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 2014. The following changes were made to northern rockfish assessment relative to the November 2014 SAFE:

Summary of Changes in Assessment Inputs

Changes in the input data:

1) Catch data was updated through 2015, and total catch for 2016 was projected.
2) The 2016 AI survey biomass estimate and length composition was included in the assessment.
3) The 2014 AI survey age composition was included in the assessment.
4) The 2013 fishery age composition replaced the 2013 fishery length composition data in the assessment.
5) The 2014 and 2015 fishery length composition data was included in the assessment.
6) The fishery age and length composition data were recomputed to weight the length composition within subareas by the observed subarea catch.
7) 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.

Changes in the Assessment Methodology

1) In the 2014 assessment, the weights for the age/length composition data were obtained such that the standardized deviation of normalized residuals was a constant value (1) for all composition data types. Several methods for weighting the composition data were considered in this assessment, with the preferred model using the McAllister-Ianelli method.

Summary of Results

BSAI northern rockfish are not overfished or approaching an overfished condition. The recommended 2017 ABC and OFL are 13,264 t and 16,242 t, which are 16% and 15% increases from the values specified last year for 2017 of 11,468 t and 14,242 t. The Aleutian Islands survey biomass estimates remains high, which has resulted in increased biomass estimates relative to the 2014 assessment. The F_{abc} decreased 7.1% from the 2014 assessment (from 0.070 to 0.065), which is attributed to a 6.1% decrease in estimate natural mortality (from 0.049 to 0.046). 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: 2016	2017	As estimated or recommended this year for: 2017*	2018*
M (natural mortality rate)	0.049	0.049	0.046	0.046
Tier	3a	3a	3a	3a
Projected total (age 3+) biomass (t)	213,674	209,369	248,160	245,693
Female spawning biomass (t)				
Projected	91,648	88,326	107,660	106,184
$B_{100\%}$	144,420	144,420	164,674	164,674
$B_{40\%}$	57,768	57,768	65,870	65,870
$B_{35\%}$	50,547	50,547	57,636	57,636
F_{OFL}	0.087	0.087	0.080	0.080
$maxF_{ABC}$	0.070	0.070	0.065	0.065
F_{ABC}	0.070	0.070	0.065	0.065
OFL (t)	14,689	14,085	16,242	15,854
maxABC (t)	11,960	11,468	13,264	12,947
ABC (t)	11,960	11,468	13,264	12,947
Status	As determined last year for: for: 2014	2015	As determined this year for: 2015	2016
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

*Projections are based on estimated catches of 4,375 t and 5,631 t used in place of maximum permissible ABC for 2017 and 2018.

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
2015	218,901	15,337	12,488	3,250	7,197
2016	213,674	14,689	11,960	4,500	4,258[2]
2017	248,160	16,242	13,264		
2018	245,693	15,584	12,947		

[1] Total biomass from age-structured projection model.
[2] Catch as of October 10, 2016.

Responses to SSC and Plan Team Comments on Assessments in General

(Joint Plan Team, November, 2014) *For assessments involving age-structured models, this year's CIE review of BSAI and GOA rockfish assessments included three main recommendations for future research:*

1. Selectivity/fit to plus group (e.g., explore dome-shaped selectivity, cubic splines)

2. Reevaluation of natural mortality

3. Alternative statistical models for survey data (e.g., GAM, GLM, hurdle models)

The Team agreed that development of alternative survey estimators is a high priority, but concluded that this priority is not specific to rockfish, and should be explored in a Center-wide initiative (see "Alternative statistical models for survey data" under Joint Team minutes). For the remaining two items, the Team recommended that selectivity and fit to the plus group should be given priority over reevaluation of the natural mortality rate.

Selectivity curves and natural mortality rates were evaluated in the 2014 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. Recently, scientists at the NWFSC has developed geostatistical models for survey standardization.

The minutes of the September, 2016 meeting of the Joint Groundfish Plan Team indicate that a workgroup is currently being formed to evaluate statistical models for survey standardization.

(SSC, October 2016) *The SSC requests that stock assessment authors bookmark their assessment documents and commends those that have already adopted this practice.*

Bookmarks for the major sections of the assessment were added to the 2016 document.

Responses to SSC and Plan Team Comments Specific to this Assessment

(BSAI Plan Team, November, 2014) *The Team expressed some concern about the substantial increase in the natural mortality estimate from 2012. The Plan Team recommends that Paul report back on what values for natural mortality were used in Then et al. (2014) to determine whether longevity-based estimators were superior.*

(SSC, December, 2014) *The SSC shares PT concern about the substantial increase in the natural mortality estimate from 2012 and requests the author provide further evaluation.*

A review of information used to develop prior distributions on natural mortality was presented in the 2015 assessment, and noted that the mean of prior used in the assessment (0.06) was lower than an updated estimate from Then et al. (2014) of 0.08. Additionally, the value of M in the 2014 assessment (0.041) is lower than the value estimated in the 2015 GOA assessment (0.059).

In this assessment, the mean (0.06) and CV (0.15) were unchanged from the 2014 assessment, and resulted in a value of M of 0.046. Alternative prior distributions can be considered in future assessment, and would raise the mean of the prior distribution to be consistent with the results of Then et al (2014) and the estimate from the GOA northern rockfish.

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 Bertalanffy 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. Additionally, size at age in the GOA is larger than that in the AI, indicating an east-west cline in growth (Clausen and Heifetz 2002)

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 Samalga 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 from 2011-2014 have restricted the current northern rockfish harvest in this area, and during these years 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).

Although northern rockfish are generally harvested as a bycatch species, targeting of northern rockfish has occurred in recent years, perhaps as a result of restrictions of the Atka mackerel fishery. Observer catch records were used to identify the targeted species of tows, based on the dominant species in the catch. The number of tows targeting northern rockfish, and the amount and percentage of northern rockfish caught in these tows, increased in the central Aleutian Islands beginning in 2011, and in the eastern Aleutian Islands beginning in 2013 (Spencer 2016). In 2015, this targeting resulted in a catch of 7197 t exceeding the TAC of 3250 t, although the 2015 catch was below the ABC of 12,488 t (in recent years, the TAC for northern rockfish is usually set the much lower than the ABC). Additionally, the catch in 2015 in eastern AI resulted in an estimated exploitation rate in this area that exceeded what expected exploitation rate had subarea ABCs been in place (Spencer 2016). Efforts by the fishing industry to reduce targeting in 2016 has resulted in lower catches.

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 15% from 2011 – 2014 with the closure of the western AI to Atka mackerel fishing in these years. 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 14% from 2008 – 2015.

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 5). Discard rates in the AI have declined from 90% in 2003 to < 10% in most years since 2011. In the Eastern Bering Sea, discard rates have declined from 75% in 2003 to < 5% in 2010, and have ranged from 29% to 50% from 2012 to 2015.

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.

Length measurements and otoliths read from the EBS and AI management areas were combined to create fishery age/size composition matrices, with the length composition within management subareas weighted by the estimated catch numbers from observed tows. 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, 2012, and 2014-2015 were used, and the length and age data from 2000-2009, 2011 and 2013 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 is generally larger that 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, but abundance in this area decreased to 48,382 t in 2016. Abundance in the western Aleutian Islands also showed a large increase in the 2014 survey (to 346,392 t), but decreased to 124,310 t in the 2016 survey. Areas of particularly high survey abundance are Amchitka Island, Kiska Island, Buldir Island, and Tahoma Bank. 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 2016 Aleutian Island survey biomass was 253,217 t, which represents a decrease of 46% from the 2014 estimate of 472,895 t, but is more similar to the 2012 estimate of 285,164 t. As mentioned above, much of this decrease occurred in the western AI. The coefficient of variation (CV) for the 2016 estimate is 0.31, which is the lowest CV since the 1991 survey.

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 2002-2016 surveys ranged between 3 t (in the 2008, 2012, and

2016) and 42 t (2010), with CVs between 0.38 (2002) and 1.0 (in 2008, 2012, and 2016). Given these low levels of biomass, the slope survey results are not used in this assessment.

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 1991-2014. 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	-0.34

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 0.11 at age 3 to 0.08 at age 40.

A length-weight relationship of the form $W = aL^b$ was fit from the survey data from 1991-2014, and produced estimates of $a = 1.33 \times 10^{-5}$ 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	1977-2016
Fishery age composition	2000-2009, 2011, 2013
Fishery size composition	1977-1978, 1996, 1998-1999, 2010, 2012, 2014-2015
Survey age composition	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014
Survey length composition	2016
Survey biomass estimates	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016

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. Population size in numbers at age *a* in year *t* was modeled as

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

where Z is the sum of the instantaneous fishing mortality rate ($F_{t,a}$) and the natural mortality rate (M), A is the maximum number of age groups modeled in the population, and T is the terminal year of the analysis (defined as 2016).

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 γ is an age-dependant deviation assumed to be normally distributed with mean of zero and a standard deviation equal to σ_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 2013 are estimated as parameters in the model, and are modeled with a lognormal distribution

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

where μ_R is the log-scale mean and ν_t is a time-variant deviation. The number of age 3 from 2014-2016 are set the expected mean recruitment (based upon the log-scale mean, and the value of σ_r).

The fishing mortality rate for a specific age and time ($F_{t,a}$) is modeled as the product of a 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 (μ_f) and a year-specific deviation (ε_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.

Selectivity for the AI trawl survey was modeled with a logistic function.

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, σ_r, was fixed at 0.75. 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.

Sample sizes for age and length composition data

The “models” in this assessment differ in the types of data included and the weighting of the age and length composition data (rather than structural changes in the modelling equations):

Model 0) The 2014 model results (Spencer and Ianelli 2014). This is shown in some plots as a basis for comparing the new models.

Model 14) The 2014 model with data updated through 2016. The weighting of the age and length composition data was unchanged from 2014.

Models 16.1 – 16.3 involve different methods for reweighting the age and length composition data. In each of these methods, the multinomial sample size $N_{j,y}$ for data type *j* and year *y* is computed as

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

where $\tilde{N}_{j,y}$ is the original "first stage" sample size (set to the of hauls with produced fish lengths or read otoliths), and w_j is a weight for data type *j*. The weights are a function of the fit of to the age and length composition data, and iterated in successive model runs until they converge. Note that this method preserves the relative weighting between years within a given data type.

Model 16.1) Model 14, but computes the weights as the harmonic mean of the ratio of effective sample size to first stage sample size (method TA1.1 in Francis (2011), which is from McAllister and Ianelli (1997) and often referred to as the "McAllister-Ianelli method").

Model 16.2) Model 14, but computes the weights as the inverse of the variance of the standardized residuals (method TA1.2 in Francis (2011); this method was used in the 2014 assessment).

Model 16.3) Model 14, bit computes the weights as the variance of a standardized residual between the means of observed and predicted ages (or lengths) (i.e., one residual is computed for each year within a data type. This is method TA1.8 in Francis (2011) and often referred to as the "Francis method".

Because the differences between the "models" above pertain to differences in the input data, standard model selection criteria such as AIC do not apply. The root mean squared error (RMSE) was used to evaluate the relative size of residuals within data types across the different models:

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

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 source of these quantities are described above.

Parameters Estimated Inside the Assessment Model

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

The 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 σ_r is fixed, the term n ln (σ_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 λ_2 is a weighting factor. The negative log-likelihood of the catch biomass was modeled with a lognormal distribution:

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

where obs_cat_t and $pred\_cat_t$ are the observed and predicted catch. The "observed" catch for 2016 is obtained by estimating the Oct-Dec catch (based on the remaining ABC available after October, and the average proportion in recent years of the remaining ABC caught from Oct-Dec) and adding this to the observed catch through October. Because the catch biomass is generally thought to be observed with higher precision that other variables, λ_3 is given a very high weight so as to fit the catch biomass nearly exactly. 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, λ_1, λ_2, and λ_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	40
3) recruitment mean	1
4) recruitment deviations	37
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	125

Results

Model Evaluation

All models estimate increased biomass in recent years relative to the model 0. The three models that re-weight the age and length data are very similar to each other and to Model 14 (which used the weights from 2014 assessment) with respect to estimated total biomass (Figure 5) and the fit the AI trawl survey (Figure 6), and this is also revealed in the RMSE of the various data components (Table 11) . However, model 16.3 (with the Francis weights) puts lower weight on all age and length composition data, including substantially lower weights on the fishery length data and the survey age data (Figure 7). The similarity estimated biomass and predicted survey biomass between the data weighting methods may indicate a relative lack of tension between the data components.

A potential concern with the Francis method is that unreliable estimates of the variance of the residuals may be obtained with data types with a small number of years (as a single residual is computed for each year). For the northern rockfish model, not data type exceeds 12 years, and there is 1 year of AI survey length composition data (the weight for this year was paired to the survey age composition). It is unclear how the choice of pairing would affect the model results or, more generally, how sensitive the results of the Francis method are to small numbers available years for some data types.

Models 16.1 and 16.2 provide very similar results. We recommend model 16.1 (the McAllister-Ianelli method), partly because its common usage in other assessment models eases communication of the methodology. Estimated parameter values and their variances for model 16.1 are shown in Table 12.

A retrospective analysis on model 16.1 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 2016 to 2006, 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 8. All retrospective runs show reduced biomass relative to the 2016 run, as the 23016 model shows an improved fit to the relatively high recent survey biomass estimates. A relatively large decrease in estimated biomass exists between the 2015 and 2014 retrospective runs and the 2006-2013 retrospective runs, indicating the influence of the 2014 AI survey data. 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 -0.176, and increase (in absolute value) from the value of -0.150 in the 2014 assessment.

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.

The estimated values for total biomass, spawning biomass, and recruitment, and their CVs (from the Hessian approximation) are shown in Table 13, and the estimated numbers at age are shown in Table 14.

Biomass trends

The estimated survey biomass shows an increasing trend, starting at 100,760 t in 1977 and increasing to a peak of 240,367 t in 2013 (Figure 9). The estimated total biomass shows a similar trend, increasing to peak values of 260,000 t from 2010, and the estimated spawner biomass increases from 44,381 in 1977 to its highest value of 113,000 in 2014 (Table 13, Figure 10).

Age/size compositions

The model fits to the fishery age and size compositions are shown in Figures 11-12, and the model fit to the survey age and length composition are shown in Figures 13-14. 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 6.0, whereas this parameter was 9.2 for the fishery selectivity curve (Figure 15). These values are similar to the estimates of 5.5 and 9.6, respectively, in the 2014 model.

Fishing mortality

The estimates of instantaneous fishing mortality rate are shown in Figure 16. 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 2015 estimate is 0.033. 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 17).

Recruitment

Recruitment strengths by year class are shown in Figure 18. 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 11 and 13). Additionally, the model estimate of the 2005 year class of 98,600 is sunstantially larger than the estimate of 35,429 in the 2014 model. 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 1977-2010 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 65,870 t. The year 2017 spawning stock biomass is estimated as 107,660 t.

