CHAPTER 13

# Assessment of Blackspotted and Rougheye Rockfish Stock Complex in the Bering Sea/Aleutian Islands

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## Executive Summary

Fish previous referred to as rougheye rockfish are now recognized as consisting of two species, the rougheye rockfish (*Sebastes aleutianus*) and blackspotted rockfish (*Sebastes melanostictus*) (Orr and Hawkins 2007). The current information on these two species is not sufficient to support species-specific assessments, so they are combined in this assessment. Beginning in 2008, an age-structured model is applied to the Aleutian Islands portion of the population whereas the EBS portion of the population are assessed with Tier 5 methods applied to survey biomass estimates.

The blackspotted/rougheye complex is currently managed with BSAI-wide ABC and OFL levels. In the September, 2010, Plan Team meeting, a report on available information on stock structure was presented to the Plan Team, and is included in this assessment as an appendix. The Plan Team concluded that subarea structure exists within the BSAI, and area-specific ABCs should be considered. Two options for area-specific ABCs are presented in this assessment.

*Summary of Changes in Assessment Inputs*

Changes in the input data

1) Catch updated through October 2, 2010.
2) The biomass estimate from the 2010 AI survey was added to the model input data.
3) The 2008 fishery age composition and 2009 fishery length composition were added to the model input data.
4) The 1983 and 2010 survey length compositions were added to the model input data.

Changes in the assessment methodology

1) It is recommended that the input variance of recruitment residuals ($\sigma_r$) be lowered from 0.75 to 0.5 in order to limit the ability of the model to increase recruitment to fit the pattern in recent length composition data, which provide information on cohorts that have not been fully selected and does not appear to be consistent with age/length composition data in previous years.
2) The growth parameters were re-estimated.
3) The years in which recruitment for recent year classes is not estimated was increased from 0 to 3.

*Summary of Results*

As mentioned above, an age-structure population model was used to estimate the population size and harvest levels for the AI portion of the population. A summary of the 2010 assessment recommended ABC's for the AI portion of the population relative to the 2009 recommendations is shown below.

| | Last year | | This year | |
|---|---|---|---|---|
| **Quantity/Status** | 2010 | 2011 | 2011 | 2012 |
| *M* (natural mortality) | 0.032 | 0.032 | 0.034 | 0.034 |
| Specified/recommended Tier | 3b | 3b | 3b | 3b |
| Projected total biomass (ages 3+) | 19,415 | 19,530 | 18,813 | 19,160 |
| **Female spawning biomass (t)** Projected | 6,571 | 6,482 | 5,514 | 5,605 |
| $B_{100\%}$ | 16,808 | 16,808 | 17,239 | 17,239 |
| $B_{40\%}$ | 6,723 | 6,723 | 6,896 | 6,896 |
| $B_{35\%}$ | 5,883 | 5,883 | 6,034 | 6,034 |
| $F_{OFL}$ | 0.047 | 0.046 | 0.035 | 0.035 |
| $maxF_{ABC}$ | 0.039 | 0.038 | 0.029 | 0.029 |
| Specified/recommended $F_{ABC}$ | 0.039 | 0.038 | 0.029 | 0.029 |
| Specified/recommended OFL (t) | 613 | 594 | 395 | 407 |
| Specified/recommended ABC (t) | 505 | 489 | 327 | 337 |
| Is the stock being subjected to overfishing? | No | No | No | No |
| Is the stock currently overfished? | No | No | No | No |
| Is the stock approaching a condition of being overfished? | No | No | No | No |

The population size and harvest levels for the EBS portion of the population were obtained by applying Tier 5 methods to recent survey biomass estimates. A summary of the 2010 assessment recommended ABC's for the EBS portion of the population relative to the 2009 recommendations is shown below.

| | Last year | | This year | |
|---|---|---|---|---|
| **Quantity/Status** | 2010 | 2011 | 2011 | 2012 |
| *M* (natural mortality) | 0.03 | 0.03 | 0.03 | 0.03 |
| Specified/recommended Tier | 5 | 5 | 5 | 5 |
| Biomass | 1,775 | 1,775 | 1500 | 1500 |
| $F_{OFL}$ (F=M) | 0.03 | 0.03 | 0.03 | 0.03 |
| $maxF_{ABC}$ (maximum allowable = 0.75$x$ $F_{OFL}$) | 0.0225 | 0.0225 | 0.0225 | 0.0225 |
| Specified/recommended $F_{ABC}$ | 0.0225 | 0.0225 | 0.0225 | 0.0225 |
| Specified/recommended OFL (t) | 53 | 53 | 45 | 45 |
| Specified/recommended ABC (t) | 40 | 40 | 34 | 34 |
| Is the stock being subjected to overfishing? | No | No | No | No |
| (for Tier 5 stocks, data are not available to determine whether the stock is in an overfished condition) | | | | |

The overall BSAI ABC and OFL are shown below. Various options for subarea ABCs within the BSAI are considered in the assessment

| Quantity/Status | Last year | | This year | |
|---|---|---|---|---|
| | 2010 | 2011 | 2011 | 2012 |
| OFL (t) | 669 | 650 | 440 | 452 |
| ABC (t) | 547 | 531 | 361 | 371 |

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

| Year | Biomass[1] | OFL | ABC | TAC | Catch |
|---|---|---|---|---|---|
| 2009 | 20,753 | 660 | 539 | 539 | 209 |
| 2010 | 21,178 | 669 | 547 | 547 | 202[2] |
| 2011 | 20,313 | 440 | 361 | | |
| 2012 | 20,660 | 452 | 371 | | |

[1] Total biomass from AI age-structured projection model, and survey biomass estimates from EBS.
[2] BSAI catch as of October 2, 2010.

*Responses to the comments of the Scientific and Statistical Committee*

The SSC December 2008 minutes include the following request concerning the blackspotted and rougheye rockfish complex:

*The SSC encourages the author to consider the implications of adopting area-specific ABCs*

This comment was address in the 2009 BSAI blackspotted/rougheye assessment. Developments since that include the production of a "stock structure evaluation document" that was discussed at the September, 2010 Plan Team meeting, and is included in this assessment as an appendix, and which considers the implications of area-specific ABCs. Various options for area-specific ABCs are also considered in this assessment.

There were no comments or requests from the December 2009 SSC meetings pertaining to BSAI blackspotted/rougheye rockfish

## INTRODUCTION

Rougheye rockfish (*Sebastes aleutianus*) have historically been managed within various stock complexes within the Bering Sea/Aleutian Islands (BSAI) region. For example, from 1991 to 2000 rougheye rockfish in the eastern Bering Sea (EBS) area were managed under the "other red rockfish" species complex, which consisted of shortraker (*Sebastes borealis*), rougheye (*S. aleutianus*), sharpchin (*S. zacentrus*), and northern rockfish (*S. polyspinis*), whereas in the Aleutian Islands (AI) area during this time rougheye rockfish were managed within the rougheye/shortraker complex. In 2001, the other red rockfish complex in the eastern Bering Sea was split into two groups, rougheye/shortraker and sharpchin/northern, matching the complexes used in the Aleutian Islands. Additionally, separate TACs were established for the EBS and AI management areas, but the overfishing level (OFL) pertained to the entire BSAI area. By 2004, rougheye, shortraker, and northern rockfish were managed with species-specific OFLs applied to the BSAI management area.

Fish historically referred to as "rougheye" rockfish are now recognized as consisting of two separate species (Orr and Hawkins 2008), with rougheye rockfish retaining the name *Sebastes aleutianus* and resurrection of a new species, blackspotted rockfish (*S. melanostictus*). Both species are distributed widely throughout the north Pacific, and several studies (Hawkins et al. 2005; Gharrett et al. 2005; Orr and Hawkins 2008) have used genetic and morphometric analyses to document the scarcity of rougheye rockfish west of the eastern Aleutian Islands (AI) and the occurrence of blackspotted rockfish throughout the BSAI area, thus establishing differences in species composition between areas in the BSAI. This distribution pattern has also been observed in the 2006 and 2010 AI trawl survey, where rougheye rockfish rarely found in the central and western AI. Some differences in species composition based upon field identification may be due to errors in species identification, particularly in areas where both species are common, as blackspotted and rougheye rockfish are similar in appearance. This issue appears to be particularly problematic in the Gulf of Alaska (GOA), where a field test in the 2009 GOA trawl survey reported high misidentification rates. However, the distribution pattern in the AI survey biomass estimates is consistent with information obtained cited above from genetic and morphometric analyses, which do not rely on field identification. The title of this assessment was changed to "blackspotted and rougheye rockfish" in 2008 upon recognition of blackspotted rockfish and its high abundance in the BSAI relative to rougheye rockfish. Data for the two species are combined in the assessment, as species-specific specific catch records do not exist and identification by species has occurred in the AI trawl survey only since 2006.

The most recent full assessment of rougheye rockfish occurred in 2008, when rougheye were assessed an age-structured model for the first time. In developing the 2008 assessment, a variety of information was considered by the authors and BSAI Plan Team when determining both the spatial scale of both the assessment model and management units. In 2008, the authors proposed and the Plan Team accepted application of the age-structure model to only the AI portion of the population, with abundance being determined from averages of recent trawl surveys. The primary rationale for this recommendation was the distribution pattern mentioned above, genetic and age/size composition data suggesting structure within the BSAI area, and the small population size in the EBS area. The discussion in the 2008 Plan Team regarding BSAI blackspotted led, in part, to the formation of Plan Team/SSC workgroup to identify a consistent methodology to determine spatial management units. BSAI blackspotted/rougheye was one case study considered by the workgroup, and a "stock structure evaluation report" that considers several types of genetic and non-genetic data was produced and presented to the BSAI Plan Team at the September, 2010, meeting. The report is included in this assessment as an appendix. Discussion of the information in the report at the September, 2010, Plan Team meeting resulted in the conclusion that spatial structure exists within the BSAI for blackspotted and rougheye rockfish, and area-specific ABCs should be considered.

## FISHERY

*Historical Background*

Catches of rougheye rockfish have been reported in a variety of species groups in the foreign and domestic Alaskan fisheries. Foreign catch records did not identify rougheye rockfish by species, but reported catches in categories such as "other species" (1977, 1978), "POP complex" (1979-1985, 1989), and "rockfish without POP" (1986-1988). Rougheye rockfish have been managed in the domestic fishery as part of the “other red rockfish” or “shortraker/rougheye” complexes. Reported ABCs, TACs, and catches by management complex from 1988-2010 are shown in Table 1. Since 2004, the catch accounting system (CAS) has reported catch of rougheye by species and area. From 1991-2002, species catches were reconstructed by computing the harvest proportions within management groups from the North Pacific Foreign Observer Program database, and applying these proportions to the estimated total catch obtained from the NOAA Fisheries Alaska Regional Office “blend” database. An identical procedure was used to reconstruct the estimates of catch by species from the 1977-1989 foreign and joint venture fisheries. Estimated domestic catches in 1990 were obtained from Guttormsen et al. 1992. Catches from the domestic fishery prior to the domestic observer program were obtained from PACFIN records. Catches of rougheye since 1977 by area are shown in Table 2. Catches were relatively high during the late 1970s, declined during the late 1980s as the foreign fishery was reduced, increased in the early 1990s, and declined in the mid-1990s.

*Discards*

Estimates of discarding by species complex are shown in Table 3. Estimates of discarding of the other red rockfish complex in the EBS were generally above 56% from 1993 to 2000, which the exception of 1993 and 1995 when discard rates were less than 26%. The variation in discard rates may reflect different species composition of the other red rockfish catch. Discard rates of EBS RE/SR complex from 2001 to 2003 have been below 52%, and discard rates of AI SR/RE complex from 1993-2003 have been below 41%. In general, the discard rates of EBS RE/SR (2001-2003) are less than the discard rates of EBS other red rockfish (1993-200), likely reflecting the relatively higher value of rougheye and shortraker rockfishes over other members of the complex. From 2004 to 2010, discard rates of rougheye in the Aleutian Islands and EBS average 22% and 41%, respectively.

*Catch in Research Surveys*

The removals from trawl and hydroacoustic surveys are shown in Table 4.

*Recent Distribution of Catch across Areas and Target Fisheries*

Rougheye rockfish in the Aleutian Islands have been caught primarily in the rockfish trawl, Pacific cod longline, and Atka mackerel trawl fisheries in recent years. From 2004-2010, these three fisheries accounted for 87% of the AI rougheye catch. Catches of AI rougheye rockfish from 2004-2010 were primarily taken in the western and central Aleutians, with 44% and 31% in areas 543 and 542, respectively (Table 5). Approximately 77% of the catches of rougheye rockfish from 2004-2010 in the EBS management area were in the arrowtooth flounder trawl fishery, Pacific cod longline , halibut longline fishery, rockfish trawl fishery, turbot longline fishery, pollock midwater trawl fishery, and “other flatfish” trawl fisheries. Catches of rougheye in the EBS management area were concentrated in areas 517, 518, 519 and 521, the areas occupying much of the EBS slope (Table 5).

Given the information on stock structure presented in the appendix, and the history of previously managing the EBS rockfish as separate stock complexes, it is prudent to examine how current catches compare to potential area-specific harvest levels, and temporal nature of the fishery removals. A comparison of 2001-2010 rougheye catch by area with what might have been used as an area-specific ABC level is shown in Table 6, where the area-specific ABC is obtained by partitioning the BSAI ABC in accordance with the relative distribution of survey biomass estimates by area. Note that the management groups have varied over these years in these areas. For example, in 2001-2003, separate TACs existed for rougheye/shortraker complexes in the EBS and AI with a single BSAI OFL. In contrast, since 2004, rougheye and shortraker have been managed as separate species with the single-species BSAI ABCs and OFLs. Care should be taken not to interpret the results as evidence of overfishing, as this definition depends upon the definition of the stock or stock complex, and at no point has the catch of a stock or stock complex exceeded its OFL level. The intent of this comparison is to investigate how our historical estimates of catch compare with species biomass estimates, and if disproportionate catch levels (relative to the biomass levels) have occurred in the past. Catches of AI blackspotted/rougheye exceeded the potential AI ABC by a large amount in 2001 (585 t compared to 230 t) and smaller amounts in 2002, 2004, and 2008. Catches of EBS blackspotted/rougheye have been below their potential EBS ABC level in most years the exceptions of 2004 and 2009. The increase of the AI ABC in 2009 coincided with the initial use of the age-structured assessment model for the rougheye complex.

## DATA

### *Fishery data*

The catch data used in the assessment model are the estimates of single species catch described above and shown in Table 2.

Prior to 1999, the fishery data is characterized by inconsistent sampling of length (Table 7) and age (Table 8), as many fish were measured in some years whereas other years had no data. In 1979, 1990, 1992, and 1993 over 1000 fish were measured in the Aleutians Islands and the size compositions were used in the assessment model. In the domestic fishery, changes in observer sampling protocol since 1999 increased the number of fish and hauls from which rougheye rockfish age and length data were collected, increasing the utility for stock assessment modeling. The size compositions in 2003 and 2009, and the age compositions in 2004-2005 and 2007-2008 were used in the assessment model.

### *Survey data*

Biomass estimates for rougheye rockfish were produced from cooperative U.S.-Japan trawl survey from 1979-1985 on the eastern Bering Sea slope, and from 1980-1986 in the Aleutian Islands. U.S trawl surveys, conducted by the National Marine Fisheries Service (NMFS) were conducted in 1988 and 1991 on the eastern Bering Sea slope, and in 1991, 1994, 1997, 2000, 2002, 2004, 2006, and 2010 in the Aleutian Islands (Table 9). The Aleutian Islands survey scheduled for 2008 was canceled due to lack of funding. Differences exist between the 1980-1986 cooperative surveys and the 1991-2006 U.S. domestic surveys with regard to the vessels and gear design used. For example, the Japanese nets used in the 1980, 1983, and 1986 cooperative surveys of the Aleutian Islands varied between years and included large roller gear, in contrast to the poly-nor'eastern nets used since 1991 (Ronholt et al 1994, Stauffer 2004), and similar variations in gear between surveys occurred in the cooperative EBS surveys.

In the 1991 -2006 AI surveys, blackspotted and rougheye rockfish were found throughout the Aleutian Islands with the high densities in the central Aleutians from the southern portion of Petral Bank to Tahoma Bank, and near Atka Island. Several particularly high CPUE tows were located to the northwest of Amcitka Island, inside the western border of the central Aleutian Islands. In the 2010 survey, higher densities were also observed in these areas (Figure 1). The 2010 survey biomass estimate for rougheye and blackspotted rockfish from the portion of the AI survey in the AI management area was 8,541 t, which represents an increase of 3% from the 2006 estimate of 8,281 t. The bulk of the biomass in the AI survey comes from the central and eastern Aleutian Islands, contributing 43% and 40% of the average biomass from the 1991-2010 surveys.

The biennial EBS slope survey was initiated in 2002. The most recent slope survey prior to 2002 (excluding some experimental tows in 2000 to evaluate survey gear) was in 1991. The 2008 EBS slope survey was completed, but the 2006 survey was canceled due to lack of funding. The survey biomass estimates of blackspotted and rougheye rockfish from the 2002-2010 EBS slope surveys have ranged between 553 t (2002) and 999 t (2010), with CVs between 0.16 and 0.25. Given these low levels of biomass, the slope survey results are not used in this assessment, and the feasibility of incorporating this time series in the age-structured model will be evaluated as new data becomes available.

Identification to species within the blackspotted/rougheye complex was initiated in the 2006 AI survey and the 2008 EBS slope survey. These data show the complex is composed nearly entirely of blackspotted rockfish in the AI management area (97% and 95% by weight in the 2006 and 2010 surveys, respectively), with the proportion of rougheye rockfish increasing in the southern Bering Sea (SBS) and EBS slope. Field identification of these species can be difficult in areas where both species are abundant, such as the Gulf of Alaska, but blackspotted rockfish in the Aleutian Islands have been observed to have more clearly identifiable characteristics than blackspotted rockfish in other areas (Jay Orr, AFSC, pers. comm.)

*Biological Data*

The AI survey provides data on age and length composition of the population, growth rates, and length-weight relationships. The number of lengths measured and otoliths sampled are shown in Tables 10 and 11, along with the number of hauls producing these data. The survey data produce reasonable sample sizes of lengths and otoliths throughout the survey area. The maximum age observed in the survey samples was 121 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 multiple independent readings on GOA otoliths collected in 1990, 1999, and 2003 (Shotwell et al. 2007). These data were used to estimate the error in age reading based on the percent agreement between the readers. A fitted relationship describing the standard deviation in age read by age was used to produce the aging error matrix.

The AI survey otolith data was used to estimate size at age and von Bertalannfy growth parameters. Unbiased estimates of mean length at age were generated from multiplying the survey length composition by the 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. Preliminary analyses did not reveal any patterns by year or subarea within the AI survey areas, so the mean length at age from each survey year from 1986 to 2006 was used to fit the growth curve. The estimated von Bertalannfy parameters are as follows, and were used to create a conversion matrix and a weight-at-age vector:

| $L_{inf}$ | K | $t_0$ |
|---|---|---|
| 51.99 | 0.05 | -5.15 |

A conversion matrix was created to convert modeled number at ages to modeled number at length bin, and consists of the proportion of each age that is expected in each length bin. This matrix was created by regressing the observed standard deviation in length at each age (obtained from the aged fish from the 1980-2006 surveys) against age, and the predicted relationship was used to produce some variation around the predicted size at age from the von Bertalanffy relationship. The resulting CVs of length at age of the conversion matrix decrease from 0.16 at age 3 to 0.08 at age 45.

A length-weight relationship of the form $W = aL^b$ was fit from the survey data, and produced estimates of $a = 6.32 \times 10^{-6}$ and $b = 3.25$. 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).

The following table summarizes the data available for the both the AI and combined BSAI rougheye rockfish assessment models:

| Component | BSAI |
|---|---|
| Fishery catch | 1977-2010 |
| Fishery age composition | 2004-2005, 2007-2008 |
| Fishery size composition | 1979, 1990, 1992, 1993, 2003, 2009 |
| Survey age composition | 1986, 1991, 1994, 1997, 2000, 2002, 2004, 2006 |
| Survey size composition | 2010 |
| Survey biomass estimates | 1980, 1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004 2006, 2010 |

## ANALYTIC APPROACH

*Model structure*

The assessment model for rougheye rockfish is very similar to that currently used for other BSAI rockfish, 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 45), and $T$ is the terminal year of the analysis (defined as 2010). The numbers at age $A$ are a "pooled" group consisting of fish of age $A$ and older, and are estimated as

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

The numbers at age in the first year are estimated as

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

where $R_0$ is the mean number of age 3 recruits prior to the start year if the model, and $\gamma_a$ is an age-dependant deviation assumed to be normally distributed with mean of zero and a standard deviation equal to $\sigma_r$, the recruitment standard deviation. Estimation of the vector of age-dependant deviations from average recruitment allows estimation of year class strength.

The total numbers of age 3 fish from 1977 to 2007 are estimated as parameters in the model, and are modeled with a lognormal distribution

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

where $\nu_t$ is a time-variant deviation. Little information exists to estimate the recruitment in the most recent years due to the relatively late age of recruitment to both the fishery and survey, and recruitment for 2008-2010 was specified as the median recruitment.

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 ($\mu_f$) and a year-specific deviation ($\varepsilon_t$), 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% selectivity and the slope of the curve at this point, respectively. Survey selectivity and maturity are also modeled with the logistic function.

