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 2016. The following changes were made to northern rockfish assessment relative to the November 2016 SAFE:

Summary of Changes in Assessment Inputs

Changes in the input data:

1) Catch data was updated through 2018, and total catch for 2019 was projected.
2) The 2018 AI survey biomass estimate and age composition was included in the assessment.
3) The 2016 AI survey age composition replaced the 2016 survey length composition, and the 2018 AI survey age compositions were included in the assessment.
4) The 2015 fishery age composition replaced the 2015 fishery length composition, and the 2017 fishery age composition was included in the assessment.
5) The 2016 and 2018 fishery length composition data were included in the assessment.
6) The fishery and survey age compositions were recomputed by applying subarea (i.e., not global) age-length keys to subarea length compositions, due to spatial differences in size at age.
7) Separate weight at age curves were computed for the fishery and the population, and each were computed as an average of subarea weights at age (weighted by subarea survey abundance and fishery catch, respectively).

Changes in the Assessment Methodology

1) A constraint was placed on the asymptotic survey selectivity curve to ensure the selectivity at age 15 was close to 1.

Summary of Results

BSAI northern rockfish are not overfished or approaching an overfished condition. The recommended 2020 ABC and OFL are 16,243 t and 19,751 t, which are 30% and 31% increases from the values specified last year for 2020 of 12,396 t and 15,180 t. The reason for the increase in the harvest level is updated data showing larger weight at age for the fishery than was used in previous assessments, and a change in the estimated survey selectivity curve that scaled the population higher than previous assessments. We used the following risk table in the assessment:

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ ecosystem considerations*	*Fishery Performance considerations*	*Overall score (highest of the individual scores)*

Level 2: Substantially increased concerns	Level 1: Normal	Level 2: No apparent concern	Level 1: Normal	Level 2: Substantially increased concerns

The assessment –related concerns relate to the retrospective pattern in the assessment, and the use of strong priors for several key model parameters that cannot be reliably estimated (in effect understating the level of uncertainty in the assessment.) A population dynamics concern is that the spatial management of the stock is not consistent with the genetic spatial structure, which could lead to subarea depletion and loss of fishery yield, particularly as the target fishery for northern rockfish is developing. However, this risk has not been realized yet, and the stock abundance is high and exploitation rates are low. Given the current stock status, we recommend the full ABC.

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:		As estimated or recommended this year for:	
	2019	2020	2020*	2021*
M (natural mortality rate)	0.046	0.046	0.048	0.048
Tier	3a	3a	3a	3a
Projected total (age 3+) biomass (t)	244,196	242,426	250,235	246,384
Female spawning biomass (t)				
Projected	104,201	102,480	111,476	108,063
$B_{100\%}$	164,674	164,674	159,850	159,850
$B_{40\%}$	65,870	65,870	63,940	63,940
$B_{35\%}$	57,636	57,636	55,947	55,947
F_{OFL}	0.080	0.080	0.075	0.075
$maxF_{ABC}$	0.065	0.065	0.061	0.061
F_{ABC}	0.065	0.065	0.061	0.061
OFL (t)	15,507	15,180	19,751	19,070
maxABC (t)	12,664	12,396	16,243	15,683
ABC (t)	12,664	12,396	16,243	15,683
Status	As determined last year for: for:		As determined this year for:	
	2017	2018	2018	2019
Overfishing	No	n/a	No	n/a
Overfished	n/a	No	n/a	No
Approaching overfished	n/a	No	n/a	No

*Projections are based on estimated catches of 6,930 t and 6,691 t used in place of maximum permissible ABC for 2020 and 2021.

Summaries for the Plan Team

The following table gives the recent biomass estimates, catch, and harvest specifications, and projected biomass, OFL and ABC for 2015-2016.

Year	Biomass[1]	OFL	ABC	TAC	Catch[2]
2018	246,160	15,888	12,975	6,100	5,767
2019	244,196	15,507	12,664	6,500	
2020	256,262	19,751	16,243		
2021	250,235	19,070	15,683		

[1] Total biomass from age-structured projection model.
[2] Catch as of September 28, 2019.

Responses to SSC and Plan Team Comments on Assessments in General

(SSC, December 2018) *The SSC considers the risk table approach an efficient method to organize and report this information and worthy of further investigation. . . . The SSC recommends that one additional column be added to include concerns related to fishery/resource-use performance and behavior, considering commercial as well as local/traditional knowledge for a broader set of observations. . . . The SSC requests that all authors fill out the risk table in 2019, and that the PTs provide comment on the author's results in any cases where a reduction to the ABC may be warranted (concern levels 2-4).*

(SSC, June 2019) *. . . risk tables only need to be produced for groundfish assessments that are in a "full" year in the cycle.*

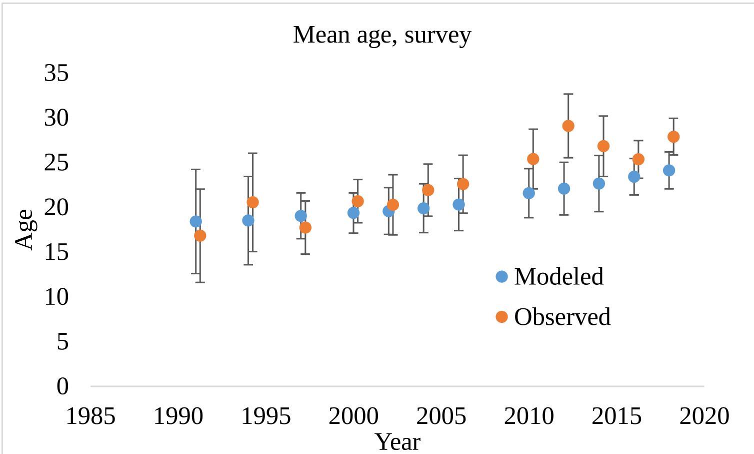
(SSC, October 2019) *The SSC recommends the authors complete the risk table and note important concerns or issues associated with completing the table.*

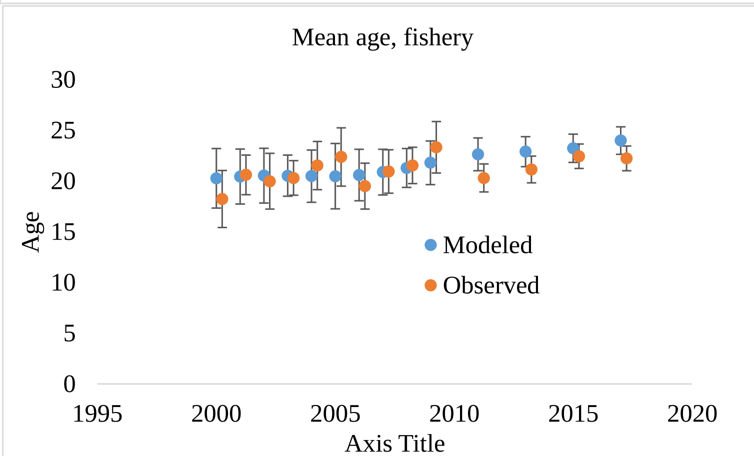
We computed the risk table, which is summarized above and described in more detail in the *Harvest Recommendations* section.

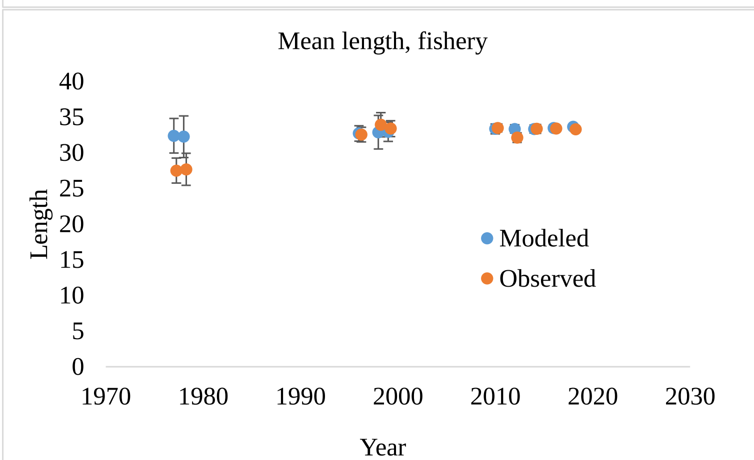
Responses to SSC and Plan Team Comments Specific to this Assessment

(BSAI Plan Team, November 2016) *The Team recommends that the authors present plots of the predicted mean age and length compared to the observed age and length means over time (with confidence intervals)*

The mean survey lengths and ages, and mean fishery lengths, are shown below; errors bars are twice the standard errors (based on the multinomial distribution, with the final reweighted sample sizes).

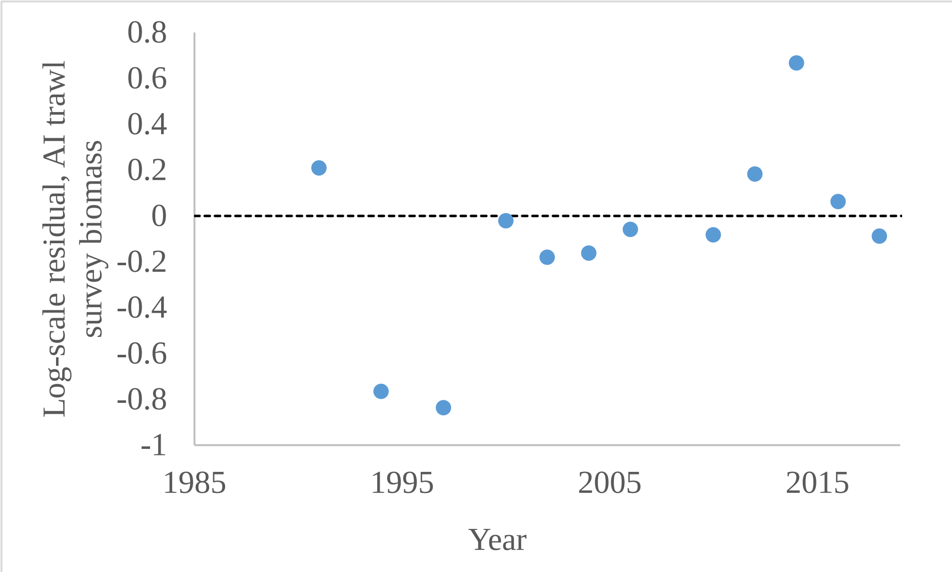






(BSAI Plan Team, November, 2016) *The Team recommends examining the residual pattern in the fit to the AI survey to see if there was a substantial change in the survey design or potential model misspecification that would explain the change in sign of the residuals between 2006 and 2010.*

The log-scale residuals for the AI trawl survey biomass estimates are shown below. There was no change in the survey methodology or design between the 2006 and 2010 surveys.



(SSC, October 2019) *The SSC supports the PT recommendation to use abundance-weighted length at age but requests the author reports on the difference between how the survey group produces mean length at age compared to this method.*

Consultation with personnel in the RACE Division of the Alaska Fisheries Science Center revealed that estimates of AI trawl survey age composition and mean size are based on "global" age-length keys (i.e., all the otoliths collected in a given survey year are combined to produce a single age-length key, without consideration to differences in population size or growth patterns across subareas). Application of subarea age-length keys (i.e., the age-length key for each survey subarea is applied to the subarea length composition, and the subarea age compositions are combined, which was applied in this assessment) can be produced by RACE personnel on request, but these requests are generally rare.

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 included as an appendix to the 2012 stock assessment (Spencer and Ianelli 2012). 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 Bertalanffy 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. Additionally, size at age in the GOA is larger than that in the AI, indicating an east-west cline in growth (Clausen and Heifetz 2002)

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 Samalga 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. In 1991, the "other red rockfish" species group was used in both the EBS and AI, but beginning in 1992 northern rockfish in the AI were managed in the "northern/sharpchin" species group. Prior to 2001, northern rockfish were managed with separate ABCs and TACs for the AI and EBS, and in 2001 the two areas were combined into a single management unit under the "sharpchin/northern" species complex. In 2002, sharpchin rockfish were dropped from the complex because of their sparse catches, leaving single-species management category of northern rockfish. The OFLs, ABCs, TACS, and catches by management complex from 1977-2000 are shown in Table 1, and those from 2001 to present are shown in Table 2.

