	3.68E-01
Initial age 5 ln(abundance) dev	1.17E+00	2.16E-01	1.33E+00	2.64E-01	2.00E+00	3.68E-01
Initial age 6 ln(abundance) dev	1.06E+00	3.26E-01	1.22E+00	3.68E-01	2.07E+00	4.22E-01
Initial age 7 ln(abundance) dev	1.04E-01	5.08E-01	2.08E-01	5.69E-01	-3.35E-01	8.18E-01
Initial age 8 ln(abundance) dev	-4.42E-01	4.60E-01	-4.01E-01	4.99E-01	-7.50E-01	7.24E-01
Initial age 9 ln(abundance) dev	-6.61E-01	4.42E-01	-6.43E-01	4.74E-01	-9.98E-01	6.86E-01
Initial age 10 ln(abundance) dev	-7.43E-01	4.36E-01	-7.44E-01	4.65E-01	-1.07E+00	6.75E-01
Log-scale recruit. dev for 1991	2.85E-01	1.45E-01	2.59E-01	1.46E-01	8.19E-02	1.38E-01
Log-scale recruit. dev for 1992	-2.28E-01	2.34E-01	-2.51E-01	2.37E-01	-6.63E-01	1.85E-01
Log-scale recruit. dev for 1993	8.52E-01	1.26E-01	8.38E-01	1.26E-01	1.17E+00	9.67E-02
Log-scale recruit. dev for 1994	-1.43E-01	1.58E-01	-1.59E-01	1.60E-01	-3.19E-01	1.93E-01
Log-scale recruit. dev for 1995	4.95E-01	1.62E-01	4.83E-01	1.62E-01	2.15E-01	1.61E-01
Log-scale recruit. dev for 1996	9.39E-01	1.21E-01	9.30E-01	1.21E-01	1.15E+00	1.18E-01
Log-scale recruit. dev for 1997	6.33E-01	1.15E-01	6.28E-01	1.16E-01	6.87E-01	1.11E-01
Log-scale recruit. dev for 1998	9.86E-02	1.82E-01	9.45E-02	1.83E-01	-3.21E-01	2.05E-01
Log-scale recruit. dev for 1999	7.55E-01	1.21E-01	7.61E-01	1.21E-01	7.47E-01	1.21E-01
Log-scale recruit. dev for 2000	5.17E-02	1.54E-01	5.93E-02	1.55E-01	8.05E-01	1.13E-01
Log-scale recruit. dev for 2001	-1.92E-01	1.33E-01	-1.79E-01	1.34E-01	1.34E-02	1.54E-01
Log-scale recruit. dev for 2002	-5.86E-01	1.56E-01	-5.76E-01	1.59E-01	-5.20E-01	1.85E-01
Log-scale recruit. dev for 2003	-2.94E-01	1.36E-01	-2.75E-01	1.38E-01	-6.45E-03	1.39E-01
Log-scale recruit. dev for 2004	-6.21E-01	1.87E-01	-6.09E-01	1.91E-01	-1.01E+00	2.51E-01
Log-scale recruit. dev for 2005	-1.88E-01	1.59E-01	-1.70E-01	1.61E-01	1.08E-01	1.32E-01
Log-scale recruit. dev for 2006	-4.61E-01	1.60E-01	-4.58E-01	1.62E-01	-5.24E-01	2.15E-01
Log-scale recruit. dev for 2007	3.00E-01	1.24E-01	3.12E-01	1.25E-01	5.53E-01	1.16E-01
Log-scale recruit. dev for 2008	-9.69E-02	1.52E-01	-9.89E-02	1.54E-01	-3.89E-02	1.54E-01
Log-scale recruit. dev for 2009	-9.96E-01	2.06E-01	-1.00E+00	2.08E-01	-9.35E-01	2.00E-01
Log-scale recruit. dev for 2010	-4.38E-01	4.06E-01	-4.42E-01	4.22E-01	-8.68E-01	2.44E-01
Log-scale recruit. dev for 2011	-1.65E-01	5.09E-01	-1.44E-01	5.42E-01	-3.33E-01	4.31E-01

Table 2A.1.2c—Base selectivity parameters estimated by the models.

	Model 1		Model 2		Model 3	
Parameter	Value	SD	Value	SD	Value	SD
Fishery age 1 selectivity parameter	3.29E+00	3.42E-01	3.29E+00	3.42E-01	3.29E+00	3.42E-01
Fishery age 2 selectivity parameter	3.41E+00	3.19E-01	3.41E+00	3.19E-01	3.42E+00	3.18E-01
Fishery age 3 selectivity parameter	3.20E+00	1.88E-01	3.20E+00	1.89E-01	3.41E+00	2.05E-01
Fishery age 4 selectivity parameter	1.24E+00	1.82E-01	1.25E+00	1.82E-01	1.28E+00	1.88E-01
Fishery age 5 selectivity parameter	2.92E-01	1.16E-01	2.95E-01	1.16E-01	2.60E-01	1.42E-01
Fishery age 6 selectivity parameter	1.51E-01	2.86E-01	1.54E-01	2.86E-01	1.77E-01	2.87E-01
Fishery age 7 selectivity parameter	-9.38E-02	1.99E-01	-8.94E-02	1.98E-01	-1.79E-03	2.07E-01
Fishery age 8 selectivity parameter	-4.88E-03	2.52E-01	1.71E-02	2.52E-01	4.23E-01	2.90E-01
Fishery age 9 selectivity parameter	1.02E-01	2.71E-01	1.23E-01	2.72E-01	3.73E-01	2.64E-01
Fishery age 10 selectivity parameter	2.79E-01	2.84E-01	2.93E-01	2.85E-01	2.30E-01	3.13E-01
Fishery age 11 selectivity parameter	1.14E-01	3.13E-01	1.26E-01	3.13E-01	-1.21E-01	3.21E-01
Fishery age 12 selectivity parameter	-2.21E-01	3.46E-01	-2.02E-01	3.45E-01	-2.73E-01	3.42E-01
Fishery age 13 selectivity parameter	-4.43E-01	3.20E-01	-4.35E-01	3.20E-01	-3.74E-01	3.19E-01
Fishery age 14 selectivity parameter	-3.35E-01	3.20E-01	-3.32E-01	3.20E-01	-2.80E-01	3.24E-01
Fishery age 15 selectivity parameter	-2.40E-01	3.23E-01	-2.38E-01	3.24E-01	-2.11E-01	3.27E-01
Fishery age 16 selectivity parameter	-2.06E-01	3.24E-01	-2.04E-01	3.24E-01	-1.68E-01	3.29E-01
Fishery age 17 selectivity parameter	-1.62E-01	3.26E-01	-1.60E-01	3.27E-01	-1.33E-01	3.30E-01
Fishery age 18 selectivity parameter	-1.22E-01	3.29E-01	-1.21E-01	3.29E-01	-9.80E-02	3.33E-01
Fishery age 19 selectivity parameter	-8.58E-02	3.32E-01	-8.52E-02	3.32E-01	-7.01E-02	3.35E-01
Fishery age 20 selectivity parameter	-6.74E-02	3.34E-01	-6.67E-02	3.34E-01	-5.22E-02	3.36E-01
Survey age 1 selectivity parameter	5.29E+00	3.19E-01	5.29E+00	3.19E-01	5.29E+00	3.19E-01
Survey age 2 selectivity parameter	9.25E-01	2.88E-01	9.26E-01	2.88E-01	1.26E+00	1.69E-01
Survey age 3 selectivity parameter	6.20E-01	2.17E-01	6.21E-01	2.17E-01	7.82E-01	1.26E-01
Survey age 4 selectivity parameter	3.45E-01	1.12E-01	3.53E-01	1.13E-01	6.05E-02	9.56E-02
Survey age 5 selectivity parameter	-3.95E-01	1.30E-01	-3.91E-01	1.30E-01	0.00E+00	n/a
Survey age 6 selectivity parameter	-1.95E-01	2.25E-01	-1.81E-01	2.26E-01	0.00E+00	n/a
Survey age 7 selectivity parameter	9.20E-03	3.12E-01	8.62E-03	3.12E-01	0.00E+00	n/a
Survey age 8 selectivity parameter	-4.12E-01	2.38E-01	-3.74E-01	2.41E-01	0.00E+00	n/a
Survey age 9 selectivity parameter	-2.97E-01	2.67E-01	-2.79E-01	2.68E-01	0.00E+00	n/a
Survey age 10 selectivity parameter	-1.14E-01	2.88E-01	-1.02E-01	2.88E-01	0.00E+00	n/a
Survey age 11 selectivity parameter	-1.35E-01	3.00E-01	-1.26E-01	3.00E-01	0.00E+00	n/a
Survey age 12 selectivity parameter	-1.77E-01	3.04E-01	-1.70E-01	3.05E-01	0.00E+00	n/a
Survey age 13 selectivity parameter	-1.54E-01	3.05E-01	-1.48E-01	3.05E-01	0.00E+00	n/a
Survey age 14 selectivity parameter	-1.18E-01	3.08E-01	-1.13E-01	3.08E-01	0.00E+00	n/a
Survey age 15 selectivity parameter	-1.02E-01	3.09E-01	-9.75E-02	3.09E-01	0.00E+00	n/a
Survey age 16 selectivity parameter	-7.96E-02	3.10E-01	-7.62E-02	3.11E-01	0.00E+00	n/a
Survey age 17 selectivity parameter	-5.27E-02	3.13E-01	-5.07E-02	3.13E-01	0.00E+00	n/a
Survey age 18 selectivity parameter	-3.64E-02	3.14E-01	-3.50E-02	3.14E-01	0.00E+00	n/a
Survey age 19 selectivity parameter	-2.55E-02	3.16E-01	-2.46E-02	3.16E-01	0.00E+00	n/a
Survey age 20 selectivity parameter	-1.81E-02	3.16E-01	-1.75E-02	3.17E-01	0.00E+00	n/a

Table 2A.1.2d—Deviations (*dev*s) for fishery selectivity parameters estimated by the models.