Specification of OFL and maximum permissible ABC

Since reliable estimates of the 2017 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B>B_{0.40}$ (107,660 t > 65,870 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 0.065 and 0.080, respectively.

The ABC associated with the $F_{0.40}$ level of 0.070 is 13,264 t.

The estimated catch level for year 2017 associated with the overfishing level of F = 0.087 is 16,242 t. A summary of these values is below.

2017 SSB estimate (B)	**=**	**107,660 t**
$B_{0.40}$	=	65,870 t
$F_{ABC} = F_{0.40}$	=	0.065
$F_{OFL} = F_{0.35}$	=	0.080
MaxPermABC	=	13,264 t
OFL	=	16,242 t

ABC recommendation

We recommend the maximum permissible ABC 13,264 t for 2017.

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 2016 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2017 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2016. 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 2017, 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 2017. (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 2011-2015 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 2016 or 2) above ½ of its MSY level in 2016 and above its MSY level in 2015 under this scenario, then the stock is not overfished.)
>
> *Scenario 7*: In 2017 and 2018, 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 2029 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 15.

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 2017, it does not provide the best estimate of OFL for 2018, because the mean 2017 catch under Scenario 6 is predicated on the 2017 catch being equal to the 2017 OFL, whereas the actual 2017 catch will likely be less than the 2017 OFL. Catches for 2017 and 2018 were obtained by setting the F rate for these years to the average of the estimated F rates for 2015 and 2016.

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 (2015) is 2,038 t. This is less than the 2015 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 2016:

a. If spawning biomass for 2016 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2016 is estimated to be above $B_{35\%}$ the stock is above its MSST.

c. If spawning biomass for 2016 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 15). If the mean spawning biomass for 2026 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 2019 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2019 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2019 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2029. If the mean spawning biomass for 2029 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 2016 stock size is 1.9 its $B_{35\%}$. value of 57,636 t. With regard to whether BSAI northern rockfish is likely to be overfished in the future, the expected stock size in 2019 of Scenario 7 is 1.7 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 Krieger (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 known 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.

Several aspects of estimation of size at age should be evaluated in the next full assessment. First, the plus group in the length composition data is consistently underestimated by the models for years 1996 and later, suggesting that either separate fishery and survey growth curves (and conversion matrices) should be evaluated. Second, although spatial differences in size at age exist, the model currently uses a global age-length key that does not weight each area by its fishery catch (or survey abundance). Accounting for spatial differences in growth may affect the fit to age composition data. Finally, the aging error matrix is derived from GOA data, but the slower growth in the AI than in the GOA may result in increased aging error if the otolith age marks are more closely grouped together.

References

Alverson, D.L. and M.J. Carney. 1975. A graphic review of the growth and decay of population cohorts. J. Cons Int. Explor. Mer 36(2):133-143.

Buonaccorsi, V. P., C. A. Kimbrell, E. A. Lynn, and R. D. Vetter. 2005. Limited realized dispersal and introgressive hybridization influence genetic structure and conservation strategies for brown rockfish, *Sebastes auriculatus*. Conservation Genetics 6:697–713.

Buonaccorsi, V. P.,M.Westerman, J. Stannard, C. Kimbrell, E. Lynn, and R. D. Vetter. 2004. Molecular genetic structure suggests limited larval dispersal in grass rockfish, *Sebastes rastrelliger*. Marine Biology 145:779–788.

Carlson, H. R., and R. R. Straty. 1981. Habitat and nursery grounds of Pacific rockfish, *Sebastes* spp., in rocky coastal areas of Southeastern Alaska. Mar. Fish. Rev. 43: 13-19.

Chilton, D. E., and R. J. Beamish. 1982. Age determination methods for fishes studied by the Groundfish Program at the Pacific Biological Station. Can. Spec. Publ. Fish. Aquat. Sci. 60, 102 p.

Clausen, D. M., and Heifetz, J.. 2002. The northern rockfish, *Sebastes polyspinis,* in Alaska: Commercial fishery, distribution, and biology. Mar. Fish. Rev. 64(4):1-28.

Courtney, D.L., J. Heifetz, M.F. Sigler, and D.M. Clausen. 1999. An age-structured model of northern rockfish, *Sebastes polyspinus*, recruitment and biomass in the Gulf of Alaska. *In* Stock assessment and fishery evaluation report for the groundfish resources for the Gulf of Alaska as projected for 2000. pp. 361-404. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501.

Dupanloup, I., S. Schneider, and L. Excoffier. 2002. A simulated annealing approach to define the genetic structure of populations. Molecular Ecology 11:2571–2581.

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. Can . J. Fish. Aquat. Sci. 54:284-300.

Gharrett, A.J., R.J. Riley, and P.D. Spencer. 2012. Genetic analysis reveals restricted dispersal of northern rockfish along the continental margin of the Bering Sea and Aleutian Islands. Trans. Am. Fish. Soc. 141:370-382.

Gomez-Uchida, D., and M. A. Banks. 2005. Microsatellite analyses of spatial genetic structure in darkblotched rockfish (*Sebastes crameri*): is pooling samples safe? Canadian Journal of Fisheries and Aquatic Sciences 62:1874–1886.

Guttormsen, M, J. Gharrett, G. Tromble, J. Berger, and S.Murai. 1992. Summaries of domestic and joint venture groundfish catches (metric tons) in the northeast Pacific ocean and Bering Sea. AFSC Processed Report 92-06.

Hyde, J. R., and R. D. Vetter. 2009. Population genetic structure in the redefined vermilion rockfish (*Sebastes miniatus*) indicates limited larval dispersal and reveals natural management units. Canadian Journal of Fisheries and Aquatic Sciences 66:1569–1581.

Kreiger, K.J., 1993. Distribution and abundance of rockfish determined from a submersible and by bottom trawling. Fish. Bull. 91, 87-96.

Logerwell, E.A., K. Aydin, S. Barbeaux, E. Brown, M. E. Conners, S. Lowe, J. W. Orr, I. Ortiz, R. Reuter, and P. Spencer. 2005. Geographic patterns in the demersal ichthyofauna of the Aleutian Islands. Fish. Oceanogr. 14 (Suppl. 1), 93–112.

Major, R. L., and H. H. Shippen. 1970. Synopsis of biological data on Pacific ocean perch, *Sebastodes alutus*. FAO Fisheries Synopsis No. 79, NOAA Circular 347, 38 p.

McAllister, M.K. and J.N. Ianelli. 1997. Bayesian stock assessment using catch-age data and the sampling-importance resampling algorithm. Can . J. Fish. Aquat. Sci. 54:284-300.

Palof, K. J., J. Heifetz, and A. J. Gharrett. 2011. Geographic structure in Alaskan Pacific ocean perch (*Sebastes alutus*) indicates limited lifetime dispersal. Marine Biology 158:779–792.

Ronholt, L.L., K. Teshima, and D.W. Kessler. 1994. The groundfish resources of the Aleutian Islands region and southern Bering Sea 1980, 1983, and 1986. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-31, 351 pp.

Spencer, P.D., and J.N. Ianelli. 2012. Assessment of the northern rockfish stock in the eastern Bering Sea and Aleutian Islands. In Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, pp. 1349-1422. North Pacific Fishery Management Council, 605 W. 4th Ave, suite 306. Anchorage, AK 99501

Spencer, P.D., and J.N. Ianelli. 2014. Assessment of the northern rockfish stock in the eastern Bering Sea and Aleutian Islands. In Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions, pp. 1395-1451. North Pacific Fishery Management Council, 605 W. 4th Ave, suite 306. Anchorage, AK 99501

Spencer, P.D. 2016. Re-evaluation of stock structure for the Bering Sea/Aleutian Islands northern rockfish. Report presented to the BSAI Groundfish Plan Team, September, 2016.

Then, A.Y., J.M. Hoenig, N.G Hall, and D.A. Hewitt. 2014. Evaluating the predictive performance of empricical estimators of natural mortality rate using information on over 200 species.

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	2763
2012	Northern rockfish	10500	8610	4700	2487
2013	Northern rockfish	12200	9850	3000	2038
2014	Northern rockfish	12077	9761	2594	2342
2015	Northern rockfish	15337	12488	3250	7197
2016*	Northern rockfish	14689	11960	4500	4258

*Catch data through October 10, 2016, 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			197			2,566	2,763
2012			91			2,395	2,487
2013			137			1,900	2,038
2014			147			2,195	2,342
2015			199			6,998	7,197
2016*			179			4,079	4,258

*Catch data through October 10, 2016, 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	1,926	2,430	211	116	4,684
2005	1,822	1,759	271	112	3,964
2006	1,127	2,149	306	246	3,828
2007	974	1,821	1151	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	197	2,763
2012	140	1,651	605	91	2,487
2013	115	1,308	478	137	2,038
2014	83	1,111	1002	147	2,342
2015	3,346	1,600	2052	199	7,197
2016*	1,619	1,695	765	179	4,258

* Estimated removals through October 10, 2016.

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	3596	3943	91.19%	Northerns	9	105	114	92.50%
2003	Northerns	465	4397	4862	90.45%	Northerns	17	51	67	75.22%
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	70	66.46%
2008	Northerns	1523	1742	3265	53.34%	Northerns	8	14	22	64.25%
2009	Northerns	1941	1122	3064	36.63%	Northerns	40	8	48	15.90%
2010	Northerns	3070	963	4033	23.88%	Northerns	285	15	299	4.92%
2011	Northerns	2442	124	2566	4.85%	Northerns	167	30	197	15.20%
2012	Northerns	2015	381	2395	15.89%	Northerns	45	46	91	50.31%
2013	Northerns	1720	181	1900	9.52%	Northerns	97	40	137	29.27%
2014	Northerns	2113	82	2195	3.76%	Northerns	76	71	147	47.97%
2015	Northerns	6619	379	6998	5.41%	Northerns	126	73	199	36.85%
2016*	Northerns	3862	217	4079	5.33%	Northerns	116	63	179	35.18%

* Estimated removals through October 10, 2016.

Table 6. Samples sizes of otoliths and lengths from fishery sampling, with the number of hauls from which these data were collected, from 1977-2015.

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	256	255	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	596	251
2014	1542	224	484		
2015	3006	341	869		

*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 Survey				
Year	Western	Central	Eastern	southern BS	Total AI survey
1980	3,024 (0.98)	316 (0.63)	34,170 (0.99)	83 (0.95)	37,593 (0.90)
1983	34,361 (0.21)	9,106 (0.48)	11,765 (0.10)	1,136 (0.57)	56,368 (0.15)
1986	20,691 (0.44)	105,608 (0.44)	4,014 (0.55)	10,092 (0.64)	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)	206,329 (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	102,651 (0.29)	70,834 (0.51)	22,982 (0.45)	22,883 (1.00)	219,350 (0.24)
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)
2016	124,310 (0.21)	78,869(0.37)	48,382 (0.52)	1,656 (0.55)	253,217 (0.18)

Table 8. Sample sizes of otoliths and length measurement from the AI trawl survey, 1991-2016, 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	14894	210	551	60
2016	15116	240		

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
2014	201	147	150	53	551
2016					

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

Age	Predicted weight (g)	Proportion mature
3	59	0.026
4	100	0.050
5	146	0.096
6	193	0.176
7	239	0.301
8	282	0.464
9	321	0.636
10	355	0.779
11	386	0.876
12	412	0.934
13	435	0.966
14	454	0.983
15	470	0.991
16	484	0.996
17	495	0.998
18	505	0.999
19	513	0.999
20	519	1
21	525	1
22	530	1
23	533	1
24	537	1
25	539	1
26	541	1
27	543	1
28	545	1
29	546	1
30	547	1
31	548	1
32	548	1
33	549	1
34	549	1
35	550	1
36	550	1
37	550	1
38	550	1
39	551	1
40	551	1

Table 11. Negative log likelihood of model components, root mean squared errors, and estimates and standard deviations of key quantities.

	Model 0	Model 14	Model 16.1	Model 16.2	Model 16.3
Negative log-likelihood					
Data components					
AI survey biomass	11.10	10.42	9.72	10.07	9.08
Catch biomass	0.00	0.00	0.00	0.00	0.00
Fishery age comp	198.40	235.89	217.17	236.31	183.63
Fishery length comp	66.33	53.24	70.30	83.02	10.98
AI survey age comp	160.26	176.01	115.91	200.75	21.23
AI survey lengths comp	14.74	3.12	13.05	14.54	0.99
Maturity	7.21	7.21	7.21	7.21	7.21
Priors and penalties					
Recruitment	1.92	0.36	-0.11	1.21	-3.22
Prior on survey q	0.00	0.00	0.00	0.00	0.00
Prior on M	0.89	1.15	1.35	1.65	0.43
Total negative log-likelihood	465.28	491.91	438.98	559.18	234.73
Parameters	121	125	125	125	125
Root mean square error					
AI survey biomass	0.511	0.462	0.448	0.453	0.441
Recruitment	0.699	0.703	0.698	0.708	0.667
Fishery age comp	0.014	0.013	0.013	0.013	0.012
Fishery length comp	0.047	0.034	0.034	0.034	0.035
AI survey age comp	0.016	0.015	0.015	0.014	0.017
AI survey lengths comp	0.021	0.007	0.007	0.007	0.008
Estimated key quantities					
M	0.049	0.047	0.046	0.045	0.052
standard deviation	0.005	0.005	0.005	0.004	0.005
CV	0.098	0.098	0.097	0.096	0.102
2016 total biomass		238,070	249,850	246,220	261,530
standard deviation		22,811	23,786	23,057	27,300
CV		0.10	0.10	0.09	0.10

Table 12. Estimated parameter values and standard deviations.

