12. Assessment of the Pacific ocean perch stock in the Bering Sea/Aleutian Islands

by

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Executive Summary

The last full assessment for Pacific ocean perch (POP) was presented to the Plan Team in 2016. The following changes were made to POP assessment relative to the November 2016 SAFE:

Summary of Changes in Assessment Inputs

Changes in the Input Data

1) Catch data was updated through 2017, and total catch for 2018 was projected.
2) The 2018 AI survey biomass estimate and length composition were included in the assessment.
3) The 2016 age compositions from the AI trawl survey and EBS slope trawl survey were included in the assessment.
4) The 2016 fishery length compositions, and 2015 and 2017 fishery age compositions, were included in the assessment.
5) The length-at-age, weights-at-age, and age-to-length conversion matrix were updated based on data from the NMFS AI trawl survey beginning in 1991.
6) The weights for the age and length composition data were reweighted using the McAllister-Ianelli iterative reweighting procedure.

Changes in the Assessment Methodology

1) The number of year nodes for the fishery selectivity spline was increased from 4 to 5 to account for the additional years since the 2014 stock assessment, when this spline was initially used.

Summary of Results

A summary of the 2018 assessment recommended ABCs relative to the 2017 recommendations is shown below. BSAI Pacific ocean perch are not overfished or approaching an overfished condition. The recommended 2019 ABC and OFL are 50,594 t and 61,067 t, which are increases of 19% and 18%, respectively, from the maximum ABC and OFL specified last year for 2018 of 42,509 t and 51,675 t. The 2018 AI survey biomass is large and consistent with the survey biomass estimates in 2010-2016, and the size composition data continue to show relatively strong recent cohorts. The model is better able to fit the large AI survey biomass estimates since 2010. A summary of the recommended ABCs and OFLs from this assessment relative the ABC and OFL specified last year is shown below:

Quantity	As estimated or specified last year for: 2018	2019	As estimated or recommended this year for: 2019	2020
M (natural mortality rate)	0.058	0.058	0.056	0.056
Tier	3a	3a	3a	3a
Projected total (age 3+) biomass	749,925	734,431	934,293	914,577
Female spawning biomass (t)				
Projected	305,804	295,593	399,024	386,835
$B_{100\%}$	536,713	536,713	645,738	645,738
$B_{40\%}$	214,685	214,685	258,295	258,295
$B_{35\%}$	187,849	187,849	226,008	226,008
F_{OFL}	0.101	0.101	0.095	0.095
$maxF_{ABC}$	0.082	0.082	0.079	0.079
F_{ABC}	0.082	0.082	0.079	0.079
OFL (t)	51,675	50,098	61,067	59,396
maxABC (t)	42,509	41,212	50,594	49,211
ABC (t)	42,509	41,212	50,594	49,211
Status	As determined last year for: 2016	2017	As determined this year for: 2017	2018
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

*Projections are based on estimated catches of 34,699 t and 33,752 t used in place of maximum permissible ABC for 2019 and 2020.

Area Apportionment

The ABC for BSAI Pacific ocean perch is currently apportioned among four areas: the western, central, and eastern Aleutian Islands, and eastern Bering Sea. A random effects model was used to smooth the time series of subarea survey biomass and obtain the proportions. The estimated proportion of the stock in each subarea is shown below.

ABC apportionments

	Area WAI	CAI	EAI	SBS	EBS slope
2018 smoothed biomass estimate	388,948	204,741	278,146	110,304	245,905
percentage	31.7%	16.7%	22.6%	9.0%	20.0%

The following table gives the projected OFLs and apportioned ABCs for 2019 and 2020, and the recent OFLs, ABCs, TACs, and catches.

Area	Year	Age 3 Bio (t)	OFL	ABC	TAC	Catch[1]
BSAI	2017	767,767	53,152	43,723	34,900	32,543
	2018	749,925	51,675	42,509	37,361	28,606
	2019	934,293	61,067	50,594		
	2020	914,577	59,396	49,211		
Eastern Bering Sea	2017			12,199	11,000	8,987
	2018			11,861	11,861	5,577
	2019			14,675	n/a	n/a
	2020			14,274	n/a	n/a
Eastern Aleutian Islands	2017			10,307	7,900	7,803
	2018			10,021	9,000	6,858
	2019			11,459	n/a	n/a
	2020			11,146	n/a	n/a
Central Aleutian Islands	2017			8,009	7,000	6,868
	2018			7,787	7,500	7,311
	2019			8,435	n/a	n/a
	2020			8,205	n/a	n/a
Western Aleutian Islands	2017			13,208	9,000	8,886
	2018			12,840	9,000	8,859
	2019			16,025	n/a	n/a
	2020			15,586	n/a	n/a

[1] Catch through October 6, 2018

Responses to SSC and Plan Team Comments on Assessments in General

Comments from the October 2017 SSC meeting

SSC1: "The SSC recommends that, for those sets of environmental and fisheries observations that support the inference of an impending severe decline in stock biomass, the issue of concern be brought to the SSC, with an integrated analysis of the indices in future stock assessment cycles. To be of greatest value, to the extent possible, this information should be presented at the October Council meeting so that there is sufficient time for the Plan Teams and industry to react to the possible reduction in fishing opportunity."

To facilitate a coordinated response to this request, the co-chairs and coordinators of the BSAI and GOA Groundfish Plan Teams, with concurrence from stock assessment program leadership at the AFSC, have suggested that authors address it by using the previous year's Ecosystem Status Report (ESR) as follows:

"No later than the summer of each year, the lead author of each assessment should review the previous year's ESR and determine whether any factor or set of factors described in that ESR implies an impending severe decline in stock/complex biomass, where "severe decline" means a decline of at least 20% (or any alternative value that may be established by the SSC), and where biomass is measured as spawning biomass for Tiers 1-3 and survey biomass as smoothed by the standard Tier 5 random effects model for Tiers 4-5. If an author determines that an impending severe decline is likely and if that decline was not anticipated in the most recent stock assessment, he or she should summarize that evidence in a document that will be reviewed by the respective Team in September of that year and by the SSC in

October of that year, including a description of at least one plausible mechanism linking the factor or set of factors to an impending severe decline in biomass, and also including an estimate or range of estimates regarding likely impacts on ABC. In the event that new survey or relevant ESR data become available after the document is produced but prior to the October Council meeting of that year, the document should be amended to include those data prior to its review by the SSC, and the degree to which they corroborate or refute the predicted severe decline should be noted, with the estimate or range of estimates regarding likely impacts on ABC modified in light of the new data as necessary."

This suggestion was followed, and new information is added to the "Ecosystem considerations" section. The estimated spawning stock biomass for BSAI Pacific ocean perch has not shown a severe decline.

SSC2: "The SSC also recommends explicit consideration and documentation of ecosystem and stock assessment status for each stock ... during the December Council meeting to aid in identifying stocks of concern."

This recommendation was subsequently clarified, at some length, in the minutes of the December 2017 SSC meeting and then re-clarified in the minutes of the June 2018 SSC meeting. In the interest of efficiency, the clarification from the December 2017 minutes is not included here. The relevant portion of the clarification from the June 2018 minutes reads as follows:

"This request was recently clarified by the SSC by replacing the terms 'ecosystem status' and 'stock assessment status' with 'Ecosystem Status Report information' and 'Stock Assessment Information,' where the potential determinations for each will consist of 'Okay' and 'Not Okay,' and by issuing the following guidance:

- *The SSC clarifies that 'stock assessment status' is a fundamental requirement of the SAFEs and is not really very useful to this exercise, because virtually all stocks are never overfished nor is overfishing occurring.*

- *Rather the SSC suggests that recent trends in recruitment and stock abundance could indicate warning signs well before a critical official status determination is reached. It may also be useful to consider some sort of ratio of how close a stock is to a limit or target reference point (e.g., B/B35). Thus, additional results for the stock assessments will need to be considered to make the 'Okay' or 'Not Okay' determinations.*

- *The SSC retracts its previous request for development of an ecosystem status for each stock/complex. Instead, while considering ecosystem status report information, it may be useful to attempt to develop thresholds for action concerning broad-scale ecosystem changes that are likely to impact multiple stocks/complexes.*

- *Implementation of these stock and ecosystem determinations will be an iterative process and will require a dialogue between the stock assessment authors, Plan Teams, ecosystem modelers, ESR editors, and the SSC."*

The iterative process described in the final bullet above is scheduled to begin at this year's September meeting of the Joint BSAI and GOA Plan Teams. We will revisit this recommendation when the criteria for these determinations are finalized.

Comments from the December 2017 SSC meeting

SSC3: "The SSC reminds authors of the need to balance the desire to improve model fit with increased risk of model misspecification." This recommendation was subsequently clarified in the minutes of the June 2018 SSC meeting as follows: *"In the absence of strict objective guidelines, the SSC recommends that thorough documentation of model evaluation and the logical basis for changes in model complexity be provided in all cases."*

The complexity of the BSAI POP stock assessment model has not changed since the 2016 assessment, with the minor exception of increasing the number in year nodes in the spline for fishing selectivity. An initial evaluation of a model that considers time-varying survey catchability is presented in an appendix.

SSC4: "Report a consistent metric (or set of metrics) to describe fish condition among assessments and ecosystem documents where possible." Fish condition is not reported in this assessment and will be considered for future assessments.

SSC5: "Projections ... clearly illustrate the lack of uncertainty propagation in the 'proj' program used by assessment authors. The SSC encourages authors to investigate alternative methods for projection that incorporate uncertainty in model parameters in addition to recruitment deviations. Further, the SSC noted that projections made on the basis of fishing mortality rates (Fs) only will tend to underestimate the uncertainty (and perhaps introduce bias if the population distribution is skewed). Instead, a two-stage approach that first includes a projection using F to find the catch associated with that F and then a second projection using that fixed catch may produce differing results that may warrant consideration."

Following a consensus recommendation from the co-chairs and coordinators of the BSAI and GOA Groundfish Plan Teams, stock assessment program leadership at the AFSC has agreed to take the following steps:

1. Notify assessment authors that, for the purpose of the standard projection scenarios, the previous requirements for use of the standard Tier 3 projection model and measurement of spawning biomass at the time of peak spawning no longer apply, thereby enabling authors to use Stock Synthesis (SS) or other software to make the projections.

2. Task one or more individuals with modifying the current standard projection code so as to accommodate this request for non-SS Tier 3 assessments, with the understanding that it may not be possible to accomplish this in time for use in the 2018 assessments.

3. Task the authors of Tier 1 assessments with modifying their projection code so as to accommodate this request for Tier 1 assessments, with the understanding that it may not be possible to accomplish this in time for use in the 2018 assessments.

This recommendation will be revisited when the set of individuals tasked with modifying the projection code completes this task. Additionally, for some rockfish stocks there may be a period of several years in which rockfish are partially selected to either a fishery or survey, so incorporating the uncertainties in the recruitment strengths is also of interest for the projection model.

Comments from the October 2018 SSC meeting

SSC6: "Stock assessment authors are encouraged to work with ESR analysts to identify a small subset of indicators prior to analysis, and preferably based on mechanistic hypotheses."

Prior to the next full assessment for BSAI POP, we will work with ESR analysts for assess whether a small set of informative indicators can be identified.

SSC7: "The SSC supports the PT recommendation to make the use of model-based survey estimates at the individual author's discretion for 2018."

The minutes of the September 2017, Joint Plan Team contained several research recommendations for model-based survey estimates, and plans to create an AFSC workgroup to address these recommendations are developing. Several of these recommendations can be addressed by developing a detailed simulation framework that incorporates the catchability and availability for Alaska surveys. Model-based survey estimates will be considered as these Plan Team research recommendations are addressed.

SSC8: "The SSC also noted that, in order to save resources, authors should not conduct additional assessments beyond the prioritized schedule unless they specifically trigger one or more of the criteria identified."

In future off-years for BSAI Pacific ocean perch, the criteria identified for triggering a full assessment will be evaluated.

SSC9: "The general approach to accounting for costs and benefits of this [stock] prioritization during the initial four years seems to be a reasonable response to the SSCs request. However, specific benefits (e.g., 'additional' analyses completed) may be difficult to assign unambiguously to reduced assessment frequency. The SSC recognizes these challenges in light of its previous requests."

The frequency of BSAI rockfish age-structured stock assessments has not been reduced, but the scheduling has changed such that no more than 2 full age-structured assessments are conducted within a single year (reduced from 3 full age-structure assessments in a single year). For this year's assessment, this allowed time to more fully investigate the retrospective pattern.

Responses to SSC and Plan Team Comments Specific to this Assessment

BSAIPT1 (November 2016): "The Team recommends examining the residual pattern in the fit to the AI survey to see if there was a substantial change in the survey design or potential model misspecification that would explain the change in sign of the residuals between 2006 and 2010."

SSC10 (December 2016): The SSC appreciates the work addressing several SSC comments from the December 2014 minutes and looks forward to continued work on several of these topics including:

- *Continued investigation into the large and problematic retrospective pattern observed for this model.*
- *Further examine the evidence supporting the survey selectivity changes in the most recent years in the model.*
- *Explore estimates of biological parameters like maturity to see if there are trends in these estimates.*
- *Continue work on empirical studies of rockfish densities on trawlable and untrawlable grounds to help inform a prior distribution for survey catchability.*
- *The Plan Team's recommendation to further investigate the poor residual pattern observed in the fit to the AI survey index.*

The SSC also recommends continued investigation into the estimation of natural mortality and the apparently constraining effect of the current prior.

As the comment from the SSC notes, several of these comments have been raised in the 2014 assessment, Responses to comments were presented in the 2015 and 2016 assessments, some of which are summarized below.

Survey selectivity is modeled as constant over time. An examination of the fishery and survey age composition data, conducted in the 2014 assessment, indicates that the relative age composition of old fish (i.e., within the plus group of 40+ years) is lower in the fishery than the survey in the 1990s, suggesting that the catchability for these old fish is lower than the fishery than the survey. Around 2010, the proportion of older fish in the survey and fishery are more equal to each other, suggesting that fishery selectivity may have become less dome-shaped over time. Although the mechanisms for these changes are unclear, the spatial areas where POP are captured have changed from the mid-1990s to the present.

Evaluation of trends in maturity estimates requires ongoing maturity sampling, which does not currently exist. Ongoing sampling may occur in the future as the result of the efforts of the MARVLS (Maturity Assessment, Reproductive Viability, and Life Strategies) workgroup. Evaluation of trends in growth parameters are examined each full assessment year and have not been observed to date.

A research paper studying the use of using acoustic and optic technology to estimate the densities of rockfish in trawlable and untrawlable grounds is currently in internal review at AFSC. Because the survey catchability coefficient for rockfish is a function of the difference in density between the trawlable and untrawlable habitat (i.e., the "availability"), these data should help inform a prior distribution of survey catchability in future assessments.

The estimate of M in the 2018 assessment M was 0.056, slightly above the mean of the prior distribution of 0.05. Exploratory models runs conducted in the 2014 assessment indicated that a freely estimated M was ~0.07, which is on the same scale of values from several empirical estimators of M. Given these results, it would be expected that reasonable values of M could be obtaining from relaxing the prior distribution, which will be explored in future assessments.

The poor retrospective pattern and poor residual pattern for the AI survey are related issues. Appendix 12C in this assessment contains an initial examination of a model with time-varying catchability for the AI survey, which improves these issues. However, little empirical information exists to infer the degree to which the AI survey catchability has changed over time.

Introduction

Pacific ocean perch (POP, *Sebastes alutus*) inhabit the outer continental shelf and upper slope regions of the North Pacific Ocean and Bering Sea. Pacific ocean perch were occasionally managed within a species complex with four other associated rockfish species (northern rockfish, *S. polyspinis*; rougheye rockfish, *S. aleutianus*; shortraker rockfish, *S. borealis*; and sharpchin rockfish, *S. zacentrus*) in the eastern Bering Sea (EBS) and Aleutian Islands (AI) subareas from 1979 to 1990. Known as the POP complex, these five species were managed as a single entity with a single TAC (total allowable catch) for each of these two areas. In 1991, the North Pacific Fishery Management Council separated POP from the other red rockfish in order to provide protection from possible overfishing. Of the five species in the former POP complex, *S. alutus* has historically been the most abundant rockfish in this region and has contributed most to the commercial rockfish catch.

Information on Stock Structure

A variety of types of research can be used to infer stock structure of POP, including age and length compositions, growth patterns and other life-history information, and genetic studies. Spatial differences in age or length compositions can be used to infer differences in recruitment patterns that may correspond to population structure. In Queen Charlotte Sound, British Columbia, Gunderson (1972) found substantial differences in the mean lengths of POP in fishery hauls taken at similar depths which were related to differences in growth rates and concluded that POP likely form aggregations with distinct biological characteristics. In a subsequent study, Gunderson (1977) found differences in size and age composition between Moresby Gully and two other gullies in Queen Charlotte Sound. Westrheim (1970, 1973) recognized “British Columbia” and “Gulf of Alaska” POP stocks off the western coast of Canada based upon spatial differences in length frequencies, age frequencies, and growth patterns observed from a trawl survey. In a study that has influenced management off Alaska, Chikuni (1975) recognized distinct POP stocks in four areas – eastern Pacific (British Columbia), Gulf of Alaska, Aleutian Islands, and Bering Sea. However, Chikuni (1975) states that the eastern Bering Sea (EBS) stock likely receives larvae from both the Gulf of Alaska (GOA) and Aleutian Islands (AI) stock, and the AI stock likely receives larvae from the GOA stock.

An alternative approach to evaluating stock structure involves examination of rockfish life-history stages directly. Stock differentiation occurs from separation at key life-history stages. Because many rockfish species are not thought to exhibit large-scale movements as adults, movement to new areas and boundaries of discrete stocks may depend largely upon the pelagic larval and juvenile life-history stages. Simulation modeling of ocean currents in the Alaska region suggest that larval dispersal may occur over very broad areas, and may be dependent on month of parturition (Stockhausen and Hermann 2007).

Analysis of field samples of rockfish larvae are hindered by difficulties in identifying species. Analyses of archived *Sebastes* larvae was undertaken by Dr. Art Kendall revealed that species identification based on morphological characteristics is difficult because of overlapping characteristics among species, as few rockfish species in the north Pacific have published descriptions of the complete larval developmental series. However, all of the larvae examined could be assigned to four morphs identified by Kendall (1991), where each morph is associated with one or more species. Rockfish identification can be aided by studies that combine genetic and morphometric techniques and information has been developed to identify individual species based on allozymes (Seeb and Kendall 1991) and mitochondrial DNA (Gharrett et al. 2001, Rocha-Olivares 1998). The Ocean Carrying Capacity (OCC) field program, conducted by the Auke Bay laboratory, uses surface trawls to collect juvenile salmon and incidentally collects juvenile rockfish. These juvenile rockfish are large enough (approximately 25 mm and larger) to allow extraction of a tissue sample for genetic analysis without impeding morphometric studies. In 2002, species identifications were made for an initial sample of 55 juveniles with both morphometric and genetic techniques. The two techniques showed initial agreement on 39 of the 55 specimens, and the genetic results motivated re-evaluation of some of the morphological species identifications. Forty of the specimens were identified as POP, and showed considerably more morphological variation for this species than previously documented.

Because stocks are, by definition, reproductively isolated population units, it is expected that different stocks would show differences in genetic material due to random drift or natural selection. Seeb and Gunderson (1988) used protein electrophoresis to infer genetic differences based upon differences in allozymes from POP collected from Washington to the Aleutian Islands. Discrete genetic stock groups were not observed, but instead gradual genetic variation occurred that was consistent with the isolation by distance model. The study included several samples in Queen Charlotte Sound where Gunderson (1972, 1977) found differences in size compositions and growth characteristics. Seeb and Gunderson (1988) concluded that the gene flow with Queen Charlotte Sound is sufficient to prevent genetic differentiation, but adult migrations were insufficient to prevent localized differences in length and age compositions. More recent studies of POP using microsatellite DNA revealed population structure at small spatial scales, consistent with the work of Gunderson (1972, 1977). These findings suggest that adult POP do not migrate far from their natal grounds and larvae are entrained by currents in localized retention areas (Withler et al. 2001).

Interpretations of stock structure are influenced by the technique used to assess genetic analysis differentiation, as illustrated by the differing conclusions produced from the POP allozyme work of Seeb and Gunderson (1988) and the microsatellite work of Withler et al. (2001). Note that these two techniques assess components of the genome that diverge on very different time scales and that, in this case, microsatellites are much more sensitive to genetic isolation. Protein electrophoresis examines DNA variation only indirectly via allozyme frequencies, and does not recognize situations where differences in DNA may result in identical allozymes (Park and Moran 1994). In addition, many microsatellite loci may be selectively neutral or near-neutral, whereas allozymes are central metabolic pathway enzymes and do not have quite the latitude to produce viable mutations. The mutation rate of microsatellite alleles can be orders of magnitude higher than allozyme locus mutation rates. Most current studies on rockfish genetic population structure involve direct examination of either mitochondrial DNA (mtDNA) or microsatellite DNA.

Dr. Anthony Gharrett (UAF-Fairbanks) has examined the mtDNA and microsatellite variation for POP samples collected in the GOA and BSAI. The POP mtDNA analysis was performed on 124 fish collected from six regions ranging from southeast Alaska to the Bering Sea slope and central Aleutian Islands. No population structure was observed, as most fish (102) were characterized by a common haplotype. Preliminary results from an analysis of 10 microsatellite loci from the six regions resulted in seven loci with significant heterogeneity in the distribution of allele frequencies. Additionally, the sample in each region was statistically distinct from those in adjacent regions, suggesting population structure on a relatively fine spatial scale consistent with the results on Gunderson (1972, 1977) and Withler et al. (2001). Ongoing genetic research with POP is focusing on increasing the sample sizes and collection sites for the microsatellite analysis in order to further refine our perception of stock structure.

Fishery

POP were highly sought by Japanese and Soviet fisheries and supported a major trawl fishery throughout the 1960s. Catches in the eastern Bering Sea peaked at 47,000 (metric tons, t) in 1961; the peak catch in the Aleutian Islands region occurred in 1965 at 109,100 t. These stocks were not productive enough to support such large removals. Catches continued to decline throughout the 1960s and 1970s, reaching their lowest levels in the mid-1980s. With the gradual phase-out of the foreign fishery in the 200-mile U.S.

Exclusive Economic Zone (EEZ), a small joint-venture fishery developed but was soon replaced by a domestic fishery by 1990. In 1990 the domestic fishery recorded the highest POP removals since 1977. The OFLs, ABCs, TACs, and catches by management complex from 1977 to 2001 (when POP were managed as separate stocks in the EBS and AI) are shown in Table 12.1. Note that in some years, POP were managed in the “POP complex” management group, which also included rougheye rockfish, shortraker rockfish, northern rockfish, and sharpchin rockfish. Beginning in 2002 POP were managed as a single stock across the BSAI (with the ABC subdivided between the EBS and AI subareas), and the BSAI OFLs, ABCs, TACs, and catches from 2002 to 2018 are shown in Table 12.2. The catches of POP from 1977 by fishery type (i.e., foreign, joint venture, or domestic) is shown in Table 12.3.

Estimates of retained and discarded POP from the fishery have been available since 1990 (Table 12.4). From 1990-2009, the eastern Bering Sea region generally showed a higher discard rate than in the Aleutian Islands region, with the average rates 33% and 14%, respectively. From 2010-2016, discard rates in the eastern Bering Sea and the Aleutian Islands were low, averaging 10% and 1% respectively. In 2017 and 2018, the discard rates in the AI area increased to 22% and 32%, respectively.

Initial age-structured assessments for BSAI POP modeled separate selectivity curves for the foreign and domestic fisheries (Ianelli and Ito 1992), although examination of the distribution of observer catch reveals interannual changes in the depth and areas in which POP are observed to be caught within the foreign and domestic periods. For example, POP are predominately taken in depths between 200 m and 300 m, although during the late 1970s to early1980s, and again in the mid-1990s, a relatively large portion of POP were observed to be captured at depths greater than 300 m (Table 12.5, Figure 12.1). Additionally, the proportion caught between 100 m and 200 m increased from ~ 20% in the early to mid-1990s to 28% from 2000-2010. The area of capture has changed as well; during the late 1970s POP were predominately captured in the western Aleutians (area 543), whereas from the early 1980s to the mid-1990s POP were captured predominately in the eastern Aleutians (area 541). Establishment of area-specific TACs in the mid-1990s redistributed the POP catch such that about 50% of the current catch is now taken in the western Aleutians (Table 12.6, Figure 12.1). Note that the extent to which the patterns of observed catch can be used as a proxy for patterns in total catch is dependent upon the degree to which the observer sampling represents the true fishery. In particular, the proportions of total POP caught that were actually sampled by observers were very low in the foreign fishery, due to low sampling ratio prior to 1984 (Megrey and Wespestad 1990).

Non-commercial catches are shown in Appendix 12.A.

An Economic Performance Report (EPR) for BSAI rockfish is included at Appendix 12B, and contains information on the value and per-unit price of BSAI rockfish. In 2017, the first-wholesale value of BSAI rockfish was 42 million UD$, of which 88% was BSAI Pacific ocean perch. The price per pound of BSAI POP increased from 1.05 UD$ in 2015 to 1.12 US$ in 2017.

Data

Fishery Data

Length measurements and otoliths read from the EBS and AI management areas (Tables 12.7 and 12.8) were combined to create fishery age and size compositions, with the length composition within management subareas weighted by the estimated catch numbers from observed tows. Age and/or length composition were not included for several years due to low samples sizes of fish measured (years 1973-1976, 1985-1986), and/or otoliths read (years 1984-86). In 1982, the method for aging otoliths at the Alaska Fisheries Science Center changed from surface reading to the break and burn method (Betty Goetz, Alaska Fisheries Science Center, pers. comm.), as the latter method is considered more accurate for older fish (Tagart 1984). The time at which the otoliths collected from 1977 to 1982 were read is not known for many vessels and cruises. However, the information available suggests that otoliths from 1977 to 1980 were read prior to 1981, whereas otoliths from 1981 and 1982 were read after 1982. Thus, fishery otoliths from 1977 to 1980 were not used because they were believed to be read by surface ageing and thought to be biased.

Beginning in 1998, samples of otoliths from the fishery catch have been read almost annually or biennially, and show relatively strong year classes from 1984-1988. Fishery age compositions from 2005-2017 indicate several strong recent year classes from 2003-2007 (Figure 12.2).

Survey Data

Cooperative U.S. – Japan trawl surveys were conducted in the AI 1980, 1983, and 1986, and have been used in previous BSAI POP assessments. However, differences exist in gear design and vessels used between these surveys and the NMFS surveys beginning in 1991 (Skip Zenger, National Marine Fisheries Service, personal communication). For example, the Japanese nets used in the 1980, 1983, and 1986 cooperative surveys varied between years and included large roller gear (Ronholt et al. 1994), in contrast to the poly-nor'eastern nets used in the current surveys (von Szalay et al. 2017), and similar variations in gear between surveys occurred in the cooperative EBS surveys. Given the difficulty of documenting the methodologies for these surveys, and standardizing these surveys with the NMFS surveys, this assessment model is conducted with only the NMFS surveys.

The Aleutian Islands survey biomass estimates were used as an index of abundance for the BSAI POP stock. Since 2000 the survey has occurred biennially, although the 2008 survey was canceled due to a lack of funding. Note that there is wide variability among survey estimates from the southern Bering Sea portion of the survey (from 165 ° W to 170 ° W), as the post-1991 coefficients of variation (CVs) range from 0.41 to 0.64 (Table 12.9), although the trend in the region appears to be increasing. The biomass indices of Pacific ocean perch in the Aleutian Islands management area region (170° W to 170° E) appears to be less variable, with CVs ranging from 0.11 in 2016 to 0.23 in 1994 (Table 12.9). The biomass estimates for the AI subarea (excluding the southern Bering Sea area) have ranged between a low of 342,785 t in 1991 and 901,263 t in 2018. From 2010-2018, the total AI survey biomasses have exceeded 900,000 t for each survey, whereas the survey estimates prior to 2010 have not exceeded 665,000 t.

The 2018 survey biomass estimate of 1,016,309 t is a 3% increase from the 2016 estimate of 982,503 t (Table 12.9). The 2018 AI survey biomass was within 6% of the 2016 estimates for the WAI, CAI, and EAI subareas, where the 2018 estimate for the SBS area (115,046 t) was 30% larger than the 2016 estimate (87,952 t). Maps of survey CPUE are shown in Figure 12.3, and indicate relatively high abundance throughout much of the Aleutian Islands. The coefficient of variation (CV) for 2016 and 2018 surveys of 0.11 were the lowest CVs observed.

The increase in the survey biomass has resulted in an increase in the minimum area occupied by the stock, as computed from the strata-specific survey population estimates. The minimum area covered by the stock was obtained from the computing the area associated with trawl tows contributing 95% ($D_{95\%}$) of abundance estimate, where the area for any given tow is the area of its strata divided by the strata sample size (Swain and Sinclair, 1994). This metric produces measure of area that is independent of the scale of population abundance, and reflects the spatial extent of a core portion of the population that excludes the area for tows with very small CPUE values. The $D_{95\%}$ values for POP increased from 5,934 km^2 in 1991 to 12,300 km^2 in 2018 (Figure 12.4), an increase by a factor of 2.1.