The mean number 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 conversion matrix, which gives the proportion of each age (rows) in each length group (columns). The age bins range from 3 to 45 and the length bins range from 12 to 50, with the terminal bin being a plus group that includes all older (or larger) fish. 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 0.03 and with the coefficient of variation (CV) set to 0.05. The value used for $M$ in previous assessments was 0.025, and the increase to 0.03 was based on an estimate from McDermott (1994) using the gonadosomatic index and is consistent with estimates of $M$ from several methods (Shotwell et al. 2007). The prior distribution for *qsurv* followed a lognormal distribution with a mean of 1.0 and a CV of 0.05, essentially fixing *qsurv* at 1.0. In previous assessments, attempts to obtain reasonable estimates of survey catchability have not been successful.

In previous assessments, the standard deviation of log recruits, $\sigma_r$, was fixed at 0.75 after conducting several runs comparing the consistency between $\sigma_r$ and the root mean square error (RMSE; defined below) of the recruitment residuals. In this assessment, it was observed that the level of $\sigma_r$ affects the ability to fit the new 2010 survey and 2009 fishery length composition data, and in turn affects the estimation of the biomass reference point $B_{40\%}$ which is calculated from average recruitment. Thus, two models are presented: **model 1** specifies $\sigma_r$ at 0.75, and **model 2** lowers $\sigma_r$ to 0.50.

Several quantities were computed in order to compare the variance of the residuals to the assumed input variances. The root mean squared error (RMSE) 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) is closely related to the RMSE; values of SDNR approximately at 1 indicate that the model is fitting a data component as well as would be expected for a given specified input variance. The normalized residuals for a given year $i$ of the AI trawl survey data were computed as

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

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

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

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 conversion matrix, individual weight at age, and proportion mature females at age. The derivation of the age error matrix, the age-length conversion matrix, and the weight at age vector are described above. The proportion of females mature at age (Table 12) was obtained from data on Gulf of Alaska rougheye rockfish in McDermott (1994).

*Parameters Estimated Conditionally*

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

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

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

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

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

The negative log-likelihoods of the fishery and survey age and length compositions were modeled with a multinomial distribution. The 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 negative log-likelihood for the age and length proportions in the survey, $p_{surv,t,a}$ and $p_{surv,t,l}$, respectively, follow similar equations.

The negative log-likelihood of the survey biomass was modeled with a lognormal distribution:

$$\lambda_2\sum_t(\ln(obs\_biom_t)-\ln(pred\_biom_t))^2/2cv_t^{\;2}$$

where $obs\_biom_t$ is the observed survey biomass at time *t*, $cv_t$ is the coefficient of variation of the survey biomass in year *t*, and $\lambda_2$ is a weighting factor. The negative log-likelihood of the catch biomass was modeled with a lognormal distribution:

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

where $obs\_cat_t$ and $pred\_cat_t$ are the observed and predicted catch. Because the catch biomass is generally thought to be observed with higher precision than other variables, $\lambda_3$ is given a very high weight so as to fit the catch biomass nearly exactly. This can be accomplished by varying the *F* levels, and the deviations in *F* are not included in the overall likelihood function. The overall negative log-likelihood function (excluding the catch component) is

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

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

$$\lambda_2\sum_t\left(\ln(obs\_biom_t)-\ln(pred\_biom_t)\right)^2/2cv_t^2+$$

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

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

$$-n_{surv,t,a}\sum_{s,t,a}(p_{surv,t,a}\ln(\hat{p}_{surv,t,a})+p_{surv,t,a}\ln(p_{surv,t,a}))+$$

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

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

For the model runs in this assessment, $\lambda_1$, $\lambda_2$, and $\lambda_3$ were assigned weights of 1,1, and 50, 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, the fishery length and age compositions were assigned one-half the weight of the survey age composition as it was generally perceived as a less reliable source of information. In the results below, comparisons of effective sample size to input sample size were made after scaling the input sample sizes by their weights (Table 13).

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

| *Parameter type* | *Number* |
|---|---|
| 1) fishing mortality mean | 1 |
| 2) fishing mortality deviations | 34 |
| 3) recruitment mean | 1 |
| 4) recruitment deviations | 31 |
| 5) historic recruitment | 1 |
| 6) first year recruitment deviations | 42 |
| 7) biomass survey catchability | 1 |
| 8) natural mortality rate | 1 |
| 9) survey selectivity parameters | 2 |
| 10) fishery selectivity parameters | 2 |
| Total parameters | 116 |

## RESULTS

*Model Evaluation*

The negative log-likelihood associated with the various data components of the two models (unscaled by the various λ terms or weights) are shown in Table 13. The negative value of the recruitment component of the negative log-likelihood in model 2 comes from the *n* ln($\sigma_r$) and (A-3) ln($\sigma_r$) terms. With $\sigma_r < 1$, these terms are negative, and the change in $\sigma_r$ to 0.5 results in a negative value of negative log-likelihood for recruitment. When these terms are removed, the recruitment component of the negative log-likelihood is lower in model 1, as are most other model components; this would be expected as model 1 allows more freedom for recruitment. Both models result in a RMSE of the recruitment residuals that is comparable to the level of $\sigma_r$, and both appear to be biologically plausible.

A large difference between the models is reflected in the ability to fit the recent 2010 survey and 2009 fishery length composition data, both of which indicate a population with relatively more smaller individuals than would be expected from age/length compositions in other years. However, the 2010 survey biomass estimate is similar to biomass estimates in recent surveys and the model increases recruitment to attempt to fit a similar biomass level that is composed of smaller individuals. For example, the mean recruitments in model 1and model 2 are 1.59 million and 1.25 million, respectively, a difference of 22%. The estimate of the biomass-based reference point $B_{40\%}$ also decreases by a similar amount between the models, but the estimate of spawning stock biomass is relatively unchanged due, in part, by the tight prior in survey catchability and the low proportion of recent year classes which are mature. The result is that the size of the current spawning biomass relative to $B_{40\%}$ is 62% in model 1 but 79% in model 2. The following table highlights some of the differences in these quantities between the models.

| | 2010 SSB (t) | $B_{40\%}$ (t) | Mean Recruitment (millions) | 2010 SSB/ $B_{40\%}$ |
|---|---|---|---|---|
| Model 1 | 5662 | 9198 | 1.59 | 0.62 |
| Model 2 | 5423 | 6896 | 1.25 | 0.79 |
| % difference | -4.21% | -25.03% | -21.54% | 27.77% |
| | | | | |

The differences above are due largely to the recent 2010 survey and 2009 fishery length composition data. When these data are not used, the two models show less difference in average recruitment and stock status relative to $B_{40\%}$:

| | 2010 SSB (t) | $B_{40\%}$ (t) | Mean Recruitment (millions) | 2010 SSB/ $B_{40\%}$ |
|---|---|---|---|---|
| Model 1 w/o recent length comp data | 5657 | 6409 | 1.08 | 0.8827 |
| Model 2 w/o recent length comp data | 5653 | 5731 | 1.01 | 0.9864 |
| % difference | -0.07% | -10.58% | -7.19% | 11.76% |

Given that the 2010 survey and 2009 fishery length composition data have a large influence on the model results, are somewhat inconsistent with the age/length composition data in other years, and provide information on cohorts incompletely recruited to either the fishery or survey, it seems reasonable to interpret these data as somewhat uncertain. Model 2, with the recent length composition data, is chosen as the recommended model for this assessment because while it still uses the recent length composition data, the lower level of $\sigma_r$ limits the ability of the model to attempt to fit these data while still providing an input level of recruitment variability that is consistent with the RMSE. The results below refer to output from model 2. The choice of $\sigma_r$ can be revisited in future assessments as more data becomes available on the relative strength of the cohorts in these data.

*Biomass trends*

The estimated survey biomass decreases from 12,180 t in 1977 to 8,694 t in 1980 due to large catches in the late 1970s, increased to 12,299 t in 1989, declined throughout the 1990s and has gradually increased to 11,441 t in 2010 (Figure 2). The total and spawning biomass also show a decline in the late 1970s, increases throughout the 1980s, and a decline in most of the 1990s. Since 1999, the spawning biomass has increased from 4,919 to 5,423 in 2010, and the total biomass has increased from 13,995 t to 18,365 t over this period (Figures 3). The time series of estimated total biomass, spawner biomass, and recruitment are shown in Table 14.

*Age/size compositions*

The model fits to the fishery age and size compositions are shown in Figures 4 and 5 and the model fit to the survey age and length compositions are shown in Figures 6 and 7. The model does not capture some of the pattern in the fishery age and length composition data (i.e. length compositions in 1990 and 1992, age composition in 2008), reflecting the relatively low number of hauls sampled for otoliths and the down-weighting of the fisheries data relative to the survey data. The model does not fit the peaks in the 2009 fishery length composition data and the 2010 survey length composition data, which are approximately 30-35 cm and 20-30 cm respectively. This size range corresponds to fish between 12 and 16 years for the 2009 fishery length composition (the 1997 to 1993 cohorts), and between 5 and 12 years for the survey data (the 2005 to 1998 cohorts). In general, most cohorts since 2000 are too recent to be observed prominently in the age/length compositions in previous years. The 1993-1997 cohorts are either weak and/or inconsistently observed in previous years, and do not appear as strong as implied from the recent length composition data. For example, the 1993-1997 cohorts are not strongly revealed in any of the survey age compositions. In the fisheries age data, the 1993 cohort appears strong in the 2005 and 2008 fishery age compositions, but are absent from the 2007 fishery age composition. Similarly, the 1996 cohort appears strong in the 2008 fishery age composition, but does not appear in any other survey or fishery age composition. Given the inconsistent picture of relative cohort strength that appears to vary between years of observed data, the model smooths across the peaks in the age/length compositions for most years. One exception to this general pattern is the 1998 year-class, which appears strong in the 2004 and 2006 survey data and leads to the high estimate of recruitment for this cohort (see below).

*Natural mortality and survey catchability*

The CVs of 5% for the priors on survey catchability and natural mortality constrained these parameters to values of 1.062 and 0.0335, respectively, a slight increase from the prior distribution means of 1.0 and 0.03, respectively.

*Fishery and survey selectivity*

Similar asymptotic selection curves were obtained for the AI survey and fishery, with an age at 50% selection for the fishery and AI survey of 19.2 years and 20.2 years, respectively (Figure 8).

*Fishing mortality*

The estimates of instantaneous fishing mortality rate are shown in Figure 9. Very high rates of fishing mortality are required in 1978 and 1979 to account for the high catches during these years, followed by rapid decreases in the early 1980s. Fishing mortality rates began to increase during the late 1980s, and were relatively high for several years between the late 1980s and mid 1990s. Fishing mortality rates began to decline in late 1990s, and have been below the $F_{35\%}$ reference rate since 2000 (with the exception if 2001). The catches of rougheye rockfish in the 1990s must be viewed in the context of the existing management for the rougheye/shortraker species complex. A plot of fishing mortality rates and spawning stock biomass in reference to the ABC and OFL harvest control rules indicates that the current rate of fishing stock is currently below $F_{35\%}$ and the spawning stock biomass is below $B_{40\%}$ (Figure 10).

*Recruitment*

Recruitment strengths by year class are shown in Figure 11. There is little information to discern strong recruitments in the early years of the model, although relatively strong year classes were estimated for 1976 and 1981 and were observed in several years of survey sampling. A strong year class was estimated for 1998 and is observed in the 2004 and 2006 survey age compositions, but as mentioned above do not appear strong in the 2009 fishery or 2010 survey length compositions. The plot of recruitment against spawning stock biomass is shown in Figure 12.

*Population Projections*

The reference fishing mortality rate for rougheye rockfish is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{0.40}$, $F_{0.35}$, and $SPR_{0.40}$ were obtained from a spawner-per-recruit analysis. Assuming that the average recruitment from the 1977-2007 year classes estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{0.40}$ is calculated as the product of $SPR_{0.40}$ * equilibrium recruits, and this quantity is 6,896 t. The year 2011 spawning stock biomass is estimated as 5,414 t. Since reliable estimates of the 2010 spawning biomass ($B$), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B<B_{0.40}$ (5,414 t < 6,896 t ), rougheye rockfish reference fishing mortality is defined in tier 3b. For this tier, $F_{ABC}$ is constrained to be < $F_{0.40}$, and $F_{OFL}$ is constrained to be < $F_{0.35}$. The values of $F_{0.40}$ and $F_{0.35}$ are 0.037 and 0.045, respectively, whereas the values $F_{abc}$ and $F_{ofl}$ are 0.029 and 0.035. The 2011 ABC and OFL resulting from these rates are 327 t and 395 t, respectively. A summary of these values is below.

| | | |
|---|---|---|
| 2010 SSB estimate (B) | = | 5,414 t |
| $B_{0.40}$ | = | 6,896 t |
| $F_{0.40}$ | = | 0.037 |
| $F_{ABC}$ | = | 0.029 |
| $F_{0.35}$ | = | 0.045 |
| $F_{OFL}$ | = | 0.035 |

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

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

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

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

*Scenario 2*: In all future years, $F$ is set equal to a constant fraction of *max* $F_{ABC}$, where this fraction is equal to the ratio of the $F_{ABC}$ value for 2011 recommended in the assessment to the *max* $F_{ABC}$ for 2011. (Rationale: When $F_{ABC}$ is set at a value below *max* $F_{ABC}$, it is often set at the value recommended in the stock assessment.)

*Scenario 3*: In all future years, $F$ is set equal to 50% of max $F_{ABC}$. (Rationale: This scenario provides a likely lower bound on $F_{ABC}$ that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

*Scenario 4*: In all future years, $F$ is set equal to the 2005-2009 average $F$. (Rationale: For some stocks, TAC can be well below ABC, and recent average $F$ may provide a better indicator of $F_{TAC}$ than $F_{ABC}$.)

*Scenario 5*: In all future years, $F$ is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

*Scenario 6*: In all future years, $F$ is set equal to $F_{OFL}$. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above 1) above its MSY level in 2010 or 2) above ½ of its MSY level in 2010 and above its MSY level in 2020 under this scenario, then the stock is not overfished.)

*Scenario 7*: In 2011 and 2012, $F$ is set equal to *max* $F_{ABC}$, and in all subsequent years $F$ is set equal to $F_{OFL}$. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2023 under this scenario, then the stock is not approaching an overfished condition.)

The recommended $F_{ABC}$ and the maximum $F_{ABC}$ are equivalent in this assessment, and projections of the mean harvest and spawning stock biomass for the remaining six scenarios are shown in Table 15.

*Status Determination*

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2011, it does not provide the best estimate of OFL for 2012, because the mean 2011 catch under Scenario 6 is predicated on the 2011 catch being equal to the 2011 OFL, whereas the actual 2010 catch will likely be less than the 2010 OFL. The executive summary contains the appropriate one- and two-year ahead projections for both ABC and OFL.

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

*Is the stock being subjected to overfishing?* The official BSAI catch estimate for the most recent complete year (2009) is 209 t. This is less than the 2009 BSAI OFL of 509 t. Therefore, the stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. In this assessment, determination of whether the stock is overfished is complicated in that the age-structured model is applied only to the AI portion of the population; thus an estimate of MSST is only available for this portion of the population. Because current management regulations use a single OFL for the BSAI area, a meaningful measure of MSST and overfished status would need to reflect the entire BSAI population. However, the AI portion of the population composes the majority of the BSAI blackspotted/rougheye rockfish, and evaluation of its population size relative the MSST computed for the AI provides a useful index of stock condition. Harvest Scenarios #6 and #7 are used in these determinations for the AI portion of the population as follows:

*Is the AI portion of the population currently below its MSST?* This depends on the estimated spawning biomass in 2010:
a. If spawning biomass for 2010 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b. If spawning biomass for 2010 is estimated to be above $B_{35\%}$ the stock is above its MSST.
c. If spawning biomass for 2010 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 15). If the mean spawning biomass for 2020 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

*Is the AI portion of the population projected to go below its MSST?* This is determined by referring to harvest Scenario #7:
a. If the mean spawning biomass for 2013 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.
b. If the mean spawning biomass for 2013 is above $B_{35\%}$, the stock is not approaching an overfished condition.
c. If the mean spawning biomass for 2013 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2023. If the mean spawning biomass for 2023 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

The results of these two scenarios indicate that the AI portion of the blackspotted/rougheye rockfish stock is neither below its MSST or projected to go below its MSST. With regard whether this portion of the stock is currently below its MSST, the expected stock size in the year 2010 of Scenario 6 is 0.90 times its $B_{35\%}$ value of 6,034 t, and the expected stock size in 2020 is 1.11 times the $B_{35\%}$ value. With regard to whether AI portion of the blackspotted/rougheye is to go below its MSST, the expected stock size in 2013 of Scenario 7 is 0.95 times the $B_{35\%}$ value, and the expected stock size in 2023 is 1.15 times the $B_{35\%}$ value.

*Area Allocation of Harvests*

The age-structured model pertains to the AI management area, and harvest recommendations for the EBS management area can be obtained from applying Tier 5 methods to the survey data in the EBS management area. The available survey biomass estimates for EBS blackspotted and rougheye rockfish includes the southern Bering Sea portion of the AI survey, and the 2004, 2008 and 2010 EBS slope survey estimates. For each survey, weights of 4-6-9 are used to compute a weight average of survey biomass by area from the three most recent surveys, with higher weights given to more recent years. A weighted average of the three most recent biomass estimates of the southern Bering Sea (2004,2006,2010) is 629 t, and was added to a weighted average of the three most recent EBS slope survey estimates (2004,2008,2010) of 871 t, yielding an EBS biomass estimate of 1,500 t. An estimate of $M$ of 0.03 was used to obtain $F_{abc}$ and $F_{ofl}$ of values of 0.0225 and 0.03, respectively, resulting in an ABC and OFL of 34 t and 45 t, respectively. Summing the EBS ABC and OFL values with those obtained from the age-structured model for the AI portion of the population results in an overall BSAI ABC and OFL of 361 t and 440 t, respectively.

In the September, 2010, Plan Team meeting, it was noted that the available information on stock structure (presented in the appendix) indicated subarea structure within the BSAI, and area-specific ABCs should be considered. In addition, recent catch data indicates that the harvest of blackspotted/rougheye rockfish in the western AI is disproportionate to the biomass level in this area, thus motivating consideration of sub-area ABCs within the AI. The weighted biomass estimates within the AI, their relative proportions, and proportional ABC levels are below:

| | Area | | |
|---|---|---|---|
| | WAI | CAI | EAI |
| Weighted average biomass (2004,2006,2010) | 1,172 | 4,220 | 4,275 |
| Proportion of AI biomass | 12.1% | 43.7% | 44.2% |
| Area ABC | 40 | 143 | 144 |
| | | | |

In the table above, the biomass estimates for the AI subarea ABCs were obtained by allocating the ABC from the age-structured AI model (327 t) in proportion to weighted area biomass estimates. The table above indicates that 12% of the AI biomass is in the western AI; however, recent harvest data (shown below) indicates that 44% of the harvest in the Aleutian Islands is obtained from the western Aleutian Islands.

**Harvest (t) of blackspotted/rougheye by AI subarea**

| | Area | | |
|---|---|---|---|
| Year | WAI | CAI | EAI |
| 2004 | 115 | 58 | 12 |
| 2005 | 43 | 24 | 11 |
| 2006 | 109 | 45 | 42 |
| 2007 | 44 | 42 | 71 |
| 2008 | 61 | 74 | 50 |
| 2009 | 74 | 84 | 39 |
| 2010 | 78 | 41 | 66 |
| Average | 75 | 53 | 42 |
| Proportion | 44% | 31% | 25% |

In addition, the recent average harvest of 75 t in the western AI exceeds the current estimate of proportional ABC for this area of 40 t.

The primary reason for adopting area-specific ABC levels is to reduce the likelihood of disproportionate harvest that appears to be occurring within the western Aleutian Islands. The primary source of rougheye harvest is bycatch in the Pacific ocean perch (POP) fishery, which have a higher relative abundance in the western AI than blackspotted/rougheye rockfish. Given the estimated increase in POP biomass observed in the 2010 trawl survey and 2010 stock assessment, it is likely the future harvest of blackspotted/rougheye would become even more disproportionate unless management actions were undertaken to spatially allocate harvest. Because the available genetic information on stock structure for blackspotted rockfish indicates an isolation by distance pattern rather than a specific point where genetic separation occurs, there is some flexibility in defining the management boundaries – the key point is to attempt to create spatial management units that are consistent with the scale of the lifetime population movement (currently estimated to be no larger than ~ 500 km). The ABCs for a number of potential spatial management units can be examined by combining the area ABCs above. Two options are shown below:

**Option 1:**

| | |
|---|---|
| Western and Central AI ABC: | 183 t |
| Eastern AI and EBS ABC: | 177 t |

This option divides the ABC nearly equally across areas within the BSAI. However, given the pattern of harvest in the western and central AI, it is likely that disproportionate harvesting would still occur in the western AI.

**Option 2:**

| | |
|---|---|
| Western AI ABC: | 40 t |
| Central AI ABC | 143 t |
| Eastern AI and EBS ABC: | 177 t |

This option separates the western and central AI ABCs, and would presumably motivate changes in fishing practices to reduce the harvest of blackspotted/rougheye harvest in the western AI. The western and central AI subareas are considerably smaller that the management areas currently used, but are consistent with the available information on the spatial scale of lifetime population movement.

