CHAPTER 12

NORTHERN ROCKFISH

by

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Executive Summary

The last full assessment for northern rockfish was presented to the Plan Team in 2006, and an updated assessment was presented in 2007. The following changes were made to northern rockfish assessment relative to the November 2006 SAFE:

Summary of Changes in Assessment Inputs

Changes in the Input Data

(1) The harvest time series have revised and updated through August 30, 2008.

(2) The 2006 Aleutian Islands (AI) survey age composition was included in the assessment.

(3) The 2006 and 2007 fishery length compositions were included in the assessment.

(4) The historical Aleutian Islands survey data were updated based on the estimates provided by the AFSC/RACE Division.

Changes in the Assessment Methodology

In order to stabilize model performance, the coefficient of variation on the prior distribution for natural mortality was reduced from 0.25 to 0.15.

Changes in the Assessment Results

A summary of the 2008 assessment recommended ABC's relative to the 2007 recommendations is shown below. BSAI northern rockfish are not overfished or approaching an overfished condition.

Assessment Year	2007		2008	
Projection Year	2008	2009	2009	2010
M	0.045	0.045	0.041	0.041
Tier	3a	3a	3a	3a
$B_{100\%}$ (mt)	129,879 t	129,879 t	138,283 t	138,283 t
$B_{40\%}$ (mt)	51,952 t	51,952 t	55,313 t	55,313 t
$B_{35\%}$ (mt)	45,458 t	45,458 t	48,399 t	48,399 t
SSB (mt)	73,455 t	73,649 t	68,223 t	67,459 t
Total Biomass (mt)	212,009 t	211,493 t	200,179 t	201,064 t
Max F_{abc} ($=F_{40\%}$)	0.044693	0.044693	0.0426	0.0426
F_{ofl} ($F_{35\%}$)	0.05342	0.05342	0.0511	0.0511
Max ABC (mt, yield at $F_{40\%}$)	8,180 t	8,129 t	7,160 t	7,193 t
Recommended ABC	8,180 t	8,129 t	7,160 t	7,193 t
OFL	9,736 t	9,676 t	8,544 t	8,584 t

Responses to the comments of the Statistical and Scientific Committee

The SSC December 2007 minutes included the following comments concerning all stock assessments:

The SSC notes that the approach for calculating ABC and other biological reference points is not fully described in the SAFE's. It would be desirable to have a general description in the introduction of the SAFE. In each SAFE chapter, specific details could be provided, if the calculation is done differently. For example, the range of years that is used to calculate average recruitment for converting SPR to B_{40} should be given.

We continue to assume that the equilibrium level of recruitment is equal to the average of age 3 recruits from 1980-2008 (year classes between 1980 and 2005) for northern rockfish as detailed in the Amendment 56 Reference Points section of the Projections and Harvest Alternatives of this stock assessment.

The SSC December 2007 minutes included the following comments concerning all rockfish:

For all of the rockfish assessments, the SSC recognizes the efforts of the stock assessment authors to respond fully to the 2006 CIE review comments. The SSC requests that the draft response to the CIE review be finalized and made available.

The response to the 2006 CIE rockfish review is available online at the following web address: ftp://ftp.afsc.noaa.gov/afsc/public/rockfish/RWG%20response%20to%20CIE%20review.pdf

The SSC December 2006 minutes included the following comments concerning northern rockfish:

Consider splitting the survey data to account for differences between the 1980-1986 cooperative surveys and the 1991-2006 U.S. domestic surveys.

Separating the AFSC-Japan cooperative AI surveys (1980, 1983, and 1986) from the AFSC domestic AI surveys (post-1991) requires estimating separate survey catchability coefficient and selectivity parameters for each time period. Estimates of the survey catchability coefficients obtained without prior distributions were 0.10 and 0.24, respectively, for the cooperative and domestic surveys, and these values of catchability were considered unrealistically low. Fixing the catchability coefficients at 1.0 and estimating separate selectivity curves yields an unusually low selectivity for the cooperative survey, with an age at 50% selection of approximately 17 years. A larger variance on the prior distribution for survey catchability leads to more reasonable estimates of survey catchability and selectivity; however, estimates of current stock are relatively similar to that obtained by treating the survey as a single time series.

Because prior distributions for survey catchability appear to be necessary to obtain reasonable estimates, an important question is how the expected value of these distributions should differ between the surveys. Presumably, any differences in survey methodology that would motivate separating the two periods may also imply differences in prior expectation of survey catchability. A more detailed look at the methodology of the cooperative surveys should be conducted as part of a more thorough examination of separating the two surveys, and these items remain as tasks for future research.

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 calculated 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 made 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 1988-2008 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 2004-2007 indicates that approximately 90% of the BSAI northern rockfish are harvested in the Atka mackerel fishery. From 2004 to 2006, 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), whereas in 2007 the Aleutian Island catch in September was more evenly distributed. 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 remain high, but appear to be decreasing. For example, the discard rate in the EBS has declined from 92% in 2002 to 66% in 2007, and the discard rate in the Aleutian Islands has declined from 91% to 78% 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 2006-2007 were used, and the length and age data from 2000-2005 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 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 1991-2006 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 2008 EBS slope survey was completed, but the 2006 survey was canceled due to lack of funding. The survey biomass estimates of northern rockfish from the 2002 and 2004 were surveys were 33 t and 16 t, respectively, with CVs of 0.38 and 0.42. In the 2008 survey, only one northern rockfish was caught. 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 1991-2006 Aleutian Islands trawl surveys are considered an index of the BSAI population.

In the 1980 -2004 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 2006 survey CPUE showed a similar pattern, with much of the catch occurring in the Tahoma Bank area (Figure 1). An average of 68% of the estimated biomass from the 1991-2006 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 0.60 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 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 8). Use of the aging error matrix from GOA northern rockfish for the BSAI stock is considered appropriate because longevity is similar between the areas.

Differences exist in the length-at-age curves from the three management areas within the Aleutian Islands, and the development of a single length-at-age curve representing all areas should consider the different population sizes between the areas. Average length for each Aleutian Islands management area (i.e., areas 541,542,543) were computed by multiplying the area-specific population numbers at length by the area specific age-length key in order to produce a matrix of estimated population numbers by age and length, from which an unbiased average length for each age can be determined. A single average length at age was obtained by taking an average of the three estimates (weighted by population size). This procedure was applied to the 1997 and 2000 data; the lower samples sizes of otoliths by area in other years hinder the utility of this procedure (Table 9). The resulting length-at-age curve obtained from the 2000 AI survey is similar to the length at age curve used in assessments prior to 2004, which was based upon directly using all available samples from the 1980-2002 Aleutian Island surveys. 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
34.39	0.18	-0.2659

A transition 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 1986-2000 surveys) against age, and the predicted relationship was used to produce some 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 0.16 at age 3 to 0.12 at age 23.