Examination of the AI survey abundance estimate by strata indicates that high abundance and rates of increase are widespread throughout the AI survey area. Of the 45 AI survey strata, 79% of the 2018 population estimate was contained in 10 strata, with at least one of these ten strata occurring in each of the 4 major strata regions (i.e., 5 in the WAI, 1 in the CAI, and 2 each in the EAI and SBS) (Table 12.10). In 9 of these strata, the average population estimate from the 2010-2018 surveys exceeded population estimate from the 1991-2006 surveys (Figure 12.5). The average value for this ratio of abundances was 1.82 in the top 4 strata for 2018 population abundance (Table 12.10).

Age composition data exists for each Aleutian Islands survey, and the numbers of length measurements taken and otoliths read are shown in Table 12.11. The survey age compositions from 1991-2000 indicate relatively strong year classes in 1977, 1984, and 1988. Recent age composition data from 2004 -2012 indicate relatively strong year classes from 1996 to 2000, and the 2014 and 2016 age compositions indicates relative strong 2004 and 2005 year classes (Figure 12.6).

The current EBS slope survey was initiated as a biennial survey in 2002. The most recent slope survey prior to 2002, excluding some preliminary tows in 2000 intended for evaluating survey gear, was in 1991. The biomass indices in the EBS slope survey have been increasing, ranging from 72,665 t in 2002 to 357,369 t in the 2016 survey, with CVs ranging from 0.68 in 2016 to 0.53 in 2002 (Table 12.9). EBS survey CPUE from the 2016, 2012, and 2010 surveys are shown in Figure 12.7. The slope survey was not conducted in 2006, 2014, and 2018 due to lack of funding or vessels. Age composition data for the EBS survey are available for all survey years (Figure 12.8).

Biological data

A large number of samples are collected from the surveys for age determination, length-weight relationships, sex ratio information, and for estimating the length distribution of the population. The age compositions for inclusion in the model were estimated outside the model by constructing age-length keys for each year and using them to estimate the survey age distribution from the estimated survey length distribution from the same year. Because the survey length distributions are used to create the survey age distributions, the survey length distributions are removed from the model in years in which we have survey ages. The survey age data were based on the break and burn method of ageing POP, so they were treated as unbiased but measured with error. Kimura and Lyons (1991) reported that the percent agreement between readers varies from 60% for age 3 fish to 13% for age 25 fish data. The information on percent agreement was used to derive the variability of observed age around the “true” age, assuming a normal distribution. The mean number of fish at age available to the survey or fishery is multiplied by the aging error matrix to produce the expected observed survey or fishery age compositions.

Aging methods have improved since the start of the time series. Historically, POP age determinations were done using scales and surface readings from otoliths. These gave estimates of natural mortality of about 0.15 and longevity of about 30 years (Gunderson 1977). Based on the now accepted break and burn method of age determination using otoliths, Chilton and Beamish (1982) determined the maximum age of POP to be 90 years. Using similar information, Archibald et al. (1981) concluded that natural mortality for POP should be on the order of 0.05.

Aleutian Islands survey data from 1991 through 2016 were used to estimate growth curves. The resulting von Bertalanffy growth parameters were $L_{inf} = 41.55$ cm, $k = 0.14$, and $t_0 = -1.317$. Growth information from the Aleutian Islands was used to convert estimated numbers-at-age within the model to estimated numbers-at-length.

A conversion matrix was created to convert modeled number at ages to modeled number at length bin, and consists of the proportion of each age that is expected in each length bin. This matrix was created by fitting a polynomial relationship to the observed CV in length at each age (obtained for each survey from 1991-2016 by the multiplying the estimated survey length distribution by the age-length key), and the predicted relationship was used to produce variation around the predicted size at age from the von Bertalanffy relationship. The resulting CVs of length at age of the transition matrix decrease from 0.15 at age 3 to 0.07 at age 40.

The estimated length(cm)-weight(g) relationship was estimated from data obtained in the AI trawl survey from the same years, with the length-weight parameters estimated as $a = 1.1 \times 10^{-5}$ and $b = 3.07$, where weight = a*(length)^b. The Aleutian Islands length-weight relationship was used to produce estimated weights at age.

The following table summarizes the data available for the recommended BSAI POP model:

Component	BSAI
Fishery catch	1960-2018
Fishery age composition	1981-82, 1990, 1998, 2000-2009, 2011, 2013, 2015, 2017
Fishery size composition	1964-72, 1983-1984, 1987-1989, 1991-1997, 1999, 2010, 2012, 2014, 2016
AI Survey age composition	1991, 1994, 1997, 2000, 2002, 2004, 2006,2010,2012,2014,2016
AI Survey length composition	2018
AI Survey biomass estimates	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018
EBS Survey age composition	2002,2004,2008,2010,2012,2016
EBS Survey biomass estimates	2002,2004,2008,2010,2012,2016

Analytic Approach

Model Structure

An age-structured population dynamics model, implemented in the software program AD Model Builder, was used to obtain estimates of recruitment, numbers at age, and catch at age. Population size in numbers at age a in year t was modeled as

$$N_{t,a} = N_{t-1,a-1} e^{-Z_{t-1,a-1}} \qquad 3 < a < A, \ 1960 < t \le T$$

where Z is the sum of the instantaneous fishing mortality rate ($F_{t,a}$) and the natural mortality rate (M), A is the maximum number of age groups modeled in the population, and T is the terminal year of the analysis (defined as 2018).

The numbers at age A are a “pooled” group consisting of fish of age A and older, and are estimated as

$$N_{t,A} = N_{t-1,A-1} e^{-Z_{t-1,A-1}} + N_{t-1,A} e^{-Z_{t-1,A}}$$

The plus group was set to 40+, following a sensitivity analysis conducted in the 2012 stock assessment (Spencer and Ianelli 2012)

The numbers at age in the first year of the model are estimated as

$$N_a = R_0 e^{-M(a-3)}$$

where R_0 is the number of age 3 recruits for an unfished population, thus producing an age structure in equilibrium with an unfished stock. It is generally thought that little fishing for rockfish occurred prior to 1960, so an equilibrium unfished age-structure seems reasonable.

The total numbers of age 3 fish (recruitment) from 1960 to 2015 are estimated as parameters in the model, and are modeled with a lognormal distribution

$$N_{t,3} = e^{\mu_R + \nu_t}$$

where ν_t is a time-variant deviation with a log-scale recruitment standard deviation of σ_r . Little information exists to determine the year-class strength for the three most recent cohorts (2016-2018), which were set to the estimated mean recruitment (based upon the log-scale mean, and the value of σ_r).

The fishing mortality rate for a specific age and time ($F_{t,a}$) is modeled as the product of a $s^f_{a,t}$ and a year-specific fully-selected fishing mortality rate f. The fully selected mortality rate is modeled as the product of a mean (μ_f) and a year-specific deviation (ε_t), thus $F_{t,a}$ is

$$F_{t,a} = s^f_{a,t} f_t = s^f_{a,t} e^{(\mu_f + \varepsilon_t)}$$

The mean number-at-age for each year was computed as

$$\overline{N}_{t,a} = N_{t,a}(1 - e^{-Z_{t,a}}) / Z_{t,a}$$

Catch biomass-at-age was computed as the product of mean numbers at age, instantaneous fishing mortality, and weight at age.

The incorporation of the EBS trawl survey catchability requires consideration of how much of the BSAI stock is “available” to the each survey. The availability ($a_{\mathrm{AI},t}$) in each year to the AI survey was obtained by using the random effects model to smooth the AI and EBS survey biomass and computing the proportion of the total smoothed biomass in the AI area. The predicted survey biomass for the AI trawl survey biomass $\hat{B}^{twl}_{AI,t}$ was computed as

$$\hat{B}^{twl}_{AI,t} = a_{AI,t} q^{twl} \sum_a (\overline{N}_{t,a} s^{twl}_a W_a)$$

where W_a is the population weight-at-age, s^{twl}_a is the survey selectivity, and q^{twl} is the trawl survey catchability. The predicted survey biomass for the EBS trawl survey biomass $\hat{B}^{twl}_{EBS,t}$ is similar but model availability as (1- $a_{\mathrm{AI},t}$):

$$\hat{B}^{twl}_{EBS,t} = (1 - a_{AI,t}) q^{twl} \sum_a (\overline{N}_{t,a} s^{twl}_a W_a)$$

Selectivity curves for the AI and EBS trawl surveys were modeled with logistic functions.

To facilitate parameter estimation, prior distributions were used for the survey catchability and the natural mortality rate *M*. A lognormal distribution was also used for the natural mortality rate *M*, with the mean set to 0.05 and the CV set *to* 0.05. The standard deviation of log recruits, σ_r, was fixed at 0.75. Similarly, the prior distribution for Aleutian Islands survey selectivity followed a lognormal distribution with a mean of 1.0 and a coefficient of variation (CV) of 0.45. EBS survey selectivity was estimated freely.

Beginning in the 2014 assessment, fishery selectivity has been modeled with a bicubic spline with four year nodes and five age nodes, for a total of 20 selectivity parameters. Values at these nodes are the log-scale fishery selectivity and estimated as parameters, and fishery selectivity at ages and years between the nodes are interpolated with the bicubic spline. The smoothness of the surface is controlled by the number of nodes, and also by a series of penalties estimated within the model. Four types of penalties were used: 1) smoothness across the ages (modeled with the sum of second differences); 2) the slope of the rate of decline when selectivity decreases with age (modeled with the sum of first differences); 3) the inter-annual smoothness across years (modeled with the sum of second differences); and 4) the inter-annual variation across years (modeled with the first difference; this addresses situations in which the selectivity across years was relatively smooth but also non-constant, as would occur with a trend). The number of year nodes in the 2018 assessment was increased from four to five to reflect the additional years accrued since the 2014 assessment.

The weights for the age and length composition data were obtained from an iterative reweighting procedure. The multinomial sample size $N_{j,y}$ for data type *j* and year *y* is computed as

$$N_{j,y} = w_j \tilde{N}_{j,y}$$

where $\tilde{N}_{j,y}$ is the original "first stage" sample size (set to the square root of fish lengthed or aged), and w_j is a weight for data type *j,* computed as the harmonic mean of the ratio of effective sample size to first stage sample size (method TA1.1 in Francis (2011); often referred to as the "McAllister-Ianelli method"). The weights are a function of the fit of to the age and length composition data, and iterated in successive model runs until they converge. Note that this method preserves the relative weighting between years within a given data type.

A bridging model (model 16.3 below) was developed to examine how additional data, the change in number of year nodes for fishery selectivity, and updated composition weights result in changes in assessment results between the 2016 assessment and the 2018 model (model 16.3a below):

Model 16.3) The 2016 model with data updated through 2018, and updated weights for the age and length composition data. This is presented as a "bridging" model between the 2016 assessment and the 2018 assessment.

Model 16.3a) Model 16, but with the number of fishery selectivity year nodes increased from 4 to 5.

The root mean squared error (RMSE) was used to evaluate the relative size of residuals within data types across the different models:

$$RMSE = \sqrt{\frac{\sum_{n} (\ln(y) - \ln(\hat{y}))^2}{n}}$$

where y and $\hat{y}$ are the observed and estimated values, respectively, of a series length n.

Parameters Estimated Outside the Assessment Model

The parameters estimated independently include the age error matrix, the age-length conversion matrix, individual weight at age, and the proportion of the stock available to the AI survey. The calculations for these quantities are described above.

Parameters Estimated Inside the Assessment Model

Parameter estimation is facilitated by comparing the model output to several observed quantities, such as the age and length composition of the survey and fishery catch, the survey biomass, and the catch biomass. The general approach is to assume that deviations between model estimates and observed quantities are attributable to observation error and can be described with statistical distributions. Each data component provides a contribution to a total log-likelihood function, and parameter values that minimize the negative log-likelihood are selected.

The likelihood of the initial recruitments were modeled with a lognormal distribution, yielding the following negative log-likelihood (excluding some constant terms)

$$\lambda_1\left[\sum_{t=1}^{n}\frac{\left(\nu_t+\sigma_r^{\,2}/2\right)^2}{2\sigma_r^{\,2}}+n\ln(\sigma_r)\right]$$

where n is the number of years where recruitment is estimated. The adjustment of adding $\sigma^2/2$ to the deviation was made in order to produce deviations from the mean, rather than the median, recruitment. If σ_r is fixed, the term n ln (σ_r) adds a constant value to the negative log-likelihood.

The likelihoods of the fishery and survey age and length compositions were modeled with a multinomial distribution. The negative log of the multinomial function (excluding constant terms) for the fishery length composition data, with the addition of a term that scales the likelihood, is

$$-n_{f,t,l}\sum_{s,t,l}(p_{f,t,l}\ln(\hat{p}_{f,t,l})-p_{f,t,l}\ln(p_{f,t,l}))$$

where n is the reweighted sample size, and $p_{f,t,l.}$ and $\hat{p}_{f,t,l}$ are the observed and estimated proportion at length in the fishery by year and length. The likelihood for the age and length proportions in the survey, $p_{surv,t,a}$ and $p_{surv,t,l}$, respectively, follow similar equations.

The negative log-likelihood of the survey biomass was modeled with a lognormal distribution:

$$\lambda_2\sum_t(\ln(obs\_biom_t)-\ln(pred\_biom_t))^2/2cv_t^{\,2}$$

where obs_biom_t is the observed survey biomass at time t, cv_t is the coefficient of variation of the survey biomass in year t, and λ_2 is a weighting factor. The negative log-likelihood of the catch biomass was modeled with a lognormal distribution:

$$\lambda_3\sum_t(\ln(obs\_cat_t)-\ln(pred\_cat_t))^2$$

where obs_cat_t and $pred\_cat_t$ are the observed and predicted catch. The “observed” catch for 2018 is obtained by estimating the Oct-Dec catch (based on the remaining TAC available after October, and the average proportion in recent years of the remaining TAC caught from Oct-Dec) and adding this to the observed catch through October. Because the catch biomass is generally thought to be observed with higher precision that other variables, λ_3 is given a very high weight so as to fit the catch biomass nearly exactly.

A maturity ogive was fit within the assessment model to samples collected in 2010 from fishery and survey vessels (*n*=280; TenBrink and Spencer 2013) and in 2004 by fishery observers (*n*=165). The samples were analyzed using histological methods. Parameters of the logistic equation were estimated by maximizing the bionomial likelihood within the assessment model. The number of fish sampled and number of mature fish by age for each collection were the input data, thus weighting the two collections by sample size. Due to the low number of young fish, high weights were applied to age 3 and 4 fish in order to preclude the logistic equation from predicting a high proportion of mature fish at age 0. The estimated age at 50% maturity is 9.1 years.

The overall negative log-likelihood function, excluding the priors on *M* and survey catchability, the penalties on time-varying fishery selectivity parameters, and the maturity ogive parameters, is

$$
\begin{aligned}
&\lambda_1\left[\sum_{t=1}^{n}\frac{\left(\nu_t+\sigma_r{}^2/2\right)^2}{2\sigma_r{}^2}+n\ln(\sigma_r)\right]+\\
&\lambda_2\sum_{t}\left(\ln(obs\_biom_t)-\ln(pred\_biom_t)\right)^2/2cv_t^2+\\
&-n_{f,t,l}\sum_{s,t,l}(p_{f,t,l}\ln(\hat{p}_{f,t,l})-p_{f,t,l}\ln(p_{f,t,l}))+\\
&-n_{f,t,a}\sum_{s,t,l}(p_{f,t,a}\ln(\hat{p}_{f,t,a})-p_{f,t,a}\ln(p_{f,t,a}))+\\
&-n_{surv,t,a}\sum_{s,t,a}(p_{surv,t,a}\ln(\hat{p}_{surv,t,a})-p_{surv,t,a}\ln(p_{surv,t,a}))+\\
&-n_{surv,t,l}\sum_{s,t,a}(p_{surv,t,l}\ln(\hat{p}_{surv,t,l})-p_{surv,t,l}\ln(p_{surv,t,l}))+\\
&\lambda_3\sum_{t}\left(\ln(obs\_cat_t)-\ln(pred\_cat_t)\right)^2
\end{aligned}
$$

For the models run in this analysis, λ_1, λ_2, and λ_3 were assigned weights of 1,1, and 50, reflecting a strong emphasis on fitting the catch data. The negative log-likelihood function was minimized by varying the following parameters (using the bicubic fishery selectivity, and inclusion the EBS slope survey and exclusion of the CPUE index):

Parameter type	Number
1) Fishing mortality mean	1
2) Fishing mortality deviations	59
3) Recruitment mean	1
4) Recruitment deviations	56
5) Unfished recruitment	1
6) Biomass survey catchabilities	2
7) Fishery selectivity parameters	25
8) Survey selectivity parameters	4
9) Natural mortality rate	1
10) Maturity parameters	2
Total parameters	152

Finally, a Monte Carlo Markov Chain (MCMC) algorithm was used to obtain estimates of parameter uncertainty (Gelman et al. 1995). One million MCMC simulations were conducted, with every 1,000th sample saved for the sample from the posterior distribution after excluding the first 50,000 simulations. Ninety-five percent confidence intervals were produced as the values corresponding to the 5th and 95th percentiles of the MCMC evaluation. For this assessment, confidence intervals on total biomass, spawning biomass, and recruitment strength are presented.

Results

Model Evaluation

The bridging model 16.3 and the 2018 model (model 16.3a) show similar RMSE values for the data components (Table 12.12). The fit to the AI survey biomass for models 16.3 and 16.3a were very similar to the 2016 assessment up to 2010, but the addition the high biomass estimate in 2018 resulted in increased estimated AI survey biomass since 2010 for models 16.3 and 16.3a relative to the 2016 assessment (Figure 12.9). Estimated total biomass in models 16.3 and 16.3a were nearly identical to each other, and larger than the 2016 assessment results (Figure 12.10, Table 12.12). The estimated parameters for model 16.3a are shown in Table 12.13. The data weights for the model 16.3a were very similar to the weights used in the 2016 assessment model (Figure 12.11), with the exception of the AI survey length composition.

The plot of retrospective estimates of spawning biomass is shown in Figure 12.12. The 2018 model run shows the largest biomass than any of the retrospective runs, as new data in 2018 allows improved fit to the recent high AI trawl survey biomass index. Large changes in retrospective pattern occur in 2010, 2012, 2016, and 2018, years with high survey biomass estimates.

Mohn's rho can be used to evaluate the severity of any retrospective pattern, and compares an estimated quantity (in this case, spawning stock biomass) in the terminal year of each retrospective model run with the estimated quantity in the same year of the model using the full data set. The Mohn's rho for this retrospective runs was -0.45, higher in magnitude than the value of -0.35 obtained in the 2016 assessment.

The change in estimated spawning biomass from the 2009 to 2010 end years was particularly large, as the 2010 survey biomass estimate was substantially increased from the 2006 estimate. A series of exploratory models runs conducted in the 2010 assessment revealed that a combination of the high survey biomass and new observations of strong 1994-2000 year classes observed in both the fishery and survey age and length composition data lowered the estimates of survey catchability and increased estimated biomass. A similar analysis is presented in Appendix 12C, focusing on a model with differential survey catchability between years.

Time series results

In this assessment, spawning biomass is defined as the biomass estimate of mature females age 3 and older. Total biomass is defined as the biomass estimate of POP age 3 and older. Recruitment is defined as the number of age 3 POP.

Prior and Posterior Distributions

Posterior distributions for *M*, *q*, total 2018 biomass, and median recruitment, based upon the MCMC integrations, are shown in Figure 12.13. The estimate of *M* was 0.056, slightly above the mean of the prior distribution for *M* of 0.05. Exploratory models runs conducted in the 2014 assessment indicated that a freely estimated *M* was ~0.07, which is on the same scale of values from several empirical estimators of *M*. The mean of the posterior distribution for the Aleutian Islands survey catchability was 1.18, slightly larger than the prior distribution mean of 1.0.

Biomass Trends

The estimated AI survey biomass index has increased from 386,389 t in 1991 to 859,303 t in 2013, and declined to 811,665 in 2018 (Figure 12.14). The relative proportion of the stock in the AI survey area between 1991 and 2018 ranged between 0.79 and 0.84 (Figure 12.15). The product of the survey catchability and the proportion available in the Aleutian Islands has ranged between 0.94 and 0.99 over these years, averaging 0.95. This is a decrease from an average of 1.12 in the 2016 model. In previous assessments, estimated catchabilities greater than 1 were hypothesized to result from the expansion of survey trawl estimates to untrawlable areas (Kreiger and Sigler 1996). The addition of high AI survey biomass estimates has resulted in rescaling the population abundance (i.e., lowering survey catchability) in order to fit both the survey biomass time series and the composition data.

The predicted EBS survey biomass generally matches the observed data, although the high biomass in 2016 is not fit well due to its high CV (Figure 12.16). The estimate of EBS survey catchability was 1.44.

The total biomass showed a similar trend as the survey biomass, with the 2018 total biomass estimated as 955,868 t. The estimated time series of total biomass and spawning biomass, with 95% credibility bounds obtained from MCMC integration, are shown in Figure 12.17. Total biomass, spawning biomass, and recruitment (and their CVs from the Hessian approximation) are given in Table 12.14, and numbers at age are shown in Table 12.15.

Age/size compositions

The fits to the fishery age and length composition are shown in Figures 12.18-12.19. The observed proportion in the binned length group of 39+ cm for 1964 and 1965 was lower than the estimated proportion, reflecting the modeling of the initial numbers at age as an equilibrium population. However, by 1966 reasonable fits were observed for the binned length group in the fishery length composition (Figure 12.19). Some of the lack of fit in the mid- to late-1980s is attributable to the low sample size of lengths observed from a reduced fishery. Good fits are obtained for most age groups in the 1991-2016 AI surveys (Figure 12.20), although the 2004 and 2005 year classes are overestimated in the 2010 and 2012 composition data, and underestimated in the 2014 composition data. The model provides a reasonable fit to the 2018 length composition from the AI survey (Figure 12.21).

The model fit the 2002 EBS survey age composition data well, with worse fits to other years of EBS survey age composition data. In particular, the 2004 and 2005 year classes, which appear strong in the AI survey composition data, are consistently overestimated for the EBS survey composition data (Figure 12.22).

Fishing and Survey Selectivity

Younger fish show higher survey selection in the AI survey than in the EBS survey, with the ages at 50% selection estimated as 6.25 and 11.12, respectively (Figure 12.23). The estimated fishery selectivity by age and year is shown in Figure 12.24, and shows a pattern consistent with the empirical data in fishery catch examined above. Strong dome-shaped selectivity is estimated in the early 1960s to allow fish of age 20 older from this period to survive the large fully-selected fishing rates in the 1960s and early 1970s and be available for capture in the fishery and survey in the early 1980s (by which time they have entered the 40+ group). The model estimates that dome-shaped selectivity has gradually become less peaked over time, and the average selectivity from the most recent 5 years shows slight reductions in selectivity for fish between 14 – 20, and > 27, years old.

Fishing Mortality

The estimates of instantaneous fishing mortality for POP range from highs during the 1970’s to low levels in the 1980’s (Figure 12.25). Fishing mortality rates since the early 1980's, however, have moderated considerably due to the phase out of the foreign fleets and quota limitations imposed by the North Pacific Fishery Management Council. Note that because of the change in the fishery selectivity over time, the fully-selected rates are not completely comparable over time with respect to the degree to which the stock has been harvested. Nonetheless, the average fully-selected fishing mortality from 1965 to 1980 was 0.40, whereas the average from 1981 to 2017 was 0.03.

The plot of estimated fishing mortality rates and spawning stock biomass relative to the harvest control rules (Figure 12.26) indicate that BSAI POP would be considered overfished (using current definitions) during much of the period from the mid-1960s to the mid-1980s, although it should be noted the current definitions of $B_{35\%}$ are based on the estimated recruitment of the post-1977 year classes and the average fishery selectivity from the most recent 5 years.

Recruitment

Year-class strength varies widely for BSAI POP (Figure 12.27; Table 12.14). The relationship between spawning stock and recruitment also displays a high degree of variability (Figure 12.28). The 1957 and 1961-62 year classes are particularly large and sustained the heavy fishing in the 1960s. The rebuilding of the stock in the 1980s and 1990s was based upon recruitments for the 1981, 1984, 1986, and 1988-89 year classes. Recruitment appears to be lower in early 1990s, but several cohorts from 1994 to 2008 generally show relatively strong recruitment (with the exception the 1997 and 1999 year classes), which is consistent with the increasing trend of biomass and the fishery and AI survey age compositions shown in Figures 12.18 and 12.20. In particular, the largest estimated year class occurred in 2000, at 370 million. Strong recent recruitments are estimated for the 2004-05 and 2008 year classes (consistent with the 2016 model), although some of these cohorts have only been partially selected in the EBS trawl survey.

Harvest recommendations

Amendment 56 reference points

The reference fishing mortality rate for Pacific ocean perch is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{0.40}$, $F_{0.35}$, and $SPR_{0.40}$ were obtained from a spawner-per-recruit analysis. Assuming that the average recruitment from the 1977-2012 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{0.40}$ is calculated as the product of $SPR_{0.40}$ * equilibrium recruits, and this quantity is 258,295 t. The estimated spawning stock biomass for 2019 is 399,024 t.

Specification of OFL and maximum permissible ABC

Since reliable estimates of the 2019 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B>B_{0.40}$ (399,024 t > 258,295 t), POP reference fishing mortality have been classified in tier 3a. For this tier, F_{ABC} maximum permissible F_{ABC} is $F_{0.40}$, and F_{OFL} is equal to $F_{0.35}$. The values of $F_{0.40}$ and $F_{0.35}$ are 0.079 and 0.095, respectively.

The 2019 ABC associated with the $F_{0.40}$ level of 0.079 is 50,594 t.

The estimated catch level for year 2019 associated with the overfishing level of F = 0.095 is 61,067 t. A summary of these values is below.

2019 SSB estimate (B) = 399,024 t
$B_{0.40}$ = 258,295 t
$F_{ABC} = F_{0.40}$ = 0.079
$F_{OFL} = F_{0.35}$ = 0.095
MaxPermABC = 50,594 t
OFL = 61,067 t

ABC recommendation

We recommend the maximum permissible ABC 50,594 t in 2019.

Projections

A standard set of projections is conducted 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 the vector of 2018 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2019 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2018. 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.

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.

Five of the seven standard scenarios will be 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 TAC for 2019, 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 2019 recommended in the assessment to the *max* F_{ABC} for 2019. (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 50% of max F_{ABC}. (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 4*: In all future years, F is set equal to the 2013-2017 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 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 the Pacific ocean perch 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 expected to be above 1) above its MSY level in 2018 or 2) above ½ of its MSY level in 2018 and above its MSY level in 2028 under this scenario, then the stock is not overfished.)
>
> *Scenario 7*: In 2019 and 2020, 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 expected to be above its MSY level in 2030 under this scenario, then the stock is not approaching an overfished condition.)

The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, and projections of the mean harvest and spawning stock biomass for the remaining six scenarios are shown in Table 12.16.

Status Determination

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 2019, it does not provide the best estimate of OFL for 2020, because the mean 2019 catch under Scenario 6 is predicated on the 2019 catch being equal to the 2019

OFL, whereas the actual 2019 catch will likely be less than the 2019 OFL. The executive summary contains the appropriate one- and two-year ahead projections for both ABC and OFL. Catches for 2019 and 2020 were obtained by setting the F rate for these years to the estimated F rate for 2018.

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

Is the stock being subjected to overfishing? The official BSAI catch estimate for the most recent complete year (2017) is 32,543 t. This is less than the 2017 BSAI OFL of 53,152 t. Therefore, the 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 2018:

a. If spawning biomass for 2018 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b. If spawning biomass for 2018 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c. If spawning biomass for 2018 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 12.16). If the mean spawning biomass for 2028 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:

a. If the mean spawning biomass for 2020 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.
b. If the mean spawning biomass for 2020 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c. If the mean spawning biomass for 2020 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2030. If the mean spawning biomass for 2030 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

The results of these two scenarios indicate that the BSAI POP stock is neither overfished nor approaching an overfished condition. With regard whether the stock is currently overfished, the expected stock size in the year 2018 of Scenario 6 is 1.81 times its $B_{35\%}$ value of 226,008 t. With regard to whether the BSAI POP stock is likely to be overfished in the future, the expected stock size in 2020 of Scenario 7 is 1.67 times the $B_{35\%}$ value.

Area Allocation of Harvests

The ABC of BSAI POP is currently partitioned into subarea ABCs based on estimates of relative biomass across BSAI subareas, which are obtained from research surveys. A random effects model is used to smooth the subarea survey biomass estimates to obtain the proportional biomass across the subareas, shown below:

ABC apportionments

	Area				
	WAI	CAI	EAI	SBS	EBS slope
2018 smoothed biomass estimate	388,948	204,741	278,146	110,304	245,905
percentage	31.7%	16.7%	22.6%	9.0%	20.0%

The apportioned ABCs for 2019 and 2020 are as follows:

	Area				
	WAI	CAI	EAI	EBS	Total ABC
2019 ABC	16,025	8,435	11,459	14,675	50,594
2020 ABC	15,586	8,205	11,146	14,274	49,211

Ecosystem Considerations

Ecosystem Effects on the stock

1) Prey availability/abundance trends

POP feed upon calanoid copepods, euphausids, myctophids, and other miscellaneous prey (Yang 2003). From a sample of 292 Aleutian Island specimens collected in 1997, calanoid copepods, euphausids, and myctophids contributed 70% of the total diet by weight. The diet of small POP was composed primarily of calanoid copepods (89% by weight), with euphausids and myctophids contributing approximately 35% and 10% of the diet, respectively, of larger POP. The availability and abundance trends of these prey species are unknown.

2) Predator population trends

POP are not commonly observed in field samples of stomach contents, although previous studies have identified sablefish, Pacific halibut, and sperm whales as predators (Major and Shippen 1970). The population trends of these predators can be found in separate chapters within this SAFE document.

