CHAPTER 12

NORTHERN ROCKFISH

by

Paul D. Spencer and James N. Ianelli

Executive Summary

The last full assessment for northern rockfish was presented to the Plan Team in 2004, and an updated assessment using 2005 catch data was presented in 2005. The following changes were made to northern rockfish assessment relative to the November 2004 SAFE:

Changes in the Input Data

(1) The harvest time series have revised and updated through August 5, 2006.

(2) The survey biomass and length composition from the 2006 AI survey were included in the assessment.

(3) The survey age composition from 1983, 1986, and 2004 were included in the assessment

(4) The fishery age composition from 2001, 2004, and 2005 were included in the assessment.

Changes in Assessment Methodology

(1) The standard deviation of recruitment residuals, σ_r, was fixed at 0.75. In previous assessments, this parameter was fit with very tight Bayesian prior, which essentially also served to also fix the parameter at 0.75.

Changes in the Assessment Results

A summary of the 2006 assessment recommended ABC's relative to the 2005 recommendations is as follows:

Assessment Year	2005		2006	
Projection Year	2006	2007	2007	2008
Total Biomass	203,823 t	199,599 t	211,893 t	211,336 t
ABC	8,532 t	8,321 t	8,194 t	8,151 t
OFL	10,137 t	9,799 t	9,753 t	9,702 t

Responses to the Comments of the Statistical and Scientific Committee (SSC)

There were no specific comments on the northern rockfish assessment.

Preliminary Responses to the Comments of the Center of Independent Experts (CIE)

A CIE review of rockfish stock assessments was conducted in June 2006. The CIE panel commented on several aspects of Alaska rockfish assessments, including estimation of numbers at age in the first year of the model, evaluating the utility of using fishery CPUE data, the estimation of survey catchability if rockfish densities differ between trawlable and untrawlable grounds, and estimation of natural mortality from age data. The issue of natural mortality (M) estimation is addressed by estimating this parameter within the model. The question of trawl survey catchability may require the most effort to address, and will likely require field research. It is expected that future research will address the proportions of the survey area that consists of trawlable and untrawlable grounds, and the potential differences in densities between these habitat types, in order to gain more precise information on survey q. Further discussion on rockfish research, and responses to the CIE review, will occur at the February 2007 SSC meeting.

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 have been assessed under Tier 5 of Amendment 56 of the NPFMC BSAI Groundfish FMP until 2004, and have historically relied solely upon recent survey biomass estimates for an estimation of stock size. The reading of archived otoliths from the AI surveys allowed the development of an age-structured model for northern rockfish beginning in 2003.

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 Aleutian Islands 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 included in a variety of management 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.

Northern rockfish catch prior to 1990 was small relative to more recent years (with the exception of 1977 and 1978) (Table 12.1). Harvest data from 2003-2005 indicates that approximately 90% of the BSAI northern rockfish are harvested in the Atka mackerel fishery, with a large amount of the catch occurring in September in the central and western Aleutians (areas 542 and 543). The distribution of northern rockfish harvest by Aleutian Islands subarea reflects both the spatial regulation of the Atka mackerel fishery and the increased biomass of northern rockfish in the western Aleutian Islands. 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 12.2.

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 discard. This management category was used in 2001 in the EBS, and from 1993-2001 in the AI. The discards rates are generally above 80%, with the exception of the mid-1990s when some targeting occurred in the Aleutians Islands (Table 12.3). 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 55% in 2005, and the discard rate in the Aleutian Islands has decline form 91% to 76% over the same period.

DATA

Fishery Data

The fishery data is characterized by inconsistent sampling of lengths and ages (Table 12.4). 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 improved the distribution of hauls from which northern rockfish age and length data were 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, and 1998-1999, 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 12.5). 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. In future assessments, the feasibility of reanalyzing the data from the cooperative surveys will be investigated, which would involve estimating fishing power corrections and re-estimating biomass levels and survey length with current (post 1990) survey strata. For the current assessment, the inclusion of the age and length composition data and catch data reduces the degree of influence of these biomass estimates (relative to a Tier 5 approach of averaging of biomass estimates), as does the rather large standard deviations of estimated biomass; for example, the coefficient of variation (CV) ranges between 0.36 in 1983 to 1.3 in 1980 (Table 12.5).

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 2002 EBS slope survey northern rockfish biomass estimate and its coefficient of variation were 33 t and 0.38, respectively, and the 2004 biomass estimate and it coefficient of variation were 16 t and 0.41, respectively. As in the BSAI POP assessment, the slope survey results are not used in this assessment and the 1991-2004 Aleutian Islands trawl surveys are considered an index of the BSAI population. A 2006 slope survey was scheduled but was canceled due to lack of funding. The feasibility of incorporating EBS slope survey time series will be evaluated in future years.

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 12.1). An average of 68% of the estimated biomass from the 1991-2006 NMFS AI trawl surveys occurs in the western Aleutian Islands (Table 12.5). 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.

<u>Biological Data</u>

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 12.6, 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. 1991, 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 is shown in Table 12.7.

Differences exist in the length-at-age curves from the three management area 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 12.8). 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 12.9). 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 x 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 12.10).

In recent years, the proportion of older northern rockfish captured by the AI trawl survey has been less than that in the fishery (Figure 12.2), and it will be seen later that this pattern influences the estimated fishery selectivity curve.

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

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

ANALYTIC APPROACH

Model structure

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

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

where Z is the sum of the instantaneous fishing mortality rate ($F_{t,a}$) and the natural mortality rate (M), A is the maximum number of age groups modeled in the population (defined as 23), and T is the terminal year of the analysis (defined as 2006). 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 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 1999 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 recruitments from 2000 to 2006 are set at the median recruitment, e^{μ_r}.

The fishing mortality rate for a specific age and time ($F_{t,a}$) is modeled as the product of a fishery age-specific selectivity (*fishsel*) 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.

