CHAPTER 12

Assessment of the Northern Rockfish Stock in the Bering Sea/Aleutian Islands

by

Paul D. Spencer and James N. Ianelli

Executive Summary

The last full assessment for northern rockfish was presented to the Plan Team in 2008, and an updated assessment was presented in 2009. The following changes were made to northern rockfish assessment relative to the November 2008 SAFE:

Summary of Changes in Assessment Inputs

Changes in the input data:

1) Catch updated through October 2, 2010.
2) The biomass estimate and length composition from the 2010 AI survey was added to the model input data.
3) The 2006-2007 fishery age compositions and 2008-2009 fishery length compositions were added to the model input data.

Changes in the assessment methodology:

1) In previous assessments, we constrained the parameters of the fishery selectivity by forcing them to be similar to the survey selectivity curve. In this assessment, we recommend estimation of the fishery selectivity curve without this constraint.
2) The growth parameters were re-estimated.
3) The years in which recruitment for recent year classes is not estimated was reduced from 7 to 3.

Changes in the Assessment Results

A summary of the 2010 assessment recommended ABC's relative to the 2009 recommendations is shown below. BSAI northern rockfish are not overfished or approaching an overfished condition.

Quantity/Status	Last year 2010	2011	This year 2011	2012
M (natural mortality)	0.041	0.041	0.0427	0.0427
Specified/recommended Tier	3a	3a	3a	3a
Projected total biomass (ages 3+)	202,267	203,410	201,429	196,815
Female spawning biomass (t) Projected	69,290	69,364	71,516	69,319
$B_{100\%}$	138,283	138,283	126,528	126,528
$B_{40\%}$	55,313	55,313	50,611	50,611
$B_{35\%}$	48,399	48,399	44,285	44,285
F_{OFL}	0.051	0.051	0.071	0.071
$maxF_{ABC}$	0.043	0.043	0.058	0.058
Specified/recommended F_{ABC}	0.043	0.043	0.058	0.058
Specified/recommended OFL (t)	8,642	8,701	10,575	10,423
Specified/recommended ABC (t)	7,242	7,291	8,669	8,328
Is the stock being subjected to overfishing?	No	No	No	No
Is the stock currently overfished?	No	No	No	No
Is the stock approaching a condition of being overfished?	No	No	No	No

The following table gives the recent biomass estimates, catch, and harvest specifications, and projected biomass, OFL and ABC for 2011-2012.

Year	Biomass[1]	OFL	ABC	TAC	Catch
2009	200,179	8,540	7,160	7,160	3,111
2010	202,267	8,640	7,240	7,240	3,387[2]
2011	201,429	10,575	8,669		
2012	196,815	10,423	8,328		

[1] Total biomass from age-structured projection model.
[2] Catch as of October 2, 2010.

Responses to the comments of the Scientific and Statistical Committee

There were no comments or requests from the December 2008 or December 2009 SSC meetings pertaining to BSAI 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 variety of types of research can be used to infer stock structure of northern rockfish, including larval distribution patterns and other life-history information, and genetic studies. In 2002, an analysis of archived *Sebastes* larvae was undertaken by Dr. Art Kendall; using data collected in 1990 off southeast Alaska (650 larvae) and the AFSC ichthyoplankton database (16,895 *Sebastes* larvae, collected on 58 cruises from 1972 to 1999, primarily in the Gulf of Alaska). The southeast Alaska larvae all showed the same morph, and were too small to have characteristics that would allow species identification. A preliminary examination of the AFSC ichthyoplankton database indicates that most larvae were collected in the spring, the larvae were widespread in the areas sampled, and most are small (5-7 mm). The larvae were organized into three size classes for analysis: <7.9 mm, 8.0-13.9 mm, and >14.0 mm. A subset of the abundant small larvae was examined, as were all larvae in the medium and large groups. Species identification based on morphological characteristics is difficult because of overlapping characteristics among species, as few rockfish species in the north Pacific have published descriptions of the complete larval developmental series. However, all of the larvae examined could be assigned to four morphs identified by Kendall (1991), where each morph is associated with one or more species. Most of the small larvae examined belong to a single morph, which contains the species *S. alutus* (POP), *S. polyspinus* (northern rockfish), and *S. ciliatus* (dusky rockfish).

An initial genetic analysis revealed no evidence of population structure in Alaskan northern rockfish from either mtDNA or microsatellite analysis (Gharrett 2003), based upon small samples of 20 fish from each of three locations (Kodiak Island, Unimak Pass, and Stalemate Bank). Although the sample sizes were small and had little power, the authors concluded that the analysis was sufficient to conclude that existing structure is not pronounced. However, this study looked at only a portion of the mtDNA genome and a handful of microsatellite loci, and had small sample sizes. Also, the failure to identify population structure does not necessarily imply that northern rockfish consist of a single population unit. If subtle differences occur, much larger sample sizes would be required in order to identify stock structure. Additional northern rockfish genetic samples were collected from each of the four major areas in the 2004 AI survey (100 samples each), as well as 100 samples from the 2004 EBS slope survey, and a genetic analysis of these samples by Dr. Anthony Gharrett and his colleagues at the University of Alaska is currently in progress.

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). Foreign harvest was reconstructed by estimating the species composition of observed catches from the North Pacific Observer Program database, and applying those estimates to the "blend" estimates of total catch of the appropriate management category.

Rockfish management categories in the domestic fishery since 1991 have also included multiple species. From 1991 to 2000, northern rockfish harvest in the EBS was included in the "other red rockfish" category, whereas harvest in the Aleutian Islands was reported in a "northern/sharpchin" category. In 2001, northern rockfish in the EBS were managed in a "northern/sharpchin" category, matching the species complex in the AI, and the management was combined across the BSAI area. In 2002, sharpchin rockfish were dropped from the complex because of their sparse catches, leaving single-species management category of northern rockfish. Estimates of domestic catch since 1991 were reconstructed in a similar manner as the foreign catches. Estimates of domestic catch in 1990 were obtained from Guttormsen et al. 1992. Northern rockfish catches from the domestic fishery prior to the start of the domestic observer program were obtained from PACFIN records. The ABCs, TACS, and catches by management complex from 1988-2010 are shown in Table 1.

Northern rockfish catch prior to 1990 was small relative to more recent years (with the exception of 1977 and 1978) (Table 2). Harvest data from 2004-2010 indicates that approximately 89% of the BSAI northern rockfish are harvested in the Atka mackerel fishery. From 2004 to 2010, a large amount of the northern rockfish bycatch in the Atka mackerel fishery occurred in September in the central and western Aleutians (areas 542 and 543). 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). The removals of northern rockfish from the trawl and hydroacoustic surveys are shown in Table 3.

Information on proportion discarded is generally not available for northern rockfish in years where the management categories consist of multi-species complexes. However, because the catches of sharpchin rockfish are generally rare in both the fishery and survey, the discard information available for the "sharpchin/northern" complex can interpreted as northern rockfish discards. This management category was used in 2001 in the EBS, and from 1993-2001 in the AI. Prior to 2003 the discard rates were generally above 80%, with the exception of the mid-1990s when some targeting occurred in the Aleutians Islands (Table 4). Recent discard rates have been decreasing. For example, the discard rate in the EBS has declined from 92% in 2002 to 16% in 2009, and the discard rate in the Aleutian Islands has declined from 91% to 37% over the same period.

DATA

Fishery Data

The fishery data is characterized by inconsistent sampling of lengths and ages (Table 5). 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.

In this assessment annual length frequency data were selected on the basis of 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, 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, and 2008-2009 were used, and the length and age data from 2000-2007 were used to estimate the age-frequency of the fishery catch.

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, conducted by the National Marine Fisheries Service (NMFS) were conducted in 1988 and 1991 on the eastern Bering Sea slope, and in 1991, 1994, 1997, 2000, 2002, 2004, 2006, and 2010 in the Aleutian Islands (Table 6). The Aleutian Islands survey scheduled for 2008 was canceled to due lack of funding. Differences exist between the 1980-1986 cooperative surveys and the 1991-2010 from the U.S. domestic surveys with regard to the vessels and gear design used (Skip Zenger, National Marine Fisheries Service, pers. comm.). 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 this assessment, the AI surveys from the 1980s are used to provide some indication of biomass during this time period. The survey time series beginning in 1980 is considered as one data set, and no attempt is made to estimate a separate catchability coefficient for the cooperative surveys in the 1980s. Relative to a Tier 5 approach of averaging of biomass estimates, the degree of influence of these biomass estimates is reduced by the inclusion of the age and length composition data as well as the large standard deviations of estimated biomass; the coefficient of variation (CV) ranged between 0.34 in 1983 to 0.87 in 1980 (Table 6).