	Model 1		Model 2		Model 3	
Parameter	Value	SD	Value	SD	Value	SD
Fishery age 4 sel. dev for 1991	-2.66E-03	5.47E-02	-2.89E-03	5.49E-02	-3.57E-03	6.16E-02
Fishery age 4 sel. dev for 1992	8.03E-02	3.24E-02	8.19E-02	3.25E-02	1.02E-01	3.06E-02
Fishery age 4 sel. dev for 1993	-7.38E-02	3.66E-02	-7.47E-02	3.68E-02	-1.01E-01	4.05E-02
Fishery age 4 sel. dev for 1994	-1.33E-02	3.96E-02	-1.24E-02	3.96E-02	-2.46E-02	4.05E-02
Fishery age 4 sel. dev for 1995	-1.13E-02	4.72E-02	-1.09E-02	4.73E-02	-1.35E-02	4.81E-02
Fishery age 4 sel. dev for 1996	7.47E-02	3.58E-02	7.55E-02	3.59E-02	1.41E-01	3.66E-02
Fishery age 4 sel. dev for 1997	-3.29E-02	5.08E-02	-3.28E-02	5.10E-02	-4.66E-02	5.81E-02
Fishery age 4 sel. dev for 1998	-1.20E-02	2.99E-02	-1.20E-02	2.99E-02	-4.79E-02	2.95E-02
Fishery age 4 sel. dev for 1999	3.20E-02	3.18E-02	3.22E-02	3.19E-02	7.01E-02	3.41E-02
Fishery age 4 sel. dev for 2000	-1.92E-02	2.79E-02	-1.89E-02	2.79E-02	-1.92E-02	3.01E-02
Fishery age 4 sel. dev for 2001	-6.54E-02	2.94E-02	-6.51E-02	2.94E-02	-1.08E-01	3.02E-02
Fishery age 4 sel. dev for 2002	1.90E-04	3.68E-02	8.66E-04	3.68E-02	1.72E-02	3.85E-02
Fishery age 4 sel. dev for 2003	-1.15E-01	3.70E-02	-1.15E-01	3.70E-02	-4.95E-02	3.83E-02
Fishery age 4 sel. dev for 2004	-1.03E-01	3.15E-02	-1.03E-01	3.15E-02	-9.98E-02	3.38E-02
Fishery age 4 sel. dev for 2005	-1.99E-02	4.12E-02	-1.98E-02	4.13E-02	-5.07E-02	4.28E-02
Fishery age 4 sel. dev for 2006	2.77E-02	3.77E-02	2.83E-02	3.78E-02	3.08E-02	4.01E-02
Fishery age 4 sel. dev for 2007	3.59E-02	4.08E-02	3.56E-02	4.10E-02	-1.11E-04	4.55E-02
Fishery age 4 sel. dev for 2008	-1.06E-02	3.41E-02	-1.07E-02	3.41E-02	1.25E-02	3.44E-02
Fishery age 4 sel. dev for 2009	1.96E-02	3.71E-02	1.86E-02	3.72E-02	1.94E-02	4.15E-02
Fishery age 4 sel. dev for 2010	7.23E-03	2.96E-02	7.31E-03	2.97E-02	3.40E-02	2.97E-02
Fishery age 4 sel. dev for 2011	2.58E-02	5.30E-02	2.54E-02	5.32E-02	2.40E-02	5.80E-02
Fishery age 4 sel. dev for 2012	5.64E-02	5.95E-02	5.61E-02	5.96E-02	5.15E-02	6.25E-02
Fishery age 4 sel. dev for 2013	2.14E-02	6.58E-02	2.20E-02	6.60E-02	-5.61E-03	6.87E-02
Fishery age 6 sel. dev for 1991	5.24E-02	4.10E-02	5.81E-02	4.14E-02	9.57E-02	4.40E-02
Fishery age 6 sel. dev for 1992	-4.31E-02	3.54E-02	-3.90E-02	3.56E-02	-1.92E-02	3.68E-02
Fishery age 6 sel. dev for 1993	3.71E-02	3.86E-02	4.23E-02	3.88E-02	7.66E-02	3.84E-02
Fishery age 6 sel. dev for 1994	-2.05E-02	3.80E-02	-1.65E-02	3.81E-02	-1.03E-02	3.87E-02
Fishery age 6 sel. dev for 1995	1.90E-02	3.90E-02	2.21E-02	3.91E-02	8.58E-03	4.06E-02
Fishery age 6 sel. dev for 1996	-6.73E-02	3.75E-02	-6.46E-02	3.76E-02	-9.09E-02	3.88E-02
Fishery age 6 sel. dev for 1997	6.24E-02	3.95E-02	6.51E-02	3.96E-02	9.64E-02	4.10E-02
Fishery age 6 sel. dev for 1998	2.44E-03	3.36E-02	4.46E-03	3.37E-02	1.84E-02	3.45E-02
Fishery age 6 sel. dev for 1999	2.49E-02	3.57E-02	2.60E-02	3.57E-02	1.78E-03	3.67E-02
Fishery age 6 sel. dev for 2000	8.45E-02	3.45E-02	8.58E-02	3.45E-02	1.12E-01	3.68E-02
Fishery age 6 sel. dev for 2001	1.11E-02	3.31E-02	1.20E-02	3.32E-02	2.64E-02	3.46E-02
Fishery age 6 sel. dev for 2002	7.02E-02	3.87E-02	7.07E-02	3.88E-02	4.62E-02	4.06E-02
Fishery age 6 sel. dev for 2003	1.18E-01	3.81E-02	1.19E-01	3.81E-02	1.22E-01	4.07E-02
Fishery age 6 sel. dev for 2004	2.72E-02	3.59E-02	2.76E-02	3.58E-02	6.12E-02	3.75E-02
Fishery age 6 sel. dev for 2005	-4.87E-03	3.66E-02	-5.07E-03	3.66E-02	2.04E-02	3.75E-02
Fishery age 6 sel. dev for 2006	-5.35E-02	3.61E-02	-5.44E-02	3.61E-02	-6.62E-02	3.76E-02
Fishery age 6 sel. dev for 2007	-7.58E-03	3.56E-02	-8.82E-03	3.56E-02	-1.99E-02	3.72E-02
Fishery age 6 sel. dev for 2008	2.00E-02	3.57E-02	1.77E-02	3.58E-02	-2.60E-02	3.76E-02
Fishery age 6 sel. dev for 2009	2.62E-02	3.67E-02	2.35E-02	3.68E-02	3.84E-03	3.90E-02
Fishery age 6 sel. dev for 2010	5.78E-02	3.69E-02	5.39E-02	3.71E-02	4.71E-02	3.82E-02
Fishery age 6 sel. dev for 2011	1.08E-01	4.15E-02	1.04E-01	4.16E-02	1.31E-01	4.20E-02
Fishery age 6 sel. dev for 2012	7.31E-02	4.13E-02	6.87E-02	4.15E-02	9.20E-02	4.23E-02
Fishery age 6 sel. dev for 2013	1.07E-01	5.26E-02	1.03E-01	5.27E-02	1.01E-01	5.59E-02

Table 2A.1.2e—Deviations (*dev*s) for survey selectivity parameters estimated by the models.

	Model 1		Model 2		Model 3	
Parameter	Value	SD	Value	SD	Value	SD
Survey age 2 sel. dev for 1991	3.43E-01	8.51E-02	3.42E-01	8.52E-02	5.12E-01	1.29E-01
Survey age 2 sel. dev for 1994	-1.24E-01	4.45E-02	-1.24E-01	4.46E-02	-5.08E-01	1.21E-01
Survey age 2 sel. dev for 1997	-6.81E-04	4.26E-02	-3.87E-04	4.26E-02	1.10E-01	1.05E-01
Survey age 2 sel. dev for 2000	2.55E-02	5.16E-02	2.62E-02	5.17E-02	2.06E-01	1.14E-01
Survey age 2 sel. dev for 2002	1.34E-01	5.12E-02	1.34E-01	5.12E-02	9.60E-02	1.30E-01
Survey age 2 sel. dev for 2004	8.21E-02	6.44E-02	8.24E-02	6.45E-02	2.44E-01	1.31E-01
Survey age 2 sel. dev for 2006	-1.29E-01	5.37E-02	-1.29E-01	5.38E-02	-2.30E-01	1.33E-01
Survey age 2 sel. dev for 2010	-5.10E-02	5.49E-02	-5.17E-02	5.49E-02	-8.11E-02	1.50E-01
Survey age 2 sel. dev for 2012	9.20E-03	7.16E-02	1.26E-02	7.45E-02	-1.58E-02	1.76E-01
Survey age 3 sel. dev for 1991	-4.29E-02	2.79E-02	-4.11E-02	2.79E-02	-9.77E-02	6.75E-02
Survey age 3 sel. dev for 1994	6.66E-03	3.64E-02	8.08E-03	3.66E-02	-1.03E-01	6.74E-02
Survey age 3 sel. dev for 1997	6.11E-02	3.11E-02	6.06E-02	3.11E-02	3.12E-02	7.28E-02
Survey age 3 sel. dev for 2000	1.07E-01	3.71E-02	1.07E-01	3.71E-02	8.56E-02	7.83E-02
Survey age 3 sel. dev for 2002	-1.16E-01	3.02E-02	-1.16E-01	3.02E-02	-6.81E-02	6.95E-02
Survey age 3 sel. dev for 2004	7.72E-02	3.77E-02	7.73E-02	3.78E-02	6.44E-02	7.70E-02
Survey age 3 sel. dev for 2006	1.12E-01	4.27E-02	1.12E-01	4.28E-02	7.86E-03	7.34E-02
Survey age 3 sel. dev for 2010	1.03E-01	3.44E-02	1.02E-01	3.45E-02	1.41E-01	7.54E-02
Survey age 3 sel. dev for 2012	5.95E-02	4.64E-02	5.82E-02	4.76E-02	5.68E-03	7.72E-02
Survey age 7 sel. dev for 1991	3.07E-02	5.58E-02	3.74E-02	5.64E-02	n/a	n/a
Survey age 7 sel. dev for 1994	6.88E-02	4.39E-02	6.93E-02	4.40E-02	n/a	n/a
Survey age 7 sel. dev for 1997	-1.94E-02	4.77E-02	-1.82E-02	4.78E-02	n/a	n/a
Survey age 7 sel. dev for 2000	-1.62E-02	5.00E-02	-1.66E-02	5.01E-02	n/a	n/a
Survey age 7 sel. dev for 2002	1.27E-01	4.11E-02	1.26E-01	4.12E-02	n/a	n/a
Survey age 7 sel. dev for 2004	-3.18E-02	4.89E-02	-3.37E-02	4.91E-02	n/a	n/a
Survey age 7 sel. dev for 2006	3.04E-02	4.56E-02	2.72E-02	4.58E-02	n/a	n/a
Survey age 7 sel. dev for 2010	3.32E-02	5.25E-02	2.68E-02	5.28E-02	n/a	n/a
Survey age 7 sel. dev for 2012	-4.62E-02	5.47E-02	-5.23E-02	5.51E-02	n/a	n/a

