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 2012. The following changes were made to POP assessment relative to the November 2012 SAFE:

Summary of Changes in Assessment Inputs

Changes in the Input Data

1) The harvest time series were updated through October 11, 2014.
2) The survey biomass estimates and age composition data from the U.S.-Japan cooperative survey in 1980,1983, and 1986 were removed from the assessment.
3) The 2014 AI survey biomass estimate and length composition was included in the assessment.
4) The 2012 AI survey age compositon was included in the assessment.
5) The 2013 fishery age composition were included in the assessment.
6) The 2012 fishery length composition was included in the assessment

Changes in the Assessment Methodology

1) Several fishery selectivity models were evaluated, with the recommended model using a bicubic spline to model to estimate fishery selectivity as a function of year and age.
2) The multinomial input sample sizes for the age and length composition data were obtained by an iterative reweighting procedure that ensures that the standard deviation of the normalized residuals for each composition data type is 1.
3) 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.

Summary of Results

A summary of the 2014 assessment recommended ABC's relative to the 2013 recommendations is shown below. BSAI Pacific ocean perch are not overfished or approaching an overfished condition. The recommended 2015 ABC and OFL are 34,988 t and 42,588 t, which are 11%and 13% increases, respectively, from the maximum ABC and OFL specified last year for 2015 of 31,641 t and 37,817 t. The 2014 AI survey biomass is large and consistent with the survey biomass estimates in 2010 and 2012, and the size composition data continue to show relatively strong cohorts from 1994 to 2000. 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: 2014	2015	As estimated or recommended this year for: 2015	2016
M (natural mortality rate)	0.062	0.062	0.062	0.062
Tier	3a	3a	3a	3a
Projected total (age 3+) biomass (t)	639,505	620,270	577,967	561,090
Female spawning biomass (t)				
Projected	257,878	243,400	234,426	223,744
$B_{100\%}$	459,436	459,436	423,008	423,008
$B_{40\%}$	183,774	183,774	169,203	169,203
$B_{35\%}$	160,803	160,803	148,053	148,053
F_{OFL}	0.076	0.076	0.109	0.109
$maxF_{ABC}$	0.063	0.063	0.089	0.089
F_{ABC}	0.063	0.063	0.089	0.089
OFL (t)	39,585	37,817	42,558	40,809
maxABC (t)	33,122	31,641	34,988	33,550
ABC (t)	33,122	31,641	34,988	33,550
Status	As determined last year for: 2012	2013	As determined this year for: 2013	2014
Overfishing	No	n/a	No	n/a
Overfished	n/a		n/a	No
Approaching overfished	n/a		n/a	No

Summaries for the Plan Team

The ABC for BSAI Pacific ocean perch is currently apportioned among four areas: the western, central, and eastern Aleutian Islands, and eastern Bering Sea. The current method of determining area apportionments uses a weighted average of the three most recent trawl survey biomass estimates in each of these areas is used to apportion the ABC. Weights of 4, 6, and 9 are used, with higher weights being applied to the more recent surveys. It is also of interest to estimate the area proportions using the random effects model. The survey averaging workgroup is evaluating the use of the random effects model to smooth survey time series for computing area apportionments, and its use for computing area proportion might logically be delayed until after the workgroup has completed their evaluations. However, a comparison between the two methods may be useful. The following table gives the projected OFLs and apportioned ABCs for 2015 and 2016 from the two methods, and the recent OFLs, ABCs, TACs, and catches.

	BSAI	Western AI	Central AI	Eastern AI	EBS	Total
Apportionment (weighted average)		28.5%	23.6%	24.6%	23.3%	100%
Apportionment (RE model)		29.1%	22.1%	23.8%	25.1%	100%
OFL (2013)	41,900					
ABC (2013)		10,200	6,980	9,790	8,130	35,100
TAC (2013)		10,200	6,980	9,790	8,130	35,100
Catch (2013)		10,065	6,747	9,530	5,050	31,393
OFL (2014)	39,585					
ABC (2014)		9,598	6,594	9,246	7,684	33,122
TAC (2014)		9,598	6,594	9,246	7,684	33,122
Catch (2014)[1]		9,485	6,438	8,124	1,842	25,889
OFL (2015)	42,558					
ABC (2015, weighted average)		9,981	8,240	8,623	8,143	34,988
ABC (2015, RE model)		10,182	7,723	8,312	8,771	34,988
OFL (2016)	40,809					
ABC (2016, weighted average)		9,571	7,902	8,269	7,809	33,550
ABC (2016, RE model)		9,763	7,406	7,970	8,411	33,550

Catch through October 11, 2014

Responses to SSC and Plan Team Comments in General

The SSC requests that all assessment authors of AI species evaluate AI survey information to ensure that the same standardized survey time series is used. (SSC, December 2012)

Model runs in this assessment exclude the cooperative surveys conducted in the 1980s.

"The Teams recommended that each stock assessment model incorporate the best possible estimate of the current year's removals. The Teams plan to inventory how their respective authors address and calculate total current year removals. Following analysis of this inventory, the Teams will provide advice to authors on the appropriate methodology for calculating current year removals to ensure consistency across assessments and FMPs." (Plan Team, September 2013)

The estimates of current year catch are inferred by expanding the catch through September, 2014, by the recent pattern of the proportion of the remaining ABC that is caught by the end of the year.

"For assessments involving age-structured models, this year's CIE review of BSAI and GOA rockfish assessments included three main recommendations for future research: Authors should consider: (1) development of alternative survey estimators, (2) evaluating selectivity and fits to the plus group, and (3) re-evaluating natural mortality rates. The SSC recommends that authors address the CIE review during full assessment updates scheduled in 2014." (SSC, December 2013)

Selectivity curves and natural mortality rates are evaluated in this assessment. The development of alternative survey estimators (i.e., model-based standardization of survey catch data) affects all NPFMC assessments that use survey data. Potential methodologies have been discussed in a limited number of meetings in 2014 among AFSC scientists, and between AFSC scientists and NWFSC scientists, who are in the process of developing more refined standardization methods. Continuation of these meetings will hopefully result in progress on this task.

"During public testimony, it was proposed that assessment authors should consider projecting the reference points for the future two years (e.g., 2014 and 2015) on the phase diagrams. It was suggested that this forecast would be useful to the public. The SSC agrees. The SSC appreciated this suggestion and asks the assessment authors to do so in the next assessment." (SSC December 2013)

These projections were added to the phase-plane plots.

Responses to SSC and Plan Team Comments Specific to this Assessment

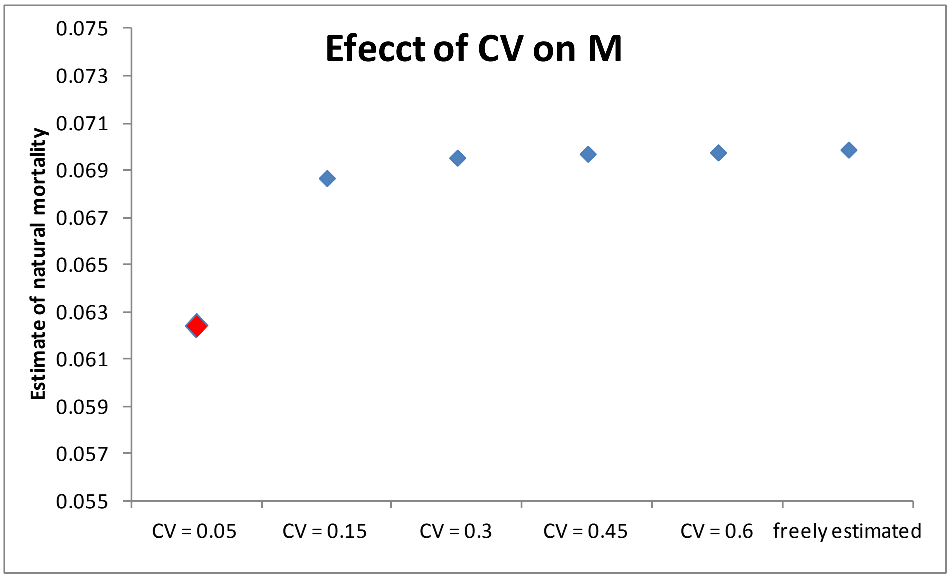
The SSC offers the following advice to assessment authors:

- *Explore alternative selectivity patterns*
- *Evaluate alternative selectivity time periods*
- *Provide model sensitivity to Q and M*
- *Explore lack of fit to the plus age group*
- *Fit to the maturity data should be evaluated for potential bias from excess data consisting of 100% and 0% maturity because the logistic model cannot predict 0 and 1.* (SSC, December 2012)

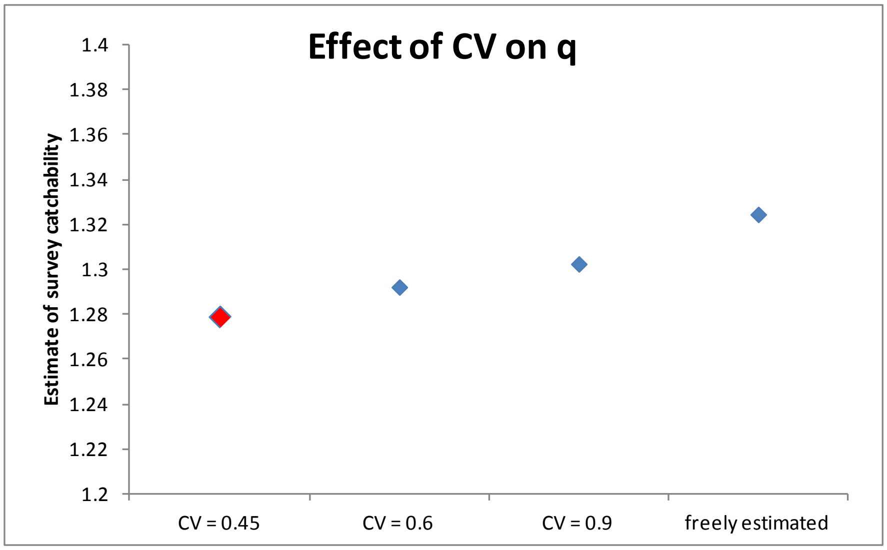
Several methods for modeling fishery selectivity over age and year were considered in this assessment, with a bicubic spline (used in the preferred model) providing improved fits to the survey and fishery age composition plus group.

Although predicted proportion mature obtained from the logistic model asymptotically approaches 1 as age increases, the difference between the asymptote of 1 and the predicted value for older ages is sufficiently small such that any effect on the model fit is not a concern. For example, the predicted proportion mature at age 25 is 0.99999905.

A series of models runs were conducted to address how sensitive the model estimates of natural mortality (*M*) and survey catchability (*q*) are to the prior distributions. Because *M* and *q* are inversely correlated, the runs for *M* were conducted by holding *q* fixed at the value estimated in the preferred model (and vice versa). The current model uses a prior distribution for *M* with a mean and CV each set to 0.05, and produces and estimate of 0.062 (shown in red in the graph below). Increasing the CV, or allowing *M* to be freely estimated, produces estimates ranging between 0.069 and 0.070. This value of *M* is consistent with a recent meta-analysis relating natural mortality estimates to maximum age (Then et al. 2014). Future assessments will consider increasing expected value of the prior distribution for *M* from 0.05 to 0.07.



The prior for *q* has a mean of 1 and a CV of 0.45, and a similar plot showing the effect of increasing the CV of the prior is shown below. The estimates of *q* ranges from 1.28 estimated in the current model to 1.32 when *q* is freely estimated (while holding *M* fixed at 0.0062). For this stock, estimates of *q* are more sensitive to the addition of age and length composition data and survey biomass estimates, which motivate obtaining information on *q* outside the assessment model in order to develop more informative priors.


Effect of CV on q
Estimate of survey catchability
1.4
1.38
1.36
1.34
1.32
1.3
1.28
1.26
1.24
1.22
1.2
CV = 0.45
CV = 0.6
CV = 0.9
freely estimated

Introduction

Pacific ocean perch (*Sebastes alutus*) inhabit the outer continental shelf and upper slope regions of the North Pacific Ocean and Bering Sea. Pacific ocean perch, and four other associated species of rockfish (northern rockfish, *S. polyspinis*; rougheye rockfish, *S. aleutianus*; shortraker rockfish, *S. borealis*; and sharpchin rockfish, *S. zacentrus*) were managed as a complex in the two distinct areas 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). 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 Herman 2007).

Analysis of field samples of rockfish larvae are hindered by difficulties in indentifying 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. Thus, analysis of genetic material from North Pacific rockfish is currently an active area of research.

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 of the Juneau Center of Fisheries and Ocean Sciences 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 7 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 Wither 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 2000 (when POP were managed as separate stocks in the EBS and AI) are shown in Table 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. 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 for this period is shown in Table 2. The ABCs, TACs, and catches from 1988 to 2012 are shown in Table 2. The catches of POP from 1977 by fishery type (i.e., foreign, joint venture, or domestic) is shown in Table 3.

Estimates of retained and discarded POP from the fishery have been available since 1990 (Table 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 2010-2013, the eastern Bering Sea discard rate was less than 7% but increased to 41% in 2014, although this may be an artifact of only including the catches through Oct 11, 2014. In contrast, the Aleutian Islands discard rates from 2010-2014 were less than 3%.

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-early-1980s a relatively large portion of POP were observed to be captured at depths greater than 300 m (Table 5, Figure 1). Additionally, from 1999 through the early 2000s the proportion caught between 100 m and 200 m increased from ~ 20% in the early to mid 1990s to ~ 30%,and since the mid 2000s the proportion caught between 200 m and 300 m has increased. The area of capture has changed as well; during the late 1970s POP were predominately captured in the western Aleutians, whereas from the early 1980s to the mid-1990s POP were captured predominately in the eastern Aleutians. 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 6, Figure 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 A.

Data

Fishery Data

Catch per unit effort (CPUE) data from Japanese trawl fisheries indicate that POP stock abundance has declined to very low levels in the Aleutian Islands region (Ito 1986). By 1977, CPUE values had dropped by more than 90-95% from those of the early 1960s. Japanese CPUE data after 1977, however, is not a good index of stock abundance because most of the fishing effort has been directed to species other than POP. Standardizing and partitioning total groundfish effort into effort directed solely toward POP is difficult. Increased quota restrictions, effort shifts to different target species, and rapid improvements in fishing technology undoubtedly affect our estimates of effective fishing effort. Consequently, we included CPUE data primarily to evaluate its consistency with other sources of information. We used nominal CPUE data for class 8 trawlers in the eastern Bering Sea and Aleutian Islands regions from 1968-

1979. During this time period these vessels were known to target on POP (Ito 1982).

Length measurements and otoliths read from the EBS and AI management areas (Tables 7 and 8) were combined to create fishery age/size composition matrices. Years that were not selected for age or length composition were rejected 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 2005-2013 indicate several strong recent year classes from 1995-2000 (Figure 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 cooperative surveys varied between years and included large roller gear, in contrast to the poly-nor'eastern nets used in the current surveys (Ronholt et al 1994). 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 portion of the southern Bering Sea portion of the survey (from 165 ^{o} W to 170 ^{o} W), as the post-1991 coefficients of variation (CVs) range from 0.41 to 0.63 (Table 9). The biomass estimates in this region increased from 1,501 t in 1991 to 18,217 t in 1994, and have since ranged between 12,099 t (1997) and 87,794 t (2010). The estimated biomass of Pacific ocean perch in the Aleutian Islands management area region (170^{o} W to 170^{o} E) appears to be less variable, with CVs ranging from 0.12 to 0.24. The biomass estimates for the AI area have ranged between a low of 342,785 t in 1991 and 887,559 t in 2014, with the estimates from the 2010, 2012, and 2014 survey ranging between 864,000 t (2012) and 888,000 t (2014).

From 1991-2010, the Aleutian Island surveys have indicated higher abundances in the western Aleutian Islands than in other subareas. However, in the 2012 survey the biomass estimate for the western AI was 263,661 t, a decrease from the 2010 estimate of 395,933 t, whereas the estimates for the eastern AI increased from 266,607 in the 2010 survey to 366,413 in the 2012 survey (Table 10). The estimated biomass from the 2014 survey for the western AI and eastern AI are 338,000 t and 234,000 t, respectively, which are more similar to the 2010 survey than the 2012 survey. The 2014 estimate for the central AI is 316,000 t, a 35% increase from the 2012 estimate. The total AI 2014 survey biomass estimate was 970,968 t with a CV of 0.19, which is a 8% increase from the 2012 estimate of 902,398 t (CV=0.17). Maps of survey CPUE are shown in Figure 3, and indicate relatively high abundance throughout much of the Aleutian Islands.

