# 13. Assessment of the Northern Rockfish stock in the Bering Sea/Aleutian Islands

by

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## Executive Summary

The last full assessment for northern rockfish was presented to the Plan Team in 2012. The following changes were made to northern rockfish assessment relative to the November 2012 SAFE:

***Summary of Changes in Assessment Inputs***

Changes in the input data:

1) Catch updated through October 11, 2014.
2) The survey biomass estimates and age composition data from the U.S.-Japan cooperative surveys 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 composition was included in the assessment.
5) The 2012 fishery length composition was included in the assessment

Changes in the Assessment Methodology

1) 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.
2) 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***

BSAI northern rockfish are not overfished or approaching an overfished condition. The recommended 2015 ABC and OFL are 12,488 t and 15,337 t, which are 28% and 29% increases from the values specified last year for 2015 of 9,652 t and 12,488 t. The 1980s cooperative surveys had low biomass estimates relative to the remainder of the time series, and removal of these data increased the estimated population size. 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) | 0.0413 | 0.0413 | 0.049 | 0.049 |
| Tier | 3a | 3a | 3a | 3a |
| Projected total (age 3+) biomass (t) | 196,519 | 197,541 | 218,901 | 218,898 |
| Female spawning biomass (t) | | | | |
| Projected | 84,237 | 83,698 | 94,873 | 93,540 |
| $B_{100\%}$ | 147,918 | 147,918 | 144,420 | 144,420 |
| $B_{40\%}$ | 59,167 | 59,167 | 57,768 | 57,768 |
| $B_{35\%}$ | 51,771 | 51,771 | 50,547 | 50,547 |
| $F_{OFL}$ | 0.079 | 0.079 | 0.088 | 0.088 |
| $maxF_{ABC}$ | 0.063 | 0.063 | 0.070 | 0.070 |
| $F_{ABC}$ | 0.063 | 0.063 | 0.070 | 0.070 |
| OFL (t) | 12,077 | 11,943 | 15,337 | 15,100 |
| maxABC (t) | 9,761 | 9,652 | 12,488 | 12,295 |
| ABC (t) | 9,761 | 9,652 | 12,488 | 12,295 |
| **Status** | As determined last year for: for: 2012 | 2013 | As determined this year for: 2013 | 2014 |
| Overfishing | No | n/a | No | n/a |
| Overfished | n/a | No | n/a | No |
| Approaching overfished | n/a | No | n/a | No |

**Summaries for the Plan Team**

The following table gives the recent biomass estimates, catch, and harvest specifications, and projected biomass, OFL and ABC for 2015-2016.

| Year | Biomass[1] | OFL | ABC | TAC | Catch |
|---|---|---|---|---|---|
| 2013 | 195,446 | 12,200 | 9,850 | 3000 | 2038 |
| 2014 | 197,541 | 12,077 | 9,761 | 2594 | 2282 |
| 2015 | 218,901 | 15,337 | 12,488 | | |
| 2016 | 218,898 | 15,100 | 12,295 | | |

[1] Total biomass from age-structured projection model.
[2] Catch as of October 11, 2014.

***Responses to SSC and Plan Team Comments on Assessments 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.

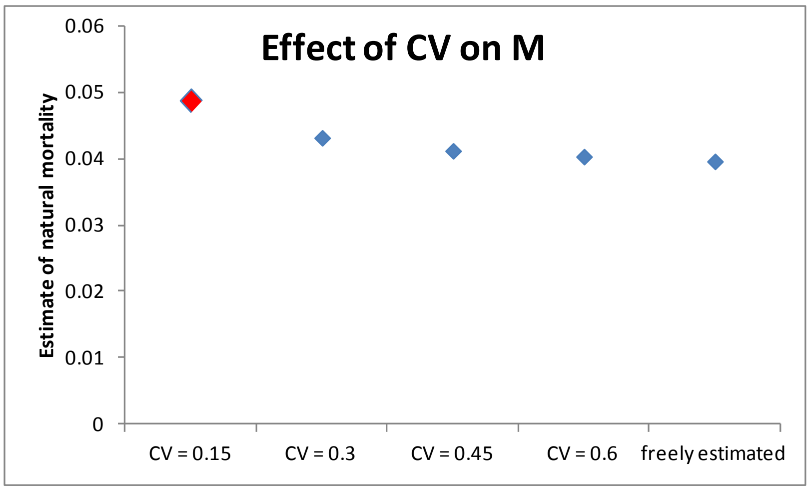
***Responses to SSC and Plan Team Comments Specific to this Assessment***

*The SSC offers the following advice to assessment authors:*

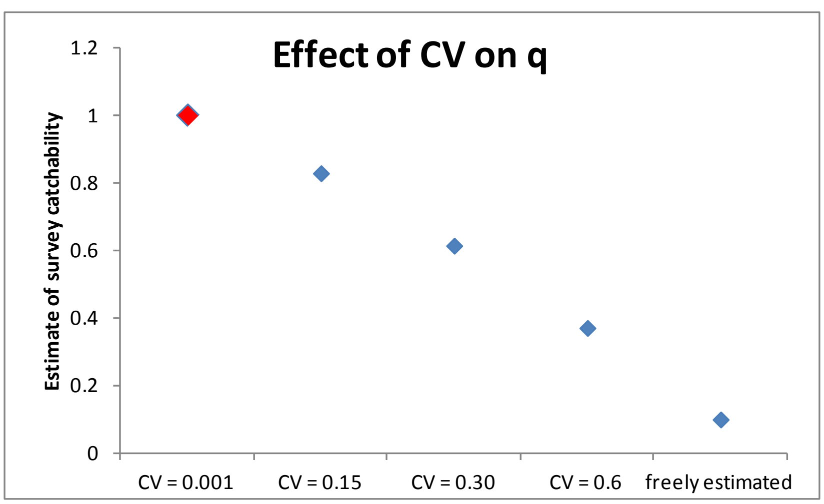
- *Evaluate priors on survey catchability and natural mortality.*
- *Explore alternative selectivity patterns*
- *Evaluate alternative selectivity time periods*
- *Evaluate/compare mean vs. median recruitment and which time period should be used for estimating fishery bench marks and provide rationale* (SSC, Dec 2012)

Alternative selectivity functional forms, including time-varying selectivity, are included in this assessment. The preferred model used a time-invariant double logistic equation to model fishery selectivity.

Previous attempts to estimate natural mortality (*M*) and survey catchability (*q*) within the assessment model have produced estimates that are implausible, which necessitated prior distributions with tight CVs. A series of models runs were conducted to address how sensitive the model estimates of *M* and *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 set to 0.06 (based on the method of Alverson and Carney (1975)) and CV set to 0.15, and produces and estimate of 0.049 (shown in red in the graph below). The estimate obtained when *M* is freely estimated declines to 0.04. These estimates are lower those obtained from a recent analysis of empirical estimators of natural mortality, in which an estimator based on a power function of maximum age was developed (Then et al. 2014) and yields an estimate of 0.08 for northern rockfish. Additionally, Then at al. (2014) found that estimators that rely on maximum age had less prediction error than the Alverson-Carney method. In future assessments, the effect of increasing the mean and/or lowering the CV for the prior on *M* will be considered.




The prior for *q* has a mean of 1 and a CV of 0.001, and a similar plot showing the effect of increasing the CV of the prior is shown below. The estimates of *q* range from 1.0 fixed in the current model to 0.1 when estimated freely (while holding *M* fixed at 0.049). The inability to estimate *q* within the model is not surprising given that there is little contrast in the survey time series regarding how the stock has responded to exploitation, and motivates obtaining information on *q* outside the assessment model in order to develop more informative priors.



# Introduction

Northern rockfish (*Sebastes polyspinus*) inhabit the outer continental shelf and upper slope regions of the North Pacific Ocean and Bering Sea. Northern rockfish (*Sebastes polyspinus*) in the Bering Sea/Aleutians Islands (BSAI) region were assessed under Tier 5 of Amendment 56 of the NPFMC BSAI Groundfish FMP until 2004. The reading of archived otoliths from the Aleutian Islands (AI) surveys allowed the development of an age-structured model for northern rockfish beginning in 2003. Since 2004, BSAI northern rockfish have been assessed as a Tier 3 species in the BSAI Groundfish FMP.

## *Information on Stock Structure*

A stock structure evaluation was included as an appendix to the 2012 stock assessment (Spencer and Ianelli 2012). A variety of types of data were considered, including genetic data, potential barriers to movement, growth differences, and spatial differences in growth and age and size structure.

Several genetic tests were conducted on northern rockfish samples obtained in the 2004 Aleutian Islands and EBS trawl surveys (Gharrett et al. 2012). A total of 499 samples were collected at six locations ranging from the EBS slope to the western Aleutian Islands, and analyses were applied to 11 microsatellite loci. Information on the spatial population structure was obtained from the spatial analysis of molecular variance (SAMOVA; Dupanloup et al. 2002), which identified sets of collections that showed maximum differentiation. Three groups were identified: 1) the eastern Bering Sea; 2) two collections west of Amchitka Pass; and 3) three collections between Amchitka Pass and Unimak Pass. The genetic data also show a statistically significant pattern of isolation by distance, indicating genetic structure being produced from the dispersal of individuals being smaller than the spatial extent of the sampling locations. A range of expected lifetime dispersal distance were estimated, reflecting different assumptions regarding effective population size and migration rates of spawners, and the estimated lifetime dispersal distances did not exceed 250 km. This estimated dispersal distance is comparable to other *Sebastes* species in the north Pacific, which have ranged from 4 to 40 for near shore species such as grass rockfish (Buonaccorsi et al. 2004), brown rockfish ((Buonaccorsi et al. 2005), and vermilion rockfish (Hyde and Vetter 2009), and up to 111 km for deeper species such as POP (Palof et al. 2011) and darkblotched rockfish (Gomez-Uchida and Banks 2005). The demographic implication is that movement of fish from birth to reproduction is at a much smaller scale than the geographic scale of the BSAI area. Finally, it is important to recall that the time unit for the estimated dispersal is not years, but generations, and the generation time for northern rockfish is more than 36 years.

Aleutian Island trawl survey data was used to estimate von Bertalannfy growth curves by areas, and show increasing size at age from the western AI to the eastern AI. The largest difference in the growth curves was in the rate parameter *K*, which was smallest in the western Aleutians, indicating that fish in this area approached their asymptotic size more slowly than fish in the EAI and SBS.

Spatial differences in age compositions, obtained from the AI trawl surveys from 2002, 2004, and 2006, were evaluated by testing for significant differences in mean age between areas. Significant differences were observed in the mean age between subareas for individual years, but a consistent pattern did not emerge across the years.

Finally, any potential physical limitations to movement were considered. Physical barriers are rare in marine environments, but the Aleutian Islands are unique due to the occurrence of deep passes, typically exceeding 500 m, that may limit the movement of marine biota. For example, Logerwell et al. (2005) identify a “biophysical transition zone” occurs at Samaga Pass. Northern rockfish are a demersal species captured during the AI trawl survey at depths between 100 m and 200 m, so adult rockfish traversing the much deeper AI passes would require greater utilization of pelagic habitats or deeper depths than currently observed in the AI trawl surveys. Movement of larvae between areas is likely a function of ocean currents. On the north side of archipelago, the connection between the east and west Aleutians is limited due to the break associated with Petral Bank and Bowers Ridge, which results in water flowing away from the Aleutian Islands archipelago. On the south side of the Aleutian Islands, the Alaska Stream provides much of the source of the Alaska North Slope Current (ANSC) via flow through Amutka Pass and Amchitka Pass. However, The Alaska Stream separates from the slope west of the Amchitka Pass and forms meanders and eddies, perhaps limiting the connection between the east and west Aleutians.

# Fishery

BSAI foreign and joint venture rockfish catch records from 1977 to 1989 are available from foreign "blend" estimates of total catch by management group, and observed catches from the North Pacific Observer Program database. The foreign catch of BSAI rockfish during this time was largely taken by Japanese trawlers, whereas the joint-venture fisheries involved partnerships with the Republic of Korea. Because northern rockfish are taken as bycatch in the BSAI area, historical foreign catch records have not identified northern rockfish catch by species. Instead, northern rockfish catch has been reported in a variety of categories such as "other species" (1977, 1978), "POP complex" (1979-1985, 1989), and "rockfish without POP" (1986-1988).

Rockfish management categories in the domestic fishery since 1991 have also included multiple species. In 1991, the "other red rockfish" species group was used in both the EBS and AI, but beginning in 1992 northern rockfish in the AI were managed in the "northern/sharpchin" species group. Prior to 2001, northern rockfish were managed with separate ABCs and TACs for the AI and EBS, and in 2001 the two areas were combined into a single management unit under the "sharpchin/northern" species complex. In 2002, sharpchin rockfish were dropped from the complex because of their sparse catches, leaving single-species management category of northern rockfish. The OFLs, ABCs, TACS, and catches by management complex from 1977-2000 are shown in Table 1, and those from 2001 to present are shown in Table 2.

Since 2002, the blend and catch accounting system (CAS) databases has reported catch of northern rockfish within the EBS and AI subareas. From 1991-2001, species catches were reconstructed by computing the harvest proportions within management groups from the North Pacific Foreign Observer Program database, and applying these proportions to the estimated total catch obtained from the NOAA Fisheries Alaska Regional Office "blend" database. This reconstruction was conducted by estimating the northern rockfish catch for each area (i.e., the EBS and each of the three AI areas) and gear type from 1994-2001. For 1991-1993, the Regional Office blend catch data for the Aleutian Islands was not reported by AI subarea, and the AI catch was obtained using the observer harvest proportions by gear type for the entire AI area. Similar procedures were used to reconstruct the estimates of catch by species from the 1977-1989 foreign and joint venture fisheries. Estimated domestic catches in 1990 were obtained from Guttormsen et al. 1992. Catches from the domestic fishery prior to the domestic observer program were obtained from PACFIN records.

Catches of northern rockfish since 1977 by area are shown in Table 3. Northern rockfish catch prior to 1990 was small relative to more recent years (with the exception of 1977 and 1978). Harvest data from 2004 -2010 indicates that approximately 88% of the BSAI northern rockfish are harvested in the Atka mackerel fishery. Prior to 2011, much of the northern rockfish catch occurred in the western and central Aleutian Islands, reflecting the high proportion of Atka mackerel fishing in these areas (Table 4). However, restrictions on Atka mackerel fishing in the western Aleutians beginning in 2011 have restricted the current northern rockfish harvest in this area, and from 2011-2014 the proportion of northern rockfish harvested in the Atka mackerel fishery has declined to 55%. Northern rockfish are patchily distributed and are harvested in relatively few areas within the broad management subareas of the Aleutian Islands, with important fishing grounds being Petral Bank, Sturdevant Rock, south of Amchitka I., and Seguam Pass (Dave Clausen, NMFS-AFSC, personal communication).

Temporal variability has occurred in AI subareas in which northern rockfish are captured, and to a lesser extent in the depth of capture (Figure 1). The domestic fishery observer data indicates that the eastern AI accounted for 49% and 63% of the AI harvest in 1990 and 1991, respectively, decreasing to less than 15% of the observed catch from 1997 to 2006 (except 1999 and 2000). In contrast, the proportion of observed catch in the western AI increased from less than 20% from 1991 to 1993 to greater than 40% in most years from 1996-2005, and has decreased to less than 20% from 2011 – 2014 with the closure of the western AI to Atka mackerel fishing since 2010. The observed catch of northern rockfish is predominately captured at depths between 100 m and 200 m, although percentage obtained at depths between 200 m and 300 m has been variable, ranging from less than 5% during 2000 – 2007 to between 5% and 13% from 2008 – 2013.

Information on proportion discarded is generally not available for northern rockfish in years where the management categories consist of multi-species complexes. However, because the catches of sharpchin rockfish are generally rare in both the fishery and survey, the discard information available for the "sharpchin/northern" complex can interpreted as northern rockfish discards. This management category was used in 2001 in the EBS, and from 1993-2001 in the AI. Prior to 2003 the discard rates were generally above 80%, with the exception of the mid-1990s when some targeting occurred in the Aleutians Islands (Table 4). Discard rates in the AI have declined from 96% in 2003 to < 10% in 2013 and 2014. In the Aleutian Islands, discard rates have declined from 80% in 2003 to < 10% in 2010, and increased in year to 50% in 2012 and 46% in 2014.

Non-commercial catch data are shown in Appendix A.

# Data

### *Fishery Data*

The fishery data is characterized by inconsistent sampling of lengths and ages (Table 6). In some years, such as 1984 and 1987 over 700 fish lengths were obtained but these data samples came from a limited number of hauls. Additionally, the length data from the foreign fishery tended to originate from predominately one location in each year, and was not consistent between years. For example, the 1977 and 1978 fishery length data were collected from Tahoma Bank in the western Aleutians, whereas samples in 1984 were obtained from Seguam Pass and samples in 1987 were obtained from Petral Bank. In the domestic fishery, changes in observer sampling protocol since 1999 have improved the distribution of hauls from which northern rockfish age and length data are collected.

The selection of fishery length frequency data for the age-structured assessment model was based on the consistency in sampling location and the number of samples collected. Foreign fishery length data from 1977 and 1978 were used, in part, because of the consistency in their sampling location with other sampling years, the increased numbers of hauls from which they were obtained, and the absence of other length composition data during this portion of the time series. Domestic fishery length data from 1996, 1998-1999, 2010, and 2012-2013 were used, and the length and age data from 2000-2009 and 2011 were used to estimate the age-frequency of the fishery catch.

The fishery age composition data indicates the relatively strong cohorts in 1984-1985 and 1995, as each of these cohorts was observed as relatively abundant in multiple years of fishery age composition data (Figure 2).

