13. Assessment of the Northern Rockfish stock in the Bering Sea/Aleutian Islands

by

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Executive Summary

The last full assessment for northern rockfish was presented to the Plan Team in 2010, and an updated assessment was presented in 2011. The 2012 assessment includes a maturity ogive fit to data collected in 2004 and 2010, and decreases the estimated age at 50% maturity from 12.8 to 8.2.

An evaluation of stock structure was presented at the September, 2012, meeting of the BSAI Groundfish Plan Team, and is included as an Appendix to this assessment. Genetic data show stock structure within the BSAI area, and the maximum estimate of dispersal distance was ~ 200 km. Differences in size at age and were also detected, with smaller northern rockfish in the western AI and larger northern rockfish in the eastern AI and southern Bering Sea (SBS) area.

While harvest rates for the BSAI area are relatively low, the exploitation rates vary by BSAI subarea with higher rates in the eastern and central AI than in the western AI. Since 2004, the exploitation rates in eastern and central AI have occasionally exceeded the exploitation rate that would occur from fishing at F40% (defined as $U_{F40\%}$), which were calculated based on the estimates of maturity and selectivity in the 2012 assessment and applied retrospectively to numbers at age for previous years as estimated in the 2012 assessment. The estimates of $U_{F40\%}$ are substantially higher than those obtained from using the maturity ogive in previous assessments.

The following changes were made to northern rockfish assessment relative to the November 2010 SAFE:

Summary of Changes in Assessment Inputs

Changes in the input data:

1) Catch updated through October 6, 2012.
2) The biomass estimate and length composition from the 2012 AI survey was added to the model input data.
3) The 2008, 2009, and 2011 fishery age compositions and the 2010 fishery length composition.
4) The maturity curve was estimated based on recent data from the Aleutian Islands.

Changes in the assessment methodology:

1) A sensitivity analysis was conducted to evaluate how the age and length plus groups affect the fit to various model components. Based on this analysis, the age and length plus groups were increased to 40 years and 38 cm (previous values were 23 years and 34 cm).

2) The age error matrix was recomputed to better account for aging error within the plus group.

Summary of Results

BSAI northern rockfish are not overfished or approaching an overfished condition. The recommended 2013 ABC and OFL are 9,850 t and 12,187 t, which are 16% and 18% increases from the values specified last year for 2013 of 8,489 t and 10,354 t. A summary of the recommended ABCs and OFLs from this assessment relative the ABC and OFL specified last year is shown below:

Quantity	As estimated or specified last year for: 2012	2013	As estimated or recommended this year for: 2013	2014
M (natural mortality rate)	0.0427	0.0427	0.0413	0.0413
Tier	3a	3a	3a	3a
Projected total (age 3+) biomass (t)	202,173	202,623	195,446	195,779
Female spawning biomass (t)				
Projected	72,211	71,764	84,697	83,784
$B_{100\%}$	126,528	126,528	147,918	147,918
$B_{40\%}$	50,611	50,611	59,167	59,167
$B_{35\%}$	44,285	44,285	51,771	51,771
F_{OFL}	0.071	0.071	0.079	0.079
$maxF_{ABC}$	0.058	0.058	0.063	0.063
F_{ABC}	0.058	0.058	0.063	0.063
OFL (t)	10,500	10,354	12,187	12,024
maxABC (t)	8,608	8,489	9,850	9,322
ABC (t)	8,608	8,489	9,850	9,322
Status	As determined in 2011 for: 2010	2011	As determined in 2012 for: 2011	2012
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

Summaries for the Plan Team

The following table gives the recent biomass estimates, catch, and harvest specifications, and projected biomass, OFL and ABC for 2013-2014.

Year	Biomass[1]	OFL	ABC	TAC	Catch
2011	201,429	10,600	8,670	4,000	2,762
2012	202,173	10,500	8,608	4,700	2,232[2]
2013	195,446	12,187	9,850		
2014	195,779	12,024	9,322		

[1] Total biomass from age-structured projection model.
[2] Catch as of October 6, 2012.

Responses to SSC and Plan Team Comments on Assessments in General

The minutes of the December, 2011, meeting of the SSC includes the following general request for age-structured assessments:

We recommend that all assessment authors (Tier 3 and higher) bring retrospective analyses forward in next year's assessments.

Retrospective model runs are included in this assessment.

Responses to SSC and Plan Team Comments Specific to this Assessment

1) *The model consistently underestimates the early fishery age composition and overestimates the recent fishery age compositions. This should be evaluated and model improvements should be explored to resolve this pattern and/or attempt to better fit age composition data.*
2) *Consider alternative selectivity patterns for the fishery.*
3) *Consider alternate selectivity time periods and state the rationale.*
4) *Explore increasing the number of age bins and evaluate model fit to the data.*

With regard to item 1) above, the issue was the overestimation of the proportion at age for older fish (i.e. ages 20 and above). This issue has been resolved by better accounting for aging error within the age-plus group.

Items 2) and 3) will be evaluated at the Center of Independent Experts review of Alaska rockfish, which is scheduled for spring, 2013. Sufficient time was not available at the September, 2012 Plan Team meeting to review alternate selectivity, in part because of the focus on stock structure issues for northern rockfish and blackspotted/rougheye rockfish.

The effect of the number of age and length bins on model fits to data is explored in this assessment.

Introduction

Northern rockfish (*Sebastes polyspinus*) inhabit the outer continental shelf and upper slope regions of the North Pacific Ocean and Bering Sea. Northern rockfish (*Sebastes polyspinus*) in the Bering Sea/Aleutians Islands (BSAI) region were assessed under Tier 5 of Amendment 56 of the NPFMC BSAI Groundfish FMP until 2004. The reading of archived otoliths from the Aleutian Islands (AI) surveys allowed the development of an age-structured model for northern rockfish beginning in 2003. Since 2004, BSAI northern rockfish have been assessed as a Tier 3 species in the BSAI Groundfish FMP.

Information on Stock Structure

A stock structure evaluation was conducted in 2012 and is included in this assessment as Appendix A. A variety of types of data were considered, including genetic data, potential barriers to movement, growth differences, and spatial differences in growth and age and size structure.

Several genetic tests were conducted on northern rockfish samples obtained in the 2004 Aleutian Islands and EBS trawl surveys (Gharrett et al. 2012). A total of 499 samples were collected at six locations ranging from the EBS slope to the western Aleutian Islands, and analyses were applied to 11 microsatellite loci. Information on the spatial population structure was obtained from the spatial analysis of molecular variance (SAMOVA; Dupanloup et al. 2002), which identified sets of collections that showed maximum differentiation. Three groups were identified: 1) the eastern Bering Sea; 2) two collections west of Amchitka Pass; and 3) three collections between Amchitka Pass and Unimak Pass. The genetic data also show a statistically significant pattern of isolation by distance, indicating genetic structure being produced from the dispersal of individuals being smaller than the spatial extent of the sampling locations. A range of expected lifetime dispersal distance were estimated, reflecting different assumptions regarding effective population size and migration rates of spawners, and the estimated lifetime dispersal distances did not exceed 250 km. This estimated dispersal distance is comparable to other *Sebastes* species in the north Pacific, which have ranged from 4 to 40 for near shore species such as grass rockfish (Buonaccorsi et al. 2004), brown rockfish ((Buonaccorsi et al. 2005), and vermilion rockfish (Hyde and Vetter 2009), and up to 111 km for deeper species such as POP (Palof et al. 2011) and darkblotched rockfish (Gomez-Uchida and Banks 2005). The demographic implication is that movement of fish from birth to reproduction is at a much smaller scale than the geographic scale of the BSAI area. Finally, it is important to recall that the time unit for the estimated dispersal is not years, but generations, and the generation time for northern rockfish is more than 36 years.

Aleutian Island trawl survey data was used to estimate von Bertalannfy growth curves by areas, and show increasing size at age from the western AI to the eastern AI. The largest difference in the growth curves was in the rate parameter *K*, which was smallest in the western Aleutians, indicating that fish in this area approached their asymptotic size more slowly than fish in the EAI and SBS.

Spatial differences in age compositions, obtained from the AI trawl surveys from 2002, 2004, and 2006, were evaluated by testing for significant differences in mean age between areas. Significant differences were observed in the mean age between subareas for individual years, but a consistent pattern did not emerge across the years.

Finally, any potential physical limitations to movement were considered. Physical barriers are rare in marine environments, but the Aleutian Islands are unique due to the occurrence of deep passes, typically exceeding 500 m, that may limit the movement of marine biota. For example, Logerwell et al. (2005) identify a “biophysical transition zone” occurs at Samaga Pass. Northern rockfish are a demersal species captured during the AI trawl survey at depths between 100 m and 200 m, so adult rockfish traversing the much deeper AI passes would require greater utilization of pelagic habitats or deeper depths than currently observed in the AI trawl surveys. Movement of larvae between areas is likely a function of ocean currents. On the north side of archipelago, the connection between the east and west Aleutians is limited due to the break associated with Petral Bank and Bowers Ridge, which results in water flowing away from the Aleutian Islands archipelago. On the south side of the Aleutian Islands, the Alaska Stream provides much of the source of the Alaska North Slope Current (ANSC) via flow through Amutka Pass and Amchitka Pass. However, The Alaska Stream separates from the slope west of the Amchitka Pass and forms meanders and eddies, perhaps limiting the connection between the east and west Aleutians.

Fishery

BSAI foreign and joint venture rockfish catch records from 1977 to 1989 are available from foreign “blend” estimates of total catch by management group, and observed catches from the North Pacific Observer Program database. The foreign catch of BSAI rockfish during this time was largely taken by Japanese trawlers, whereas the joint-venture fisheries involved partnerships with the Republic of Korea. Because northern rockfish are taken as bycatch in the BSAI area, historical foreign catch records have not identified northern rockfish catch by species. Instead, northern rockfish catch has been reported in a variety of categories such as “other species” (1977, 1978), “POP complex” (1979-1985, 1989), and “rockfish without POP” (1986-1988).

Rockfish management categories in the domestic fishery since 1991 have also included multiple species. From 1991 to 2000, northern rockfish harvest in the EBS was included in the “other red rockfish” category, whereas harvest in the Aleutian Islands was reported in a “northern/sharpchin” category. In 2001, northern rockfish in the EBS were managed in a “northern/sharpchin” category, matching the species complex in the AI, and the management was combined across the BSAI area. In 2002, sharpchin rockfish were dropped from the complex because of their sparse catches, leaving single-species management category of northern rockfish. The ABCs, TACS, and catches by management complex from 1988-2012 are shown in Table 1.

Since 2002, the blend and catch accounting system (CAS) databases has reported catch of northern rockfish by area. From 1991-2001, species catches were reconstructed by computing the harvest proportions within management groups from the North Pacific Foreign Observer Program database, and applying these proportions to the estimated total catch obtained from the NOAA Fisheries Alaska Regional Office “blend” database. This reconstruction was conducted by estimating the northern rockfish catch for each area (i.e., the EBS and each of the three AI areas) and gear type from 1994-2001. For 1991-1993, the Regional Office blend catch data for the Aleutian Islands was not reported by AI subarea, and the AI catch was obtained using the observer harvest proportions by gear type for the entire AI area. Similar procedures were used to reconstruct the estimates of catch by species from the 1977-1989 foreign and joint venture fisheries. Estimated domestic catches in 1990 were obtained from Guttormsen et al. 1992. Catches from the domestic fishery prior to the domestic observer program were obtained from PACFIN records.

Catches of northern rockfish since 1977 by area are shown in Table 2. Northern rockfish catch prior to 1990 was small relative to more recent years (with the exception of 1977 and 1978) (Table 2). Harvest data from 2004-2012 indicates that approximately 84% of the BSAI northern rockfish are harvested in the Atka mackerel fishery. Prior to 2011, much of the northern rockfish catch occurred in the western and central Aleutian Islands, reflecting the high proportion of Atka mackerel fishing in these areas (Table 3). However, restrictions on Atka mackerel fishing in the western Aleutians beginning in 2011 have restricted the current northern rockfish harvest in this area. Northern rockfish are patchily distributed and are harvested in relatively few areas within the broad management subareas of the Aleutian Islands, with important fishing grounds being Petral Bank, Sturdevant Rock, south of Amchitka I., and Seguam Pass (Dave Clausen, NMFS-AFSC, personal communication).

Information on proportion discarded is generally not available for northern rockfish in years where the management categories consist of multi-species complexes. However, because the catches of sharpchin rockfish are generally rare in both the fishery and survey, the discard information available for the "sharpchin/northern" complex can interpreted as northern rockfish discards. This management category was used in 2001 in the EBS, and from 1993-2001 in the AI. Prior to 2003 the discard rates were generally above 80%, with the exception of the mid-1990s when some targeting occurred in the Aleutians Islands (Table 4). Recent discard rates have been decreasing. For example, the discard rate in the EBS has declined from 92% in 2002 to 15% in 2011, and the discard rate in the Aleutian Islands has declined from 91% to 18% over the same period.

Data

Fishery Data

The fishery data is characterized by inconsistent sampling of lengths and ages (Table 5). In some years, such as 1984 and 1987 over 700 fish lengths were obtained but these data samples came from a limited number of hauls. Additionally, the length data from the foreign fishery tended to originate from predominately one location in each year, and was not consistent between years. For example, the 1977 and 1978 fishery length data were collected from Tahoma Bank in the western Aleutians, whereas samples in 1984 were obtained from Seguam Pass and samples in 1987 were obtained from Petral Bank. In the domestic fishery, changes in observer sampling protocol since 1999 have improved the distribution of hauls from which northern rockfish age and length data are collected.

In this assessment annual length frequency data were selected on the basis of consistency in sampling location and the number of samples collected. Foreign fishery length data from 1977 and 1978 were used, in part, because of the consistency in their sampling location, the increased numbers of hauls from which they were obtained, and the absence of other length composition data during this portion of the time series. Domestic fishery length data from 1996, 1998-1999, and 2010 were used, and the length and age data from 2000-2009 and 2011 were used to estimate the age-frequency of the fishery catch.

The fishery age composition data indicates the relatively strong cohorts in 1984-1985 and 1995, as each of these cohorts was observed as relatively abundant in multiple years of fishery age composition data (Figure 1).

Survey data

Biomass estimates for other red rockfish were produced from cooperative U.S.-Japan trawl survey from 1979-1985 on the eastern Bering Sea slope, and from 1980-1986 in the Aleutian Islands. U.S trawl surveys, conducted by the National Marine Fisheries Service (NMFS) were conducted in 1988, 1991, 2000, 2002, 2004, 2008, 2010, and 2012 on the eastern Bering Sea slope, and in 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, and 2012 in the Aleutian Islands (Table 6). The Aleutian Islands survey scheduled for 2008 was canceled to due lack of funding. Differences exist between the 1980-1986 cooperative surveys and the 1991-2012 from the U.S. domestic surveys with regard to the vessels and gear design used (Skip Zenger, National Marine Fisheries Service, personal communication). For example, the Japanese nets used in the 1980, 1983, and 1986 cooperative surveys varied between years and included large roller gear, in contrast to the poly-nor'eastern nets used in the current surveys (Ronholt et al 1994), and similar variations in gear between surveys occurred in the cooperative EBS surveys.

In this assessment, the AI surveys from the 1980s are used to provide some indication of biomass during this time period. The survey time series beginning in 1980 is considered as one data set, and no attempt is made to estimate a separate catchability coefficient for the cooperative surveys in the 1980s. Relative to a Tier 5 approach of averaging of biomass estimates, the degree of influence of these biomass estimates is reduced by the inclusion of the age and length composition data as well as the large standard deviations of estimated biomass; the coefficient of variation (CV) ranged between 0.34 in 1983 to 0.90 in 1980 (Table 6).

Survey abundance in the western and central Aleutians was larger from 1991-2012 than in the eastern Aleutians and eastern Bering Sea (Table 6, Figure 2). Areas of particularly high survey abundance are Amchitka Island, Kiska Island, Buldir Island, and Tahoma Bank. An average of 69% of the estimated biomass from the 1991-2012 NMFS AI trawl surveys occurs in the western Aleutian Islands. The coefficients of variation (CV) of these biomass estimates by region are generally high, but especially so in the southern Bering Sea portion of the surveyed area (165 W to 170 W), where the CV was less than 0.50 only in the 2000 survey. The 2012 Aleutian Island survey biomass was 285,164 t, which represents an increase of 31% from the 2010 estimate of 217,319 t. Much of this increase occurred in the western AI, where the estimates biomass increased from 143,953 t in 2010 to 216,325 t in 2012. The coefficient of variation (CV) for the 2012 estimate is 0.50, an increase from average CV from the 1991-2010 surveys of 0.28. The higher biomass estimates and CVs for the 2012 western AI can be attributed one very large CPUE value near Stalemate Bank (Figure 2).

In the 1991-1996 surveys, a large portion of the age composition was less than 15 year old, reflecting relative abundant 1984, 1989, and 1994 cohorts (Figure 3).

The AFSC biennial EBS slope survey was initiated in 2002. The most recent slope survey prior to 2002, excluding some preliminary tows in 2000 intended for evaluating survey gear, was in 1991, and previous slope survey results have not been used in the BSAI model due to high CVs, relatively small population sizes compared to the AI biomass estimates, and lack of recent surveys. The EBS slope survey biomass estimates of northern rockfish from the 2002-2012 surveys ranged between 3 t (2008 and 2012) and 42 t (2010), with CVs between 0.38 (2002) and 1.0 (2008 and 2012). Given these low levels of biomass, the slope survey results are not used in this assessment.

Biological Data

The AI survey provides data on age and length composition of the population, growth rates, and length-weight relationships. The number of otoliths collected and lengths measured are shown in Table 7, along with the number of hauls producing these data. The number of otoliths read by area is shown in Table 8. The survey data produce reasonable sample sizes of lengths and otoliths from throughout the survey area. The maximum age observed in the survey samples was 72 years.

The survey otoliths were read with the break and burn method, and were thus considered unbiased (Chilton and Beamish 1982); however, the potential for aging error exists. Information on aging error was obtained from Courtney et al. 1999, based on two independent readings of otoliths from the Gulf of Alaska trawl survey from 1984-1993. The raw data in Courtney et al. (1999) was used to estimate the standard deviation for each age. The standard deviations were regressed against age to provide a predicted estimate of standard deviation of observed ages for a given true age, and this linear relationship was used to produce the aging error matrix. Use of the aging error matrix from GOA northern rockfish for the BSAI stock is considered appropriate because longevity is similar between the areas.

The expected length at age was estimated by fitting a von Bertalanffy curve to estimates of mean size at age obtained from the AI surveys from 1980-2010. Within each survey year, mean size at age was obtained by multiplying the estimated population length composition by the age-length key. The estimated von Bertalanffy parameters are as follows, and were used to create a conversion matrix and a weight-at-age vector:

L_{inf}	K	t_0
33.71	0.17	-0.93

A conversion matrix was created to convert modeled number at ages to modeled number at length bin, and consists of the proportion of each age that is expected in each length bin. This matrix was created by fitting a power relationship to the observed standard deviation in length at each age (obtained from the aged fish from the 1980-2010 surveys), and the predicted relationship was used to produce variation around the predicted size at age from the von Bertalanffy relationship. The resulting CVs of length at age of the transition matrix decrease from 0.13 at age 3 to 0.09 at age 40.

A length-weight relationship of the form $W = aL^b$ was fit from the survey data from 1980-2010, and produced estimates of a = 1.41 x 10^{-5} and b = 3.01. This relationship was used in combination with the von Bertalanffy growth curve to obtain the estimated weight at age vector of the population (Table 9).

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

Component	BSAI
Fishery catch	1977-2012
Fishery age composition	2000-2009, 2011
Fishery size composition	1977-1978, 1996, 1998-1999 2010
Survey age composition	1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004, and 2006
Survey length composition	2012
Survey biomass estimates	1980, 1983, 1986, 1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012

Analytic Approach

Model structure

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

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

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, and T is the terminal year of the analysis (defined as 2012).

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 number of age groups models was 23 in previous assessments, and a sensitivity analysis was conducted this year to evaluate the how the age-plus group affects fit to model components.

The numbers at age in the first year are estimated as

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

where R_{init} is the mean number of age 3 recruits prior to the start year if the model, and γ is an age-dependant deviation assumed to be normally distributed with mean of zero and a standard deviation equal to σ_r, the recruitment standard deviation. Estimation of the vector of age-dependant deviations from average recruitment allows estimation of year class strength.

The total numbers of age 3 fish from 1977 to 2012 are estimated as parameters in the model, and are modeled with a lognormal distribution

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

where μ_R is the log-scale mean and ν_t is a time-variant deviation.