Since 2002, the blend and catch accounting system (CAS) databases has reported catch of northern rockfish within the EBS and AI subareas. 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 3. Northern rockfish catch prior to 1990 was small relative to more recent years (with the exception of 1977 and 1978). Harvest data from 2004 -2010 indicates that approximately 88% 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 4). However, restrictions on Atka mackerel fishing in the western Aleutians from 2011-2014 have restricted the current northern rockfish harvest in this area, and during these years the proportion of northern rockfish harvested in the Atka mackerel fishery has declined to 55%. 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).

Although northern rockfish are generally harvested as a bycatch species, targeting of northern rockfish has occurred in recent years, perhaps as a result of restrictions of the Atka mackerel fishery. Observer catch records were used to identify the targeted species of tows, based on the dominant species in the catch. Tows targeting northern rockfish are defined as have rockfish being that largest species group in the catch, and northern rockfish being the most abundant rockfish species. The number of tows targeting northern rockfish increased from 46 in 2014 to 118 in 2015, and this targeting resulted in in a catch of 7197 t exceeding the TAC of 3,250 t, although the 2015 catch was below the ABC of 12,488 t (in recent years, the TAC for northern rockfish is usually set the much lower than the ABC). The number of tows targeting northern rockfish increased from 66 in 2016 to 225 in 2019 (through October 11). Although these tows comprise a relatively small proportion of the total number of tows in northern rockfish is caught (Figure 1a), they contribute a large share of the observed catch (Figure 1b). In 2019, 50% of the observed northern rockfish catch was obtained in tows targeting northern rockfish, indicating the development of a growing target fishery. The catch of northern rockfish in these tows has generally exceeded 50%, and exceeded 60% in 2013 and 2014 (Figure 1c). Increased targeting of northern rockfish since 2016 has led to increased catches, from 4,540 t in 2016 to 8,712 t in 2019 (through September 28), which is the largest on record.

The observer records of catch of northern rockfish in tows targeting northern rockfish can used to compute the catch per unit effort (CPUE) per year, defined at the sum northern rockfish catch (t) divided by the sum of tow duration (hrs). Northern rockfish CPUE has been relatively stable but shows a slight increase since 2007 (Figure 2a), and years with high catches also had high CPUE values (Figure 2b).

Area-specific exploitation, defined as the yearly catch within a subarea divided by an estimate of the subarea biomass at the beginning of the year, were computed for 2004 to 2019. The subarea biomass was obtained by applying the spatial distributions observed in the survey biomass estimates (after a smoother is applied) to the estimated total biomass from the 2019 assessment model. To evaluate the potential impact upon the population, exploitation rates were compared to the exploitation rate for each year that would result from applying a fishing rate of $F_{40\%}$ to the estimated beginning-year numbers, and this rate is defined as $U_{F40\%}$. The $U_{F40\%}$ rate takes into account maturity, fishing selectivity, size-at-age, and time-varying number at age. Exploitation rates for all subareas are lower than the $U_{F40\%}$ reference, although they increased substantially from 2018 to 2019 in the EAI and WAI (Figure 3).

Temporal variability has occurred in AI subareas in which northern rockfish are captured, and to a lesser extent in the depth of capture (Figure 4). The domestic fishery observer data indicates that the eastern AI accounted for 49% and 63% of the AI harvest in 1990 and 1991, respectively, decreasing to less than 15% of the observed catch from 1997 to 2006 (except 1999 and 2000). In contrast, the proportion of observed catch in the western AI increased from less than 20% from 1991 to 1993 to greater than 40% in most years from 1996-2005, and has decreased to less than 15% from 2011 – 2014 with the closure of the western AI to Atka mackerel fishing in these years. The observed catch of northern rockfish is predominately captured at depths between 100 m and 200 m, although percentage obtained at depths between 200 m and 300 m has been variable, ranging from less than 5% during 2000 – 2007 to between 4% and 14% from 2008 – 2018.

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 5). Discard rates in the AI have declined from 90% in 2003 to < 10% in most years since 2011. In the Eastern Bering Sea, discard rates have declined from 75% in 2003 to < 5% in 2010, and have ranged from 25% to 49% from 2012 to 2017, and increased to 67% in 2018.

Non-commercial catch data are shown in Appendix A.

Data

Fishery Data

The fishery data is characterized by inconsistent sampling of lengths and ages (Table 6). 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.

Length measurements and otoliths read from the EBS and AI management areas were combined to create fishery age/size composition matrices, with the length composition within management subareas weighted by the estimated catch numbers from observed tows. The selection of fishery length frequency data for the age-structured assessment model was based on the 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 with other sampling years, 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, 2010, 2012, 2014, 2016, and 2018 were used, and the length and age data from 2000-2009, 2011, 2013, 2015, and 2017 were used to estimate the age-frequency of the fishery catch.

The estimated lengths at age by subarea, across all years, is shown in Figure 5, and indicate a cline from small fish in WAI to larger fish in the EAI and SBS areas. In previous assessments, a "global" age-length key, per year, was used to compute the fishery age compositions by ignoring any spatial differences in size at age and using the aggregate sample of otoliths across subareas (i.e., in effect weighting the spatial subareas by the number of read otoliths instead of the fishery catch). Because of the spatial differences in size at age, the fishery age compositions in this assessment were produced by applying area-specific age-length key to the fishery length composition from each area, and weighting the resulting subarea age compositions by the extrapolated catch number by subarea from the North Pacific Groundfish Observer Program. The subareas considered in the assessment are the three Aleutian Island subareas (western Aleutians (WAI), central Aleutians (CAI), and eastern Aleutians (EAI)), plus the Bering Sea (BS) area. The age compositions produced by the two methods were generally similar to each other; Figure 6 shows a typical example. The differences in the proportion at age between the global estimates and the area-weighted estimates for all years are shown in Figure 7 and are small (generally within an absolute value of 0.03) and do not show any pattern across ages. The similarity across years is related the randomized sampling of fishery otoliths, which has resulted in the distribution of read otoliths being relatively similar to the distribution of fishery catch (Figure 8).

The fishery age composition data indicates the relatively strong cohorts in 1984-1985, 1995, and 2005, as each of these cohorts was observed as relatively abundant in multiple years of fishery age composition data (Figure 9).

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 on the eastern Bering Sea slope were conducted by the National Marine Fisheries Service (NMFS) in 1988, 1991, and biennially beginning in 2002 (except 2006 and 2014, when the survey was canceled due to lack of funding). NMFS trawl survey in the Aleutian Islands were conducted in 1991, 1994, 1997, and biennially beginning in 2000. The EBS slope surveys in 2008 and 2014, and the AI trawl survey in 2008, were 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 previous assessments, these surveys were included in the assessment as to provide some indication of biomass during the 1980s. Given the difficulty of documenting the methodologies for these surveys, and standardizing these surveys with the NMFS surveys, this assessment model is conducted with only the NMFS surveys.

Survey abundance in the western and central Aleutians is generally larger that abundance in the eastern Aleutians and eastern Bering Sea (Table 7, Figure 10). In 2014, the survey abundance in the eastern AI increased sharply to 77,000 t (from an average of 20,000 t from 2006-2012) and has a large coefficient of variation of 0.79, but abundance in this area decreased to 48,382 t in 2016. Abundance in the western Aleutian Islands also showed a large increase in the 2014 survey (to 346,392 t), but decreased to 124,310 t in the 2016 survey and 98,756 t in the 2018 survey. Areas of particularly high survey abundance are Amchitka Island, Kiska Island, Buldir Island, and Tahoma Bank. The 2018 Aleutian Island survey biomass was 212,472 t, which represents a decrease of 17% from the 2018 estimate of 253,217 t. Decreases were observed in the the WAI, CAI, and EAI, but the 2018 biomass estimate in the southern Bering Sea area (i.e., the portion of the AI survey in the BS management subarea) increased from 1,656 t on 2016 to 34,120 t in 2018. The CV for the overall biomass estimate is 0.20. 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, and was 0.70 for the 2018 survey.

Similar to the fishery data, the size at age from the AI survey shows a spatial cline with length at age increasing from west to east (Figure 11), and in previous assessments a global age-length key, per year, was used that did not account for this pattern. In this assessment, the survey age compositions were produced in a similar manner as the fishery age compositions by applying the area-specific age-length key to the estimated survey length composition from each area, and weighting the resulting subarea survey age compositions by the estimated survey population number. In general, application of the weighted subarea age-length keys produces survey age compositions with relatively fewer young fish and relatively more older fish; examples for some years are shown in Figure 12. This pattern is generally consistent between across all survey years, as indicated by a plot of the differences in the age composition between the global and weighted subarea methods (Figure 13). The survey abundance is concentrated in the WAI (Figure 14) which has the smallest size at age; any population-level estimate of size at age and age compositions should reflect that most of the stock is located in an area with smaller size at age. However, the spatial distribution of otoliths has generally not been proportional to the spatial distribution of the population. In years prior to 2016, length-stratified sampling of otoliths occurred in the AI survey, which resulted in relatively similar numbers of otoliths being sampled across subareas irrespective of the abundance. Beginning in 2016, random sampling of otoliths have occurred in the AI survey, which has resulted in the spatial distribution of otoliths samples more closely corresponding to the spatial distribution of abundance (Figure 15). Application of the global age-length key (i.e., weighing the spatial areas by the otolith sample size rather than abundance) give disproportionate weight to areas with larger size at age, and fish of a given length would be estimated to have a younger age relative to the age composition obtained from applying the subarea age-length keys.

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, and more recent survey age composition data indi cates a relativelu strong 2005 year class (Figure 16).

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 2002-2016 surveys ranged between 3 t (in the 2008, 2012, and 2016) and 42 t (2010), with CVs between 0.38 (2002) and 1.0 (in 2008, 2012, and 2016). 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 8, along with the number of hauls producing these data. The number of otoliths read by area is shown in Table 9. 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.

As indicated above, the expected length at age differs between the four AI survey subareas (Figure 11). Variability occurs between years but without any apparent direction trend, and indicated by the L_{inf} and K parameters (Figure 17). Additionally, the weight-at-length relationship ($W = aL_b$) also shows spatial differences, with generally larger values of the exponential parameter b in the WAI and CAI (Figure 18). The estimated survey weight at age curves by AI subarea are shown in Figure 19. A similar pattern across areas is seen in the subareas weights at age in the fishery (Figure 20); additionally, the fishery weights at age are generally larger than those from the AI survey.

In previous assessments, “global” estimates of length and weight at age were computed by ignoring any spatial differences and using the aggregate sample of otoliths across subareas to construct a single age-length key for each year (i.e., in effect weighting the spatial distribution of read otoliths by their sample size instead of the population size). In this assessment, the size at age for population was obtained from the 1991-2018 AI survey data as an average of each of the 4 subarea weight at age curves shown in Figure 19 (weighted by a smoothed estimate of survey abundance). Years prior to 1991 were set to the weight at values from 1991, whereas the values for 2019 were set to the 2018 values. A similar procedure was used for the fishery weights at age from 1990 - 2018, with the subarea curves weighted by the extrapolated catch number by subarea from the North Pacific Groundfish Observer Program. Fishery weights at age prior to 1990 were set to an average of the 1990-1992 values, whereas fishery weights at age in 2019 were set to the 2018 values. An average of the 2014-2018 survey weight at age curves is shown in Table 10.

Fishery length data are used in the model, and 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. The expected size at age for the conversion matrix is an average of the yearly fishery size at age curves from 1990-2018 described above. The conversion matrix was created by fitting a power relationship to the observed standard deviation in length at each age (obtained from the aged fish in the fishery from 1998-2019), 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 0.10 at age 3 to 0.08 at age 40.