### *Survey data*

Biomass estimates for other red rockfish were produced from cooperative U.S.-Japan trawl survey from 1979-1985 on the eastern Bering Sea slope, and from 1980-1986 in the Aleutian Islands. U.S trawl surveys on the eastern Bering Sea slope were conducted by the National Marine Fisheries Service

(NMFS) in 1988, 1991, and biennially beginning in 2002 (except 2006 and 2014, when the survey was canceled due to lack of funding). NMFS trawl survey in the Aleutian Islands were conducted in 1991, 1994, 1997, and biennially beginning in 2000. The EBS slope surveys in 2008 and 2014, and the AI trawl survey in 2008, were canceled to due lack of funding. Differences exist between the 1980-1986 cooperative surveys and the 1991-2012 from the U.S. domestic surveys with regard to the vessels and gear design used (Skip Zenger, National Marine Fisheries Service, personal communication). For example, the Japanese nets used in the 1980, 1983, and 1986 cooperative surveys varied between years and included large roller gear, in contrast to the poly-nor'eastern nets used in the current surveys (Ronholt et al 1994), and similar variations in gear between surveys occurred in the cooperative EBS surveys. In previous assessments, these surveys were included in the assessment as to provide some indication of biomass during the 1980s. 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.

Survey abundance in the western and central Aleutians from 1991-2012 was larger than abundance in the eastern Aleutians and eastern Bering Sea (Table 7, Figure 3). In 2014, the survey abundance in the eastern AI increased sharply to 77,000 t (from an average of 20,000 t from 2006-2012) and has a large coefficient of variation of 0.79. Areas of particularly high survey abundance are Amchitka Island, Kiska Island, Buldir Island, and Tahoma Bank. An average of 70% of the estimated biomass from the 1991-2014 NMFS AI trawl surveys occurs in the western Aleutian Islands. The coefficients of variation (CV) of these biomass estimates by region are generally high, but especially so in the southern Bering Sea portion of the surveyed area (165 W to 170 W), where the CV was less than 0.50 only in the 2000 survey. The 2014 Aleutian Island survey biomass was 472,895 t, which represents an increase of 36% from the 2012 estimate of 285,164 t. Much of this increase occurred in the eastern AI (mentioned above) and the western AI, where the estimates biomass increased from 216,325 t in 2012 to 346,392 in 2014. The coefficient of variation (CV) for the 2014 estimate is 0.31, approximately equal to the average CV from the 1991-2012 surveys of 0.30. In the western AI in 2012, and in the eastern AI in 2012 and 2014, a single large tow accounted for the high CVs of the survey biomass estimate (Figure 3).

In the 1991-1996 surveys, a large portion of the age composition was less than 15 year old, reflecting relative abundant 1984, 1989, and 1994 cohorts (Figure 4).

The AFSC 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, and 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. The EBS slope survey biomass estimates of northern rockfish from the 2002-2012 surveys ranged between 3 t (2008 and 2012) and 42 t (2010), with CVs between 0.38 (2002) and 1.0 (2008 and 2012). Given these low levels of biomass, the slope survey results are not used in this assessment.

### *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. The catch-weighted mean depth in the fishery (from 1991 – 2013) similar to the catch-weighted depth in the AI trawl survey (Figure 5), with the exceptions being the early 1990s in the central AI, and the western AI since 2010 (when a relatively higher proportion of the northern rockfish catch was obtained in rockfish fisheries).

Dome-shaped fishery selectivity indicates a decrease in the proportion of the population captured by the fishery for older-aged fish. Assuming that old fish in the survey are fully selected, a comparison of fishery and survey age compositions can reveal the potential presence of dome-shaped selectivity. The plus group for the northern rockfish 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 three periods from 2000 to 2011 (2000-2002, 2004-2006, and 2009-2011), the age composition of ages 40 to 70+ are shown in Figure 6. Overall, survey age composition is similar to fishery age composition for the ages in the plus group. For example, in the 2000 - 2002 period, the survey age composition exceeded the fishery age composition for 14 of 31 ages, whereas the fishery age composition exceeded the survey age composition in 8 of the 31 ages (8 ages were captured by neither the fishery or the survey). 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. Overall, these data do not suggest that the fishery is selecting older northern rockfish in different proportions than the survey since 2000. Fishery age data are not available to conduct a similar analysis for years prior to 2000.

### *Biological Data*

The AI survey provides data on age and length composition of the population, growth rates, and length-weight relationships. The number of otoliths collected and lengths measured are shown in Table 8, along with the number of hauls producing these data. The number of otoliths read by area is shown in Table 9. The survey data produce reasonable sample sizes of lengths and otoliths from throughout the survey area. The maximum age observed in the survey samples was 72 years.

The survey otoliths were read with the break and burn method, and were thus considered unbiased (Chilton and Beamish 1982); however, the potential for aging error exists. Information on aging error was obtained from Courtney et al. 1999, based on two independent readings of otoliths from the Gulf of Alaska trawl survey from 1984-1993. The raw data in Courtney et al. (1999) was used to estimate the standard deviation for each age. The standard deviations were regressed against age to provide a predicted estimate of standard deviation of observed ages for a given true age, and this linear relationship was used to produce the aging error matrix. Use of the aging error matrix from GOA northern rockfish for the BSAI stock is considered appropriate because longevity is similar between the areas.

The expected length at age was estimated by fitting a von Bertalanffy curve to estimates of mean size at age obtained from the AI surveys from 1991-2012. Within each survey year, mean size at age was obtained by multiplying the estimated population length composition by the age-length key. The estimated von Bertalanffy parameters are as follows, and were used to create a conversion matrix and a weight-at-age vector:

| $L_{inf}$ | K | $t_0$ |
|---|---|---|
| 33.77 | 0.19 | -0.30 |

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 0.10 at age 40.

A length-weight relationship of the form $W = aL^b$ was fit from the survey data from 1991-2012, and produced estimates of $a = 1.32 \times 10^{-5}$ and $b = 3.02$. This relationship was used in combination with the von Bertalanffy growth curve to obtain the estimated weight at age vector of the population (Table 10).

The following table summarizes the data available for the BSAI northern rockfish model:

| Component | BSAI |
|---|---|
| Fishery catch | 1977-2014 |
| Fishery age composition | 2000-2009, 2011 |
| Fishery size composition | 1977-1978, 1996, 1998-1999, 2010, 2012-2013 |
| 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 model, implemented in the software program AD Model Builder, was used to obtain estimates of recruitment, numbers at age, and catch at age. The assessment model for northern rockfish is very similar to that currently used for BSAI Pacific ocean perch, which was used as a template for the current model. Population size in numbers at age *a* in year *t* was modeled as

$$N_{t,a} = N_{t-1,a-1} e^{-Z_{t-1,a-1}} \quad 3 < a < A, \quad 1977 < t \le T$$

where $Z$ is the sum of the instantaneous fishing mortality rate ($F_{t,a}$) and the natural mortality rate ($M$), $A$ is the maximum number of age groups modeled in the population, and $T$ is the terminal year of the analysis (defined as 2012).

The numbers at age $A$ are a "plus" 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 are estimated as

$$N_a = R_{init} e^{-M(a-3)+\gamma_a}$$

where $R_{init}$ is the mean number of age 3 recruits prior to the start year if the model, and $\gamma$ is an age-dependant deviation assumed to be normally distributed with mean of zero and a standard deviation equal to $\sigma_r$, the recruitment standard deviation. Estimation of the vector of age-dependant deviations from average recruitment allows estimation of year class strength.

The total numbers of age 3 fish from 1977 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 $\mu_R$ is the log-scale mean and $v_t$ is a time-variant deviation. The number of age 3 from 2012-2014 are set the expected mean recruitment (based upon the log-scale mean, and the value of $\sigma_r$ ).

The fishing mortality rate for a specific age and time ($F_{t,a}$) is modeled as the product of a fishery age-specific selectivity (*fishsel*) and a year-specific fully-selected fishing mortality rate *f*. The fully selected mortality rate is modeled as the product of a mean ($\mu_f$) and a year-specific deviation ($\varepsilon_t$), thus $F_{t,a}$ is

$$F_{t,a} = S_{f,a} f_t \equiv S_{f,a} e^{(\mu_f + \varepsilon_t)}$$

The mean numbers at age for each year was computed as

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

The predicted length composition data were calculated by multiplying the mean numbers at age by a transition matrix, which gives the proportion of each age (rows) in each length group (columns); the sum across each age is equal to one. 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.

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 (*pred_biom*) was computed as

$$pred\_biom_t = qsurv \sum_a \left( \overline{N}_{t,a} * survsel_a * W_a \right)$$

where $W_a$ is the population weight at age, $survsel_a$ is the survey selectivity, and *qsurv* is the trawl survey catchability.

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 0.06 (the value used in previous assessments, based upon expected relationships between *M*, longevity, and the von Bertalanffy growth parameter *K* (Alverson and Carney 1975)) and the CV set to 0.15. The standard deviation of log recruits, $\sigma_r$, 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 0.001, essentially fixing *qsurv* at 1.0.

Several quantities were computed in order to compare the variance of the residuals to the assumed input variances. The RSME 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 greater 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 $\sigma_i$ 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

$$E_i = \frac{\sum_a \hat{p}_a(1-\hat{p}_a)}{\sum_a (\hat{p}_a - p_a)^2}.$$

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*

Four models were evaluated that differed in the parameterization for fishery selectivity at age ($S_{f,a}$).

**Model 1**) *Logistic curve* (used in previous assessments):

$$S_{f,a} = \frac{1}{1+e^{-\phi(a-a_{50\%})}}$$

where the $a_{50\%}$ and $\phi$ parameters control the age at 50% maturity and the slope of the curve at this point, respectively.

**Model 2**) *Double logistic curve*:

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

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

**Model 3**) Cubic spline

**Model 4**) 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).

Cubic and bicubic splines were implemented with the “vcubic_spline_function” and “bicubic_spline” functions in AD Modelbuilder. The cubic spline models time-invariant selectivity, whereas the bicubic spline model selectivity varying across time and age; each function was developed from code provided in Press et al. (1992).

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 were set to the number of hauls, and multiplied by 2/3 for the fishery data and 4/3 for the survey data based upon the notion that the fishery data are less reliable. 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. Additionally, the reliability of the fishery composition data is largely reflected in the reduced number of sample for some years, thus application of reduced weight to these data may be redundant.

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.

***Parameters Estimated Outside the Assessment Model***

The parameters estimated independently include the age error matrix, the age-length conversion matrix, individual weight at age, and proportion mature females at age. The derivation of the age error matrix, the age-length transition matrix, and the weight at age vector 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 negative log-likelihood of the initial recruitments were modeled with a lognormal distribution

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

where *n* is the number of year where recruitment is estimated. The adjustment of adding $\sigma_r^2/2$ to the deviation was made in order to produce deviations from the mean recruitment, rather than the median. If $\sigma_r$ is fixed, the term *n* ln ($\sigma_r$) adds a constant value to the negative log-likelihood. The negative log-likelihood of the recruitment of cohorts represented in the first year (excluding age 3, which is included in the recruitment negative log-likelihood) of the model treated in a similar manner:

$$\lambda_1 \left[ \sum_{a=4}^{A} \frac{\left(\gamma_a + \sigma_r^{\,2}/2\right)^2}{2\sigma_r^{\,2}} + (A-3)\ln(\sigma_r) \right]$$

The negative log-likelihoods of the fishery and survey age and length compositions were modeled with a multinomial distribution. The negative log likelihood 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 negative log 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 $\lambda_2$ is a weighting factor. The negative log-likelihood of the catch biomass was modeled with a lognormal distribution:

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

where $obs\_cat_t$ and $pred\_cat_t$ are the observed and predicted catch. Because the catch biomass is generally thought to be observed with higher precision that other variables, $\lambda_3$ 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 a large λ is used to constrain the predicted catches to closely match the input catches.

A maturity ogive was fit in the assessment model to samples collected in 2010 (*n*=322; TenBrink and Spencer 2013) and in 2004 by fishery observers (*n*=256). 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 collection 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 8.2 years.

The overall negative log-likelihood function (excluding the catch component, and the maturity likelihood) is

$$\lambda_1\left[\sum_{t=1}^{n}\frac{\left(\nu_t+\sigma_r^{\,2}/2\right)^2}{2\sigma_r^{\,2}}+n\ln(\sigma_r)\right]+$$
$$\lambda_1\left[\sum_{a=4}^{A}\frac{\left(\gamma_a+\sigma_r^{\,2}/2\right)^2}{2\sigma_r^{\,2}}+(A-3)\ln(\sigma_r)\right]+$$
$$\lambda_2\sum_t\left(\ln(obs\_biom_t)-\ln(pred\_biom_t)\right)^2/2cv_t^2+$$
$$-n_{f,t,l}\sum_{s,t,l}(p_{f,t,l}\ln(\hat{p}_{f,t,l})+p_{f,t,l}\ln(p_{f,t,l}))+$$
$$-n_{f,t,a}\sum_{s,t,l}(p_{f,t,a}\ln(\hat{p}_{f,t,a})+p_{f,t,a}\ln(p_{f,t,a}))+$$
$$-n_{surv,t,a}\sum_{s,t,a}(p_{surv,t,a}\ln(\hat{p}_{surv,t,a})+p_{surv,t,a}\ln(p_{surv,t,a}))+$$
$$-n_{surv,t,l}\sum_{s,t,a}(p_{surv,t,l}\ln(\hat{p}_{surv,t,l})+p_{surv,t,l}\ln(p_{surv,t,l}))+$$
$$\lambda_3\sum_t\left(\ln(obs\_cat_t)-\ln(pred\_cat_t)\right)^2$$

For the model run in this analysis, $\lambda_1$, $\lambda_2$, and $\lambda_3$ were assigned weights of 1,1, and 200, reflecting the strong emphasis on fitting the catch data.

The negative log-likelihood function was minimized by varying the following parameters (for an age-plus group of 40 years, and with the time-invariant logistic fishery selectivity) :

| Parameter type | Number |
|---|---|
| 1) fishing mortality mean | 1 |
| 2) fishing mortality deviations | 38 |
| 3) recruitment mean | 1 |
| 4) recruitment deviations | 35 |
| 5) Initial recruitment | 1 |
| 6) first year recruitment deviations | 37 |
| 7) biomass survey catchability | 1 |
| 8) natural mortality rate | 1 |
| 9) survey selectivity parameters | 2 |
| 10) fishery selectivity parameters | 2 |
| 11) maturity parameters | 2 |
| Total number of parameters | 121 |

# Results

### *Model Evaluation*

Several attributes of the model fits are shown in Table 11, including AIC and BIC values. 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 1-4, and were produced by applying iterative reweighting to Model 1 (time-invariant logistic 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 a 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 1 (time-invariant logistic selectivity) had the lowest AIC and BIC, with the negative log-likelihood being very similar to Model 2 (time-invariant double logistic selectivity). Although the double logistic curve has the flexibility to fit dome-shaped patterns, in this case the double logistic selectivity curve was an asymptotic curve similar to that estimated in Model 1. The RMSEs and negative log-likelihoods for the components of the composition data were generally similar for all four models, with the exception of some degradation on the fit to the fishery age composition data with the time-invariant cubic spline (Model 4). Both the non-parameteric cubic spline and bicubic spline model estimated selectivity that was largely asymptotic, and the temporal variation in selectivity obtained with the bicubic spline was relatively small. Information on the composition of the fishery catches is sparse prior to the mid-1990s, and as indicated above, the recent fishery and survey data do not suggest a strong dome-shaped selectivity pattern.

The estimated spawning biomass for the models is shown in Figure 8, with the bridging Models 0 and 0.1 shown in blue. Removing the cooperative survey data increases the scale of the spawning stock for all models prior to 2010, as the cooperative survey biomass estimates were lower than those initiated by AFSC beginning in 2000.

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). Each of models 1-4 estimate similar time series of spawning stock biomass, with the spawning stock biomass estimate for 2014 in model 1 being very close to that from bridging model 0.

Model 1 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 northern rockfish age 3 and older. Recruitment is defined as the number of age northern rockfish.

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 2014 to 2004, and this was accomplished by sequentially dropping age and length composition data, survey biomass estimates, and catch 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 in the runs with end years of years 2012 and 2014, when high survey biomass estimate are added to the model. The model is limited in its capacity to increase recruitment to match the high survey estimates because the survey catchability is essentially fixed at 1. 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 these retrospective runs was -1.50.

### *Biomass trends*

The estimated survey biomass shows an increasing trend, starting at 113,792 t in 1977 and increasing to a peak of 233,818 t in 2004 (Figure 10). The estimated total biomass shows a similar trend, increasing to peak values of 250,000 t from 2001-2003, whereas the estimated spawner biomass increases from 48,463 in 1977 to its highest value of 108,216 in 2007 (Table 11, Figure 11).

### *Age/size compositions*

The model fits to the fishery age and size compositions are shown in Figures 12-13, and the model fit to the survey age and length composition are shown in Figures 14-15. The model fit the fishery and survey age composition data reasonably well (notwithstanding years with low sample sizes). The plus group in the fishery length composition data (38 cm+) is consistently underestimated by the model, whereas the fishery age plus group (40+ years) is overestimated, reflecting a trade-off in the model.

### *Fishing and survey selectivity*

The estimated survey selectivity curve had an age of 50% selection of 5.5, whereas this parameter was 9.6 for the fishery selectivity curve (Figure 16). These values are decreases from the estimates of 5.8 and 10.6, respectively, in the 2012 assessment.

### *Fishing mortality*

The estimates of instantaneous fishing mortality rate are shown in Figure 17. A relatively high rate in 1977 is required to account for the relatively high catch in this year, followed by very low levels of fishing mortality during the 1980s when catch was small. Fishing mortality rates began to increase during the early 1990s, and the 2013 estimate is 0.011. A plot of fishing mortality rates and spawning stock biomass in reference to the ABC and OFL harvest control rules indicates that the stock is currently below $F_{35\%}$ and above $B_{40\%}$ (Figure 18).