The fishing mortality rate for a specific age and time ($F_{t,a}$) is modeled as the product of a fishery age-specific selectivity (*fishsel*) that increases asymptotically with age and a year-specific fully-selected fishing mortality rate *f*. The fully selected mortality rate is modeled as the product of a mean (μ_f) and a year-specific deviation (ε_t), thus $F_{t,a}$ is

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

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

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

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

The mean numbers at age for each year was computed as

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Parameters Estimated Outside the Assessment Model

The parameters estimated independently include the age error matrix, the age-length conversion matrix, individual weight at age, and proportion mature females at age. The derivation of the age error matrix, the age-length transition matrix, and the weight at age vector are described above.

A maturity ogive was fit to samples collected in 2010 (n=322; TenBrink and Spencer, in press) and in 2004 by fishery observers (n=256). Parameters of the logistic equation were estimated by maximizing the bionomial likelihood. The number of fish sampled and number of mature fish by age for each collection were the input data, thus weighting the two collection by sample size. Due to the low number of young fish, high weights were applied to age 3 and 4 fish in order to preclude the logistic equation from predicting a high proportion of mature fish at age 0. The data and model fits are shown in Figure 4. The estimated age at 50% maturity is 8.2 years, a decrease for the estimate of 12.8 used in previous assessments.

Parameters Estimated Inside the Assessment Model

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

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

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

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

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

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

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

where *n* is the number of hauls that produced the data, and $p_{f,t,l.}$ and $\hat{p}_{f,t,l}$ are the observed and estimated proportion at length in the fishery by year and length. The negative log likelihood for the age and length proportions in the survey, $p_{surv,t,a}$ and $p_{surv,t,l}$, respectively, follow similar equations.

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

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

where obs_biom_t is the observed survey biomass at time *t*, cv_t is the coefficient of variation of the survey biomass in year *t*, and λ_2 is a weighting factor. The negative log-likelihood of the catch biomass was modeled with a lognormal distribution:

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

where obs_cat_t and $pred\_cat_t$ are the observed and predicted catch. Because the catch biomass is generally thought to be observed with higher precision that other variables, λ_3 is given a very high weight so as to fit the catch biomass nearly exactly. This can be accomplished by varying the *F* levels, and a large λ is used to constrain the predicted catches to closely match the input catches. The overall negative log-likelihood function (excluding the catch component) is

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

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

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

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

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

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

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

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

For the model run in this analysis, λ_1, λ_2, and λ_3 were assigned weights of 1,1, and 200, reflecting the strong emphasis on fitting the catch data. The sample sizes for the age and length compositions were set to the number of hauls from which these demographic data were obtained, but capped to not exceed 150. 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. Weights of 2/3 and 4/3 were chosen for the fisheries and survey age/length compositions so that the average of the weights remains 1. In the results below, comparisons of effective sample size to input sample size were made after scaling the input sample sizes by their weights.

The negative log-likelihood function was minimized by varying the following parameters (for an age-plus group of 40 years) :

Parameter type	**Number**
1) fishing mortality mean	1
2) fishing mortality deviations	36
3) recruitment mean	1
4) recruitment deviations	33
5) Initial recruitment	1
6) first year recruitment deviations	37
7) biomass survey catchability	1
8) natural mortality rate	1
9) survey selectivity parameters	2
10) fishery selectivity parameters	2
Total number of parameters	115

Results

Model Evaluation

A series of model runs were conducted to evaluate the choice of the age plus group on the fits to age composition data and the model results. The choice of the age plus group affected the survey and fishery compositions, the ageing error matrix, and the age-length conversion matrix. Data files were created for age plus groups from 20 to 70, and length-plus groups from 34 to 40. The criteria for evaluation was the total likelihood and likelihood for the age compositions, and the standard deviation of normalized residuals for the age and length composition data.

The total likelihood and the survey and fishery age likelihood both increased monotonically as the age for the plus group increased (Figure 5a), which is expected because of the additional number of data points that contribute to the likelihood. The results in Figure 5 are for a length-plus bin of 38 cm; other length-plus bins show similar results. The SDNR give a measure of the fit to the data that is independent of the number of data points, as a relatively poor fit will be characterized by larger residuals and a higher SDNR. The SDNR for the age composition data decreases with the plus group age (Figure 5b), as the additional age groups allows a better fit to the age composition data. The SDNR for the length composition data is relatively invariant to the plus group age. The end-year total biomass decreases at a gradual rate as the plus group increases.

The current plus age and length plus group are set to 23 years and 34 cm, respectively. The total likelihood and likelihoods of the age and length composition data for the plus group of 23 years are a relatively large distance from their "asymptotic" levels. It is proposed to for this assessment to increase to the plus age group to 40 and the length plus group to 38 cm, as this represents a tradeoff between model parsimony and improved fits to the age composition data. The negative log-likelihood associated with the various data components (unscaled by the various λ terms or weights) of the mode with the age and length plus group in previous assessments, and the proposed new age and length plus groups, is shown in Table 10.

Time series results

In this assessment, spawning biomass is defined as the biomass estimate of mature females age 3 and older. Total biomass is defined as the biomass estimate of northern rockfish age 3 and older. Recruitment is defined as the number of age northern rockfish.

A retrospective analysis was conducted to evaluate the effect of recent data on estimated spawning stock biomass. For the current assessment model, a series of model runs were conducted in which the end year of the model was varied from 2012 to 2002, and this was accomplished by sequentially dropping age and length composition data, survey biomass estimates, and catch from the input data files.

The plot of retrospective estimates of spawning biomass is shown in Figure 6. The largest changes in estimated survey biomass occurred in years 2004, 2006, 2010, and 2012, when survey biomass estimates and survey age composition data are added to the model. Estimates of spawning biomass show a retrospective pattern, which likely reflects continued observations of strong year classes in the fishery and survey age and length composition data and increased biomass estimates. The retrospective pattern is strongest for estimates of spawning biomass in the mid-1990s, and terminal biomass for the models with end years from 2004-2011 are relatively consistent with each other. Mohn's rho can be used to evaluate the severity of any retrospective pattern, and compares an estimated quantity (in this case, spawning stock biomass) in the terminal year of each retrospective model run with the estimated quantity in the same year of the model using the full data set . The absence of any retrospective pattern would result in a Mohn's rho of 0, and would result from either identical estimates in the model runs, or from positive deviations from the reference model being offset by negative deviations. The Mohn's rho for these retrospective runs was -0.94.

Biomass trends

The estimated survey biomass shows an increasing trend, starting at 86,032 t in 1977 and increasing to a peak of 192,778 t in 2005 (Figure 7). The estimated total biomass shows a similar trend, increasing to peak values of 207,683 t 2003, whereas the estimated spawner biomass increases from 38,115 in 1977 to its highest value of 90,694 in 2007 (Table 11, Figure 8).

Age/size compositions

The model fits to the fishery age and size compositions are shown in Figures 9-10, and the model fit to the survey age and length composition are shown in Figures 11-12. The model fit the fishery and survey age composition data reasonably well (notwithstanding years with low sample sizes), as indicated by relatively low SDNR values of 0.62 and 0.66, respectively. Fishery and survey length composition data were fit less well (SDNR values of 1.53 and 1.47, respectively), reflecting the low sample sizes and weights and low number of years within each data type.

Fishing and survey selectivity

The estimated survey selectivity curve had an age of 50% selection of 5.8, whereas this parameter was 10.6 for the fishery selectivity curve (Figure 13). These values are decreases from the estimates of 6.4 and 12.0, respectively, in the 2010 assessment.

Fishing mortality

The estimates of instantaneous fishing mortality rate are shown in Figure 14. A relatively high rate in 1977 is required to account for the relatively high catch in this year, followed by very low levels of fishing mortality during the 1980s when catch was small. Fishing mortality rates began to increase during the early 1990s, and the 2011 estimate is 0.017. A plot of fishing mortality rates and spawning stock biomass in reference to the ABC and OFL harvest control rules indicates that the stock is currently below $F_{35\%}$ and above $B_{40\%}$ (Figure 15).

Recruitment

Recruitment strengths by year class are shown in Figure 16. Relatively strong year classes are observed in 1981, 1984, 1989, and 1993-1998, reflecting several of the strong year classes observed in the age composition input data (Figures 1 and 3). The scatterplot of recruitment against spawning stock biomass is shown in Figure 17, indicating substantial variability in the pattern between recruitment and spawning stock size.

Harvest recommendations

Amendment 56 reference points

The reference fishing mortality rate for northern rockfish is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Estimates of $F_{0.40}$, $F_{0.35}$, and $SPR_{0.40}$ were obtained from a spawner-per-recruit analysis. Assuming that the average recruitment from the 1977-2009 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 59,167 t. The year 2013 spawning stock biomass is estimated as 84,697 t.

Specification of OFL and maximum permissible ABC

Since reliable estimates of the 2013 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B>B_{0.40}$ (84,697 t > 59,167 t), northern rockfish reference fishing mortality is defined in tier 3a. For this tier, F_{ABC} is defined as $F_{0.40}$ and F_{OFL} is defined as $F_{0.35}$. The values of $F_{0.40}$ and $F_{0.35}$ are 0.063 and 0.079, respectively.

The ABC associated with the $F_{0.40}$ level of 0.063 is 9,850 t.

The estimated catch level for year 2013 associated with the overfishing level of F = 0.079 is 12,187 t. A summary of these values is below.

2013 SSB estimate (B)	**=**	**84,697 t**
$B_{0.40}$	=	59,167 t
$F_{ABC} = F_{0.40}$	=	0.063
$F_{OFL} = F_{0.35}$	=	0.079
MaxPermABC	=	9,850 t
OFL	=	12,187 t

ABC recommendation

We recommend the maximum permissible ABC 9,850 t.

Projections

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

For each scenario, the projections begin with the vector of 2012 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2013 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2012. 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 2013, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

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

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2013 recommended in the assessment to the *max* F_{ABC} for 2013. (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 2007-2011 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 2012 or 2) above ½ of its MSY level in 2012 and above its MSY level in 2013 under this scenario, then the stock is not overfished.)

Scenario 7: In 2013 and 2014, 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 2025 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 12.

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 2013, it does not provide the best estimate of OFL for 2014, because the mean 2014 catch under Scenario 6 is predicated on the 2013 catch being equal to the 2013 OFL, whereas the actual 2013 catch will likely be less than the 2013 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 (2011) is 2,762 t. This is less than the 2011 BSAI OFL of 10,600 t. Therefore, the stock is not being subjected to overfishing.

Harvest Scenarios #6 and #7 are intended to permit determination of the status of a stock with respect to its minimum stock size threshold (MSST). Any stock that is below its MSST is defined to be *overfished*. Any stock that is expected to fall below its MSST in the next two years is defined to be *approaching* an overfished condition. Harvest Scenarios #6 and #7 are used in these determinations as follows:

Is the stock currently overfished? This depends on the stock's estimated spawning biomass in 2012:

a. If spawning biomass for 2012 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2012 is estimated to be above $B_{35\%}$ the stock is above its MSST.

c. If spawning biomass for 2012 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 12). If the mean spawning biomass for 2022 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario #7:

a. If the mean spawning biomass for 2015 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2015 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2015 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2025. If the mean spawning biomass for 2023 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

The results of these two scenarios indicate that the BSAI northern rockfish stock is neither overfished nor approaching an overfished condition. With regard whether the stock is currently overfished, the estimated 2012 stock size is 1.68 its $B_{35\%.}$ value of 51,771 t. With regard to whether BSAI northern rockfish is likely to be overfished in the future, the expected stock size in 2015 of Scenario 7 is 1.48 times the $B_{35\%}$ value.

Ecosystem Considerations

Ecosystem Effects on the stock

1) Prey availability/abundance trends

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

2) Predator population trends

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

3) Changes in habitat quality

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

Fishery Effects on the ecosystem

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

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

Data Gaps and Research Priorities

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

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Table 1. Total allowable catch (TAC), acceptable biological catch (ABC), and catch of the species groups used to manage northern rockfish from 1988 to 2012. The "other red rockfish" group includes, shortraker rockfish, rougheye rockfish, northern rockfish, and sharpchin rockfish. The "POP complex" includes the other red rockfish species plus POP.

Year	Area	Management Group	ABC (t)	TAC (t)	Catch (t)
1988	BS	POP Complex	6,000		1,509
	AI	POP Complex	16,600		2,629
1989	BS	POP Complex	6,000		2,873
	AI	POP Complex	16,600		3,780
1990	BS	POP Complex	6,300		7,231
	AI	POP Complex	16,600		15,224
1991	BS	Other Red Rockfish	1,670	1,670	942
	AI	Northern/Sharpchin	3,440	3,440	233
1992	BS	Other Red Rockfish	1,400	1,400	467
	AI	Northern/Sharpchin	5,670	5,670	1,549
1993	BS	Other Red Rockfish	1,400	1,200	1,226
	AI	Northern/Sharpchin	5,670	5,100	4,535
1994	BS	Other Red Rockfish	1,400	1,400	129
	AI	Northern/Sharpchin	5,670	5,670	4,667
1995	BS	Other Red Rockfish	1,400	1,260	344
	AI	Northern/Sharpchin	5,670	5,103	3,873
1996	BS	Other Red Rockfish	1,400	1,260	207
	AI	Northern/Sharpchin	5,810	5,229	6,653
1997	BS	Other Red Rockfish	1,050	1,050	218
	AI	Northern/Sharpchin	4,360	4,360	1,997
1998	BS	Other Red Rockfish	267	267	112
	AI	Northern/Sharpchin	4,230	4,230	3,747
1999	BS	Other Red Rockfish	356	267	238
	AI	Northern/Sharpchin	5,640	4,230	5,493
2000	BS	Other Red Rockfish	259	194	253
	AI	Northern/Sharpchin	6,870	1,180	5,084
2001	BSAI	Northern/Sharpchin	6,764		
	BS	Northern/Sharpchin		19	180
	AI	Northern/Sharpchin		6,745	6,309
2002	BSAI	Northern	6,760		
	BS	Northern		19	113
	AI	Northern		6,741	3,943
2003	BSAI	Northern	7,101		
	BS	Northern		121	67
	AI	Northern		5,879	4,862
2004	BSAI	Northern	6,880	5,000	4,684
2005	BSAI	Northern	8,260	5,000	3,964
2006	BSAI	Northern	8,530	4,500	3,829
2007	BSAI	Northern	8,190	8,190	4,016
2008	BSAI	Northern	8,180	8,180	3,287
2009	BSAI	Northern	7,160	7,160	3,111
2010	BSAI	Northern	7,240	7,240	4,332
2011	BSAI	Northern	8,670	4,000	2,762
2012*	BSAI	Northern	8,610	4,700	2,223*

*Catch data through October 6, 2012, from NMFS Alaska Regional Office.

Table 2. Catch of northern rockfish (t) in the BSAI area.

	Eastern Bering Sea			Aleutian Islands			
Year	Foreign	Joint Venture	Domestic	Foreign	Joint Venture	Domestic	Total
1977	5	0		3,264	0		3,270
1978	32	0		3,655	0		3,687
1979	46	0		601	0		647
1980	84	5		549	0		638
1981	35	0		111	0		145
1982	63	8		177	0		248
1983	10	32		47	0		89
1984	26	6		11	185		229
1985	5	1		0	189		195
1986	5	41	15	0	193	15	270
1987	1	45	31	0	248	60	385
1988	0	4	36	0	438	55	534
1989	0	12	66	0	0	306	384
1990			247			1,235	1,481
1991			626			233	859
1992			309			1,548	1,857
1993			859			4,530	5,389
1994			61			4,666	4,727
1995			266			3,858	4,124
1996			87			6,637	6,724
1997			164			1,996	2,161
1998			45			3,746	3,791
1999			157			5,492	5,650
2000			97			5,066	5,162
2001			180			6,309	6,488
2002			113			3,943	4,056
2003			67			4,862	4,929
2004			116			4,567	4,684
2005			112			3,852	3,964
2006			247			3,582	3,829
2007			69			3,946	4,016
2008			22			3,265	3,287
2009			48			3,064	3,111
2010			299			4,033	4,332
2011			196			2,566	2,762
2012*			64			2,159	2,223

*Catch data through October 6, 2012, from NMFS Alaska Regional Office.

Table 3. Area-specific catches of northern rockfish (t) in the BSAI area, obtained from the North Pacific Groundfish Observer Program, NMFS Alaska Regional Office.

Year	WAI	CAI	EAI	EBS	Total
1994	1,572	2,534	560	61	4,727
1995	1,421	1,641	796	266	4,124
1996	3,146	1,978	1,514	87	6,724
1997	1,287	490	219	164	2,161
1998	2,392	916	438	45	3,791
1999	3,185	1,104	1,203	157	5,650
2000	1,516	2,347	1,202	97	5,162
2001	3,725	1,840	743	180	6,488
2002	2,328	1,317	297	113	4,056
2003	2,506	1,994	361	67	4,929
2004	1,947	2,410	211	116	4,684
2005	1,885	1,697	271	112	3,964
2006	1,139	2,138	306	247	3,829
2007	1,013	1,782	1,151	69	4,016
2008	1,341	1,317	608	22	3,287
2009	1,195	1,311	557	48	3,111
2010	1,989	1,266	778	299	4,332
2011	311	1,351	905	196	2,762
2012*	140	1,586	433	64	2,223

* Estimated removals through October 6, 2012.

Table 4. Estimated retained, discarded, and percent discarded sharpchin/northern (SC/NO), and northern rockfish catch in the eastern Bering Sea (EBS) and Aleutian Islands (AI) regions. The catches of the SC/NO group consist nearly entirely of northern rockfish. Prior to 2001, northern rockfish were managed as part of the Other Red Rockfish (ORR) complex in the EBS. Beginning in 2002, sharpchin rockfish were removed from ORR and northern rockfish were managed with single-species catch levels. Unless otherwise noted, catch data were obtained from BLEND data and CAS data.

Area	Species Group	Year	Catch (t) Retained	Discard	Total	Percentage
EBS	SC/NO	2001	16	164	180	91.1%
EBS	Northerns	2002	9	105	113	92.4%
		2003	14	59	73	80.4%
		2004	35	82	117	70.2%
		2005	45	67	112	59.6%
		2006	109	137	247	55.7%
		2007	23	46	69	66.4%
		2008	8	14	22	64.7%
		2009	40	8	48	15.9%
		2010	284	15	299	4.9%
		2011	166	30	196	15.3%
		2012*	31	32	64	50.8%
Aleut. Is.	SC/NO	1993	317	4,218	4,535	93.0%
		1994	797	3,870	4,667	82.9%
		1995	1,208	2,665	3,873	68.8%
		1996	2,269	4,384	6,653	65.9%
		1997	145	1,852	1,997	92.7%
		1998	458	3,288	3,747	87.8%
		1999	735	4,759	5,493	86.6%
		2000	592	4,474	5,066	88.3%
		2001	403	5,906	6,309	93.6%
AI	Northerns	2002	347	3595	3,943	91.2%
		2003	188	4397	4,585	95.9%
		2004	686	3881	4,567	85.0%
		2005	912	2940	3,852	76.3%
		2006	965	2617	3,582	73.1%
		2007	850	3096	3,946	78.5%
		2008	1,523	1742	3,265	53.3%
		2009	1,941	1122	3,064	36.6%
		2010	3,070	963	4,033	23.9%
		2011	2,442	124	2,566	4.8%
		2012*	1,781	378	2,159	17.5%

* Estimated removals through October 6, 2012.

Table 5. Samples sizes of otoliths and lengths from fishery sampling, with the number of hauls from which these data were collected, from 1977-2011.