Age composition data exists for each Aleutian Islands survey, and the length measurements and otoliths read are shown in Table 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 (Figure 4).

The biennial EBS slope survey was initiated in 2002. The most recent slope survey prior to 2002, excluding some preliminary tows in 2000 intended for evaluating survey gear, was in 1991. Previous slope survey results have not been used in the BSAI model due to high CVs, relatively small population sizes compared to the AI biomass estimates, and lack of recent surveys. However, the biomass estimates in the EBS slope survey have been increasing, ranging from 76,665 t in 2002 to 231,383 in the 2012 survey, with CVs ranging from 0.33 in 2012 to 0.53 in 2002 (Table 9). The slope survey was canceled in 2008 and 2014 due to lack of funding. The slope survey results are not used in this assessment, but the feasibility of incorporating this time series will be evaluated in future years given the increased length of the time series and increased levels of biomass.

Comparison of Fishery and Survey Catches by Depth and Age

A comparison of fishery and survey catches can indicate whether fishery selectivity is suspected of being time-varying and/or dome-shaped. For example, some of the variation in depths and areas fished mentioned above could be related to changes in the stock distribution, which would suggest that availability to the stock is more constant than implied by examining only the catch data. This issue was examined by comparing the catch-weighted mean depth in the fishery (from 1991 – 2013) to that in tows from the Aleutian Islands trawl survey from 1991 to 2014. The survey tows show a relatively constant mean depth of capture across years, whereas the fishery depth of capture show higher of interannual variation (Figure 5).

The plus group for the POP assessment model is 40 years, and of interest is the relative age composition of the old fish within the plus group. Fishery and survey data were binned across years in each of five periods from 1990 to 2011, the age composition of ages 40 to 70+ are shown in Figure 6. Overall, survey age composition generally exceeds the fishery age composition, and this pattern seems to be more pronounced in the earlier time periods. For example, in the 1990-1991 period, the survey age composition exceeded the fishery age composition for each age from 41 – 52 (except age 53); a similar pattern is seen in the 1997-1998 period for ages greater than 58. The pattern can be seen more clearly in the histogram of differences between survey and fishery age proportions (Figure 7); positive differences indicate that the survey proportion exceeded the fishery proportion for a given age. Of the ages with a non-zero difference, the proportion of ages with a positive difference ranged between 0.78 and 0.82 for the four earliest periods, and decreased to 0.6 in the 2009-2011 period. Overall, these data suggest that the some dome-shaped fishery selectivity has likely occurred since 1991, and that it may be diminishing in recent years.

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 were determined by constructing age-length keys for each year and using them to convert the observed length frequencies from each year. Because the survey age data were based on the break and burn method of ageing POP, 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 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 *S. alutus* 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 2012 were used to estimate growth curves. The resulting von Bertalannfy growth parameters were L_{inf} = 41.53 cm, k = 0.14, and t_0 = -1.202. 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 power relationship to the observed standard deviation in length at each age (obtained from the aged fish from the 1991-2012 surveys), 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 0.13 at age 3 to 0.07 at age 40.

The estimated length(cm)-weight(g) relationship for Aleutian Islands POP was estimated with survey information from the same years, with the length-weight parameters estimated as $a = 9.56 \times 10^{-6}$ and b = 3.11, 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 BSAI POP model:

Component	BSAI
Fishery catch	1960-2014
Fishery age composition	1981-82, 1990, 1998, 2000-2009, 2011, 2013
Fishery size composition	1964-72, 1983-1984, 1987-1989, 1991-1997, 1999, 2010, 2012
Fishery CPUE	1968-79
Survey age composition	1991, 1994, 1997, 2000, 2002, 2004, 2006,2010,2012
Survey length composition	2014
Survey biomass estimates	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014

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

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

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 2014).

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. Previous assessments have estimated non-equilibrium numbers at age in the first year of the model (as a function of cohort-dependent deviations from average recruitment), although this formulation tended to put most of abundance in the first year in a single cohort. 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 from 1960 to 2011 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 (2012-2014), 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 predicted trawl survey biomass $\hat{B}^{twl}_t$ was computed as

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

where W_a is the population weight-at-age, s^{twl}_a is the survey selectivity, and q^{twl} is the trawl survey catchability. A CPUE index from 1968 to 1979 is also included in the assessment and is computed as

$$\hat{I}^{cpue}_t = q^{cpue} \sum_a (\overline{N}_{t,a} s^f_{a,t} W_a)$$

where q^{cpue} is the scaling factor for the CPUE index.

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, a value consistent with the root mean squared error (RMSE; defined below) of recruitment deviations. Similar, the prior distribution for *qsurv* followed a lognormal distribution with a mean of 1.0 and a coefficient of variation (CV) of 0.05.

Several quantities were computed in order to compare the variance of the residuals to the assumed input variances. The RMSE should be comparable to the assumed coefficient of variation of a data series. This quantity was computed for the AI trawl survey and the estimated recruitments, and for lognormal distribution is defined as

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

where y and $\hat{y}$ are the observed and estimated values, respectively, of a series length n. The standardized deviation of normalized residuals (SDNR) are closely related to the RMSE. Values of SDNR approximately 1 indicate that the model is fitting a data component as well as would be expected for a given specified input variance. The normalized residuals for a given year i of the AI trawl survey data was computed as

$$\delta_i = \frac{\ln(B_i) - \ln(\hat{B}_i)}{\sigma_i}$$

where σ_i is the input sampling standard deviation of the estimated survey biomass. For age or length composition data assumed to follow a multinomial distribution, the normalized residuals for age/length group a in year i were computed as

$$\delta_{i,a} = \frac{(p_{i,a} - \hat{p}_{i,a})}{\sqrt{\hat{p}_{i,a}(1 - \hat{p}_{i,a})/n_i}}$$

where p and $\hat{p}$ are the observed and estimated proportion, respectively, and n is the input assumed sample size for the multinomial distribution. The effective sample size was also computed for the age and length compositions modeled with a multinomial distribution, and for a given year i was computed as

$$E_i = \frac{\sum_a \hat{p}_a(1 - \hat{p}_a)}{\sum_a (\hat{p}_a - p_a)}.$$

An effective sample size that is nearly equal to the input sample size can be interpreted as having a model fit that is consistent with the input sample size.

Parameterization of fishery selectivity

Three models were evaluated that differed in the parameterization for fishery selectivity at age ($s^f_{a,t}$).

Model 1) *Logistic curve varying between 4-year blocks* (used in previous assessments):

A time-varying fishery selectivity curve is used to account for the interannual changes in terms of depth and management area fished (Tables 5 and 6). Fishery selectivity is modeled with a logistic equation in which deviations are allowed in the parameters specifying the age (a_{50}) and slope (*slp*) at 50% selection such that the fishing selectivity $s^f_{a,t}$ for age *a* and year *t* is modeled as

$$s_a^f = \frac{1}{1+e^{-(\phi_{asc}+\gamma_t)(a-(a_{50\%}+\eta_t)}}$$

where η_t and γ_t are time-varying deviations that sum to zero and are constrained by adding a lognormal prior to the likelihood function with mean of zero and a CV of 0.1. Deviations in ϕ_{asc} and $a_{50\%}$ allowed between 4-year blocks (i.e., 1964-67, 1968-71, etc.). Little information exists to estimate the selectivity for the 1960-1963 period, so years were combined with those from 1964-1967.

Model 2) *Time-invariant double logistic*

$$s_a^f = \frac{1}{1+e^{-\phi_{asc}(a-a_{50\%})}}\frac{1}{1+e^{-\phi_{des}(a-d_{50\%})}}$$

where fishing selectivity is the product of two logistic curve, and allows for dome-shaped selectivity when the descending slope parameter (ϕ_{des}) is negative.

Model 3) Bicubic spline

A mathematical definition of a spline is a smooth function that is used for either interpolating between fixed points (referred to as “knots” or “nodes”) or smoothing a dataset. Splines are of interest when the underlying process for which the spline represents is a smooth, nonlinear function. Splines are constructed from separate piecewise functions that are joined at the knots, and smoothness is ensured by requiring that at each knot, the two functions joined have equal function values, first derivatives, and second derivatives. These conditions can only be met by using polynomial splines of order 3 or higher, and cubic splines are often used because they limit unnecessary bending between the knots. Splines are implemented in non-parametric modeling such as generalized additive models, and been examined in ecological modeling as an approach for modeling time-varying parameters (Thorson et al. 2013). In stock assessment modeling, non-parameteric selectivity curves (a category that includes splines) performed well in an evaluation of various approaches for modeling fishery selectivity (Thorson and Taylor 2013).

The bicubic splines was implemented with the “vcubic_spline_function” function in AD Modelbuilder and models selectivity varying across time and age, and was developed from code provided in Press et al. (1992). Four year knots and 5 age knots were used, for a total of 20 selectivity parameters.

Briefly, the bicubic spline function requires the user to specify a number of age and year nodes that form a grid in the year-age matrix of time-varying selectivity (with equal grid spacing), and values at these nodes are the log-scale fishery selectivity and estimated as parameters. Fishery selectivity at ages and years between the nodes are interpolated with a 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. The bicubic spline function was original developed by Dr. Steve Martell for the Integrated Statistical Catch at Age (iSCAM) model, which included penalties for: 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); and 3) the smoothness across years (modeled with the sum of second differences). In addition to these penalties, an additional penalty on the interannual variability across years (modeled with the first difference) was used in this assessment to address situations in which the selectivity across years was relatively smooth but also non-constant (as would occur with a trend).

Sample sizes for age and length composition data

In previous assessments, the sample sizes for the age and length composition data were set to the square root of the number of fish lengthed or otoliths read. This procedure has resulted in the SDNR for the age and length compositions differing substantially from 1, indicating a mismatch between the precision of the model fit and the assumed input variance.

In this assessment, the sample sizes for the composition data are obtained from an iteratively reweighted procedure using the SDNR (method TA1.2 in Francis 2011). An initial model run in which the sample sizes are specified as in the 2012 assessment is conducted, and a weight that is the inverse of the variance of the normalized residuals for each composition dataset is obtained. The sample sizes for the next model run are the original sample sizes multiplied by the estimated weights, which then produced a new set of weights, and process is iterated until the weights converge. The reweighting was applied to Model 3, and the final sample sizes were applied to Models 1 and 2.

Parameters Estimated Outside the Assessment Model

The parameters estimated independently include the age error matrix, the age-length conversion matrix, and individual weight at age. 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 year 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 CPUE index is computed in a similar manner, and is weighted by λ_3. The negative log-likelihood of the catch biomass was modeled with a lognormal distribution:

$$\lambda_4 \sum_t (\ln(obs\_cat_t) - \ln(pred\_cat_t))^2$$

where obs_cat_t and $pred\_cat_t$ are the observed and predicted catch. Because the catch biomass is generally thought to be observed with higher precision that other variables, λ_4 is given a very high weight so as to fit the catch biomass nearly exactly. This can be accomplished by varying the F levels, and the deviations in F are not included in the overall likelihood function.

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

$$
\begin{aligned}
&\lambda_1\left[\sum_{t=1}^{n}\frac{\left(\nu_t+\sigma_r{}^2/2\right)^2}{2\sigma_r{}^2}+n\ln(\sigma_r)\right]+\\
&\lambda_2\sum_t\left(\ln(obs\_biom_t)-\ln(pred\_biom_t)\right)^2/2cv_t^2+\\
&\lambda_3\sum_t\left(\ln(obs\_cpue_t)-\ln(pred\_cpue_t)\right)^2/2cv_{CPUE}^2+\\
&-n_{f,t,l}\sum_{s,t,l}(p_{f,t,l}\ln(\hat{p}_{f,t,l})-p_{f,t,l}\ln(p_{f,t,l}))+\\
&-n_{f,t,a}\sum_{s,t,l}(p_{f,t,a}\ln(\hat{p}_{f,t,a})-p_{f,t,a}\ln(p_{f,t,a}))+\\
&-n_{surv,t,a}\sum_{s,t,a}(p_{surv,t,a}\ln(\hat{p}_{surv,t,a})-p_{surv,t,a}\ln(p_{surv,t,a}))+\\
&-n_{surv,t,l}\sum_{s,t,a}(p_{surv,t,l}\ln(\hat{p}_{surv,t,l})-p_{surv,t,l}\ln(p_{surv,t,l}))+\\
&\lambda_4\sum_t\left(\ln(obs\_cat_t)-\ln(pred\_cat_t)\right)^2
\end{aligned}
$$

For the model run in this analysis, λ_1, λ_2, λ_3, and λ_4 were assigned weights of 1,1, 0.5, and 500, reflecting a strong emphasis on fitting the catch data and a de-emphasis of the CPUE index. The negative log-likelihood function was minimized by varying the following parameters (using the bicubic fishery selectivity):

Parameter type	Number
1) Fishing mortality mean	1
2) Fishing mortality deviations	55
3) Recruitment mean	1
4) Recruitment deviations	52
5) Unfished recruitment	1
6) Biomass survey catchability	1
7) CPUE index catchability	1
8) Fishery selectivity parameters	20
10) Survey selectivity parameters	2
11) Natural mortality rate	1
12) Maturity parameters	2
Total parameters	137

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

Several attributes of the model fits are shown in Table 12. Models 0 and 0.1 are presented for to demonstrate intermediate steps between the 2012 model and the recommended 2014 model (i.e., a “bridging” analysis). Model 0 has the updated data through 2014, Model 0.1 excludes the cooperative survey biomass estimates and age/size composition data, and each uses the age and length composition sample weights as produced for the 2012 assessment. The sample sizes for the composition are identical in Models 1-3, and were produced by applying iterative reweighting to Model 3 (bicubic spline selectivity). Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) were used to evaluate model selection. Each of these metrics penalize the negative log-likelihood by multiple of the number of parameters; in AIC, this multiple is 2 whereas in BIC is the natural log of the number of data points.

For all the models, the number of parameters is “nominal” number of parameters, which overestimates the number of independent parameters because of the use of penalties and prior distributions in the models. Deviance Information Criterion (DIC) could be used, but will often select the models with higher number of parameters (Martell and Stewart 2014). For these reasons, model selection considered additional information such as the root mean squared errors and negative log-likelihoods in the fits to the data, and the residual patterns in fitting the composition data.

Model 3 (bicubic spline selectivity) had the lowest AIC and BIC, and produced better fits to the fishery length composition and survey age composition data than Models 1 and 2 (as revealed by both the negative log-likelihoods and the RMSE). Model 2 has the lowest number of parameters, and was considered to evaluate whether the lack of fit to the age-plus group in the fishery and survey data is more related to the selectivity shape its variation over time. Both appear to be important, as the improvement in Model 3 is achieved by allowing the dome-shaped selectivity curves to vary over time. Additionally, Model 3 achieves to the best fit the time series of survey biomass estimates, which show a strong trend that is informative on the dynamics of the stock.

The estimated spawning biomass for the models is shown in Figure 8, with the bridging Models 0 and 0.1 shown in blue. Relative to the bridging models, Model 3 estimates higher biomass in the early 1980s (resulting from the dome-shaped selectivity in the 1960s and 1970s), and relative similar levels of biomass in the recent years (resulting from the shift from dome-shaped to near asymptotic selectivity).

Model 3 was selected as the preferred model, and the results below were obtained from this model.

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.

A retrospective analysis was conducted to evaluate the effect of recent data on estimated spawning stock biomass. For the current assessment model, a series of model runs were conducted in which the end year of the model was varied from 2012 to 2002, and this was accomplished by sequentially dropping age and length composition data, survey biomass estimates, and catch estimates from the input data files.

The plot of retrospective estimates of spawning biomass is shown in Figure 9. The largest changes in estimated survey biomass occurred with end years 2004, 2006, 2010, and 2012, when survey biomass estimates and survey age composition data are added to the model. The 2014 survey contains similar information as in the 2012 survey and thus has relatively little effect on the retrospective pattern.

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.

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 absence of any retrospective pattern would result in a Mohn’s rho of 0, and would result from either identical estimates in the model runs, or from positive deviations from the reference model being offset by negative deviations. The Mohn’s rho for this retrospective runs was -3.43.