The biennial EBS slope survey was initiated in 2002. The most recent slope survey prior to 2002, excluding some preliminary tows in 2000 intended for evaluating survey gear, was in 1991, 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 survey biomass estimates of northern rockfish from the 2002, 2004, 2008, and 2010 surveys (the 2006 survey was canceled due to lack of funding) ranged between 3 t (2008) and 42 t (2010), with CVs between 0.38 (2002) and 1.0 (2008. Given these low levels of biomass, the slope survey results are not used in this assessment. As in the BSAI POP assessment, the slope survey results are not used in this assessment and the 1991-2010 Aleutian Islands trawl surveys are considered an index of the BSAI population.

In the 1980 -2006 AI surveys, the northern rockfish population was largely concentrated in the area between Amchitka Islands and the Buldir Island-Tahoma Bank area, with additional high biomass areas near Attu Island and Petral Bank. The 2010 survey CPUE (kg/km^2) showed a similar pattern, with a concentration of biomass in the Tahoma Bank area (Figure 1). An average of 68% of the estimated biomass from the 1991-2010 NMFS AI trawl surveys occurs in the western Aleutian Islands (Table 6). 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.

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 7, along with the number of hauls producing these data. The number of otoliths read by area is shown in Table 8. 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 assigned by one reader, and it was assumed the age assigned by the other reader was accurate. 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 (Table 9). 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 Bertalannfy curve to estimates of mean size at age obtained from the AI surveys from 1980-2006. 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 Bertalannfy parameters are as follows, and were used to create a transition matrix and a weight-at-age vector:

L_{inf}	K	t_0
33.35	0.19	-0.4879

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 (Table 10). This matrix was created by regressing the observed standard deviation in length at each age (obtained from the aged fish from the 1980-2006 surveys) against age, 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 0.12 at age 3 to 0.11 at age 23.

A length-weight relationship of the form $W = aL^b$ was fit from the survey data from 1980-2006, and produced estimates of a = 1.44 x 10^{-5} and b = 3.00. This relationship was used in combination with the von Bertalanffy growth curve to obtain the estimated weight at age vector of the population (Table 11).

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

Component	BSAI
Fishery catch	1977-2010
Fishery age composition	2000-2007
Fishery size composition	1977-1978, 1996, 1998-1999, 2008-2009
Survey age composition	1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004, and 2006
Survey length composition	2010
Survey biomass estimates	1980, 1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004 2006, 2010

ANALYTIC APPROACH

Model structure

An age-structured population model, implemented in the software program AD Model Builder, was used to obtain estimates of recruitment, numbers at age, and catch at age. The assessment model for northern rockfish is very similar to that currently used for BSAI Pacific ocean perch, which was used as a template for the current model. Population size in numbers at age a in year t was modeled as

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

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 (defined as 23), and T is the terminal year of the analysis (defined as 2010). The numbers at age A are a "pooled" group consisting of fish of age A and older, and are estimated as

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

The 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 2006 are estimated as parameters in the model, and are modeled with a lognormal distribution

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

where ν_t is a time-variant deviation.

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*) that increases asymptotically with age 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

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

The logistic curve is used to model fishery selectivity at age:

$$fishsel_a = \frac{1}{1+\exp(-slope(a-a_{50\%}))}$$

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

In previous assessments (Spencer et al. 2004), the age at 50% selectivity was much larger than that estimated in the survey, which motivated constraining the fishery selectivity curve to be close to the survey selectivity curve (using a penalty term in the likelihood function) given the limited information on fishery age composition. Given the increased amount of fishery otoliths collected since 2000 which have now been read, we attempt to estimate the fishery selectivity in this assessment. The two models considered are described below.

Model 1: The fishery selectivity parameters were constrained by estimating them as the survey selectivity parameters multiplied by e^{δ} , where δ was normally distributed with a mean of zero and a standard deviation of 0.03 and 0.05, respectively, for the $a_{50\%}$ and *slope* parameters, respectively. This was the method used for estimating fishery selectivity in the 2008 assessment.

Model 2: The fishery selectivity parameters were not constrained.

The mean numbers at age for each year was computed as

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

The predicted length composition data were calculated by multiplying the mean numbers at age by a transition matrix, which gives the proportion of each age (rows) in each length group (columns); the sum across each age is equal to one. The mean number of fish at age available to the survey or fishery is multiplied by the aging error matrix to produce the observed survey or fishery age compositions.

Catch biomass at age was computed as the product of mean numbers at age, instantaneous fishing mortality, and weight at age. The predicted trawl survey biomass (*pred_biom*) was computed as

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

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

To facilitate parameter estimation, prior distributions were used for the survey catchability and the natural mortality rate *M*. A lognormal distribution was also used for the natural mortality rate *M*, with the mean set to 0.06 (the value used in previous assessments, based upon expected relationships between *M*, longevity, and the von Bertalanffy growth parameter *K* (Alverson and Carney 1975)) and the CV set to 0.15. The standard deviation of log recruits, σ_r, was fixed at 0.75, a value consistent with the root mean squared error (RMSE; defined below) of recruitment deviations. Similar, the prior distribution for *qsurv* followed a lognormal distribution with a mean of 1.0 and a coefficient of variation (CV) of 0.001, essentially fixing *qsurv* at 1.0.

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

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

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

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

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

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

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

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

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

Parameters Estimated Independently

The parameters estimated independently include the age error matrix, the age-length transition matrix, individual weight at age, and proportion mature females at age. The derivation of the age error matrix, the age-length transition matrix, and the weight at age vector are described above. The proportion of females mature at age (Table 11) was obtained from the Gulf of Alaska northern rockfish model (Courtney et al. 1999), and a logistic curve was fit to data collected by Chris Lunsford of the Auke Bay Laboratory.

Parameters Estimated Conditionally

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, rather than the median, recruitment. If σ_r is fixed, the term n ln (σ_r) adds a constant value to the negative log-likelihood. The 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 number of hauls that produced the data, 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. 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 the deviations in F are not included in the overall likelihood function. The overall negative log-likelihood function (excluding the catch component) 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 sample sizes for the age and length compositions were set to the number of hauls from which these demographic data were obtained. Additionally, because of the difficulty in fitting a fishery selectivity curve to the fishery age and length data, these data components were assigned one-half the weight assigned to the survey age compositions. Weights of 4/6 and 8/6 were chosen for the fisheries and survey age/length compositions so that the average of the weights remains 1. In the results below, comparisons of effective sample size to input sample size were made after scaling the input sample sizes by their weights.

The negative log-likelihood function was minimized by varying the following parameters:

Parameter type	Number
1) fishing mortality mean	1
2) fishing mortality deviations	34
3) recruitment mean	1
5) recruitment deviations	31
6) Initial recruitment	1
7) first year recruitment deviations	20
8) biomass survey catchability	1
9) natural mortality rate	1
10) survey selectivity parameters	2
11) fishery selectivity parameters	2
Total parameters	94

RESULTS

Model Evaluation

The negative log-likelihood associated with the various data components (unscaled by the various λ terms or weights) for the models are shown in Table 12. Model 2, which does not constrain the fishery selectivity curve, has a negative log-likelihood which is 40 units lower than Model 1, with the largest differences in the fishery age and length composition data, and the survey age composition data. The fit to the other data components are similar between the models. The effective sample size for the age and length composition data ranged from 21% to 76% of the input sample sizes, whereas the standard deviation of the normalized residuals were greater than one for all data components except fishery ages, which was 0.98.

Model 2 is recommended for several reasons. First, in contrast with previous assessments, there are now several years of fishery age composition data available, as fishery age composition data exist for each year between 2000 and 2007. Second, the estimated age at 50% selection in the fishery is estimated as 12.0, which is lower than that obtained in previous assessments with more limited data and is comparable with other rockfish species. The following table shows the available data on fishery and length composition and estimates of age at 50% in the fishery from previous assessments.

Assessment Year	Years of Fishery Ages	Estimated Age at 50% Fishery Selection
2003	2002	19
2004	2000, 2002-2003	15
2006	2000-2005	13.3
2010	2000-2007	12

As more fishery age composition has become available, the estimated age at 50% fishery selection has been reduced, and the current estimate is based upon 8 years of fishery age data. The age at 50% selection in the GOA is 8 years and thus between the BSAI fishery and AI survey estimates of age at 50% selection of 12 and 6.4 years, respectively. However, the GOA northern rockfish is a targeted stock, and one might thus expect a lower age at selection than in the bycatch fishery in the BSAI. Although the fishery selectivity may change if targeting were to occur on northern rockfish, the unconstrained estimate of fishing selectivity remains the best available information on the current fishing selection. The results in the remainder of this assessment refer to the preferred model that does not constrain the fishery selectivity curve.