Year	Lengths	Hauls	Otoliths collected	Otoliths read	Hauls (read otoliths)
1977	1202	16	230	224**	11
1978	759	11	148	148**	16
1979					
1980					
1981					
1982	334**	5			
1982					
1984	703**	4			
1985	12**	9	12	0	0
1986	100**	2	100	0	0
1987	976**	9	79	0	0
1988					
1989	80**	1	80	0	0
1990	403**	11			
1991	145**	8			
1992					
1993	1809**	16			
1994	767**	8			
1995	833**	14			
1996	4554	68			
1997	1**	1			
1998	543	14	30	29**	5
1999	917	42	50	0	0
2000	995*	69	170	169*	49
2001	661*	70	136	135*	58
2002	889*	68	200	195*	60
2003	1362*	124	318	317*	110
2004	842*	78	198	196*	69
2005	466*	47	120	118*	44
2006	895*	73	231	230*	71
2007	843*	98	230	228*	90
2008	897*	127	271		
2009	834*	108	247		
2010	1281	148	346		
2011	1596*	210	369		

*Used to create age composition

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

	Aleutian Islands Management Sub-Areas			EBS estimates	
Year	Western	Central	Eastern	southern BS	Total
1980					37,593 (0.90)
1983					56,368 (0.15)
1986					140,405 (0.34)
1991	144,043 (0.21)	64,119 (0.18)	4,068 (0.52)	582 (0.63)	212,813 (0.15)
1994	65,843 (0.65)	15,832 (0.58)	5,933 (0.54)	855 (0.60)	88,463 (0.50)
1997	65,493 (0.38)	18,363 (0.55)	3,331 (0.58)	204 (0.68)	87,391 (0.31)
2000	143,348 (0.39)	37,949 (0.44)	24,982 (0.70)	49 (0.40)	205,369 (0.30)
2002	136,440 (0.33)	38,819 (0.43)	3,242 (0.42)	290 (0.67)	178,791 (0.27)
2004	146,179 (0.27)	26,913 (0.39)	10,375 (0.37)	5,980 (0.93)	189,446 (0.22)
2006	101,276 (0.29)	72,961 (0.52)	22,982 (0.45)	22,883 (1.00)	220,102 (0.25)
2010	143,953 (0.29)	51,331 (0.40)	21,847 (0.50)	189 (0.52)	217,319 (0.22)
2012	216,325 (0.65)	52,674 (0.40)	15,615 (0.60)	550 (0.73)	285,164 (0.50)
1991-2012 mean	129,211	42,107	12,486	3,509	187,313
Percentage	68.98%	22.48%	6.67%	1.87%	

Table 7. Sample sizes of otoliths and length measurement from the AI trawl survey, 1991-2012, with the number of hauls from which these data were collected.

Year	Lengths	Hauls	Otoliths read	Hauls
1980	3351	31	473	4
1983	6535	71	625	11
1986	5881	41	565	18
1991	4853	47	456	14
1994	6252	118	409	19
1997	7554	153	652	68
2000	7779	135	725	92
2002	9459	153	259	69
2004	12176	201	515	65
2006	8404	160	535	57
2010	11796	198	538	72
2012	10523	188		

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

Year	Western AI	Central AI	Eastern AI	Southern Bering Sea	Total
1980	201	92	180		473
1983	268	225	93	39	625
1986	132	293	25	115	565
1991		243	159	54	456
1994	180	61	127	41	409
1997	234	219	199		652
2000	229	275	200	21	725
2002	88	74	66	31	259
2004	193	156	120	46	515
2006	197	148	113	77	535
2010	195	186	139	18	538

Table 9. Predicted weight and proportion mature at age for BSAI northern rockfish.

Age	Predicted weight (g)	Proportion mature
3	68	0.029
4	107	0.056
5	149	0.104
6	192	0.186
7	235	0.310
8	274	0.469
9	311	0.634
10	344	0.773
11	374	0.870
12	401	0.929
13	424	0.963
14	444	0.981
15	461	0.990
16	476	0.995
17	488	0.997
18	499	0.999
19	508	0.999
20	516	1.000
21	523	1.000
22	529	1.000
23	533	1.000
24	537	1.000
25	541	1.000
26	544	1.000
27	546	1.000
28	548	1.000
29	550	1.000
30	551	1.000
31	552	1.000
32	553	1.000
33	554	1.000
34	555	1.000
35	556	1.000
36	556	1.000
37	557	1.000
38	557	1.000
39	557	1.000
40	558	1.000

Table 10. Negative log likelihood of model components, average effective and input sample sizes, root mean squared errors and standard deviation of normalized residuals for the two models considered in this assessment.

Negative log-likelihood	Age and length plus groups	
	Age=40, length=38	Age=23, length=34
Recruitment	-2.65	-2.28
AI survey biomass	16.01	14.75
Catch	0.00	0.00
F penalty	4.26	4.13
Fishery ages	3113.91	2224.91
Fishery lengths	809.40	520.78
Survey ages	1629.85	1287.67
Survey lengths	396.72	310.05
Prior for *q_srv*	0.00	0.00
Prior for *M*	2.91	4.01
Total likelihood	5338.19	3981.38
Average Effective Sample Size		
Fishery ages	143.46	163.64
Fishery lengths	22.47	9.17
Survey ages	116.85	87.80
Survey lengths	60.53	53.95
Average Sample Sizes		
Fishery ages	56.30	56.30
Fishery lengths	33.22	33.22
Survey ages	59.27	59.27
Survey lengths	200.00	200.00
Root Mean Squared Error		
Survey	0.46	0.44
recruitment	0.60	0.60
Standard Deviation of Normalized Residuals		
AI trawl survey	1.60	1.54
Fishery ages	0.62	0.66
Fishery lengths	1.53	1.22
Survey ages	0.66	0.76
Survey lengths	1.47	1.20

Table 11. Estimated time series of northern rockfish total biomass (t), spawner biomass (t), and recruitment (thousands) for each region.

	Total Biomass (ages 3+) Assessment Year		Spawner Biomass (ages 3+) Assessment Year		Recruitment (age 3) Assessment Year	
Year	2012	2010	2012	2010	2012	2010
1977	98,338	104,943	38,155	33,335	27,256	29,185
1978	100,084	105,361	38,719	32,969	29,365	24,403
1979	101,233	105,587	39,715	32,908	21,848	24,146
1980	105,438	109,881	41,822	33,929	21,633	37,268
1981	110,591	113,970	43,963	35,102	35,921	24,662
1982	115,927	118,423	46,255	36,500	25,535	20,848
1983	120,675	122,542	48,557	37,941	18,679	19,358
1984	126,763	126,418	50,967	39,463	40,048	16,690
1985	131,692	129,538	53,376	40,980	18,658	12,774
1986	135,963	132,477	55,820	42,543	13,492	17,794
1987	144,325	139,780	58,284	44,154	82,887	93,353
1988	152,477	145,539	60,726	45,758	53,943	31,342
1989	159,683	150,806	63,189	47,374	30,272	21,092
1990	166,993	156,079	65,751	48,951	30,108	22,652
1991	173,030	162,443	68,312	50,291	30,058	63,128
1992	181,018	169,597	71,432	51,774	54,837	47,227
1993	186,276	174,420	74,143	52,580	21,804	20,280
1994	187,562	175,045	75,786	52,467	24,906	17,721
1995	188,059	176,120	77,571	52,817	10,873	26,307
1996	190,575	179,187	79,002	53,309	45,744	54,837
1997	189,608	179,909	79,754	53,712	30,425	47,457
1998	195,847	190,207	81,672	55,521	71,525	119,833
1999	200,409	197,038	82,478	56,744	53,351	42,186
2000	203,176	201,281	82,536	57,530	44,272	27,204
2001	206,016	204,694	82,712	58,363	34,834	15,422
2002	206,040	205,291	83,109	59,081	14,081	12,840
2003	207,683	207,070	84,747	60,550	16,249	13,512
2004	207,188	206,589	86,415	61,887	10,971	14,519
2005	206,322	205,290	88,213	63,525	17,324	14,850
2006	205,118	203,849	89,812	65,476	13,227	17,872
2007	203,544	203,046	90,694	67,522	17,303	34,245
2008	201,281	201,952	90,761	69,252	18,584	
2009	198,981	201,776	90,410	70,844	12,296	
2010	197,816	201,138	89,445	71,999		
2011	195,771	201,429	87,925	71,516		
2012	195,712		86,792			
2013	195,446					

Table 12. Projections of BSAI northern rockfish catch (t), spawning biomass (t), and fishing mortality rate for each of the several scenarios. The values of $B_{40\%}$ and $B_{35\%}$ are 59,167 t and 51,771 t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2012	3,223	3,223	3,223	3,223	3,223	3,223	3,223
2013	9,850	9,850	4,999	3,436	0	12,187	9,850
2014	9,322	9,322	4,873	3,381	0	11,368	9,322
2015	8,840	8,840	4,755	3,330	0	10,630	10,939
2016	8,420	8,420	4,655	3,288	0	9,990	10,270
2017	8,070	8,070	4,577	3,259	0	9,457	9,711
2018	7,793	7,793	4,525	3,247	0	9,031	9,260
2019	7,580	7,580	4,496	3,249	0	8,697	8,903
2020	7,418	7,418	4,486	3,263	0	8,435	8,622
2021	7,292	7,292	4,488	3,284	0	8,191	8,382
2022	7,188	7,188	4,496	3,308	0	7,951	8,141
2023	7,097	7,097	4,507	3,334	0	7,737	7,913
2024	7,011	7,011	4,520	3,360	0	7,555	7,711
2025	6,931	6,931	4,532	3,385	0	7,402	7,538
Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2012	86,792	86,792	86,792	86,792	86,792	86,792	86,792
2013	84,697	84,697	85,320	85,517	85,947	84,393	84,697
2014	80,500	80,500	83,428	84,376	86,469	79,098	80,500
2015	76,975	76,975	81,958	83,604	87,292	74,642	76,703
2016	74,172	74,172	80,981	83,273	88,488	71,055	72,919
2017	72,018	72,018	80,448	83,341	90,020	68,240	69,922
2018	70,366	70,366	80,246	83,699	91,787	66,032	67,545
2019	69,062	69,062	80,246	84,224	93,675	64,255	65,614
2020	67,989	67,989	80,355	84,828	95,603	62,779	63,995
2021	67,078	67,078	80,520	85,464	97,529	61,526	62,610
2022	66,279	66,279	80,705	86,094	99,419	60,453	61,407
2023	65,573	65,573	80,898	86,711	101,264	59,546	60,374
2024	64,948	64,948	81,094	87,310	103,065	58,783	59,497
2025	64,395	64,395	81,288	87,887	104,811	58,143	58,755
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2012	0.020	0.020	0.020	0.020	0.020	0.020	0.020
2013	0.063	0.063	0.032	0.022	0	0.079	0.063
2014	0.063	0.063	0.032	0.022	0	0.079	0.063
2015	0.063	0.063	0.032	0.022	0	0.079	0.079
2016	0.063	0.063	0.032	0.022	0	0.079	0.079
2017	0.063	0.063	0.032	0.022	0	0.079	0.079
2018	0.063	0.063	0.032	0.022	0	0.079	0.079
2019	0.063	0.063	0.032	0.022	0	0.079	0.079
2020	0.063	0.063	0.032	0.022	0	0.079	0.079
2021	0.063	0.063	0.032	0.022	0	0.079	0.079
2022	0.063	0.063	0.032	0.022	0	0.078	0.078
2023	0.063	0.063	0.032	0.022	0	0.077	0.078
2024	0.063	0.063	0.032	0.022	0	0.076	0.077
2025	0.063	0.063	0.032	0.022	0	0.076	0.076

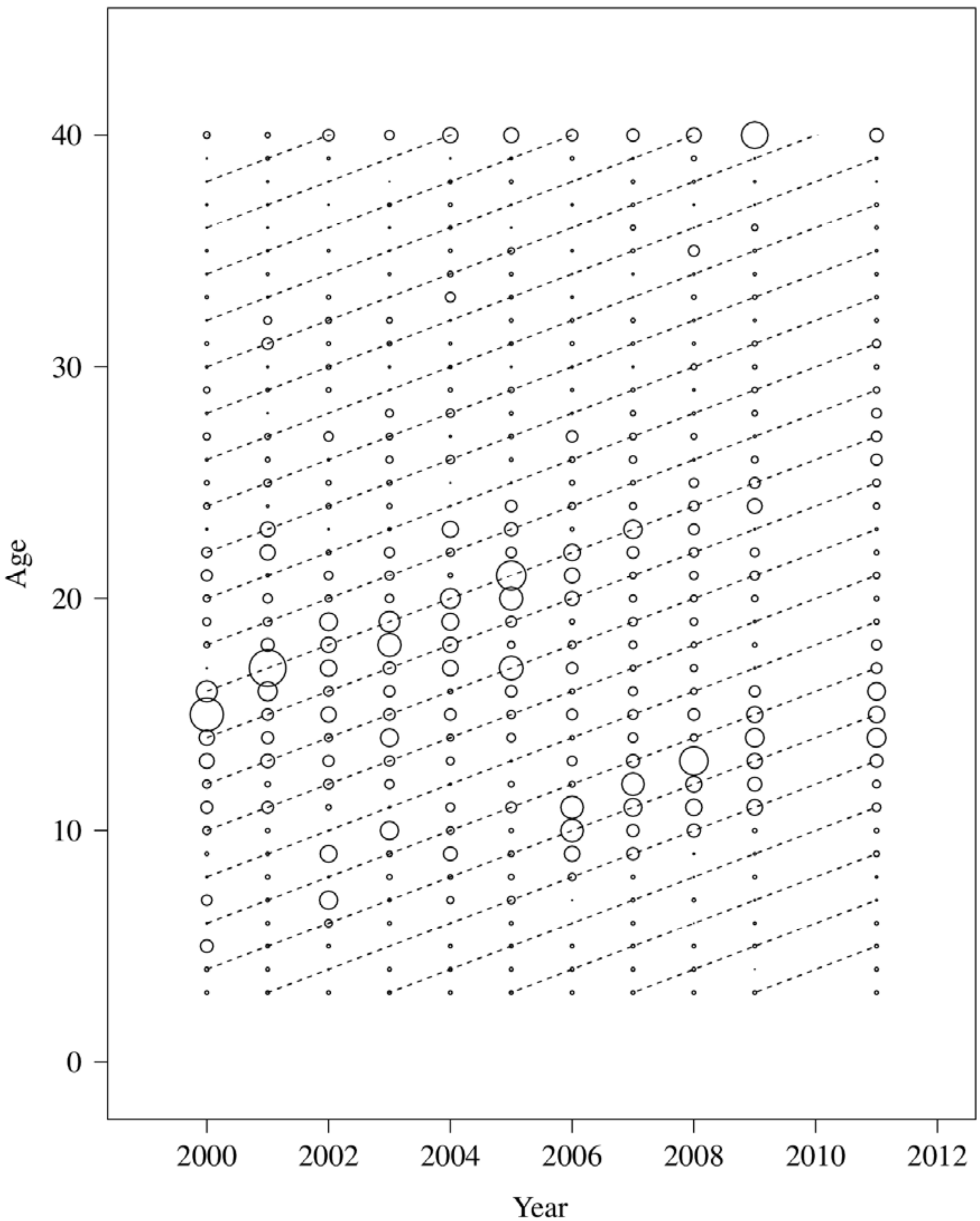

Figure 1. Fishery age composition data for the Aleutian Islands; bubbles are scaled within each year of samples; and dashed lines denote cohorts.

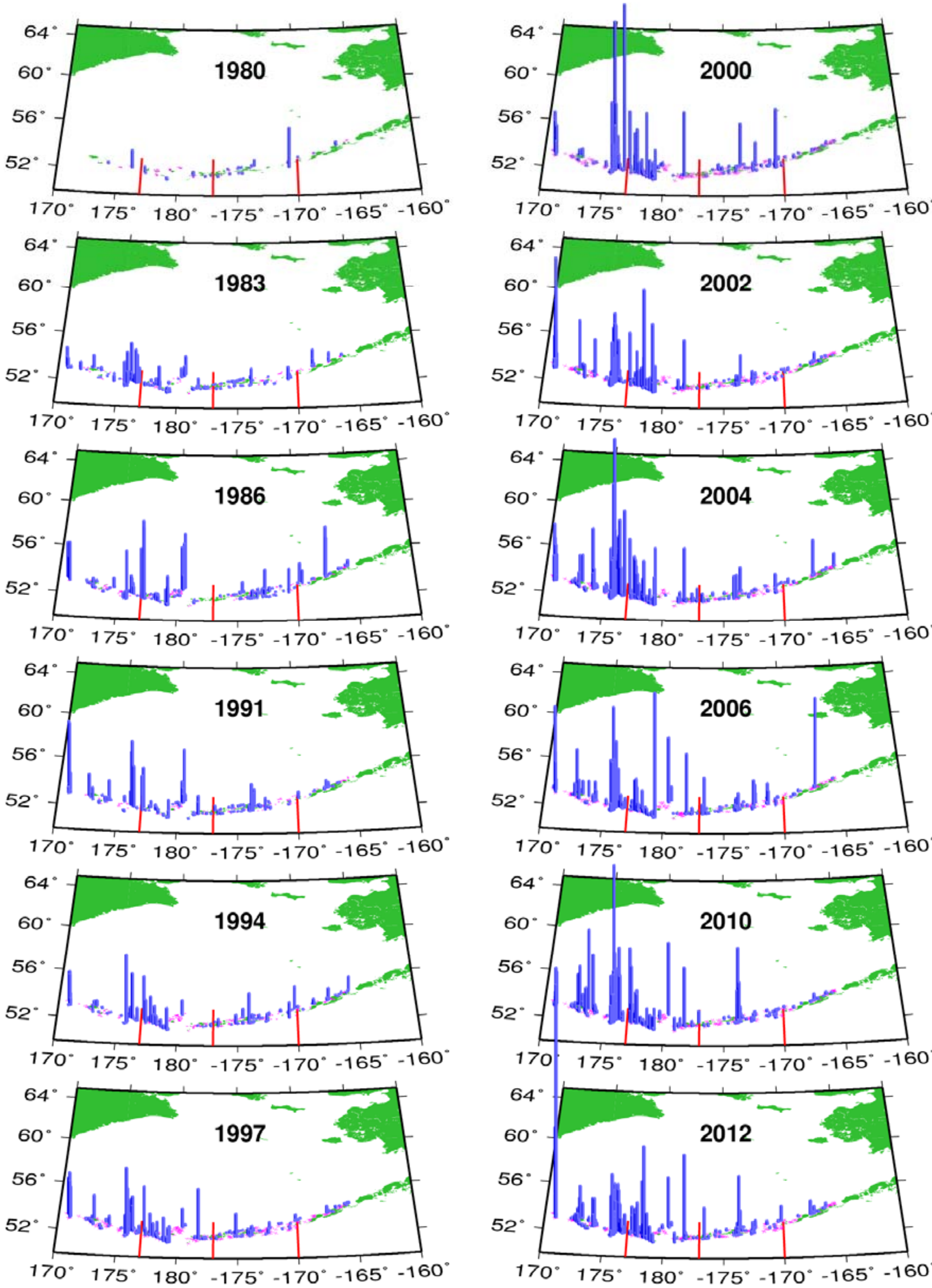

Figure 2. Scaled AI survey northern rockfish CPUE from (square root of kg/km^2) from 1980-2012; the red lines indicate boundaries between the WAI, CAI, EAI, and EBS areas.

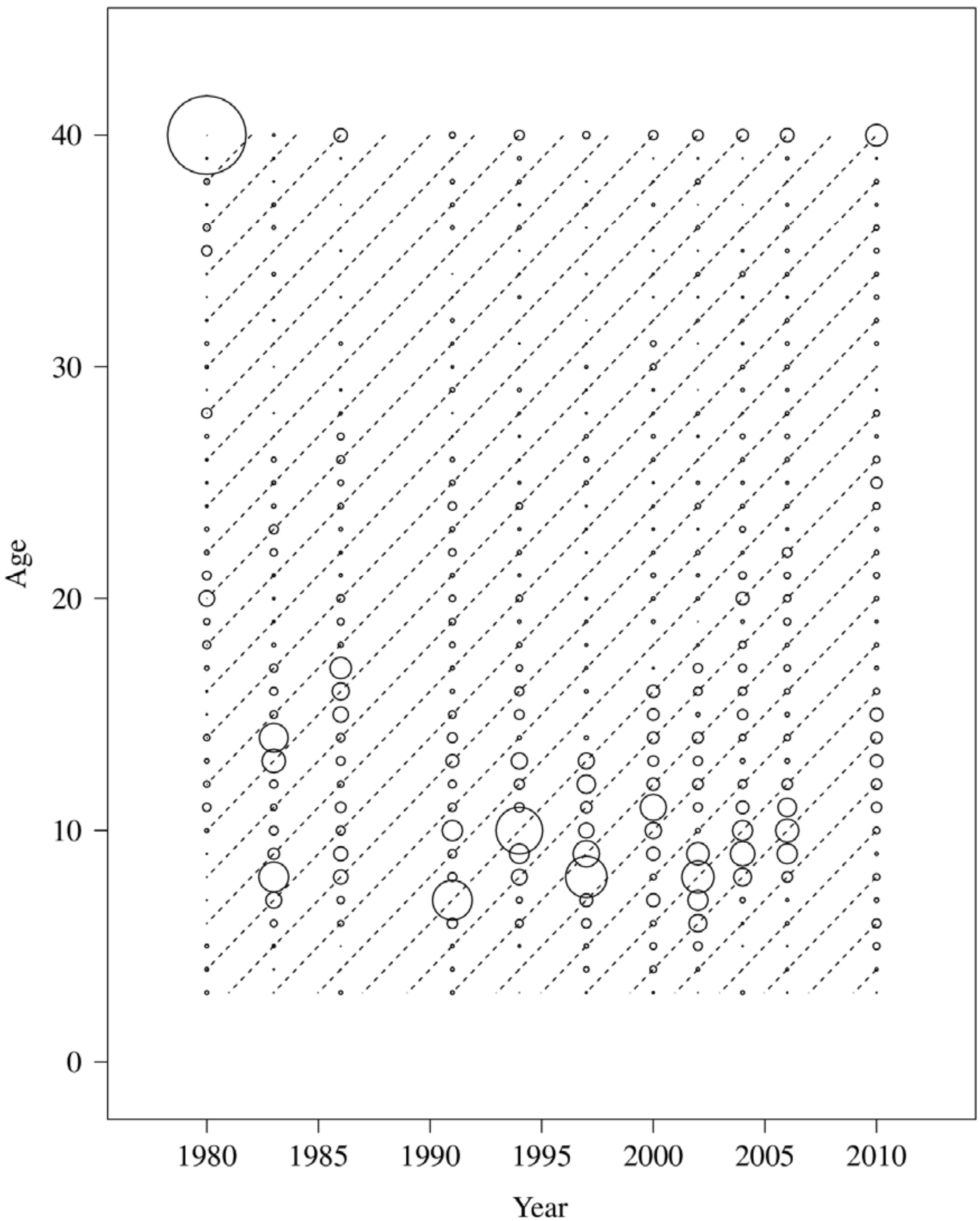

Figure 3. Age composition data from the Aleutian Islands trawl survey; bubbles are scaled within each year of samples; and dashed lines denote cohorts.