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 12.2). Because and it is not expected that the fishery selectivity would differ substantially from the survey selectivity, in the 2004 assessment the fishing selectivity parameters were estimated as the survey selectivity parameters multiplied by e^{γ}, where γ 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. Because more fishery and length composition data have been obtained since the 2004 assessment, two model runs were conducted in this assessment:

Model 1	Fishing selectivity curve estimated without constraints
Model 2	Fishing selectivity curve estimated by constraining it to be close to the survey selectivity curve (as in 2004 assessment)

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 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 a 0.25. The standard deviation of log recruits, σ_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 σ_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 12.10) 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

$$\lambda_1\left(\sum_t\left(\frac{\nu_t+\sigma^2/2}{2\sigma^2}\right)^2+n\ln(\sigma)\right)+$$
$$\lambda_1\left(\sum_{a-1}\left(\frac{\gamma_t}{2\sigma^2}\right)^2+(a-1)\ln(\sigma)\right)+$$
$$\lambda_2\sum_t(\ln(obs\_biom_t)-\ln(pred\_biom_t))^2/2*cv_t^2+$$
$$n_{f,t,l}\sum_{s,t,l}p_{f,t,l}\ln(\hat{p}_{f,t,l})-p_{f,t,l}\ln(p_{f,t,l})+$$
$$n_{f,t,a}\sum_{s,t,l}p_{f,t,a}\ln(\hat{p}_{f,t,a})-p_{f,t,a}\ln(p_{f,t,a})+$$
$$n_{surv,t,a}\sum_{s,t,a}p_{surv,t,a}\ln(\hat{p}_{surv,t,a})-p_{surv,t,a}\ln(p_{surv,t,a})+$$
$$n_{surv,t,l}\sum_{s,t,a}p_{surv,t,l}\ln(\hat{p}_{surv,t,l})-p_{surv,t,l}\ln(p_{surv,t,l})+$$
$$\lambda_3\sum_t(\ln(obs\_cat_t)-\ln(pred\_cat_t))^2$$

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; the sum of the weights add to 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 (μ_f)	1
2) fishing mortality deviations (ϵ_t)	30
3) recruitment mean (μ_r)	1
5) recruitment deviations (ν_t)	23
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	82

RESULTS

The estimated fishing selectivity curve of Model 1 showed an age at 50% of 13.3 years as compared to 7.8 years for Model 2, resulting in levels of $F_{40\%}$ of 0.068 and 0.045 for Models 1 and 2, respectively. Both of these features are shown in Figure 12.3, which shows the product of the selectivity curve and $F_{40\%}$ for each model. The two age-specific fishing mortality curves intersect at approximately 14 years; ages less than this would receive heavier fishing mortality under Model 2, whereas older ages would receive heavier fishing mortality under Model 1. The 2007 catch level for the two models depends upon the estimated age composition in 2006, and the 2007 Fabc catch level for Models 1 and 2 were 9,541 t and 8,194 t, respectively.

Model 2 was chosen as the preferred model 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 12.4), 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. Given these considerations, Model 2 is viewed as a conservative estimate of fishing selectivity, and the results below refer to Model 2.

The negative log-likelihood associated with the various data components of the two models are shown in Table 12.11. The two models produced similar fits in many respects, with the improved fit of Model 1 coming from improved fits to the fishery age and length composition data and the survey age composition data. The effective sample size for the survey age and length composition were 64% and 138% of the input sample size, respectively, and the high effective n for the survey length composition reflects that only one year (2006) exists for this data component. The effective sample sizes for the fishery age and size compositions were 64% and 51% of the input sample sizes, reflectively, and as these data components were down-weighted relative to the survey age and length composition.

Prior and Posterior Distributions

Posterior distributions for *M* and total 2006 biomass, and mean recruitment, based upon the MCMC integrations, are shown in Figure 12.4. The posterior distribution for *M* is shifted slightly 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 110,200 t in 1977 and increasing gradually to 190,804 t in 2006 (Figure 12.5). The total biomass and spawner biomass showed similar patterns as the survey biomass, with the 2006 estimates being 211,890 t and 72,748 t, respectively (Figure 12.6). The time series of estimated total biomass, spawner biomass, and recruitment are shown in Table 12.12.

Age/size compositions

The model fits to the fishery age and size compositions are shown in Figures 12.7-12.8, and the model fit to the survey age and length compositions are shown in Figures 12.9- 12.10. 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. As mentioned above, the estimated age at 50% selection for the fishery selectivity curves was 7.7 years, whereas a value of 7.1 years was obtained for the survey selectivity (Figure 12.11).

Fishing mortality

The estimates of instantaneous fishing mortality rate are shown in Figure 12.12. 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 2006 estimate is 0.005. The low value for fishing mortality for 2006 reflects the unusually low catch taken by the end of summer, 2006, that was used in the assessment. 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 12.13).

Recruitment

Recruitment strengths by year class are shown in Figure 12.14. 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 and 2004 age composition data. The scatterplot of recruitment against spawning stock biomass is shown in Figure 12.15, indicating little variation in estimated spawning stock biomass but more substantial variation in estimated recruitment for the modeled years.

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 1977-2003 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 51,952 t. The year 2007 spawning stock biomass is estimated as 72,830 t. Since reliable estimates of the 2007 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B>B_{0.40}$ (72,830 t > 51,952 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 0.045 and 0.053, respectively. The ABC associated with the $F_{0.40}$ level of 0.045 is 8,194 t. This ABC is 338 t lower than last year's recommendation of 8,532 t, a 4% decrease. The estimated catch level for year 2007 associated with the overfishing level of F = 0.053 is 9,753 t. A summary of these values is below.

2007 SSB estimate (B)	= 72,830 t
$B_{0.40}$	= 51,952 t
$F_{0.40}$	= 0.045
F_{ABC}	= 0.045
$F_{0.35}$	= 0.053
F_{OFL}	= 0.053

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 2006 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2007 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2006. 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 2007, 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 2007 recommended in the assessment to the *max* F_{ABC} for 2007. (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 2001-2005 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 12.13.

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 2007, then the stock is not overfished.)

Scenario 7: In 2007 and 2008, 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 2009 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 12.13. 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 2007 of scenario 6 is 1.60 times its $B_{35\%}$ value of 45,458 t. With regard to whether northern rockfish stock is likely to be overfished in the future, the expected stock size in 2009 of scenario 7 is 1.55 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 Staty (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 depth 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	0.045
Tier	3a
Year 2007 Total Biomass	211,893 t
Year 2008 Total Biomass	211,336 t
Year 2007 Spawning stock biomass	72,830 t
$B_{100\%}$	129,879 t
$B_{40\%}$	51,952 t
$B_{35\%}$	45,458 t
F_{OFL}	0.053
Maximum F_{ABC}	0.045
Recommended F_{ABC}	0.045
OFL (2007)	9,753 t
OFL (2008)	9,702 t
Maximum allowable ABC (2007)	8,194 t
Recommended ABC (2007)	8,194 t
Maximum allowable ABC (2008)	8,151 t
Recommended ABC (2008)	8,151 t

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.

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.

Gelman, A., J.B. Carlin, H.S. Stern, and D.A. Rubin. 1995. Bayesian data analysis. Chapman and Hall, New York. 552 pp.

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.

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

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.

Yang, M-S. 1993. Food habits of the important groundfishes in the Aleutian Islands in the Gulf of Alaska in 1990. NOAA Tech. Memo., NMFS-AFSC-22, U.S. Dept. Com., NOAA. 150 pp.