A length-weight relationship of the form $W = aL^b$ was fit from the survey data from 1986-2000, and produced estimates of $a = 1.25 \times 10^{-5}$ and $b = 3.05$. 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).

In recent years, the proportion of older northern rockfish captured by the AI trawl survey has been less than that in the fishery (Figure 2), which has hindered the estimation of the fishery selectivity curve and motivated the choice of constraining the fishery selectivity curve to be similar to the survey selectivity curve.

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

Component	BSAI
Fishery catch	1977-2008
Fishery age composition	2000-2005
Fishery size composition	1977, 1978, 1996, 1998,1999, 2006-2007
Survey age composition	1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004
Survey biomass estimates	1980, 1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004 2006

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 2008). 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

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

where R_0 is the mean number of age 3 recruits prior to the start year if the model, and (is an age-dependant deviation assumed to be normally distributed with mean of zero and a standard deviation equal to Φ_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 1998 are estimated as parameters in the model, and are modeled with a lognormal distribution

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

where $<_t$ 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 ($:_f$) and a year-specific deviation ($,_t$), 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.

Previous assessments have indicated that age at 50% selectivity was much larger than that estimated in the survey (Spencer et al. 2004). This result stems from the greater proportion of older/larger fish in the fishery age/length compositions relative to the survey age/length compositions (Figure 2). Because it is not expected that the fishery selectivity would differ substantially from the survey selectivity, the fishing selectivity parameters were estimated as the survey selectivity parameters multiplied by $e^{(}$, where (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.

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, Φ_r, was fixed at 0.75. This choice was motivated by previous assessments (Spencer et al. 2004) which indicated that the root mean squared error (RMSE; defined below) of recruitment deviations were consistent with a Φ_r of 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.

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

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

where y and $\hat{y}$ 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

$$E_i = \frac{\sum_a \hat{y}_a * (1 - \hat{y}_a)}{\sum_a (\hat{y}_a - y_a)^2}.$$

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 maximize the log-likelihood are selected.

The log-likelihood of the initial recruitments were modeled with a lognormal distribution

$$\lambda_1 \sum_t \frac{\left(\nu_t + \frac{\sigma^2}{2}\right)^2}{2\sigma^2} + n\ln(\sigma)$$

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. The log-likelihood of the recruitment of cohorts represented in the first year of the model treated in a similar manner:

$$\lambda_1 \sum_{a-1} \frac{(\gamma_t)^2}{2\sigma^2} + (a-1)\ln(\sigma)$$

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

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

where n is the 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 likelihood for the age and length proportions in the survey, $p_{surv,t,a}$ and $p_{surv,t,l}$, respectively, follow similar equations.

The 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 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

$$\begin{aligned}
&\lambda_1 \left(\sum_t \left(\frac{\nu_t + \sigma^2/2}{2\sigma^2} \right)^2 + n\ln(\sigma) \right) + \\
&\lambda_1 \left(\sum_{a-1} \left(\frac{\gamma_t}{2\sigma^2} \right)^2 + (a-1)\ln(\sigma) \right) + \\
&\lambda_2 \sum_t (\ln(obs_biom_t) - \ln(pred_biom_t))^2 / 2 * cv_t^2 + \\
&n_{f,t,l} \sum_{s,t,l} p_{f,t,l} \ln(\hat{p}_{f,t,l}) - p_{f,t,l} \ln(p_{f,t,l}) + \\
&n_{f,t,a} \sum_{s,t,l} p_{f,t,a} \ln(\hat{p}_{f,t,a}) - p_{f,t,a} \ln(p_{f,t,a}) + \\
&n_{surv,t,a} \sum_{s,t,a} p_{surv,t,a} \ln(\hat{p}_{surv,t,a}) - p_{surv,t,a} \ln(p_{surv,t,a}) + \\
&n_{surv,t,l} \sum_{s,t,a} p_{surv,t,l} \ln(\hat{p}_{surv,t,l}) - p_{surv,t,l} \ln(p_{surv,t,l}) + \\
&\lambda_3 \sum_t (\ln(obs_cat_t) - \ln(pred_cat_t))^2
\end{aligned}$$

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 3/4 and 6/4 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 ($:_f$)	1
2) fishing mortality deviations ($,_t$)	32
3) recruitment mean ($:_r$)	1
5) recruitment deviations ($<_t$)	32
6) historic recruitment (R_0)	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	93

RESULTS

Model Evaluation

The model is the recommended model presented in the 2006 assessment, which was accepted by the Plan Team. At this time modifications to the model do not appear to be necessary, although future evaluation of the fishery selectivity curve is likely as more fishery data is obtained.

The choice of constraining the fishery selectivity curve was made for several reasons. First, although more data on fishery age compositions now exists, consistent collection of otoliths in the fishery has occurred only since 2000 and is still below 200 fish sampled for most years (Table 5), leading to some uncertainty in the fishery selectivity curve. Additionally, northern rockfish in the Aleutian Islands are currently predominately taken as bycatch, and if a target fishery were to develop it is likely that the fishery selectivity would be different than that estimated from the available data.

The negative log-likelihood associated with the various data components are shown in Table 12. The effective sample size for the age and length composition data ranged from 34% to 57% of the input sample sizes. The standard deviation of the normalized residuals were close to 1 for the fishery age and length composition, 1.38 for the survey age composition, and 1.79 for the trawl survey biomass estimates.

Prior and Posterior Distributions

Posterior distributions for *M* and total 2008 biomass, and mean recruitment, based upon the MCMC integrations, are shown in Figure 3. The posterior distribution for *M* is shifted to the left of the prior distribution, indicating that the data suggest a slightly lower value of *M* than the median of the prior distribution.

Biomass trends

The estimated survey biomass shows a slightly increasing trend, starting at 88,694 t in 1977 and increasing gradually to 176,376 t in 2008 (Figure 4). The total biomass and spawning biomass show similar trends, increasing to peak values of 199,321 t and 68,488 t in 2008, respectively (Figure 5).

Age/size compositions

The model fits to the fishery age and size compositions are shown in Figures 6-7, and the model fit to the survey age compositions is shown in Figure 8. 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.

Fishing and survey selectivity

The estimated survey selectivity curve had an age of 50% selection of 7.11, whereas this parameter was 8.06 for the fishery selectivity curve (Figure 9).

Fishing mortality

The estimates of instantaneous fishing mortality rate are shown in Figure 10. 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 2007 estimate is 0.024. 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 the $F_{35\%}$ and $B_{40\%}$ reference points (Figure 11).