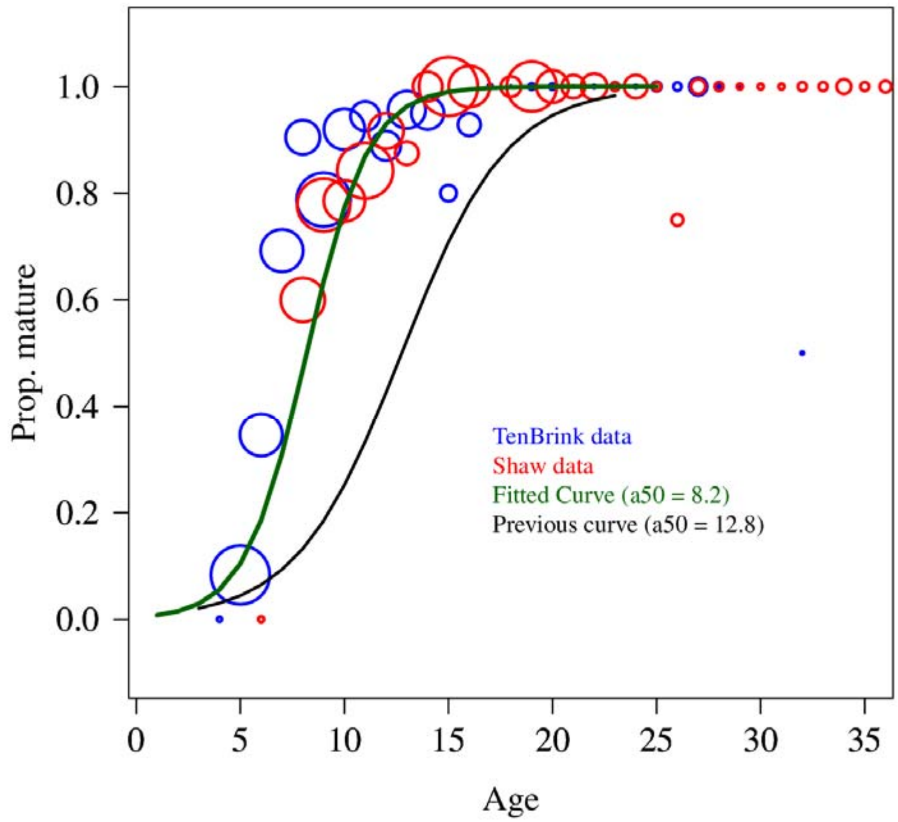

Figure 4. Maturity ogive fof BSAI northern rockfish; data points are maturity samples (scaled by sample size) read by Frank Shaw (red circles, collected in 2004) and Todd TenBrink (blue circles, collected in 2010).

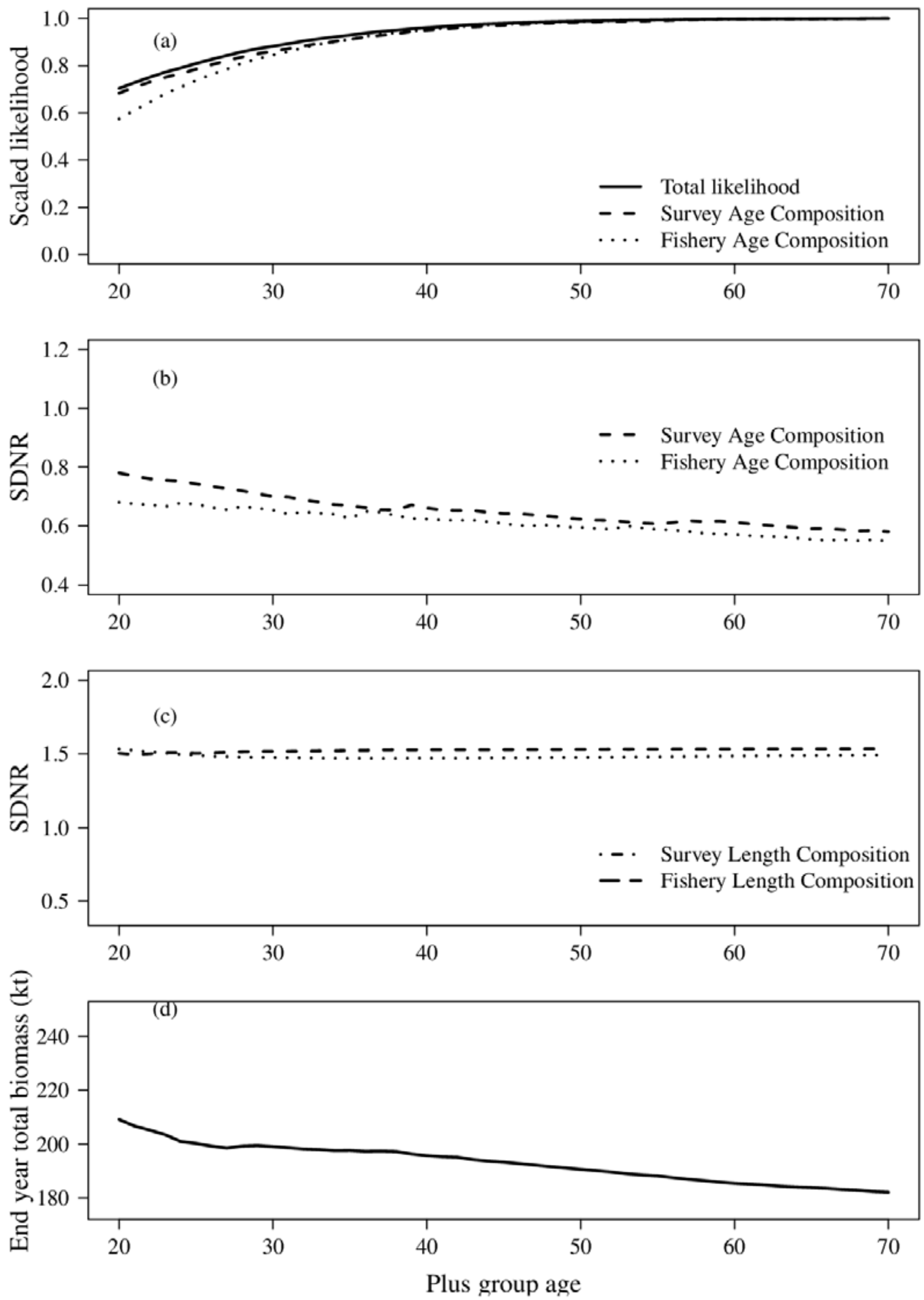

Figure 5. Scaled total likelihood and age compositions components (a), standard deviations of normalized residuals for the age (b) and length (c) composition data, and end year total biomass (d) as a function of the plus group age.

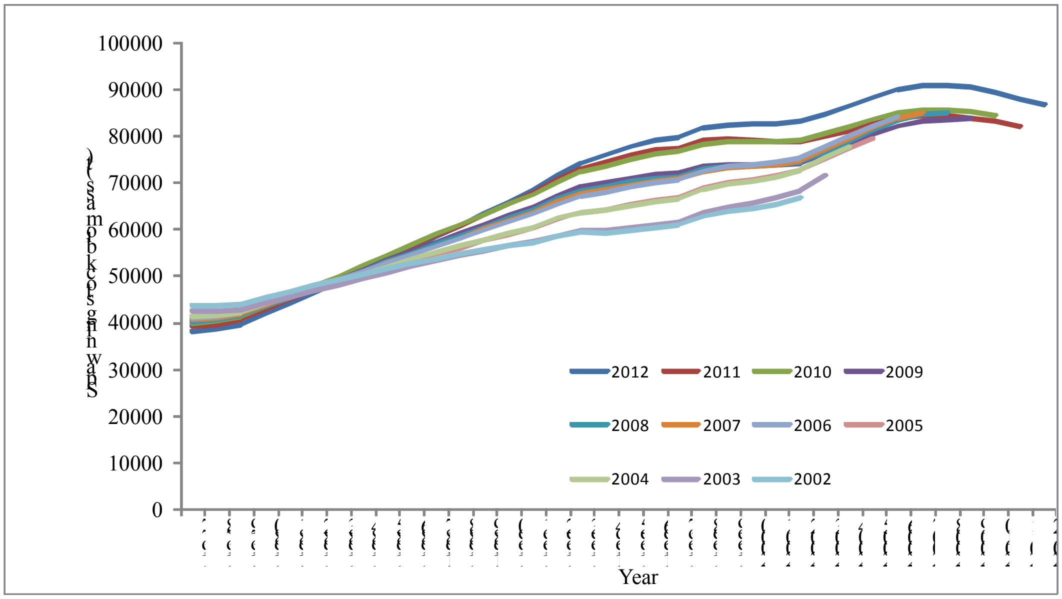

Figure 6. Retrospective estimates of spawning stock biomass for model runs with end years of 2002 to 2012.

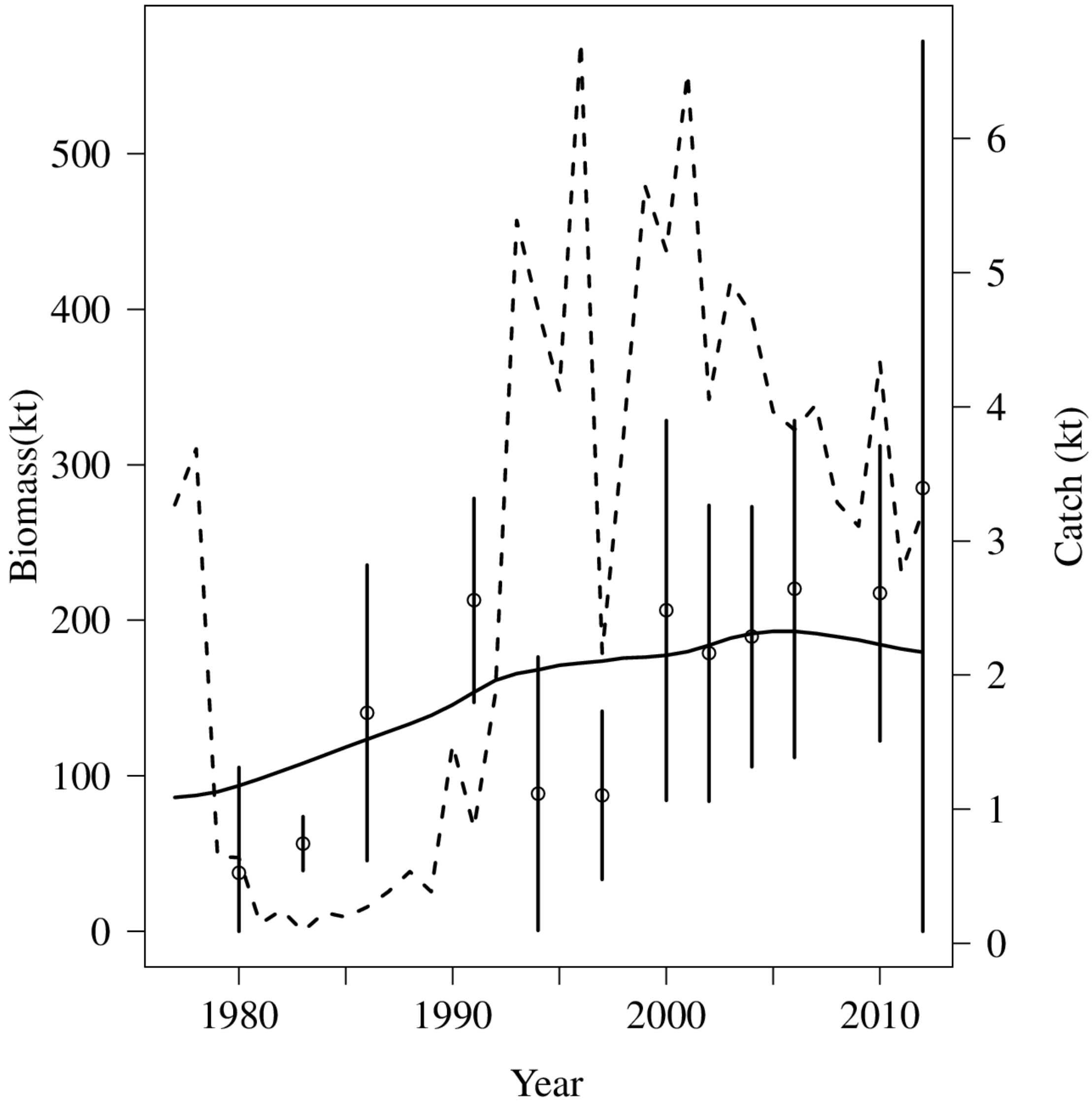

Figure 7. Observed Aleutian Islands survey biomass (data points, ± 2 standard deviations), predicted survey biomass (solid line) and BSAI harvest (dashed line).

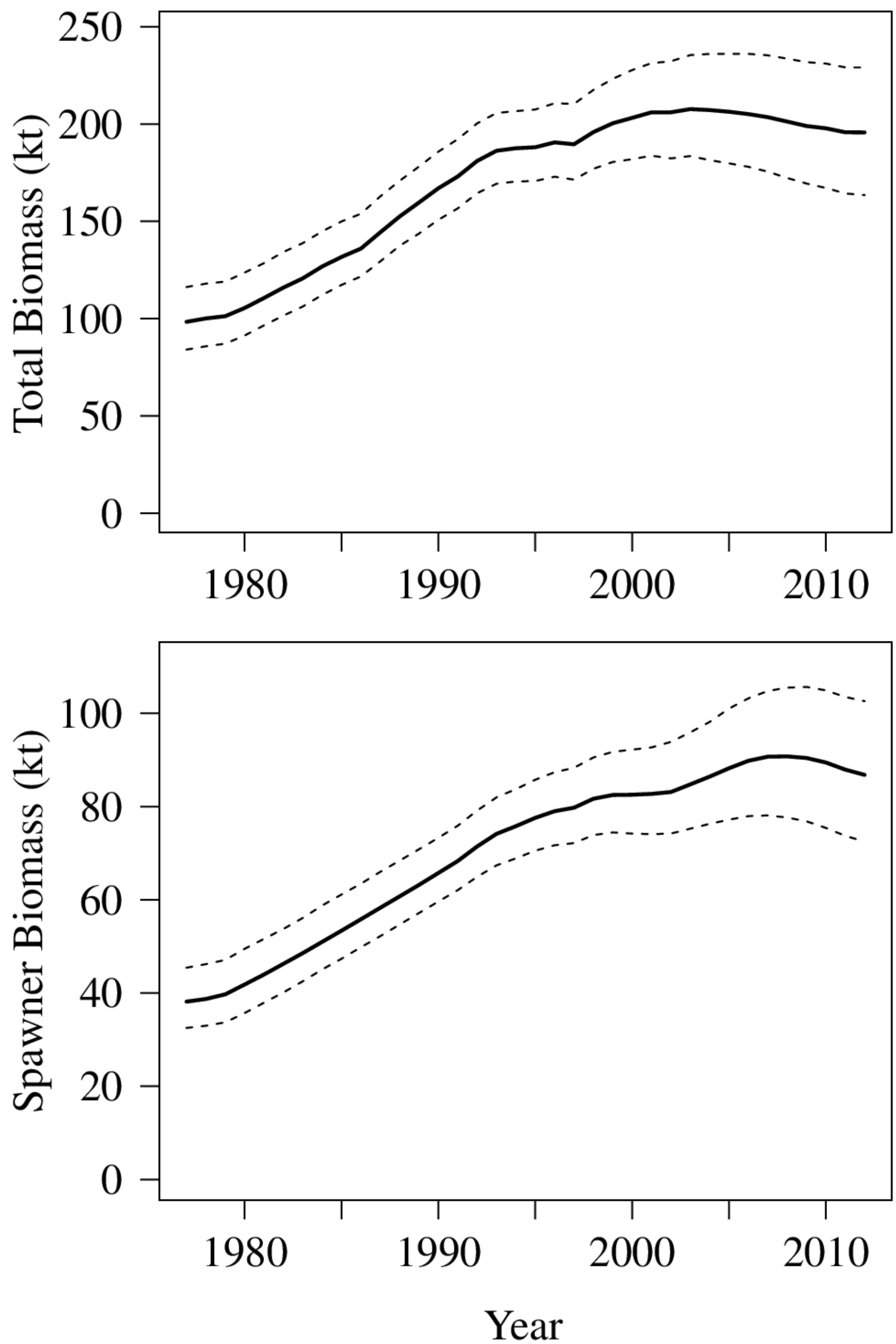

Figure 8. Total and spawner biomass for BSAI northern rockfish with 95% confidence intervals from MCMC integration.

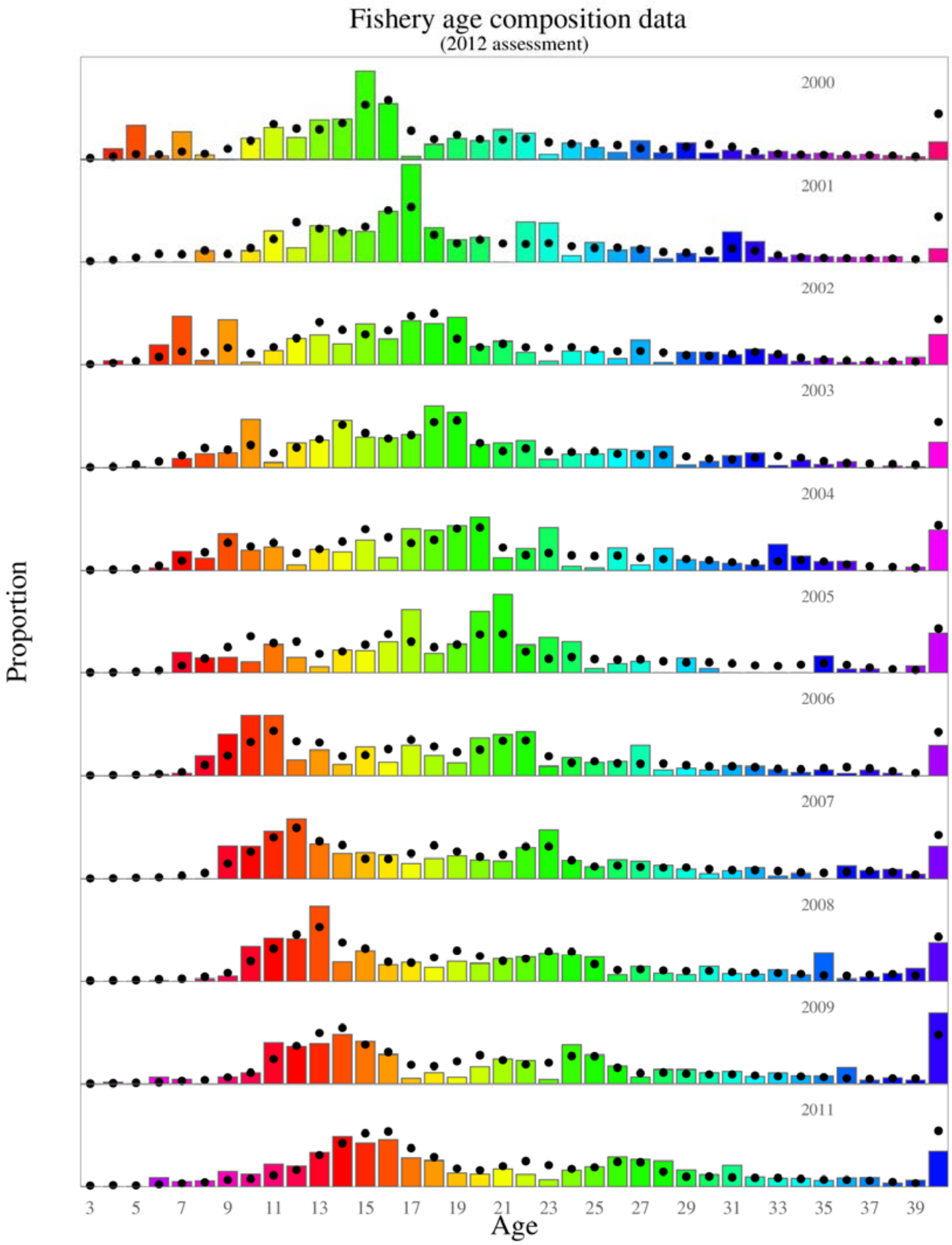

Figure 9. Model fits (dots) to the fishery age composition data (columns) for BSAI northern rockfish. Colors of the bars correspond to cohorts (except for the 40+ group).