3) Changes in habitat quality

POP appear to exhibit ontogenetic shifts in habitat use. Carlson and Straty (1981) used a submersible off southeast Alaska to observe juvenile red rockfish they believed to be POP at approximately 90-100 m in rugged habitat including boulder fields and rocky pinnacles. Kreiger (1993) also used a submersible to observe that the highest densities of small red rockfish in untrawlable rough habitat. As POP mature, they move into deeper and less rough habitats. Length frequencies of the Aleutian Islands survey data indicate that large POP (> 25 cm) are generally found at depths greater than 150 m. Brodeur (2001) also found that POP was associated with epibenthic sea pens and sea whips along the Bering Sea slope. There has been little information identifying how rockfish habitat quality has changed over time.

Warmer temperatures have been recorded in the fall of 2015 and summer of 2016 in the Alaska Peninsula and Aleutian Islands, and the Bering Sea shelf experienced much warmer winter and spring temperatures (Bond 2016). Warmer temperatures have also been observed in the bottom temperatures from the AI trawl survey (Figure 12.29).

An indication of temperature preferences can be obtained by plotting the catch-weighted cumulative frequency distributions of temperature against the cumulative frequency distributions (CDFs) of temperature available in the EBS survey area (Perry and Smith 1994, Spencer 2008). The quantiles from the two CDF can be plotted against each other (i.e., a Q-Q plot), and plots that deviate from the 1:1 line would indicate that fish occupy habitats with different temperature characteristics than is available in survey area. Multiple years can be summarized by plotting the 10% and 90% percentiles. POP occupy cooler water than is available, as the 90th percentiles fall below the 1:1 line (Figure 12.30).

Fishery Effects on the ecosystem

Catch of prohibited species from 2003-2008 by fishery are available from the NMFS Regional Office. The rockfish fishery in the BSAI area, which consists only of the AI POP target fishery, contributed approximately 2% of the gold/brown king crab catch and approximately 1% of the halibut bycatch. For other prohibited species, the BSAI rockfish fisheries contributed much lower that 1% of the bycatch.

Estimates of non-target catches in the rockfish fishery are also available from the Catch Accounting System database maintained by the NMFS Regional Office. BSAI rockfish fisheries contribute mostly to the bycatch of coral, sponge, and polychaetes. From 2003 to 2008, the BSAI rockfish fisheries contributed 31% of the coral and bryozoan bycatch, 18% of the sponge bycatch, 8% of the red tree coral bycatch, and 7% of the polychaete bycatch. The relative contribution was variable between years; for example, the annual relative contribution corals and bryozoans ranged from 5% in 2004 to 53% in 2003, and the other groups listed above show similar levels of variability.

The POP fishery is not likely to diminish the amount of POP available as prey due to its low selectivity for fish less than 27 cm. Additionally, the fishery is not suspected of affecting the size-structure of the population due to the relatively light fishing mortality, averaging 0.05 over the last 5 years. It is not known what effects the fishery may have on the maturity-at-age of POP.

Data Gaps and Research Priorities

Although Pacific ocean perch may be considered a “data-rich” species relative to other rockfish, little information is known regarding most aspects of their biology, including reproductive biology and the distribution, duration, and habitat requirements of various life-history stages. Given the relatively unusual reproductive biology of rockfish and its importance in establishing management reference points, data on reproductive capacity should be collected on a periodic basis.

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Tables

Table 12.1. Total allowable catch (TAC), acceptable biological catch (ABC), and catch of the species groups used to manage Pacific ocean perch from 1977 to 2001 in the Aleutian Islands and the eastern Bering Sea. The "POP complex" includes the other red rockfish species (shortraker rockfish, rougheye rockfish, northern rockfish, and sharpchin rockfish) plus POP.

	Aleutian Islands					Eastern Bering Sea				
Year	Management Group	OFL (t)	ABC (t)	TAC (t)	Catch (t)	Management Group	OFL (t)	ABC (t)	TAC (t)	Catch (t)
1977	POP				7927	POP				2406
1978	POP				5286	POP				2230
1979	POP				5486	POP				1722
1980	POP				4010	POP				959
1981	POP				3668	POP				1186
1982	POP complex				979	POP complex				205
1983	POP complex				471	POP complex				192
1984	POP complex				564	POP complex				315
1985	POP complex				216	POP complex				61
1986	POP			6800	302	POP			825	670
1987	POP			8175	1055	POP			2850	1178
1988	POP		16600	6000	2024	POP		6000	5000	1326
1989	POP complex		16600	6000	2963	POP complex		6000	5000	2533
1990	POP complex		16600	6000	11826	POP complex		6300	6300	6499
1991	POP		10775	10775	2785	POP		4570	4570	5099
1992	POP	11700	11700	11700	10280	POP	3540	3540	3540	3255
1993	POP	16800	13900	13900	13376	POP	3750	3330	3330	3764
1994	POP	16600	10900	10900	10866	POP	2920	1910	1910	1688
1995	POP	15900	10500	10500	10304	POP	2910	1850	1850	1208
1996	POP	25200	12100	12100	12827	POP	2860	1800	1800	2855
1997	POP	25300	12800	12800	12648	POP	5400	2800	2800	681
1998	POP	20700	12100	12100	9047	POP	3300	1400	1400	956
1999	POP	19100	13500	13500	12484	POP	3600	1900	1400	421
2000	POP	14400	12300	12300	9328	POP	3100	2600	2600	452
2001	POP	11800	10200	10200	8557	POP	2040	1730	1730	896

Table 12.2. Overfishing level (OFL), total allowable catch (TAC), acceptable biological catch (ABC), and catch for BSAI POP from 2002 to present. Catch data is through October 6, 2018, from NMFS Alaska Regional Office.

		Bering Sea/Aleutian Islands			
Year	Management Group	OFL (t)	ABC (t)	TAC (t)	Catch (t)
2002	POP	17500	14800	14800	11215
2003	POP	18000	15100	14100	14744
2004	POP	15800	13300	12580	11896
2005	POP	17300	14600	12600	10427
2006	POP	17600	14800	12600	12867
2007	POP	26100	21900	19900	18451
2008	POP	25700	21700	21700	17436
2009	POP	22300	18800	18800	15347
2010	POP	22400	18860	18860	17852
2011	POP	36300	24700	24700	24004
2012	POP	35000	24700	24700	24161
2013	POP	41900	35100	35100	31362
2014	POP	39585	33122	33122	32381
2015	POP	42588	34988	32021	31422
2016	POP	40529	33320	31900	31270
2017	POP	53152	43723	34900	32543
2018	POP	51675	42509	37361	28606

Table 12.3. Foreign, Joint Vessel Program, and Domestic catch of POP by area from 1977 to 2018.

	Eastern Bering Sea			Aleutian Islands			BSAI
Year	Foreign	JVP	Domestic	Foreign	JVP	Domestic	Total catch
1977	2,406	0		7,927	0		10,333
1978	2,230	0		5,286	0		7,516
1979	1,722	0		5,486	0		7,208
1980	907	52		4,010	0		4,969
1981	1,185	1		3,668	0		4,854
1982	186	19		977	2		1,183
1983	99	93		463	8		663
1984	172	142		324	241		879
1985	30	31		0	216		277
1986	18	103	549	0	163	139	972
1987	5	49	1,123	0	502	554	2,233
1988	0	46	1,280	0	1,512	512	3,350
1989	0	26	2,507	0	0	2,963	5,496
1990			6,499			11,826	18,324
1991			5,099			2,785	7,884
1992			3,255			10,280	13,534
1993			3,764			13,376	17,139
1994			1,688			10,866	12,554
1995			1,208			10,304	11,511
1996			2,855			12,827	15,681
1997			681			12,648	13,329
1998			956			9,047	10,003
1999			421			12,484	12,905
2000			451			9,328	9,780
2001			896			8,557	9,453
2002			639			10,575	11,215
2003			1,145			13,600	14,744
2004			731			11,165	11,896
2005			879			9,548	10,427
2006			1,041			11,826	12,867
2007			870			17,581	18,451
2008			513			16,923	17,436
2009			623			14,725	15,347
2010			3,547			14,304	17,852
2011			5,602			18,403	24,004
2012			5,591			18,570	24,161
2013			5,051			26,311	31,362
2014			7,437			24,944	32,380
2015			7,915			23,507	31,422
2016			8,172			23,097	31,270
2017			8,987			23,557	32,543
2018*			5,577			23,029	28,606

*Estimated removals through October 6, 2018.

Table 12.4. Estimated retained and discarded catch (t), and percent discarded, of Pacific ocean perch from the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions.

	EBS			AI			BSAI		
Year	Retained	Discarded	Percent Discarded	Retained	Discarded	Percent Discarded	Retained	Discard	Percent Discarded
1990	5,069	1,275	20	10,288	1,551	13	15,357	2,826	16
1991	4,126	972	19	1,815	970	35	5,942	1,942	25
1992	2,732	522	16	8,666	1,614	16	11,398	2,136	16
1993	2,601	1,163	31	11,479	1,896	14	14,080	3,059	18
1994	1,187	501	30	9,491	1,375	13	10,678	1,876	15
1995	839	368	30	8,603	1,701	17	9,442	2,069	18
1996	2,522	333	12	9,831	2,995	23	12,353	3,328	21
1997	420	261	38	10,854	1,794	14	11,274	2,055	15
1998	813	143	20	8,041	1,006	11	8,854	1,149	12
1999	277	144	34	10,985	1,499	12	11,261	1,644	13
2000	230	221	49	8,586	743	8	8,816	964	10
2001	399	497	55	7,195	1,362	16	7,594	1,859	20
2002	286	354	55	9,315	1,260	12	9,601	1,614	14
2003	564	581	53	11,558	2,042	16	12,122	2,622	19
2004	536	196	27	9,286	1,879	17	9,822	2,074	17
2005	627	253	29	8,100	1,448	15	8,727	1,700	16
2006	751	290	28	9,869	1,957	17	10,620	2,246	17
2007	508	363	42	15,051	2,530	14	15,558	2,893	16
2008	318	195	38	16,640	283	2	16,959	477	3
2009	463	160	26	14,011	713	5	14,474	873	6
2010	3,347	200	6	13,988	316	2	17,335	516	3
2011	5,249	353	6	18,021	382	2	23,269	735	3
2012	5,182	408	7	18,169	401	2	23,352	810	3
2013	4,746	304	6	26,063	249	1	30,809	553	2
2014	6,614	823	11	24,770	174	1	31,384	997	3
2015	6,749	1,166	15	23,267	240	1	30,016	1,406	4
2016	7,419	754	9	22,899	199	1	30,317	952	3
2017	6,986	2,001	22	23,293	264	1	30,279	2,265	7
2018*	3,785	1,792	32	22,635	394	2	26,419	2,186	8

*Estimated removals through October 6, 2018.
Source: NMFS Alaska Regional Office

Table 12.5. Percentage catch (by weight) of Aleutians Islands POP in the foreign/joint venture fisheries and the domestic fishery by depth.

	Depth Zone (m)									
Year	0	100	200	300	400	500	501	Observed catch (t)	Estimated total catch	Percent sampled
1977	25	23	39	11	2	1	0	173	7,927	2
1978	0	40	36	19	3	1	1	145	5,286	3
1979	0	13	60	23	4	0	0	311	5,486	6
1980	0	7	45	49	0	0	0	108	4,010	3
1981	0	9	67	23	0	0	0	138	3,668	4
1982	0	34	56	5	2	1	2	115	979	12
1983	0	11	85	0	1	1	1	54	471	11
1984	0	53	42	5	0	1	0	85	565	15
1985	0	87	13	0	0	0	0	109	216	50
1986	0	74	25	2	0	0	0	66	163	40
1987	0	39	61	0	0	0	0	258	502	51
1988	0	78	21	1	0	0	0	76	1,512	5
1989										
1990	2	23	58	14	2	1	0	7,726	11,826	65
1991	0	23	70	5	1	1	0	1,588	2,785	57
1992	0	21	71	8	0	0	0	6,785	10,280	66
1993	0	20	77	3	0	0	0	8,867	13,376	66
1994	0	20	69	11	0	0	0	7,562	10,866	70
1995	0	15	68	14	2	0	0	6,154	10,304	60
1996	0	17	54	26	2	1	0	8,547	12,827	67
1997	0	13	66	21	0	0	0	9,320	12,648	74
1998	0	21	72	7	0	0	0	7,380	9,047	82
1999	0	30	63	7	0	0	0	10,369	12,484	83
2000	0	21	63	15	0	0	0	7,456	9,328	80
2001	0	29	61	10	0	0	0	5,679	8,557	66
2002	2	36	57	5	1	0	0	8,124	10,575	77
2003	0	26	70	3	0	0	0	11,266	13,600	83
2004	1	26	65	7	1	0	0	10,083	11,165	90
2005	2	36	55	6	1	0	0	7,403	9,548	78
2006	1	33	61	5	0	0	0	9,895	11,826	84
2007	0	23	68	7	1	0	0	15,551	17,581	88
2008	1	20	74	5	0	0	0	16,685	16,923	99
2009	1	26	65	8	1	0	1	14,495	14,725	98
2010	1	21	71	7	1	0	0	14,299	14,304	100
2011	0	13	78	7	1	0	0	18,391	18,403	100
2012	0	22	67	11	1	0	0	18,569	18,570	100
2013	0	12	76	11	1	0	0	26,297	26,311	100
2014	0	12	79	8	0	0	0	24,882	24,944	100
2015	1	21	73	4	0	0	0	23,421	23,507	100
2016	1	27	68	4	0	0	0	23,002	23,097	100
2017	0	27	71	2	0	0	0	23,536	23,557	100

Table 12.6. Proportional catch (by weight) of Aleutians Islands POP in the foreign and joint venture fisheries and the domestic fishery by management area.

	Area					
	541	542	543	Observed catch (t)	Estimated total catch	Percent sampled
1977	17	22	61	173	7,927	2
1978	30	36	35	145	5,286	3
1979	21	25	55	311	5,486	6
1980	11	42	47	108	4,010	3
1981	42	40	17	138	3,668	4
1982	42	38	20	115	979	12
1983	85	8	7	54	471	11
1984	84	8	7	85	565	15
1985	66	34	0	109	216	50
1986	99	1	0	66	163	40
1987	94	6	0	258	502	51
1988	6	94	0	76	1,512	5
1989						
1990	63	16	21	7,726	11,826	65
1991	27	57	16	1,588	2,785	57
1992	81	15	3	6,785	10,280	66
1993	67	22	11	8,867	13,376	66
1994	64	31	5	7,562	10,866	70
1995	70	25	5	6,154	10,304	60
1996	27	20	54	8,547	12,827	67
1997	20	23	57	9,320	12,648	74
1998	21	27	52	7,380	9,047	82
1999	22	23	56	10,369	12,484	83
2000	22	24	54	7,456	9,328	80
2001	27	25	48	5,679	8,557	66
2002	24	28	48	8,124	10,575	77
2003	30	22	48	11,266	13,600	83
2004	24	27	49	10,083	11,165	90
2005	23	24	52	7,403	9,548	78
2006	24	28	48	9,895	11,826	84
2007	30	26	45	15,551	17,581	88
2008	28	28	44	16,685	16,923	99
2009	27	28	44	14,495	14,725	98
2010	28	28	44	14,299	14,304	100
2011	30	26	44	18,391	18,403	100
2012	30	26	44	18,569	18,570	100
2013	36	26	38	26,297	26,311	100
2014	36	26	38	24,882	24,944	100
2015	33	29	38	23,421	23,507	100
2016	32	29	39	23,002	23,097	100
2017	33	29	38	23,536	23,557	100

Table 12.7. Number of length measurements from the EBS and AI POP fisheries during 1964-1972, from Chikuni (1975).

Year	EBS	AI	Total
1964	24,150	55,599	79,749
1965	14,935	66,120	81,055
1966	26,458	25,502	51,960
1967	48,027	59,576	107,603
1968	38,370	36,734	75,104
1969	28,774	27,206	55,980
1970	11,299	27,508	38,807
1971	14,045	18,926	32,971
1972	10,996	18,926	29,922

Table 12.8. Number of length measurements and otoliths read from the EBS and AI POP fisheries, from the NORPAC Observer database.

	Fish lengths			Otoliths read		
Year	EBS	AI	Total	EBS	AI	Total
1973	1		1**			
1974	84		84**	84		84**
1975	271		271**	125		125**
1976	633		633**	114	19	133**
1977	1,059	9,318	10,377*	139	404	543
1978	7,926	7,283	15,209*	583	641	1,224
1979	1,045	10,921	11,966*	248	353	601
1980		3,995	3,995*		398	398
1981	1,502	7,167	8,669*	78	432	510
1982		4,902	4,902*		222	222
1983	232	441	673			
1984	1,194	1,210	2,404	72		72**
1985	300		300**	160		160**
1986		100	100**		99	99**
1987	11	384	395			
1988	306	1,366	1,672			
1989	957	91	1,048			
1990	22,228	47,198	69,426	144	184	328
1991	8,247	8,221	16,468			
1992	13,077	24,932	38,009			
1993	8,379	26,433	34,812			
1994	2,654	11,546	14,200			
1995	272	11,452	11,724			
1996	2,967	13,146	16,113			
1997	143	10,402	10,545			
1998	989	11,106	12,095		823	823
1999	289	3,839	4,128			
2000	284	3,382	3,666*		487	487
2001	327	2,388	2,715*		524	524
2002	78	3,671	3,749*	11	455	466
2003	247	4,681	4,928*	11	386	397
2004	135	3,270	3,405*	30	754	784
2005	237	2,243	2,480*	42	539	581
2006	274	3,757	4,031*	25	424	449
2007	74	5,629	5,703*	11	664	675
2008	250	7,001	7,251*	17	555	572
2009	460	5,593	6,053*	49	670	719
2010	2,584	5,384	7,968			
2011	4,144	7,965	12,109*	316	616	932
2012	5,686	7,896	13,582			
2013	3,897	13,082	16,979*	233	810	1,043
2014	4,044	12,125	16,169			
2015	4,117	12,213	16,330*	243	773	1,016
2016	3,707	12,209	15,916			
2017	4,772	16,702	21,474*	239	841	1,080
2018	809	11,285	12,094			

*Used to create age composition. **Not used.

Table 12.9. Pacific ocean perch biomass estimates (t) and coefficients of variation (in parentheses) from the 1991-2018 triennial trawl surveys for the three management sub-areas in the Aleutian Islands region, and the 2002-2016 EBS slope surveys.

			Aleutian Islands Survey			
Year	Western	Central	Eastern	southern BS	Total AI survey	EBS slope survey
1991	208,465 (0.31)	78,776 (0.25)	55,545 (0.40)	1,501 (0.51)	344, 286 (0.21)	
1994	184,703 (0.39)	84,411 (0.33)	100,585 (0.42)	18,217 (0.64)	387,916 (0.23)	
1997	178,437 (0.19)	166,816 (0.28)	220,633 (0.28)	12,099 (0.58)	577,984 (0.15)	
2000	222,632 (0.32)	129,740 (0.32)	140,528 (0.25)	18,870 (0.54)	518,770 (0.18)	
2002	196,704 (0.26)	140,361 (0.41)	109,795 (0.14)	16,311 (0.41)	463,171 (0.17)	72,665 (0.53)
2004	212,639 (0.21)	153,477 (0.17)	137,112 (0.29)	74,208 (0.45)	577,436 (0.13)	112,273 (0.38)
2006	278,990 (0.16)	170,942 (0.23)	190,752 (0.37)	23,701 (0.47)	664,384 (0.14)	
2008						107,886 (0.41)
2010	395,944 (0.21)	221,700 (0.17)	266,607 (0.18)	87,794 (0.55)	972,046 (0.12)	203,421 (0.38)
2012	263,661 (0.23)	233,666 (0.17)	366,413 (0.37)	38,658 (0.63)	902,398 (0.17)	231,046 (0.33)
2014	338,455 (0.21)	315,544 (0.49)	233,560 (0.28)	83,409 (0.50)	970,968 (0.19)	
2016	403,049 (0.19)	206,593 (0.19)	284,909 (0.17)	87,952 (0.47)	982,503 (0.11)	357,369 (0.68)
2018	427,440 (0.20)	195,497 (0.19)	278,326 (0.21)	115,046 (0.29)	1,016,309 (0.11)	

Table 12.10. Region, depth, estimated 2018 survey abundance, and ratio of average survey abundances between the 2010-2018 and 1991-2006 time periods for the 10 AI trawl survey strata with the largest abundance estimates in the 2018 survey.

Survey area	Depth (m)	Strata	2018 survey survey abudance (millions)	Cumulative proportion of 2018 total abundance estimate	Ratio of 2010-2018 abundance to 1991-2006 abundance
WAI	101-200	212	274.07	0.19	2.22
WAI	201-300	213	207.82	0.33	1.90
EAI	201-300	523	166.15	0.44	2.07
EAI	201-300	623	108.09	0.51	1.09
WAI	301-500	214	100.04	0.58	25.88
CAI	101-200	412	81.79	0.64	2.95
SBS	101-200	722	76.45	0.69	22.51
WAI	101-200	222	61.82	0.73	1.24
WAI	201-300	223	46.21	0.76	0.76
SBS	201-300	793	44.39	0.79	1.88

Table 12.11. Number of length measurements and otoliths read from the Aleutian Islands and eastern Bering Sea slope surveys.

	Aleutian Islands survey		Eastern Bering Sea slope survey	
Year	Length	Otoliths read	Length	Otoliths read
1980	20,796	890		
1983	22,873	2,495		
1986	14,804	1,860		
1991	14,262	1,015		
1994	18,922	849		
1997	22,823	1,224		
2000	21,972	1,238		
2002	20,284	337	2,040	299
2004	24,949	1,031	4,084	425
2006	19,737	462		
2008			2,818	413
2010	22,725	951	3,348	415
2012	31,450	1,140	3,459	472
2014	30,204	1,078		
2016	36,277	1,062	3,398	400
2018	30,980			

Table 12.12. Negative log likelihoods, root mean squared errors, and estimates and CV for key model quantities, for BSAI POP models.

	2016 Assessment	Model 16.3	Model 16.3a
Negative log-likelihood			
Data components			
AI survey biomass	8.65	8.31	8.89
EBS survey biomass	1.40	1.30	1.34
Catch biomass	0.00	0.00	0.00
Fishery age comp	206.52	230.83	233.06
Fishery length comp	248.72	232.94	232.94
AI survey age comp	131.25	143.30	142.23
AI survey lengths comp	4.43	12.89	12.88
EBS survey age comp	64.64	74.72	74.52
EBS survey lengths co	7.19		
Maturity	2.71	2.71	2.71
Priors and penalties			
Recruitment	9.62	14.37	14.21
Prior on survey q	5.00	2.34	2.49
Prior on M	0.42	0.17	0.17
Fishery selectivity	108.78	107.95	114.92
Total negative log-likelihood	806.38	839.17	847.61
Parameters	143	147	152
Root mean square error			
AI survey biomass	0.188	0.174	0.179
EBS survey biomass	0.353	0.340	0.345
Recruitment	0.777	0.832	0.830
Fishery age comp	0.013	0.013	0.013
Fishery length comp	0.022	0.023	0.022
AI survey age comp	0.011	0.011	0.011
AI survey lengths comp	0.026	0.009	0.009
EBS survey age comp	0.015	0.015	0.015
EBS survey lengths co	0.017		
Estimated key quantities			
M	0.058	0.056	0.056
CV	0.031	0.032	0.032
AI survey q	1.367	1.175	1.176
CV	0.147	0.144	0.145
2018 total biomass(t)		962,630	955,868
CV		0.164	0.166

Table 12.13. Estimated parameter values and standard deviations for the BSAI POP assessment model.

Parameter	Estimate	Standard Deviation	Parameter	Estimate	Standard Deviation	Parameter	Estimate	Standard Deviation
sel_par	-3.0991	0.2367	fmort_dev	0.0335	0.2986	rec_dev	-0.9363	0.4432
sel_par	-0.8527	0.1605	fmort_dev	-0.0221	0.2979	rec_dev	-0.4663	0.3728
sel_par	-2.5696	0.1574	fmort_dev	-1.4878	0.2972	rec_dev	-0.6765	0.4249
sel_par	-2.8574	0.1392	fmort_dev	-2.1409	0.2965	rec_dev	-0.5385	0.3150
sel_par	-2.6966	0.2978	fmort_dev	-1.9420	0.2960	rec_dev	-1.2234	0.4076
sel_par	2.0330	0.1279	fmort_dev	-3.1840	0.2957	rec_dev	-1.0715	0.3221
sel_par	1.1365	0.0827	fmort_dev	-2.0217	0.2956	rec_dev	-1.1155	0.3571
sel_par	0.9624	0.0815	fmort_dev	-1.2941	0.2956	rec_dev	-0.1652	0.2259
sel_par	0.5178	0.0605	fmort_dev	-0.9928	0.2958	rec_dev	-0.2578	0.2961
sel_par	0.2133	0.1106	fmort_dev	-0.6056	0.2960	rec_dev	-0.5785	0.4571
sel_par	0.3780	0.1268	fmort_dev	0.5098	0.2962	rec_dev	0.0069	0.4379
sel_par	0.0681	0.0866	fmort_dev	-0.4266	0.2963	rec_dev	0.2792	0.4429
sel_par	0.2166	0.0853	fmort_dev	0.0112	0.2964	rec_dev	0.6929	0.3093
sel_par	0.4007	0.0602	fmort_dev	0.1592	0.2964	rec_dev	0.1027	0.4317
sel_par	0.2106	0.1194	fmort_dev	-0.2361	0.2963	rec_dev	-0.1822	0.4730
sel_par	-0.6347	0.1392	fmort_dev	-0.4047	0.2962	rec_dev	1.5459	0.1201
sel_par	-0.4357	0.0848	fmort_dev	-0.1614	0.2960	rec_dev	-0.2323	0.5109
sel_par	-0.0041	0.0911	fmort_dev	-0.3727	0.2959	rec_dev	0.7699	0.2034
sel_par	0.3246	0.0768	fmort_dev	-0.6972	0.2958	rec_dev	-0.0398	0.4030
sel_par	0.5850	0.1208	fmort_dev	-0.4659	0.2958	rec_dev	1.1648	0.1562
sel_par	-1.2452	0.2232	fmort_dev	-0.7525	0.2959	rec_dev	0.5605	0.2624
sel_par	-1.0729	0.1249	fmort_dev	-0.7877	0.2960	rec_dev	0.0417	0.3101
sel_par	-0.3199	0.1327	fmort_dev	-0.6084	0.2962	rec_dev	-0.7131	0.4090
sel_par	-0.1187	0.1189	fmort_dev	-0.3214	0.2964	rec_dev	-0.2456	0.2668
sel_par	0.2271	0.2128	fmort_dev	-0.5260	0.2966	rec_dev	-0.4657	0.3630
sel_aslope_srv3	0.8316	0.0680	fmort_dev	-0.6613	0.2968	rec_dev	0.7183	0.1723
sel_a50_srv3	6.2534	0.1800	fmort_dev	-0.4656	0.2969	rec_dev	0.4315	0.2648
sel_aslope_srv_ebs	0.6952	0.0942	fmort_dev	-0.1252	0.2971	rec_dev	1.2303	0.1406
sel_a50_srv_ebs	11.1220	0.4484	fmort_dev	-0.2055	0.2974	rec_dev	-0.2740	0.4293
logM	-2.8854	0.0323	fmort_dev	-0.3616	0.2977	rec_dev	1.1100	0.1468
log_avg_fmort	-3.9434	0.3113	fmort_dev	-0.2386	0.2981	rec_dev	-0.0816	0.4119
fmort_dev	-2.1162	0.3107	fmort_dev	0.0365	0.2987	rec_dev	1.5733	0.1179
fmort_dev	-0.0207	0.3104	fmort_dev	0.0308	0.2994	rec_dev	-0.4181	0.5006
fmort_dev	-0.7999	0.3100	fmort_dev	0.2886	0.3003	rec_dev	0.5912	0.2239
fmort_dev	0.0748	0.3095	fmort_dev	0.3269	0.3016	rec_dev	-0.3694	0.4986
fmort_dev	1.1951	0.3082	fmort_dev	0.3066	0.3030	rec_dev	0.9426	0.2254
fmort_dev	1.6307	0.3052	fmort_dev	0.3138	0.3046	rec_dev	1.1717	0.2212
fmort_dev	1.8035	0.3032	fmort_dev	0.3695	0.3065	rec_dev	0.3298	0.4229
fmort_dev	1.7151	0.3026	fmort_dev	0.4795	0.3088	rec_dev	0.5240	0.3457
fmort_dev	1.9058	0.3023	rec_dev	1.1209	0.2550	rec_dev	1.1951	0.1928
fmort_dev	1.6354	0.3018	rec_dev	-0.5354	0.6002	rec_dev	-0.6780	0.5033
fmort_dev	2.0733	0.3011	rec_dev	-0.6474	0.5762	rec_dev	-0.6043	0.4307
fmort_dev	1.2376	0.3011	rec_dev	-0.3765	0.6475	rec_dev	-0.3492	0.3961
fmort_dev	1.4778	0.3013	rec_dev	1.2684	0.4272	rec_dev	-0.7126	0.4867
fmort_dev	0.6055	0.3017	rec_dev	1.3694	0.3741	mean_log_rec	4.3410	0.0987
fmort_dev	1.5619	0.3012	rec_dev	-0.4830	0.6208	log_rinit	4.2984	0.0803
fmort_dev	1.3625	0.3006	rec_dev	-0.7844	0.5405	logq_srv3	0.1620	0.1439
fmort_dev	1.6674	0.3003	rec_dev	-0.7903	0.5039	logq_srv_ebs	0.3618	0.2237
fmort_dev	0.7508	0.3005	rec_dev	-0.6940	0.4687	mat_beta1	-6.6118	3.6559
fmort_dev	0.4609	0.2999	rec_dev	-0.8709	0.4505	mat_beta2	0.7270	0.4473
fmort_dev	0.4221	0.2993	rec_dev	-1.1635	0.4597			

Table 12.14. Estimated time series of POP total biomass (t), spawning biomass (t), and recruitment (thousands).