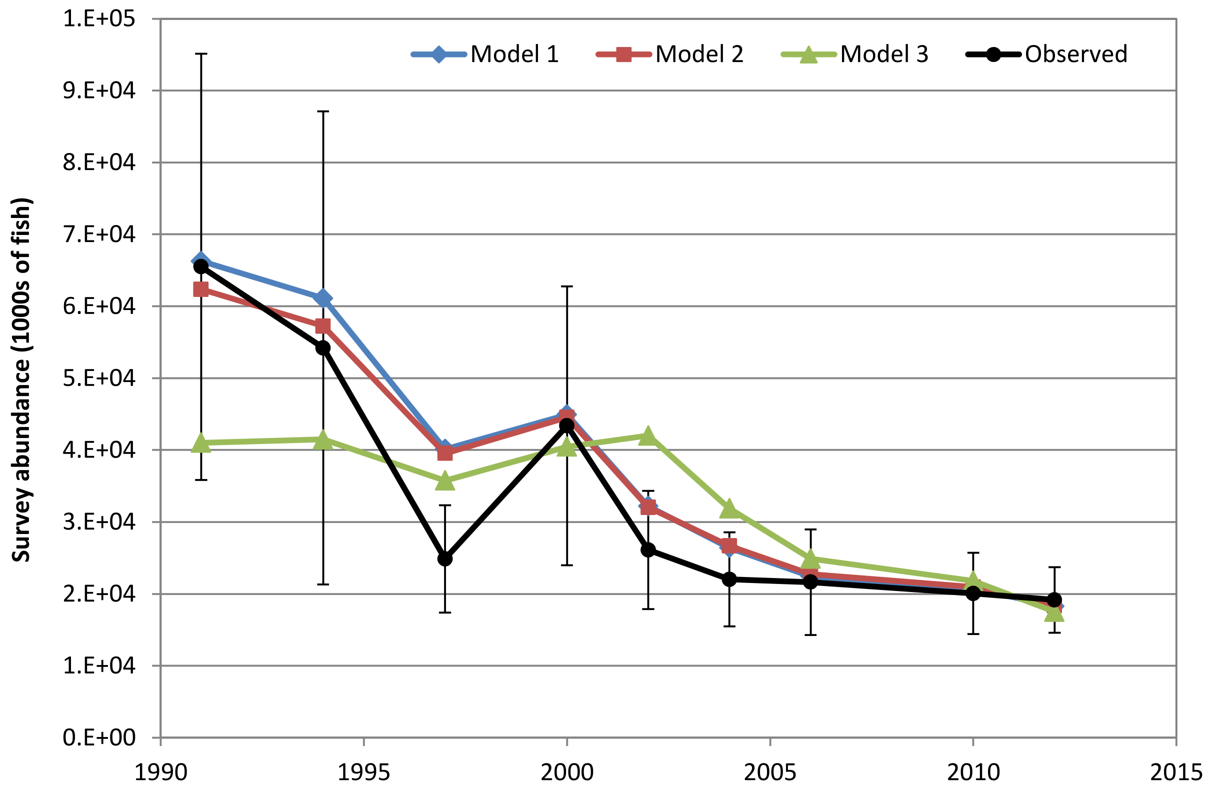


Figure 2A.1.1—Model fits to the survey abundance time series.

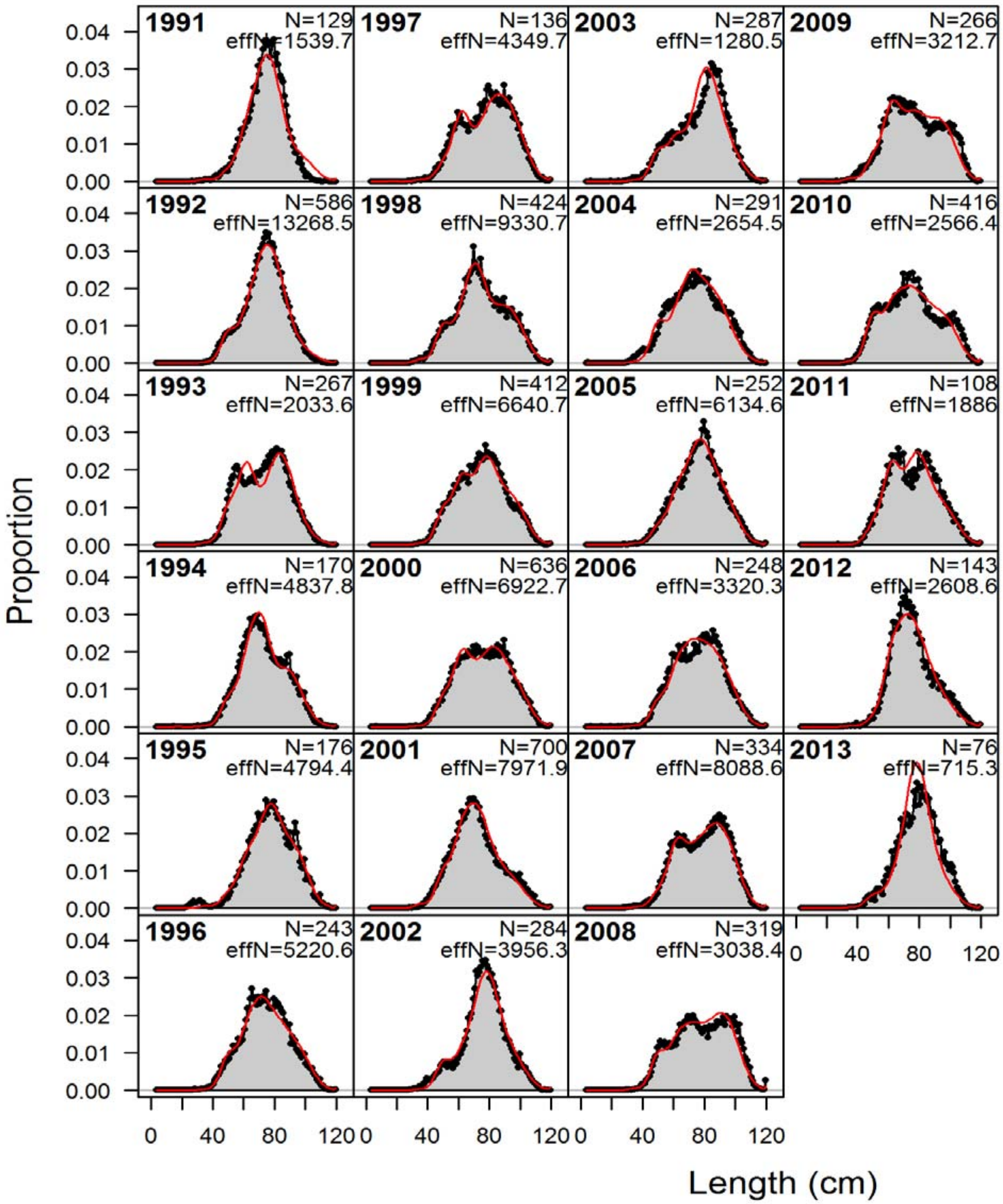


Figure 2.A.1.2a—Model 1 fits to the fishery size composition data.