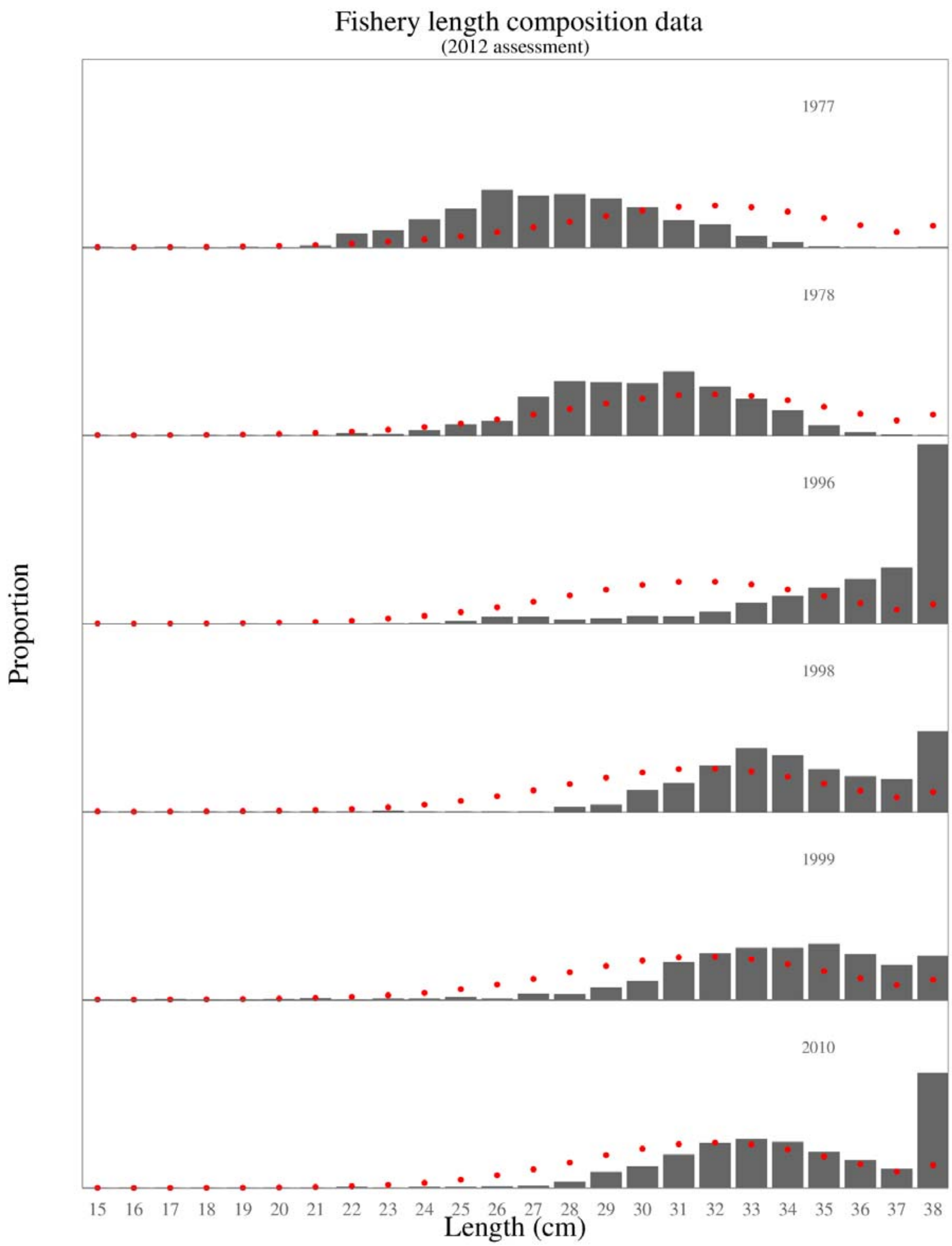

Figure 10. Model fits (dots) to the fishery length composition data (columns) for BSAI northern rockfish.

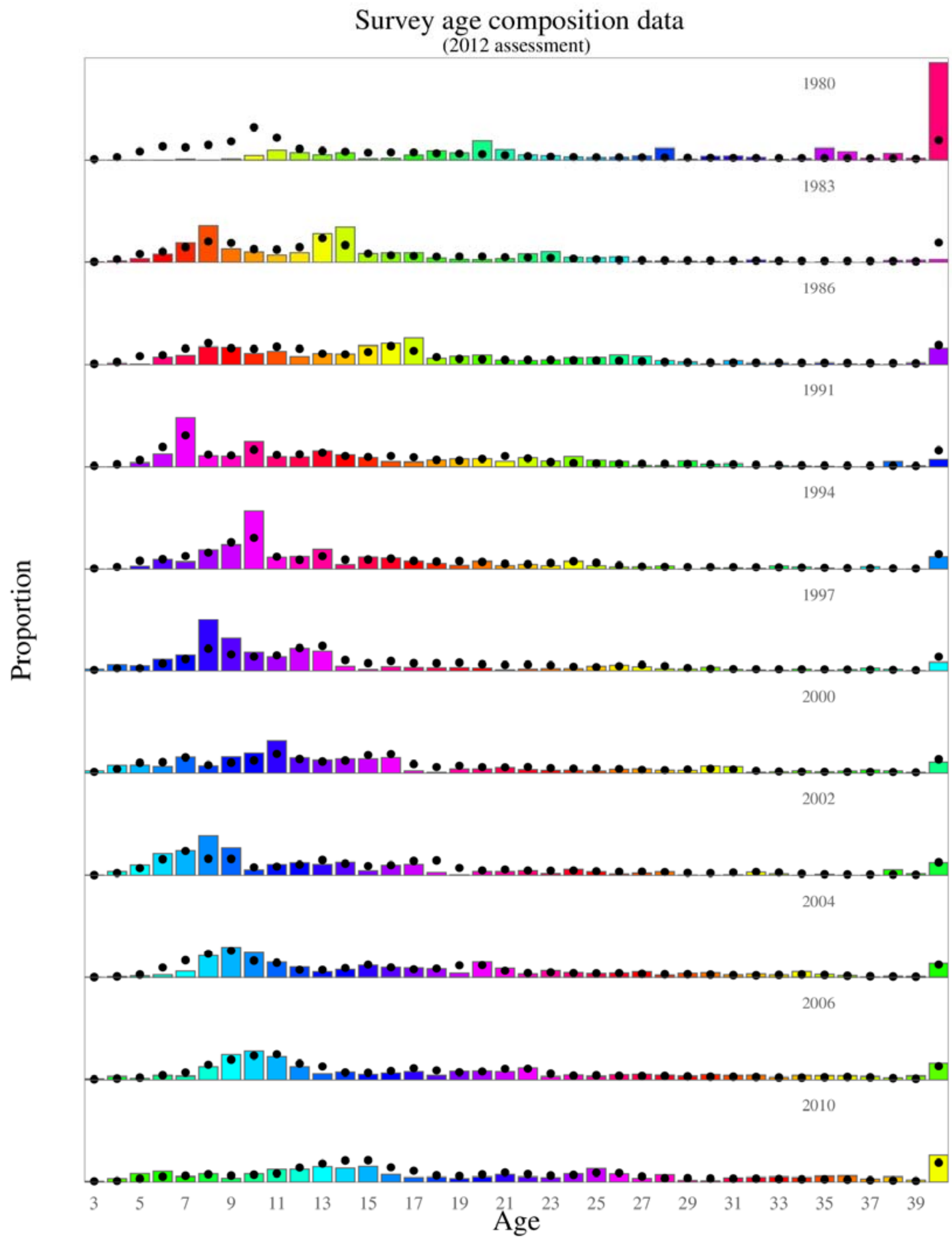

Figure 11. Model fits (dots) to the survey age composition data (columns) for BSAI northern rockfish. Colors of the bars correspond to cohorts (except for the 40+ group).

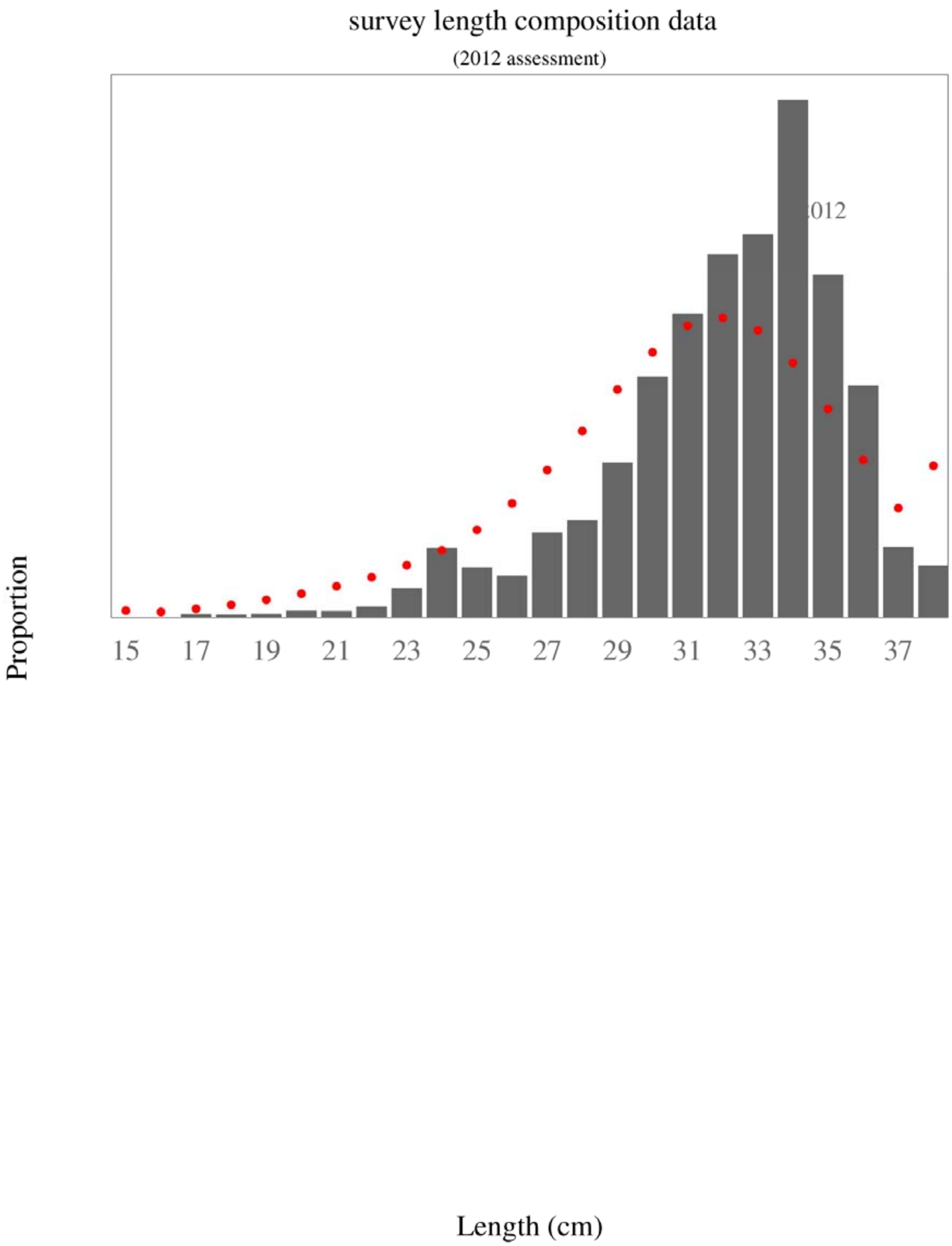

Figure 12. Model fits (dots) to the 2012 survey length composition data (columns) for BSAI northern rockfish.

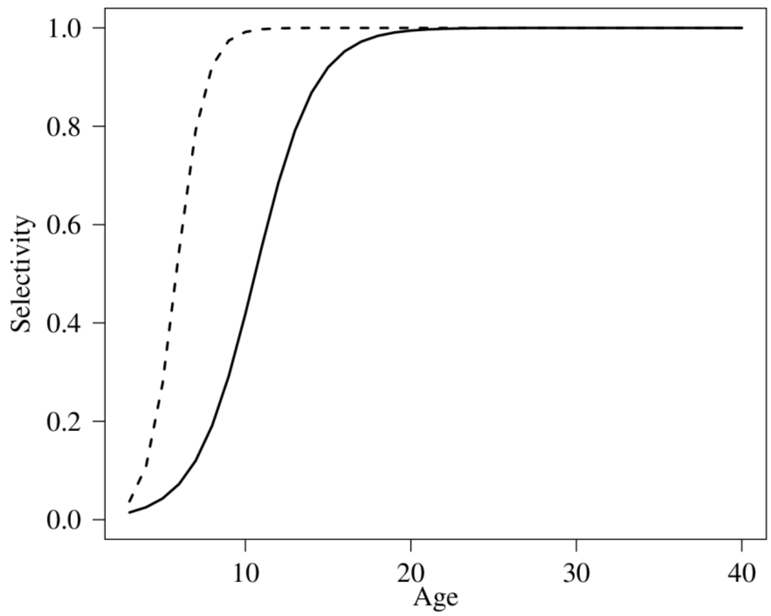

Figure 13. Estimated fishery (solid line) and survey (dashed line) selectivity at age for BSAI northern rockfish.

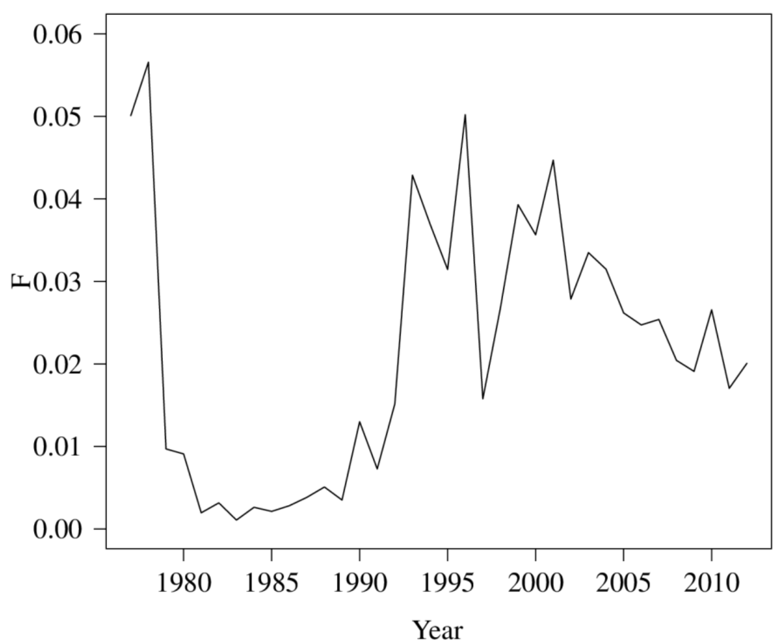

Figure 14. Estimated fully-selected fishing mortality rate for BSAI northern rockfish.

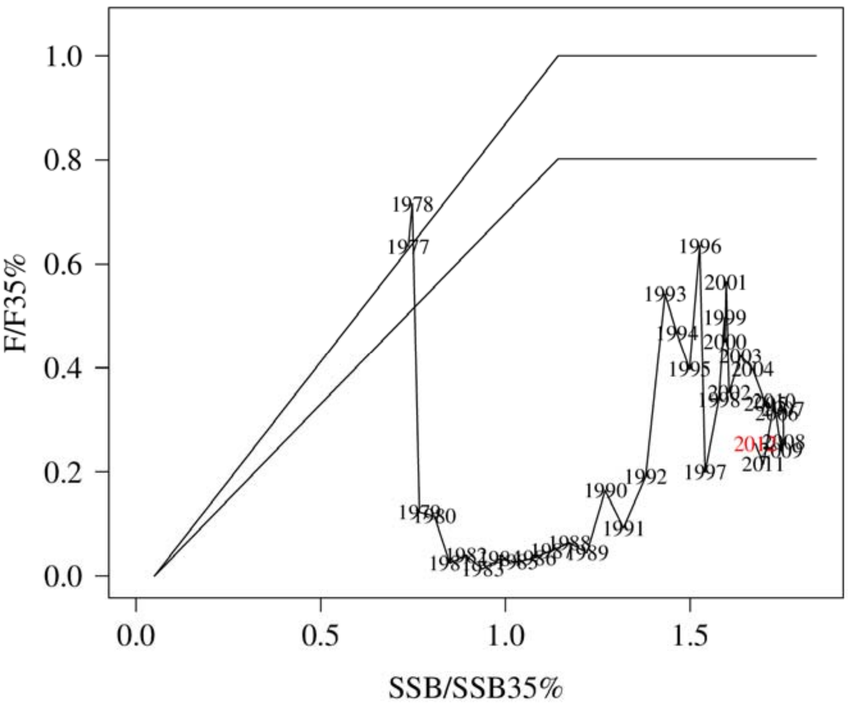

Figure 15. Estimated fishing mortality and SSB from 1977-2012 (with 2012 in red) in reference to OFL (upper line) and ABC (lower line) harvest control rules.

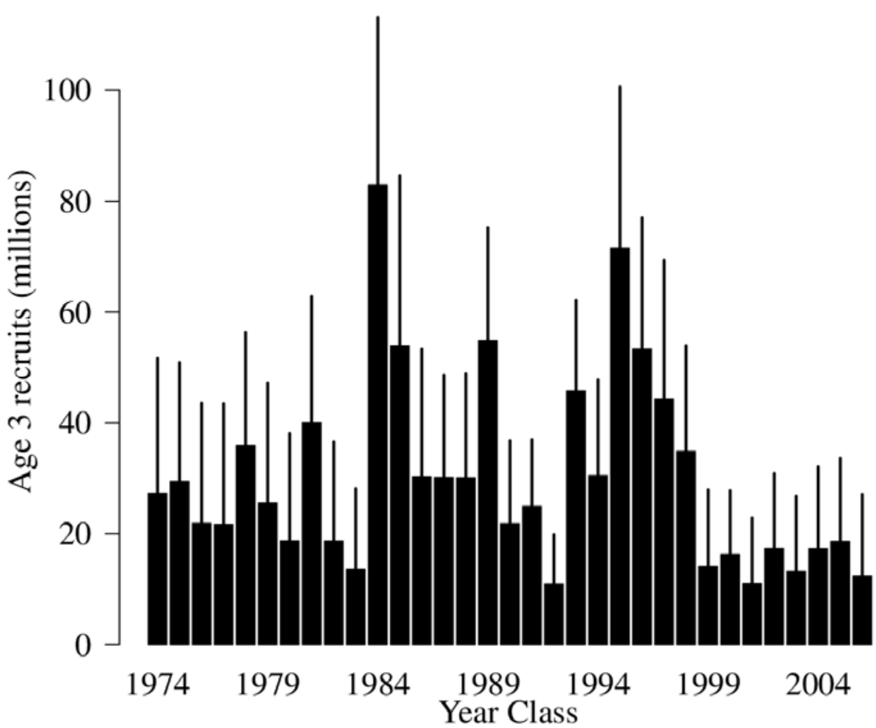

Figure 16. Estimated recruitment (age 3) of BSAI northern rockfish, with 95% CI limits obtained from MCMC integration.