	Total Biomass (ages 3+)				Spawner Biomass (ages 3+)				Recruitment (age 3)			
	Assessment Year				Assessment Year				Assessment Year			
	2018		2016		2018		2016		2018		2016	
Year	Est	CV	Est	CV	Est	CV	Est	CV	Est	CV	Est	CV
1977	294,390	0.105	274,888	0.100	125,540	0.117	116,033	0.113	26,299	0.332	26,008	0.326
1978	282,420	0.108	262,984	0.102	119,810	0.121	110,276	0.117	25,167	0.369	24,665	0.364
1979	277,300	0.109	257,861	0.104	115,700	0.125	106,198	0.122	65,091	0.238	63,180	0.231
1980	274,020	0.110	254,398	0.105	112,560	0.129	103,135	0.127	59,335	0.306	55,807	0.302
1981	273,430	0.110	253,569	0.105	110,620	0.132	101,289	0.131	43,058	0.467	40,599	0.454
1982	277,040	0.110	256,237	0.105	109,470	0.134	100,247	0.133	77,315	0.443	67,986	0.444
1983	288,930	0.108	267,115	0.104	110,060	0.135	100,882	0.134	101,510	0.453	95,357	0.430
1984	309,190	0.106	285,325	0.101	111,670	0.138	102,464	0.138	153,530	0.317	138,426	0.313
1985	328,370	0.104	302,560	0.099	114,520	0.145	105,161	0.144	85,090	0.442	78,283	0.426
1986	348,340	0.102	320,399	0.098	119,020	0.153	109,328	0.152	63,998	0.487	58,289	0.473
1987	394,530	0.100	360,821	0.096	125,060	0.161	114,775	0.160	360,310	0.144	315,248	0.141
1988	425,340	0.099	387,848	0.096	132,670	0.172	121,516	0.171	60,866	0.529	56,146	0.506
1989	464,230	0.099	420,835	0.095	142,220	0.185	129,852	0.183	165,830	0.219	142,581	0.217
1990	495,810	0.099	447,206	0.096	152,320	0.196	138,411	0.193	73,787	0.421	64,421	0.407
1991	527,770	0.103	471,337	0.100	161,810	0.205	145,982	0.202	246,130	0.183	208,307	0.179
1992	565,950	0.104	501,836	0.101	176,320	0.212	157,974	0.209	134,500	0.284	112,821	0.277
1993	593,680	0.106	522,102	0.104	190,930	0.218	169,576	0.214	80,056	0.326	66,169	0.319
1994	611,310	0.108	532,982	0.107	206,050	0.217	181,230	0.213	37,636	0.426	31,925	0.410
1995	630,890	0.110	545,964	0.109	222,710	0.207	194,101	0.204	60,062	0.285	50,410	0.282
1996	646,470	0.112	555,839	0.111	238,580	0.198	206,095	0.196	48,196	0.383	42,388	0.368
1997	663,100	0.114	565,460	0.114	252,380	0.192	215,875	0.190	157,480	0.201	132,189	0.202
1998	679,040	0.116	575,365	0.117	265,590	0.183	225,248	0.182	118,210	0.291	102,451	0.284
1999	710,880	0.118	599,003	0.119	276,970	0.170	233,016	0.170	262,780	0.176	223,462	0.178
2000	727,270	0.119	609,566	0.121	284,400	0.157	237,412	0.158	58,380	0.450	51,858	0.438
2001	759,800	0.121	635,219	0.123	290,700	0.149	241,135	0.151	233,000	0.181	208,919	0.186
2002	782,510	0.122	653,000	0.125	296,370	0.148	244,435	0.152	70,769	0.434	67,519	0.431
2003	827,520	0.123	695,586	0.127	302,520	0.154	248,170	0.159	370,310	0.162	387,507	0.167
2004	850,210	0.125	716,500	0.129	310,300	0.164	253,395	0.170	50,547	0.521	53,321	0.526
2005	879,990	0.126	744,056	0.131	321,940	0.172	262,357	0.180	138,680	0.250	127,975	0.270
2006	902,840	0.128	765,602	0.133	335,710	0.176	273,625	0.186	53,070	0.518	46,697	0.521
2007	931,070	0.129	791,935	0.135	349,210	0.179	285,167	0.191	197,080	0.255	178,087	0.261
2008	959,230	0.132	811,004	0.139	361,720	0.181	296,483	0.197	247,830	0.253	150,752	0.313
2009	979,350	0.134	823,258	0.142	375,020	0.182	309,251	0.201	106,780	0.443	66,111	0.465
2010	1,001,300	0.136	834,091	0.144	387,810	0.180	321,869	0.198	129,670	0.369	67,396	0.449
2011	1,030,100	0.138	845,050	0.147	397,240	0.175	330,686	0.193	253,690	0.230	140,127	0.330
2012	1,036,800	0.142	841,177	0.151	402,900	0.174	334,878	0.189	38,978	0.525	47,677	0.552
2013	1,038,300	0.145	832,801	0.156	407,490	0.177	336,258	0.189	41,959	0.453	46,194	0.566
2014	1,027,900	0.149	817,728	0.161	409,910	0.183	333,615	0.193	54,152	0.421		
2015	1,010,200	0.154	800,496	0.166	412,180	0.187	329,214	0.196	37,654	0.511		
2016	994,060	0.158	783,492	0.171	413,760	0.190	323,393	0.199				
2017	976,200	0.162	767,767		413,160	0.192	316,117					
2018	955,868	0.166			408,484	0.192						
2019	934,293				399,024							
Mean recruitment of post-1976 year classes									124,229		109,512	

Table 12.15. Estimated numbers at age for POP (millions).

	Age																
Year	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1960	235.5	92.2	87.2	82.4	78.0	73.7	69.7	65.9	62.4	59.0	55.8	52.7	49.9	47.2	44.6	42.2	39.9	37.7
1961	45.0	222.7	87.2	82.4	77.9	73.6	69.5	65.6	61.8	58.2	54.8	51.7	48.9	46.3	43.9	41.7	39.5	37.5
1962	40.2	42.5	210.2	82.1	77.3	72.6	67.7	62.6	57.5	52.4	47.9	44.3	41.8	40.0	38.8	37.7	36.6	35.4
1963	52.7	38.0	40.1	198.5	77.4	72.6	67.7	62.6	57.2	51.7	46.5	42.1	39.0	37.0	35.8	35.1	34.5	33.7
1964	273.0	49.8	35.9	37.8	186.1	72.0	66.6	60.8	54.5	48.0	42.0	37.0	33.5	31.5	30.6	30.4	30.6	30.7
1965	302.0	257.4	46.8	33.5	34.8	167.3	61.9	53.6	44.5	35.7	28.4	23.4	20.5	19.5	19.7	20.9	22.4	24.0
1966	47.4	284.0	240.6	43.2	30.3	30.3	136.1	45.7	34.6	24.7	17.3	12.7	10.5	9.8	10.3	11.7	13.8	16.2
1967	35.0	44.4	264.0	220.3	38.5	25.7	23.8	95.8	27.8	18.0	11.2	7.3	5.4	4.7	4.9	5.9	7.5	9.6
1968	34.8	32.8	41.2	241.2	195.9	32.8	20.4	17.2	61.5	15.7	9.1	5.4	3.5	2.7	2.6	3.0	4.0	5.4
1969	38.4	32.4	30.2	37.1	210.1	161.6	25.0	14.0	10.3	32.2	7.4	4.1	2.4	1.7	1.4	1.5	2.0	2.8
1970	32.1	35.7	29.9	27.4	32.8	177.8	129.1	18.5	9.5	6.4	18.6	4.1	2.3	1.4	1.1	1.0	1.1	1.5
1971	24.0	29.5	32.3	26.2	23.0	25.8	128.6	83.7	10.6	4.8	3.0	8.2	1.9	1.1	0.7	0.6	0.6	0.8
1972	30.1	22.3	27.3	29.4	23.5	20.0	21.7	103.4	64.1	7.7	3.4	2.1	5.8	1.3	0.8	0.6	0.5	0.5
1973	48.2	27.8	20.4	24.5	25.8	19.9	16.3	16.7	75.5	44.5	5.2	2.2	1.4	4.0	1.0	0.6	0.5	0.4
1974	39.0	45.1	25.9	18.9	22.4	23.3	17.6	14.1	14.3	63.2	36.8	4.3	1.9	1.2	3.4	0.8	0.5	0.4
1975	44.8	35.7	40.7	22.9	16.3	18.7	18.6	13.5	10.3	9.9	42.8	24.7	2.9	1.3	0.8	2.6	0.7	0.4
1976	22.6	41.2	32.4	36.3	20.1	13.8	15.4	14.8	10.3	7.6	7.3	31.1	18.1	2.2	1.0	0.7	2.1	0.5
1977	26.3	20.5	36.7	28.3	30.8	16.4	10.9	11.6	10.6	7.2	5.2	4.9	21.1	12.7	1.6	0.7	0.5	1.7
1978	25.2	24.4	18.9	33.6	25.7	27.6	14.5	9.4	9.9	8.9	5.9	4.3	4.1	17.8	10.8	1.4	0.7	0.5
1979	65.1	23.5	22.7	17.5	30.8	23.3	24.7	12.8	8.3	8.5	7.7	5.1	3.7	3.5	15.6	9.6	1.2	0.6
1980	59.3	60.8	21.9	21.0	16.0	28.0	21.0	22.0	11.3	7.2	7.4	6.7	4.4	3.2	3.1	13.9	8.6	1.1
1981	43.1	55.7	56.9	20.4	19.5	14.8	25.7	19.1	19.9	10.1	6.4	6.6	5.9	4.0	2.9	2.8	12.7	7.9
1982	77.3	40.5	52.2	53.2	19.0	18.0	13.6	23.4	17.3	17.9	9.1	5.8	5.9	5.3	3.6	2.7	2.6	11.7
1983	101.5	73.0	38.2	49.2	50.1	17.8	16.9	12.8	21.9	16.1	16.7	8.5	5.4	5.5	5.0	3.4	2.5	2.4
1984	153.5	95.9	69.0	36.1	46.5	47.3	16.8	16.0	12.0	20.6	15.2	15.7	8.0	5.1	5.2	4.7	3.2	2.3
1985	85.1	145.1	90.6	65.2	34.0	43.8	44.6	15.8	15.0	11.3	19.4	14.2	14.7	7.5	4.7	4.9	4.4	3.0
1986	64.0	80.5	137.2	85.7	61.6	32.2	41.4	42.1	15.0	14.2	10.6	18.3	13.4	13.9	7.1	4.5	4.6	4.2
1987	360.3	60.5	76.0	129.6	80.9	58.1	30.3	39.0	39.6	14.1	13.3	10.0	17.2	12.6	13.1	6.6	4.2	4.4
1988	60.9	340.5	57.1	71.8	122.3	76.2	54.7	28.5	36.5	37.0	13.1	12.4	9.3	16.0	11.8	12.2	6.2	4.0
1989	165.8	57.5	321.6	53.9	67.7	115.1	71.6	51.2	26.6	34.0	34.3	12.1	11.5	8.6	14.9	11.0	11.4	5.8
1990	73.8	156.7	54.3	303.3	50.8	63.6	107.8	66.8	47.5	24.6	31.3	31.5	11.1	10.5	7.9	13.7	10.1	10.6
1991	246.1	69.6	147.5	51.0	283.4	47.1	58.5	97.9	59.8	41.9	21.4	27.0	27.1	9.6	9.2	7.0	12.2	9.1
1992	134.5	232.5	65.7	139.1	48.0	266.2	44.1	54.5	90.7	55.1	38.4	19.5	24.6	24.7	8.8	8.4	6.4	11.2
1993	80.1	127.0	219.4	61.9	130.7	44.9	248.0	40.8	50.0	82.4	49.6	34.4	17.4	22.0	22.2	7.9	7.6	5.9
1994	37.6	75.6	119.8	206.7	58.1	122.3	41.8	228.8	37.3	45.2	73.8	44.1	30.5	15.5	19.6	19.9	7.2	6.9
1995	60.1	35.6	71.4	113.0	194.6	54.6	114.4	38.9	211.7	34.3	41.2	67.0	40.0	27.6	14.1	17.9	18.3	6.6
1996	48.2	56.8	33.6	67.4	106.5	183.0	51.2	106.8	36.1	195.4	31.5	37.7	61.2	36.5	25.3	12.9	16.5	16.9
1997	157.5	45.5	53.6	31.7	63.4	100.1	171.2	47.7	98.8	33.2	178.2	28.5	34.1	55.4	33.1	23.0	11.8	15.1
1998	118.2	148.8	43.0	50.6	29.9	59.7	93.8	160.0	44.3	91.3	30.5	163.2	26.1	31.2	50.6	30.4	21.2	10.9
1999	262.8	111.7	140.6	40.6	47.7	28.1	56.1	88.0	149.5	41.2	84.7	28.2	150.6	24.1	28.8	46.9	28.1	19.7
2000	58.4	248.3	105.6	132.8	38.3	44.9	26.4	52.5	82.0	138.7	38.1	77.9	25.9	138.2	22.1	26.5	43.2	26.0
2001	233.0	55.2	234.7	99.7	125.3	36.1	42.3	24.8	49.1	76.5	128.9	35.3	72.1	24.0	128.0	20.5	24.6	40.2
2002	70.8	220.2	52.1	221.6	94.1	118.1	34.0	39.7	23.2	45.9	71.2	119.6	32.7	66.8	22.2	118.7	19.0	22.9
2003	370.3	66.9	208.1	49.2	209.1	88.6	111.1	31.9	37.1	21.6	42.6	65.9	110.5	30.2	61.7	20.5	110.0	17.7
2004	50.5	349.9	63.2	196.4	46.4	196.8	83.2	103.9	29.7	34.4	20.0	39.2	60.5	101.4	27.7	56.7	18.9	101.4
2005	138.7	47.8	330.6	59.6	185.2	43.7	185.0	78.0	97.1	27.7	32.0	18.5	36.2	55.8	93.6	25.6	52.4	17.5
2006	53.1	131.1	45.1	312.2	56.3	174.6	41.1	173.7	73.1	90.7	25.7	29.7	17.1	33.5	51.7	86.7	23.8	48.7
2007	197.1	50.2	123.8	42.6	294.4	53.0	164.1	38.6	162.3	68.1	84.2	23.8	27.4	15.8	30.9	47.7	80.2	22.0
2008	247.8	186.2	47.4	116.8	40.1	276.8	49.7	153.4	35.9	150.4	62.7	77.3	21.8	25.1	14.5	28.3	43.8	73.7
2009	106.8	234.1	175.8	44.7	110.1	37.8	259.8	46.5	142.9	33.3	139.0	57.8	71.0	20.0	23.0	13.3	26.0	40.3
2010	129.7	100.9	221.1	165.9	42.1	103.6	35.5	243.5	43.4	133.1	30.9	128.6	53.3	65.5	18.5	21.2	12.3	24.1
2011	253.7	122.5	95.3	208.7	156.4	39.6	97.3	33.2	227.2	40.4	123.2	28.5	118.4	49.1	60.2	17.0	19.6	11.3
2012	39.0	239.6	115.6	89.8	196.5	146.9	37.1	90.8	30.9	210.1	37.2	112.9	26.1	108.1	44.8	55.0	15.5	17.9
2013	42.0	36.8	226.2	109.0	84.6	184.6	137.7	34.7	84.4	28.6	193.4	34.1	103.3	23.8	98.7	40.9	50.4	14.3
2014	54.2	39.6	34.7	213.1	102.5	79.3	172.5	128.1	32.1	77.6	26.1	176.0	30.9	93.6	21.6	89.5	37.2	45.8
2015	37.7	51.1	37.4	32.7	200.3	96.1	74.1	160.4	118.4	29.5	70.9	23.7	159.5	28.0	84.6	19.5	81.2	33.8
2016	101.7	35.5	48.2	35.2	30.8	187.8	89.8	68.9	148.4	109.0	27.0	64.6	21.6	144.6	25.4	76.8	17.8	73.9
2017	101.7	96.0	33.5	45.4	33.1	28.8	175.5	83.6	63.8	136.6	99.7	24.6	58.7	19.6	131.2	23.0	69.8	16.2
2018	101.7	96.0	90.6	31.6	42.7	31.0	26.9	163.2	77.3	58.6	124.8	90.7	22.3	53.2	17.7	119.0	20.9	63.6

Table 12.15 (continued). Estimated numbers at age for POP (millions).

	Age																			
Year	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40+
1960	35.7	33.7	31.9	30.2	28.5	27.0	25.5	24.1	22.8	21.6	20.4	19.3	18.3	17.3	16.3	15.4	14.6	13.8	13.1	227.5
1961	35.5	33.6	31.8	30.1	28.5	26.9	25.5	24.1	22.8	21.6	20.4	19.3	18.2	17.2	16.3	15.4	14.6	13.8	13.1	227.3
1962	34.0	32.5	31.0	29.5	28.0	26.5	25.1	23.8	22.5	21.3	20.2	19.1	18.1	17.1	16.2	15.3	14.5	13.7	13.0	226.1
1963	32.8	31.7	30.4	29.1	27.7	26.3	24.9	23.6	22.4	21.2	20.1	19.0	18.0	17.0	16.1	15.2	14.4	13.7	12.9	225.5
1964	30.5	30.0	29.2	28.1	27.0	25.7	24.5	23.3	22.1	20.9	19.8	18.8	17.8	16.8	15.9	15.1	14.3	13.5	12.8	224.1
1965	25.2	25.9	26.1	25.8	25.1	24.2	23.2	22.2	21.1	20.1	19.1	18.1	17.2	16.3	15.5	14.7	13.9	13.2	12.5	220.0
1966	18.5	20.4	21.6	22.2	22.3	22.0	21.4	20.6	19.7	18.9	18.0	17.1	16.3	15.5	14.8	14.1	13.4	12.7	12.1	213.7
1967	12.1	14.6	16.7	18.1	18.9	19.2	19.1	18.7	18.1	17.4	16.7	16.0	15.3	14.6	13.9	13.3	12.7	12.1	11.6	206.4
1968	7.4	9.8	12.1	14.1	15.6	16.5	16.8	16.8	16.5	16.0	15.5	14.9	14.3	13.7	13.1	12.6	12.1	11.6	11.1	199.8
1969	4.1	5.8	7.9	10.1	11.9	13.3	14.2	14.6	14.6	14.4	14.1	13.7	13.2	12.7	12.2	11.8	11.3	10.9	10.5	192.1
1970	2.2	3.3	4.9	6.8	8.7	10.4	11.7	12.5	12.9	13.0	12.9	12.6	12.3	11.9	11.5	11.1	10.7	10.3	9.9	186.1
1971	1.1	1.7	2.7	4.0	5.6	7.3	8.8	10.0	10.7	11.1	11.2	11.2	11.0	10.7	10.5	10.2	9.9	9.6	9.3	177.3
1972	0.7	1.0	1.5	2.4	3.6	5.0	6.6	8.0	9.0	9.7	10.1	10.2	10.2	10.1	9.8	9.6	9.3	9.1	8.8	173.0
1973	0.4	0.6	0.8	1.3	2.1	3.2	4.5	5.9	7.1	8.1	8.7	9.1	9.2	9.2	9.1	9.0	8.8	8.6	8.3	167.7
1974	0.4	0.4	0.5	0.8	1.2	1.9	2.9	4.1	5.4	6.6	7.5	8.1	8.4	8.6	8.6	8.5	8.4	8.2	8.0	164.7
1975	0.3	0.3	0.3	0.4	0.7	1.1	1.7	2.6	3.7	4.8	5.9	6.7	7.3	7.6	7.8	7.8	7.7	7.6	7.5	158.7
1976	0.4	0.3	0.3	0.3	0.4	0.6	0.9	1.5	2.3	3.3	4.4	5.3	6.1	6.6	6.9	7.1	7.1	7.1	7.0	153.5
1977	0.4	0.3	0.2	0.2	0.3	0.3	0.5	0.8	1.3	2.0	2.9	3.9	4.7	5.4	5.9	6.2	6.4	6.5	6.4	146.8
1978	1.5	0.4	0.3	0.2	0.2	0.2	0.3	0.5	0.8	1.2	1.9	2.7	3.6	4.4	5.0	5.5	5.8	5.9	6.0	142.9
1979	0.4	1.4	0.4	0.3	0.2	0.2	0.2	0.3	0.4	0.7	1.1	1.7	2.5	3.3	4.1	4.7	5.1	5.4	5.5	139.3
1980	0.5	0.4	1.3	0.3	0.2	0.2	0.2	0.2	0.3	0.4	0.7	1.1	1.6	2.3	3.1	3.8	4.4	4.8	5.0	135.5
1981	1.0	0.5	0.4	1.2	0.3	0.2	0.2	0.2	0.2	0.2	0.4	0.6	1.0	1.5	2.2	2.9	3.5	4.1	4.5	131.9
1982	7.3	0.9	0.5	0.3	1.1	0.3	0.2	0.2	0.2	0.2	0.2	0.4	0.6	0.9	1.4	2.0	2.7	3.3	3.8	128.0
1983	11.0	6.8	0.9	0.4	0.3	1.0	0.3	0.2	0.2	0.1	0.2	0.2	0.3	0.5	0.9	1.3	1.9	2.5	3.1	124.4
1984	2.3	10.3	6.5	0.8	0.4	0.3	1.0	0.3	0.2	0.1	0.1	0.2	0.2	0.3	0.5	0.8	1.3	1.8	2.4	120.5
1985	2.2	2.2	9.7	6.1	0.8	0.4	0.3	0.9	0.2	0.2	0.1	0.1	0.1	0.2	0.3	0.5	0.8	1.2	1.7	116.0
1986	2.8	2.1	2.0	9.2	5.8	0.7	0.4	0.3	0.9	0.2	0.2	0.1	0.1	0.1	0.2	0.3	0.5	0.7	1.1	111.3
1987	3.9	2.7	2.0	1.9	8.7	5.4	0.7	0.3	0.2	0.8	0.2	0.2	0.1	0.1	0.1	0.2	0.3	0.4	0.7	106.2
1988	4.1	3.7	2.5	1.9	1.8	8.2	5.1	0.7	0.3	0.2	0.8	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.4	100.8
1989	3.7	3.8	3.5	2.4	1.7	1.7	7.7	4.8	0.6	0.3	0.2	0.7	0.2	0.1	0.1	0.1	0.1	0.2	0.2	95.2
1990	5.4	3.5	3.6	3.3	2.2	1.6	1.6	7.2	4.5	0.6	0.3	0.2	0.7	0.2	0.1	0.1	0.1	0.1	0.1	89.6
1991	9.5	4.9	3.1	3.3	3.0	2.0	1.5	1.5	6.6	4.1	0.5	0.3	0.2	0.6	0.2	0.1	0.1	0.1	0.1	83.0
1992	8.4	8.9	4.6	2.9	3.1	2.8	1.9	1.4	1.4	6.2	3.8	0.5	0.2	0.2	0.6	0.2	0.1	0.1	0.1	77.9
1993	10.3	7.8	8.2	4.2	2.7	2.8	2.6	1.7	1.3	1.3	5.7	3.6	0.5	0.2	0.2	0.5	0.1	0.1	0.1	72.7
1994	5.4	9.5	7.1	7.6	3.9	2.5	2.6	2.4	1.6	1.2	1.2	5.3	3.3	0.4	0.2	0.1	0.5	0.1	0.1	67.6
1995	6.4	5.0	8.8	6.6	7.0	3.6	2.3	2.4	2.2	1.5	1.1	1.1	4.9	3.1	0.4	0.2	0.1	0.5	0.1	63.2
1996	6.1	6.0	4.6	8.2	6.2	6.5	3.4	2.2	2.3	2.1	1.4	1.0	1.0	4.6	2.9	0.4	0.2	0.1	0.4	59.3
1997	15.5	5.6	5.5	4.3	7.6	5.7	6.1	3.1	2.0	2.1	1.9	1.3	1.0	0.9	4.3	2.7	0.3	0.2	0.1	55.7
1998	14.0	14.4	5.2	5.1	4.0	7.1	5.3	5.7	2.9	1.9	2.0	1.8	1.2	0.9	0.9	4.0	2.5	0.3	0.2	52.2
1999	10.1	13.0	13.4	4.9	4.8	3.7	6.6	5.0	5.3	2.7	1.8	1.8	1.7	1.1	0.8	0.8	3.7	2.3	0.3	49.1
2000	18.2	9.4	12.1	12.5	4.6	4.5	3.5	6.1	4.6	4.9	2.5	1.6	1.7	1.6	1.1	0.8	0.8	3.5	2.2	46.3
2001	24.2	17.0	8.8	11.3	11.7	4.3	4.2	3.2	5.7	4.3	4.6	2.4	1.5	1.6	1.5	1.0	0.7	0.7	3.2	45.5
2002	37.5	22.6	15.9	8.2	10.6	10.9	4.0	3.9	3.0	5.4	4.1	4.3	2.2	1.4	1.5	1.4	0.9	0.7	0.7	45.7
2003	21.3	34.9	21.1	14.8	7.7	9.9	10.2	3.7	3.6	2.8	5.0	3.8	4.0	2.1	1.3	1.4	1.3	0.9	0.6	43.5
2004	16.3	19.7	32.3	19.5	13.7	7.1	9.2	9.5	3.4	3.4	2.6	4.7	3.5	3.7	1.9	1.2	1.3	1.2	0.8	41.2
2005	94.1	15.2	18.3	30.1	18.2	12.8	6.6	8.5	8.8	3.2	3.1	2.4	4.3	3.3	3.5	1.8	1.2	1.2	1.1	39.3
2006	16.3	87.6	14.1	17.1	28.0	17.0	11.9	6.2	8.0	8.2	3.0	2.9	2.3	4.0	3.1	3.3	1.7	1.1	1.1	37.9
2007	45.2	15.1	81.4	13.1	15.9	26.1	15.8	11.1	5.7	7.4	7.6	2.8	2.7	2.1	3.8	2.9	3.0	1.6	1.0	36.5
2008	20.2	41.6	13.9	75.2	12.1	14.7	24.1	14.6	10.2	5.3	6.8	7.0	2.6	2.5	2.0	3.5	2.6	2.8	1.5	34.9
2009	68.0	18.7	38.5	12.9	69.5	11.2	13.5	22.2	13.5	9.5	4.9	6.3	6.5	2.4	2.3	1.8	3.2	2.5	2.6	33.9
2010	37.3	63.0	17.3	35.7	12.0	64.5	10.4	12.6	20.6	12.5	8.8	4.5	5.8	6.0	2.2	2.2	1.7	3.0	2.3	34.1
2011	22.3	34.5	58.3	16.1	33.1	11.1	59.7	9.6	11.6	19.1	11.5	8.1	4.2	5.4	5.6	2.0	2.0	1.6	2.8	33.9
2012	10.4	20.4	31.8	53.6	14.8	30.4	10.2	54.8	8.8	10.6	17.5	10.6	7.4	3.8	5.0	5.1	1.9	1.9	1.4	34.0
2013	16.5	9.6	18.8	29.2	49.3	13.6	27.9	9.3	50.2	8.1	9.8	16.0	9.7	6.8	3.5	4.6	4.7	1.7	1.7	32.8
2014	13.0	15.0	8.7	17.2	26.7	45.0	12.4	25.4	8.5	45.6	7.3	8.8	14.5	8.8	6.2	3.2	4.2	4.3	1.6	31.7
2015	41.7	11.8	13.7	8.0	15.7	24.3	40.9	11.2	23.0	7.7	41.3	6.6	8.0	13.1	8.0	5.6	2.9	3.8	4.0	30.6
2016	30.8	38.1	10.8	12.5	7.3	14.3	22.1	37.2	10.2	20.9	7.0	37.3	6.0	7.2	11.9	7.2	5.1	2.7	3.5	31.7
2017	67.4	28.1	34.8	9.9	11.4	6.6	13.0	20.1	33.7	9.2	18.9	6.3	33.7	5.4	6.5	10.8	6.6	4.6	2.4	32.2
2018	14.7	61.5	25.7	31.8	9.0	10.4	6.0	11.8	18.2	30.5	8.3	17.0	5.7	30.3	4.9	5.9	9.8	6.0	4.2	31.7

