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

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EXECUTIVE SUMMARY

Summary of Changes in Assessment Inputs

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

Changes in the Input Data

1) Catch data for 1991-2014 were updated, and preliminary catch data for 2015 were incorporated.
2) Commercial fishery size composition data for 2014 were updated, and preliminary size composition data from the 2015 commercial fisheries were incorporated.
3) Fishery data (catch and size composition) from years prior to 1991 were included.
4) Age composition data from the 2002, 2006, and 2014 AI bottom trawl survey were incorporated.

Changes in the Assessment Methodology

Although harvest specifications for AI Pacific cod have been based on Tier 5 methods ever the AI and EBS stocks began to be managed separately (in 2014), age-structured models of this stock have been explored in every version of every assessment since 2012 (Thompson and Lauth 2012). One Tier 5 model and four age-structured models were presented in this year's preliminary assessment (Appendix 2A.1). After reviewing this year's preliminary assessment, the Plan Team and SSC requested three models for inclusion in the final assessment: the base model (Tier 5) used for setting harvest specifications last year (Thompson and Palsson 2014), a variant of that model, and a modified version of one of the age-structured models presented in the preliminary assessment. The authors recommend retaining the base model for the purpose of setting final harvest specifications for 2016 and preliminary harvest specifications for 2017.

Summary of Results

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

Quantity	As estimated or *specified last* year for: 2015	2016	As estimated or *recommended this* year for: 2016	2017
M (natural mortality rate)	0.34	0.34	0.34	0.34
Tier	5	5	5	5
Biomass (t)	68,900	68,900	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)	23,400	23,400	23,400	23,400
maxABC (t)	17,600	17,600	17,600	17,600
ABC (t)	17,600	17,600	17,600	17,600
Status	As determined *last* year for: 2013	2014	As determined *this* year for: 2014	2015
Overfishing	No	n/a	No	n/a

Responses to SSC and Plan Team Comments on Assessments in General

Two comments on assessments in general were addressed in the preliminary assessment (Appendix 2.1). In the interest of efficiency, they are not repeated in this section. One Joint Plan Team (JPT) comment that was developed following completion of the preliminary assessment is shown below.

JPT1 (9/15 minutes): *"For this year's final assessments, the Teams recommend that each author of an age-structured assessment use one of the following model naming conventions…."* [The remainder of this recommendation consists of a list of options, too lengthy to reproduce here (see link below).] This recommendation was made in response to a request from the SSC that the JPT *"refine the model numbering system to avoid confusion and ensure that the origin of the model can be traced back to the original derivation"* (6/15 minutes). Option 4a in the JPT's list consists of a model naming convention described in the "Team procedures" document that was presented at the September JPT meeting (see link below), and is the option used in this assessment. Names of final models adopted since the SSC first accepted a model for use in setting harvest specifications for AI Pacific cod (in 2013), and all models included in this year's preliminary assessment, are translated according to the new naming convention in the "Model Structure" subsection of the "Analytic Approach" section.

The minutes from the September JPT meeting can be found at: https://npfmc.legistar.com/LegislationDetail.aspx?ID=2449669&GUID=BC4E6655-EEF8-480C-BDBC-D5E6B5DD2D8A&Options=&Search= (click on "C2_1. GFPT September 2015 report.pdf")

The "Team procedures" document can be found at: http://legistar2.granicus.com/npfmc/meetings/2015/9/927_A_Groundfish_Plan_Team_15-09-21_Meeting_Agenda.pdf (click on "Team procedures, updated")

JPT2 (9/15 minutes): *"The Teams recommend that the random effects survey smoothing model be used as a default for determining current survey biomass and apportionment among areas…. In addition to results from the default method, authors may present alternative survey averaging and apportionment strategies…."* The random effects survey smoothing model is included here and used for determining current survey biomass and apportionment among areas. An alternative Tier 5 model is also included.

Responses to SSC and Plan Team Comments Specific to this Assessment

Five comments specific to this assessment, one of which contained several parts, were addressed in the preliminary assessment (Appendix 2A.1). In the interest of efficiency, they are not repeated in this section. BSAI Plan Team (BPT) and SSC comments that were developed following completion of the preliminary assessment are shown below.

BPT1 (9/15 minutes): "*For November, the Team recommends three models:*

i. *Model 0 (random effects).*

ii. *Model 2, also a random effects model but with the IPHC longline survey CPUE added as a second time series.*

iii. *Model 3, same as Model 3 seen at this meeting but with enough equality constraints imposed on survey selectivity to cure the U-shape (e.g., the Bering Sea Model 5 where selectivity is estimated only to age 8).*" The requested models are included here, now numbered 13.4, 15.6, and 15.7 respectively, following the new model numbering protocol. See also comment SSC1 (below).

SSC1 (10/15 minutes): "*The Plan Team did not consider any of the age-structured model versions credible, but encouraged further development of an age-structured model for the Plan Team. The SSC concurs with this recommendation and with the Plan Team request to bring forward the random effects model (model 0), a variant of model 0 that includes IPHC longline survey CPUE as a second index, and one of the age-structured models (model 3) with additional constraints on survey selectivity.*" See response to comment BPT1.

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. Neidetcher et al. (2014) have identified spawning locations throughout the Bering Sea and Aleutian Islands.

It is conceivable that mortality rates, both fishing and natural, may vary with age in Pacific cod. In particular, very young fish likely have higher natural mortality rates than older fish (note that this may not be particularly important from the perspective of single-species stock assessment, so long as these higher natural mortality rates do not occur at ages or sizes that are present in substantial numbers in the data). For example, Leslie matrix analysis of a Pacific cod stock occurring off Korea estimated the instantaneous natural mortality rate of 0-year-olds at 2.49% per day (Jung et al. 2009). This may be compared to a mean estimate for age 0 Atlantic cod (*Gadus morhua*) in Newfoundland of 4.17% per day, with a 95% confidence interval ranging from about 3.31% to 5.03% (Robert Gregory, DFO, *pers. commun.*); and age 0 Greenland cod (*Gadus ogac*) of 2.12% per day, with a 95% confidence interval ranging from about 1.56% to 2.68% (Robert Gregory and Corey Morris, *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 34 t since 1993). The breakdown of catch by gear during the most recent complete five-year period (2010-2014) is as follows: trawl gear accounted for an average of 67% of the catch, longline gear accounted for an average of 18%, and pot gear accounted for an average of 15%.

Historically, Pacific cod were caught throughout the AI. For the last five years prior to enactment of additional Steller sea lion (*Eumetopias jubatus*) protective regulations in 2011, the proportions of Pacific cod catch in statistical areas 541 (Eastern AI), 542 (Central AI), and 543 (Western AI) averaged 58%, 19%, and 23%, respectively. For the period 2011-2014, the average distribution has been 84%, 16%, and 0%, respectively. In 2015, area 543 was reopened to limited fishing for Pacific cod (see "Management History" below). As of October 18, the 2015 catch distribution was 39%, 26%, and 35%, respectively.

Catches of Pacific cod taken in the AI for the periods 1964-1980, 1981-1990, and 1991-2015 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 1994-2015 by 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 2014 and 2015 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 (P=0.04 and P=0.05 for the trawl and longline slope coefficients, respectively).

Discards

The catches shown in Tables 2A.1b and 2A.1c include estimated discards. Discard amounts and rates of Pacific cod in the AI Pacific cod fisheries are shown for each year 1991-2015 in Table 2A.2. Amendment 49, which mandated increased retention and utilization of Pacific cod, was implemented in 1998. From 1991-1997, discard rates in the Pacific cod fishery averaged about 5.6%. Since then, they have averaged about 0.8%.

Management History

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

History with Respect to the EBS Stock

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

The history of acceptable biological catch (ABC), overfishing level (OFL), and total allowable catch (TAC) levels is summarized and compared with the time series of aggregate (i.e., all-gear, combined area) commercial catches in Table 2A.3. Note that, prior to 2014, this time series pertains to the combined BSAI region, so the catch time series differs from that shown in Table 2.1, which pertains to the AI only. Total catch has been less than OFL in every year since 1993.

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

Changes in ABC over time are typically attributable to three factors: 1) changes in resource abundance, 2) changes in management strategy, and 3) changes in the stock assessment model. Because ABC for all years through 2013 were based on the EBS assessment model (with an expansion factor for the AI), readers are referred to Chapter 2 for a history of changes in that model. During the period of separate AI and EBS management, the assessment of the AI stock has been based on a simple, random effects (Tier 5) model.

History with Respect to the State Fishery

Beginning with the 2006 fishery, the State of Alaska managed a fishery for AI Pacific cod inside State waters, with a guideline harvest level (GHL) equal to 3% of the BSAI ABC. Beginning with the 2014 fishery, this practice was modified by establishing two separate GHL fisheries, one for the AI and one for the EBS (inside State waters between 164 and 167 degrees west longitude only), each equal to 3% of the sum of the AI and EBS ABCs (i.e., AI GHL = EBS GHL = 0.03×(AI ABC + EBS ABC)).

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

History with Respect to Steller Sea Lion Protection Measures

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

DATA

This section describes data used in the models presented in this stock assessment, two of which are of the Tier 5 (non-age-structured) variety, and one of which is 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 one or both of the Tier 5 models (IPHC = International Pacific Halibut Commission).

Source	Type	Years
AI bottom trawl survey	Biomass	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014
IPHC longline survey	Relative abundance	1997-2014

The following table summarizes the sources, types, and years of data included in the data file for the Tier 3 model:

Source	Type	Years
Fishery	Catch biomass	1977-2015
Fishery	Size composition	1978-1979, 1982-1985, 1990-2015
AI bottom trawl survey	Numerical abundance	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014
AI bottom trawl survey	Size composition	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014
AI bottom trawl survey	Age composition	2002, 2006, 2010, 2012, 2014

Fishery

Catch Biomass

The catch data used in the model consist of the totals for 1977-2014 shown in Tables 2A.1, and a total for 2015 obtained by projecting a year-end value on the basis of the catch taken through the end of July. Catch for the August-December portion of 2015 were estimated by the method described in the 2014 assessment, which consists of inflating the January-July catch by the average ratio of January-July:January-December catches from the previous five years. This gave a 2015 year-end estimate of 8,433/0.890 = 9,478 t. The catches shown in Table 2A.1 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 1978 through the first part of 2015 (the exceptions are the periods 1980-1981 and 1986-1989).

For use in the age-structured model, 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:	1978	1979	1982	1983	1984	1985	1990	1991	1992	1993	1994
N:	1729	1814	4437	5072	5565	3602	4206	22653	102653	46775	29716
Year:	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
N:	30870	42610	23762	74286	34027	52435	57750	23442	23690	23990	20754
Year:	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	
N:	20446	27543	26282	21954	34329	8879	11789	8590	4276	8891	

Survey

NMFS Bottom Trawl Survey Biomass and Abundance

The time series of NMFS bottom 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 were 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 the assessments of Pacific cod in the EBS, the Tier 3 model developed here uses survey estimates of population size measured in units of individual fish rather than biomass, and treats it as a relative index. The Tier 5 models, on the other hand, use survey biomass, and treat it as an absolute index.

NMFS Bottom Trawl 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 bottom trawl 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

NMFS Bottom Trawl Survey Age Composition

Age data from the 2002, 2006, and 2014 bottom trawl surveys became available in time for use in this year's final assessment, supplementing the two years (2010 and 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
2002	328	0.0000	0.0000	0.1808	0.2437	0.2178	0.1397
2006	764	0.0000	0.1233	0.0295	0.1864	0.1722	0.1961
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
2014	564	0.0000	0.0409	0.1795	0.1563	0.2073	0.1876

Year	6	7	8	9	10	11	12+
2002	0.1083	0.0845	0.0233	0.0018	0.0000	0.0000	0.0000
2006	0.1682	0.0815	0.0223	0.0108	0.0066	0.0032	0.0000
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
2014	0.1452	0.0581	0.0171	0.0059	0.0018	0.0003	0.0000

IPHC Longline Survey Relative Abundance

A portion of the longline survey conducted annually by the IPHC takes place in the AI. Mean values of CPUE (in units of individuals per effective hook), with standard deviations, are shown below:

Year:	1997	1998	1999	2000	2001	2002	2003	2004	2005
Mean:	0.11282	0.15923	0.12571	0.11933	0.08143	0.04396	0.05099	0.04952	0.06127
St. Dev.:	0.01361	0.01948	0.016	0.01332	0.01133	0.00678	0.00883	0.00916	0.01102

Year:	2006	2007	2008	2009	2010	2011	2012	2013	2014
Mean:	0.10819	0.08428	0.08271	0.0693	0.03404	0.06456	0.02965	0.04937	0.04888
St. Dev.:	0.01454	0.01094	0.01001	0.0098	0.00553	0.00849	0.00646	0.00675	0.00766

ANALYTIC APPROACH

Model Structure (General)

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

In response to a request from the Joint Plan Teams (which was, in turn, a response to a request from the SSC), a new protocol for model numbering is adopted in this assessment (see comment JPT1 in the Executive Summary). The goal of the new protocol is to make it easy to distinguish between major and minor changes in models and to identify the years in which major model changes were introduced. Names of models constituting *major* changes get linked to the year that they are introduced (e.g., Model 14.2 is one of at least two models introduced in 2014 that constituted a major change from the then-current base model), while names of models constituting *minor* changes get linked to the model that they modify (e.g., the first minor modification of Model 14.2 would be labeled 14.2a).

Names of all final models adopted since the first assessment (2013) associated with separate management of the AI Pacific cod stock are translated according to the new naming convention below (shaded cells indicate the final model for the respective year):

Assessment	Models included in final assessment (original names)				Final model name	
					Original	New
2013	1	2	KF	RE	RE	13.4
2014	1	2	3		1	13.4

Names of all models included in the preliminary assessment (Appendix 2A.1) are translated below:

Original name:	0	2	3	4	5
New name:	13.4	15.2	15.3	14.2	15.5

Names of all models included in this assessment are translated below:

Team/SSC name:	0	2	3
New name:	13.4	15.6	15.7

Tier 5 Model Structures

Model 13.4 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 both 2013 and 2014 for the purpose of setting AI Pacific cod harvest specifications. Model 15.6 is a modification of Model 13.4 that fits the NMFS bottom trawl survey and IPHC longline survey simultaneously, with equal emphasis was given to both surveys. Both of the Tier 5 models are programmed using the ADMB software package (Fournier et al. 2012).

Both of the Tier 5 models are very simple, state-space models of the "random walk" variety. The only parameter in Model 13.4 is the log of the log-scale process error standard deviation. Model 15.6 estimates this parameter also (the model assumes that both of the surveys have the same process error standard deviation). In addition, Model 15.6 estimates a catchability coefficient for converting the IPHC relative abundance index (in numbers of fish per effective hook) into units of area-swept biomass.

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

Both of the Tier 5 models assume 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 Structure: Main Features

Model 15.7 is the only Tier 3 model presented in this assessment. It is based on Model 3—now relabeled as Model 15.3—from the preliminary assessment (Appendix 2A.1), the only difference being that both fishery and survey selectivity are held constant (with respect to age) above age 8 in Model 15.7, as opposed to being free at all ages (1-20) in Model 15.3.

Model 15.7 was developed using the Stock Synthesis (SS) program (Methot and Wetzel 2013). Version 3.24u (compiled on 08/29/14) 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

Model 15.7 bears some similarities to the model that has been accepted for use in management of the EBS Pacific cod stock since 2011 (Thompson 2014). Some of the main differences between Model 15.7 and the 2011-2014 EBS model are as follow:

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

10. Potentially, each selectivity parameter was allowed to be time-varying with annual additive *dev*s (normally distributed random deviations added to the base value of their respective parameter).

Tier 3 Model Structure: Iterative Tuning

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

Iterative Tuning of Prior Distributions for Selectivity Parameters

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

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

Iterative Tuning of Time-Varying Selectivity Parameters

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

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

The iteration was conducted separately for the fishery and survey.

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

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

The Tier 3 model and all applications of the Tier 5 harvest control rules in this assessment 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 reader-tester sample (n=952) of AI Pacific cod age data yielded an estimated slope of 0.08849 (i.e, the standard deviation of estimated age was modeled as 0.08849 × age) and a weighted R^2 of 0.74. This regression corresponds to a standard deviation at age 1 of 0.088 and a standard deviation at age 20 of 1.77. These parameter estimates, which are very close to those estimated for the EBS stock, were used for Model 15.7.

Weight at Length (Tier 3 Only)

In Model 15.7, 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 5.367×10^{-6} and 3.194, respectively, based on 9,053 samples collected from the AI fishery between 1974 and 2014.

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 Model 15.7.

Catchability (Tier 3 and Tier 5)

As noted above, "catchability" for the IPHC longline survey was estimated internally in Model 15.6. This parameter does not correspond to *Q* in the usual sense, for two reasons: 1) it scales one survey to another rather than total biomass or abundance (although, in this case, the NMFS bottom trawl survey is assumed to represent total biomass), and 2) it also serves the purpose of converting relative abundance (in numbers) into units of biomass.

Also noted above, *Q* for the NMFS bottom trawl survey was estimated internally in Model 15.7, 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 estimated on a log scale in SS), with mean 0 and standard deviation 0.11.

Stock-Recruitment "Steepness" (Tier 3 Only)

Following the standard Tier 3 approach, Model 15.7 assumes that there is no relationship between stock and recruitment, so the "steepness" parameter is set at 1.0.

Parameters Estimated Inside the Assessment Model (Tier 3 Only)

Parameters estimated inside SS for Model 15.7 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., 1977) abundance at ages 1 through 10
7. annual log-scale recruitment *dev*s for 1977-2011
8. initial (equilibrium) fishing mortality
9. log survey catchability
10. base values of fishery selectivity parameters for ages 1 through 8
11. base values of survey selectivity parameters for ages 1 through 8
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 other than *Q*, 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)

Models 13.4 and 15.6 incorporate both process error and observation error in the likelihood. Both are assumed to be lognormal. As random effects models, 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 parameters (one parameter in the case of Model 13.4, two in the case of Model 15.6).

Objective Function (Tier 3)

The Tier 3 models in this assessment include objective function components for 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 in this assessment.

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 2014): 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:	1978	1979	1982	1983	1984	1985	1990	1991	1992	1993	1994
N:	13	14	34	38	42	27	32	171	777	354	225

Year:	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
N:	234	322	180	562	547	843	928	377	381	386	334

Year:	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
N:	329	443	422	353	552	143	189	138	69	143

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, five years of age composition data are available. 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 thus translate into the input sample sizes shown below:

Year:	2002	2006	2010	2012	2014
N:	168	391	345	307	289

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 the goodness of fit achieved with respect to the NMFS bottom trawl survey biomass data are shown for the two Tier 5 models below:

Statistic	Model 13.4	Model 15.6
Correlation (observed:expected)	0.98	0.36
Root mean squared error	0.11	0.17
Mean normalized residual	0.06	0.06
Standard deviation of normalized residuals	0.63	1.15

Model 15.6 would not be expected to fit the bottom trawl survey data as well as Model 13.4, because Model 15.6 is also trying to fit the IPHC longline survey data.

Figure 2A.3 shows the time series of biomass estimated by the two Tier 5 models together with the trawl survey and longline survey data.

Goodness of Fit (Tier 3)

The values for the objective function components obtained by Model 15.7 are shown below:

Objective function component	Model 15.7
Survey abundance	-8.183
Fishery size composition	149.689
Survey size composition	232.466
Age composition	41.148
Recruitment	0.998
Priors	12.478
"Softbounds"	0.001
Parameter *dev*s	20.233
Total	448.829

Parameter counts were as follow:

Parameter counts	Model 15.7
Unconstrained parameters	10
Parameters with priors	17
Constrained deviations	172
Total	199

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 Model 15.7 compare to the input sample sizes (Ninp) for these data. A(·) represents the arithmetic mean and H(·) represents the harmonic mean.

Fleet	Nrec	A(Ninp)	A(Neff/Ninp)	A(Neff)/A(Ninp)	H(Neff)/A(Ninp)
Fishery	32	300	15.72	12.02	4.99
Survey	10	300	3.29	3.01	2.00

All ratios are well above unity.

Figures 2A.4 and 2A.5 show Model 15.7's fit to the fishery size composition and survey size composition data, respectively.

Because there are far fewer years of age composition data than size composition data, it is not too cumbersome to report the ratio of Neff to Ninp for each year, as well as the overall arithmetic mean ("Mean") and harmonic mean ("Harm."). These are shown in the table below:

Year	Ninp	Neff	Ratio
2002	168	166	0.99
2006	391	447	1.14
2010	345	51	0.15
2012	307	284	0.93
2014	289	106	0.37
Mean	300	211	0.71
Harm.	276	123	0.40

Unlike the ratios for the size composition data, the ratios for the age composition data tend to be less than unity.

Figure 2A.6 shows Model 15.7's fits to the survey age composition data.

The table below shows four statistics related to Model 15.7's goodness of fit with respect to the survey abundance data:

Statistic	Model 15.7
Correlation (observed:expected)	0.78
Root mean squared error	0.27
Mean normalized residual	-0.02
Standard deviation of normalized residuals	1.44

Comparing the root mean squared error shown above (0.27) with the mean log-scale standard error from the survey observations (0.18) indicates that Model 15.7 is not fitting the survey abundance data as well as it should. The fact that the standard deviation of normalized residuals exceeds unity suggests a similar conclusion.

Figure 2A.7 shows Model 15.7's fit to the trawl survey abundance data. The point estimates from the model falls within the 95% confidence intervals of the observations in 9 of the 10 years.

Parameter Estimates (Tier 5)

Models 13.4 and 15.6 have one and two estimated parameters, respectively. Both estimate the log of the log-scale process error, and Model 15.6 also estimates a log catchability coefficient that puts the IPHC longline survey data on the same scale as the NMFS bottom trawl survey. The estimates of the parameters, with their standard deviations, are shown below:

	Model 13.4		Model 15.6	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.
Log of log-scale process error st. dev.	-1.762	0.671	-1.340	0.223
Log of IPHC survey catchability	n/a	n/a	-13.949	0.079

The correlation between the two parameters estimated by Model 15.6 was –0.194.

Parameter Estimates (Tier 3)

Table 2A.8 displays all of the parameters (except fishing mortality rates) estimated internally in Model 15.7, along with the standard deviations of those estimates:

- Table 2A.8a shows growth, ageing bias, recruitment (except annual *dev*s), initial fishing mortality, log catchability, and initial age composition parameters
- Table 2A.8b shows annual log-scale recruitment *dev*s (these are plotted in Figure 2A.8)
- Table 2A.8c shows baseline selectivity parameters
- Table 2A.8ed shows fishery selectivity *dev*s; and Table 2A.8f shows survey selectivity *dev*s.

The estimate of log catchability in Table 2A.8a translates into a *Q* values of 0.86.

Table 2A.9 shows estimates of fishing mortality. Two measures of annual fishing mortality are shown. 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.

Derived Quantities

Figure 2A.9 shows the time series of spawning biomass relative to $B_{100\%}$ as estimated by Model 15.7.

Figure 2A.10 shows the time series of total (age 0+) biomass as estimated by Model 15.7, with the survey biomass time series included for comparison. After 1993, the model's estimate of total biomass is consistently higher than the survey biomass. For the time series as a whole, the model's estimate of total biomass is 59% higher than the survey biomass on average.

Figure 2A.11 shows trawl survey selectivity as estimated by Model 15.7. Selectivity is at least 0.85 for ages 4-6 (peaking at age 6), drops to 0.56 at age 7, then remains constant at 0.72 for ages 8 and above.

Figure 2A.12 shows fishery selectivity as estimated by Model 15.7. The selectivity schedule is marked by an extremely abrupt increase from a value of 0.33 at age 7 to a value of 1.00 at ages 8 and above.

Figure 2A.13 shows likelihood profiles with respect to *M* for Model 15.7. The value of survey catchability is also shown. The model assumes a value of 0.34 for *M*, and the likelihood profile indicates that a very similar value of *M* (0.33) would minimize the objective function.

Table 2A.10 contains selected management reference points. Many of the quantities cannot be estimated by the Tier 3 models. For Models 15.7, 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 SS. The last seven rows (Model 15.7 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

Three criteria were considered in evaluating the models. The first two are the criteria used last year. The third was added this year.

1. Does the model contain new features that merit further evaluation before being adopted?
2. Would use of the model for setting harvest specifications pose a significant risk to the stock?
3. Would adoption of the model be consistent with respect to the peer review procedures described in the NS2 guidelines?

<u>Criterion #1</u>

Model 13.4 uses the simple random effects method developed by the Survey Averaging Working Group. This method has been evaluated by the Working Group, as well as the Teams and SSC, for several years now and was the method adopted last year by the BSAI Plan Team and the SSC for all BSAI Tier 5 stocks and stock complexes.

Model 15.6 was developed under a variant, new this year, of the simple random effects method. The new method allows incorporation of data from more than one survey time series to estimate the state variable time series. Evaluation of the new method requires clarification of the state variable time series being modeled:

- Interpretation #1 is that the state variable is the biomass "seen" by a particular survey (e.g., the NMFS bottom trawl survey), as distinguished from the biomass of the actual population. In this interpretation, process error includes changes in the actual biomass *and* changes in the survey's catchability or selectivity, while observation error consists of sampling variability only.
- Interpretation #2 is that the state variable is the biomass of the actual population. In this interpretation, process error consists of changes in the actual biomass only, while observation error consists of sampling variability *and* changes in the survey's catchability or selectivity.

Both interpretations imply difficulties for Model 15.6. In the context of Interpretation #1, unless all of the surveys experience the same changes in catchability and selectivity, it is not clear why inclusion of additional surveys would improve the estimation of the survey actually being modeled, or why the biomass "seen" by all surveys should have the same process error standard deviation. In the context of Interpretation #2, it is not clear how one would estimate the variability in catchability and selectivity needed to specify the observation error standard deviations, given the data limitations associated with Tier 5 by definition (currently, as implemented in all assessments of BSAI Tier 5 stocks and stock complexes, the observation error standard deviations are simply set equal to the standard errors of the survey estimates, which involve sampling variability only).

Two features of Model 15.7 that stand out are its use of SS selectivity pattern #17, which treats selectivity as a random walk with respect to age, and the method used to estimate the "sigma" parameters governing the amount of time-variability in *dev* vectors.

Although selectivity pattern #17 has several benefits (see "Discussion" section in Appendix 2A.1), some aspects could benefit from further evaluation, specifically:

- This selectivity pattern 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 (this may be 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 (e.g., Model 3—now relabeled as Model 15.3—in this year's preliminary assessment).

The method of Thompson and Lauth (2012, Annex 2.1.1) was used to estimate the sigma parameters governing the amount of time-variability in *dev* vectors in Model 14.2. This method was developed as an alternative to estimating the sigma parameters by iteratively tuning each sigma to match the standard deviation of the elements in the respective *dev* vector, which is known to be biased low and is prone to "false negatives" (i.e., returning a zero estimate for σ when the true value is non-zero). For a univariate model (i.e., a model with only one *dev* vector), *if* the method of Thompson and Lauth (2012) returns a non-zero estimate of σ, this estimate will be unbiased (at least in a linear-normal model). However, the method is still prone to false negatives (Thompson in prep.), and generalizations to the multivariate case are awkward at best, with unknown statistical properties.

Two of the models presented in this year's preliminary assessment (Appendix 2A.1) use an alternative method that addresses the shortcomings of the method of Thompson and Lauth (2012), at least in a linear-normal model. While its performance in the context of a typical stock assessment model remains to be evaluated, the new method so far shows considerable promise, and it might be worth waiting for further studies of the new method rather than switching to the method of Thompson and Lauth (2012) this year and then switching to a different method in the near future.

Finally, the nearly knife-edged fishery selectivity pattern estimated by Model 15.7 is at least somewhat suspicious, and may indicate either that the selectivity sigmas need to be retuned (they were tuned most recently—for a different model—in 2014), or that the tuning method itself is problematic.

<u>Criterion #2</u>

With regard to the second criterion, a formal risk analysis has not been undertaken in this assessment, but one feature of Model 15.7 that merits attention in this context is the difference between this model's estimates of total biomass and the biomass estimated by the survey (Figure 2A.10). As noted above, the ratio of model biomass to survey biomass has an average (across the time series) value of about 1.59. While it would be desirable to have this result confirmed by field studies, at least this is a much more believable value than those obtained by the age-structured models considered in the preliminary assessment, which ranged from 3.31 to 4.68. Models 13.4 and 15.6 track survey biomass very closely on average (average ratio = 0.98 and 1.00, respectively).

<u>Criterion #3</u>

The Federal guidelines for National Standard 2 of the Magnuson-Stevens Fishery Conservation and Management Act encourage use of external peer reviewers before adopting major model changes. Although the guidelines do not prohibit making major model changes in the course of a typical assessment cycle, the fact that the Center for Independent Experts is scheduled to review the assessment early next year might suggest that it is appropriate to wait until the next assessment cycle to make a major change in the final model.

Conclusion

On the basis of the above, Model 13.4 is recommended for use in setting final harvest specifications for 2016 and preliminary harvest specifications for 2017, 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 model are shown in Table 2A.8. Estimates of fishing mortality rates from the Tier 3 model are shown in Table 2A.9. Estimates of the only statistically estimated parameter(s) in the Tier 5 models are shown in the main text, under "Parameter Estimates (Tier 5)."

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

Schedules of length at age and weight at age for the population, fishery, and survey as estimated by the Tier 3 model are shown in Table 2A.13.

Time Series Results

As in the previous subsection, results for all three models (Tier 3 Model 15.7 and Tier 5 Models 13.4 and 15.6) will be presented here to the extent possible.

Definitions

The biomass estimates presented here will be defined in three ways for the Tier 3 model: 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 1977-2015 as estimated by the Tier 3 model (projections through 2016 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 by the Tier 5 models (because these are "random walk" models, projected biomass for 2015-2016 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 model are shown, together with the observed time series of trawl survey biomass, in Figure 2A.10, and the time series of survey biomass as estimated by the Tier 5 models are shown in Figure 2A.3. The time series of female spawning biomass as estimated by the Tier 3 model is shown, together with the observed time series of trawl survey biomass, in Figure 2A.14.

Recruitment and Numbers at Age

Table 2A.15 shows the time series of age 0 recruitment (1000s of fish), with standard deviations, for the years 1977-2013 as estimated by the Tier 3 model.

For the time series as a whole, the Tier 3 model estimates that 1993 was the largest cohort. The model estimates that the first eight cohorts (1977-1984) in the time series were also the eight smallest. With those cohorts included, the time series average is 35.3 million fish. With those cohorts excluded, the time series average is 42.0 million fish. Recent recruitments have tended to be low. No cohorts larger than the post-1984 average have been spawned since 2007. The autocorrelation coefficient for the entire time series is 0.42. With the 1977-1984 cohorts excluded, the autocorrelation coefficient is 0.06.

Tier 3 model estimates of recruitment for the entire time series (1977-2013) are shown in Figure 2A.15, along with their respective 95% confidence intervals.

The time series of numbers at age as estimated by the Tier 3 model is 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 model.

For the Tier 3 model, Figure 2A.16 plots the estimated trajectory of relative fishing mortality and relative female spawning biomass from 1977 through 2017 based on full-selection fishing mortality, overlaid with the current harvest control rules (projected values for 2016 and 2017 are from Scenario 2 under "Harvest Recommendations," below). It should be noted that, except for the projection years, this trajectory is based on SS output, which may not match the estimates obtained by the standard projection program exactly.

Retrospective Analysis

Figure 2A.17 shows the retrospective behavior of the Tier 3 model with respect to female spawning biomass over the years 2005-2015. This figure was obtained by conducting ten additional model runs, dropping the 2015 data to create the run labeled “2014,” dropping the 2014-2015 data to create the run labeled “2013,” and so forth (the run labeled “2015” 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 15.7, $\rho = 0.199$, indicating that this model tends to overestimate spawning biomass in the current year by nearly 20%. Not only is the retrospective bias of Model 15.7 high and positive on average, it is positive in all but one of the runs shown in Figure 2A.17.

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 Model 15.7 (except those that get eliminated from the model during the peeling process, leaving a total of 132), correlation coefficients with respect to number of peels were computed.

The results are shown in Figure 2A.17, in the form of a cumulative distribution function. For example, 20 parameters (15% of the total) in Model 15.7 had a correlation (in absolute value) of at least 0.90 with respect to number of peels.

The parameters with correlations of at least 0.90 in absolute value were the base parameters for age 3 fishery selectivity and age 5 survey selectivity, and the following *dev*s:

Type	Year
Recruitment *dev*	1984
Recruitment *dev*	1992
Recruitment *dev*	1994
Recruitment *dev*	1997
Recruitment *dev*	1999
Recruitment *dev*	2000
Recruitment *dev*	2001
Survey age 3 selectivity *dev*	1991
Survey age 3 selectivity *dev*	1997

Type	Year
Fishery age 4 selectivity *dev*	1978
Fishery age 4 selectivity *dev*	1979
Fishery age 4 selectivity *dev*	1984
Fishery age 4 selectivity *dev*	1991
Fishery age 4 selectivity *dev*	1996
Fishery age 4 selectivity *dev*	2000
Fishery age 4 selectivity *dev*	2002
Fishery age 6 selectivity *dev*	1980
Fishery age 6 selectivity *dev*	1996

Given that all but two of the parameters that varied most directly with the number of peels were all *dev*s, it is not clear that adding time variability to an existing estimated parameter will solve the problem.

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 2016-2017 spawning biomass and the Tier 3 reference points from Model 15.7 are all reliable, then AI Pacific cod will be managed under Tier 3. If the SSC determines that Model 15.7 does not produce 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 13.4), the estimates are as follow:

Quantity	2016	2017
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, Tier 3 Model 15.7 projects that female spawning biomass will be above $B_{40\%}$ in both 2016 and 2017, which implies that the stock would be managed under Tier 3a in both years. Tier 5 has no sub-tiers.

Estimates of OFL, maximum permissible ABC, and the associated fishing mortality rates for 2016 and 2017 are shown for the respective models in Table 2A.10. For the authors' recommended model (Tier 5, Model 13.4), 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 2016 and 2017 from Tier 3 Model 15.7 (using SS rather than the standard projection model) are 118,000 t and 109,000 t, respectively.

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 2015. 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. In last year's final assessment, twelve estimators were evaluated to determine the best method of estimating total current-year catch as a function of previous intra-annual fishery performance. This evaluation concluded that the best estimator consisted of inflating the current year's January-July catch by the average proportion (January-July catch divided by January-December catch) 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 2015 fishery, the estimator resulted in a catch of 9,478 t, which is less than the 2015 ABC of 17,600 t, so 9,478 t was used as the best estimate of the catch for 2015.

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 predicting future catches under Scenario 2, the 2014 assessment also described development of the following estimator for future total catch as a function of future ABC: catch = 0.95×ABC – 900 t. This estimator was used again in the present assessment.

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 2016 recommended in the assessment to the *max* F_{ABC} for 2016. (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 2010-2014 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 2015 or 2) above 1/2 of its MSY level in 2015 and expected to be above its MSY level in 2025 under this scenario, then the stock is not overfished.)
>
> *Scenario 7*: In 2016 and 2017, 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 2017 or 2) above 1/2 of its MSY level in 2017 and expected to be above its MSY level in 2027 under this scenario, then the stock is not approaching an overfished condition.)

Projections corresponding to the standard scenarios are shown for Model 15.7 in Tables 2A.18-2A.24.

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 2016, it does not provide the best estimate of OFL for 2017, because the mean 2017 catch under Scenario 6 is predicated on the 2016 catch being equal to the 2016 OFL, whereas the actual 2016 catch will likely be less than the 2016 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 2016 and 2017 are the maximum permissible values from Model 13.4 (Tier 5): 17,600 t in both years, which is also the current specification.

Area Allocation of Harvests

As noted in the "Management History" subsection of the "Fishery" section, the current (as of 2015) Steller sea lion protection measures require an estimate of the proportion of the AI Pacific cod stock residing in Area 543, which will be used to set the harvest limit in 543 after subtraction of the State GHL from the overall AI ABC. The Area 543 proportion could be computed on the basis of the survey observations themselves, or by running Model 13.4 for Area 543 and then computing the ratios of the resulting estimates to those of Model 13.4. More specifically, some possible estimators of this proportion are: 1) the 1991-2014 average proportion from the survey (26.5%), 2) the most recent proportion from the survey (24.6%), 3) the 1991-2014 average proportion from Model 13.4 (25.6%), and 4) the most recent proportion from Model 13.4 (26.3%). All of these estimates are quite close to one another, with an average value of 25.7%. If Model 13.4 is used to set the 2016 ABC based on the model's most recent estimate of biomass, it seems reasonable to estimate the biomass proportion in Area 543 accordingly, by using the most recent estimate from Model 13.4 (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 AI catch estimate for the most recent complete year (2014) is 10,595 t. This is less than the 2014 AI OFL of 23,400 t. Therefore, the AI Pacific cod stock is not being subjected to overfishing.

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

Is the stock currently overfished? This depends on the stock's estimated spawning biomass in 2015:

a. If spawning biomass for 2015 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b. If spawning biomass for 2015 is estimated to be above $B_{35\%}$, the stock is above its MSST.
c. If spawning biomass for 2015 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 2A.23). If the mean spawning biomass for 2025 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 2A.24):

a. If the mean spawning biomass for 2017 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2017 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2017 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2027. If the mean spawning biomass for 2027 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 the Tier 3 model 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 1991-2015 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 2003-2015, aggregated across gear types. Table 2A.27 shows incidental catch of prohibited species taken from 1991-2015, plus mortality estimates for halibut, aggregated across gear types. Table 2A.28 shows incidental catch of non-target species groups taken from 2003-2015, 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. A study conducted in 2002-2005 using pot fishing gear demonstrated that the local concentration of cod in the Unimak Pass area is very dynamic, so that fishery removals did not create a measurable decline in fish abundance (Conners and Munro 2008). A preliminary tagging study in 2003 – 2004 showed some cod remaining in the vicinity of the release area in the southeast Bering Sea for several months, while other fish moved distances of 150 km or more north-northwest along the shelf, some within a matter of two weeks (Rand et al. 2015). Further work has been planned to determine the overall scale of movement of Pacific cod in the Bering Sea and Aleutian Islands.

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 1991-2015 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 2015 are through September 27.

	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	978	32,457		32,457
2004	25,770	3,103	28,873		28,873
2005	19,624	3,069	22,694		22,694
2006	16,956	3,535	20,490	3,721	24,211
2007	25,714	4,495	30,208	4,146	34,355
2008	19,404	7,506	26,910	4,319	31,229
2009	20,277	6,245	26,522	2,060	28,582
2010	16,757	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	8,779	4,793	13,572
2014	5,716	429	6,145	4,451	10,595
2015	5,535	3,080	8,615	161	8,776

Table 2A.1d—Summary of 1994-2015 catches (t) of Pacific cod in the AI, by NMFS 3-digit statistical area (area breakdowns not available prior to 1994). Catches for 2015 are through October 18.

	Amount			Proportion		
Year	Western	Central	Eastern	Western	Central	Eastern
1994	2,059	7,441	12,039	0.096	0.345	0.559
1995	1,713	5,086	9,735	0.104	0.308	0.589
1996	4,023	4,509	23,077	0.127	0.143	0.730
1997	894	4,440	19,830	0.036	0.176	0.788
1998	3,487	9,299	21,940	0.100	0.268	0.632
1999	2,322	5,276	20,532	0.083	0.188	0.730
2000	9,073	8,799	21,812	0.229	0.222	0.550
2001	12,767	7,358	14,082	0.373	0.215	0.412
2002	2,259	7,133	21,408	0.073	0.232	0.695
2003	2,997	6,707	22,752	0.092	0.207	0.701
2004	3,649	6,833	18,391	0.126	0.237	0.637
2005	4,239	3,582	14,873	0.187	0.158	0.655
2006	4,570	4,675	14,967	0.189	0.193	0.618
2007	4,974	4,692	24,689	0.145	0.137	0.719
2008	7,319	5,555	18,355	0.234	0.178	0.588
2009	7,929	6,899	13,754	0.277	0.241	0.481
2010	8,213	6,291	14,497	0.283	0.217	0.500
2011	24	1,768	9,066	0.002	0.163	0.835
2012	29	2,816	15,374	0.002	0.155	0.844
2013	53	2,874	10,680	0.004	0.211	0.785
2014	30	1,044	9,522	0.003	0.098	0.899
2015	3,139	2,368	3,559	0.346	0.261	0.393

Table 2A.2—Discards (t) and discard rates of Pacific cod in the AI Pacific cod fishery, by gear and year for the period 1991-2015 (2015 data are current through October 18). 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. The symbol “n/a” indicates that confidentiality requirements preclude listing the particular datum. Note that Amendment 49, which mandated increased retention and utilization, was implemented in 1998.