## DATA GAPS AND RESEARCH PRIORITIES

Little information is known regarding most aspects of the biology of blackspotted and rougheye rockfish, particularly in the Aleutian Islands. Distinguishing blackspotted rockfish from rougheye rockfish in the field is a pressing issue, particularly along the EBS slope where both species are found. Further studies to examine the distribution and movement of early life-history stages are needed. Given the results of recent genetic work, further information on the population structure associated with distinctive oceanographic features such as Aleutian Island passes is needed. Finally, given the relatively unusual reproductive biology of rockfish and its importance in establishing management reference points, data on reproductive capacity should be collected on a periodic basis.

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Table 1. Total allowable catch (TAC), acceptable biological catch (ABC), and catch of the species groups used to manage blackspotted and rougheye rockfish from 1988 to 2010. The "other red rockfish" group includes, shortraker rockfish, rougheye rockfish, northern rockfish, and sharpchin rockfish. The "POP complex" includes the other red rockfish species plus POP.

| Year | Area | Management Group | ABC (t) | TAC (t) | Catch (t) |
|---|---|---|---|---|---|
| 1988 | BS | POP Complex | 6,000 | | 1,509 |
| | AI | POP Complex | 16,600 | | 2,629 |
| 1989 | BS | POP Complex | 6,000 | | 2,873 |
| | AI | POP Complex | 16,600 | | 3,780 |
| 1990 | BS | POP Complex | 6,300 | | 7,231 |
| | AI | POP Complex | 16,600 | | 15,224 |
| 1991 | BS | Other Red Rockfish | 1,670 | 1,670 | 942 |
| | AI | Rougheye/Shortraker | 1,245 | 1,245 | 388 |
| 1992 | BS | Other Red Rockfish | 1,400 | 1,400 | 467 |
| | AI | Rougheye/Shortraker | 1,220 | 1,220 | 1,470 |
| 1993 | BS | Other Red Rockfish | 1,400 | 1,200 | 1,226 |
| | AI | Rougheye/Shortraker | 1,220 | 1,100 | 1,139 |
| 1994 | BS | Other Red Rockfish | 1,400 | 1,400 | 129 |
| | AI | Rougheye/Shortraker | 1,220 | 1,220 | 925 |
| 1995 | BS | Other Red Rockfish | 1,400 | 1,260 | 344 |
| | AI | Rougheye/Shortraker | 1,220 | 1,098 | 559 |
| 1996 | BS | Other Red Rockfish | 1,400 | 1,260 | 207 |
| | AI | Rougheye/Shortraker | 1,250 | 1,125 | 959 |
| 1997 | BS | Other Red Rockfish | 1,050 | 1,050 | 218 |
| | AI | Rougheye/Shortraker | 938 | 938 | 1,043 |
| 1998 | BS | Other Red Rockfish | 267 | 267 | 112 |
| | AI | Rougheye/Shortraker | 965 | 965 | 685 |
| 1999 | BS | Other Red Rockfish | 356 | 267 | 238 |
| | AI | Rougheye/Shortraker | 1,290 | 965 | 514 |
| 2000 | BS | Other Red Rockfish | 259 | 194 | 253 |
| | AI | Rougheye/Shortraker | 1,180 | 885 | 480 |
| 2001 | BSAI | Rougheye/Shortraker | 1,028 | | |
| | BS | Rougheye/Shortraker | | 116 | 72 |
| | AI | Rougheye/Shortraker | | 912 | 722 |
| 2002 | BSAI | Rougheye/Shortraker | 1,028 | | |
| | BS | Rougheye/Shortraker | | 116 | 105 |
| | AI | Rougheye/Shortraker | | 912 | 478 |
| 2003 | BSAI | Rougheye/Shortraker | 967 | | |
| | BS | Rougheye/Shortraker | | 137 | 124 |
| | AI | Rougheye/Shortraker | | 830 | 306 |
| 2004 | BSAI | Rougheye | 195 | 195 | 208 |
| 2005 | BSAI | Rougheye | 223 | 223 | 90 |
| 2006 | BSAI | Rougheye | 224 | 224 | 203 |
| 2007 | BSAI | Rougheye | 202 | 202 | 167 |
| 2008 | BSAI | Rougheye | 202 | 202 | 213 |
| 2009 | BSAI | Rougheye | 539 | 539 | 209 |
| 2010* | BSAI | Rougheye | 547 | 547 | 202 |

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

Table 2. Catch of blackspotted and rougheye rockfish (t) in the BSAI area.

| | Eastern Bering Sea | | | | Aleutian Islands | | | | BSAI |
|---|---|---|---|---|---|---|---|---|---|
| Year | Foreign | JV | Domestic | Total | Foreign | JV | Domestic | Total | Total |
| 1977 | 2 | 0 | | 2 | 155 | 0 | | 155 | 157 |
| 1978 | 99 | 0 | | 99 | 2423 | 0 | | 2423 | 2522 |
| 1979 | 477 | 0 | | 477 | 3077 | 0 | | 3077 | 3553 |
| 1980 | 160 | 0 | | 160 | 660 | 0 | | 660 | 820 |
| 1981 | 283 | 0 | | 283 | 595 | 0 | | 595 | 878 |
| 1982 | 124 | 0 | | 124 | 189 | 0 | | 189 | 312 |
| 1983 | 53 | 0 | | 53 | 56 | 2 | | 57 | 111 |
| 1984 | 79 | 0 | | 79 | 31 | 4 | | 35 | 114 |
| 1985 | 18 | 0 | | 18 | 1 | 9 | | 9 | 27 |
| 1986 | 3 | 1 | 48 | 52 | 0 | 2 | 19 | 22 | 74 |
| 1987 | 1 | 2 | 96 | 100 | 0 | 3 | 76 | 79 | 179 |
| 1988 | 0 | 1 | 110 | 110 | 0 | 5 | 70 | 75 | 185 |
| 1989 | 0 | 2 | 202 | 203 | 0 | 0 | 381 | 381 | 585 |
| 1990 | | | 369 | 369 | | | 1,619 | 1,619 | 1,988 |
| 1991 | | | 106 | 106 | | | 137 | 137 | 243 |
| 1992 | | | 77 | 77 | | | 1,181 | 1,181 | 1,258 |
| 1993 | | | 146 | 146 | | | 924 | 924 | 1,070 |
| 1994 | | | 22 | 22 | | | 747 | 747 | 769 |
| 1995 | | | 28 | 28 | | | 393 | 393 | 421 |
| 1996 | | | 34 | 34 | | | 821 | 821 | 855 |
| 1997 | | | 15 | 15 | | | 958 | 958 | 973 |
| 1998 | | | 16 | 16 | | | 528 | 528 | 543 |
| 1999 | | | 9 | 9 | | | 383 | 383 | 392 |
| 2000 | | | 26 | 26 | | | 267 | 267 | 294 |
| 2001 | | | 15 | 15 | | | 585 | 585 | 600 |
| 2002 | | | 11 | 11 | | | 249 | 249 | 260 |
| 2003 | | | 17 | 17 | | | 175 | 175 | 192 |
| 2004 | | | 24 | 24 | | | 185 | 185 | 209 |
| 2005 | | | 12 | 12 | | | 78 | 78 | 90 |
| 2006 | | | 7 | 7 | | | 196 | 196 | 203 |
| 2007 | | | 10 | 10 | | | 157 | 157 | 167 |
| 2008 | | | 29 | 29 | | | 185 | 185 | 213 |
| 2009 | | | 12 | 12 | | | 197 | 197 | 209 |
| 2010* | | | 17 | 17 | | | 185 | 185 | 202 |

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

Table 3. Estimated retained, discarded, and percent discarded of other red rockfish (ORR), shortraker/rougheye (SR/RE), and rougheye (RE) from the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions.

| Species | | Catch (t) | | | | Percent |
|---|---|---|---|---|---|---|
| Area | Group | Year | Retained | Discard | Total | Discarded |
| EBS | ORR | 1993 | 916 | 308 | 1226 | 25.2% |
| | | 1994 | 29 | 100 | 129 | 77.6% |
| | | 1995 | 273 | 70 | 343 | 20.4% |
| | | 1996 | 58 | 149 | 207 | 71.9% |
| | | 1997 | 43 | 174 | 217 | 80.0% |
| | | 1998 | 42 | 70 | 112 | 62.4% |
| | | 1999 | 75 | 162 | 238 | 68.4% |
| | | 2000 | 111 | 141 | 252 | 55.9% |
| EBS | RE/SR | 2001 | 27 | 16 | 43 | 37.8% |
| | | 2002 | 50 | 54 | 104 | 52.0% |
| | | 2003 | 66 | 58 | 124 | 46.8% |
| AI | RE/SR | 1993 | 737 | 403 | 1,139 | 35.3% |
| | | 1994 | 701 | 224 | 925 | 24.2% |
| | | 1995 | 456 | 103 | 558 | 18.4% |
| | | 1996 | 751 | 208 | 959 | 21.7% |
| | | 1997 | 733 | 310 | 1,043 | 29.7% |
| | | 1998 | 447 | 238 | 685 | 34.8% |
| | | 1999 | 319 | 195 | 514 | 38.0% |
| | | 2000 | 285 | 196 | 480 | 40.8% |
| | | 2001 | 476 | 246 | 722 | 34.1% |
| | | 2002 | 333 | 146 | 478 | 30.4% |
| | | 2003 | 214 | 92 | 306 | 29.9% |
| AI RE | | 2004 | 83 | 102 | 185 | 55.1% |
| | | 2005 | 72 | 6 | 78 | 8.1% |
| | | 2006 | 166 | 30 | 196 | 15.2% |
| | | 2007 | 127 | 30 | 157 | 19.1% |
| | | 2008 | 142 | 43 | 185 | 23.3% |
| | | 2009 | 162 | 35 | 197 | 17.8% |
| | | 2010 | 159 | 26 | 185 | 14.0% |
| EBS RE | | 2004 | 15 | 9 | 24 | 38.2% |
| | | 2005 | 3 | 9 | 12 | 72.7% |
| | | 2006 | 5 | 2 | 7 | 27.3% |
| | | 2007 | 7 | 3 | 10 | 26.9% |
| | | 2008 | 12 | 17 | 29 | 58.3% |
| | | 2009 | 9 | 3 | 12 | 25.5% |
| | | 2010 | 9 | 8 | 17 | 48.3% |

Table 4. Estimated catch (t) of blackspotted and rougheye rockfish in Aleutian Islands and eastern Bering Sea trawl surveys, and the eastern Bering Sea hydroacoustic survey.

| | **Area** | | |
|---|---|---|---|
| Year | AI | BS | BS-Hydroacoustic |
| 1977 | | | 0.07 |
| 1978 | | | 0.00 |
| 1979 | | 0.47 | |
| 1980 | 6.84 | 0.00 | |
| 1981 | | 1.09 | |
| 1982 | 0.04 | 0.93 | |
| 1983 | 9.75 | 0.03 | |
| 1984 | | | |
| 1985 | | 3.72 | |
| 1986 | 24.24 | | |
| 1987 | | 0.01 | |
| 1988 | | 0.20 | |
| 1989 | | 0.00 | |
| 1990 | | 0.01 | 0.00 |
| 1991 | 1.81 | 0.18 | 0.01 |
| 1992 | | | 0.01 |
| 1993 | | | |
| 1994 | 2.77 | 0.00 | |
| 1995 | | | 0.00 |
| 1996 | | | 0.00 |
| 1997 | 2.60 | 0.00 | |
| 1998 | | | |
| 1999 | | 0.01 | |
| 2000 | 3.21 | 0.13 | |
| 2001 | | 0.00 | |
| 2002 | 2.18 | 0.09 | |
| 2003 | | 0.01 | |
| 2004 | 3.29 | 0.21 | |
| 2005 | | 0.00 | |
| 2006 | 1.97 | 0.00 | |
| 2007 | | 0.00 | |
| 2008 | | 0.21 | |
| 2009 | | 0.01 | |
| 2010 | 1.05 | 0.25 | |

Table 5. Aleutian Islands and eastern Bering Sea catch (t) of blackspotted and rougheye rockfish from top gear and target combinations by management area and target fishery in 2004-2010, from the NMFS Alaska Regional Office catch accounting system database.

## Aleutian Islands

| | | Management Area | | | |
|---|---|---|---|---|---|
| Target | Gear | 541 | 542 | 543 | Total |
| Rockfish | Bottom trawl | 171.09 | 142.69 | 395.28 | 709.07 |
| Pacific cod | Longline | 22.59 | 88.24 | 58.24 | 169.06 |
| Atka mackerel | Bottom trawl | 15.65 | 74.16 | 65.29 | 155.10 |
| Arrowtooth | Bottom trawl | 56.52 | | | 56.52 |
| Sablefish | Longline | 12.09 | 18.67 | | 30.76 |
| Halibut | Longline | 7.66 | 13.02 | 3.52 | 24.20 |
| Arrowtooth | Longline | 0.02 | 16.31 | | 16.33 |
| Turbot | Longline | 0.10 | 9.73 | | 9.84 |
| Pacific cod | Bottom trawl | 2.17 | 3.82 | 0.35 | 6.34 |
| Total (all targets and gears) | | 291.51 | 367.67 | 523.45 | 1182.63 |

## Eastern Bering Sea

| | | Management Area | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Target | Gear | 509 | 513 | 517 | 518 | 519 | 521 | 523 | 524 | Total |
| Arrowtooth | Bottom Trawl | | | 10.50 | 12.86 | 4.89 | 0.10 | | | 28.35 |
| Pacific cod | Longline | | 0.03 | 1.61 | 0.07 | 0.90 | 15.96 | 2.39 | 0.04 | 21.01 |
| Halibut | Longline | | | 1.71 | 7.97 | 0.86 | 4.30 | 1.33 | 0.12 | 16.29 |
| Rockfish | Bottom Trawl | | | 11.10 | 0.19 | 0.09 | | | | 11.38 |
| Turbot | Longline | | | 0.10 | 0.08 | 0.05 | 5.73 | 3.03 | 0.03 | 9.02 |
| Pollock | Pelagic Trawl | 0.06 | 0.02 | 4.73 | | 1.36 | 1.37 | 0.01 | 0.03 | 7.58 |
| other flatfish | Bottom Trawl | | | 3.08 | | 3.40 | | | | 6.48 |
| Pacific cod | Bottom Trawl | 0.10 | 0.00 | 0.69 | | 0.62 | 0.34 | 0.28 | | 2.02 |
| Flathead sole | Bottom Trawl | | 0.99 | 0.76 | | | 0.11 | | | 1.87 |
| Total (all targets and gears) | | 0.17 | 1.05 | 38.04 | 21.77 | 14.81 | 28.19 | 7.15 | 0.23 | 111.40 |

Table 6. Comparison of catch (t) of rougheye rockfish in the Aleutian Islands and eastern Bering Sea from 2001 to 2010 with potential area-specific ABC levels.

| | Aleutian Islands | | Eastern Bering Sea | |
|---|---|---|---|---|
| Year | Total Catch | ABC | Total Catch | ABC |
| 2001 | 585 | 230 | 15 | 32 |
| 2002 | 249 | 230 | 11 | 33 |
| 2003 | 175 | 215 | 17 | 32 |
| 2004 | 185 | 174 | 24 | 21 |
| 2005 | 78 | 198 | 12 | 25 |
| 2006 | 196 | 199 | 7 | 25 |
| 2007 | 157 | 179 | 10 | 23 |
| 2008 | 185 | 179 | 29 | 23 |
| 2009 | 197 | 499 | 12 | 40 |
| 2010* | 185 | 505 | 17 | 42 |

*Catch data through Oct 2, 2010

Table 7. Samples sizes of blackspotted/rougheye lengths from fishery sampling, with the number of hauls from which these data were collected, from 1977-2010.

| | EBS | | AI | | BSAI | |
|---|---|---|---|---|---|---|
| Year | Lengths | Hauls | Lengths | Hauls | Lengths | Hauls |
| 1977 | | | | | | |
| 1978 | | | 54 | 6 | 54 | 6 |
| 1979 | 2340 | 132 | 4406 | 93 | 6746 | 225 |
| 1980 | | | | | | |
| 1981 | | | | | | |
| 1982 | | | | | | |
| 1983 | | | 33 | 1 | 33 | 1 |
| 1984 | | | | | | |
| 1985 | | | | | | |
| 1986 | | | | | | |
| 1987 | | | | | | |
| 1988 | | | | | | |
| 1989 | | | | | | |
| 1990 | 800 | 29 | 1161 | 20 | 1961 | 49 |
| 1991 | 95 | 16 | 49 | 1 | 144 | 17 |
| 1992 | 61 | 1 | 1182 | 67 | 1243 | 68 |
| 1993 | 2 | 2 | 1046 | 39 | 1048 | 41 |
| 1994 | | | 27 | 1 | 27 | 1 |
| 1995 | 42 | 3 | | | 42 | 3 |
| 1996 | 14 | 3 | | | 14 | 3 |
| 1997 | | | | | | |
| 1998 | | | | | | |
| 1999 | 4 | 2 | 53 | 4 | 57 | 6 |
| 2000 | 4 | 1 | 160 | 21 | 164 | 22 |
| 2001 | 10 | 1 | 277 | 42 | 287 | 43 |
| 2002 | | | 336 | 49 | 336 | 49 |
| 2003 | 76 | 18 | 832 | 100 | 908 | 118 |
| 2004 | 215 | 41 | 1265 | 242 | 1480 | 283 |
| 2005 | 71 | 39 | 314 | 94 | 385 | 133 |
| 2006 | 61 | 16 | 266 | 56 | 327 | 72 |
| 2007 | 104 | 40 | 716 | 160 | 820 | 200 |
| 2008 | 38 | 20 | 371 | 105 | 409 | 125 |
| 2009 | 16 | 10 | 1002 | 211 | 1018 | 221 |
| 2010 | 29 | 10 | 338 | 84 | 367 | 94 |

Table 8. Samples sizes of blackspotted/rougheye otoliths from fishery sampling, with the number of hauls from which these data were collected, from 1977-2010.

| | Otoliths Sampled | | | Otoliths Read | | | Hauls (Otoliths Read) | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | EBS | AI | BSAI | EBS | AI | BSAI | EBS | AI | BSAI |
| 1977 | | | | | | | | | |
| 1978 | | | | | | | | | |
| 1979 | 440 | 383 | 823 | 14 | 38 | 52 | 6 | 4 | 10 |
| 1980 | | | | | | | | | |
| 1981 | | | | | | | | | |
| 1982 | | | | | | | | | |
| 1983 | | | | | | | | | |
| 1984 | | | | | | | | | |
| 1985 | | | | | | | | | |
| 1986 | | | | | | | | | |
| 1987 | | | | | | | | | |
| 1988 | | | | | | | | | |
| 1989 | | | | | | | | | |
| 1990 | 54 | 0 | 54 | | | | | | |
| 1991 | | | | | | | | | |
| 1992 | | 50 | 50 | | | | | | |
| 1993 | | | | | | | | | |
| 1994 | | | | | | | | | |
| 1995 | | | | | | | | | |
| 1996 | | | | | | | | | |
| 1997 | | | | | | | | | |
| 1998 | | | | | | | | | |
| 1999 | 4 | 4 | 8 | | | | | | |
| 2000 | 2 | 24 | 26 | | | | | | |
| 2001 | 2 | 76 | 78 | | | | | | |
| 2002 | | 67 | 67 | | | | | | |
| 2003 | 19 | 120 | 139 | | | | | | |
| 2004 | 14 | 147 | 161 | 14 | 146 | 160 | 11 | 90 | 101 |
| 2005 | 37 | 100 | 137 | 35 | 97 | 132 | 23 | 65 | 88 |
| 2006 | 5 | 83 | 88 | | 82 | 82 | 10 | 47 | 47 |
| 2007 | 14 | 138 | 152 | 14 | 134 | 148 | 13 | 83 | 93 |
| 2008 | 17 | 125 | 142 | 17 | 121 | 138 | | 74 | 87 |
| 2009 | 13 | 138 | 151 | | | | | | |
| 2010 | 12 | 87 | 99 | | | | | | |

Table 9. Estimated biomass (t) of blackspotted/rougheye rockfish from the EBS slope survey and AI trawl survey (by management), with the coefficient of variation (CV) is shown in parentheses.

| | AI survey | | | EBS Slope survey |
|---|---|---|---|---|
| Year | AI | S. Bering Sea | Total | |
| 1979 | | | | 1053 |
| 1980 | 8,987 (0.07) | 6 (1.00) | 8,993 (0.07) | |
| 1981 | | | | 816 |
| 1982 | | | | 605 |
| 1983 | 13,100 (0.19) | 2,111 (0.33) | 15,211 (0.17) | |
| 1984 | | | | |
| 1985 | | | | 1716 |
| 1986 | 57,363 (0.51) | 2,724 (0.49) | 60,087 (0.49) | |
| 1987 | | | | |
| 1988 | | | | 876 (0.32) |
| 1989 | | | | |
| 1990 | | | | |
| 1991 | 10,638 (0.47) | 676 (0.12) | 11,314 (0.44) | 884 (0.30) |
| 1992 | | | | |
| 1993 | | | | |
| 1994 | 13,374 (0.28) | 1,208 (0.49) | 14,582 (0.26) | |
| 1995 | | | | |
| 1996 | | | | |
| 1997 | 11,035 (0.22) | 561 (0.66) | 11,596 (0.21) | |
| 1998 | | | | |
| 1999 | | | | |
| 2000 | 14,218 (0.23) | 1,054 (0.26) | 15,271 (021) | |
| 2001 | | | | |
| 2002 | 8,361 (0.21) | 1,251 (0.48) | 9,613 (0.19) | 553 (0.20) |
| 2003 | | | | |
| 2004 | 14,275 (0.26) | 654 (0.31) | 14,929 (0.25) | 646 (0.16) |
| 2005 | | | | |
| 2006 | 8,281 (0.25) | 1,224 (0.33) | 9,505 (0.23) | |
| 2007 | | | | |
| 2008 | | | | 829 (0.24) |
| 2009 | | | | |
| 2010 | 8541 (0.26) | 221 (0.28) | 8762 (0.26) | 999 (0.25) |