Yang, M-S. 2003. Food habits of the important groundfishes in the Aleutian Islands in 1994 and 1997. U.S. Dep. Commer., AFSC Proc. Rep. 2003-07. 233 pp.

Table 12.1. 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			614			233	847
1992			636			3,094	3,730
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			3,747	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			76			4,862	4,937
2004			116			4,567	4,684
2005			112			3,852	3,964
2006*			141			722	863

*Catch data through August 5, 2006, from NMFS Alaska Regional Office.

Table 12.2. Estimated 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	55.03	1.76	
2005		0.00	
2006	41.11	0.01	

Table 12.3. Estimated retained, discarded, and percent discarded sharpchin/northern (SC/NR), 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 ORR complex in the eastern Bering. Beginning in 2002, sharpchin rockfish were removed from other red rockfish 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%
EBS	Northerns	2003	14	59	73	80.4%
EBS	Northerns	2004	35	82	117	70.2%
EBS	Northerns	2005	45	67	112	54.9%
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%

Table 12.4. Samples sizes of otoliths and lengths from fishery sampling, with the number of hauls from which these data were collected, from 1974-2005.

Year	Lengths	Hauls	Otoliths collected	Otoliths read	Hauls (read otoliths)
1974					
1975					
1976					
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	166	165*	49
2001	661*	70	136	135*	58
2002	889*	68	200	195*	60
2003	1362*	124	318	317*	110
2004	842*	78	196	196*	69
2005	466*	47	120	118*	44

*Used to create age composition
**Not used

Table 12.5. Northern rockfish biomass estimates (t) from Aleutian Islands trawl survey, with coefficients of variation shown in parentheses.

YEAR	Aleutian Islands Management Sub-Areas western	central	eastern	EBS estimates southern BS	Total
1980					43,653 (1.33)
1983					44,974 (0.34)
1986					181,056 (0.40)
1991	146,403 (0.21)	64,202 (0.18)	4,068 (0.52)	582 (0.63)	215,255 (0.16)
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)	24,957 (0.70)	49 (0.40)	205,348 (0.29)
2002	134,519 (0.33)	38,189 (0.43)	3,242 (0.42)	290 (0.67)	176,240 (0.27)
2004	147,584 (0.28)	27,612 (0.39)	10,375 (0.37)	5,980 (0.93)	191,551 (0.22)
2006	101,276 (0.29)	70,834 (0.50)	22,982 (0.45)	22,883 (1.00)	217,974 (0.24)
Average (1991-2006)	115,477	38,997	10,698	4,406	169,578
Percentage	68.1%	23.0%	6.3%	2.6%	

Table 12.6. 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	NA	NA

Table 12.7. Aging error matrix for BSAI northern rockfish, based upon data from Courtney et al 1999.

True age	Observed 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 12.8. 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	0	473
1983	268	225	93	39	625
1986	132	293	25	115	565
1991	0	243	159	54	456
1994	180	61	127	41	409
1997	234	219	199	0	652
2000	229	275	200	21	725
2002	88	74	66	31	259
2004	193	156	120	46	515

Table 12.9. 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 12.10. 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 12.11. Negative log likelihood of model components, average effective and input sample sizes, root mean squared errors and standard deviation of normalized residuals for models 1 and 2.

Component	Negative log likelihood	
	Model 1	Model 2
Recruitment	-0.41	-1.61
AI survey biomass	11.00	11.09
Catch	0.00	0.00
F penalty	4.82	4.63
Fishery ages	1028.13	1048.57
Fishery lengths	254.60	271.18
Survey ages	985.28	995.46
Survey lengths	370.84	369.93
Prior for *q_srv*	0.00	0.00
Prior for *M*	0.40	0.53
Prior for fish sel slope	NA	0.02
Prior for fish sel 50%	NA	4.83
Total likelihood	2679.14	2719.86
Average Effective Sample Size		
Fishery ages	35.40	27.58
Fishery lengths	10.50	10.23
Survey ages	40.35	38.14
Survey lengths	263.09	294.92
Average Sample Sizes		
Fishery ages	43.33	43.33
Fishery lengths	20.13	20.13
Survey ages	59.33	59.33
Survey lengths	213.33	213.33
Root Mean Squared Error		
survey	0.56	0.57
recruitment	0.68	0.62
Standard Deviation of Normalized Residuals		
Fishery ages	0.93	1.01
Fishery lengths	0.94	1.07
Survey ages	0.99	1.05
Survey lengths	0.96	0.93
AI trawl survey	1.42	1.43

Table 12.12. Estimated time series of northern rockfish total biomass (t), spawner biomass (t), and recruitment (thousands) for each region.

	Total Biomass (ages 3+)		Spawner Biomass (ages 3+)		Recruitment (age 3)	
	Assessment Year		Assessment Year		Assessment Year	
Year	2006	2004	2006	2004	2006	2004
1977	129,445	132,687	38,970	41,067	29,631	28,755
1978	131,273	133,341	39,596	41,843	25,279	23,951
1979	132,455	136,637	40,497	43,393	24,081	25,324
1980	137,036	140,548	42,335	45,045	32,885	33,238
1981	141,220	144,068	44,322	46,695	22,202	23,052
1982	145,578	147,533	46,486	48,337	19,665	22,117
1983	149,461	150,615	48,618	49,892	19,344	22,123
1984	152,982	153,338	50,703	51,403	16,918	17,176
1985	155,684	155,364	52,648	52,797	12,717	14,896
1986	158,014	157,202	54,480	54,122	16,192	20,192
1987	165,083	163,731	56,213	55,395	117,479	117,682
1988	170,767	168,942	57,815	56,575	32,072	34,389
1989	176,296	173,990	59,319	57,706	21,505	22,923
1990	181,868	179,044	60,728	58,775	22,746	24,051
1991	188,736	185,502	61,897	59,633	75,068	79,297
1992	196,148	192,523	63,091	60,636	45,425	52,820
1993	199,526	197,540	63,258	61,165	19,635	21,344
1994	200,244	198,041	63,204	60,979	14,955	17,283
1995	200,951	198,639	63,642	61,285	19,740	24,099
1996	202,933	200,138	64,275	61,777	48,592	44,569
1997	203,447	200,162	64,871	62,222	63,756	64,713
1998	208,944	203,795	66,688	63,856	53,670	
1999	211,569	205,443	67,900	64,906	18,695	
2000	212,292	204,908	68,621	65,451		
2001	212,993	204,446	69,204	65,846		
2002	211,900	202,279	69,533	65,954		
2003	212,840	202,283	70,399	66,561		
2004	212,432	201,307	70,959	66,896		
2005	211,927	200,013	71,620	66,558		
2006	211,890		72,748			
2007	211,893		72,830			