### *Recruitment*

Recruitment strengths by year class are shown in Figure 19. Relatively strong year classes are observed in 1978, 1981, 1984-1985, 1989, and 1993-1998, reflecting several of the strong year classes observed in the age composition input data (Figures 12 and 14). The scatterplot of recruitment against spawning stock biomass is shown in Figure 20, indicating substantial variability in the pattern between recruitment and spawning stock size.

## Harvest recommendations

### *Amendment 56 reference points*

The reference fishing mortality rate for northern rockfish 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 57,768 t. The year 2015 spawning stock biomass is estimated as 94,873 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 $B > B_{0.40}$ (94,873 t > 57,768 t ), northern rockfish reference fishing mortality is defined in tier 3a. For this tier, $F_{ABC}$ is defined as $F_{0.40}$ and $F_{OFL}$ is defined as $F_{0.35}$. The values of $F_{0.40}$ and $F_{0.35}$ are 0.070 and 0.087, respectively.

**The ABC associated with the $F_{0.40}$ level of 0.070 is 12,488 t**.

The estimated catch level for year 2015 associated with the overfishing level of $F$ = 0.087 is 15,337 t. A summary of these values is below.

| | | |
|---|---|---|
| **2015 SSB estimate (B)** | **=** | **94,873 t** |
| $B_{0.40}$ | = | 57,768 t |
| $F_{ABC} = F_{0.40}$ | = | 0.070 |
| $F_{OFL} = F_{0.35}$ | = | 0.087 |
| *MaxPermABC* | = | 12,488 t |
| OFL | = | 15,337 t |

### *ABC recommendation*

We recommend the maximum permissible ABC 12,488 t.

## Projections

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

For each scenario, the projections begin with 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 2015, 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 2013 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 a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

> *Scenario 6*: In all future years, $F$ is set equal to $F_{OFL}$. (Rationale: This scenario determines whether a stock is overfished. If the stock is 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 2015 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 12.

### *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 2,038 t. This is less than the 2013 BSAI OFL of 12,200 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 12). 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 northern rockfish stock is neither overfished nor approaching an overfished condition. With regard whether the stock is currently overfished, the estimated 2014 stock size is 1.9 its $B_{35\%}$. value of 50,547 t. With regard to whether BSAI northern rockfish is likely to be overfished in the future, the expected stock size in 2015 of Scenario 7 is 1.9 times the $B_{35\%}$ value.

# Ecosystem Considerations

*Ecosystem Effects on the stock*

1) Prey availability/abundance trends

Northern rockfish feed primarily upon zooplankton, including calanoid copepods, euphausids, and chaetonaths. From a sample of 118 Aleutian Island specimens collected in 1994, calanoid copepods, euphausids, and chaetognaths contributed 84% of the total diet by weight. Small northern rockfish (<30 cm FL) consumed a higher proportion of calanoid copepods than larger northern rockfish, whereas euphausids were consumed primarily by fish larger than 25 cm. Myctophids and cephalopods were consumed mainly by the largest size group, contributing 11% and 16%, respectively, of the diet for fish > 35 cm. The availability and abundance trends of these prey species are unknown.

2) Predator population trends

Northern rockfish are not commonly observed in field samples of stomach contents. Pacific ocean perch, a rockfish with similar life-history characteristics as northern rockfish, has been found in the stomachs of Pacific halibut and sablefish (Major and Shippen 1970), and it is likely that these also prey upon northern rockfish as well. The population trends of these predators can be found in separate chapters within this SAFE document.

3) Changes in habitat quality

Little information exists on the habitat use of northern rockfish. Carlson and Straty (1981) and Kreiger (1993) used submersibles to observe that other species of rockfish appear to use rugged, shallower habitats during their juvenile stage and move deeper with age. Although these studies did not specifically observe northern rockfish, it is reasonable to suspect a similar ontogenetic shift in habitat. Length frequencies of the Aleutian Islands survey data indicate that small northern rockfish (< 25 cm) are generally found at depths less than 100 m. The mean depths of northern rockfish from recent AI trawl surveys have ranged between 100 and 150 m. There has been little information identifying how rockfish habitat quality has changed over time.

*Fishery Effects on the ecosystem*

A northern rockfish target fishery does not currently exist in the BSAI management area. As previously discussed, most northern rockfish catch in the BSAI management area occurs in the Atka mackerel fishery. The ecosystem effects of the Atka mackerel fishery can be found in the Atka mackerel assessment in this SAFE document.

Harvesting of northern rockfish is not likely to diminish the amount of northern rockfish available as prey due to the low fishery selectivity for fish less than 20 cm. Although the recent fishing mortality rates have been relatively light, averaging 0.03 over the last five years, it is not know what the effect of harvesting is on the size structure of the population or the maturity at age.

## Data Gaps and Research Priorities

Little information is known regarding most aspects of the biology of northern rockfish, particularly in the Aleutian Islands. Recent genetic data suggests that the spatial movement of northern rockfish, per generation, may be much smaller that the currently-used BSAI management area. The evaluation of spatial management units can be conducted with a template developed by the Plan Team-SSC working group on stock structure. More generally, little is known regarding the 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 northern rockfish from 1977 to 2000 in the Aleutian Islands and the eastern Bering Sea. The "other red rockfish" group includes, shortraker rockfish, rougheye rockfish, northern rockfish, and sharpchin rockfish. The "POP complex" includes the other red rockfish species 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 | Other species | | | | 3264 | Other species | | | | 5 |
| 1978 | Other species | | | | 3655 | Other species | | | | 32 |
| 1979 | POP complex | | | | 601 | POP complex | | | | 46 |
| 1980 | POP complex | | | | 549 | POP complex | | | | 89 |
| 1981 | POP complex | | | | 111 | POP complex | | | | 35 |
| 1982 | POP complex | | | | 177 | POP complex | | | | 71 |
| 1983 | POP complex | | | | 47 | POP complex | | | | 42 |
| 1984 | POP complex | | | | 196 | POP complex | | | | 32 |
| 1985 | POP complex | | | | 189 | POP complex | | | | 6 |
| 1986 | Other rockfish | n/a | UN | 5800 | 208 | Other rockfish | n/a | UN | 825 | 61 |
| 1987 | Other rockfish | n/a | UN | 1430 | 308 | Other rockfish | n/a | UN | 450 | 77 |
| 1988 | Other rockfish | n/a | 1100 | 1100 | 493 | Other rockfish | n/a | 400 | 400 | 40 |
| 1989 | POP complex | n/a | 16600 | 6000 | 306 | POP complex | n/a | 6000 | 5000 | 78 |
| 1990 | POP complex | n/a | 16600 | 6000 | 1235 | POP complex | n/a | 6300 | 6300 | 247 |
| 1991 | Other red rockfish | 0 | 4685 | 4685 | 233 | Other red rockfish | 0 | 1670 | 1670 | 626 |
| 1992 | Sharpchin/northern | 5670 | 5670 | 5670 | 1548 | Other red rockfish | 1400 | 1400 | 1400 | 309 |
| 1993 | Sharpchin/northern | 5670 | 5670 | 5100 | 4530 | Other red rockfish | 1400 | 1400 | 1200 | 859 |
| 1994 | Sharpchin/northern | 5670 | 5670 | 5670 | 4666 | Other red rockfish | 1400 | 1400 | 1400 | 61 |
| 1995 | Sharpchin/northern | 5670 | 5670 | 5103 | 3858 | Other red rockfish | 1400 | 1400 | 1260 | 266 |
| 1996 | Sharpchin/northern | 5810 | 5810 | 5229 | 6637 | Other red rockfish | 1400 | 1400 | 1260 | 87 |
| 1997 | Sharpchin/northern | 5810 | 4360 | 4360 | 1996 | Other red rockfish | 1400 | 1050 | 1050 | 164 |
| 1998 | Sharpchin/northern | 5640 | 4230 | 4230 | 3746 | Other red rockfish | 356 | 267 | 267 | 45 |
| 1999 | Sharpchin/northern | 5640 | 4230 | 4230 | 5492 | Other red rockfish | 356 | 267 | 267 | 157 |
| 2000 | Sharpchin/northern | 6870 | 5150 | 5150 | 5066 | Other red rockfish | 259 | 194 | 194 | 97 |

Table 2. Total allowable catch (TAC), acceptable biological catch (ABC), and catch of the species groups used to manage northern rockfish from 2001 to present to 2000 in the eastern Bering Sea and Aleutian Islands.

| | | Bering Sea and Aleutian Islands | | | |
|---|---|---|---|---|---|
| Year | Management Group | OFL (t) | ABC (t) | TAC (t) | Catch (t) |
| 2001 | Sharpchin/northern | 9020 | 6764 | 6764 | 6488 |
| 2002 | Northern rockfish | 9020 | 6760 | 6760 | 4057 |
| 2003 | Northern rockfish | 9468 | 7101 | 6000 | 4929 |
| 2004 | Northern rockfish | 8140 | 6880 | 5000 | 4684 |
| 2005 | Northern rockfish | 9810 | 8260 | 5000 | 3964 |
| 2006 | Northern rockfish | 10100 | 8530 | 4500 | 3828 |
| 2007 | Northern rockfish | 9750 | 8190 | 9190 | 4016 |
| 2008 | Northern rockfish | 9740 | 8180 | 8180 | 3287 |
| 2009 | Northern rockfish | 8540 | 7160 | 7160 | 3111 |
| 2010 | Northern rockfish | 8640 | 7240 | 7240 | 4332 |
| 2011 | Northern rockfish | 10600 | 8670 | 4000 | 2764 |
| 2012 | Northern rockfish | 10500 | 8610 | 4700 | 2479 |
| 2013 | Northern rockfish | 12200 | 9850 | 3000 | 2038 |
| 2014* | Northern rockfish | 12077 | 9761 | 2594 | 2282 |

*Catch data through October 11, 2014, from NMFS Alaska Regional Office.

Table 3. Catch of northern rockfish (t) in the BSAI area.

| | Eastern Bering Sea | | | Aleutian Islands | | | |
|---|---|---|---|---|---|---|---|
| Year | Foreign | Joint Venture | Domestic | Foreign | Joint Venture | Domestic | Total |
| 1977 | 5 | 0 | | 3,264 | 0 | | 3,270 |
| 1978 | 32 | 0 | | 3,655 | 0 | | 3,687 |
| 1979 | 46 | 0 | | 601 | 0 | | 647 |
| 1980 | 84 | 5 | | 549 | 0 | | 638 |
| 1981 | 35 | 0 | | 111 | 0 | | 145 |
| 1982 | 63 | 8 | | 177 | 0 | | 248 |
| 1983 | 10 | 32 | | 47 | 0 | | 89 |
| 1984 | 26 | 6 | | 11 | 185 | | 229 |
| 1985 | 5 | 1 | | 0 | 189 | | 195 |
| 1986 | 5 | 41 | 15 | 0 | 193 | 15 | 270 |
| 1987 | 1 | 45 | 31 | 0 | 248 | 60 | 385 |
| 1988 | 0 | 4 | 36 | 0 | 438 | 55 | 534 |
| 1989 | 0 | 12 | 66 | 0 | 0 | 306 | 384 |
| 1990 | | | 247 | | | 1,235 | 1,481 |
| 1991 | | | 626 | | | 233 | 859 |
| 1992 | | | 309 | | | 1,548 | 1,857 |
| 1993 | | | 859 | | | 4,530 | 5,389 |
| 1994 | | | 61 | | | 4,666 | 4,727 |
| 1995 | | | 266 | | | 3,858 | 4,124 |
| 1996 | | | 87 | | | 6,637 | 6,724 |
| 1997 | | | 164 | | | 1,996 | 2,161 |
| 1998 | | | 45 | | | 3,746 | 3,791 |
| 1999 | | | 157 | | | 5,492 | 5,650 |
| 2000 | | | 97 | | | 5,066 | 5,162 |
| 2001 | | | 180 | | | 6,309 | 6,488 |
| 2002 | | | 114 | | | 3,943 | 4,057 |
| 2003 | | | 67 | | | 4,862 | 4,929 |
| 2004 | | | 116 | | | 4,567 | 4,684 |
| 2005 | | | 112 | | | 3,852 | 3,964 |
| 2006 | | | 246 | | | 3,582 | 3,828 |
| 2007 | | | 70 | | | 3,946 | 4,016 |
| 2008 | | | 22 | | | 3,265 | 3,287 |
| 2009 | | | 48 | | | 3,064 | 3,111 |
| 2010 | | | 299 | | | 4,033 | 4,332 |
| 2011 | | | 198 | | | 2,566 | 2,764 |
| 2012 | | | 91 | | | 2,388 | 2,479 |
| 2013 | | | 137 | | | 1,900 | 2,038 |
| 2014* | | | 125 | | | 2,156 | 2,282 |

*Catch data through October 11, 2014, from NMFS Alaska Regional Office.

Table 4. Area-specific catches of northern rockfish (t) in the BSAI area, obtained from the North Pacific Groundfish Observer Program, NMFS Alaska Regional Office.

| Year | WAI | CAI | EAI | EBS | Total |
|---|---|---|---|---|---|
| 1994 | 1,572 | 2,534 | 560 | 61 | 4,727 |
| 1995 | 1,421 | 1,641 | 796 | 266 | 4,124 |
| 1996 | 3,146 | 1,978 | 1,514 | 87 | 6,724 |
| 1997 | 1,287 | 490 | 219 | 164 | 2,161 |
| 1998 | 2,392 | 916 | 438 | 45 | 3,791 |
| 1999 | 3,185 | 1,104 | 1,203 | 157 | 5,650 |
| 2000 | 1,516 | 2,347 | 1,202 | 97 | 5,162 |
| 2001 | 3,725 | 1,840 | 743 | 180 | 6,488 |
| 2002 | 2,328 | 1,318 | 298 | 114 | 4,057 |
| 2003 | 2,506 | 1,994 | 361 | 67 | 4,929 |
| 2004 | 1,947 | 2,410 | 211 | 116 | 4,684 |
| 2005 | 1,885 | 1,697 | 271 | 112 | 3,964 |
| 2006 | 1,139 | 2,138 | 306 | 246 | 3,828 |
| 2007 | 1,013 | 1,782 | 1,151 | 70 | 4,016 |
| 2008 | 1,314 | 1,344 | 608 | 22 | 3,287 |
| 2009 | 1,191 | 1,315 | 558 | 48 | 3,111 |
| 2010 | 1,988 | 1,266 | 778 | 299 | 4,332 |
| 2011 | 311 | 1,351 | 905 | 198 | 2,764 |
| 2012 | 140 | 1,651 | 597 | 91 | 2,479 |
| 2013 | 115 | 1,308 | 478 | 137 | 2,038 |
| 2014* | 83 | 1,110 | 963 | 125 | 2,282 |

* Estimated removals through October 11, 2014.

Table 5. Estimated retained, discarded, and percent discarded sharpchin/northern (SC/NO), and northern rockfish catch in the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions. The catches of the SC/NO group consist nearly entirely of northern rockfish.

| | Aleutian Islands | | | | | Eastern Bering Sea | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Species Group | Retained | Discarded | Total | Percent Discarded | Species Group | Retained | Discarded | Total | Percent Discarded |
| 1993 | SC/NO | 317 | 4218 | 4535 | 93.00% | Other red rockfish | 367 | 97 | 464 | 20.92% |
| 1994 | SC/NO | 797 | 3870 | 4667 | 82.92% | Other red rockfish | 29 | 100 | 129 | 77.59% |
| 1995 | SC/NO | 1208 | 2665 | 3873 | 68.82% | Other red rockfish | 274 | 70 | 344 | 20.42% |
| 1996 | SC/NO | 2269 | 4384 | 6653 | 65.89% | Other red rockfish | 58 | 149 | 207 | 71.92% |
| 1997 | SC/NO | 145 | 1852 | 1997 | 92.74% | Other red rockfish | 44 | 174 | 218 | 80.02% |
| 1998 | SC/NO | 458 | 3288 | 3747 | 87.76% | Other red rockfish | 38 | 59 | 97 | 61.06% |
| 1999 | SC/NO | 735 | 4759 | 5493 | 86.63% | Other red rockfish | 75 | 163 | 238 | 68.33% |
| 2000 | SC/NO | 592 | 4492 | 5084 | 88.37% | Other red rockfish | 111 | 140 | 155 | 90.22% |
| 2001 | SC/NO | 403 | 5906 | 6309 | 93.62% | SC/NO | 15 | 164 | 180 | 91.11% |
| 2002 | Northerns | 347 | 3595 | 3943 | 91.19% | Northerns | 9 | 105 | 113 | 92.42% |
| 2003 | Northerns | 188 | 4397 | 4585 | 95.89% | Northerns | 14 | 59 | 73 | 80.36% |
| 2004 | Northerns | 686 | 3881 | 4567 | 84.97% | Northerns | 35 | 82 | 116 | 70.23% |
| 2005 | Northerns | 912 | 2940 | 3852 | 76.32% | Northerns | 45 | 67 | 112 | 59.56% |
| 2006 | Northerns | 965 | 2617 | 3582 | 73.06% | Northerns | 109 | 137 | 246 | 55.56% |
| 2007 | Northerns | 850 | 3096 | 3946 | 78.45% | Northerns | 23 | 46 | 69 | 66.40% |
| 2008 | Northerns | 1523 | 1742 | 3265 | 53.34% | Northerns | 8 | 14 | 22 | 64.28% |
| 2009 | Northerns | 1941 | 1122 | 3064 | 36.63% | Northerns | 40 | 8 | 48 | 15.92% |
| 2010 | Northerns | 3070 | 963 | 4033 | 23.88% | Northerns | 284 | 15 | 299 | 4.91% |
| 2011 | Northerns | 2442 | 124 | 2566 | 4.85% | Northerns | 166 | 32 | 198 | 16.06% |
| 2012 | Northerns | 2009 | 379 | 2388 | 15.87% | Northerns | 45 | 46 | 91 | 50.38% |
| 2013 | Northerns | 1720 | 181 | 1900 | 9.51% | Northerns | 97 | 40 | 137 | 29.26% |
| 2014* | Northerns | 2078 | 78 | 2156 | 3.61% | Northerns | 68 | 57 | 125 | 45.73% |

* Estimated removals through October 11, 2014.