	Discarded catch (t)			Discard rate		
Year	Trawl	Long.+pot	Total	Trawl	Long.+pot	Total
1991	21	84	105	0.029	0.018	0.020
1992	633	452	1,085	0.061	0.016	0.028
1993	1,371	2,156	3,527	0.111	0.128	0.121
1994	1,091	211	1,302	0.152	0.030	0.091
1995	115	345	460	0.020	0.069	0.042
1996	343	516	859	0.028	0.050	0.038
1997	580	639	1,220	0.038	0.083	0.053
1998	140	473	613	0.008	0.033	0.020
1999	225	196	420	0.016	0.017	0.016
2000	138	466	605	0.008	0.024	0.016
2001	213	243	455	0.016	0.013	0.014
2002	526	79	604	0.020	0.028	0.021
2003	187	29	216	0.006	0.033	0.007
2004	181	57	238	0.008	0.019	0.009
2005	101	38	139	0.006	0.013	0.007
2006	100	113	214	0.005	0.028	0.010
2007	352	131	483	0.013	0.023	0.015
2008	30	113	143	0.001	0.012	0.005
2009	33	115	149	0.002	0.015	0.006
2010	38	154	192	0.002	0.015	0.007
2011	20	24	45	0.003	0.017	0.005
2012	14	70	84	0.001	0.012	0.005
2013	87	38	125	0.013	0.007	0.011
2014	22	n/a	27	0.004	n/a	0.003
2015	n/a	41	41	n/a	0.014	0.007

Table 2A.3—History of **BSAI** Pacific cod catch, TAC, ABC, and OFL (t) through 2013, and **AI** catch and specifications for 2014-2015. Catch for 2015 is through September 27. Note that specifications through 2013 were for the combined BSAI region, so BSAI catch is shown rather than the AI catches from Table 2A.1 for the period 1977-2013. Source for historical specifications: NPFMC staff.

Year	Catch	TAC	ABC	OFL
1977	36,597	58,000	-	-
1978	45,838	70,500	-	-
1979	39,354	70,500	-	-
1980	51,649	70,700	148,000	-
1981	63,941	78,700	160,000	-
1982	69,501	78,700	168,000	-
1983	103,231	120,000	298,200	-
1984	133,084	210,000	291,300	-
1985	150,384	220,000	347,400	-
1986	142,511	229,000	249,300	-
1987	163,110	280,000	400,000	-
1988	208,236	200,000	385,300	-
1989	182,865	230,681	370,600	-
1990	179,608	227,000	417,000	-
1991	220,038	229,000	229,000	-
1992	207,278	182,000	182,000	188,000
1993	167,391	164,500	164,500	192,000
1994	193,802	191,000	191,000	228,000
1995	245,033	250,000	328,000	390,000
1996	240,676	270,000	305,000	420,000
1997	257,765	270,000	306,000	418,000
1998	193,256	210,000	210,000	336,000
1999	173,998	177,000	177,000	264,000
2000	191,060	193,000	193,000	240,000
2001	176,749	188,000	188,000	248,000
2002	197,356	200,000	223,000	294,000
2003	207,907	207,500	223,000	324,000
2004	212,618	215,500	223,000	350,000
2005	205,635	206,000	206,000	265,000
2006	193,025	194,000	194,000	230,000
2007	174,486	170,720	176,000	207,000
2008	171,277	170,720	176,000	207,000
2009	175,756	176,540	182,000	212,000
2010	171,875	168,780	174,000	205,000
2011	220,109	227,950	235,000	272,000
2012	251,055	261,000	314,000	369,000
2013	250,274	260,000	307,000	359,000
2014	10,595	6,997	15,100	20,100
2015	8,776	9,422	17,600	23,400

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 4)—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	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
1978	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	2	1	1	5	3	7	4	9
1979	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	1
1982	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	5	4	2	6	7	7	9	15	19
1983	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	2	5	8	6	16	16	23	25	45	70	64	68	66	60	58	69	86
1984	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	1	2	2	7	12	13	17	31	28	21	22	6
1985	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	1	7	12	25	21	37
1990	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	4	2	5	7	15
1991	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	2	8	2	4	9	13	11	15	7	9	21	28
1992	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4	4	9	21	27	46	40	62	116	153	226
1993	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	7	11	9	12	17	20	30	29	33	39	45	67	76
1994	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	1	0	0	0	0	0	0	0	1	2	4	7	5	3	8	3	14	8	19	19	26	33	52
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	1	5	14	22	34	38	59	51	49	54	66	56	51	33	22	19	11	12	11	23	20
1996	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	2	0	2	5	15	6	9	8	14	18	15	12	29	39	39	50	63	108
1997	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	7	4	5	9	12	6	9	17	22	17	25	25
1998	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	4	1	8	9	25	28	43	51	47	88	92	94	87	122	183	200	212
1999	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3	0	1	3	3	7	6	8	25	21	19	30	32	38	62	75
2000	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4	6	5	6	13	7	6	7	20	30	52	62	98	140
2001	0	4	5	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	10	5	11	12	15	15	23	34	64	72	93	130	163	211
2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	2	5	3	9	11	12	8	24	22	33	37	48	71	65	68
2003	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	3	5	5	12	16	22	15	21	25	21	17	33	50	53
2004	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	0	1	1	2	2	5	5	14	22	17	44	43	49	69	71	81	94	81
2005	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	1	1	2	5	2	6	12	4	7	11	16	20	30
2006	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	1	3	4	0	4	3	5	0	3	6	14	11	31
2007	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	0	1	0	5	3	5	7	12	12	12	20	15	19	17	20	27	31	31
2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	1	3	0	3	2	7	5	10	9	19	21	43	41	47
2009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	4	3	4	10	14	15	20	20	39	52	53	67
2010	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	2	0	0	2	1	0	6	12	14	13	22	40	45	72	87	120
2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	1	2	3
2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	1	3	2	4	5	1	12	4	2
2013	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	1	2	1	3	6	10
2014	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3	1	0	2	0	4	2
2015	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	2	5	5	8	6	19	24	24	25

Table 2A.5 (page 2 of 4)—Fishery size composition, by year and cm.

Year	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
1978	18	26	29	39	35	41	39	46	38	25	25	27	32	31	32	44	26	46	44	42	51	59	72	58	69	73
1979	1	4	2	8	10	9	26	25	28	40	47	60	62	71	81	82	84	71	79	64	67	54	52	53	53	44
1982	14	26	31	50	56	57	67	100	98	110	125	112	151	149	155	146	154	180	207	144	166	173	151	155	122	131
1983	103	130	138	149	181	170	171	191	182	182	143	133	146	127	121	123	118	115	116	127	101	107	82	74	78	66
1984	6	9	15	27	27	36	61	73	94	136	145	186	191	186	183	195	164	161	161	138	150	178	154	201	155	175
1985	61	58	74	75	68	85	85	63	60	36	37	32	35	49	52	59	73	96	85	120	122	131	142	136	147	129
1990	17	11	8	9	11	9	16	19	31	52	24	41	35	63	33	39	67	50	70	75	105	128	167	179	174	158
1991	39	24	36	56	63	62	76	62	92	103	141	140	186	214	255	252	312	285	324	359	360	380	428	463	565	575
1992	310	463	550	587	621	705	792	820	872	826	886	898	962	990	1025	1183	1297	1328	1454	1522	1752	1800	2141	2134	2337	2558
1993	113	121	218	240	274	321	433	573	674	751	827	861	957	985	937	846	857	793	754	764	775	783	828	829	856	775
1994	73	101	83	139	160	161	223	233	257	291	297	333	359	389	466	512	572	632	654	720	750	762	853	800	865	828
1995	30	26	29	33	55	83	81	83	107	137	181	186	195	254	269	308	318	385	404	430	451	554	556	590	642	635
1996	136	168	197	268	249	296	334	335	362	416	423	508	453	502	583	534	558	572	685	800	926	914	1040	1158	1030	1056
1997	32	43	56	83	78	110	103	165	147	191	227	248	298	348	351	329	366	440	426	397	371	363	352	349	317	362
1998	296	359	455	483	523	639	629	793	723	718	804	822	798	867	808	882	931	1092	1143	1176	1298	1407	1664	1689	1616	1766
1999	131	118	173	183	215	305	292	317	366	374	380	400	436	471	464	541	516	516	595	592	646	621	616	628	560	717
2000	169	170	246	286	291	362	375	367	462	488	559	582	658	752	825	841	855	875	946	971	968	972	991	977	1054	1028
2001	230	296	321	347	424	466	495	563	643	741	772	762	851	951	948	1041	1078	1195	1312	1324	1493	1383	1452	1495	1607	1693
2002	65	74	89	102	110	122	152	164	179	156	147	154	174	165	139	172	164	198	218	224	255	279	324	370	451	447
2003	64	62	110	105	141	140	164	199	228	232	229	229	253	271	290	239	239	311	279	274	304	277	272	357	337	307
2004	86	84	82	112	116	145	174	186	237	264	307	320	362	381	348	398	371	367	405	399	439	416	437	460	483	496
2005	30	51	51	79	67	79	87	118	127	145	154	193	172	229	253	249	258	297	309	334	340	340	366	319	362	408
2006	33	41	49	70	108	121	137	154	163	199	186	215	211	261	298	315	314	395	395	378	388	440	429	364	392	449
2007	50	30	65	56	64	71	92	112	153	197	201	229	271	331	352	409	468	483	491	496	544	461	498	466	532	488
2008	67	88	96	128	172	209	235	299	308	341	323	316	338	300	310	331	301	308	335	316	358	408	460	438	427	481
2009	86	65	90	78	100	104	121	133	154	167	167	190	234	318	324	359	337	407	414	482	485	491	452	486	447	486
2010	143	184	226	232	307	370	399	444	490	459	519	530	496	490	499	504	531	502	493	509	531	577	618	531	583	634
2011	15	16	18	31	37	47	61	49	72	72	94	102	93	118	132	150	145	187	168	191	212	210	210	208	228	195
2012	7	5	11	10	15	19	32	28	26	51	45	56	76	100	115	126	174	168	214	256	292	330	327	307	315	351
2013	10	13	17	26	37	51	42	55	48	44	53	62	64	48	41	64	65	94	87	85	116	103	129	158	147	172
2014	6	1	7	6	10	20	21	31	27	31	50	42	42	46	51	57	39	55	55	54	70	62	63	52	56	77
2015	45	76	65	83	81	95	95	115	105	93	98	109	94	96	138	131	136	155	173	186	185	182	191	147	163	155

Table 2A.5 (page 3 of 4)—Fishery size composition, by year and cm.

Year	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
1978	62	71	62	48	51	47	45	50	45	25	18	28	20	12	9	8	8	3	4	1	2	4	2	0
1979	57	59	40	62	54	51	31	42	35	35	22	25	27	13	10	15	9	7	13	5	2	0	4	4
1982	126	106	116	77	86	89	67	60	64	52	47	32	41	51	41	32	37	32	22	24	20	27	17	6
1983	72	70	66	65	52	55	60	46	58	45	48	37	35	20	17	22	21	14	17	28	14	20	19	18
1984	166	144	157	143	117	116	111	73	90	84	79	78	61	59	59	55	52	36	52	48	37	48	25	33
1985	103	118	73	75	56	51	48	58	37	45	50	43	29	34	35	35	39	34	37	35	33	44	51	27
1990	157	168	140	170	113	132	162	155	122	150	153	140	106	85	92	82	64	58	55	40	55	38	21	13
1991	544	698	648	732	801	852	829	852	827	753	829	856	703	774	707	642	619	600	515	463	393	311	263	259
1992	2797	2940	2871	3149	3267	3427	3578	3478	3549	3297	3289	3169	2878	2726	2644	2441	2466	2071	1887	1768	1679	1534	1265	1227
1993	903	891	866	922	938	992	1035	972	1105	1007	1162	1105	1184	1208	1162	1165	1170	1104	1048	955	913	780	728	713
1994	881	827	808	780	804	766	730	617	655	598	545	550	520	535	498	533	480	480	516	499	564	573	423	391
1995	686	782	748	735	733	782	890	778	857	837	864	880	821	776	736	741	736	683	646	580	525	629	499	552
1996	965	1062	977	992	1071	1042	1125	1010	933	926	931	1037	954	1006	982	936	903	876	791	761	750	747	524	607
1997	371	351	355	402	383	407	489	458	445	513	582	608	572	548	531	511	563	509	484	523	492	611	491	480
1998	1826	2306	1998	1888	1881	1781	2067	1667	1564	1513	1483	1604	1368	1262	1249	1122	1276	1163	1043	1227	1098	1286	1038	910
1999	715	702	664	735	783	829	797	773	808	906	800	836	826	820	808	775	747	738	655	640	581	569	514	473
2000	1040	1124	1002	1133	1112	1053	1053	1012	1050	990	1002	1053	972	1084	988	1066	1006	1139	991	1064	1102	1210	1008	1027
2001	1659	1697	1651	1631	1558	1564	1361	1349	1263	1122	1076	973	962	898	924	834	722	678	662	653	677	655	611	543
2002	481	571	637	744	718	738	768	809	790	814	779	757	702	726	671	648	603	574	496	495	412	377	322	328
2003	366	408	415	372	398	349	420	418	432	469	500	547	580	593	688	669	748	731	710	685	675	699	604	560
2004	481	530	552	515	491	578	510	552	591	523	537	544	518	532	537	472	439	415	408	366	351	394	347	359
2005	405	464	454	460	518	534	561	559	561	563	637	685	632	623	598	485	516	466	445	387	421	408	336	311
2006	361	377	368	389	394	447	411	435	411	479	477	500	457	503	472	478	461	525	468	492	457	442	406	366
2007	493	456	453	428	440	473	458	491	472	519	502	523	532	531	539	596	559	634	593	662	659	689	640	611
2008	493	521	515	473	524	498	468	471	437	429	403	422	438	425	372	447	431	449	433	445	485	480	470	484
2009	404	475	406	414	453	434	457	413	451	413	390	379	400	359	363	346	322	322	279	322	301	304	342	336
2010	668	821	620	695	775	809	822	825	759	764	763	770	687	618	605	580	480	457	502	427	433	429	388	383
2011	214	217	155	162	147	145	172	135	179	155	161	221	182	184	201	210	216	213	198	182	179	157	164	152
2012	386	407	384	427	374	391	345	376	343	354	293	297	261	272	208	186	188	202	156	171	128	165	145	159
2013	187	171	200	231	204	198	196	209	254	227	259	248	217	247	234	228	227	223	225	202	210	196	164	176
2014	68	74	90	75	56	74	75	83	75	70	87	92	109	95	95	127	99	111	113	98	127	115	94	111
2015	171	160	140	140	142	138	157	152	124	114	137	144	137	128	133	138	136	126	132	137	149	156	142	157

Table 2A.5 (page 4 of 4)—Fishery size composition, by year and cm.

Year	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	120+
1978	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1979	1	2	4	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	10	12	6	3	6	4	3	0	4	3	3	2	0	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1983	11	12	20	4	4	3	6	9	4	4	2	2	3	0	1	0	1	0	1	0	0	0	0	0	1	0	0	1
1984	33	28	26	22	17	31	21	18	17	12	9	14	7	7	4	1	1	1	0	0	0	1	0	0	0	0	0	0
1985	23	24	27	28	9	9	21	10	15	6	6	3	1	9	0	0	0	0	3	0	0	0	0	1	0	0	0	0
1990	28	15	11	8	9	7	10	5	8	1	2	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	212	174	171	115	133	103	72	60	28	42	29	22	16	9	5	2	1	2	0	0	1	1	1	0	0	0	0	0
1992	1047	982	879	750	690	635	592	406	314	270	237	211	147	128	115	82	59	67	49	26	16	14	5	3	0	6	1	1
1993	609	548	567	498	423	407	364	298	279	252	213	172	142	120	70	78	41	40	29	20	14	7	3	4	2	1	0	1
1994	388	344	395	293	255	276	271	269	178	143	145	107	81	59	40	34	27	44	18	11	16	5	9	5	4	3	1	1
1995	620	709	623	496	383	334	330	403	236	263	253	218	203	113	90	82	66	112	40	47	26	11	25	9	3	0	1	2
1996	522	564	459	427	428	376	392	409	299	273	267	239	247	191	166	120	98	123	50	55	18	18	6	4	5	1	0	5
1997	528	476	465	408	429	394	335	361	287	264	239	210	196	145	137	120	99	77	51	37	28	22	26	14	4	6	2	9
1998	1028	1066	1076	969	903	924	846	964	726	640	618	586	619	419	331	299	250	244	134	99	74	50	48	24	14	4	9	24
1999	413	382	354	362	330	357	328	360	300	287	249	260	223	188	144	124	88	86	49	42	33	24	12	2	6	2	5	13
2000	906	890	760	769	636	624	566	574	520	468	458	406	384	343	338	244	177	194	126	93	46	27	29	17	8	3	3	14
2001	546	525	509	534	481	460	492	527	408	371	384	306	294	254	224	218	167	193	81	86	54	33	42	16	14	12	16	21
2002	309	280	257	237	197	182	143	224	165	153	142	140	111	102	81	64	53	46	27	29	12	5	1	4	1	1	1	0
2003	556	485	430	406	362	319	282	320	201	213	160	153	108	98	84	73	49	48	25	29	13	6	4	6	0	5	2	2
2004	361	329	327	313	321	317	233	269	245	216	178	193	128	117	98	78	72	64	30	29	16	10	4	4	1	5	3	2
2005	340	296	261	240	238	202	205	188	182	158	155	136	126	100	92	70	46	46	26	24	17	9	5	6	3	1	4	9
2006	362	325	279	249	233	210	190	197	168	170	131	130	115	94	94	79	65	57	34	26	25	15	12	1	2	4	2	6
2007	662	585	606	544	550	518	474	418	363	357	315	263	209	196	171	145	113	86	50	36	28	19	11	10	3	3	2	0
2008	516	454	518	505	497	503	445	515	470	412	459	357	328	287	231	209	169	156	89	63	35	21	18	15	10	7	5	67
2009	318	342	341	309	314	320	323	343	286	318	326	280	273	261	251	222	151	130	95	74	40	30	24	9	3	0	2	2
2010	396	354	340	398	392	353	383	436	364	446	458	387	391	343	316	306	257	218	148	117	62	51	47	20	13	4	1	8
2011	153	125	116	123	113	97	97	87	80	72	55	72	58	55	42	41	27	24	26	12	10	3	6	4	3	1	2	4
2012	118	140	128	131	107	97	102	104	84	99	81	74	73	61	37	48	37	38	25	27	12	15	12	6	6	3	4	8
2013	152	153	112	124	126	107	104	103	108	89	86	65	56	45	51	39	27	18	16	4	6	4	0	2	0	0	1	0
2014	117	119	96	86	82	75	60	51	51	43	40	37	28	38	24	18	16	12	10	9	3	3	0	0	0	1	0	0
2015	154	138	147	157	157	142	147	141	131	122	126	111	101	89	87	69	48	34	33	17	16	7	4	4	2	2	1	1

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—Growth, ageing bias, recruitment (except annual *dev*s), catchability, initial fishing mortality, and initial age composition parameters, as estimated internally by Model 15.7.

Parameter	Estimate	St. dev.
Length at age 1 (cm)	1.80E+01	1.91E-01
Asymptotic length (cm)	1.21E+02	2.77E+00
Brody growth coefficient	1.88E-01	7.41E-03
SD of length at age 1 (cm)	3.07E+00	1.34E-01
SD of length at age 20 (cm)	9.47E+00	4.73E-01
Ageing bias at age 1 (years)	4.20E-01	2.33E-02
Ageing bias at age 20 (years)	-1.99E-01	3.78E-01
ln(mean recruitment)	1.05E+01	6.79E-02
σ(recruitment)	6.10E-01	6.97E-02
Initial fishing mortality rate	5.85E-02	5.64E-03
ln(catchability)	-1.51E-01	8.56E-02
Initial age 1 ln(abundance) dev	-6.61E-01	4.26E-01
Initial age 2 ln(abundance) dev	-4.54E-01	3.82E-01
Initial age 3 ln(abundance) dev	-7.07E-01	3.92E-01
Initial age 4 ln(abundance) dev	-6.09E-01	4.27E-01
Initial age 5 ln(abundance) dev	-6.17E-01	4.89E-01
Initial age 6 ln(abundance) dev	-5.53E-01	4.98E-01
Initial age 7 ln(abundance) dev	-4.92E-01	5.09E-01
Initial age 8 ln(abundance) dev	-4.06E-01	5.22E-01
Initial age 9 ln(abundance) dev	-3.16E-01	5.37E-01
Initial age 10 ln(abundance) dev	-2.39E-01	5.52E-01

Table 2A.8b—Annual log-scale recruitment *dev*s estimated by Model 15.7. Color scale extends from red (low) to green (high).

Year	Estimate	St. dev.
1977	-1.08E+00	3.72E-01
1978	-8.57E-01	2.97E-01
1979	-1.01E+00	2.60E-01
1980	-8.40E-01	2.26E-01
1981	-1.12E+00	3.06E-01
1982	-1.22E+00	3.48E-01
1983	-1.24E+00	4.04E-01
1984	-6.11E-01	3.74E-01
1985	4.09E-01	2.16E-01
1986	7.40E-01	1.66E-01
1987	6.59E-01	1.31E-01
1988	-3.76E-02	1.46E-01
1989	8.42E-01	1.10E-01
1990	3.81E-01	1.33E-01
1991	2.79E-01	1.17E-01
1992	-9.64E-02	1.95E-01
1993	9.59E-01	8.76E-02
1994	1.86E-02	1.38E-01
1995	3.64E-01	1.26E-01
1996	9.57E-01	8.06E-02
1997	7.16E-01	8.78E-02
1998	8.94E-03	1.49E-01
1999	9.02E-01	9.13E-02
2000	6.33E-01	1.15E-01
2001	3.99E-01	1.11E-01
2002	-1.80E-01	1.33E-01
2003	2.15E-01	9.24E-02
2004	-5.46E-01	1.71E-01
2005	2.10E-01	1.11E-01
2006	4.29E-02	1.13E-01
2007	4.78E-01	9.68E-02
2008	2.69E-01	1.22E-01
2009	-4.57E-01	1.65E-01
2010	1.55E-01	1.61E-01
2011	-1.41E-01	1.69E-01
2012	4.74E-02	4.06E-01
2013	-2.50E-01	5.43E-01

Table 2A.8c—Base selectivity parameters as estimated by Model 15.7.

Fleet	Age	Estimate	St. dev.
Fishery	1	3.29E+00	3.42E-01
Fishery	2	3.46E+00	3.11E-01
Fishery	3	3.34E+00	1.72E-01
Fishery	4	1.27E+00	1.65E-01
Fishery	5	4.51E-01	9.66E-02
Fishery	6	-6.64E-02	2.72E-01
Fishery	7	-1.00E-01	1.96E-01
Fishery	8	1.10E+00	1.88E-01
Survey	1	5.29E+00	3.19E-01
Survey	2	9.39E-01	2.85E-01
Survey	3	6.39E-01	2.09E-01
Survey	4	4.83E-01	1.01E-01
Survey	5	-6.94E-02	1.15E-01
Survey	6	1.60E-01	1.24E-01
Survey	7	-5.73E-01	1.80E-01
Survey	8	2.47E-01	2.30E-01

Table 2A.8d—Fishery selectivity *dev*s as estimated by Model 15.7.

Fleet	Year	Age	Estimate	St. dev.	Age	Estimate	St. dev.
Fishery	1978	4	-2.84E-02	6.62E-02	6	-3.48E-01	1.22E-01
Fishery	1979	4	5.65E-03	7.52E-02	6	-3.44E-01	1.18E-01
Fishery	1980	4	-1.13E-03	9.26E-02	6	-1.43E-02	2.49E-01
Fishery	1981	4	-7.32E-04	9.23E-02	6	-1.34E-02	2.47E-01
Fishery	1982	4	-2.59E-02	5.88E-02	6	-3.66E-01	9.86E-02
Fishery	1983	4	-1.58E-01	4.96E-02	6	-3.23E-01	9.48E-02
Fishery	1984	4	7.58E-03	5.90E-02	6	-3.21E-01	7.95E-02
Fishery	1985	4	-2.32E-02	6.28E-02	6	-2.69E-01	8.86E-02
Fishery	1986	4	-6.66E-03	9.47E-02	6	-1.96E-01	2.33E-01
Fishery	1987	4	1.54E-02	8.85E-02	6	-4.83E-02	1.97E-01
Fishery	1988	4	9.76E-03	8.87E-02	6	1.57E-01	1.64E-01
Fishery	1989	4	6.63E-03	8.94E-02	6	2.63E-01	1.45E-01
Fishery	1990	4	5.23E-02	6.39E-02	6	1.60E-01	6.37E-02
Fishery	1991	4	1.80E-02	5.07E-02	6	1.46E-01	3.89E-02
Fishery	1992	4	5.28E-02	2.71E-02	6	3.95E-02	3.33E-02
Fishery	1993	4	-5.11E-02	3.19E-02	6	7.64E-02	3.48E-02
Fishery	1994	4	9.43E-03	3.60E-02	6	9.45E-03	3.54E-02
Fishery	1995	4	1.03E-02	4.17E-02	6	4.85E-02	3.55E-02
Fishery	1996	4	8.55E-02	3.16E-02	6	-2.11E-02	3.51E-02
Fishery	1997	4	-2.54E-02	4.60E-02	6	9.42E-02	3.52E-02
Fishery	1998	4	-3.61E-02	2.57E-02	6	3.57E-02	3.09E-02
Fishery	1999	4	4.95E-02	2.73E-02	6	2.59E-02	3.18E-02
Fishery	2000	4	-2.28E-03	2.49E-02	6	1.20E-01	3.19E-02
Fishery	2001	4	-6.95E-02	2.49E-02	6	2.77E-02	3.05E-02
Fishery	2002	4	3.75E-02	3.10E-02	6	7.67E-02	3.43E-02
Fishery	2003	4	-6.55E-02	3.29E-02	6	1.62E-01	3.44E-02
Fishery	2004	4	-7.09E-02	2.78E-02	6	8.24E-02	3.31E-02
Fishery	2005	4	-3.00E-02	3.62E-02	6	5.13E-02	3.36E-02
Fishery	2006	4	1.48E-02	3.29E-02	6	-9.22E-03	3.31E-02
Fishery	2007	4	1.05E-02	3.74E-02	6	-1.78E-03	3.20E-02
Fishery	2008	4	-2.48E-03	2.87E-02	6	-6.08E-04	3.24E-02
Fishery	2009	4	4.66E-02	3.26E-02	6	1.15E-02	3.41E-02
Fishery	2010	4	-6.52E-03	2.52E-02	6	8.72E-02	3.32E-02
Fishery	2011	4	3.97E-02	4.76E-02	6	1.07E-01	3.66E-02
Fishery	2012	4	8.63E-02	5.49E-02	6	7.17E-02	3.63E-02
Fishery	2013	4	2.26E-02	4.69E-02	6	8.91E-02	4.00E-02
Fishery	2014	4	3.46E-03	6.25E-02	6	7.89E-02	4.47E-02
Fishery	2015	4	-5.89E-02	4.93E-02	6	1.44E-02	3.78E-02

Table 2A.8e—Survey selectivity *dev*s as estimated by Model 15.7.

Fleet	Year	Age	Estimate	St. dev.
Survey	1991	2	3.71E-01	8.43E-02
Survey	1994	2	-1.31E-01	4.19E-02
Survey	1997	2	1.46E-02	4.15E-02
Survey	2000	2	4.24E-02	5.07E-02
Survey	2002	2	1.74E-01	5.06E-02
Survey	2004	2	8.22E-02	6.42E-02
Survey	2006	2	-1.52E-01	4.97E-02
Survey	2010	2	8.35E-03	4.95E-02
Survey	2012	2	-7.66E-02	4.17E-02
Survey	2014	2	8.34E-03	7.28E-02
Survey	1991	3	-7.59E-02	2.49E-02
Survey	1994	3	2.97E-02	3.36E-02
Survey	1997	3	1.71E-02	2.90E-02
Survey	2000	3	8.55E-02	3.55E-02
Survey	2002	3	-4.64E-02	2.61E-02
Survey	2004	3	6.89E-02	3.75E-02
Survey	2006	3	1.12E-01	4.12E-02
Survey	2010	3	1.06E-01	2.83E-02
Survey	2012	3	6.73E-02	2.90E-02
Survey	2014	3	1.36E-02	4.48E-02

Table 2A.9— Annual fishing mortality rates as estimated by Model 15.7. "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.

	F averaged over 8-18		Apical F	
Year	Estimate	St. dev.	Estimate	St. dev.
1977	4.495E-02	4.495E-02	4.495E-02	4.495E-02
1978	1.224E-02	1.354E-01	1.354E-01	1.354E-01
1979	2.347E-02	2.505E-01	2.505E-01	2.505E-01
1980	9.713E-02	9.713E-02	9.713E-02	9.713E-02
1981	1.429E-01	1.429E-01	1.429E-01	1.429E-01
1982	4.684E-02	6.050E-01	6.050E-01	6.050E-01
1983	5.720E-02	5.042E-01	5.042E-01	5.042E-01
1984	8.373E-02	7.248E-01	7.248E-01	7.248E-01
1985	1.095E-01	5.904E-01	5.904E-01	5.904E-01
1986	1.731E-01	4.701E-01	4.701E-01	4.701E-01
1987	7.696E-01	7.696E-01	7.696E-01	7.696E-01
1988	6.839E-01	6.839E-01	6.839E-01	6.839E-01
1989	8.114E-01	8.114E-01	8.114E-01	8.114E-01
1990	6.951E-01	6.951E-01	6.951E-01	6.951E-01
1991	4.599E-01	4.599E-01	4.599E-01	4.599E-01
1992	1.168E+00	1.168E+00	1.168E+00	1.168E+00
1993	9.476E-01	9.476E-01	9.476E-01	9.476E-01
1994	4.295E-01	4.295E-01	4.295E-01	4.295E-01
1995	3.299E-01	3.299E-01	3.299E-01	3.299E-01
1996	5.803E-01	5.803E-01	5.803E-01	5.803E-01
1997	5.419E-01	5.419E-01	5.419E-01	5.419E-01
1998	7.060E-01	7.060E-01	7.060E-01	7.060E-01
1999	6.064E-01	6.064E-01	6.064E-01	6.064E-01
2000	1.273E+00	1.273E+00	1.273E+00	1.273E+00
2001	7.021E-01	7.021E-01	7.021E-01	7.021E-01
2002	8.032E-01	8.032E-01	8.032E-01	8.032E-01
2003	9.570E-01	9.570E-01	9.570E-01	9.570E-01
2004	6.784E-01	6.784E-01	6.784E-01	6.784E-01
2005	4.319E-01	4.319E-01	4.319E-01	4.319E-01
2006	4.165E-01	4.165E-01	4.165E-01	4.165E-01
2007	5.926E-01	5.926E-01	5.926E-01	5.926E-01
2008	6.351E-01	6.351E-01	6.351E-01	6.351E-01
2009	7.614E-01	7.614E-01	7.614E-01	7.614E-01
2010	1.366E+00	1.366E+00	1.366E+00	1.366E+00
2011	5.237E-01	5.237E-01	5.237E-01	5.237E-01
2012	7.407E-01	7.407E-01	7.407E-01	7.407E-01
2013	4.678E-01	4.678E-01	4.678E-01	4.678E-01
2014	3.085E-01	3.085E-01	3.085E-01	3.085E-01
2015	1.961E-01	1.961E-01	1.961E-01	1.961E-01

Table 2A.10—Summary of key management reference points. Values for Model 15.7 come from the standard projection algorithm (except the last seven rows, which come from SS). All biomass figures are in t.

Quantity	Model 13.4	Model 15.6	Model 15.7
B100%	n/a	n/a	81,100
B40%	n/a	n/a	32,400
B35%	n/a	n/a	28,400
B(2016)	68,900	61,500	35,700
B(2017)	68,900	61,500	33,200
B(2016)/B100%	n/a	n/a	0.44
B(2017)/B100%	n/a	n/a	0.41
F40%	n/a	n/a	0.47
F35%	n/a	n/a	0.58
maxFABC(2016)	0.26	0.26	0.47
maxFABC(2017)	0.26	0.26	0.47
maxABC(2016)	17,600	15,700	23,200
maxABC(2017)	17,600	15,700	19,700
FOFL(2016)	0.34	0.34	0.58
FOFL(2017)	0.34	0.34	0.58
OFL(2016)	23,400	20,900	24,400
OFL(2017)	23,400	20,900	32,600
Pr(maxABC(2016)>truOFL(2016))	n/a	n/a	0.13
Pr(maxABC(2017)>truOFL(2017))	n/a	n/a	0.38
Pr(B(2016)<B20%)	n/a	n/a	0.00
Pr(B(2017)<B20%)	n/a	n/a	0.00
Pr(B(2018)<B20%)	n/a	n/a	0.00
Pr(B(2019)<B20%)	n/a	n/a	0.00
Pr(B(2020)<B20%)	n/a	n/a	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.11—Fishery selectivity as estimated by Model 15.7.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1977	0.000	0.000	0.002	0.070	0.250	0.392	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1978	0.000	0.000	0.008	0.238	0.637	1.000	0.033	0.030	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090	0.090
1979	0.000	0.000	0.006	0.170	0.637	1.000	0.034	0.031	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
1980	0.000	0.000	0.003	0.082	0.288	0.452	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1981	0.000	0.000	0.003	0.081	0.285	0.448	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1982	0.000	0.000	0.008	0.232	0.637	1.000	0.028	0.026	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077
1983	0.000	0.001	0.031	0.864	0.637	1.000	0.042	0.038	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113
1984	0.000	0.000	0.006	0.167	0.637	1.000	0.042	0.038	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116	0.116
1985	0.000	0.000	0.008	0.226	0.637	1.000	0.068	0.062	0.185	0.185	0.185	0.185	0.185	0.185	0.185	0.185	0.185	0.185	0.185	0.185	0.185
1986	0.000	0.000	0.007	0.192	0.637	1.000	0.135	0.122	0.368	0.368	0.368	0.368	0.368	0.368	0.368	0.368	0.368	0.368	0.368	0.368	0.368
1987	0.000	0.000	0.003	0.098	0.404	0.635	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1988	0.000	0.000	0.000	0.013	0.052	0.082	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1989	0.000	0.000	0.000	0.005	0.019	0.030	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1990	0.000	0.000	0.000	0.009	0.051	0.080	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1991	0.000	0.000	0.000	0.014	0.058	0.091	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1992	0.000	0.000	0.001	0.028	0.168	0.264	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1993	0.000	0.000	0.002	0.054	0.116	0.183	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1994	0.000	0.000	0.002	0.058	0.227	0.356	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1995	0.000	0.000	0.001	0.039	0.154	0.241	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1996	0.000	0.000	0.001	0.038	0.308	0.484	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1997	0.000	0.000	0.001	0.035	0.098	0.153	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1998	0.000	0.000	0.002	0.070	0.175	0.274	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1999	0.000	0.000	0.001	0.034	0.193	0.302	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2000	0.000	0.000	0.001	0.022	0.076	0.119	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2001	0.000	0.000	0.004	0.106	0.189	0.297	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2002	0.000	0.000	0.001	0.023	0.116	0.182	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2003	0.000	0.000	0.001	0.027	0.050	0.078	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2004	0.000	0.000	0.002	0.062	0.110	0.172	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2005	0.000	0.000	0.002	0.057	0.149	0.235	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2006	0.000	0.000	0.002	0.067	0.274	0.430	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2007	0.000	0.000	0.002	0.065	0.254	0.399	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2008	0.000	0.000	0.003	0.073	0.251	0.394	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2009	0.000	0.000	0.001	0.040	0.222	0.349	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2010	0.000	0.000	0.001	0.031	0.105	0.164	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2011	0.000	0.000	0.001	0.016	0.086	0.134	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2012	0.000	0.000	0.001	0.015	0.122	0.191	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2013	0.000	0.000	0.001	0.023	0.103	0.161	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2014	0.000	0.000	0.001	0.031	0.114	0.178	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2015	0.000	0.000	0.004	0.109	0.216	0.339	0.367	0.332	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 2A.12—Survey selectivity as estimated by Model 15.7.

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	0.008	0.635	0.564	0.913	0.852	1.000	0.564	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721
1994	0.000	0.321	0.222	0.564	0.913	0.852	1.000	0.564	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721
1997	0.000	0.085	0.251	0.564	0.913	0.852	1.000	0.564	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721
2000	0.000	0.033	0.128	0.564	0.913	0.852	1.000	0.564	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721
2002	0.000	0.034	0.473	0.564	0.913	0.852	1.000	0.564	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721
2004	0.000	0.026	0.150	0.564	0.913	0.852	1.000	0.564	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721
2006	0.000	0.175	0.099	0.564	0.913	0.852	1.000	0.564	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721
2010	0.000	0.038	0.105	0.564	0.913	0.852	1.000	0.564	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721
2012	0.000	0.128	0.153	0.564	0.913	0.852	1.000	0.564	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721
2014	0.000	0.093	0.260	0.564	0.913	0.852	1.000	0.564	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721	0.721

Table 2A.13—Schedules of population length (cm) and weight (kg) by age as estimated by Model 15.7. Lengths and weights correspond to mid-point of the year. Population, fishery, and survey schedules are all the same, because both fishery and survey selectivity are age based.

	Population		Fishery		Survey	
Age	Length	Weight	Length	Weight	Length	Weight
0	6.34	0.00	6.39	0.00	6.39	0.00
1	18.03	0.06	18.03	0.06	18.03	0.06
2	35.67	0.51	35.67	0.51	35.67	0.51
3	50.29	1.51	50.29	1.51	50.29	1.51
4	62.40	3.00	62.40	3.00	62.40	3.00
5	72.45	4.82	72.45	4.82	72.45	4.82
6	80.77	6.81	80.77	6.81	80.77	6.81
7	87.67	8.83	87.67	8.83	87.67	8.83
8	93.39	10.80	93.39	10.80	93.39	10.80
9	98.13	12.64	98.13	12.64	98.13	12.64
10	102.05	14.33	102.05	14.33	102.05	14.33
11	105.31	15.83	105.31	15.83	105.31	15.83
12	108.01	17.16	108.01	17.16	108.01	17.16
13	110.24	18.32	110.24	18.32	110.24	18.32
14	112.10	19.32	112.10	19.32	112.10	19.32
15	113.63	20.17	113.63	20.17	113.63	20.17
16	114.91	20.90	114.91	20.90	114.91	20.90
17	115.96	21.52	115.96	21.52	115.96	21.52
18	116.84	22.04	116.84	22.04	116.84	22.04
19	117.56	22.48	117.56	22.48	117.56	22.48
20	118.77	23.24	118.77	23.24	118.77	23.24

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 Model 15.7. Spawning biomass for 2016 represents output from the standard projection model.

Year	Age 0+	Age 3+	Spawn.	SB SD
1977	116,408	114,121	46,582	6,414
1978	110,135	108,309	43,476	6,344
1979	104,059	102,778	41,101	6,157
1980	95,011	93,473	37,975	5,921
1981	86,139	84,767	34,156	5,656
1982	76,941	75,395	30,067	5,267
1983	67,376	66,189	26,713	4,688
1984	57,339	56,254	23,050	4,044
1985	48,042	46,869	19,007	3,378
1986	41,877	39,480	15,585	2,764
1987	41,741	35,962	12,813	2,368
1988	47,190	39,552	9,184	1,922
1989	72,811	66,092	12,528	2,126
1990	104,749	100,654	21,253	2,974
1991	133,296	125,114	33,178	3,962
1992	158,622	153,297	45,066	4,701
1993	147,261	142,556	42,426	5,030
1994	140,477	136,448	41,196	5,182
1995	144,467	135,519	44,423	5,104
1996	155,385	151,457	47,929	4,759
1997	150,680	144,913	45,326	4,282
1998	154,537	145,197	45,652	3,937
1999	154,317	147,203	43,736	3,773
2000	161,945	157,639	45,067	3,883
2001	157,353	148,526	43,252	4,199
2002	158,948	152,188	45,210	4,582
2003	163,019	157,802	46,469	4,834
2004	161,639	158,406	46,905	4,919
2005	157,020	152,726	49,264	4,666
2006	152,051	149,653	51,465	4,057
2007	140,602	136,138	49,616	3,312
2008	119,214	115,142	40,721	2,701
2009	104,697	98,894	32,689	2,429
2010	97,977	93,438	27,169	2,549
2011	93,049	90,502	23,722	2,977
2012	103,820	99,647	29,220	3,564
2013	104,846	101,580	31,803	4,093
2014	108,361	104,612	34,338	4,564
2015	113,319	110,280	36,950	5,012
2016	118,013	113,581	35,700	5,522

Table 2A.14b—Time series of survey biomass (t) and 95% confidence intervals as estimated by the Tier 5 models. Values for 2015-2016 (not shown) are equal to the last year in the series.

	Model 13.4			Model 15.6		
Year	Mean	L95%CI	U95%CI	Mean	L95%CI	U95%CI
1991	171,637	131,586	223,879	177,157	135,933	230,882
1992	158,994	110,631	228,499	167,059	104,043	268,244
1993	147,282	101,221	214,304	157,537	96,556	257,032
1994	136,433	99,759	186,588	148,558	105,621	208,950
1995	115,818	80,527	166,577	132,881	82,097	215,081
1996	98,318	69,377	139,333	118,859	75,773	186,446
1997	83,463	64,498	108,004	106,317	89,747	125,946
1998	89,714	63,684	126,385	161,942	130,689	200,669
1999	96,434	67,642	137,482	144,095	116,826	177,730
2000	103,657	76,612	140,250	129,878	109,519	154,022
2001	91,773	66,335	126,968	92,342	73,943	115,318
2002	81,252	62,827	105,080	63,856	52,392	77,828
2003	80,844	58,305	112,097	61,637	47,542	79,912
2004	80,439	60,311	107,284	67,769	54,188	84,754
2005	78,661	54,753	113,007	76,725	58,881	99,976
2006	76,921	53,841	109,895	105,790	85,689	130,606
2007	72,373	47,738	109,719	97,029	78,390	120,100
2008	68,093	44,469	104,268	91,724	74,737	112,571
2009	64,067	43,355	94,673	75,273	59,991	94,448
2010	60,278	44,959	80,818	51,829	41,702	64,415
2011	60,701	43,837	84,052	65,744	52,708	82,005
2012	61,126	48,014	77,817	52,629	42,775	64,752
2013	64,887	46,763	90,035	56,588	45,345	70,617
2014	68,880	50,604	93,757	61,517	49,537	76,393

Table 2A.15—Time series of EBS Pacific cod age 0 recruitment (1000s of fish), with standard deviations, as estimated by Model 15.7. Color scale extends from red (low) to green (high).