Table 12.13. Projections of BSAI northern rockfish catch (t), spawning biomass (t), and fishing mortality rate for each of the several scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 51,952 t and 45,458 t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2006	4,500	4,500	4,500	4,500	4,500	4,500	4,500
2007	8,194	8,194	4,141	4,910	0	9,753	8,194
2008	7,995	7,995	4,127	4,875	0	9,438	7,995
2009	7,799	7,799	4,110	4,835	0	9,133	9,283
2010	7,615	7,615	4,093	4,797	0	8,849	8,990
2011	7,460	7,460	4,086	4,772	0	8,606	8,736
2012	7,320	7,320	4,080	4,750	0	8,387	8,508
2013	7,199	7,199	4,080	4,734	0	8,197	8,309
2014	7,098	7,098	4,085	4,726	0	8,036	8,138
2015	7,011	7,011	4,093	4,722	0	7,895	7,989
2016	6,938	6,938	4,105	4,724	0	7,775	7,861
2017	6,874	6,874	4,118	4,727	0	7,668	7,747
2018	6,814	6,814	4,129	4,729	0	7,566	7,640
2019	6,754	6,754	4,136	4,728	0	7,445	7,524
Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2006	72,395	72,395	72,395	72,395	72,395	72,395	72,395
2007	72,830	72,830	73,233	73,157	73,638	72,674	72,830
2008	71,740	71,740	73,734	73,354	75,784	70,976	71,740
2009	70,528	70,528	74,075	73,394	77,804	69,189	70,376
2010	69,224	69,224	74,274	73,296	79,699	67,349	68,488
2011	67,967	67,967	74,463	73,194	81,595	65,590	66,679
2012	66,560	66,560	74,417	72,868	83,230	63,728	64,761
2013	65,113	65,113	74,238	72,425	84,692	61,873	62,845
2014	63,745	63,745	74,053	71,987	86,108	60,137	61,047
2015	62,503	62,503	73,914	71,610	87,533	58,566	59,412
2016	61,450	61,450	73,902	71,368	89,058	57,213	57,997
2017	60,529	60,529	73,953	71,201	90,609	56,022	56,746
2018	59,683	59,683	74,002	71,045	92,102	54,937	55,602
2019	58,870	58,870	73,999	70,854	93,468	53,922	54,527
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2006	0.02429	0.02429	0.02429	0.02429	0.02429	0.02429	0.02429
2007	0.04469	0.04469	0.02235	0.02655	0.0	0.05342	0.04469
2008	0.04469	0.04469	0.02235	0.02655	0.0	0.05342	0.04469
2009	0.04469	0.04469	0.02235	0.02655	0.0	0.05342	0.05342
2010	0.04469	0.04469	0.02235	0.02655	0.0	0.05342	0.05342
2011	0.04469	0.04469	0.02235	0.02655	0.0	0.05342	0.05342
2012	0.04469	0.04469	0.02235	0.02655	0.0	0.05342	0.05342
2013	0.04469	0.04469	0.02235	0.02655	0.0	0.05342	0.05342
2014	0.04469	0.04469	0.02235	0.02655	0.0	0.05342	0.05342
2015	0.04469	0.04469	0.02235	0.02655	0.0	0.05342	0.05342
2016	0.04469	0.04469	0.02235	0.02655	0.0	0.05342	0.05342
2017	0.04469	0.04469	0.02235	0.02655	0.0	0.05342	0.05342
2018	0.04469	0.04469	0.02235	0.02655	0.0	0.05339	0.05341
2019	0.04469	0.04469	0.02235	0.02655	0.0	0.05318	0.05329

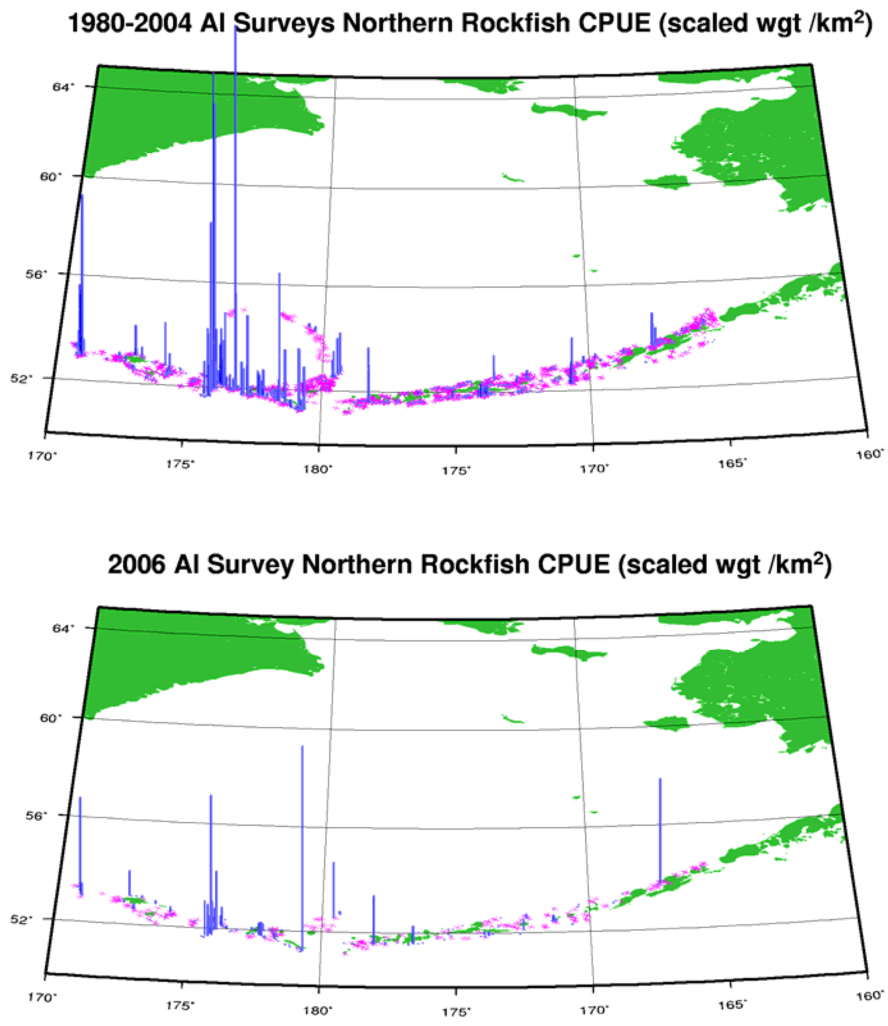


Figure 12.1. Scaled AI survey northern rockfish CPUE from 1980-2004 (top panel), and 2006 (bottom panel)