The practice of estimating survey catchability within the model likely contributes to the retrospective pattern. The increasing trend in survey biomass cannot be explained by simply increasing the estimates of recruitments in recent years, but instead require an increase in the recruitment estimates for many year classes. This increases the scale of the biomass estimates, and thus lowers the survey catchability. The estimates of survey catchability is greater than 2 for the retrospective runs with 2004 and 2005 end years, and gradually decrease to the estimate of 1.28 obtained with data through 2014. The sensitivity of estimated survey catchability to the sequential addition of survey biomass estimates and age/length composition data motivates the estimation of survey catchability outside the model.

Prior and Posterior Distributions

Posterior distributions for *M*, *q*, total 2014 biomass, and median recruitment, based upon the MCMC integrations, are shown in Figure 10. The posterior distribution for *M* shows little overlap with the prior distribution. However, a sensitivity analysis on the estimation on *M* (presented in the Executive Summary) indicates that the estimate of *M* obtained without a prior would be 0.07 (with fixing survey catchabilitity at its current value), and this value of *M* is also supported by a recent meta-analysis relating estimates of natural mortality to maximum age (Then at al. 2014). In future assessment, increasing the expected value of the prior distribution for *M* from 0.05 to 0.07 will be considered.

Biomass Trends

The estimated survey biomass index begins with 1,304,450 t in 1960, declines to 238,512 t in 1981, and increases to 751,086 t in 2010, and declines to 671,125 t in 2012 (Figure 11). The survey point estimates are used in a relative sense rather than in an absolute sense, with a survey catchability (*q*) estimated at 1.28 rather than fixed at 1.0, which is to 16% increase from the value of 1.10 in the 2012 assessment. The model estimate of survey biomass still does not match the high 2010 - 2014 survey biomass estimates very well. Because the AI survey biomass estimates are taken as an index for the entire BSAI area, one might expect that *q* would be below 1.0 to the extent that the total BSAI biomass is higher than the Aleutian Islands biomass. One factor that may cause an increase in survey catchability is the expansion of survey trawl estimates to untrawlable areas (Kreiger and Sigler 1996). The fit to the CPUE index is shown in Figure 12.

The total biomass showed a similar trend as the survey biomass, with the 2014 total biomass estimated as 597,506 t. The estimated time series of total biomass and spawning biomass, with 95% credibility bounds obtained from MCMC integration, are shown in Figure 13. Total biomass, spawning biomass, and recruitment are given in Table 13.

Age/size compositions

The fits to the fishery age and length composition is shown in Figures 14-15. The observed proportion in the binned age 25+ group for years 1981 and 1982 is higher than the estimated proportion, although the fits improve for the remainder of the fishery age compositions. 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 15). 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 1991-2012 surveys (Figure 16). The model provides a reasonable fit to the 2014 survey length composition (Figure 17).

Fishing and Survey Selectivity

The estimated age at 50% selection for the survey is 6.02 (Figure 18). The estimated fishery selectivity by age and year is shown in Figure 19, and shows 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 decreased over time (with the exception of dome-shaped selectivity for ages 35 and above since 2010).

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 20). 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 0.57, whereas the average from 1981 to 2011 was 0.04.

The plot of estimated fishing mortality rates and spawning stock biomass relative to the harvest control rules (Figure 21) 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 22; Table 12). The relationship between spawning stock and recruitment also displays a high degree of variability (Figure 23). The 1957 and 1962 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 year classes. Recruitment appears to be lower in early 1990s, but cohorts from 1994 to 2000 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 survey age compositions shown in Figures 14 and 16.

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 1977-2011 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 169,203 t. The year 2015 estimated spawning stock biomass is 234,426 t.

Specification of OFL and maximum permissible ABC

Since reliable estimates of the 2015 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B > B_{0.40}$ (234,426 t > 169,203 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 0.089 and 0.109, respectively.

The 2015 ABC associated with the $F_{0.40}$ level of 0.089 is 34,988 t.

The estimated catch level for year 2015 associated with the overfishing level of $F = 0.074$ is 42,558 t. A summary of these values is below.

2015 SSB estimate (B)	**=**	**234,426 t**
$B_{0.40}$	=	169,203 t
$F_{ABC} = F_{0.40}$	=	0.089
$F_{OFL} = F_{0.35}$	=	0.109
MaxPermABC	=	34,988 t
OFL	=	42,558 t

ABC recommendation

We recommend the maximum permissible ABC 34,988 t.

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 2014 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2015 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2014. 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 2011, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

> *Scenario 1*: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)
>
> *Scenario 2*: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2015 recommended in the assessment to the *max* F_{ABC} for 2015. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)
>
> *Scenario 3*: In all future years, F is set equal to 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 2009-2013 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)
>
> *Scenario 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 2014 or 2) above ½ of its MSY level in 2014 and above its MSY level in 2014 under this scenario, then the stock is not overfished.)
>
> *Scenario 7*: In 2015 and 2016, F is set equal to *max* F_{ABC}, and in all subsequent years F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2027 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 14.

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 2015, it does not provide the best estimate of OFL for 2016, because the mean 2015 catch under Scenario 6 is predicated on the 2015 catch being equal to the 2015 OFL, whereas the actual 2015 catch will likely be less than the 2015 OFL. The executive summary contains the appropriate one- and two-year ahead projections for both ABC and OFL.

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

Is the stock being subjected to overfishing? The official BSAI catch estimate for the most recent complete year (2013) is 31,393 t. This is less than the 2013 BSAI OFL of 41,900 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 2014:

a. If spawning biomass for 2014 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b. If spawning biomass for 2014 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c. If spawning biomass for 2014 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 14). If the mean spawning biomass for 2024 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

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

a. If the mean spawning biomass for 2017 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.
b. If the mean spawning biomass for 2017 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c. If the mean spawning biomass for 2017 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2027. If the mean spawning biomass for 2027 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

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 2014 of Scenario 6 is 1.66 times its $B_{35\%}$ value of 148,053 t. With regard to whether the BSAI POP stock is likely to be overfished in the future, the expected stock size in 2017 of Scenario 7 is 1.41 times the $B_{35\%}$ value.

Area Allocation of Harvests

The ABC of BSAI POP is currently partitioned into subarea ABCs based on the relative biomass from research surveys. The current method of obtaining the subarea is a weighted average was applied to the AI trawl surveys in order to compute the average biomass from each of the four subareas, and applies weights of 4, 6, and 9 to the 2010, 2012, and 2014 surveys. A weighted average was also applied to EBS slope survey estimates, with weights of 4, 6, and 9 applied to 2008, 2010, and 2012 surveys.

It is also of interest to estimate the area proportions using the random effects model. The survey averaging workgroup is evaluating the use of the random effects model to smooth survey time series for computing area apportionments, and its use for computing area proportion might logically be delayed until after the workgroup has completed their evaluations. However, a comparison between the two methods may be useful. A comparison between the biomass estimates and proportions is shown below, with the average biomass in the EBS area being the sum of the estimate from the AI SBWS area and the EBS slope area.

	WAI	CAI	EAI	EBS
Weighted average biomass	326,939	269,931	282,471	266,753
Proportion of biomass	28.5%	23.6%	24.6%	23.3%
Estimated 2014 biomass				
(from random effects model)	311,678	236,416	254,448	268,506
Proportion of biomass	29.1%	22.1%	23.8%	25.1%

The apportionments for the 2015 and 2016 ABC are shown below:

	BSAI	WAI	CAI	EAI	EBS	Total
OFL (2015)	42,558					
ABC (2015, weighted average)		9,981	8,240	8,623	8,143	34,988
ABC (2015, RE model)		10,182	7,723	8,312	8,771	34,988
OFL (2016)	40,809					
ABC (2016, weighted average)		9,571	7,902	8,269	7,809	33,550
ABC (2016, RE model)		9,763	7,406	7,970	8,411	33,550

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.

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 0.04 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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Table 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	9299	POP	3300	1400	1400	1022
1999	POP	19100	13500	13500	12484	POP	3600	1900	1400	421
2000	POP	14400	12300	12300	9328	POP	3100	2600	2600	451
2001	POP	11800	10200	10200	8557	POP	2040	1730	1730	896

Table 2. Total allowable catch (TAC), acceptable biological catch (ABC), and catch for BSAI POP from 2002 to present. Catch data is through October 11, 2014, 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	24143
2013	POP	41900	35100	35100	31393
2014	POP	39585	33122	33122	25889

Table 3. Total allowable catch (TAC), acceptable biological catch (ABC), and catch of POP by area and management group from 1977 to 2014.

	Eastern Bering Sea			Aleutian Islands			BSAI
Year	Foreign	JVP	DAP	Foreign	JVP	DAP	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			1,022			9,299	10,320
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			5,601			18,403	24,004
2012			5,589			18,554	24,143
2013			5,050			26,342	31,393
2014[*]			1,842			24,047	25,889

[*] Estimated removals through October 11, 2014.

Table 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	20.1	10,288	1,551	13.1	15,357	2,826	15.54
1991	4,126	972	19.07	1,815	970	34.82	5,941	1,942	24.63
1992	5,464	1044	16.05	17,332	3,227	15.7	22,797	4,271	15.78
1993	2,601	1163	30.9	11,479	1,896	14.18	14,080	3,059	17.85
1994	1,187	501	29.69	9,491	1,374	12.65	10,678	1,876	14.94
1995	839	368	30.49	8,603	1,701	16.51	9,442	2,069	17.97
1996	2,522	333	11.66	9,831	2,995	23.35	12,353	3,328	21.22
1997	420	261	38.35	10,854	1,794	14.18	11,274	2,055	15.42
1998	821	200	19.62	8,282	1,017	10.93	9,103	1,217	11.79
1999	277	144	34.28	10,985	1,499	12.01	11,261	1,643	12.73
2000	230	221	49.01	8,586	743	7.96	8,816	964	9.85
2001	399	497	55.45	7,195	1,362	15.92	7,594	1,859	19.66
2002	286	355	55.44	9,315	1,260	11.91	9,601	1,615	14.4
2003	549	627	53.31	10,720	2,042	16	11,269	2,668	19.14
2004	536	196	26.75	9,286	1,879	16.83	9,822	2,074	17.44
2005	627	253	28.74	8,100	1,448	15.16	8,727	1,700	16.31
2006	751	290	27.83	9,869	1,957	16.55	10,620	2,246	17.46
2007	508	363	41.68	15,051	2,530	14.39	15,558	2,893	15.68
2008	318	195	37.94	16,640	283	1.67	16,959	477	2.74
2009	463	160	25.67	14,011	713	4.84	14,474	873	5.69
2010	3347	200	5.64	13,988	316	2.21	17,335	516	2.89
2011	5249	353	6.30	18,021	382	2.08	23,269	735	3.06
2012	5181	409	7.32	18,162	392	2.12	23,343	801	3.32
2013	4746	304	6.03	26,094	249	0.94	30,840	553	1.76
2014*	1096	747	40.53	23,873	174	0.72	24,969	920	3.56

*Estimated removals through October 11, 2014.

Source: NMFS Alaska Regional Office

Table 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	13,375	66
1994	0	20	69	11	0	0	0	7,562	10,866	70
1995	0	15	68	14	2	0	0	6,154	10,303	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	9,299	79
1999	0	30	63	7	0	0	0	10,369	12,483	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	16,682	16,923	99
2009	1	26	65	8	1	0	1	14,495	14,724	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	21	67	11	1	0	0	18,553	18,554	100
2013	0	12	76	11	1	0	0	26,297	26,342	100

Table 6. Proportional catch (by weight) of Aleutians Islands POP in the foreign and joint venture fisheries and the domestic fishery by management area.

	Area			Observed catch (t)	Estimated total catch	Percent sampled
	541	542	543			
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	13,375	66
1994	64	31	5	7,562	10,866	70
1995	70	25	5	6,154	10,303	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	9,299	79
1999	22	23	56	10,369	12,483	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	16,682	16,923	99
2009	27	28	44	14,495	14,724	98
2010	28	28	44	14,299	14,304	100
2011	30	26	44	18,391	18,403	100
2012	30	26	44	18,553	18,554	100
2013	36	26	38	26,297	26,342	100

Table 7. 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 8. 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	1043
2014	754	7,910	8,664			

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

Table 9. Pacific ocean perch estimated biomass (t) from the eastern Bering Sea slope and Aleutian Islands trawl surveys (by management area).

	Southern Bering Sea			Aleutian Islands			Total Aleutian Islands Survey			EBS Slope survey		
Year	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1979												
1980	5,833	5,658	97%	76,545	45,686	60%	82,378	46,035	56%			
1981												
1982												
1983	90,622	72,317	80%	141,261	37,075	26%	231,883	81,267	35%			
1984												
1985												
1986	26,784	13,031	49%	197,656	42,463	21%	224,440	44,418	20%			
1987												
1988												
1989												
1990												
1991	1,501	758	51%	342,785	70,773	21%	344,286	70,777	21%			
1992												
1993												
1994	18,217	11,685	64%	369,699	88,327	24%	387,916	89,096	23%			
1995												
1996												
1997	12,099	7,008	58%	565,885	84,524	15%	577,984	84,814	15%			
1998												
1999												
2000	18,870	10,150	54%	500,118	91,099	18%	518,988	91,662	18%			
2001												
2002	16,311	6,637	41%	446,860	77,841	17%	463,171	78,123	17%	72,665	38,586	53%
2003												
2004	74,208	33,397	45%	503,228	64,592	13%	577,436	72,715	13%	112,273	42,681	38%
2005												
2006	23,701	11,194	47%	623,549	90,482	15%	647,250	91,172	14%			
2007												
2008										107,886	43,711	41%
2009												
2010	87,794	47,952	55%	884,241	104,840	12%	972,035	115,286	12%	203,421	78,235	38%
2011												
2012	38,658	24,190	63%	863,741	153,111	18%	902,398	155,010	17%	231,383	75,235	33%
2013												
2014	83,409	41,568	50%	887,559	180,704	20%	970,968	185,423	19%			

Table 10. Pacific ocean perch biomass estimates (t) from the 1991-2014 triennial trawl surveys for the three management sub-areas in the Aleutian Islands region.

	Aleutian Islands Management Sub-Areas		
Year	Western	Central	Eastern
1991	208,465	78,776	55,545
1994	184,703	84,411	100,585
1997	178,437	166,816	220,633
2000	229,850	129,740	140,528
2002	196,704	140,361	109,795
2004	212,639	153,477	137,112
2006	281,946	150,851	190,752
2010	395,944	221,700	266,607
2012	263,661	233,666	366,413
2014	338,455	315,544	233,560
Weighted Average (2010-2014)	326,939	269,931	282,471
Percentage	37.18%	30.70%	32.12%

Table 11. Length measurements and otoliths read from the Aleutian Islands surveys.

Year	Length measurements	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
2004	24,949	1,031
2006	19,737	462
2010	22,725	951
2012	31,450	1,140
2014	30,206	

Table 12. Negative log likelihoods, and several measures of model fits, for the evaluated models for BSAI POP.

	Model 0	Model 0.1	Model 1	Model 2	Model 3
Negative log-likelihood					
Data components					
AI survey biomass	9.97	7.67	9.49	20.92	8.52
CPUE	23.74	24.89	33.59	22.16	26.28
Catch biomass	0.00	0.00	0.00	0.00	0.00
Fishery age comp	41.38	43.80	209.27	225.20	226.03
Fishery length comp	326.17	313.63	416.90	467.54	358.98
AI survey age comp	120.78	52.96	261.75	177.14	150.23
AI survey lengths comp	6.74	6.48	13.32	23.27	10.54
Maturity	2.71	2.71	2.71	2.71	2.71
Priors and penalties					
Recruitment	8.29	6.98	10.48	13.40	11.95
Prior on survey q	14.69	14.38	16.46	0.00	9.89
Prior on M	0.19	0.21	0.01	1.30	0.30
Fishery selectivity	14.32	13.51	23.48	67.66	142.86
Total negative log-likelihood	565.00	483.02	988.71	1018.15	942.41
Parameters	121	145	145	121	137
Number of data points			1024	1024	1024
BIC			2982.49	2875.01	2834.43
AIC			2267.43	2278.30	2158.81
Effective sample size					
Fishery age comp	266	266	324	269	199
Fishery length comp	189	215	144	138	164
AI survey age comp	101	120	158	173	210
AI survey lengths comp	88	93	41	24	52
Sample weights					
Fishery age comp	24	24	153	153	153
Fishery length comp	147	147	168	168	168
AI survey age comp	33	30	224	224	224
AI survey lengths comp	174	174	175	175	175
Root mean square error					
AI survey biomass	0.245	0.198	0.227	0.351	0.222
CPUE	0.778	0.790	0.875	0.761	0.804
Recruitment	0.763	0.744	0.793	0.832	0.813
Fishery age comp	0.013	0.013	0.012	0.013	0.014
Fishery length comp	0.025	0.025	0.027	0.027	0.023
AI survey age comp	0.020	0.016	0.014	0.013	0.011
AI survey lengths comp	0.020	0.019	0.029	0.037	0.026
Standard Deviation of Normalized Residuals					
AI survey biomass	1.24	1.24	1.38	2.04	1.30
CPUE	2.59	2.63	2.92	2.54	2.68
Fishery age comp	0.47	0.53	0.88	1.05	1.00
Fishery length comp	1.05	1.03	1.16	1.20	1.00
AI survey age comp	1.42	1.16	1.77	1.07	1.00
AI survey lengths comp	0.80	0.78	1.14	1.51	1.00

Table 13. Estimated time series of POP total biomass (t), spawning biomass (t), and recruitment (thousands) for each region.