Recruitment

Recruitment strengths by year class are shown in Figure 12. 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 1993-1995. 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 1993-1995 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 13, indicating substantial variability in the pattern between recruitment and spawning stock size.

Projections and Harvest Alternatives

The reference fishing mortality rate for BSAI 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 1977-2005 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 55,313 t. The year 2009 female spawning stock biomass is estimated as 68,233 t. Since reliable estimates of the 2009 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and B>$B_{0.40}$ (68,233 t > 55,313 t), northern rockfish reference fishing mortality is defined in tier 3a. For this tier, the maximum permissible F_{ABC} is $F_{0.40}$, and F_{OFL} is constrained to be equal to $F_{0.35}$; the values of $F_{0.40}$ and $F_{0.35}$ are 0.043 and 0.051, respectively. The 2009 ABC associated with the $F_{0.40}$ level of 0.043 is 7,160 t. This ABC is 1,020 t lower than last year's 2008 ABC recommendation of 8,180t, a 12% decrease. The estimated catch level for year 2009 associated with the overfishing level of F = 0.051 is 8,544 t. A summary of these values is below.

2009 SSB estimate (B)	=	63,619 t
$B_{0.40}$	=	55,313 t
$F_{0.40}$	=	0.043
F_{ABC}	=	0.043
$F_{0.35}$	=	0.051
F_{OFL}	=	0.051

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 2008 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2009 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2008. 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 2009, 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 2009 recommended in the assessment to the *max* F_{ABC} for 2009. (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 2003-2007 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.)

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

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the northern rockfish 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 its MSY level in 2009, then the stock is not overfished.)

Scenario 7: In 2009 and 2010, 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 2011 under this scenario, then the stock is not approaching an overfished condition.)

The projections of the mean spawning stock biomass, fishing mortality rate, and harvest for these scenarios are shown in Table 14. The results of these scenarios 6 and 7 indicate that the BSAI northern rockfish stock is neither overfished or approaching an overfished condition. With regard to assessing the current stock level, the expected stock size in the year 2009 of scenario 6 is 1.41 times its $B_{35\%}$ value of 48,399 t. With regard to whether northern rockfish stock is likely to be overfished in the future, the expected stock size in 2011 of scenario 7 is 1.38 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.

SUMMARY

The management parameters for northern rockfish as presented in this assessment are summarized as follows:

Quantity	Value
M	0.041
Tier	3a
Year 2009 Total Biomass	200,179 t
Year 2010 Total Biomass	201,064 t
Year 2009 Spawning stock biomass	68,223 t
$B_{100\%}$	138,283 t
$B_{40\%}$	55,313 t
$B_{35\%}$	48,399 t
F_{OFL}	0.051
Maximum F_{ABC}	0.043
Recommended F_{ABC}	0.043
OFL (2009)	8,544 t
OFL (2010)	8,584 t
Maximum allowable ABC (2009)	7,160 t
Recommended ABC (2009)	7,160 t
Maximum allowable ABC (2010)	7,193 t
Recommended ABC (2010)	7,193 t

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Table 1. Total allowable catch (TAC), acceptable biological catch (ABC), and catch of the species groups used to manage northern rockfish from 1988 to 2008. 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	4,015
2008*	BSAI	Northern	8,180	8,180	885

*Catch data through August 30, 2008, 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			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			113			3,943	4,056
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	4,015
2008*			13			872	885

*Catch data through August 30, 2008, 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

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%
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%

Table 5. Samples sizes of otoliths and lengths from fishery sampling, with the number of hauls from which these data were collected, from 1977-2007.

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		
2007	843	98	230		

*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)
Average (1991-2006)	114,939	39,310	10,702	4,406	169,357
Percentage	67.9%	23.2%	6.3%	2.6%	

Table 7. Sample sizes of otoliths and length measurement from the AI trawl survey, 1991-2006, 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

Table 8. 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 9. 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 10. Transition 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	0.60	0.16	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	0.00	0.00	0.00	0.00
16	0.15	0.11	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	0.00
17	0.11	0.14	0.06	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	0.07	0.16	0.09	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	0.04	0.15	0.12	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	0.12	0.15	0.08	0.03	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	0.00
21	0.01	0.08	0.15	0.12	0.06	0.03	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
22	0.00	0.05	0.13	0.14	0.09	0.05	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
23	0.00	0.02	0.10	0.15	0.12	0.07	0.04	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
24	0.00	0.01	0.07	0.13	0.14	0.10	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
25	0.00	0.00	0.04	0.11	0.14	0.13	0.09	0.07	0.05	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
26	0.00	0.00	0.02	0.08	0.13	0.14	0.12	0.09	0.07	0.05	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
27	0.00	0.00	0.01	0.05	0.10	0.13	0.13	0.12	0.09	0.08	0.06	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.02
28	0.00	0.00	0.00	0.02	0.07	0.11	0.13	0.13	0.12	0.10	0.08	0.07	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.04	0.04
29	0.00	0.00	0.00	0.01	0.04	0.09	0.12	0.13	0.13	0.12	0.10	0.09	0.08	0.08	0.07	0.07	0.06	0.06	0.06	0.06	0.05
30	0.00	0.00	0.00	0.00	0.02	0.06	0.09	0.12	0.13	0.13	0.12	0.11	0.10	0.10	0.09	0.08	0.08	0.08	0.07	0.07	0.06
31	0.00	0.00	0.00	0.00	0.01	0.04	0.07	0.10	0.11	0.12	0.12	0.12	0.11	0.11	0.10	0.10	0.09	0.09	0.09	0.09	0.08
32	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.07	0.09	0.11	0.11	0.12	0.12	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.09
33	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.07	0.08	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10
34	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.10	0.15	0.20	0.26	0.30	0.34	0.38	0.41	0.43	0.45	0.47	0.48	0.52

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

Age	Predicted weight (g)	Proportion mature
3	52	0.021
4	91	0.030
5	137	0.044
6	185	0.065
7	233	0.093
8	278	0.132
9	321	0.185
10	359	0.252
11	393	0.333
12	423	0.426
13	450	0.524
14	473	0.621
15	492	0.708
16	509	0.783
17	523	0.843
18	535	0.888
19	546	0.922
20	554	0.946
21	562	0.963
22	568	0.975
23	591	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.