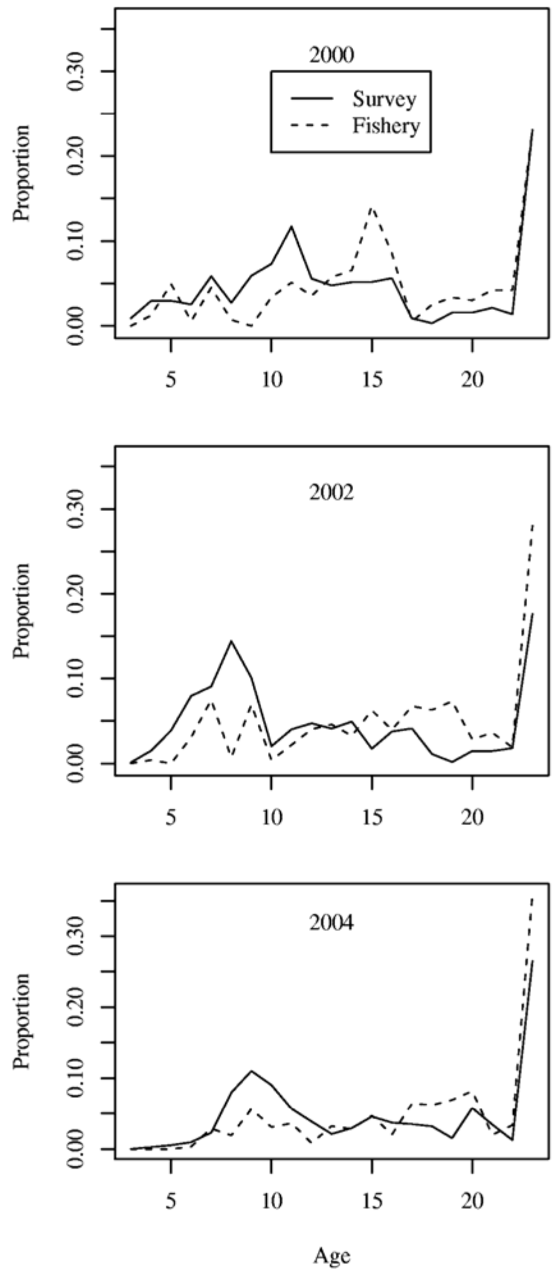


Figure 12.2. Age frequency distribution of northern rockfish from the 2000, 2002 and 2004 AI survey and fishery samples.

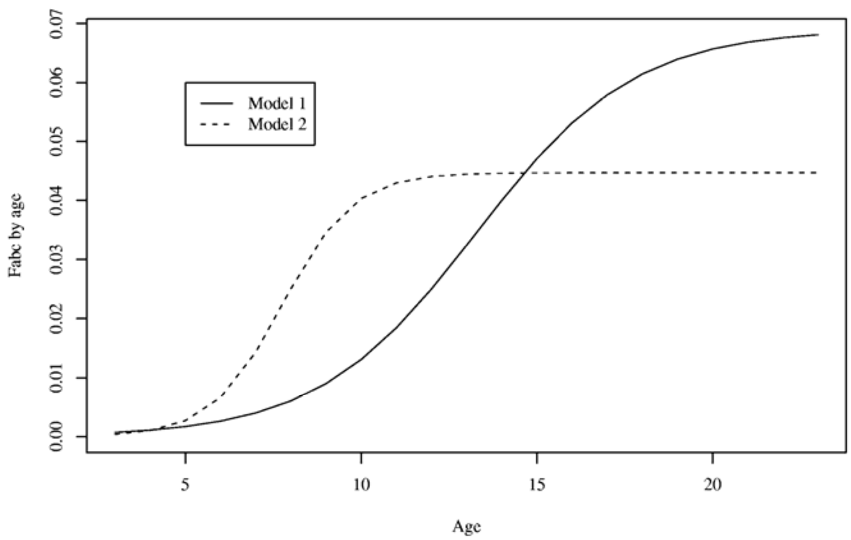
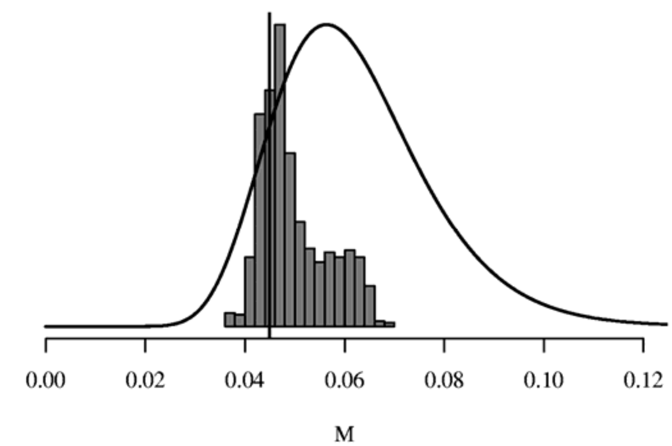


Figure 12.3. Product for F_{abc} and fishery selectivity at age for Model 1 and Model 2.



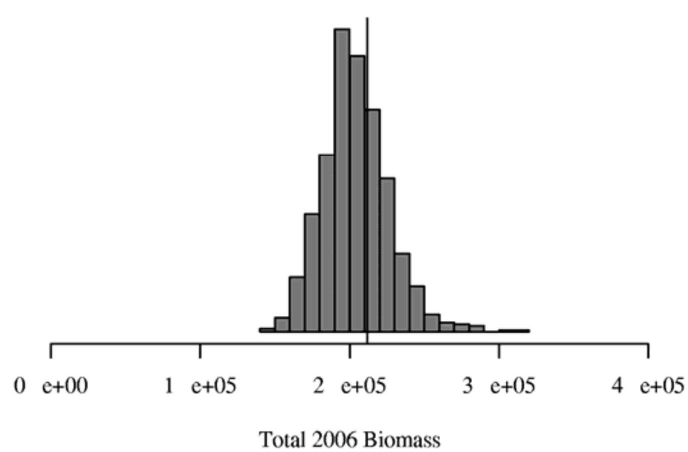


Figure 12.4 Posterior distributions for natural mortality (M) and 2006 total biomass. The prior distribution for M is shown as the solid line, and the MLE estimates are indicated by the vertical lines.