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

Component	BSAI
Fishery catch	1977-2019
Fishery age composition	2000-2009, 2011, 2013, 2015, 2017
Fishery size composition	1977-1978, 1996, 1998-1999, 2010, 2012, 2014, 2016, 2018
Survey age composition	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018
Survey biomass estimates	1991, 1994, 1997, 2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018

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. 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 2019).

The numbers at age A are a "plus" 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 plus group was set to 40+, following a sensitivity analysis conducted in the 2012 stock assessment (Spencer and Ianelli 2012).

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-dependent 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 2016 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 number of age 3 fish from 2017-2019 are set to the expected mean recruitment (based upon the log-scale mean, and the value of σ_r).

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

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

The mean numbers at age for each year were 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. Selectivity for the AI trawl survey was modeled with a logistic function.

To facilitate parameter estimation, prior distributions were used for the survey catchability, the natural mortality rate *M*, and the survey selectivity curve. A lognormal distribution was 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. Similarly, 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. It is expected that northern rockfish would be nearly fully selected to the trawl survey at about age 15 (based on other age-structure assessments of Alaska rockfish), so a normal prior distribution on the deviation between survey selectivity at age 15 and 1 was used with the mean and standard deviation set to 0 and 0.03, respectively.

Sample sizes for age and length composition data

The multinomial sample size $N_{j,y}$ for data type *j* and year *y* is computed as

$$N_{j,y} = w_j \tilde{N}_{j,y}$$

where $\tilde{N}_{j,y}$ is the original "first stage" sample size (set to the number of hauls with produced fish lengths or read otoliths), and w_j is a weight for data type *j*. The weights are a function of the fit of to the age and length composition data, and iterated in successive model runs until they converge. The weights are the harmonic mean of the ratio of effective sample size to first stage sample size (method TA1.1 in Francis (2011), which is from McAllister and Ianelli (1997) and often referred to as the "McAllister-Ianelli method"). Note that this method preserves the relative weighting between years within a given data type.

The root mean squared error (RMSE) was used to evaluate the relative size of residuals within data types:

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

Description of Alternative Models

In this assessment, alternative models are not considered. The only relatively minor change from the 2016 model (labeled Model 16.1) is the incorporation of a prior on the AI survey selectivity curve, and this is labeled Model 16.1a. The main difference from the 2016 assessment is in how the fishery and survey age compositions, and the fishery and survey weight at age vectors, are computed.

Parameters Estimated Outside the Assessment Model

The parameters estimated independently include the age error matrix, the age-length conversion matrix, and the individual fishery and population (i.e., AI survey) weights at age. The source of these quantities are described above.

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 reweighted sample size, 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. The "observed" catch for 2019 is obtained by estimating the Oct-Dec catch (based on the remaining ABC available after October, and the average proportion in recent years of the remaining ABC caught from Oct-Dec) and adding this to the observed catch through October. 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.

A maturity ogive was fit in the assessment model to samples collected in 2010 (*n*=322; TenBrink and Spencer 2013) and in 2004 by fishery observers (*n*=256). Parameters of the logistic equation were estimated by maximizing the bionomial likelihood within the assessment model. 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 estimated age at 50% maturity is 8.2 years.

The overall negative log-likelihood function (excluding the catch component, and the maturity likelihood) 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 negative log-likelihood function was minimized by varying the following parameters (for an age-plus group of 40 years, and with the time-invariant logistic fishery selectivity) :

Parameter type	Number
1) fishing mortality mean	1
2) fishing mortality deviations	43
3) recruitment mean	1
4) recruitment deviations	40
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
11) maturity parameters	2
Total number of parameters	131

Results

Model Evaluation

In this assessment, alternative models are not considered. For comparison with the previous assessment, the model used in 2016 was run with data through 2019 that were processed in same manner used in 2016 (i.e., survey and fishery age composition, and survey size at age obtained from global age-length keys, survey size at age used for the fishery, and the transition matrix based on the survey size at age, and the 2016 weighting of the composition data); this run is labeled Model 16.1(2019). Model 16.1a(2019) incorporates the prior on survey selectivity, the updated methodology using subarea age-length keys, and the updated weighting of the composition data. Likelihood components, RMSE values, and key model parameters for these two runs are shown for comparison in Table 11. The model that uses the subarea age-length keys provides a better fit to the AI survey, although this comparison is complicated by the changes in the input data. A plot of the total biomass from the two models, as well as that from the 2016 assessment (labeled Model 0) is shown in Figure 21. The re-iterated weights for the composition data are shown in Figure 22; relative to the 2016 assessment, weights for the fishery and survey age composition data decreased where weights for the fishery length composition increased. The results and harvest recommendations below refer to Model 16.1a(2019). A list of parameter estimates and their standard deviations is shown in Table 12.

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.

The estimated values for total biomass, spawning biomass, and recruitment, and their CVs (from the Hessian approximation) are shown in Table 13, and the estimated numbers at age are shown in Table 14.

Biomass trends

The estimated survey biomass shows an increasing trend, starting at 92,049 t in 1977 and increasing to a peak of 242,606 t in 2014, and declining to 225,656 in 2019 (Figure 23). The estimated total biomass shows a similar trend, increasing to a peak value of 277,760 t in 2013, and the estimated spawner biomass increases from 47,111 in 1977 to its highest value of 124,780 in 2014 (Table 13, Figure 24).

Age/size compositions

The model fits to the fishery age and size compositions are shown in Figures 25-26, and the model fit to the survey age composition data is shown in Figures 27. The model fit the fishery and survey age composition data reasonably well (notwithstanding years with low sample sizes). The number of hauls in which otoliths or length measurements has increased in recent year (in part due to the random sampling of otoliths initiated in the AI survey beginning in 2016), which results in the higher weights placed on the recent composition data relative to the earlier years. The plus group in the fishery length composition data (38 cm+) and the fishery age plus group (40+ years) is often overestimated whereas the survey age plus group is often underestimated, reflecting a trade-off in the model.

Fishing and survey selectivity

The estimated survey selectivity curve had an age at 50% selection of 8.3, whereas this parameter was 6.0 in the 2016 assessment, and the selectivity slope was reduced to 0.49 relative to the value of 1.2 in the 2016 assessment. These estimated parameter values resulted in a decrease in survey selectivity at ages less than 15 (Figure 28) and accounts for the change in the scale observed in total biomass between the 2016 and 2019 assessments. The fishery selectivity had an age of 50% selection of 8.8, similar to the value of 9.2 obtained in the 2016 assessment (Figure 29).

Fishing mortality

The estimates of instantaneous fishing mortality rate are shown in Figure 30. 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 2018 estimate is 0.019. Fishery mortality values are lower than in the 2016 assessment due to the updated fishery weight at age vector showing increased size (i.e., a given level of catch biomass is obtained with a lower number of individual fish). 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 31).

Recruitment

Recruitment strengths by year class are shown in Figure 32. Relatively strong year classes are observed in 1978-1979, 1981, 1984-1985, 1989,1993-1998, and 2005, reflecting several of the strong year classes observed in the age composition input data (Figures 25 and 27). The model estimate of the 2005 year class of 122,650 is substantially larger than the estimate of 98,600 in the 2016 model. The scatterplot of recruitment against spawning stock biomass is shown in Figure 33, indicating substantial variability in the pattern between recruitment and spawning stock size.

Retrospective analysis

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 2019 to 2009, 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 34. All retrospective runs show reduced biomass relative to the 2019 run, as the 2019 model shows an improved fit to the relatively high recent survey biomass estimates. A relatively large decrease in estimated biomass exists between the 2014 - 2019 retrospective runs and the 2009-2013 retrospective runs, indicating the influence of the 2014 AI survey data. 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 -0.14, a decrease (in absolute value) from the value of -0.18 in the 2016 assessment.

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 1977-2013 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 63,940 t. The year 2020 spawning stock biomass is estimated as 111,476 t.

Specification of OFL and maximum permissible ABC

Since reliable estimates of the 2020 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and B>$B_{0.40}$ (111,476 t > 63,940 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 0.061 and 0.075, respectively.

The ABC associated with the $F_{0.40}$ level of 0.061 is 16,243 t.

The estimated catch level for year 2020 associated with the overfishing level of F = 0.075 is 19,751 t. A summary of these values is below.

2020 SSB estimate (B)	**=**	**111,476 t**
$B_{0.40}$	=	63,940 t
$F_{ABC} = F_{0.40}$	=	0.061
$F_{OFL} = F_{0.35}$	=	0.075
MaxPermABC	=	16,243 t
OFL	=	19,751 t

Should the ABC be reduced to below the maximum permissible ABC?

The SSC in its December 2018 minutes recommended that all assessment authors use the risk table when determining whether to recommend an ABC lower than the maximum permissible. The SSC also requested the addition of a fourth column on fishery performance, which has been included in the table below.

	Assessment-related considerations	*Population dynamics considerations*	*Environmental/ecosystem considerations*	*Fishery Performance*
Level 1: Normal	Typical to moderately increased uncertainty/minor unresolved issues in assessment.	Stock trends are typical for the stock; recent recruitment is within normal range.	No apparent environmental/ecosystem concerns	No apparent fishery/resource-use performance and/or behavior concerns
Level 2: Substantially increased concerns	Substantially increased assessment uncertainty/ unresolved issues.	Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.	Some indicators showing an adverse signals relevant to the stock but the pattern is not consistent across all indicators.	Some indicators showing adverse signals but the pattern is not consistent across all indicators
Level 3: Major Concern	Major problems with the stock assessment; very poor fits to data; high level of uncertainty; strong retrospective bias.	Stock trends are highly unusual; very rapid changes in stock abundance, or highly atypical recruitment patterns.	Multiple indicators showing consistent adverse signals a) across the same trophic level as the stock, and/or b) up or down trophic levels (i.e., predators and prey of the stock)	Multiple indicators showing consistent adverse signals a) across different sectors, and/or b) different gear types
Level 4: Extreme concern	Severe problems with the stock assessment; severe retrospective bias. Assessment considered unreliable.	Stock trends are unprecedented; More rapid changes in stock abundance than have ever been seen previously, or a very long stretch of poor recruitment compared to previous patterns.	Extreme anomalies in multiple ecosystem indicators that are highly likely to impact the stock; Potential for cascading effects on other ecosystem components	Extreme anomalies in multiple performance indicators that are highly likely to impact the stock

The table is applied by evaluating the severity of four types of considerations that could be used to support a scientific recommendation to reduce the ABC from the maximum permissible. These considerations are stock assessment considerations, population dynamics considerations, environmental/ecosystem considerations, and fishery performance. Examples of the types of concerns that might be relevant include the following:

1. Assessment considerations—data-inputs: biased ages, skipped surveys, lack of fishery-independent trend data; model fits: poor fits to fits to fishery or survey data, inability to simultaneously fit multiple data inputs; model performance: poor model convergence, multiple minima in the likelihood surface, parameters hitting bounds; estimation uncertainty: poorly-estimated but influential year classes; retrospective bias in biomass estimates.

2. Population dynamics considerations—decreasing biomass trend, poor recent recruitment, inability of the stock to rebuild, abrupt increase or decrease in stock abundance.

3. Environmental/ecosystem considerations—adverse trends in environmental/ecosystem indicators, ecosystem model results, decreases in ecosystem productivity, decreases in prey abundance or availability, increases or increases in predator abundance or productivity.

4. Fishery performance—fishery CPUE is showing a contrasting pattern from the stock biomass trend, unusual spatial pattern of fishing, changes in the percent of TAC taken, changes in the duration of fishery openings.

Assessment considerations

Several major aspects of the biology of the northern rockfish, and our ability to infer abundance from the AI trawl survey are uncertain, including the natural mortality rate, survey catchability, and survey selectivity. These parameters are highly constrained by prior distributions, which underestimates the level of uncertainty in the assessment. In addition, the retrospective bias is the assessment is still relatively high and can be attributed to a large biomass estimate from the 2014 AI trawl survey. The retrospective bias has been reduced relative to previous assessments due to the biomass estimates from the 2016 and 2018 surveys being that from the 2014 estimate. More generally, the retrospective bias indicates that the increase in biomass observed in the data is not consistent with the modeled estimates of survey catchability and mortality. We rank the assessment considerations as a 2 (*Substantially increased assessment uncertainty/ unresolved issues*).