Parameter	Estimate	Standard Deviation	parameter	estimate	Standard Deviation	parameter	estimate	Standard Deviation
sel_aslope_forfish	0.7544	0.0620	fmort_dev	-0.1504	0.0874	log_rinit	2.6269	0.2106
sel_a50_forfish	9.1825	0.2400	fmort_dev	-0.0206	0.0912	fydev	0.5094	0.7633
sel_aslope_srv3	1.1711	0.1475	fmort_dev	1.1052	0.0959	fydev	0.5715	0.7180
sel_a50_srv3	6.0220	0.2136	fmort_dev	0.6226	0.1010	fydev	0.3638	0.8420
M	0.0464	0.0045	rec_dev	0.1163	0.5254	fydev	1.6974	0.3921
log_avg_fmort	-4.5039	0.0768	rec_dev	0.1030	0.5283	fydev	0.4224	0.8407
fmort_dev	1.2866	0.1001	rec_dev	-0.0138	0.4880	fydev	0.2732	0.7269
fmort_dev	1.3879	0.0983	rec_dev	-0.3650	0.5595	fydev	0.3212	0.6778
fmort_dev	-0.3956	0.0953	rec_dev	0.3590	0.3705	fydev	0.1001	0.6825
fmort_dev	-0.4725	0.0908	rec_dev	0.1326	0.4075	fydev	0.0520	0.6859
fmort_dev	-2.0145	0.0867	rec_dev	-0.5488	0.5449	fydev	0.3404	0.7506
fmort_dev	-1.5343	0.0828	rec_dev	0.5980	0.2481	fydev	0.5312	0.7582
fmort_dev	-2.6111	0.0789	rec_dev	-0.2096	0.4225	fydev	0.1949	0.7486
fmort_dev	-1.7166	0.0752	rec_dev	-0.7286	0.5223	fydev	0.0386	0.6973
fmort_dev	-1.9248	0.0716	rec_dev	1.2929	0.1560	fydev	-0.0463	0.6761
fmort_dev	-1.6448	0.0683	rec_dev	0.9249	0.2314	fydev	-0.1769	0.6591
fmort_dev	-1.3333	0.0653	rec_dev	0.1500	0.3745	fydev	-0.2637	0.6460
fmort_dev	-1.0477	0.0626	rec_dev	0.1805	0.2899	fydev	-0.2931	0.6410
fmort_dev	-1.4178	0.0602	rec_dev	0.0368	0.2909	fydev	-0.3104	0.6409
fmort_dev	-0.1068	0.0581	rec_dev	0.6248	0.1677	fydev	-0.3057	0.6443
fmort_dev	-0.6904	0.0564	rec_dev	-0.2199	0.2874	fydev	-0.2609	0.6530
fmort_dev	0.0361	0.0550	rec_dev	-0.0796	0.2013	fydev	-0.2160	0.6599
fmort_dev	1.0617	0.0540	rec_dev	-1.3043	0.4219	fydev	-0.2166	0.6633
fmort_dev	0.8938	0.0535	rec_dev	0.6034	0.1286	fydev	-0.2337	0.6625
fmort_dev	0.7198	0.0530	rec_dev	-0.1891	0.2942	fydev	-0.2391	0.6619
fmort_dev	1.1841	0.0525	rec_dev	1.1046	0.1234	fydev	-0.2341	0.6634
fmort_dev	0.0291	0.0523	rec_dev	0.6838	0.1780	fydev	-0.2264	0.6656
fmort_dev	0.5696	0.0524	rec_dev	0.6839	0.1711	fydev	-0.2183	0.6679
fmort_dev	0.9623	0.0528	rec_dev	0.3885	0.1824	fydev	-0.2105	0.6702
fmort_dev	0.8740	0.0535	rec_dev	-1.0187	0.4042	fydev	-0.2028	0.6724
fmort_dev	1.1086	0.0545	rec_dev	-0.2089	0.2111	fydev	-0.1954	0.6746
fmort_dev	0.6406	0.0559	rec_dev	-1.2364	0.4254	fydev	-0.1881	0.6768
fmort_dev	0.8244	0.0576	rec_dev	0.2645	0.2001	fydev	-0.1811	0.6789
fmort_dev	0.7570	0.0597	rec_dev	0.1469	0.2595	fydev	-0.1742	0.6810
fmort_dev	0.5658	0.0619	rec_dev	-0.1236	0.3548	fydev	-0.1675	0.6830
fmort_dev	0.5049	0.0643	rec_dev	1.1125	0.1746	fydev	-0.1610	0.6850
fmort_dev	0.5344	0.0669	rec_dev	-0.7462	0.4940	fydev	-0.1547	0.6870
fmort_dev	0.3247	0.0698	rec_dev	-0.7088	0.4682	fydev	-0.5400	0.5919
fmort_dev	0.2675	0.0730	rec_dev	-0.4884	0.4664	q_srv3	1.0000	0.0010
fmort_dev	0.6043	0.0765	rec_dev	-0.6243	0.5072	mat_beta1	-5.7428	0.6954
fmort_dev	0.1609	0.0802	rec_dev	-0.6928	0.5268	mat_beta2	0.7000	0.0094
fmort_dev	0.0551	0.0838	mean_log_	3.4786	0.0946			

Table 13. 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			
	2016		2014		2016		2014		2016		2014	
Year	Est.	CV	Est.	CV	Est.	CV	Est.	CV	Est.	CV	Est.	CV
1977	117,293	0.128	129,004	0.130	44,381	0.145	48,863	0.146	36,410	0.540	38,346	0.135
1978	120,392	0.128	132,501	0.129	45,573	0.147	50,241	0.148	35,929	0.536	40,140	0.517
1979	123,091	0.127	135,330	0.129	47,283	0.146	52,158	0.147	31,970	0.497	31,119	0.510
1980	128,356	0.123	140,643	0.125	50,092	0.141	55,188	0.141	22,502	0.574	21,970	0.575
1981	134,728	0.120	147,186	0.121	52,900	0.135	58,175	0.135	46,413	0.378	52,577	0.334
1982	141,458	0.115	153,777	0.116	55,801	0.130	61,199	0.130	37,009	0.418	35,902	0.409
1983	147,142	0.111	159,187	0.112	58,694	0.125	64,144	0.125	18,723	0.562	17,266	0.555
1984	154,710	0.107	166,657	0.108	61,643	0.121	67,084	0.120	58,941	0.255	64,087	0.222
1985	160,998	0.103	172,448	0.104	64,550	0.116	69,903	0.116	26,284	0.436	22,698	0.436
1986	166,337	0.099	177,175	0.100	67,474	0.112	72,693	0.112	15,642	0.538	13,649	0.524
1987	176,761	0.095	186,891	0.096	70,422	0.108	75,459	0.108	118,088	0.171	120,272	0.157
1988	187,775	0.091	196,793	0.092	73,387	0.105	78,201	0.104	81,736	0.247	75,467	0.238
1989	197,697	0.088	205,810	0.089	76,456	0.102	80,982	0.101	37,658	0.385	38,798	0.344
1990	207,632	0.085	215,055	0.086	79,741	0.101	83,927	0.099	38,824	0.299	42,171	0.267
1991	215,728	0.082	222,496	0.083	83,239	0.101	87,005	0.099	33,628	0.305	36,447	0.273
1992	225,284	0.079	231,578	0.081	87,578	0.101	90,863	0.100	60,543	0.181	66,356	0.163
1993	231,835	0.077	237,564	0.079	91,681	0.100	94,468	0.099	26,015	0.303	24,682	0.292
1994	233,945	0.076	239,305	0.078	94,657	0.097	96,990	0.097	29,935	0.212	32,104	0.194
1995	234,537	0.075	239,610	0.077	97,435	0.092	99,441	0.093	8,796	0.440	9,311	0.423
1996	237,066	0.074	241,577	0.076	99,429	0.088	101,191	0.090	59,261	0.145	58,545	0.144
1997	235,349	0.074	239,532	0.077	100,398	0.085	102,010	0.088	26,830	0.311	29,604	0.267
1998	241,742	0.073	244,822	0.076	102,239	0.082	103,748	0.085	97,824	0.141	87,768	0.144
1999	246,387	0.072	248,386	0.076	102,758	0.080	104,157	0.084	64,225	0.195	59,051	0.189
2000	250,119	0.072	250,266	0.077	102,454	0.080	103,645	0.084	64,231	0.187	51,504	0.201
2001	254,077	0.072	252,523	0.077	102,304	0.082	103,208	0.086	47,802	0.195	44,089	0.204
2002	254,688	0.073	251,638	0.079	102,585	0.086	103,045	0.090	11,704	0.419	13,480	0.397
2003	257,131	0.073	252,437	0.080	104,392	0.089	104,224	0.093	26,303	0.220	22,841	0.260
2004	256,599	0.074	250,573	0.082	106,474	0.091	105,497	0.095	9,414	0.441	10,222	0.432
2005	256,620	0.074	248,379	0.083	108,809	0.090	106,888	0.095	42,227	0.211	25,434	0.275
2006	256,786	0.075	245,614	0.085	110,905	0.087	107,974	0.094	37,541	0.270	16,830	0.388
2007	256,194	0.076	242,560	0.087	112,064	0.085	108,216	0.094	28,645	0.369	25,097	0.342
2008	259,086	0.078	239,459	0.090	112,337	0.084	107,541	0.094	98,600	0.183	35,429	0.311
2009	259,941	0.079	236,034	0.093	112,224	0.084	106,402	0.096	15,369	0.509	14,606	0.477
2010	260,200	0.081	231,995	0.095	111,784	0.086	104,654	0.098	15,955	0.479	10,986	0.519
2011	258,588	0.084	226,224	0.099	111,296	0.089	102,437	0.101	19,890	0.474	12,338	0.550
2012	257,556	0.086	223,088	0.101	111,726	0.092	100,753	0.105	17,361	0.517		
2013	255,887	0.088	220,860	0.104	112,561	0.095	99,230	0.108	16,213	0.541		
2014	255,388	0.090	219,801	0.105	113,399	0.096	97,785	0.111				
2015	254,794	0.092	218,901	0.107	112,995	0.098						
2016	249,850	0.095			110,592	0.101						
2017	248,160				107,660							
Mean recruitment of post-1976 year classes									40,004		37,237	

Table 14. Estimated numbers at age for BSAI northern rockfish (millions).

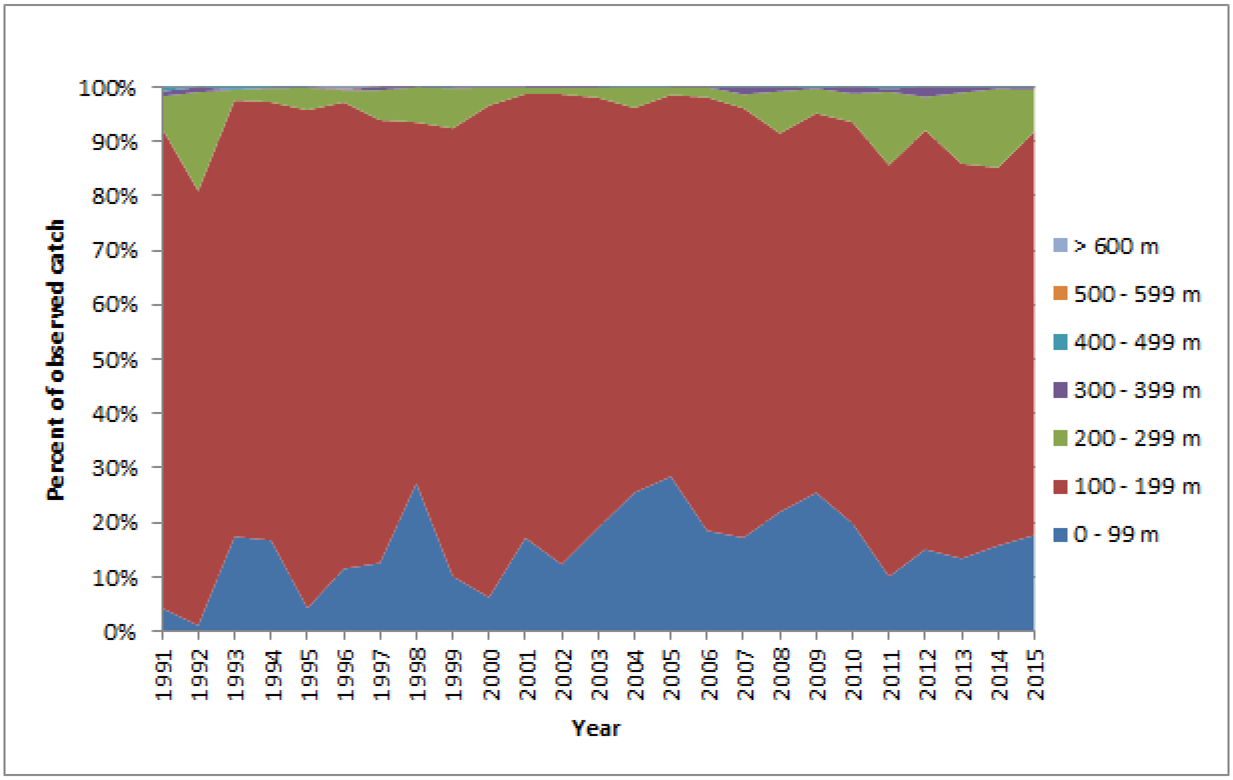
	Age																	
Year	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1977	36.41	21.98	22.32	17.31	62.73	16.73	13.76	13.78	10.55	9.60	12.22	14.12	9.63	7.87	6.90	5.78	5.06	4.69
1978	35.93	34.75	20.96	21.28	16.48	59.50	15.79	12.89	12.82	9.75	8.84	11.24	12.97	8.84	7.22	6.33	5.30	4.64
1979	31.97	34.29	33.14	19.98	20.24	15.62	56.07	14.77	11.96	11.81	8.95	8.09	10.27	11.85	8.07	6.59	5.78	4.84
1980	22.50	30.52	32.73	31.63	19.06	19.30	14.88	53.34	14.03	11.35	11.20	8.48	7.67	9.74	11.23	7.65	6.25	5.48
1981	46.41	21.48	29.13	31.23	30.18	18.18	18.39	14.16	50.70	13.32	10.77	10.63	8.05	7.27	9.23	10.65	7.25	5.92
1982	37.01	44.31	20.51	27.81	29.82	28.80	17.34	17.54	13.50	48.34	12.70	10.27	10.13	7.67	6.93	8.80	10.15	6.92
1983	18.72	35.33	42.30	19.57	26.54	28.45	27.48	16.54	16.72	12.86	46.05	12.10	9.78	9.65	7.30	6.60	8.38	9.67
1984	58.94	17.87	33.73	40.38	18.69	25.34	27.16	26.22	15.78	15.95	12.27	43.93	11.54	9.33	9.20	6.97	6.30	7.99
1985	26.28	56.27	17.06	32.20	38.54	17.83	24.17	25.90	25.00	15.04	15.20	11.69	41.86	10.99	8.89	8.77	6.64	6.00
1986	15.64	25.09	53.72	16.29	30.73	36.79	17.02	23.06	24.70	23.84	14.34	14.49	11.15	39.90	10.48	8.47	8.36	6.33
1987	118.09	14.93	23.95	51.28	15.55	29.33	35.10	16.23	21.99	23.54	22.72	13.66	13.80	10.62	38.01	9.98	8.07	7.96
1988	81.74	112.73	14.26	22.87	48.94	14.84	27.98	33.46	15.46	20.94	22.42	21.63	13.01	13.14	10.11	36.18	9.50	7.68
1989	37.66	78.03	107.61	13.61	21.82	46.69	14.15	26.66	31.86	14.72	19.92	21.32	20.57	12.37	12.50	9.61	34.41	9.04
1990	38.82	35.95	74.49	102.73	12.99	20.82	44.54	13.49	25.41	30.35	14.02	18.97	20.30	19.58	11.78	11.90	9.15	32.76
1991	33.63	37.06	34.31	71.08	97.99	12.38	19.82	42.33	12.79	24.06	28.72	13.26	17.94	19.19	18.51	11.13	11.25	8.65
1992	60.54	32.10	35.38	32.75	67.83	93.46	11.80	18.87	40.26	12.16	22.86	27.28	12.59	17.03	18.22	17.58	10.57	10.68
1993	26.02	57.79	30.64	33.76	31.24	64.63	88.93	11.20	17.89	38.09	11.49	21.59	25.75	11.88	16.07	17.20	16.59	9.97
1994	29.93	24.83	55.14	29.21	32.14	29.67	61.13	83.64	10.48	16.64	35.34	10.64	19.98	23.82	10.99	14.86	15.90	15.34
1995	8.80	28.57	23.69	52.58	27.83	30.55	28.10	57.63	78.46	9.79	15.51	32.88	9.90	18.57	22.13	10.21	13.81	14.78
1996	59.26	8.40	27.26	22.60	50.10	26.47	28.97	26.54	54.21	73.56	9.16	14.49	30.70	9.24	17.33	20.66	9.53	12.89
1997	26.83	56.56	8.01	25.99	21.51	47.55	25.00	27.20	24.75	50.28	67.99	8.45	13.36	28.28	8.51	15.96	19.02	8.77
1998	97.82	25.61	53.98	7.64	24.79	20.49	45.25	23.74	25.77	23.42	47.52	64.21	7.97	12.61	26.70	8.03	15.06	17.95
1999	64.23	93.37	24.44	51.49	7.28	23.59	19.45	42.80	22.38	24.23	21.97	44.53	60.14	7.47	11.80	24.99	7.52	14.10
2000	64.23	61.30	89.09	23.31	49.04	6.92	22.33	18.32	40.10	20.88	22.54	20.40	41.33	55.80	6.93	10.95	23.18	6.97
2001	47.80	61.30	58.49	84.96	22.20	46.62	6.56	21.06	17.19	37.48	19.47	20.98	18.98	38.44	51.88	6.44	10.18	21.55
2002	11.70	45.62	58.49	55.76	80.88	21.08	44.07	6.16	19.67	15.98	34.73	18.00	19.39	17.53	35.49	47.90	5.95	9.40
2003	26.30	11.17	43.53	55.79	53.14	76.95	20.00	41.66	5.80	18.47	14.97	32.50	16.84	18.13	16.39	33.18	44.78	5.56
2004	9.41	25.11	10.66	41.52	53.15	50.52	72.93	18.87	39.13	5.43	17.24	13.96	30.27	15.68	16.88	15.26	30.89	41.69
2005	42.23	8.99	23.96	10.17	39.56	50.54	47.90	68.86	17.74	36.66	5.08	16.09	13.02	28.24	14.62	15.74	14.23	28.80
2006	37.54	40.31	8.57	22.85	9.69	37.65	47.98	45.32	64.91	16.68	34.39	4.76	15.07	12.19	26.44	13.69	14.73	13.32
2007	28.65	35.83	38.46	8.18	21.78	9.22	35.75	45.42	42.75	61.07	15.66	32.27	4.46	14.13	11.43	24.78	12.83	13.81
2008	98.60	27.34	34.20	36.69	7.80	20.73	8.76	33.83	42.83	40.21	57.33	14.69	30.24	4.18	13.24	10.71	23.22	12.02
2009	15.37	94.12	26.09	32.63	34.98	7.42	19.70	8.30	31.98	40.39	37.86	53.94	13.81	28.44	3.93	12.45	10.07	21.83
2010	15.96	14.67	89.83	24.90	31.11	33.32	7.06	18.68	7.85	30.18	38.07	35.65	50.78	13.00	26.76	3.70	11.71	9.47
2011	19.89	15.23	14.00	85.68	23.73	29.60	31.62	6.68	17.60	7.37	28.29	35.65	33.37	47.51	12.16	25.04	3.46	10.96
2012	17.36	18.99	14.53	13.36	81.71	22.61	28.15	30.01	6.32	16.63	6.96	26.68	33.61	31.45	44.78	11.46	23.60	3.26
2013	16.21	16.57	18.12	13.87	12.74	77.86	21.51	26.73	28.43	5.98	15.71	6.57	25.18	31.71	29.68	42.25	10.82	22.26
2014	42.94	15.48	15.82	17.29	13.23	12.14	74.12	20.44	25.36	26.94	5.66	14.87	6.21	23.82	29.99	28.07	39.96	10.23
2015	42.94	40.99	14.77	15.09	16.49	12.61	11.56	70.41	19.38	24.00	25.47	5.35	14.04	5.87	22.49	28.32	26.51	37.73
2016	42.94	40.98	39.11	14.08	14.37	15.66	11.92	10.86	65.77	18.01	22.24	23.56	4.94	12.97	5.42	20.77	26.15	24.47