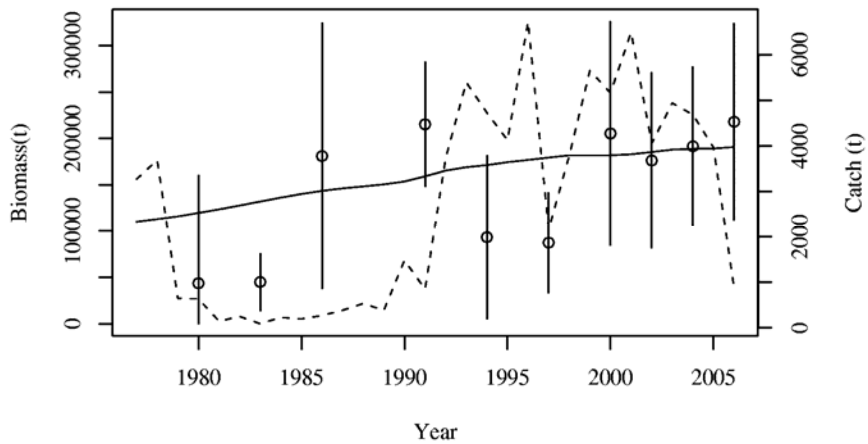


Figure 12.5. Observed AI survey biomass(data points, +/− 2 standard deviations), predicted survey biomass(solid line), and BSAI harvest (dashed line).

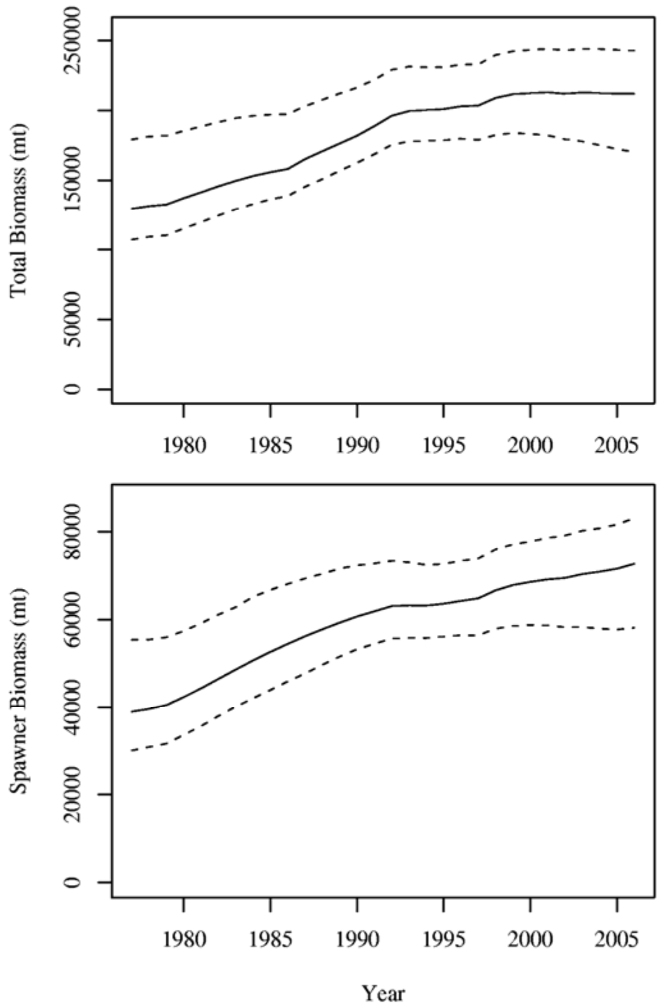


Figure 12.6. Total and spawner biomass for BSAI northern rockfish with 95% confidence intervals from MCMC integration.

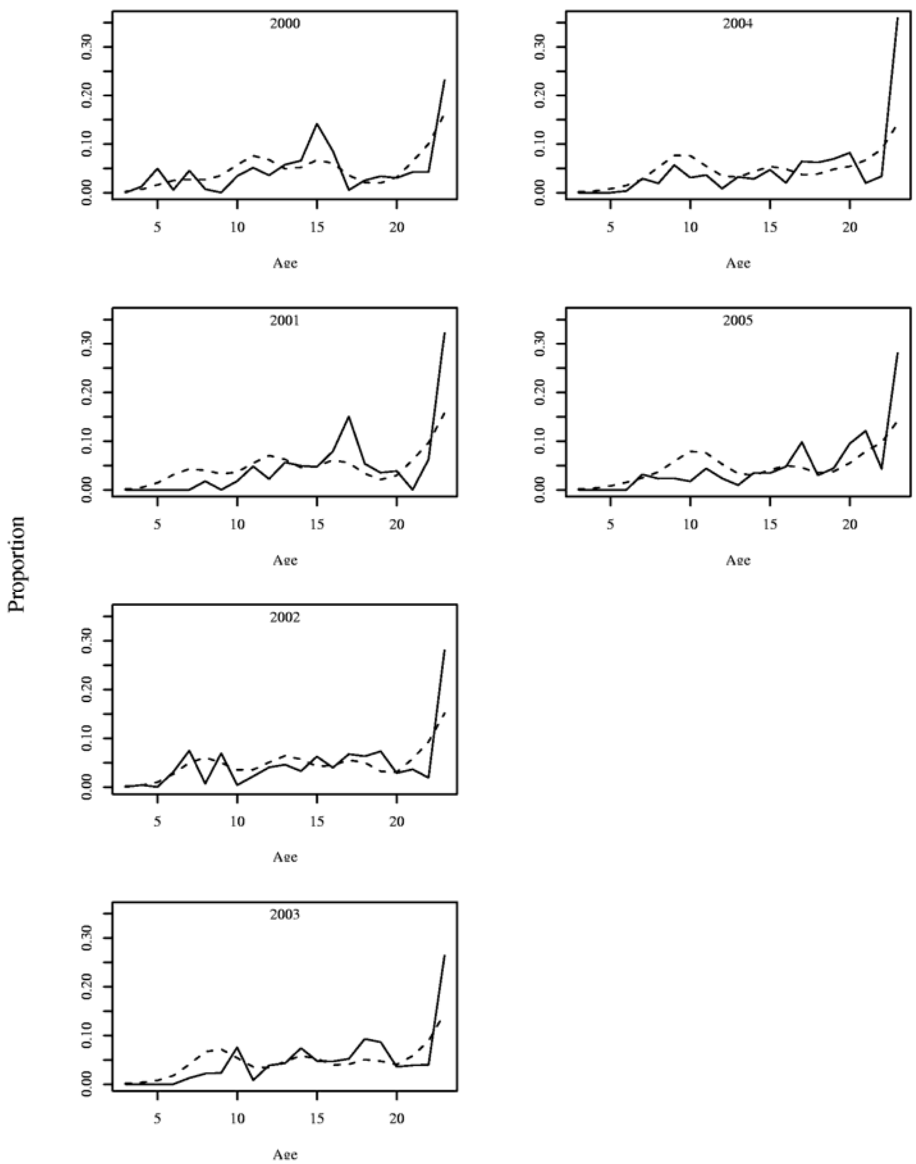


Figure 12.7. Fishery age composition by year (solid line = observed, dotted line = predicted)