Table 6. Samples sizes of otoliths and lengths from fishery sampling, with the number of hauls from which these data were collected, from 1977-2013.

| Year | Lengths | Hauls | Otoliths collected | Otoliths read | Hauls (read otoliths) |
|---|---|---|---|---|---|
| 1977 | 1202 | 16 | 230 | 224** | 11 |
| 1978 | 759 | 11 | 148 | 148** | 16 |
| 1979 | | | | | |
| 1980 | | | | | |
| 1981 | | | | | |
| 1982 | 334** | 5 | | | |
| 1982 | | | | | |
| 1984 | 703** | 4 | | | |
| 1985 | 12** | 9 | 12 | 0 | 0 |
| 1986 | 100** | 2 | 100 | 0 | 0 |
| 1987 | 976** | 9 | 79 | 0 | 0 |
| 1988 | | | | | |
| 1989 | 80** | 1 | 80 | 0 | 0 |
| 1990 | 403** | 11 | | | |
| 1991 | 145** | 8 | | | |
| 1992 | | | | | |
| 1993 | 1809** | 16 | | | |
| 1994 | 767** | 8 | | | |
| 1995 | 833** | 14 | | | |
| 1996 | 4554 | 68 | | | |
| 1997 | 1** | 1 | | | |
| 1998 | 543 | 14 | 30 | 29** | 5 |
| 1999 | 917 | 42 | 50 | 0 | 0 |
| 2000 | 995* | 69 | 170 | 169* | 49 |
| 2001 | 661* | 70 | 136 | 135* | 58 |
| 2002 | 889* | 68 | 200 | 195* | 60 |
| 2003 | 1362* | 124 | 318 | 317* | 110 |
| 2004 | 842* | 78 | 198 | 196* | 69 |
| 2005 | 466* | 47 | 120 | 118* | 44 |
| 2006 | 895* | 73 | 231 | 230* | 71 |
| 2007 | 843* | 98 | 230 | 228* | 90 |
| 2008 | 897* | 127 | 271 | 270 | 125 |
| 2009 | 834* | 108 | 247 | 247 | 103 |
| 2010 | 1281 | 148 | 346 | | |
| 2011 | 1596* | 210 | 469 | 462 | 200 |
| 2012 | 1785 | 219 | 507 | | |
| 2013 | 2081 | 268 | 609 | | |

*Used to create age composition

Table 7. Northern rockfish biomass estimates (t) from Aleutian Islands trawl survey, with coefficients of variation shown in parentheses.

| | Aleutian Islands Management Sub-Areas | | | EBS estimates | |
|---|---|---|---|---|---|
| Year | Western | Central | Eastern | southern BS | Total |
| 1980 | | | | | 37,593 (0.90) |
| 1983 | | | | | 56,368 (0.15) |
| 1986 | | | | | 140,405 (0.34) |
| 1991 | 144,043 (0.21) | 64,119 (0.18) | 4,068 (0.52) | 582 (0.63) | 212,813 (0.15) |
| 1994 | 65,843 (0.65) | 15,832 (0.58) | 5,933 (0.54) | 855 (0.60) | 88,463 (0.50) |
| 1997 | 65,493 (0.38) | 18,363 (0.55) | 3,331 (0.58) | 204 (0.68) | 87,391 (0.31) |
| 2000 | 143,348 (0.39) | 37,949 (0.44) | 24,982 (0.70) | 49 (0.40) | 205,369 (0.30) |
| 2002 | 136,440 (0.33) | 38,819 (0.43) | 3,242 (0.42) | 290 (0.67) | 178,791 (0.27) |
| 2004 | 146,179 (0.27) | 26,913 (0.39) | 10,375 (0.37) | 5,980 (0.93) | 189,446 (0.22) |
| 2006 | 101,276 (0.29) | 72,961 (0.52) | 22,982 (0.45) | 22,883 (1.00) | 220,102 (0.25) |
| 2010 | 143,953 (0.29) | 51,331 (0.40) | 21,847 (0.50) | 189 (0.52) | 217,319 (0.22) |
| 2012 | 216,325 (0.65) | 52,674 (0.40) | 15,615 (0.60) | 550 (0.73) | 285,164 (0.50) |
| 2014 | 346,392 (0.38) | 48,049 (0.44) | 76,787 (0.79) | 1,668 (0.80) | 472,895 (0.31) |
| 1991-2014 mean | 150,929 | 42,701 | 18,916 | 3,325 | 215,871 |
| Percentage | 69.92% | 19.78% | 8.76% | 1.54% | |

Table 8. Sample sizes of otoliths and length measurement from the AI trawl survey, 1991-2014, with the number of hauls from which these data were collected.

| Year | Lengths | Hauls | Otoliths read | Hauls |
|---|---|---|---|---|
| 1980 | 3351 | 31 | 473 | 4 |
| 1983 | 6535 | 71 | 625 | 11 |
| 1986 | 5881 | 41 | 565 | 18 |
| 1991 | 4853 | 47 | 456 | 14 |
| 1994 | 6252 | 118 | 409 | 19 |
| 1997 | 7554 | 153 | 652 | 68 |
| 2000 | 7779 | 135 | 725 | 92 |
| 2002 | 9459 | 153 | 259 | 69 |
| 2004 | 12176 | 201 | 515 | 65 |
| 2006 | 8404 | 160 | 535 | 57 |
| 2010 | 11796 | 198 | 538 | 72 |
| 2012 | 10523 | 188 | 576 | 67 |
| 2014 | 14760 | 208 | | |

Table 9. Sample sizes of read otoliths by area and year in the Aleutian Islands surveys.

| Year | Western AI | Central AI | Eastern AI | Southern Bering Sea | Total |
|---|---|---|---|---|---|
| 1980 | 201 | 92 | 180 | | 473 |
| 1983 | 268 | 225 | 93 | 39 | 625 |
| 1986 | 132 | 293 | 25 | 115 | 565 |
| 1991 | | 243 | 159 | 54 | 456 |
| 1994 | 180 | 61 | 127 | 41 | 409 |
| 1997 | 234 | 219 | 199 | | 652 |
| 2000 | 229 | 275 | 200 | 21 | 725 |
| 2002 | 88 | 74 | 66 | 31 | 259 |
| 2004 | 193 | 156 | 120 | 46 | 515 |
| 2006 | 197 | 148 | 113 | 77 | 535 |
| 2010 | 195 | 186 | 139 | 18 | 538 |
| 2012 | 206 | 156 | 160 | 54 | 576 |

Table 10. Predicted weight and proportion mature at age for BSAI northern rockfish.

| Age | Predicted weight (g) | Proportion mature |
|---|---|---|
| 3 | 68 | 0.026 |
| 4 | 107 | 0.050 |
| 5 | 149 | 0.096 |
| 6 | 192 | 0.176 |
| 7 | 235 | 0.301 |
| 8 | 274 | 0.464 |
| 9 | 311 | 0.636 |
| 10 | 344 | 0.779 |
| 11 | 374 | 0.876 |
| 12 | 401 | 0.934 |
| 13 | 424 | 0.966 |
| 14 | 444 | 0.983 |
| 15 | 461 | 0.991 |
| 16 | 476 | 0.996 |
| 17 | 488 | 0.998 |
| 18 | 499 | 0.999 |
| 19 | 508 | 0.999 |
| 20 | 516 | 1 |
| 21 | 523 | 1 |
| 22 | 529 | 1 |
| 23 | 533 | 1 |
| 24 | 537 | 1 |
| 25 | 541 | 1 |
| 26 | 544 | 1 |
| 27 | 546 | 1 |
| 28 | 548 | 1 |
| 29 | 550 | 1 |
| 30 | 551 | 1 |
| 31 | 552 | 1 |
| 32 | 553 | 1 |
| 33 | 554 | 1 |
| 34 | 555 | 1 |
| 35 | 556 | 1 |
| 36 | 556 | 1 |
| 37 | 557 | 1 |
| 38 | 557 | 1 |
| 39 | 557 | 1 |
| 40 | 558 | 1 |

Table 11. Negative log likelihood of model components, average effective and input sample sizes, root mean squared errors and standard deviation of normalized residuals for the two models considered in this assessment.

| | Model 0 | Model 0.1 | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|---|---|
| **Negative log-likelihood** | | | | | | |
| *Data components* | | | | | | |
| AI survey biomass | 19.65 | 10.67 | 11.10 | 11.01 | 10.71 | 10.80 |
| Catch biomass | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Fishery age comp | 77.75 | 78.80 | 198.40 | 198.57 | 227.59 | 208.27 |
| Fishery length comp | 137.42 | 136.29 | 66.33 | 65.70 | 65.80 | 64.86 |
| AI survey age comp | 90.29 | 78.88 | 160.26 | 160.49 | 163.38 | 162.25 |
| AI survey lengths comp | 25.81 | 26.90 | 14.74 | 14.70 | 13.61 | 14.06 |
| Maturity | 7.21 | 7.21 | 7.21 | 7.21 | 7.21 | 7.21 |
| *Priors and penalties* | | | | | | |
| Recruitment | -1.01 | -2.19 | 1.92 | 1.64 | 2.45 | 1.62 |
| Prior on survey q | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Prior on M | 4.56 | 1.35 | 0.89 | 0.81 | 0.86 | 0.74 |
| Fishery selectivity | 0.00 | 0.00 | 0.00 | 0.00 | 4.97 | 4.57 |
| | | | | | | |
| Total negative log-likelihood | 365.78 | 342.34 | 465.28 | 464.54 | 500.95 | 478.73 |
| Parameters | 121 | 121 | 121 | 123 | 124 | 134 |
| Number of data points | | | 1024 | 1024 | 1024 | 1024 |
| BIC | | | 1769.26 | 1781.65 | 1861.40 | 1886.27 |
| AIC | | | 1172.56 | 1175.08 | 1249.89 | 1225.45 |
| | | | | | | |
| **Effective sample size** | | | | | | |
| Fishery age comp | 144 | 139 | 174 | 172 | 144 | 156 |
| Fishery length comp | 28 | 29 | 28 | 29 | 29 | 28 |
| AI survey age comp | 118 | 140 | 140 | 138 | 130 | 132 |
| AI survey lengths comp | 95 | 94 | 87 | 87 | 92 | 90 |
| | | | | | | |
| **Sample weights** | | | | | | |
| Fishery age comp | 59 | 59 | 167 | 167 | 167 | 167 |
| Fishery length comp | 66 | 66 | 30 | 30 | 30 | 30 |
| AI survey age comp | 62 | 78 | 157 | 157 | 157 | 157 |
| AI survey lengths comp | 277 | 277 | 132 | 132 | 132 | 132 |
| | | | | | | |
| **Root mean square error** | | | | | | |
| AI survey biomass | 0.502 | 0.497 | 0.511 | 0.508 | 0.498 | 0.500 |
| Recruitment | 0.622 | 0.642 | 0.699 | 0.695 | 0.717 | 0.701 |
| Fishery age comp | 0.015 | 0.015 | 0.014 | 0.014 | 0.014 | 0.014 |
| Fishery length comp | 0.047 | 0.047 | 0.047 | 0.047 | 0.047 | 0.047 |
| AI survey age comp | 0.022 | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 |
| AI survey lengths comp | 0.020 | 0.020 | 0.021 | 0.021 | 0.021 | 0.021 |
| | | | | | | |
| **Standard Deviation of Normalized Residuals** | | | | | | |
| AI survey biomass | 1.71 | 1.42 | 1.45 | 1.44 | 1.42 | 1.42 |
| Fishery age comp | 0.63 | 0.64 | 1.00 | 1.00 | 1.03 | 0.99 |
| Fishery length comp | 1.43 | 1.42 | 1.00 | 0.99 | 0.98 | 0.98 |
| AI survey age comp | 0.66 | 0.70 | 1.00 | 1.00 | 1.01 | 1.01 |
| AI survey lengths comp | 1.34 | 1.36 | 1.00 | 1.00 | 0.96 | 0.98 |

Table 12. Estimated time series of northern rockfish total biomass (t), spawner biomass (t), and recruitment (thousands) for each region.

| | Total Biomass (ages 3+) | | Spawner Biomass (ages 3+) | | Recruitment (age 3) | |
|---|---|---|---|---|---|---|
| | Assessment Year | | Assessment Year | | Assessment Year | |
| Year | 2014 | 2012 | 2014 | 2012 | 2014 | 2012 |
| 1977 | 129,004 | 98,338 | 48,863 | 38,155 | 38,346 | 27,256 |
| 1978 | 132,501 | 100,084 | 50,241 | 38,719 | 40,140 | 29,365 |
| 1979 | 135,330 | 101,233 | 52,158 | 39,715 | 31,119 | 21,848 |
| 1980 | 140,643 | 105,438 | 55,188 | 41,822 | 21,970 | 21,633 |
| 1981 | 147,186 | 110,591 | 58,175 | 43,963 | 52,577 | 35,921 |
| 1982 | 153,777 | 115,927 | 61,199 | 46,255 | 35,902 | 25,535 |
| 1983 | 159,187 | 120,675 | 64,144 | 48,557 | 17,266 | 18,679 |
| 1984 | 166,657 | 126,763 | 67,084 | 50,967 | 64,087 | 40,048 |
| 1985 | 172,448 | 131,692 | 69,903 | 53,376 | 22,698 | 18,658 |
| 1986 | 177,175 | 135,963 | 72,693 | 55,820 | 13,649 | 13,492 |
| 1987 | 186,891 | 144,325 | 75,459 | 58,284 | 120,272 | 82,887 |
| 1988 | 196,793 | 152,477 | 78,201 | 60,726 | 75,467 | 53,943 |
| 1989 | 205,810 | 159,683 | 80,982 | 63,189 | 38,798 | 30,272 |
| 1990 | 215,055 | 166,993 | 83,927 | 65,751 | 42,171 | 30,108 |
| 1991 | 222,496 | 173,030 | 87,005 | 68,312 | 36,447 | 30,058 |
| 1992 | 231,578 | 181,018 | 90,863 | 71,432 | 66,356 | 54,837 |
| 1993 | 237,564 | 186,276 | 94,468 | 74,143 | 24,682 | 21,804 |
| 1994 | 239,305 | 187,562 | 96,990 | 75,786 | 32,104 | 24,906 |
| 1995 | 239,610 | 188,059 | 99,441 | 77,571 | 9,311 | 10,873 |
| 1996 | 241,577 | 190,575 | 101,191 | 79,002 | 58,545 | 45,744 |
| 1997 | 239,532 | 189,608 | 102,010 | 79,754 | 29,604 | 30,425 |
| 1998 | 244,822 | 195,847 | 103,748 | 81,672 | 87,768 | 71,525 |
| 1999 | 248,386 | 200,409 | 104,157 | 82,478 | 59,051 | 53,351 |
| 2000 | 250,266 | 203,176 | 103,645 | 82,536 | 51,504 | 44,272 |
| 2001 | 252,523 | 206,016 | 103,208 | 82,712 | 44,089 | 34,834 |
| 2002 | 251,638 | 206,040 | 103,045 | 83,109 | 13,480 | 14,081 |
| 2003 | 252,437 | 207,683 | 104,224 | 84,747 | 22,841 | 16,249 |
| 2004 | 250,573 | 207,188 | 105,497 | 86,415 | 10,222 | 10,971 |
| 2005 | 248,379 | 206,322 | 106,888 | 88,213 | 25,434 | 17,324 |
| 2006 | 245,614 | 205,118 | 107,974 | 89,812 | 16,830 | 13,227 |
| 2007 | 242,560 | 203,544 | 108,216 | 90,694 | 25,097 | 17,303 |
| 2008 | 239,459 | 201,281 | 107,541 | 90,761 | 35,429 | 18,584 |
| 2009 | 236,034 | 198,981 | 106,402 | 90,410 | 14,606 | 12,296 |
| 2010 | 231,995 | 197,816 | 104,654 | 89,445 | 10,986 | |
| 2011 | 226,224 | 195,771 | 102,437 | 87,925 | 12,338 | |
| 2012 | 223,088 | 195,712 | 100,753 | 86,792 | | |
| 2013 | 220,860 | 195,446 | 99,230 | | | |
| 2014 | 219,801 | | 97,785 | | | |
| 2015 | 218,901 | | | | | |

Table 13. Projections of BSAI northern rockfish catch (t), spawning biomass (t), and fishing mortality rate for each of the several scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 59,167 t and 51,771 t, respectively.