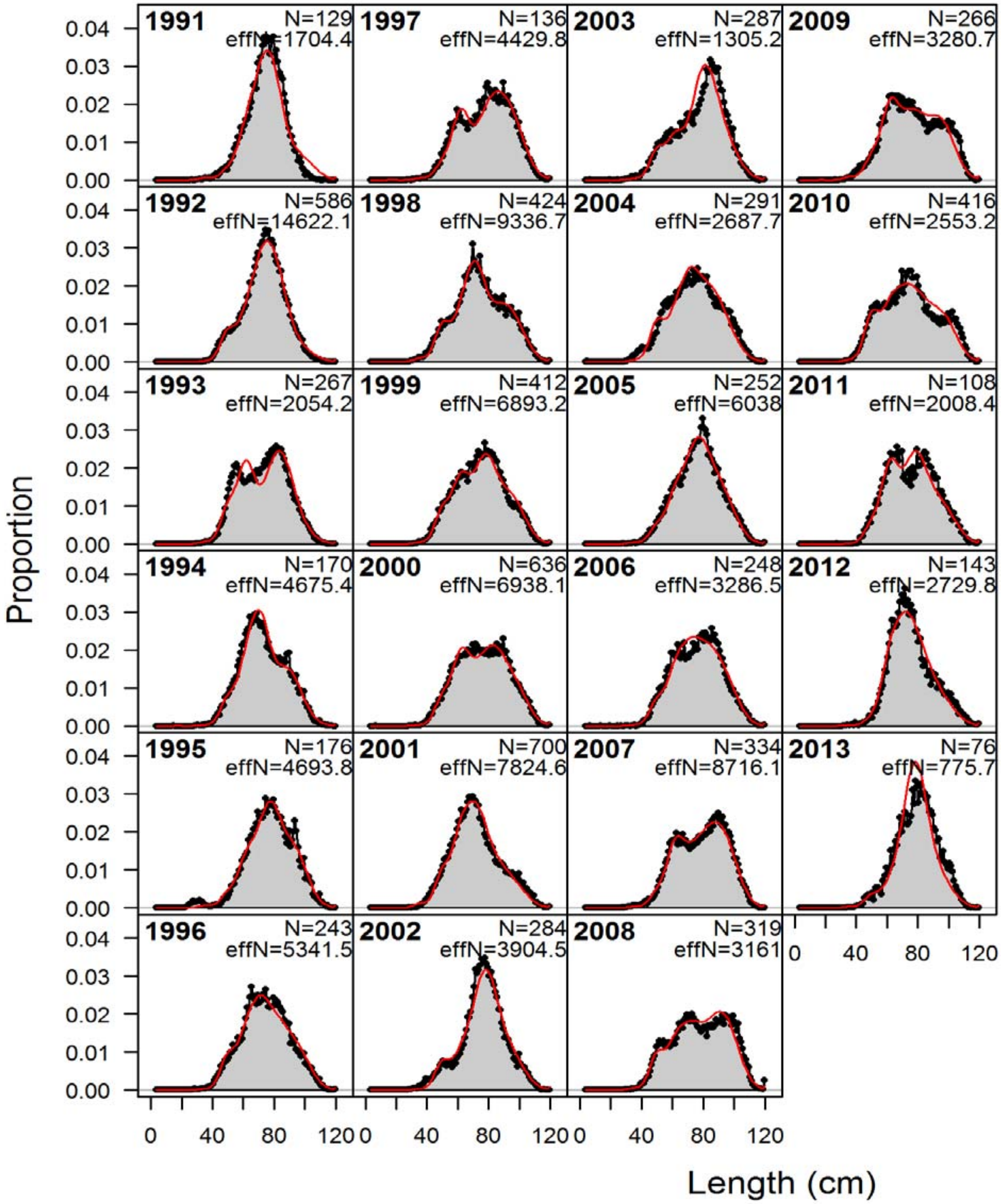


Figure 2A.1.2b—Model 2 fits to the fishery size composition data.

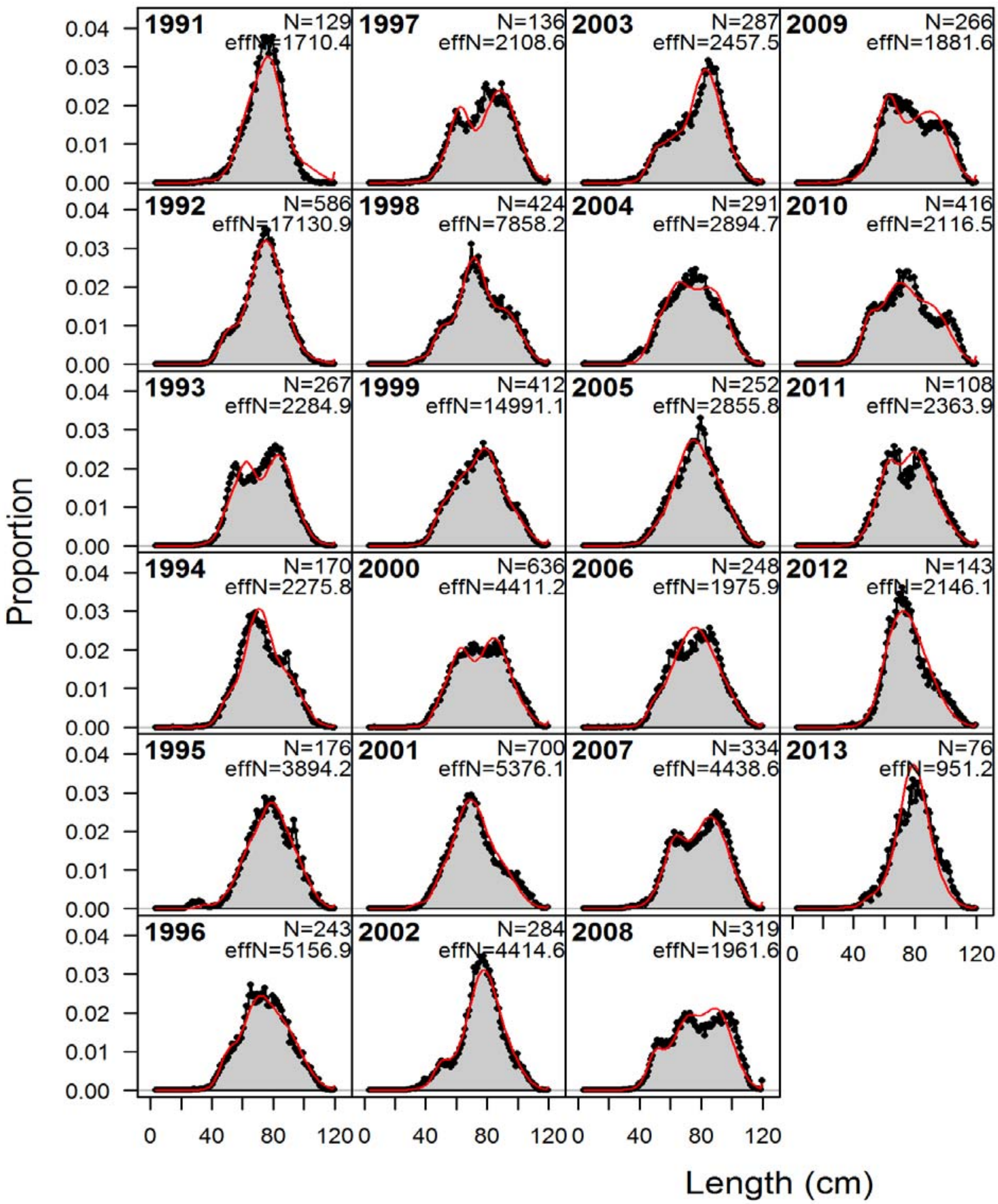


Figure 2A.1.2c—Model 3 fits to the fishery size composition data.

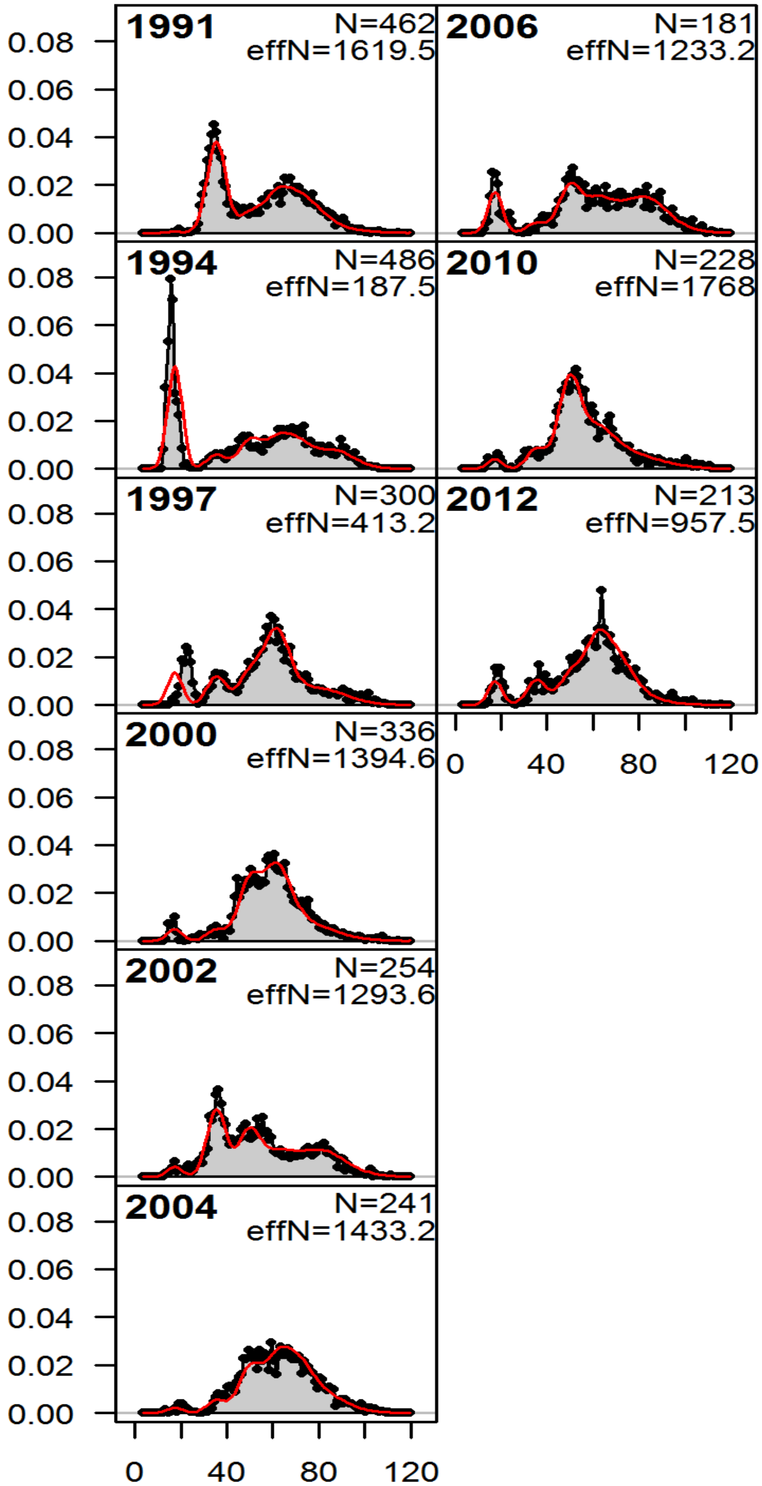


Figure 2A.1.3a—Model 1 fits to the survey size composition data.