Component	Negative log likelihood
Recruitment	-1.35
AI survey biomass	16.35
Catch	0.01
F penalty	4.40
Fishery ages	783.66
Fishery lengths	425.53
Survey ages	1737.77
Prior for *q_srv*	0.00
Prior for *M*	2.97
Prior for fish sel slope	0.02
Prior for fish sel 50%	8.71
Total likelihood	2978.06
Average Effective Sample Size	
Fishery ages	27.78
Fishery lengths	11.64
Survey ages	33.89
Average Sample Sizes	
Fishery ages	48.75
Fishery lengths	34.50
Survey ages	62.55
Root Mean Squared Error	
survey	0.46
recruitment	0.63
Standard Deviation of Normalized Residuals	
Fishery ages	1.06
Fishery lengths	1.13
Survey ages	1.13
AI trawl survey	1.79

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	2008	2006	2008	2006	2008	2006
1977	103,319	129,445	32,488	38,970	27,369	29,631
1978	104,204	131,273	32,517	39,596	22,437	25,279
1979	104,722	132,455	32,832	40,497	21,959	24,081
1980	109,325	137,036	34,122	42,335	39,453	32,885
1981	113,691	141,220	35,576	44,322	21,735	22,202
1982	118,517	145,578	37,253	46,486	19,282	19,665
1983	123,091	149,461	38,971	48,618	18,829	19,344
1984	127,448	152,982	40,745	50,703	15,818	16,918
1985	131,080	155,684	42,500	52,648	11,515	12,717
1986	134,464	158,014	44,278	54,480	16,119	16,192
1987	142,109	165,083	46,096	56,213	106,924	117,479
1988	148,258	170,767	47,913	57,815	24,896	32,072
1989	154,271	176,296	49,741	59,319	18,926	21,505
1990	160,284	181,868	51,553	60,728	20,179	22,746
1991	167,202	188,736	53,160	61,897	65,467	75,068
1992	174,588	196,148	54,959	63,091	39,528	45,425
1993	179,951	199,526	56,101	63,258	16,960	19,635
1994	180,803	200,244	56,430	63,204	12,975	14,955
1995	181,675	200,951	57,170	63,642	17,214	19,740
1996	183,780	202,933	58,017	64,275	44,225	48,592
1997	183,677	203,447	58,750	64,871	45,006	63,756
1998	189,329	208,944	60,653	66,688	59,988	53,670
1999	192,504	211,569	61,908	67,900	26,286	18,695
2000	193,252	212,292	62,657	68,621	15,434	
2001	193,408	212,993	63,203	69,204	10,273	
2002	192,445	211,900	63,486	69,533		
2003	193,734	212,840	64,320	70,399		
2004	194,032	212,432	64,866	70,959		
2005	194,573	211,927	65,538	71,620		
2006	195,919	211,890	66,419	72,748		
2007	197,955	211,893	67,519	72,830		
2008	199,321		68,488			
2009	200,179		68,233			

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 55,313 t and 48,399 t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2008	4,500	4,500	4,500	4,500	4,500	4,500	4,500
2009	7,160	7,160	3,617	4,329	0	8,544	7,160
2010	7,086	7,086	3,651	4,353	0	8,389	7,086
2011	7,032	7,032	3,694	4,387	0	8,262	8,391
2012	6,977	6,977	3,733	4,417	0	8,138	8,260
2013	6,921	6,921	3,768	4,443	0	8,018	8,132
2014	6,867	6,867	3,801	4,467	0	7,905	8,011
2015	6,817	6,817	3,832	4,489	0	7,799	7,897
2016	6,774	6,774	3,864	4,514	0	7,707	7,797
2017	6,731	6,731	3,893	4,535	0	7,618	7,702
2018	6,691	6,691	3,921	4,555	0	7,536	7,613
2019	6,645	6,645	3,942	4,567	0	7,444	7,519
2020	6,600	6,600	3,960	4,578	0	7,335	7,417
2021	6,559	6,559	3,977	4,588	0	7,216	7,302
Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2008	68,128	68,128	68,128	68,128	68,128	68,128	68,128
2009	68,233	68,233	68,591	68,519	68,951	68,091	68,233
2010	67,459	67,459	69,235	68,878	71,059	66,769	67,459
2011	66,757	66,757	69,930	69,285	73,256	65,542	66,619
2012	65,945	65,945	70,477	69,549	75,329	64,233	65,271
2013	65,115	65,115	70,962	69,755	77,352	62,938	63,930
2014	64,367	64,367	71,487	70,005	79,426	61,753	62,697
2015	63,716	63,716	72,065	70,314	81,562	60,694	61,587
2016	63,206	63,206	72,748	70,731	83,813	59,799	60,641
2017	62,725	62,725	73,405	71,131	86,028	58,963	59,752
2018	62,306	62,306	74,075	71,551	88,245	58,214	58,949
2019	61,814	61,814	74,592	71,834	90,257	57,428	58,109
2020	61,344	61,344	75,068	72,085	92,190	56,695	57,320
2021	60,906	60,906	75,518	72,322	94,062	56,033	56,600
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2008	0.0266	0.0266	0.0266	0.0266	0.0266	0.0266	0.0266
2009	0.0426	0.0426	0.0213	0.0256	0	0.0511	0.0426
2010	0.0426	0.0426	0.0213	0.0256	0	0.0511	0.0426
2011	0.0426	0.0426	0.0213	0.0256	0	0.0511	0.0511
2012	0.0426	0.0426	0.0213	0.0256	0	0.0511	0.0511
2013	0.0426	0.0426	0.0213	0.0256	0	0.0511	0.0511
2014	0.0426	0.0426	0.0213	0.0256	0	0.0511	0.0511
2015	0.0426	0.0426	0.0213	0.0256	0	0.0511	0.0511
2016	0.0426	0.0426	0.0213	0.0256	0	0.0511	0.0511
2017	0.0426	0.0426	0.0213	0.0256	0	0.0511	0.0511
2018	0.0426	0.0426	0.0213	0.0256	0	0.0510	0.0511
2019	0.0426	0.0426	0.0213	0.0256	0	0.0510	0.0510
2020	0.0426	0.0426	0.0213	0.0256	0	0.0508	0.0509
2021	0.0426	0.0426	0.0213	0.0256	0	0.0504	0.0506