| **Catch** | *Scenario 1* | *Scenario 2* | *Scenario 3* | *Scenario 4* | *Scenario 5* | *Scenario 6* | *Scenario 7* |
|---|---|---|---|---|---|---|---|
| 2014 | 2,468 | 2,468 | 2,468 | 2,468 | 2,468 | 2,468 | 2,468 |
| 2015 | 12,488 | 12,488 | 6,348 | 2,744 | 0 | 15,337 | 12,488 |
| 2016 | 11,640 | 11,640 | 6,116 | 2,694 | 0 | 14,074 | 11,640 |
| 2017 | 10,879 | 10,879 | 5,901 | 2,647 | 0 | 12,956 | 13,362 |
| 2018 | 10,235 | 10,235 | 5,723 | 2,612 | 0 | 12,017 | 12,379 |
| 2019 | 9,722 | 9,722 | 5,589 | 2,593 | 0 | 11,268 | 11,590 |
| 2020 | 9,332 | 9,332 | 5,502 | 2,591 | 0 | 10,693 | 10,979 |
| 2021 | 9,035 | 9,035 | 5,448 | 2,601 | 0 | 10,248 | 10,501 |
| 2022 | 8,802 | 8,802 | 5,416 | 2,619 | 0 | 9,896 | 10,119 |
| 2023 | 8,611 | 8,611 | 5,397 | 2,640 | 0 | 9,581 | 9,796 |
| 2024 | 8,449 | 8,449 | 5,385 | 2,663 | 0 | 9,255 | 9,468 |
| 2025 | 8,299 | 8,299 | 5,376 | 2,686 | 0 | 8,954 | 9,150 |
| 2026 | 8,156 | 8,156 | 5,368 | 2,708 | 0 | 8,698 | 8,869 |
| 2027 | 8,023 | 8,023 | 5,363 | 2,729 | 0 | 8,486 | 8,634 |
| **Sp. Biomass** | *Scenario 1* | *Scenario 2* | *Scenario 3* | *Scenario 4* | *Scenario 5* | *Scenario 6* | *Scenario 7* |
| 2014 | 97,785 | 97,785 | 97,785 | 97,785 | 97,785 | 97,785 | 97,785 |
| 2015 | 94,873 | 94,873 | 95,662 | 96,116 | 96,457 | 94,500 | 94,873 |
| 2016 | 88,665 | 88,665 | 92,333 | 94,502 | 96,160 | 86,974 | 88,665 |
| 2017 | 83,372 | 83,372 | 89,536 | 93,277 | 96,186 | 80,601 | 83,050 |
| 2018 | 79,148 | 79,148 | 87,464 | 92,643 | 96,738 | 75,500 | 77,682 |
| 2019 | 75,885 | 75,885 | 86,058 | 92,556 | 97,777 | 71,528 | 73,466 |
| 2020 | 73,377 | 73,377 | 85,169 | 92,888 | 99,189 | 68,443 | 70,158 |
| 2021 | 71,379 | 71,379 | 84,597 | 93,455 | 100,796 | 65,970 | 67,485 |
| 2022 | 69,743 | 69,743 | 84,230 | 94,160 | 102,512 | 63,940 | 65,276 |
| 2023 | 68,360 | 68,360 | 83,981 | 94,923 | 104,259 | 62,232 | 63,404 |
| 2024 | 67,156 | 67,156 | 83,795 | 95,694 | 105,988 | 60,778 | 61,796 |
| 2025 | 66,099 | 66,099 | 83,646 | 96,448 | 107,673 | 59,556 | 60,428 |
| 2026 | 65,179 | 65,179 | 83,534 | 97,187 | 109,317 | 58,546 | 59,286 |
| 2027 | 64,390 | 64,390 | 83,454 | 97,910 | 110,916 | 57,720 | 58,345 |
| **F** | *Scenario 1* | *Scenario 2* | *Scenario 3* | *Scenario 4* | *Scenario 5* | *Scenario 6* | *Scenario 7* |
| 2014 | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 | 0.013 |
| 2015 | 0.070 | 0.070 | 0.035 | 0.015 | 0.000 | 0.087 | 0.070 |
| 2016 | 0.070 | 0.070 | 0.035 | 0.015 | 0.000 | 0.087 | 0.070 |
| 2017 | 0.070 | 0.070 | 0.035 | 0.015 | 0.000 | 0.087 | 0.087 |
| 2018 | 0.070 | 0.070 | 0.035 | 0.015 | 0.000 | 0.087 | 0.087 |
| 2019 | 0.070 | 0.070 | 0.035 | 0.015 | 0.000 | 0.087 | 0.087 |
| 2020 | 0.070 | 0.070 | 0.035 | 0.015 | 0.000 | 0.087 | 0.087 |
| 2021 | 0.070 | 0.070 | 0.035 | 0.015 | 0.000 | 0.087 | 0.087 |
| 2022 | 0.070 | 0.070 | 0.035 | 0.015 | 0.000 | 0.087 | 0.087 |
| 2023 | 0.070 | 0.070 | 0.035 | 0.015 | 0.000 | 0.086 | 0.087 |
| 2024 | 0.070 | 0.070 | 0.035 | 0.015 | 0.000 | 0.086 | 0.086 |
| 2025 | 0.070 | 0.070 | 0.035 | 0.015 | 0.000 | 0.084 | 0.085 |
| 2026 | 0.070 | 0.070 | 0.035 | 0.015 | 0.000 | 0.083 | 0.084 |
| 2027 | 0.070 | 0.070 | 0.035 | 0.015 | 0.000 | 0.083 | 0.083 |

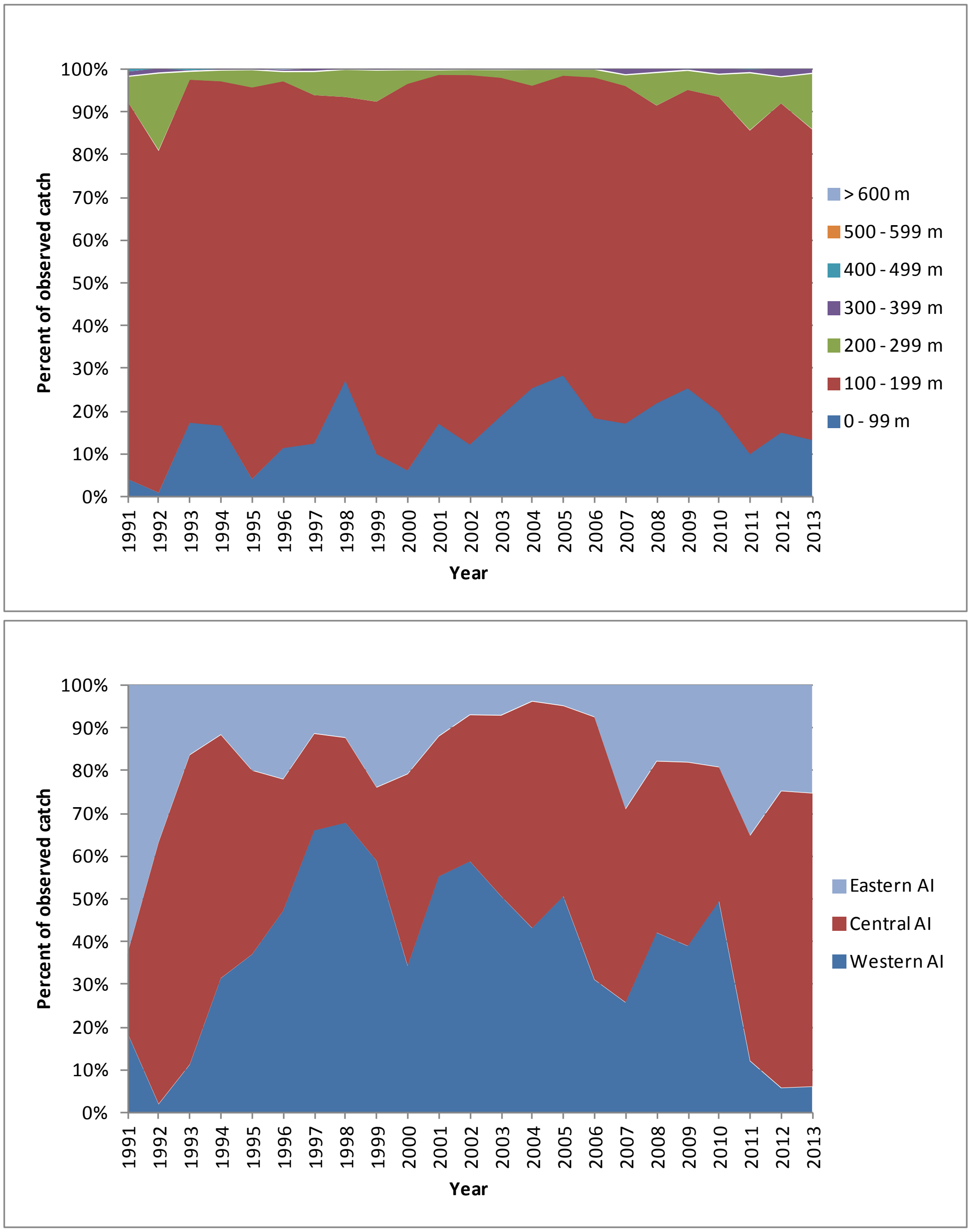


Figure 1. Distribution of observed Aleutian Islands northern rockfish catch (from North Pacific Groundfish Observer Program) by depth zone (top panel) and AI subarea (bottom panel) from 1991 to 2013.

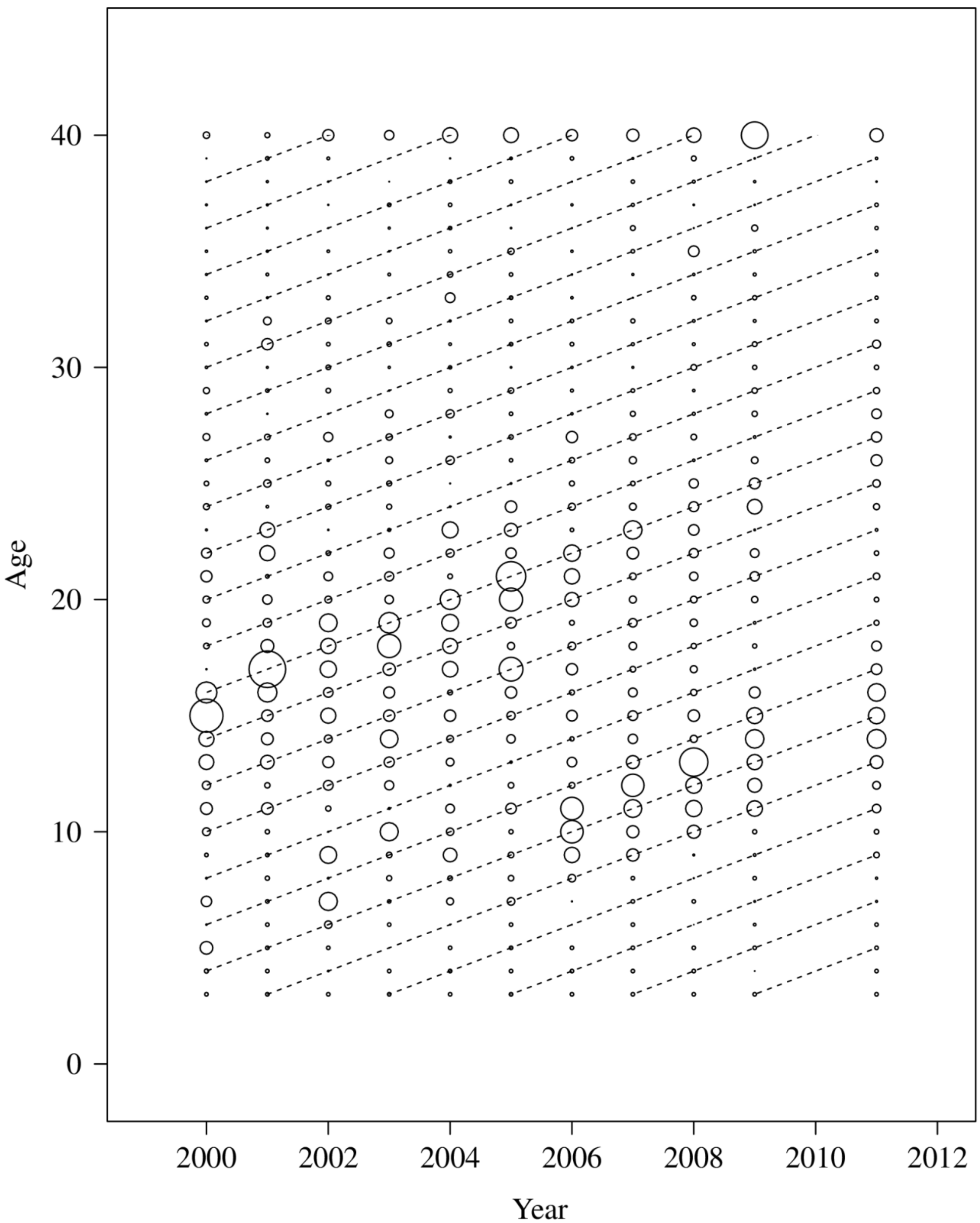


Figure 2. Fishery age composition data for the Aleutian Islands; bubbles are scaled within each year of samples; and dashed lines denote cohorts.

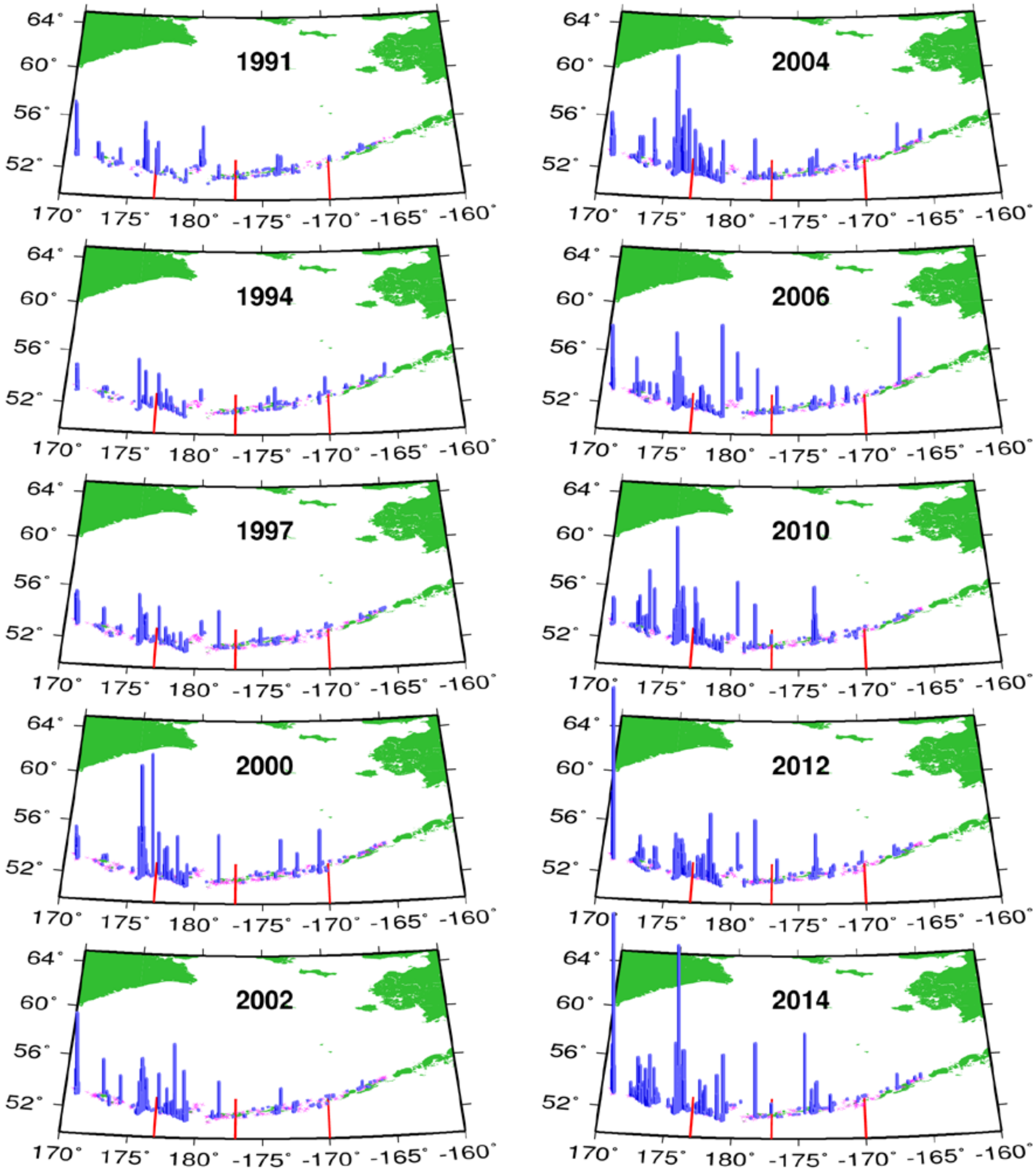


Figure 3. Scaled AI survey northern rockfish CPUE from (square root of $kg/km^2$) from 1991-2014; the red lines indicate boundaries between the WAI, CAI, EAI, and EBS areas.