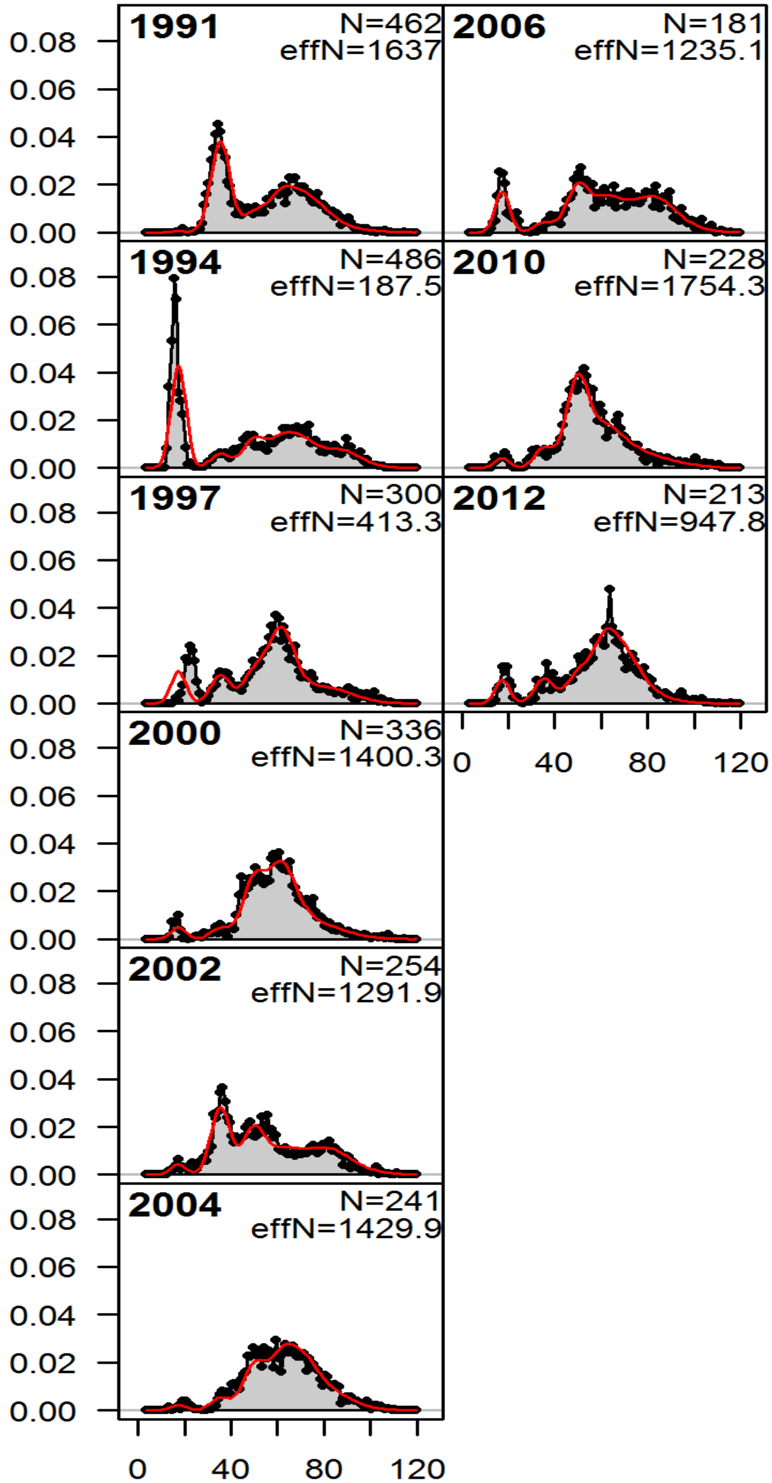


Figure 2A.1.3b—Model 2 fits to the survey size composition data.

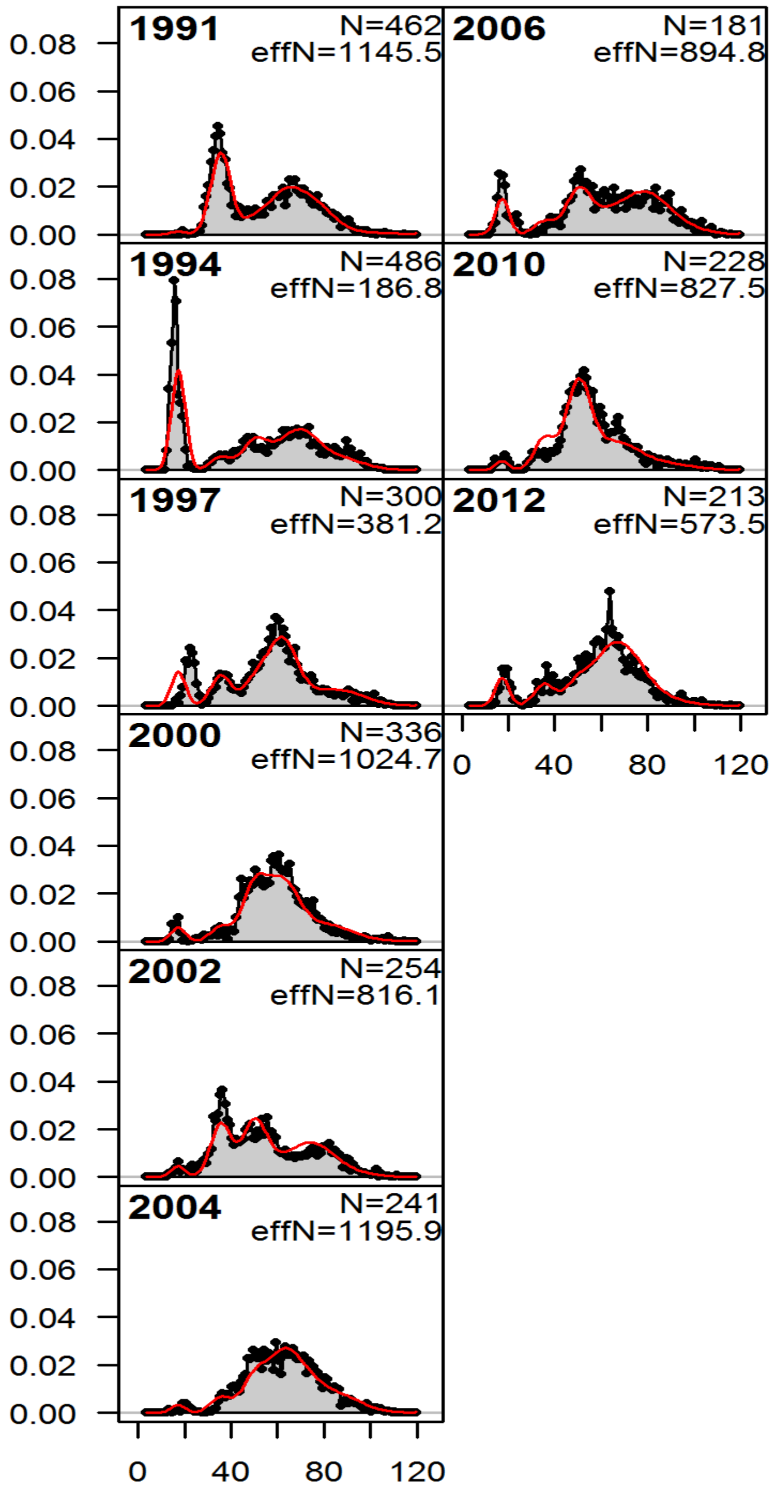
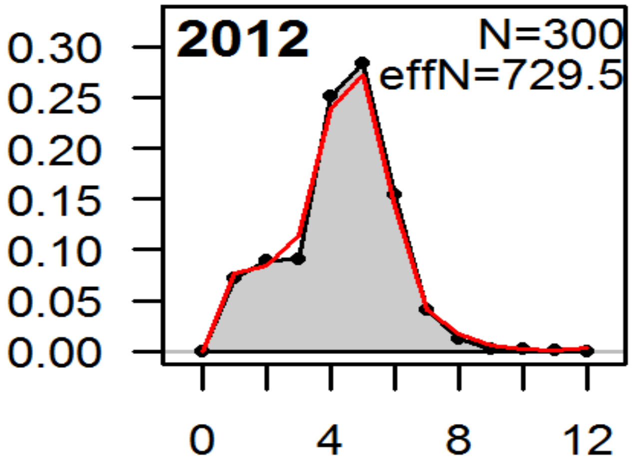
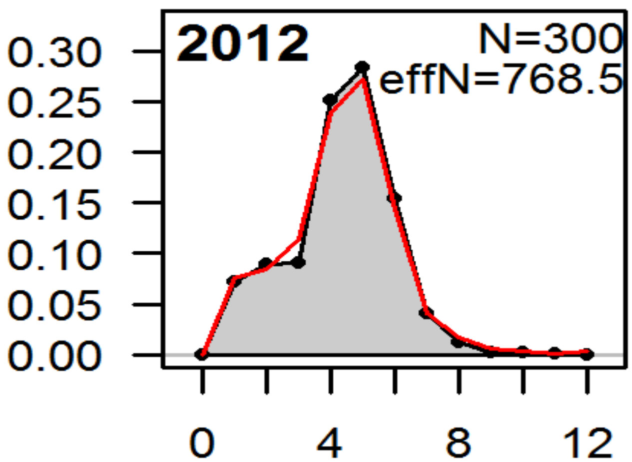


Figure 2A.1.3c—Model 3 fits to the survey size composition data.