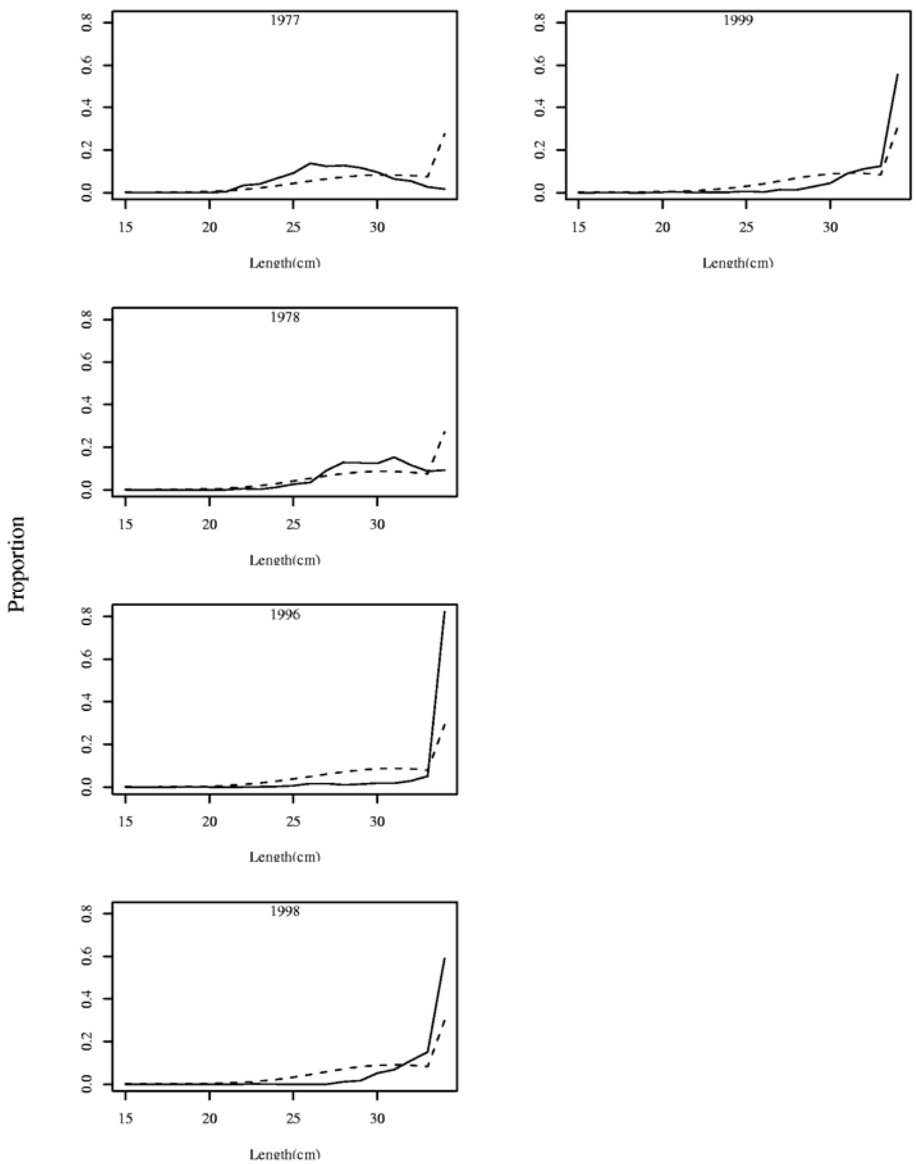


Figure 12.8. Fishery length composition by year (solid line = observed, dotted line = predicted)

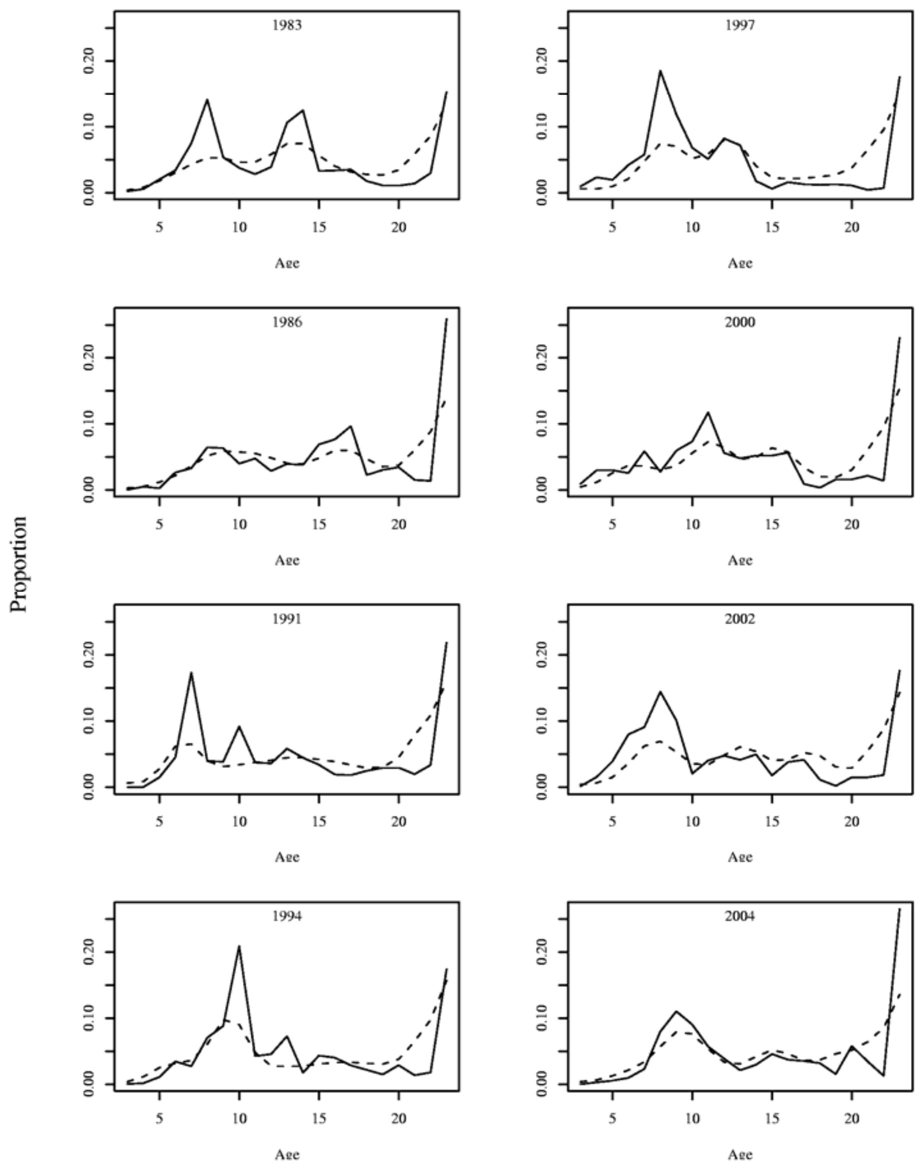


Figure 12.9. AI Survey age composition by year (solid line = observed, dotted line = predicted)