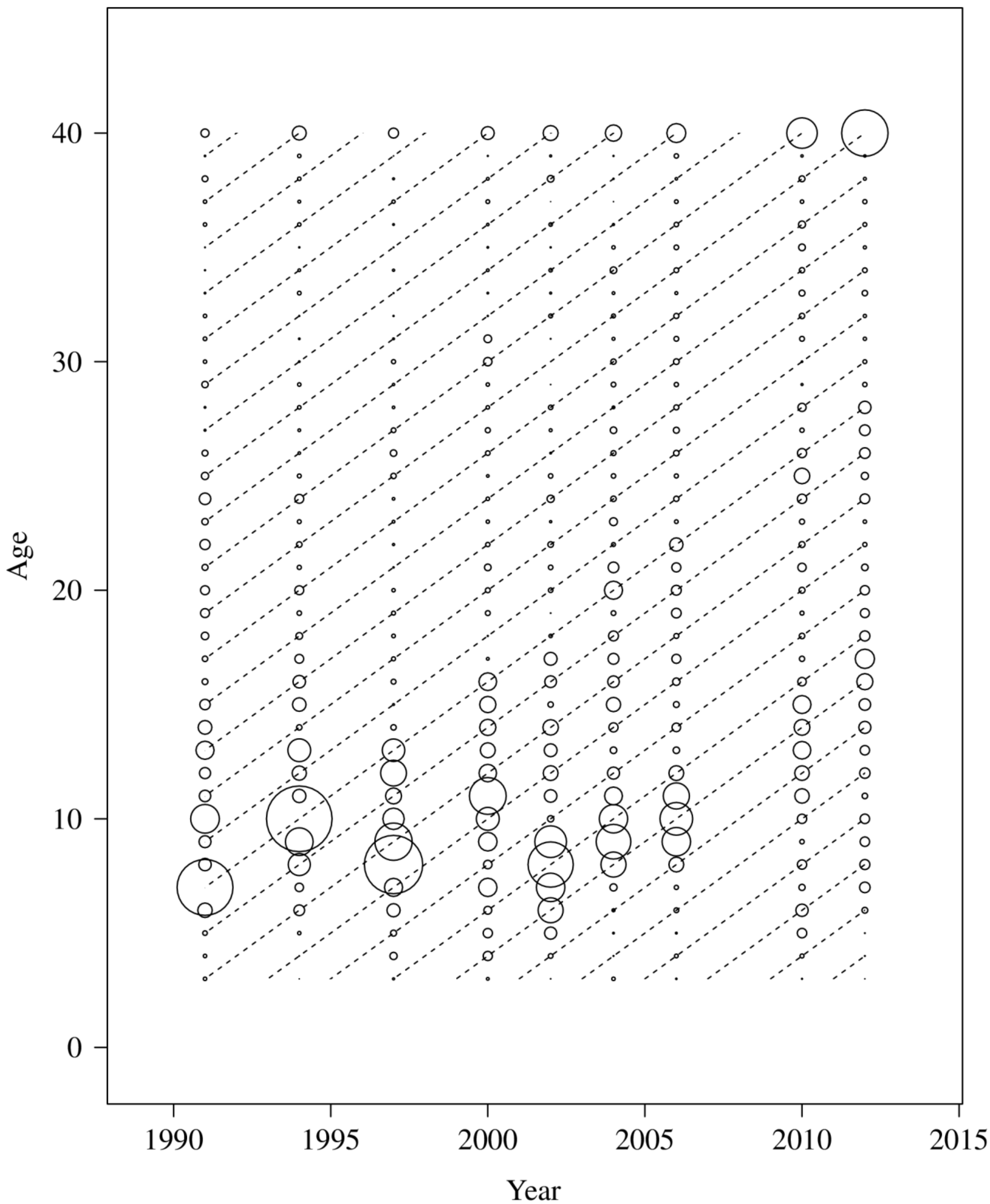


Figure 4. Age composition data from the Aleutian Islands trawl survey; bubbles are scaled within each year of samples; and dashed lines denote cohorts.

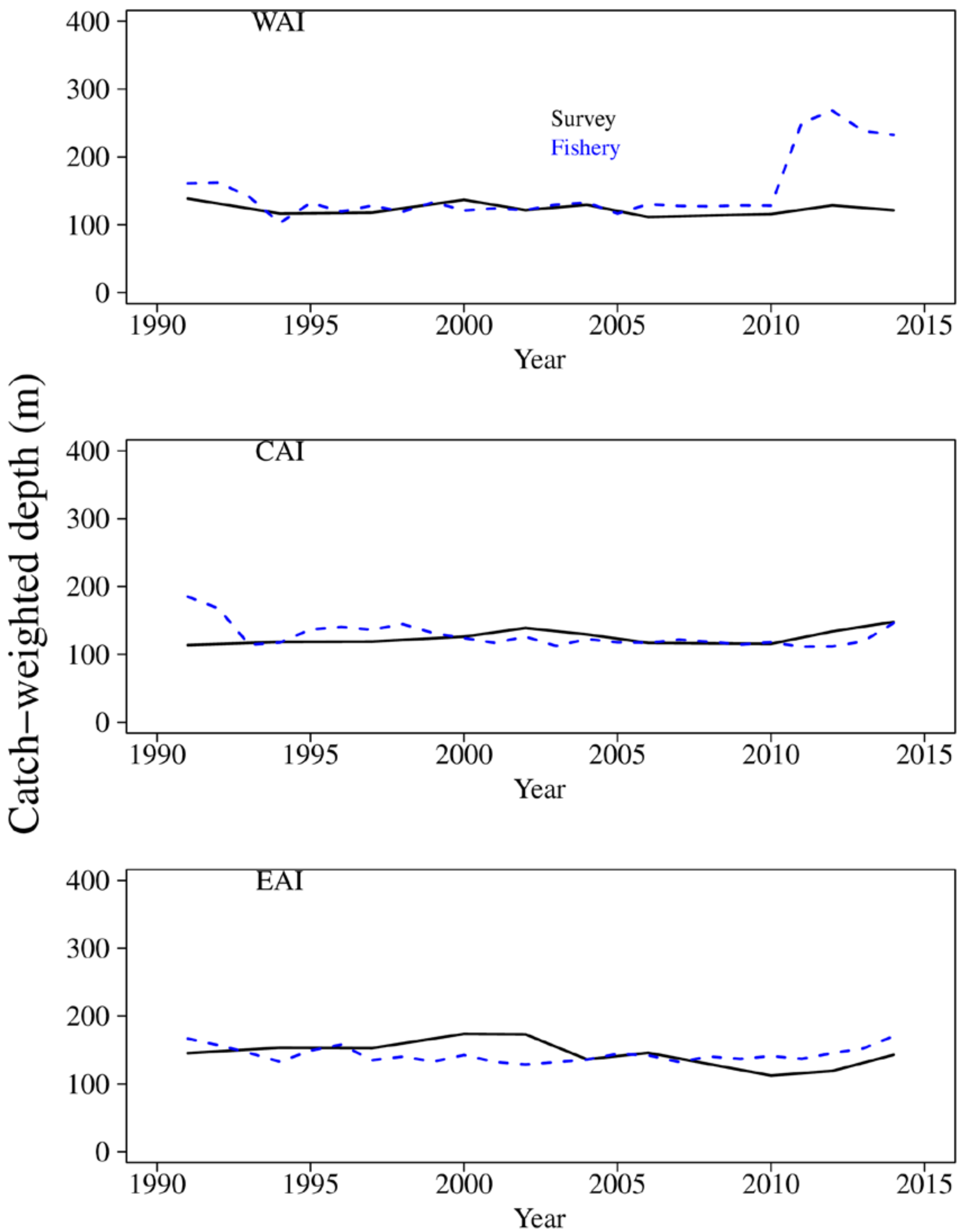


Figure 5. Catch-weighted (by numbers) depth of capture for northern rockfish in the fishery and AI survey by AI subarea from 1991 to 2014.

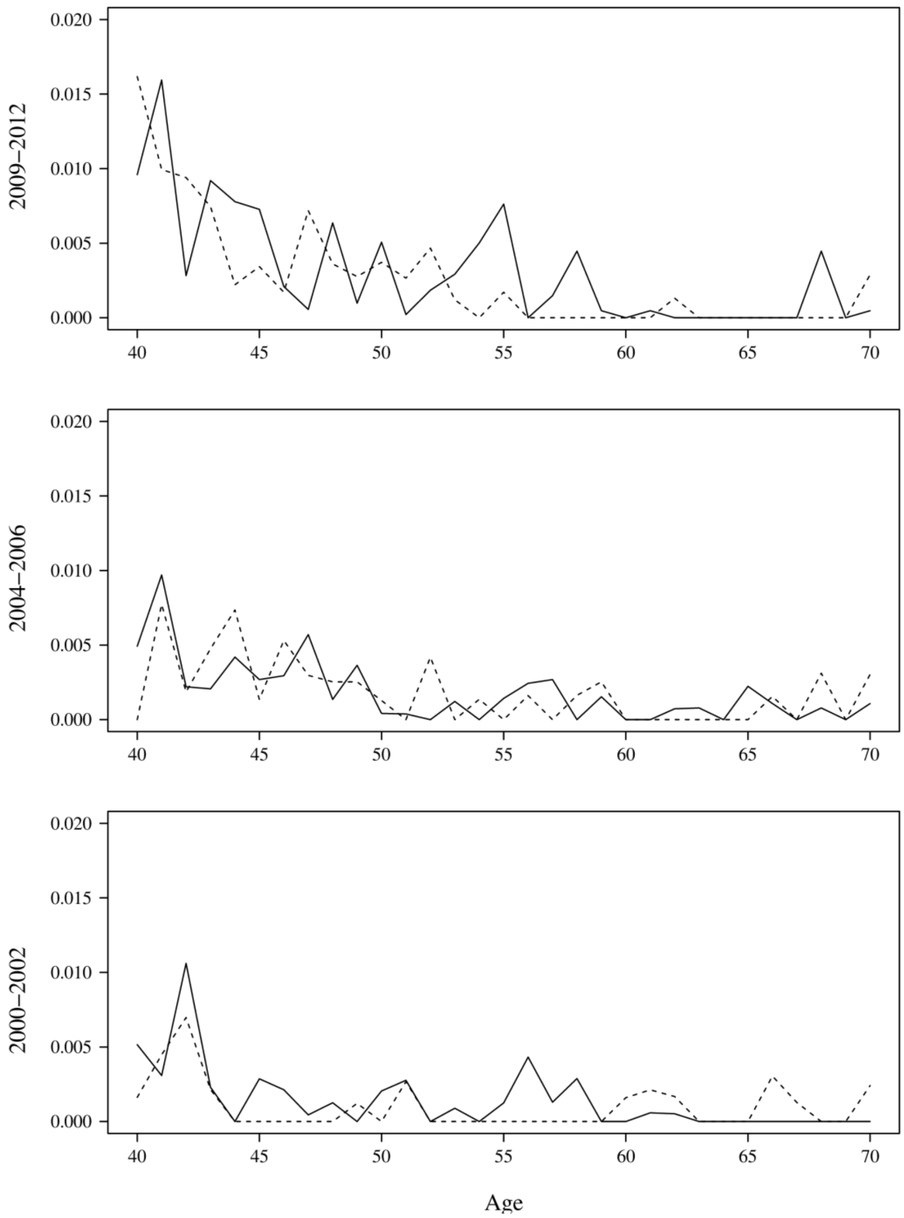


Figure 6. Age compositions in the Aleutian Islands survey (solid line) and fishery (dashed line) for ages 40 to 70+ for three time periods.

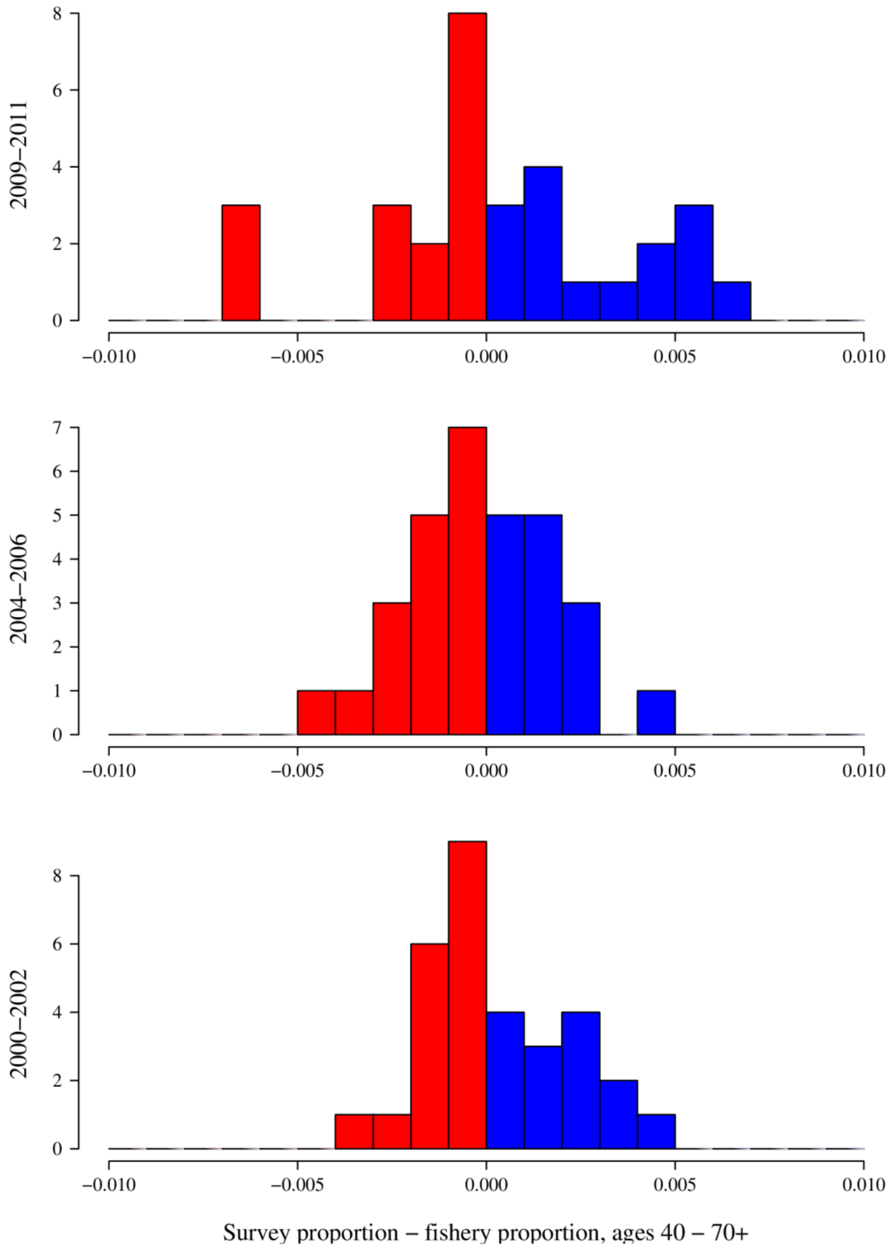


Figure 7. Histograms of the difference (survey proportion – fishery proportion) for ages 40 to 70+ for three time periods.

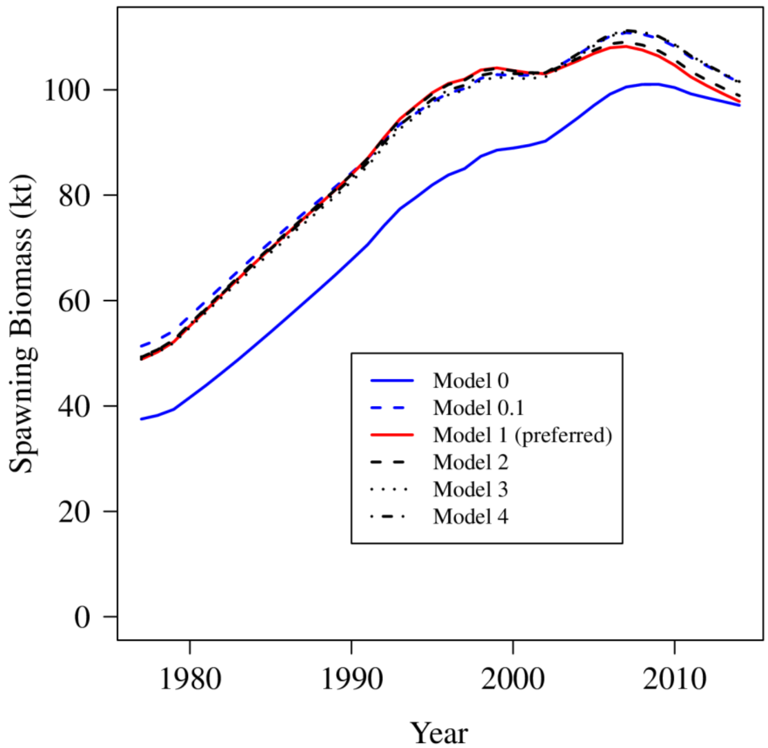


Figure 8. Estimated time series of spawning stock biomass across the models.

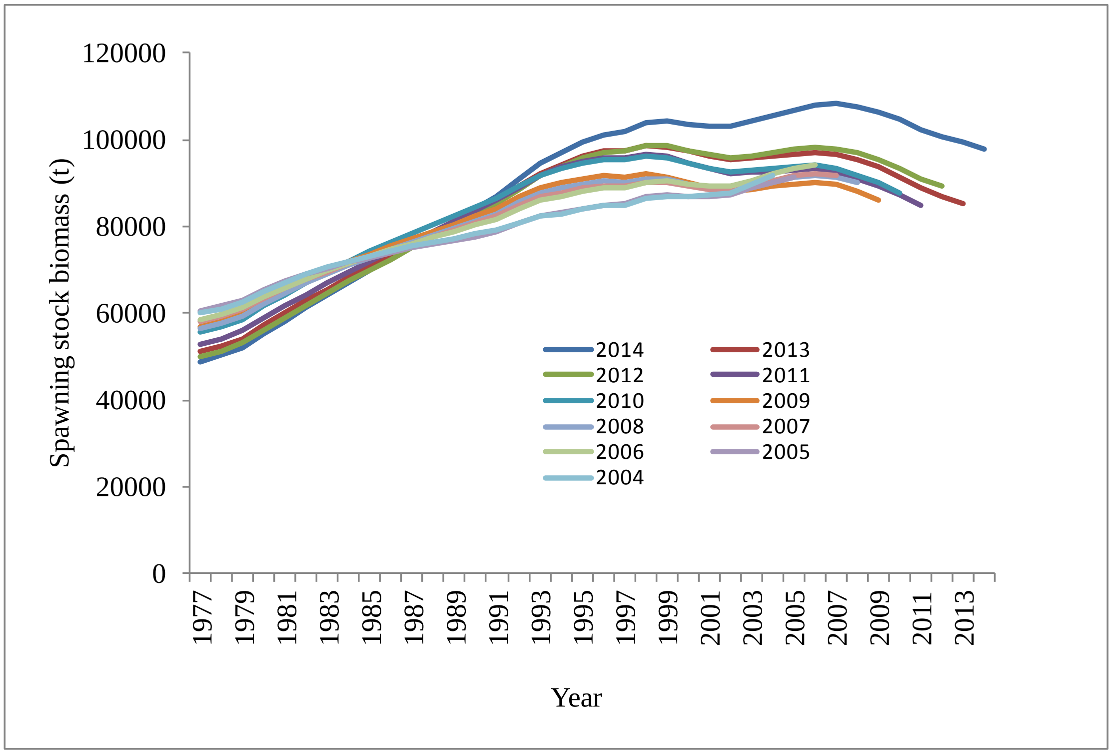


Figure 9. Retrospective estimates of spawning stock biomass for model runs with end years of 2004 to 2014.