	Total Biomass (ages 3+) Assessment Year		Spawning Biomass (ages 3+) Assessment Year		Recruitment (age 3) Assessment Year	
Year	2014	2012	2014	2012	2014	2012
1977	238,630	124,658	99,038	40,191	25,581	26,044
1978	226,774	122,886	93,438	39,443	23,814	35,844
1979	221,931	128,670	89,477	39,942	65,542	84,341
1980	218,921	137,002	86,494	41,018	57,894	85,676
1981	218,423	152,553	84,678	42,955	38,725	113,845
1982	221,874	165,729	83,672	45,547	72,287	52,563
1983	231,810	185,825	84,372	49,941	78,598	80,592
1984	250,389	216,581	86,102	55,711	145,384	176,053
1985	267,617	241,708	89,001	63,190	76,490	67,223
1986	285,047	267,573	93,376	72,676	51,875	67,491
1987	324,368	316,811	98,946	83,575	311,366	329,776
1988	349,846	356,870	105,631	95,212	45,770	140,299
1989	381,769	396,998	113,713	107,429	140,206	131,150
1990	406,537	431,007	121,809	118,965	59,069	84,057
1991	427,526	464,005	128,713	128,974	192,205	236,082
1992	454,119	500,992	139,920	143,481	92,298	123,119
1993	470,393	525,969	150,480	157,834	52,015	68,419
1994	477,652	541,359	160,910	172,697	26,405	46,977
1995	486,685	557,206	172,343	188,861	43,833	51,764
1996	492,300	569,967	182,568	203,668	33,146	56,337
1997	498,090	581,483	190,338	215,652	127,572	133,733
1998	503,929	594,244	197,447	226,765	92,073	125,087
1999	522,414	617,922	202,870	235,761	201,659	209,310
2000	529,217	630,674	205,025	240,999	48,880	84,719
2001	549,735	654,299	206,720	245,314	188,650	181,061
2002	563,361	673,980	208,269	248,953	59,844	113,471
2003	597,042	702,078	210,198	252,743	331,236	228,612
2004	611,396	713,418	213,591	257,607	38,212	48,243
2005	629,571	723,660	220,422	265,526	81,642	43,243
2006	643,005	730,659	229,350	274,802	29,979	40,220
2007	654,833	731,429	238,001	282,981	94,791	48,897
2008	657,981	722,295	245,839	288,902	78,861	46,016
2009	656,210	710,471	254,326	293,817	36,897	43,792
2010	653,665	702,831	261,815	296,276	45,917	
2011	646,482	692,564	264,704	293,527	59,397	
2012	633,007	676,409	262,190	285,289		
2013	618,851	661,440	256,200	273,683		
2014	597,506		246,104			
2015	577,967					

Table 14. 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 169,203 t and 148,053 t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2014	31,162	31,162	31,162	31,162	31,162	31,162	31,162
2015	34,988	34,988	17,819	12,337	0	42,558	34,988
2016	33,194	33,194	17,534	12,280	0	39,716	33,194
2017	31,413	31,413	17,187	12,170	0	36,996	38,210
2018	29,768	29,768	16,838	12,049	0	34,544	35,625
2019	28,299	28,299	16,507	11,929	0	32,398	33,354
2020	27,088	27,088	16,247	11,848	0	30,554	31,484
2021	26,131	26,131	16,064	11,810	0	28,391	29,574
2022	25,348	25,348	15,976	11,832	0	26,840	27,831
2023	24,634	24,634	15,966	11,903	0	25,850	26,640
2024	24,133	24,133	16,020	12,012	0	25,262	25,887
2025	23,837	23,837	16,123	12,152	0	24,946	25,442
2026	23,676	23,676	16,247	12,303	0	24,792	25,184
2027	23,605	23,605	16,381	12,458	0	24,741	25,054
Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2014	246,105	246,105	246,105	246,105	246,105	246,105	246,105
2015	234,426	234,426	236,594	237,273	238,782	233,451	234,426
2016	221,197	221,197	231,347	234,610	241,995	216,756	221,197
2017	208,987	208,987	226,189	231,857	244,930	201,666	208,118
2018	198,647	198,647	222,008	229,894	248,429	188,971	194,699
2019	190,249	190,249	218,933	228,845	252,576	178,678	183,739
2020	183,936	183,936	217,242	229,013	257,706	170,851	175,298
2021	179,344	179,344	216,654	230,127	263,543	165,173	168,988
2022	176,272	176,272	217,096	232,144	270,096	161,558	164,690
2023	174,328	174,328	218,199	234,709	277,021	159,394	161,943
2024	173,230	173,230	219,732	237,614	284,150	158,192	160,261
2025	172,627	172,627	221,405	240,573	291,195	157,533	159,205
2026	172,341	172,341	223,123	243,505	298,094	157,207	158,553
2027	172,283	172,283	224,857	246,386	304,831	157,113	158,192
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2014	0.076	0.076	0.076	0.076	0.076	0.076	0.076
2015	0.089	0.089	0.045	0.031	0	0.109	0.089
2016	0.089	0.089	0.045	0.031	0	0.109	0.089
2017	0.089	0.089	0.045	0.031	0	0.109	0.109
2018	0.089	0.089	0.045	0.031	0	0.109	0.109
2019	0.089	0.089	0.045	0.031	0	0.109	0.109
2020	0.089	0.089	0.045	0.031	0	0.109	0.109
2021	0.089	0.089	0.045	0.031	0	0.106	0.108
2022	0.089	0.089	0.045	0.031	0	0.103	0.105
2023	0.088	0.088	0.045	0.031	0	0.102	0.103
2024	0.087	0.087	0.045	0.031	0	0.100	0.102
2025	0.086	0.086	0.045	0.031	0	0.100	0.101
2026	0.086	0.086	0.045	0.031	0	0.099	0.100
2027	0.086	0.086	0.045	0.031	0	0.099	0.100

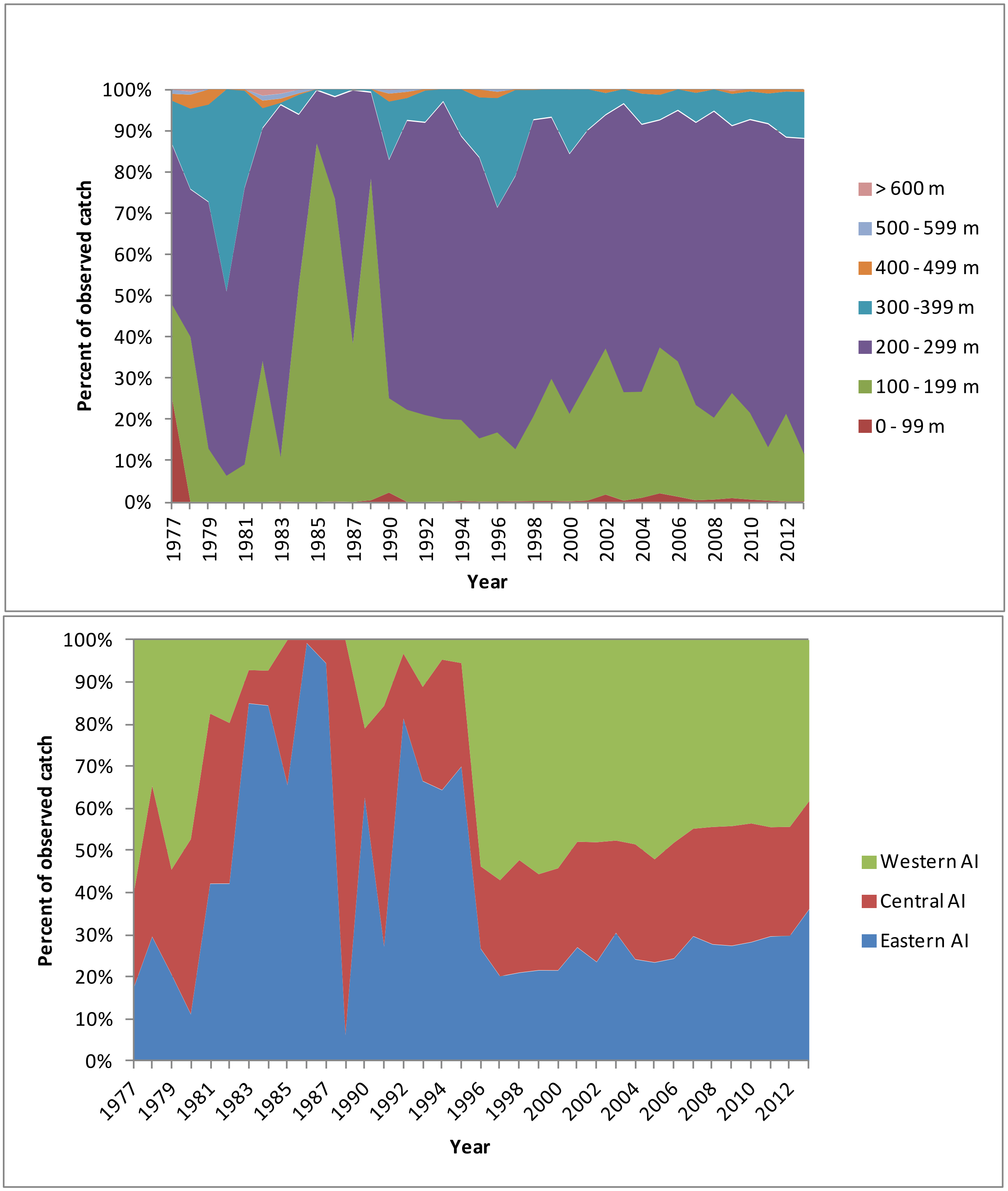

Figure 1. Distribution of observed Aleutian Islands Pacific ocean perch catch (from North Pacific Groundfish Observer Program) by depth zone (top panel) and AI subarea (bottom panel) from 1977 to 2013.

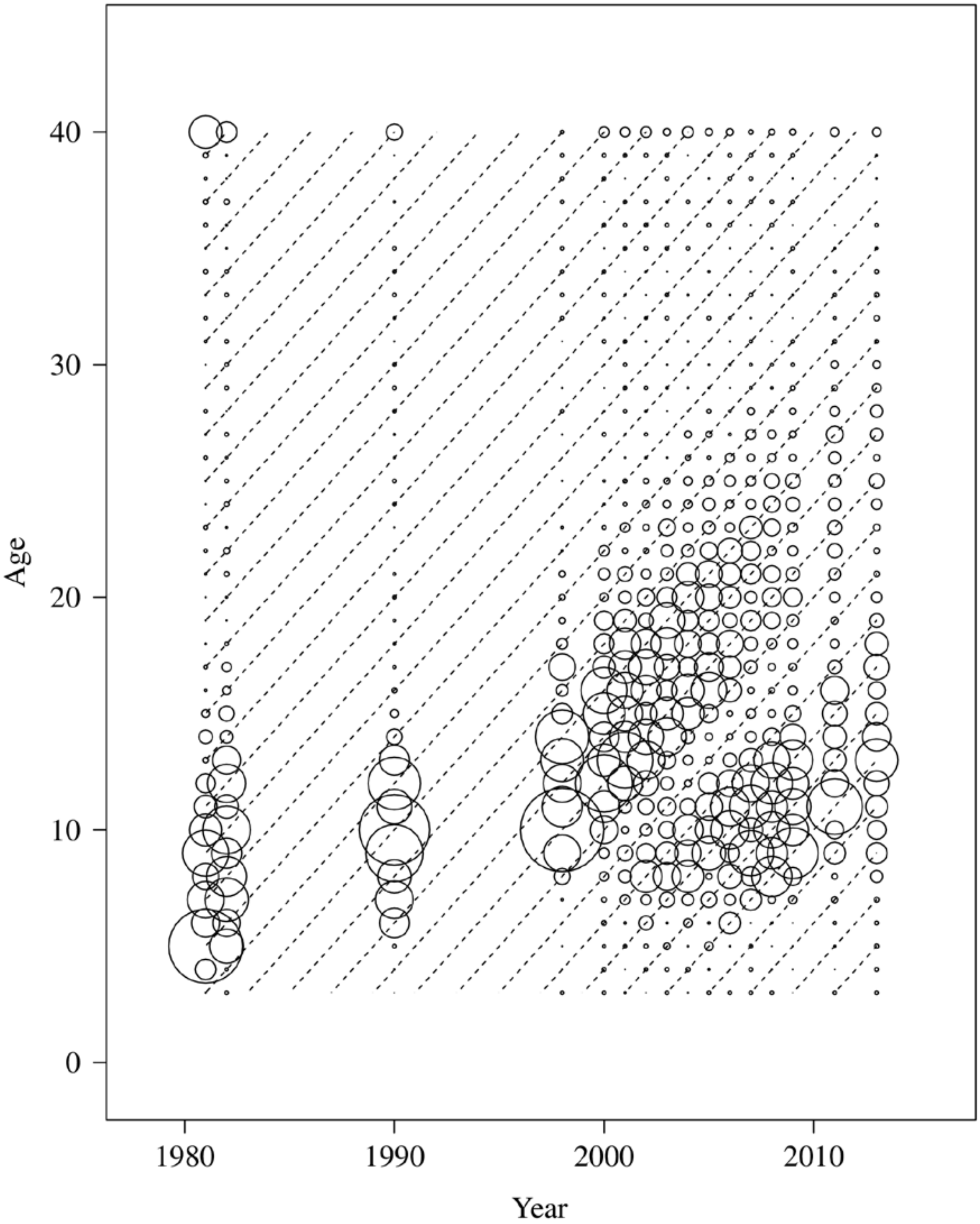

Figure 2. Fishery age composition data for the BSAI POP; The diameter of the circles are scaled within each year of samples, and dashed lines denote cohorts.