Year	Recruits	Std. dev.
1977	9,953	3,825
1978	12,465	3,784
1979	10,743	2,842
1980	12,683	2,884
1981	9,580	2,986
1982	8,672	3,086
1983	8,478	3,527
1984	15,942	6,135
1985	44,201	10,264
1986	61,576	11,036
1987	56,748	7,588
1988	28,282	4,275
1989	68,138	8,390
1990	43,001	5,501
1991	38,832	4,620
1992	26,666	5,114
1993	76,633	6,934
1994	29,917	3,999
1995	42,242	5,995
1996	76,444	7,186
1997	60,115	5,326
1998	29,630	4,890
1999	72,404	7,493
2000	55,294	5,645
2001	43,777	4,218
2002	24,518	2,992
2003	36,420	3,169
2004	17,006	3,016
2005	36,237	4,735
2006	30,653	4,091
2007	47,366	5,392
2008	38,420	4,959
2009	18,591	3,237
2010	34,285	5,834
2011	25,501	4,520
2012	30,792	12,999
2013	22,869	12,850
Average	35,272	

Table 2A.16—Numbers (1000s) at age at the beginning of the year as estimated by Model 15.7.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1977	9953	10792	9451	5222	4082	2842	2106	1560	1187	872	632	649	436	293	196	132	89	59	40	27	55
1978	12465	7085	7681	6726	3705	2873	1987	1475	1094	808	593	430	442	297	199	134	90	60	40	27	55
1979	10743	8872	5042	5461	4636	2419	1786	1408	1045	769	568	417	302	311	209	140	94	63	42	28	58
1980	12683	7647	6314	3584	3725	2813	1340	1260	995	727	535	395	290	210	216	145	97	65	44	29	60
1981	9580	9027	5443	4493	2530	2578	1916	921	869	642	469	345	255	187	136	139	94	63	42	28	58
1982	8672	6819	6425	3872	3161	1729	1721	1294	625	536	396	290	213	157	116	84	86	58	39	26	53
1983	8478	6173	4853	4551	2395	1530	672	1204	907	424	364	269	197	145	107	78	57	58	39	26	54
1984	15942	6035	4391	3401	2095	1236	658	468	841	610	285	245	181	132	97	72	53	38	39	26	54
1985	44201	11347	4295	3112	2145	940	426	454	324	551	399	187	160	118	87	64	47	35	25	26	53
1986	61576	31461	8075	3042	1939	1048	371	292	312	207	351	255	119	102	76	55	41	30	22	16	50
1987	56748	43828	22391	5729	1979	1023	466	248	196	187	124	210	152	71	61	45	33	24	18	13	39
1988	28282	40391	31193	15894	3782	1032	447	250	137	65	62	41	69	50	24	20	15	11	8	6	17
1989	68138	20130	28749	22195	11210	2597	694	247	142	49	23	22	15	25	18	8	7	5	4	3	8
1990	43001	48498	14328	20460	15733	7856	1804	367	135	45	16	7	7	5	8	6	3	2	2	1	4
1991	38832	30607	34519	10196	14476	10810	5291	995	207	48	16	6	3	2	2	3	2	1	1	1	2
1992	26666	27639	21785	24564	7212	10031	7378	3181	608	93	21	7	2	1	1	1	1	1	0	0	1
1993	76633	18980	19672	15488	16915	4218	5246	3422	1537	135	21	5	2	1	0	0	0	0	0	0	0
1994	29917	54545	13509	13977	10469	10783	2525	2638	1779	424	37	6	1	0	0	0	0	0	0	0	0
1995	42242	21294	38822	9607	9702	6759	6585	1535	1628	824	196	17	3	1	0	0	0	0	0	0	0
1996	76444	30067	15156	27620	6750	6564	4443	4153	980	833	422	101	9	1	0	0	0	0	0	0	0
1997	60115	54411	21400	10779	19232	4018	3529	2556	2439	390	332	168	40	4	1	0	0	0	0	0	0
1998	29630	42788	38727	15222	7527	12984	2632	2059	1520	1010	162	137	70	17	1	0	0	0	0	0	0
1999	72404	21090	30454	27516	10309	4736	7616	1446	1160	534	355	57	48	24	6	1	0	0	0	0	0
2000	55294	51535	15011	21660	19191	6528	2806	4340	842	450	207	138	22	19	9	2	0	0	0	0	0
2001	43777	39357	36680	10674	14994	12402	3993	1252	2025	168	90	41	27	4	4	2	0	0	0	0	0
2002	24518	31159	28011	26039	7051	9345	7167	2197	706	714	59	32	15	10	2	1	1	0	0	0	0
2003	36420	17451	22178	19924	18199	4572	5746	3800	1198	225	228	19	10	5	3	0	0	0	0	0	0
2004	17006	25922	12421	15771	13820	12348	3019	2880	1969	328	62	62	5	3	1	1	0	0	0	0	0
2005	36237	12104	18450	8828	10760	9131	7820	1676	1637	711	118	22	22	2	1	0	0	0	0	0	0
2006	30653	25792	8615	13121	6131	7180	5873	4751	1033	756	329	55	10	10	1	0	0	0	0	0	0
2007	47366	21818	18358	6126	9083	3894	4273	3588	2945	485	355	154	26	5	5	0	0	0	0	0	0
2008	38420	33714	15529	13049	4196	5561	2188	2447	2098	1159	191	140	61	10	2	2	0	0	0	0	0
2009	18591	27346	23995	11035	8869	2547	3082	1234	1411	791	437	72	53	23	4	1	1	0	0	0	0
2010	34285	13233	19464	17061	7620	5329	1389	1659	682	469	263	145	24	18	8	1	0	0	0	0	0
2011	25501	24403	9418	13833	11633	4701	3031	599	751	124	85	48	26	4	3	1	0	0	0	0	0
2012	30792	18151	17369	6702	9762	7917	3119	1781	359	317	52	36	20	11	2	1	1	0	0	0	0
2013	22869	21917	12919	12358	4718	6348	4890	1692	991	122	107	18	12	7	4	1	0	0	0	0	0
2014	35375	16277	15600	9192	8701	3201	4190	2932	1031	442	54	48	8	5	3	2	0	0	0	0	0
2015	35375	25179	11586	11100	6480	5980	2156	2664	1884	539	231	28	25	4	3	2	1	0	0	0	0

Table 2A.17—"Effective" fishing mortality (= $-\ln(N_{a+1,t+1}/N_{a,t})-M$) at age and year, as estimated by Model 15.7

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1977	0.000	0.000	0.003	0.011	0.018	0.016	0.015	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045	0.045
1978	0.000	0.001	0.032	0.086	0.135	0.004	0.004	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
1979	0.000	0.002	0.043	0.160	0.251	0.009	0.008	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
1980	0.000	0.000	0.008	0.028	0.044	0.036	0.032	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097
1981	0.000	0.000	0.012	0.041	0.064	0.052	0.047	0.143	0.143	0.143	0.143	0.143	0.143	0.143	0.143	0.143	0.143	0.143	0.143
1982	0.000	0.005	0.140	0.385	0.605	0.017	0.016	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047	0.047
1983	0.000	0.015	0.436	0.321	0.504	0.021	0.019	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
1984	0.000	0.004	0.121	0.462	0.725	0.031	0.028	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084	0.084
1985	0.000	0.005	0.133	0.376	0.590	0.040	0.036	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109	0.109
1986	0.000	0.003	0.090	0.300	0.470	0.063	0.057	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173	0.173
1987	0.000	0.003	0.075	0.311	0.489	0.282	0.255	0.770	0.770	0.770	0.770	0.770	0.770	0.770	0.770	0.770	0.770	0.770	0.770
1988	0.000	0.000	0.009	0.036	0.056	0.251	0.227	0.684	0.684	0.684	0.684	0.684	0.684	0.684	0.684	0.684	0.684	0.684	0.684
1989	0.000	0.000	0.004	0.015	0.024	0.297	0.269	0.811	0.811	0.811	0.811	0.811	0.811	0.811	0.811	0.811	0.811	0.811	0.811
1990	0.000	0.000	0.006	0.035	0.055	0.255	0.231	0.695	0.695	0.695	0.695	0.695	0.695	0.695	0.695	0.695	0.695	0.695	0.695
1991	0.000	0.000	0.006	0.027	0.042	0.169	0.153	0.460	0.460	0.460	0.460	0.460	0.460	0.460	0.460	0.460	0.460	0.460	0.460
1992	0.000	0.001	0.033	0.196	0.308	0.428	0.387	1.168	1.168	1.168	1.168	1.168	1.168	1.168	1.168	1.168	1.168	1.168	1.168
1993	0.000	0.002	0.052	0.110	0.173	0.347	0.314	0.948	0.948	0.948	0.948	0.948	0.948	0.948	0.948	0.948	0.948	0.948	0.948
1994	0.000	0.001	0.025	0.098	0.153	0.157	0.142	0.430	0.430	0.430	0.430	0.430	0.430	0.430	0.430	0.430	0.430	0.430	0.430
1995	0.000	0.000	0.013	0.051	0.080	0.121	0.109	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330
1996	0.000	0.001	0.022	0.179	0.281	0.213	0.192	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580	0.580
1997	0.000	0.001	0.019	0.053	0.083	0.199	0.180	0.542	0.542	0.542	0.542	0.542	0.542	0.542	0.542	0.542	0.542	0.542	0.542
1998	0.000	0.002	0.050	0.123	0.193	0.259	0.234	0.706	0.706	0.706	0.706	0.706	0.706	0.706	0.706	0.706	0.706	0.706	0.706
1999	0.000	0.001	0.020	0.117	0.183	0.222	0.201	0.606	0.606	0.606	0.606	0.606	0.606	0.606	0.606	0.606	0.606	0.606	0.606
2000	0.000	0.001	0.028	0.097	0.152	0.467	0.422	1.273	1.273	1.273	1.273	1.273	1.273	1.273	1.273	1.273	1.273	1.273	1.273
2001	0.000	0.003	0.075	0.133	0.208	0.257	0.233	0.702	0.702	0.702	0.702	0.702	0.702	0.702	0.702	0.702	0.702	0.702	0.702
2002	0.000	0.001	0.018	0.093	0.146	0.294	0.266	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803	0.803
2003	0.000	0.001	0.026	0.048	0.075	0.351	0.317	0.957	0.957	0.957	0.957	0.957	0.957	0.957	0.957	0.957	0.957	0.957	0.957
2004	0.000	0.002	0.042	0.074	0.117	0.249	0.225	0.678	0.678	0.678	0.678	0.678	0.678	0.678	0.678	0.678	0.678	0.678	0.678
2005	0.000	0.001	0.024	0.065	0.101	0.158	0.143	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432	0.432
2006	0.000	0.001	0.028	0.114	0.179	0.153	0.138	0.417	0.417	0.417	0.417	0.417	0.417	0.417	0.417	0.417	0.417	0.417	0.417
2007	0.000	0.001	0.038	0.151	0.236	0.217	0.197	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593	0.593
2008	0.000	0.002	0.046	0.159	0.250	0.233	0.211	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635	0.635
2009	0.000	0.001	0.030	0.169	0.266	0.279	0.253	0.761	0.761	0.761	0.761	0.761	0.761	0.761	0.761	0.761	0.761	0.761	0.761
2010	0.000	0.002	0.043	0.143	0.224	0.501	0.453	1.366	1.366	1.366	1.366	1.366	1.366	1.366	1.366	1.366	1.366	1.366	1.366
2011	0.000	0.000	0.009	0.045	0.070	0.192	0.174	0.524	0.524	0.524	0.524	0.524	0.524	0.524	0.524	0.524	0.524	0.524	0.524
2012	0.000	0.000	0.011	0.090	0.142	0.272	0.246	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741	0.741
2013	0.000	0.000	0.011	0.048	0.075	0.172	0.155	0.468	0.468	0.468	0.468	0.468	0.468	0.468	0.468	0.468	0.468	0.468	0.468
2014	0.000	0.000	0.010	0.035	0.055	0.113	0.102	0.309	0.309	0.309	0.309	0.309	0.309	0.309	0.309	0.309	0.309	0.309	0.309
2015	0.000	0.001	0.021	0.042	0.067	0.072	0.065	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196

Table 2A.18—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in 2016-2028 (Scenario 1), with random variability in future recruitment, based on Model 15.7.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	23,200	23,200	23,200	23,200	0
2017	19,700	19,700	19,700	19,700	0
2018	18,400	18,400	18,400	18,400	2
2019	17,500	17,500	17,500	17,600	47
2020	17,400	18,100	18,300	19,800	800
2021	15,800	17,800	18,200	21,800	1,955
2022	14,600	18,600	19,000	25,100	3,272
2023	13,300	19,100	19,200	26,700	4,199
2024	12,200	19,300	19,400	27,000	4,704
2025	11,200	19,200	19,500	29,600	5,711
2026	10,600	19,200	19,500	29,800	5,808
2027	10,800	19,400	19,500	29,400	5,795
2028	11,000	19,400	19,600	29,300	5,703

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	35,500	35,500	35,500	35,500	0
2017	32,200	32,200	32,200	32,200	0
2018	30,400	30,400	30,400	30,400	3
2019	29,700	29,800	29,800	29,900	71
2020	29,900	30,300	30,400	31,400	510
2021	29,400	30,900	31,300	34,700	1,754
2022	28,000	31,300	32,200	39,500	3,782
2023	26,000	31,500	32,700	44,400	5,740
2024	24,400	31,600	33,000	46,700	7,119
2025	23,400	31,600	33,300	47,300	7,900
2026	22,900	31,900	33,500	48,500	8,084
2027	23,300	31,900	33,500	48,500	7,953
2028	23,500	31,900	33,400	48,500	7,676

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	0.47	0.47	0.47	0.47	0.00
2017	0.46	0.46	0.46	0.46	0.00
2018	0.44	0.44	0.44	0.44	0.00
2019	0.43	0.43	0.43	0.43	0.00
2020	0.43	0.43	0.44	0.45	0.01
2021	0.42	0.44	0.45	0.47	0.02
2022	0.40	0.45	0.44	0.47	0.02
2023	0.37	0.45	0.44	0.47	0.04
2024	0.34	0.45	0.43	0.47	0.04
2025	0.33	0.45	0.43	0.47	0.05
2026	0.32	0.46	0.43	0.47	0.05
2027	0.33	0.46	0.43	0.47	0.05
2028	0.33	0.46	0.43	0.47	0.05

Table 2A.19—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the authors' best estimates of 2016-2017 catches given ABC = maxABC in 2016-2017, with $F = max\ F_{ABC}$ thereafter (Scenario 2), and with random variability in future recruitment, based on Model 15.7.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	21,100	21,100	21,100	21,100	0
2017	17,800	17,800	17,800	17,800	0
2018	20,000	20,000	20,000	20,000	2
2019	18,200	18,300	18,300	18,400	48
2020	17,800	18,400	18,600	20,100	797
2021	15,900	17,900	18,300	21,900	1,944
2022	14,600	18,600	19,000	25,100	3,275
2023	13,200	19,100	19,200	26,700	4,204
2024	12,200	19,300	19,300	27,000	4,707
2025	11,200	19,100	19,500	29,600	5,711
2026	10,600	19,200	19,500	29,700	5,807
2027	10,800	19,400	19,500	29,400	5,794
2028	11,000	19,400	19,600	29,300	5,703

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	35,700	35,700	35,700	35,700	0
2017	33,200	33,200	33,200	33,200	0
2018	31,700	31,700	31,700	31,700	3
2019	30,400	30,400	30,500	30,600	71
2020	30,200	30,600	30,700	31,700	511
2021	29,500	31,000	31,400	34,800	1,756
2022	28,000	31,300	32,200	39,500	3,787
2023	26,000	31,400	32,700	44,400	5,742
2024	24,400	31,500	33,000	46,700	7,119
2025	23,400	31,600	33,300	47,300	7,899
2026	22,900	31,900	33,400	48,500	8,083
2027	23,300	31,900	33,500	48,500	7,952
2028	23,500	31,900	33,400	48,500	7,676

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	0.42	0.42	0.42	0.42	0.00
2017	0.40	0.40	0.40	0.40	0.00
2018	0.46	0.46	0.46	0.46	0.00
2019	0.44	0.44	0.44	0.44	0.00
2020	0.43	0.44	0.44	0.46	0.01
2021	0.42	0.45	0.45	0.47	0.02
2022	0.40	0.45	0.44	0.47	0.02
2023	0.37	0.45	0.44	0.47	0.04
2024	0.34	0.45	0.43	0.47	0.04
2025	0.33	0.45	0.43	0.47	0.05
2026	0.32	0.46	0.43	0.47	0.05
2027	0.33	0.46	0.43	0.47	0.05
2028	0.33	0.46	0.43	0.47	0.05

Table 2A.20—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 2016-2028 (Scenario 3), with random variability in future recruitment, based on Model 15.7.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	30,000	30,000	30,000	30,000	0
2017	23,600	23,600	23,600	23,600	0
2018	22,200	22,200	22,200	22,200	0
2019	20,600	20,600	20,600	20,700	13
2020	19,800	20,400	20,600	22,000	750
2021	17,700	19,500	20,000	23,900	2,035
2022	16,600	20,100	20,800	28,100	3,518
2023	15,700	20,600	21,200	29,600	4,359
2024	15,000	20,700	21,500	29,800	4,785
2025	14,000	20,700	21,500	32,400	5,781
2026	13,200	20,600	21,400	32,200	5,801
2027	13,400	20,800	21,400	31,300	5,742
2028	13,600	20,700	21,400	31,500	5,595

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	34,900	34,900	34,900	34,900	0
2017	29,300	29,300	29,300	29,300	0
2018	26,200	26,200	26,200	26,200	4
2019	24,600	24,700	24,700	24,800	74
2020	24,100	24,600	24,700	25,700	543
2021	23,200	24,800	25,300	28,800	1,847
2022	21,500	25,000	26,000	33,300	3,844
2023	19,400	25,300	26,300	37,500	5,642
2024	17,500	25,400	26,500	39,100	6,865
2025	16,400	25,400	26,600	39,200	7,526
2026	16,000	25,500	26,600	40,500	7,627
2027	16,100	25,500	26,500	40,300	7,460
2028	16,300	25,400	26,400	40,500	7,215

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	0.63	0.63	0.63	0.63	0.00
2017	0.63	0.63	0.63	0.63	0.00
2018	0.63	0.63	0.63	0.63	0.00
2019	0.63	0.63	0.63	0.63	0.00
2020	0.63	0.63	0.63	0.63	0.00
2021	0.63	0.63	0.63	0.63	0.00
2022	0.63	0.63	0.63	0.63	0.00
2023	0.63	0.63	0.63	0.63	0.00
2024	0.63	0.63	0.63	0.63	0.00
2025	0.63	0.63	0.63	0.63	0.00
2026	0.63	0.63	0.63	0.63	0.00
2027	0.63	0.63	0.63	0.63	0.00
2028	0.63	0.63	0.63	0.63	0.00

Table 2A.21—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 2016-2028 (Scenario 4), with random variability in future recruitment, based on Model 15.7.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	11,100	11,100	11,100	11,100	0
2017	10,900	10,900	10,900	10,900	0
2018	11,700	11,700	11,700	11,700	0
2019	11,900	11,900	11,900	11,900	4
2020	12,300	12,500	12,500	13,000	250
2021	11,700	12,300	12,500	13,900	718
2022	11,600	12,900	13,200	15,800	1,353
2023	11,500	13,400	13,700	17,300	1,798
2024	11,300	13,700	14,100	17,600	2,056
2025	10,500	13,800	14,300	19,800	3,007
2026	9,730	13,900	14,300	20,400	3,303
2027	9,750	14,000	14,400	20,600	3,439
2028	9,660	14,000	14,500	20,700	3,462

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	36,500	36,500	36,500	36,500	0
2017	37,600	37,600	37,600	37,600	0
2018	38,500	38,500	38,500	38,500	4
2019	39,600	39,700	39,700	39,800	74
2020	40,800	41,200	41,400	42,400	548
2021	41,100	42,700	43,200	47,000	1,960
2022	39,900	43,800	44,900	53,400	4,431
2023	37,600	44,800	46,100	60,600	7,154
2024	35,000	45,500	47,000	64,900	9,399
2025	32,800	46,000	47,600	67,100	10,954
2026	32,200	46,100	48,000	68,500	11,698
2027	31,400	46,700	48,100	69,900	11,869
2028	31,500	46,500	48,100	69,900	11,687

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	0.21	0.21	0.21	0.21	0.00
2017	0.21	0.21	0.21	0.21	0.00
2018	0.21	0.21	0.21	0.21	0.00
2019	0.21	0.21	0.21	0.21	0.00
2020	0.21	0.21	0.21	0.21	0.00
2021	0.21	0.21	0.21	0.21	0.00
2022	0.21	0.21	0.21	0.21	0.00
2023	0.21	0.21	0.21	0.21	0.00
2024	0.21	0.21	0.21	0.21	0.00
2025	0.21	0.21	0.21	0.21	0.00
2026	0.21	0.21	0.21	0.21	0.00
2027	0.21	0.21	0.21	0.21	0.00
2028	0.21	0.21	0.21	0.21	0.00

Table 2A.22—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that *F* = 0 in 2016-2029 (Scenario 5), with random variability in future recruitment, based on Model 15.7.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
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
2028	0	0	0	0	0

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	37,300	37,300	37,300	37,300	0
2017	42,700	42,700	42,700	42,700	0
2018	47,600	47,600	47,600	47,600	4
2019	52,400	52,500	52,500	52,600	74
2020	56,800	57,300	57,400	58,400	551
2021	59,900	61,600	62,100	66,000	2,017
2022	60,800	65,000	66,200	75,200	4,751
2023	60,000	68,000	69,600	86,000	8,064
2024	58,500	70,500	72,300	93,800	11,064
2025	56,700	72,400	74,500	99,000	13,406
2026	55,900	73,900	76,200	102,000	15,025
2027	55,600	75,500	77,300	106,000	15,914
2028	55,000	76,200	78,100	108,000	16,236

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
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
2028	0.00	0.00	0.00	0.00	0.00

Table 2A.23—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = F_{OFL}$ in 2016-2028 (Scenario 6), with random variability in future recruitment, based on Model 15.7.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	27,800	27,800	27,800	27,800	0
2017	21,200	21,200	21,200	21,200	0
2018	19,200	19,200	19,200	19,200	2
2019	18,100	18,100	18,100	18,200	52
2020	18,000	18,700	19,000	20,600	917
2021	16,200	18,500	19,100	24,400	2,546
2022	14,900	19,300	20,200	28,300	4,167
2023	13,500	19,800	20,400	29,500	5,100
2024	12,500	19,800	20,500	29,600	5,578
2025	11,400	19,700	20,500	32,000	6,445
2026	11,000	19,700	20,400	31,700	6,438
2027	11,300	19,600	20,400	31,100	6,395
2028	11,400	19,600	20,500	31,200	6,281

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	35,100	35,100	35,100	35,100	0
2017	30,300	30,300	30,300	30,300	0
2018	28,100	28,100	28,100	28,100	3
2019	27,500	27,500	27,500	27,700	70
2020	27,600	28,000	28,200	29,100	505
2021	27,200	28,600	29,000	32,200	1,696
2022	25,800	29,000	29,800	36,300	3,506
2023	23,900	29,100	30,100	40,400	5,143
2024	22,400	29,100	30,200	41,900	6,245
2025	21,600	29,000	30,300	42,000	6,834
2026	21,300	29,200	30,300	43,100	6,929
2027	21,600	29,100	30,300	43,100	6,766
2028	21,800	29,100	30,200	43,100	6,509

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	0.58	0.58	0.58	0.58	0.00
2017	0.54	0.54	0.54	0.54	0.00
2018	0.50	0.50	0.50	0.50	0.00
2019	0.48	0.49	0.49	0.49	0.00
2020	0.49	0.50	0.50	0.52	0.01
2021	0.48	0.51	0.51	0.57	0.03
2022	0.45	0.51	0.52	0.58	0.04
2023	0.42	0.52	0.51	0.58	0.06
2024	0.39	0.51	0.51	0.58	0.07
2025	0.37	0.51	0.50	0.58	0.07
2026	0.37	0.52	0.50	0.58	0.07
2027	0.38	0.51	0.50	0.58	0.07
2028	0.38	0.51	0.50	0.58	0.07

Table 2A.24—Projections for AI Pacific cod catch (t), spawning biomass (t), and fishing mortality under the assumption that $F = max\ F_{ABC}$ in each year 2016-2017 and $F = F_{OFL}$ thereafter (Scenario 7), with random variability in future recruitment, based on Model 15.7.

Catch projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	23,200	23,200	23,200	23,200	0
2017	19,700	19,700	19,700	19,700	0
2018	21,900	21,900	21,900	21,900	2
2019	19,200	19,300	19,300	19,400	54
2020	18,500	19,200	19,400	21,100	926
2021	16,400	18,600	19,200	24,600	2,543
2022	14,900	19,200	20,200	28,300	4,169
2023	13,500	19,700	20,400	29,400	5,103
2024	12,500	19,700	20,500	29,600	5,578
2025	11,400	19,700	20,500	32,000	6,443
2026	11,000	19,700	20,400	31,700	6,437
2027	11,300	19,600	20,400	31,100	6,394
2028	11,400	19,600	20,500	31,200	6,281

Biomass projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	35,500	35,500	35,500	35,500	0
2017	32,200	32,200	32,200	32,200	0
2018	30,100	30,100	30,100	30,100	3
2019	28,300	28,400	28,400	28,500	70
2020	28,000	28,400	28,500	29,400	505
2021	27,200	28,700	29,100	32,300	1,694
2022	25,800	28,900	29,800	36,300	3,504
2023	23,900	29,100	30,000	40,300	5,139
2024	22,300	29,100	30,200	41,900	6,241
2025	21,600	29,000	30,300	42,000	6,831
2026	21,300	29,200	30,300	43,100	6,927
2027	21,600	29,100	30,300	43,100	6,765
2028	21,800	29,100	30,200	43,100	6,509

Fishing mortality projections:

Year	L90%CI	Median	Mean	U90%CI	Std. Dev.
2016	0.47	0.47	0.47	0.47	0.00
2017	0.46	0.46	0.46	0.46	0.00
2018	0.53	0.53	0.53	0.53	0.00
2019	0.50	0.50	0.50	0.50	0.00
2020	0.49	0.50	0.50	0.52	0.01
2021	0.48	0.51	0.51	0.57	0.03
2022	0.45	0.51	0.52	0.58	0.04
2023	0.42	0.51	0.51	0.58	0.06
2024	0.39	0.51	0.51	0.58	0.07
2025	0.37	0.51	0.50	0.58	0.07
2026	0.37	0.52	0.50	0.58	0.07
2027	0.37	0.51	0.50	0.58	0.07
2028	0.38	0.51	0.50	0.58	0.07

Table 2A.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, 1991-2015 (2015 data current through October 18).

Species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Pollock	26	205	135	164	12	29	279	270	482	778	312	719	785
Sablefish								6				1	1
Atka Mackerel	164	2981	3176	239	124	579	94	567	499	260	842	378	1075
Alaska Plaice													
Arrowtooth Flounder	5	72	95	58	6	97	47	76	72	95	130	225	230
Flathead Sole					7	4	17	17	31	71	37	105	39
Flounder		26	27	19									
Greenland Turbot	1	5	11	15				16	1	8	6	7	8
Rock Sole	19	161	178	116	185	204	193	380	540	456	462	1080	802
Yellowfin Sole													0
Other Flatfish						0	0	25	9	15	8	20	8
Northern Rockfish												117	215
Pacific Ocean Perch	24	235	366	88	22	50	99	234	48	102	72	63	185
Rougheye Rockfish													
Sharpchin/Northern Rockfish		195	313	132	37	157	88	158	191	274	182		
Short/Rough/Sharp/Northern	13												
Shortraker Rockfish													
Shortraker/Rougheye Rockfish		28	9	2		1	2	3	1	3	4	1	7
Other Rockfish	0	17	7	2	3	11	76	48	29	18	12	19	13
Other	74	473	224	58	56	128	147	321	225	349	180	324	307

Table 2A.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, 1991-2015 (2015 data current through October 18).

Species/group	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Pollock	537	669	314	395	54	51	18	57	78	23	11	
Sablefish	1	0	1	1								
Atka Mackerel	549	482	447	361	456	359	124	101	384			
Alaska Plaice				0	0							
Arrowtooth Flounder	199	244	206	134	24	35	35	16	19	18	5	
Flathead Sole	34	24	33	22	10	14	17	3	9	5	2	
Flounder												
Greenland Turbot	6	5		7	1	1						
Rock Sole	699	437	449	585	258	432	427	196	217	146	101	
Yellowfin Sole	9		3	0	0							
Other Flatfish	10	6	11	9	13	3	2	0	7	3	8	
Northern Rockfish	129	210	185	89	51	59	29	21	9	11	14	
Pacific Ocean Perch	160	180	134	96	105	32	5	2	43	3	1	
Rougheye Rockfish	2	3	1	0	0		0	1				
Sharpchin/Northern Rockfish												
Short/Rough/Sharp/Northern												
Shortraker Rockfish	3		2	0								
Shortraker/Rougheye Rockfish												
Other Rockfish	12	8	7	9	9	7	4	4	9	3	1	
Other	305	181	279	325	139	168	93					

Table 2A.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 and pot** fisheries for Pacific cod, 1991-2015 (2015 data current through October 18).

Species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Pollock	7	15	41	5	19	9	41	35	12	44	72	5	9
Sablefish	94	72	56	66	10	67	32	12	14	24	37	62	14
Atka Mackerel		58	20	40	41	33	40	90	73	151	273	41	14
Alaska plaice													
Arrowtooth Flounder	32	137	61	37	15	21	44	59	49	152	214	35	14
Flathead Sole					0	1	2	2	0	5	8	1	0
Flounder		3	4	1									
Greenland Turbot	71	78	57	32	13	14	24	30	30	30	26	6	12
Rock Sole	0	4	7	5	5	15	5	12	3	3	7	4	1
Yellowfin Sole													
Other Flatfish						0	1	2	1	4	13	1	
Northern Rockfish												28	18
Pacific Ocean Perch		120	2	1	0	1	0	0	0	9	3	0	1
Rougheye Rockfish													
Sharpchin/Northern Rockfish		45	19	10	4	20	17	54	35	75	132		
Short/Rough/Sharp/Northern	132												
Shortraker Rockfish													
Shortraker/Rougheye Rockfish		454	191	104	14	117	61	201	107	147	166	36	12
Other Rockfish	34	164	36	33	4	22	36	92	62	68	97	30	12
Other	82	1665	1375	325	345	499	676	1420	933	1929	3003	486	176

Table 2A.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 and pot** fisheries for Pacific cod, 1991-2015 (2015 data current through October 18).

Species/group	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Pollock	15	3	8	6	9	29	47	6	8	0		5
Sablefish	2		37	22	23	3	30	6	15	1		
Atka Mackerel	12	19	21	25	47	89	93		19	23		10
Alaska plaice												
Arrowtooth Flounder	18	34	36	66	42	45	65	8	10	2		4
Flathead Sole	0	0	1	2	2	3	3		1			
Flounder												
Greenland Turbot	3		11	15	4	5	5	1	2			
Rock Sole	2	4	3	3	2	2	3		2	0		1
Yellowfin Sole												
Other Flatfish	10		0	0	1	16	2					
Northern Rockfish	27	19	8	33	54	56	119		12	34		25
Pacific Ocean Perch	0	2	1	4	3	1	1		1			0
Rougheye Rockfish	26	2	3	28	46	23	30		27	15		16
Sharpchin/Northern Rockfish												
Short/Rough/Sharp/Northern												
Shortraker Rockfish	3	6	8	12	6	6	28	2	7	11		3
Shortraker/Rougheye Rockfish												
Other Rockfish	55	12	21	51	45	77	81	14	20	15		24
Other	612	518	577	734	809	1103	1392					

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, 2003-2015 (2015 data are current through October 18).

Species/group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Octopus, North Pacific	14	14	12	44	14	13	19	39	10	7	12	4	12
Sculpins	n/a								114	359	272	62	370
Shark, Pacific sleeper	0	2	2	n/a	n/a	n/a	n/a	0				n/a	n/a
Shark, salmon							n/a		n/a				n/a
Shark, spiny dogfish	0	0	0	1	0	3	1	1	0	0	n/a	n/a	0
Shark, other		n/a											
Skate, Alaska								161					
Skate, big		0	n/a	4	0	n/a	0	0					
Skate, longnose		0	n/a	n/a		n/a	0	n/a					
Skate, other	152	335	355	313	333	373	512	463	109	260	134	19	212
Squid, majestic	3	2	1	1	0	0	0	0	0	0	0	0	n/a

Table 2A.27—Catches of prohibited species by Aleutian Islands fisheries for Pacific cod, 1991-2015 (2015 data are current through October 18). Herring and halibut catches (and halibut mortality totals) are in t, salmon and crab are in 1000s of individuals.

Species/group	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Bairdi Tanner Crab	2	2	1	1	1	7	3	1	6	48	5	14	11
Opilio Tanner (Snow) Crab	2	1	1	0	0	0	0	0	0	0	0	1	0
Red King Crab	0	0	0	0	0	0	0	1	0	1	1	8	9
Blue King Crab													0
Golden (Brown) King Crab													0
Other King Crab	2	5	1	2	0	1	0	1	7	1	1	1	
Herring													0
Chinook Salmon	0	0	0	0	1	0	1	1	0	1	0	2	2
Non-Chinook Salmon		0			0		0	0		0	0	0	0

Species/group	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Bairdi Tanner Crab	8	3	7	28	199	41	7	1	11	16	6	0
Opilio Tanner (Snow) Crab	0	0	12	73	108	126	24	1	2	1	1	0
Red King Crab	1	3	0	3	6	1	1	1	0	8	0	0
Blue King Crab	0	0	0	9	0	0	13	0	0	0	0	0
Golden (Brown) King Crab	0	0	0	1	2	1	0	1	0	0	0	0
Other King Crab												
Herring	0	0	0	0	0	0	0	0	0	0	0	0
Chinook Salmon	1	1	1	1	1	1	1	0	0	0	0	0
Non-Chinook Salmon	0	0	0	1	0	0	0	0	0	0	0	0

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Catch	313	1626	531	423	386	546	438	1023	457	643	1294	261	176
Mortality				62	48	122	75	190	86	111	172	50	60

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Catch	329	287	317	847	671	695	614	206	241	69	58	150
Mortality	61	79	82	148	89	102	74	33	55	24	23	25

Table 2A.28—Incidental catch of non-target species groups by Aleutian Islands Pacific cod fisheries, 2003-2015 (2015 data are current through October 18), sorted in order of descending average. All units are t, except for birds, which are in numbers of individuals.

Species/group	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Ave.
Giant Grenadier	0	0	1	95	31	26	10	189	18	51	1	23	4	34
Grenadier	46	13	1	26	10	0	2	70	0	4	1			16
Misc fish	29	18	20	17	26	17	18	17	9	9	6	4	1	15
Sponge unidentified	25	23	26	28	19	4	15	9	3	7	2	1	7	13
Corals Bryozoans	25	13	12	12	16	11	11	10	6	4	4	1	4	10
Sea star	6	9	6	7	9	11	21	18	2	8	5	4	4	8
Invertebrate unidentified	0	1	0	14	2	4	0	10	0	0	0	0	1	3
Bivalves	15	1	1	3	2	1	0	0	0	0	0	0	0	2
Dark Rockfish						2	4	4	0	0	0	0	0	1
Scypho jellies	0	0	1	2	0	0	0	0	0	3	6	2	0	1
Snails	1	1	0	1	1	2	3	1	0	1	1	1	0	1
Misc crabs	1	1	0	1	2	1	1	1	0	0	2	1	0	1
Greenlings	1	0	0	4	1	1	0	1	0	0	0	0	0	1
Urchins dollars cucumbers	1	1	0	1	1	0	1	0	0	0	0	0	0	1
Sea anemone unidentified	0	0	1	1	1	0	1	1	0	1	0	0	0	0
Sea pens whips	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Eelpouts	0	1	0	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	0
Misc crustaceans	0	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	0
Brittle star unidentified	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Pandalid shrimp	0	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	0
Pacific Sandfish												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
Lanternfishes (myctophidae)													0	0
Birds	*185*	*79*	*298*	*184*	*145*	*310*	*147*	*366*	*19*	*26*	*14*	*4*	*831*	*201*

FIGURES

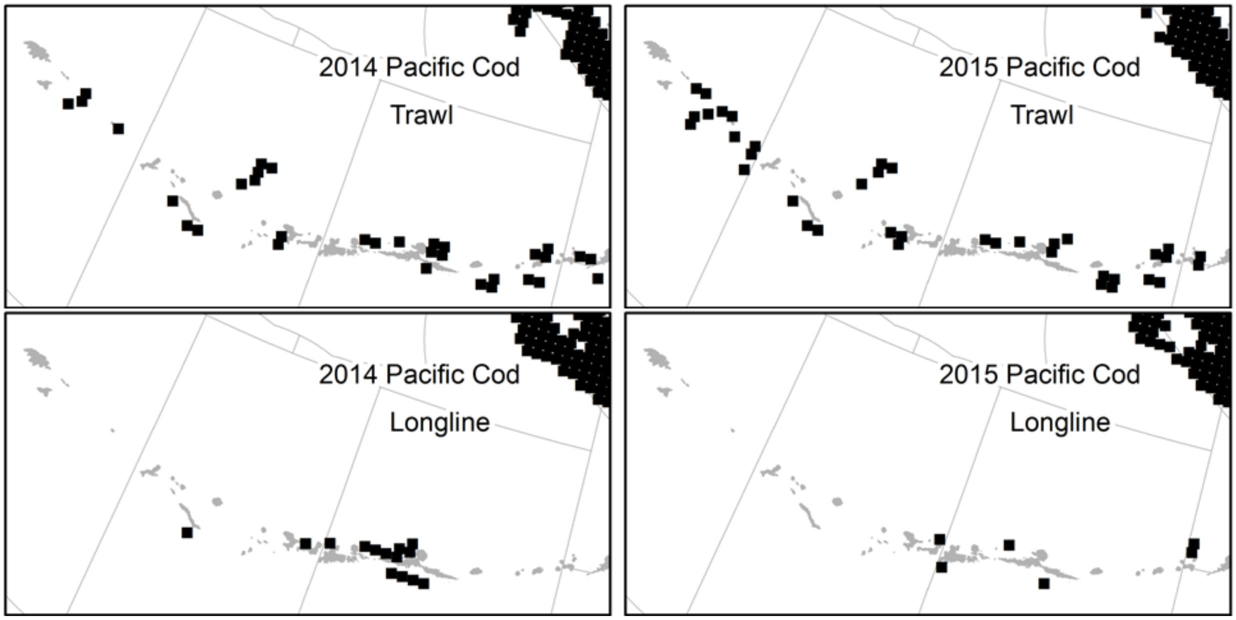


Figure 2A.1--AI maps showing each 400 square km cell with trawl hauls or longline sets containing Pacific cod from at least 3 distinct vessels in 2014-2015, overlaid against NMFS 3-digit statistical areas.