Population dynamics considerations

The trend in survey biomass abundance based on the estimates from the 1994 to 2014 show a rapid increase, resulting from low biomass in the 1994 and 1997 surveys and a high biomass in the 2014 survey. However, reduced biomass estimates from the 2016 and 2018 survey are more consistent with the remainder of the time series than the 2014 estimate, and have resulted in a more stable trend in biomass over time. The recruitment of some recent year classes, such as 2005, are estimated to be relatively high.

Northern rockfish show genetic structure within the Aleutian Islands, with the lifetime dispersal distances estimated as not exceeding 250 km (Gharrett et al. 2012). Spatial management of the harvest does not occur within the BSAI, so a population dynamics consideration is that the spatial management of the stock is not consistent with the spatial structure of the stock. This could lead to disproportionate harvest rates within BSAI subareas, with depletion and loss of fishery yield. This risk has not been realized yet as exploitation rates are currently relatively low, and this risk would be lessened if the catches only occurred as bycatch in other target fisheries. However, the recent increased catches and relatively high proportion of catch taken in targeted tows, when combined with the lack of spatial harvest management, increase the risk of disproportionately high subarea harvest rates in the future. Overall, we rank the assessment considerations as a 1 (*Stock trends are typical for the stock; recent recruitment is within normal range*)

Environmental/Ecosystem considerations

The status of the Aleutian Island region was last assessed in 2018, therefore the indicators noted here largely reflect conditions in 2018 and earlier. Northern rockfish have shown a declining trend in condition (defined as mean weight-length residuals) since 2010, indicating that insufficient prey have been available to promote optimal growth. Fish sampled during the biennial surveys in 2016 and 2018 had the lowest condition in the time series. Condition was also below the time series mean (1984-2018) when analyzed at smaller spatial scales, indicating that suboptimal foraging conditions was widespread throughout the large marine ecosystem.

Given that the majority of the biomass of northern rockfish is in the western AI ecoregion, we reviewed indicators from this ecoregion. Reproductive success of planktivorous birds can serve as indirect indicators of prey abundance for northern rockfish, particularly those <30 cm that primarily eat zooplankton. At Buldir Island in 2018, black-legged kittiwakes, storm-petrels and auklets (which consume a mix of fish and invertebrates) showed average to above average fledging rates, indicating that sufficient zooplankton prey were available to support reproduction in the western AI. Piscivorous murres and piscivorous/cephlapod-eating tufted puffins had below average to complete reproductive failures, indicating that forage fish to support chick-rearing was limited in 2018. In general, tufted puffins can adapt their foraging to what is available, so their failure suggests a potentially broad lack of prey (that includes forage fish and squid) that overlaps with prey of large >35 cm rockfish.

The distribution of northern rockfish has been trending more shallow and westward over the time series, although there is no trend in their mean-weighted temperature distribution. Although zooplankton indicators indicate sufficient prey may be available for northern rockfish, the negative condition factor indicates that foraging was not optimal. Based on indicators of poor body condition and lack of forage fish and cephlapod prey, we consider the concern level to be 2 (*Some indicators showing adverse signals relevant to the stock but the pattern is not consistent across all indicators)*.

Fishery performance

The growth of the northern rockfish stock since the mid-200s has led to the development of a target fishery, initially during 2011-2014 when the Atka mackerel fishing in the WAI was closed, and more recently since 2016. The catch as a percentage of the ABC has increased since 2014 (Table 2) and the fishery CPUE values have remained relatively high (Figure 2), indicating that the fishing fleet has not encountered reduced performance in their ability to target this stock. We rank the fishery performance as a 1 (*No apparent fishery/resource-use performance and/or behavior concerns*).

ABC recommendation

We recommend the maximum permissible ABC 16,243 t for 2020.

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 2019 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2020 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2019. 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 2020, 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}. (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. For this assessment, the fraction used was 1.)

Scenario 3: In all future years, *F* is set equal to $F_{75\%}$. (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 2014-2018 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 2019 or 2) above ½ of its MSY level in 2019 and above its MSY level in 2019 under this scenario, then the stock is not overfished.)

Scenario 7: In 2020 and 2021, *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 2032 under this scenario, then the stock is not approaching an overfished condition.)

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

Status Determination

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2020, it does not provide the best estimate of OFL for 2021, because the mean 2020 catch under Scenario 6 is predicated on the 2020 catch being equal to the 2020 OFL, whereas the actual 2020 catch will likely be less than the 2020 OFL. Catches for 2020 and 2021 were obtained by setting the *F* rate for these years to the average of the estimated *F* rates for 2018 and 2019.

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 (2018) is 5,767 t. This is less than the 2018 BSAI OFL of 15,888 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 2019:

a. If spawning biomass for 2019 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.

b. If spawning biomass for 2019 is estimated to be above $B_{35\%}$ the stock is above its MSST.

c. If spawning biomass for 2019 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest Scenario #6 (Table 15). If the mean spawning biomass for 2029 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 2022 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2022 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2022 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2032. If the mean spawning biomass for 2032 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 2019 stock size is 2.1 times its $B_{35\%.}$ value of 55,947 t. With regard to whether BSAI northern rockfish is likely to be overfished in the future, the expected stock size in 2022 of Scenario 7 is 1.7 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 Krieger (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

Northern rockfish has historically been a bycatch fishery, with the catches largely occurring in the BSAI Atka mackerel and Pacific ocean perch fisheries. The ecosystem effects of these fisheries can be found in their respective SAFE documents. Targeted fishing for northern rockfish has been increasing in recent years.

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 0.02 over the last five years, it is not known 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. 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.

Further research on survey selectivity functional form should be investigated, with the aim of achieving estimates of survey selectivity with the use of a prior distribution. Previous assessments have consideration alternative fishery selectivity formulations (i.e., dome-shaped and/or time-varying), and this procedure could be applied to the survey as well. The aging error matrix should be investigated, as it is derived from GOA data but the slower growth in the AI may result in increased aging error if the otolith age marks are more closely grouped together. Studies on the distribution of fish in trawlable and untrawlable grounds may help refine our prior distribution of survey catchability.

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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 1977 to 2000 in the Aleutian Islands and the eastern Bering Sea. 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.

	Aleutian Islands					Eastern Bering Sea				
	Management					Management				
Year	Group	OFL (t)	ABC (t)	TAC (t)	Catch (t)	Group	OFL (t)	ABC (t)	TAC (t)	Catch (t)
1977	Other species				3264	Other species				5
1978	Other species				3655	Other species				32
1979	POP complex				601	POP complex				46
1980	POP complex				549	POP complex				89
1981	POP complex				111	POP complex				35
1982	POP complex				177	POP complex				71
1983	POP complex				47	POP complex				42
1984	POP complex				196	POP complex				32
1985	POP complex				189	POP complex				6
1986	Other rockfish	n/a	UN	5800	208	Other rockfish	n/a	UN	825	61
1987	Other rockfish	n/a	UN	1430	308	Other rockfish	n/a	UN	450	77
1988	Other rockfish	n/a	1100	1100	493	Other rockfish	n/a	400	400	40
1989	POP complex	n/a	16600	6000	306	POP complex	n/a	6000	5000	78
1990	POP complex	n/a	16600	6000	1235	POP complex	n/a	6300	6300	247
1991	Other red rockfish	0	4685	4685	233	Other red rockfish	0	1670	1670	626
1992	Sharpchin/northern	5670	5670	5670	1548	Other red rockfish	1400	1400	1400	309
1993	Sharpchin/northern	5670	5670	5100	4530	Other red rockfish	1400	1400	1200	859
1994	Sharpchin/northern	5670	5670	5670	4666	Other red rockfish	1400	1400	1400	61
1995	Sharpchin/northern	5670	5670	5103	3858	Other red rockfish	1400	1400	1260	266
1996	Sharpchin/northern	5810	5810	5229	6637	Other red rockfish	1400	1400	1260	87
1997	Sharpchin/northern	5810	4360	4360	1996	Other red rockfish	1400	1050	1050	164
1998	Sharpchin/northern	5640	4230	4230	3746	Other red rockfish	356	267	267	45
1999	Sharpchin/northern	5640	4230	4230	5492	Other red rockfish	356	267	267	157
2000	Sharpchin/northern	6870	5150	5150	5066	Other red rockfish	259	194	194	97

Table 2. Total allowable catch (TAC), acceptable biological catch (ABC), and catch of the species groups used to manage northern rockfish from 2001 to present to 2000 in the eastern Bering Sea and Aleutian Islands.

		Bering Sea and Aleutian Islands			
Year	Management Group	OFL (t)	ABC (t)	TAC (t)	Catch (t)
2001	Sharpchin/northern	9020	6764	6764	6488
2002	Northern rockfish	9020	6760	6760	4057
2003	Northern rockfish	9468	7101	6000	4929
2004	Northern rockfish	8140	6880	5000	4684
2005	Northern rockfish	9810	8260	5000	3964
2006	Northern rockfish	10100	8530	4500	3828
2007	Northern rockfish	9750	8190	9190	4016
2008	Northern rockfish	9740	8180	8180	3287
2009	Northern rockfish	8540	7160	7160	3111
2010	Northern rockfish	8640	7240	7240	4332
2011	Northern rockfish	10600	8670	4000	2765
2012	Northern rockfish	10500	8610	4700	2487
2013	Northern rockfish	12200	9850	3000	2038
2014	Northern rockfish	12077	9761	2594	2342
2015	Northern rockfish	15337	12488	3250	7197
2016	Northern rockfish	14689	11960	4500	4540
2017	Northern rockfish	16242	13264	5000	4699
2018	Northern rockfish	15888	12975	6100	5767
2019*	Northern rockfish	15507	12664	6500	8712

*Catch data through September 28, 2019, from NMFS Alaska Regional Office.

Table 3. 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			114			3,943	4,057
2003			67			4,862	4,929
2004			116			4,567	4,684
2005			112			3,852	3,964
2006			246			3,582	3,828
2007			70			3,946	4,016
2008			22			3,265	3,287
2009			48			3,063	3,111
2010			299			4,033	4,332
2011			199			2,566	2,765
2012			91			2,396	2,487
2013			137			1,901	2,038
2014			147			2,195	2,342
2015			199			6,998	7,197
2016			206			4,334	4,540
2017			227			4,472	4,699
2018			188			5,579	5,767
2019*			196			8,516	8,712

*Catch data through September 28, 2019, from NMFS Alaska Regional Office.

Table 4. 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	2,327	1,318	298	114	4,057
2003	2,507	1,994	361	67	4,929
2004	1,926	2,430	211	116	4,684
2005	1,822	1,759	271	112	3,964
2006	1,127	2,149	306	246	3,828
2007	974	1,821	1,151	70	4,016
2008	1,314	1,345	608	22	3,287
2009	1,191	1,314	558	48	3,111
2010	1,988	1,267	778	299	4,332
2011	311	1,350	905	199	2,765
2012	140	1,651	605	91	2,487
2013	115	1,308	478	137	2,038
2014	83	1,110	1,002	147	2,342
2015	3,346	1,600	2,052	199	7,197
2016	1,624	1,729	981	206	4,540
2017	1,776	2,013	683	227	4,699
2018	2,072	2,791	716	188	5,767
2019*	5,105	1,763	1,648	196	8,712

* Estimated removals through September 28, 2019.

Table 5. 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.