Table 14 (continued). Estimated numbers at age for BSAI northern rockfish (millions).

	Age																			
Year	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40+
1977	4.40	4.22	4.21	4.21	4.01	3.77	3.58	3.43	3.30	3.18	3.06	2.94	2.83	2.72	2.62	2.51	2.42	2.32	2.23	7.76
1978	4.30	4.04	3.87	3.86	3.86	3.68	3.46	3.28	3.15	3.03	2.91	2.80	2.70	2.59	2.50	2.40	2.31	2.22	2.13	9.17
1979	4.24	3.93	3.69	3.53	3.53	3.52	3.36	3.16	3.00	2.87	2.77	2.66	2.56	2.46	2.37	2.28	2.19	2.11	2.02	10.32
1980	4.59	4.01	3.72	3.49	3.35	3.34	3.34	3.19	2.99	2.84	2.72	2.62	2.52	2.43	2.33	2.25	2.16	2.08	2.00	11.69
1981	5.19	4.35	3.81	3.53	3.31	3.18	3.17	3.17	3.02	2.83	2.69	2.58	2.48	2.39	2.30	2.21	2.13	2.05	1.97	12.98
1982	5.64	4.95	4.15	3.63	3.36	3.16	3.03	3.02	3.02	2.88	2.70	2.57	2.46	2.37	2.28	2.19	2.11	2.03	1.95	14.25
1983	6.59	5.38	4.71	3.95	3.46	3.20	3.01	2.88	2.88	2.87	2.74	2.57	2.44	2.34	2.26	2.17	2.09	2.01	1.93	15.43
1984	9.22	6.28	5.13	4.50	3.77	3.30	3.06	2.87	2.75	2.75	2.74	2.62	2.46	2.33	2.24	2.15	2.07	1.99	1.92	16.56
1985	7.62	8.78	5.99	4.89	4.28	3.59	3.14	2.91	2.73	2.62	2.62	2.61	2.49	2.34	2.22	2.13	2.05	1.97	1.90	17.61
1986	5.72	7.26	8.37	5.71	4.66	4.08	3.42	2.99	2.78	2.60	2.50	2.49	2.49	2.38	2.23	2.12	2.03	1.95	1.88	18.59
1987	6.03	5.45	6.92	7.98	5.44	4.44	3.89	3.26	2.85	2.64	2.48	2.38	2.38	2.37	2.26	2.12	2.02	1.93	1.86	19.50
1988	7.58	5.74	5.19	6.58	7.59	5.17	4.22	3.70	3.10	2.71	2.52	2.36	2.26	2.26	2.26	2.15	2.02	1.92	1.84	20.33
1989	7.30	7.21	5.46	4.93	6.26	7.22	4.92	4.02	3.52	2.95	2.58	2.39	2.25	2.15	2.15	2.15	2.05	1.92	1.83	21.09
1990	8.60	6.95	6.86	5.20	4.70	5.96	6.87	4.68	3.82	3.35	2.81	2.46	2.28	2.14	2.05	2.05	2.04	1.95	1.83	21.82
1991	30.97	8.13	6.57	6.49	4.91	4.44	5.63	6.50	4.43	3.61	3.17	2.65	2.32	2.15	2.02	1.94	1.94	1.93	1.84	22.35
1992	8.21	29.40	7.72	6.24	6.16	4.66	4.21	5.35	6.17	4.20	3.43	3.01	2.52	2.21	2.04	1.92	1.84	1.84	1.83	22.97
1993	10.08	7.75	27.75	7.29	5.89	5.81	4.40	3.98	5.05	5.82	3.97	3.24	2.84	2.38	2.08	1.93	1.81	1.74	1.73	23.41
1994	9.22	9.32	7.17	25.65	6.74	5.45	5.37	4.07	3.68	4.67	5.38	3.67	2.99	2.63	2.20	1.92	1.78	1.67	1.61	23.25
1995	14.25	8.57	8.66	6.66	23.84	6.26	5.06	4.99	3.78	3.42	4.34	5.00	3.41	2.78	2.44	2.04	1.79	1.66	1.56	23.10
1996	13.79	13.30	8.00	8.08	6.21	22.25	5.84	4.72	4.66	3.53	3.19	4.05	4.67	3.18	2.60	2.28	1.91	1.67	1.55	23.00
1997	11.87	12.70	12.25	7.36	7.44	5.72	20.48	5.38	4.35	4.29	3.25	2.94	3.73	4.30	2.93	2.39	2.10	1.76	1.54	22.61
1998	8.28	11.20	11.98	11.56	6.95	7.02	5.40	19.33	5.08	4.10	4.05	3.07	2.77	3.52	4.06	2.76	2.26	1.98	1.66	22.79
1999	16.81	7.75	10.49	11.22	10.82	6.51	6.57	5.06	18.10	4.75	3.84	3.79	2.87	2.59	3.29	3.80	2.59	2.11	1.85	22.89
2000	13.08	15.59	7.19	9.72	10.40	10.04	6.03	6.10	4.69	16.78	4.41	3.56	3.52	2.66	2.41	3.05	3.52	2.40	1.96	22.94
2001	6.48	12.16	14.49	6.68	9.04	9.67	9.33	5.61	5.67	4.36	15.60	4.10	3.31	3.27	2.47	2.24	2.84	3.27	2.23	23.15
2002	19.90	5.98	11.23	13.38	6.17	8.35	8.93	8.61	5.18	5.23	4.02	14.41	3.78	3.06	3.02	2.28	2.07	2.62	3.02	23.43
2003	8.79	18.60	5.59	10.49	12.51	5.77	7.80	8.35	8.05	4.84	4.89	3.76	13.47	3.54	2.86	2.82	2.14	1.93	2.45	24.73
2004	5.17	8.18	17.31	5.21	9.77	11.64	5.37	7.26	7.77	7.50	4.51	4.55	3.50	12.54	3.29	2.66	2.63	1.99	1.80	25.30
2005	38.87	4.82	7.63	16.14	4.86	9.11	10.86	5.01	6.77	7.25	6.99	4.20	4.25	3.27	11.69	3.07	2.48	2.45	1.85	25.27
2006	26.96	36.39	4.52	7.14	15.11	4.55	8.53	10.16	4.69	6.34	6.78	6.54	3.93	3.97	3.06	10.94	2.87	2.32	2.29	25.39
2007	12.49	25.27	34.11	4.23	6.69	14.17	4.26	7.99	9.53	4.39	5.94	6.36	6.13	3.69	3.73	2.87	10.26	2.69	2.18	25.95
2008	12.94	11.70	23.68	31.96	3.97	6.27	13.27	3.99	7.49	8.92	4.12	5.57	5.96	5.75	3.45	3.49	2.68	9.61	2.52	26.35
2009	11.30	12.16	11.00	22.26	30.04	3.73	5.89	12.48	3.75	7.04	8.39	3.87	5.23	5.60	5.40	3.25	3.28	2.52	9.03	27.15
2010	20.54	10.64	11.45	10.35	20.95	28.27	3.51	5.55	11.74	3.53	6.62	7.90	3.64	4.93	5.27	5.08	3.06	3.09	2.38	34.04
2011	8.86	19.22	9.95	10.71	9.68	19.60	26.45	3.28	5.19	10.98	3.30	6.20	7.39	3.41	4.61	4.93	4.75	2.86	2.89	34.07
2012	10.33	8.35	18.11	9.38	10.09	9.12	18.47	24.92	3.09	4.89	10.35	3.11	5.84	6.96	3.21	4.34	4.65	4.48	2.69	34.83
2013	3.08	9.74	7.88	17.09	8.85	9.52	8.61	17.42	23.52	2.92	4.61	9.77	2.94	5.51	6.57	3.03	4.10	4.38	4.23	35.41
2014	21.05	2.91	9.21	7.45	16.16	8.37	9.00	8.14	16.48	22.24	2.76	4.36	9.24	2.78	5.21	6.21	2.86	3.87	4.15	37.48
2015	9.66	19.88	2.75	8.70	7.04	15.26	7.90	8.50	7.69	15.56	21.00	2.61	4.12	8.72	2.62	4.92	5.87	2.71	3.66	39.31
2016	34.84	8.92	18.36	2.54	8.03	6.50	14.09	7.29	7.85	7.10	14.37	19.39	2.41	3.80	8.05	2.42	4.54	5.42	2.50	39.67

Table 15. 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 65,870 t and 57,636 t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2016	4,375	4,375	4,375	4,375	4,375	4,375	4,375
2017	13,264	13,264	6,735	3,288	0	16,242	13,264
2018	12,493	12,493	6,541	3,244	0	15,081	12,493
2019	11,786	11,786	6,357	3,202	0	14,033	14,433
2020	11,187	11,187	6,205	3,172	0	13,147	13,509
2021	10,712	10,712	6,098	3,160	0	12,440	12,764
2022	10,340	10,340	6,028	3,163	0	11,881	12,171
2023	10,047	10,047	5,985	3,178	0	11,433	11,693
2024	9,804	9,804	5,958	3,198	0	11,062	11,293
2025	9,594	9,594	5,937	3,219	0	10,739	10,947
2026	9,412	9,412	5,922	3,242	0	10,424	10,627
2027	9,246	9,246	5,908	3,264	0	10,103	10,300
2028	9,090	9,090	5,896	3,284	0	9,806	9,988
2029	8,945	8,945	5,886	3,305	0	9,550	9,713
Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2016	110,592	110,592	110,592	110,592	110,592	110,592	110,592
2017	107,660	107,660	108,493	108,925	109,332	107,274	107,660
2018	101,605	101,605	105,519	107,598	109,590	99,830	101,605
2019	96,327	96,327	102,967	106,578	110,092	93,385	95,985
2020	91,986	91,986	101,018	106,045	111,013	88,075	90,417
2021	88,539	88,539	99,675	106,015	112,376	83,823	85,925
2022	85,777	85,777	98,776	106,341	114,042	80,390	82,269
2023	83,520	83,520	98,185	106,902	115,905	77,567	79,243
2024	81,612	81,612	97,774	107,580	117,847	75,182	76,674
2025	79,936	79,936	97,440	108,270	119,765	73,105	74,429
2026	78,468	78,468	97,184	108,985	121,676	71,304	72,475
2027	77,154	77,154	96,956	109,672	123,523	69,736	70,761
2028	75,987	75,987	96,760	110,338	125,312	68,399	69,286
2029	74,975	74,975	96,616	111,008	127,073	67,286	68,049
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2016	0.021	0.021	0.021	0.021	0.021	0.021	0.021
2017	0.065	0.065	0.032	0.016	0.000	0.080	0.065
2018	0.065	0.065	0.032	0.016	0.000	0.080	0.065
2019	0.065	0.065	0.032	0.016	0.000	0.080	0.080
2020	0.065	0.065	0.032	0.016	0.000	0.080	0.080
2021	0.065	0.065	0.032	0.016	0.000	0.080	0.080
2022	0.065	0.065	0.032	0.016	0.000	0.080	0.080
2023	0.065	0.065	0.032	0.016	0.000	0.080	0.080
2024	0.065	0.065	0.032	0.016	0.000	0.080	0.080
2025	0.065	0.065	0.032	0.016	0.000	0.080	0.080
2026	0.065	0.065	0.032	0.016	0.000	0.080	0.080
2027	0.065	0.065	0.032	0.016	0.000	0.079	0.079
2028	0.065	0.065	0.032	0.016	0.000	0.078	0.078
2029	0.065	0.065	0.032	0.016	0.000	0.077	0.078