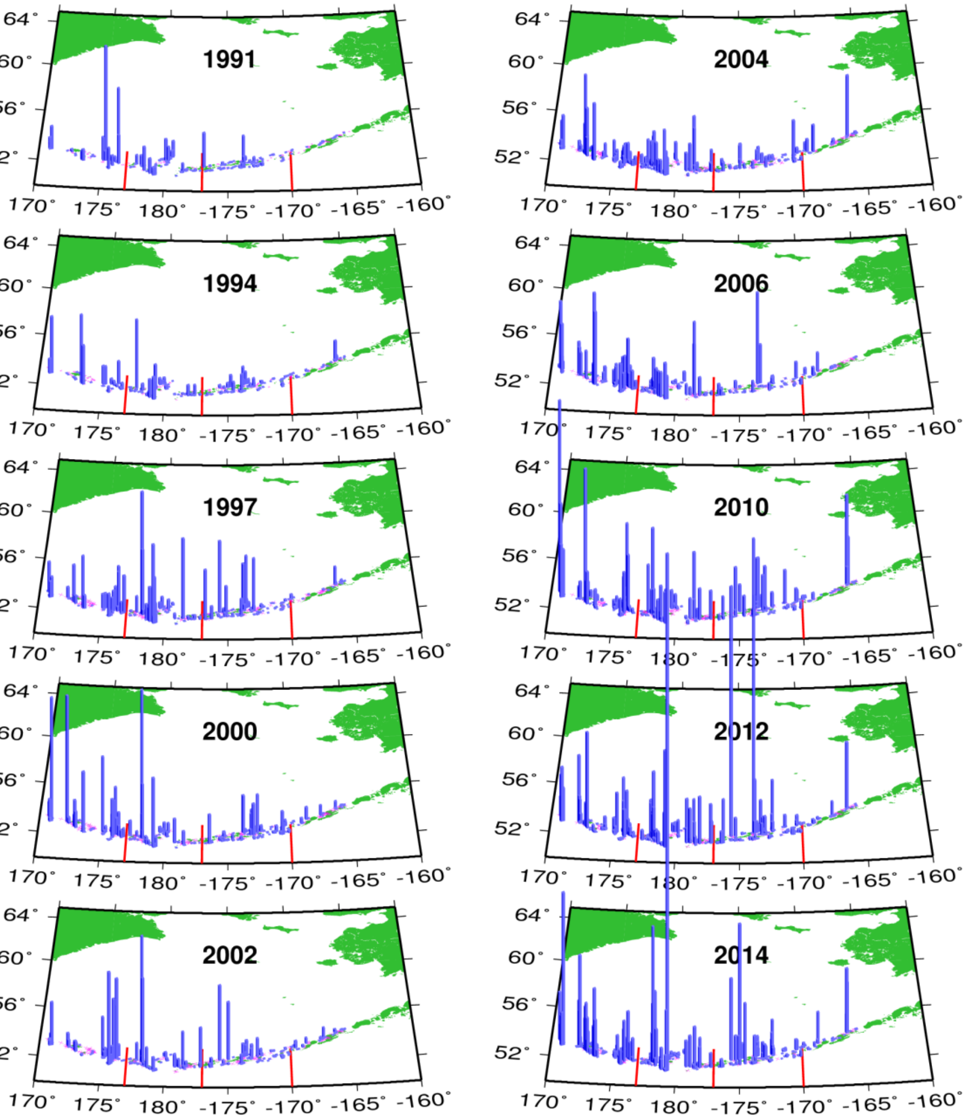

Figure 3. AI survey POP CPUE (kg/km^2) from 1991-2014; the symbol × denotes tows with no catch. The red lines indicate boundaries between the WAI, CAI, EAI, and EBS areas.

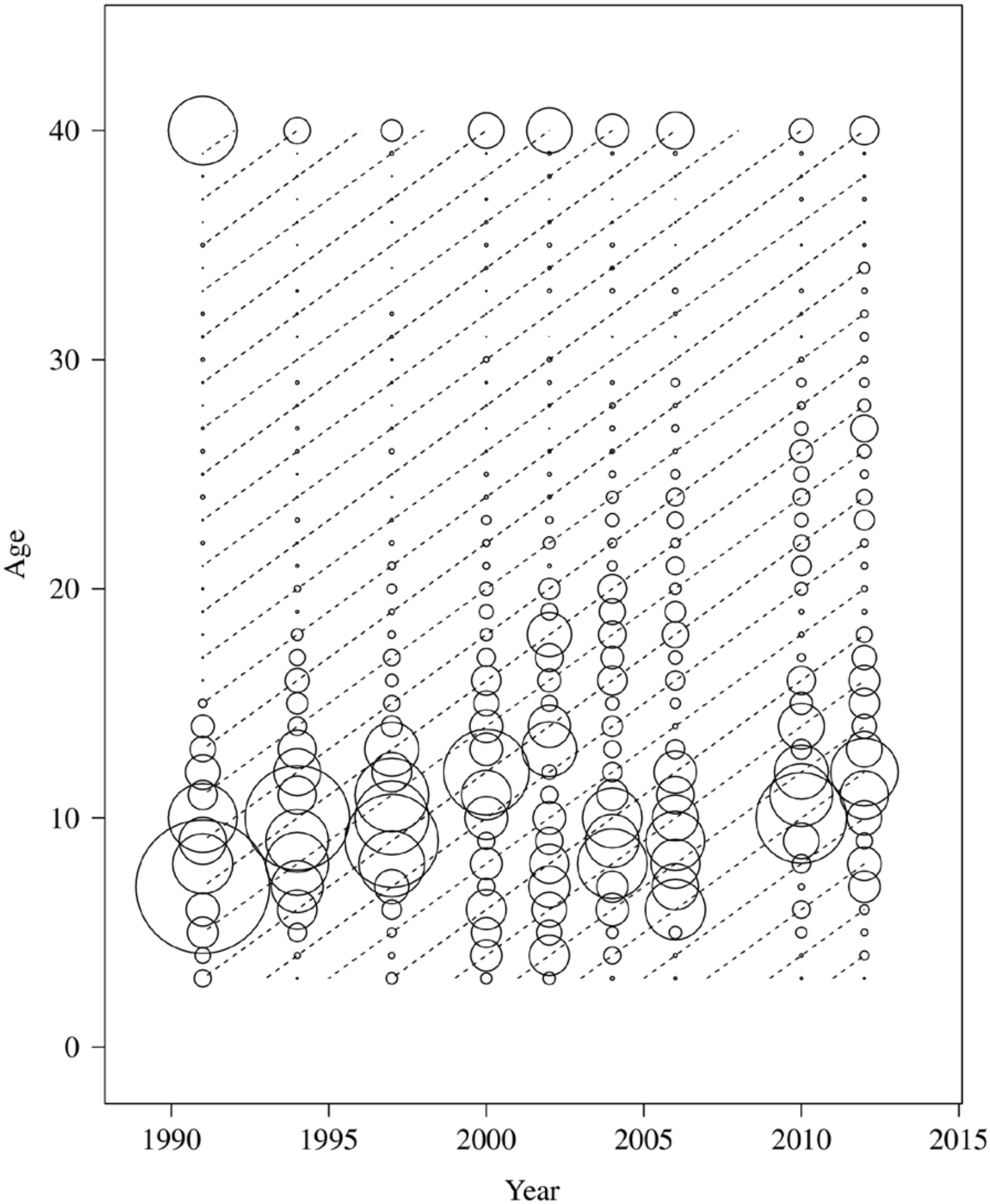

Figure 4. Age composition data from the Aleutian Islands trawl survey; bubbles are scaled within each year of samples; and dashed lines denote cohorts.

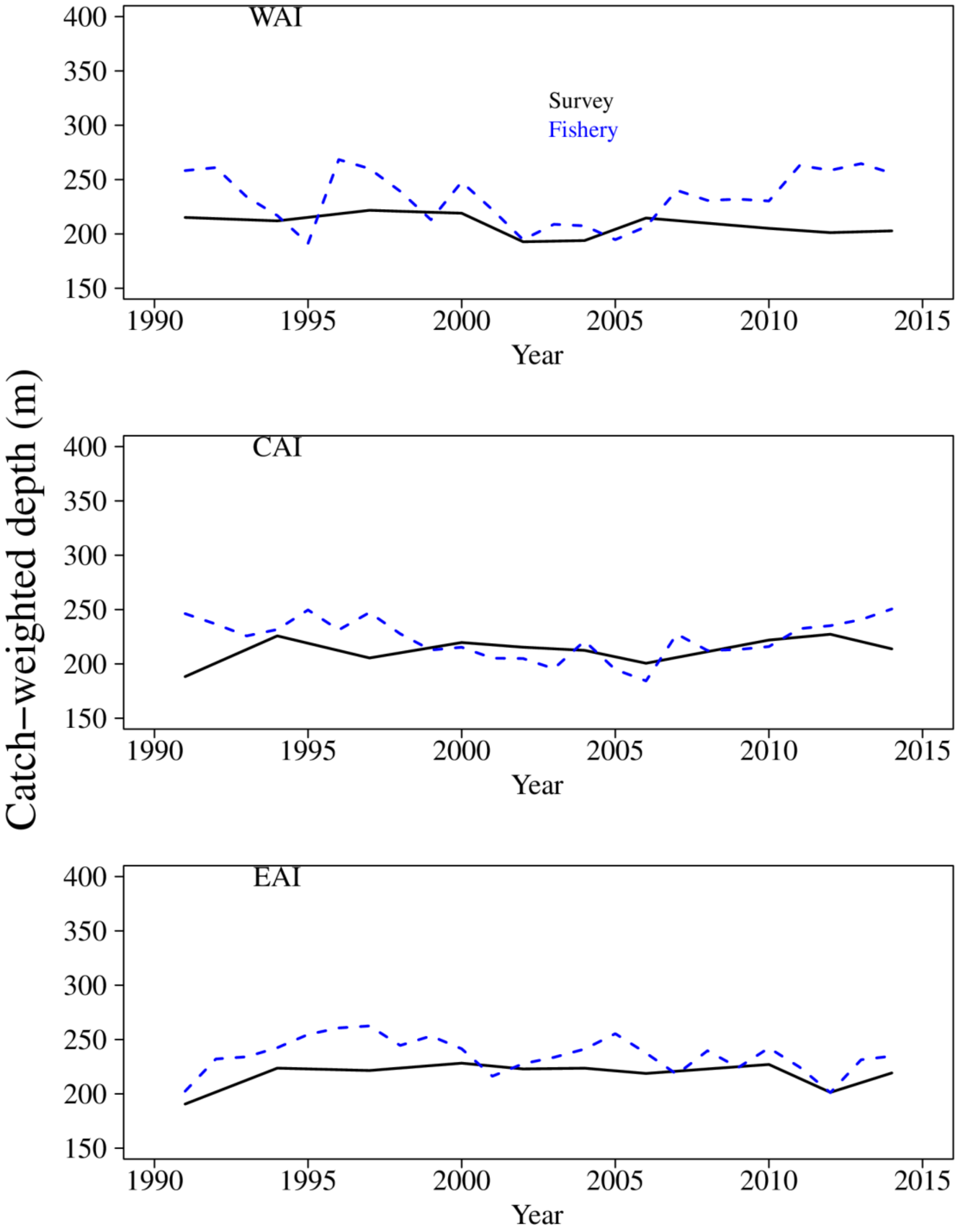

Figure 5. Catch-weighted (by numbers) depth of capture for Pacific ocean perch in the fishery and AI survey by AI subarea from 1991 to 2014.

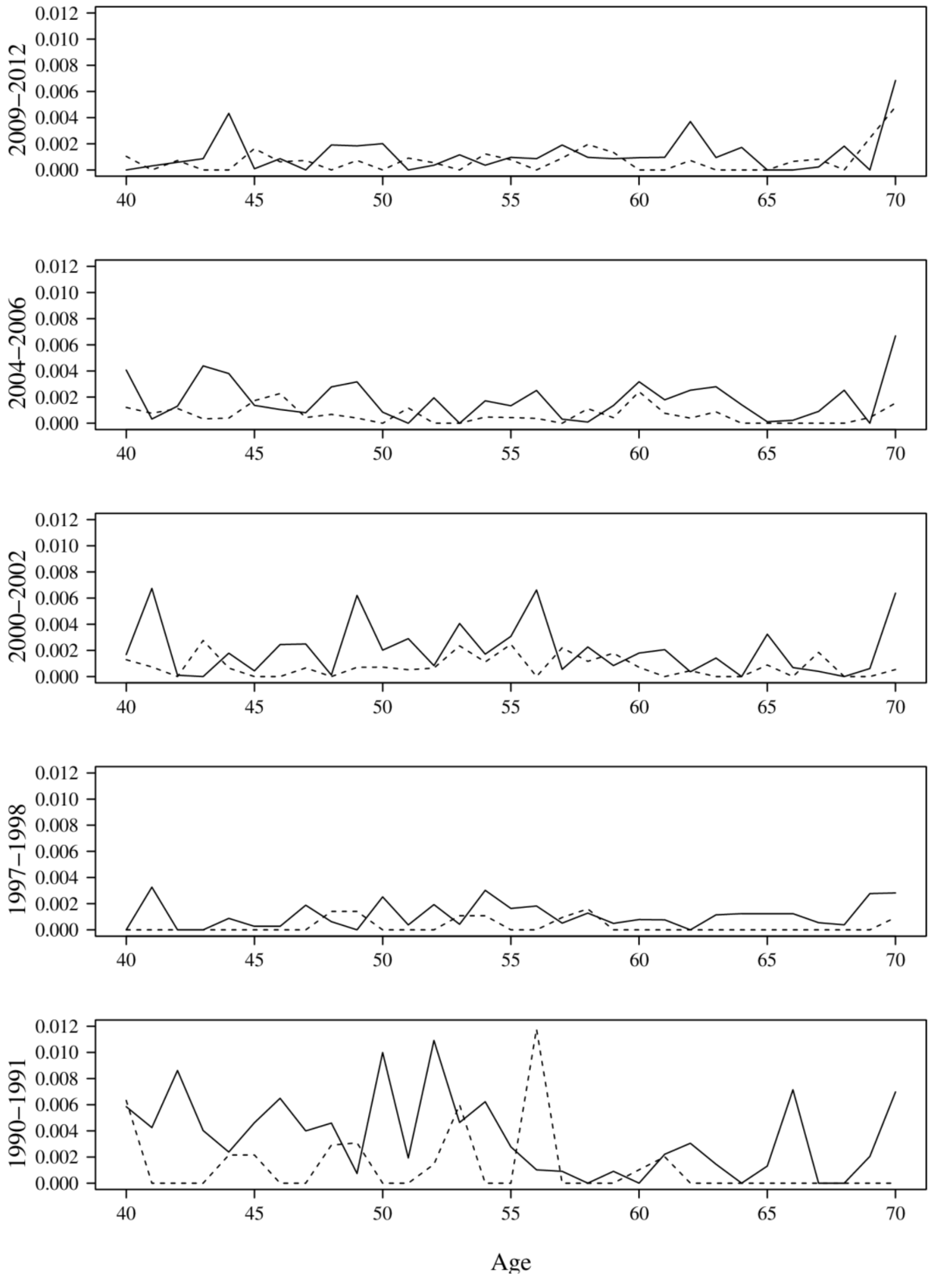

Figure 6. Age compositions in the Aleutian Islands survey (solid line) and fishery (dashed line) for ages 40 to 70+ for five time periods.

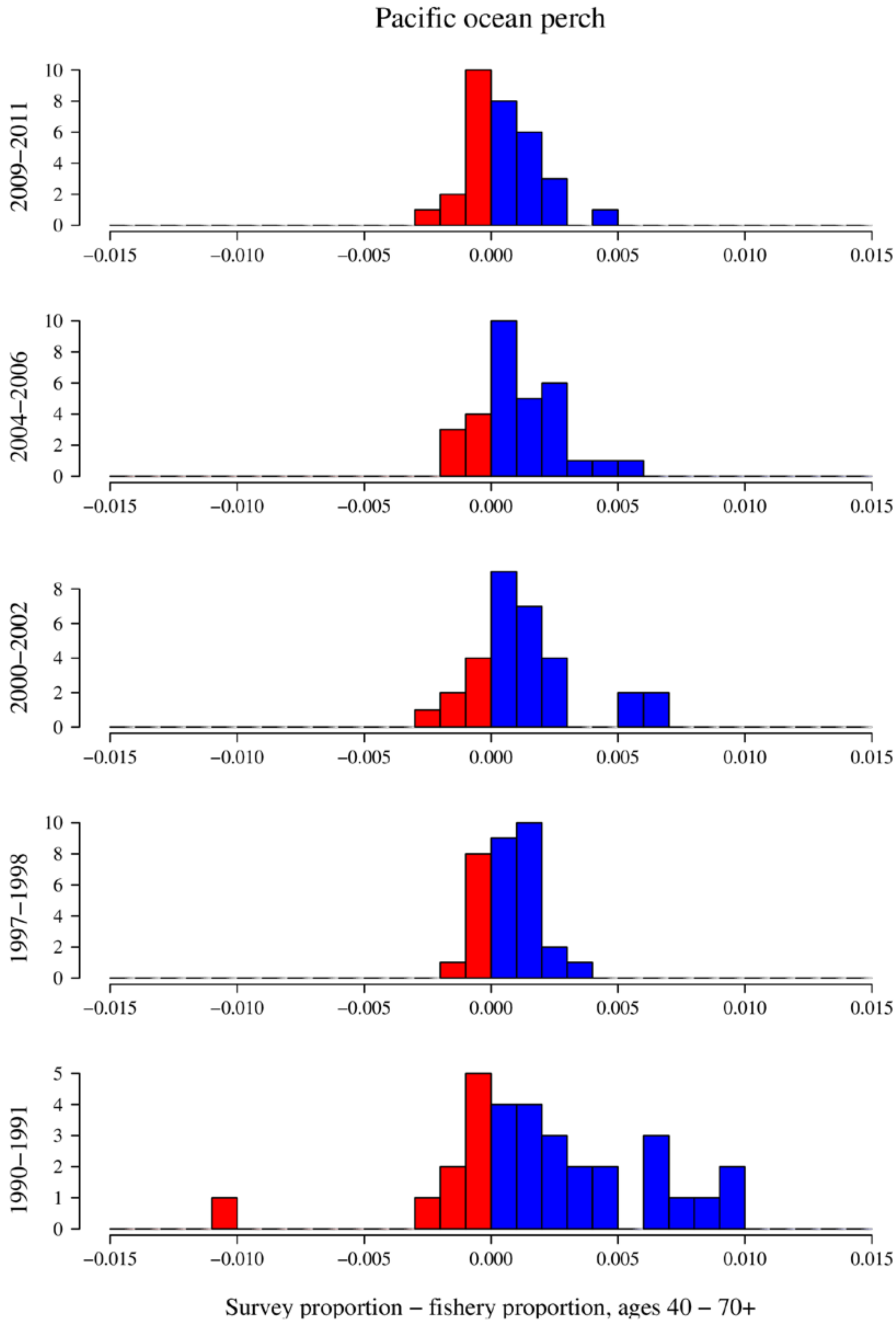

Figure 7. Histograms of the difference (survey proportion – fishery proportion) for ages 40 to 70+ for five time periods.