	Aleutian Islands					Eastern Bering Sea				
Year	Species Group	Retained	Discarded	Total	Percent Discarded	Species Group	Retained	Discarded	Total	Percent Discarded
1993	SC/NO	317	4218	4535	93.00%	Other red rockfish	367	97	464	20.92%
1994	SC/NO	797	3870	4667	82.92%	Other red rockfish	29	100	129	77.59%
1995	SC/NO	1208	2665	3873	68.82%	Other red rockfish	274	70	344	20.42%
1996	SC/NO	2269	4384	6653	65.89%	Other red rockfish	58	149	207	71.92%
1997	SC/NO	145	1852	1997	92.74%	Other red rockfish	44	174	218	80.02%
1998	SC/NO	458	3288	3747	87.76%	Other red rockfish	38	59	97	61.06%
1999	SC/NO	735	4759	5493	86.63%	Other red rockfish	75	163	238	68.33%
2000	SC/NO	592	4492	5084	88.37%	Other red rockfish	111	140	155	90.22%
2001	SC/NO	403	5906	6309	93.62%	SC/NO	15	164	180	91.11%
2002	Northerns	347	3596	3943	91.19%	Northerns	9	105	114	92.50%
2003	Northerns	465	4397	4862	90.45%	Northerns	17	50	67	74.29%
2004	Northerns	686	3881	4567	84.97%	Northerns	35	81	116	69.57%
2005	Northerns	912	2940	3852	76.32%	Northerns	45	67	112	59.56%
2006	Northerns	965	2617	3582	73.06%	Northerns	109	137	246	55.56%
2007	Northerns	850	3096	3946	78.45%	Northerns	23	47	70	67.55%
2008	Northerns	1523	1742	3265	53.34%	Northerns	8	14	22	64.25%
2009	Northerns	1941	1122	3063	36.64%	Northerns	40	8	48	15.90%
2010	Northerns	3075	958	4033	23.75%	Northerns	284	15	299	4.92%
2011	Northerns	2442	124	2566	4.85%	Northerns	167	32	199	16.00%
2012	Northerns	2016	380	2396	15.88%	Northerns	46	45	91	49.26%
2013	Northerns	1720	181	1901	9.52%	Northerns	103	34	137	24.51%
2014	Northerns	2115	80	2195	3.66%	Northerns	88	59	147	40.21%
2015	Northerns	6619	379	6998	5.41%	Northerns	127	72	199	36.39%
2016	Northerns	4112	222	4334	5.12%	Northerns	134	72	206	34.92%
2017	Northerns	4191	281	4472	6.28%	Northerns	181	46	227	20.24%
2018	Northerns	5182	397	5579	7.12%	Northerns	63	125	188	66.51%
2019*	Northerns	8121	395	8516	4.64%	Northerns	115	81	196	41.64%

* Estimated removals through September 28, 2019.

Table 6. Samples sizes of otoliths and lengths from fishery sampling, with the number of hauls from which these data were collected, from 1977-2019.

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	256	255	125
2009	834*	108	247	247	103
2010	1281	148	346		
2011	1596*	210	469	462	200
2012	1785	219	506		
2013	2081	268	609	596	251
2014	1542	224	484		
2015	3006	341	869	574	294
2016	2447	311	716		
2017	3924	431	869	434	308
2018	5478	559	1148		
2019	4908	423	950		

*Used to create age composition

Table 7. Northern rockfish biomass estimates (t) from Aleutian Islands trawl survey, with coefficients of variation shown in parentheses.

	Aleutian Islands Survey				
Year	Western	Central	Eastern	southern BS	Total AI survey
1980	3,024 (0.98)	316 (0.63)	34,170 (0.99)	83 (0.95)	37,593 (0.90)
1983	34,361 (0.21)	9,106 (0.48)	11,765 (0.10)	1,136 (0.57)	56,368 (0.15)
1986	20,691 (0.44)	105,608 (0.44)	4,014 (0.55)	10,092 (0.64)	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	142,393 (0.39)	37,949 (0.44)	24,982 (0.70)	49 (0.40)	205,373 (0.29)
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	102,651 (0.29)	70,834 (0.51)	22,982 (0.45)	22,883 (1.00)	219,350 (0.24)
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)
2014	346,392 (0.38)	48,049 (0.44)	76,787 (0.79)	1,668 (0.80)	472,895 (0.31)
2016	124,310 (0.21)	78,869 (0.37)	48,382 (0.52)	1,656 (0.55)	253,217 (0.18)
2018	98,756 (0.24)	54,500 (0.40)	20,096 (0.63)	34,120 (0.70)	212,472 (0.20)

Table 8. Sample sizes of otoliths and length measurement from the AI trawl survey, 1991-2018, 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	576	67
2014	14884	209	550	60
2016	15116	240	576	146
2018	14640	230	588	140

Table 9. 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
2012	206	156	160	54	576
2014	201	147	150	52	550
2016	288	167	106	15	576
2018	289	150	119	30	588

Table 10. Predicted weight (average from 2014 – 2018) and proportion mature at age for BSAI northern rockfish.

Age	Predicted weight (g)	Proportion mature
3	46	0.026
4	74	0.050
5	107	0.096
6	143	0.176
7	179	0.301
8	214	0.464
9	248	0.636
10	280	0.779
11	309	0.876
12	336	0.934
13	360	0.966
14	382	0.983
15	402	0.991
16	419	0.996
17	434	0.998
18	448	0.999
19	460	0.999
20	471	1
21	480	1
22	489	1
23	496	1
24	502	1
25	508	1
26	513	1
27	518	1
28	521	1
29	525	1
30	528	1
31	530	1
32	533	1
33	535	1
34	537	1
35	538	1
36	539	1
37	541	1
38	542	1
39	543	1
40	547	1

Table 11. Negative log likelihood of model components, root mean squared errors, and estimates and standard deviations of key quantities.

	Model 16.1(2019)	Model 16.1a(2019)
Negative log-likelihood		
Data components		
AI survey biomass	10.08	8.89
Catch biomass	0.00	0.00
Fishery age comp	276.84	227.69
Fishery length comp	96.06	70.73
AI survey age comp	162.12	165.91
Maturity	7.21	7.21
Priors and penalties		
Recruitment	5.16	1.09
Prior on survey q	0.00	0.00
Prior on M	2.30	0.93
penalty on survey sel	0.00	0.74
Fishing mortality penalty	4.51	5.24
Total negative log-likelihood	564.29	488.45
Parameters	131	131
Root mean square error		
AI survey biomass	0.431	0.397
Recruitment	0.784	0.699
Fishery age comp	0.013	0.014
Fishery length comp	0.031	0.030
AI survey age comp	0.014	0.017
Estimated key quantities		
M	0.043	0.048
standard deviation	0.004	0.004
CV	0.095	0.092
2019 total biomass	224,130	257,480
standard deviation	20,849	24,878
CV	0.09	0.10

Table 12. Estimated parameter values and standard deviations.

Parameter	Estimate	Standard Deviation	parameter	estimate	Standard Deviation	parameter	estimate	Standard Deviation
sel_aslope_forfish	0.8185	0.0697	fmort_dev	1.1068	0.0880	rec_dev	-0.8068	0.5553
sel_a50_forfish	8.7882	0.2328	fmort_dev	0.6435	0.0924	mean_log_r	3.5824	0.0992
sel_aslope_srv3	0.4885	0.0752	fmort_dev	0.7039	0.0968	log_rinit	2.8450	0.2209
sel_a50_srv3	8.2974	0.4887	fmort_dev	0.9291	0.1014	fydev	0.4647	0.7831
M	0.0483	0.0045	fmort_dev	1.3879	0.1067	fydev	0.5256	0.7057
log_avg_fmort	-4.8523	0.0761	rec_dev	0.3377	0.4969	fydev	0.2812	0.8120
fmort_dev	1.1475	0.1081	rec_dev	0.1213	0.5726	fydev	1.9358	0.3215
fmort_dev	1.2243	0.1046	rec_dev	0.0490	0.5226	fydev	0.3368	0.8211
fmort_dev	-0.5782	0.1004	rec_dev	-0.1149	0.5577	fydev	0.2388	0.7198
fmort_dev	-0.6631	0.0957	rec_dev	0.2751	0.4576	fydev	0.2838	0.6744
fmort_dev	-2.2057	0.0914	rec_dev	0.2873	0.4167	fydev	0.0704	0.6861
fmort_dev	-1.7229	0.0872	rec_dev	-0.3446	0.5699	fydev	0.1114	0.7117
fmort_dev	-2.7961	0.0832	rec_dev	0.5857	0.2969	fydev	0.5251	0.7493
fmort_dev	-1.8974	0.0792	rec_dev	-0.0890	0.4770	fydev	0.4462	0.7924
fmort_dev	-2.1003	0.0755	rec_dev	-0.3286	0.5388	fydev	0.1538	0.7357
fmort_dev	-1.8145	0.0721	rec_dev	1.1118	0.2182	fydev	0.1099	0.7071
fmort_dev	-1.4973	0.0689	rec_dev	1.0282	0.2453	fydev	0.0439	0.6887
fmort_dev	-1.2061	0.0660	rec_dev	0.0678	0.4628	fydev	-0.1438	0.6649
fmort_dev	-1.5705	0.0633	rec_dev	0.2796	0.3139	fydev	-0.2601	0.6457
fmort_dev	-0.2298	0.0609	rec_dev	-0.1153	0.3939	fydev	-0.2952	0.6395
fmort_dev	-0.8759	0.0589	rec_dev	0.7831	0.1858	fydev	-0.3154	0.6392
fmort_dev	-0.0829	0.0571	rec_dev	0.0464	0.3128	fydev	-0.3199	0.6409
fmort_dev	0.9623	0.0557	rec_dev	-0.1048	0.2934	fydev	-0.2950	0.6465
fmort_dev	0.8622	0.0547	rec_dev	-0.7116	0.4312	fydev	-0.2614	0.6530
fmort_dev	0.6826	0.0537	rec_dev	0.7455	0.1530	fydev	-0.2456	0.6573
fmort_dev	1.1846	0.0528	rec_dev	-0.1965	0.3636	fydev	-0.2442	0.6596
fmort_dev	0.0669	0.0523	rec_dev	1.1238	0.1448	fydev	-0.2436	0.6606
fmort_dev	0.6103	0.0520	rec_dev	0.6960	0.2126	fydev	-0.2383	0.6622
fmort_dev	0.9819	0.0520	rec_dev	0.7322	0.1914	fydev	-0.2305	0.6644
fmort_dev	0.8589	0.0523	rec_dev	0.2275	0.2282	fydev	-0.2222	0.6668
fmort_dev	1.1229	0.0529	rec_dev	-0.9206	0.4064	fydev	-0.2142	0.6691
fmort_dev	0.6628	0.0539	rec_dev	-0.2763	0.2305	fydev	-0.2066	0.6714
fmort_dev	0.8281	0.0551	rec_dev	-1.0718	0.4064	fydev	-0.1990	0.6736
fmort_dev	0.7480	0.0567	rec_dev	0.0914	0.2145	fydev	-0.1916	0.6758
fmort_dev	0.5671	0.0584	rec_dev	0.2209	0.2301	fydev	-0.1844	0.6780
fmort_dev	0.4786	0.0604	rec_dev	0.0336	0.3002	fydev	-0.1774	0.6801
fmort_dev	0.4874	0.0626	rec_dev	1.2270	0.1345	fydev	-0.1704	0.6822
fmort_dev	0.3229	0.0651	rec_dev	-0.9072	0.4465	fydev	-0.1638	0.6842
fmort_dev	0.2689	0.0679	rec_dev	-0.6930	0.3572	fydev	-0.1576	0.6861
fmort_dev	0.6153	0.0709	rec_dev	-0.2268	0.3303	fydev	-0.5474	0.59071
fmort_dev	0.1013	0.0741	rec_dev	0.0225	0.2912	q_srv3	1.0000	0.0010
fmort_dev	-0.0018	0.0772	rec_dev	-1.2433	0.4810	mat_beta1	-5.7428	0.6954
fmort_dev	-0.2112	0.0805	rec_dev	-0.9565	0.4643	mat_beta2	0.7000	0.0094
fmort_dev	-0.1022	0.0840	rec_dev	-0.9857	0.5212			

Table 13. Estimated time series of northern rockfish total biomass (t), spawner biomass (t), and recruitment (thousands) for each region.