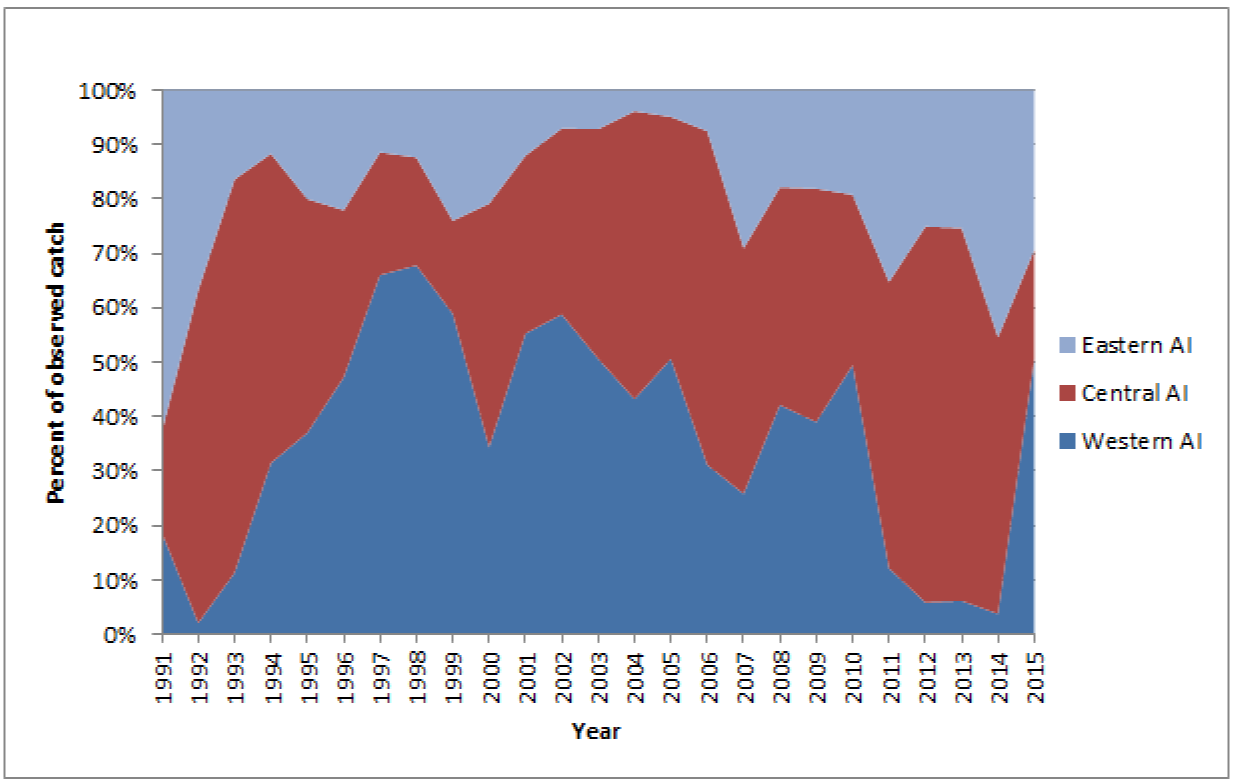


Figure 1. Distribution of observed Aleutian Islands northern rockfish catch (from North Pacific Groundfish Observer Program) by depth zone (top panel) and AI subarea (bottom panel) from 1991 to 2015.

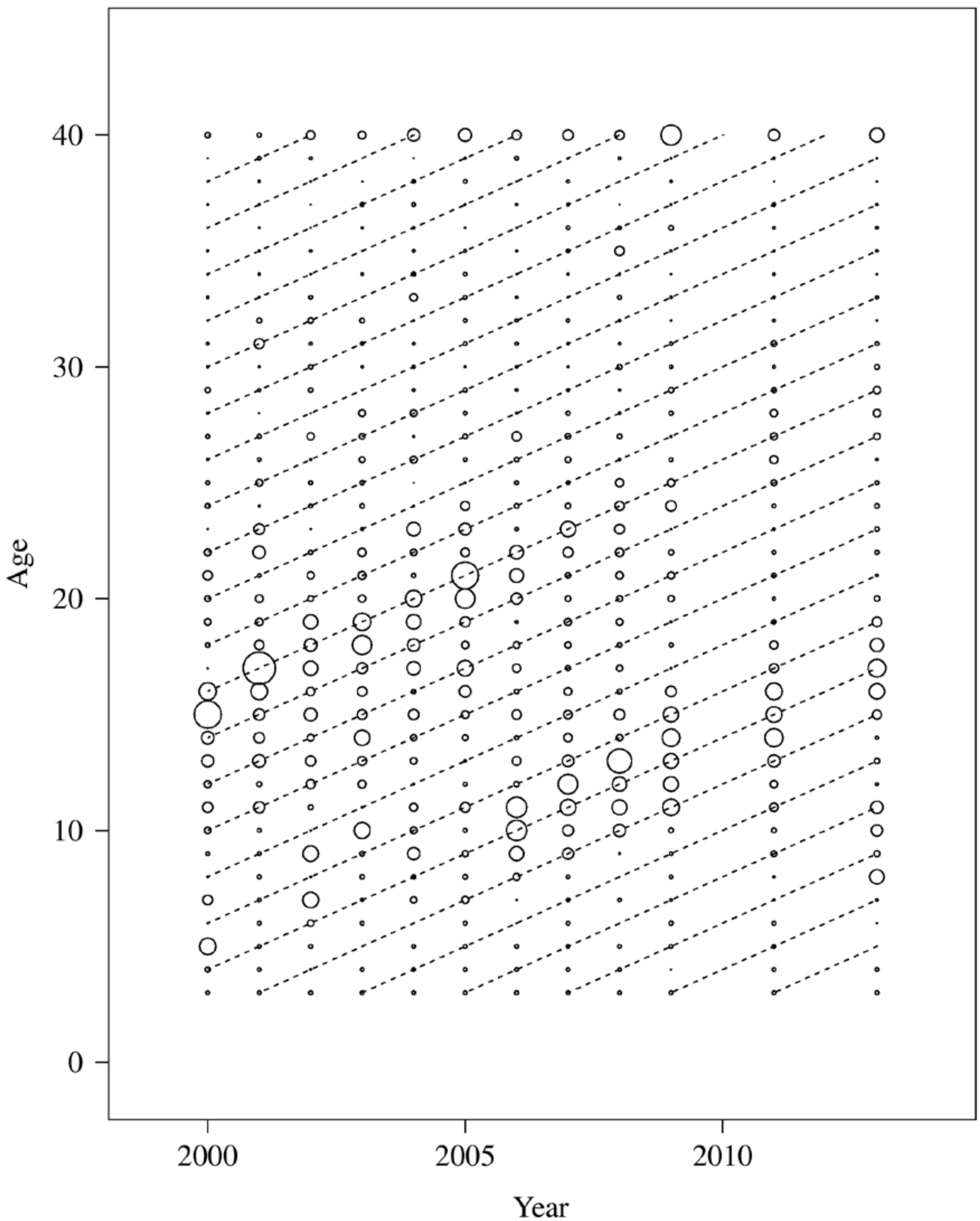


Figure 2. Fishery age composition data for the Aleutian Islands; bubbles are scaled within each year of samples; and dashed lines denote cohorts.

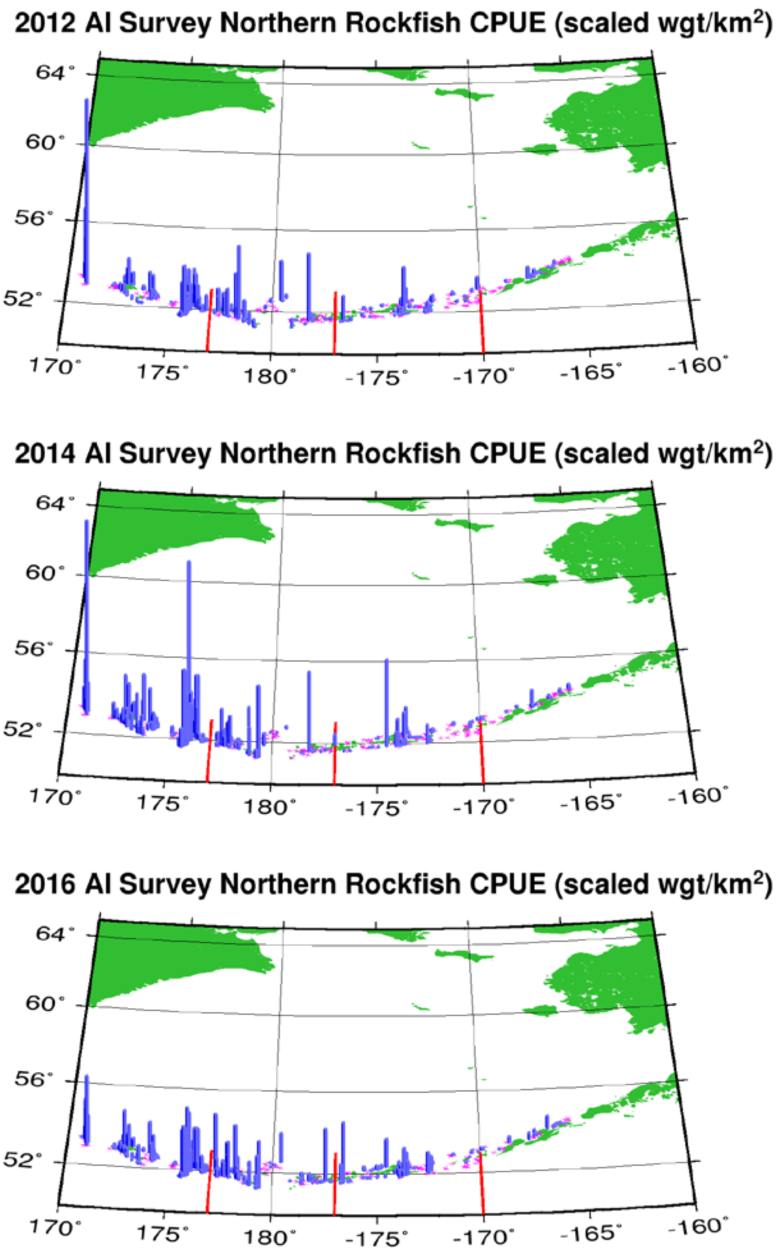


Figure 3. Scaled AI survey northern rockfish CPUE from (square root of kg/km^2) from 2012-2016; the red lines indicate boundaries between the WAI, CAI, EAI, and EBS areas.

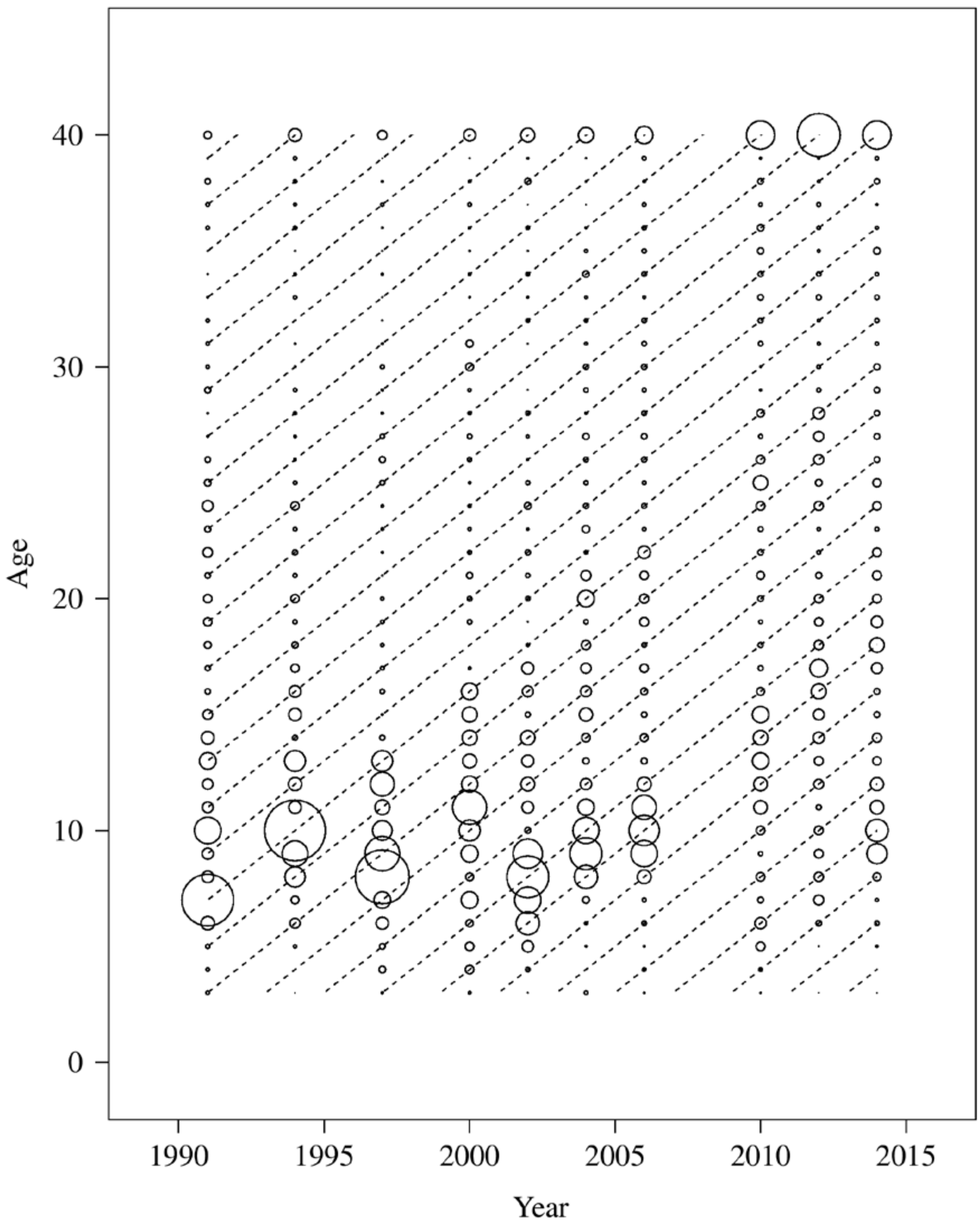


Figure 4. Age composition data from the Aleutian Islands trawl survey; bubbles are scaled within each year of samples; and dashed lines denote cohorts.