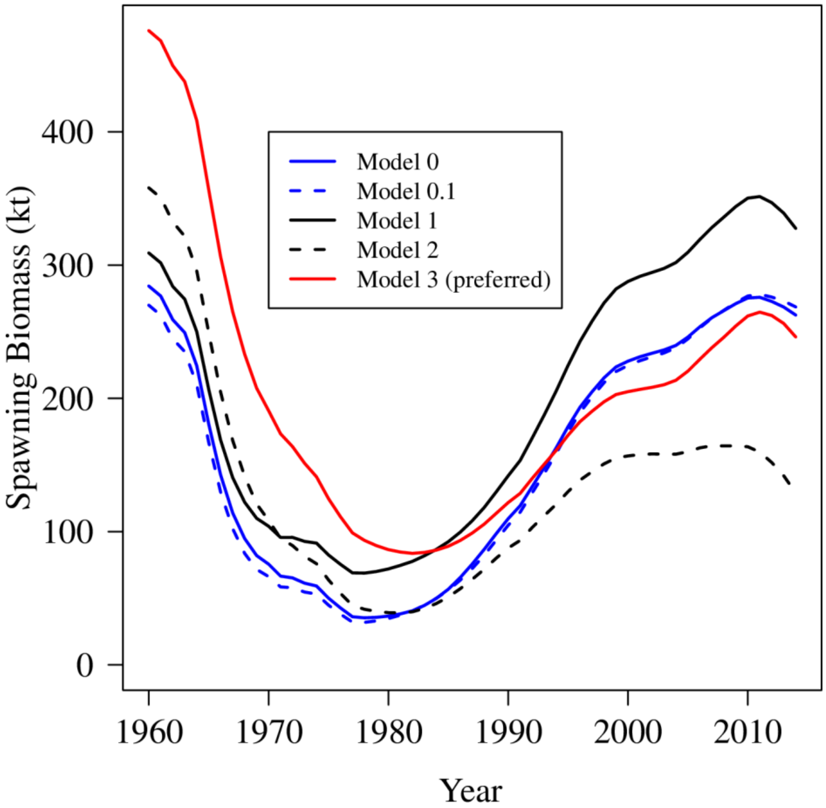

Figure 8. Estimated time series of spawning stock biomass across the models.

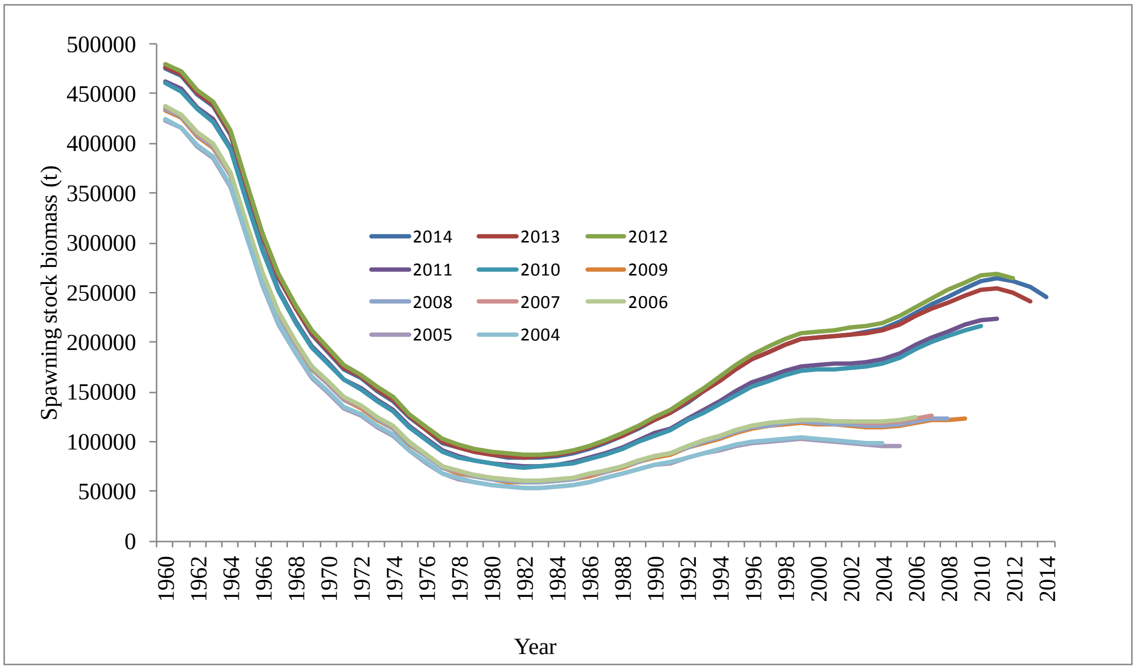

Figure 9. Retrospective estimates of spawning stock biomass for model runs with end years of 2004 to 2014.

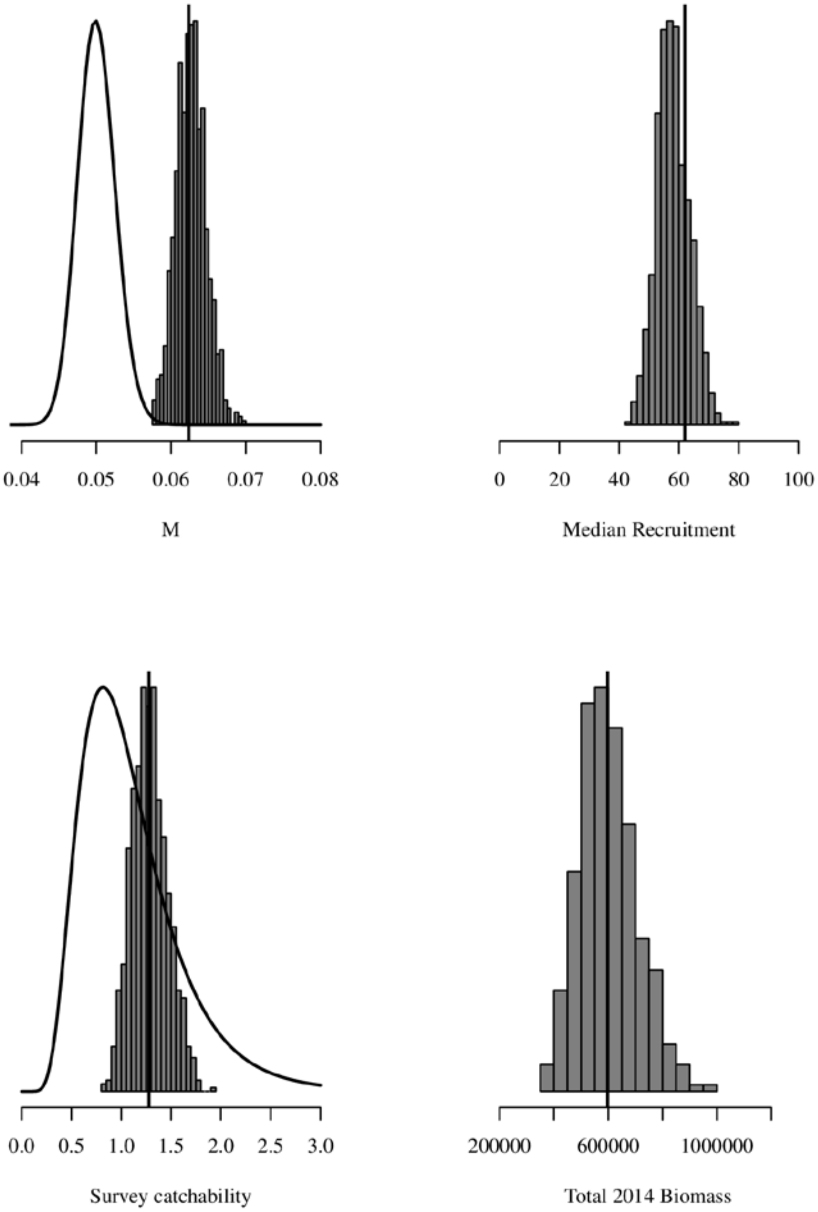

Figure 10. Posterior distributions for key model quantities *M*, survey catchability, median recruitment, and 2014 total biomass. For *M* and survey catchability, the prior distributions are also shown in the solid lines. The MLE estimates are indicated by the vertical lines.

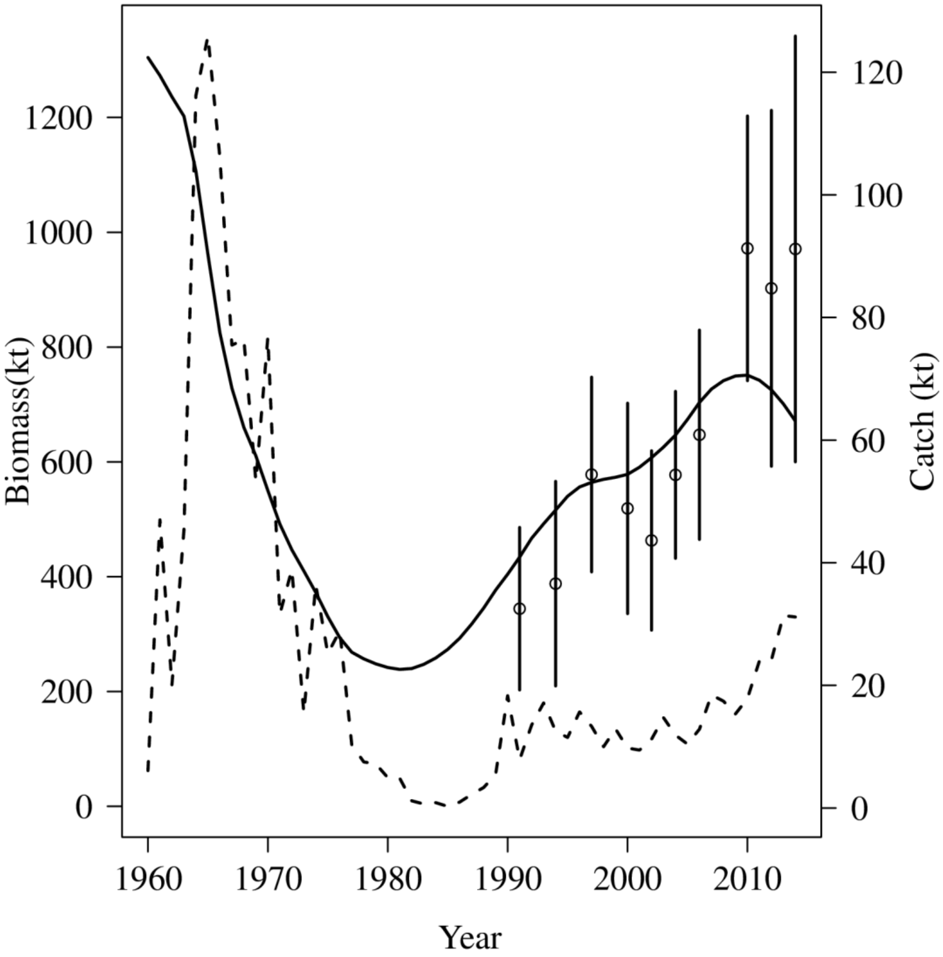

Figure 11. Observed AI survey biomass (data points, +/- 2 standard deviations), predicted survey biomass(solid line), and BSAI harvest (dashed line).

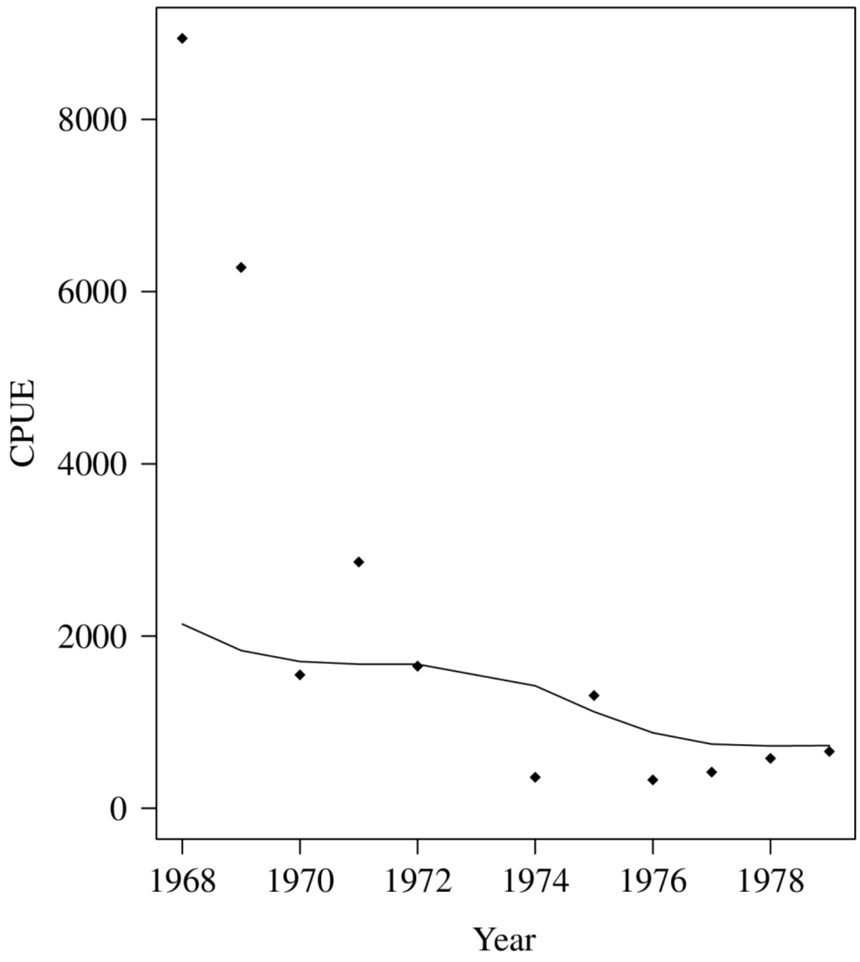

Figure 12. Observed AI CPUE (data points) and predicted CPUE (solid line) for BSAI POP.