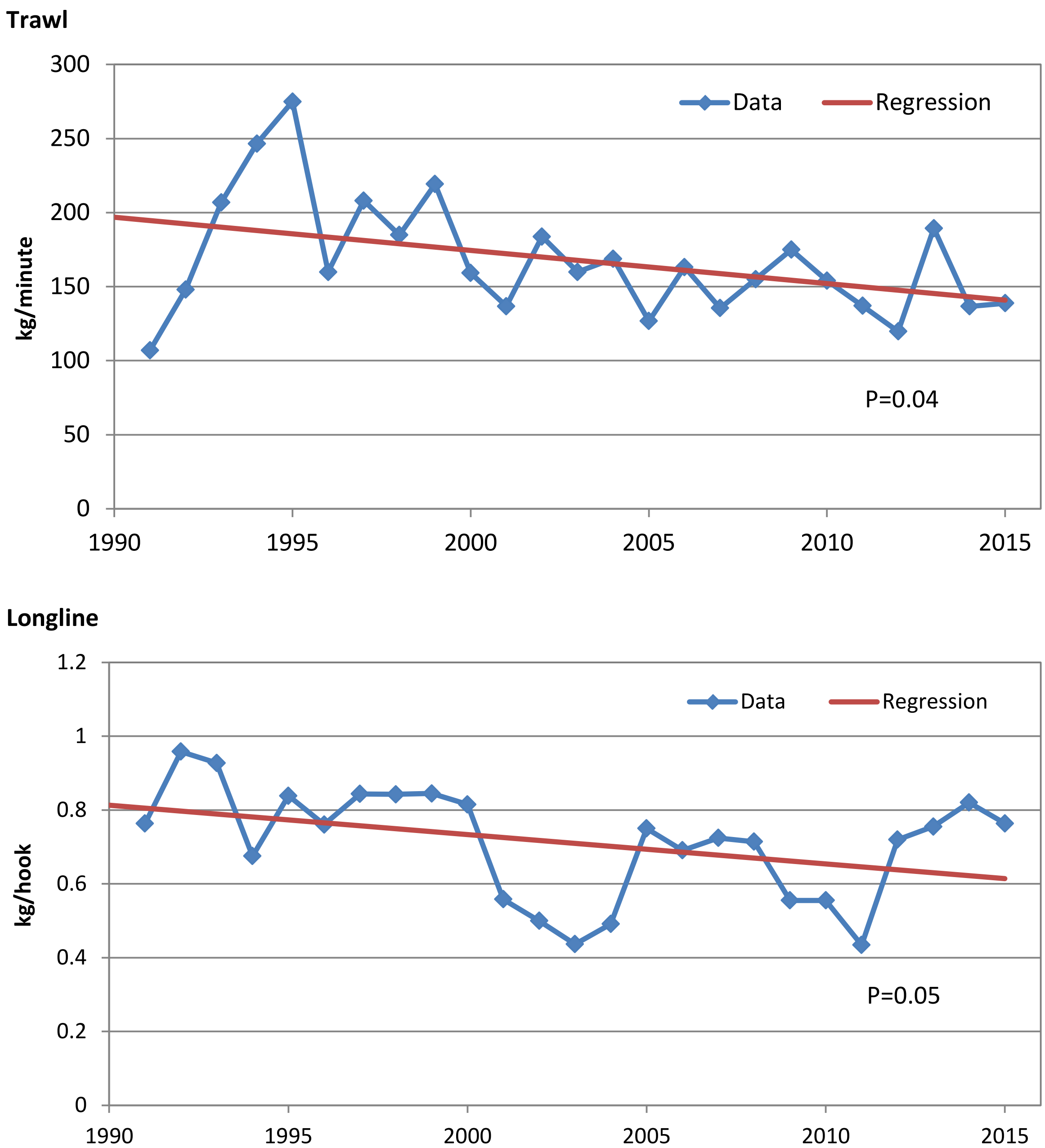


Figure 2A.2—Catch per unit effort for the trawl and longline fisheries, 1991-2015 (2015 data are partial).

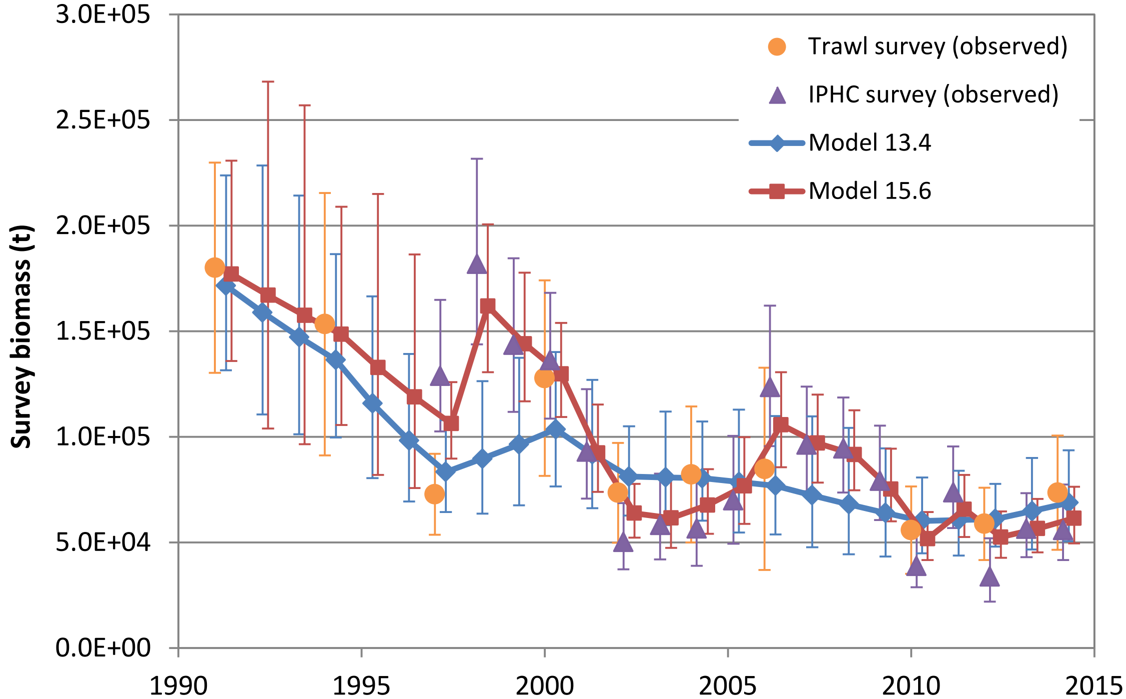


Figure 2A.3—Fit of Tier 5 models to survey biomass time series, with 95% confidence intervals for the observations and the estimates.

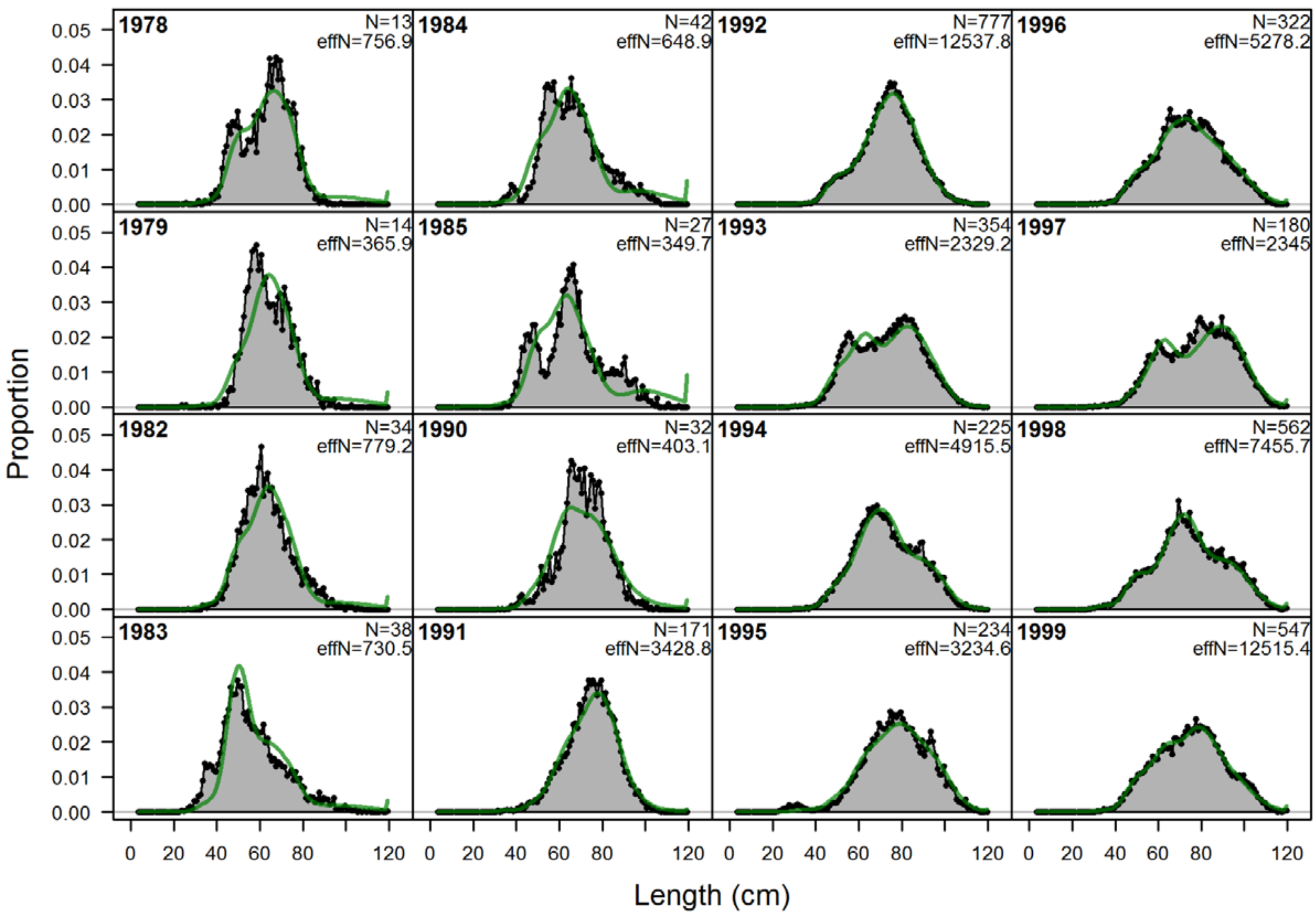


Figure 2A.4 (1 of 2)—Fit to fishery size composition data obtained by Model 15.7 (grey = observed, green = estimated).

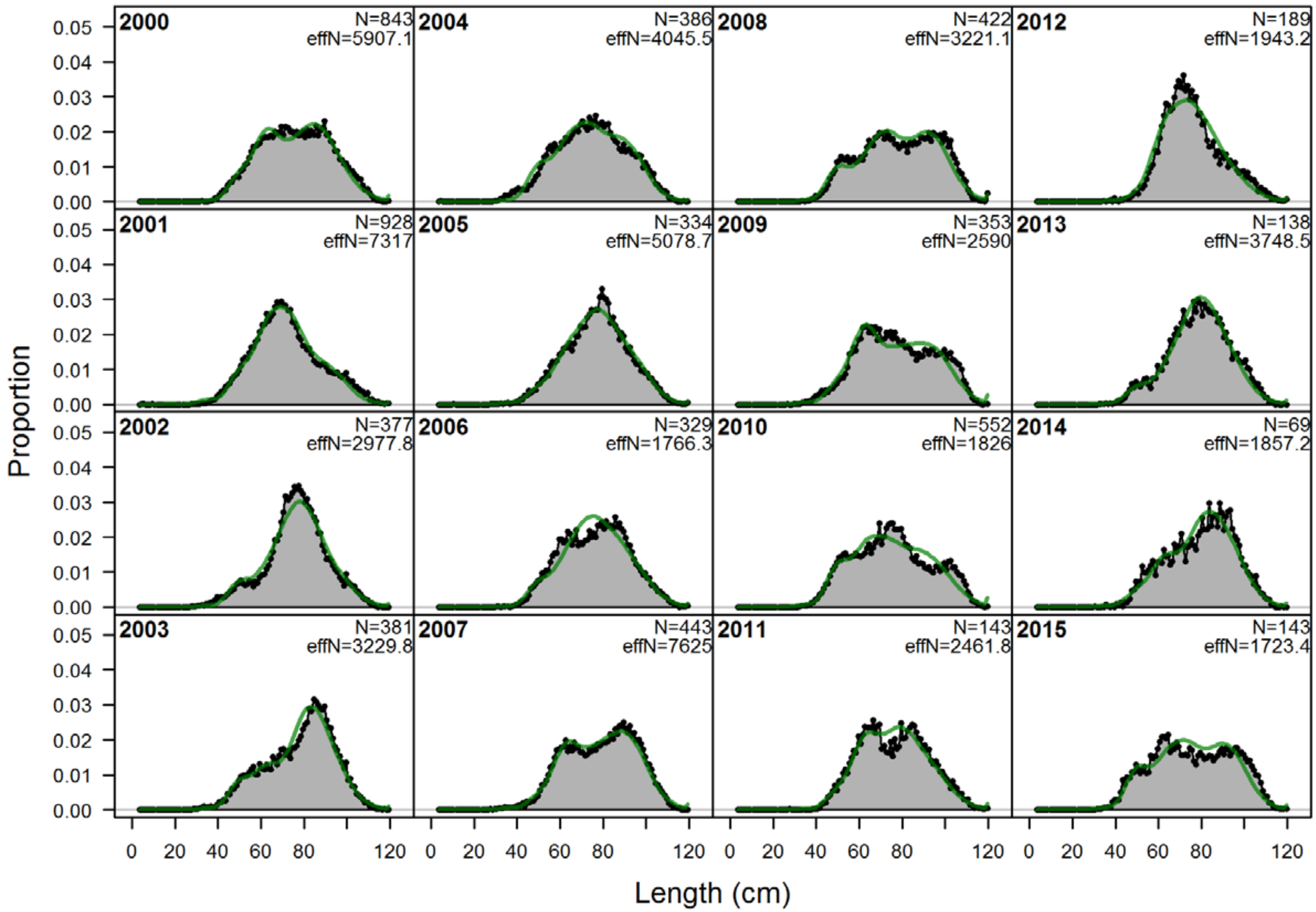


Figure 2A.4 (2 of 2)—Fit to fishery size composition data obtained by Model 15.7 (grey = observed, green = estimated).

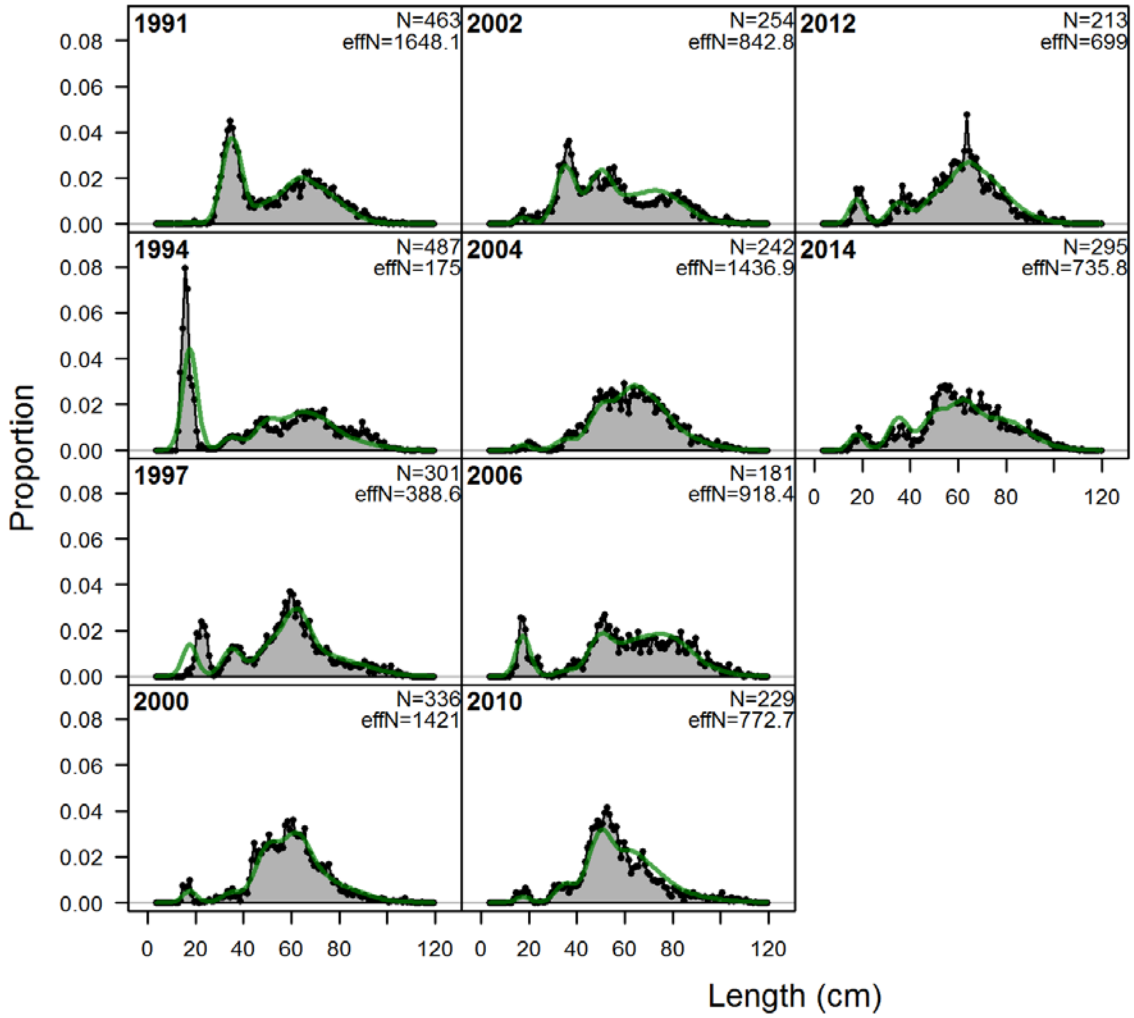


Figure 2A.5—Fit to survey size composition data obtained by Model 15.7 (grey = observed, green = estimated).

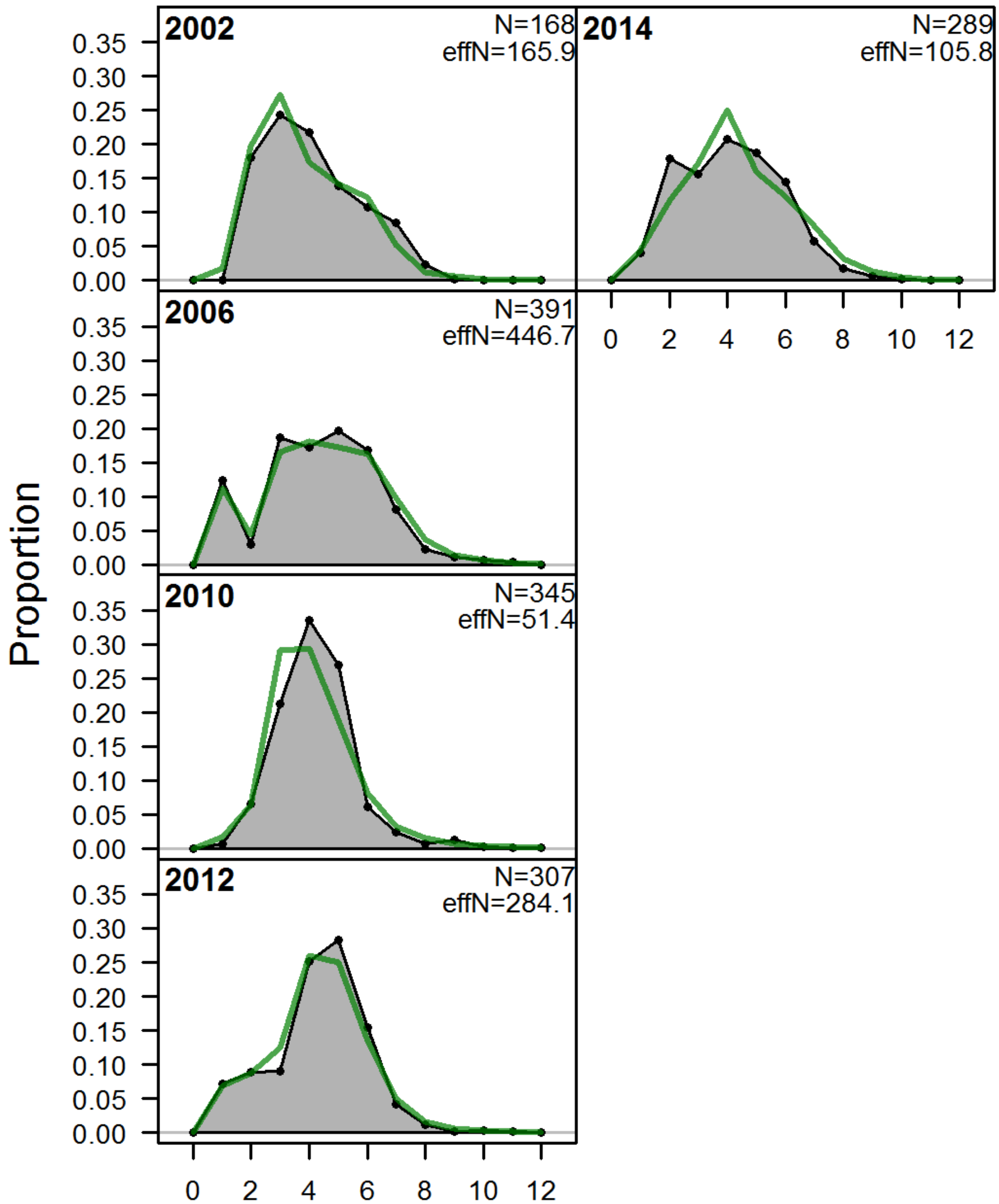


Figure 2A.6—Fit to survey age composition data obtained by Model 15.7 (grey = observed, green = estimated).

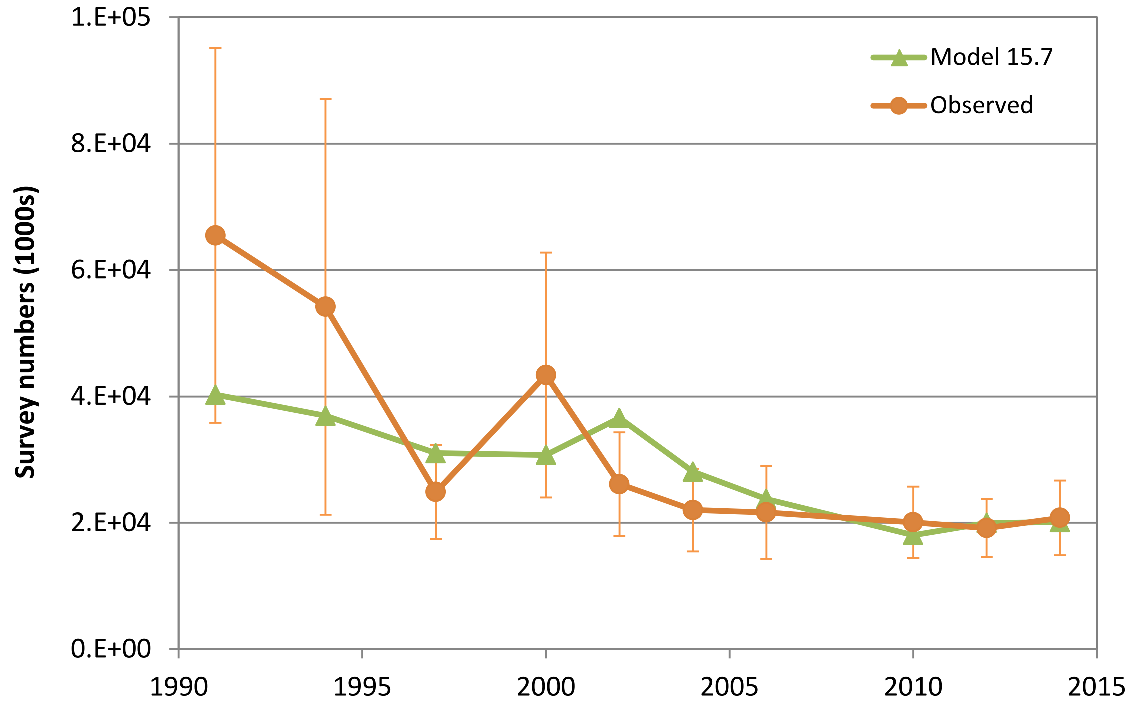


Figure 2A.7—Model 15.7's fit to the survey abundance time series, with 95% confidence intervals for the observations.

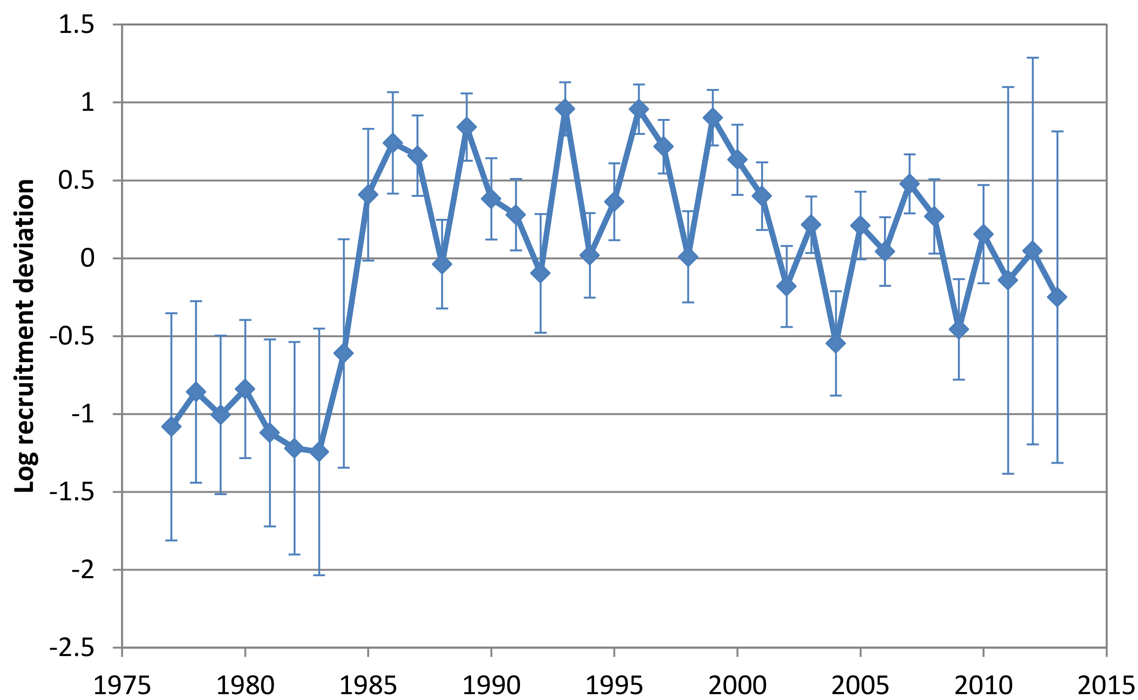


Figure 2A.8—Time series of estimated log recruitment deviations from Model 15.7, with 95% confidence intervals.

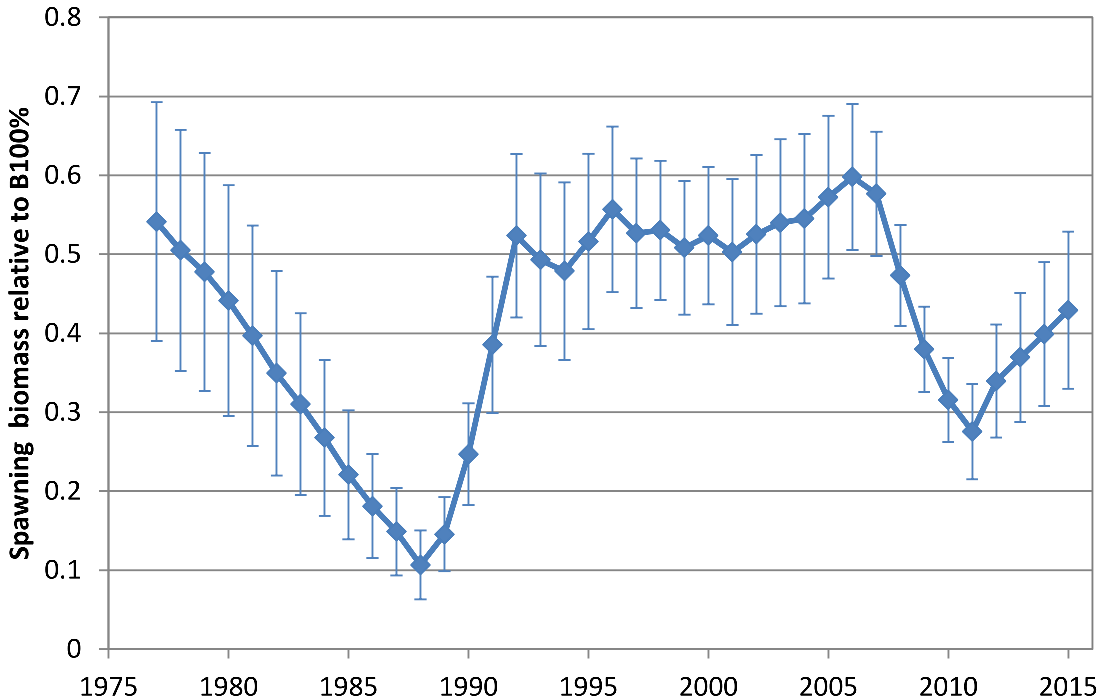


Figure 2A.9—Time series of spawning biomass relative to $B_{100\%}$ as estimated by Model 15.7.

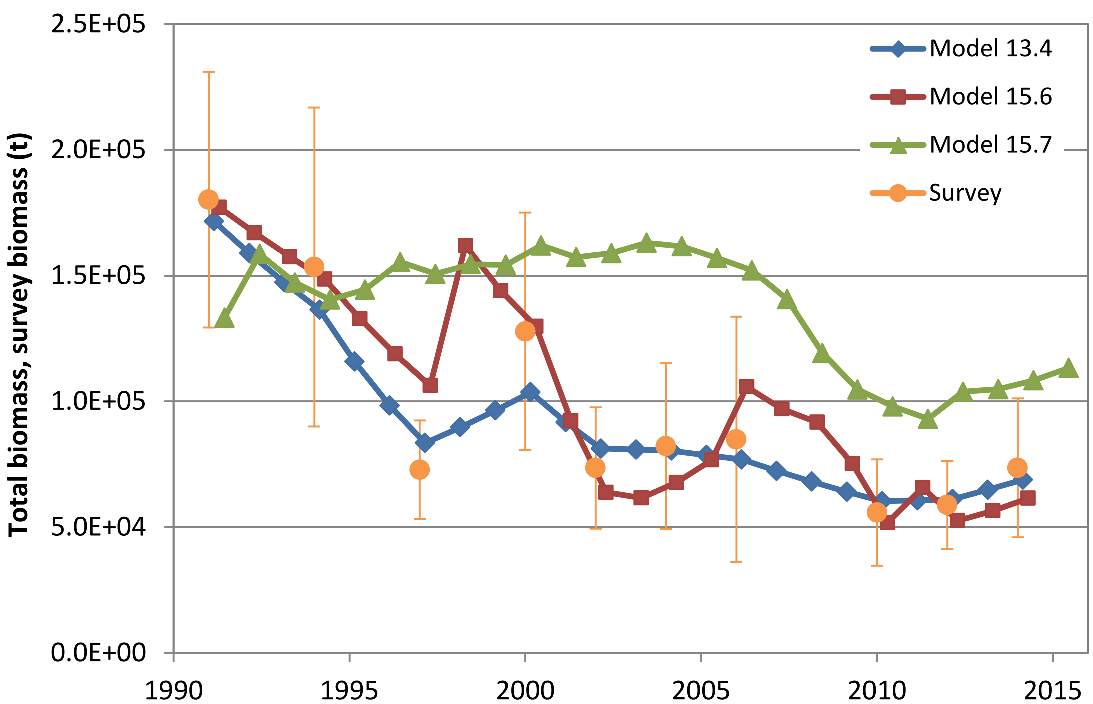


Figure 2A.10—Time series of total (age 0+) biomass as estimated by all models, together with survey biomass observations (horizontal axis values have been offset slightly to prevent over-plotting).

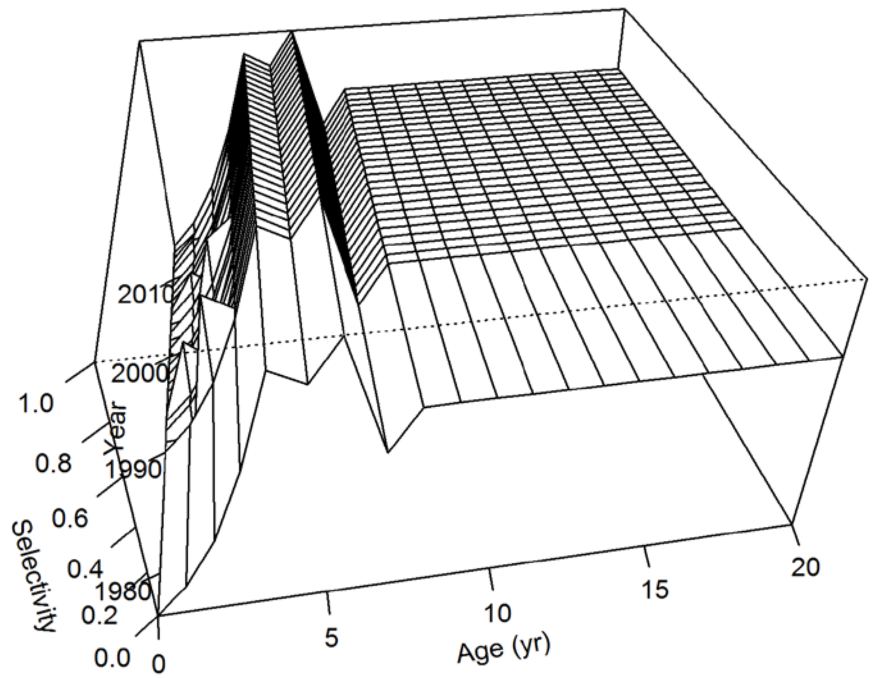


Figure 2A.11—Survey selectivity at age as estimated by Model 15.7.

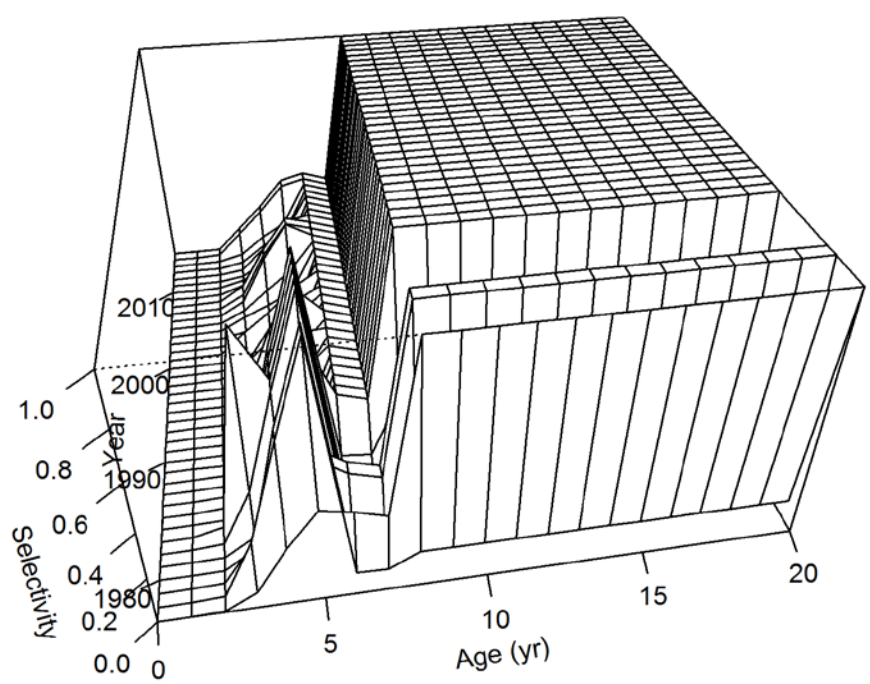


Figure 2A.12—Fishery selectivity at age as estimated by Model 15.7.

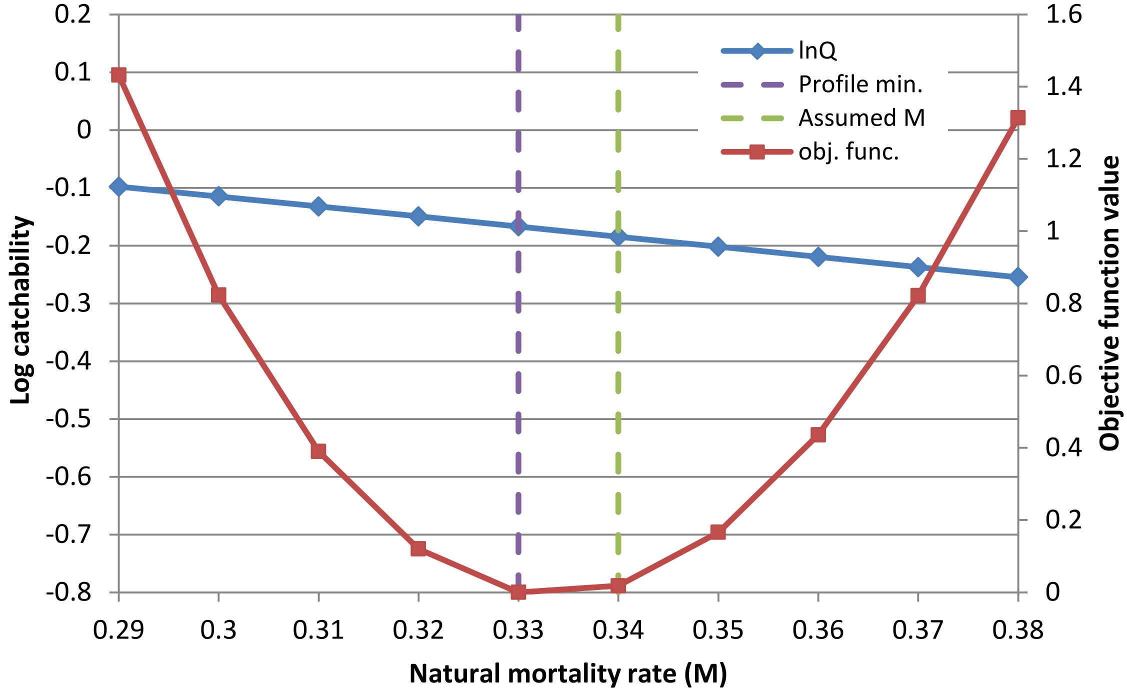


Figure 2A.13— Likelihood profiles with respect to the natural mortality rate for Model 15.7. Objective function minimum occurs at *M*=0.33. The relationship between *M* and log *Q* is also shown.

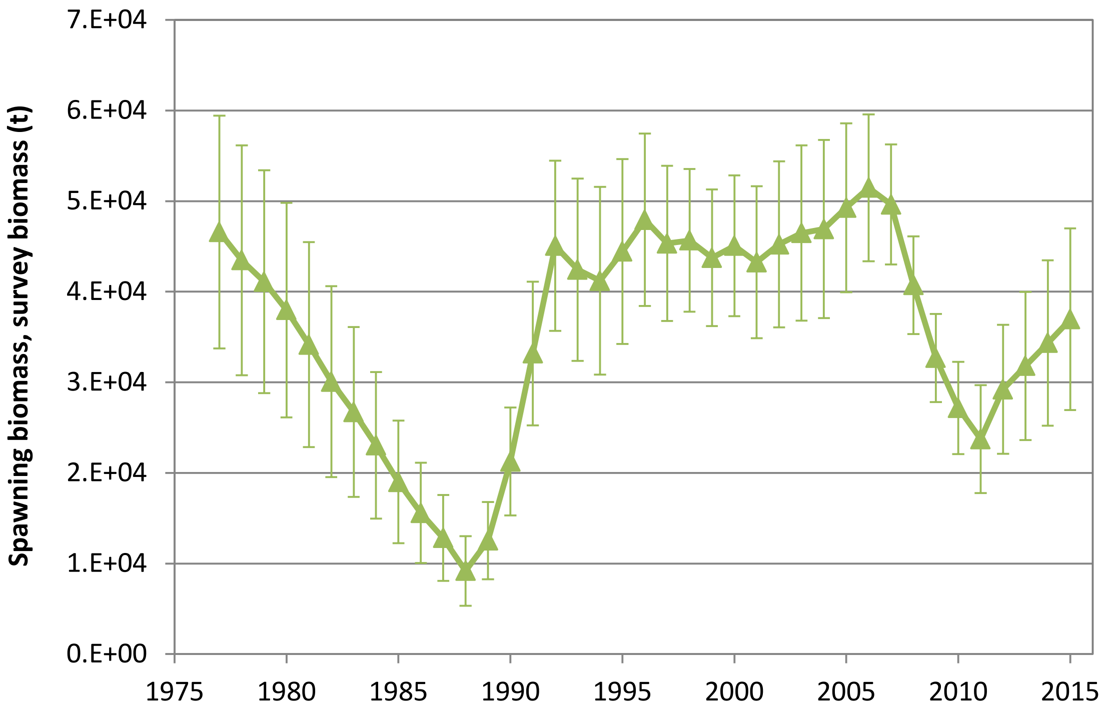


Figure 2A.14—Time series of female spawning biomass as estimated by Model 15.7, with 95% confidence intervals. Survey biomass is shown for comparison.

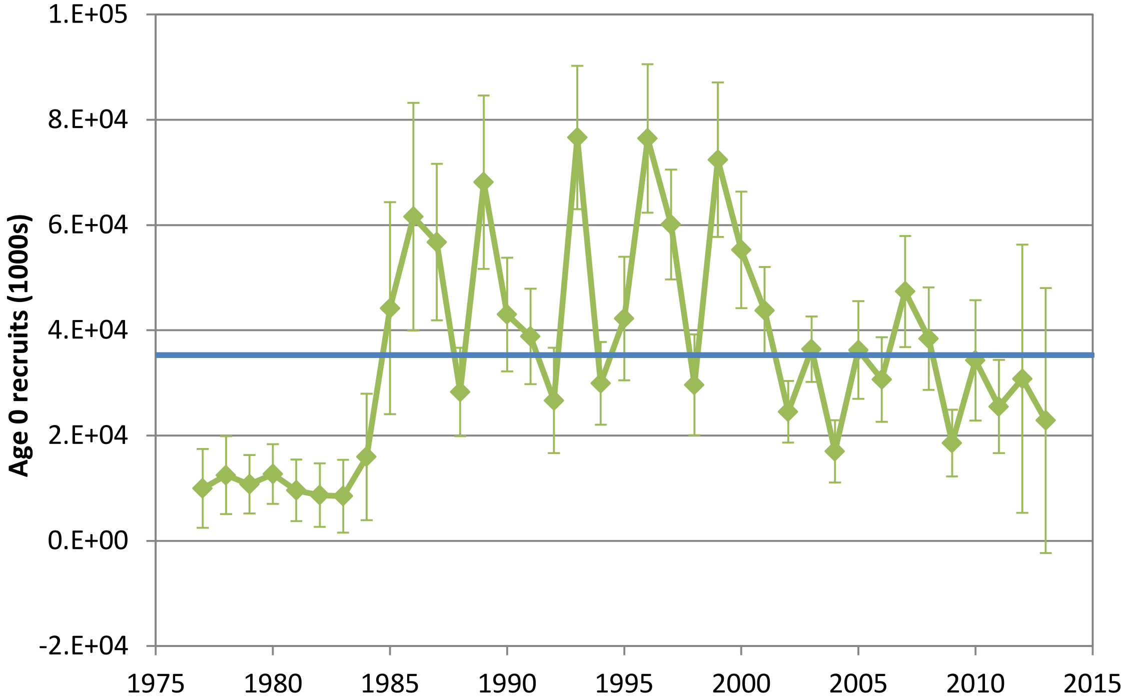


Figure 2A.15—Time series of recruitment at age 0 as estimated by Model 15.7 (horizontal line represents time series average).