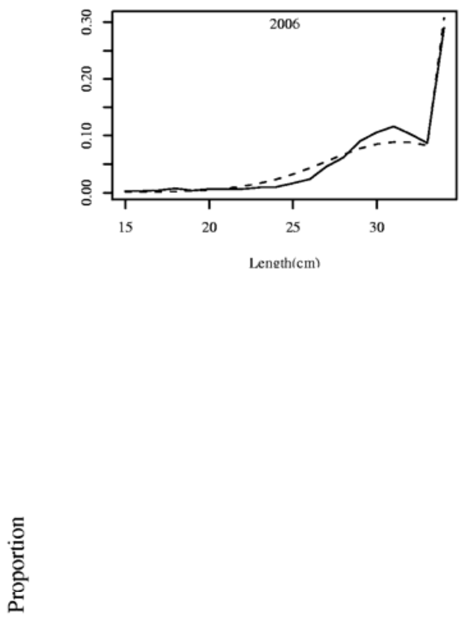


Figure 12.10. AI Survey length composition by year (solid line = observed, dotted line = predicted)

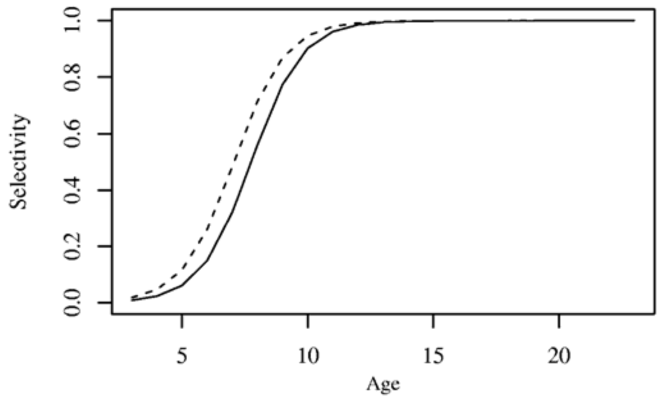


Figure 12.11. Estimated fishery (solid line) and survey (dashed line) selectivity curve by age.

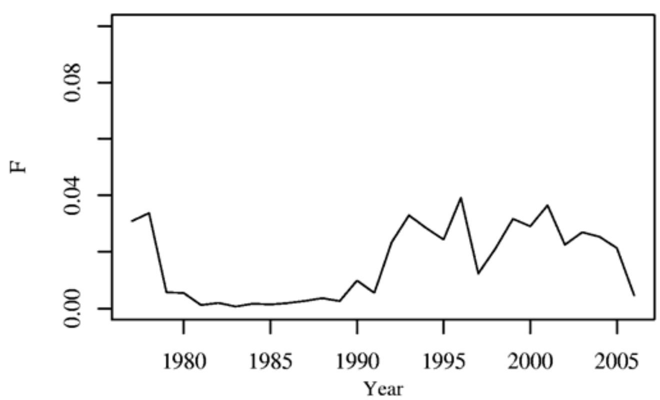


Figure 12.12. Estimated fully selected fishing mortality for BSAI northern rockfish.

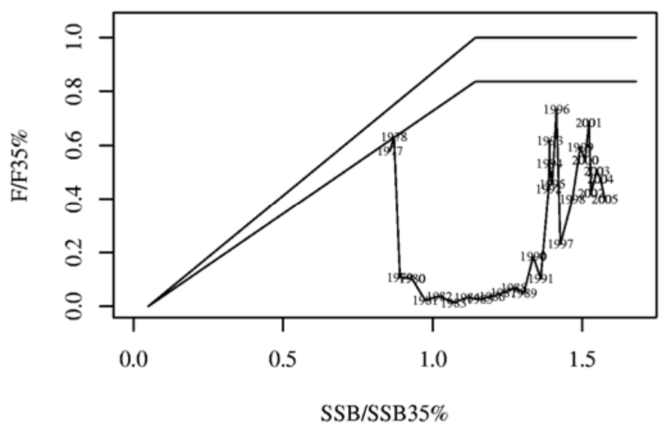


Figure 12.13. Estimated fishing mortality and SSB in reference to OFL (upper line) and ABC (lower line) harvest control rules

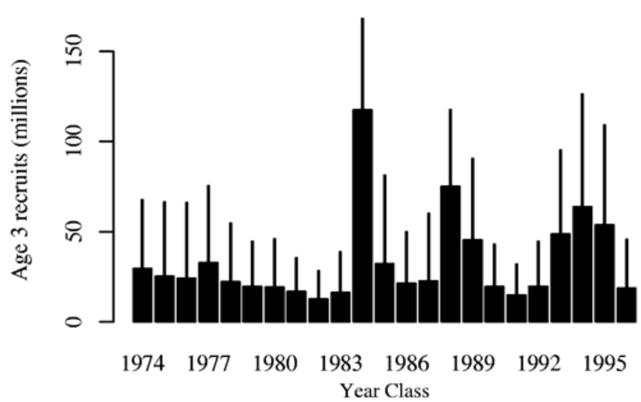


Figure 12.14. Estimated recruitment (age 3) of BSAI northern rockfish with 95% CI limits obtained from MCMC integration.

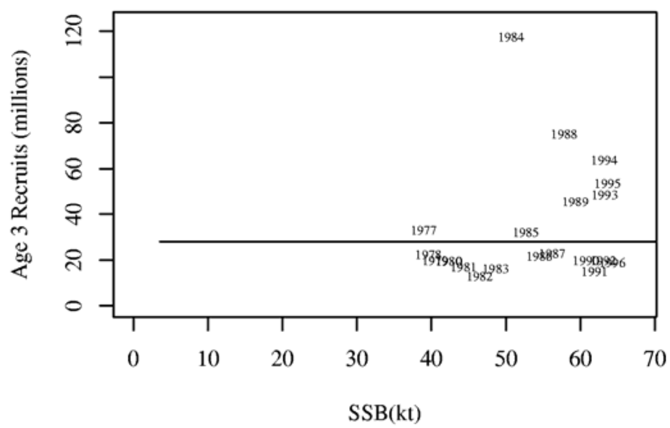


Figure 12.15. Scatterplot of BSAI northern rockfish spawner–recruit data; label is year class.