	Total Biomass (ages 3+)				Spawner Biomass (ages 3+)				Recruitment (age 3)			
	Assessment Year				Assessment Year				Assessment Year			
	2019		2016		2019		2016		2019		2016	
Year	Est.	CV	Est.	CV	Est.	CV	Est.	CV	Est.	CV	Est.	CV
1977	125,250	0.137	117,293	0.128	47,111	0.154	44,381	0.145	50,404	0.511	36,410	0.540
1978	129,720	0.135	120,392	0.128	49,176	0.155	45,573	0.147	40,597	0.583	35,929	0.536
1979	133,820	0.133	123,091	0.127	51,732	0.152	47,283	0.146	37,765	0.532	31,970	0.497
1980	139,590	0.129	128,356	0.123	55,019	0.145	50,092	0.141	32,055	0.570	22,502	0.574
1981	146,040	0.125	134,728	0.120	58,193	0.139	52,900	0.135	47,348	0.467	46,413	0.378
1982	152,960	0.121	141,458	0.115	61,338	0.133	55,801	0.130	47,925	0.426	37,009	0.418
1983	158,560	0.117	147,142	0.111	64,390	0.128	58,694	0.125	25,477	0.587	18,723	0.562
1984	166,140	0.113	154,710	0.107	67,427	0.124	61,643	0.121	64,591	0.304	58,941	0.255
1985	172,160	0.109	160,998	0.103	70,370	0.119	64,550	0.116	32,897	0.489	26,284	0.436
1986	177,450	0.105	166,337	0.099	73,271	0.115	67,474	0.112	25,889	0.553	15,642	0.538
1987	187,180	0.101	176,761	0.095	76,175	0.111	70,422	0.108	109,310	0.232	118,088	0.171
1988	197,820	0.098	187,775	0.091	79,079	0.107	73,387	0.105	100,550	0.259	81,736	0.247
1989	205,910	0.094	197,697	0.088	82,029	0.104	76,456	0.102	38,480	0.475	37,658	0.385
1990	214,330	0.091	207,632	0.085	85,114	0.102	79,741	0.101	47,558	0.321	38,824	0.299
1991	220,780	0.088	215,728	0.082	88,317	0.100	83,239	0.101	32,045	0.409	33,628	0.305
1992	229,730	0.085	225,284	0.079	92,075	0.099	87,578	0.101	78,684	0.199	60,543	0.181
1993	235,880	0.083	231,835	0.077	95,693	0.097	91,681	0.100	37,667	0.328	26,015	0.303
1994	238,610	0.081	233,945	0.076	98,513	0.095	94,657	0.097	32,381	0.302	29,935	0.212
1995	239,820	0.079	234,537	0.075	101,080	0.091	97,435	0.092	17,652	0.448	8,796	0.440
1996	244,000	0.078	237,066	0.074	103,140	0.087	99,429	0.088	75,787	0.167	59,261	0.145
1997	243,700	0.077	235,349	0.074	104,430	0.085	100,398	0.085	29,545	0.381	26,830	0.311
1998	251,430	0.075	241,742	0.073	106,590	0.082	102,239	0.082	110,620	0.160	97,824	0.141
1999	256,930	0.074	246,387	0.072	107,800	0.081	102,758	0.080	72,123	0.229	64,225	0.195
2000	261,690	0.074	250,119	0.072	108,410	0.080	102,454	0.080	74,782	0.205	64,231	0.187
2001	265,090	0.073	254,077	0.072	108,910	0.081	102,304	0.082	45,145	0.239	47,802	0.195
2002	265,200	0.073	254,688	0.073	109,650	0.083	102,585	0.086	14,323	0.420	11,704	0.419
2003	268,010	0.072	257,131	0.073	112,000	0.084	104,392	0.089	27,278	0.238	26,303	0.220
2004	269,190	0.072	256,599	0.074	114,850	0.085	106,474	0.091	12,312	0.420	9,414	0.441
2005	270,950	0.073	256,620	0.074	117,810	0.083	108,809	0.090	39,400	0.225	42,227	0.211
2006	273,670	0.073	256,786	0.075	120,760	0.081	110,905	0.087	44,848	0.240	37,541	0.270
2007	272,070	0.073	256,194	0.076	121,210	0.079	112,064	0.085	37,186	0.314	28,645	0.369
2008	276,320	0.074	259,086	0.078	121,350	0.078	112,337	0.084	122,650	0.147	98,600	0.183
2009	277,010	0.075	259,941	0.079	121,270	0.078	112,224	0.084	14,516	0.462	15,369	0.509
2010	277,530	0.076	260,200	0.081	121,040	0.080	111,784	0.086	17,982	0.368	15,955	0.479
2011	276,890	0.078	258,588	0.084	120,790	0.082	111,296	0.089	28,663	0.342	19,890	0.474
2012	277,630	0.080	257,556	0.086	121,480	0.085	111,726	0.092	36,779	0.304	17,361	0.517
2013	277,760	0.081	255,887	0.088	123,040	0.087	112,561	0.095	10,371	0.499	16,213	0.541
2014	277,710	0.083	255,388	0.090	124,780	0.088	113,399	0.096	13,817	0.481		
2015	274,890	0.085	254,794	0.092	124,750	0.089	112,995	0.098	13,419	0.540		
2016	267,440	0.089	249,850	0.095	122,870	0.092	110,592	0.101	16,048	0.574		
2017	263,270	0.091	248,160		121,070	0.094	107,660					
2018	261,560	0.094			119,610	0.098						
2019	257,480	0.097			115,667	0.101						
2020	250,235				111,476							
Mean recruitment of post-1976 year classes									44,003		40,004	

Table 14. Estimated numbers at age for BSAI northern rockfish (millions).

	Age																	
Year	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1977	50.40	26.09	26.42	19.71	98.24	18.92	16.34	16.29	12.54	12.45	17.94	15.79	11.23	10.24	9.14	7.22	6.12	5.63
1978	40.60	48.01	24.84	25.14	18.74	93.17	17.87	15.37	15.24	11.70	11.59	16.69	14.69	10.44	9.52	8.49	6.71	5.69
1979	37.77	38.67	45.73	23.64	23.90	17.77	87.97	16.79	14.36	14.20	10.87	10.76	15.49	13.63	9.69	8.84	7.88	6.22
1980	32.05	35.98	36.84	43.56	22.52	22.75	16.90	83.62	15.94	13.63	13.47	10.31	10.21	14.69	12.93	9.19	8.38	7.48
1981	47.35	30.54	34.28	35.10	41.49	21.44	21.65	16.07	79.44	15.14	12.94	12.79	9.79	9.69	13.94	12.27	8.72	7.95
1982	47.93	45.11	29.10	32.66	33.44	39.52	20.42	20.62	15.30	75.63	14.41	12.32	12.17	9.32	9.22	13.27	11.68	8.31
1983	25.48	45.66	42.98	27.72	31.12	31.86	37.64	19.44	19.62	14.56	71.97	13.71	11.72	11.58	8.87	8.78	12.63	11.11
1984	64.59	24.27	43.51	40.95	26.42	29.65	30.35	35.86	18.52	18.69	13.87	68.54	13.06	11.16	11.03	8.44	8.36	12.03
1985	32.90	61.54	23.13	41.45	39.02	25.16	28.24	28.90	34.14	17.63	17.79	13.20	65.23	12.43	10.62	10.50	8.04	7.95
1986	25.89	31.34	58.64	22.04	39.49	37.17	23.97	26.89	27.51	32.50	16.78	16.93	12.56	62.10	11.83	10.11	9.99	7.65
1987	109.31	24.67	29.86	55.87	20.99	37.62	35.40	22.82	25.60	26.19	30.93	15.97	16.11	11.96	59.09	11.26	9.62	9.51
1988	100.55	104.15	23.50	28.45	53.22	20.00	35.82	33.70	21.72	24.35	24.91	29.42	15.19	15.33	11.37	56.21	10.71	9.15
1989	38.48	95.80	99.23	22.39	27.10	50.69	19.04	34.09	32.05	20.65	23.15	23.68	27.97	14.44	14.57	10.81	53.43	10.18
1990	47.56	36.66	91.28	94.55	21.33	25.82	48.27	18.12	32.44	30.50	19.65	22.03	22.53	26.60	13.74	13.86	10.28	50.82
1991	32.04	45.31	34.93	86.95	90.03	20.30	24.55	45.84	17.19	30.75	28.89	18.61	20.86	21.33	25.19	13.01	13.12	9.74
1992	78.68	30.53	43.17	33.28	82.82	85.73	19.32	23.35	43.57	16.33	29.21	27.44	17.67	19.81	20.26	23.92	12.35	12.46
1993	37.67	74.97	29.09	41.12	31.69	78.80	81.48	18.34	22.13	41.26	15.46	27.64	25.96	16.72	18.74	19.17	22.63	11.69
1994	32.38	35.88	71.40	27.69	39.11	30.07	74.56	76.78	17.21	20.72	38.57	14.44	25.81	24.24	15.61	17.50	17.89	21.13
1995	17.65	30.85	34.18	67.98	26.34	37.13	28.47	70.33	72.18	16.14	19.40	36.10	13.51	24.14	22.67	14.60	16.36	16.74
1996	75.79	16.82	29.38	32.54	64.68	25.02	35.19	26.90	66.26	67.87	15.16	18.21	33.87	12.68	22.65	21.27	13.70	15.35
1997	29.55	72.20	16.02	27.97	30.93	61.33	23.63	33.07	25.16	61.76	63.14	14.09	16.92	31.47	11.77	21.04	19.76	12.72
1998	110.62	28.15	68.78	15.25	26.63	29.43	58.27	22.42	31.32	23.80	58.39	59.68	13.32	15.99	29.73	11.13	19.88	18.67
1999	72.12	105.39	26.81	65.49	14.51	25.30	27.90	55.09	21.14	29.47	22.38	54.87	56.06	12.51	15.02	27.93	10.45	18.67
2000	74.78	68.71	100.38	25.53	62.28	13.78	23.94	26.29	51.70	19.78	27.54	20.89	51.21	52.32	11.67	14.01	26.06	9.75
2001	45.14	71.24	65.44	95.57	24.28	59.14	13.04	22.58	24.71	48.48	18.53	25.78	19.55	47.91	48.94	10.92	13.11	24.38
2002	14.32	43.01	67.85	62.29	90.85	23.03	55.88	12.27	21.14	23.06	45.17	17.25	23.99	18.19	44.57	45.53	10.16	12.19
2003	27.28	13.65	40.96	64.61	59.27	86.32	21.83	52.81	11.56	19.88	21.67	42.41	16.19	22.51	17.07	41.83	42.73	9.53
2004	12.31	25.99	13.00	39.00	61.45	56.28	81.74	20.60	49.67	10.85	18.63	20.29	39.70	15.15	21.07	15.98	39.15	39.99
2005	39.40	11.73	24.75	12.37	37.10	58.37	53.32	77.19	19.39	46.66	10.18	17.47	19.02	37.22	14.20	19.75	14.97	36.69
2006	44.85	37.54	11.17	23.57	11.78	35.26	55.36	50.43	72.81	18.26	43.89	9.57	16.42	17.88	34.98	13.35	18.56	14.07
2007	37.19	42.73	35.76	10.64	22.43	11.19	33.45	52.38	47.61	68.63	17.19	41.31	9.00	15.45	16.82	32.91	12.56	17.46
2008	122.65	35.43	40.70	34.05	10.13	21.32	10.62	31.65	49.45	44.87	64.62	16.18	38.87	8.47	14.54	15.82	30.96	11.81
2009	14.52	116.86	33.75	38.76	32.41	9.63	20.24	10.06	29.92	46.68	42.32	60.93	15.26	36.64	7.98	13.70	14.92	29.18
2010	17.98	13.83	111.32	32.14	36.90	30.82	9.14	19.18	9.51	28.26	44.06	39.93	57.47	14.39	34.56	7.53	12.92	14.07
2011	28.66	17.13	13.17	106.00	30.58	35.06	29.22	8.64	18.08	8.95	26.57	41.40	37.51	53.98	13.51	32.45	7.07	12.14
2012	36.78	27.31	16.32	12.55	####	29.09	33.31	27.71	8.18	17.10	8.46	25.10	39.11	35.43	50.99	12.77	30.66	6.68
2013	10.37	35.04	26.02	15.55	11.95	96.02	27.65	31.60	26.26	7.75	16.18	8.00	23.74	36.97	33.50	48.21	12.07	28.98
2014	13.82	9.88	33.38	24.78	14.80	11.37	91.29	26.25	29.97	24.88	7.34	15.32	7.58	22.47	35.01	31.72	45.65	11.43
2015	13.42	13.16	9.41	31.80	23.60	14.09	10.81	86.65	24.89	28.39	23.55	6.94	14.50	7.17	21.26	33.12	30.01	43.19
2016	16.05	12.78	12.54	8.96	30.23	22.38	13.31	10.17	81.15	23.23	26.46	21.93	6.46	13.49	6.67	19.79	30.82	27.92
2017	47.64	15.29	12.18	11.94	8.53	28.72	21.22	12.58	9.58	76.34	21.83	24.85	20.59	6.07	12.67	6.26	18.58	28.94
2018	47.64	45.38	14.56	11.59	11.36	8.10	27.22	20.04	11.85	9.01	71.67	20.49	23.31	19.32	5.69	11.88	5.87	17.42
2019	47.64	45.38	43.23	13.86	11.03	10.78	7.67	25.66	18.83	11.10	8.42	66.99	19.14	21.78	18.05	5.32	11.10	5.49

Table 14 (continued). Estimated numbers at age for BSAI northern rockfish (millions).