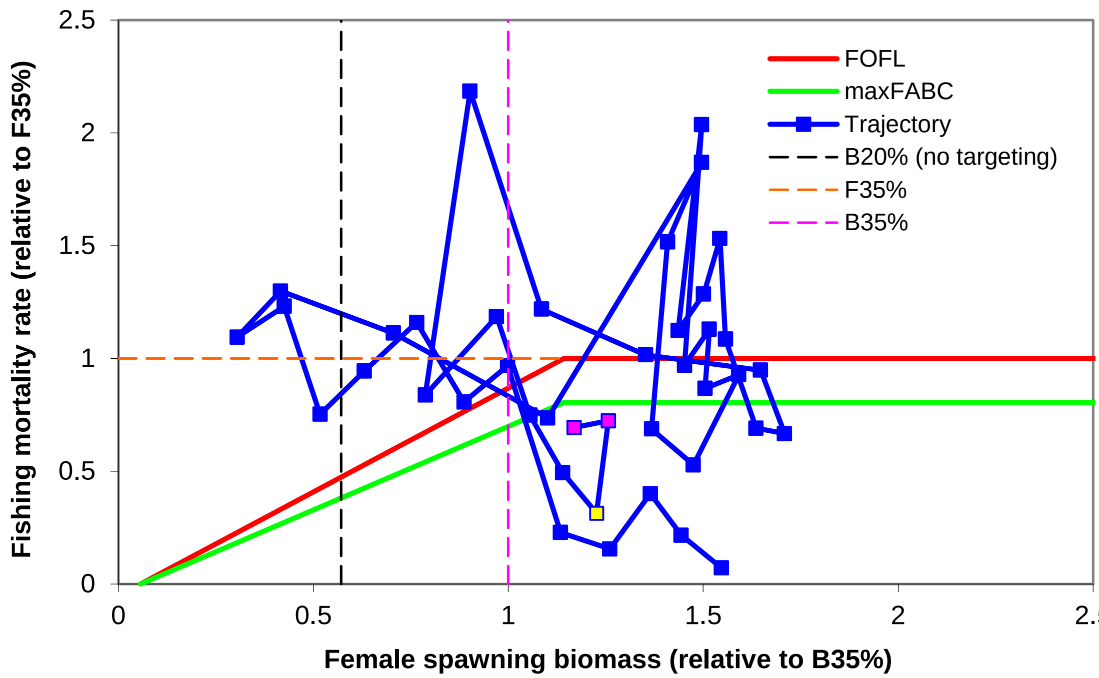
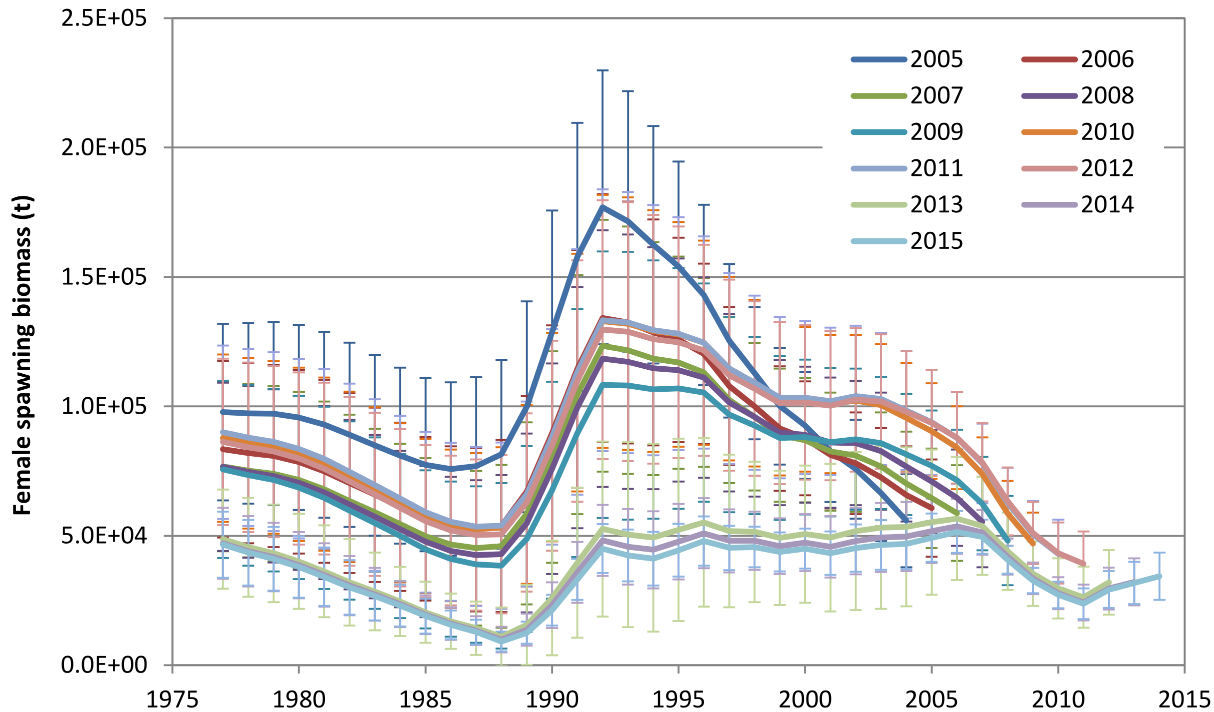


Figure 2A.16—Trajectory of AI Pacific cod fishing mortality and female spawning biomass as estimated by Model 15.7, 1991-2017 (yellow square = 2016, magenta squares = first two projection years).



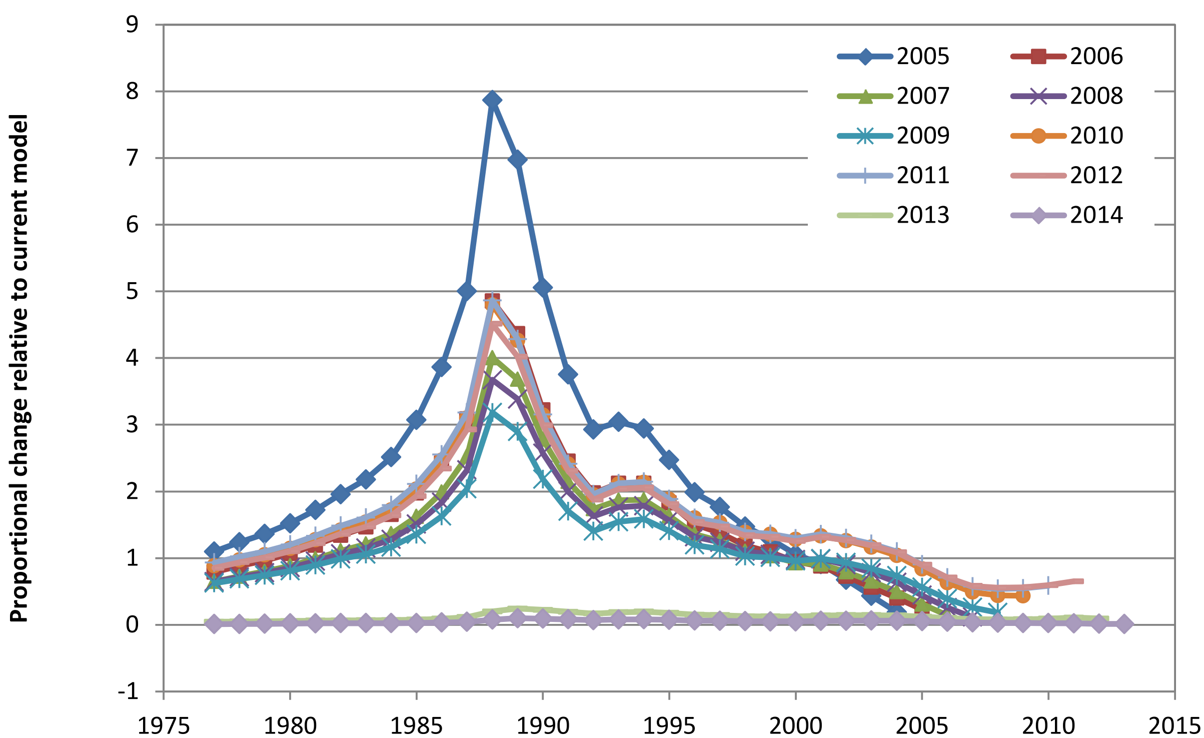


Figure 2A.17—Retrospective analysis of spawning biomass estimates from Model 15.5. Top panel: spawning biomass time series with 95% confidence intervals from the current version of the model (2015) and 10 retrospective runs (2005-2014) obtained by dropping one year of data at a time. Bottom panel: change in spawning biomass relative to current version of Model 15.7 for each of 10 retrospective runs.

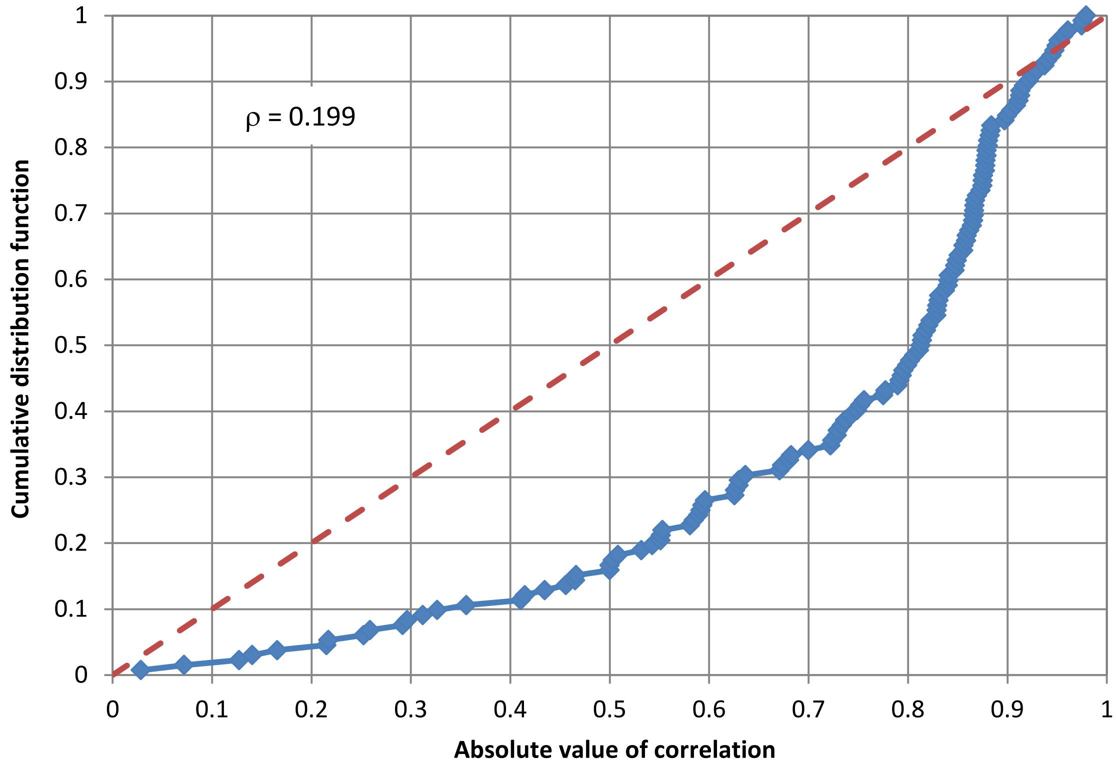


Figure 2A.18—Cumulative distribution function (cdf) of correlations (absolute value) between parameters and number of “peels” in retrospective runs in Model 15.7. The diagonal dashed line represents the cdf that would be obtained from a uniform distribution. The statistic ρ represents the average (across peels) relative bias in terminal year estimates of spawning biomass.

APPENDIX 2.1: PRELIMINARY ASSESSMENT OF THE PACIFIC COD STOCK IN THE ALEUTIAN ISLANDS

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Introduction

This document represents an effort to respond to comments made by the BSAI Plan Team, the Joint Team Subcommittee on Pacific cod models (JTS), and the SSC on last year's assessment of the Pacific cod (*Gadus macrocephalus*) stock in the Aleutian Islands (AI, Thompson and Palsson 2014).

Responses to SSC and Plan Team comments on assessments in general

SSC1 (12/14 minutes): *"The SSC requests that stock assessment authors use the following model naming conventions in SAFE chapters:*

- *Model 0: last years' model with no new data,*
- *Model 1: last years' model with updated data, and*
- *Model numbers higher than 1 are for proposed new models."*

Model nomenclature in this preliminary assessment adheres to the above conventions, with the exception that not all model numbers higher than 1 correspond to proposed *new* models (in addition to last year's final model, another of the models presented in this preliminary assessment was also included in last year's assessment).

SSC2 (12/14 minutes): *"The SSC also requests that stock assessment authors use the random effects model for area apportionment of ABCs."* The AI Pacific cod ABC is not apportioned by area.

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

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

BPT1 (11/14 minutes): *"The Team … recommend[s] … continue[d] work on the problems with Model 2 so as to make progress toward an age-structured AI assessment."* This comment was forwarded to the JTS for consideration at its May 2015 meeting.

BPT2 (11/14 minutes): *"Specifically, the Team recommends examining NMFS trawl survey data, IPHC longline survey data, AFSC longline survey data, and commercial data to investigate the distribution of AI Pacific cod relative to the NMFS trawl survey stations."* This comment was forwarded to the JTS for consideration at its May 2015 meeting.

JTS1 (5/15 minutes): *"For the AI, the subcommittee recommended that the following models be developed for this year's preliminary assessment:*

- *Model 0: Final model from 2014*

- *Model 2: Model 2 from the final 2014 assessment, but with:*
  - *continued work on the problems with the model so as to make progress toward an age-structured AI assessment*
- *Model 3: Model 2 from the final 2014 assessment, but with:*
  - *inclusion of the pre-1991 fishery data"*

The above models are included in this preliminary assessment (see also comment SSC3). In addition, the assessment author has included two of his own models. See section entitled "Model structures."

JTS2 (5/15 minutes): *"For the AI, the subcommittee recommended that the following non-model analysis be conducted for this year's preliminary assessment:*

- *Analysis 1: Examine NMFS trawl survey data, IPHC longline survey data, AFSC longline survey data, and commercial data to investigate the distribution of AI Pacific cod relative to the NMFS trawl survey stations"*

The above analysis is shown in Figure 2A.1.1 (see also comment SSC3).

SSC3 (6/15 minutes): *"The SSC agreed that this suite of models was appropriate and practicable and had no suggestions for additional models and analyses…. Our initial suggestion is to keep the numbering system the same throughout all three stages of the annual stock assessment cycle."* See comments JST1 and JST2.

Data

The data used in this preliminary assessment are identical to those used in last year's final assessment (Thompson and Palsson 2014), with the exception of two age-structured models that extended the fishery data time series back from 1991 to 1977.

The following table summarizes the sources, types, and years of data included in the data file for the Tier 5 random effects 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 age-structured models presented in this preliminary assessment (two of the age-structured models excluded fishery data from years prior to 1991):

Source	Type	Years
Fishery	Catch biomass	1977-2014
Fishery	Size composition	1978-1985, 1990-2014
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

Catch (t) for the pre-1991 period is shown below:

Year:	1,977	1978	1979	1980	1981	1982	1983
Catch (t):	3,262	3,295	5,593	5,788	7,434	8,397	8,430

Year:	1984	1985	1986	1987	1988	1989	1990
Catch (t):	7,981	6,937	6,906	13,207	5,165	4,542	7,541

Length composition sample sizes for the pre-1991 period are shown below:

Year:	1978	1979	1982	1983	1984	1985	1990
N(observed):	1,729	1,814	4,437	5,072	5,565	3,602	4,206
N(input):	13	13	33	38	41	27	31

Length composition data for the pre-1991 period are shown in Table 2A.1.1.

All other data used in this preliminary assessment were provided in last year's assessment.

In response to Team and SSC requests (comments JTS2 and SSC3), Figure 2A.1.1 shows locations of, and Pacific cod densities encountered by, three surveys (NMFS bottom trawl survey, NMFS longline survey, and IPHC longline survey), each overlaid against corresponding data from the observed fishery.

Model structures

Last year's final model, here labeled Model 0, was 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). The model is programmed using the ADMB software package (Fournier et al. 2012).

Model 0 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, Model 0 also requires an estimate of the natural mortality rate.

Model 0 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.

In addition to Model 0, four age-structured models are included in this preliminary assessment. All of these age-structured models were developed using Stock Synthesis (SS, Methot and Wetzel 2013). The version used to run all of the age-structured models was SS V3.24u, as compiled on 8/29/2014. Stock Synthesis is programmed using the ADMB software package (Fournier et al. 2012). The current SS user manual is available at: https://drive.google.com/a/noaa.gov/?tab=mo#folders/0Bz1UsDoLaOMLN2FiOTI3MWQtZDQwOS00YWZkLThmNmEtMTk2NTA2M2FjYWVh.

The structures of the four age-structured models span a 2×2 factorial design. The factors were:

- New features or methods based on experience with this year's preliminary assessment of the EBS Pacific cod stock (see "Models 2 and 5: main features" and "Models 2 and 5: iterative tuning").
- Historic fishery time series data from 1977-1990 (see "Data").

The four age-structured models are all based on Model 2 from last year's final assessment, and are numbered as followed:

Model 2. Incorporates the new features/methods; does not use the historic fishery data
Model 3. Does not incorporate the new features/methods; uses the historic fishery data
Model 4. Does not incorporate the new features/methods; does not use the historic fishery data
Model 5. Incorporates the new features/methods; uses the historic fishery data

Note that Model 4 is identical to Model 2 from last year's final assessment (see "Model 4: main features" and "Model 4: iterative tuning"); numbering of Models 2 and 3 follows comments JPT1 and SSC3.

Development of the final versions of all models included calculation of the Hessian matrix. All models also passed a "jitter" test of 50 runs. The jitter rate (equal to half the standard deviation of the logit-scale distribution from which initial values are drawn) was set at 0.1. In the event that a jitter run produced a better value for the objective function than the base run, then:

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

Except for selectivity parameters and *dev* vectors in Models 2-5 and annual catchability deviations in Model 5, all parameters were estimated with uniform prior distributions.

Models 3 and 4: main features

Models 3 and 4 are identical except for use (Model 3) or non-use (Model 4) of the pre-1991 fishery data. These models bear some similarities to the model that has been accepted for use in management of the EBS Pacific cod stock since 2011 (Thompson 2014). Some of the main differences between AI Models 3 and 4 and the 2011-2014 EBS model are as follow:

11. 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.
12. Each year consisted of a single season instead of five.
13. A single fishery was defined instead of nine season-and-gear-specific fisheries.
14. The survey was assumed to sample age 1 fish at true age 1.5 instead of 1.41667.
15. The standard deviation of log-scale age 0 recruitment (σ_R) was estimated internally instead of being estimated outside the model.
16. Log-scale survey catchability (ln(Q)) was estimated internally instead of being estimated outside the model, using a normal prior distribution with μ=0.00 and σ=0.11 (values of prior parameters were obtained by averaging the values of the prior parameters from other age-structured AI groundfish assessments).
17. Initial abundances were estimated for the first ten age groups instead of the first three.
18. 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.
19. 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.
20. 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).

Models 3 and 4: iterative tuning

For Models 3-4, the parameters described in this section were tuned most recently in last year's preliminary assessment (i.e., they were not re-tuned in last year's final assessment nor in this preliminary assessment).

Iterative tuning of prior distributions for selectivity parameters

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

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

Iterative tuning of time-varying selectivity parameters

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

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

The iteration was conducted separately for the fishery and survey.

It was common for some ages to be "tuned out" during the second loop (i.e., the σs converged on zero). For Models 3 and 4, all ages were tuned out except ages 4 and 6 for the fishery and ages 2, 3, and 7 for the survey.

Models 2 and 5: main features

Except for some procedures related to iterative tuning (see next section), the differences between Models 2 and 5 and Models 3 and 4 were as follow:

1. The standard deviation of log-scale age 0 recruitment (σ_R) was estimated iteratively instead of being estimated internally.
2. Richards growth was assumed instead of von Bertalanffy growth (a special case of Richards).
3. 20 age groups were estimated in the initial numbers-at-age vector instead of 10.
4. Survey catchability was allowed to vary annually if the root-mean-squared-standardized residual exceeded unity (this resulted in time-varying Q for Model 5 but not for Model 3).
5. Selectivity at ages 8+ was constrained to equal selectivity at age 7 for the fishery, and selectivity at ages 9+ was constrained to equal selectivity at age 8 for the survey.
6. A superfluous selectivity parameter was fixed at the mean of the prior (in Models 3 and 4, the estimate of this parameter automatically went to the mean of the prior).
7. Composition data were given a weight of unity if the harmonic mean of the effective sample size was greater than the mean input sample size of 300; otherwise, composition data were weighted by tuning the mean input sample size to the harmonic mean of the effective sample size.

Models 2 and 5: iterative tuning

A major difference between the iterative tuning procedures used in the two sets of models was that the procedures used for Models 3 and 4 were applied sequentially (i.e., to one group of tuning parameters at a time), whereas in Models 2 and 5 all iterative tunings were conducted simultaneously.

Iterative tuning of prior distributions for selectivity

Except for the difference noted above, iterative tuning of prior distributions for selectivity parameters in Models 2 and 5 proceeded as in Model 3 and 4.

Iterative tuning of selectivity and recruitment

For time-varying selectivity, the approach used in Models 3-4, which was based on the method of Thompson and Lauth (2012), was not retained in Models 2 and 5. For a univariate model, *if* the method of Thompson and Lauth (2012) returns a non-zero estimate of σ, there is reason to believe that this estimate will be unbiased. However, the method carries a fairly high probability of returning a "false negative;" that is, returning a zero estimate for σ when the true value is non-zero (Thompson in prep.). To reduce this bias toward under-parameterization, the following algorithm was used in Models 2 and 5 (Thompson in prep.; note that this is a multivariate generalization of one of the methods mentioned by Methot and Taylor (2011, *viz*., the third method listed on p. 1749)):

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

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

The same procedure was used for iterative tuning of σ_R.

Iterative tuning of time-varying catchability

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

Unlike the size composition or age composition data sets, the time series of survey abundance data includes not only a series of expected values, but a corresponding series of standard errors as well. This fact formed the basis for the iterative tuning of the σ term for time-varying *Q* in Models 2 and 5. The procedure involved iteratively adjusting σ until the root-mean-squared-standardized-residual for survey abundance equaled unity.

Parameters estimated outside the assessment model

Parameters estimated outside the assessment model were detailed in last year's final assessment (Thompson and Palsson 2014). For Model 0 (the Tier 5 random effects model), no parameters were estimated outside the model (however, an estimate of the natural mortality rate is required in order to use the results of Model 0 to specify OFL and ABC). For the age-structured models, the natural mortality rate *M* was fixed at 0.34, the proportionality constant in the weight-length relationship was fixed at a value of 5.68×10^{-6}, weight-length exponent was fixed at a value of 3.18, the standard deviations of the ageing error matrix extended linearly from a value of 0.093 at age 1 to a value of 1.860 at age 20, and the parameters of the logistic maturity-at-age relationship were set at values of $age_{50\%}$=4.883 years and slope=–0.965.

Parameters estimated inside the assessment model

Parameters estimated inside SS vary to some extent between the four models. Internally estimated parameters common to 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; *dev*s for log-scale initial abundance at ages 1 through 10; annual log-scale recruitment *devs*; initial (equilibrium) fishing mortality; base values for all fishery and survey selectivity parameters; annual fishery selectivity *dev*s at ages 4 and 6; and annual survey selectivity *dev*s at ages 2, 3, and 7. A complete list of estimated parameters is presented in the "Parameters, schedules, and time series estimates" subsection of the "Results" section.

Parameters estimated inside some models but not others include the Richards growth coefficient (Models 2 and 5), σ_R (Models 3 and 4), annual catchability deviations (Model 5), and additional fishery and survey selectivity *dev*s for various ages (Models 2 and 5). Also, the lengths of the recruitment and selectivity *dev* vectors are longer for those models that use the pre-1991 data (Models 3 and 5).

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 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 Wetzel 2013).

Objective function components

All four models include likelihood components for initial (equilibrium) catch, trawl survey relative abundance, fishery size composition, survey size composition, survey age composition, recruitment, “softbounds” (equivalent to an extremely weak prior distribution used to keep parameters from hitting bounds), and parameter deviations. In addition, all four models include an objective function component for prior distributions.

In SS, emphasis factors are specified to determine which objective function components receive the greatest weight during the parameter estimation process. All objective function components were given an emphasis of 1.0 in all models, except for the age composition component in Models 2 and 5.

Results

Overview

Model 0 estimates 2015 total biomass (under the assumption that survey biomass represents total biomass) at a value of 68,880 t, about 75% of the estimated time series average.

The following table summarizes the status of the stock as estimated by the four age-structured models (“Value” is the point estimate, “SD” is the standard deviation of the point estimate, “FSB 2015” is female spawning biomass in 2015 (t), and “Bratio 2015” is the ratio of FSB 2015 to $B_{100\%}$):

	Model 2		Model 3		Model 4		Model 5	
Quantity	Value	SD	Value	SD	Value	SD	Value	SD
FSB 2015	69,931	10,219	95,654	25,010	58,459	8,764	61,293	9,838
Bratio 2015	0.514	0.044	0.577	0.081	0.452	0.046	0.397	0.046

The four models span wide ranges for these quantities. Estimates of FSB 2015 range from 58,000 t (Model 4) to 96,000 t (Model 3), and estimates of Bratio 2015 range from 0.397 (Model 5) to 0.577 (Model 3).

Goodness of Fit (Model 0)

Statistics related to Model 0’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

Figure 2A.1.2a shows the fit of Model 0 to the trawl survey biomass data (note that the age-structured models use numbers of fish as the survey index, while Model 0 uses biomass).

Goodness of fit (Models 2-5)

Objective function values and parameter counts are shown for Models 2-5 in Table 2A.1.2. Objective function values are not directly comparable across models, because different data files are used for some models, different constraints are imposed, and the number and types of parameters vary considerably.

Figure 2A.1.2b shows the fits of the four models to the trawl survey abundance data.

Four measures of goodness of fit for the survey abundance data are shown in the table below: root mean squared error (for comparison, the average log-scale standard error in the data is 0.180), mean normalized residual, standard deviation of normalized residuals, and correlation (observed:estimated).

Statistic	Model 2	Model 3	Model 4	Model 5
Correlation (observed:expected)	0.96	0.88	0.95	0.98
Root mean squared error	0.15	0.21	0.17	0.17
Mean normalized residual	-0.51	0.05	1.09	-0.60
Standard deviation of normalized residuals	0.99	1.03	1.09	1.00

Sample size ratios for the size composition data are shown below (Nrec = number of records, Ninp = input sample size, Neff = effective sample size, A(·) = arithmetic mean, H(·) = harmonic mean):

Model	Fleet	Nrec	A(Ninp)	A(Neff/Ninp)	A(Neff)/A(Ninp)	H(Neff)/A(Ninp)
2	Fishery	24	300	17.12	15.22	11.27
3	Fishery	31	300	16.24	13.04	4.82
4	Fishery	24	300	15.32	14.62	8.77
5	Fishery	31	300	18.32	16.63	4.61
2	Survey	10	300	3.99	3.59	2.17
3	Survey	10	300	3.97	3.53	2.30
4	Survey	10	300	3.96	3.50	2.29
5	Survey	10	300	4.38	3.87	2.27

Sample size ratios for the age composition data are shown below (shading indicates models for which the arithmetic mean input sample size was adjusted during the iterative tuning process):

Model	Fleet	Nrec	A(Ninp)	A(Neff/Ninp)	A(Neff)/A(Ninp)	H(Neff)/A(Ninp)
2	Survey	2	182	1.35	1.31	1.00
3	Survey	2	300	0.65	0.64	0.51
4	Survey	2	300	1.08	1.05	0.79
5	Survey	2	175	1.46	1.41	1.00

Parameters, schedules, and time series estimates

Table 2A.1.3 lists all the parameters estimated internally in at least one of the four models, along with their standard deviations. Table 2A.1.3 consists of the following parts:

- Table 2A.1.3a: scalar parameters
- Table 2A.1.3b: initial age structure *dev*s
- Table 2A.1.3c: recruitment *dev*s

- Table 2A.1.3d: ln(*Q*) deviations
- Table 2A.1.3e: base selectivity parameters
- Table 2A.1.3f: fishery selectivity *dev*s
- Table 2A.1.3g: survey selectivity *dev*s

As noted previously, SS treats fishing mortality rates somewhat differently from other parameters. Estimates of full-selection fishing mortality rates and their corresponding standard deviations are listed in Table 2A.1.4.

Table 2A.1.5 lists all the parameters involved in iterative tuning.

Selectivity schedules are plotted in Figures 2A.1.3 (fishery) and 2A.1.4 (survey).

Time series estimated by the four models are shown for total biomass, female spawning biomass relative to $B_{100\%}$, and age 0 recruitment in Figures 2A.1.5, 2A.1.6, and 2A.1.7, respectively.

Other diagnostics

Figure 2A.1.8 shows 10-year retrospectives of spawning biomass for each of the four models. Mohn's rho (revised) values for the four models are as shown below:

Model 2	Model 3	Model 4	Model 5
-0.300	-0.037	-0.391	-0.400

Discussion

The models presented here span a wide range of structures, and in many cases the estimates produced by the models are similarly wide ranging. For example, as reported in the "Overview" subsection of the "Results" section, the four age-structured models span wide ranges for these quantities. Estimates of FSB 2015 range from 58,000 t (Model 4) to 96,000 t (Model 3), and estimates of Bratio 2015 range from 0.397 (Model 5) to 0.577 (Model 3). The survey catchability coefficient was estimated at values of 0.65-0.67 in Models 2, 4, and 5, while Model 3 provided a considerably higher estimate of 0.93.

Depending on the goodness-of-fit measure used, all of the age-structured models could be judged to provide fairly good fits to the survey abundance data. All four models resulted in root mean squared errors fairly close to the mean standard error in the data, and gave standard deviations for the normalized residuals close to unity. All but Model 3 had mean normalized residuals far from zero, however.

All of the age-structured models provided good-to-excellent fits to the size composition data. By any of the measures shown, Models 2 and 5 fit the age composition data well, but Model 3 did not, and Model 4's acceptability depends on which goodness-of-fit measure is used. Note that Models 2 and 5 tune the arithmetic mean input sample size to match the harmonic mean effective sample size (in the case of age composition data).

Appropriate weighting of composition data remains an issue in contemporary stock assessments (Maunder and Piner 2015). Two different procedures were used in this preliminary assessment:

1. Fix the mean input sample size at a value of 300, unless the *arithmetic* mean effective sample size is less than the mean input sample size, in which case tune the mean input sample size to the *arithmetic* mean effective sample size (Models 3 and 4).

2. Fix the mean input sample size at a value of 300, unless the *harmonic* mean effective sample size is less than the mean input sample size, in which case tune the mean input sample size to the *harmonic* mean effective sample size (Models 2 and 5).

Based on Mohn's rho (revised), the retrospective performance of all age-structured models except Model 3 was questionable.

All of the age-structured models used SS selectivity-at-age pattern #17 (random walk with age). As noted in last year's assessment, 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).

All of the age-structured models emphasized the potential time-variability of both fishery and survey selectivity, and Model 5 allowed time-variability in survey catchability as well. 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 (or at least fishery selectivity) to vary over time. However, specification of the input standard deviations for *dev* vectors remains a difficult problem; Maunder and Piner (2015) list this as one of the outstanding problems in contemporary fisheries stock assessment. Models 3 and 4 use the method of Thompson and Lauth (2012), but this approach is tedious when more than one parameter is time-varying, and is also prone to false negatives (Thompson in prep.). Models 2 and 5 use an approach that appears to perform well in multivariate linear-normal models, but its performance in stock assessment models has not been thoroughly evaluated (Thompson in prep.).

Model 3's estimated survey selectivity schedule is very difficult to rationalize (Figure 2A.1.4), and suggests that it is unwise to leave selectivity parameters free at ages rarely encountered (this is why selectivities at older ages were fixed in Models 2 and 5).

Models 2, 4, and 5 tend to estimate extremely "pointy" survey selectivity (Figure 2A.1.4). Coupled with estimates of catchability well below unity (except for Model 3), this feature results in estimates of total biomass for all of the age-structured models that are vastly greater than the biomasses estimated by the survey. For example, the average value of the ratio between total biomass (as estimated by the respective model) and survey biomass is shown below for each model:

Model 2	Model 3	Model 4	Model 5
3.40	4.68	3.31	3.72

Another issue to consider is whether the attempt at restoring the pre-1991 fishery data in this preliminary assessment (Models 3 and 5) was successful. When these data were last included (in the 2013 assessment), the results showed very low biomasses at the start of the time series, accompanied by extremely high fishing mortality rates—a combination which did not seem reasonable. Here, however, different patterns were obtained. For the start of the time series, both Models 3 and 5 estimated biomasses at the start of the time series that were roughly comparable to present levels, accompanied by very low fishing mortality rates. This improvement may be due to allowing for greater time-variability in selectivity in Models 3 and 5 than was the case in the 2013 models. If the pre-1991 fishery data are to be included in future models, it may also be appropriate to consider including a "regime shift" parameter, as has been done for many years in the EBS Pacific cod model, to account for lower expected recruitment in the pre-1977 regime.

Finally, determinations need to be made as to whether Figure 2A.1.1 indicates that the NMFS trawl survey is missing significant areas of high fishing effort, and whether any such gaps would be filled by including the AFSC or IPHC longline surveys as additional data sources.

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Tables

Table 2A.1.1—Fishery size compositions (cm) from years prior to 1991.

Year	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
1978	0	0	1	0	0	0	0	0	2	0	0	2	1	1	5	3	7	4	9	18	26	29	39
1979	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	1	1	4	2	8
1982	0	0	0	1	0	0	0	0	0	0	5	4	2	6	7	7	9	15	19	14	26	31	50
1983	2	1	2	5	8	6	16	16	23	25	45	70	64	68	66	60	58	69	86	103	130	138	149
1984	0	0	1	0	2	0	0	1	2	2	7	12	13	17	31	28	21	22	6	6	9	15	27
1985	0	0	0	0	0	0	0	0	0	0	0	3	1	1	7	12	25	21	37	61	58	74	75
1990	0	0	0	0	0	0	0	0	1	0	1	0	1	1	4	2	5	7	15	17	11	8	9

Year	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69
1978	35	41	39	46	38	25	25	27	32	31	32	44	26	46	44	42	51	59	72	58	69	73	62
1979	10	9	26	25	28	40	47	60	62	71	81	82	84	71	79	64	67	54	52	53	53	44	57
1982	56	57	67	100	98	110	125	112	151	149	155	146	154	180	207	144	166	173	151	155	122	131	126
1983	181	170	171	191	182	182	143	133	146	127	121	123	118	115	116	127	101	107	82	74	78	66	72
1984	27	36	61	73	94	136	145	186	191	186	183	195	164	161	161	138	150	178	154	201	155	175	166
1985	68	85	85	63	60	36	37	32	35	49	52	59	73	96	85	120	122	131	142	136	147	129	103
1990	11	9	16	19	31	52	24	41	35	63	33	39	67	50	70	75	105	128	167	179	174	158	157

Year	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92
1978	71	62	48	51	47	45	50	45	25	18	28	20	12	9	8	8	3	4	1	2	4	2	0
1979	59	40	62	54	51	31	42	35	35	22	25	27	13	10	15	9	7	13	5	2	0	4	4
1982	106	116	77	86	89	67	60	64	52	47	32	41	51	41	32	37	32	22	24	20	27	17	6
1983	70	66	65	52	55	60	46	58	45	48	37	35	20	17	22	21	14	17	28	14	20	19	18
1984	144	157	143	117	116	111	73	90	84	79	78	61	59	59	55	52	36	52	48	37	48	25	33
1985	118	73	75	56	51	48	58	37	45	50	43	29	34	35	35	39	34	37	35	33	44	51	27
1990	168	140	170	113	132	162	155	122	150	153	140	106	85	92	82	64	58	55	40	55	38	21	13

Year	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115+
1978	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1979	1	2	4	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
1982	10	12	6	3	6	4	3	0	4	3	3	2	0	2	1	1	0	0	0	0	0	0	0
1983	11	12	20	4	4	3	6	9	4	4	2	2	3	0	1	0	1	0	1	0	0	0	2
1984	33	28	26	22	17	31	21	18	17	12	9	14	7	7	4	1	1	1	0	0	0	1	0
1985	23	24	27	28	9	9	21	10	15	6	6	3	1	9	0	0	0	0	3	0	0	0	1
1990	28	15	11	8	9	7	10	5	8	1	2	0	1	2	0	0	0	0	0	0	0	0	0

Table 2A.1.2—Objective function components and parameter counts for Models 2-5.

Obj. func. component	Model 2	Model 3	Model 4	Model 5
Equilibrium catch	0.000	0.000	0.001	0.000
Survey abundance index	-12.647	-12.231	-11.619	-12.496
Fishery size composition	93.254	127.750	102.218	110.742
Survey size composition	212.719	208.823	211.073	206.992
Age composition	9.462	21.218	11.519	10.188
Recruitment	-19.306	-12.688	-4.511	-15.839
Priors	8.171	9.971	17.680	9.577
"Softbounds"	0.000	0.001	0.001	0.000
Deviations	31.611	16.809	12.039	43.694
Total	323.265	359.652	338.400	352.860

Parameter counts	Model 2	Model 3	Model 4	Model 5
Unconstrained parameters	10	10	10	10
Parameters with priors	14	41	41	24
Constrained deviations	330	192	152	409
Total	354	243	203	443

Table 2A.1.3a—Scalar parameters estimated by at least one of the four age-structured models. A blank indicates that the parameter (row) was not used in that model (column). A "_" symbol under St. dev. indicates that the parameter (row) was fixed (not estimated) in that model (column).

	Model 2		Model 3		Model 4		Model 5	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
Length at age 1 (cm)	1.82E+01	2.01E-01	1.80E+01	1.93E-01	1.80E+01	1.93E-01	1.82E+01	2.03E-01
Asymptotic length (cm)	1.05E+02	1.20E+00	1.05E+02	1.40E+00	1.10E+02	1.91E+00	1.05E+02	1.13E+00
Brody growth coefficient	2.96E-01	2.01E-02	2.30E-01	6.11E-03	2.17E-01	6.94E-03	2.77E-01	1.73E-02
Richards growth coefficient	6.41E-01	8.32E-02					7.34E-01	7.58E-02
SD of length at age 1 (cm)	3.20E+00	1.42E-01	3.17E+00	1.36E-01	3.16E+00	1.37E-01	3.25E+00	1.42E-01
SD of length at age 20 (cm)	7.77E+00	3.79E-01	7.78E+00	3.38E-01	8.11E+00	4.03E-01	7.59E+00	3.41E-01
Ageing bias at age 1 (years)	4.78E-01	4.10E-02	4.87E-01	2.88E-02	4.81E-01	3.14E-02	4.78E-01	4.12E-02
Ageing bias at age 20 (years)	1.49E+00	4.82E-01	6.60E-01	5.05E-01	1.14E+00	4.41E-01	1.41E+00	4.98E-01
ln(mean post-1976 recruitment)	1.10E+01	8.29E-02	1.13E+01	1.77E-01	1.10E+01	8.13E-02	1.12E+01	1.00E-01
SigmaR	4.18E-01	_	4.61E-01	6.38E-02	4.94E-01	6.73E-02	5.65E-01	_
Initial F (fishery)	2.82E-02	6.20E-03	3.20E-02	1.10E-02	4.24E-02	1.06E-02	2.11E-02	2.78E-03
ln(trawl survey catchability)	-4.06E-01	8.71E-02	-7.61E-02	1.09E-01	-4.35E-01	8.67E-02	-4.15E-01	8.72E-02

Table 2A.1.3b—Initial age structure *dev*s for Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
Initial age 1 ln(abundance) dev	3.12E-01	1.42E-01	-3.49E-01	3.85E-01	2.83E-01	1.74E-01	-5.24E-01	4.17E-01
Initial age 2 ln(abundance) dev	6.29E-01	1.49E-01	-1.42E-01	3.62E-01	1.03E+00	1.48E-01	-4.54E-02	3.78E-01
Initial age 3 ln(abundance) dev	4.31E-02	1.54E-01	-3.14E-01	3.69E-01	-1.74E-01	1.84E-01	-2.54E-01	4.14E-01
Initial age 4 ln(abundance) dev	6.21E-01	1.48E-01	-1.31E-01	3.85E-01	4.90E-01	1.69E-01	-3.37E-01	4.49E-01
Initial age 5 ln(abundance) dev	8.63E-01	1.97E-01	-2.14E-01	4.21E-01	1.13E+00	1.98E-01	-4.82E-01	4.65E-01
Initial age 6 ln(abundance) dev	7.29E-01	2.96E-01	-2.06E-01	4.23E-01	8.69E-01	3.27E-01	-4.31E-01	4.79E-01
Initial age 7 ln(abundance) dev	-1.17E-01	3.85E-01	-1.79E-01	4.28E-01	7.77E-03	4.36E-01	-3.66E-01	4.89E-01
Initial age 8 ln(abundance) dev	-3.28E-01	3.61E-01	-1.46E-01	4.34E-01	-4.99E-01	4.05E-01	-2.94E-01	5.01E-01
Initial age 9 ln(abundance) dev	-4.00E-01	3.55E-01	-1.19E-01	4.38E-01	-6.91E-01	3.93E-01	-2.27E-01	5.13E-01
Initial age 10 ln(abundance) dev	-3.97E-01	3.57E-01	-9.42E-02	4.43E-01	-7.35E-01	3.91E-01	-1.71E-01	5.24E-01
Initial age 11 ln(abundance) dev	-3.57E-01	3.62E-01					-1.27E-01	5.33E-01
Initial age 12 ln(abundance) dev	-3.03E-01	3.69E-01					-9.26E-02	5.41E-01
Initial age 13 ln(abundance) dev	-2.45E-01	3.76E-01					-6.68E-02	5.47E-01
Initial age 14 ln(abundance) dev	-1.93E-01	3.84E-01					-4.78E-02	5.52E-01
Initial age 15 ln(abundance) dev	-1.47E-01	3.91E-01					-3.39E-02	5.56E-01
Initial age 16 ln(abundance) dev	-1.10E-01	3.97E-01					-2.40E-02	5.58E-01
Initial age 17 ln(abundance) dev	-8.08E-02	4.02E-01					-1.69E-02	5.60E-01
Initial age 18 ln(abundance) dev	-5.86E-02	4.06E-01					-1.19E-02	5.62E-01
Initial age 19 ln(abundance) dev	-4.21E-02	4.10E-01					-8.33E-03	5.63E-01
Initial age 20 ln(abundance) dev	-9.25E-02	4.00E-01					-1.91E-02	5.60E-01

Table 2A.1.3c—Log-scale age 0 recruitment *dev*s as estimated by Models 2-5. Shading in each column extends from red (low) to green (high).