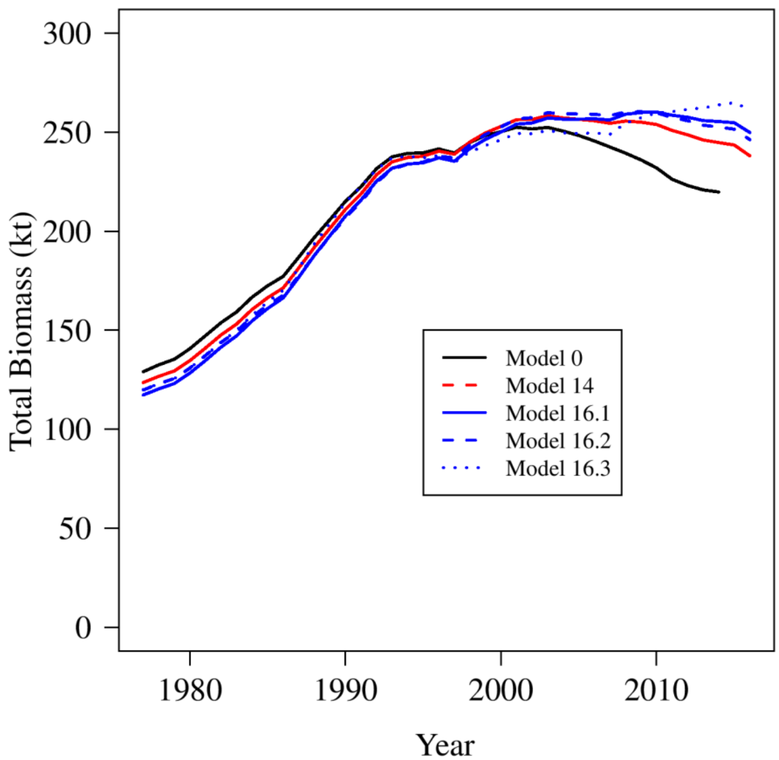


Figure 5. Estimated time series of total stock biomass across the models.

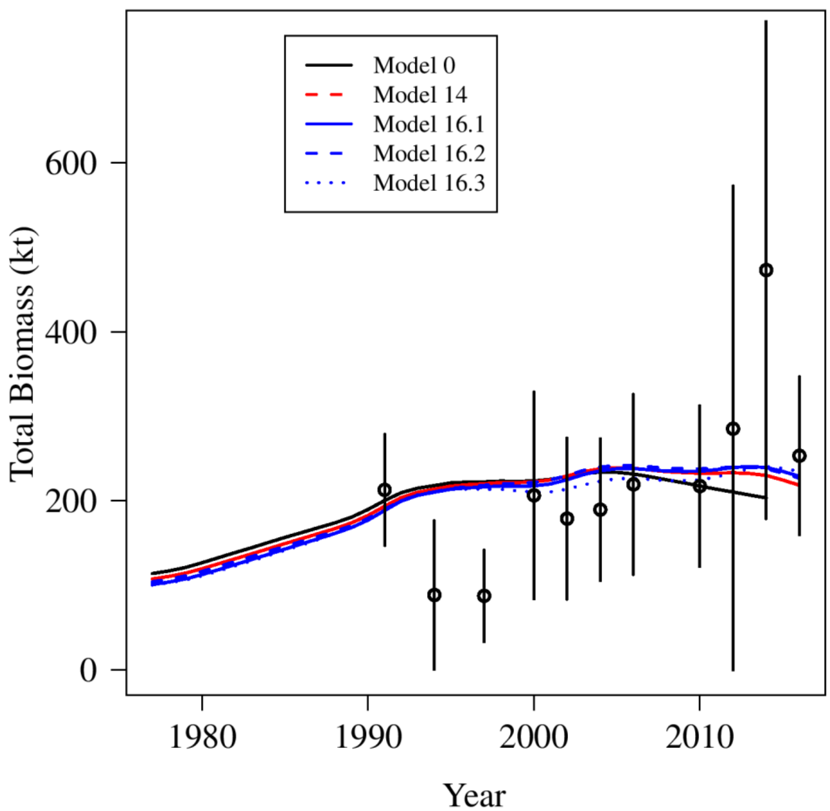


Figure 6. Model fit to the AI survey biomass across models.

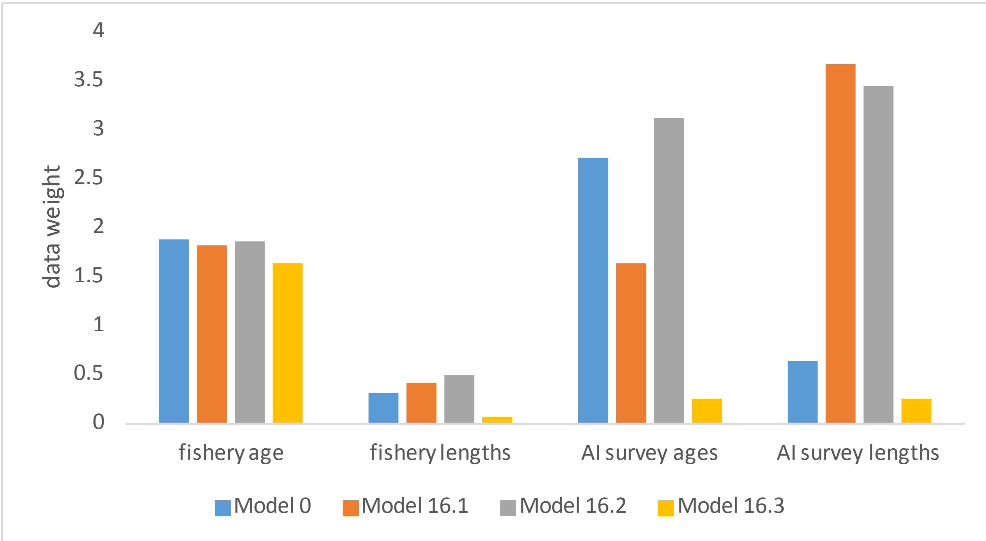


Figure 7. Data weights for the age and length composition data across the models.

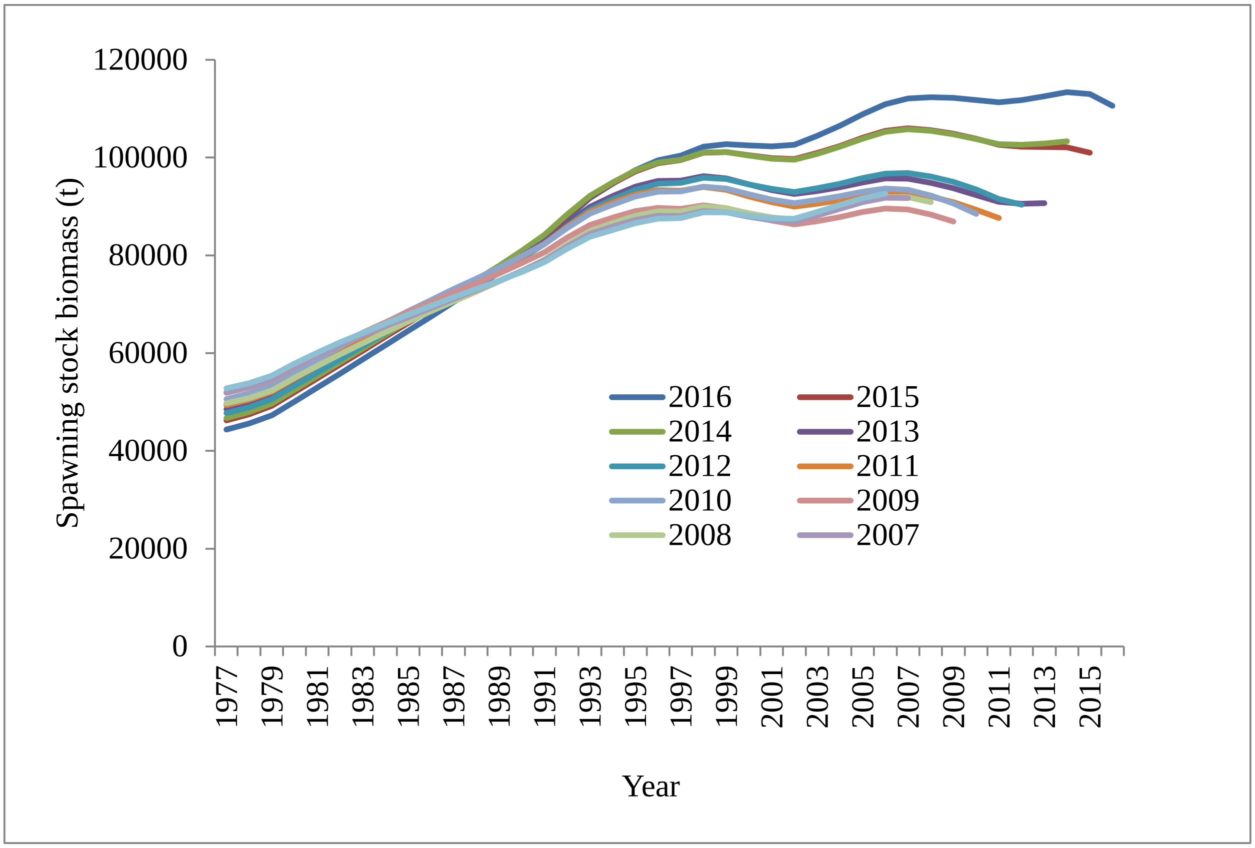


Figure 8. Retrospective estimates of spawning stock biomass for model runs with end years of 2006 to 2016.

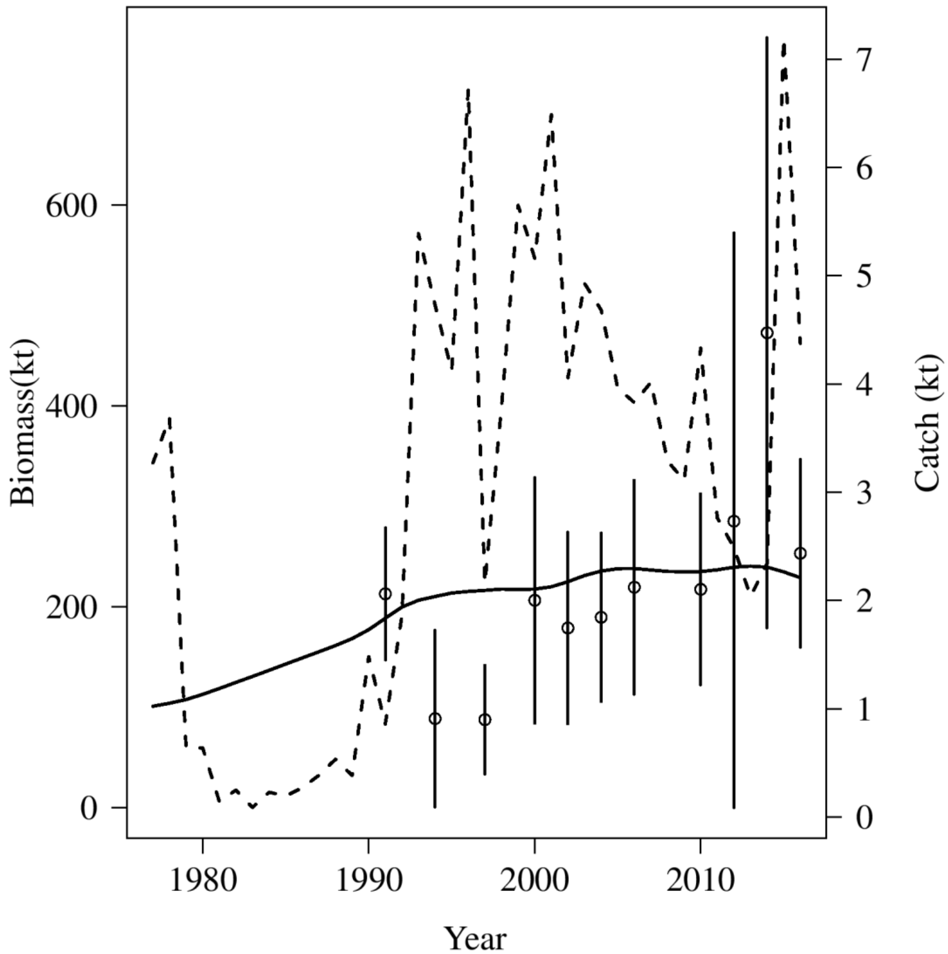


Figure 9. Observed Aleutian Islands survey biomass (data points, ± 2 standard deviations), predicted survey biomass (solid line) and BSAI harvest (dashed line).

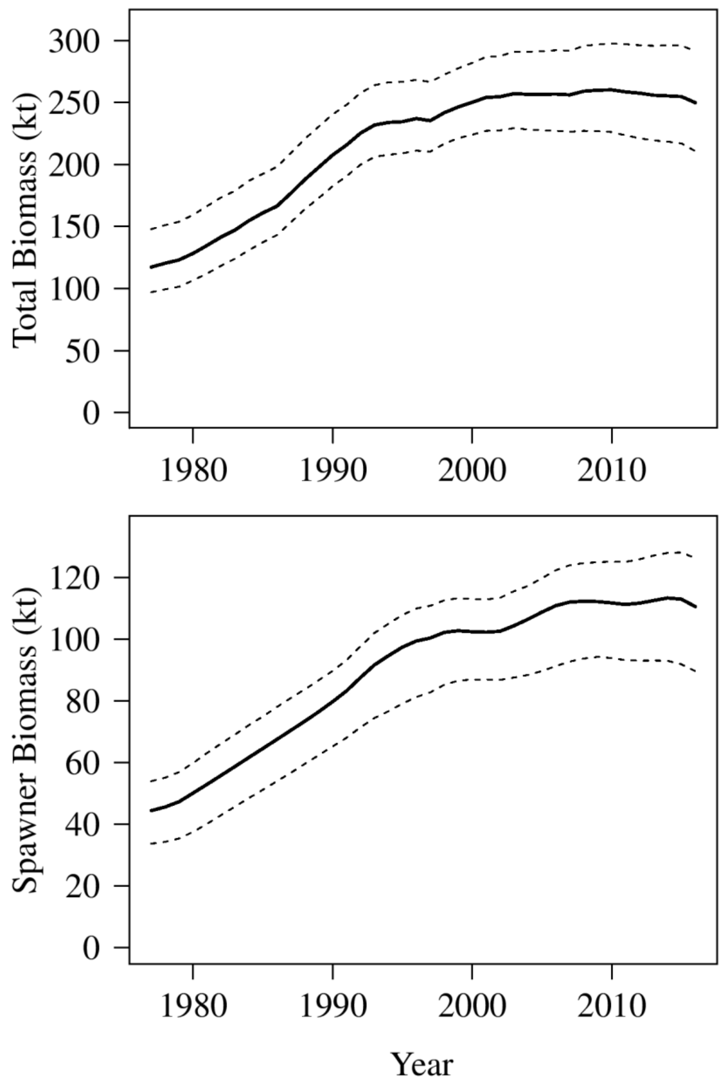


Figure 10. Total and spawner biomass for BSAI northern rockfish with 95% confidence intervals from MCMC integration.