Biomass trends

The estimated survey biomass shows a slightly increasing trend, starting at 92,325 t in 1977 and increasing gradually to 191,141 t in 2004 (Figure 2). The estimated total biomass shows a similar trend, increasing to peak values of 207,070 t 2003, whereas the estimated spawner biomass increases from 33,325 in 1977 to its highest value of 71,999 in 2010 (Table 13, Figure 3).

Age/size compositions

The model fits to the fishery age and size compositions are shown in Figures 4-5, and the model fit to the survey age and length composition are shown in Figures 6-7. The model captures the general trends in the survey age data, but does not completely match the magnitude of some of the peaks of these data, particularly in the survey age composition data in 1983, 1991, 1994, and 1999, and the fishery age composition data for 2000-2001 and 2006-2007.

Fishing and survey selectivity

The estimated survey selectivity curve had an age of 50% selection of 6.4, whereas this parameter was 12.0 for the fishery selectivity curve (Figure 8).

Fishing mortality

The estimates of instantaneous fishing mortality rate are shown in Figure 9. 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 2009 estimate is 0.022. 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 10).

Recruitment

Recruitment strengths by year class are shown in Figure 11. There is little information to discern strong recruitments in the early years of the model, although relatively strong year classes are observed in 1984, 1988, 1989, and 1993-1996. These year class strengths can be seen in the survey age composition data, where the 1984 year class is revealed in the 1991 and 1994 age composition data, the 1989 year class is revealed in the 1997 and 2000 age composition data, and the 1993-1996 year classes are revealed in the 2000, 2002, 2004, and 2006 age composition data. The scatterplot of recruitment against spawning stock biomass is shown in Figure 12, indicating substantial variability in the pattern between recruitment and spawning stock size.

Population Projections

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 1977-2007 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 50,611 t. The year

2011 spawning stock biomass is estimated as 71,516 t. Since reliable estimates of the 2011 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B>B_{0.40}$ (71,516 t > 50,611 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 0.058 and 0.071, respectively. The 2011 ABC and OFL resulting from these rates are 330 t and 398 t, respectively. A summary of these values is below.

2011 SSB estimate (B)	=	71,516 t
$B_{0.40}$	=	50,611 t
$F_{0.40}$	=	0.058
F_{ABC}	=	0.058
$F_{0.35}$	=	0.071
F_{OFL}	=	0.035

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 2010 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2011 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2010. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2011, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2011 recommended in the assessment to the *max* F_{ABC} for 2011. (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 2005-2009 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 2010 or 2) above ½ of its MSY level in 2010 and above its MSY level in 2011 under this scenario, then the stock is not overfished.)
>
> *Scenario 7*: In 2011 and 2012, 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 2023 under this scenario, then the stock is not approaching an overfished condition.)

The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, and projections of the mean harvest and spawning stock biomass for the remaining six scenarios are shown in Table 14.

Status Determination

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2010, it does not provide the best estimate of OFL for 2011, because the mean 2010 catch under Scenario 6 is predicated on the 2010 catch being equal to the 2010 OFL, whereas the actual 2010 catch will likely be less than the 2009 OFL. The executive summary contains the appropriate one- and two-year ahead projections for both ABC and OFL.

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

Is the stock being subjected to overfishing? The official BSAI catch estimate for the most recent complete year (2009) is 3,111 t. This is less than the 2009 BSAI OFL of 7,160 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 2010:
a. If spawning biomass for 2010 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b. If spawning biomass for 2010 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c. If spawning biomass for 2010 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 2020 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 2013 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2013 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c. If the mean spawning biomass for 2013 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2023. If the mean spawning biomass for 2023 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 expected stock size in the year 2011 of Scenario 6 is 1.62 times its $B_{35\%}$. value of 44,285 t. With regard to whether BSAI northern rockfish is likely to be overfished in the future, the expected stock size in 2013 of Scenario 7 is 1.51 times the $B_{35\%}$ value.

ECOSYSTEM CONSIDERATIONS

Ecosystem Effects on the stock

1) Prey availability/abundance trends

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

2) Predator population trends

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

3) Changes in habitat quality

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

Fishery Effects on the ecosystem

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

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

DATA GAPS AND RESEARCH PRIORITIES

Little information is known regarding most aspects of the biology of northern rockfish, particularly in the Aleutian Islands. Recent genetic data suggests that the spatial movement of northern rockfish, per generation, may be much smaller that the currently-used BSAI management area. The evaluation of spatial management units can be conducted with a template developed by the Plan Team-SSC working group on stock structure. More generally, little is known regarding the reproductive biology and the distribution, duration, and habitat requirements of various life-history stages. Given the relatively unusual reproductive biology of rockfish and its importance in establishing management reference points, data on reproductive capacity should be collected on a periodic basis.

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.

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.

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.

Gharrett, A..J. 2003. Population structure of rougheye, shortraker, and northern rockfish based on analysis of mitochondrial DNA variation and microsatellites: completion. Juneau Center of Fisheries and Ocean Sciences, University of Alaska-Fairbanks. 136 pp.

Guttormsen, M, J. Gharrett, G. Tromble, J. Berger, and S.Murai. Summaries of domestic and joint venture groundfish catches (metric tons) in the northeast Pacific ocean and Bering Sea, 1990. AFSC Processed Report 92-06.

Kendall, A.W. Jr. 1991. Systematics and identification of larvae and juveniles of the genus *Sebastes*. Env. Biol. Fish. 30:173-190.

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

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.

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. 2002. Pacific ocean perch. pp.515-558 *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands region as projected for 2003. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK.

Spencer, P.D. J.N. Ianelli, and Y.-W. Lee. 2004. Northern rockfish. pp.747-788 *In* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands region as projected for 2003. North Pacific Fishery Management Council, P.O. Box 103136, Anchorage, AK.

Table 1. Total allowable catch (TAC), acceptable biological catch (ABC), and catch of the species groups used to manage northern rockfish from 1988 to 2010. 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.

Year	Area	Management Group	ABC (t)	TAC (t)	Catch (t)
1988	BS	POP Complex	6,000		1,509
	AI	POP Complex	16,600		2,629
1989	BS	POP Complex	6,000		2,873
	AI	POP Complex	16,600		3,780
1990	BS	POP Complex	6,300		7,231
	AI	POP Complex	16,600		15,224
1991	BS	Other Red Rockfish	1,670	1,670	942
	AI	Northern/Sharpchin	3,440	3,440	233
1992	BS	Other Red Rockfish	1,400	1,400	467
	AI	Northern/Sharpchin	5,670	5,670	1,549
1993	BS	Other Red Rockfish	1,400	1,200	1,226
	AI	Northern/Sharpchin	5,670	5,100	4,535
1994	BS	Other Red Rockfish	1,400	1,400	129
	AI	Northern/Sharpchin	5,670	5,670	4,667
1995	BS	Other Red Rockfish	1,400	1,260	344
	AI	Northern/Sharpchin	5,670	5,103	3,873
1996	BS	Other Red Rockfish	1,400	1,260	207
	AI	Northern/Sharpchin	5,810	5,229	6,653
1997	BS	Other Red Rockfish	1,050	1,050	218
	AI	Northern/Sharpchin	4,360	4,360	1,997
1998	BS	Other Red Rockfish	267	267	112
	AI	Northern/Sharpchin	4,230	4,230	3,747
1999	BS	Other Red Rockfish	356	267	238
	AI	Northern/Sharpchin	5,640	4,230	5,493
2000	BS	Other Red Rockfish	259	194	253
	AI	Northern/Sharpchin	6,870	1,180	5,084
2001	BSAI	Northern/Sharpchin	6,764		
	BS	Northern/Sharpchin		19	180
	AI	Northern/Sharpchin		6,745	6,309
2002	BSAI	Northern	6,760		
	BS	Northern		19	113
	AI	Northern		6,741	3,943
2003	BSAI	Northern	7,101		
	BS	Northern		121	67
	AI	Northern		5,879	4,862
2004	BSAI	Northern	6,880	5,000	4,684
2005	BSAI	Northern	8,260	5,000	3,964
2006	BSAI	Northern	8,530	4,500	3,829
2007	BSAI	Northern	8,190	8,190	4,016
2008	BSAI	Northern	8,180	8,180	3,287
2009	BSAI	Northern	7,160	7,160	3,111
2010*	BSAI	Northern	7,240	7,240	3,387

*Catch data through October 2, 2010, from NMFS Alaska Regional Office.

Table 2. 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			3,264			3,270
1978	32			3,655			3,687
1979	46			601			647
1980	84	5		549			638
1981	35	0		111			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		248	60	385
1988		4	36		438	55	534
1989		12	66		0	306	384
1990			247			1,235	1,481
1991			1,253			233	1,486
1992			618			1,548	2,166
1993			1,717			4,530	6,247
1994			123			4,666	4,789
1995			533			3,858	4,390
1996			173			6,637	6,811
1997			329			1,996	2,325
1998			90			3,746	3,836
1999			315			5,492	5,807
2000			193			5,066	5,259
2001			360			6,309	6,668
2002			226			3,943	4,169
2003			67			4,862	4,929
2004			116			4,567	4,684
2005			112			3,852	3,964
2006			247			3,582	3,829
2007			69			3,946	4,016
2008			22			3,265	3,287
2009			48			3,064	3,111
2010*			29			3,359	3,387

*Catch data through October 2, 2010, from NMFS Alaska Regional Office.