Table 12.16. Projections of BSAI spawning biomass (t), catch (t), and fishing mortality rate for each of the several scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 258,295 t and 226,008 t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2018	35,467	35,467	35,467	35,467	35,467	35,467	35,467
2019	50,594	50,594	25,692	17,565	0	61,067	50,594
2020	48,244	48,244	25,270	17,449	0	57,462	48,244
2021	45,789	45,789	24,720	17,235	0	53,836	55,267
2022	43,379	43,379	24,107	16,966	0	50,378	51,670
2023	41,176	41,176	23,513	16,694	0	47,274	48,433
2024	39,306	39,306	23,007	16,468	0	44,664	45,698
2025	37,871	37,871	22,663	16,341	0	42,646	43,567
2026	36,832	36,832	22,476	16,315	0	41,109	41,972
2027	36,148	36,148	22,443	16,389	0	39,585	40,572
2028	35,678	35,678	22,523	16,538	0	38,332	39,257
2029	35,301	35,301	22,689	16,745	0	37,465	38,279
2030	34,975	34,975	22,883	16,971	0	36,848	37,549
2031	34,683	34,683	23,067	17,186	0	36,374	36,968
Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2018	408,484	408,484	408,484	408,484	408,484	408,484	408,484
2019	397,025	397,025	400,144	401,146	403,288	395,692	397,025
2020	377,371	377,371	392,222	397,097	407,679	371,163	377,371
2021	357,451	357,451	382,907	391,439	410,259	347,052	356,242
2022	339,071	339,071	373,917	385,840	412,558	325,154	333,494
2023	323,398	323,398	366,464	381,498	415,722	306,577	314,109
2024	310,790	310,790	361,032	378,916	420,252	291,586	298,366
2025	301,012	301,012	357,538	378,038	426,123	279,850	285,933
2026	293,680	293,680	355,781	378,706	433,248	270,891	276,328
2027	288,164	288,164	355,263	380,455	441,214	264,079	268,882
2028	283,877	283,877	355,503	382,832	449,615	258,926	263,070
2029	280,447	280,447	356,189	385,548	458,208	254,988	258,523
2030	277,607	277,607	357,053	388,342	466,737	251,874	254,868
2031	275,284	275,284	358,048	391,174	475,174	249,424	251,944
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2018	0.053	0.053	0.053	0.053	0.053	0.053	0.053
2019	0.079	0.079	0.039	0.027	0	0.095	0.079
2020	0.079	0.079	0.039	0.027	0	0.095	0.079
2021	0.079	0.079	0.039	0.027	0	0.095	0.095
2022	0.079	0.079	0.039	0.027	0	0.095	0.095
2023	0.079	0.079	0.039	0.027	0	0.095	0.095
2024	0.079	0.079	0.039	0.027	0	0.095	0.095
2025	0.079	0.079	0.039	0.027	0	0.095	0.095
2026	0.079	0.079	0.039	0.027	0	0.095	0.095
2027	0.079	0.079	0.039	0.027	0	0.094	0.095
2028	0.078	0.078	0.039	0.027	0	0.092	0.093
2029	0.078	0.078	0.039	0.027	0	0.091	0.092
2030	0.078	0.078	0.039	0.027	0	0.090	0.091
2031	0.077	0.077	0.039	0.027	0	0.089	0.090

Figures

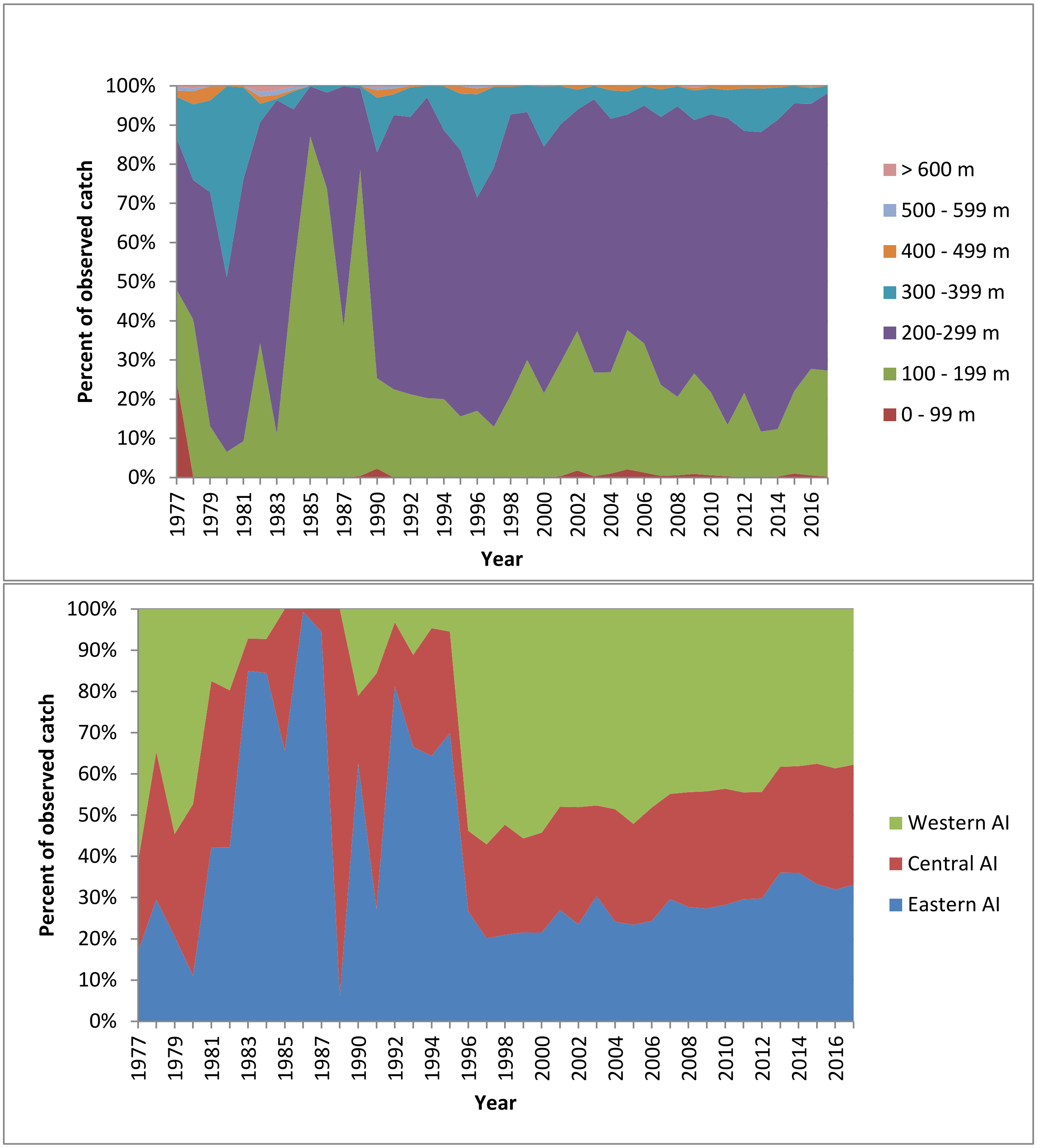

Figure 12.1. Distribution of observed Aleutian Islands Pacific ocean perch catch (from North Pacific Groundfish Observer Program) by depth zone (top panel) and AI subarea (bottom panel) from 1977 to 2017.

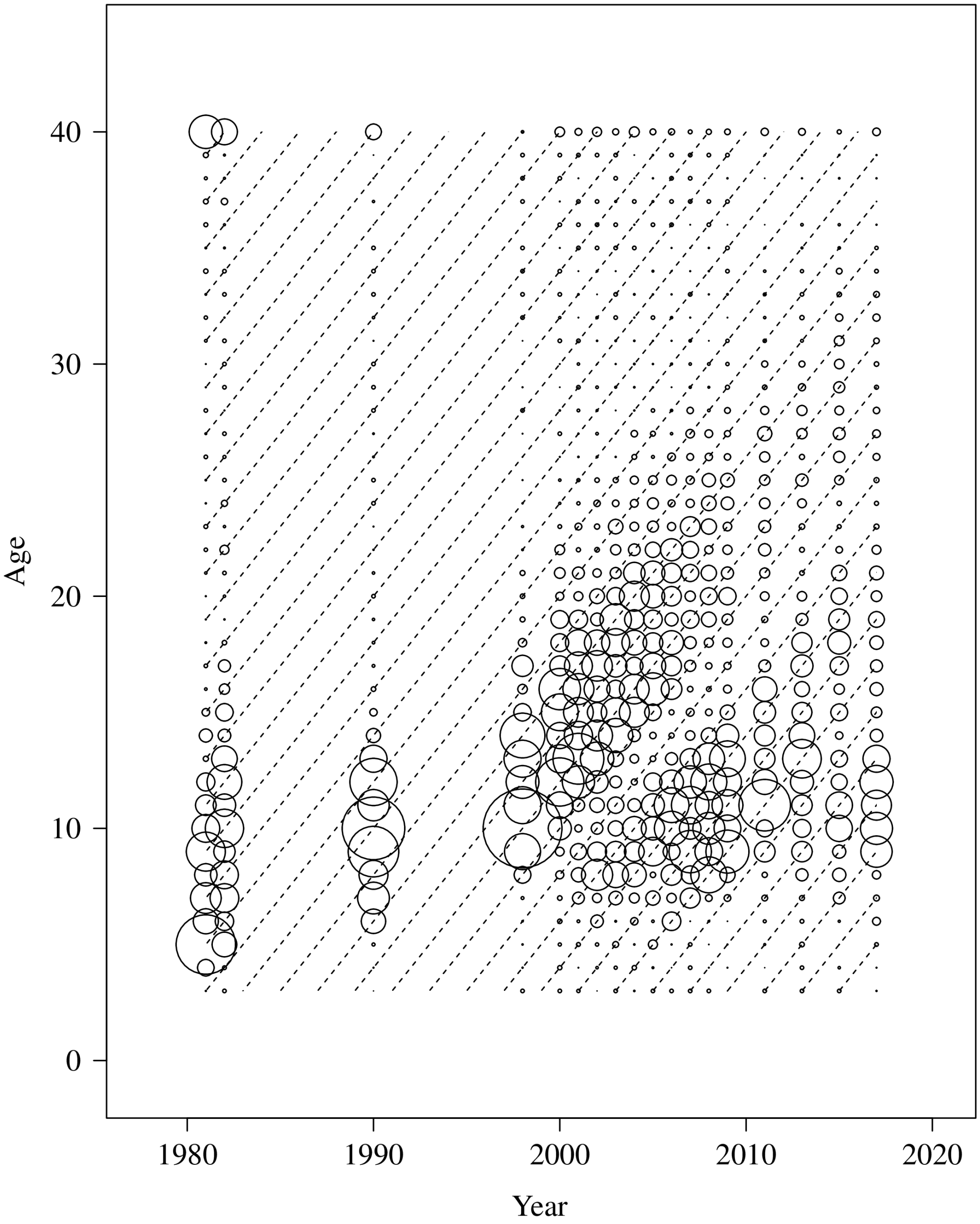

Figure 12.2. Fishery age composition data for the BSAI POP; The diameter of the circles are scaled within each year of samples, and dashed lines denote cohorts.

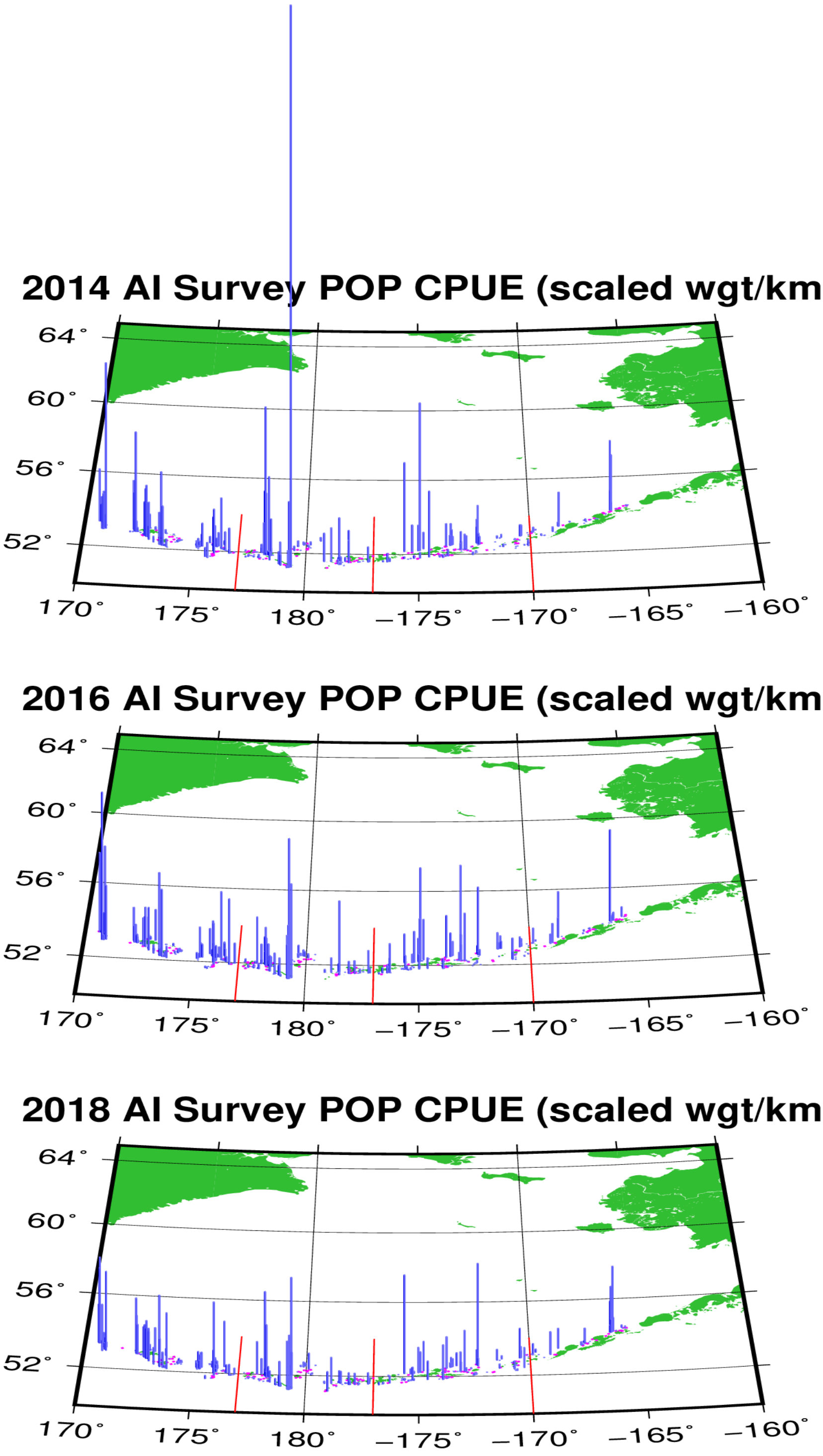

Figure 12.3. AI survey POP CPUE (kg/km^2) from 1992-2018; the symbol × denotes tows with no catch. The red lines indicate boundaries between the WAI, CAI, EAI, and EBS areas.

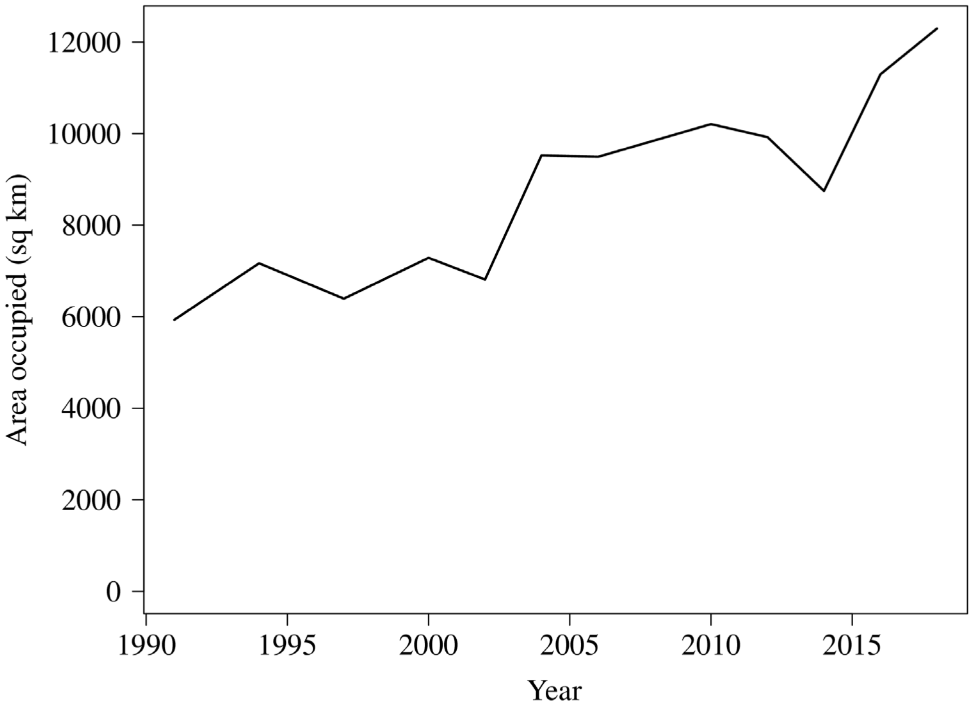

Figure 12.4. The minimum area occupied for 95% of the AI trawl survey abundance estimate for POP from 1991 to 2018.

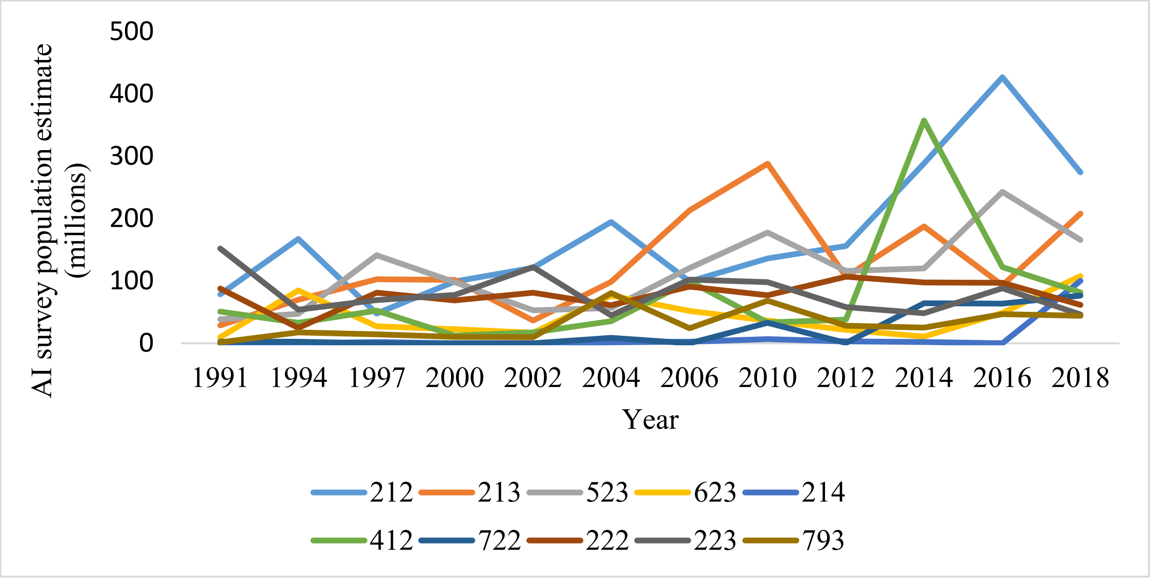

Figure 12.5. AI trawl survey abundance estimates for 10 strata with the largest abundance estimates for 2018. See Table 10 for the depth and region of the strata.

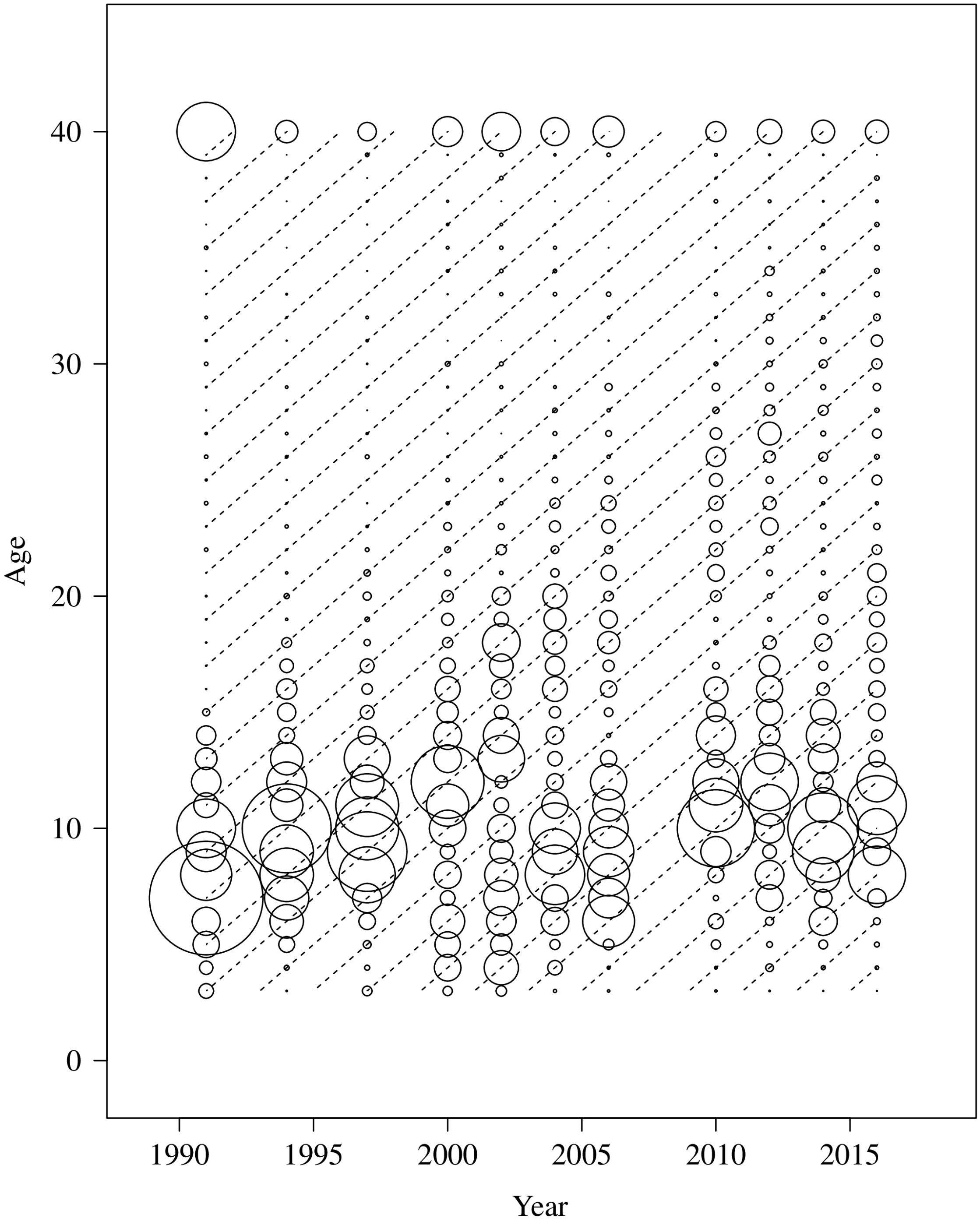

Figure 12.6. Age composition data from the Aleutian Islands trawl survey; bubbles are scaled within each year of samples; and dashed lines denote cohorts.

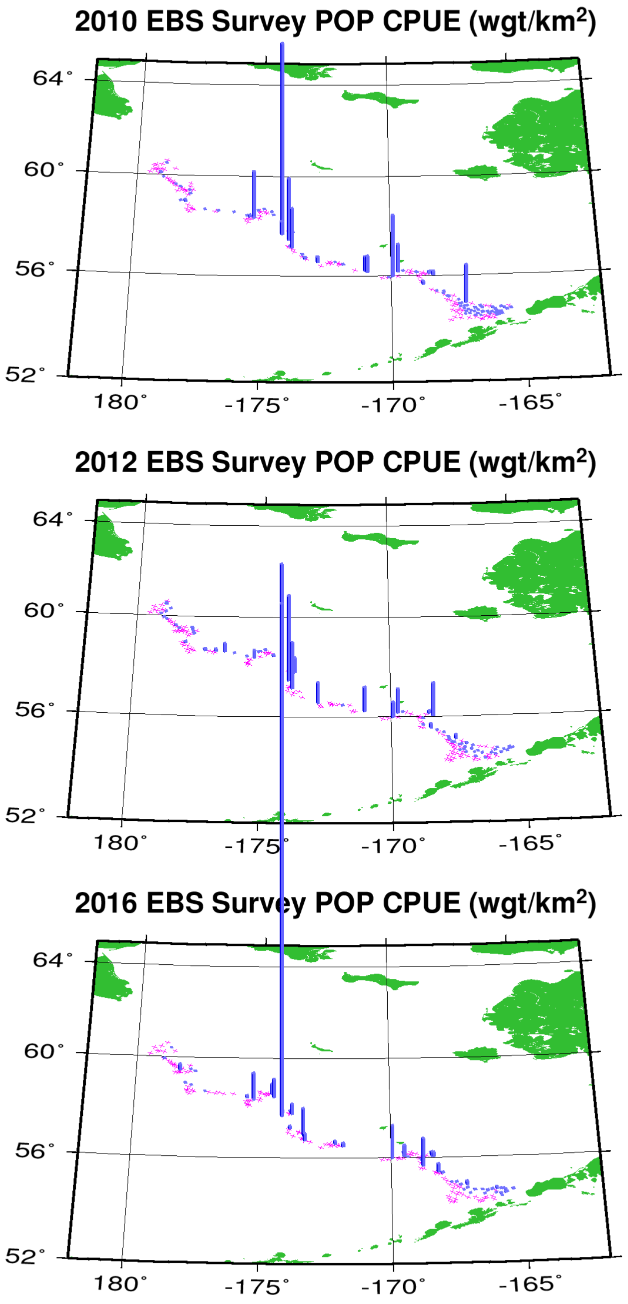

Figure 12.7. EBS slope survey POP CPUE (kg/km^2) from 2010-2016; the symbol × denotes tows with no catch.

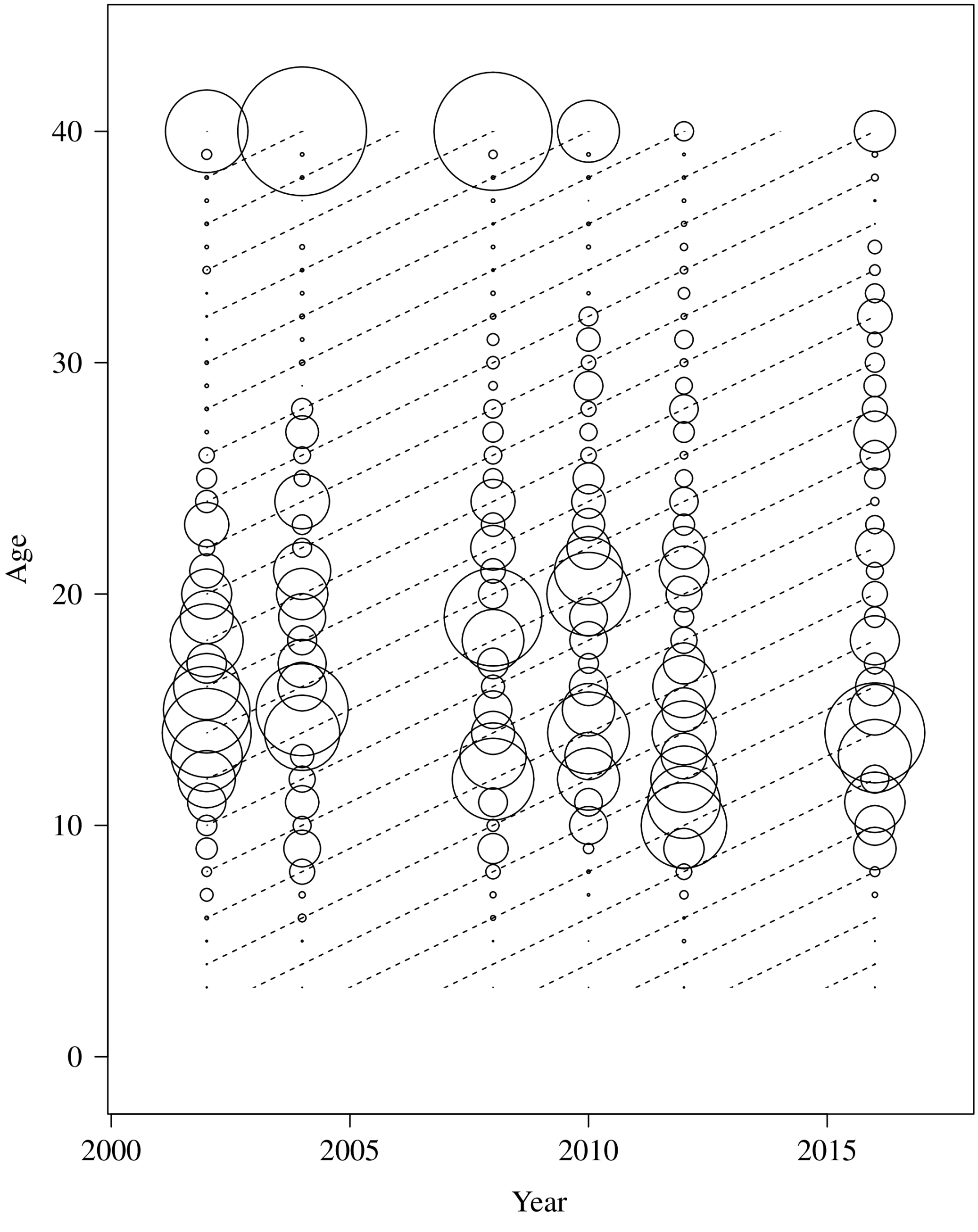

Figure 12.8. Age composition data from the eastern Bering Sea trawl survey; bubbles are scaled within each year of samples; and dashed lines denote cohorts.