Table 10. Samples sizes of blackspotted/rougheye lengths from the Aleutian Island trawl survey, with the number of hauls from which these data were collected, from 1980-2010.

| | Lengths | | | Hauls | | |
|---|---|---|---|---|---|---|
| Year | SBS | AI | Total | SBS | AI | Total |
| 1980 | 440 | 5009 | 5449 | 6 | 68 | 74 |
| 1981 | | | | | | |
| 1982 | | | | | | |
| 1983 | 602 | 3312 | 3914 | 8 | 84 | 92 |
| 1984 | | | | | | |
| 1985 | | | | | | |
| 1986 | 622 | 3768 | 4390 | 7 | 54 | 61 |
| 1987 | | | | | | |
| 1988 | | | | | | |
| 1989 | | | | | | |
| 1990 | | | | | | |
| 1991 | 79 | 981 | 1060 | 5 | 30 | 35 |
| 1992 | | | | | | |
| 1993 | | | | | | |
| 1994 | 412 | 1963 | 2375 | 14 | 90 | 104 |
| 1995 | | | | | | |
| 1996 | | | | | | |
| 1997 | 90 | 1727 | 1817 | 13 | 108 | 121 |
| 1998 | | | | | | |
| 1999 | | | | | | |
| 2000 | 165 | 1508 | 1673 | 18 | 101 | 119 |
| 2001 | | | | | | |
| 2002 | 258 | 1030 | 1288 | 19 | 79 | 98 |
| 2003 | | | | | | |
| 2004 | 103 | 1419 | 1522 | 13 | 104 | 117 |
| 2005 | | | | | | |
| 2006 | 177 | 1082 | 1259 | 20 | 102 | 122 |
| 2007 | | | | | | |
| 2008 | | | | | | |
| 2009 | | | | | | |
| 2010 | 27 | 959 | 986 | 10 | 82 | 92 |

Table 11. Samples sizes of blackspotted/rougheye otoliths from the Aleutian Island trawl survey, with the number of hauls from which these data were collected, from 1980-2006.

| | Otoliths sampled | | | Otoliths Read | | | Hauls (Otoliths Read) | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | SBS | AI | Total | SBS | AI | Total | SBS | AI | Total |
| 1980 | | | | | | | | | |
| 1981 | | | | | | | | | |
| 1982 | | | | | | | | | |
| 1983 | 0 | 36 | 36 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1984 | | | | | | | | | |
| 1985 | | | | | | | | | |
| 1986 | 70 | 343 | 413 | 64 | 341 | 405 | 2 | 11 | 13 |
| 1987 | | | | | | | | | |
| 1988 | | | | | | | | | |
| 1989 | | | | | | | | | |
| 1990 | | | | | | | | | |
| 1991 | 79 | 401 | 480 | 79 | 397 | 476 | 6 | 23 | 29 |
| 1992 | | | | | | | | | |
| 1993 | | | | | | | | | |
| 1994 | 194 | 535 | 729 | 130 | 356 | 486 | 13 | 55 | 68 |
| 1995 | | | | | | | | | |
| 1996 | | | | | | | | | |
| 1997 | 76 | 790 | 866 | 52 | 526 | 578 | 9 | 83 | 92 |
| 1998 | | | | | | | | | |
| 1999 | | | | | | | | | |
| 2000 | 116 | 376 | 492 | 115 | 375 | 490 | 16 | 71 | 87 |
| 2001 | | | | | | | | | |
| 2002 | 114 | 359 | 473 | 114 | 337 | 451 | 15 | 66 | 81 |
| 2003 | | | | | | | | | |
| 2004 | 103 | 372 | 475 | 102 | 370 | 472 | 14 | 83 | 97 |
| 2005 | | | | | | | | | |
| 2006 | 120 | 339 | 459 | 120 | 339 | 459 | 13 | 76 | 89 |
| 2007 | | | | | | | | | |
| 2008 | | | | | | | | | |
| 2009 | | | | | | | | | |
| 2010 | 27 | 464 | 491 | | | | | | |

Table 12. Predicted weight and proportion mature at age for BSAI rougheye rockfish.

| Age | Predicted weight (g) | Proportion mature |
|---|---|---|
| 3 | 77 | 0 |
| 4 | 103 | 0 |
| 5 | 134 | 0 |
| 6 | 168 | 0.001 |
| 7 | 206 | 0.001 |
| 8 | 247 | 0.003 |
| 9 | 290 | 0.008 |
| 10 | 336 | 0.015 |
| 11 | 385 | 0.03 |
| 12 | 435 | 0.053 |
| 13 | 486 | 0.09 |
| 14 | 539 | 0.141 |
| 15 | 592 | 0.209 |
| 16 | 646 | 0.29 |
| 17 | 700 | 0.378 |
| 18 | 755 | 0.467 |
| 19 | 809 | 0.551 |
| 20 | 862 | 0.625 |
| 21 | 916 | 0.689 |
| 22 | 968 | 0.742 |
| 23 | 1020 | 0.785 |
| 24 | 1071 | 0.82 |
| 25 | 1121 | 0.847 |
| 26 | 1170 | 0.87 |
| 27 | 1218 | 0.888 |
| 28 | 1264 | 0.902 |
| 29 | 1310 | 0.914 |
| 30 | 1354 | 0.924 |
| 31 | 1396 | 0.932 |
| 32 | 1437 | 0.939 |
| 33 | 1477 | 0.944 |
| 34 | 1516 | 0.949 |
| 35 | 1553 | 0.953 |
| 36 | 1589 | 0.956 |
| 37 | 1624 | 0.959 |
| 38 | 1657 | 0.962 |
| 39 | 1689 | 0.964 |
| 40 | 1720 | 0.966 |
| 41 | 1750 | 0.968 |
| 42 | 1778 | 0.969 |
| 43 | 1806 | 0.97 |
| 44 | 1832 | 0.971 |
| 45 | 2101 | 0.977 |

Table 13. Negative log likelihood of model components, average effective and input sample sizes, root mean squared errors and standard deviation of normalized residuals for model 1 ($\sigma_r$ = 0.75) and model 2 ($\sigma_r$ = 0.50)

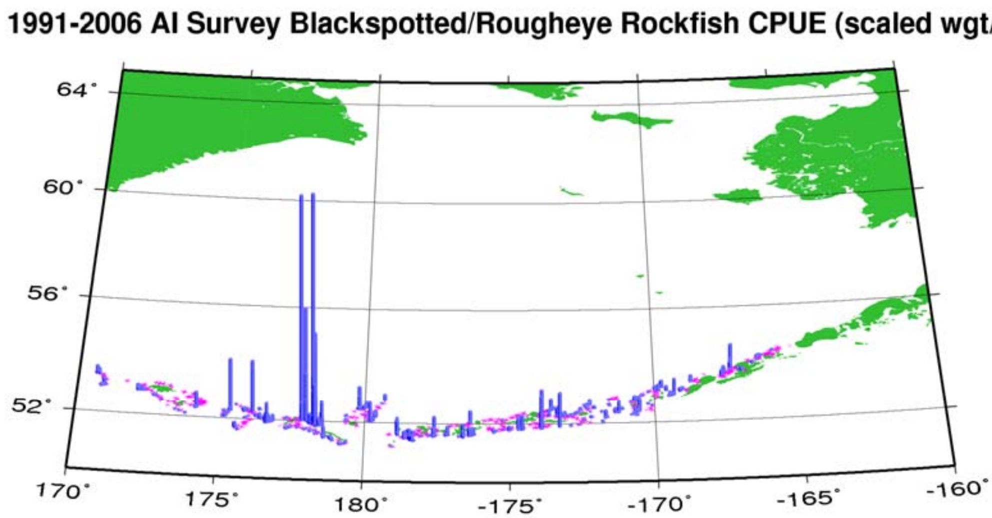
| **Component** | Negative log likelihood | |
|---|---|---|
| | Model 1 | Model 2 |
| Recruitment | 11.48 | -13.65 |
| AI survey biomass | 10.98 | 10.76 |
| Catch | 0.00 | 0.00 |
| F penalty | 5.63 | 5.63 |
| Fishery ages | 1059.12 | 1062.00 |
| Fishery lengths | 1660.25 | 1672.14 |
| Survey ages | 1663.35 | 1668.90 |
| Survey lengths | 553.07 | 555.67 |
| Prior for *q_srv* | 0.62 | 0.75 |
| Prior for *M* | 1.49 | 2.53 |
| **Total likelihood** | 4798.45 | 4795.07 |
| | | |
| **Average Effective Sample Size** | | |
| Fishery ages | 74.68 | 72.32 |
| Fishery lengths | 175.54 | 93.59 |
| Survey ages | 186.36 | 173.66 |
| Survey lengths | 102.65 | 79.03 |
| | | |
| **Average Sample Sizes** | | |
| Fishery ages | 52.00 | 52.00 |
| Fishery lengths | 58.89 | 58.89 |
| Survey ages | 79.17 | 79.17 |
| Survey lengths | 110.67 | 110.67 |
| | | |
| **Root Mean Squared Error** | | |
| Survey | 0.55 | 0.55 |
| Recruitment | 0.80 | 0.53 |
| | | |
| **Standard Deviation of Normalized Residuals** | | |
| Fishery ages | 0.82 | 0.85 |
| Fishery lengths | 0.72 | 0.78 |
| Survey ages | 0.44 | 0.46 |
| Survey lengths | 0.66 | 0.70 |
| AI trawl survey | 1.35 | 1.28 |

Table 14. Estimated time series of AI blackspotted rougheye total biomass (t), spawner biomass (t), and recruitment (thousands).

| | Total Biomass (ages 3+) | | Spawner Biomass (ages 3+) | | Recruitment (age 3) | |
|---|---|---|---|---|---|---|
| | Assessment Year | | Assessment Year | | Assessment Year | |
| Year | 2010 | 2008 | 2010 | 2008 | 2010 | 2008 |
| 1977 | 19,039 | 18,738 | 6,008 | 5,798 | 1,023 | 933 |
| 1978 | 19,501 | 19,328 | 6,088 | 5,944 | 1,159 | 1,138 |
| 1979 | 17,562 | 17,551 | 5,278 | 5,219 | 1,402 | 1,778 |
| 1980 | 14,913 | 15,092 | 4,428 | 4,455 | 1,295 | 1,377 |
| 1981 | 14,811 | 15,117 | 4,425 | 4,508 | 1,055 | 960 |
| 1982 | 14,768 | 15,200 | 4,468 | 4,603 | 1,045 | 1,016 |
| 1983 | 15,146 | 15,706 | 4,658 | 4,844 | 1,187 | 1,454 |
| 1984 | 15,660 | 16,350 | 4,898 | 5,134 | 1,234 | 1,588 |
| 1985 | 16,184 | 17,013 | 5,147 | 5,436 | 1,092 | 1,272 |
| 1986 | 16,716 | 17,695 | 5,406 | 5,748 | 909 | 1,079 |
| 1987 | 17,211 | 18,349 | 5,656 | 6,052 | 745 | 775 |
| 1988 | 17,626 | 18,926 | 5,882 | 6,334 | 665 | 653 |
| 1989 | 18,025 | 19,486 | 6,084 | 6,590 | 641 | 642 |
| 1990 | 18,085 | 19,707 | 6,073 | 6,628 | 584 | 563 |
| 1991 | 16,837 | 18,592 | 5,715 | 6,310 | 517 | 451 |
| 1992 | 17,096 | 19,000 | 5,810 | 6,457 | 491 | 396 |
| 1993 | 16,262 | 18,293 | 5,541 | 6,234 | 503 | 378 |
| 1994 | 15,676 | 17,822 | 5,372 | 6,116 | 541 | 382 |
| 1995 | 15,261 | 17,504 | 5,289 | 6,088 | 639 | 440 |
| 1996 | 15,209 | 17,523 | 5,299 | 6,157 | 828 | 578 |
| 1997 | 14,723 | 17,075 | 5,137 | 6,054 | 1,017 | 662 |
| 1998 | 14,118 | 16,463 | 4,949 | 5,926 | 1,343 | 731 |
| 1999 | 13,995 | 16,275 | 4,919 | 5,958 | 1,763 | 744 |
| 2000 | 14,021 | 16,223 | 4,942 | 6,040 | 1,516 | 917 |
| 2001 | 14,520 | 16,414 | 4,973 | 6,125 | 5,907 | 5,703 |
| 2002 | 14,523 | 16,255 | 4,900 | 6,099 | 2,201 | 1,818 |
| 2003 | 14,906 | 16,501 | 4,947 | 6,183 | 1,991 | 2,433 |
| 2004 | 15,359 | 16,847 | 5,014 | 6,280 | 1,412 | 1,199 |
| 2005 | 15,825 | 17,207 | 5,078 | 6,356 | 1,359 | 1,116 |
| 2006 | 16,413 | 17,697 | 5,168 | 6,446 | 1,306 | 1,049 |
| 2007 | 16,890 | 18,107 | 5,219 | 6,492 | 1,238 | 925 |
| 2008 | 17,405 | 18,552 | 5,283 | 6,534 | | |
| 2009 | 17,893 | 18,978 | 5,347 | 6,535 | | |
| 2010 | 18,365 | | 5,423 | | | |
| 2011 | 18,813 | | | | | |

Table 15. Projections of AI spawning biomass (t), catch (t), and fishing mortality rate for each of the several scenarios resulting from the AI model. The values of $B_{40\%}$ and $B_{35\%}$ are 6,986 t and 6,034 t, respectively.

| **Catch** | *Scenario 1* | *Scenario 2* | *Scenario 3* | *Scenario 4* | *Scenario 5* | *Scenario 6* | *Scenario 7* |
|---|---|---|---|---|---|---|---|
| 2010 | 225 | 225 | 225 | 225 | 225 | 225 | 225 |
| 2011 | 327 | 327 | 165 | 173 | 0 | 395 | 327 |
| 2012 | 337 | 337 | 174 | 177 | 0 | 402 | 337 |
| 2013 | 351 | 351 | 186 | 182 | 0 | 415 | 424 |
| 2014 | 369 | 369 | 200 | 188 | 0 | 433 | 441 |
| 2015 | 392 | 392 | 217 | 195 | 0 | 455 | 463 |
| 2016 | 416 | 416 | 235 | 203 | 0 | 480 | 487 |
| 2017 | 441 | 441 | 253 | 211 | 0 | 505 | 512 |
| 2018 | 466 | 466 | 263 | 219 | 0 | 530 | 537 |
| 2019 | 491 | 491 | 272 | 228 | 0 | 553 | 560 |
| 2020 | 507 | 507 | 282 | 236 | 0 | 574 | 580 |
| 2021 | 517 | 517 | 291 | 245 | 0 | 591 | 597 |
| 2022 | 526 | 526 | 299 | 252 | 0 | 604 | 609 |
| 2023 | 533 | 533 | 307 | 259 | 0 | 611 | 615 |
| **Sp. Biomass** | *Scenario 1* | *Scenario 2* | *Scenario 3* | *Scenario 4* | *Scenario 5* | *Scenario 6* | *Scenario 7* |
| 2010 | 5423 | 5423 | 5423 | 5423 | 5423 | 5423 | 5423 |
| 2011 | 5514 | 5514 | 5526 | 5525 | 5538 | 5509 | 5514 |
| 2012 | 5605 | 5605 | 5687 | 5683 | 5772 | 5570 | 5605 |
| 2013 | 5735 | 5735 | 5889 | 5884 | 6050 | 5673 | 5730 |
| 2014 | 5903 | 5903 | 6129 | 6127 | 6372 | 5813 | 5867 |
| 2015 | 6096 | 6096 | 6396 | 6399 | 6728 | 5978 | 6029 |
| 2016 | 6296 | 6296 | 6673 | 6686 | 7101 | 6150 | 6198 |
| 2017 | 6491 | 6491 | 6949 | 6976 | 7482 | 6318 | 6362 |
| 2018 | 6672 | 6672 | 7213 | 7259 | 7860 | 6470 | 6511 |
| 2019 | 6835 | 6835 | 7469 | 7534 | 8234 | 6605 | 6643 |
| 2020 | 6973 | 6973 | 7707 | 7792 | 8596 | 6715 | 6749 |
| 2021 | 7091 | 7091 | 7927 | 8034 | 8947 | 6802 | 6833 |
| 2022 | 7186 | 7186 | 8126 | 8254 | 9279 | 6862 | 6891 |
| 2023 | 7257 | 7257 | 8300 | 8449 | 9589 | 6898 | 6924 |
| **F** | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 | Scenario 7 |
| 2010 | 0.020 | 0.020 | 0.020 | 0.020 | 0.020 | 0.020 | 0.020 |
| 2011 | 0.029 | 0.029 | 0.015 | 0.015 | 0 | 0.035 | 0.029 |
| 2012 | 0.030 | 0.030 | 0.015 | 0.015 | 0 | 0.036 | 0.030 |
| 2013 | 0.030 | 0.030 | 0.016 | 0.015 | 0 | 0.036 | 0.037 |
| 2014 | 0.031 | 0.031 | 0.016 | 0.015 | 0 | 0.037 | 0.038 |
| 2015 | 0.032 | 0.032 | 0.017 | 0.015 | 0 | 0.039 | 0.039 |
| 2016 | 0.034 | 0.034 | 0.018 | 0.015 | 0 | 0.040 | 0.040 |
| 2017 | 0.035 | 0.035 | 0.018 | 0.015 | 0 | 0.041 | 0.041 |
| 2018 | 0.036 | 0.036 | 0.018 | 0.015 | 0 | 0.042 | 0.042 |
| 2019 | 0.037 | 0.037 | 0.018 | 0.015 | 0 | 0.043 | 0.043 |
| 2020 | 0.037 | 0.037 | 0.018 | 0.015 | 0 | 0.044 | 0.044 |
| 2021 | 0.037 | 0.037 | 0.018 | 0.015 | 0 | 0.044 | 0.044 |
| 2022 | 0.037 | 0.037 | 0.018 | 0.015 | 0 | 0.045 | 0.045 |
| 2023 | 0.037 | 0.037 | 0.018 | 0.015 | 0 | 0.045 | 0.045 |



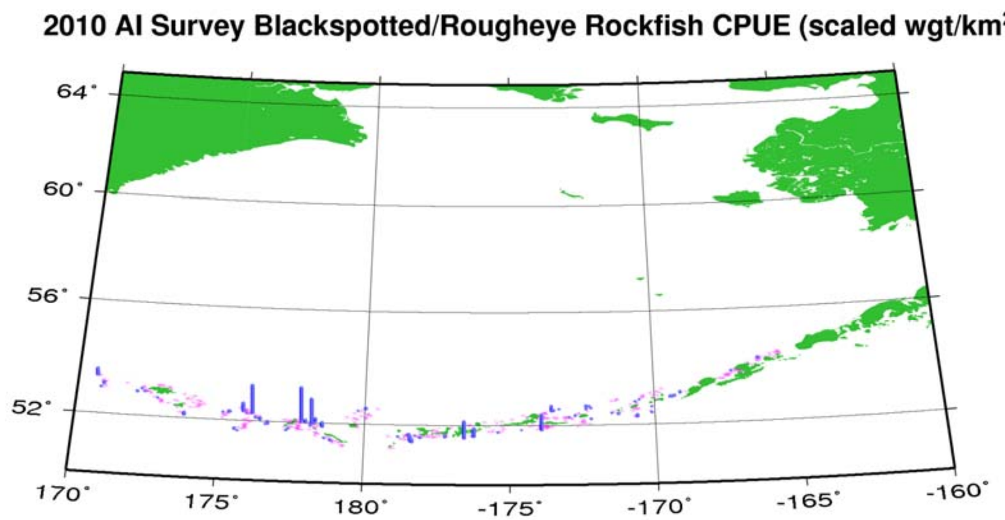




Figure 1. Scaled AI survey combined blackspotted and rougheye rockfish CPUE from 1991-2006 (top panel) and 2010 (bottom panel).

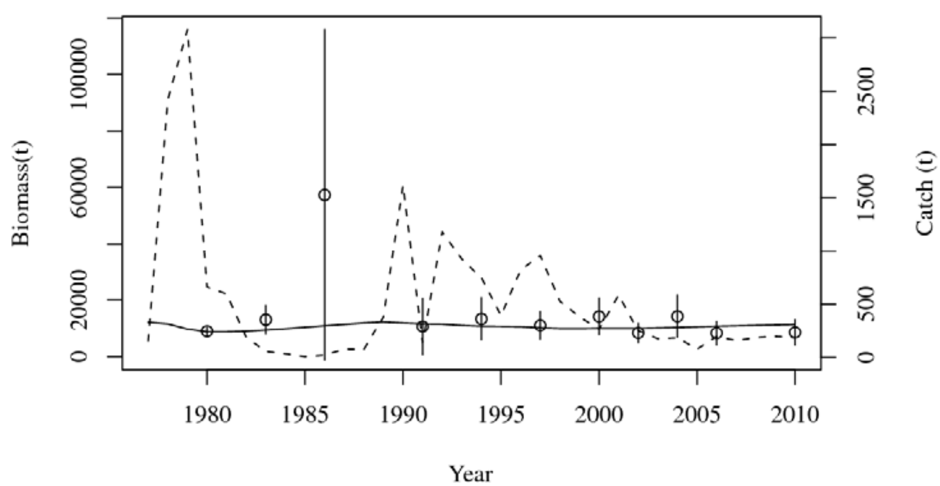



Figure 2. Observed AI survey biomass(data points, +/– 2 standard deviations), predicted survey biomass(solid line), and AI harvest (dashed line).