Table 3. Estimated research catch (t) of northern rockfish in Aleutian Islands and eastern Bering Sea trawl surveys, and the eastern Bering Sea hydroacoustic survey.

		Area	
Year	AI	BS	BS-Hydroacoustic
1977			0.02
1978		0.00	
1979		0.01	
1980	3.55	0.03	
1981		0.06	
1982	0.83	0.07	
1983	29.23	0.06	
1984		0.09	
1985		0.02	
1986	56.86	0.03	
1987		0.17	
1988		0.13	
1989		0.06	
1990		0.74	
1991	15.46	0.01	
1992		0.08	
1993		0.00	
1994	13.15	0.01	
1995			0.01
1996		0.00	
1997	17.67	0.03	0.03
1998		0.25	
1999		0.09	
2000	39.49	0.11	0.29
2001		0.04	
2002	36.32	0.02	0.32
2003		0.12	
2004	55.01	1.76	
2005		0.00	
2006	41.11	0.01	
2007		0.17	
2008		0.02	0.01
2009		0.01	
2010	50.31	0.04	

Table 4. 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. Prior to 2001, northern rockfish were managed as part of the Other Red Rockfish (ORR) complex in the EBS. Beginning in 2002, sharpchin rockfish were removed from ORR and northern rockfish were managed with single-species catch levels. Unless otherwise noted, catch data were obtained from BLEND data and CAS data.

Area	Species Group	Year	Catch (t) Retained	Discard	Total	Percentage
EBS	SC/NO	2001	16	164	180	91.1%
EBS	Northerns	2002	9	105	113	92.4%
		2003	14	59	73	80.4%
		2004	35	82	117	70.2%
		2005	45	67	112	54.9%
		2006	109	137	247	55.7%
		2007	23	46	69	66.3%
		2008	8	14	22	64.7%
		2009	40	8	48	15.9%
		2010	21	7	29	25.6%
AI	SC/NO	1993	317	4,218	4,535	93.0%
		1994	797	3,870	4,667	82.9%
		1995	1,208	2,665	3,873	68.8%
		1996	2,269	4,384	6,653	65.9%
		1997	145	1,852	1,997	92.7%
		1998	458	3,288	3,747	87.8%
		1999	735	4,759	5,493	86.6%
		2000	592	4,474	5,066	88.3%
		2001	403	5,906	6,309	93.6%
AI	Northerns	2002	347	3595	3943	91.2%
		2003	188	4397	4585	95.9%
		2004	686	3881	4567	85.0%
		2005	912	2940	3852	76.3%
		2006	965	2617	3582	73.1%
		2007	850	3096	3946	78.5%
		2008	1523	1742	3265	53.3%
		2009	1941	1122	3064	36.6%
		2010	2453	905	3359	27.0%

Table 5. Samples sizes of otoliths and lengths from fishery sampling, with the number of hauls from which these data were collected, from 1977-2010.

Year	Lengths	Hauls	Otoliths collected	Otoliths read	Hauls (read otoliths)
1977	1202	16	230	224**	11
1978	759	11	148	148**	16
1979					
1980					
1981					
1982	334**	5			
1982					
1984	703**	4			
1985	12**	9	12	0	0
1986	100**	2	100	0	0
1987	976**	9	79	0	0
1988					
1989	80**	1	80	0	0
1990	403**	11			
1991	145**	8			
1992					
1993	1809**	16			
1994	767**	8			
1995	833**	14			
1996	4554	68			
1997	1**	1			
1998	543	14	30	29**	5
1999	917	42	50	0	0
2000	995*	69	170	169*	49
2001	661*	70	136	135*	58
2002	889*	68	200	195*	60
2003	1362*	124	318	317*	110
2004	842*	78	198	196*	69
2005	466*	47	120	118*	44
2006	895*	73	231	230*	71
2007	843*	98	230	228*	90
2008	897	127	271		
2009	834	108	247		
2010	319	38	89		

*Used to create age composition
**Not used

Table 6. Northern rockfish biomass estimates (t) from Aleutian Islands trawl survey, with coefficients of variation shown in parentheses.

	Aleutian Islands Management Sub-Areas			EBS estimates	
YEAR	western	central	eastern	southern BS	Total
1980					39,076 (0.87)
1983					56,376 (0.15)
1986					140,479 (0.34)
1991	144,043 (0.21)	66,370 (0.17)	4,068 (0.52)	582 (0.63)	215,064 (0.15)
1994	70,669 (0.61)	15,832 (0.58)	5,933 (0.54)	855 (0.60)	93,289 (0.47)
1997	65,492 (0.38)	18,363 (0.55)	3,331 (0.58)	204 (0.68)	87,390 (0.31)
2000	142,393 (0.39)	37,949 (0.44)	24,982 (0.70)	49 (0.40)	205,373 (0.29)
2002	134,519 (0.33)	38,772 (0.43)	3,242 (0.42)	290 (0.67)	176,823 (0.27)
2004	146,179 (0.27)	27,050 (0.39)	10,375 (0.37)	5,980 (0.93)	189,583 (0.22)
2006	101,276 (0.29)	70,834 (0.51)	22,982 (0.45)	22,883 (1.00)	217,357 (0.24)
2010	143,953 (0.29)	51,331 (0.40)	21,847 (0.50)	189 (0.52)	217,319 (0.22)
Average (1991-2010)	118,566	40,812	12,095	3,879	175,532
Percentage	67.62%	23.27%	6.90%	2.21%	

Table 7. Sample sizes of otoliths and length measurement from the AI trawl survey, 1991-2010, 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		

Table 8. Sample sizes of read otoliths by area and year in the Aleutian Islands surveys.

	Area				
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

Table 9. Aging error matrix for BSAI northern rockfish, based upon data from Courtney et al 1999.

	Observed age																				
True age	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
3	0.89	0.50	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.10	0.38	0.38	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.01	0.11	0.38	0.37	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.01	0.11	0.37	0.37	0.12	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.01	0.12	0.37	0.36	0.13	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.01	0.12	0.36	0.35	0.13	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.01	0.12	0.35	0.35	0.13	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.01	0.13	0.35	0.34	0.14	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.13	0.34	0.34	0.14	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.13	0.34	0.33	0.14	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.14	0.33	0.33	0.14	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.14	0.33	0.32	0.15	0.03	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.14	0.32	0.32	0.15	0.04	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.14	0.32	0.31	0.15	0.04	0.01	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.15	0.31	0.31	0.15	0.04	0.01	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.15	0.31	0.31	0.15	0.04	0.01	0.00
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.15	0.31	0.30	0.15	0.04	0.01
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.15	0.30	0.30	0.16	0.05
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.15	0.30	0.29	0.16
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.15	0.29	0.29
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.21	0.50

Table 10. Conversion matrix for BSAI northern rockfish, showing the proportion of a given age group expected in each length group.

Length (cm)	Age 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
15	0.45	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.20	0.09	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.17	0.13	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	0.11	0.16	0.07	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	0.05	0.17	0.11	0.05	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.02	0.15	0.14	0.07	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	0.01	0.11	0.15	0.10	0.06	0.03	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.06	0.15	0.13	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	0.00	0.03	0.12	0.14	0.11	0.07	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00
24	0.00	0.01	0.09	0.14	0.13	0.10	0.07	0.05	0.04	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
25	0.00	0.00	0.05	0.12	0.13	0.12	0.09	0.07	0.06	0.04	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01
26	0.00	0.00	0.03	0.09	0.12	0.13	0.11	0.09	0.08	0.06	0.05	0.05	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.02
27	0.00	0.00	0.01	0.06	0.10	0.12	0.12	0.11	0.09	0.08	0.07	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.04	0.03
28	0.00	0.00	0.00	0.03	0.08	0.11	0.12	0.12	0.11	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.06	0.06	0.06	0.05	0.05
29	0.00	0.00	0.00	0.02	0.05	0.09	0.11	0.12	0.12	0.11	0.10	0.10	0.09	0.09	0.08	0.08	0.08	0.07	0.07	0.07	0.07
30	0.00	0.00	0.00	0.01	0.03	0.06	0.09	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.08
31	0.00	0.00	0.00	0.00	0.02	0.04	0.07	0.09	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10
32	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.07	0.08	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.10
33	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.05	0.06	0.07	0.08	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
34	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.10	0.15	0.19	0.23	0.26	0.29	0.31	0.33	0.35	0.36	0.38	0.39	0.41

Table 11. Predicted weight and proportion mature at age for BSAI northern rockfish.