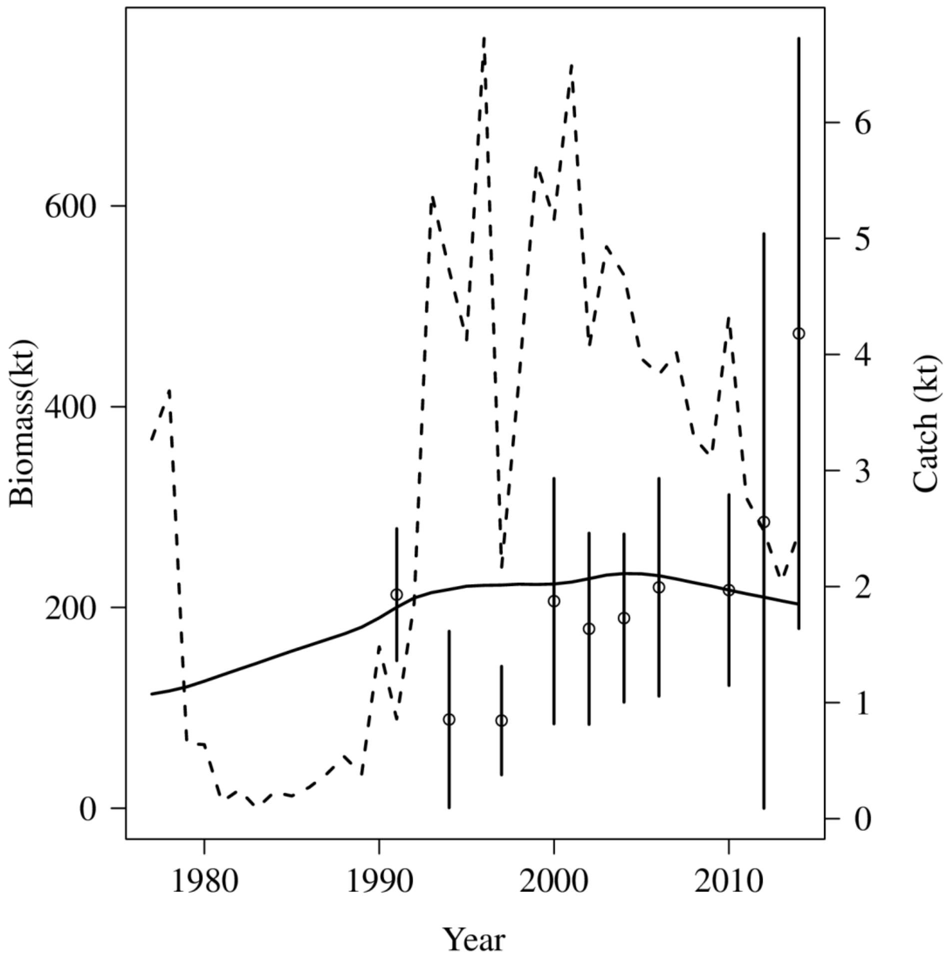


Figure 10. Observed Aleutian Islands survey biomass (data points, ± 2 standard deviations), predicted survey biomass (solid line) and BSAI harvest (dashed line).

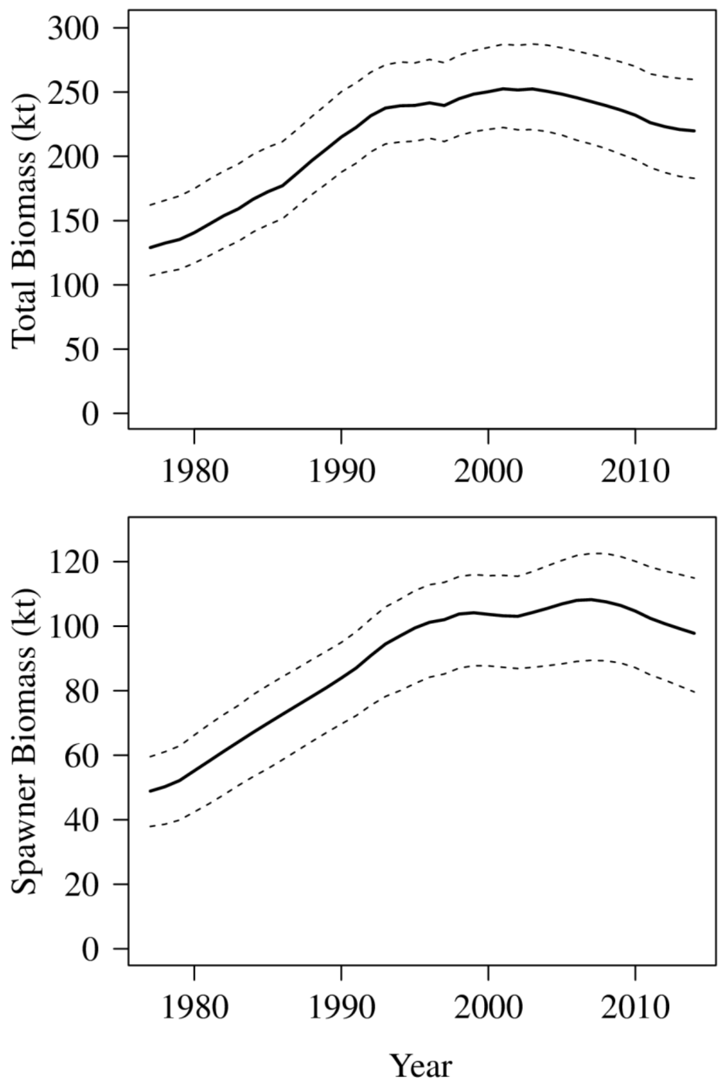


Figure 11. Total and spawner biomass for BSAI northern rockfish with 95% confidence intervals from MCMC integration.

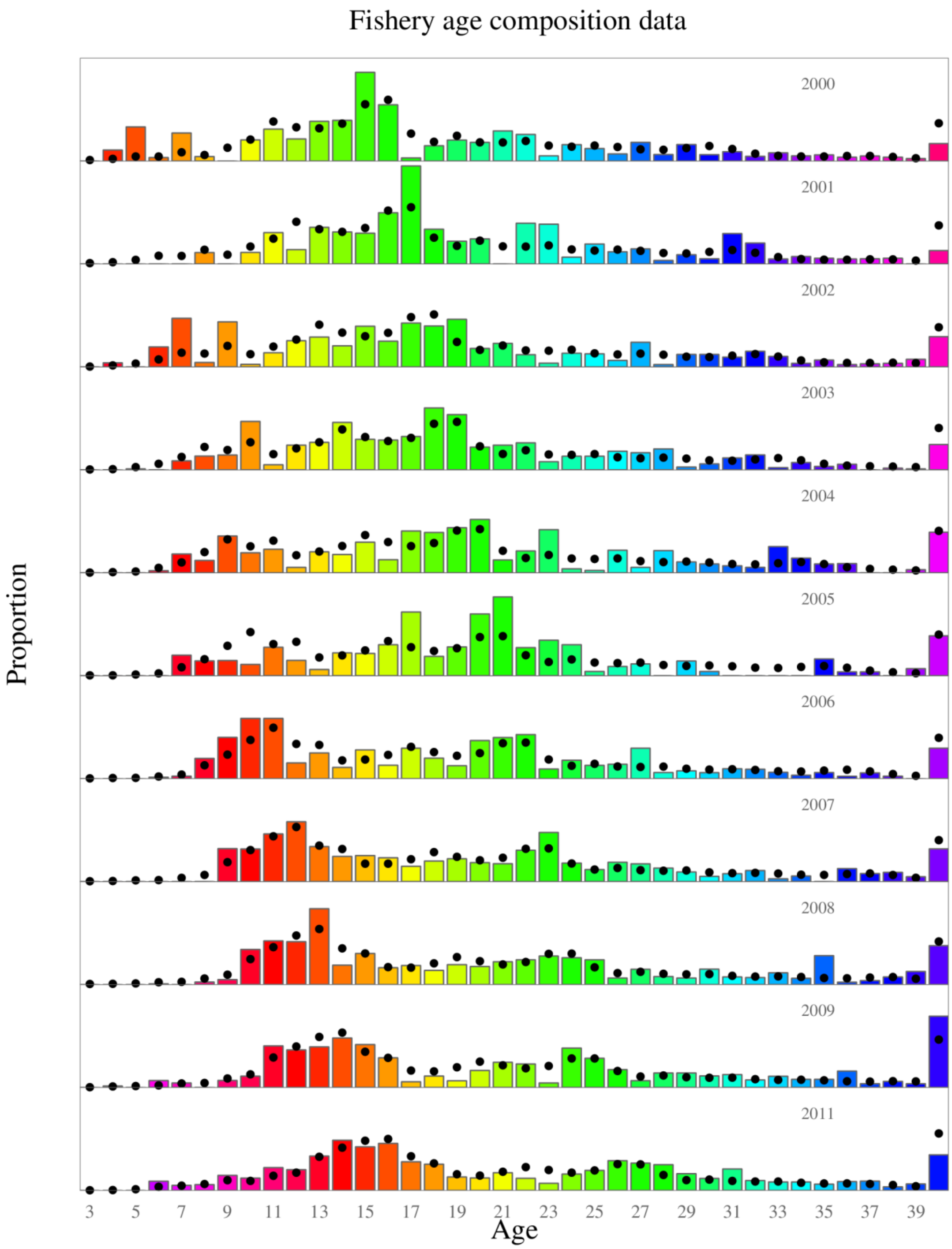


Figure 12. Model fits (dots) to the fishery age composition data (columns) for BSAI northern rockfish. Colors of the bars correspond to cohorts (except for the 40+ group).

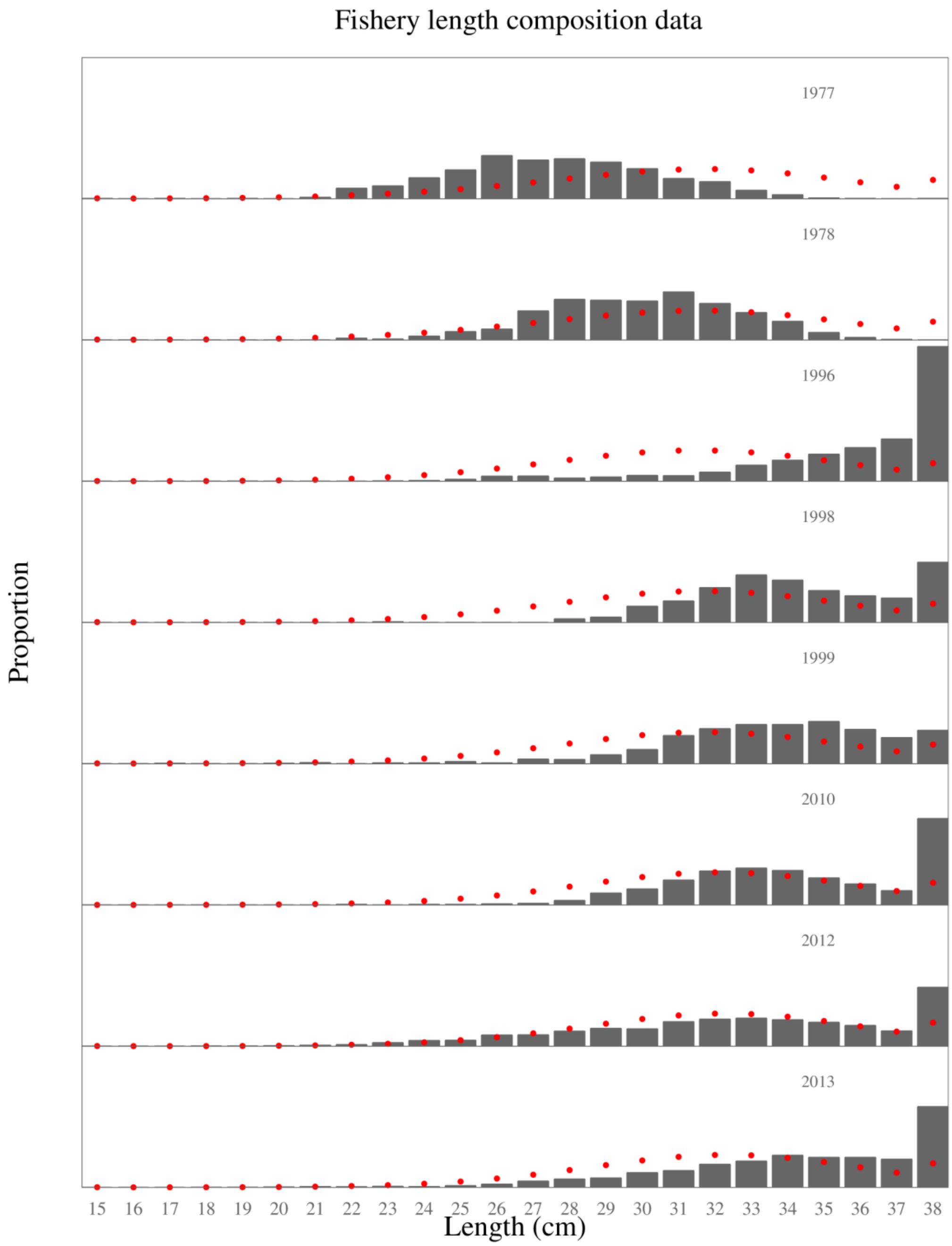


Figure 13. Model fits (dots) to the fishery length composition data (columns) for BSAI northern rockfish.

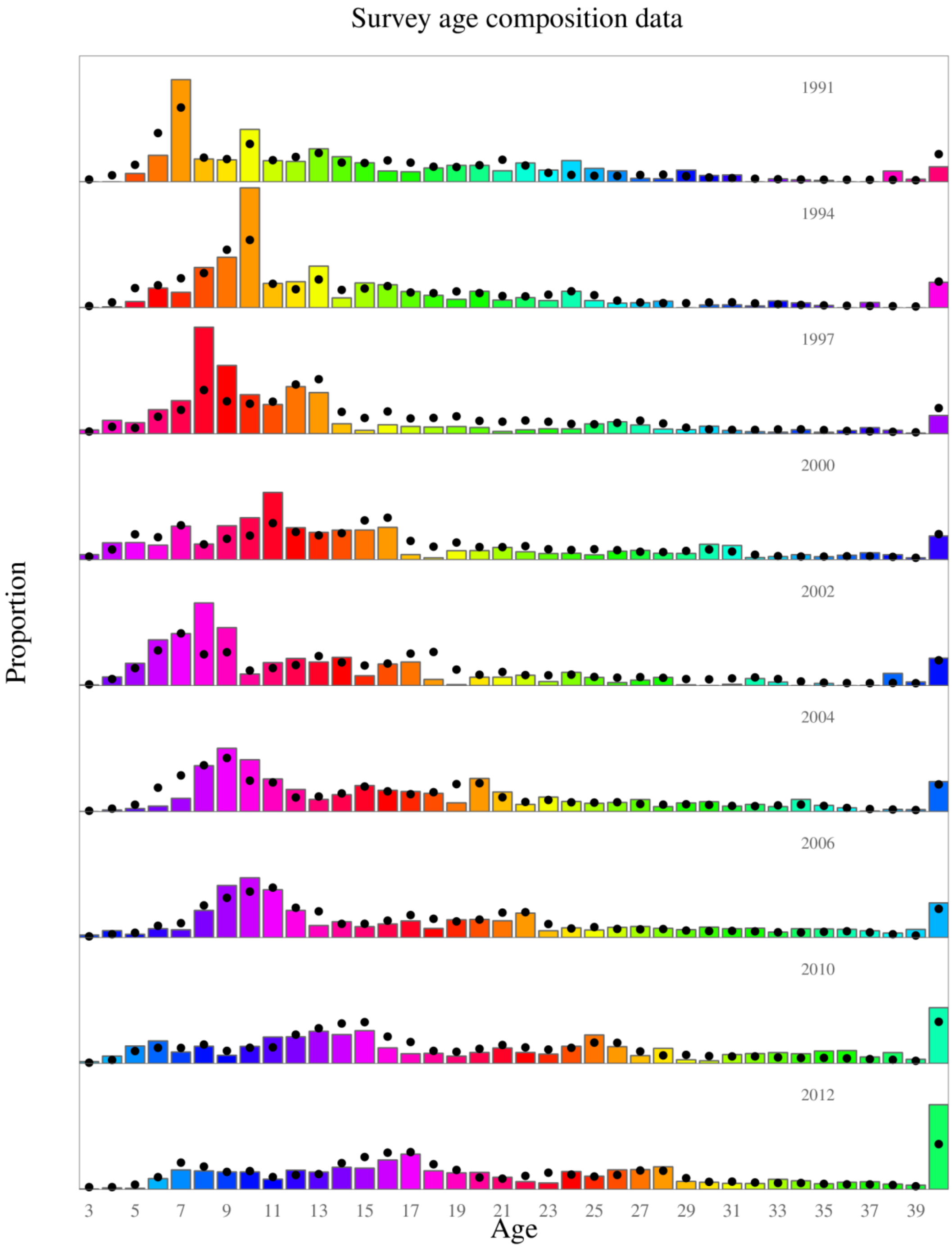


Figure 14. Model fits (dots) to the survey age composition data (columns) for BSAI northern rockfish. Colors of the bars correspond to cohorts (except for the 40+ group).