Model 1



Model 2



Model 3

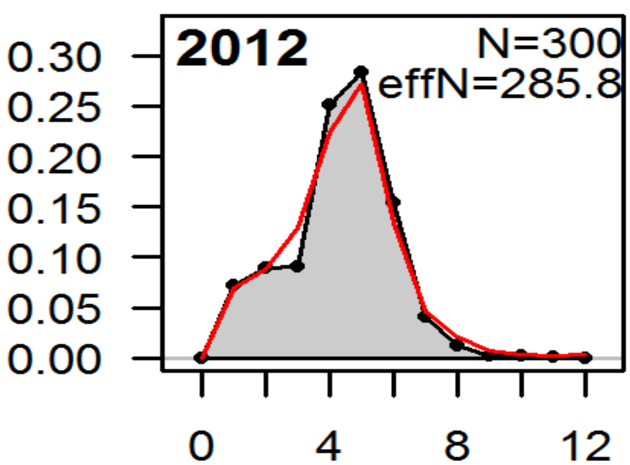
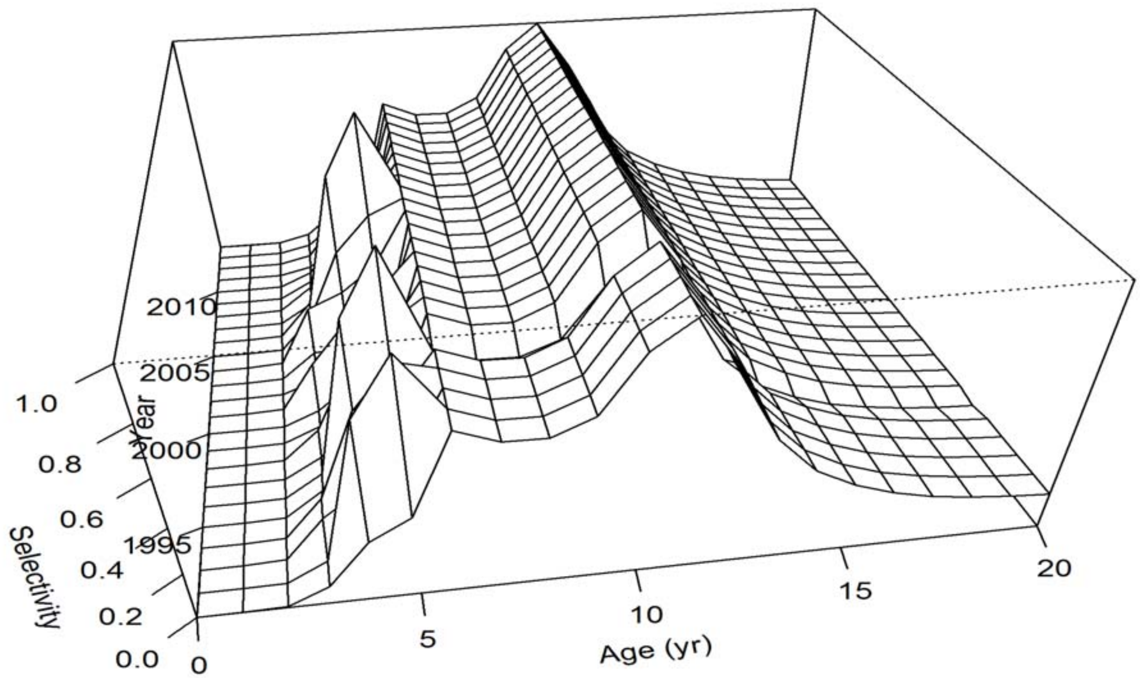


Figure 2A.1.4—Model fits to the single year of age data.

Fishery



Survey

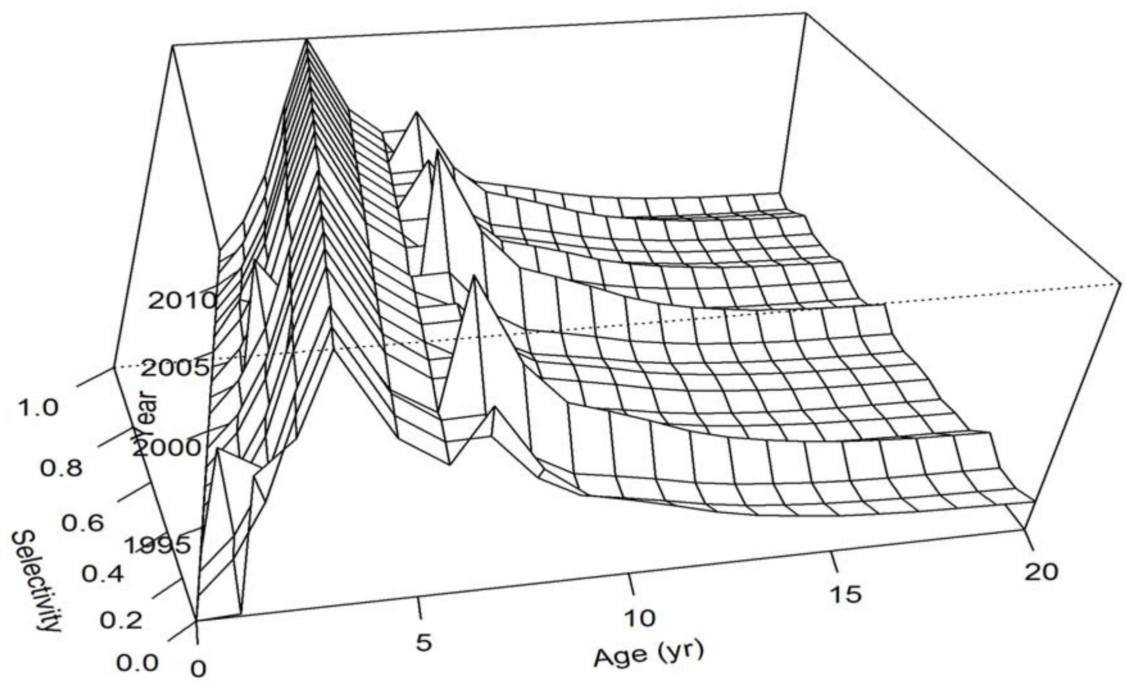
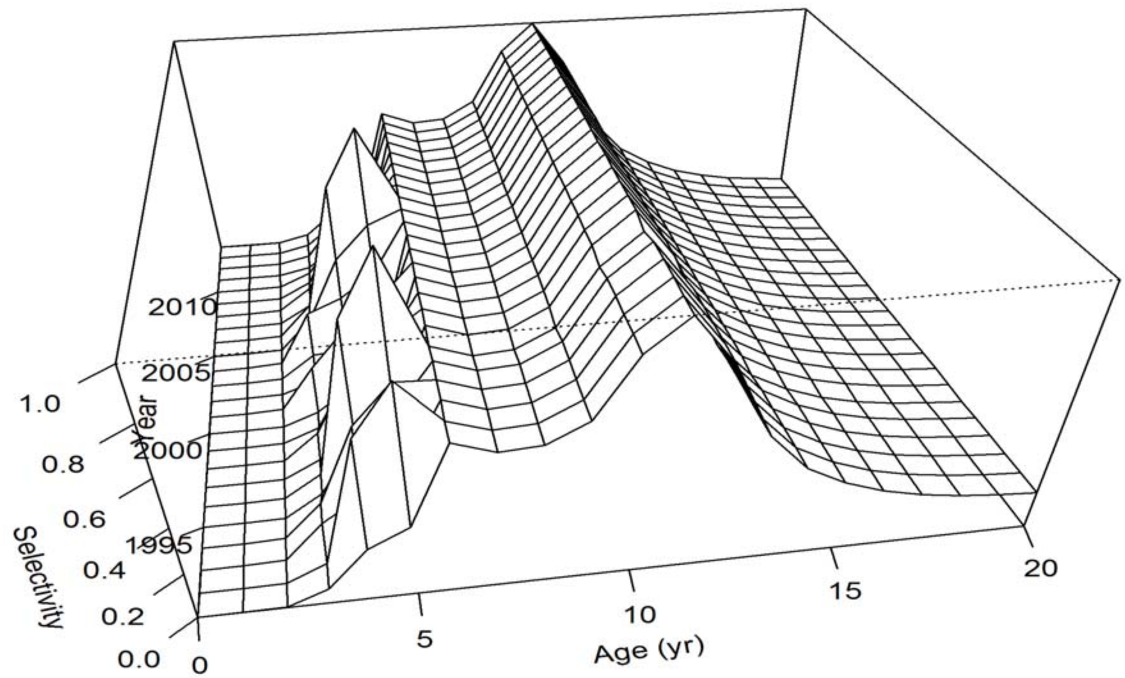


Figure 2A.1.5a—Model 1 selectivities.