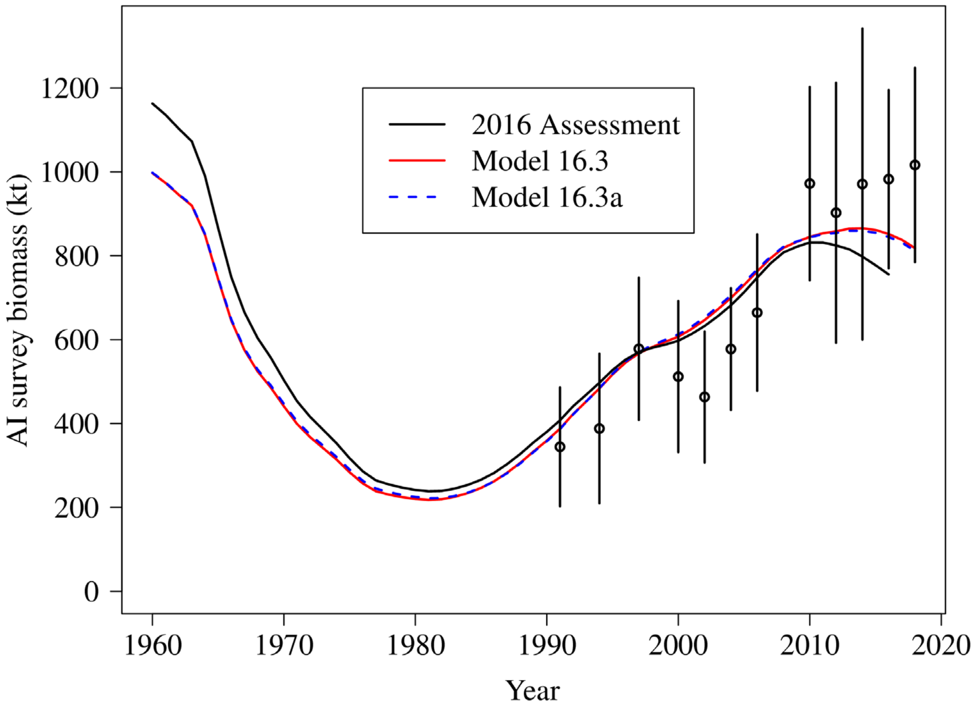

Figure 12.9. Fit to Aleutian Islands survey biomass indices across the models.

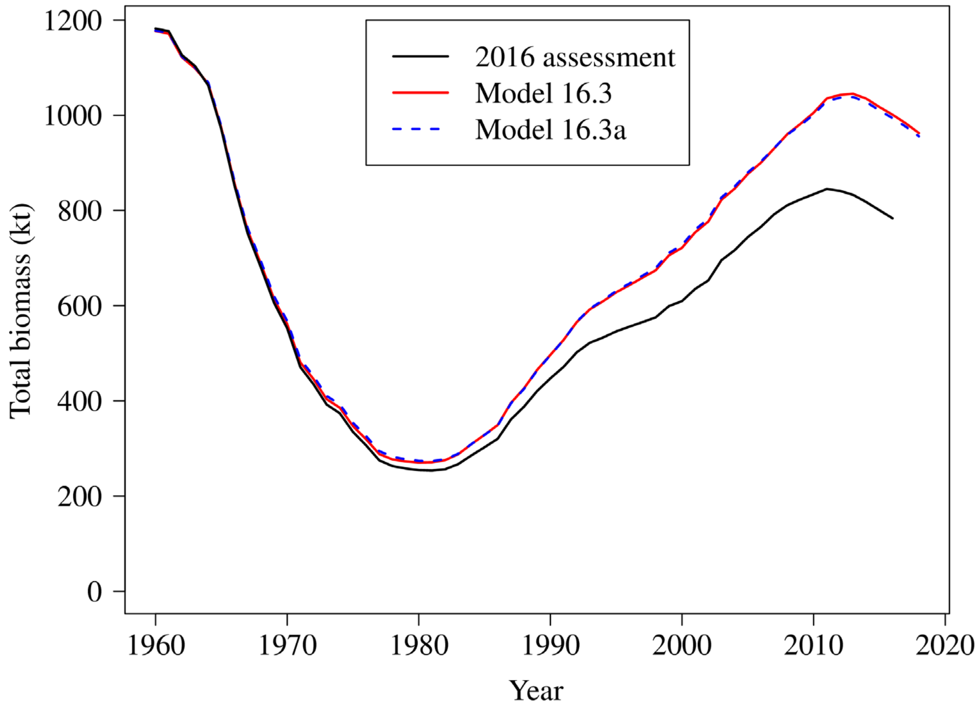

Figure 12.10. Estimated time series of total biomass across the models.

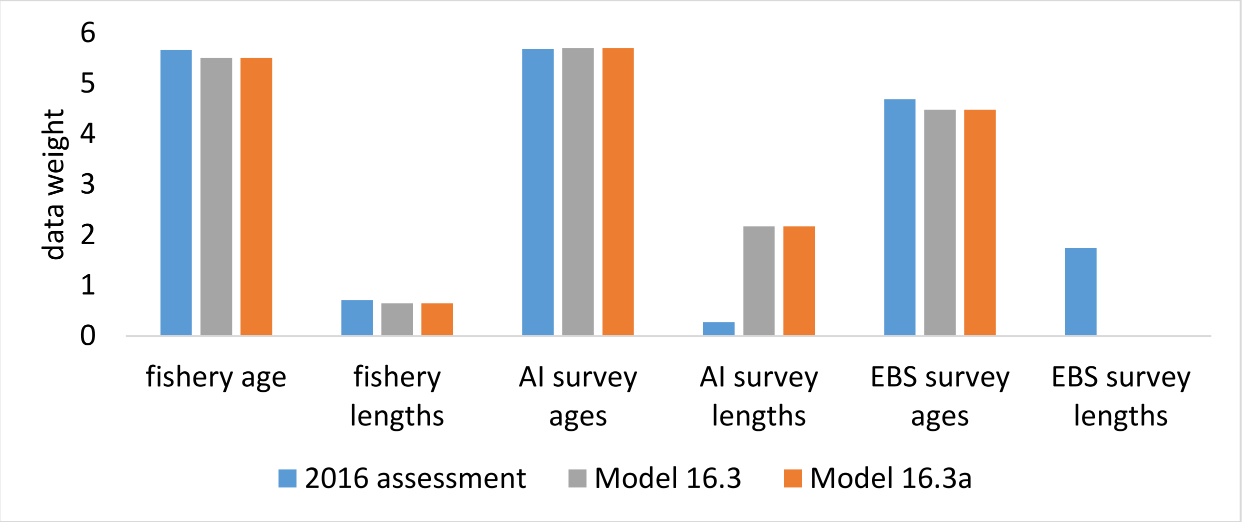

Figure 12.11. Data weights for the age and length composition data for the models considered in this assessment.

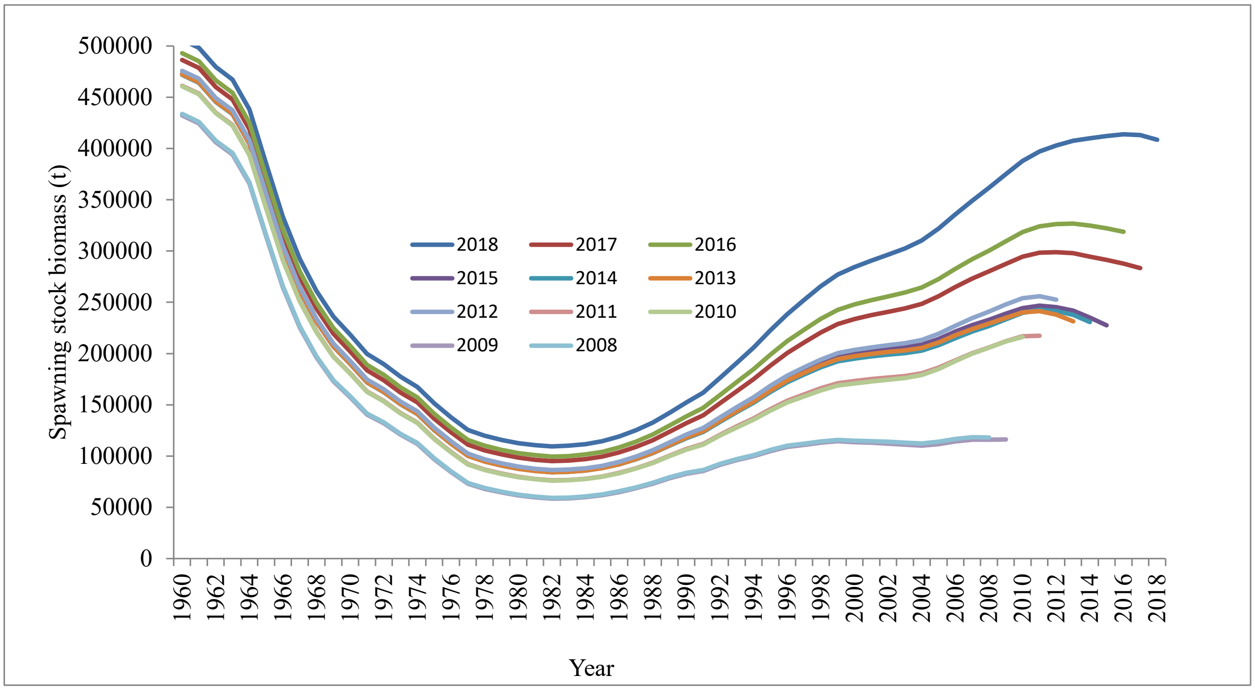

Figure 12.12. Retrospective estimates of spawning stock biomass for model runs with end years of 2008 to 2018.

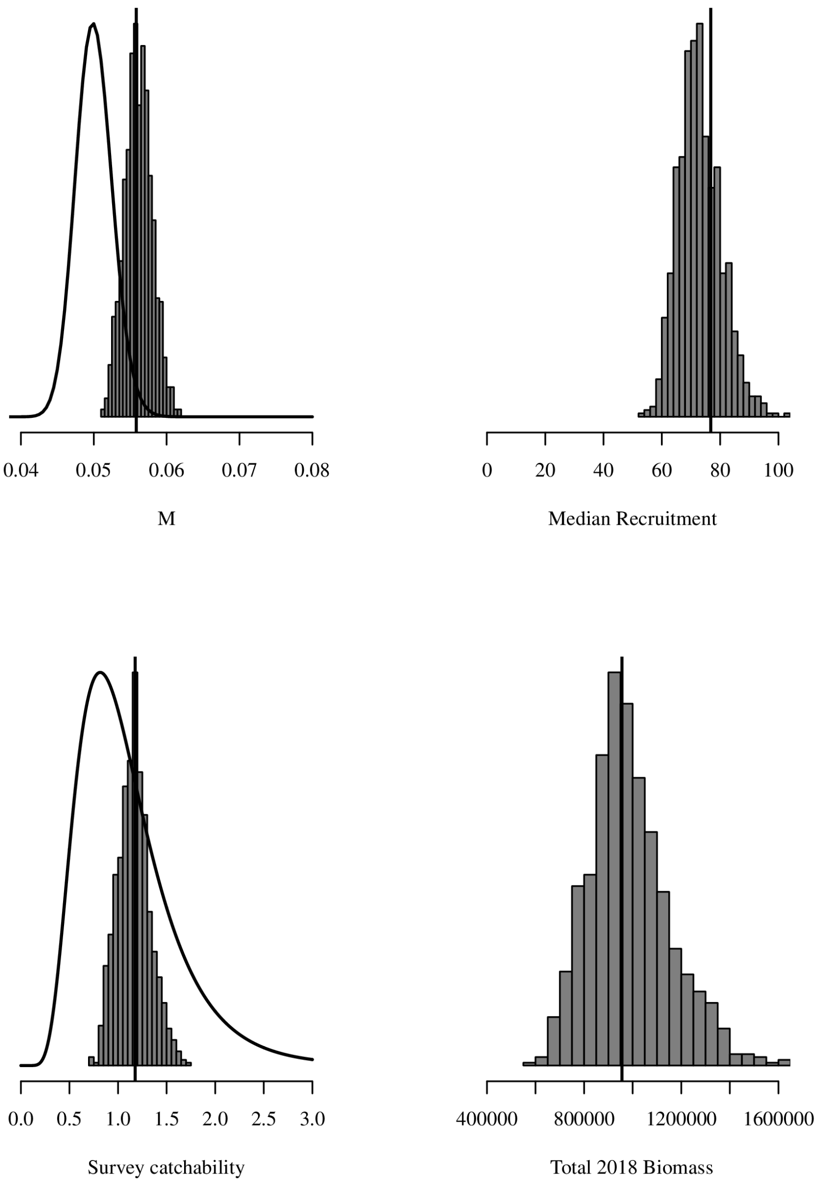

Figure 12.13. Posterior distributions for key model quantities *M*, survey catchability, median recruitment, and 2018 total biomass. For *M* and survey catchability, the prior distributions are also shown in the solid lines. The MLE estimates are indicated by the vertical lines.

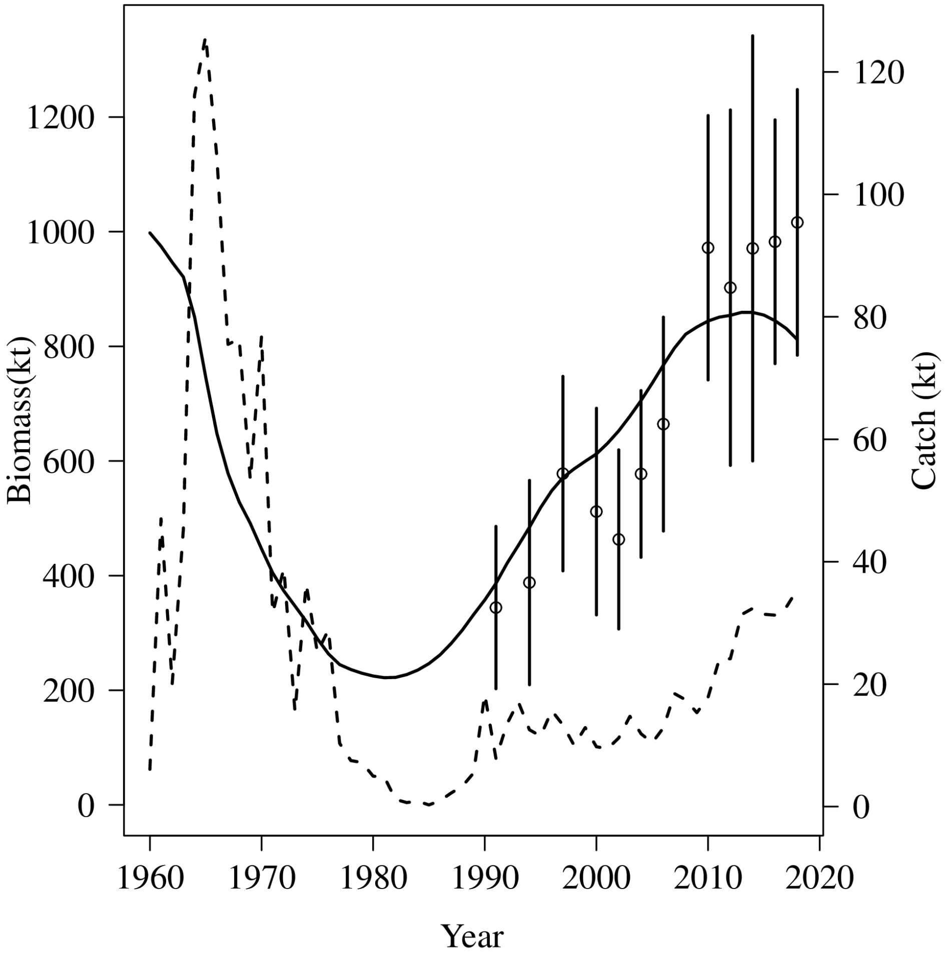

Figure 12.14. Observed AI survey biomass (data points, +/- 2 standard deviations), estimated survey biomass (solid line), and BSAI harvest (dashed line).

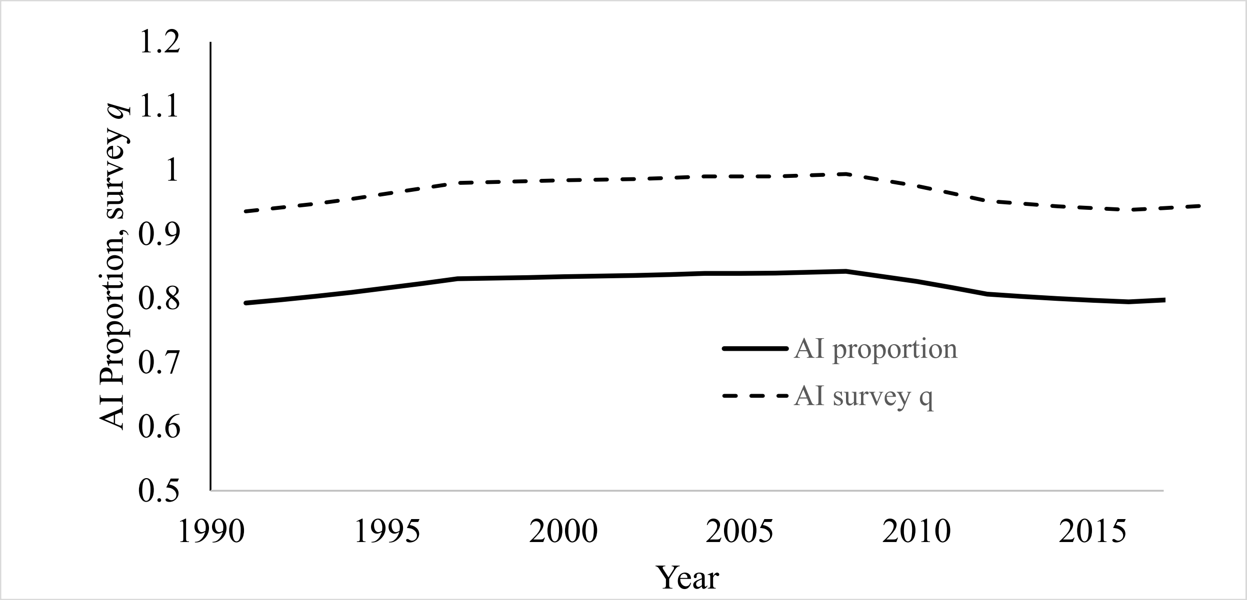

Figure 12.15. Smoothed proportion of BSAI biomass in the AI survey area (lower line, from time series of survey biomass estimates) and product of the smoothed proportion and estimated AI survey catchability (top line).

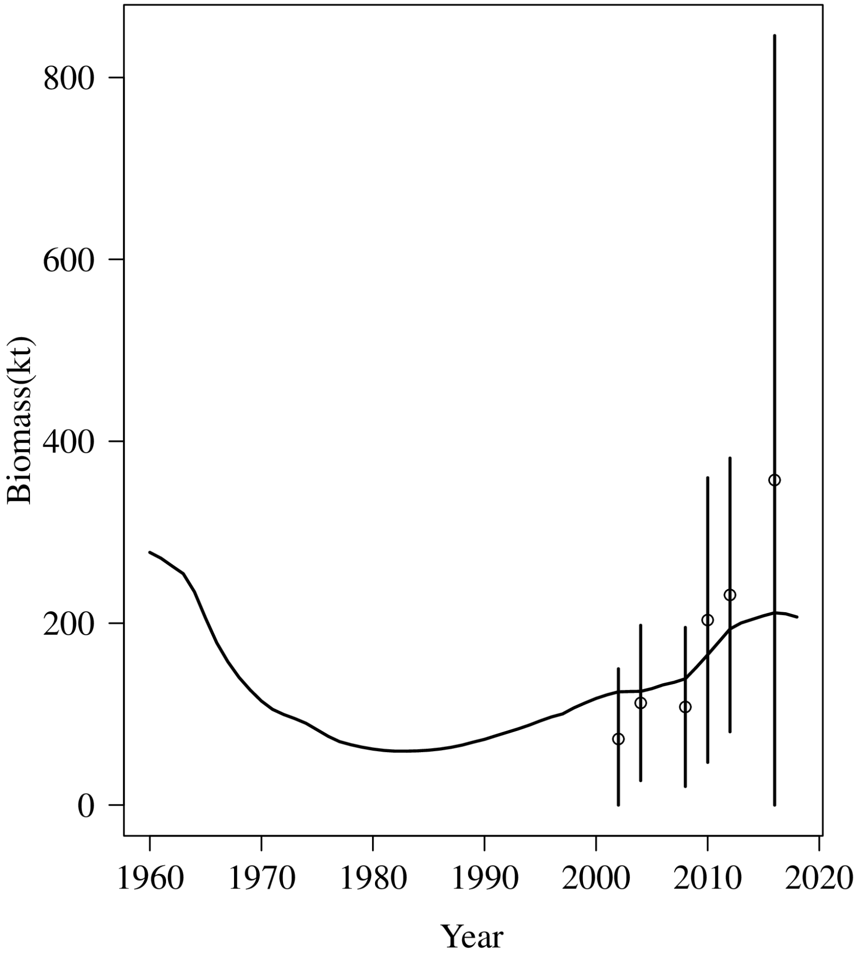

Figure 12.16. Observed EBS survey biomass (data points, +/- 2 standard deviations) and estimated survey biomass (solid line).

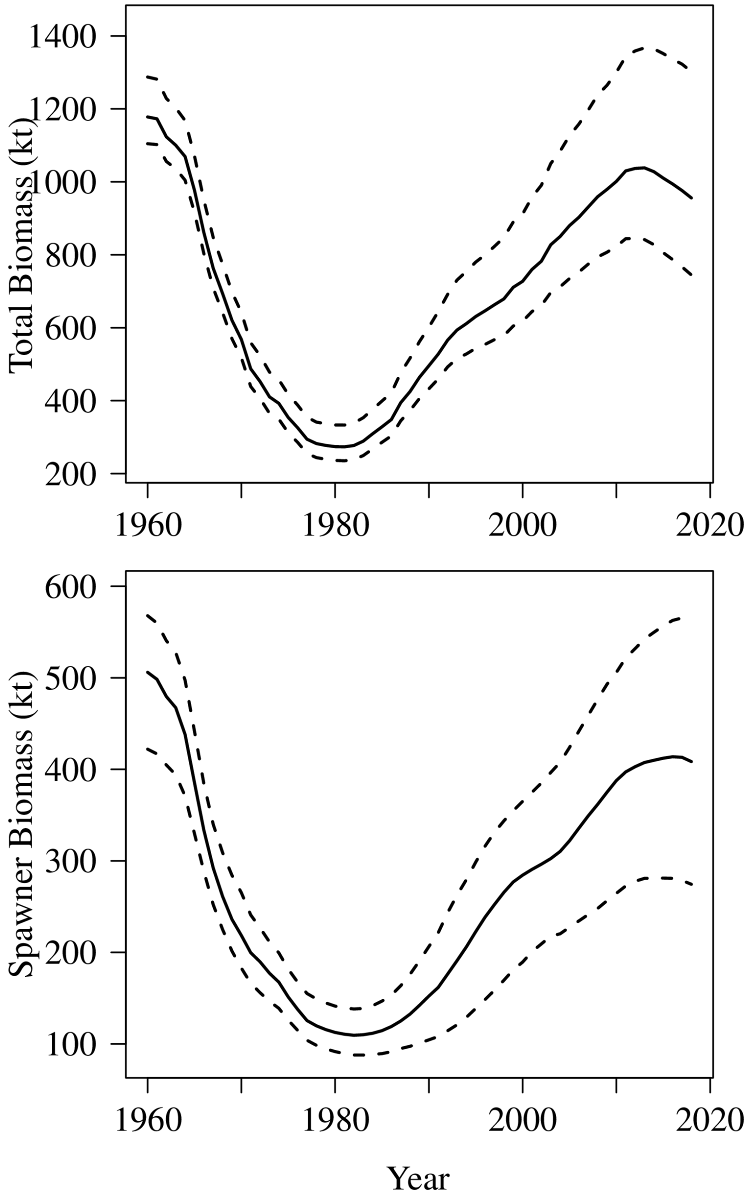

Figure 12.17. Total and spawner biomass for BSAI Pacific ocean perch, with 95% confidence intervals from MCMC integration.

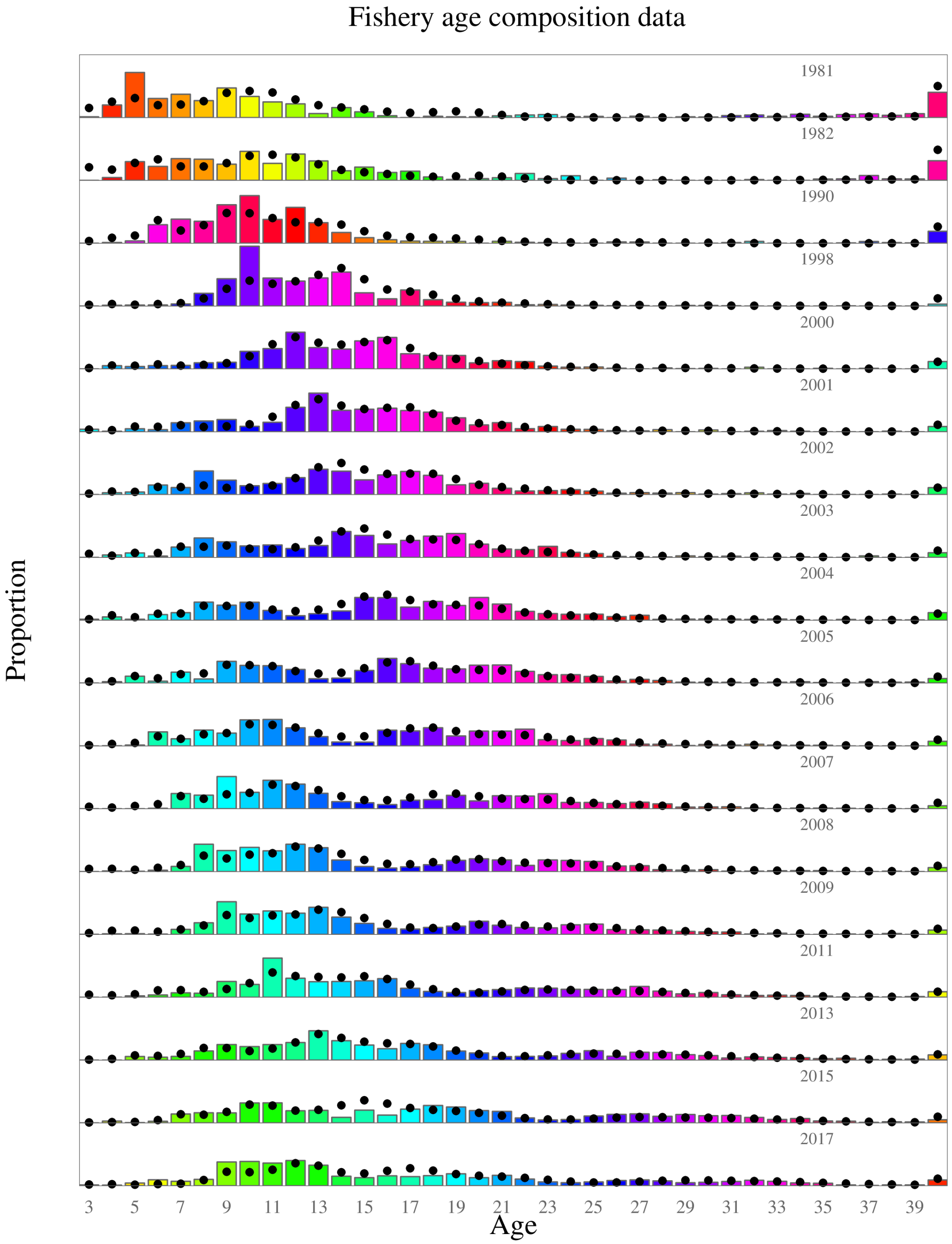

Figure 12.18. Model fits (dots) to fishery age composition data (columns) for Aleutian Islands Pacific ocean perch, 1981-2017. Colors correspond to cohorts (except for the 40+ group).