	Model 2		Model 3		Model 4		Model 5	
Year	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
1977			-5.84E-01	3.48E-01			-6.50E-01	4.19E-01
1978			-4.99E-01	3.09E-01			-1.99E-01	3.28E-01
1979			-6.30E-01	2.96E-01			-4.10E-01	3.23E-01
1980			-5.14E-01	2.88E-01			5.36E-02	2.92E-01
1981			-4.12E-01	3.28E-01			-5.26E-02	3.27E-01
1982			-3.19E-01	3.59E-01			-1.61E-01	3.86E-01
1983			-1.80E-01	4.15E-01			-3.25E-01	4.85E-01
1984			3.54E-01	4.88E-01			6.51E-02	5.34E-01
1985			1.13E+00	2.86E-01			1.22E+00	2.48E-01
1986			8.98E-01	2.31E-01			8.17E-01	2.03E-01
1987			4.73E-01	1.69E-01			7.01E-01	1.52E-01
1988			-3.21E-01	1.82E-01			-1.29E-02	1.72E-01
1989			9.64E-01	1.45E-01			7.75E-01	1.53E-01
1990			1.77E-01	1.73E-01			2.72E-01	1.55E-01
1991	2.00E-01	1.40E-01	1.54E-01	1.43E-01	2.51E-01	1.40E-01	2.01E-01	1.50E-01
1992	-1.29E-01	1.81E-01	-2.76E-01	2.21E-01	-2.51E-01	2.21E-01	-1.88E-01	2.12E-01
1993	5.39E-01	1.11E-01	9.25E-01	1.22E-01	7.78E-01	1.24E-01	6.18E-01	1.13E-01
1994	-1.73E-02	1.37E-01	-1.97E-01	1.63E-01	-1.32E-01	1.51E-01	-1.51E-01	1.58E-01
1995	3.40E-01	1.50E-01	5.17E-01	1.52E-01	4.26E-01	1.58E-01	4.75E-01	1.72E-01
1996	8.18E-01	1.06E-01	8.91E-01	1.17E-01	8.85E-01	1.19E-01	9.37E-01	1.17E-01
1997	7.07E-01	1.10E-01	4.82E-01	1.28E-01	6.45E-01	1.12E-01	6.46E-01	1.28E-01
1998	-2.50E-01	1.53E-01	-3.27E-02	1.84E-01	6.20E-02	1.81E-01	-9.15E-02	1.91E-01
1999	4.87E-01	1.16E-01	5.48E-01	1.41E-01	7.93E-01	1.17E-01	6.80E-01	1.34E-01
2000	1.12E-01	1.30E-01	-5.20E-02	1.68E-01	6.62E-02	1.52E-01	-2.97E-01	1.48E-01
2001	-1.13E-01	1.23E-01	-3.37E-01	1.54E-01	-1.24E-01	1.29E-01	-2.92E-01	1.43E-01
2002	-5.31E-01	1.39E-01	-6.21E-01	1.64E-01	-5.25E-01	1.53E-01	-7.11E-01	1.61E-01
2003	-2.39E-01	1.20E-01	-3.31E-01	1.49E-01	-2.04E-01	1.33E-01	-3.96E-01	1.41E-01
2004	-5.60E-01	1.65E-01	-5.12E-01	1.75E-01	-5.33E-01	1.76E-01	-6.62E-01	1.94E-01
2005	-4.59E-02	1.36E-01	-9.01E-02	1.70E-01	-1.57E-01	1.51E-01	-2.10E-01	1.63E-01
2006	-3.00E-01	1.23E-01	5.06E-04	1.52E-01	-1.87E-01	1.28E-01	-4.08E-01	1.48E-01
2007	3.46E-01	1.16E-01	3.13E-01	1.29E-01	2.45E-01	1.08E-01	1.66E-01	1.41E-01
2008	-8.19E-02	1.28E-01	4.64E-02	1.75E-01	-1.22E-01	1.36E-01	-2.16E-01	1.55E-01
2009	-6.15E-01	1.67E-01	-7.26E-01	2.22E-01	-7.19E-01	1.85E-01	-8.54E-01	1.98E-01
2010	-2.22E-01	1.56E-01	-1.70E-01	2.58E-01	-1.60E-01	1.74E-01	-3.57E-01	1.85E-01
2011	-3.06E-01	1.80E-01	-6.18E-01	2.67E-01	-4.91E-01	1.94E-01	-5.74E-01	2.13E-01
2012	-2.08E-01	3.16E-01	-2.84E-01	3.40E-01	-3.32E-01	3.51E-01	-3.81E-01	4.04E-01
2013	6.85E-02	3.35E-01	-1.62E-01	3.54E-01	-2.13E-01	3.68E-01	-2.89E-02	4.30E-01

Table 2A.1.3d—Annual log-scale survey catchability (*Q*) deviations as estimated by Model 5 (Models 2-4 did not use catchability deviations).

	Model 2		Model 3		Model 4		Model 5	
Year	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
1991	0	_	0	_	0	_	-1.25E-02	8.11E-02
1994	0	_	0	_	0	_	-9.50E-03	8.23E-02
1997	0	_	0	_	0	_	-1.01E-01	7.82E-02
2000	0	_	0	_	0	_	-1.63E-02	8.04E-02
2002	0	_	0	_	0	_	-8.59E-02	8.00E-02
2004	0	_	0	_	0	_	-6.14E-04	7.77E-02
2006	0	_	0	_	0	_	6.76E-03	7.93E-02
2010	0	_	0	_	0	_	-7.65E-04	7.85E-02
2012	0	_	0	_	0	_	3.61E-03	7.87E-02
2014	0	_	0	_	0	_	2.26E-02	8.09E-02

Table 2A.1.3e—Base selectivity parameters as estimated by Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
Fishery age 1	3.97E+00	_	3.29E+00	3.42E-01	3.29E+00	3.42E-01	3.97E+00	_
Fishery age 2	4.18E+00	6.62E-01	3.46E+00	3.11E-01	3.41E+00	3.18E-01	4.26E+00	6.35E-01
Fishery age 3	3.38E+00	2.32E-01	3.15E+00	1.67E-01	3.22E+00	1.86E-01	3.20E+00	2.25E-01
Fishery age 4	1.17E+00	1.13E-01	1.17E+00	1.68E-01	1.23E+00	1.80E-01	1.10E+00	1.26E-01
Fishery age 5	4.27E-01	1.08E-01	2.51E-01	1.08E-01	3.34E-01	1.13E-01	2.98E-01	1.27E-01
Fishery age 6	1.05E-01	1.53E-01	4.56E-02	2.73E-01	1.49E-01	2.84E-01	9.95E-02	1.41E-01
Fishery age 7	3.87E-02	1.62E-01	-1.21E-01	1.87E-01	-1.01E-01	1.97E-01	-1.19E-01	1.65E-01
Fishery age 8	0.00E+00	_	-1.01E-01	2.46E-01	6.94E-02	2.53E-01	0.00E+00	_
Fishery age 9	0.00E+00	_	-3.53E-02	2.71E-01	1.71E-01	2.70E-01	0.00E+00	_
Fishery age 10	0.00E+00	_	3.37E-01	2.90E-01	2.72E-01	2.90E-01	0.00E+00	_
Fishery age 11	0.00E+00	_	3.11E-01	2.91E-01	4.68E-02	3.28E-01	0.00E+00	_
Fishery age 12	0.00E+00	_	2.30E-01	3.00E-01	-3.03E-01	3.52E-01	0.00E+00	_
Fishery age 13	0.00E+00	_	-2.53E-02	3.19E-01	-4.78E-01	3.18E-01	0.00E+00	_
Fishery age 14	0.00E+00	_	5.17E-02	3.43E-01	-3.56E-01	3.18E-01	0.00E+00	_
Fishery age 15	0.00E+00	_	-2.90E-03	3.42E-01	-2.49E-01	3.23E-01	0.00E+00	_
Fishery age 16	0.00E+00	_	-1.29E-01	3.27E-01	-2.09E-01	3.24E-01	0.00E+00	_
Fishery age 17	0.00E+00	_	-1.33E-01	3.26E-01	-1.60E-01	3.27E-01	0.00E+00	_
Fishery age 18	0.00E+00	_	-1.07E-01	3.28E-01	-1.19E-01	3.29E-01	0.00E+00	_
Fishery age 19	0.00E+00	_	-6.81E-02	3.32E-01	-8.45E-02	3.32E-01	0.00E+00	_
Fishery age 20	0.00E+00	_	-6.00E-02	3.33E-01	-6.52E-02	3.34E-01	0.00E+00	_
Survey age 1	1.48E+00	_	5.29E+00	3.19E-01	5.29E+00	3.19E-01	1.53E+00	_
Survey age 2	1.16E+00	3.48E-01	9.41E-01	2.65E-01	9.46E-01	2.67E-01	1.20E+00	3.71E-01
Survey age 3	1.05E+00	2.48E-01	7.04E-01	2.10E-01	6.55E-01	2.10E-01	1.04E+00	2.93E-01
Survey age 4	5.50E-01	1.06E-01	2.75E-01	1.13E-01	4.47E-01	1.06E-01	4.41E-01	1.15E-01
Survey age 5	-5.87E-01	1.71E-01	-2.62E-01	1.37E-01	-4.33E-01	1.26E-01	-4.85E-01	1.68E-01
Survey age 6	-4.00E-02	2.76E-01	-2.54E-01	2.16E-01	-2.68E-01	2.18E-01	-1.83E-01	2.77E-01
Survey age 7	-2.29E-01	3.94E-01	-9.53E-03	3.11E-01	1.23E-02	3.11E-01	-1.02E-01	3.79E-01
Survey age 8	-5.72E-01	3.45E-01	-5.62E-02	2.85E-01	-3.14E-01	2.36E-01	-5.95E-01	3.14E-01
Survey age 9	0.00E+00	_	-6.46E-02	2.85E-01	-3.03E-01	2.69E-01	0.00E+00	_
Survey age 10	0.00E+00	_	-2.26E-01	2.82E-01	-1.79E-01	2.89E-01	0.00E+00	_
Survey age 11	0.00E+00	_	-2.00E-01	2.84E-01	-1.92E-01	2.98E-01	0.00E+00	_
Survey age 12	0.00E+00	_	-3.91E-02	2.89E-01	-2.00E-01	3.03E-01	0.00E+00	_
Survey age 13	0.00E+00	_	5.64E-02	2.91E-01	-1.65E-01	3.04E-01	0.00E+00	_
Survey age 14	0.00E+00	_	1.56E-01	2.94E-01	-1.26E-01	3.07E-01	0.00E+00	_
Survey age 15	0.00E+00	_	2.14E-01	2.95E-01	-1.03E-01	3.09E-01	0.00E+00	_
Survey age 16	0.00E+00	_	2.68E-01	2.96E-01	-7.81E-02	3.10E-01	0.00E+00	_
Survey age 17	0.00E+00	_	3.21E-01	2.96E-01	-5.32E-02	3.13E-01	0.00E+00	_
Survey age 18	0.00E+00	_	3.73E-01	2.96E-01	-3.69E-02	3.14E-01	0.00E+00	_
Survey age 19	0.00E+00	_	4.10E-01	2.95E-01	-2.59E-02	3.16E-01	0.00E+00	_
Survey age 20	0.00E+00	_	4.73E-01	2.93E-01	-1.86E-02	3.16E-01	0.00E+00	_

Table 2A.1.3f (page 1 of 5)—Annual fishery selectivity *dev*s as estimated by Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
Age_3_Fishery_1978							-3.89E-05	5.94E-01
Age_3_Fishery_1979							1.97E-02	5.92E-01
Age_3_Fishery_1980							2.40E-05	6.00E-01
Age_3_Fishery_1981							-5.90E-05	6.00E-01
Age_3_Fishery_1982							1.01E-01	5.62E-01
Age_3_Fishery_1983							-6.70E-01	5.33E-01
Age_3_Fishery_1984							-8.62E-02	5.80E-01
Age_3_Fishery_1985							1.44E-02	5.89E-01
Age_3_Fishery_1986							1.53E-04	6.00E-01
Age_3_Fishery_1987							1.40E-03	6.00E-01
Age_3_Fishery_1988							3.15E-04	6.00E-01
Age_3_Fishery_1989							1.57E-04	6.00E-01
Age_3_Fishery_1990							6.41E-03	5.95E-01
Age_3_Fishery_1991	6.79E-03	2.95E-01					5.78E-02	5.50E-01
Age_3_Fishery_1992	8.15E-02	2.85E-01					2.77E-01	5.04E-01
Age_3_Fishery_1993	3.46E-02	2.88E-01					2.01E-01	4.98E-01
Age_3_Fishery_1994	9.91E-03	2.95E-01					5.14E-02	5.53E-01
Age_3_Fishery_1995	-2.14E-01	2.89E-01					-6.97E-01	4.74E-01
Age_3_Fishery_1996	-1.18E-02	2.93E-01					-7.70E-02	5.45E-01
Age_3_Fishery_1997	9.32E-03	2.94E-01					1.03E-01	5.38E-01
Age_3_Fishery_1998	-1.18E-02	2.74E-01					5.40E-02	4.25E-01
Age_3_Fishery_1999	3.68E-02	2.84E-01					9.56E-02	4.90E-01
Age_3_Fishery_2000	5.05E-04	2.92E-01					9.14E-02	5.11E-01
Age_3_Fishery_2001	1.59E-01	2.65E-01					5.47E-01	4.12E-01
Age_3_Fishery_2002	-1.06E-01	2.97E-01					-5.39E-01	5.74E-01
Age_3_Fishery_2003	-6.95E-02	2.93E-01					-1.86E-01	5.01E-01
Age_3_Fishery_2004	-1.83E-01	2.98E-01					-6.58E-01	4.89E-01
Age_3_Fishery_2005	2.36E-02	2.91E-01					1.42E-01	5.23E-01
Age_3_Fishery_2006	3.87E-02	2.92E-01					1.87E-01	5.32E-01
Age_3_Fishery_2007	-1.89E-02	2.87E-01					-7.73E-02	4.94E-01
Age_3_Fishery_2008	5.14E-02	2.88E-01					2.49E-01	5.04E-01
Age_3_Fishery_2009	1.63E-02	2.86E-01					6.35E-02	4.93E-01
Age_3_Fishery_2010	4.95E-02	2.85E-01					2.45E-01	4.88E-01
Age_3_Fishery_2011	1.86E-02	2.97E-01					8.61E-02	5.75E-01
Age_3_Fishery_2012	1.48E-02	2.96E-01					6.02E-02	5.62E-01
Age_3_Fishery_2013	1.90E-02	2.96E-01					8.54E-02	5.70E-01
Age_3_Fishery_2014	1.13E-02	2.98E-01					6.45E-02	5.77E-01

Table 2A.1.3f (page 2 of 5)—Annual fishery selectivity *dev*s as estimated by Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
Age_4_Fishery_1978			-2.28E-02	6.53E-02			-1.81E-01	4.58E-01
Age_4_Fishery_1979			1.26E-02	7.45E-02			-9.26E-02	4.90E-01
Age_4_Fishery_1980			-7.12E-04	9.23E-02			-1.66E-03	5.20E-01
Age_4_Fishery_1981			-6.91E-04	9.23E-02			2.58E-03	5.19E-01
Age_4_Fishery_1982			-2.29E-02	5.76E-02			-1.74E-01	4.25E-01
Age_4_Fishery_1983			-1.60E-01	4.83E-02			-9.46E-01	3.92E-01
Age_4_Fishery_1984			1.46E-02	5.65E-02			-4.89E-02	4.20E-01
Age_4_Fishery_1985			-2.47E-02	5.75E-02			-3.30E-01	4.35E-01
Age_4_Fishery_1986			1.24E-03	9.15E-02			9.25E-04	5.20E-01
Age_4_Fishery_1987			4.01E-03	9.05E-02			9.34E-03	5.18E-01
Age_4_Fishery_1988			3.49E-03	9.07E-02			1.15E-02	5.18E-01
Age_4_Fishery_1989			1.68E-03	9.13E-02			4.08E-03	5.19E-01
Age_4_Fishery_1990			2.40E-02	6.75E-02			1.72E-01	4.42E-01
Age_4_Fishery_1991	9.50E-02	3.08E-01	-2.85E-03	5.15E-02	-4.21E-04	5.37E-02	6.09E-02	3.91E-01
Age_4_Fishery_1992	2.42E-01	2.36E-01	8.21E-02	3.06E-02	7.77E-02	3.19E-02	4.25E-01	2.94E-01
Age_4_Fishery_1993	-3.83E-01	2.50E-01	-7.06E-02	3.42E-02	-7.31E-02	3.59E-02	-5.35E-01	2.98E-01
Age_4_Fishery_1994	7.63E-02	2.72E-01	-5.72E-05	3.66E-02	-9.90E-03	3.90E-02	2.59E-01	3.24E-01
Age_4_Fishery_1995	6.62E-02	2.90E-01	-8.46E-05	4.36E-02	-8.12E-03	4.65E-02	1.63E-01	3.65E-01
Age_4_Fishery_1996	3.20E-01	2.51E-01	9.81E-02	3.39E-02	7.04E-02	3.51E-02	6.15E-01	3.13E-01
Age_4_Fishery_1997	-4.80E-02	2.98E-01	-3.44E-02	4.77E-02	-2.94E-02	4.99E-02	-1.32E-01	3.63E-01
Age_4_Fishery_1998	-4.13E-02	2.36E-01	-8.84E-03	2.78E-02	-1.50E-02	2.93E-02	1.96E-01	2.97E-01
Age_4_Fishery_1999	2.64E-01	2.27E-01	2.60E-02	2.97E-02	3.30E-02	3.11E-02	3.34E-01	2.77E-01
Age_4_Fishery_2000	-3.73E-02	2.14E-01	-2.68E-02	2.58E-02	-1.35E-02	2.75E-02	-1.94E-01	2.44E-01
Age_4_Fishery_2001	-7.48E-01	2.28E-01	-6.26E-02	2.73E-02	-6.62E-02	2.89E-02	-5.82E-01	2.84E-01
Age_4_Fishery_2002	3.54E-02	2.54E-01	-9.11E-03	3.44E-02	6.27E-03	3.61E-02	1.57E-02	3.21E-01
Age_4_Fishery_2003	-4.24E-01	2.55E-01	-1.05E-01	3.39E-02	-1.17E-01	3.67E-02	-9.46E-01	2.97E-01
Age_4_Fishery_2004	-4.66E-01	2.42E-01	-9.06E-02	2.91E-02	-1.02E-01	3.10E-02	-3.19E-01	2.88E-01
Age_4_Fishery_2005	-7.74E-02	2.76E-01	-4.97E-03	3.80E-02	-1.93E-02	4.07E-02	2.95E-02	3.29E-01
Age_4_Fishery_2006	1.86E-01	2.60E-01	4.21E-02	3.51E-02	2.74E-02	3.72E-02	5.00E-01	3.10E-01
Age_4_Fishery_2007	2.09E-01	2.68E-01	5.58E-02	3.78E-02	3.37E-02	4.02E-02	4.70E-01	3.26E-01
Age_4_Fishery_2008	-2.92E-03	2.48E-01	1.83E-03	3.18E-02	-1.75E-02	3.32E-02	4.49E-02	3.09E-01
Age_4_Fishery_2009	1.34E-01	2.53E-01	5.18E-02	3.39E-02	3.42E-02	3.53E-02	2.74E-01	3.02E-01
Age_4_Fishery_2010	-1.92E-02	2.19E-01	-1.87E-02	2.71E-02	-1.43E-02	2.82E-02	-7.11E-02	2.59E-01
Age_4_Fishery_2011	1.42E-01	2.98E-01	2.95E-02	4.88E-02	2.03E-02	5.16E-02	2.48E-01	3.65E-01
Age_4_Fishery_2012	3.07E-01	3.07E-01	7.73E-02	5.59E-02	7.67E-02	5.70E-02	4.83E-01	3.92E-01
Age_4_Fishery_2013	1.36E-01	3.03E-01	-8.32E-04	5.08E-02	9.38E-03	5.29E-02	2.31E-01	3.87E-01
Age_4_Fishery_2014	5.51E-02	3.29E-01	-9.98E-03	6.54E-02	-7.95E-03	6.73E-02	9.28E-02	4.26E-01

Table 2A.1.3f (page 3 of 5)—Annual fishery selectivity *dev*s as estimated by Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
Age_5_Fishery_1978							-3.24E-01	4.15E-01
Age_5_Fishery_1979							-4.28E-01	4.08E-01
Age_5_Fishery_1980							-4.98E-03	4.65E-01
Age_5_Fishery_1981							-5.15E-04	4.64E-01
Age_5_Fishery_1982							-6.80E-01	3.80E-01
Age_5_Fishery_1983							-6.93E-01	3.80E-01
Age_5_Fishery_1984							-4.23E-01	3.67E-01
Age_5_Fishery_1985							-3.88E-01	3.87E-01
Age_5_Fishery_1986							9.54E-04	4.64E-01
Age_5_Fishery_1987							1.53E-02	4.62E-01
Age_5_Fishery_1988							1.68E-02	4.62E-01
Age_5_Fishery_1989							1.89E-02	4.63E-01
Age_5_Fishery_1990							2.40E-01	3.69E-01
Age_5_Fishery_1991	2.15E-01	1.96E-01					4.23E-01	2.84E-01
Age_5_Fishery_1992	8.72E-03	1.81E-01					1.07E-01	2.55E-01
Age_5_Fishery_1993	-4.09E-03	1.88E-01					2.26E-01	2.70E-01
Age_5_Fishery_1994	-2.14E-01	1.95E-01					-3.00E-01	2.81E-01
Age_5_Fishery_1995	9.04E-02	1.94E-01					2.60E-01	2.79E-01
Age_5_Fishery_1996	-1.21E-01	1.98E-01					-9.94E-02	2.97E-01
Age_5_Fishery_1997	1.04E-01	1.99E-01					3.31E-01	2.91E-01
Age_5_Fishery_1998	-1.00E-01	1.82E-01					-5.78E-02	2.54E-01
Age_5_Fishery_1999	1.58E-01	1.84E-01					4.55E-01	2.60E-01
Age_5_Fishery_2000	2.20E-01	1.77E-01					4.49E-01	2.46E-01
Age_5_Fishery_2001	-2.78E-01	1.62E-01					-2.67E-01	2.10E-01
Age_5_Fishery_2002	1.49E-01	1.94E-01					5.06E-01	2.92E-01
Age_5_Fishery_2003	9.63E-02	1.93E-01					2.53E-01	2.80E-01
Age_5_Fishery_2004	-1.94E-01	1.89E-01					-5.62E-01	2.67E-01
Age_5_Fishery_2005	-3.77E-02	1.86E-01					-8.48E-02	2.60E-01
Age_5_Fishery_2006	-2.80E-01	1.92E-01					-3.56E-01	2.74E-01
Age_5_Fishery_2007	-1.40E-01	1.87E-01					-6.44E-02	2.60E-01
Age_5_Fishery_2008	-8.06E-02	1.96E-01					8.00E-02	2.92E-01
Age_5_Fishery_2009	1.45E-02	1.89E-01					1.61E-01	2.66E-01
Age_5_Fishery_2010	9.12E-02	1.86E-01					3.46E-01	2.63E-01
Age_5_Fishery_2011	1.45E-01	1.98E-01					3.14E-01	2.89E-01
Age_5_Fishery_2012	7.13E-02	1.99E-01					2.96E-01	2.85E-01
Age_5_Fishery_2013	7.94E-02	2.09E-01					2.16E-01	3.26E-01
Age_5_Fishery_2014	4.42E-02	2.16E-01					1.34E-01	3.48E-01

Table 2A.1.3f (page 4 of 5)—Annual fishery selectivity *dev*s as estimated by Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
Age_6_Fishery_1978			-2.41E-01	1.22E-01			-4.92E-02	1.48E-01
Age_6_Fishery_1979			-2.27E-01	1.13E-01			-4.72E-02	1.48E-01
Age_6_Fishery_1980			-5.45E-03	2.40E-01			-7.04E-04	1.50E-01
Age_6_Fishery_1981			-1.59E-02	2.47E-01			-4.54E-04	1.50E-01
Age_6_Fishery_1982			-2.47E-01	8.21E-02			-7.16E-02	1.48E-01
Age_6_Fishery_1983			-2.09E-01	8.32E-02			-5.68E-02	1.48E-01
Age_6_Fishery_1984			-1.76E-01	6.61E-02			-5.00E-02	1.47E-01
Age_6_Fishery_1985			-1.21E-01	7.01E-02			-3.27E-02	1.47E-01
Age_6_Fishery_1986			3.00E-02	2.20E-01			1.58E-05	1.50E-01
Age_6_Fishery_1987			1.03E-01	1.82E-01			1.96E-03	1.50E-01
Age_6_Fishery_1988			8.67E-02	1.98E-01			2.06E-03	1.50E-01
Age_6_Fishery_1989			9.77E-02	2.04E-01			2.47E-03	1.50E-01
Age_6_Fishery_1990			5.67E-02	6.10E-02			-2.49E-03	1.48E-01
Age_6_Fishery_1991	4.44E-02	1.25E-01	7.24E-02	3.82E-02	5.37E-02	4.05E-02	6.11E-02	1.43E-01
Age_6_Fishery_1992	-7.70E-02	1.21E-01	-2.03E-02	3.31E-02	-4.16E-02	3.50E-02	-5.54E-02	1.41E-01
Age_6_Fishery_1993	3.89E-03	1.24E-01	5.40E-02	3.63E-02	3.43E-02	3.81E-02	3.46E-02	1.44E-01
Age_6_Fishery_1994	-5.53E-02	1.24E-01	-2.65E-03	3.53E-02	-2.47E-02	3.77E-02	-2.45E-02	1.45E-01
Age_6_Fishery_1995	2.50E-03	1.24E-01	4.62E-02	3.64E-02	1.64E-02	3.87E-02	3.90E-03	1.43E-01
Age_6_Fishery_1996	-6.43E-02	1.23E-01	-3.94E-02	3.51E-02	-6.62E-02	3.69E-02	-3.61E-02	1.43E-01
Age_6_Fishery_1997	3.77E-02	1.25E-01	9.60E-02	3.65E-02	5.94E-02	3.91E-02	4.94E-02	1.46E-01
Age_6_Fishery_1998	-3.88E-02	1.23E-01	2.96E-02	3.12E-02	1.16E-03	3.33E-02	-2.06E-02	1.43E-01
Age_6_Fishery_1999	2.94E-02	1.22E-01	4.63E-02	3.32E-02	1.98E-02	3.52E-02	4.73E-02	1.41E-01
Age_6_Fishery_2000	7.16E-02	1.24E-01	9.31E-02	3.19E-02	8.15E-02	3.40E-02	7.71E-02	1.45E-01
Age_6_Fishery_2001	-5.51E-02	1.22E-01	8.47E-03	3.08E-02	1.15E-02	3.28E-02	-5.85E-02	1.41E-01
Age_6_Fishery_2002	2.30E-02	1.22E-01	7.67E-02	3.65E-02	6.81E-02	3.81E-02	4.00E-02	1.40E-01
Age_6_Fishery_2003	5.26E-02	1.24E-01	1.14E-01	3.54E-02	1.20E-01	3.76E-02	5.16E-02	1.45E-01
Age_6_Fishery_2004	-1.23E-02	1.24E-01	2.62E-02	3.32E-02	2.94E-02	3.55E-02	6.16E-03	1.44E-01
Age_6_Fishery_2005	-2.70E-03	1.23E-01	6.64E-03	3.39E-02	-5.30E-03	3.63E-02	-1.68E-02	1.43E-01
Age_6_Fishery_2006	-5.02E-02	1.23E-01	-3.66E-02	3.33E-02	-5.30E-02	3.57E-02	-9.73E-03	1.45E-01
Age_6_Fishery_2007	-1.88E-02	1.24E-01	9.87E-03	3.27E-02	-7.79E-03	3.53E-02	5.39E-03	1.44E-01
Age_6_Fishery_2008	-1.74E-02	1.24E-01	3.94E-02	3.31E-02	1.79E-02	3.54E-02	-8.28E-03	1.44E-01
Age_6_Fishery_2009	-4.38E-03	1.24E-01	4.44E-02	3.40E-02	1.60E-02	3.62E-02	4.22E-03	1.44E-01
Age_6_Fishery_2010	1.75E-02	1.24E-01	8.76E-02	3.42E-02	5.92E-02	3.63E-02	3.15E-02	1.44E-01
Age_6_Fishery_2011	6.39E-02	1.25E-01	1.01E-01	3.74E-02	8.84E-02	4.01E-02	6.85E-02	1.45E-01
Age_6_Fishery_2012	-3.25E-03	1.24E-01	6.15E-02	3.72E-02	4.31E-02	3.91E-02	-2.38E-03	1.44E-01
Age_6_Fishery_2013	3.09E-02	1.24E-01	1.02E-01	4.37E-02	8.77E-02	4.56E-02	3.40E-02	1.44E-01
Age_6_Fishery_2014	2.52E-02	1.26E-01	8.47E-02	4.91E-02	8.47E-02	5.12E-02	2.86E-02	1.46E-01

Table 2A.1.3f (page 5 of 5)—Annual fishery selectivity *dev*s as estimated by Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
Age_7_Fishery_1978							-5.46E-01	4.68E-01
Age_7_Fishery_1979							-4.89E-01	4.70E-01
Age_7_Fishery_1980							-9.29E-03	5.41E-01
Age_7_Fishery_1981							-6.41E-03	5.41E-01
Age_7_Fishery_1982							-7.42E-01	4.41E-01
Age_7_Fishery_1983							-5.66E-01	4.43E-01
Age_7_Fishery_1984							-5.03E-01	4.27E-01
Age_7_Fishery_1985							-2.92E-01	4.42E-01
Age_7_Fishery_1986							-1.05E-03	5.41E-01
Age_7_Fishery_1987							2.27E-02	5.41E-01
Age_7_Fishery_1988							2.57E-02	5.41E-01
Age_7_Fishery_1989							3.24E-02	5.43E-01
Age_7_Fishery_1990							-2.07E-01	4.54E-01
Age_7_Fishery_1991	-3.42E-01	2.98E-01					-3.34E-01	3.55E-01
Age_7_Fishery_1992	-6.62E-01	2.24E-01					-5.62E-01	2.46E-01
Age_7_Fishery_1993	-2.91E-01	2.40E-01					-2.49E-01	2.70E-01
Age_7_Fishery_1994	-3.64E-01	2.44E-01					-2.34E-01	2.81E-01
Age_7_Fishery_1995	-1.28E-01	2.33E-01					-6.24E-02	2.54E-01
Age_7_Fishery_1996	-4.79E-01	2.29E-01					-4.42E-01	2.56E-01
Age_7_Fishery_1997	1.51E-01	2.48E-01					2.33E-01	2.87E-01
Age_7_Fishery_1998	-6.78E-02	2.04E-01					6.02E-02	2.28E-01
Age_7_Fishery_1999	-2.08E-01	2.05E-01					-1.40E-01	2.18E-01
Age_7_Fishery_2000	3.84E-01	2.10E-01					5.99E-01	2.49E-01
Age_7_Fishery_2001	2.38E-01	2.05E-01					5.06E-01	2.28E-01
Age_7_Fishery_2002	-4.47E-02	2.27E-01					1.08E-01	2.45E-01
Age_7_Fishery_2003	4.49E-01	2.30E-01					7.81E-01	2.64E-01
Age_7_Fishery_2004	-5.92E-03	2.22E-01					2.79E-01	2.51E-01
Age_7_Fishery_2005	-2.75E-01	2.21E-01					-2.51E-01	2.37E-01
Age_7_Fishery_2006	-3.28E-01	2.24E-01					-3.62E-01	2.54E-01
Age_7_Fishery_2007	1.41E-02	2.14E-01					6.58E-05	2.39E-01
Age_7_Fishery_2008	1.98E-01	2.12E-01					2.39E-01	2.40E-01
Age_7_Fishery_2009	1.88E-01	2.21E-01					2.68E-01	2.46E-01
Age_7_Fishery_2010	3.14E-01	2.20E-01					4.16E-01	2.53E-01
Age_7_Fishery_2011	4.25E-01	2.73E-01					6.63E-01	3.12E-01
Age_7_Fishery_2012	1.39E-01	2.56E-01					3.33E-01	2.88E-01
Age_7_Fishery_2013	3.75E-01	2.69E-01					7.14E-01	2.99E-01
Age_7_Fishery_2014	3.30E-01	2.96E-01					6.88E-01	3.54E-01

Table 2A.1.3g (page 1 of 7)—Annual survey selectivity *dev*s as estimated by Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
Age_2_Survey_1991	3.24E+00	7.13E-01	3.39E-01	8.45E-02	3.43E-01	8.46E-02	3.07E+00	7.36E-01
Age_2_Survey_1992	0.00E+00	1.54E+00	0.00E+00	1.94E-01	0.00E+00	1.94E-01	0.00E+00	1.56E+00
Age_2_Survey_1993	0.00E+00	1.54E+00	0.00E+00	1.94E-01	0.00E+00	1.94E-01	0.00E+00	1.56E+00
Age_2_Survey_1994	########	4.43E-01	-1.15E-01	4.24E-02	-1.31E-01	4.25E-02	########	4.73E-01
Age_2_Survey_1995	0.00E+00	1.54E+00	0.00E+00	1.94E-01	0.00E+00	1.94E-01	0.00E+00	1.56E+00
Age_2_Survey_1996	0.00E+00	1.54E+00	0.00E+00	1.94E-01	0.00E+00	1.94E-01	0.00E+00	1.56E+00
Age_2_Survey_1997	-2.39E-01	4.53E-01	-1.03E-02	4.07E-02	-2.65E-03	4.09E-02	-3.06E-01	4.80E-01
Age_2_Survey_1998	0.00E+00	1.54E+00	0.00E+00	1.94E-01	0.00E+00	1.94E-01	0.00E+00	1.56E+00
Age_2_Survey_1999	0.00E+00	1.54E+00	0.00E+00	1.94E-01	0.00E+00	1.94E-01	0.00E+00	1.56E+00
Age_2_Survey_2000	-7.94E-03	5.26E-01	1.54E-02	5.00E-02	2.99E-02	5.05E-02	-1.44E-02	5.51E-01
Age_2_Survey_2001	0.00E+00	1.54E+00	0.00E+00	1.94E-01	0.00E+00	1.94E-01	0.00E+00	1.56E+00
Age_2_Survey_2002	1.07E+00	5.09E-01	1.28E-01	4.96E-02	1.37E-01	5.00E-02	1.41E+00	5.15E-01
Age_2_Survey_2003	0.00E+00	1.54E+00	0.00E+00	1.94E-01	0.00E+00	1.94E-01	0.00E+00	1.56E+00
Age_2_Survey_2004	4.93E-01	6.34E-01	8.03E-02	6.33E-02	8.26E-02	6.35E-02	4.38E-01	6.54E-01
Age_2_Survey_2005	0.00E+00	1.54E+00	0.00E+00	1.94E-01	0.00E+00	1.94E-01	0.00E+00	1.56E+00
Age_2_Survey_2006	########	5.44E-01	-1.31E-01	5.20E-02	-1.37E-01	5.22E-02	########	5.79E-01
Age_2_Survey_2007	0.00E+00	1.54E+00	0.00E+00	1.94E-01	0.00E+00	1.94E-01	0.00E+00	1.56E+00
Age_2_Survey_2008	0.00E+00	1.54E+00	0.00E+00	1.94E-01	0.00E+00	1.94E-01	0.00E+00	1.56E+00
Age_2_Survey_2009	0.00E+00	1.54E+00	0.00E+00	1.94E-01	0.00E+00	1.94E-01	0.00E+00	1.56E+00
Age_2_Survey_2010	-1.62E-01	5.51E-01	-1.27E-02	5.24E-02	1.17E-02	5.24E-02	-3.31E-01	5.72E-01
Age_2_Survey_2011	0.00E+00	1.54E+00	0.00E+00	1.94E-01	0.00E+00	1.94E-01	0.00E+00	1.56E+00
Age_2_Survey_2012	-9.26E-01	4.93E-01	-1.18E-01	4.52E-02	-1.04E-01	4.54E-02	########	5.14E-01
Age_2_Survey_2013	0.00E+00	1.54E+00	0.00E+00	1.94E-01	0.00E+00	1.94E-01	0.00E+00	1.56E+00
Age_2_Survey_2014								

Table 2A.1.3g (page 2 of 7)—Annual survey selectivity *dev*s as estimated by Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
Age_3_Survey_1991	########	2.97E-01	-5.19E-02	2.78E-02	-5.39E-02	2.71E-02	########	3.44E-01
Age_3_Survey_1992	0.00E+00	7.52E-01	0.00E+00	7.80E-02	0.00E+00	7.80E-02	0.00E+00	9.48E-01
Age_3_Survey_1993	0.00E+00	7.52E-01	0.00E+00	7.80E-02	0.00E+00	7.80E-02	0.00E+00	9.48E-01
Age_3_Survey_1994	-1.64E-01	3.49E-01	9.35E-03	3.55E-02	3.07E-03	3.55E-02	-1.88E-01	4.02E-01
Age_3_Survey_1995	0.00E+00	7.52E-01	0.00E+00	7.80E-02	0.00E+00	7.80E-02	0.00E+00	9.48E-01
Age_3_Survey_1996	0.00E+00	7.52E-01	0.00E+00	7.80E-02	0.00E+00	7.80E-02	0.00E+00	9.48E-01
Age_3_Survey_1997	1.02E-01	3.22E-01	4.32E-02	3.08E-02	4.87E-02	3.03E-02	2.94E-01	3.70E-01
Age_3_Survey_1998	0.00E+00	7.52E-01	0.00E+00	7.80E-02	0.00E+00	7.80E-02	0.00E+00	9.48E-01
Age_3_Survey_1999	0.00E+00	7.52E-01	0.00E+00	7.80E-02	0.00E+00	7.80E-02	0.00E+00	9.48E-01
Age_3_Survey_2000	3.61E-01	3.71E-01	9.36E-02	3.67E-02	9.76E-02	3.66E-02	5.29E-01	4.22E-01
Age_3_Survey_2001	0.00E+00	7.52E-01	0.00E+00	7.80E-02	0.00E+00	7.80E-02	0.00E+00	9.48E-01
Age_3_Survey_2002	########	3.06E-01	-1.18E-01	2.89E-02	-1.22E-01	2.98E-02	########	3.41E-01
Age_3_Survey_2003	0.00E+00	7.52E-01	0.00E+00	7.80E-02	0.00E+00	7.80E-02	0.00E+00	9.48E-01
Age_3_Survey_2004	4.82E-01	3.86E-01	7.28E-02	3.77E-02	7.15E-02	3.74E-02	5.86E-01	4.34E-01
Age_3_Survey_2005	0.00E+00	7.52E-01	0.00E+00	7.80E-02	0.00E+00	7.80E-02	0.00E+00	9.48E-01
Age_3_Survey_2006	7.31E-01	4.24E-01	1.20E-01	4.29E-02	1.08E-01	4.23E-02	8.87E-01	4.80E-01
Age_3_Survey_2007	0.00E+00	7.52E-01	0.00E+00	7.80E-02	0.00E+00	7.80E-02	0.00E+00	9.48E-01
Age_3_Survey_2008	0.00E+00	7.52E-01	0.00E+00	7.80E-02	0.00E+00	7.80E-02	0.00E+00	9.48E-01
Age_3_Survey_2009	0.00E+00	7.52E-01	0.00E+00	7.80E-02	0.00E+00	7.80E-02	0.00E+00	9.48E-01
Age_3_Survey_2010	4.59E-01	3.28E-01	9.00E-02	3.09E-02	7.94E-02	3.02E-02	5.34E-01	3.74E-01
Age_3_Survey_2011	0.00E+00	7.52E-01	0.00E+00	7.80E-02	0.00E+00	7.80E-02	0.00E+00	9.48E-01
Age_3_Survey_2012	3.34E-01	3.42E-01	7.77E-02	3.56E-02	8.85E-02	3.33E-02	4.13E-01	3.91E-01
Age_3_Survey_2013	0.00E+00	7.52E-01	0.00E+00	7.80E-02	0.00E+00	7.80E-02	0.00E+00	9.48E-01
Age_3_Survey_2014	3.34E-01	3.99E-01	7.99E-02	4.23E-02	6.73E-02	4.15E-02	4.10E-01	4.91E-01