Fishery



Survey

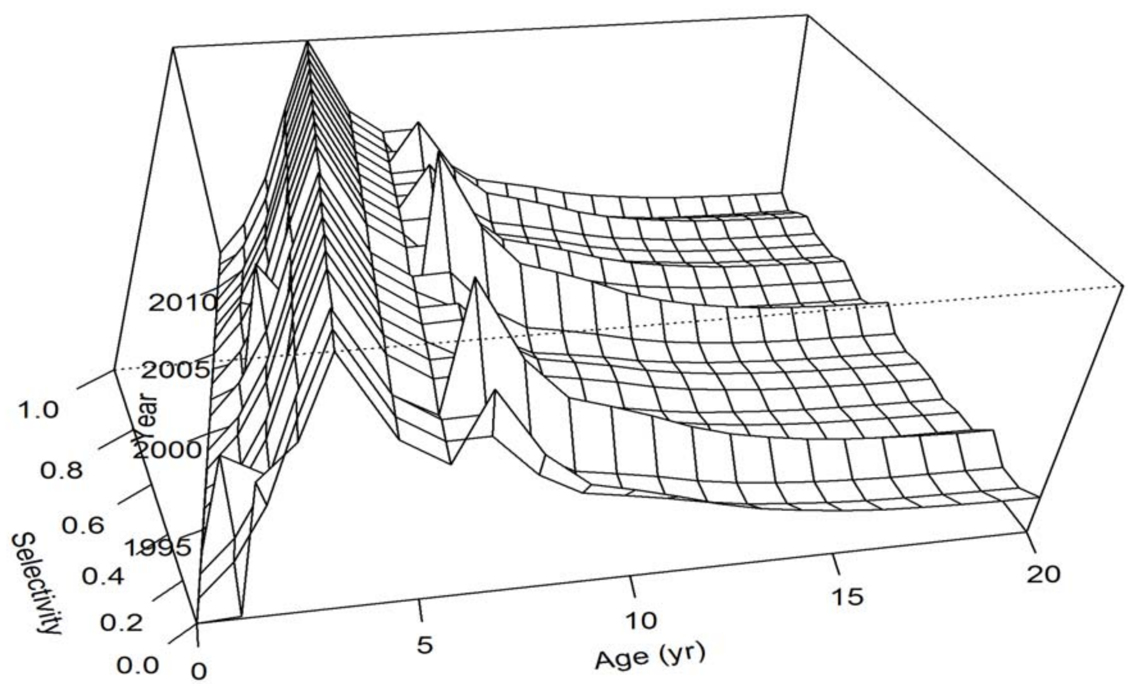
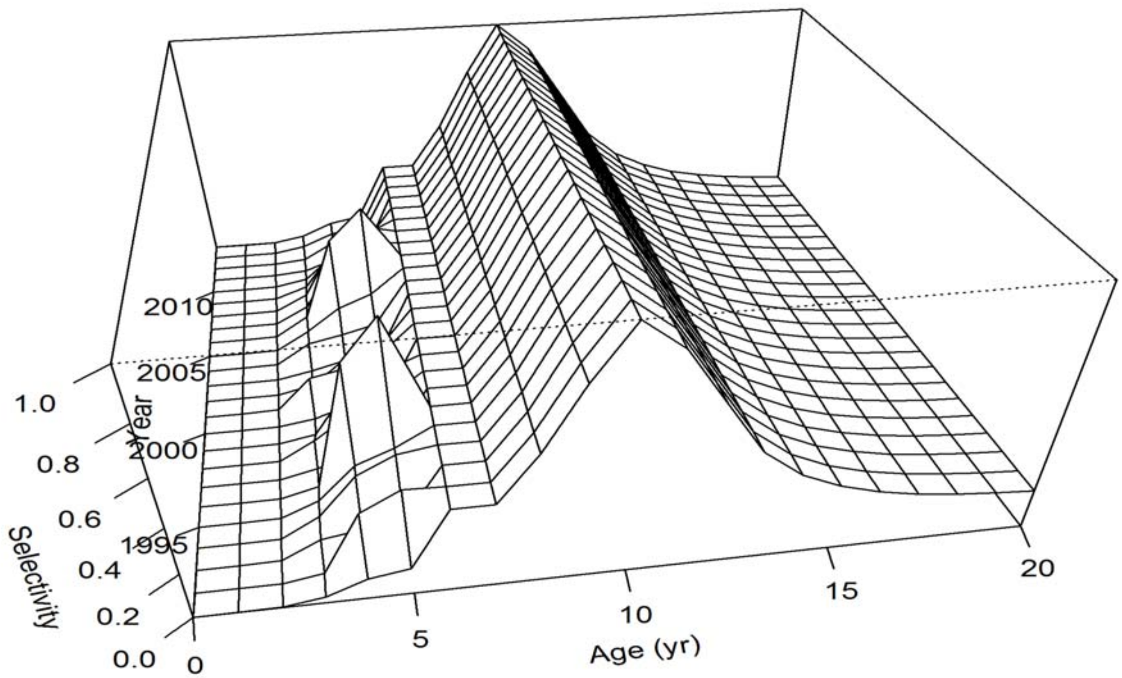


Figure 2A.1.5b—Model 2 selectivities.

Fishery



Survey

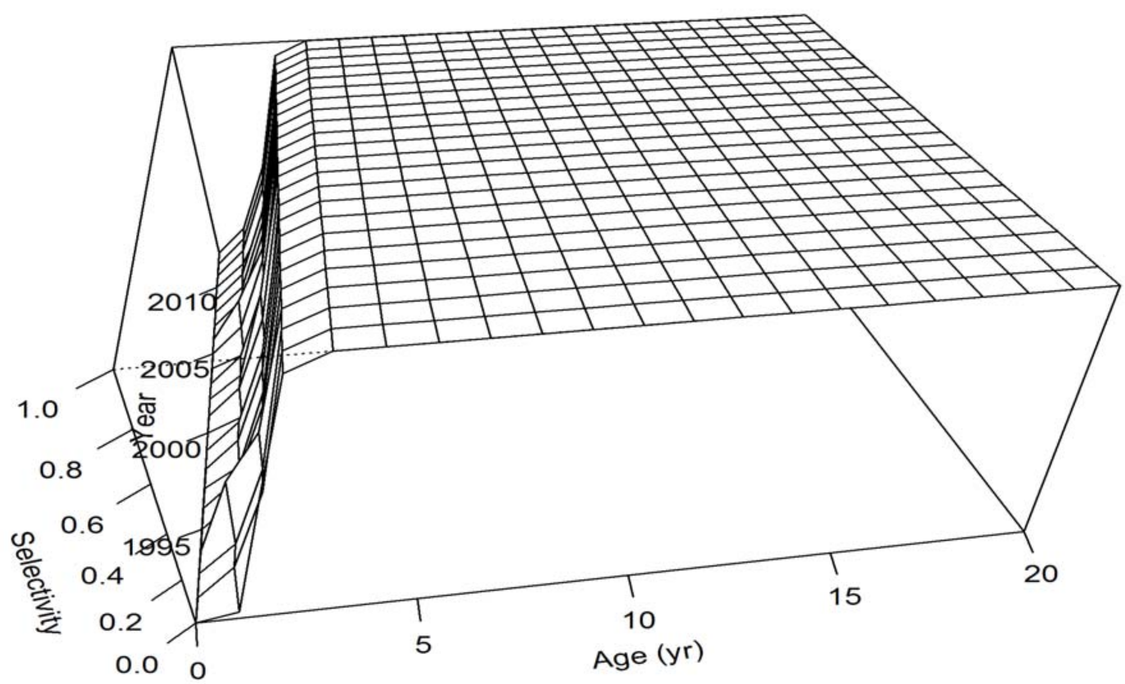


Figure 2A.1.5c—Model 3 selectivities.

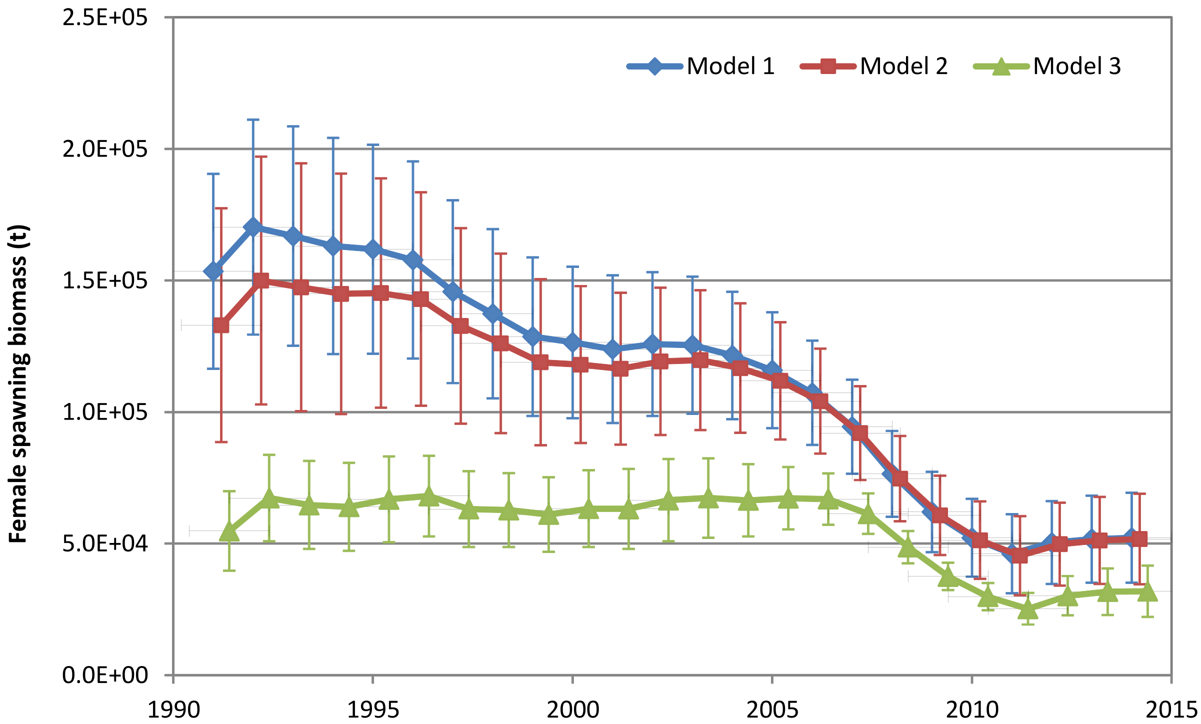


Figure 2A.1.6—Model estimates of the female spawning biomass time series.