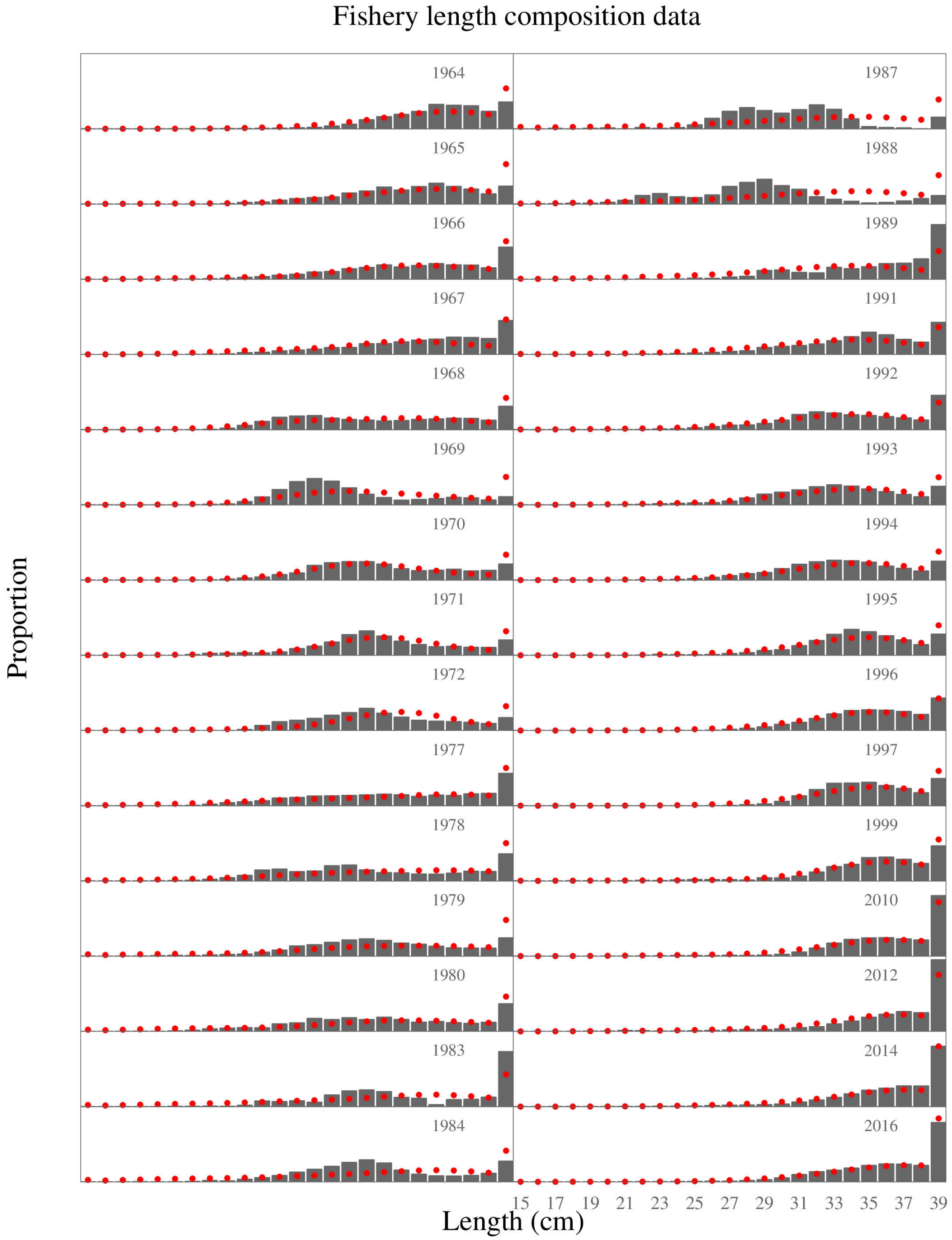

Figure 12.19. Model fits (dots) to fishery length composition data (columns) for Aleutian Islands Pacific ocean perch, 1964-2016.

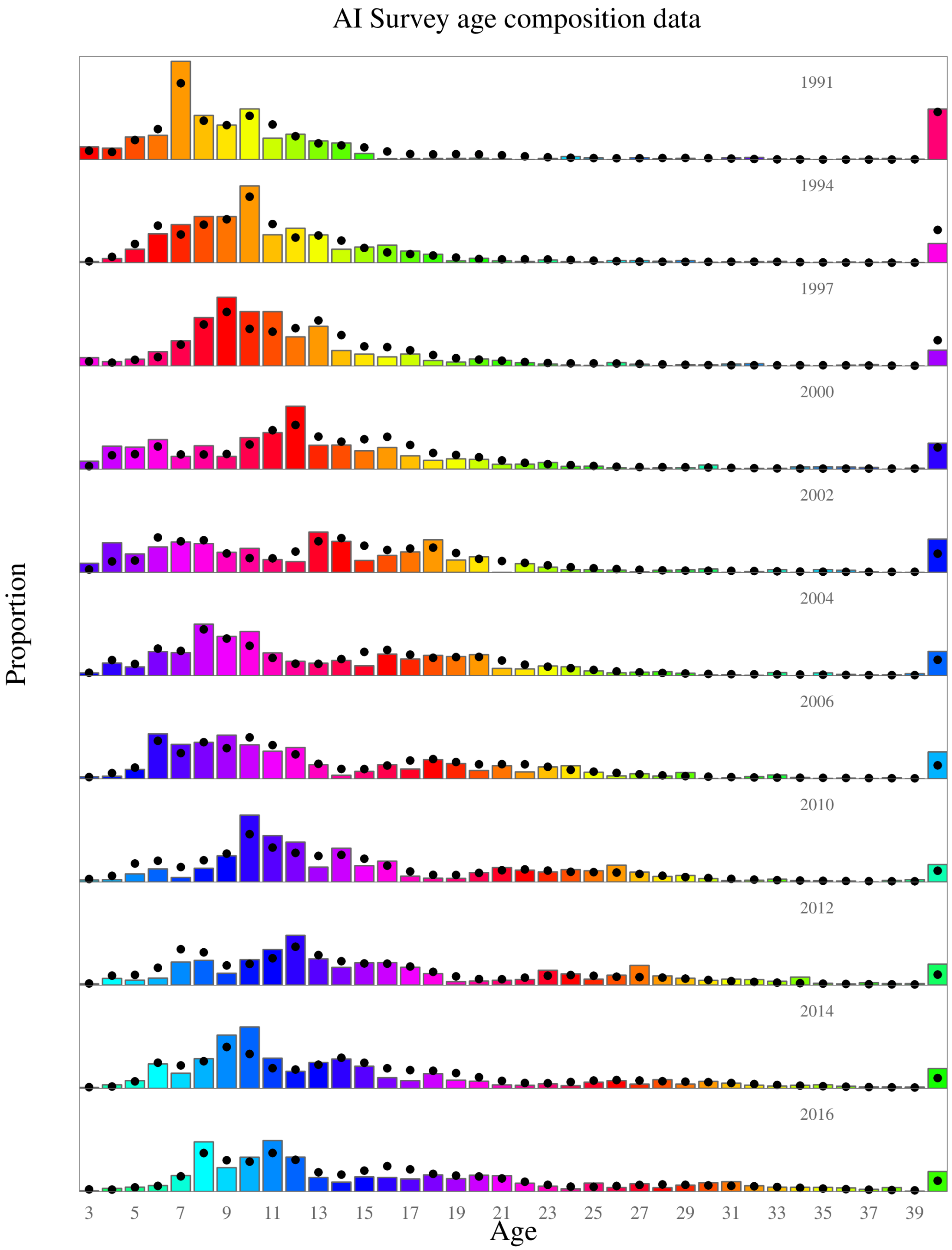

Figure 12.20. Model fits (dots) to survey age composition data (columns) for Aleutian Islands Pacific ocean perch, 1991-2016. Colors correspond to cohorts (except for the 40+ group).

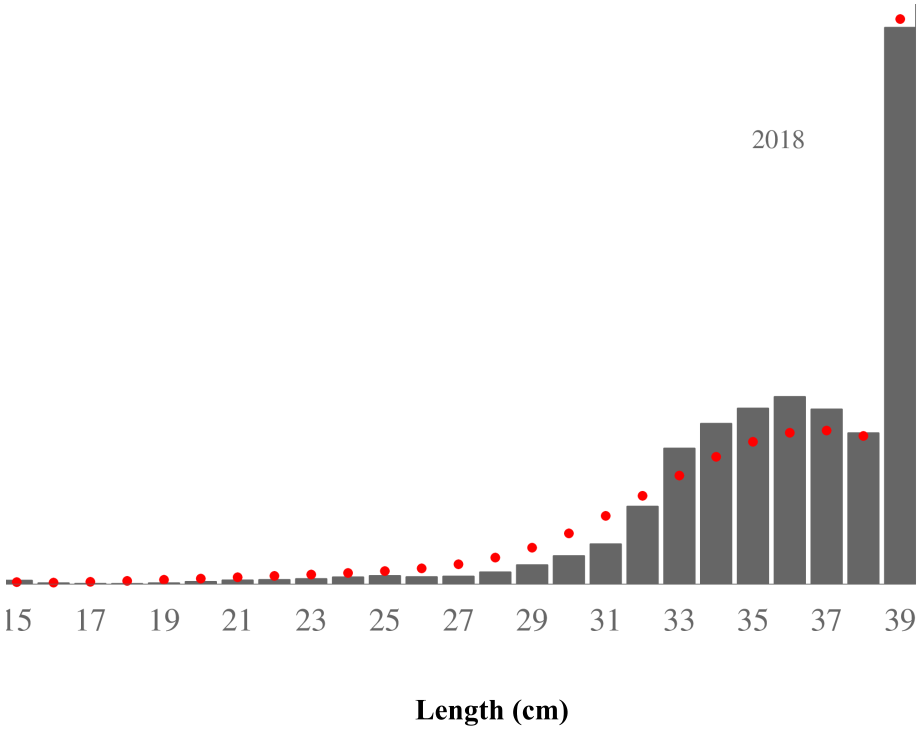

Figure 12.21. Model fits (dots) to 2018 AI survey length composition data (columns) for Pacific ocean perch.

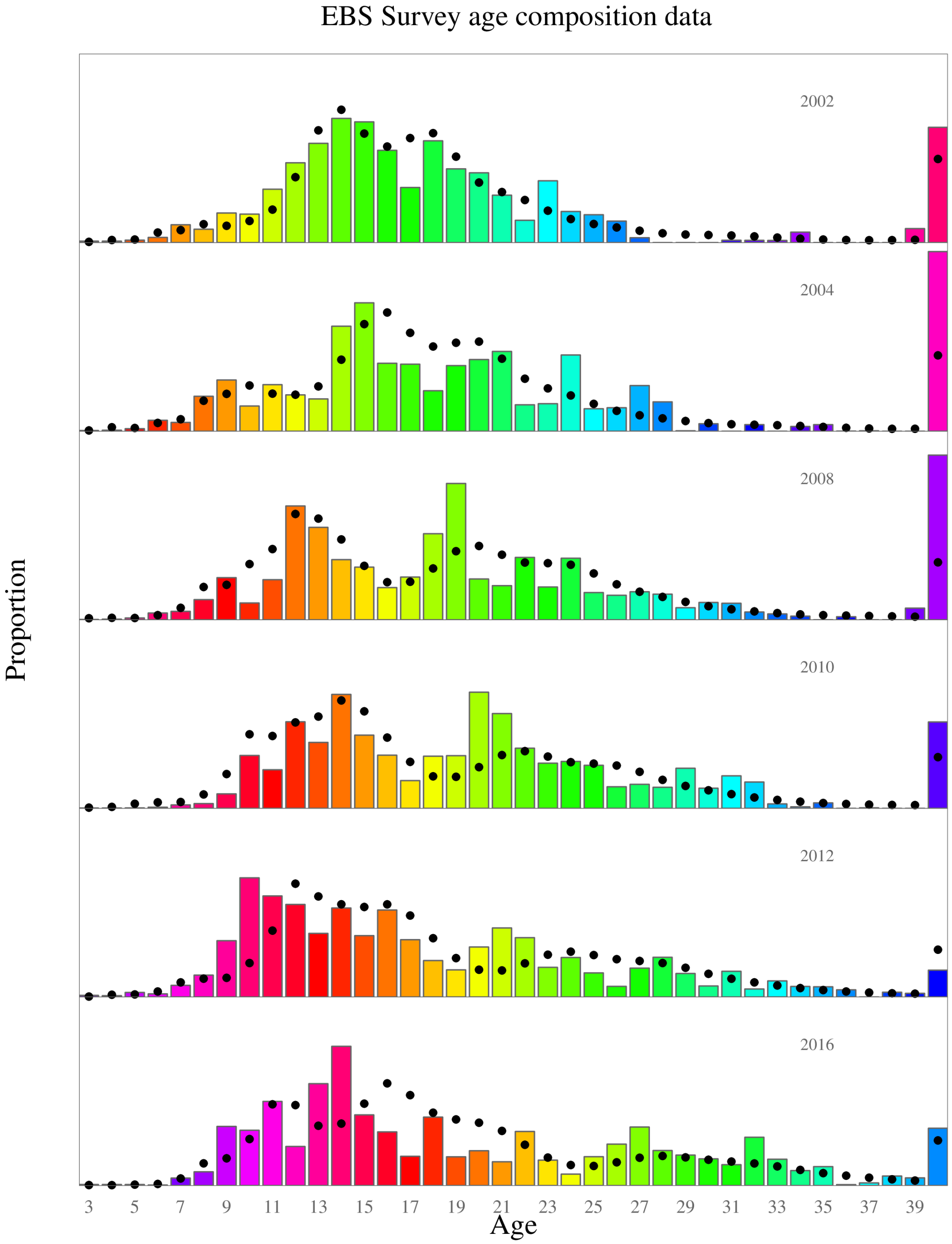

Figure 12.22. Model fits (dots) to EBS slope survey age composition data (columns) for Pacific ocean perch, 2002-2016. Colors correspond to cohorts (except for the 40+ group).

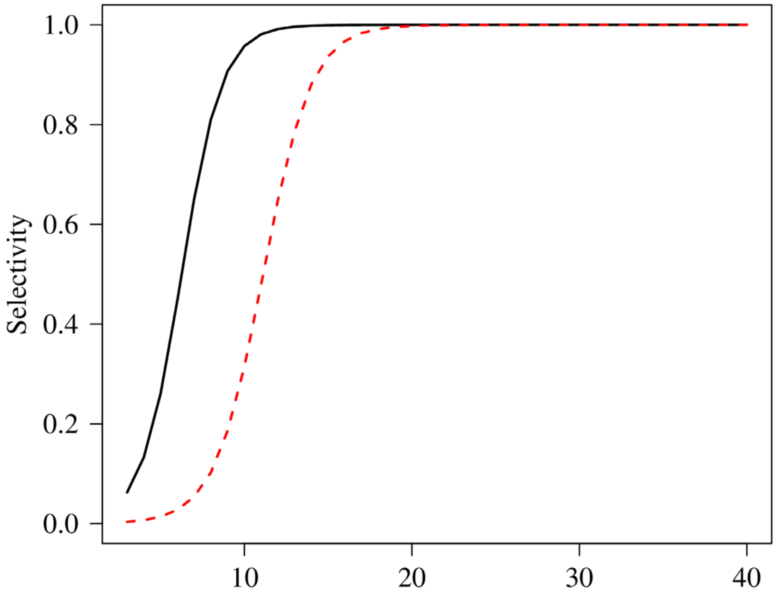

Figure 12.23. Estimated AI (black line) and EBS (red line) survey selectivity curve for BSAI POP.

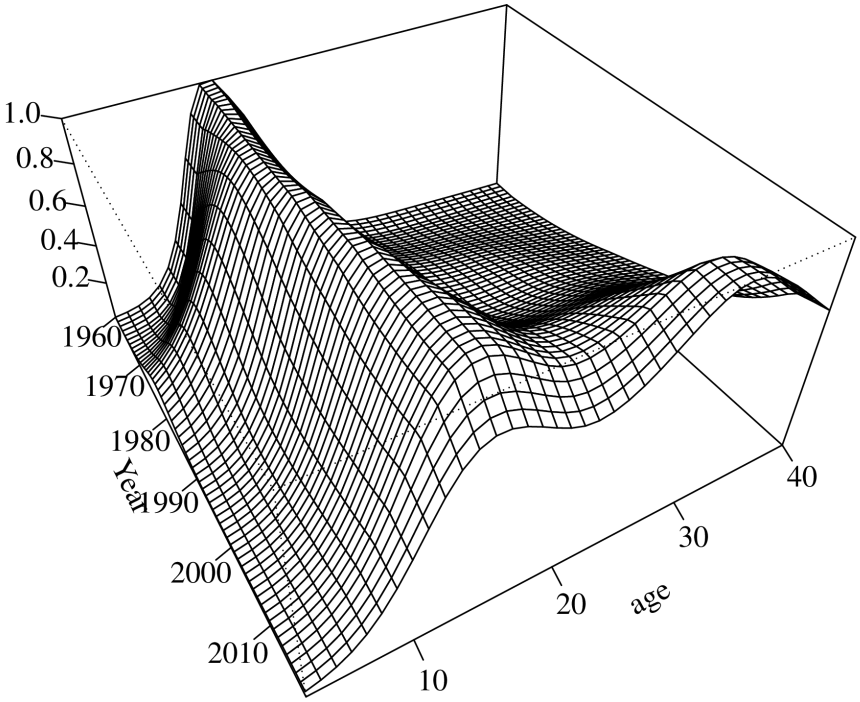

Figure 12.24. Estimated fishery selectivity from 1960-2018.

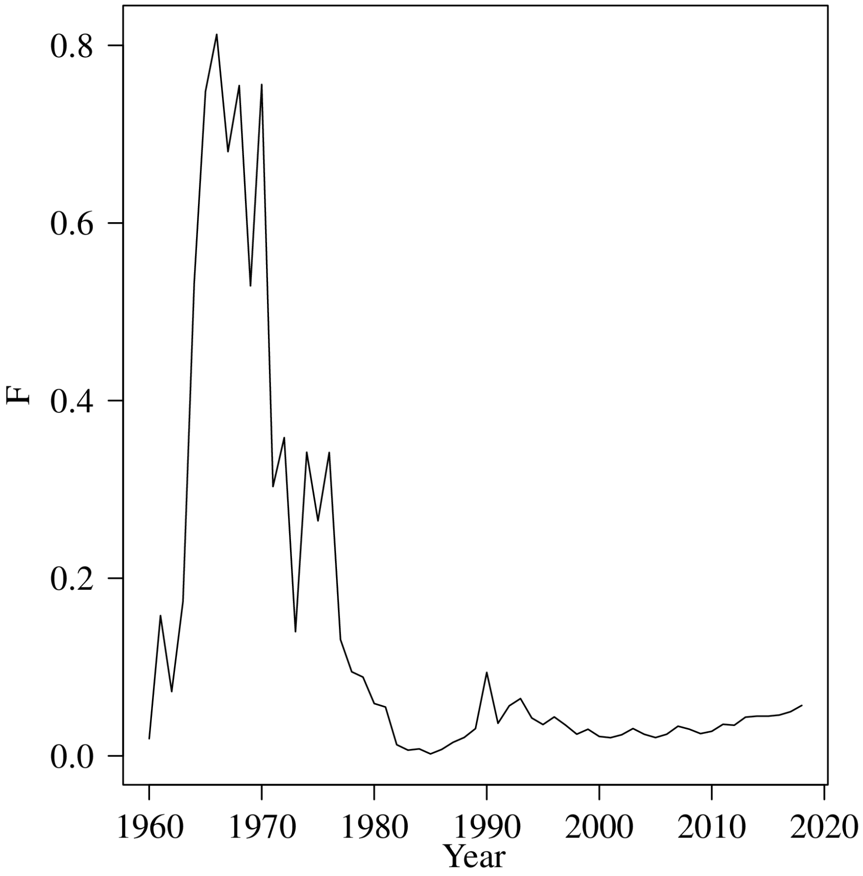

Figure 12.25. Estimated fully selected fishing mortality for BSAI POP.

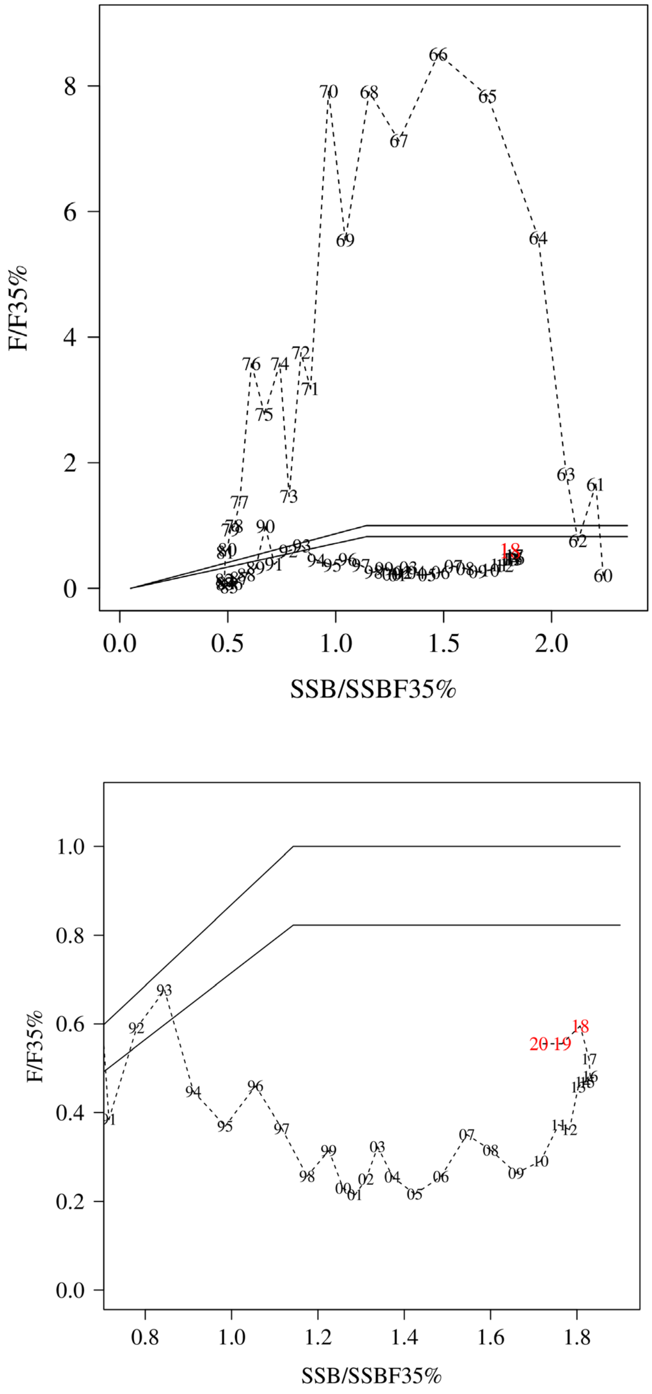

Figure 12.26. (Top panel) Estimated fishing mortality and SSB in reference to OFL (upper line) and ABC (lower line) harvest control rules, with 2018 shown in red. The bottom panel shows a reduced vertical scale, and the projected F and stock size for 2019 and 2020.

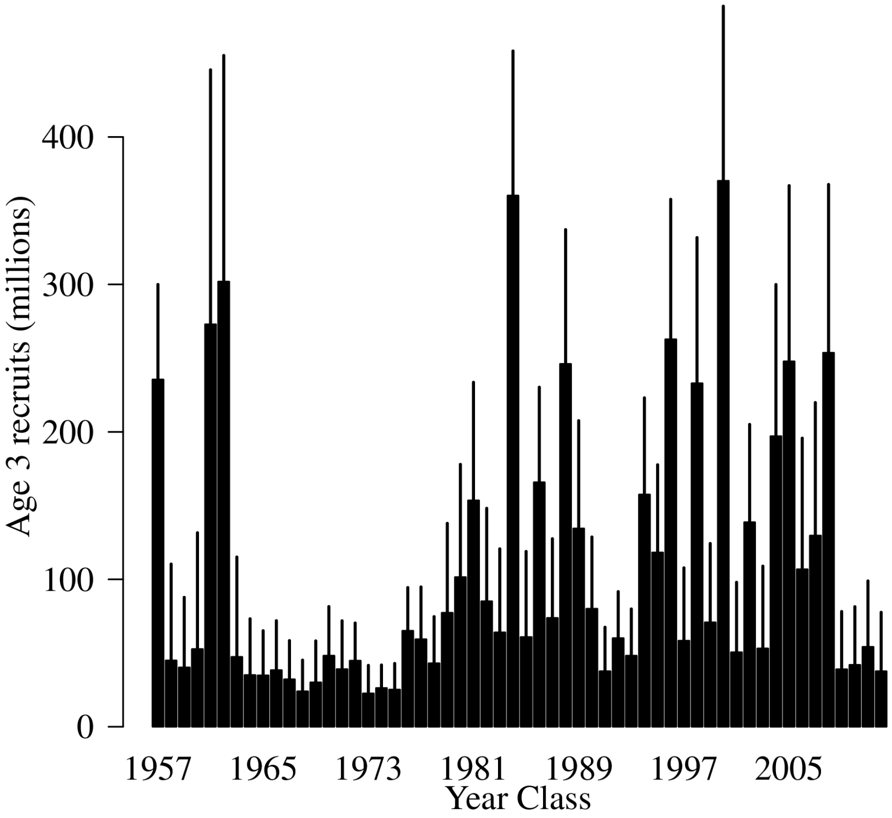

Figure 12.27. Estimated recruitment (age 3) of BSAI POP, with 95% CI limits obtained from MCMC integration.

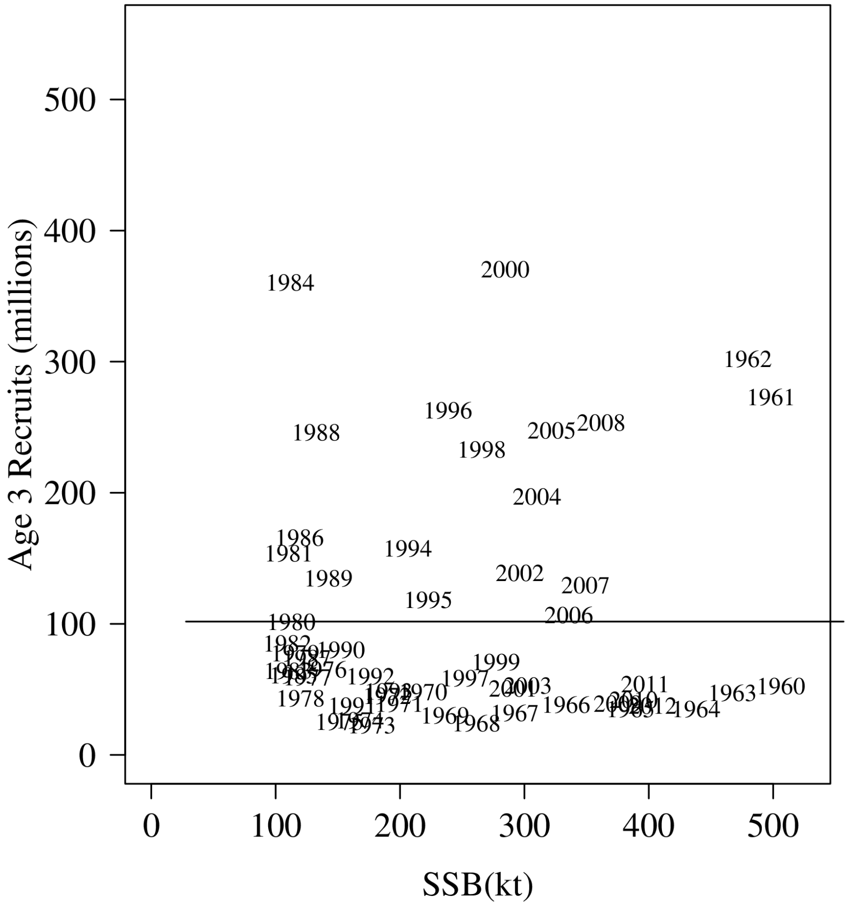

Figure 12.28. Scatterplot of BSAI POP spawner-recruit data; label is year class.

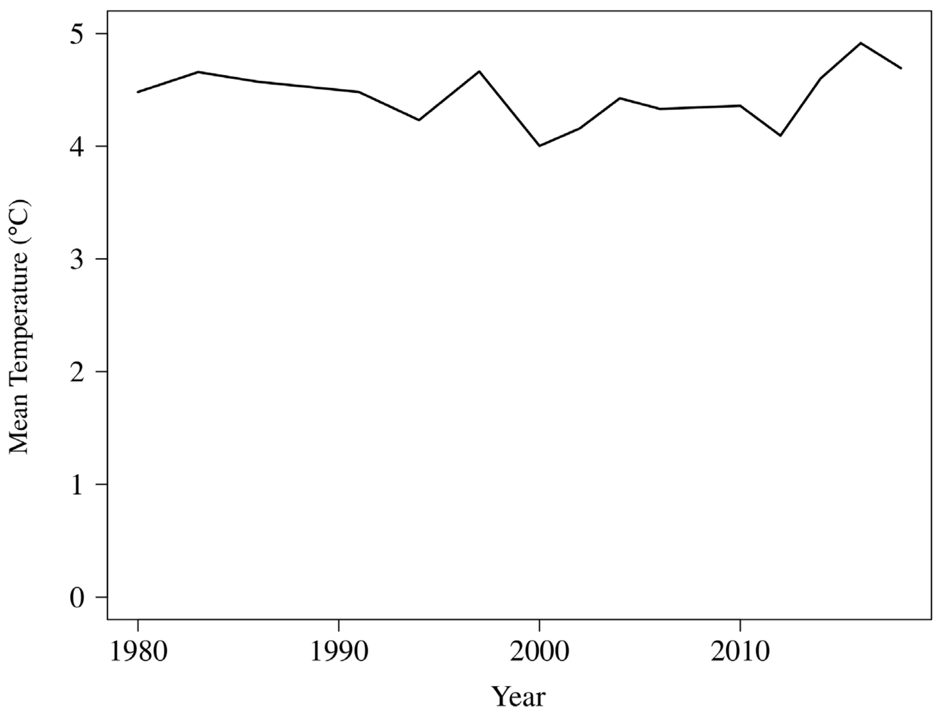

Figure 12.29. Mean temperature at trawl gear from AI bottom trawl surveys, 1980 – 2018.