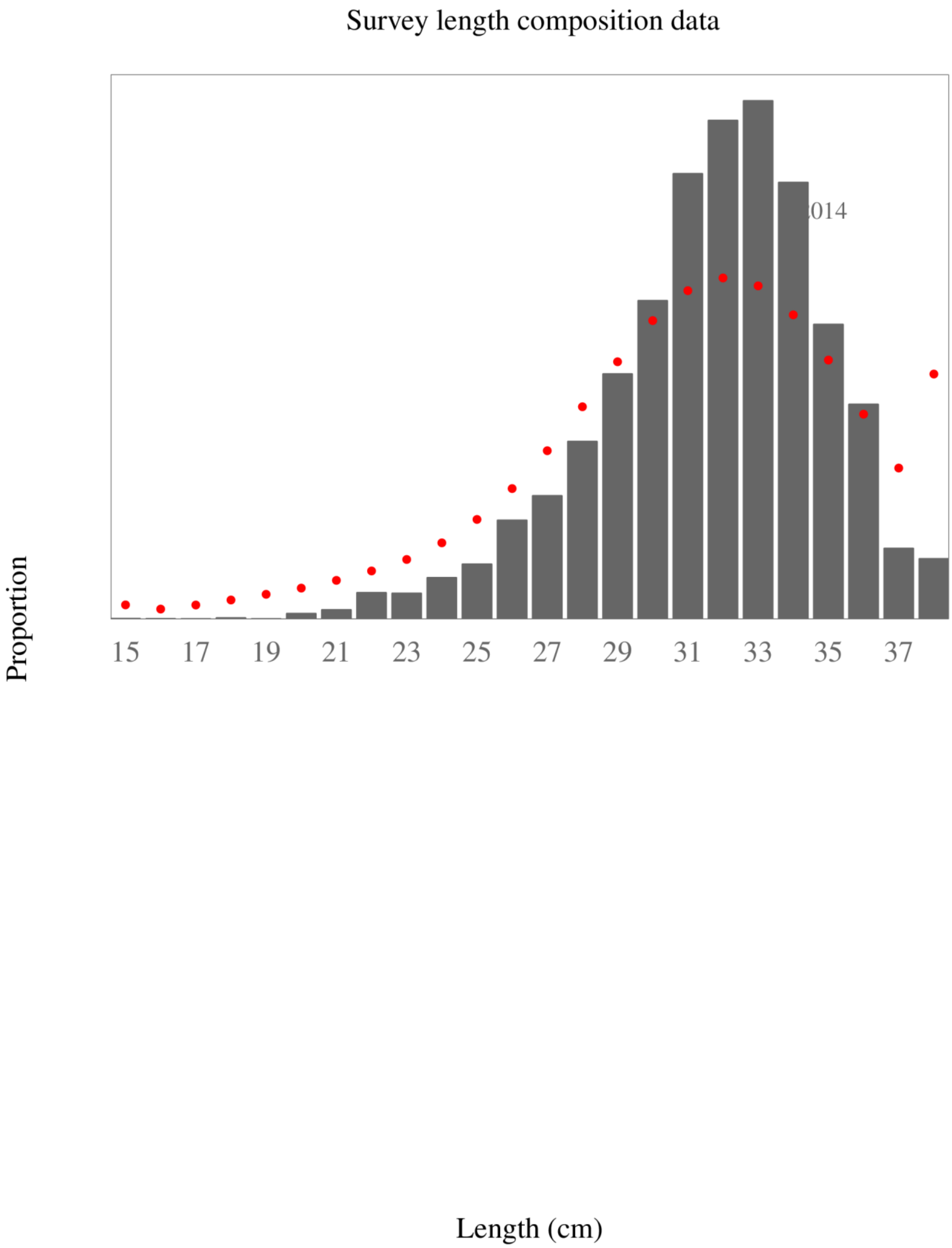


Figure 15. Model fits (dots) to the 2014 survey length composition data (columns) for BSAI northern rockfish.

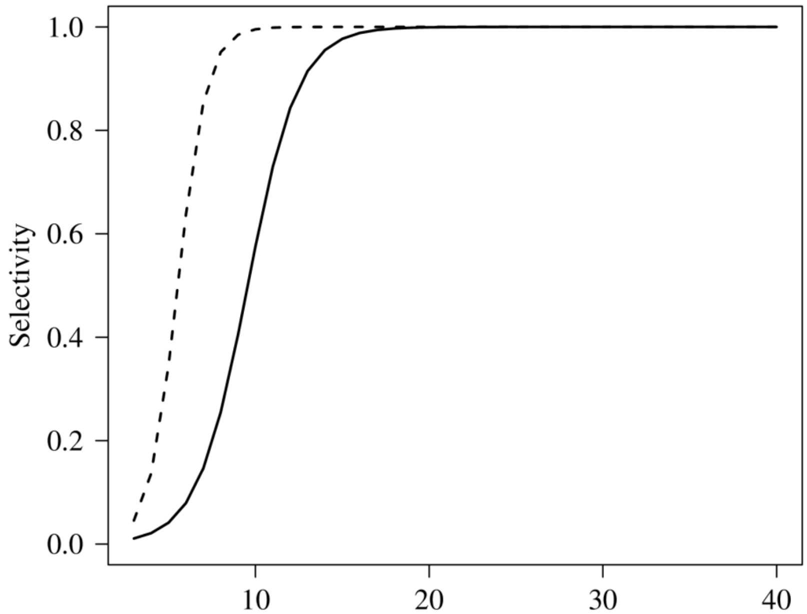


Figure 16. Estimated fishery (solid line) and survey (dashed line) selectivity at age for BSAI northern rockfish.

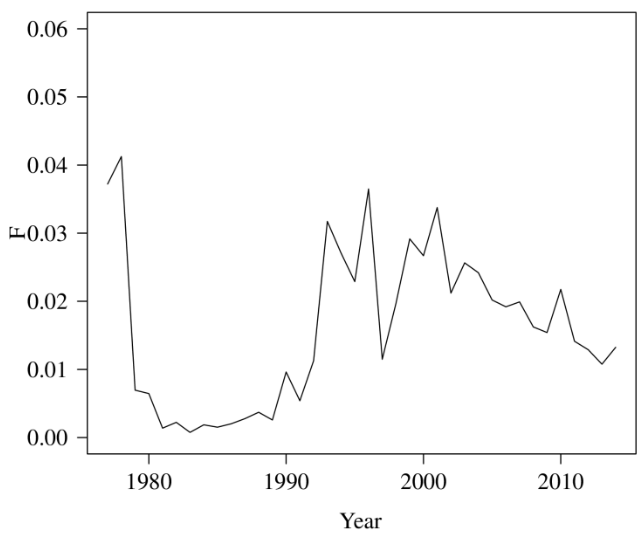


Figure 17. Estimated fully-selected fishing mortality rate for BSAI northern rockfish.

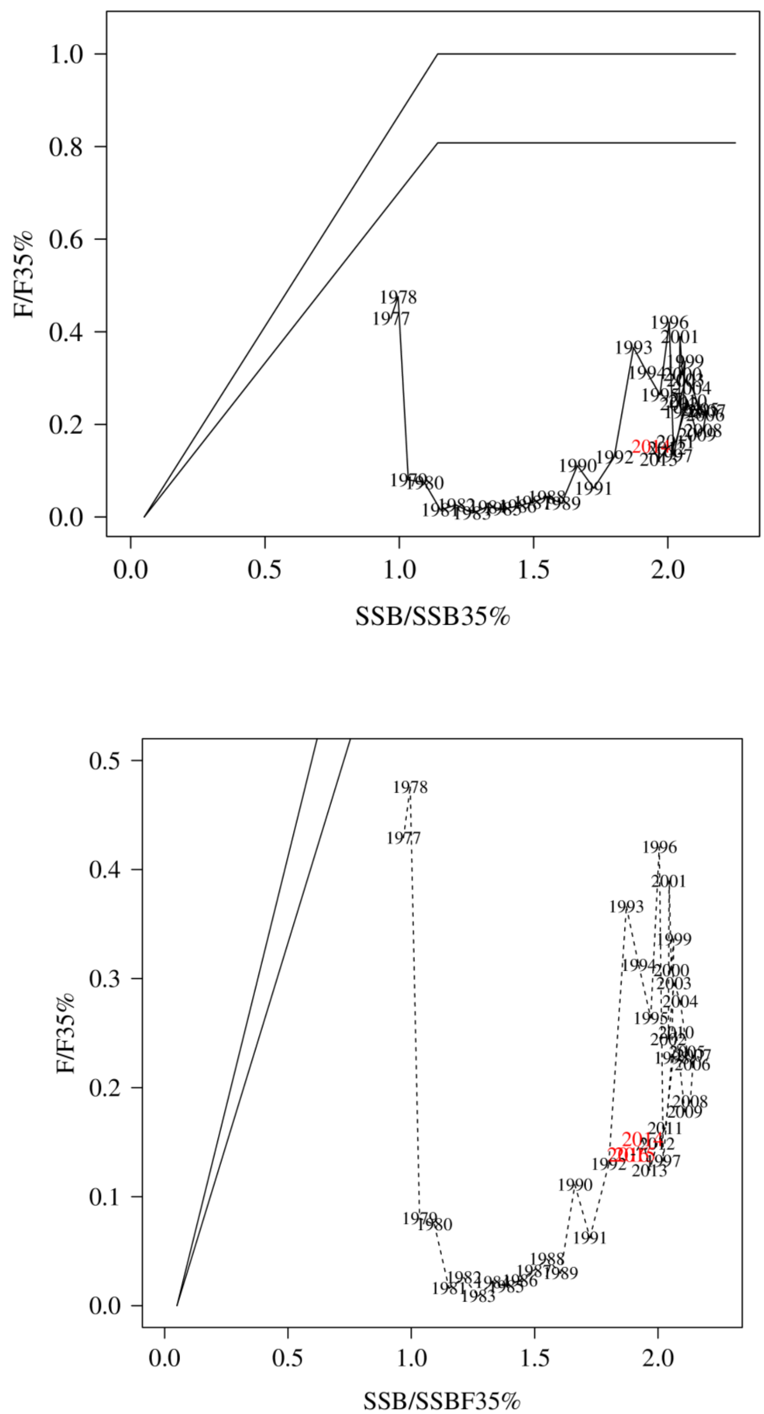


Figure 18. (Top panel) Estimated fishing mortality and SSB from 1977-2014 (with 2014 in red) in reference to OFL (upper line) and ABC (lower line) harvest control rules. The bottom panel shows a reduced vertical scale, and the projected F and stock size for 2015 and 2016.

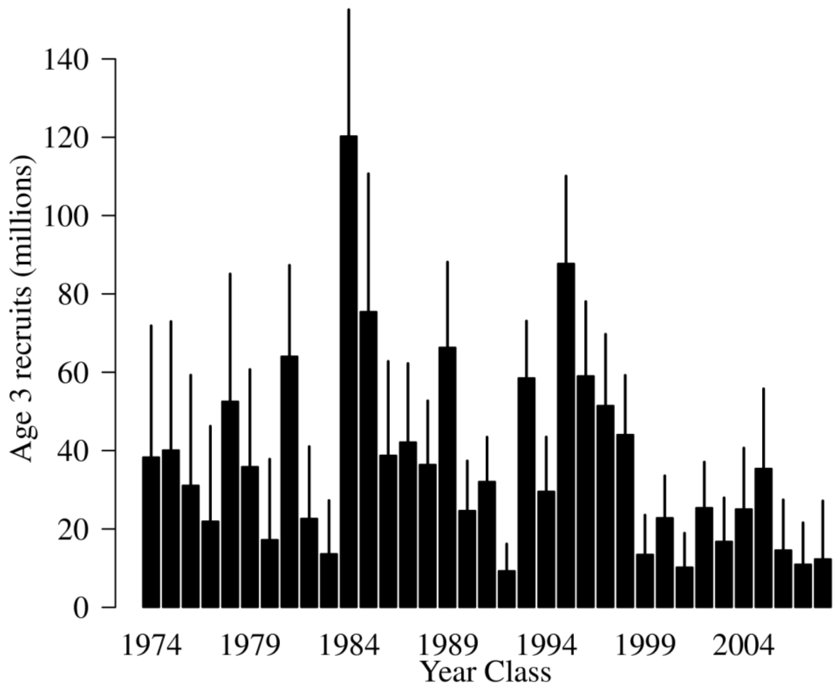


Figure 19. Estimated recruitment (age 3) of BSAI northern rockfish, with 95% CI limits obtained from MCMC integration.

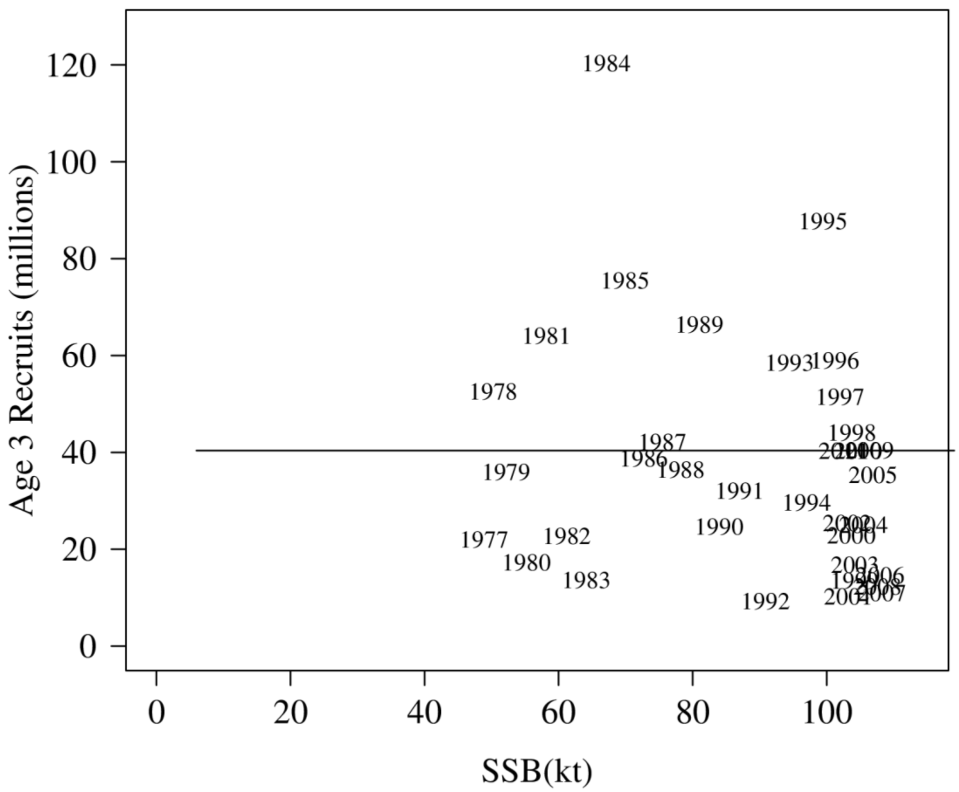


Figure 20. Scatterplot of BSAI northern rockfish spawner-recruit data; label is year class.

# 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 northern rockfish, these estimates can be compared to the trawl research removals reported in previous assessments. BSAI northern rockfish 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 northern rockfish. The annual amount of northern rockfish captured in research longline gear not exceeded 0.06 t. Total removals ranged between 0.05 t and 140 t between 2010 and 2014, which were less than 1.6% of the ABC in these years.

Appendix Table A1. Removals of BSAI northern rockfish from activities other than groundfish fishing. 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 | | | | |
| 1978 | | 0.000 | | |
| 1979 | | 0.012 | | |
| 1980 | | 3.576 | | |
| 1981 | | 0.059 | | |
| 1982 | | 0.898 | | |
| 1983 | | 29.285 | | |
| 1984 | | 0.095 | | |
| 1985 | | 0.021 | | |
| 1986 | | 56.895 | | |
| 1987 | | 0.168 | | |
| 1988 | | 0.130 | | |
| 1989 | | 0.062 | | |
| 1990 | | 0.740 | | |
| 1991 | | 15.470 | | |
| 1992 | | 0.077 | | |
| 1993 | NMFS-AFSC survey databases | 0.001 | | |
| 1994 | | 13.155 | | |
| 1995 | | 0.015 | | |
| 1996 | | 0.001 | 0.034 | |
| 1997 | | 17.728 | | |
| 1998 | | 0.252 | 0.004 | |
| 1999 | | 0.089 | | |
| 2000 | | 39.883 | 0.002 | |
| 2001 | | 0.038 | 0.006 | |
| 2002 | | 36.657 | 0.011 | |
| 2003 | | 0.124 | 0.002 | |
| 2004 | | 56.763 | 0.005 | |
| 2005 | | 0.002 | 0.002 | |
| 2006 | | 41.112 | 0.059 | |
| 2007 | | 0.172 | 0.008 | |
| 2008 | | 0.026 | 0.008 | |
| 2009 | | 0.005 | 0.023 | |
| 2010 | | 50.354 | 0.025 | |
| 2011 | | 140.163 | 0.022 | |
| 2012 | AKFIN database | 89.765 | 0.021 | |
| 2013 | | 0.014 | 0.039 | |
| 2014 | | 69.148 | 0.000 | |

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