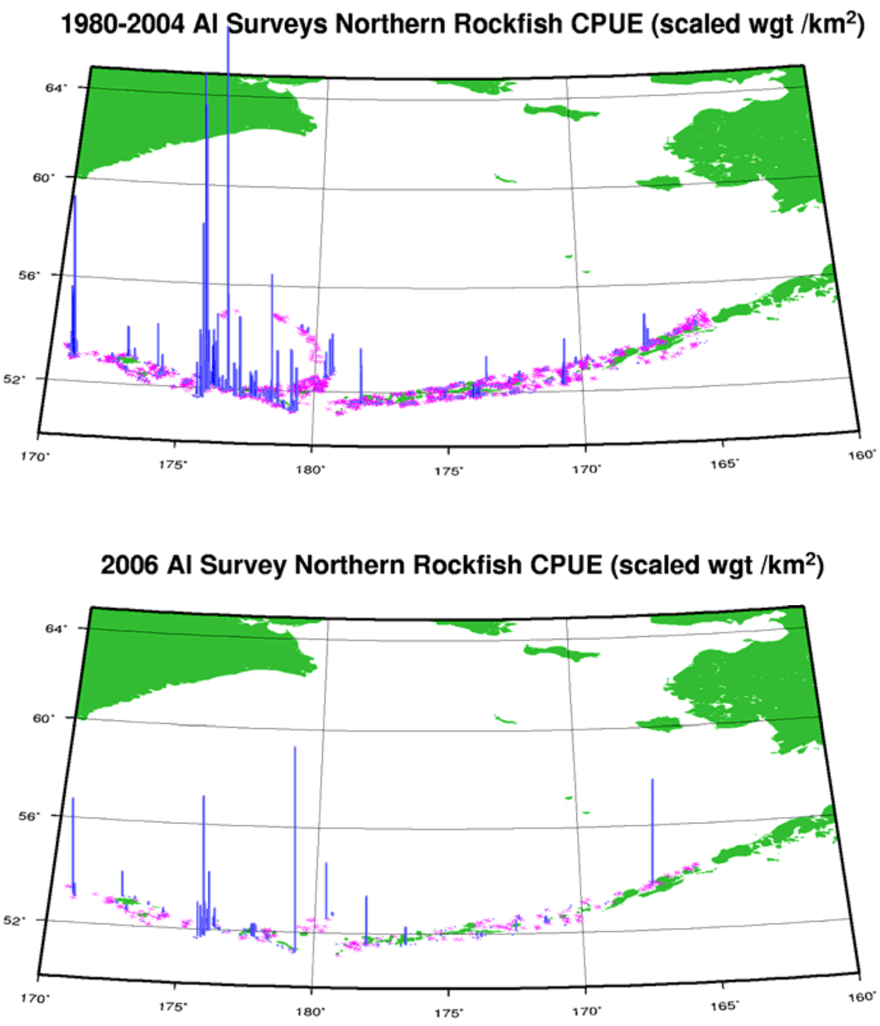

Figure 1. Scaled AI survey northern rockfish CPUE from 1980-2004 (top panel) and 2006 (bottom panel); the symbol × denotes tows with no catch.

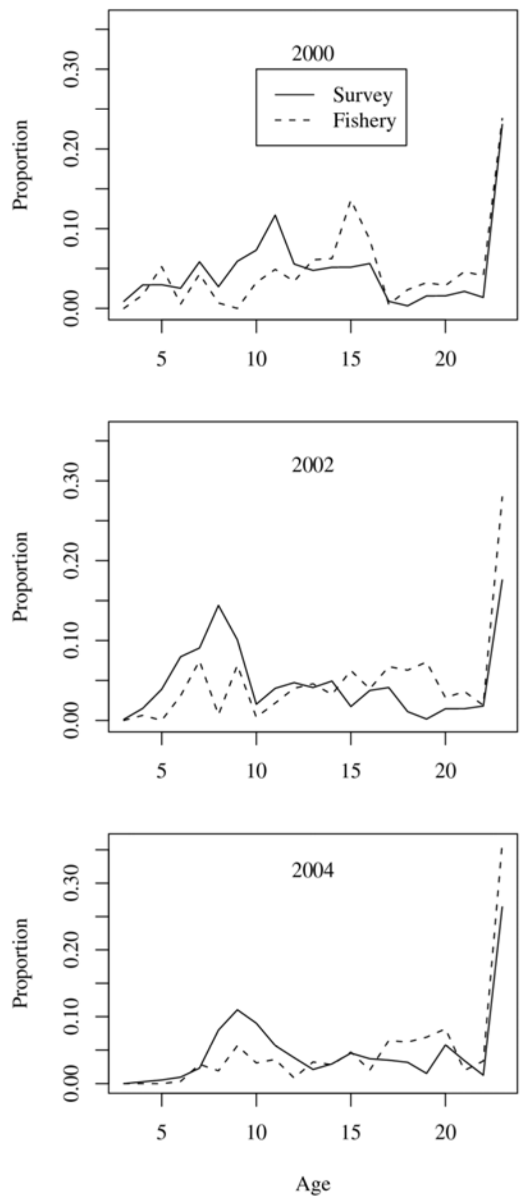

Figure 2. Age frequency distribution of northern rockfish from the 2000, 2002 and 2004 AI survey and fishery samples.

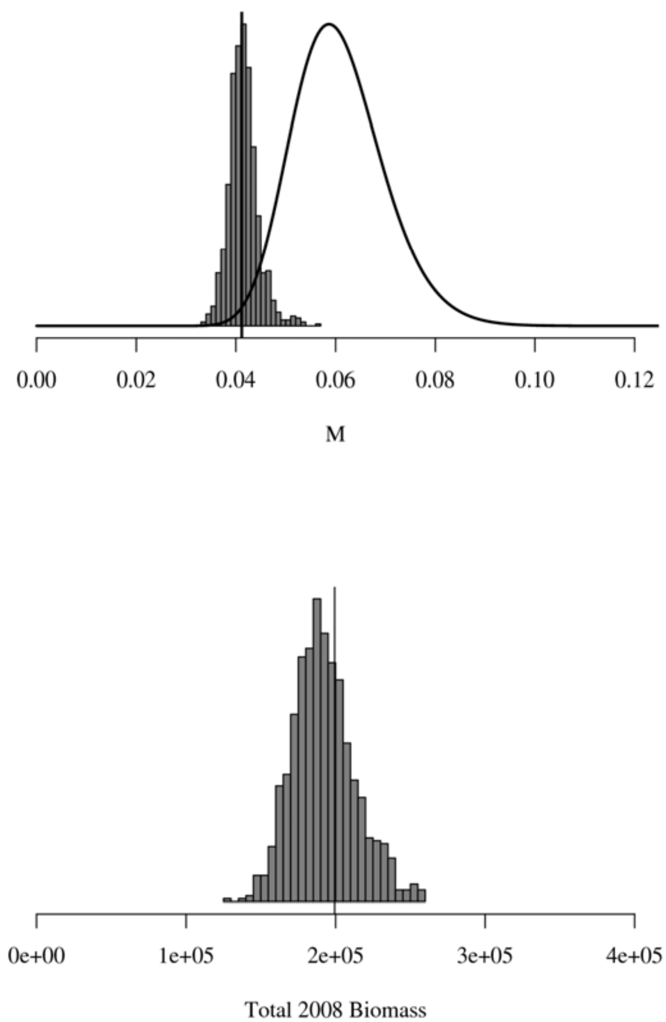

Figure 3 Posterior distributions for natural mortality (M) and 2008 total biomass. The prior distribution for *M* is shown as the solid line, and the MLE estimates are indicated by the vertical lines.