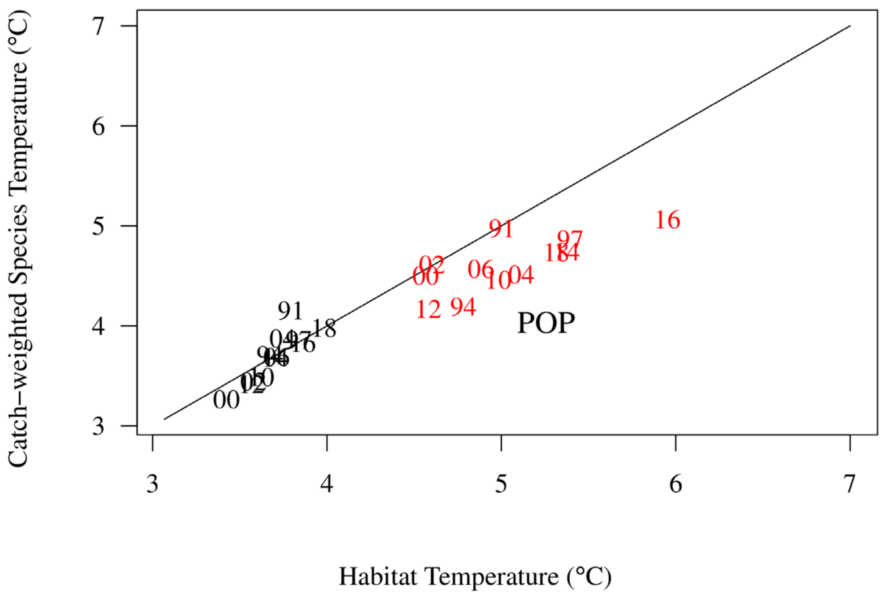

Figure 12.30. Temperatures at 10th (black) and 90th (red) percentiles of distributions of catch-weighted temperature for POP, and overall habitat temperature, from the AI trawl survey (labeled by survey year).

Appendix 12A. Supplemental Catch Data

In order to comply with the Annual Catch Limit (ACL) requirements, non-commercial removals that do not occur during directed groundfish fishing activities are reported (Table A1). This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System estimates. For BSAI POP, these estimates can be compared to the trawl research removals reported in previous assessments. POP research removals are small relative to the fishery catch. The majority of removals are taken by the Alaska Fisheries Science Center’s (AFSC) biennial bottom trawl survey which is the primary research survey used for assessing the population status of BSAI POP. The amount of POP captured in research longline gear has typically been less than 0.1 t. Total removals of POP ranged between 1.4 t and 286 t between 2010 and 2017, and did not exceed 1.4 % of the ABC for these years.

Appendix Table 12A.1. Removals of BSAI POP from activities other than groundfish fishing (t). Trawl and longline include research survey and occasional short-term projects.

Year	Source	Trawl	Longline
1977	NMFS-AFSC survey databases	0.008	
1978		0.144	
1979		3.083	
1980		71.474	
1981		13.982	
1982		14.250	
1983		133.461	
1984		0.000	
1985		98.567	
1986		164.541	
1987		0.014	
1988		10.428	
1989		0.003	
1990		0.031	
1991		76.327	
1992		0.383	
1993		0.011	
1994		112.815	
1995		0.023	
1996		1.179	0.015
1997		178.820	
1998		0.006	0.003
1999		0.192	0.014
2000		164.166	0.019
2001		0.114	0.015
2002		143.795	0.026
2003		7.595	0.012
2004		180.928	0.029
2005		10.682	0.019
2006		168.609	0.043
2007		0.063	0.036
2008		21.087	0.037
2009		1.436	0.139
2010	AKFIN database	266.674	0.097
2011		104.409	0.011
2012		285.773	0.046
2013		8.496	0.057
2014		247.868	0.058
2015		2.872	0.011
2016		316.365	0.029
2017		1.437	0.065

Appendix 12B. Rockfish (BSAI) Economic Performance Report for 2017

Ben Fissel, Alaska Fisheries Science Center

November, 2018

Rockfish catch in the BSAI showed little change in 2017 from 2016 levels with a total catch of 38 thousand t and a retained catch 35 thousand t and remains near the recent highs over the past decade (Table 1). Catches were similarly stable for both of the primary rockfish species northern rockfish and Pacific ocean perch. Rockfish are an important component of the Amendment 80 fleet's catch portfolio.[1] First-wholesale value of rockfish was up 21% in 2017 to $42 million with a 22% increase in the first-wholesale price to $1.09 per pound (Table 1).

The most significant rockfish species caught in the BSAI in terms of volume and value is Pacific ocean perch, which typically accounts for approximately 90% of the total BSAI rockfish value (Table 1). Northern rockfish is also caught in significant quantities, typically accounting for under 10% of the value. Other rockfish, such as rougheye and shortraker rockfish are caught in significantly smaller quantities. Rockfish in the BSAI are predominantly caught by catcher/processors in the Amendment 80 Fleet, which accounts for approximately 90% of the Pacific ocean perch and northern rockfish production volume and value. Vessels in the Amendment 80 fleet also target flatfish and Atka mackerel. Rockfish are among the more valuable species caught by the Amendment 80 fleet with an average price per pound that is roughly 80% higher than the flatfish prices, however the volume of catch is significantly smaller than flatfish catch. Rockfish are typically harvested close to the total allowable catch (TAC) and TACs for Pacific ocean perch are set at close to the Allowable Biological Catches (ABC). Because of this, annual changes in catch and production largely reflect changes in abundance and TAC. In recent years approximately 90-95% of the total rockfish catch has been retained.

Pacific ocean perch catch and production were stable in 2017 at 30.3 thousand t and 14.9 thousand t, respectively. Catch and production of northern rockfish was also stable at 3 thousand t and 2 thousand t, respectively. Rockfish are primarily processed in the headed-and gutted (H&G) product form which accounts for over 95% of the production value. Because of this changes in production volume largely reflect changes in catch (Table 1). First-wholesale prices increased 23% for Pacific ocean perch to $1.12 per pound and increased 18% for northern rockfish to $0.76 per pound. Commensurate with the increase in price and stable production catch production and first-wholesale values were up. BSAI Pacific ocean perch first-wholesale value increased 22% to $36.9 million and northern rockfish value increased 21% to $3.4 million.

The majority of rockfish produced in the U.S. are exported, primarily to Asian markets. Pacific ocean perch is the only rockfish species with specific information in the U.S. trade data. Other species are aggregated into a non-specific category. Approximately 60% of the Pacific ocean perch exported from the U.S. goes to China (Table 2). Exported H&G rockfish to China is re-processed (e.g., as fillets) and re-exported to domestic and international markets. Rockfish are also sold to Chinese consumers, as whole fish. The U.S. has accounted for just over 15% of global rockfish production in recent years and 85-90% of global Pacific ocean perch production. Global production of rockfish has increased 10% from the

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[1] The Amendment 80 Fleet is the group of catcher processors managed under Amendment 80 to the BSAI FMP which rationalized the non-pollock groundfish fisheries in the BSAI.

2008-2012 average to 313 thousand t in 2016 and global production of Pacific ocean perch has increased 52%. Global production of Atlantic redfish, a market competitor to Pacific ocean perch, has remained stable. The U.S. dollar was relative stability in 2017 against other currencies, such as the Chinese Yuan, which mitigates its potential impact on market price. Export price data through July 2018 indicate a potential drop in the Pacific ocean perch price (Table 2). Tariffs implemented in 2018 between the U.S. and China and the associated uncertainty with trade policy has the potential to negatively affect rockfish markets, both as a direct market for rockfish exports and because of China's significance as a re-processor of rockfish products.

Table 12B.1. BSAI rockfish catch and first-wholesale market data. Total and retained catch (thousand metric tons), Pacific ocean perch and northern share of retained catch, number of vessel, first-wholesale production (thousand metric tons), value (million US$), Pacific ocean perch and northern share of value and price (US$ per pound), and head and gut share of value; 2008-20012 average and 2013-2017.

	2008-2012 Average	2013	2014	2015	2016	2017
Total catch K mt	24.2	34.9	36.1	39.6	36.9	38.4
Retained catch K mt	21.1	31.7	32.3	37.5	35.3	35.5
Pac. Ocn. perch share of retained	85%	91%	91%	80%	86%	85%
Northern share of retained	10%	5%	6%	18%	12%	12%
Vessels #	18.4	20	23	20	21	20
First-wholesale production K mt	11.3	16.9	18.0	19.4	17.6	17.4
First-wholesale value M US$	$31.5	$39.7	$47.1	$42.8	$34.7	$42.0
First-wholesale price/lb US$	$1.26	$1.07	$1.18	$1.00	$0.90	$1.09
Pac. Ocn. perch share of value	86%	92%	90%	83%	87%	88%
Pac. Ocn. perch price/lb US$	$1.26	$1.06	$1.19	$1.05	$0.91	$1.12
Northern rockfish share of value	7%	3%	5%	14%	8%	8%
Northern rockfish price/lb US$	$1.00	$0.72	$0.91	$0.74	$0.64	$0.76
H&G share of value	96%	97%	97%	97%	94%	95%

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

Table 12B.2. Rockfish U.S. trade and global market data. Global production (thousand metric tons), U.S. share of global production, BSAI share of U.S. production. U.S. yellowfin sole and rock sole export volume (thousand metric tons), U.S. export value (million US$), U.S. export price (US$ per pound), the share of U.S. export value from China, and the Chinese Yuan/U.S. Dollar exchange rate; 2008-20012 average and 2013-2017.

	Avg 08-12	**2013**	**2014**	**2015**	**2016**	**2017**	**2018 (thru July)**
Global production of rockfish K mt	283.8	289.1	285.5	301.9	313.4	-	-
Global production of Pac. Ocn. perch K mt	38.6	49.7	53.0	55.5	58.5	-	-
perch	84.1%	86.6%	89.5%	86.6%	88.5%	-	-
U.S. Pac. Ocn. perch share of global rockfish	11.4%	14.9%	16.6%	15.9%	16.5%	-	-
Export volume of Pac. Ocn. perch K mt	10.2	20.1	23.8	22.7	25.6	22.7	11.1
Export value of Pac. Ocn. perch M US$	$19.2	$66.4	$79.6	$77.7	$84.6	$76.1	$34.0
Export price/lb of Pac. Ocn. perch US$	$0.85	$1.50	$1.52	$1.55	$1.50	$1.52	$1.39
China's share of U.S. Pac. Ocn. perch export value	63%	42%	65%	52%	67%	55%	66%
Exchange rate, Yuan/Dollar	6.66	6.20	6.14	6.23	6.64	6.76	6.31

Source: FAO Fisheries & Aquaculture Dept. Statistics http://www.fao.org/fishery/statistics/en. NOAA Fisheries, Fisheries Statistics Division, Foreign Trade Division of the U.S. Census Bureau, http://www.st.nmfs.noaa.gov/commercial-fisheries/foreign-trade/index. U.S. Department of Agriculture http://www.ers.usda.gov/data-products/agricultural-exchange-rate-data-set.aspx.

1 - The BSAI FMP share of U.S. production is calculated as the BSAI retained catch divided by the FAO's U.S. production of flounder, halibut and sole.

Appendix 12C. Further investigation into retrospective patterns

A series of exploratory models runs conducted in the 2010 assessment revealed that a combination of the high survey biomass and new observations of strong 1994-2000 year classes observed in both the fishery and survey age and length composition data lowered the estimates of survey catchability and increased estimated biomass. This topic is revisited in this Appendix with updated data, particularly focusing on the effect on non-constant AI survey catchability across survey years.

Examination of the AI survey biomass estimates by age indicate the increased estimates of survey abundance has not occurred from a series of strong recruitments aging into ages with higher survey selectivity. Rather, the abundance at age across a wide swath of ages has increased between survey years. An example are the number at age for the 1991 and 2000 surveys (Figure 12.C1(a)). The abundance estimate for the 1991 survey is larger than that for the 2000 survey for ages 7 to 10, reflecting perhaps strong recruitments. However, for all ages older than 11 the abundance in the 2000 survey was at or above that estimated in the 1991 survey, often by large margins. Comparing the abundance at age between the 2010 and 2000 survey indicates a continuation of this trend (Figure 12.C1(b)), where the abundance in 2010 exceeded that in 2000 or nearly all ages except ≤ 7 and between 17-19.

Traditional stock assessment models account for increases in abundance via recruitment, and typically assume closed populations that do not account for movement from neighboring regions. Strong recruitment of a limited number of year classes would affect the abundance estimates of a limited number of ages in subsequent surveys. The indication in the data that most ages have increased in abundance between surveys suggests that the estimated recruitment strengths for most year classes may need to be revised upwards, thus changing the scale of abundance for the entire population.

A mechanism by which the POP model scales the population abundance is the AI survey catchability (q), which is assumed to be constant over time due to the consistency in survey sampling procedures since 1991. With a constant q and lack of migration/emigration, the model cannot easily explain the increases in survey numbers over time (particularly the substantial increase biomass estimates beginning in 2010), resulting in a poor residual pattern in which the survey biomass estimates from 1991-2006 are overestimated and those from 2010-2018 are underestimated.

An exploratory model was developed in which surveys from 2010-2018 were estimated to have a separate q from the surveys from 1991-2006, with a constraint that penalizes that differences in q between the 2 periods. A single survey selectivity curve is estimated. In this model, a sharp break in estimated survey abundance is noted between the periods (Figure 12.C2), which could be addressed with more refined modeling that invoke more gradual changes over time. However, this model does indicate that the residual pattern within each of the two blocks is improved.

The retrospective pattern has a Mohn's rho of -0.30 (Figure 12.C3), which is still quite large but a decrease in magnitude from the value of -0.44 observed in the 2018 model with constant q. An additional issue is that an estimate of q is revised for each assessment run in the retrospective analysis, and estimates of the values of q for the 1991-2006 period have increased from 1.15 to 1.57 from the retrospective runs for 2018 to 2008 (Figure 12.C4). Fixing the survey catchability values to the estimates obtained in the 2018 run further reduces the variability between retrospective runs (Figure 12.C5), and lowers the magnitude of Mohn's rho to -0.17. The remaining retrospective pattern likely reflects that the increase in survey abundance within the 1991-2006 period in reflected in many age classes and cannot be entirely explained by the addition of new recruits.

A further reduction in Mohn's rho could likely be obtained finer-scale temporal changes in q than the two time blocks considered here, but the mechanisms for time-varying survey catchability are not well established. As mentioned above, the AI surveys have been conducted with consistent protocols since 1991. Of any of our Alaska trawl surveys, the AI trawl survey may be one of the most consistent between years because a high proportion of the survey stations are towed in successive surveys (due to large areas of untrawlable grounds that limit exploration of new stations). It may be possible the POP are moving into the survey area, either from untrawlable habitat or from vertically above the net height (i.e., the "availability" of the population to be surveyed has systematically increased over time), but there is not field data to support this hypothesis. There is also a danger that imposing finer-scale variations in q could degrade the information the survey provides on changes in abundance over time, such that nearly any difference between surveys in different years could be attributed to differences in catchability.

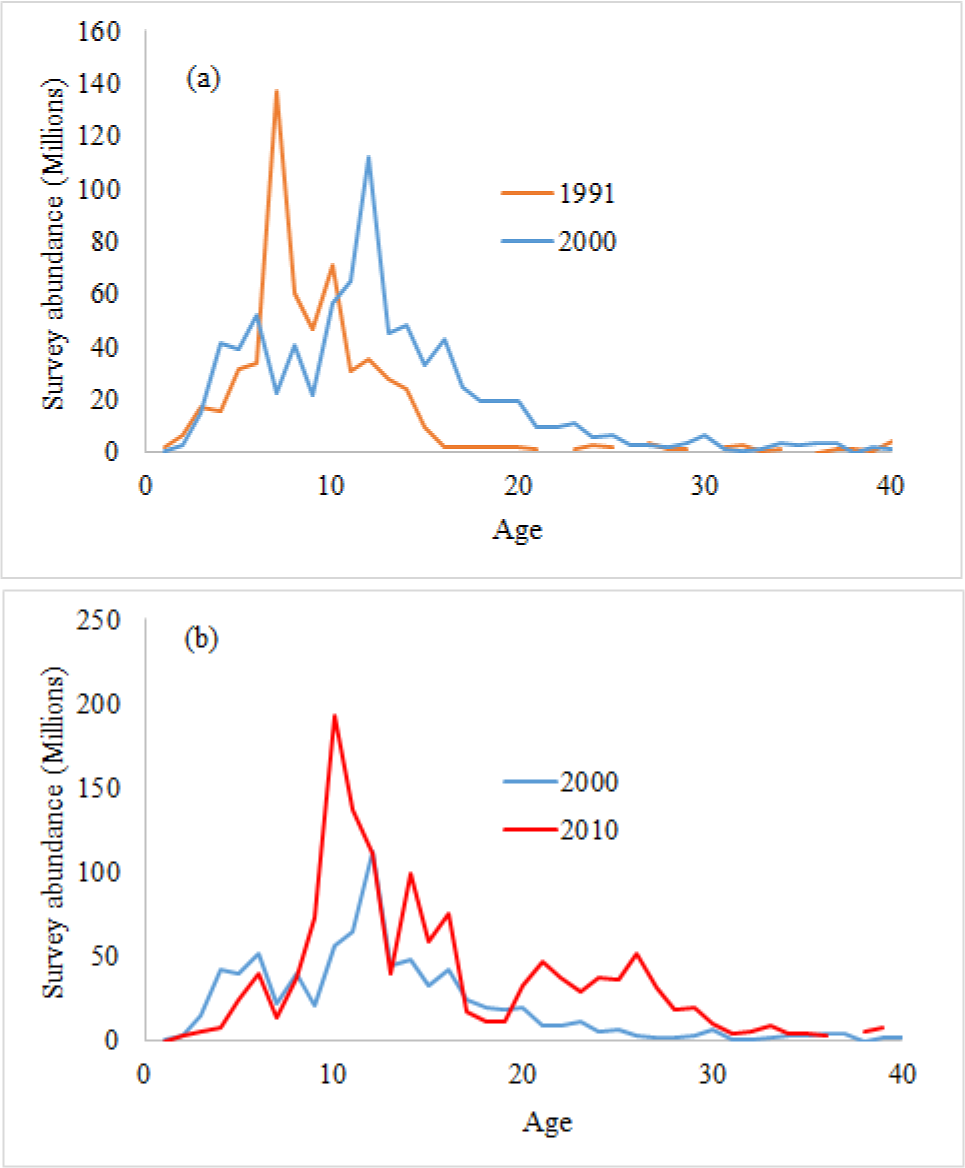

Figure 12C.1. Estimated numbers at age of POP from the 1991, 2000, and 2010 AI trawl surveys.

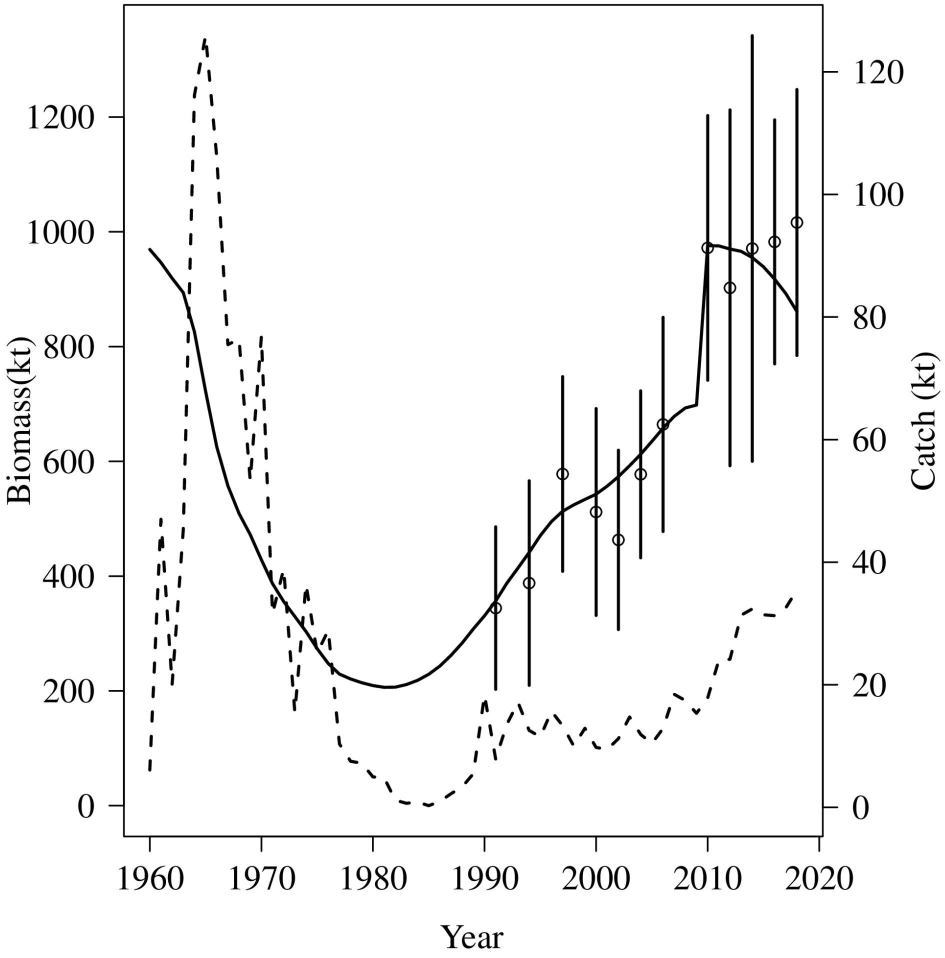

Figure 12C.2. Fit to AI survey biomass from a POP with in separate estimates for AI survey catchability for the 1991-2006 and 2010-2018 periods.

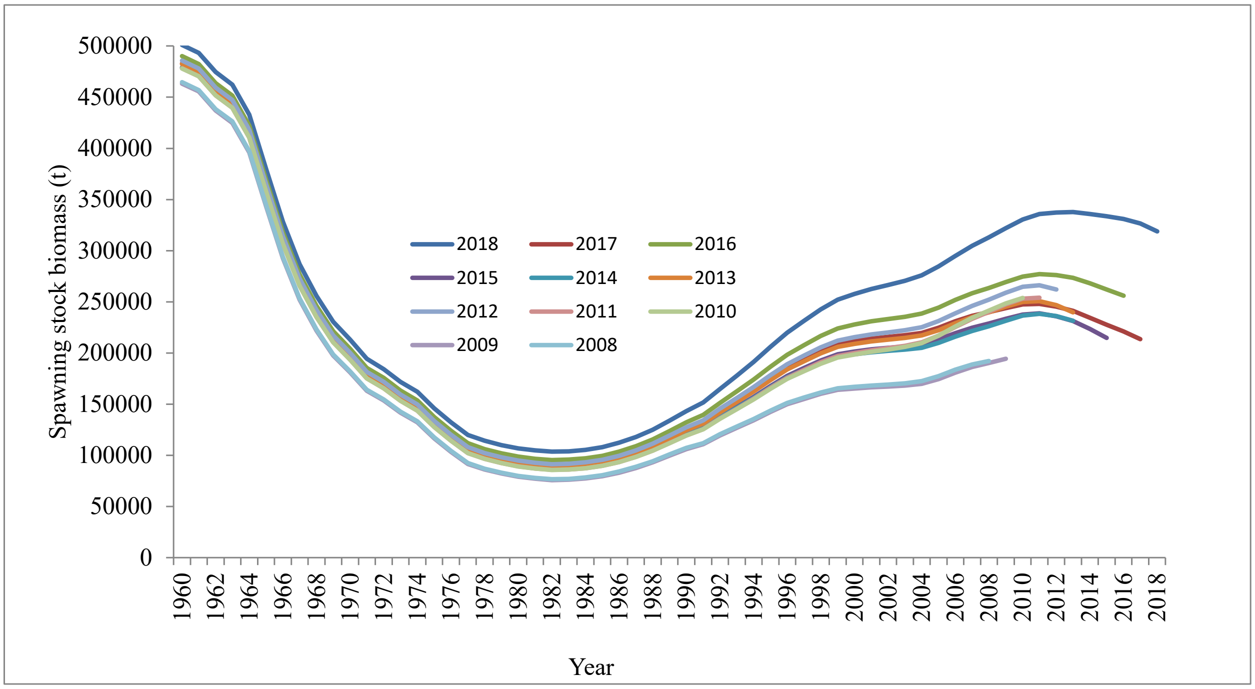

Figure 12C.3. Retrospective SSB for a POP model with separate estimates for AI survey catchability for the 1991-2006 and 2010-2018 periods. The Mohn's rho was -0.30.

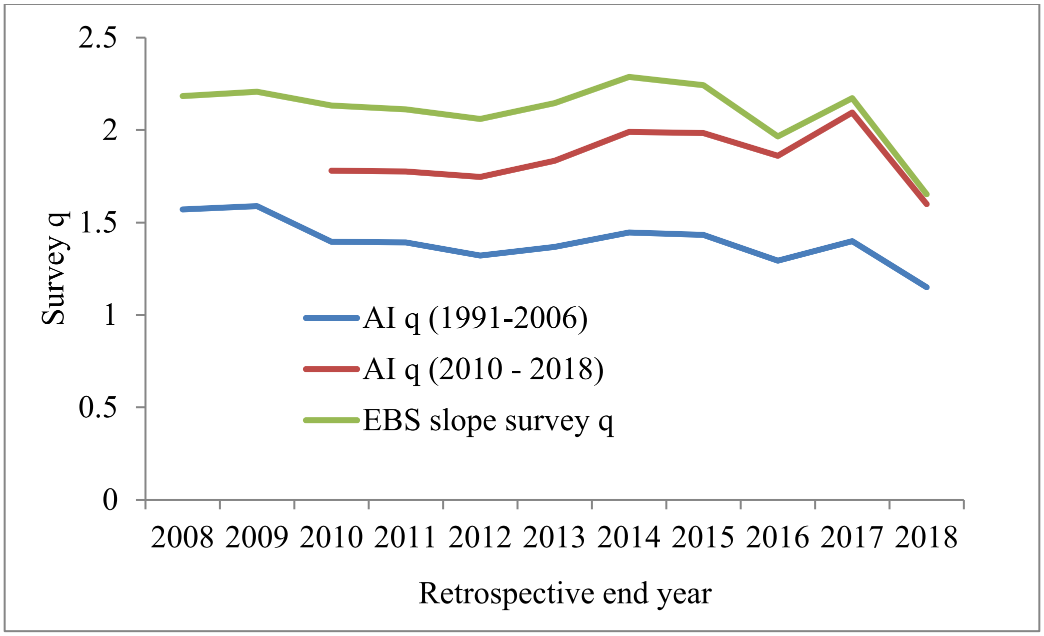

Figure 12C.4. Estimated values of survey catchability for a POP model with separate estimates for AI survey catchability for the 1991-2006 and 2010-2018 periods.

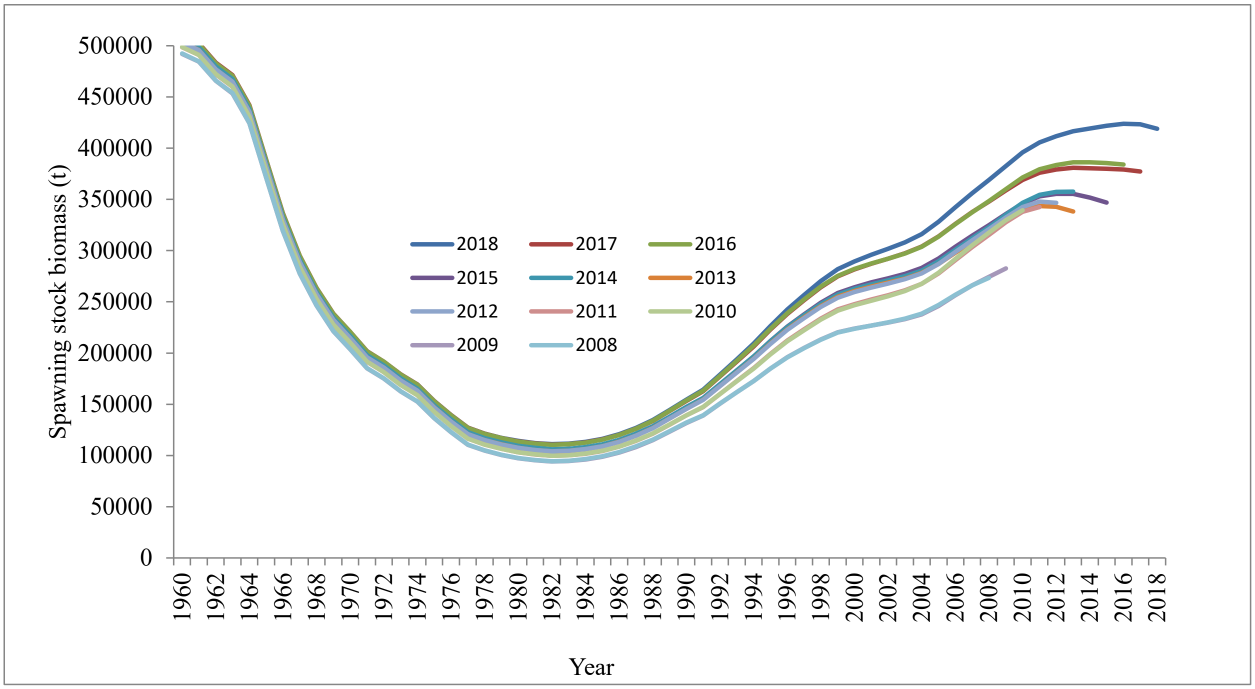

Figure 12C.5. Retrospective SSB for a POP model with separate estimates for AI survey catchability for the 1991-2006 and 2010-2018 periods, and with survey catchability for the retrospective runs fixed at the estimated values obtained in the run with data through 2018. The Mohn’s rho was -0.17.