	Age																			
Year	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40+
1977	5.26	4.99	4.87	4.80	4.65	4.43	4.23	4.05	3.89	3.73	3.59	3.44	3.31	3.17	3.05	2.92	2.80	2.69	2.58	8.88
1978	5.23	4.89	4.64	4.53	4.46	4.32	4.12	3.93	3.76	3.61	3.47	3.33	3.20	3.07	2.95	2.83	2.72	2.61	2.50	10.65
1979	5.28	4.86	4.53	4.30	4.20	4.14	4.01	3.82	3.65	3.49	3.35	3.22	3.09	2.97	2.85	2.74	2.63	2.52	2.42	12.20
1980	5.90	5.01	4.61	4.30	4.08	3.99	3.93	3.80	3.63	3.46	3.31	3.18	3.06	2.94	2.82	2.71	2.60	2.49	2.39	13.87
1981	7.09	5.60	4.75	4.37	4.08	3.87	3.78	3.73	3.61	3.44	3.28	3.14	3.02	2.90	2.79	2.67	2.57	2.46	2.37	15.43
1982	7.57	6.75	5.33	4.52	4.16	3.89	3.69	3.60	3.55	3.43	3.28	3.12	2.99	2.87	2.76	2.65	2.55	2.44	2.35	16.94
1983	7.90	7.20	6.43	5.08	4.30	3.96	3.70	3.51	3.43	3.38	3.27	3.12	2.97	2.85	2.73	2.63	2.52	2.42	2.33	18.35
1984	10.58	7.53	6.86	6.12	4.83	4.10	3.77	3.52	3.34	3.26	3.22	3.11	2.97	2.83	2.71	2.60	2.50	2.40	2.31	19.69
1985	11.45	10.07	7.16	6.53	5.82	4.60	3.90	3.59	3.35	3.18	3.11	3.06	2.96	2.83	2.69	2.58	2.48	2.38	2.29	20.94
1986	7.57	10.90	9.59	6.82	6.22	5.54	4.38	3.71	3.42	3.19	3.03	2.96	2.91	2.82	2.69	2.56	2.46	2.36	2.27	22.11
1987	7.28	7.21	10.37	9.12	6.49	5.92	5.28	4.17	3.53	3.25	3.04	2.88	2.81	2.77	2.68	2.56	2.44	2.34	2.24	23.20
1988	9.04	6.92	6.85	9.86	8.68	6.17	5.63	5.02	3.96	3.36	3.09	2.89	2.74	2.68	2.64	2.55	2.43	2.32	2.22	24.20
1989	8.70	8.60	6.58	6.51	9.38	8.25	5.87	5.35	4.77	3.77	3.20	2.94	2.74	2.60	2.54	2.51	2.43	2.31	2.21	25.12
1990	9.68	8.28	8.18	6.26	6.20	8.92	7.85	5.58	5.09	4.54	3.58	3.04	2.80	2.61	2.48	2.42	2.38	2.31	2.20	25.99
1991	48.13	9.17	7.84	7.74	5.93	5.87	8.45	7.43	5.28	4.82	4.30	3.39	2.88	2.65	2.47	2.35	2.29	2.26	2.19	26.70
1992	9.25	45.71	8.71	7.44	7.35	5.63	5.57	8.02	7.06	5.02	4.58	4.08	3.22	2.73	2.51	2.35	2.23	2.18	2.14	27.43
1993	11.79	8.75	43.24	8.24	7.04	6.96	5.33	5.27	7.59	6.68	4.75	4.33	3.86	3.05	2.59	2.38	2.22	2.11	2.06	27.98
1994	10.91	11.01	8.17	40.36	7.69	6.57	6.50	4.97	4.92	7.08	6.23	4.43	4.04	3.60	2.85	2.41	2.22	2.07	1.97	28.04
1995	19.76	10.20	10.30	7.64	37.75	7.19	6.15	6.08	4.65	4.60	6.63	5.83	4.15	3.78	3.37	2.66	2.26	2.08	1.94	28.07
1996	15.70	18.54	9.57	9.66	7.17	35.42	6.75	5.77	5.70	4.36	4.32	6.22	5.47	3.89	3.55	3.16	2.50	2.12	1.95	28.15
1997	14.26	14.58	17.22	8.89	8.97	6.66	32.90	6.27	5.36	5.29	4.05	4.01	5.77	5.08	3.61	3.29	2.94	2.32	1.97	27.96
1998	12.02	13.47	13.78	16.27	8.40	8.48	6.29	31.09	5.92	5.06	5.00	3.83	3.79	5.45	4.80	3.41	3.11	2.78	2.19	28.27
1999	17.53	11.29	12.65	12.94	15.28	7.89	7.96	5.91	29.20	5.56	4.75	4.70	3.60	3.56	5.12	4.51	3.21	2.92	2.61	28.61
2000	17.42	16.36	10.54	11.81	12.08	14.26	7.36	7.43	5.51	27.24	5.19	4.44	4.38	3.36	3.32	4.78	4.21	2.99	2.73	29.13
2001	9.12	16.30	15.31	9.85	11.05	11.30	13.34	6.89	6.95	5.16	25.49	4.86	4.15	4.10	3.14	3.11	4.47	3.94	2.80	29.80
2002	22.68	8.48	15.16	14.24	9.17	10.28	10.51	12.41	6.41	6.46	4.80	23.71	4.52	3.86	3.81	2.92	2.89	4.16	3.66	30.33
2003	11.44	21.28	7.96	14.23	13.36	8.60	9.64	9.86	11.65	6.01	6.07	4.50	22.25	4.24	3.62	3.58	2.74	2.71	3.90	31.90
2004	8.92	10.71	19.92	7.45	13.32	12.51	8.05	9.03	9.23	10.90	5.63	5.68	4.21	20.82	3.97	3.39	3.35	2.57	2.54	33.51
2005	37.48	8.36	10.04	18.67	6.98	12.48	11.72	7.55	8.46	8.65	10.22	5.27	5.32	3.95	19.52	3.72	3.18	3.14	2.40	33.78
2006	34.48	35.22	7.86	9.43	17.54	6.56	11.73	11.01	7.09	7.95	8.13	9.60	4.96	5.00	3.71	18.34	3.49	2.99	2.95	34.01
2007	13.24	32.44	33.14	7.39	8.88	16.51	6.18	11.04	10.36	6.67	7.48	7.65	9.03	4.66	4.71	3.49	17.26	3.29	2.81	34.77
2008	16.43	12.46	30.52	31.18	6.96	8.35	15.53	5.81	10.38	9.75	6.28	7.04	7.20	8.50	4.39	4.43	3.28	16.23	3.09	35.36
2009	11.14	15.49	11.74	28.77	29.39	6.56	7.87	14.64	5.48	9.79	9.19	5.92	6.63	6.78	8.01	4.14	4.17	3.10	15.30	36.24
2010	27.52	10.50	14.60	11.07	27.13	27.72	6.18	7.42	13.80	5.17	9.23	8.67	5.58	6.26	6.40	7.55	3.90	3.94	2.92	48.61
2011	13.21	25.85	9.86	13.72	10.40	25.48	26.03	5.81	6.97	12.96	4.85	8.67	8.14	5.24	5.87	6.01	7.09	3.66	3.70	48.40
2012	11.46	12.48	24.42	9.32	12.96	9.82	24.07	24.59	5.49	6.59	12.25	4.58	8.19	7.69	4.95	5.55	5.68	6.70	3.46	49.21
2013	6.32	10.84	11.80	23.08	8.81	12.25	9.29	22.76	23.25	5.19	6.23	11.58	4.33	7.74	7.27	4.68	5.25	5.37	6.34	49.79
2014	27.44	5.98	10.26	11.17	21.86	8.34	11.60	8.79	21.55	22.01	4.91	5.90	10.96	4.10	7.33	6.88	4.43	4.97	5.08	53.14
2015	10.81	25.96	5.66	9.71	10.57	20.68	7.89	10.97	8.32	20.39	20.82	4.65	5.58	10.37	3.88	6.93	6.51	4.19	4.70	55.09
2016	40.19	10.06	24.16	5.27	9.04	9.84	19.24	7.34	10.21	7.74	18.97	19.38	4.32	5.19	9.65	3.61	6.45	6.06	3.90	55.64
2017	26.21	37.73	9.44	22.68	4.94	8.48	9.23	18.06	6.89	9.59	7.27	17.81	18.19	4.06	4.87	9.06	3.39	6.06	5.69	55.89
2018	27.14	24.59	35.38	8.86	21.27	4.64	7.95	8.66	16.94	6.47	8.99	6.82	16.70	17.06	3.81	4.57	8.50	3.18	5.68	57.75
2019	16.28	25.35	22.97	33.05	8.27	19.87	4.33	7.43	8.09	15.83	6.04	8.40	6.37	15.60	15.94	3.56	4.27	7.94	2.97	59.26