Age	Predicted weight (g)	Proportion mature
3	63	0.021
4	104	0.030
5	149	0.044
6	195	0.065
7	239	0.093
8	281	0.132
9	318	0.185
10	352	0.252
11	381	0.333
12	406	0.426
13	428	0.524
14	446	0.621
15	462	0.708
16	475	0.783
17	487	0.843
18	496	0.888
19	504	0.922
20	510	0.946
21	516	0.963
22	520	0.975
23	533	0.983

Table 12. Negative log likelihood of model components, average effective and input sample sizes, root mean squared errors and standard deviation of normalized residuals for the two models considered in this assessment.

Component	Negative log likelihood	
	Model 1	Model 2
Recruitment	-0.93	-2.17
AI survey biomass	15.76	16.49
Catch	0.00	0.00
F penalty	4.25	4.45
Fishery ages	1496.74	1485.95
Fishery lengths	679.63	657.83
Survey ages	1156.82	1149.54
Survey lengths	488.14	488.01
Prior for *q_srv*	0.00	0.00
Prior for *M*	2.51	2.40
Prior for fish sel slope	0.11	0.00
Prior for fish sel 50%	8.35	0.00
Total likelihood	3674.24	3633.77
Average Effective Sample Size		
Fishery ages	33.88	35.12
Fishery lengths	8.99	8.10
Survey ages	32.90	33.96
Survey lengths	49.23	56.26
Average Sample Sizes		
Fishery ages	45.92	45.92
Fishery lengths	36.76	36.76
Survey ages	55.60	55.60
Survey lengths	264.00	264.00
Root Mean Squared Error		
survey	0.44	0.44
recruitment	0.65	0.63
Standard Deviation of Normalized Residuals		
AI trawl survey	1.68	1.71
Fishery ages	0.98	0.98
Fishery lengths	1.39	1.28
Survey ages	1.05	1.03
Survey lengths	1.62	1.60

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	
Year	2010	2008	2010	2008	2010	2008
1977	104,943	103,319	33,335	32,488	29,185	27,369
1978	105,361	104,204	32,969	32,517	24,403	22,437
1979	105,587	104,722	32,908	32,832	24,146	21,959
1980	109,881	109,325	33,929	34,122	37,268	39,453
1981	113,970	113,691	35,102	35,576	24,662	21,735
1982	118,423	118,517	36,500	37,253	20,848	19,282
1983	122,542	123,091	37,941	38,971	19,358	18,829
1984	126,418	127,448	39,463	40,745	16,690	15,818
1985	129,538	131,080	40,980	42,500	12,774	11,515
1986	132,477	134,464	42,543	44,278	17,794	16,119
1987	139,780	142,109	44,154	46,096	93,353	106,924
1988	145,539	148,258	45,758	47,913	31,342	24,896
1989	150,806	154,271	47,374	49,741	21,092	18,926
1990	156,079	160,284	48,951	51,553	22,652	20,179
1991	162,443	167,202	50,291	53,160	63,128	65,467
1992	169,597	174,588	51,774	54,959	47,227	39,528
1993	174,420	179,951	52,580	56,101	20,280	16,960
1994	175,045	180,803	52,467	56,430	17,721	12,975
1995	176,120	181,675	52,817	57,170	26,307	17,214
1996	179,187	183,780	53,309	58,017	54,837	44,225
1997	179,909	183,677	53,712	58,750	47,457	45,006
1998	190,207	189,329	55,521	60,653	119,833	59,988
1999	197,038	192,504	56,744	61,908	42,186	26,286
2000	201,281	193,252	57,530	62,657	27,204	15,434
2001	204,694	193,408	58,363	63,203	15,422	10,273
2002	205,291	192,445	59,081	63,486	12,840	
2003	207,070	193,734	60,550	64,320	13,512	
2004	206,589	194,032	61,887	64,866	14,519	
2005	205,290	194,573	63,525	65,538	14,850	
2006	203,849	195,919	65,476	66,419	17,872	
2007	203,046	197,955	67,522	67,519	34,245	
2008	201,952	199,321	69,252	68,488		
2009	201,776	200,179	70,844	68,233		
2010	201,138		71,999			
2011	201,429		71,516			

Table 14. 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 50,611 t and 44,285 t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2010	4,500	4,500	4,500	4,500	4,500	4,500	4,500
2011	8,669	8,669	4,392	3,884	0	10,575	8,669
2012	8,328	8,328	4,333	3,843	0	10,038	8,328
2013	7,972	7,972	4,256	3,786	0	9,496	9,724
2014	7,641	7,641	4,181	3,731	0	9,002	9,210
2015	7,358	7,358	4,121	3,687	0	8,580	8,769
2016	7,138	7,138	4,084	3,663	0	8,246	8,418
2017	6,970	6,970	4,065	3,654	0	7,985	8,141
2018	6,858	6,858	4,069	3,666	0	7,799	7,940
2019	6,764	6,764	4,076	3,679	0	7,641	7,770
2020	6,692	6,692	4,089	3,698	0	7,458	7,612
2021	6,634	6,634	4,106	3,720	0	7,272	7,426
2022	6,584	6,584	4,125	3,743	0	7,116	7,255
2023	6,533	6,533	4,144	3,765	0	6,990	7,111
Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2010	71,878	71,878	71,878	71,878	71,878	71,878	71,878
2011	71,516	71,516	71,997	72,054	72,482	71,298	71,516
2012	69,319	69,319	71,650	71,929	74,064	68,285	69,319
2013	66,873	66,873	70,929	71,421	75,245	65,112	66,668
2014	64,466	64,466	70,095	70,788	76,252	62,070	63,506
2015	62,248	62,248	69,292	70,172	77,208	59,309	60,627
2016	60,366	60,366	68,679	69,734	78,276	56,964	58,168
2017	58,773	58,773	68,216	69,431	79,405	54,983	56,077
2018	57,587	57,587	68,064	69,431	80,798	53,459	54,450
2019	56,535	56,535	67,921	69,425	82,101	52,127	53,020
2020	55,713	55,713	67,930	69,565	83,506	51,070	51,868
2021	55,074	55,074	68,060	69,819	84,993	50,252	50,949
2022	54,575	54,575	68,279	70,156	86,539	49,630	50,231
2023	54,178	54,178	68,552	70,543	88,112	49,154	49,669
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2010	0.030	0.030	0.030	0.030	0.030	0.030	0.030
2011	0.058	0.058	0.029	0.026	0	0.071	0.058
2012	0.058	0.058	0.029	0.026	0	0.071	0.058
2013	0.058	0.058	0.029	0.026	0	0.071	0.071
2014	0.058	0.058	0.029	0.026	0	0.071	0.071
2015	0.058	0.058	0.029	0.026	0	0.071	0.071
2016	0.058	0.058	0.029	0.026	0	0.071	0.071
2017	0.058	0.058	0.029	0.026	0	0.071	0.071
2018	0.058	0.058	0.029	0.026	0	0.071	0.071
2019	0.058	0.058	0.029	0.026	0	0.071	0.071
2020	0.058	0.058	0.029	0.026	0	0.071	0.071
2021	0.058	0.058	0.029	0.026	0	0.070	0.070
2022	0.058	0.058	0.029	0.026	0	0.069	0.069
2023	0.058	0.058	0.029	0.026	0	0.068	0.069