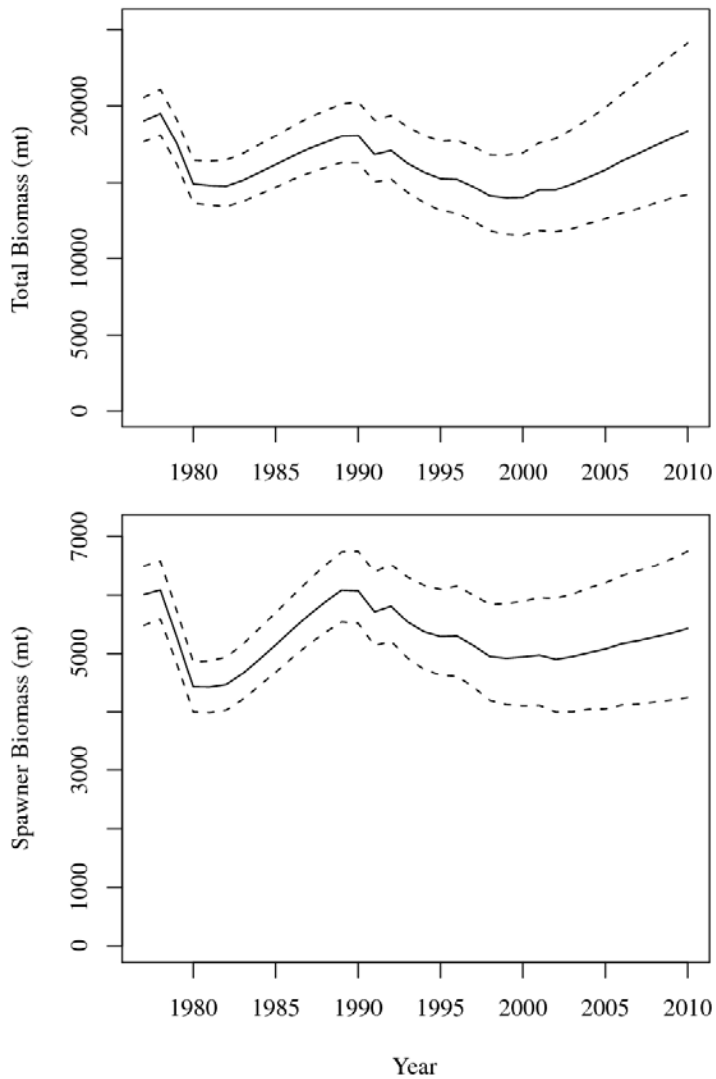



Figure 3. Total and spawner biomass for AI rougheye rockfish with 95% confidence intervals from MCMC integration.

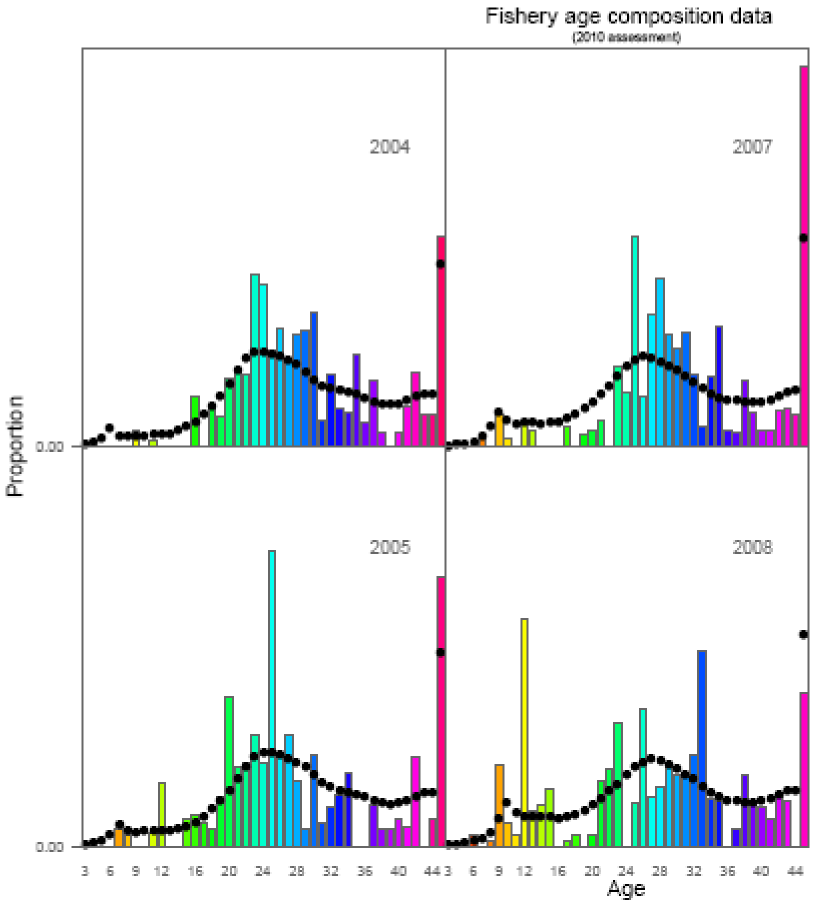



Figure 4. Model fits (dots) to the fishery age composition data (columns) for AI blackspotted/rougheye rockfish, 2004-2008. Colors of the bars correspond to cohorts (except for the 45+ group).

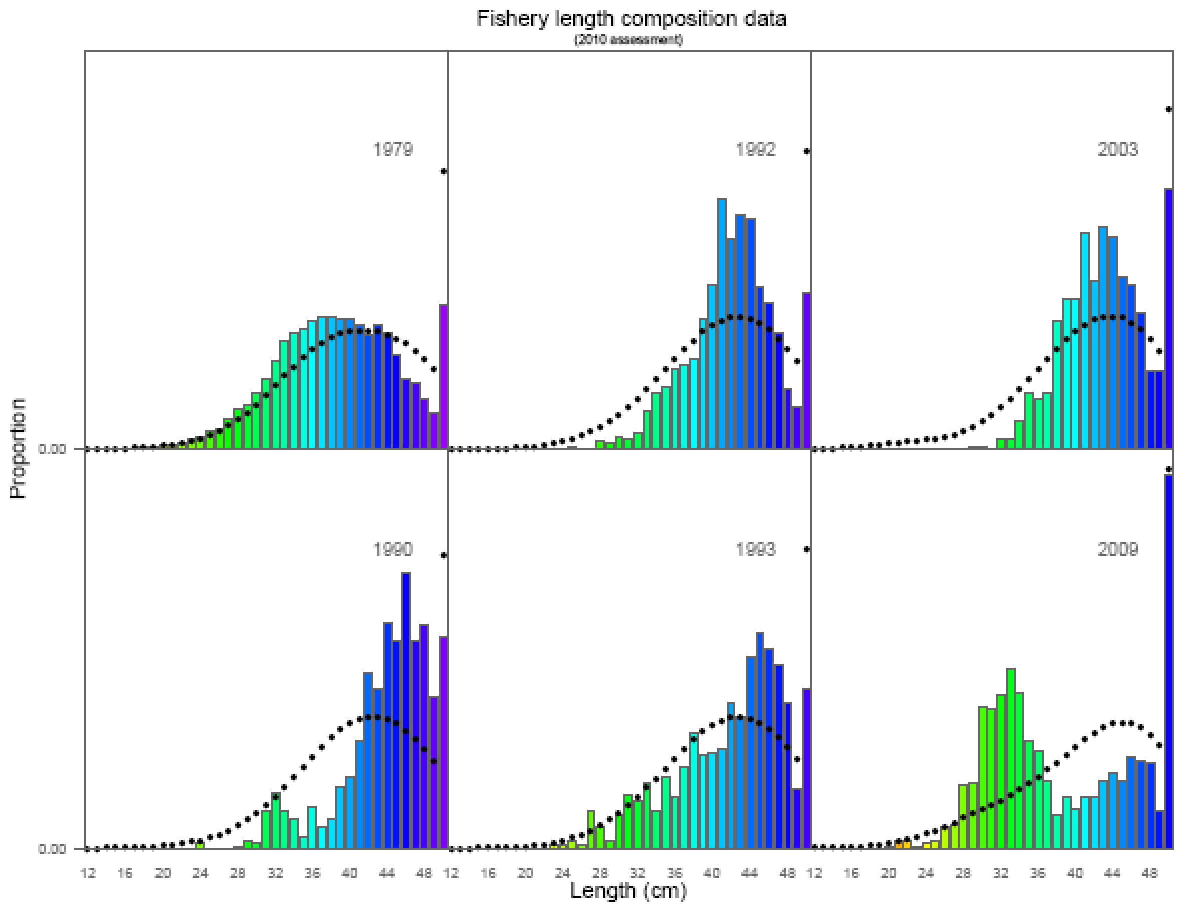



Figure 5. Model fits (dots) to the fishery length composition data (columns) for AI blackspotted/rougheye rockfish, 1979-2009. Colors of the bars correspond to cohorts (except for the 50+ group).

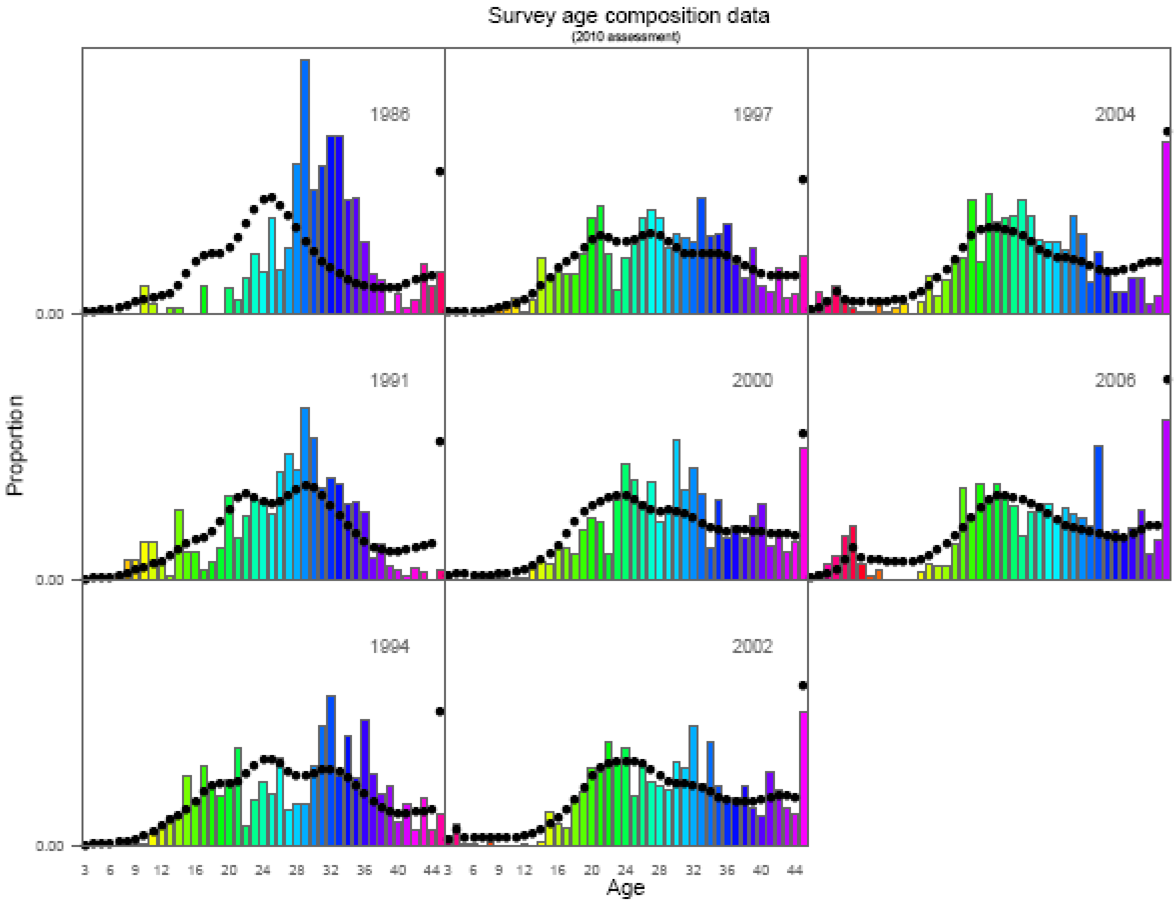



Figure 6. Model fits (dots) to the survey age composition data (columns) for AI blackspotted/rougheye rockfish, 1986-2006. Colors of the bars correspond to cohorts (except for the 45+ group).

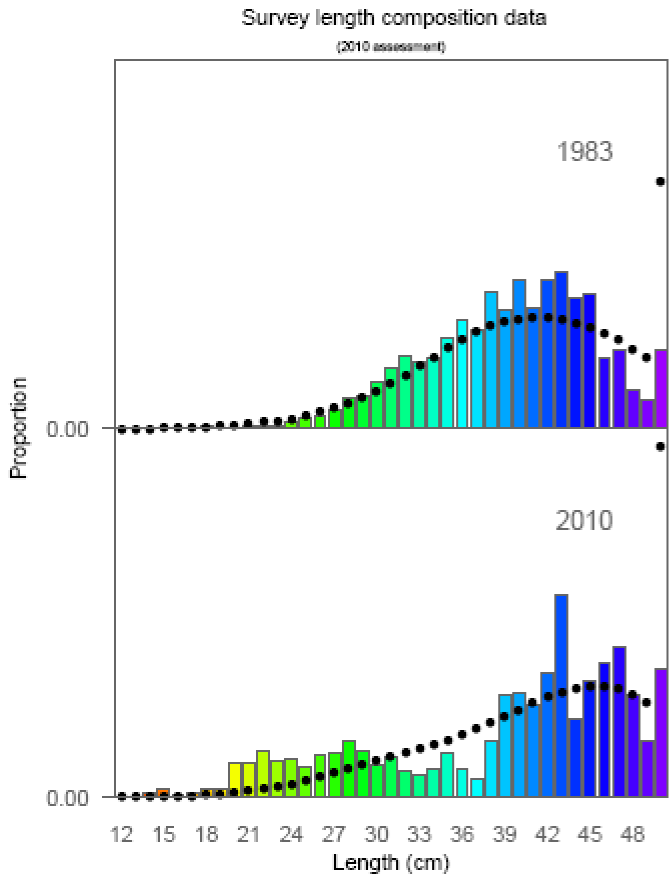



Figure 7. Model fits (dots) to the 1983 and 2010 AI survey length composition data (columns) for AI blackspotted/rougheye rockfish. Colors of the bars correspond to cohorts (except for the 50+ group).

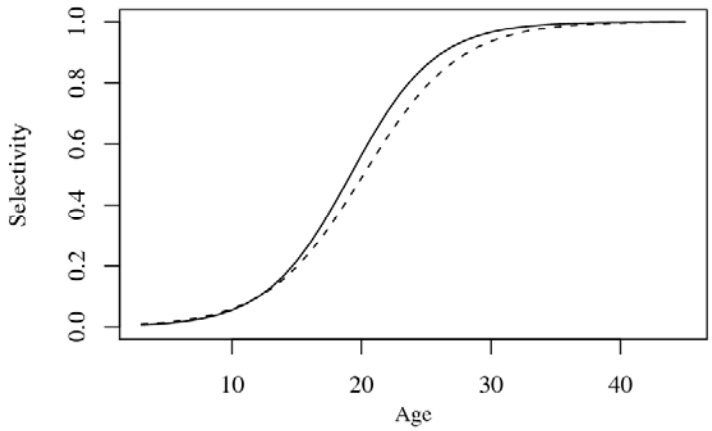



Figure 8. Estimated fishery (solid line) and survey (dashed line) selectivity curve by age.

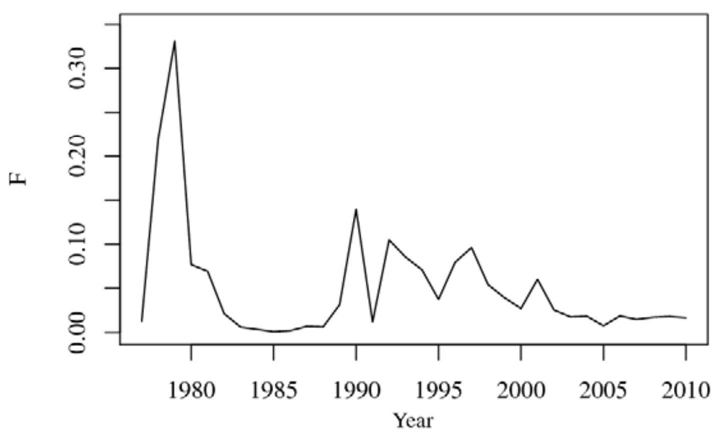



Figure 9. Estimated fully selected fishing mortality for AI rougheye rockfish.

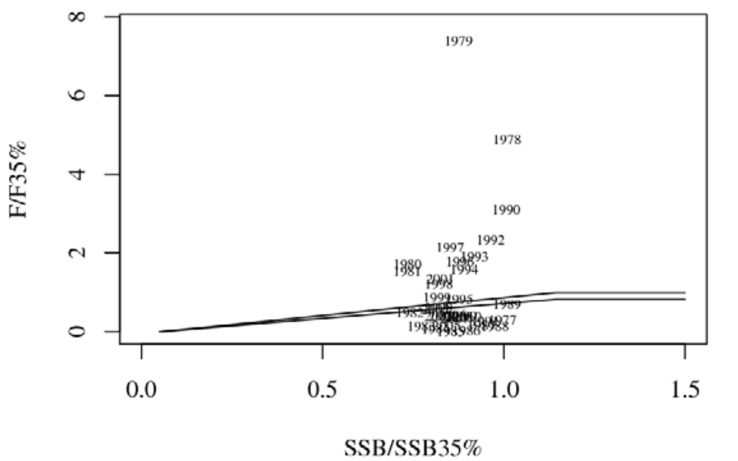



Figure 10. Estimated fishing mortality and SSB in reference to OFL (upper line) and ABC (lower line) harvest control rules

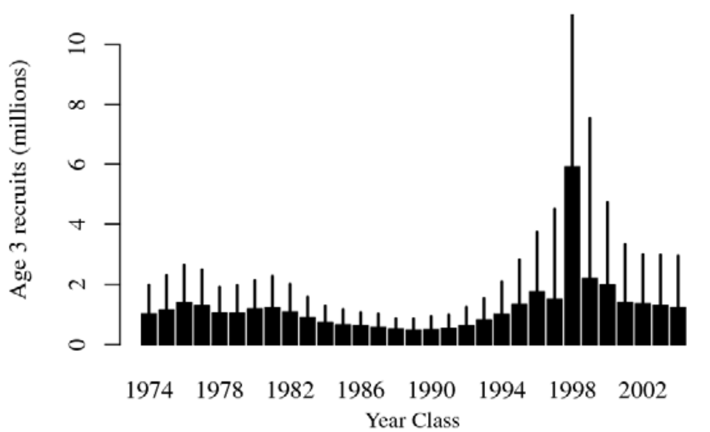



Figure 11. Estimated recruitment (age 3) of AI rougheye rockfish with 95% CI limits obtained from MCMC integration.

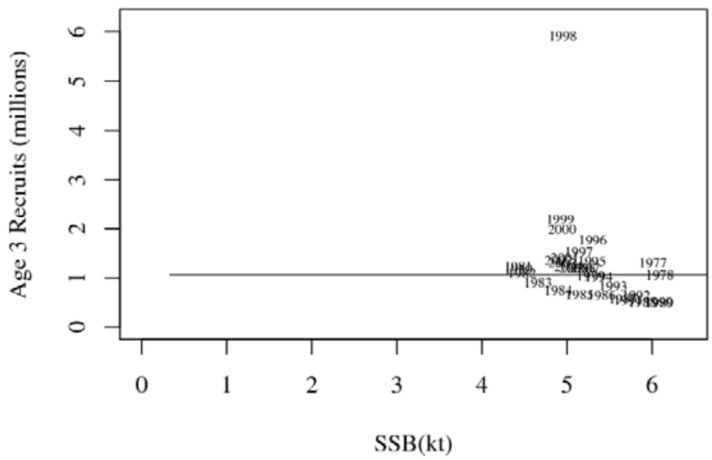



Figure 12. Scatterplot of AI rougheye rockfish spawner−recruit data; label is year class.