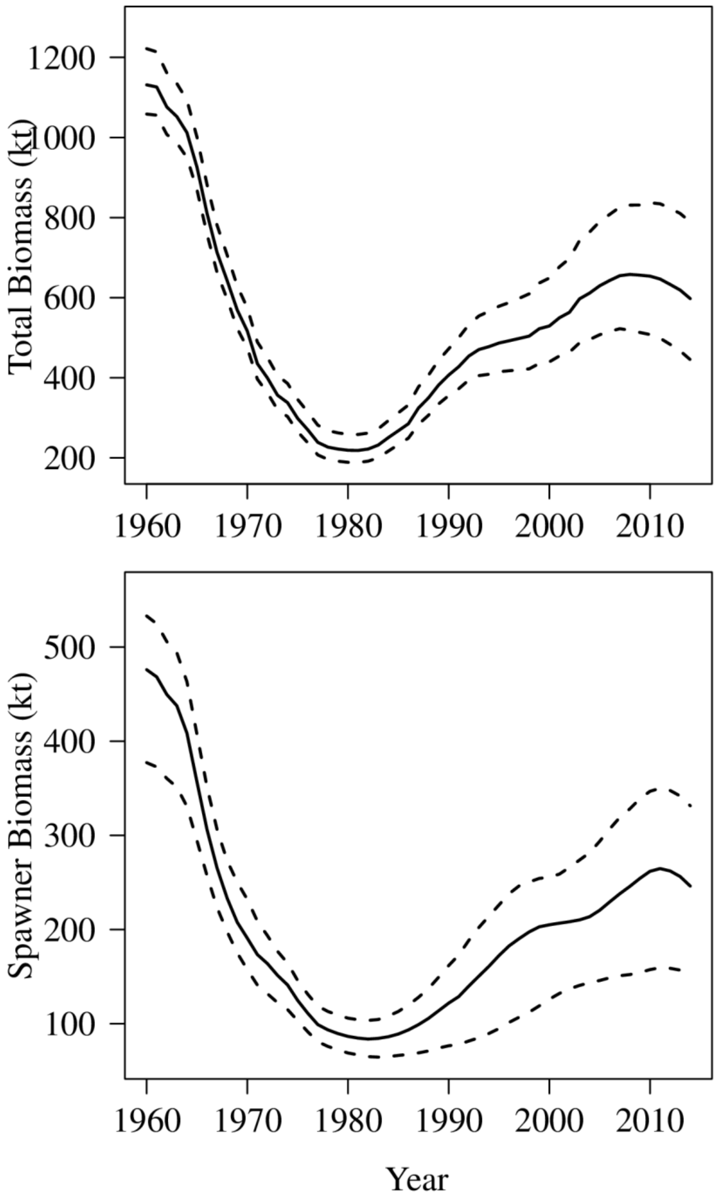

Figure 13. Total and spawner biomass for BSAI Pacific ocean perch, with 95% confidence intervals from MCMC integration.

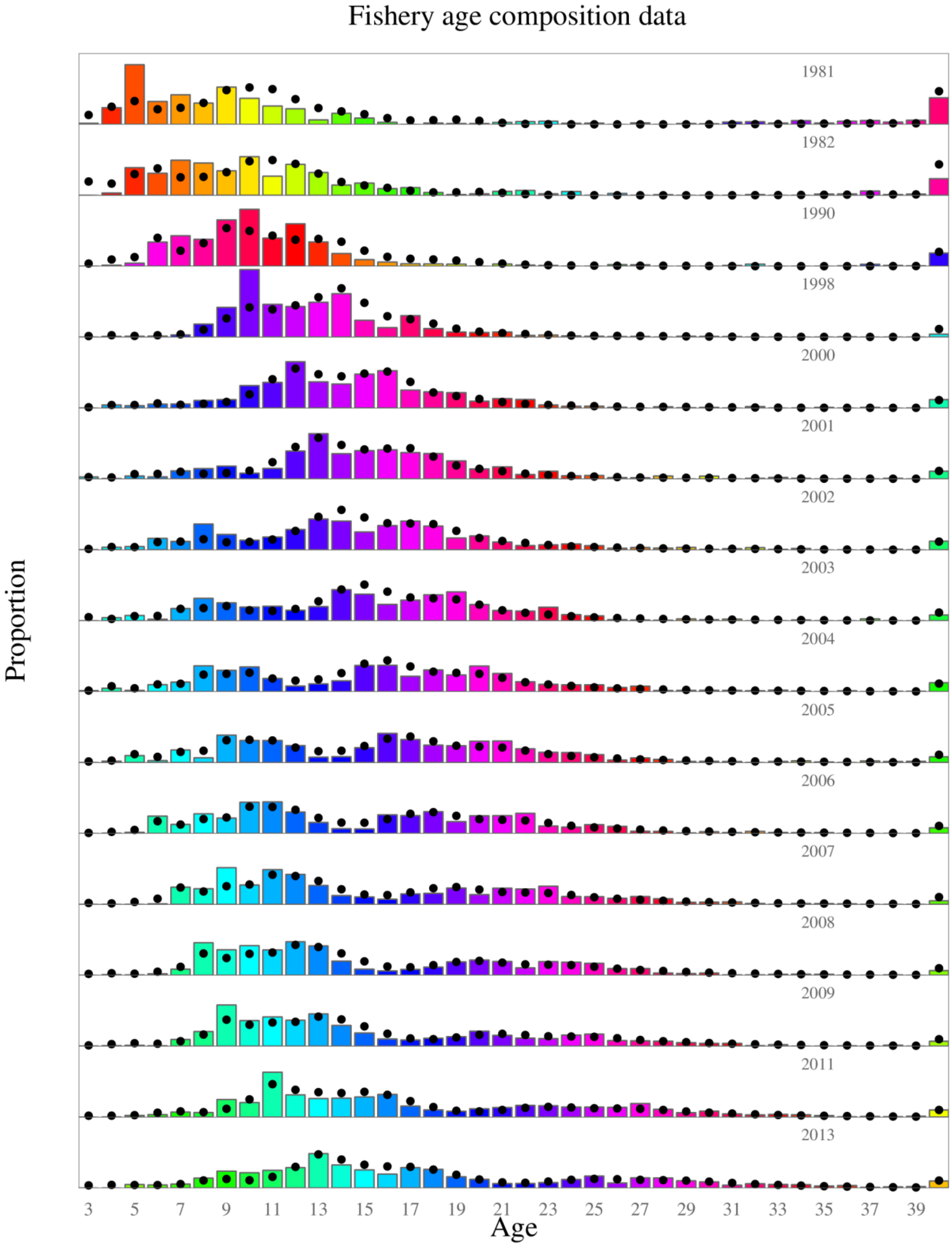

Figure 14. Model fits (dots) to fishery age composition data (columns) for Aleutian Islands Pacific ocean perch, 1981-2013. Colors correspond to cohorts (except for the 40+ group).

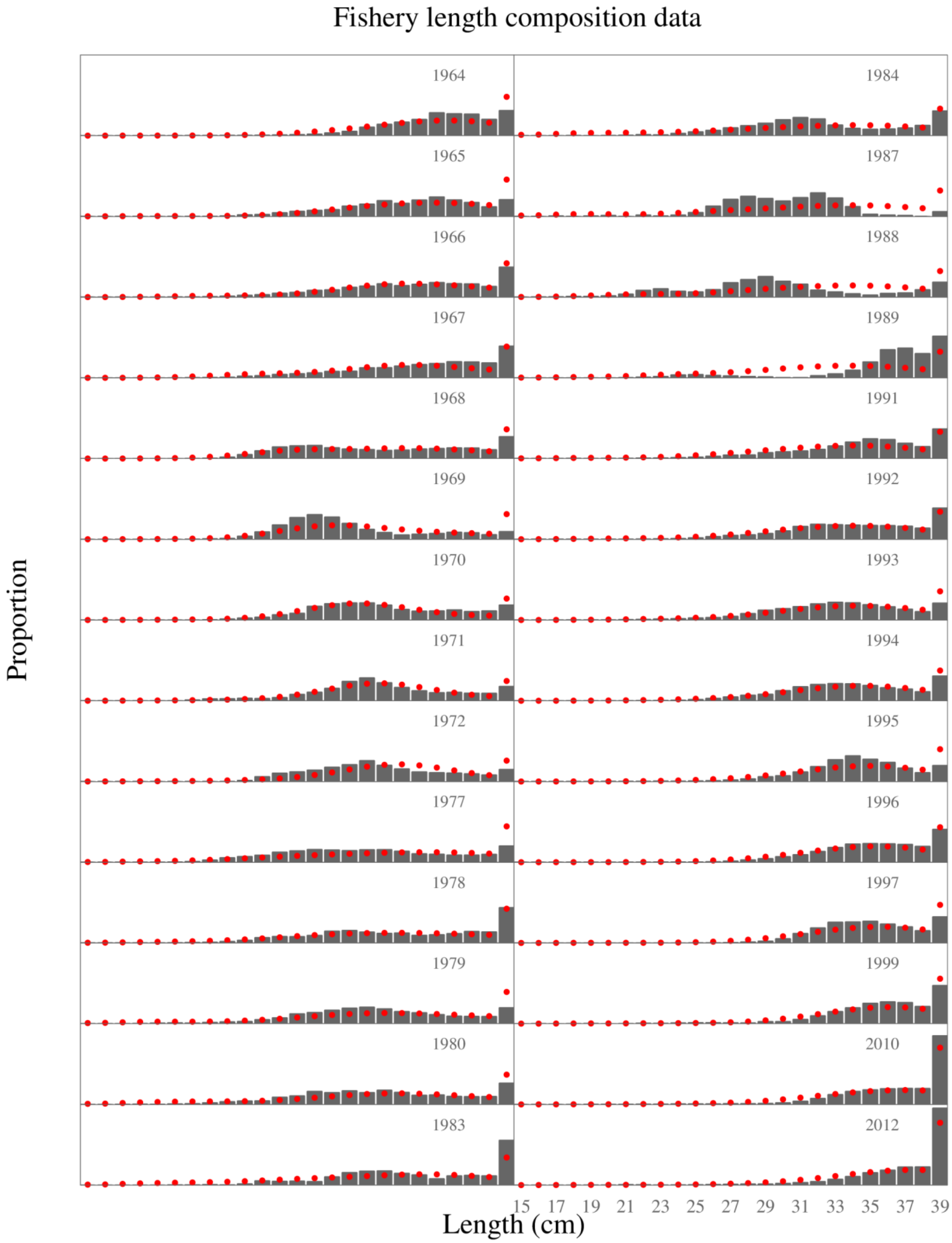

Figure 15. Model fits (dots) to fishery length composition data (columns) for Aleutian Islands Pacific ocean perch, 1964-2012.

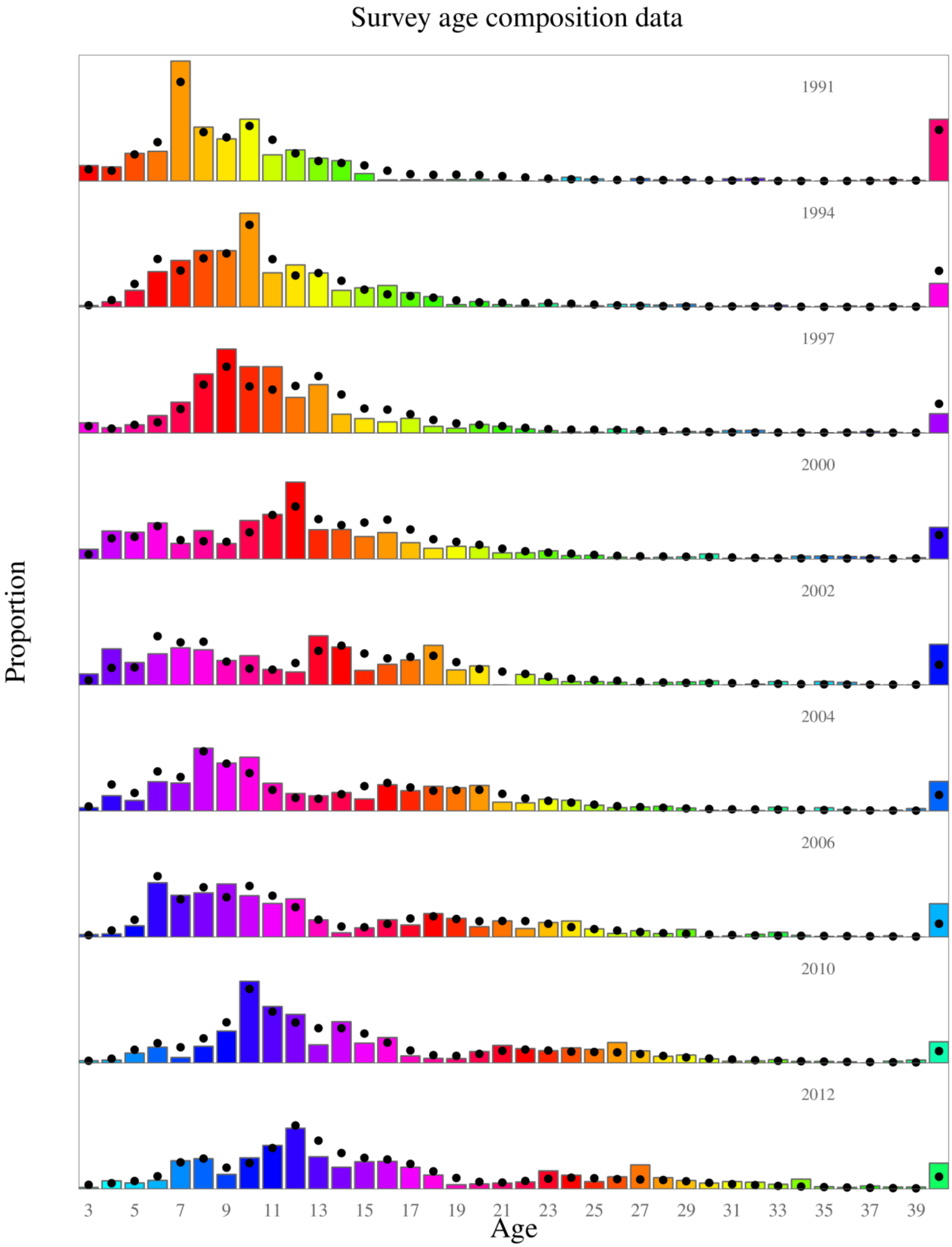

Figure 16. Model fits (dots) to survey age composition data (columns) for Aleutian Islands Pacific ocean perch, 1991-2012. Colors correspond to cohorts (except for the 40+ group).

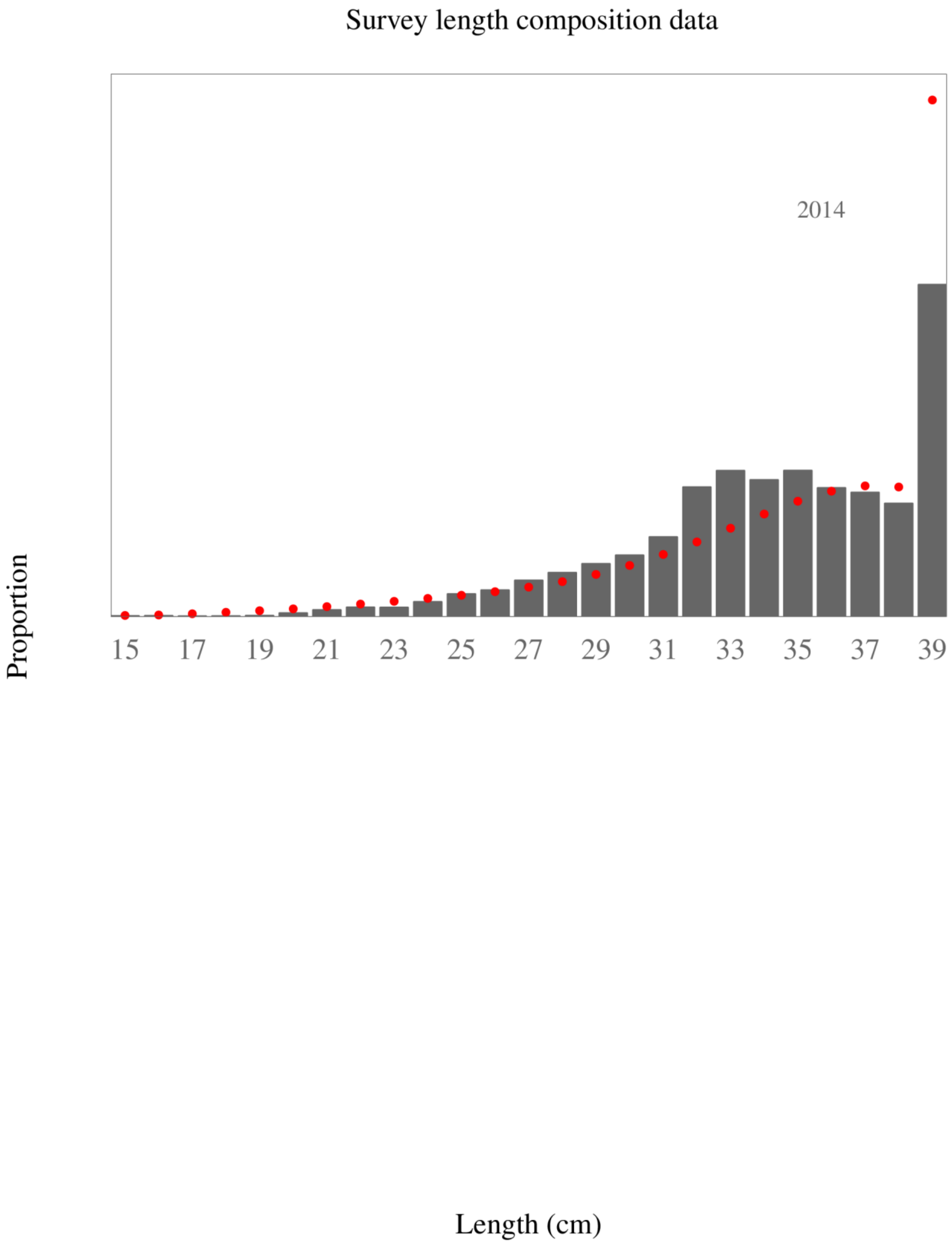

Figure 17. Model fits (dots) to 2014 survey length composition data (columns) for Aleutian Islands Pacific ocean perch.