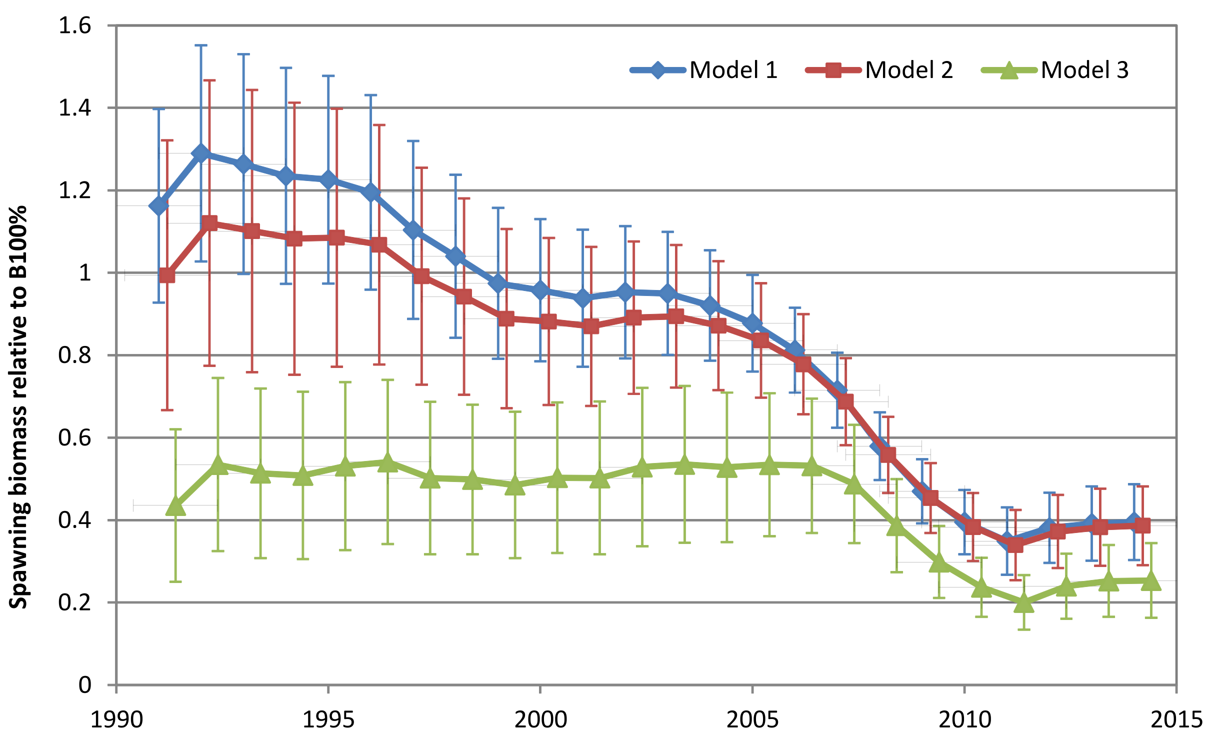


Figure 2A.1.7—Model estimates of the relative female spawning biomass time series.

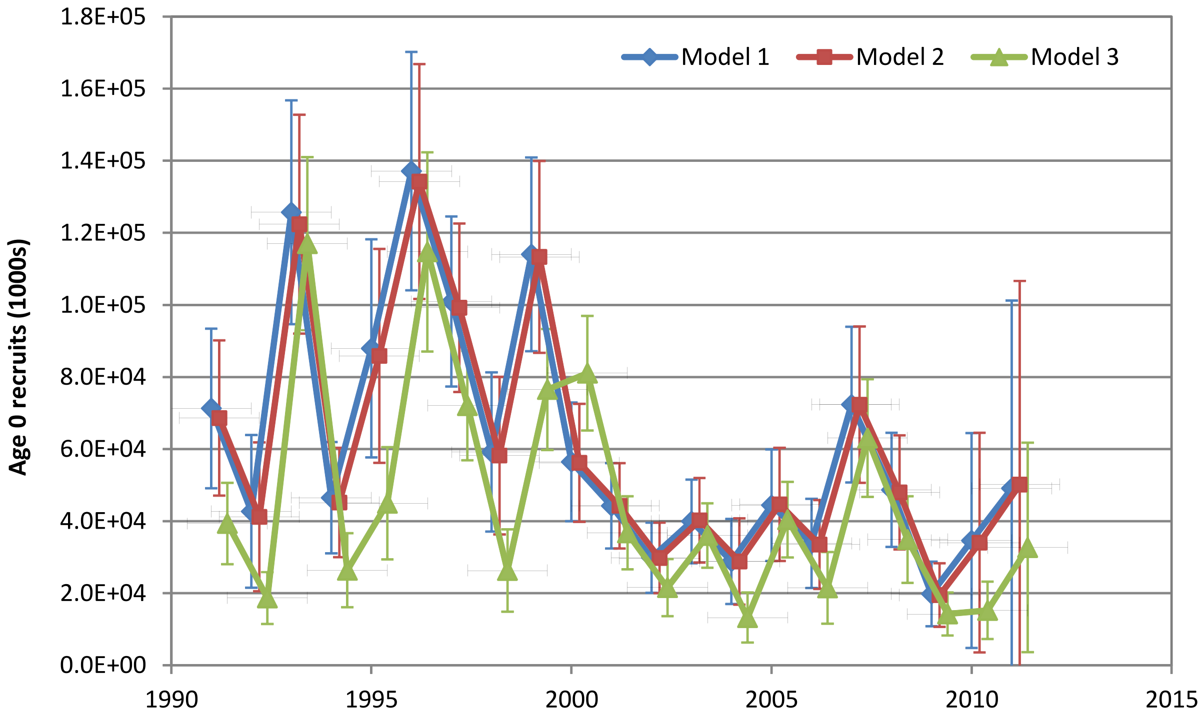


Figure 2A.1.8—Model estimates of the age 0 recruitment time series.

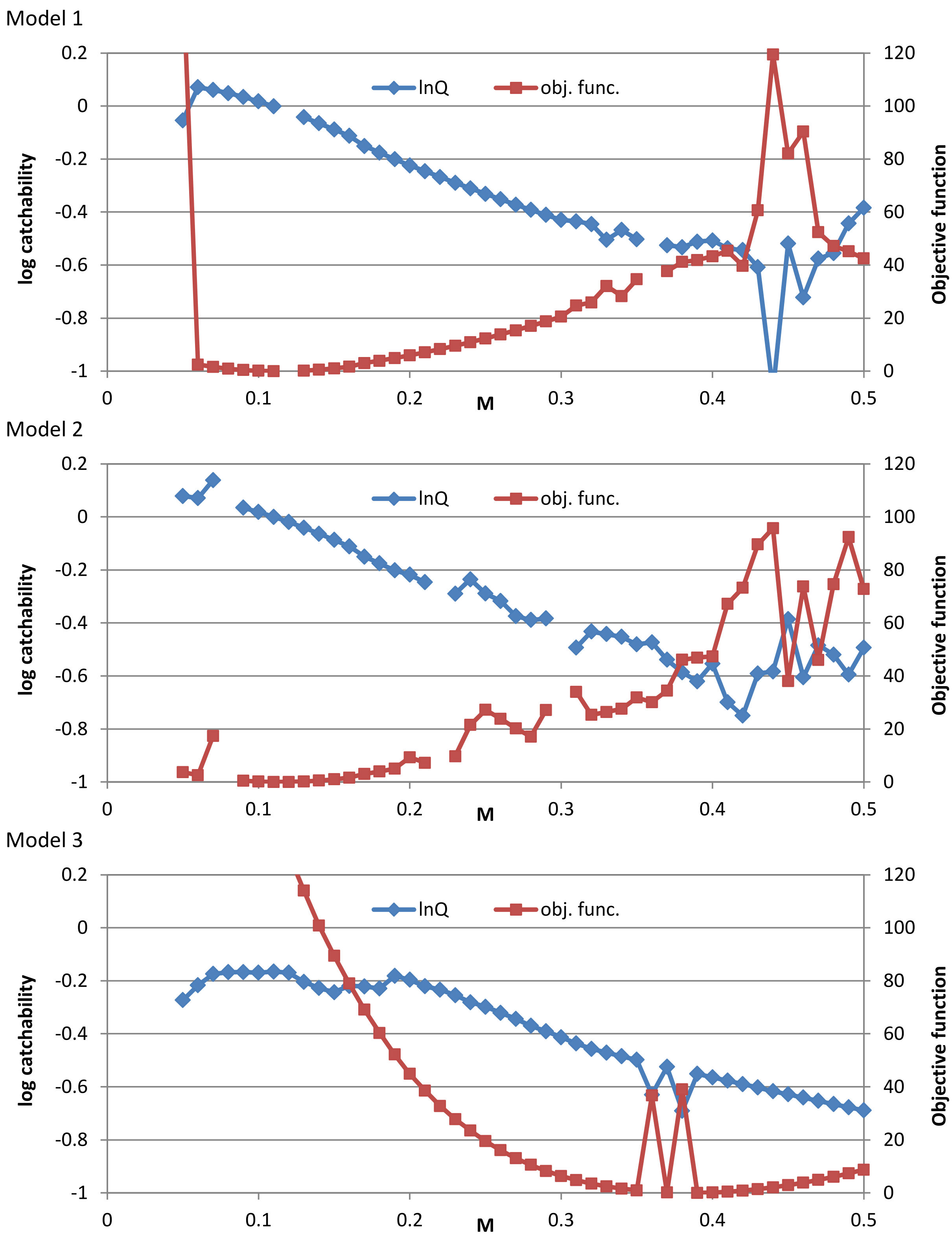


Figure 2A.1.9—Likelihood profiles with respect to the natural mortality rate. Objective function minima occur at *M*=0.11 (Model 1 and Model 2), and *M*=0.39 (Model 3). The relationship between *M* and log catchability is also shown for each model. Jaggedness indicates lack of convergence in some runs.

APPENDIX 2A.2: SUPPLEMENTAL CATCH DATA

From the minutes of the September 2013 Joint Plan Team meeting: *"The Teams recommended that SAFE chapter authors continue to include 'other' removals as an appendix. Optionally, authors could also calculate the impact of these removals on reference points and specifications, but are not required to include such calculations in final recommendations for OFL and ABC."*

This appendix is provided in response to the above recommendation. A similar compendium was provided for the combined BSAI Pacific cod stock in Attachment 2.4 of the 2012 assessment (Thompson and Lauth 2012).

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.2.1.

Although many sources of removal are documented in Table 2A.2.1, 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.2.1 for the last three complete years (2011-2013) is 92 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.

Table 2A.2.1—Total removals of Pacific cod (t) from activities not related to directed fishing. Cells shaded gray represent data contained in the NMFS database. Other entries represent extrapolations for years in which the respective activity was known or presumed to have taken place.

Activity	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Aleutian Island Bottom Trawl Survey				13			13			13					13			13	
Aleutian Islands Coop. Acoustic Survey																			
Annual Longline Survey			19	19	19	19	19	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	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	0	0	0	0	0	0

Activity	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Aleutian Island Bottom Trawl Survey		13			13		13		13		13				12		12		16
Aleutian Islands Coop. Acoustic Survey													1						
Annual Longline Survey	17		27		25		19		13		25		13		16		18		
Atka Tagging Survey					100	100	100	100	100		100	100				100	100		
Bait for Crab Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IPHC Annual Longline Survey			13	13	13	13	13	13	13	13	13	13	13	13	9	23	9	13	13
Subsistence Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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