Table 2A.1.3g (page 3 of 7)—Annual survey selectivity *dev*s as estimated by Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
Age_4_Survey_1991	-8.42E-03	6.82E-02					-2.00E-03	6.86E-02
Age_4_Survey_1992	0.00E+00	7.00E-02					0.00E+00	7.00E-02
Age_4_Survey_1993	0.00E+00	7.00E-02					0.00E+00	7.00E-02
Age_4_Survey_1994	-5.63E-03	6.80E-02					4.26E-03	6.83E-02
Age_4_Survey_1995	0.00E+00	7.00E-02					0.00E+00	7.00E-02
Age_4_Survey_1996	0.00E+00	7.00E-02					0.00E+00	7.00E-02
Age_4_Survey_1997	2.41E-02	6.78E-02					2.15E-02	6.82E-02
Age_4_Survey_1998	0.00E+00	7.00E-02					0.00E+00	7.00E-02
Age_4_Survey_1999	0.00E+00	7.00E-02					0.00E+00	7.00E-02
Age_4_Survey_2000	-1.31E-02	6.71E-02					-1.78E-02	6.75E-02
Age_4_Survey_2001	0.00E+00	7.00E-02					0.00E+00	7.00E-02
Age_4_Survey_2002	1.08E-02	6.73E-02					-1.27E-02	6.85E-02
Age_4_Survey_2003	0.00E+00	7.00E-02					0.00E+00	7.00E-02
Age_4_Survey_2004	-2.68E-02	6.74E-02					-2.18E-02	6.77E-02
Age_4_Survey_2005	0.00E+00	7.00E-02					0.00E+00	7.00E-02
Age_4_Survey_2006	-7.76E-03	6.77E-02					-1.62E-03	6.80E-02
Age_4_Survey_2007	0.00E+00	7.00E-02					0.00E+00	7.00E-02
Age_4_Survey_2008	0.00E+00	7.00E-02					0.00E+00	7.00E-02
Age_4_Survey_2009	0.00E+00	7.00E-02					0.00E+00	7.00E-02
Age_4_Survey_2010	6.56E-03	6.67E-02					1.16E-02	6.72E-02
Age_4_Survey_2011	0.00E+00	7.00E-02					0.00E+00	7.00E-02
Age_4_Survey_2012	1.15E-02	6.83E-02					1.00E-02	6.87E-02
Age_4_Survey_2013	0.00E+00	7.00E-02					0.00E+00	7.00E-02
Age_4_Survey_2014	1.08E-02	6.89E-02					9.68E-03	6.92E-02

Table 2A.1.3g (page 4 of 7)—Annual survey selectivity *dev*s as estimated by Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
Age_5_Survey_1991	2.12E-01	1.83E-01					1.26E-01	1.83E-01
Age_5_Survey_1992	0.00E+00	2.70E-01					0.00E+00	2.50E-01
Age_5_Survey_1993	0.00E+00	2.70E-01					0.00E+00	2.50E-01
Age_5_Survey_1994	3.27E-01	1.84E-01					2.51E-01	1.80E-01
Age_5_Survey_1995	0.00E+00	2.70E-01					0.00E+00	2.50E-01
Age_5_Survey_1996	0.00E+00	2.70E-01					0.00E+00	2.50E-01
Age_5_Survey_1997	-2.01E-01	1.90E-01					-1.73E-01	1.84E-01
Age_5_Survey_1998	0.00E+00	2.70E-01					0.00E+00	2.50E-01
Age_5_Survey_1999	0.00E+00	2.70E-01					0.00E+00	2.50E-01
Age_5_Survey_2000	1.58E-02	1.88E-01					2.35E-02	1.82E-01
Age_5_Survey_2001	0.00E+00	2.70E-01					0.00E+00	2.50E-01
Age_5_Survey_2002	-2.43E-01	1.81E-01					1.28E-02	1.89E-01
Age_5_Survey_2003	0.00E+00	2.70E-01					0.00E+00	2.50E-01
Age_5_Survey_2004	-8.34E-02	1.79E-01					-2.87E-01	1.73E-01
Age_5_Survey_2005	0.00E+00	2.70E-01					0.00E+00	2.50E-01
Age_5_Survey_2006	1.15E-01	1.85E-01					9.15E-02	1.83E-01
Age_5_Survey_2007	0.00E+00	2.70E-01					0.00E+00	2.50E-01
Age_5_Survey_2008	0.00E+00	2.70E-01					0.00E+00	2.50E-01
Age_5_Survey_2009	0.00E+00	2.70E-01					0.00E+00	2.50E-01
Age_5_Survey_2010	-2.54E-01	1.85E-01					-2.02E-01	1.83E-01
Age_5_Survey_2011	0.00E+00	2.70E-01					0.00E+00	2.50E-01
Age_5_Survey_2012	-1.65E-01	1.74E-01					-1.22E-01	1.73E-01
Age_5_Survey_2013	0.00E+00	2.70E-01					0.00E+00	2.50E-01
Age_5_Survey_2014	1.57E-01	1.89E-01					1.92E-01	1.87E-01

Table 2A.1.3g (page 5 of 7)—Annual survey selectivity *dev*s as estimated by Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
Age_6_Survey_1991	1.09E-03	1.40E-01					-8.24E-03	1.40E-01
Age_6_Survey_1992	0.00E+00	1.50E-01					0.00E+00	1.51E-01
Age_6_Survey_1993	0.00E+00	1.50E-01					0.00E+00	1.51E-01
Age_6_Survey_1994	7.57E-02	1.37E-01					7.45E-02	1.38E-01
Age_6_Survey_1995	0.00E+00	1.50E-01					0.00E+00	1.51E-01
Age_6_Survey_1996	0.00E+00	1.50E-01					0.00E+00	1.51E-01
Age_6_Survey_1997	-1.84E-02	1.40E-01					-2.77E-02	1.40E-01
Age_6_Survey_1998	0.00E+00	1.50E-01					0.00E+00	1.51E-01
Age_6_Survey_1999	0.00E+00	1.50E-01					0.00E+00	1.51E-01
Age_6_Survey_2000	-3.75E-02	1.41E-01					-2.68E-02	1.42E-01
Age_6_Survey_2001	0.00E+00	1.50E-01					0.00E+00	1.51E-01
Age_6_Survey_2002	7.18E-02	1.39E-01					1.09E-01	1.40E-01
Age_6_Survey_2003	0.00E+00	1.50E-01					0.00E+00	1.51E-01
Age_6_Survey_2004	-4.63E-02	1.40E-01					-7.32E-02	1.39E-01
Age_6_Survey_2005	0.00E+00	1.50E-01					0.00E+00	1.51E-01
Age_6_Survey_2006	5.94E-02	1.39E-01					2.73E-02	1.40E-01
Age_6_Survey_2007	0.00E+00	1.50E-01					0.00E+00	1.51E-01
Age_6_Survey_2008	0.00E+00	1.50E-01					0.00E+00	1.51E-01
Age_6_Survey_2009	0.00E+00	1.50E-01					0.00E+00	1.51E-01
Age_6_Survey_2010	-2.78E-02	1.39E-01					-3.19E-02	1.40E-01
Age_6_Survey_2011	0.00E+00	1.50E-01					0.00E+00	1.51E-01
Age_6_Survey_2012	-9.47E-02	1.38E-01					-8.52E-02	1.39E-01
Age_6_Survey_2013	0.00E+00	1.50E-01					0.00E+00	1.51E-01
Age_6_Survey_2014	1.32E-02	1.40E-01					3.15E-02	1.41E-01

Table 2A.1.3g (page 6 of 7)—Annual survey selectivity *dev*s as estimated by Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
Age_7_Survey_1991	-3.78E-02	1.43E-01	-3.56E-02	5.10E-02	4.85E-02	5.40E-02	-2.25E-02	1.43E-01
Age_7_Survey_1992	0.00E+00	1.49E-01	0.00E+00	4.42E-01	0.00E+00	4.42E-01	0.00E+00	1.49E-01
Age_7_Survey_1993	0.00E+00	1.49E-01	0.00E+00	4.42E-01	0.00E+00	4.42E-01	0.00E+00	1.49E-01
Age_7_Survey_1994	6.14E-02	1.39E-01	2.11E-02	4.89E-02	7.39E-02	4.34E-02	6.67E-02	1.38E-01
Age_7_Survey_1995	0.00E+00	1.49E-01	0.00E+00	4.42E-01	0.00E+00	4.42E-01	0.00E+00	1.49E-01
Age_7_Survey_1996	0.00E+00	1.49E-01	0.00E+00	4.42E-01	0.00E+00	4.42E-01	0.00E+00	1.49E-01
Age_7_Survey_1997	1.33E-02	1.41E-01	4.77E-03	4.66E-02	-7.70E-03	4.72E-02	-2.98E-03	1.40E-01
Age_7_Survey_1998	0.00E+00	1.49E-01	0.00E+00	4.42E-01	0.00E+00	4.42E-01	0.00E+00	1.49E-01
Age_7_Survey_1999	0.00E+00	1.49E-01	0.00E+00	4.42E-01	0.00E+00	4.42E-01	0.00E+00	1.49E-01
Age_7_Survey_2000	-4.26E-02	1.42E-01	-4.65E-02	4.77E-02	-5.34E-03	4.94E-02	-3.70E-02	1.41E-01
Age_7_Survey_2001	0.00E+00	1.49E-01	0.00E+00	4.42E-01	0.00E+00	4.42E-01	0.00E+00	1.49E-01
Age_7_Survey_2002	4.69E-02	1.45E-01	3.26E-02	4.83E-02	1.37E-01	4.08E-02	6.97E-02	1.44E-01
Age_7_Survey_2003	0.00E+00	1.49E-01	0.00E+00	4.42E-01	0.00E+00	4.42E-01	0.00E+00	1.49E-01
Age_7_Survey_2004	-5.39E-02	1.40E-01	-3.94E-02	4.73E-02	-2.13E-02	4.81E-02	-6.23E-02	1.39E-01
Age_7_Survey_2005	0.00E+00	1.49E-01	0.00E+00	4.42E-01	0.00E+00	4.42E-01	0.00E+00	1.49E-01
Age_7_Survey_2006	3.76E-02	1.41E-01	-2.11E-02	4.86E-02	3.76E-02	4.48E-02	7.58E-03	1.39E-01
Age_7_Survey_2007	0.00E+00	1.49E-01	0.00E+00	4.42E-01	0.00E+00	4.42E-01	0.00E+00	1.49E-01
Age_7_Survey_2008	0.00E+00	1.49E-01	0.00E+00	4.42E-01	0.00E+00	4.42E-01	0.00E+00	1.49E-01
Age_7_Survey_2009	0.00E+00	1.49E-01	0.00E+00	4.42E-01	0.00E+00	4.42E-01	0.00E+00	1.49E-01
Age_7_Survey_2010	1.05E-02	1.40E-01	-2.99E-02	4.65E-02	-2.36E-02	4.85E-02	7.89E-05	1.40E-01
Age_7_Survey_2011	0.00E+00	1.49E-01	0.00E+00	4.42E-01	0.00E+00	4.42E-01	0.00E+00	1.49E-01
Age_7_Survey_2012	-7.20E-02	1.41E-01	-3.60E-02	4.60E-02	-5.98E-02	5.34E-02	-6.78E-02	1.41E-01
Age_7_Survey_2013	0.00E+00	1.49E-01	0.00E+00	4.42E-01	0.00E+00	4.42E-01	0.00E+00	1.49E-01
Age_7_Survey_2014	2.43E-02	1.40E-01	-3.28E-02	4.97E-02	5.78E-02	4.64E-02	4.28E-02	1.40E-01

Table 2A.1.3g (page 7 of 7)—Annual survey selectivity *dev*s as estimated by Models 2-5.

	Model 2		Model 3		Model 4		Model 5	
Parameter	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
Age_8_Survey_1991	-2.31E-02	1.08E-01					-1.31E-02	1.07E-01
Age_8_Survey_1992	0.00E+00	1.10E-01					0.00E+00	1.09E-01
Age_8_Survey_1993	0.00E+00	1.10E-01					0.00E+00	1.09E-01
Age_8_Survey_1994	3.70E-03	1.08E-01					8.56E-03	1.07E-01
Age_8_Survey_1995	0.00E+00	1.10E-01					0.00E+00	1.09E-01
Age_8_Survey_1996	0.00E+00	1.10E-01					0.00E+00	1.09E-01
Age_8_Survey_1997	1.05E-02	1.08E-01					3.50E-03	1.06E-01
Age_8_Survey_1998	0.00E+00	1.10E-01					0.00E+00	1.09E-01
Age_8_Survey_1999	0.00E+00	1.10E-01					0.00E+00	1.09E-01
Age_8_Survey_2000	-1.24E-02	1.08E-01					-1.33E-02	1.07E-01
Age_8_Survey_2001	0.00E+00	1.10E-01					0.00E+00	1.09E-01
Age_8_Survey_2002	1.06E-02	1.09E-01					1.47E-02	1.08E-01
Age_8_Survey_2003	0.00E+00	1.10E-01					0.00E+00	1.09E-01
Age_8_Survey_2004	-1.91E-02	1.08E-01					-1.94E-02	1.07E-01
Age_8_Survey_2005	0.00E+00	1.10E-01					0.00E+00	1.09E-01
Age_8_Survey_2006	5.77E-03	1.08E-01					-8.35E-03	1.06E-01
Age_8_Survey_2007	0.00E+00	1.10E-01					0.00E+00	1.09E-01
Age_8_Survey_2008	0.00E+00	1.10E-01					0.00E+00	1.09E-01
Age_8_Survey_2009	0.00E+00	1.10E-01					0.00E+00	1.09E-01
Age_8_Survey_2010	1.29E-02	1.08E-01					5.86E-03	1.07E-01
Age_8_Survey_2011	0.00E+00	1.10E-01					0.00E+00	1.09E-01
Age_8_Survey_2012	-1.60E-02	1.08E-01					-1.55E-02	1.07E-01
Age_8_Survey_2013	0.00E+00	1.10E-01					0.00E+00	1.09E-01
Age_8_Survey_2014	1.07E-02	1.09E-01					2.00E-02	1.08E-01

Table 2A.1.4—Full-selection fishing mortality rates as estimated by Models 2-5. Color scale extends from red (low) to green (high).

	Model 2		Model 3		Model 4		Model 5	
Year	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.	Estimate	St. Dev.
1977			1.99E-02	7.22E-03			1.71E-02	3.58E-03
1978			3.24E-02	1.37E-02			2.05E-02	6.80E-03
1979			5.76E-02	2.50E-02			3.48E-02	1.38E-02
1980			3.78E-02	2.65E-02			3.05E-02	1.12E-02
1981			5.04E-02	3.53E-02			4.09E-02	1.54E-02
1982			1.17E-01	4.79E-02			7.85E-02	2.77E-02
1983			1.07E-01	5.00E-02			6.57E-02	2.40E-02
1984			9.99E-02	4.54E-02			5.22E-02	1.86E-02
1985			6.46E-02	3.21E-02			3.87E-02	1.48E-02
1986			6.57E-02	4.19E-02			3.58E-02	1.25E-02
1987			1.45E-01	7.15E-02			6.79E-02	2.46E-02
1988			5.10E-02	3.28E-02			2.41E-02	8.75E-03
1989			3.82E-02	3.00E-02			1.61E-02	5.52E-03
1990			4.40E-02	2.01E-02			2.34E-02	6.19E-03
1991	3.41E-02	6.76E-03	4.88E-02	1.91E-02	5.62E-02	1.54E-02	2.82E-02	5.89E-03
1992	1.57E-01	2.74E-02	1.75E-01	6.73E-02	1.91E-01	5.42E-02	1.36E-01	2.60E-02
1993	1.18E-01	2.39E-02	1.64E-01	6.38E-02	1.82E-01	5.34E-02	1.05E-01	2.27E-02
1994	7.64E-02	1.61E-02	9.23E-02	3.63E-02	9.48E-02	3.01E-02	6.31E-02	1.49E-02
1995	5.61E-02	1.08E-02	7.77E-02	2.95E-02	8.00E-02	2.34E-02	4.92E-02	9.68E-03
1996	1.33E-01	2.55E-02	1.30E-01	4.93E-02	1.43E-01	2.91E-02	1.23E-01	2.53E-02
1997	9.94E-02	1.60E-02	1.32E-01	4.85E-02	1.48E-01	3.82E-02	8.33E-02	1.42E-02
1998	1.30E-01	2.56E-02	1.72E-01	6.15E-02	1.99E-01	5.59E-02	1.14E-01	2.38E-02
1999	1.24E-01	2.13E-02	1.40E-01	4.88E-02	1.75E-01	4.82E-02	1.15E-01	1.95E-02
2000	1.91E-01	3.08E-02	2.24E-01	7.87E-02	2.97E-01	7.45E-02	1.67E-01	2.74E-02
2001	1.30E-01	2.30E-02	1.50E-01	5.35E-02	2.05E-01	5.58E-02	1.16E-01	2.08E-02
2002	1.11E-01	1.90E-02	1.65E-01	5.80E-02	2.14E-01	5.86E-02	9.64E-02	1.64E-02
2003	1.48E-01	2.33E-02	1.85E-01	6.41E-02	2.35E-01	6.31E-02	1.29E-01	1.94E-02
2004	1.07E-01	1.62E-02	1.54E-01	5.42E-02	1.84E-01	4.97E-02	9.27E-02	1.37E-02
2005	1.03E-01	1.70E-02	1.26E-01	4.43E-02	1.39E-01	3.91E-02	9.60E-02	1.49E-02
2006	1.24E-01	2.30E-02	1.39E-01	4.86E-02	1.48E-01	4.02E-02	1.32E-01	2.81E-02
2007	1.80E-01	2.40E-02	2.45E-01	8.44E-02	2.68E-01	7.01E-02	1.82E-01	3.89E-02
2008	2.09E-01	3.02E-02	2.72E-01	9.58E-02	3.10E-01	8.45E-02	1.96E-01	2.70E-02
2009	2.25E-01	3.84E-02	2.80E-01	9.96E-02	3.34E-01	9.32E-02	2.19E-01	3.60E-02
2010	2.66E-01	5.25E-02	3.32E-01	1.21E-01	4.39E-01	1.19E-01	2.72E-01	5.27E-02
2011	1.05E-01	2.44E-02	1.24E-01	4.62E-02	1.82E-01	5.34E-02	1.17E-01	2.70E-02
2012	1.31E-01	3.01E-02	1.80E-01	6.70E-02	2.59E-01	7.86E-02	1.48E-01	3.49E-02
2013	1.09E-01	2.49E-02	1.38E-01	5.13E-02	1.98E-01	6.03E-02	1.33E-01	3.12E-02
2014	8.80E-02	1.78E-02	1.17E-01	4.47E-02	1.68E-01	5.09E-02	1.07E-01	2.33E-02

Table 2A.1.5—Parameters used in iterative tuning processes by Models 2-5. A blank indicates that the parameter (row) was not used in that model (column). Shading indicates that sigma(recruitment) was estimated internally (rather than tuned iteratively) in that model.

Tuning parameter	Model 2	Model 3	Model 4	Model 5
Sigma(recruitment)	0.418	0.461	0.494	0.565
Sigma(catchability)				0.086
Sigma(fishery age 3 selectivity parm.)	0.300			0.600
Sigma(fishery age 4 selectivity parm.)	0.370	0.092	0.092	0.520
Sigma(fishery age 5 selectivity parm.)	0.240			0.464
Sigma(fishery age 6 selectivity parm.)	0.130	0.237	0.237	0.150
Sigma(fishery age 7 selectivity parm.)	0.389			0.541
Sigma(survey age 2 selectivity parm.)	1.539	0.194	0.194	1.557
Sigma(survey age 3 selectivity parm.)	0.752	0.078	0.078	0.948
Sigma(survey age 4 selectivity parm.)	0.070			0.070
Sigma(survey age 5 selectivity parm.)	0.270			0.250
Sigma(survey age 6 selectivity parm.)	0.150			0.151
Sigma(survey age 7 selectivity parm.)	0.149	0.442	0.442	0.149
Sigma(survey age 8 selectivity parm.)	0.110			0.109
Logistic alpha (fishery selectivity prior)	3.971	3.290	3.290	3.974
Logistic beta (fishery selectivity prior)	3.187	3.380	3.380	3.119
Sigma(fishery selectivity prior)	0.764	0.342	0.342	0.759
Logistic alpha (survey selectivity prior)	1.537	5.850	5.850	1.583
Logistic beta (survey selectivity prior)	2.739	1.050	1.050	2.660
Sigma(survey selectivity prior)	0.650	0.319	0.319	0.646
Fishery sizecomp multiplier	1.000	1.000	1.000	1.000
Survey sizecomp multiplier	1.000	1.000	1.000	1.000
Survey agecomp multiplier	0.606	1.000	1.000	0.583

Figures

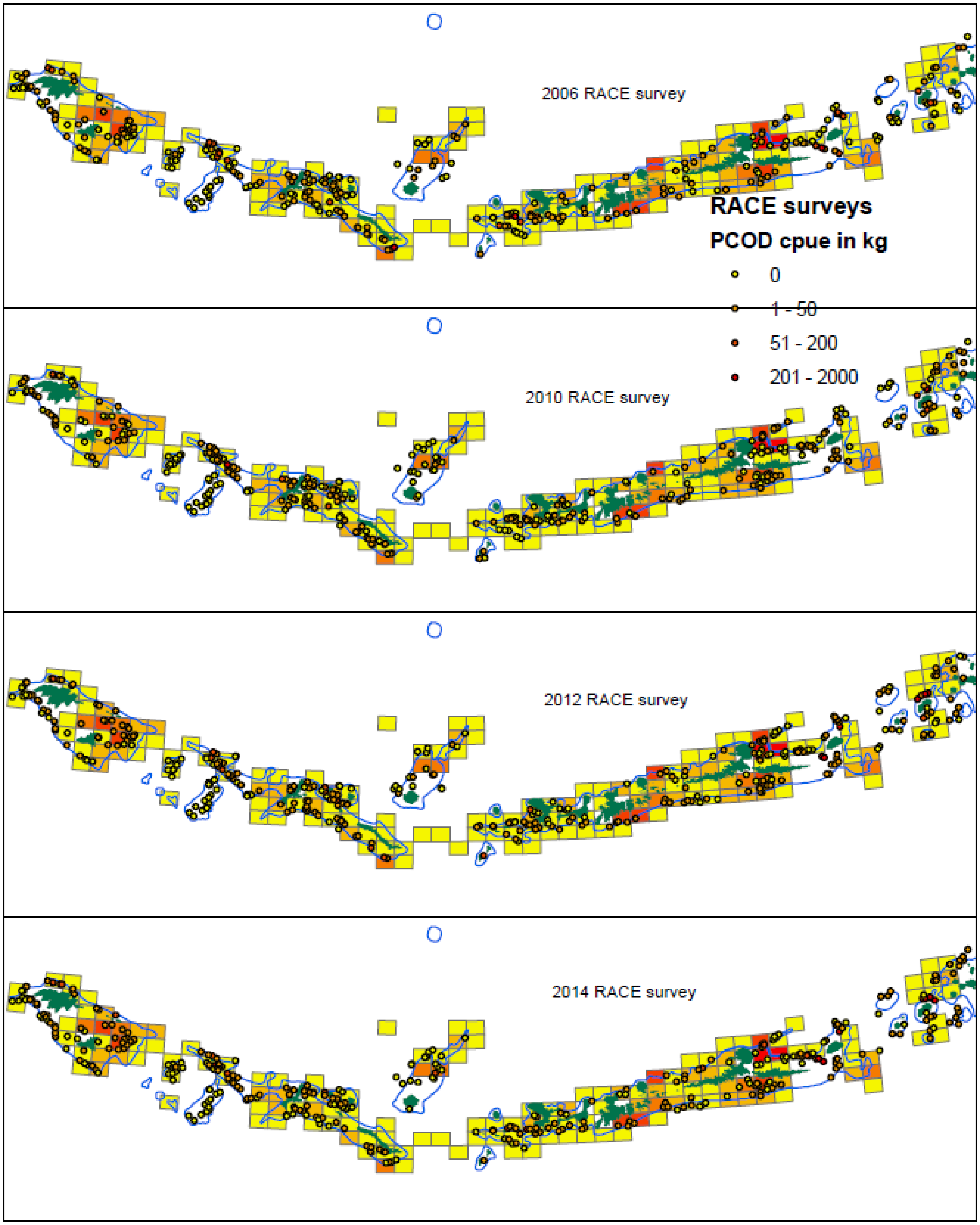


Figure 2A.1.1a—Locations of, and Pacific cod densities encountered by, the NMFS bottom trawl survey from the last 10 years (dots), overlaid against corresponding data from the observed fisheries (squares).

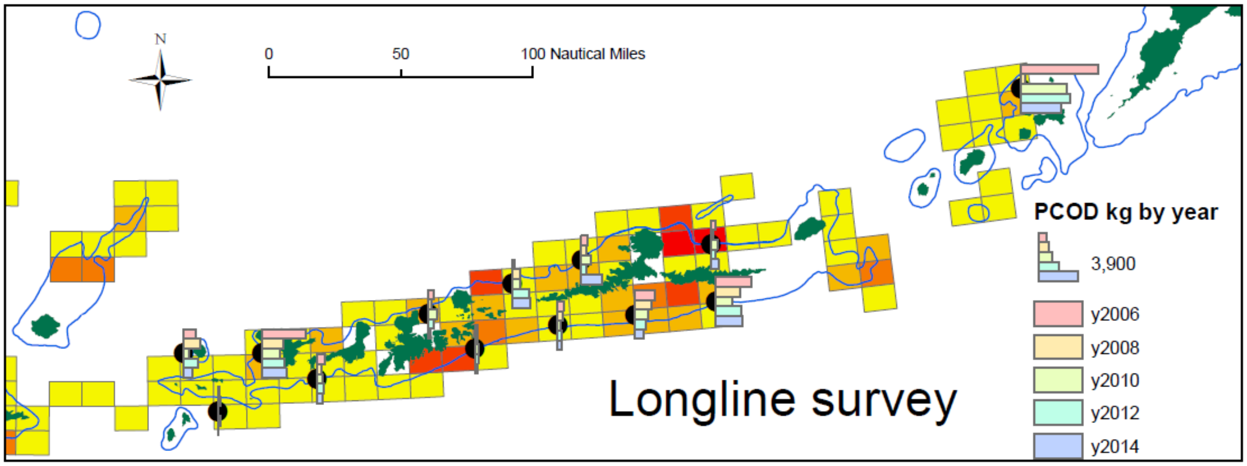


Figure 2A.1.1b—Locations of, and Pacific cod densities encountered by, the NMFS longline survey during the last 10 years (dots), overlaid against corresponding data from the observed fisheries (squares).

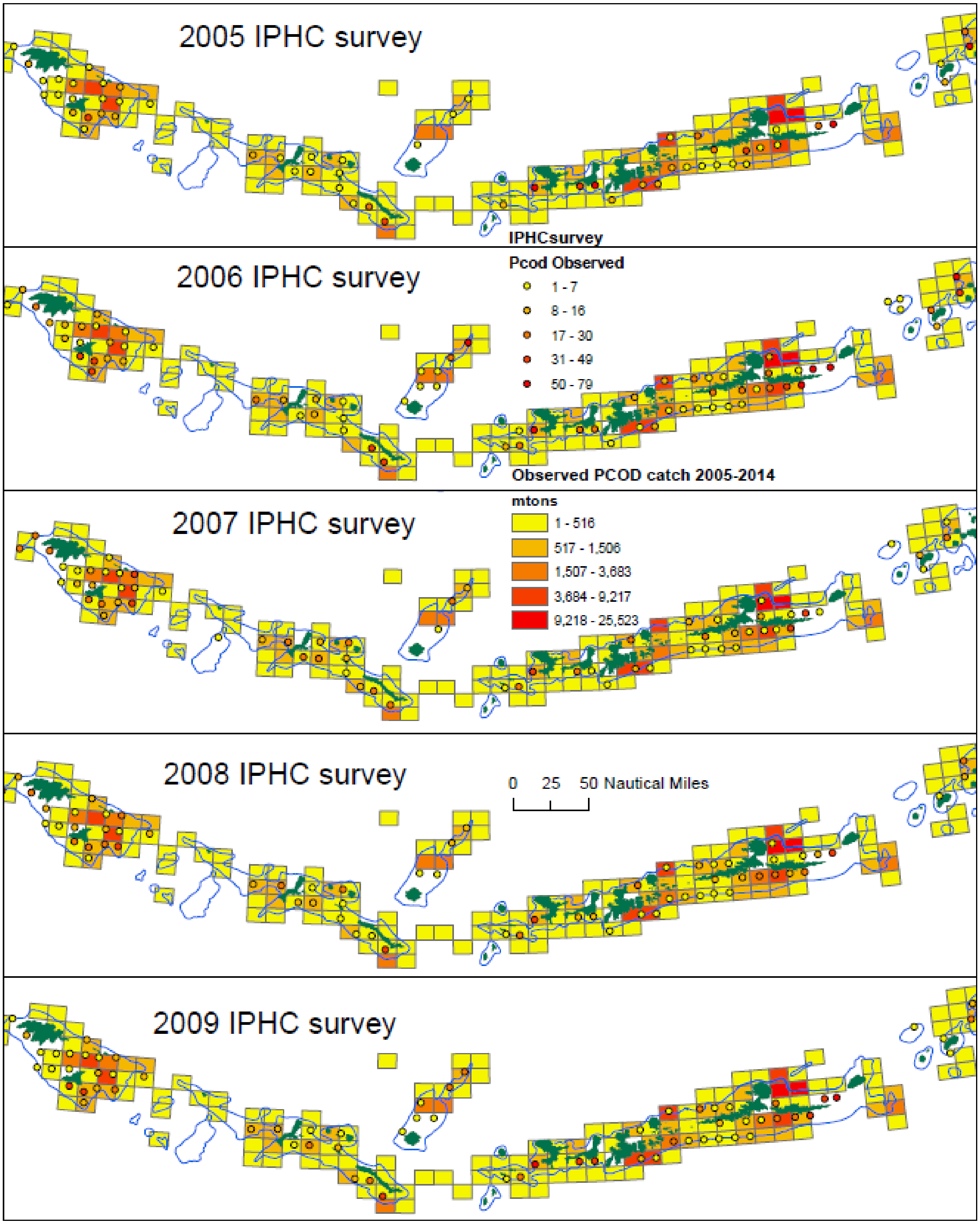


Figure 2A.1.1c—Locations of, and Pacific cod densities encountered by, the IPHC longline survey from 2005-2009 (dots), overlaid against corresponding data from the observed fisheries (squares).

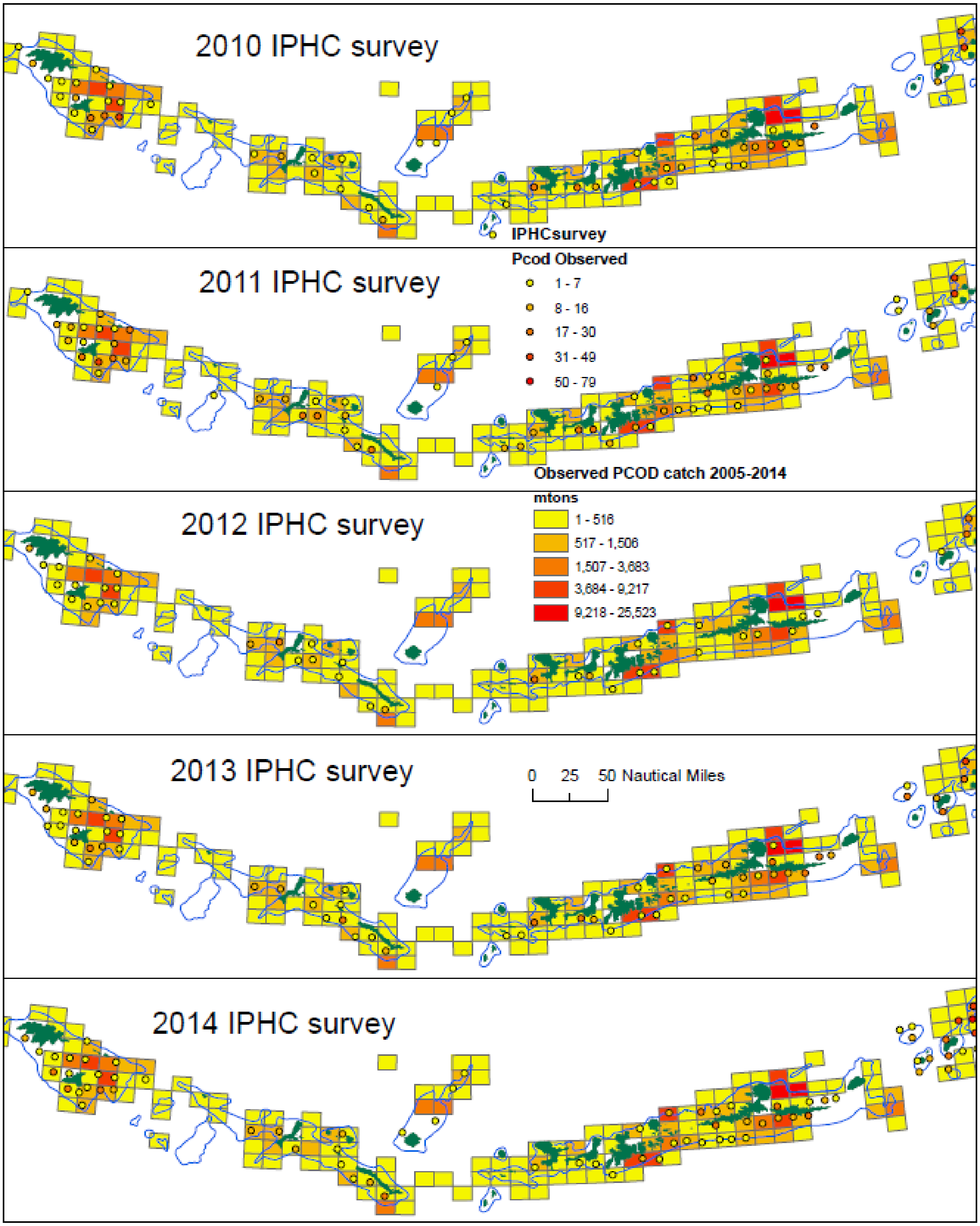


Figure 2A.1.1d—Locations of, and Pacific cod densities encountered by, the IPHC longline survey from 2010-2014 (dots), overlaid against corresponding data from the observed fisheries (squares).

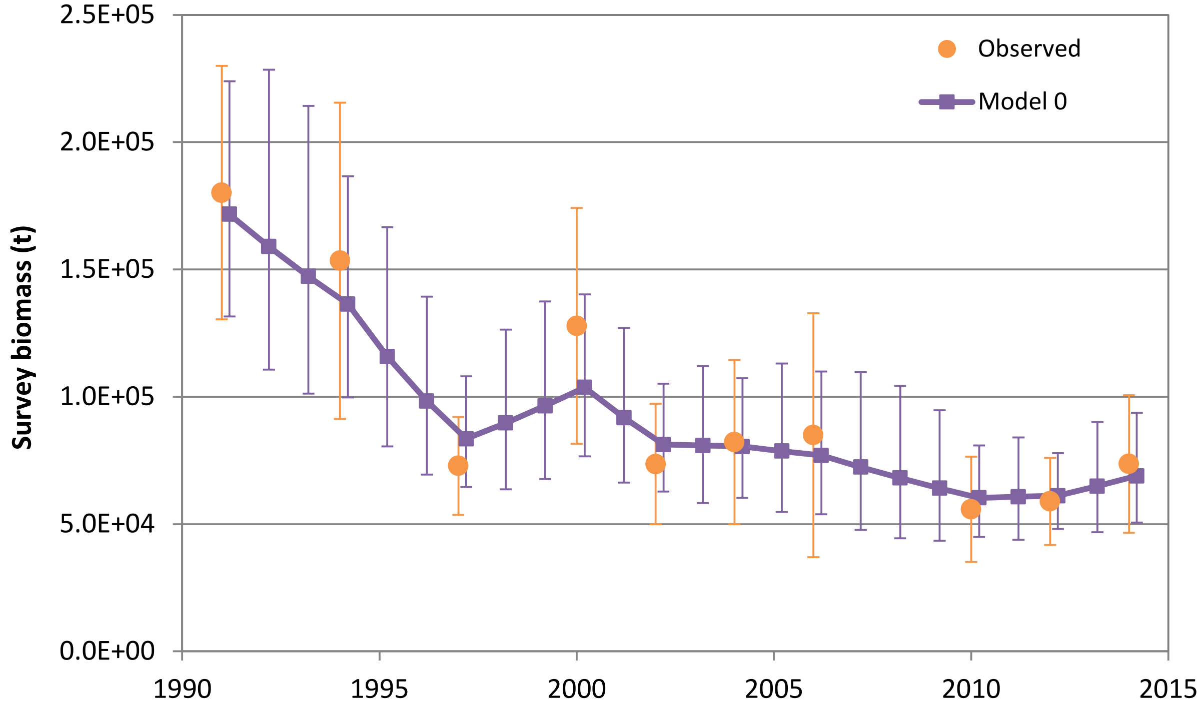


Figure 2A.1.2a—Fit of Model 0 (Tier 5 random effects) to the survey biomass time series. 95% confidence intervals are also shown.

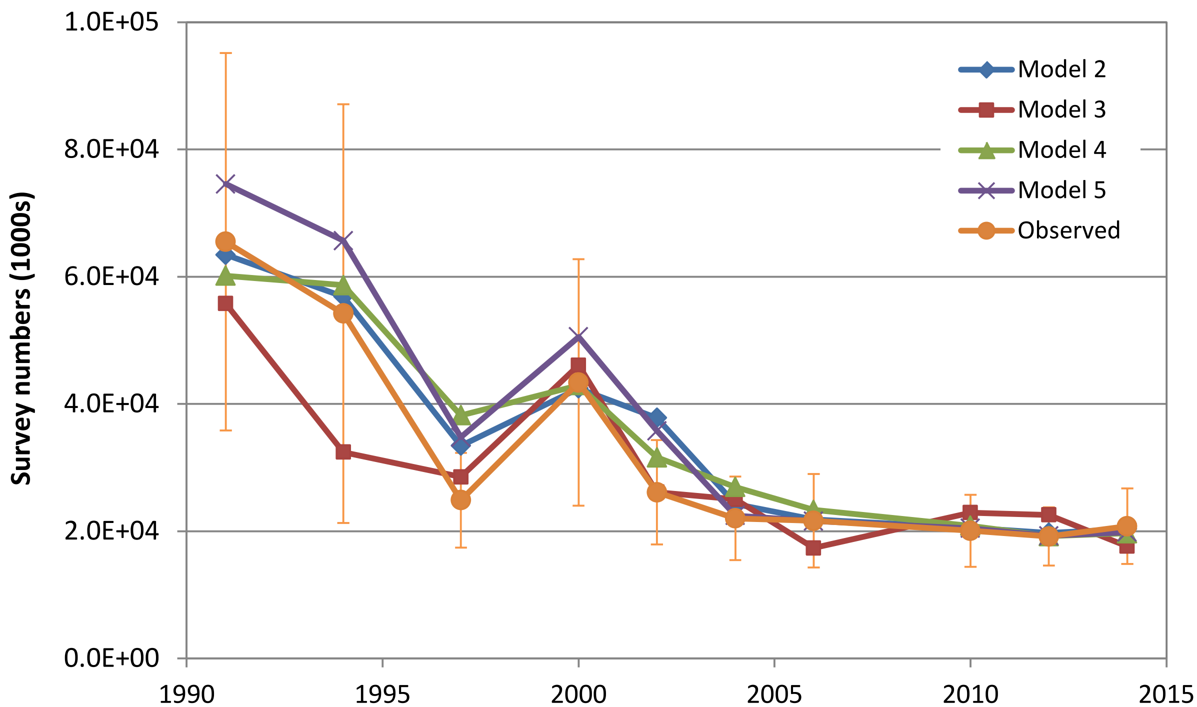
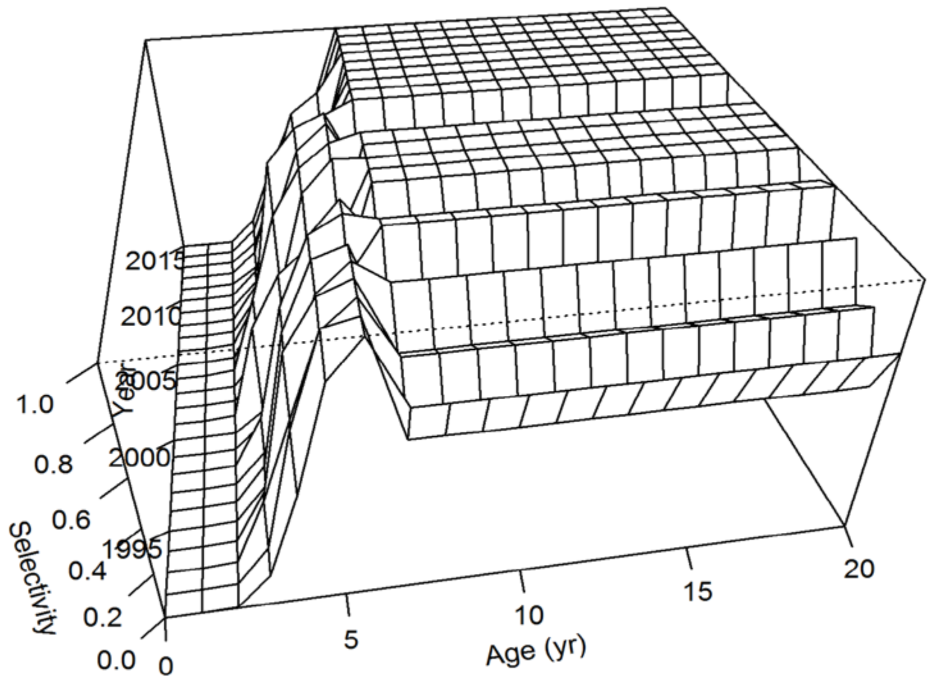


Figure 2A.1.2b—Fit of each of the age-structured models to the survey abundance time series. Survey abundance time series shows 95% confidence interval.