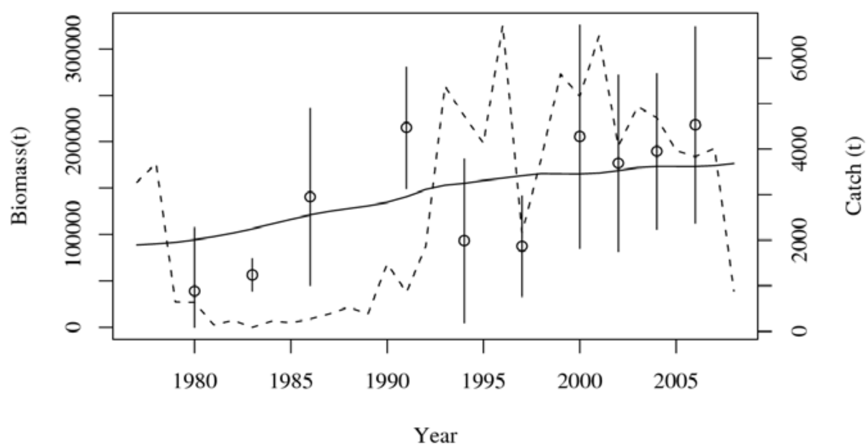

Figure 4. Observed AI survey biomass(data points, +/− 2 standard deviations), predicted survey biomass(solid line), and BSAI harvest (dashed line).

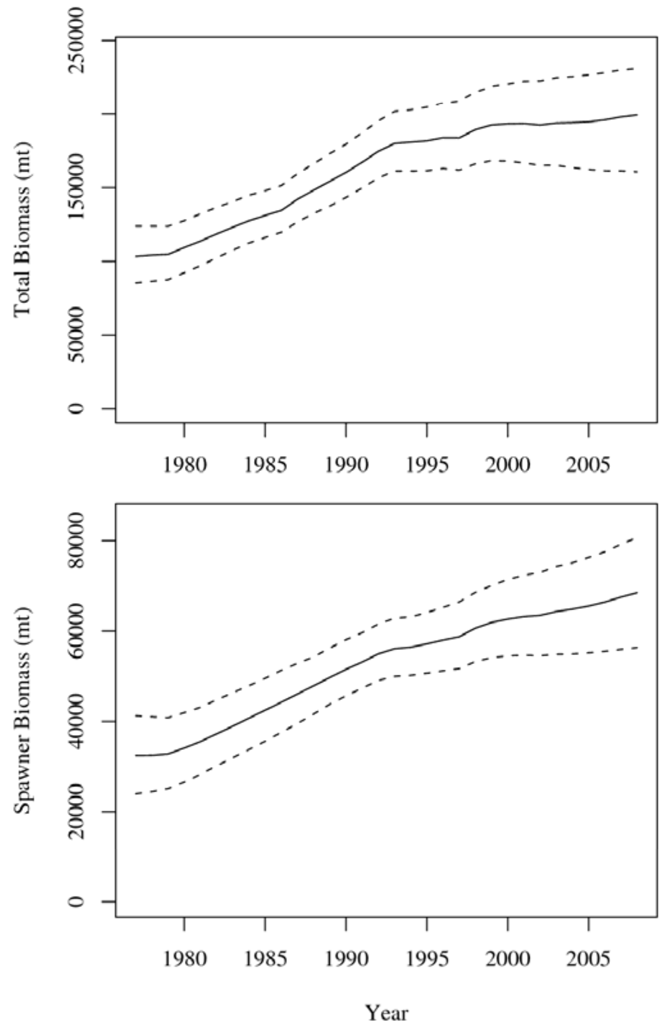

Figure 5. Total and spawner biomass for BSAI northern rockfish with 95% confidence intervals from MCMC integration.