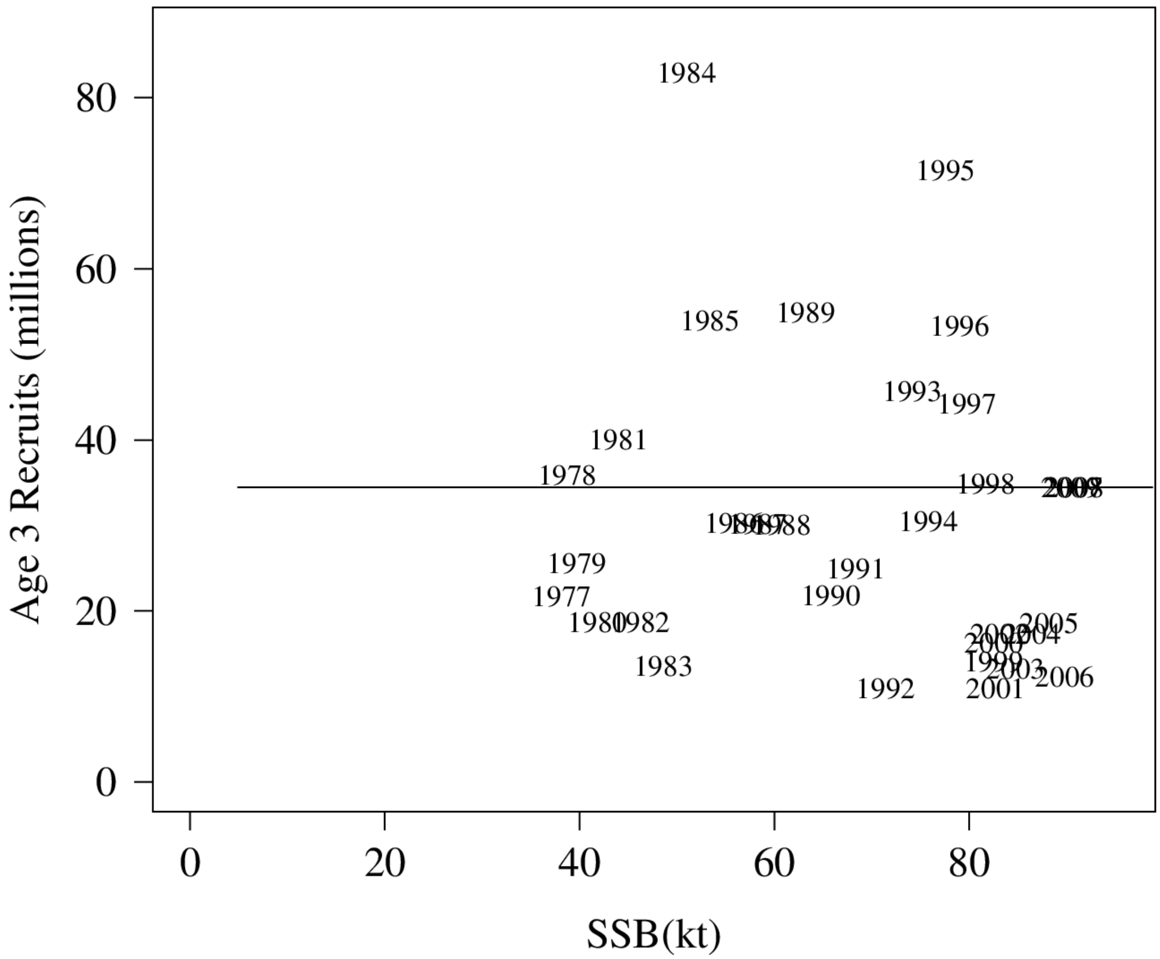

Figure 17. Scatterplot of BSAI northern rockfish spawner-recruit data; label is year class.

Appendix A. Evaluation of stock structure for the Bering Sea/Aleutian Islands northern rockfish

Executive summary

In this document, various types of information pertaining to stock structure for the BSAI northern rockfish are considered, following the template recommended by the Stock Structure Working Group (SSWG). Evaluation of spatial harvest indicated that estimated exploitation rates for the eastern AI have been consistently at or above natural mortality in recent years, which in part have motivated the evaluation of stock structure.

Tests for genetic homogeneity indicated that genetic differences occurred between samples of northern rockfish collected at six locations within the BSAI, and a significant isolation by distance (IBD) pattern also occurred within the BSAI area. Two estimates of the dispersal distance between parents and offspring were estimated from the IBD relationship (one of which considers the migration rate between populations). The maximum estimate of dispersal distance was ~ 200 km, much shorter that the linear distance of the BSAI management area.

Differences in size at age and were also detected, with smaller northern rockfish in the western AI and larger northern rockfish in the eastern AI and southern Bering Sea (SBS) area.

Given the long generation time of northern rockfish (estimated here as 36 years), the genetic structure observed for northern rockfish, and the spatial differences in growth patterns, subarea ABCs are recommended. The subarea ABCs would allow improved, in-season, monitoring of spatial harvest patterns, and could potentially allow actions to avoid exceeding the area-specific ABC levels. Additionally, sub-areas ABC would be consistent with the spatial structure of the stock, and the current management for many Alaska groundfish stocks (and most Alaska rockfish species).

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 A1) that identifies various scientific data from which we may infer stock structure. At the September, 2011, meeting of the joint Groundfish Plan Team recommended application of the template to several stocks, including BSAI northern rockfish.

The purpose of this document is to use the template produced the stock structure committee to evaluate scientific information on stock structure, and consider the management implications of potential area-specific ABCs and OFLs. The SSWG template has a number of broad categories of information relevant to BSAI northern rockfish, including spatial harvest patterns, oceanographic characteristics, differences in growth and age/size structure, and genetic information.

Harvest and Trends

The purpose of examination of 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)

Values of fishing mortality much less than the target reference point may indicate an absence of conservation concern with respect to spatially disproportionate harvesting.

The estimates of fishing mortality for the ten-year period 2002-2011 ranged from 0.017 to 0.033 with a mean of 0.025. The ratio of F to the estimated F_{abc} of 0.063 from the 2012 assessment ranged from 0.27 to 0.53 during this period, with a mean of 0.40. Although overall fishing rates are below current estimates of reference fishing rates, they are not sufficiently low that conservation concerns regarding spatially disproportionate harvesting patterns could be ruled out without further analysis.

Spatial concentration of harvest relative to abundance

The spatial concentration of harvest relative to abundance was evaluated by calculating area specific exploitation rates from 2004 to 2012. For each of the Aleutian Island subareas, an exploitation rate for a given year was obtained by dividing the yearly catch by the estimate of biomass for the subarea. The subarea biomass for each year was obtained by partitioning the estimated biomass at the beginning of the year (obtained from 2012 stock assessment) into the subareas. The biomass estimates from the 2012 stock assessment are assumed to be the best available information on the biomass time series, and using the results from the 2012 assessment can be considered a “retrospective” look at past exploitation rates. For each year, a weighted average of the three most recent surveys was applied to each subarea (weights of 4,6, and 9, with recent surveys higher weights), and the proportions from these averages were used to partition the projected biomass. Exploitation rates for 2012 are based on catches through October 6, and are preliminary because northern rockfish harvest is expected to continue in the fall of 2012.

The survey biomass estimates of northern rockfish follows a gradient, with the highest abundance in the western AI (average of 129,000 t from 1991-2012) and lowest abundance in the southern Bering Sea (SBS) portion of the AI survey (average of 3,509 t from 1991-2012) (Figure A1). Northern rockfish are rarely found in the EBS slope survey. No distinct trends in biomass are observed over time. The survey coefficients of variation (CV) are lowest in the western AI (average of 0.39 from 1991-2012) and highest in the SBS (0.69 from 1991-2012) (Figure A2). Using the weighted averages of the most recent three surveys produces relatively stable estimates of area proportions, which ranged from 0.61 to 0.75 in the WAI and from 0.17 to 0.25 in the CAI (Figure A3).

Catches of northern rockfish from 2004-2012 (through October 6, 2012) are highest in the western and central AI, although the 2011 and 2012 catch in the western AI were unusually low (311 t and 140 t, respectively, compared to a 2004-2010 average of 1,501 t for this area), which reflects the closure of the WAI to directed fishing for Atka mackerel beginning in 2011 (Figure A4). Catches in the eastern AI averaged 262 t from 2004 to 2006, but the average from 2007 to 2011 increased to 800 t.

To evaluate to the potential impact upon the population, exploitation rates were compared a measure of stock productivity. Because BSAI blackspotted/rougheye are managed as a Tier 3 stock, the F_{abc} and F_{ofl} reference points are based on conserving 40% and 35% of the lifetime spawning stock biomass produced per recruit for an unfished stock, and these reference points reflect maturity, fishery selectivity, and size at age. For comparison with the subarea exploitation rates, the exploitation rate for each year that would result from applying a fishing rate of $F_{40\%}$ to the estimated beginning-year numbers was computed, and this rate is defined as $U_{F40\%.}$ The values of $U_{F40\%}$ can change between years because of changes in the size structure of the population.

Exploitation rates for the western AI have been below $U_{F40\%}$ for all years between 2004-2012, but exploitation rates in the central AI have exceeded $U_{F40\%}$ from 2004-2006 (Figure A5). Exploitation rates in the EAI were above $U_{F40\%}$ in 2007 and were near $U_{F40\%}$ in 2010 and 2011. Exploitation rates in the EBS should be interpreted with caution because the EBS slope and shelf surveys have limited sampling in the depths occupied by northern rockfish, and thus could be underestimating the abundance. For example, the one very large EBS exploitation rate in 2004 is likely attributable to survey observation error. Nonetheless, the exploitation rate in the EBS have been below UF40% in recent years.

Because northern rockfish are taken as bycatch, high estimates of area-specific exploitation rates could suggest that the association between northern rockfish and the target species (Atka mackerel) could differ between areas. The bycatch rate of northern rockfish in tows targeting Atka mackerel (i.e., the tons of northern rockfish caught per ton on Atka mackerel caught) was calculated for AI subareas from hauls sampled by fishery observers from 2004 to 2012. From 2008 to 2011, the bycatch rates were lower in the EAI than in other AI subareas (Figure A6a), whereas in earlier years (i.e., 2005-2007) the bycatch rates in the EAI met or exceeded the bycatch rate in the central AI. Given that approximately 8% of the survey biomass (based on surveys from 2004-2012) occurs in the eastern AI, one would expected the bycatch rates to be even lower than their current level (Figure A6b). For example, the average 2008-2011 bycatch rates for the CAI is 1.88 times that in the WAI, but the ratio of survey biomass proportion in the CAI from 2004-2010 is approximately 2.9 times that in the EAI.

Population trends

Differential changes in population trends between subareas could reflect stock structure and a lack of connectivity between areas. The available information does not suggest differential trends between the subareas. However, given the high survey CVs in some subareas, any potential trend in the true area biomass may be relatively difficult to observe.

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 northern rockfish was 36 years. In general, rockfish species would be expected to have large mean generation times due to their longevity; for example, the estimated generation times for BSAI POP and blackspotted/rougheye were 28 years and 53 years, respectively.

Physical limitations (clear physical inhibitors to movement)

The Aleutian Islands is characterized by deep passes, typically exceeding 500 m, that may limit the movement of northern rockfish between Aleutian Islands subareas (Figure A7). Northern rockfish are a demersal species captured during the AI trawl survey at depths between 100 m and 200 m, so traversing the much deeper AI passes would require greater utilization of pelagic habitats or deeper depths than currently observed in the AI trawl surveys.

Field data on ocean currents can be used to infer the degree of water flow between subareas within the Aleutian Islands. On the north side of archipelago, the connection between the east and west Aleutians is limited due to the break associated with Petral Bank and Bowers Ridge, which results in water flowing away from the Aleutian Islands archipelago (Figure A7, Stabeno et al 2005). On the south side of the Aleutian Islands, the Alaska Stream provides much of the source of the Alaska North Slope Current (ANSC) via flow through Amutka Pass and Amchitka Pass. However, The Alaska Stream separates from the slope west of the Amchitka Pass and forms meanders and eddies, perhaps limiting the connection between the east and west Aleutians.

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.

Unfortunately, data on northern rockfish spatial movements (i.e., from tagging or larval drift studies) that would reveal connectivity and physical barriers do not exist. However, information on the movement of reproductively active northern rockfish can be obtained from genetic research, which is discussed elsewhere in this document.

Growth differences

Age data from northern rockfish in the Aleutian Island surveys from 1986 – 2006 provide information on size at age within Aleutian Island subarea. Otoliths were obtained by length-stratified sampling, and unbiased estimates of mean length 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). No trends were observed over time, so the data from all years were grouped together in the analysis. 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, and Akaike's Information Criterion (AIC) was used to evaluate whether growth patterns differ significantly between the AI subareas.

The data indicate increasing size at age from the western AI to the eastern AI (Figure A8). The largest difference in the growth curves was in the rate parameter K, which varied by a factor of two between the areas and reflects that fish in the WAI approached their asymptotic size more slowly than fish in the EAI and SBS. The estimated length at infinity (L_{inf}) from the von Bertalannfy relationship was approximately 5% larger in the southern Bering Sea (35.46) than in the western AI (33.63), which corresponds to a 17% difference in weight at infinity (W_{inf}) between these areas.

The resulting von-Bertalanffy growth parameters are as follows:

Area	Fish aged	t_{izero}	K	L_{inf} (cm)	W_{inf} (g)
SBS	300	0.63	0.24	35.46	651
EAI	351	0.66	0.23	35.48	652
CAI	354	-0.78	0.17	34.17	583

WAI	353	-2.15	0.12	33.63	555

The range of the K parameter for the model fits above could be affected by the confounding of this parameters with t_{zero}. However, fixing $_{zero}$ at zero revealed the same patterns of larger *K* values in the eastern AI, with the range between the WAI and SBS being reduced to 0.169 to 0.214.

Age/size structure

The estimated age compositions of northern rockfish were obtained from data from trawl surveys conducted from 2002, 2004, and 2006 (Figure A9). An ANOVA was used to test for significant differences in the mean age between areas. For each haul with aged fish, a mean 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 a significant factor, so separate analyses were applied for each year.

For each year, significant differences were observed in the mean age between subareas, but a consistent pattern did not emerge (Table A2). For example, in 2002 the mean age in the eastern AI was significantly different from the mean age in the western AI and the SBS, and marginally different from the mean age in the central AI ($P < 0.10$), but this pattern did not hold for 2004 and 2006. The mean age was significantly different between the eastern AI and the western AI for each year, but the mean age was not significantly different between the SBS and western AI for any year.

Genetics

Several genetic tests were conducted on northern rockfish samples obtained in the 2004 Aleutian Islands trawl survey (Gharrett et al. 2012). A total of 499 samples were collected at six locations ranging from the EBS slope to the western Aleutian Islands, and analyses were applied to 11 microsatellite loci.

Pairwise genetic differences (significant differences between geographically distinct collections)

Evaluation of the null hypothesis of homogeneity of allele frequency distributions between the collections were analyzed with GENEPOP 4.0 (Rousset 2008). The results were highly significant in aggregate for the 11 loci ($P < 0.001$) and for 2 of the 11 individual loci ($P < 0.01$), indicating lack of homogeneity. Information on the spatial population structure was obtained from the spatial analysis of molecular variance (SAMOVA; Dupanloup et al. 2002), which identified sets of collections that showed maximum differentiation. Three groups were identified: 1) the eastern Bering Sea; 2) two collections west of Amchitka Pass; and 3) three collections between Amchitka Pass and Unimak Pass (Figure A10). Genetic structure was not observed for samples on either side of Samaga Pass and Amutka Pass, although the structure observed with the westernmost collections may be associated with Amchitka Pass.

Isolation by distance

The fixation index F_{st} (a measure of the allele diversity between subpopulations relative to the entire population) was calculated for each pair of collections. Isolation by distance was evaluated by relating *Fst* to geographic distance (*d*) between each pair of collections with the following regression:

$$\frac{F_{st}}{1-F_{st}} = a + bd$$

The slope b is defined as $1/(4D_e\sigma^2)$, where D_e is the effective linear population density (i.e., effective spawners per km) and σ is the mean dispersal distance between parents and offspring. Calculation of F_{st} between pairs of collections, as opposed to between individuals, is recommended when samples are obtained from relatively few sites rather than uniformly throughout the range (Rousset 2000).

The relationship between F_{st} and distance was statistically significant ($P < 0.007$; Figure A11), indicating genetic structure being produced from the dispersal of individuals being smaller than the spatial extent of the sampling locations.

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 the dispersal distance is normally distributed, approximately 95% of offspring would be contained within a distance of 4σ from their parent. Estimation of the slope of the IBD relationship, and assumptions regarding the effective density, allow estimates of the dispersal distance.

Estimates of effective linear density were obtained by estimating the linear density of mature fish, and applying a ratio of effective population size to census populations size.

The linear distance from the Bering Sea slope to the western end of the Aleutian Islands is approximately 2500 km, and an estimate population size of mature (ages 13 and older) AI northern rockfish in 2010 (from the 2010 stock assessment) is 331.9 million fish, resulting in a linear density of ~ 133,000 fish per km. The width of rockfish habitat along the Aleutian Islands is probably 1/2 degree latitude (56 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. A sensitivity analysis conducted based upon five values of D_e/D_{census} that range from 0.1 to 0.001 produces estimates of dispersal distance (4σ) between 12 and 120 km.

An alternative estimate of dispersal distance can be obtained from relating the quantity $F_{st}/(1-F_{st})$ to the effective number of migrants, and using the regression parameters in Eq. 2 to solve for dispersal distance d (see Gharrett et al 2012 for derivation). Migration rates of approximately 10% would be expected to produce independent populations (Hastings 1993); thus, rates of 10% and 20% were evaluated in producing the alternative values of dispersal distance. The estimates of dispersal distance were 190 km and 229 km for rates of 10% and 20%, respectively.

Clearly, the spatial scale of genetic divergence for each estimation method is much smaller than the distance along the continental shelf break that extends around the eastern Bering Sea to the western Aleutian Islands. Further, the scale of the dispersal distances are also comparable to other *Sebastes* species in the north Pacific, which have ranged from 4 to 40 for near shore species such as grass rockfish (Buonaccorsi et al. 2004), brown rockfish ((Buonaccorsi et al. 2005), and vermilion rockfish (Hyde and Vetter 2009), and up to 111 km for deeper species such as POP (Palof et al. 2011) and darkblotched rockfish (Gomez-Uchida and Banks 2005). The demographic implication is that movement of fish from birth to reproduction is at a much smaller scale than the geographic scale of the BSAI area. Finally, it is important to recall that the time unit for the estimated dispersal is not years, but generations, and the generation time for northern rockfish is more than 36 years.

Interpretation of the information regarding stock structure

A summary of the information in the template for BSAI northern rockfish is shown in Table A3. 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.

Spatial structure could be revealed by differences in age composition between areas, as the recruitment strengths could differ spatially between areas that are not well-mixed. However, the trawl survey age composition data for northern rockfish is characterized by high levels of variability both between areas and between years, resulting in an inability to observed a consistent and informative pattern of statistical significance.

Differences in size at age between subareas in the AI trawl survey indicate a gradient, with fish in the eastern AI and SBS being similar in size and relatively large, and smaller fish in the western AI. 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.

Finally, evaluation of the genetic test identified in the stock structure template indicate spatial structure, including: 1) genetic differences between geographically distinct collections; 2) isolation by distance; and 3) dispersal distances much smaller than management areas. Given the genetic information and differences in growth patterns, the most parsimonious in interpretation of the data is that there is some spatial structuring for BSAI northern rockfish.

Management Implications

History of spatial management of BSAI rockfish

After passage of the Fishery Conservation and Management Act of 1976, POP were managed as two stocks in the BSAI -- an EBS slope stock and an AI stock. At that point, other "red" rockfish species, including northern rockfish, rougheye rockfish, shortraker rockfish, and sharchin rockfish, were managed along with POP in a "POP complex" group. The recognition of separate rockfish stocks within the BSAI area was continued from INPFC management, and likely reflects the analyses of Chikuni (1975), who recognized three POP stocks in Alaskan waters based on investigation of length composition, growth characteristics, fecundity, recruitment strengths, and oceanographic characteristics: 1) a Gulf of Alaska stock; 2) an "eastern slope" stock (corresponding to the eastern slope of Bering Sea); and a Aleutian stock. The Other Red Rockfish species were separated from POP in 1991 (with the complexes varying between the AI and EBS), and separate harvest specifications between the AI and EBS were still maintained. In 2000, the BSAI Plan Team recommended that the species comprising the Other Red Rockfish category (northern rockfish, rougheye rockfish, and shortraker rockfish; sharpchin rockfish were moved to the "Other rockfish" category) be managed as separate species, but managed with a BSAI-wide OFL and ABC (BSAI Groundfish Plan Team 2000). A concern to the Plan Team was that a low OFL for the EBS slope could result in an "immediate economic and management issue" and prove "constraining to the fleet" in their pursuit of target fisheries.