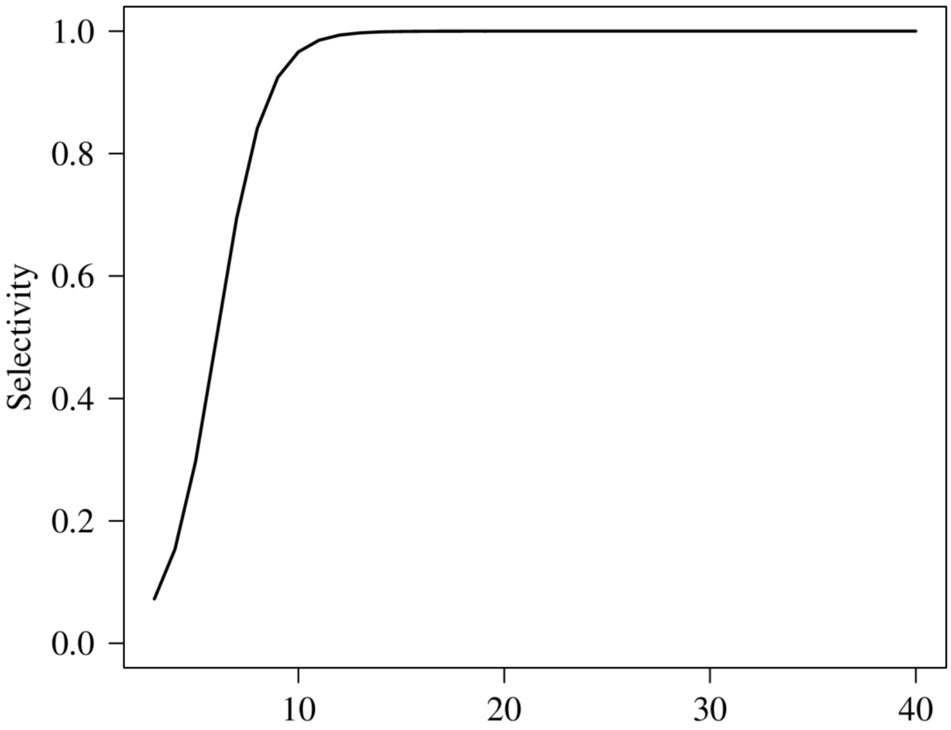

Figure 18. Estimated survey selectivity curve for BSAI POP

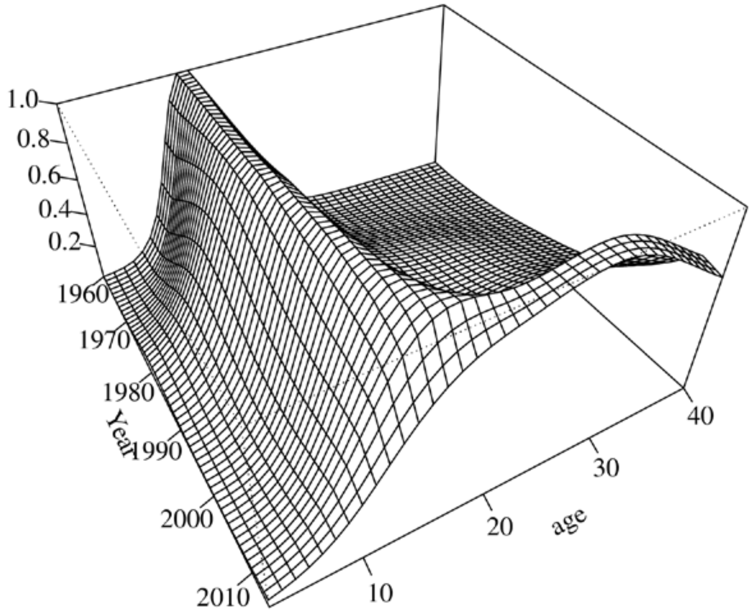

Figure 19. Estimated fishery selectivity from 1960-2014.

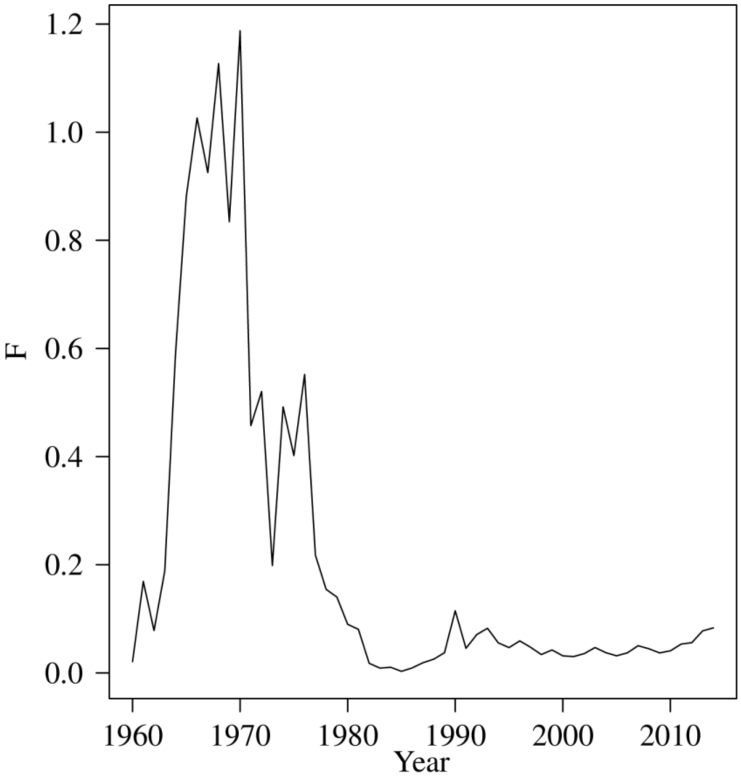

Figure 20. Estimated fully selected fishing mortality for BSAI POP.

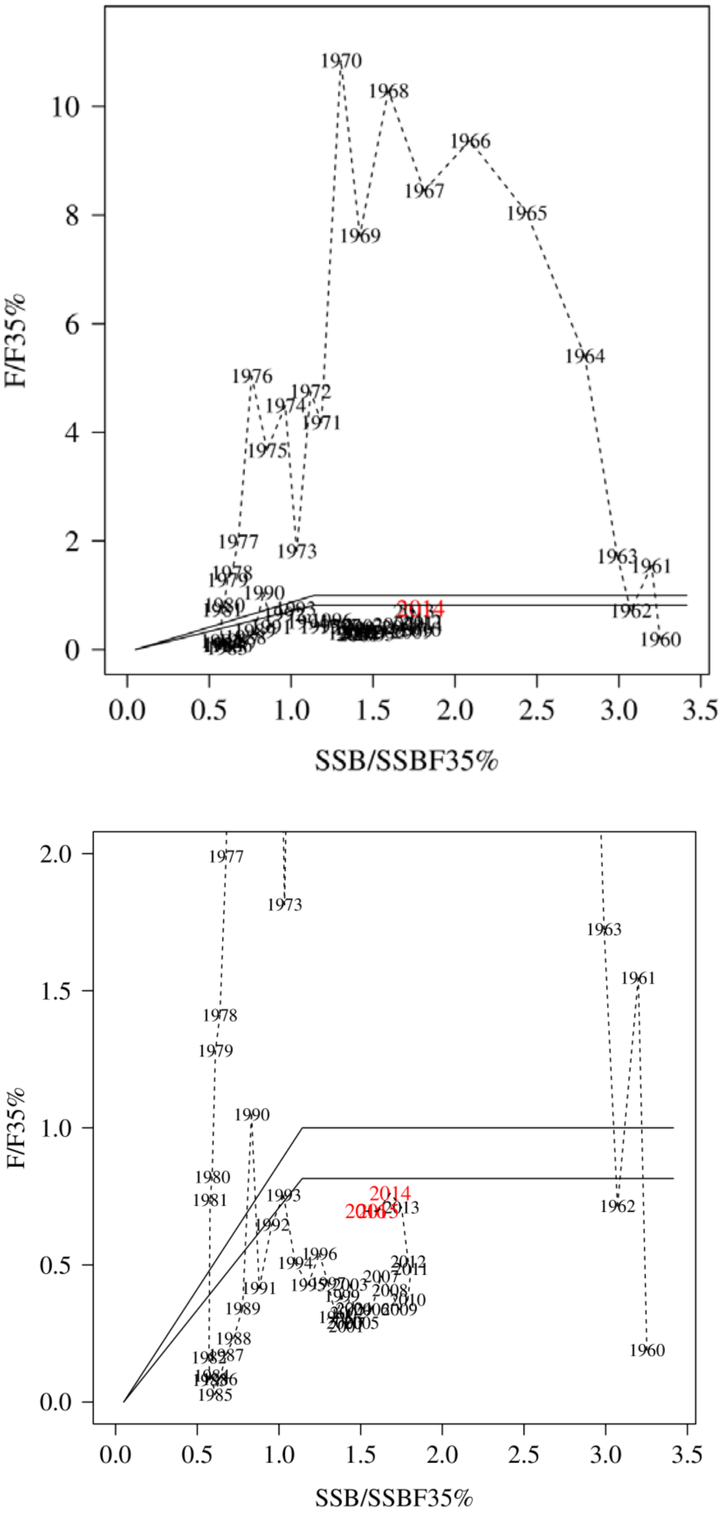

Figure 21. (Top panel) Estimated fishing mortality and SSB in reference to OFL (upper line) and ABC (lower line) harvest control rules, with 2014 shown in red. The bottom panel shows a reduced vertical scale, and the projected F and stock size for 2015 and 2016.

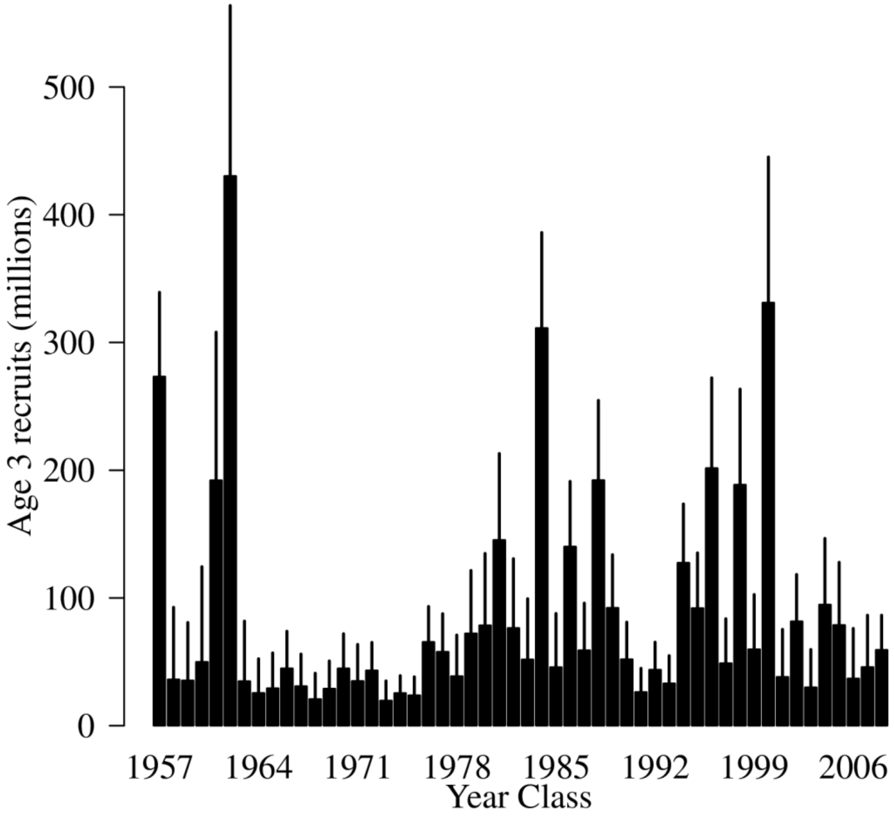

Figure 22. Estimated recruitment (age 3) of BSAI POP, with 95% CI limits obtained from MCMC

integration.

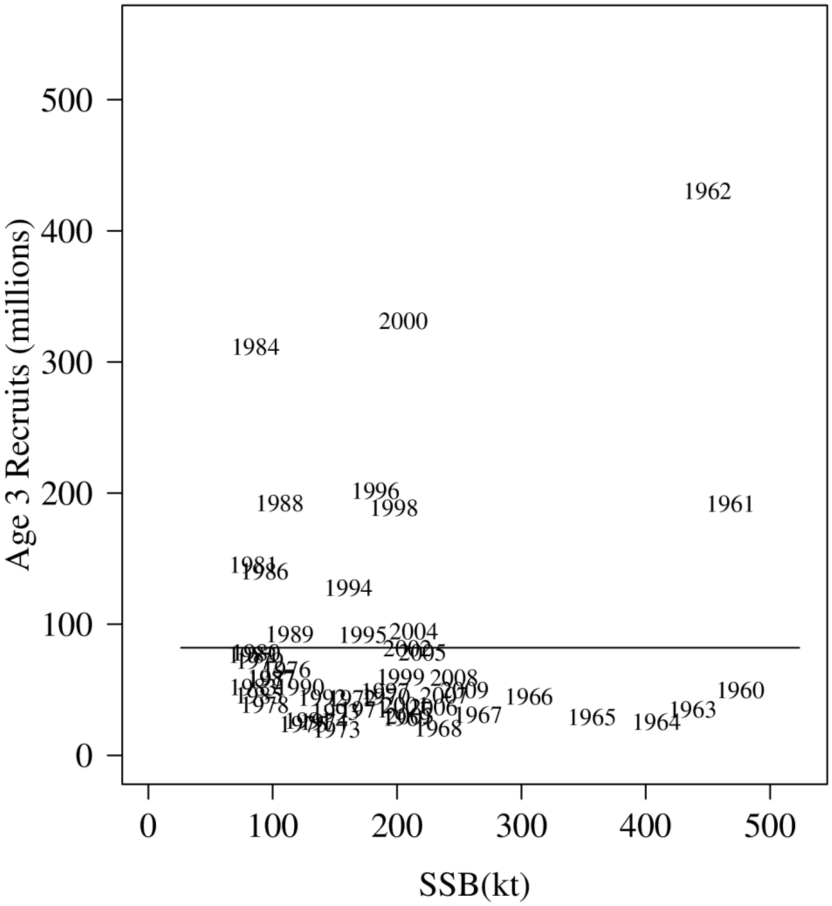

Figure 23. Scatterplot of BSAI POP spawner-recruit data; label is year class.

Appendix A. 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. There was no recorded recreational harvest or harvest that was non-research related in 2010 and 2011. Total removals of POP ranged between 8 and 267 t between 2010 and 2014, which was were 267 t in 2010 and 3 t in 2011, and did not exceed 1.4 of the ABC for these years.

Appendix Table A1. Removals of BSAI POP from activities other than groundfish fishing (t). Trawl and longline include research survey and occasional short-term projects. “Other” is recreational, personal use, and subsistence harvest.

Year	Source	Trawl	Longline	Other
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		247.860	0.000	