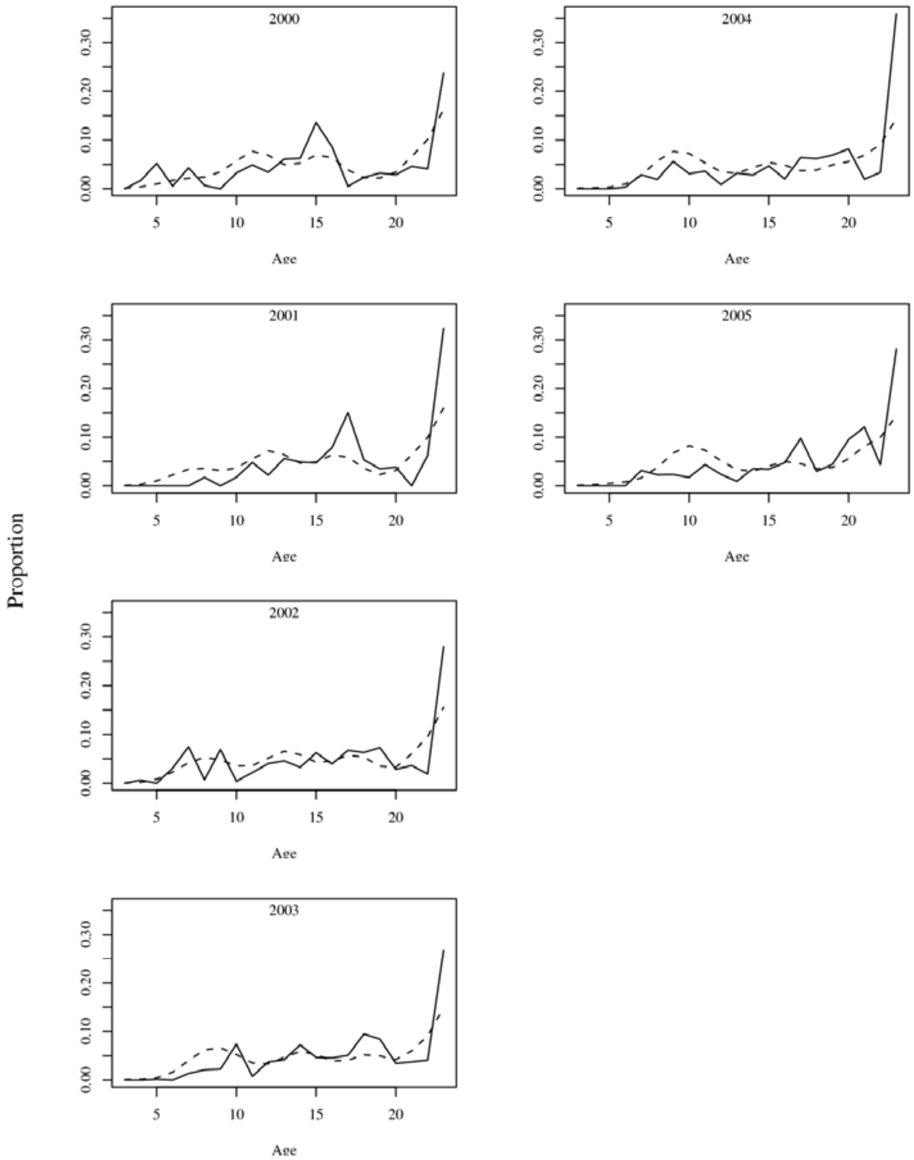

Figure 6. Fishery age composition by year (solid line = observed, dotted line = predicted)

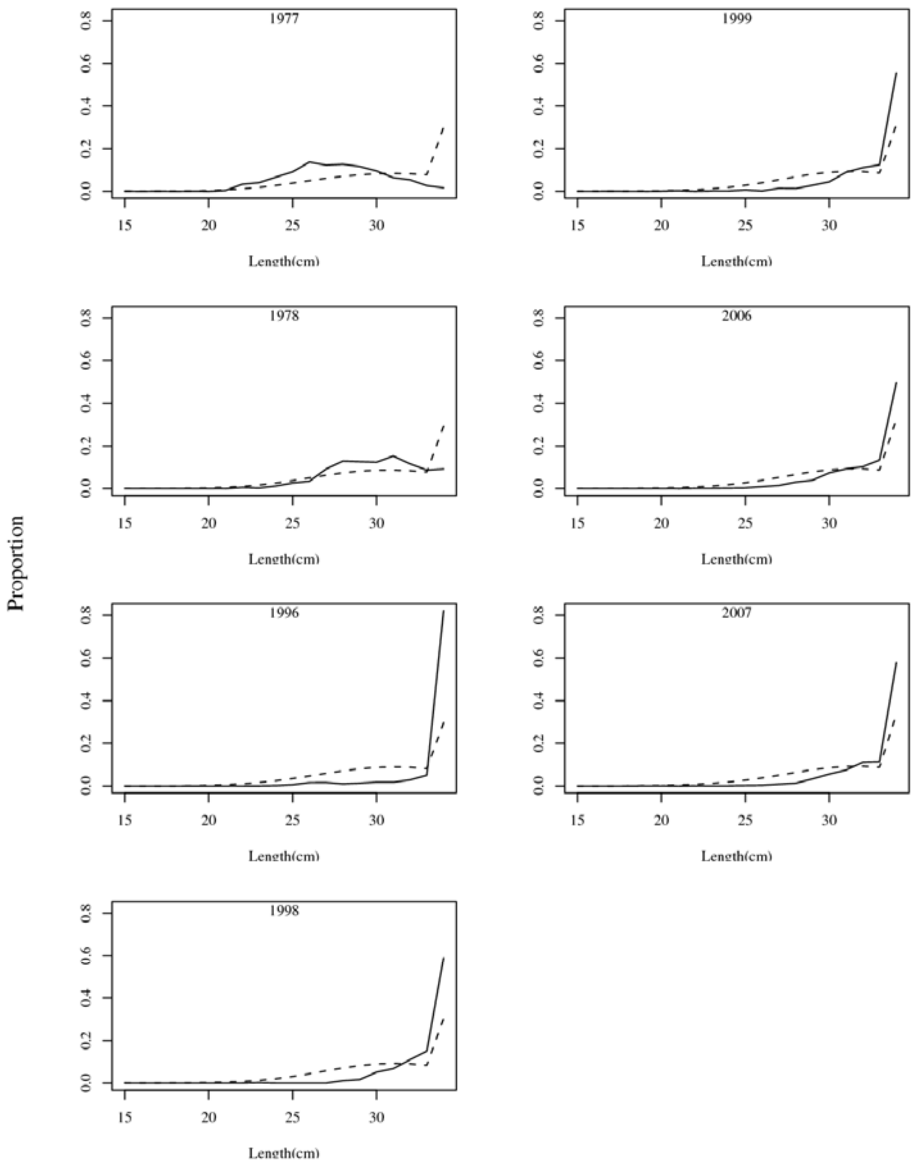

Figure 7. Fishery length composition by year (solid line = observed, dotted line = predicted)