# Appendix 13A. Evaluation of stock structure for the Bering Sea/Aleutian Islands Blackspotted/Rougheye rockfish complex

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## Executive Summary

In this document, various types of information pertaining to stock structure for the BSAI blackspotted/rougheye rockfish are considered, following the template recommended by the Stock Structure Working Group (SSWG). Additionally, variation in species composition across spatial areas is a factor considered for this two-species complex because differences in species composition could imply different levels of productivity across spatial areas. Several studies have used genetic and morphometric analyses to document the scarcity of rougheye rockfish west of the eastern Aleutian Islands (AI) and the occurrence of blackspotted rockfish throughout the BSAI area, thus establishing differences in species composition between areas in the BSAI. Tests for genetic homogeneity indicated that genetic differences occurred between samples of blackspotted rockfish grouped into four areas within the BSAI, and a significant isolation by distance (IBD) pattern also occurred within the BSAI area. Dispersal distance between parents and offspring was estimated from the IBD relationship and a sensitivity analysis was conducted to examine the influence of the slope of the IBD relationship and assumptions of effective population size upon this estimate. The maximum estimate of dispersal distance from the sensitivity analysis was ~ 500 km, much shorter that the linear distance of the BSAI management area.

Differences in size at age (for ages between about 10 and 30) and in age composition were also detected between the eastern Bering Sea (EBS) slope and the Aleutian Islands (AI) from analyses that were conducted upon the two-species blackspotted/rougheye complex. Although interpretation of these observations is confounded at the species level, it does not appear to be consistent with the concept of a well-mixed stock complex across the BSAI.

Given the long generation time of blackspotted rockfish (estimated here as 53 years), the differences in species composition between the AI and EBS, and the genetic structure observed for blackspotted rockfish, we recommended either separate ABCs for the AI and EBS, or separate OFLs and ABCs for these two areas. Catch estimates by area indicate that the current management steps of placing blackspotted/rougheye rockfish on bycatch status with low retention rates has produced catches in recent years that are below the estimated area-specific ABCs. For a stock on bycatch status, area-specific ABCs could improve catch monitoring by providing area-specific catch benchmarks.

## Introduction

In 2009 a Stock Structure Working Group (SSWG), consisting of members of the North Pacific Fisheries Management Council's (NPFMC) Scientific and Statistical Committee (SSC), Groundfish Plan Teams, geneticists, and assessment scientists, was formed to develop a set of guidelines that will help promote a rigorous and consistent procedure for making management decisions on stock structure for Alaska stocks. The committee produced a report, originally presented at the September 2009 meeting of the joint Groundfish Plan Team and updated for the September 2010 meeting (Spencer et al. 2010), which contains a template (Table 1) that identifies various scientific data from which we may infer stock structure. Part of the discussion of the September 2010 joint Plan Team meeting is application of this template to specific cases, including the Bering Sea/Aleutian Islands (BSAI) blackspotted/rougheye complex.

The SSWG report also identified a process by which the scientific information from the template would be used to inform management decisions. After using the template to review the available scientific information regarding stock structure, various hypotheses of stock structure can be identified and evaluated with respect to their consistency with the scientific information. These alternative views of stock structure can be considered as "states of nature" in a risk analysis (either quantitative or qualitative) that considers the risks to the sustainability of the stock, and the risks/costs to the fishing industry and our regulatory system. For BSAI blackspotted/rougheye rockfish, this approach is consistent with the request from the SSC in December, 2008, to consider "the implications of adopting area-specific ABCs".

The purpose of this document is to: 1) use the template produced the stock structure committee to evaluate scientific information; and 2) update the current assessment model to estimate and consider the implications of potential area-specific ABCs and OFLs. We begin by first considering whether species composition within the BSAI blackspotted/rougheye rockfish complex differs between areas, an issue not specifically addressed in the stock structure template.

## 1. Distribution and species composition within the two-species blackspotted/rougheye complex.

Fish historically referred to as "rougheye" rockfish are now recognized as consisting of two separate species (Orr and Hawkins 2008), with rougheye rockfish retaining the name *Sebastes aleutianus* and resurrection of a new species, blackspotted rockfish (*S. melanostictus*). Because the stock structure template is intended to evaluate stock structure within a single species, concerns regarding differences in species composition of multispecies complexes between areas are not specifically addressed. In general, if the productivity differs between species and separate areas have different proportions of the high or low productivity species, then the productivity would be expected to differ across areas. Managing areas with differing productivities as a single unit could result in applying high fishing rates to the lower productivity area. Note that this is also the same argument for moving, within a single area, from managing multispecies complexes to single species management. If the species distribution were completely confounded with area, then the two situations are equivalent. Consider, for example, a hypothetical situation of a two-species complex in two areas. If one of the species was only found in one area, and the other species only found in the other area, then separate management by species would be equivalent to separate management by area.

Several studies have used genetic and morphometric analyses to document the scarcity of rougheye rockfish west of the eastern Aleutian Islands (AI) and the occurrence of blackspotted rockfish throughout the BSAI area, thus establishing differences in species composition between areas in the BSAI. These studies have been used to establish the existence of two species of fish historically referred to as "rougheye" rockfish, and the analyses have generally been applied to field samples identified as "rougheye" which could be either *S. aleutianus* or *S. melanostictus*.

Hawkins et al. (2005) conducted allozyme analyses on collections obtained from bottom trawl and longline survey samples from a variety of locations in the north Pacific. Two "types" of rougheye were recognized by Hawkins et al. (2005), *S. aleutianus* and *S.* sp. cf. *aleutianus*, with the Aleutian Islands composed almost entirely of *S.* sp.cf. *aleutianus*.
The genetic basis for distinct species was also established by Gharrett et al. (2005), who applied mitochondrial DNA and microsatellite analyses to longline and trawl survey samples. "Type II" rougheye (corresponding to *S. aleutianus* of Hawkins et al. 2005) were absent from the western AI and western BS collections, and were rare elsewhere in the BSAI area. In contrast, "type I" rougheye

(corresponding to *S.* sp.cf. *aleutianus* of Hawkins et al. 2005) extended throughout the range sampled. The distributions observed in Hawkins et al 2005 and Gharrett et al. 2005 were corroborated with microsatellite and mitochondrial analyses applied to samples obtained from the north Pacific (Gharrett et al. 2007). Finally, the description of the two rougheye species was established by application of morphometric and meristic analyses by Orr and Hawkins (2008) to catalogued samples, with genetic analysis used to verify the morphometric and meristic patterns. The range of *S. aleutianus* (corresponding to *S. aleutianus* of Hawkins et al 2005 and “type II” rougheye from Gharrett et al. 2005), was found to extend westward to the eastern Aleutian Islands near Unalaska Island, whereas the range of *S. melanostictus* (corresponding to *S.* sp.cf. *aleutianus* of Hawkins et al. 2005 and “type I” rougheye from Gharrett et al. 2005) extended throughout the BSAI area (Figure 1).

Species composition data within the BSAI area also exists from the 2006 AI trawl survey and the 2008 EBS slope survey (the 2010 AI survey data were not available for this report). The biomass estimates for specific BSAI areas are shown below:

| | | Biomass (t) | | | Percentage | |
|---|---|---|---|---|---|---|
| Area | Year | Blackspotted | Rougheye | BS/RE | Blackspotted | Rougheye |
| West AI | 2006 | 518.6 | 0 | 518.6 | 100.0 | 0.0 |
| Central AI | 2006 | 4731.9 | 227.3 | 4959.2 | 95.4 | 4.6 |
| East AI | 2006 | 2763 | 40.2 | 2803.2 | 98.6 | 1.4 |
| Southern BS | 2006 | 793.5 | 430.8 | 1224.3 | 64.8 | 35.2 |
| BS Slope | 2008 | 513.2 | 315.9 | 829.1 | 61.9 | 38.1 |

In the each of the west, central, and east AI areas, the blackspotted/rougheye complex observed in the 2006 AI trawl survey was composed of > 95% blackspotted rockfish. In contrast, the percentage of blackspotted rockfish in the southern Bering Sea (between 165° W and 170° W) and Bering Sea slope areas were 65% and 62%, respectively. Some differences in species composition based upon field identification may be due to errors in species identification, particularly in areas where both species are common, as blackspotted and rougheye rockfish are similar in appearance. However, the distribution pattern of survey biomass is consistent with information cited above from genetic and morphometric analyses, which do not rely on field identification.

## 2. Application of stock structure template to the BSAI blackspotted/rougheye complex.

### 2.1 Harvest and trends

The purpose of examining harvest data and survey population trends is twofold: 1) to evaluate whether fishing mortality is large enough that spatially disproportionate harvesting represents a potential conservation concern; and 2) to identify any differences in populations trends that may indicate demographic independence.

*Fishing mortality (relative to target reference point)*

The estimates of fishing mortality for the ten-year period 1999-2008, obtained from the 2008 assessment for the AI portion of the stock (Spencer et al. 2008), ranged from 0.006 to 0.05 with a mean of 0.02. The ratio of $F$ to the estimated $F_{abc}$ of 0.038 from the 2008 assessment ranged from 0.16 to 1.32 during this period, with a mean of 0.53. Extending this examination further back to 1990 indicates that the estimated $F$ exceeded the 2008 estimate of $F_{abc}$ in 7 of the 9 years between 1990 and 1998, although it should be noted that BSAI rougheye/blackspotted rockfish were managed in complexes with other rockfish species during this time.

*Spatial concentration of harvest relative to abundance*

The occurrence of disproportionate harvest relative to biomass for subareas within the BSAI management area were obtained by comparing area-specific catches to area-specific ABC levels, which reflect area-specific biomass estimates. Estimates of area-specific ABC levels were computed from 2001-2010, and for most years were obtained directly from the biomass estimates from the AI trawl survey and EBS slope survey; for 2009 and 2010, biomass estimates for the AI area were obtained from an age-structured population model.

In the Aleutian Islands, the catch exceeded the estimated area-specific ABC in 4 of the 10 years from 2001-2010, by a large amount in 2001 (154%) and smaller amounts in 2002, 2004, and 2008 (8%, 6%, and 3%, respectively) (Table 2). With the development of an age structured AI assessment model in 2008 the estimate of AI-specific stock size and ABC increased, and the catches for 2009 and 2010 are 60% and 67% lower than the AI-specific ABC.

In the eastern Bering Sea (EBS), the catch exceeded the estimated area-specific ABC in 2 of the 10 years from 2001-2010, by 13% in 2004 and 25% in 2008 (Table 2). The EBS-specific ABCs from 2001-2007 ranged from 21 t to 32 t; an increased biomass estimate of blackspotted/rougheye rockfish in the 2008 EBS slope survey increased the area-specific ABC in 2008 to 40 t.

*Population trends*

In the Aleutian Islands, cooperative trawl surveys were conducted from 1980 to 1986, with NMFS trawl surveys initiated from 1991. Along the EBS slope, cooperative trawl surveys were conducted from 1979 to 1988, and a NMFS trawl survey was conducted in 1991. A biennial trawl survey series was initiated by NMFS in 2002. Notwithstanding the unusually large biomass estimate from the 1985 EBS slope survey and the 1986 AI trawl survey, the trends of estimated biomass have been relatively stable (Figure 2).

## 2.2 Barriers and phenotypic characters

*Generation time*

Generation time is a characteristic of a species that reflects longevity and reproductive output, with long generation times indicating increased time required to rebuild overfished stocks. The mean generation time ($G$) was computed as

$$G = \frac{\sum_{a=1}^{A} a E_a N_a}{\sum_{a=1}^{A} E_a N_a} \qquad \text{Eq. 1}$$

where $a$ is age, $A$ is expected maximum age for an unfished stock, $N$ is females per recruit in the absence of fishing, and $E$ is fecundity at age (Restrepo et al. 1998). Because fecundity is unknown, $E$ was replaced by the product of proportion mature and body weight, thus using spawning stock biomass rather than egg production (Restrepo et al. 1998).

The estimated mean generation time for BSAI blackspotted/rougheye rockfish was 53 years. In general, rockfish species would be expected to have large mean generation times due to their longevity. The estimate of 53 years is high even among rockfish species due to their very low mortality rate ($M = 0.032$) and late at maturity (50% maturation of approximately 19 years); for example, the estimated mean generation time for BSAI POP was 28 years.

*Physical limitations (clear physical inhibitors to movement)*

Although physical barriers are rare in oceanic environments, field data on ocean currents can be used to infer the degree of water flow between the Aleutian Islands and nearby areas. Research on oceanographic currents within the BSAI area reveals some connection between the EBS and the eastern AI, but limited connection with the western and central AI (Figure 3). On the north side of the Aleutian Islands, the Alaska North Slope Current (ANSC) extends from Amchitka Pass (~180° W) into the southern EBS slope area (Stabeno et al. 2005). The connection between the Bering Sea slope and the north side of the AI west of 180° W is limited due to the break associated with Petral Bank and Bowers Ridge, which results in water flowing away from the Aleutian Islands archipelago (Stabeno et al 2005). On the south side of the archipelago east of 180° W, the Alaska Coastal Current (ACC) and Alaska Stream flow westward, with the Alaska Stream providing much of the source of the ANSC through the deep Amukta Pass (~172° W) and Amchitka Pass. Ladd et al. (2005) demonstrated that the flow through the passes is influenced by water depth. Drifters deployed to the south of the Alaska Peninsula on the continental shelf entered the ANSC through Unimak Pass, whereas those deployed on the shelf break entered at Samalga Pass, and those deployed in deeper water continued on in the Alaska Stream south the Aleutian Islands (Figure 4). On the south side of the Aleutian Islands, the Alaska Stream separates from the slope west of the Amchitka Pass and forms meanders and eddies.

Although a full discussion of ecological differences between the Aleutian Islands and neighboring areas is beyond the scope of this document, a number of biological and physical measurements suggest that a "biophysical transition zone" (Logerwell et al. 2005) occurs at Samaga Pass. Field observations in 2001-2002 indicate that water west of Samaga Pass was colder, saltier, and more nutrient rich relative to water east of Samaga Pass (Ladd et al. 2005). The passes from Samaga Pass eastward are generally shallow and well mixed by tidal currents, whereas the central and western passes are generally deeper and wider. Hunt and Stabeno (2005) summarize a series of changes that occur west of Samalga Pass, including higher chlorophyll concentrations (Mordy et al 2005), relatively more neritic zooplankton (Coyle 2005), and reduced frequency and abundance of coral (Heifetz et al. 2005) In addition, Logerwell et al. (2005) found a large percentage decline in demersal fish species between Unimak/Samalga and Amutka Passes.

*Growth differences*
Age data from the blackspotted/rougheye complex in the 2002, 2004, and 2008 EBS slope surveys and the 2002, 2004, and 2006 AI trawl surveys offer information on area-specific size at age. For comparison, the size at age data from the 2003, 2005, and 2007 GOA surveys was also examined. For the EBS slope survey, otoliths were collected from each rougheye encountered, and the mean length at age was computed. For the AI and GOA surveys, length-stratified collection of otoliths occurred in each sampling region, and unbiased estimates of mean length within each area were obtained by multiplying the estimated size composition of the population by the age-length key for that area and year (Kimura and Chikuni 1987; Dorn 1992). The size at age data for the AI includes the eastern, central, and western AI. No trends were observed across time, so the years from 2002-2008 were grouped together within each area. von Bertalanffy growth curves were fit to the mean lengths by assuming the deviations between the model prediction and the observed data follow a normal distribution.

The data on length at age indicates generally larger fish in the EBS than in the AI between the ages of about 10 and 30 (Figure 5). However, no size differences between EBS and AI samples were detected in fish older than about 30 years.

The resulting von-Bertalanffy growth parameters are as follows:

| Species | Area | Fish aged | $t_{izero}$ | *K* | $L_{inf}$ |
|---|---|---|---|---|---|
| Blackspotted/Rougheye | AI | 1046 | -2.14 | 0.07 | 50.20 |
| | EBS | 526 | -1.9 | 0.9 | 50.56 |
| | GOA | 1470 | -4.14 | 0.05 | 56.13 |

The similarity in size at age for ages greater than about 30 explains the similarity in $L_{inf}$ between the areas within the BSAI. A larger value of the von Bertalannfy *K* parameter is required to fit the larger size at age for fish between 10 and 30 years in the EBS (0.09) relative to the AI (0.07). The von Bertalanffy *k* parameter is correlated with the $t_{zero}$ parameter; however, the estimated $t_{zero}$ is similar between the EBS and AI (-2.1 and -1.9, respectively). The change in model parameters results in the predicted length at age for the EBS being at least 10% larger than that for the AI for all ages less than 15. These differences are sufficient to produce statistically significant results between each two-way comparison. Although there does appear to be a different pattern of growth between the EBS and AI, it is not clear what mechanisms could lead to differences in size at age for only a portion of the ages.

*Age composition data*

The estimated age compositions of blackspotted/rougheye rockfish were obtained from data from trawl surveys conducted from 2002 to 2008 (Figure 6). Most of the fish in the EBS slope were less than ~ 15 years whereas in each of the AI subareas a large portion of the age composition was between ages 15 and 40. An ANOVA was used to test for significant differences in the mean age between areas. For each haul with aged fish, a mean length at age was obtained by multiplying the length composition of the haul by the age-length key. The mean age for each haul was then weighted by the relative contribution of each haul (indicted by numerical CPUE) to the estimated population size for the stratum in which the haul occurred. The year of sampling was not a significant factor and the table of *P*-values below reflects comparisons of mean age by area for years between 2002 and 2008.

| Area | S. Bering Sea | Central AI | Eastern AI | Western AI |
|---|---|---|---|---|
| EBS | <0.01 | <0.01 | <0.01 | <0.01 |
| S. Bering Sea | | 0.65 | 0.99 | 0.99 |
| Central AI | | | 0.70 | 0.37 |
| Eastern AI | | | | 0.97 |

The mean age observed in the EBS slope survey differs significantly from the mean age in any of the other areas. None of the comparisons between the 4 subareas sampled in AI survey were significant.

## 2.3 Genetics

*Pairwise genetic differences (significant differences between geographically distinct collections)*

Blackspotted rockfish microsatellite data were analyzed in 2009, focusing on collections made along the Aleutian Islands and the Bering Sea slope west of 165° W ($n$ = 173). A homogeneity test was conducted with samples pooled into four groups, two relatively discrete sets of collections along the Aleutian Islands and two pools of collections along the Bering Sea slope for which a break point was chosen to produce groups that were similar in numerical and geographic size. Pairs of collections that differed significantly are separated with red lines (Figure 7); usually, more than a single locus exhibited the divergence in these tests. Note: the homogeneity tests were conducted to demonstrate that there were geographically-based genetic differences and not intended to provide geographic boundaries or estimates of spatial scale of genetic structure.

*Isolation by distance*

Am individual-based modification to isolation by distance (IBD) tests have been developed to allow more sensitive analyses that examine the divergence *between individuals* relative to the geographic distance that separates them (Rousset 2000). The result can be expressed in a linear relationship for species that are distributed in one dimension, which is interpreted as a habitat width that is small relative to its length, such as along the continental shelf break. Prior to development of the individual-based approach to IBD (Rousset 2000), geneticists generally made efforts to obtain large samples from each location that was sampled, which is conceptually what was done to conduct the homogeneity tests. This approach is still appropriate in many instances in which we are evaluating little-studied species and need to verify the tools (loci) for which we obtain data. However, that has not always been possible, hence the pooling of samples over a geographic range to assemble a sufficiently large sample for analysis. In applying the individual-based approach, it was fortuitous that multiple samples were spread along the continental shelf edge from the central to the eastern Bering Sea and again from the mid to the western Aleutian Islands (Figure 8).

Rousset's (2000) expression for low mutation rates, which are appropriate at short time scales such as for fisheries conservation issues, is

$$\frac{F_{ST}}{1-F_{ST}} \approx \frac{A_1}{4\sigma D_e} + \frac{1}{4\sigma^2 D_e} * \text{distance} \qquad (2)$$

where $A_1$ is a constant, $\sigma^2$ is the variance of the distance of parents from offspring (axial displacement), and $D_e$ is the effective density, which is the effective number of individuals ($N_e$) per unit distance. Our analysis showed a significant IBD relationship for the BSAI blackspotted data, which demonstrates a gradient of genetic divergence along the shelf edge of the Bering Sea and Aleutian islands ($P = 0.0049$).

*Dispersal distance << management areas*

Given a significant IBD relationship obtained from Eq. 2, an estimate of the dispersal distance between parents and offspring over one generation can be obtained from the slope of the IBD relationship $(4\sigma^2 D_e)^{-1}$. Assuming that a 95% confidence interval for dispersal is a distance 2σ (for normally distributed dispersal) on each side of the mean, a spatial scale of dispersion can be estimated as 4σ. An estimate of the ratio of effective population size to census size is required for estimation of $D_e$, and this ratio is routinely less than 0.1 for wild populations. A simple example shows how Eq. 2 can be used to estimate spatial scale of genetic divergence for blackspotted rockfish.

The linear distance from the Bering Sea slope to the western end of the Aleutian Islands is approximately 2500 km, and an estimate of the AI blackspotted/rougheye population size (from the 2008 stock assessment) is 25,575,055 fish. A 10% increase of this value accounts for the Bering Sea fish and yields an estimate of 28,132,561 fish, and a resulting linear density of ~ 28,132,561 million/2500 km = 11,253 fish per km. The width of rockfish habitat along the Aleutian Islands is probably 1/3 degree latitude (37.04 km), much smaller than the length and meeting the criteria for a linear distribution.