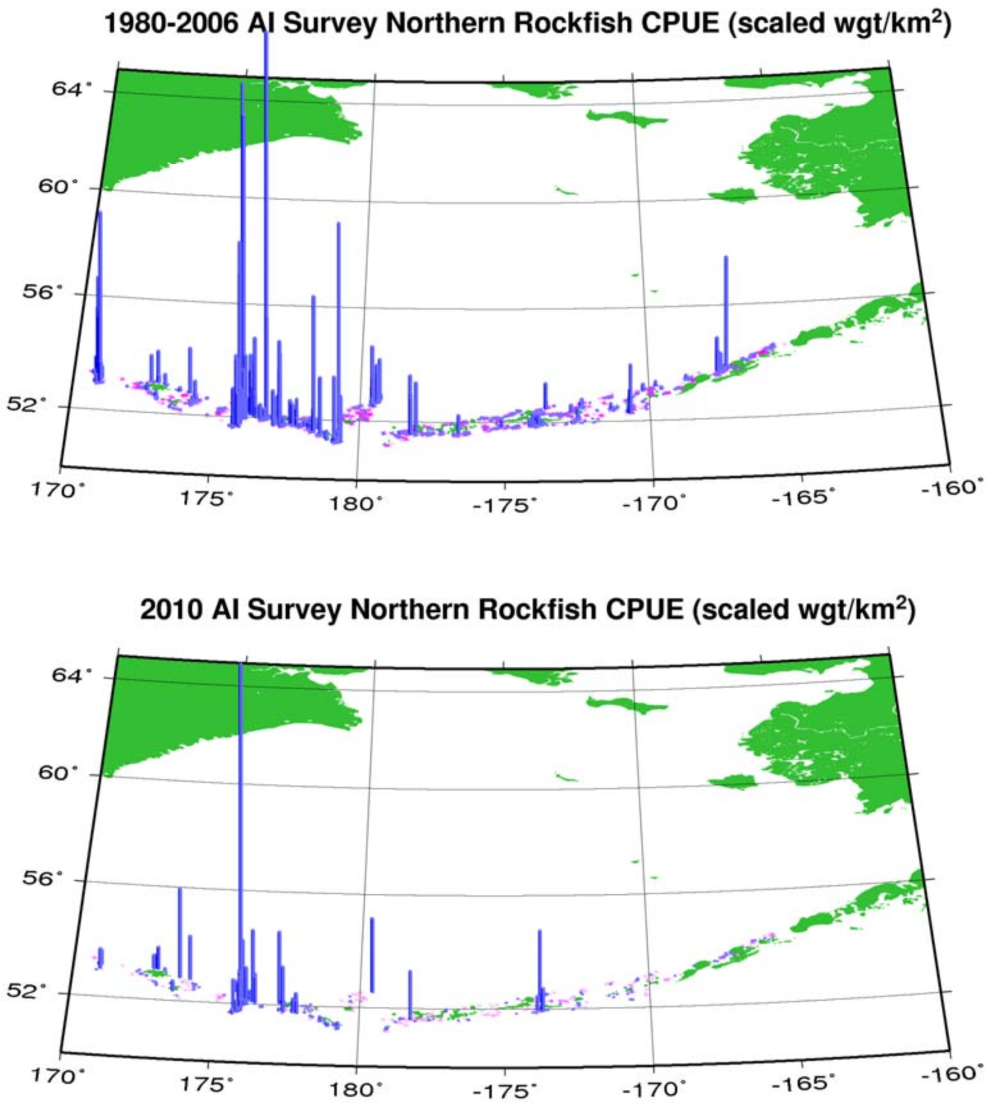

Figure 1. Scaled AI survey northern rockfish CPUE from 1980-2006 (top panel) and 2010 (bottom panel); the symbol × denotes tows with no catch.

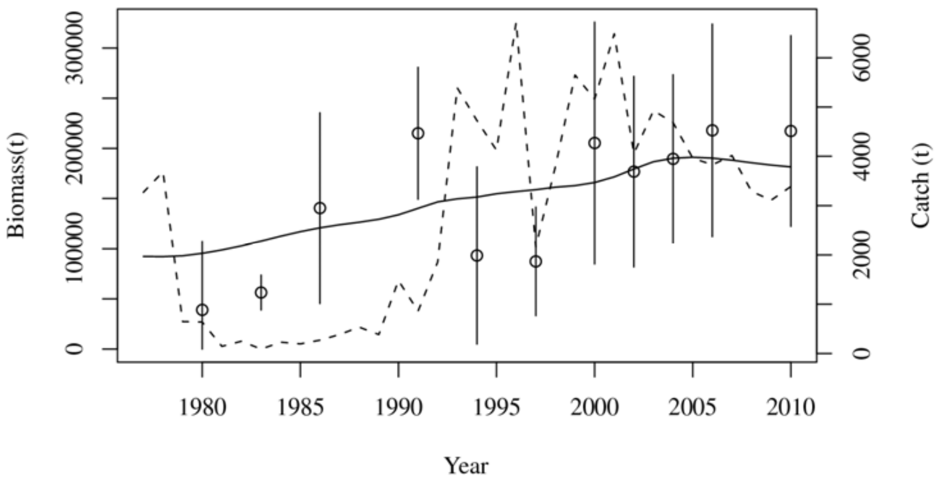

Figure 2. Observed AI survey biomass(data points, +/− 2 standard deviations), predicted survey biomass(solid line), and BSAI harvest (dashed line).

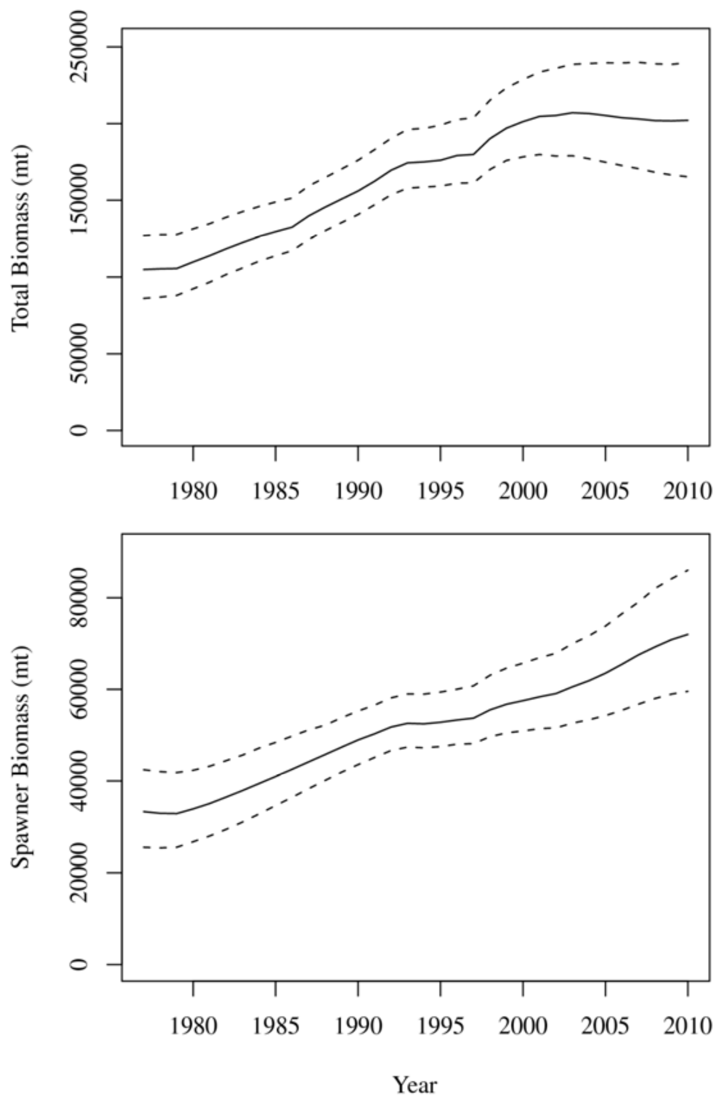

Figure 3. Total and spawner biomass for BSAI northern rockfish with 95% confidence intervals from MCMC integration.