Model 2



Model 3

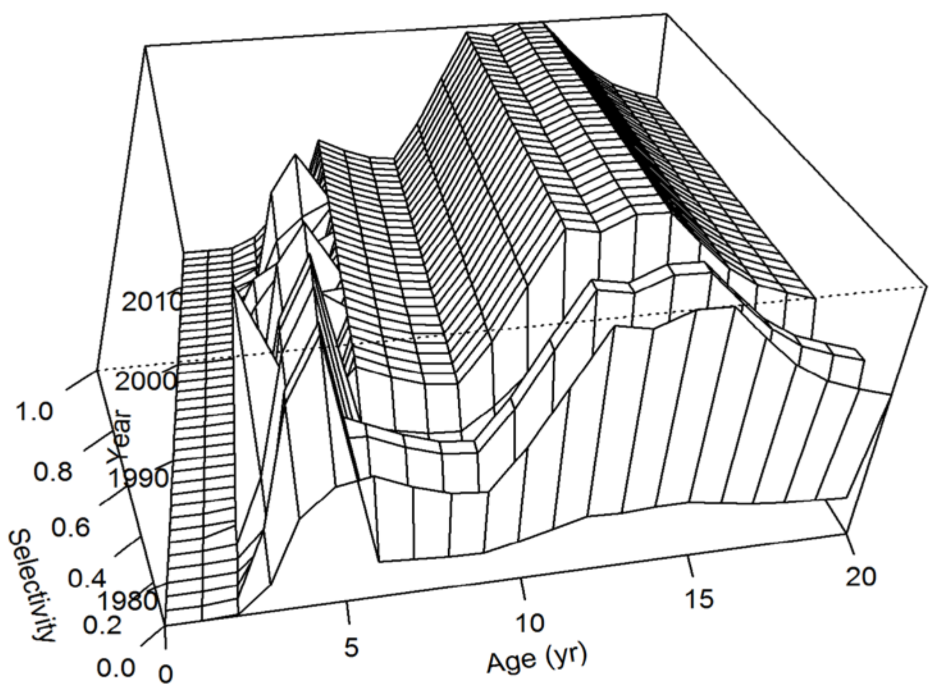
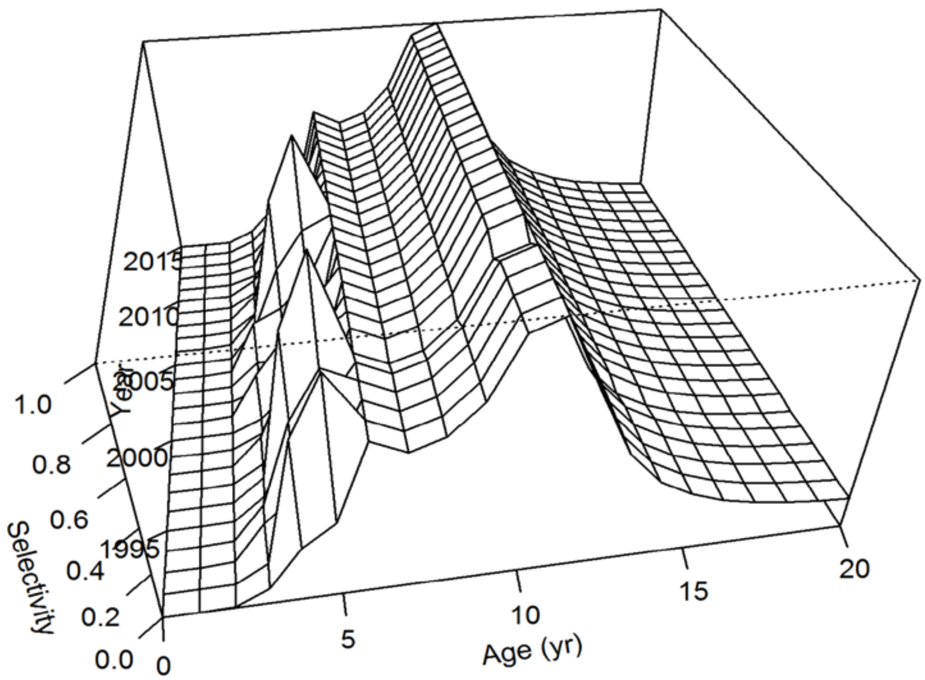


Figure 2A.1.3a—Fishery selectivity as estimated by Models 2 and 3.

Model 4



Model 5

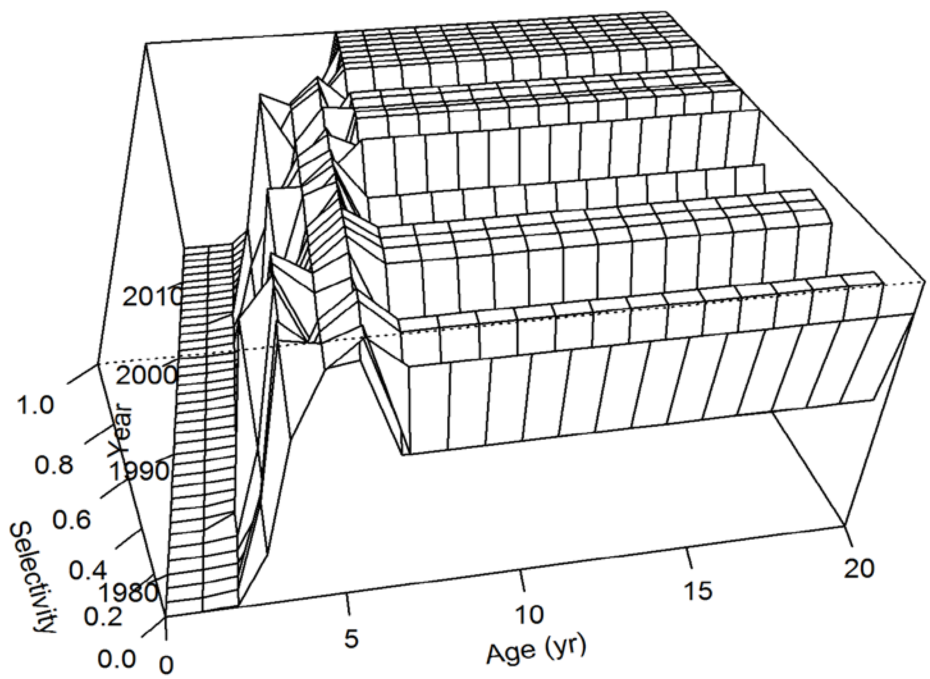
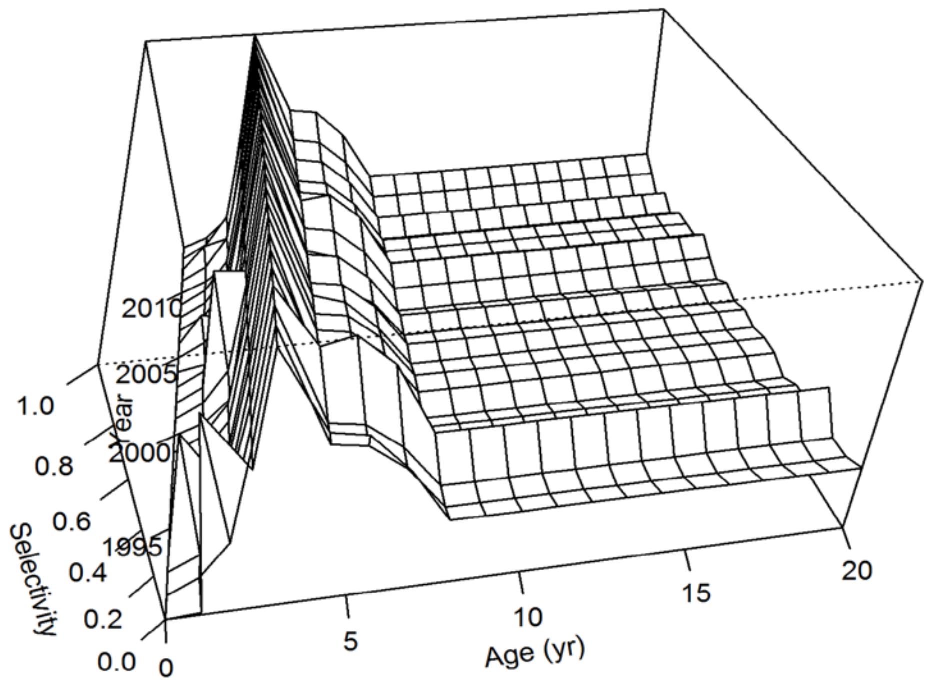


Figure 2A.1.3b—Fishery selectivity as estimated by Models 4 and 5.

Model 2



Model 3

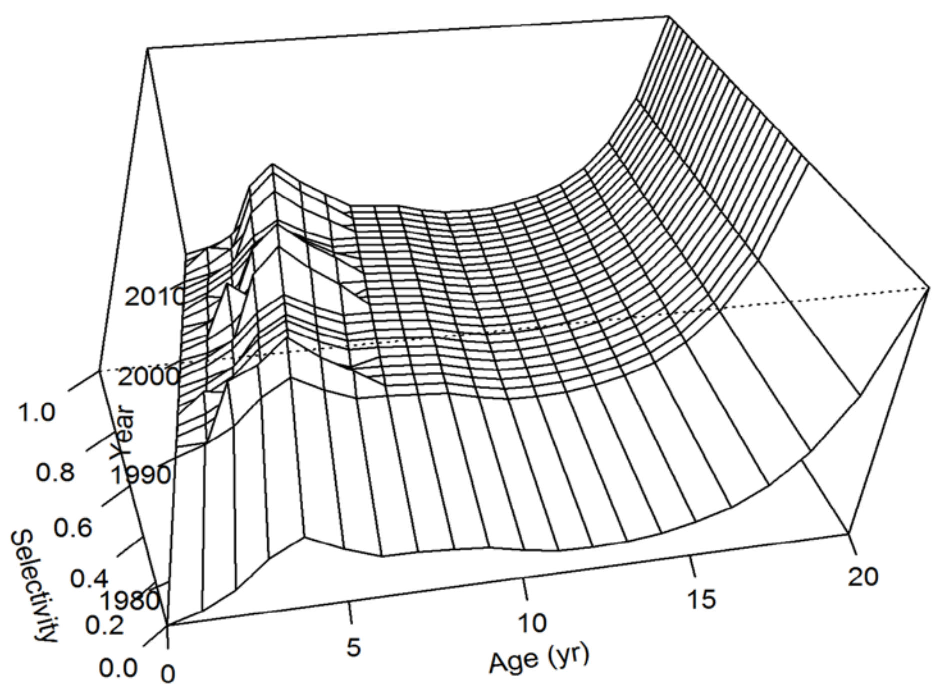
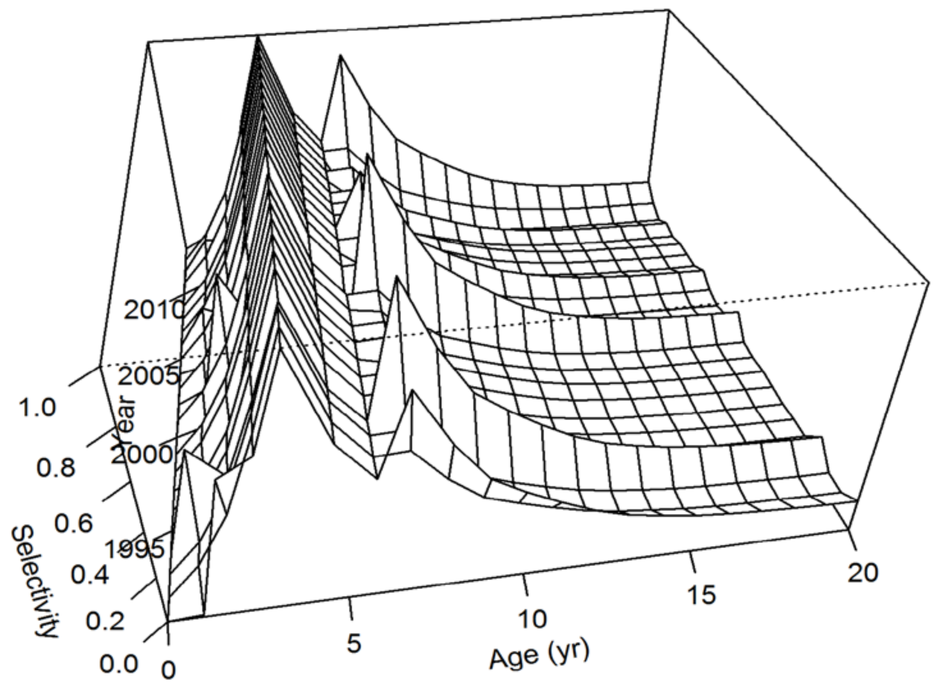


Figure 2A.1.4a—Survey selectivity as estimated by Models 2 and 3.

Model 4



Model 5

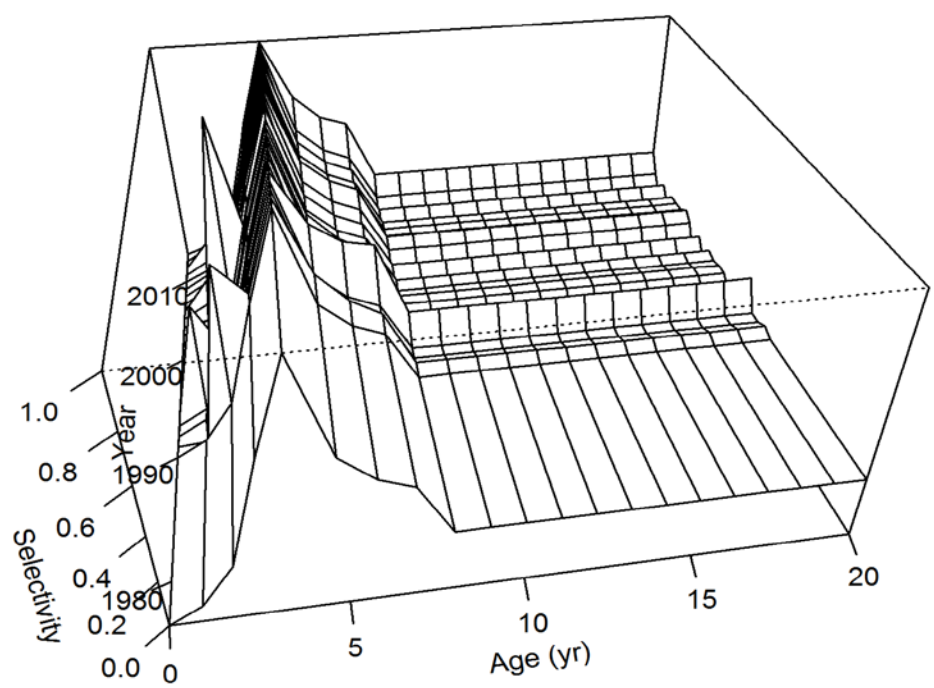


Figure 2A.1.4a—Survey selectivity as estimated by Models 4 and 5.

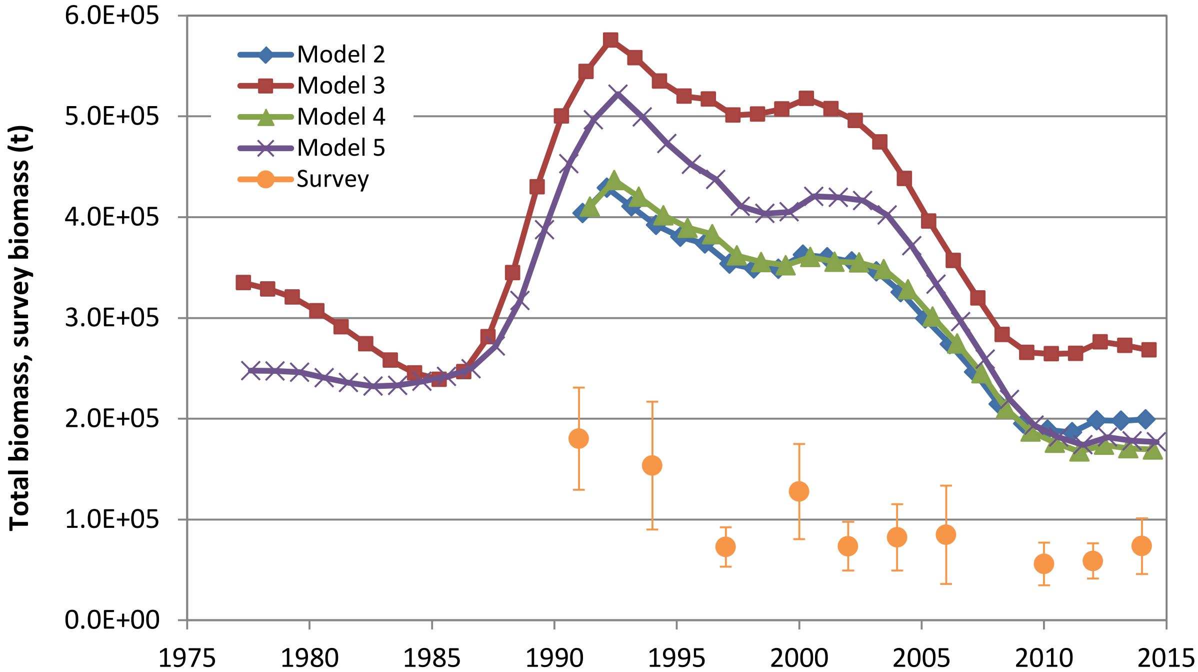


Figure 2A.1.5—Total (age 0+) biomass as estimated by Models 2-5. Survey biomass, with 95% confidence interval, is shown for comparison.

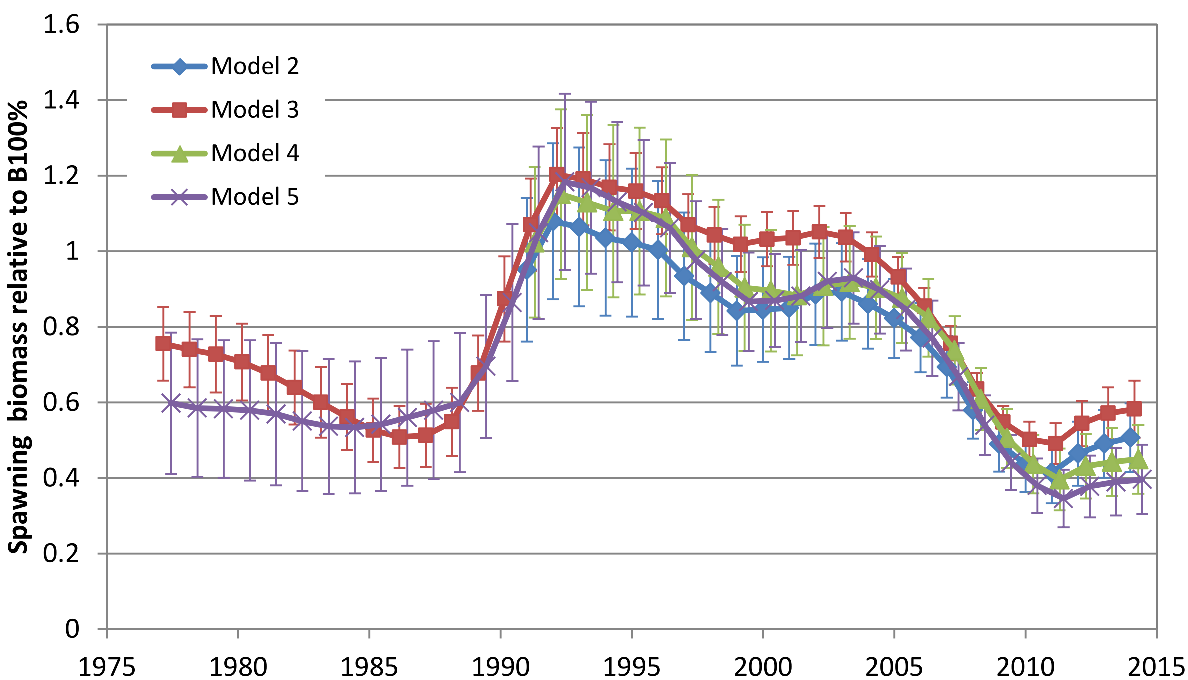


Figure 2A.1.6—Time series of spawning biomass relative to $B_{100\%}$ for each of the models, with 95% confidence intervals.

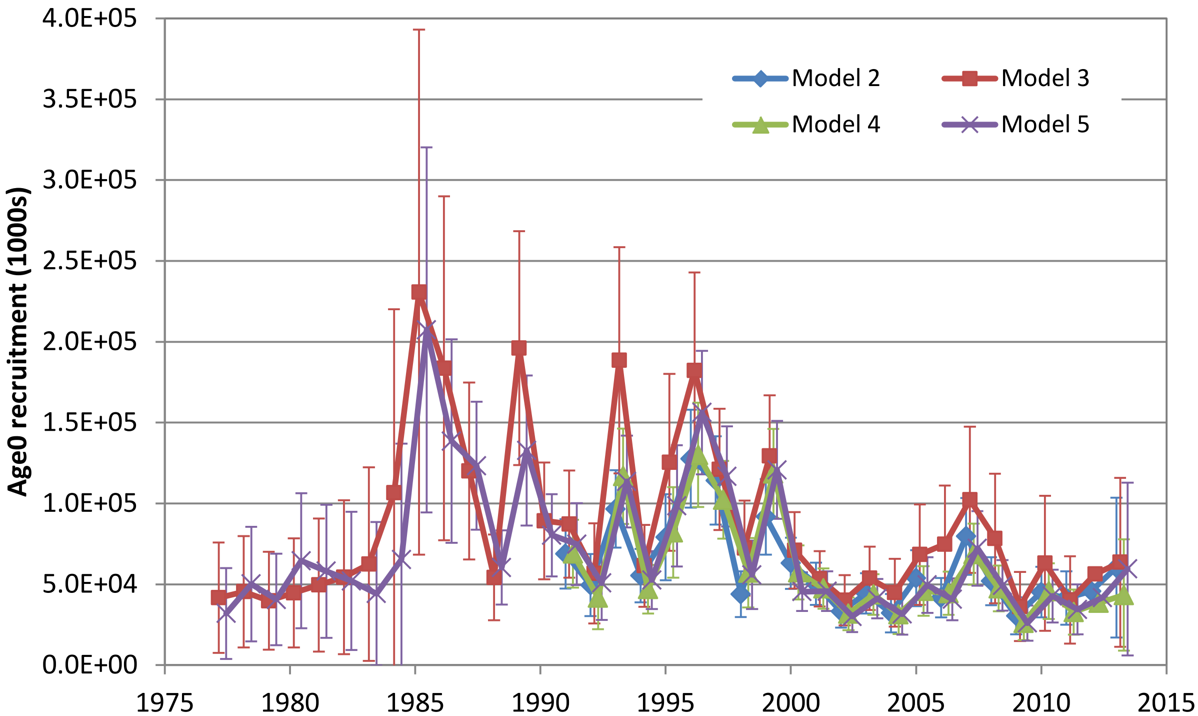


Figure 2A.1.7—Time series of age 0 recruitment (1000s of fish) for each models as estimated by Models 2-5, with 95% confidence intervals.

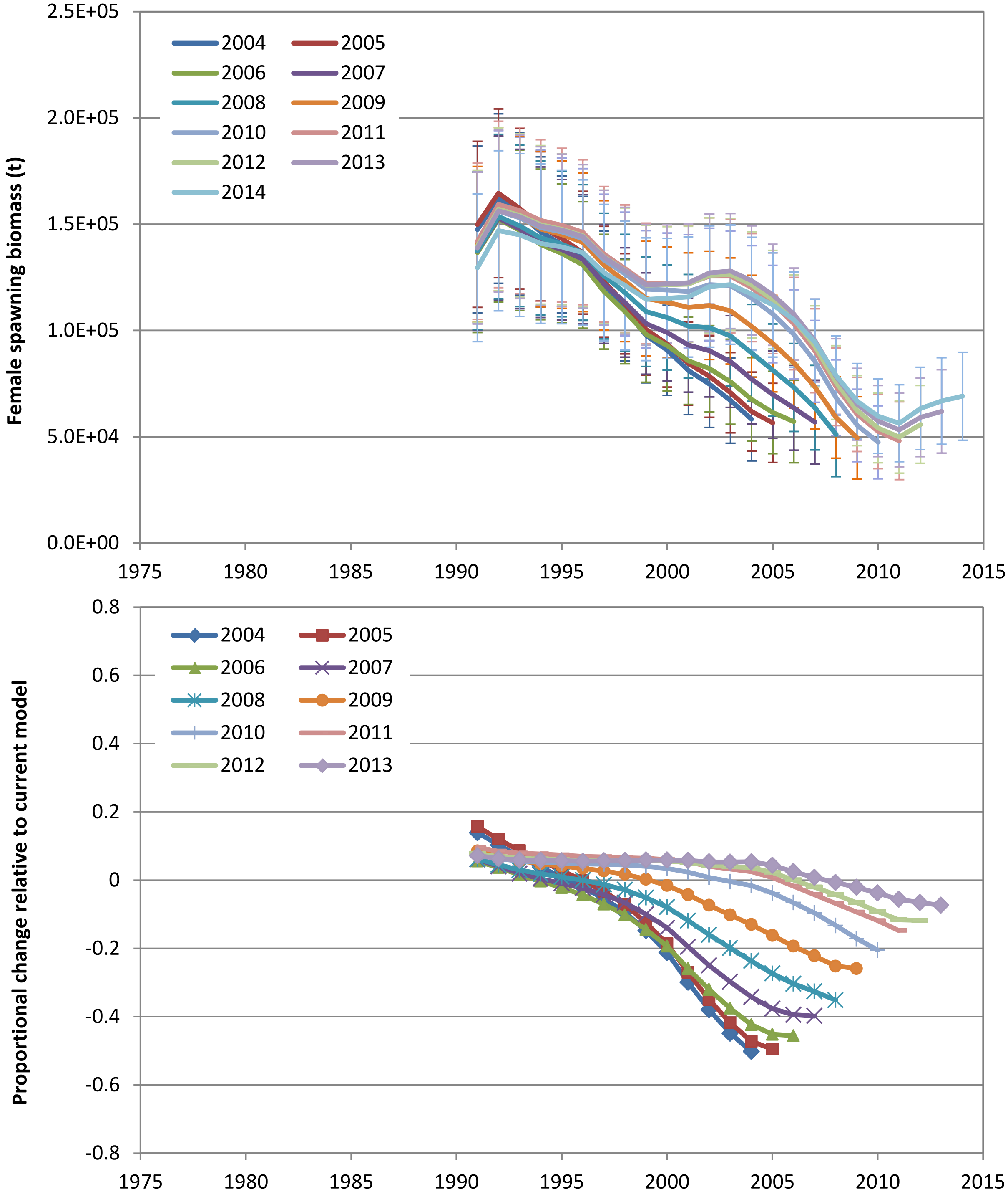


Figure 2A.1.8a—Ten-year spawning biomass retrospective analysis of Model 2.

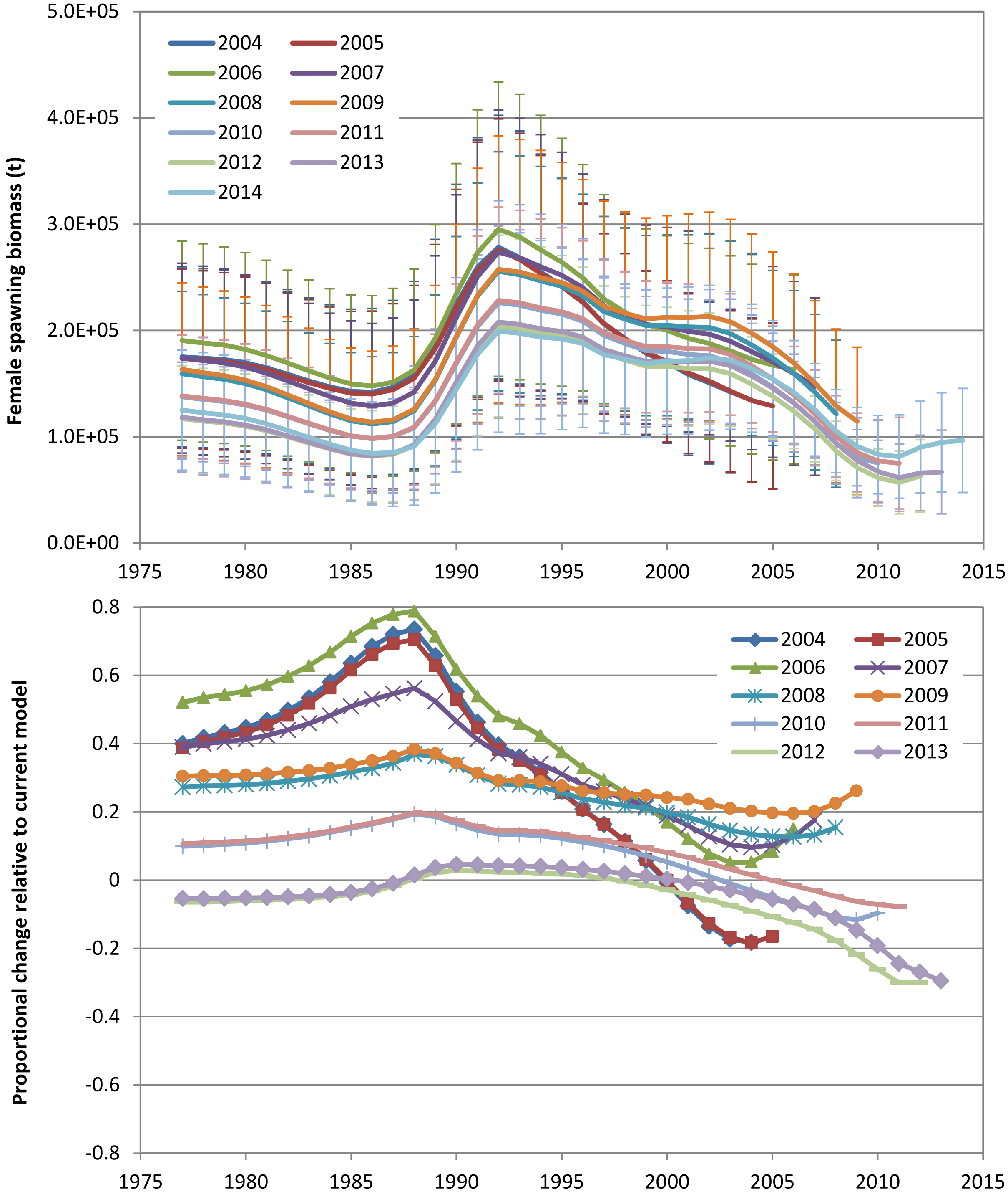


Figure 2A.1.8b—Ten-year spawning biomass retrospective analysis of Model 3.

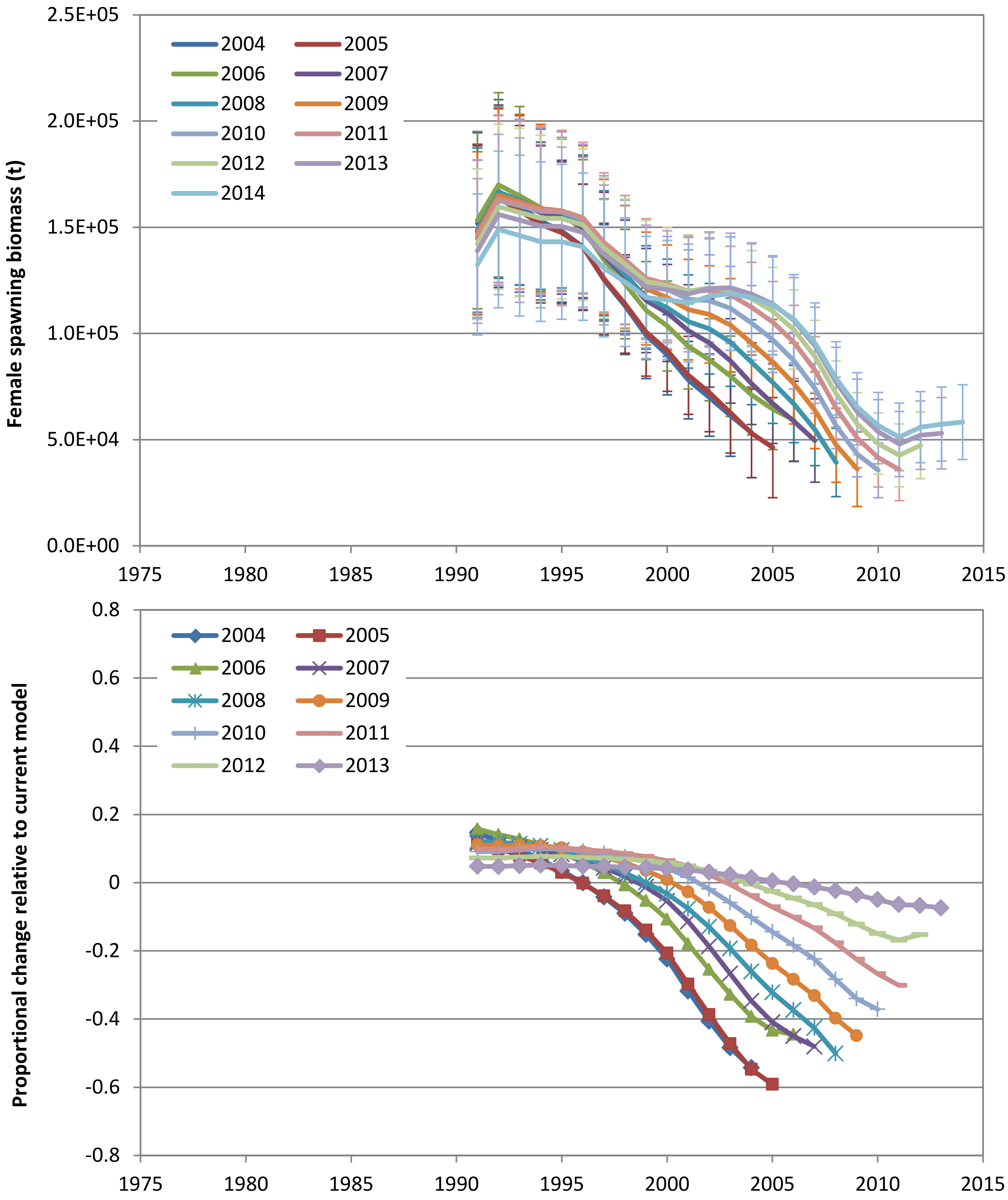


Figure 2A.1.8c—Ten-year spawning biomass retrospective analysis of Model 4.

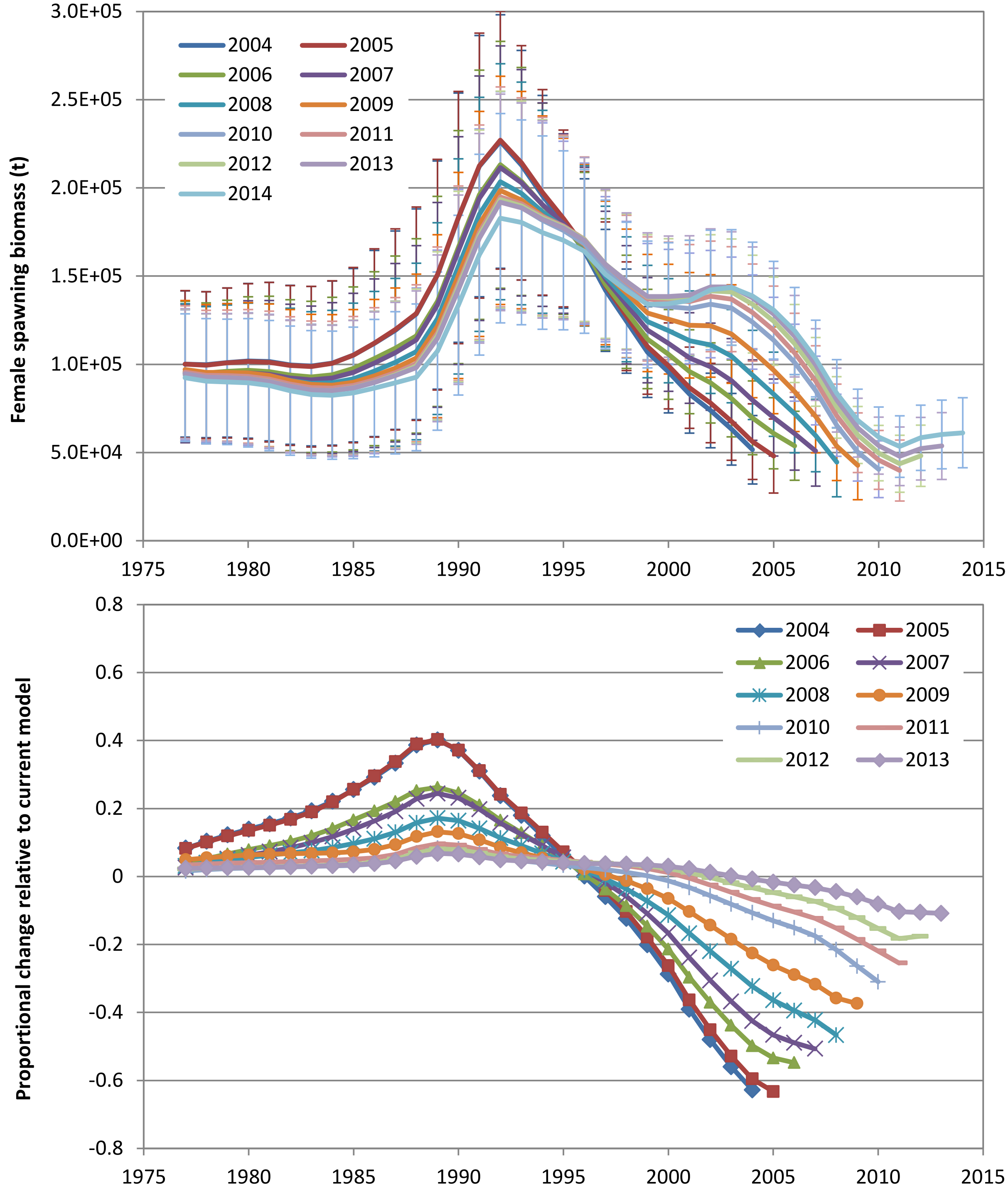


Figure 2A.1.8d—Ten-year spawning biomass retrospective analysis of Model 5.

APPENDIX 2A.2: SUPPLEMENTAL CATCH DATA

NMFS Alaska Region has made substantial progress in developing a database documenting many of the removals of FMP species that have resulted from activities outside of fisheries prosecuted under the BSAI Groundfish FMP, including removals resulting from scientific research, subsistence fishing, personal use, recreational fishing, exempted fishing permit activities, and commercial fisheries other than those managed under the BSAI groundfish FMP. Estimates for AI Pacific cod from this dataset are shown in Table 2A.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 (2012-2014) is 68 t.

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

Reference

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

Table 2A.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		19
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	1
IPHC Annual Longline Survey			14	14	14	14	14	14	14	14	14	14	14	14	9	23	9	13	15
Subsistence Fishery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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

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

Pre-2011

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

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

2011

Preliminary assessment

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

Final assessment

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

2012

Preliminary assessment

Two models were included:

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

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

Final assessment

Four models were included:

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

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

2013

Preliminary assessment

Three models were included:

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

Final assessment

Four models were included:

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

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

2014

Preliminary assessment

Three models were included:

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

Final assessment

Three models were included:

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

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