For fecund, long-lived marine species, the ratio of effective population size to census size may even be below 0.01. For BSAI blackspotted rockfish, a sensitivity analysis was conducted based upon five values of $D_e/D_{census}$ that range from 0.1 to 0.001, and three values for the slope of the IBD relationship (the mean estimate, and the upper and lower estimates associated with 95th percent confidence interval) (Table 2). From our calculations of the mean estimated for the slope of the relationship between genetic divergence and distance, and assuming a low $D_e/D_{census}$ ratio, we obtain a likely scale (4σ) of roughly 58 to 185 kilometers (Table 3). By using the lower estimate of a 95% confidence interval for the slope, the largest distance is 547 km. Clearly, the spatial scale of genetic divergence for any of the estimates in sensitivity analysis is much smaller than the distance along the continental shelf break that extends around the eastern Bering Sea to the western Aleutian Islands. The demographic implication is that movement of fish from birth to reproduction is at a much smaller scale than the geographic scale of the BSAI area. Consequently, whatever movement of fish occurs would be measured over a multigenerational time scale. The time frame of dispersal is not an annual rate, it is the generation time, which for blackspotted rockfish is more than 50 years.

## 2.4 Interpretation of the information regarding stock structure

A summary of the information in the template for BSAI blackspotted/rougheye rockfish is shown in Table 4. For any given data type, there may be multiple explanations consistent with the observed pattern; thus, an advantage of considering several types of data is more information on the potential differences between areas.

A number of hypotheses are consistent with the differences in age composition. In theory, the EBS could serve as a nursery area for fish in the AI, although the relative small population size and direction of ocean currents seem inconsistent with this hypothesis. An alternative hypothesis is that the habitat differences between the EBS slope and AI account for the differences seen in the survey. The amount of untrawlable ground is expected to be higher in the AI, and the differences in survey age compositions could occur if young blackspotted/rougheye rockfish in the AI occur more frequently in untrawlable grounds. The net used in the AI has a more rugged footrope compared to the net used for the EBS slope survey to account for a more rugged substrate, but the catchability of the nets is expected to be similar (R. Lauth, NMFS-AFSC, pers. comm.).
The differences in size at age data between the EBS and AI is interesting in that it is observed for ages approximately between 10 and 30 and not all ages; often, growth differences between areas are marked by differences in size at age for all observed ages. It is possible that the differences result from comparing a mixture of blackspotted/rougheye rockfish in the EBS to blackspotted rockfish in the AI; however, the AI growth curve for ages < 30 is similar to that for the GOA, which also has a mixture of blackspotted and rougheye rockfish. Differences in size at age between areas can be considered a type of “tag” reflecting fish movement, as one would expect little area differences if fish were moving between areas.

Given the differences in species composition between the AI and EBS, and the genetic differences observed for blackspotted rockfish, the most parsimonious interpretation of the data is that there is some structuring for blackspotted rockfish. Information on age composition and size at age for the blackspotted/rougheye complex is more difficult to interpret on a species level, although it does not appear to be consistent with a well-mixed stock complex across the BSAI.

## 3.0 Management implications

The SSWG report (Spencer et al. 2010) suggests that an “evaluation of the risks (biological and fishery) under alternative hypotheses concerning stock structure” be considered in the stock structure evaluation report. In particular, the risk evaluation would involve consideration of alternative management approaches for dealing with stock structure, such as setting separate ABCs and OFLs by area, or separate stock assessments and status determination criteria by area.

In the 2008 BSAI blackspotted rockfish assessment (Spencer et al. 2008), results from a stock assessment model for the Aleutian Islands were compared to those from a model for the entire BSAI area. For each of these models, various area allocations of ABCs and OFLs were considered, including a single ABC and OFL for the BSAI area, separate ABCs and OFLs for the BS and AI subareas, and a single BSAI OFL with separate ABCs by subarea. This analysis can be considered as the basis of a simple decision analysis, with states of nature corresponding to the two assessment models methods (either separate AI and EBS populations, or a single BSAI population) and management actions corresponding to the various spatial allocations of ABC and OFL. Both models gave similar results due to the small relative size of blackspotted/rougheye rockfish in the EBS management area. The AI-only model was accepted by the Plan Team, with EBS blackspotted/rougheye evaluated with Tier 5 methods. Currently, a single ABC and OFL is applied to the BSAI area.

For this report, the AI model was updated to include additional catch and age composition data and new estimates of growth curves, and is used to evaluate the ABC and OFL from the AI portion of the population. A full description of the methodology can be found in the 2008 BSAI blackspotted/rougheye assessment (Spencer et al. 2008). Calculations of the Tier 5 ABC and OFL for the EBS portion of the population are identical to that presented in the 2008 stock assessment. These results should be considered preliminary because the final 2010 assessment will include the 2010 AI trawl survey biomass estimate; the purpose of this analysis is to consider various area allocations of ABC and OFL computed with the most recent information. The estimated 2011 ABC and OFL are shown below:

| | Area allocation of ABC and OFL | | |
|---|---|---|---|
| Assessment Methodology | Separate ABC and OFL | Separate ABC, Combined OFL | Combined ABC and OFL |
| Age-structured AI model; BS harvest quotas obtained from Tier 5 methods | (a)<br>2011 AI ABC: 423 t<br>2011 BS ABC: 40 t<br>2011 AI OFL: 514 t<br>2011 BS OFL: 53 t | (b)<br>2011 AI ABC: 423 t<br>2011 BS ABC: 40 t<br>2011 BSAI OFL: 567 t | (c)<br>2011 BSAI ABC: 463 t<br>2011 BSAI OFL: 567 t |

The various management options presented above are considered with respect to their implications upon stock sustainability and current fishing practices.

*Implications for stock sustainability*

Much of the information in this report, including the different species composition and age composition between the EBS and AI, and the genetic data, suggest that it is likely that blackspotted/rougheye in the EBS are not well-mixed with blackspotted/rougheye in the AI. A concern for stock sustainability is that if disproportionate harvesting occurs within any BSAI subarea, fish may not be replenished quickly from other BSAI subareas. The long generation time for blackspotted/rougheye, and the nature of sporadic recruitment for rockfishes, further heightens the concern for stock sustainability.

An additional concern regarding stock sustainability is that the productivity and fishing rate reference points could differ between areas. For example, a sensitivity analysis was conducted to examine how much the difference in growth curves between the EBS and AI shown in Figure 5 would affect estimates of $F_{40\%}$ and $F_{35\%}$. The required data for this analysis was obtained from the updated AI model, and only the weight at age is changed. The results are shown below:

| SPR rate | Growth Curve AI (2002-2006) | EBS (2002-2008) | Percent Change |
|---|---|---|---|
| $F_{40\%}$ | 0.0423 | 0.0464 | 9.55 |
| $F_{35\%}$ | 0.0522 | 0.0576 | 10.27 |

Thus, the change in growth curves alone would result in an approximately 10% increase in commonly used fishing rate reference points.

The current management approach is to have the ABC and OFL apply to the BSAI area (cell c above), with additional steps such as relatively low maximum retainable allowance (MRA) levels and placing the fishery on bycatch status. Although this has resulted in relatively low levels of bycatch in recent years, there are some risks associated with this approach. First, the area-wide harvest quotas would not necessarily prevent disproportionate bycatch with BSAI subareas. For example, lower catch in the AI could be offset by higher catches in the EBS. Second, without area-specific OFLs and/or ABCs, if disproportionate bycatch occurred it would not necessarily be recognized with an in-season management system that relied upon BSAI-wide harvest levels. Although comparison of catches to potential area-specific harvest quotas are presented in the annual stock assessments, these comparisons are produced on an biennial basis and applied to historical data, but not used for in-season management.

The two alternatives to the current spatial allocation of harvest address these issues. The most conservative approach is separate AI and EBS ABCs and OFLs (cell a), as this would ensure that harvest in each area would not exceed the area-specific OFL. However, given the recent area-specific catch history (discussed below), the prevention of targeting on these species, and the low MRA levels, it is possible that the area-specific OFLs would not be reached even without area-specific OFL levels. An intermediate approach is shown in cell (b), in which has area-specific ABCs but a BSAI-wide OFL. This approach would prohibit retention of blackspotted and rougheye rockfish once the area-specific ABC has been reached, and could thus help prevent the process of “topping off” on these species.

Given that targeting is not currently allowed on BSAI blackspotted/rockfish, one may question the utility of area-specific ABCs, which would essentially prevent targeting but not necessarily bycatch. We identify several advantages to area-specific ABCs in this situation. First, as mentioned above, it allows for more effective monitoring of the area-specific catch by providing area-specific catch targets. For example, if it was observed that the catch in a particular area was approaching the area ABC level, fishing effort could potentially be directed to areas with lower rates of bycatch. Such monitoring and evaluation of catch by BSAI subarea would generally not be possible with BSAI-wide ABC levels. Second, a BSAI-wide ABC level for blackspotted/rougheye rockfish implies that management concerns over spatially disproportionate harvesting apply only to the entire BSAI area. However, given that evaluation of the spatial distribution of the catch is a common request for the biennial stock assessment, the current spatial allocation of ABC does not appear to be consistent with the management intent of spatially distributing harvest. Finally, area-specific ABCs would be consistent with the recognition of some structuring with the BSAI area, as well as being consistent with the way ABCs are applied for most stocks in the north Pacific. For these reasons, the SSWG has recommended applying area-specific ABCs as a general principle given the uncertainty of stock structure (Spencer et al. 2010).

*Risks/costs to the fishery and regulatory system*

A necessary first step to evaluate the risks/costs of area-specific harvest quotas to the fishing fleet is to identify the extent to which current fishing practices would be affected. Three factors in recent years have reduced the likelihood of exceeding ABC and OFL levels under current fishing practices. First, single species management (notwithstanding the recent discovery of *S. melanostictus*) was adopted in 2004, so blackspotted/rougheye rockfish are no longer managed in a complex along with shortraker rockfish and other rockfish species. This has helped reduce the substantial catches seen in earlier years such as 2001. Second, the development of an age-structured model for AI blackspotted/rougheye rockfish in 2008 has substantially increased the ABC and OFL levels. For example, the ABC level increased from 202 in 2008 to 539 t in 2009. Third, the fishing fleet appears to have increased their skill in avoiding blackspotted/rougheye rockfish bycatch, perhaps as a result of several years with separate management for blackspotted/rougheye and shortraker rockfish. The catch of blackspotted/rougheye rockfish has not been above 200 t since 2002, and the 2009 and 2010 AI catches are approximately 60% below the potential AI ABC level. In the EBS, catches from 2005 to 2009 exceeded 12 tons only in 2008, and catches in the other years were substantially below the ABC levels. Assuming these levels of catch occur in the future, there would appear to be limited impacts to the fishing fleet of allocation of ABC and OFL to the AI and EBS subareas.

There is also a regulatory cost of area-specific ABC and/or OFL levels. However, given that subarea ABCs are commonly used in the BSAI and a management framework exists by which subarea ABCs can be implemented, one might expect that regulatory costs would be relatively minor (particularly if only two subareas are adopted). More detailed information on regulatory costs could be obtained from personnel in the NMFS Alaska Regional Office.

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Table 1. Framework of types of information to consider when defining spatial management units (from Spencer et al. 2010).

| ***HARVEST AND TRENDS*** | |
|---|---|
| Factor and criterion | Justification |
| Fishing mortality (5-year average percent of $F_{abc}$ or $F_{ofl}$ ) | If this value is low, then conservation concern is low |
| Spatial concentration of fishery relative to abundance (Fishing is focused in areas << management areas) | If fishing is focused on very small areas due to patchiness or convenience, localized depletion could be a problem. |
| Population trends (Different areas show different trend directions) | Differing population trends reflect demographic independence that could be caused by different productivities, adaptive selection, differing fishing pressure, or better recruitment conditions |
| ***Barriers and phenotypic characters*** | |
| Generation time (e.g., >10 years) | If generation time is long, the population recovery from overharvest will be increased. |
| Physical limitations (Clear physical inhibitors to movement) | Sessile organism; physical barriers to dispersal such as strong oceanographic currents or fjord stocks |
| Growth differences (Significantly different LAA, WAA, or LW parameters) | Temporally stable differences in growth could be a result of either short term genetic selection from fishing, local environmental influences, or longer-term adaptive genetic change. |
| Age/size-structure (Significantly different size/age compositions) | Differing recruitment by area could manifest in different age/size compositions. This could be caused by different spawning times, local conditions, or a phenotypic response to genetic adaptation. |
| Spawning time differences (Significantly different mean time of spawning) | Differences in spawning time could be a result of local environmental conditions, but indicate isolated spawning stocks. |
| Maturity-at-age/length differences (Significantly different mean maturity-at-age/ length) | Temporally stable differences in maturity-at-age could be a result of fishing mortality, environmental conditions, or adaptive genetic change. |
| Morphometrics (Field identifiable characters) | Identifiable physical attributes may indicate underlying genotypic variation or adaptive selection. Mixed stocks w/ different reproductive timing would need to be field identified to quantify abundance and catch |
| Meristics (Minimally overlapping differences in counts) | Differences in counts such as gillrakers suggest different environments during early life stages. |
| ***Behavior & movement*** | |
| Spawning site fidelity (Spawning individuals occur in same location consistently) | Primary indicator of limited dispersal or homing |
| Mark-recapture data (Tagging data may show limited movement) | If tag returns indicate large movements and spawning of fish among spawning grounds, this would suggest panmixia |
| Natural tags (Acquired tags may show movement smaller than management areas) | Otolith microchemistry and parasites can indicate natal origins, showing amount of dispersal |
| ***Genetics*** | |
| Isolation by distance (Significant regression) | Indicator of limited dispersal within a continuous population |
| Dispersal distance (<<Management areas) | Genetic data can be used to corroborate or refute movement from tagging data. If conflicting, resolution between sources is needed. |
| Pairwise genetic differences (Significant differences between geographically distinct collections) | Indicates reproductive isolation. |

Table 2. Catch (t) of blackspotted/rougheye rockfish in the AI and EBS compared to potential ABCs and OFLs.

| | Aleutian Islands | | | | | EBS | | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | ABC | OFL | Catch | % change between catch and ABC | | ABC | OFL | Catch | % change between catch and ABC |
| 2001 | 230 | 306 | 585 | 154 | | 32 | 43 | 15 | -53 |
| 2002 | 230 | 306 | 249 | 8 | | 33 | 44 | 11 | -66 |
| 2003 | 215 | 287 | 175 | -19 | | 32 | 43 | 17 | -47 |
| 2004 | 174 | 231 | 184 | 6 | | 21 | 29 | 24 | 13 |
| 2005 | 198 | 265 | 78 | -61 | | 25 | 33 | 12 | -52 |
| 2006 | 199 | 265 | 196 | -1 | | 25 | 33 | 7 | -73 |
| 2007 | 179 | 238 | 156 | -13 | | 23 | 31 | 10 | -57 |
| 2008 | 179 | 238 | 185 | 3 | | 23 | 31 | 29 | 25 |
| 2009 | 499 | 607 | 197 | -61 | | 40 | 43 | 12 | -69 |
| 2010 | 505 | 613 | 163 | -68 | | 42 | 56 | 13 | -70 |

Table 3. The linear density of *S. melanostictus* that was obtained from abundance surveys was used with a set of plausible $N_e/N_{census}$ ratios to evaluate effective densities ($D_e$) which were in turn used to estimate ranges of distances (4σ) that represent the spatial scale of population structure from the slope (*b*) of the relationship between genetic divergence and geographic distance.

| | | mean | | Lower 5% | | Upper 5% | |
|---|---|---|---|---|---|---|---|
| | | $b$ | $b^{-1}=4D_e\sigma^2$ | $b$ | $b^{-1}=4D_e\sigma^2$ | $b$ | $b^{-1}=4D_e\sigma^2$ |
| | | $1.04*10^{-5}$ | $9.60*10^{4}$ | $1.19*10^{-6}$ | $8.43*10^{5}$ | $2.01*10^{-5}$ | $4.98*10^{4}$ |
| $N_e/N_{census}$ | $D_e$ | $\sigma^2$ | $4\sigma$ | $\sigma^2$ | $4\sigma$ | $\sigma^2$ | $4\sigma$ |
| 0.1 | 1125 | 21 | 18 | 187 | 55 | 11 | 13 |
| 0.05 | 563 | 43 | 26 | 375 | 77 | 22 | 19 |
| 0.01 | 113 | 213 | 58 | 1873 | 173 | 111 | 42 |
| 0.005 | 56 | 427 | 83 | 3746 | 245 | 222 | 60 |
| 0.001 | 11 | 2134 | 185 | 18732 | 547 | 1108 | 133 |

Table 4. Summary of available data on stock identification for BSAI blackspotted/rougheye rockfish.

| ***HARVEST AND TRENDS*** | |
|---|---|
| Factor and criterion | Available information |
| Fishing mortality (5-year average percent of $F_{abc}$ or $F_{ofl}$) | Recent catch in the BS and AI areas are comparable to potential area-specific ABCs |
| Spatial concentration of fishery relative to abundance (Fishing is focused in areas << management areas) | Catches are distributed throughout the Aleutian Islands and along the EBS slope north to the Pribilof Islands |
| Population trends (Different areas show different trend directions) | Population trends appear to be stable in the Aleutian Islands and EBS slope |
| ***Barriers and phenotypic characters*** | |
| Generation time (e.g., >10 years) | The generation time is approximately 53 years |
| Physical limitations (Clear physical inhibitors to movement) | The Aleutian North Slope Current does not extend west of the central AI, limiting the connection with the EBS slope for the central and western AI. Also, studies of the AI ecosystem indicate a "biophysical transition zone" at Samalga Pass (Logerwell et al. 2005) |
| Growth differences (Significantly different LAA, WAA, or LW parameters) | Differences growth curves and length-at-age relationships between the EBS and AI. However, differences in size at age are not observed for all ages |
| Age/size-structure (Significantly different size/age compositions) | Significant differences in both age and size compositions between the EBS and Aleutian Island subareas based upon survey data from 2002 to 2008. |
| Spawning time differences (Significantly different mean time of spawning) | Unknown |
| Maturity-at-age/length differences (Significantly different mean maturity-at-age/ length) | Unknown |
| Morphometrics (Field identifiable characters) | Unknown (within either blackspotted or rougheye rockfish) |
| Meristics (Minimally overlapping differences in counts) | Unknown (within either blackspotted or rougheye rockfish) |
| ***Behavior & movement*** | |
| Spawning site fidelity (Spawning individuals occur in same location consistently) | Unknown |
| Mark-recapture data (Tagging data may show limited movement) | Mark-recapture data not available |
| Natural tags (Acquired tags may show movement smaller than management areas) | Unkown |
| ***Genetics (for blackspotted rockfish only)*** | |
| Isolation by distance (Significant regression) | Significant pattern of isolation by distance |
| Dispersal distance (<<Management areas) | Single generation dispersal scale of <= ~ 550 km, which is << the combined BSAI management area |
| Pairwise genetic differences (Significant differences between geographically distinct collections) | Significant pairwise difference between EBS and Aleutian Island genetic samples |

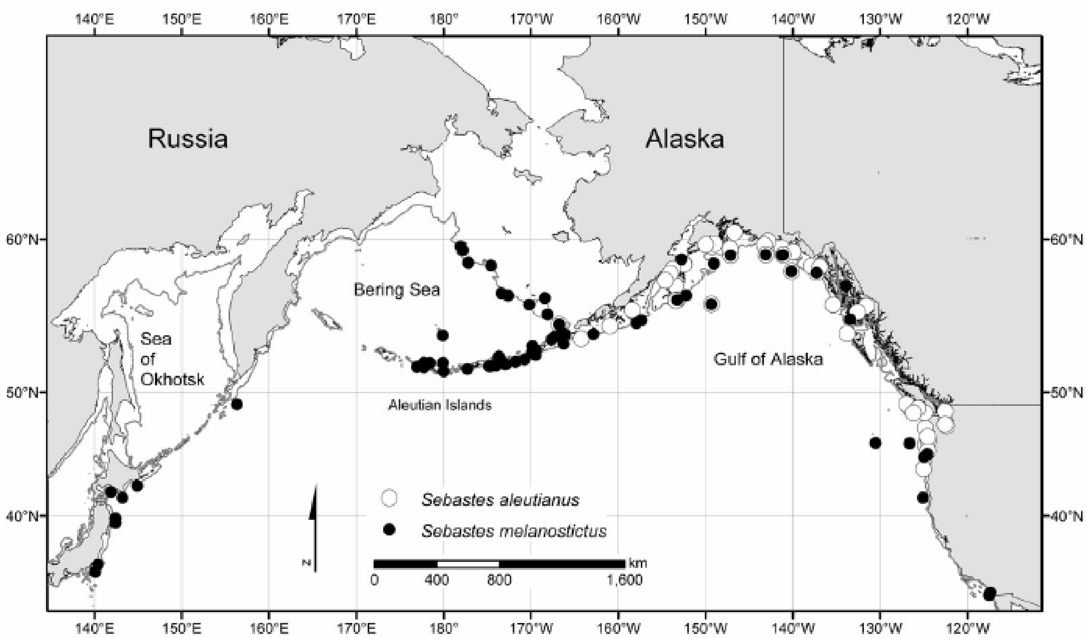



Figure 1. Distribution blackspotted rockfish (*S. melanostictus*) and rougheye rockfish (*S. aleutianus*) based upon genetic, morphometric, and meristic analyses. From Orr and Hawkins (2008).