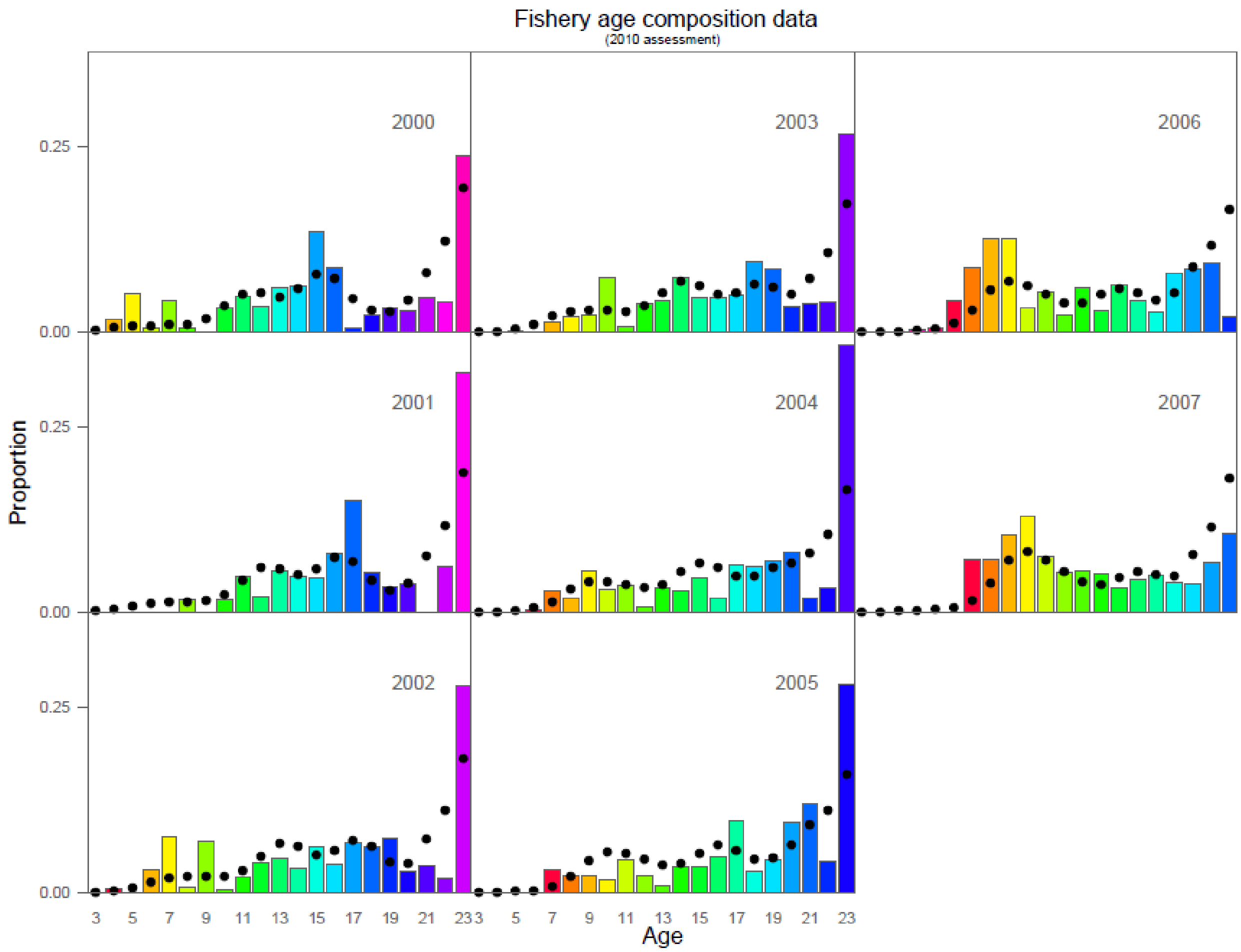

Figure 4. Model fits (dots) to the fishery age composition data (columns) for BSAI northern rockfish, 2000-2007. For contiguous years, colors of the bars correspond to cohorts (except for the 23+ group).

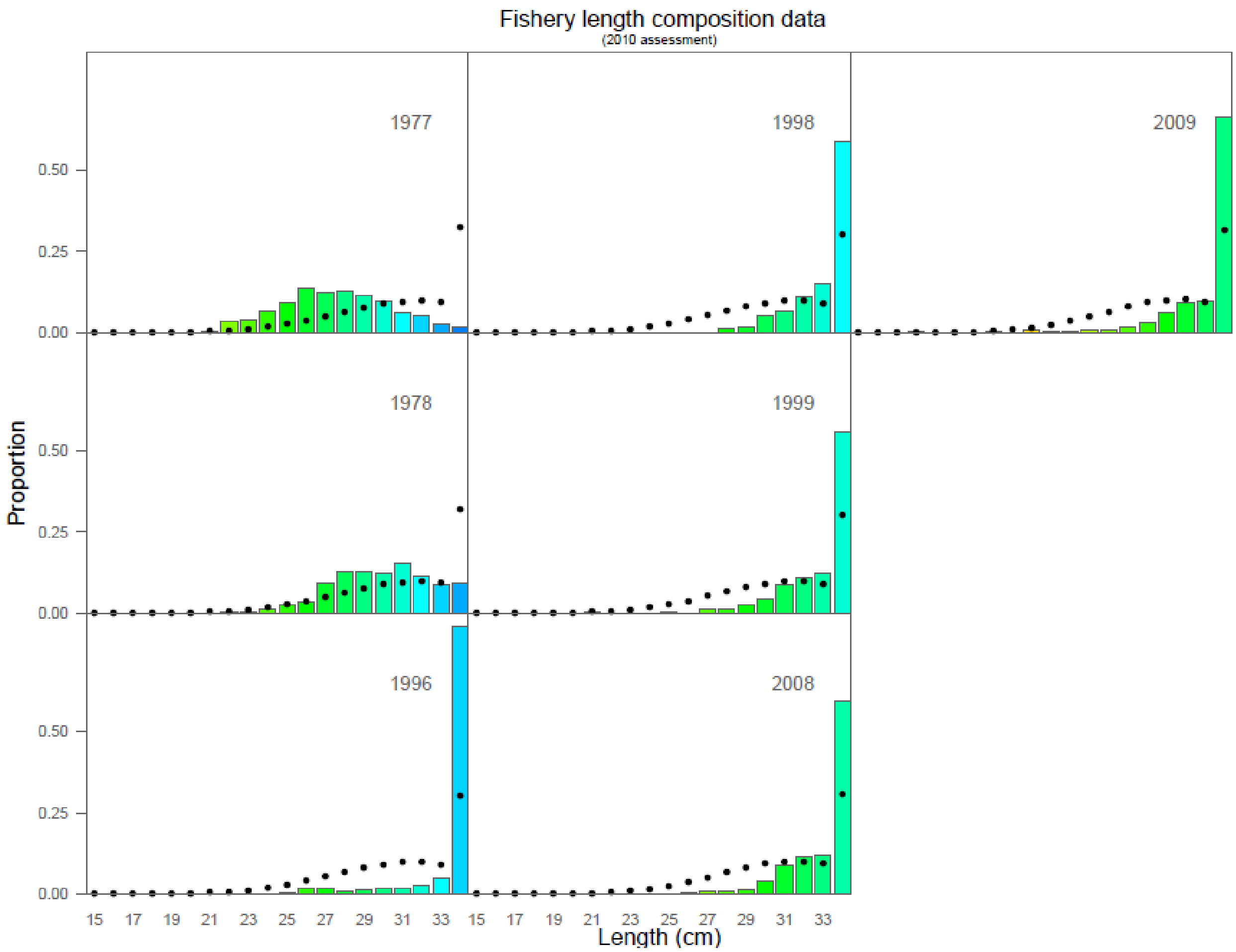

Figure 5. Model fits (dots) to the fishery length composition data (columns) for BSAI northern rockfish, 1977-2009.

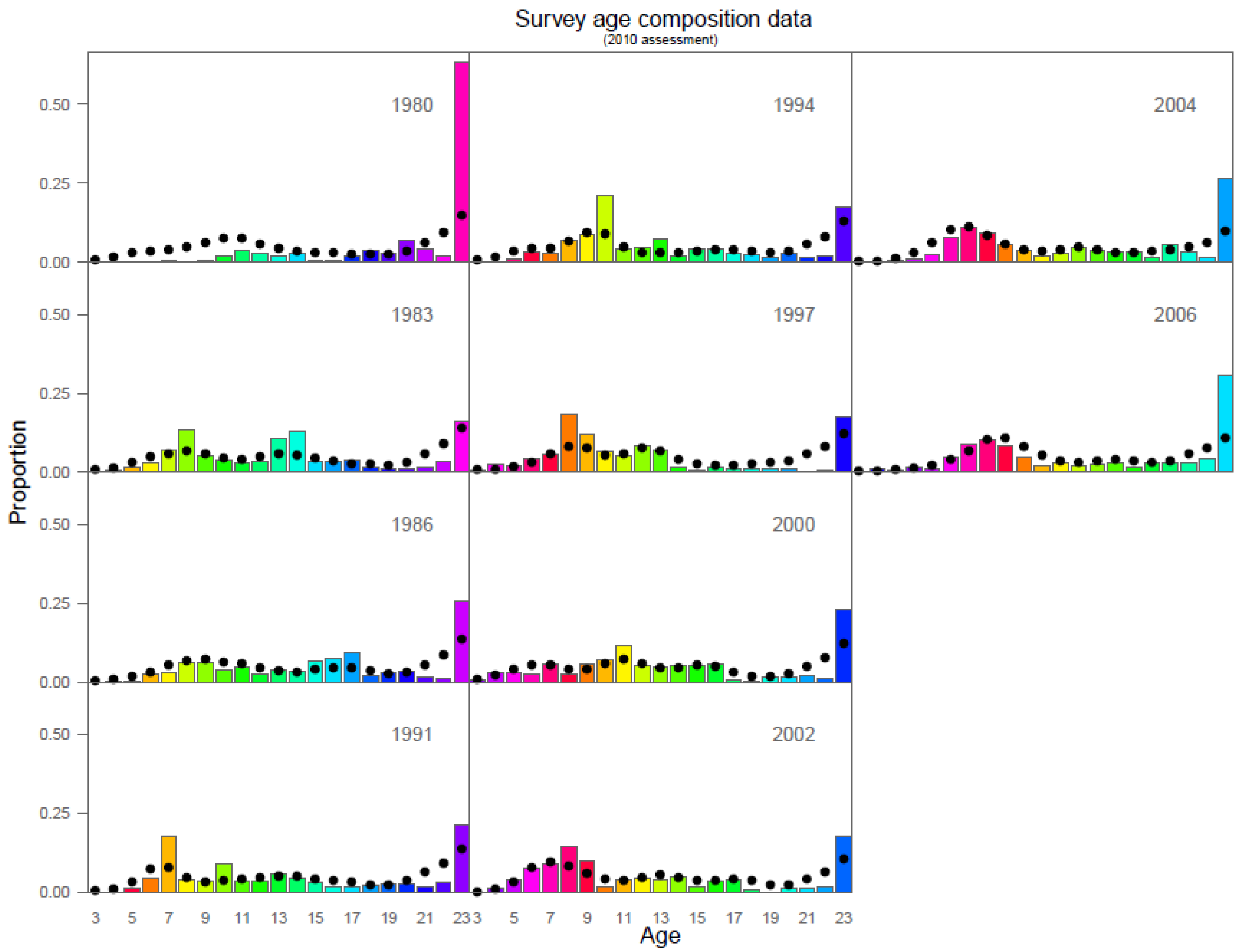

Figure 6. Model fits (dots) to the AI survey age composition data (columns) for BSAI northern rockfish, 2080-2006. For contiguous years, colors of the bars correspond to cohorts (except for the 23+ group).