The Plan Team did note in 2000 that "there is some risk associated with establishing area-wide ABCs if there are truly separate stocks of shortraker and rougheye rockfish in the AI and EBS" (BSAI Groundfish Plan Team 2000). To address this, the BS and AI areas were allocated separate TACs, which continued from 2001 to 2003. Beginning in 2004, rougheye rockfish, shortraker rockfish, and northern rockfish were managed with BSAI-wide OFLs, ABCs, and TACs.

Considerations for BSAI northern rockfish spatial management

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 northern rockfish, 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, which may result from differences in growth and reproduction between areas.

The current management approach is to have the ABC and OFL apply to the BSAI area, and placing northern rockfish 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, as indicated by recent exploitation rates in the AI subareas that have occasionally exceeded the reference values of $U_{F40\%}$.

Given the information on spatial stock structure and the current practice of BSAI OFLs and ABCs, defining subarea ABCs might be viewed as a logical next step, and would have the following advantages:

1) *More effective monitoring*. A pattern of disproportionate harvest rates may motivate more monitoring of spatially harvest patterns in the future. Currently, this monitoring is contained within the biennual stock assessments and is thus not prominently communicated to many people. Adoption of sub-area ABCs would enhance the visibility of spatial harvest patterns and thus allow more effective communication of this information. Most importantly, it would allow the fishing industry and managers to evaluate spatial harvest patterns in real-time, perhaps leading to solutions to address disproportionate harvesting.
2) *Consistency with spatial structure*. Sub-area ABCs are often interpreted as pertaining to spatial units that have biological meaning for the stock. Continuation of BSAI-wide ABC levels suggests that relevant spatial scale is entire BSAI management area, which is not consistent with current scientific data on stock structure.
3) *Consistency with current and proposed management practices*. Adopting sub-area ABCs is a commonly used management practice intended to prevent disproportionate harvesting, and it often applied in a precautionary manner to cases with uncertain or unknown stock structure. This practice was recommended by the SSWG (Spencer et al. 2010) and at the 2010 meeting of the Joint Groundfish Plan Team. Given that the information on stock structure does exist for northern rockfish and indicates spatial scales smaller than our current management areas, it seems especially fitting to apply this recommendation in this case.
4) *Proactive management*. BSAI northern rockfish are not currently targeted, but were targeted during the 1990s. Should a target fishery develop in the future, a system of sub-area ABCs would be in place to prevent disproportionate targeting, reflecting the NPFMC goal of proactive management.

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. Because BSAI northern rockfish are taken as bycatch and not targeted, adoption of sub-area ABCs (which would prevent targeting) would be expected to have little impact on current fishing practices. Under the new ACL harvest regulations there are implications of exceeding ABC levels at a frequency of > 25%. However, these regulations appear to pertain to the stock-wide ABC (in this case, the BSAI ABC) and not to the subarea allocation of ABC.

There is also a regulatory cost of area-specific ABC 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.

Adoption of subarea OFLs could potentially impact target fisheries that harvest northern rockfish, and thus adoption of this management approach would require careful consideration of the costs and benefits. Given the current practice of BSAI-wide ABC levels, a useful next step is to adopt subarea ABCs to better monitor spatially harvest patterns, and consider the costs and benefits of subarea OFLs only if the monitoring indicates a continued pattern of spatially disproportionate harvesting.

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Table A1. 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 A2. *P*-values from an ANOVA comparing mean age of northern rockfish from subareas from the Aleutian Islands survey.

	Area	Central AI	Eastern AI	Western AI
Year: 2002				
	SBS	0.22	<0.01	0.91
	Central AI		0.07	0.27
	Eastern AI			<0.01
Year: 2004				
	SBS	0.99	0.64	0.11
	Central AI		0.14	<0.01
	Eastern AI			<0.01
Year: 2006				
	SBS	0.98	0.71	0.85
	Central AI		0.54	0.10
	Eastern AI			<0.01

Table A3. Summary of available data on stock identification for BSAI northern 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 BSAI are approximately ½ the ABC level
Spatial concentration of fishery relative to abundance (Fishing is focused in areas << management areas)	Estimated exploitation rates in the eastern AI have exceeded the 0.75*M in recent years.
Population trends (Different areas show different trend directions)	Population trends do not appear to be different between areas, although the uncertainty of the survey data in the subareas increases with smaller sample sizes.
Barriers and phenotypic characters	
Generation time (e.g., >10 years)	The generation time is approximately 36 years
Physical limitations (Clear physical inhibitors to movement)	The Aleutian North Slope Current does not extend west of the central AI, limiting the connections within the 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)	Significantly different growth curves were observed between the AI subareas.
Age/size-structure (Significantly different size/age compositions)	Significant differences were found between subareas within individual years, but a consistent pattern was not observed.
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
Meristics (Minimally overlapping differences in counts)	Unknown
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	
Isolation by distance (Significant regression)	Significant pattern of isolation by distance.
Dispersal distance (<<Management areas)	Single generation dispersal scale of <= ~ 200 km, which is << the combined BSAI management area
Pairwise genetic differences (Significant differences between geographically distinct collections)	Significant pairwise differences between sets of genetic samples in the BSAI.

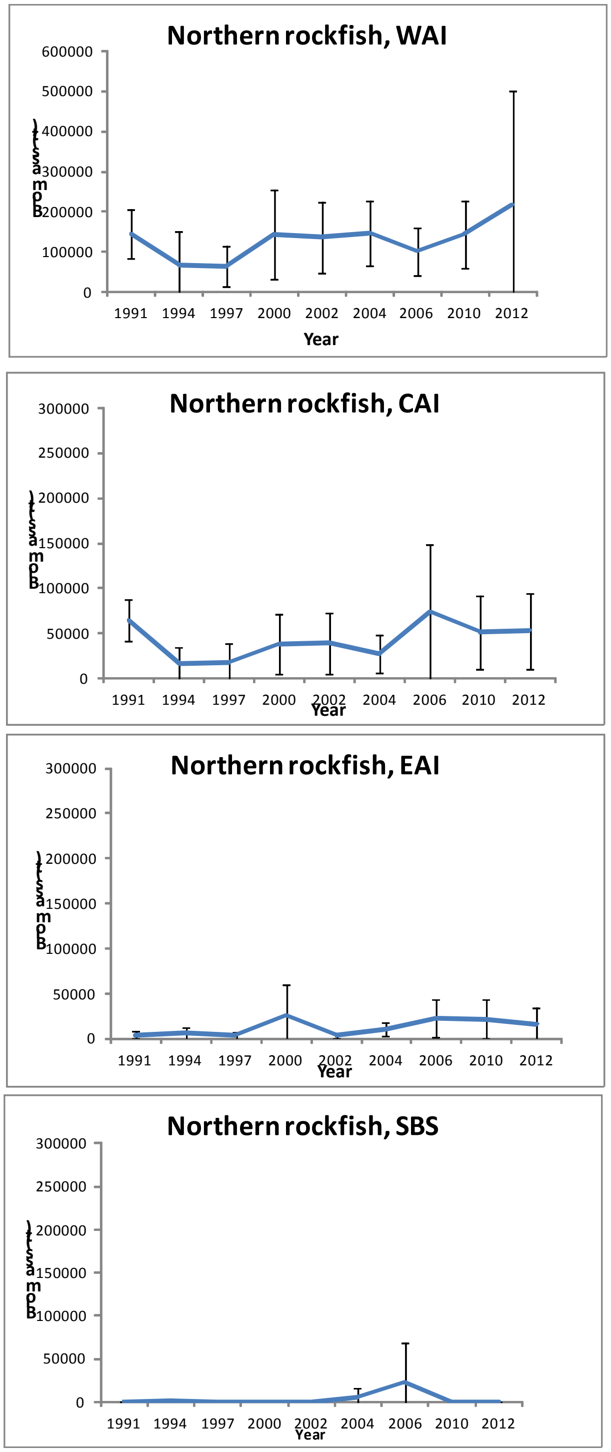


Figure A1. Northern rockfish biomass estimates from the Aleutian Islands survey.

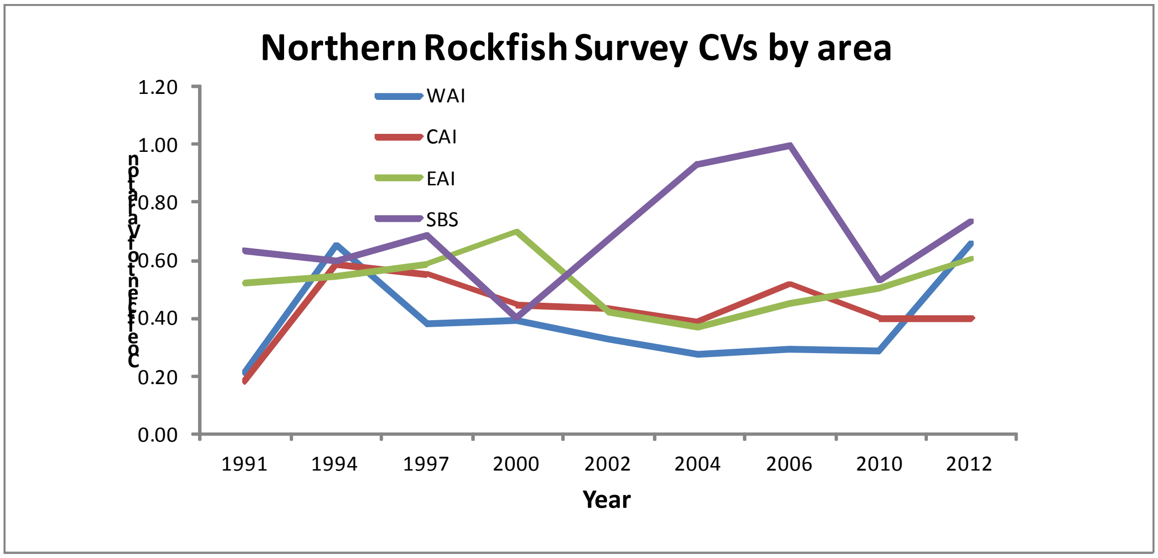


Figure A2. Coefficients of variation (CV) for northern rockfish biomass estimates from the Aleutian Islands survey.

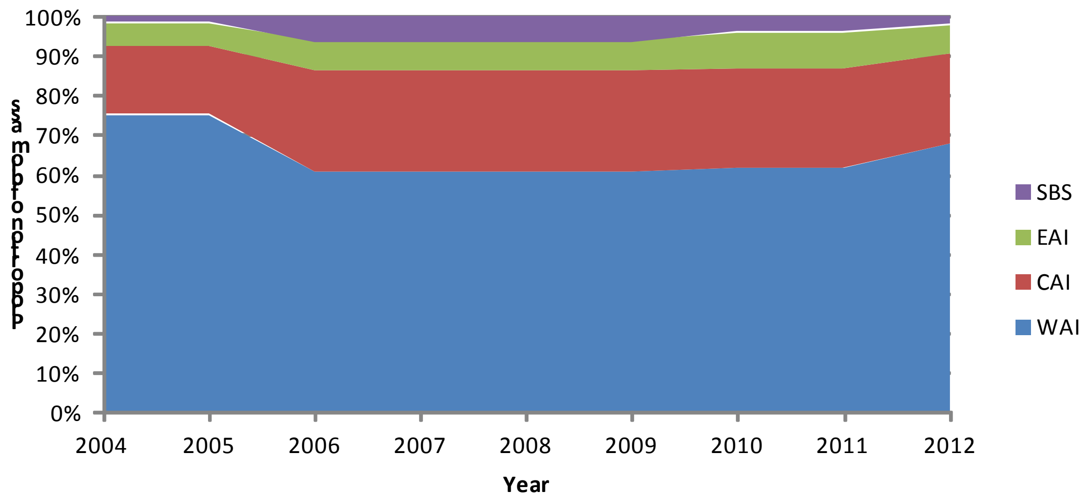


Figure A3. Estimated proportions of northern rockfish biomass for Aleutian Islands survey subareas, 2004-2012. For each year, the proportions were computed from weighted averages of the three most recent surveys.

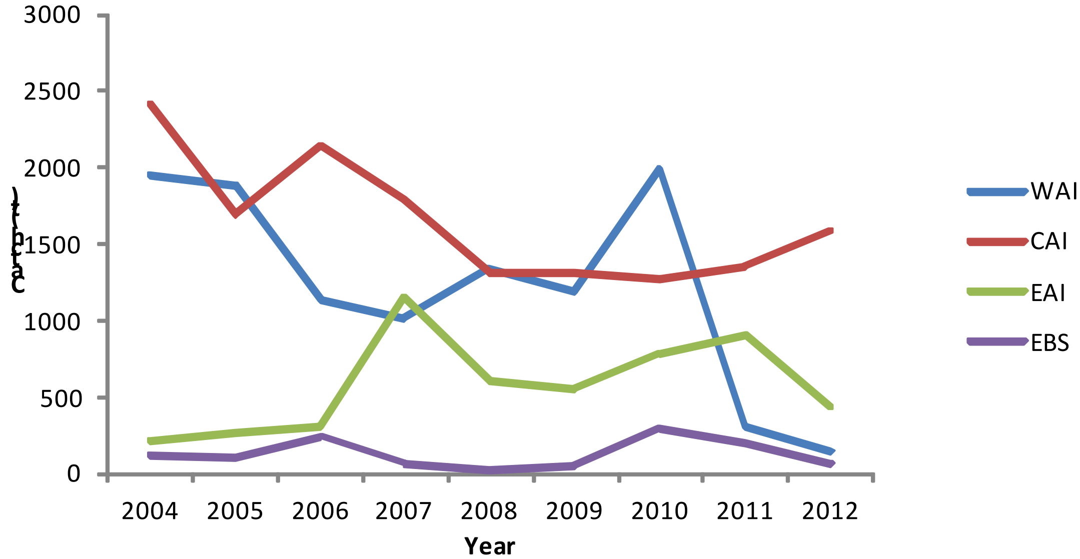
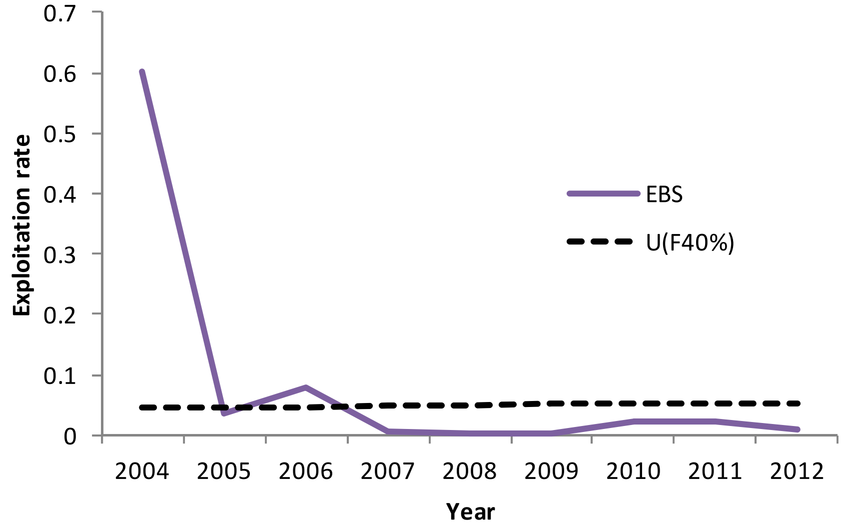


Figure A4. Catch (t) of northern rockfish by BSAI subarea, 2004-2012; 2012 data is through October 6.



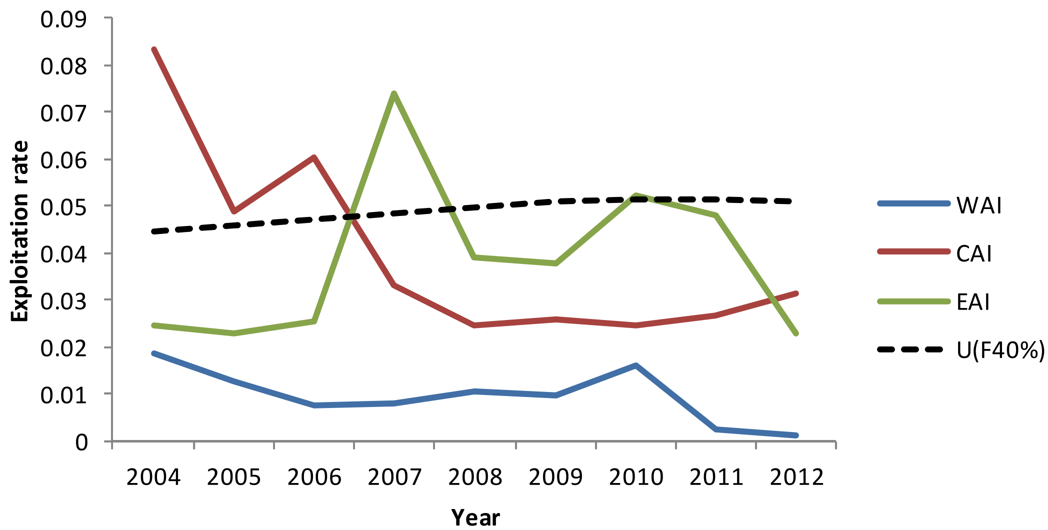


Figure A5. Estimated northern rockfish exploitation rates by area from 2004-2012.

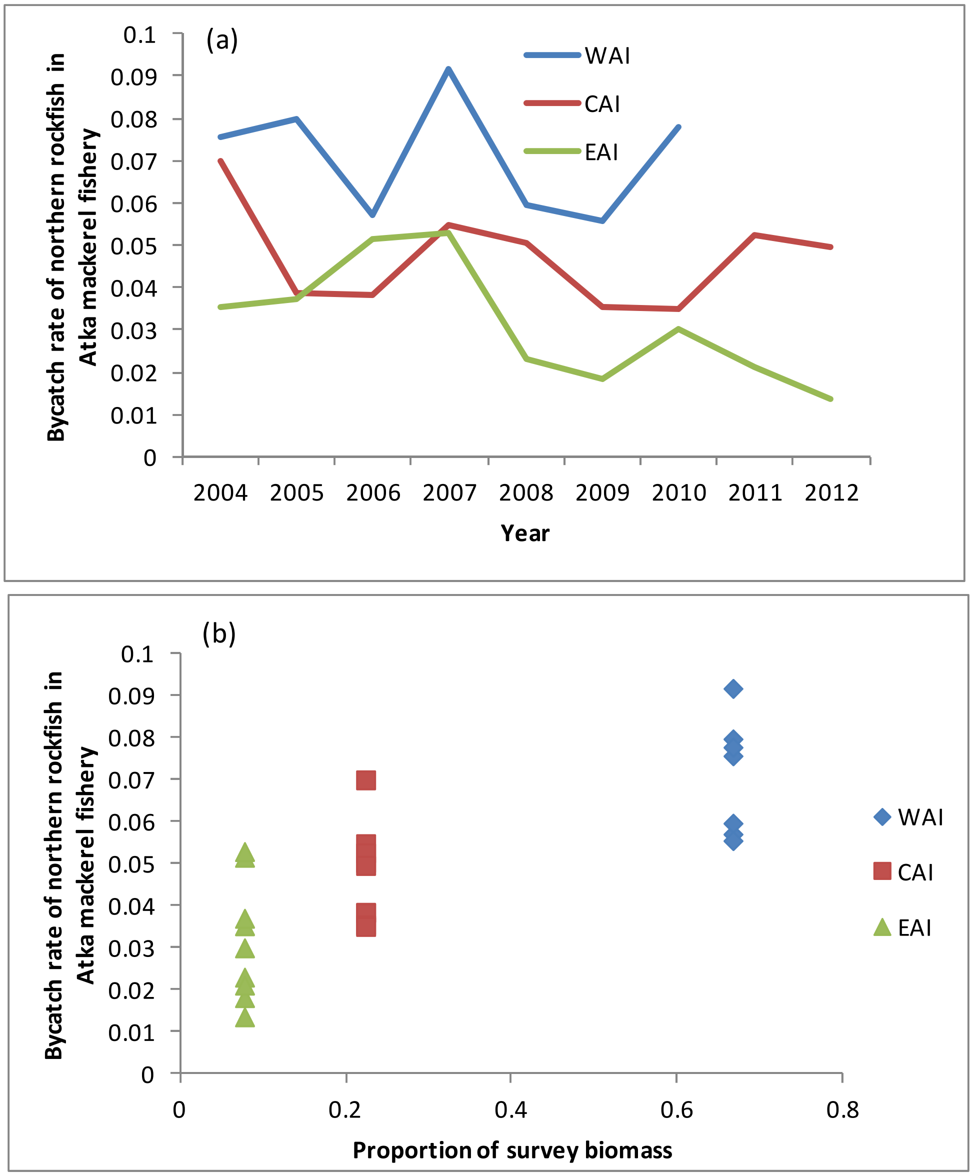


Figure A6. Northern rockfish bycatch rates from 2004-2012 (a), and bycatches as a function of average proportion of Aleutian Islands survey biomass from 2004-2012. Bycatch rates were computed as the tons of northern rockfish caught per ton of Akta mackerel caught in hauls sampled by fishery observers. Bycatch rates for 2011-2012 in the WAI are not shown due to regulations limiting Atka mackerel fishing in the area.