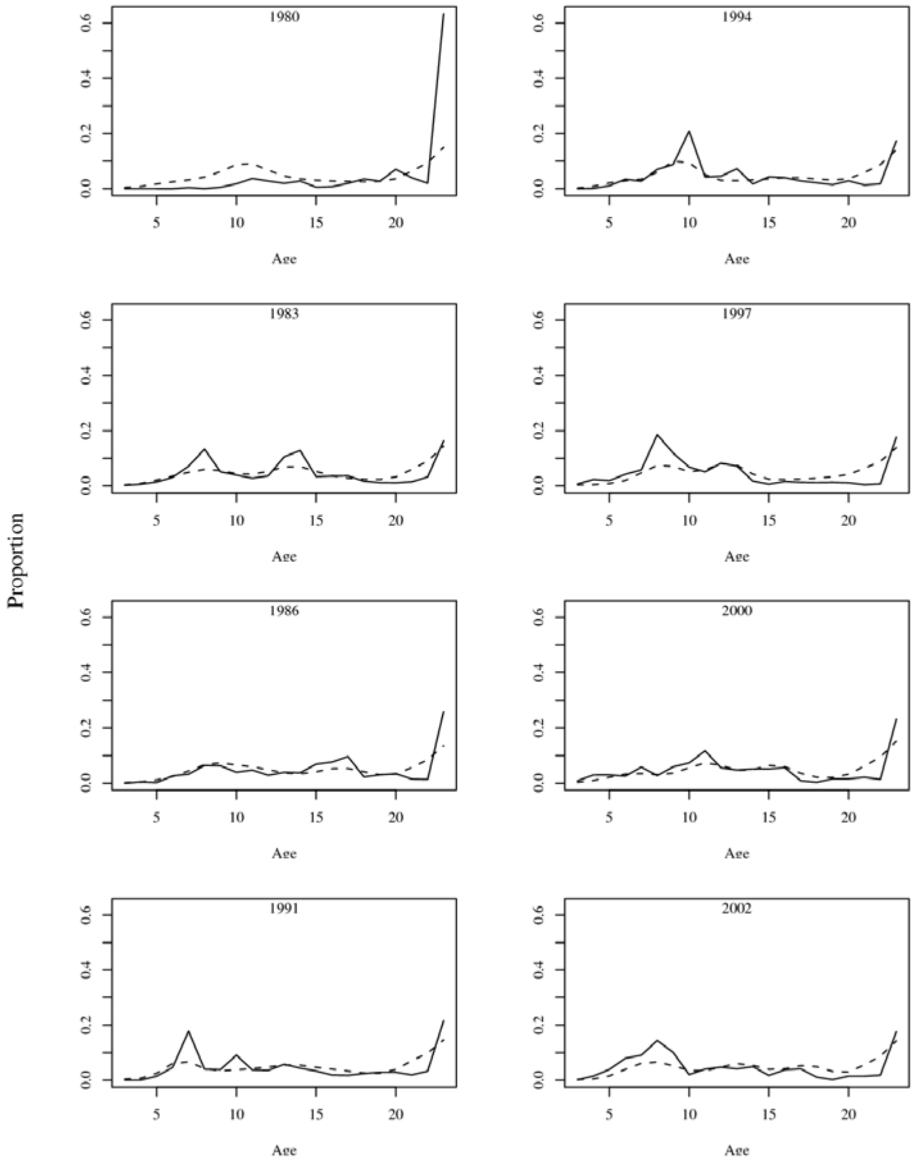

Figure 8. AI Survey age composition by year (solid line = observed, dotted line = predicted)

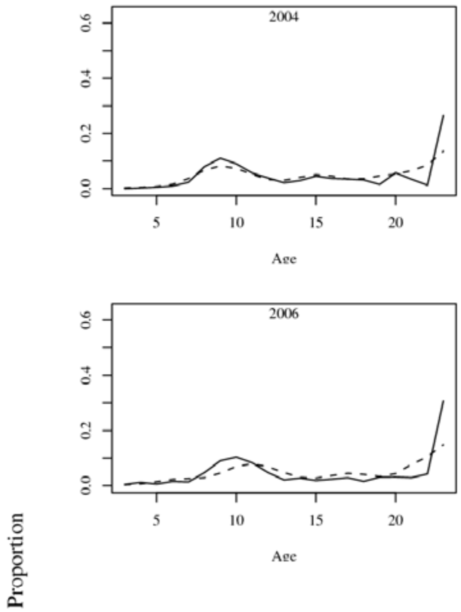

Figure 8 (continued). AI Survey age composition by year (solid line = observed, dotted line = predicted)

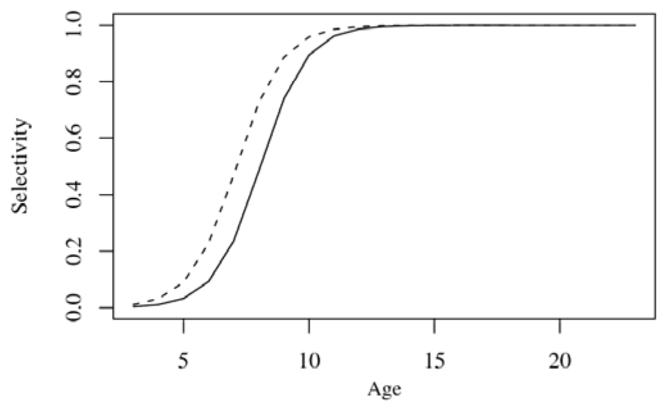

Figure 9. Estimated fishery (solid line) and survey (dashed line) selectivity curve by age.

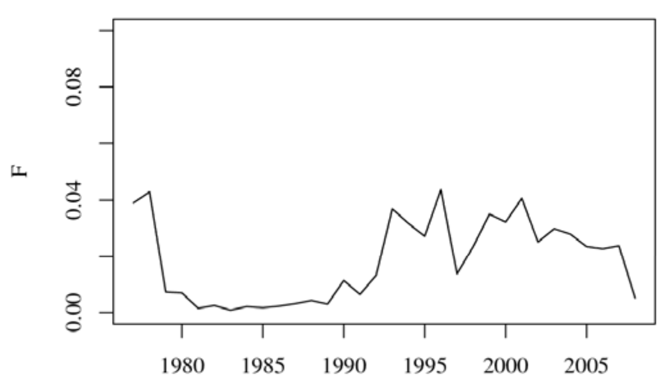

Figure 10. Estimated fully selected fishing mortality for BSAI northern rockfish.

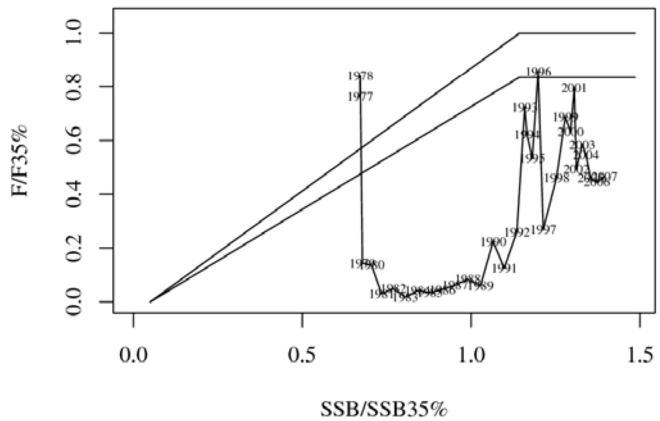

Figure 11. Estimated fishing mortality and SSB in reference to OFL (upper line) and ABC (lower line) harvest control rules

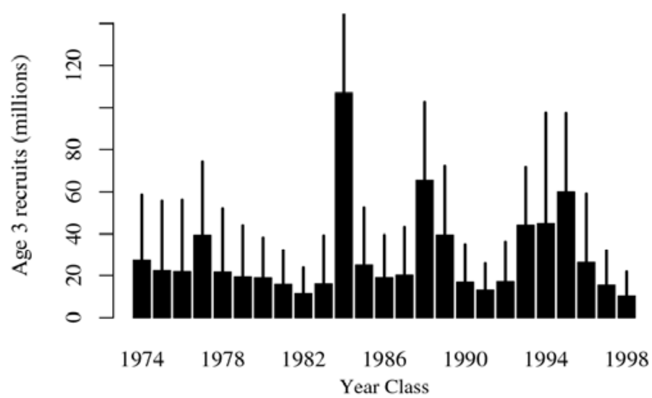

Figure 12. Estimated recruitment (age 3) of BSAI northern rockfish with 95% CI limits obtained from MCMC integration.

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