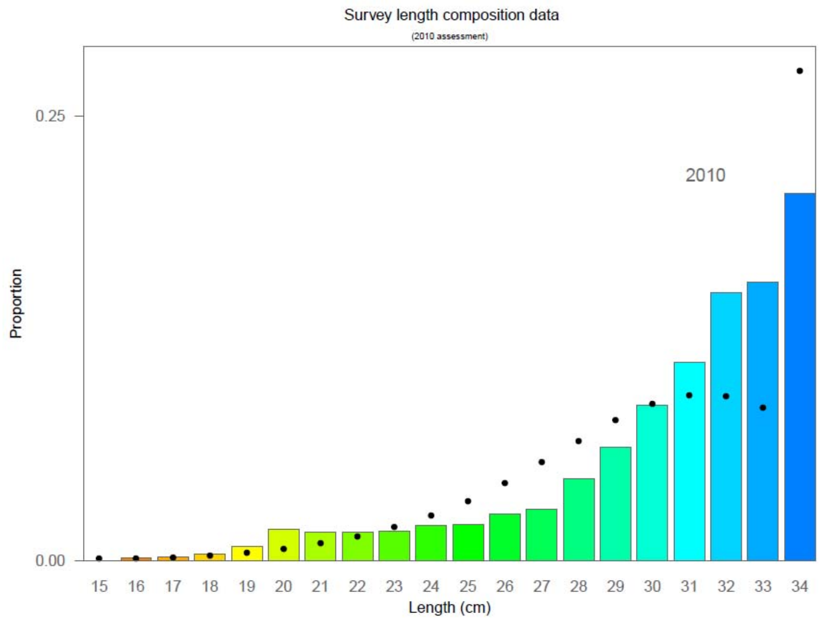

Figure 7. Model fits (dots) to the 2010 AI survey length composition data (columns) for BSAI northern rockfish.

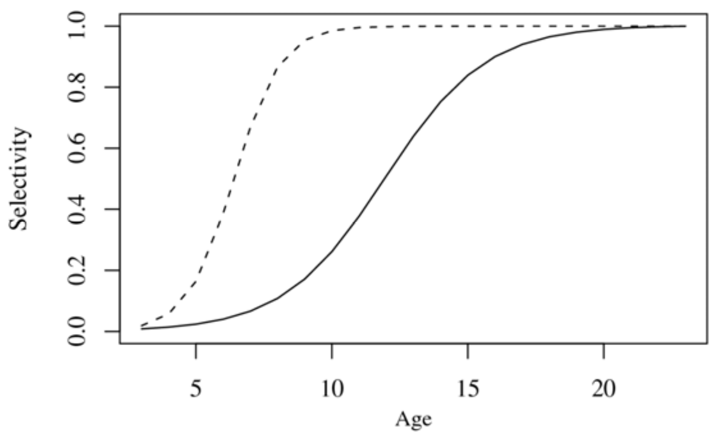

Figure 8. Estimated fishery (solid line) and survey (dashed line) selectivity curve by age.

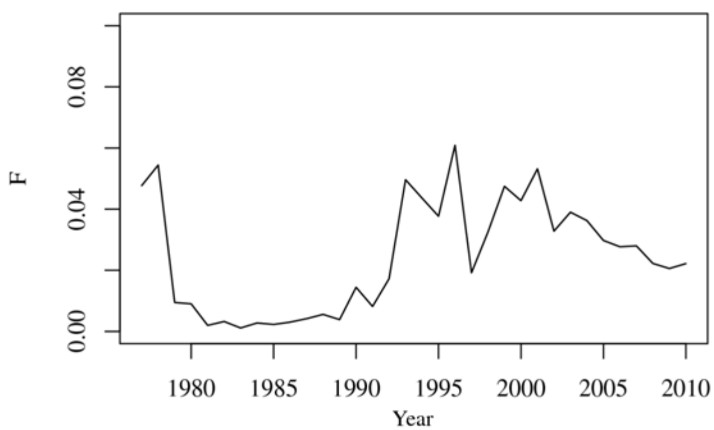

Figure 9. Estimated fully selected fishing mortality for BSAI northern rockfish.

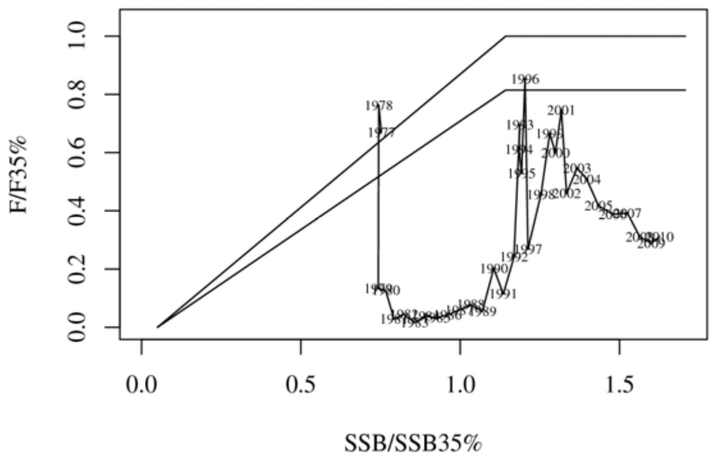

Figure 10. Estimated fishing mortality and SSB in reference to OFL (upper line) and ABC (lower line) harvest control rules

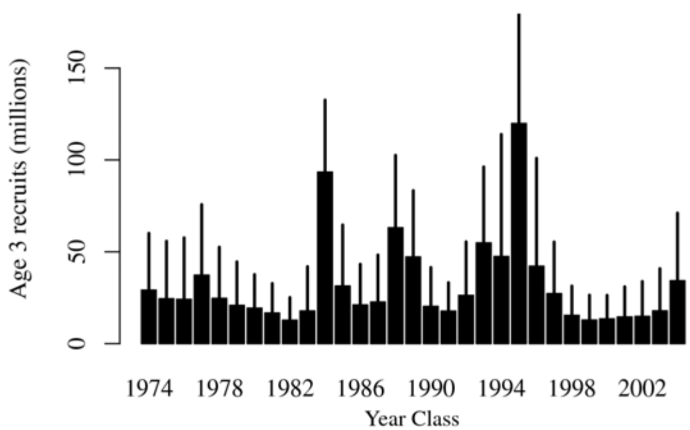

Figure 11. Estimated recruitment (age 3) of BSAI northern rockfish with 95% CI limits obtained from MCMC integration.

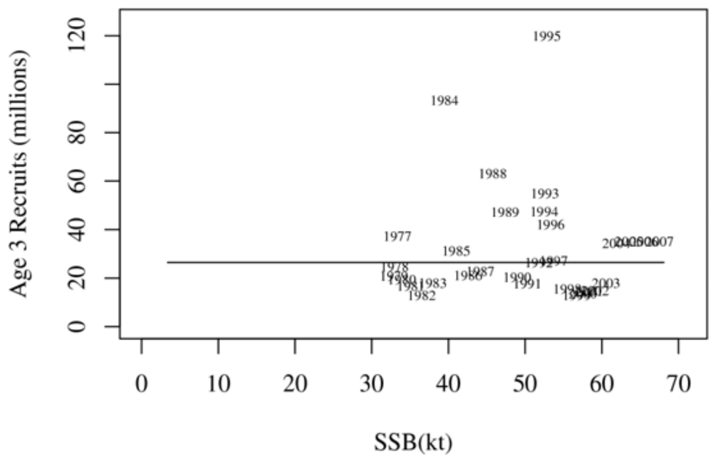

Figure 12. Scatterplot of BSAI northern rockfish spawner–recruit data; label is year class.