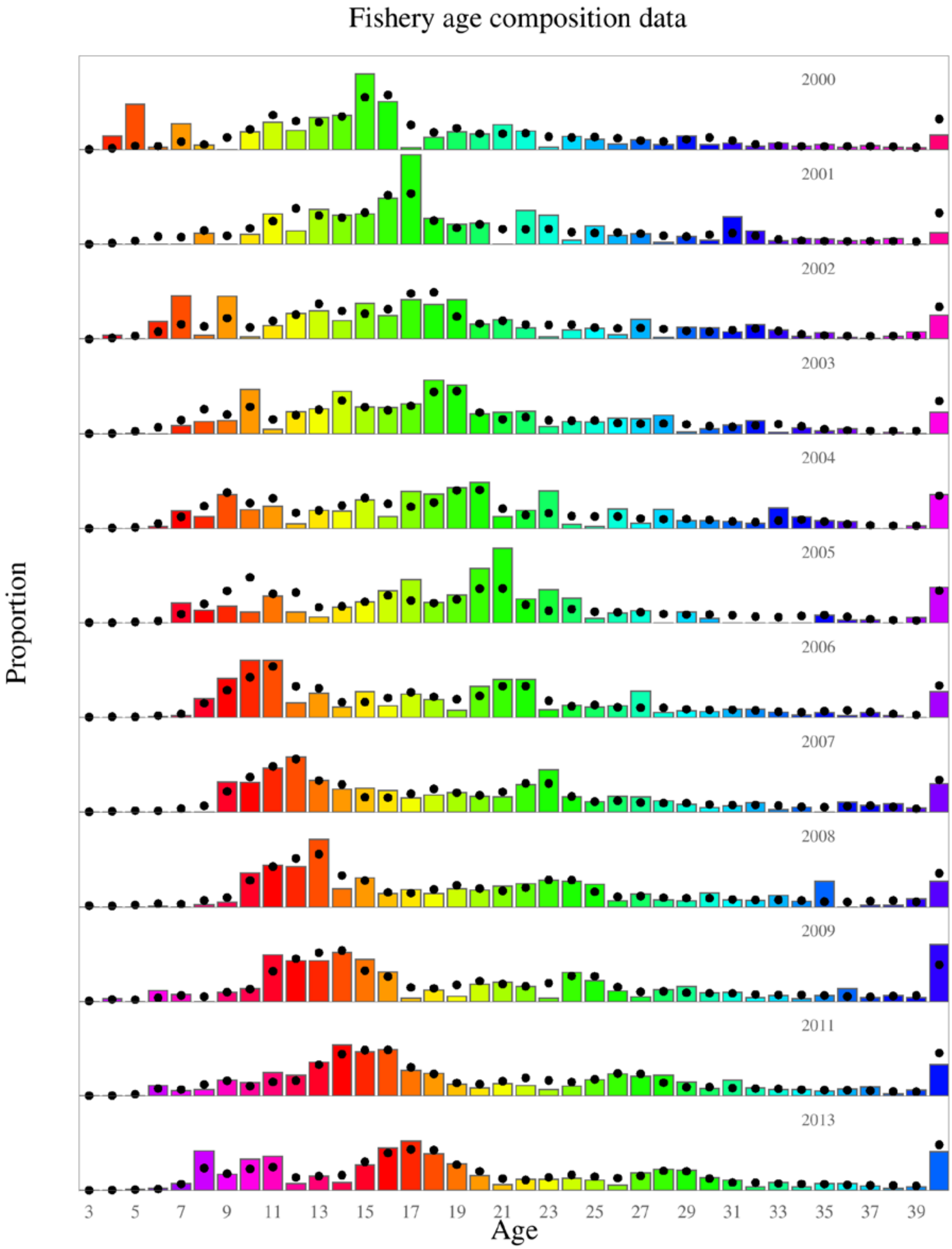


Figure 11. Model fits (dots) to the fishery age composition data (columns) for BSAI northern rockfish. Colors of the bars correspond to cohorts (except for the 40+ group).

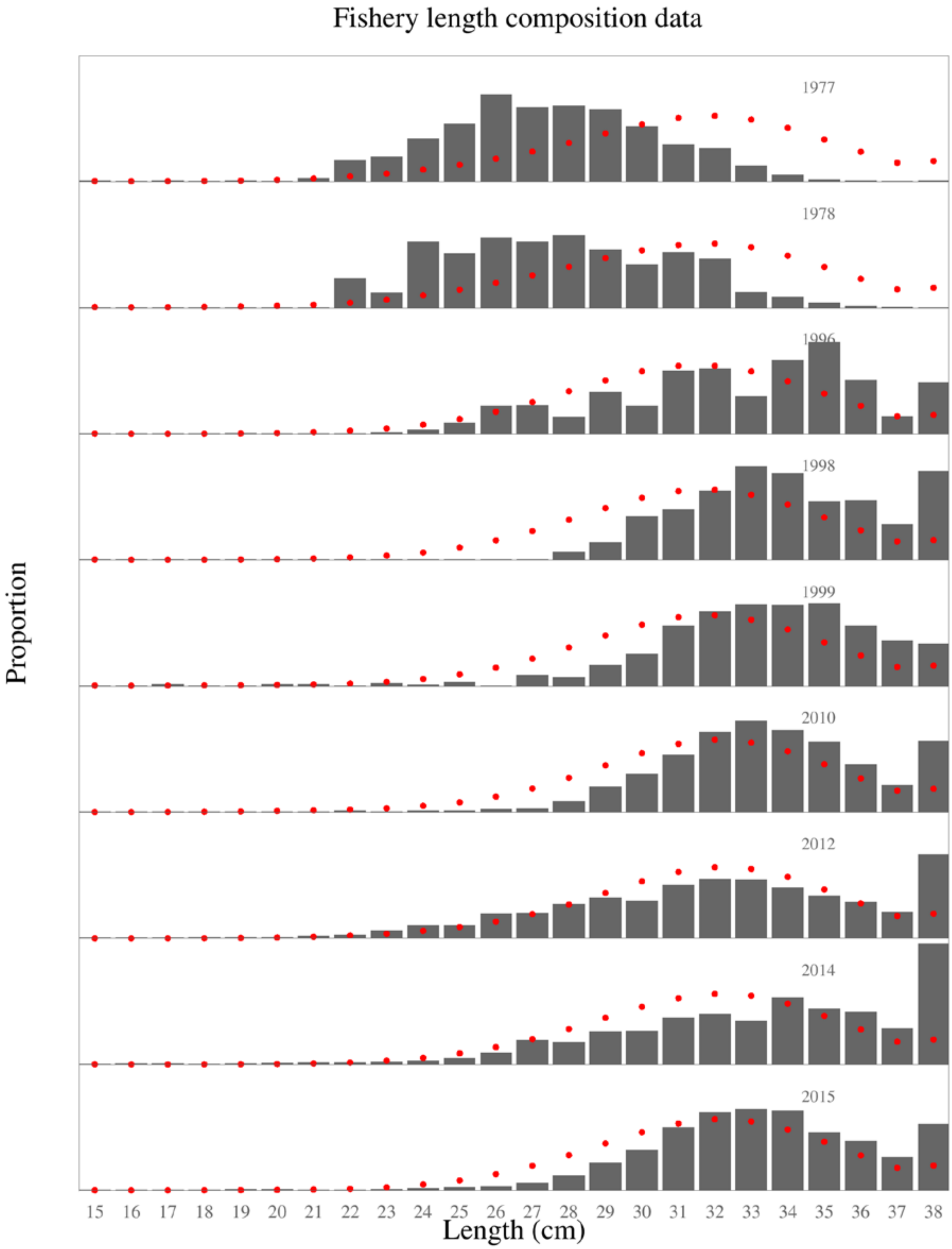


Figure 12. Model fits (dots) to the fishery length composition data (columns) for BSAI northern rockfish.

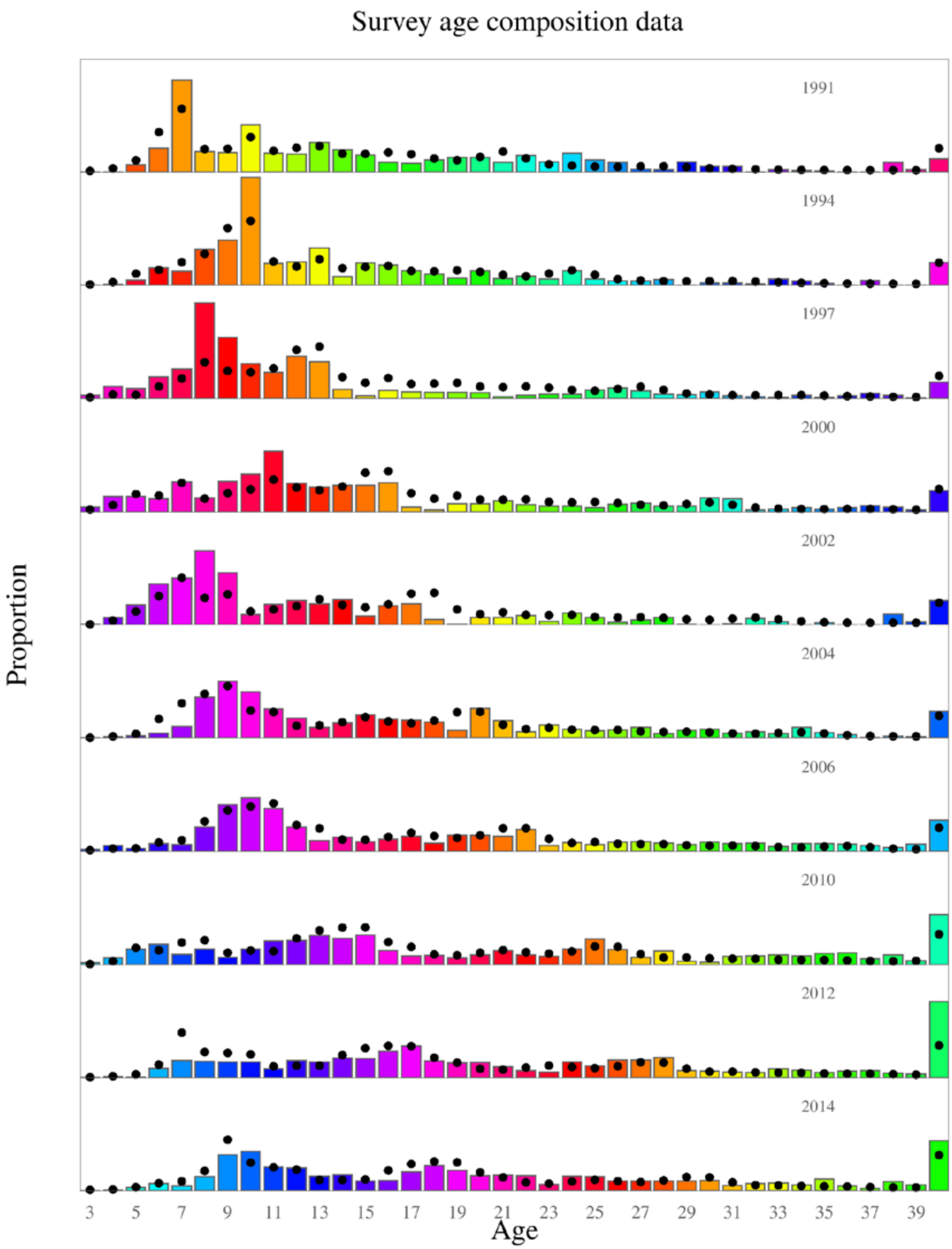


Figure 13. Model fits (dots) to the survey age composition data (columns) for BSAI northern rockfish. Colors of the bars correspond to cohorts (except for the 40+ group).

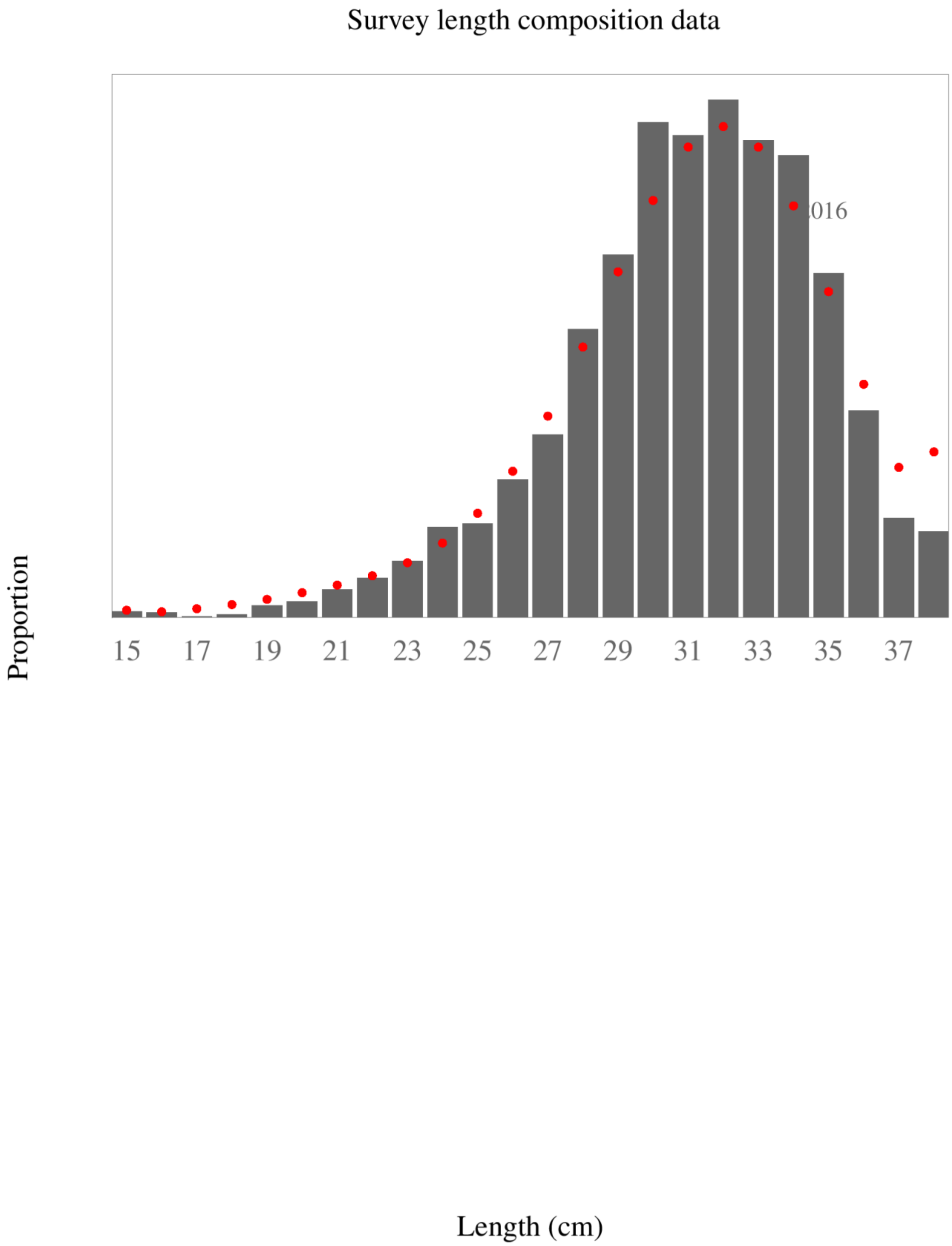


Figure 14. Model fits (dots) to the 2014 survey length composition data (columns) for BSAI northern rockfish.