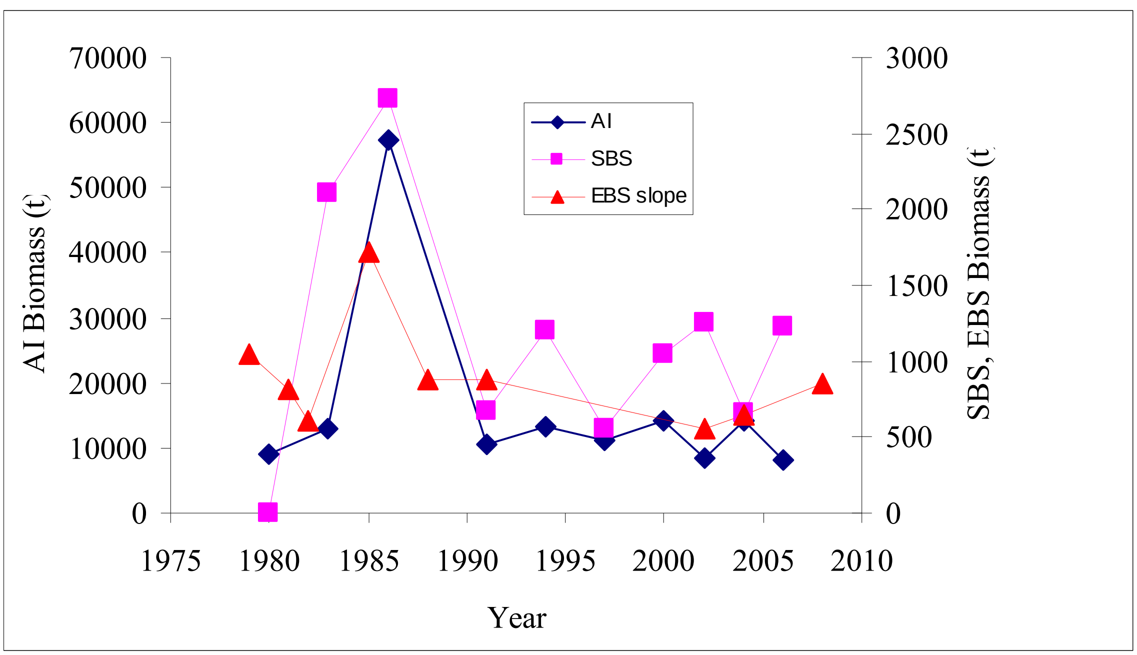



Figure 2. Biomass trends from trawl surveys in the BSAI.

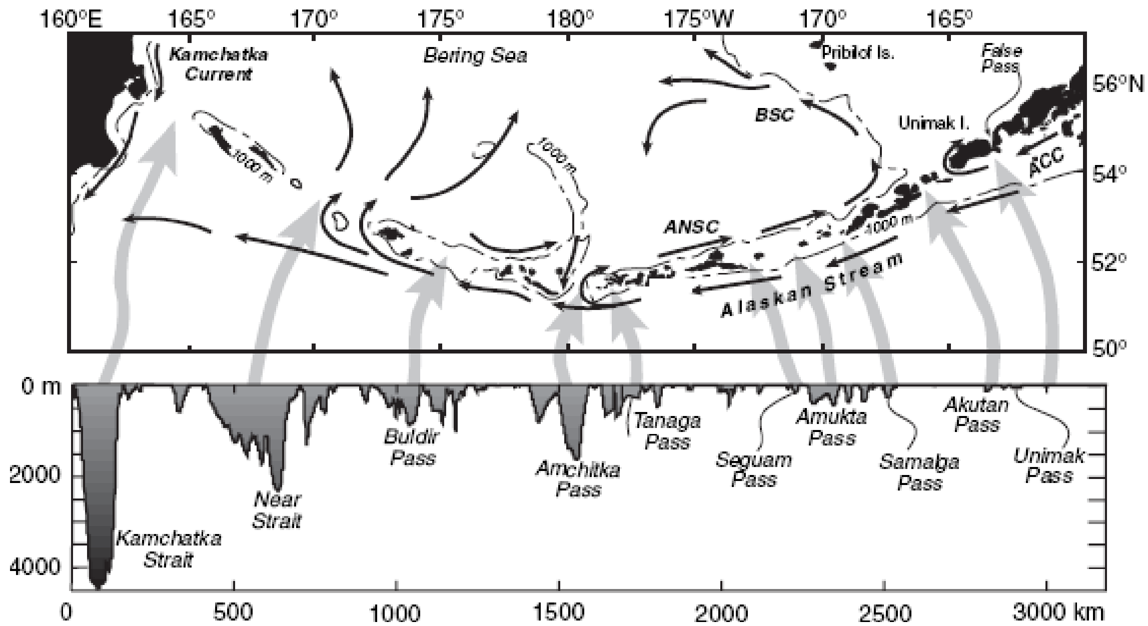



Figure 3. Schematic of ocean currents in the Aleutian Islands, showing the Alaska Steam, the Alaska Coastal Current (ACC), and the Aleutian North Slope Current (ANSC) (from Stabeno et al. 2005). The lower panel shows the location and depth of ocean passes in the Aleutian Islands archipelago.

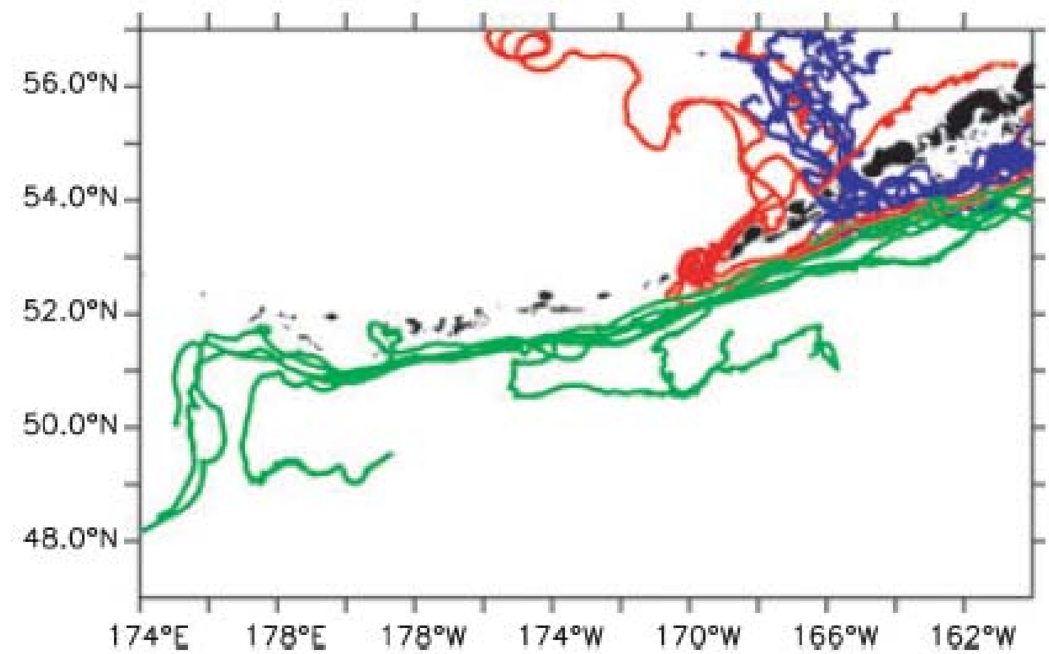



Figure 4. Trajectories for drifters deployed south of the Alaska Peninsula in 2001 and 2002 which crossed 160° W (from Ladd et al. 2005). Trajectories are color-coded to indicate which, if any, pass they enter, which corresponds to on/off shelf position of deployment. Drifters deployed in shallow water tended to go through Unimak or Akutan Pass (blue), drifters deployed on the shelf break tended to go through Samalga Pass (red), and drifters deployed offshore of the shelf break tended to continue in the Alaska Stream (green).

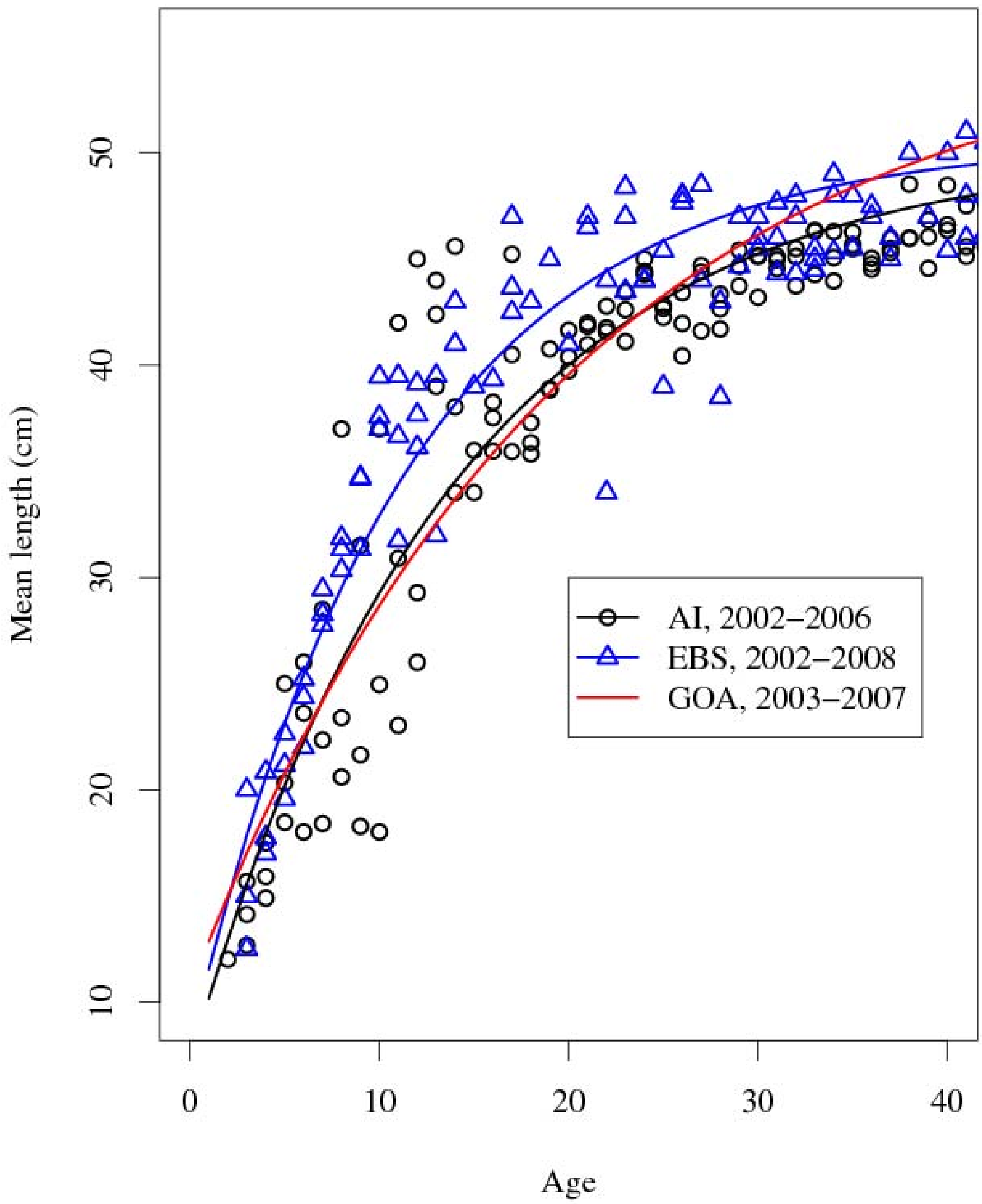
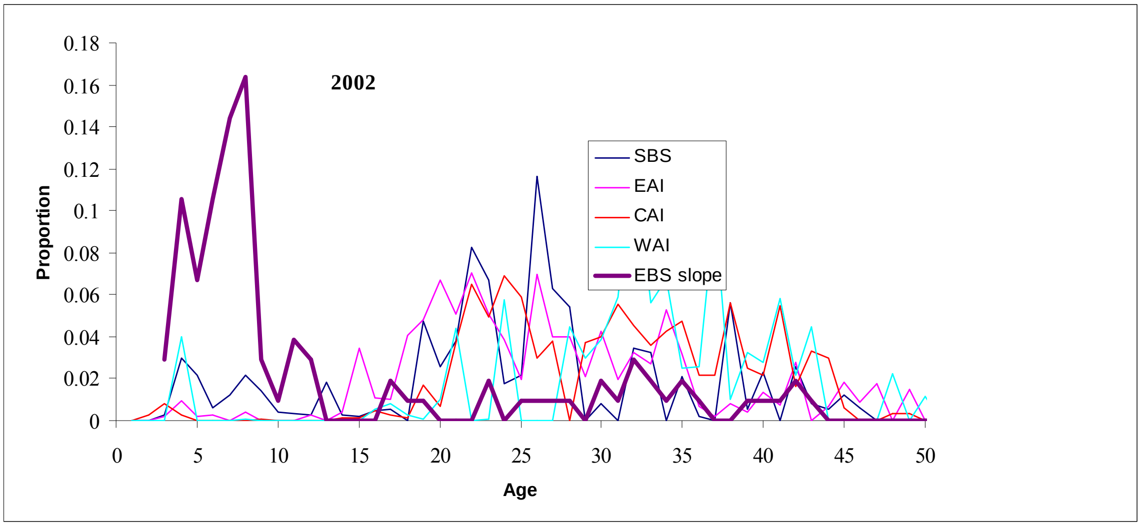
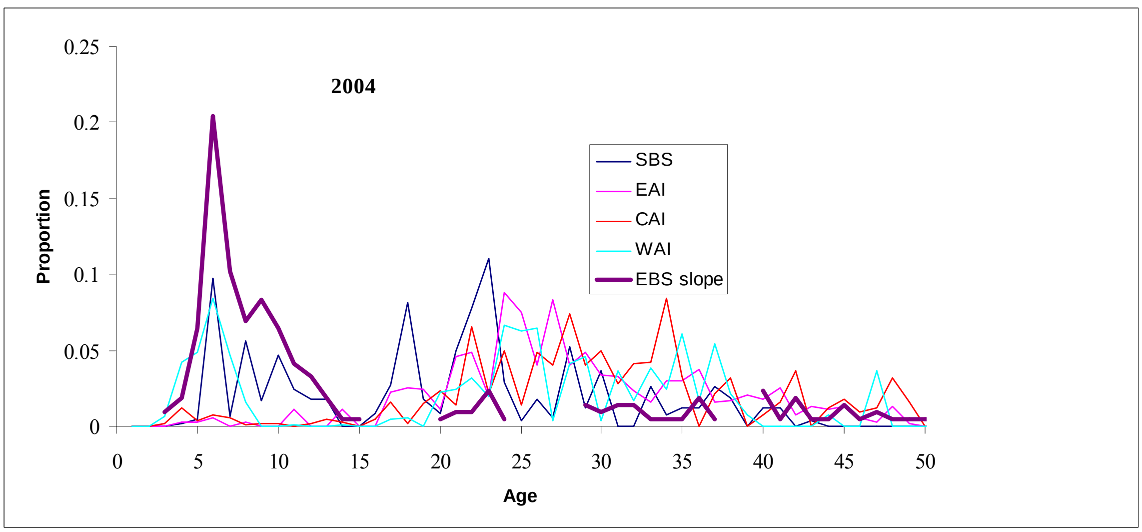



Figure 5. Size at age and estimated von Bertalanffy growth curves for the Aleutians Islands (includes western, central, and eastern AI from 2002-2006) and the Bering Sea slope from 2002-2008. Growth curves were fit to all ages; ages over 40 are not shown in order to highlight the area with the largest differences between the EBS and AI. For comparison, the fitted growth curve for the GOA (from 2003-2007) is also shown.



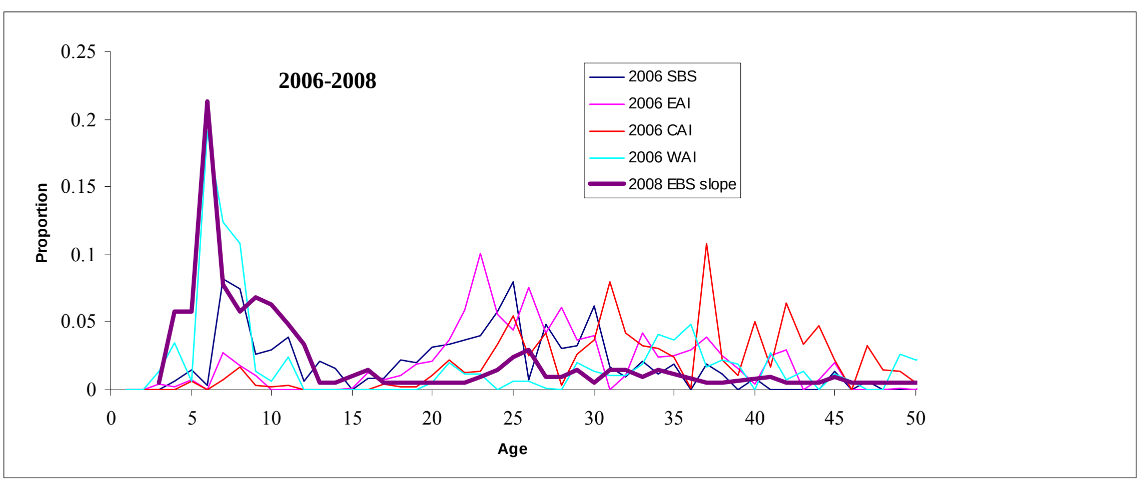




Figure 6. Age composition of rougheye rockfish from the AI and EBS slope surveys.

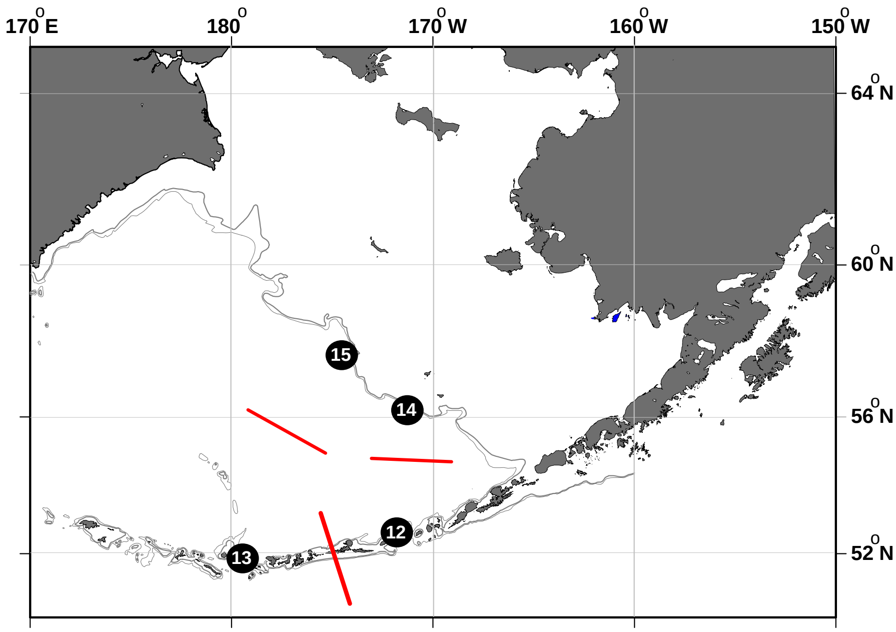



Figure 7. Map of geographic centers of collections of *S. melanostictus* which were subjected to genetic analysis. The set of populations was not genetically homogeneous. Red lines reflect significant pairwise tests (based on *G*-tests for which significance levels were estimated by Monte-Carlo simulations) with a sequential Bonferroni adjustment.

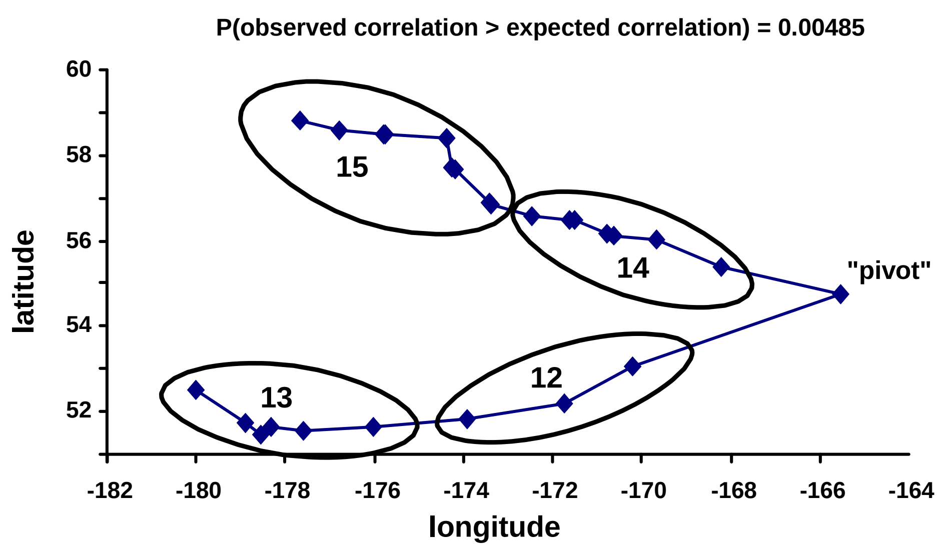



Figure 8. Distribution of all sampling locations along the Bering Sea shelf break. Diamonds demonstrate the geographic spread, but not the numbers of individuals. The ellipses in this figure represent the pools of collections analyzed previously. For example the six collection sites in 15 were combined for previous analyses. The "pivot" in the figure is the easternmost corner of the shelf edge in the Bering Sea (Figure 7).