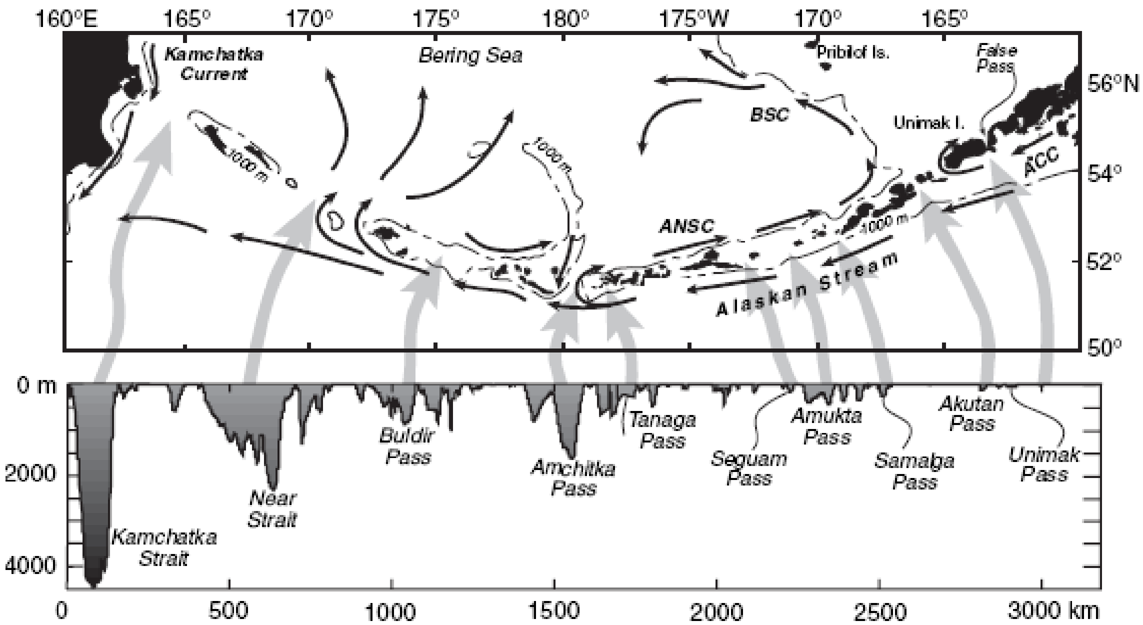


Figure A7. Schematic of ocean currents in the Aleutian Islands, showing the Alaska Steam, the Alaska Coastal Current (ACC), and the Aleutian North Slope Current (ANSC) (from Stabeno et al. 2005). The lower panel shows the location and depth of ocean passes in the Aleutian Islands archipelago.

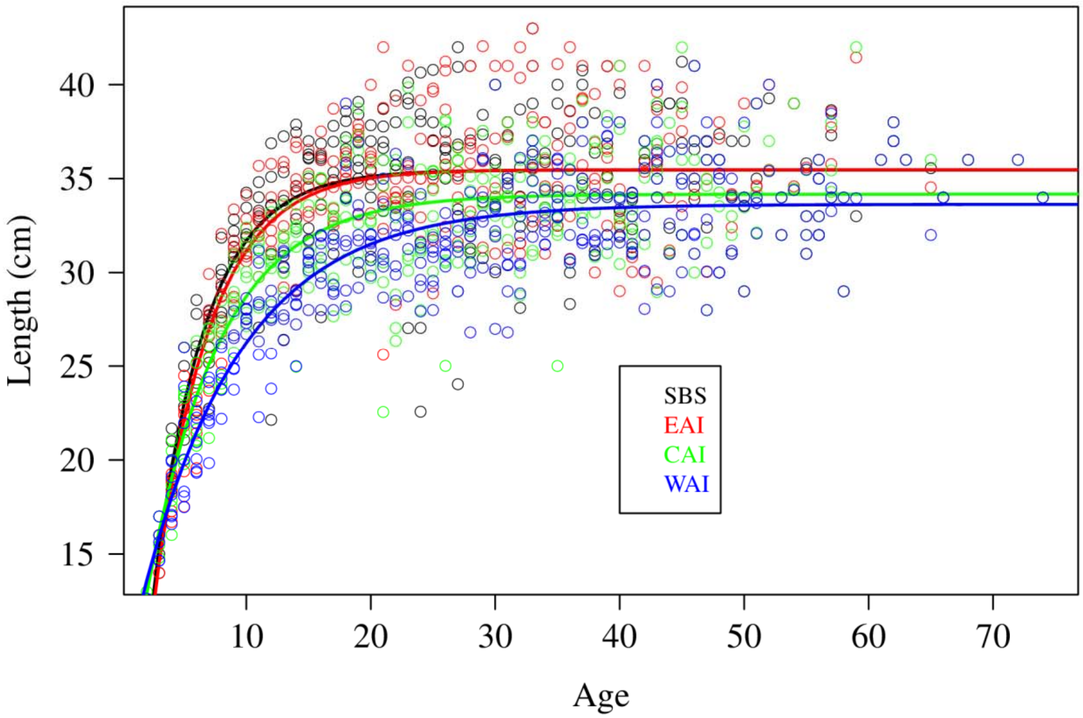
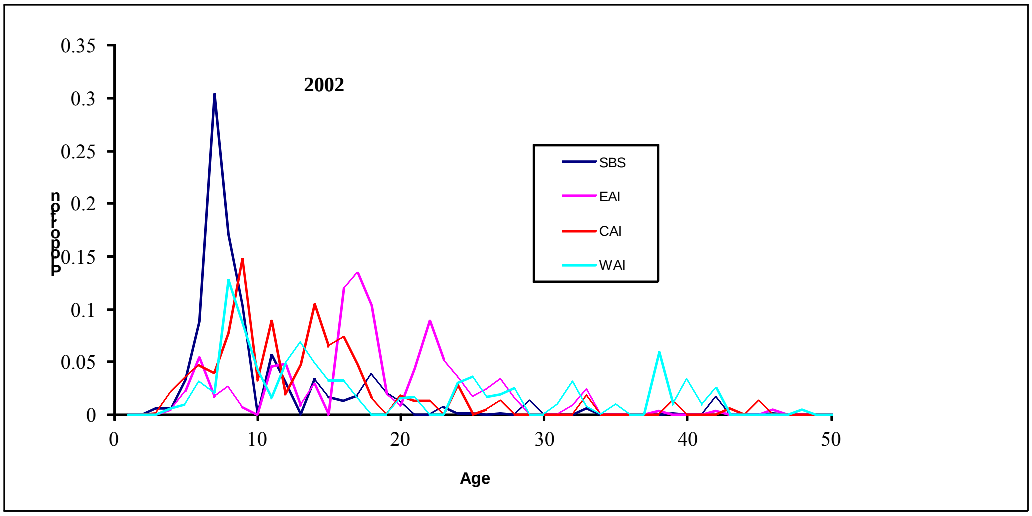
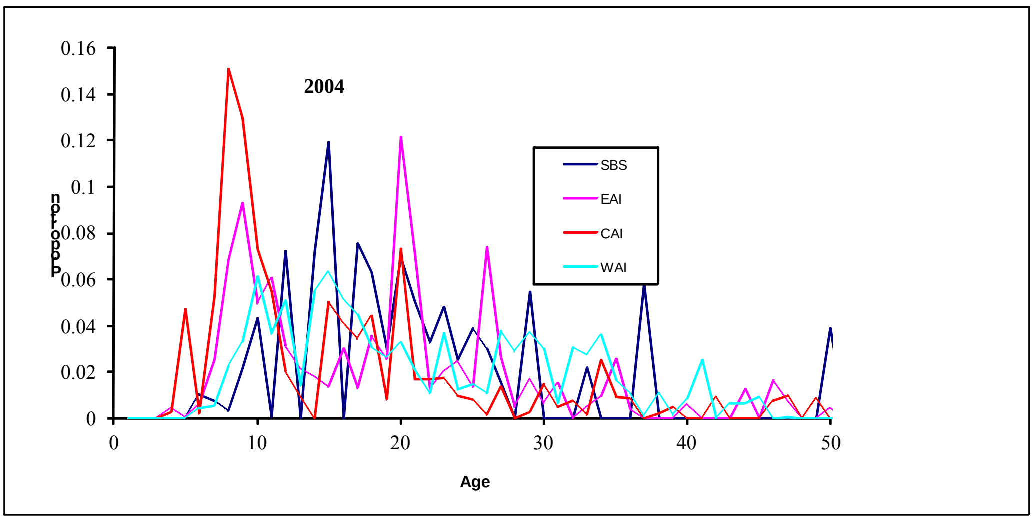


Figure A8. Estimated area-specific growth curves for northern rockfish, based Aleutian Islands survey data from 1986-2006.





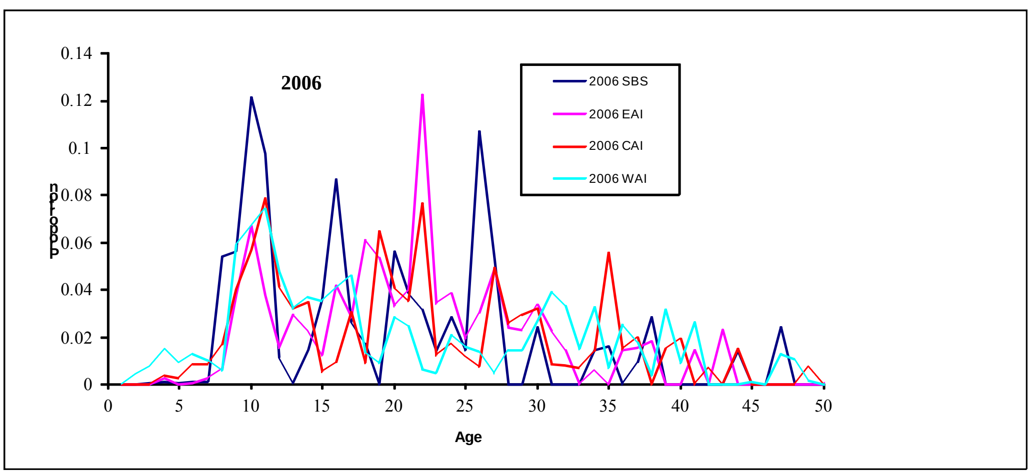


Figure A9. Survey age compositions for northern rockfish from the Aleutian Islands survey, 2002-2006.

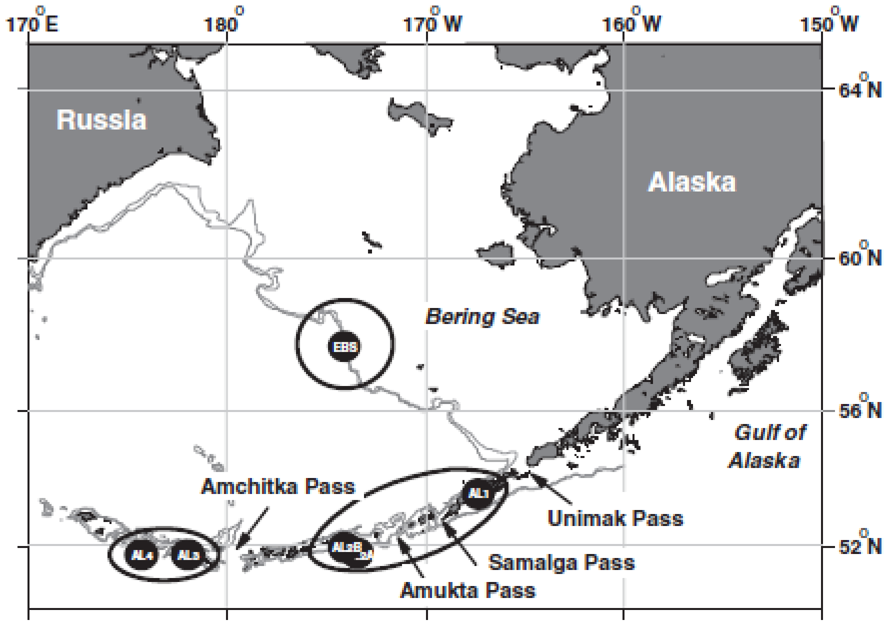


Figure A10. Locations of northern rockfish genetic samples obtained from the 2004 Aleutian Islands survey. The circles enclose sets of locations that were found to be genetically distinct based on spatial analysis of molecular variance (from Gharrett et al. 2012).

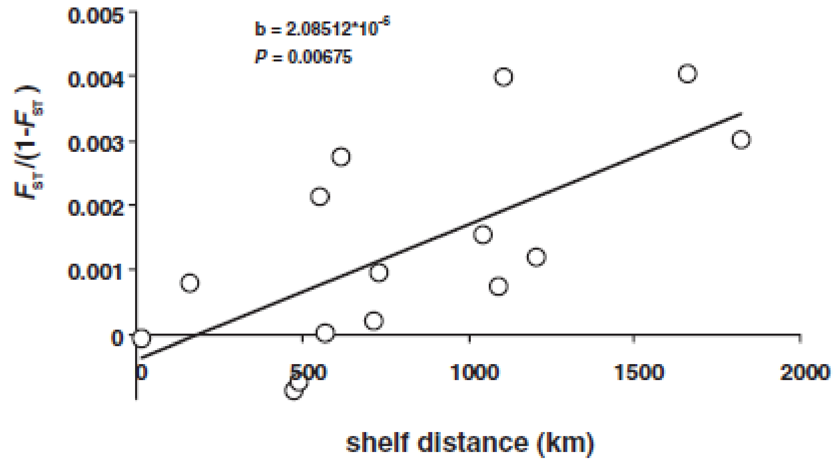


Figure A11. Relative F_{st} as function of geographical distance for six collections of northern rockfish genetics samples from the BSAI (from Gharrett et al. 2012).

Appendix B. Supplemental Catch Data.

In order to comply with the Annual Catch Limit (ACL) requirements, two new datasets have been generated to help estimate total catch and removals from NMFS stocks in Alaska. The first dataset, non-commercial removals, estimates total removals that do not occur during directed groundfish fishing activities (Table B1). This includes removals incurred during research, subsistence, personal use, recreational, and exempted fishing permit activities, but does not include removals taken in fisheries other than those managed under the groundfish FMP. These estimates represent additional sources of removals to the existing Catch Accounting System estimates. For BSAI northern rockfish, these estimates can be compared to the trawl research removals reported in previous assessments. BSAI northern rockfish research removals are small relative to the fishery catch. The majority of removals are taken by the Alaska Fisheries Science Center's (AFSC) biennial bottom trawl survey which is the primary research survey used for assessing the population status of BSAI northern rockfish. The annual amount of northern rockfish captured in research longline gear not exceeded 0.06 t. There was no recorded recreational harvest or harvest that was non-research related in 2010 and 2011. Total removals were 50 t in 2010 and 3 t in 2011, which were less than 0.7% and 0.04% of the ABC in these years. Research harvests in even years beginning in 2000 (excluding 2008, when the AI trawl survey was canceled) are higher due to the biennial cycle of the AFSC bottom trawl survey in the Aleutian Islands. These catches have varied between 41 t and 56 t.

The second dataset, Halibut Fishery Incidental Catch Estimation (HFICE), is an estimate of the incidental catch of groundfish in the halibut IFQ fishery in Alaska, which is currently unobserved. To estimate removals in the halibut fishery, methods were developed by the HFICE working group and approved by the Gulf of Alaska and Bering Sea/Aleutian Islands Plan Teams and the Scientific and Statistical Committee of the North Pacific Fishery Management Council. A detailed description of the methods is available in Tribuzio et al. (2011).

These estimates are for total catch of groundfish species in the halibut IFQ fishery and do not distinguish between "retained" or "discarded" catch. These estimates should be considered a separate time series from the current CAS estimates of total catch. Because of potential overlaps HFICE removals should not be added to the CAS produced catch estimates. The overlap will apply when groundfish are retained or discarded during an IFQ halibut trip. IFQ halibut landings that also include landed groundfish are recorded as retained in eLandings and a discard amount for all groundfish is estimated for such landings in CAS. Discard amounts for groundfish are not currently estimated for IFQ halibut landings that do not also include landed groundfish. For example, catch information for a trip that includes both landed IFQ halibut and sablefish would contain the total amount of sablefish landed (reported in eLandings) and an estimate of discard based on at-sea observer information. Further, because a groundfish species was landed during the trip, catch accounting would also estimate discard for all groundfish species based on available observer information and following methods described in Cahalan et al. (2010). The HFICE method estimates all groundfish caught during a halibut IFQ trip and thus is an estimate of groundfish caught whether landed or discarded. This prevents simply adding the CAS total with the HFICE estimate because it would be analogous to counting both retained and discarded groundfish species twice. Further, there are situations where the HFICE estimate includes groundfish caught in State waters and this would need to be considered with respect to ACLs (e.g. Chatham Strait sablefish fisheries). Therefore, the HFICE estimates should be considered preliminary estimates for what is caught in the IFQ halibut fishery. Improved estimates of groundfish catch in the halibut fishery will become available following restructuring of the Observer Program in 2013, when all vessels >25 ft will be monitored for groundfish catch.

The HFICE estimates of BSAI northern rockfish from 2001-2010 exceeded zero only in the eastern AI in 2001, when 0.25 t were captured (Table B2).

Appendix Table B1. Removals of BSAI northern rockfish from activities other than groundfish fishing. Trawl and longline include research survey and occasional short-term projects. "Other" is recreational, personal use, and subsistence harvest.

Year	Source	Trawl	Longline	Other
1977	NMFS-AFSC survey databases			
1978		0.000		
1979		0.012		
1980		3.576		
1981		0.059		
1982		0.898		
1983		29.285		
1984		0.095		
1985		0.021		
1986		56.895		
1987		0.168		
1988		0.130		
1989		0.062		
1990		0.740		
1991		15.470		
1992		0.077		
1993		0.001		
1994		13.155		
1995		0.015		
1996		0.001	0.034	
1997		17.728		
1998		0.252	0.004	
1999		0.089		
2000		39.883	0.002	
2001		0.038	0.006	
2002		36.657	0.011	
2003		0.124	0.002	
2004		56.763	0.005	
2005		0.002	0.002	
2006		41.112	0.059	
2007		0.172	0.008	
2008		0.026	0.008	
2009		0.005	0.023	
2010	NMFS-Alaska Regional Office	50.354	0.025	
2011		2.822	0.022	

Appendix Table B2. Estimates BSAI northern rockfish catch (t) from the Halibut Fishery Incidental Catch Estimation (HFICE) working group.

Year	Eastern AI	Central AI	Western AI	Central/Western AI	Total
2001	0.25	0.00	0.00		0.25
2002	0.00	0.00	0.00		0.00
2003	0.00	0.00	0.00		0.00
2004	0.00	0.00	0.00		0.00
2005	0.00	0.00	0.00		0.00
2006	0.00	0.00	0.00		0.00
2007	0.00	0.00	0.00		0.00
2008	0.00	0.00	0.00		0.00
2009	0.00			0.00	0.00
2010	0.00	0.00	0.00		0.00
Average	0.025	0.00	0.00	0.00	0.025

References

Cahalan J., J. Mondragon., and J. Gasper. 2010. Catch Sampling and Estimation in the Federal Groundfish Fisheries off Alaska. NOAA Technical Memorandum NMFS-AFSC-205. 42 p.

Heifetz, J., D. Hanselman, J. N. Ianelli, S. K. Shotwell, and C. Tribuzio. 2009. Gulf of Alaska northern rockfish. In Stock assessment and fishery evaluation report for the groundfish resources of the

Gulf of Alaska as projected for 2010. North Pacific Fishery Management Council, 605 W 4^{th} Ave, Suite 306 Anchorage, AK 99501. pp. 817-874.

Tribuzio, C.A., S. Gaichas, J. Gasper, H. Gilroy, T. Kong, O. Ormseth, J. Cahalan, J. DiCosimo, M. Furuness, H. Shen, K. Green. 2011. Methods for the estimation of non-target species catch in the unobserved halibut IFQ fleet. August Plan Team document. Presented to the Joint Plan Teams ofthe North Pacific Fishery Management Council.