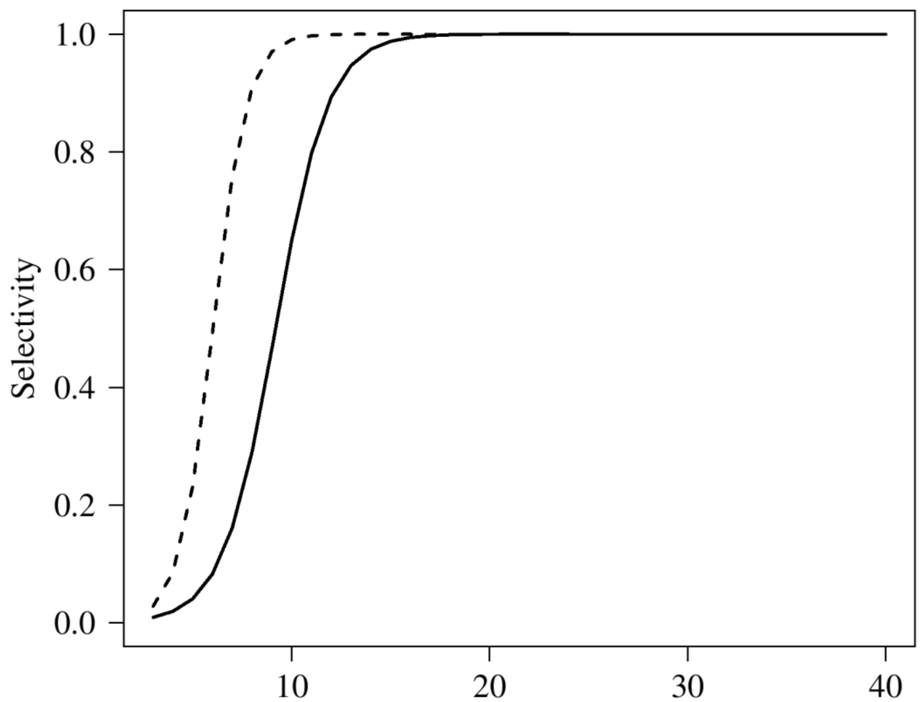


Figure 15. Estimated fishery (solid line) and survey (dashed line) selectivity at age for BSAI northern rockfish.

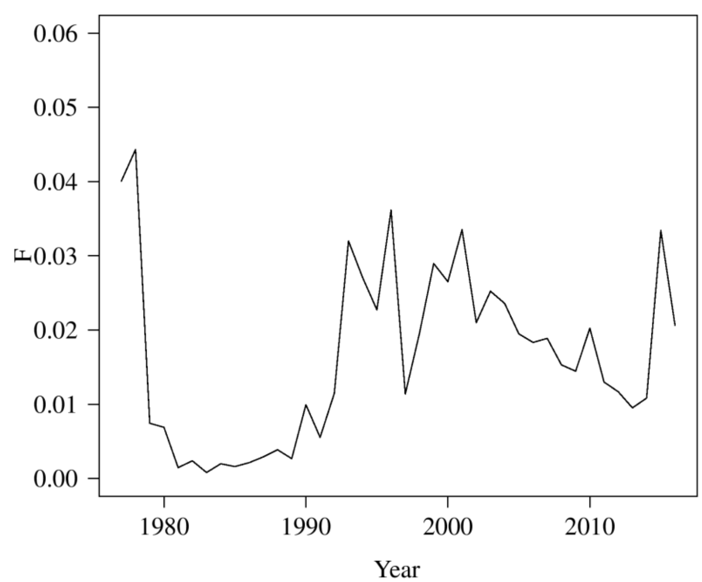


Figure 16. Estimated fully-selected fishing mortality rate for BSAI northern rockfish.

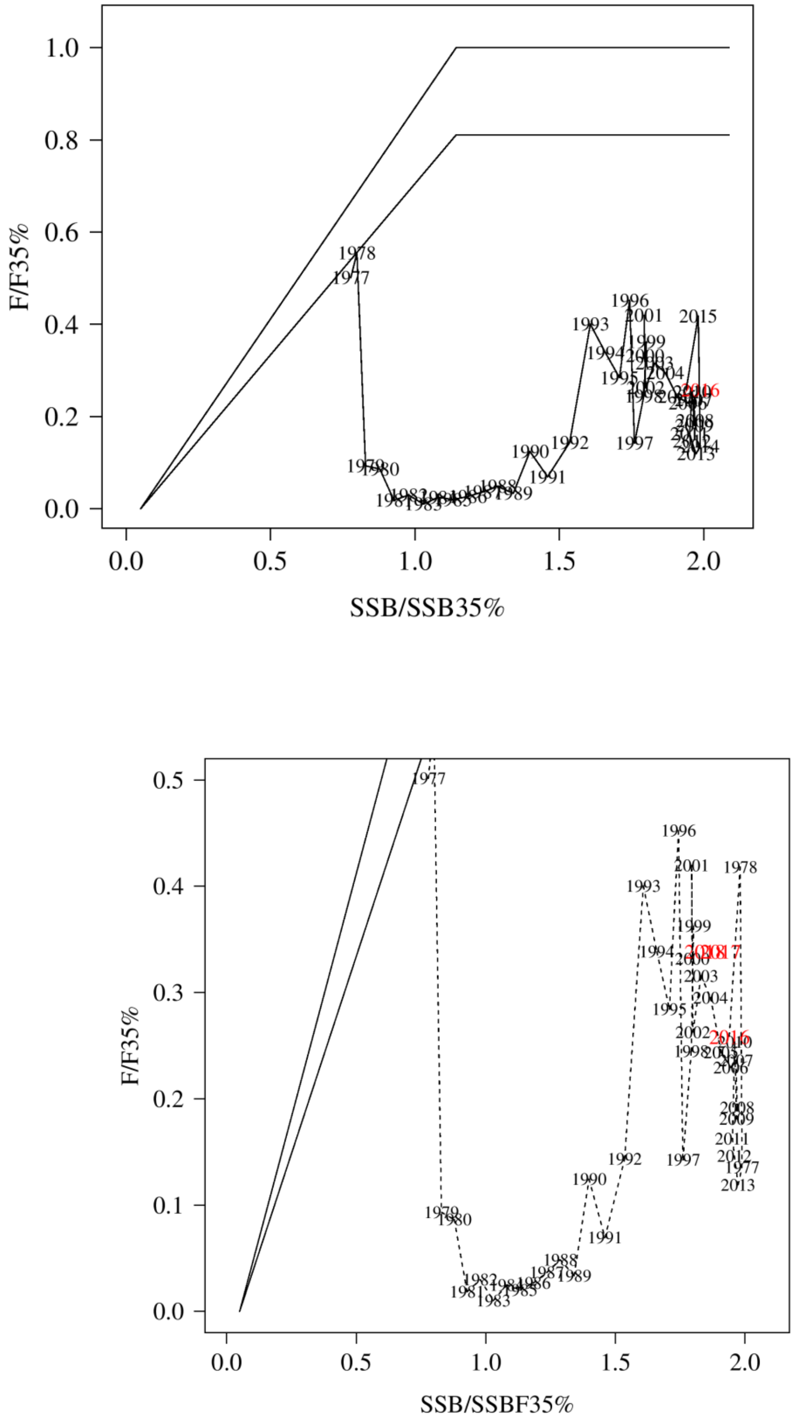


Figure 17. (Top panel) Estimated fishing mortality and SSB from 1977-2014 (with 2014 in red) in reference to OFL (upper line) and ABC (lower line) harvest control rules. The bottom panel shows a reduced vertical scale, and the projected F and stock size for 2015 and 2016.

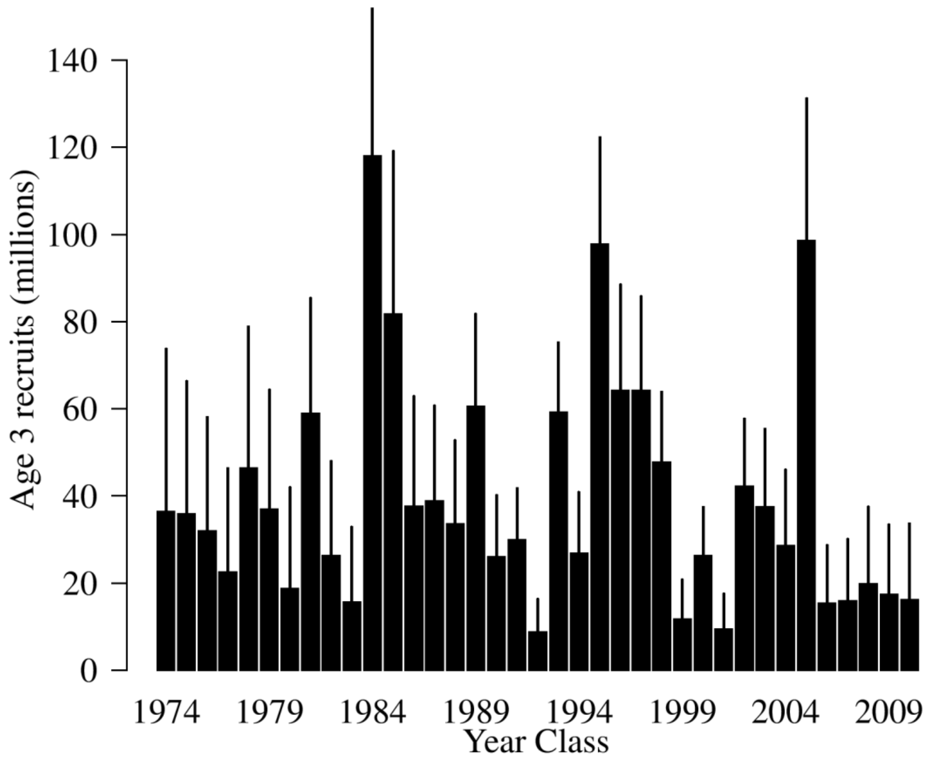


Figure 18. Estimated recruitment (age 3) of BSAI northern rockfish, with 95% CI limits obtained from MCMC integration.

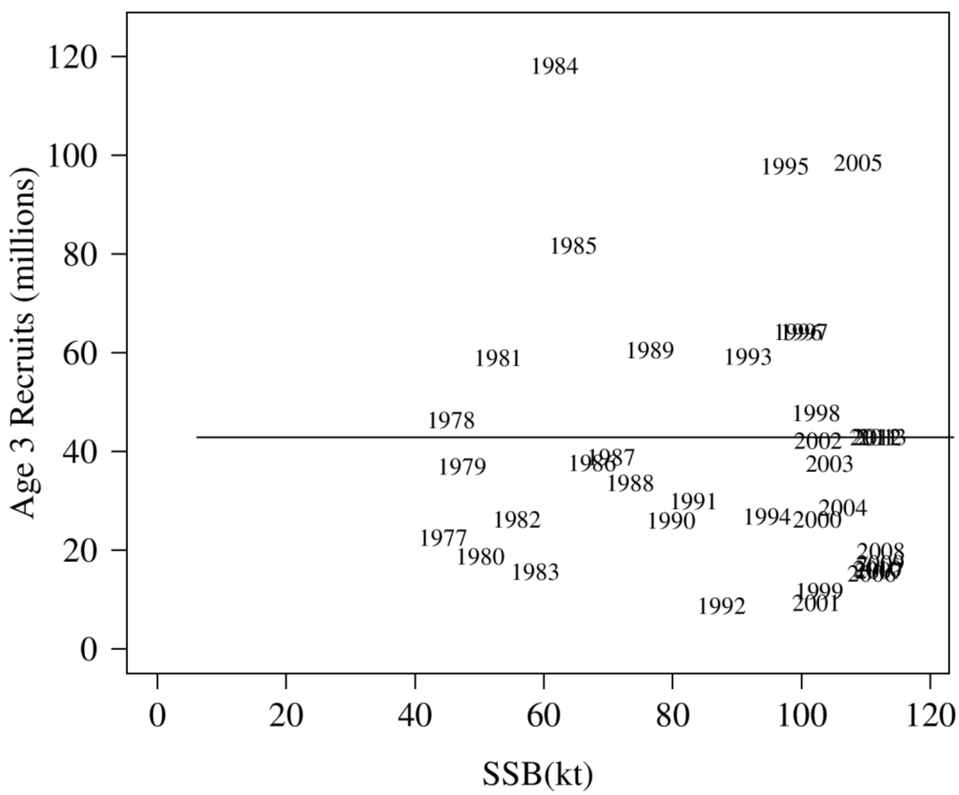


Figure 19. Scatterplot of BSAI northern rockfish spawner-recruit data; label is year class.

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 has not exceeded 0.06 t. Total removals ranged between 0.05 t and 140 t between 2010 and 2015, 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 from 1977-2015. Trawl and longline include research survey and occasional short-term projects. “Other” is recreational, personal use, and subsistence harvest.

Year	Source	Trawl	Longline
1977	NMFS-AFSC survey databases		
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		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	AKFIN database	50.354	0.025
2011		140.163	0.022
2012		89.765	0.021
2013		0.014	0.039
2014		69.154	0.032
2015		0.042	0.003

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