Table 15. 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 xx t and xx t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2019	8,828	8,828	8,828	8,828	8,828	8,828	8,828
2020	16,243	16,243	6,931	3,891	0	19,751	16,243
2021	15,159	15,159	6,691	3,797	0	18,193	15,159
2022	14,228	14,228	6,490	3,722	0	16,862	17,302
2023	13,485	13,485	6,343	3,674	0	15,795	16,192
2024	12,918	12,918	6,251	3,654	0	14,970	15,326
2025	12,481	12,481	6,199	3,655	0	14,323	14,643
2026	12,127	12,127	6,170	3,667	0	13,796	14,082
2027	11,830	11,830	6,153	3,685	0	13,351	13,607
2028	11,573	11,573	6,144	3,705	0	12,968	13,196
2029	11,350	11,350	6,139	3,727	0	12,628	12,837
2030	11,153	11,153	6,137	3,749	0	12,291	12,496
2031	10,974	10,974	6,137	3,770	0	11,954	12,151
2032	10,805	10,805	6,136	3,790	0	11,640	11,823
Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2019	115,667	115,667	115,667	115,667	115,667	115,667	115,667
2020	110,522	110,522	111,476	111,782	112,171	110,156	110,522
2021	103,582	103,582	108,063	109,534	111,424	101,906	103,582
2022	97,636	97,636	105,221	107,769	111,082	94,865	97,318
2023	92,781	92,781	103,094	106,636	111,299	89,102	91,320
2024	88,910	88,910	101,636	106,103	112,055	84,474	86,473
2025	85,784	85,784	100,667	106,002	113,196	80,713	82,510
2026	83,190	83,190	100,017	106,172	114,567	77,581	79,193
2027	80,991	80,991	99,578	106,511	116,073	74,925	76,367
2028	79,094	79,094	99,276	106,949	117,646	72,641	73,929
2029	77,445	77,445	99,076	107,450	119,251	70,665	71,813
2030	75,986	75,986	98,932	107,972	120,844	68,938	69,957
2031	74,685	74,685	98,823	108,496	122,408	67,434	68,329
2032	73,519	73,519	98,738	109,011	123,931	66,131	66,911
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2019	0.031	0.031	0.031	0.031	0.031	0.031	0.031
2020	0.061	0.061	0.026	0.014	0.000	0.075	0.061
2021	0.061	0.061	0.026	0.014	0.000	0.075	0.061
2022	0.061	0.061	0.026	0.014	0.000	0.075	0.075
2023	0.061	0.061	0.026	0.014	0.000	0.075	0.075
2024	0.061	0.061	0.026	0.014	0.000	0.075	0.075
2025	0.061	0.061	0.026	0.014	0.000	0.075	0.075
2026	0.061	0.061	0.026	0.014	0.000	0.075	0.075
2027	0.061	0.061	0.026	0.014	0.000	0.075	0.075
2028	0.061	0.061	0.026	0.014	0.000	0.075	0.075
2029	0.061	0.061	0.026	0.014	0.000	0.074	0.074
2030	0.061	0.061	0.026	0.014	0.000	0.074	0.074
2031	0.061	0.061	0.026	0.014	0.000	0.074	0.074
2032	0.061	0.061	0.026	0.014	0.000	0.073	0.073

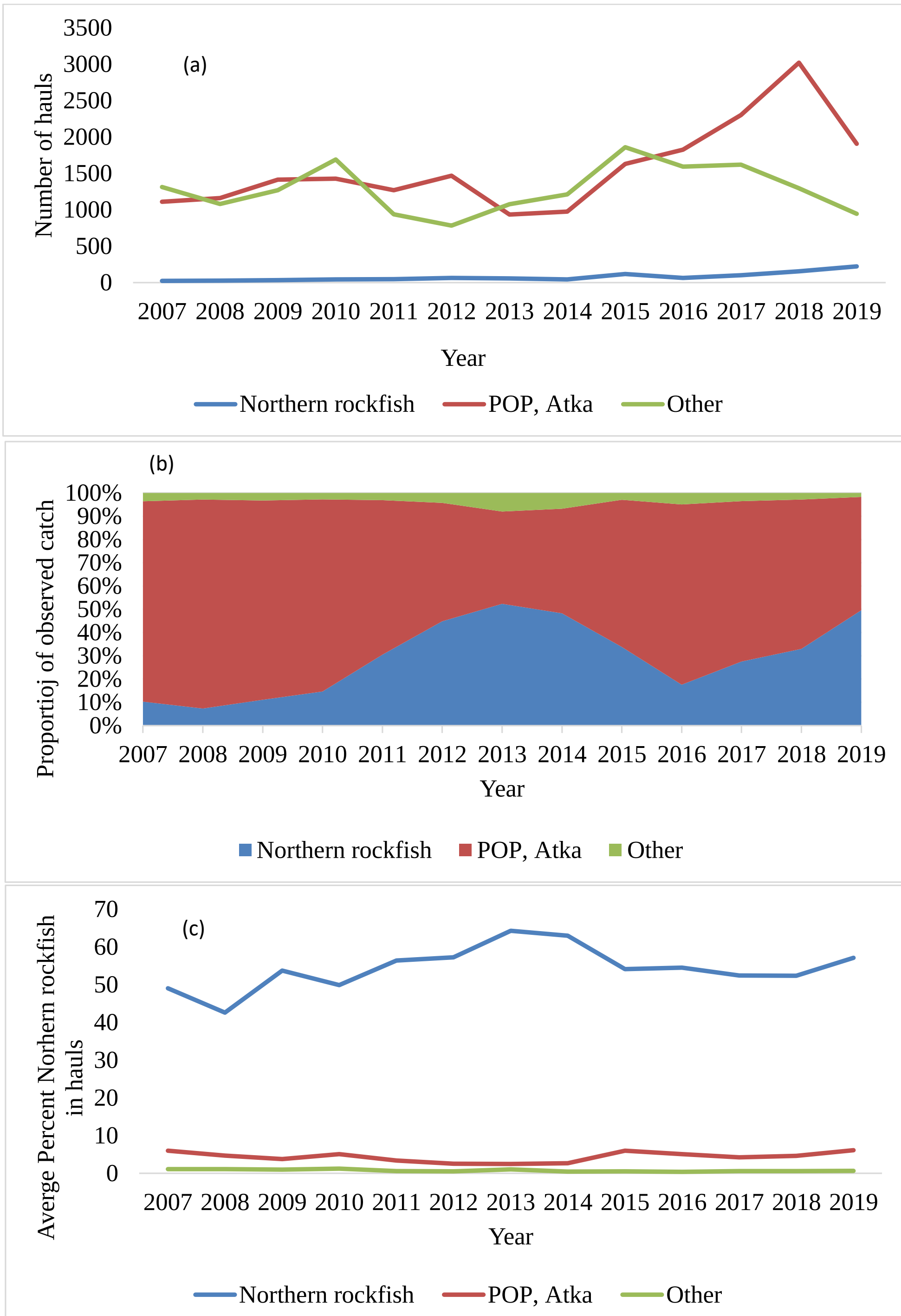


Figure 1. Number of tows, (a), percentage of observed catch (b), and average percent northern rockfish across in across hauls (c) from 2017 to 2019 (through October 11) by target fishery. Data are from the North Pacific Groundfish Observer Program.

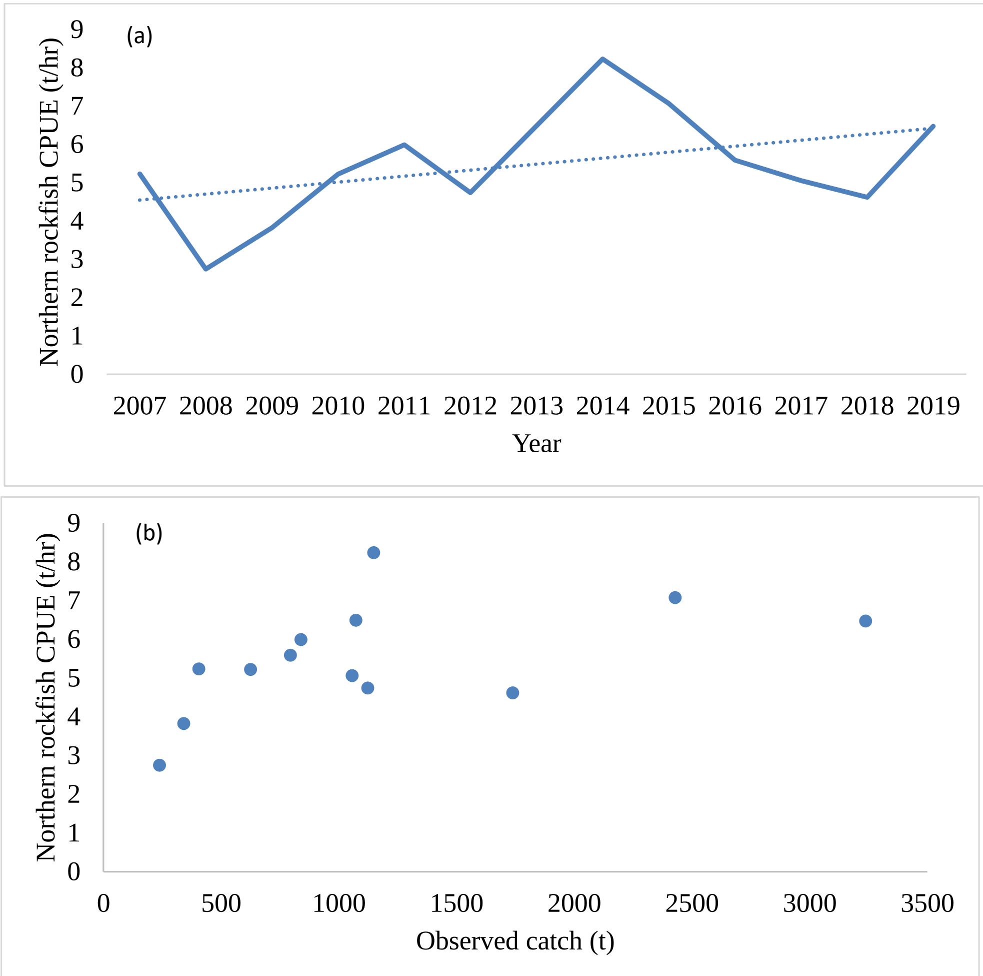


Figure 2. Catch per unit effort of northern rockfish in tows targeting northern rockfish from 2017 to 2019 (through Oct 11) (a), and plotted against observed catch (b). Data are from the North Pacific Groundfish Observer Program.

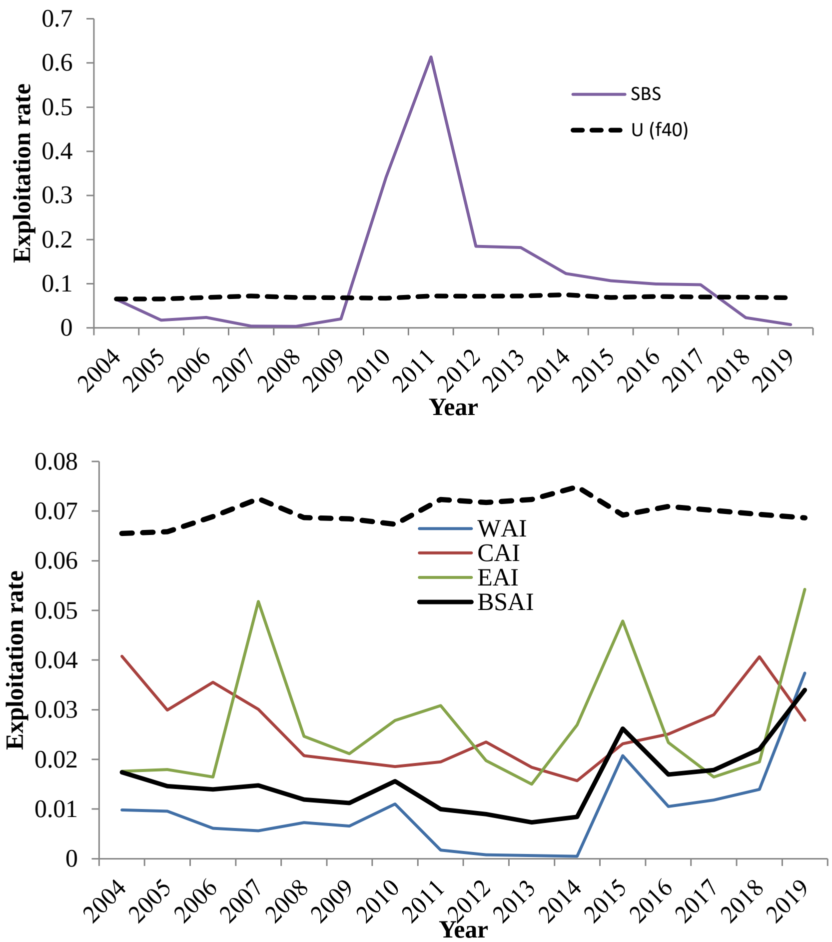


Figure 3. Exploitation rates for northern rockfish. The $U_{F40\%}$ is the exploitation rate for each year that would occur from fishing at $F_{40\%}$, and is a function of the beginning year numbers at age, size at age, and fishing selectivity. The high exploitation rates in the southern Bering Sea (SBS) area result from high variable survey biomass estimates for this area. Exploitation rates for 2019 are preliminary and based on catch through September 28, 2019.

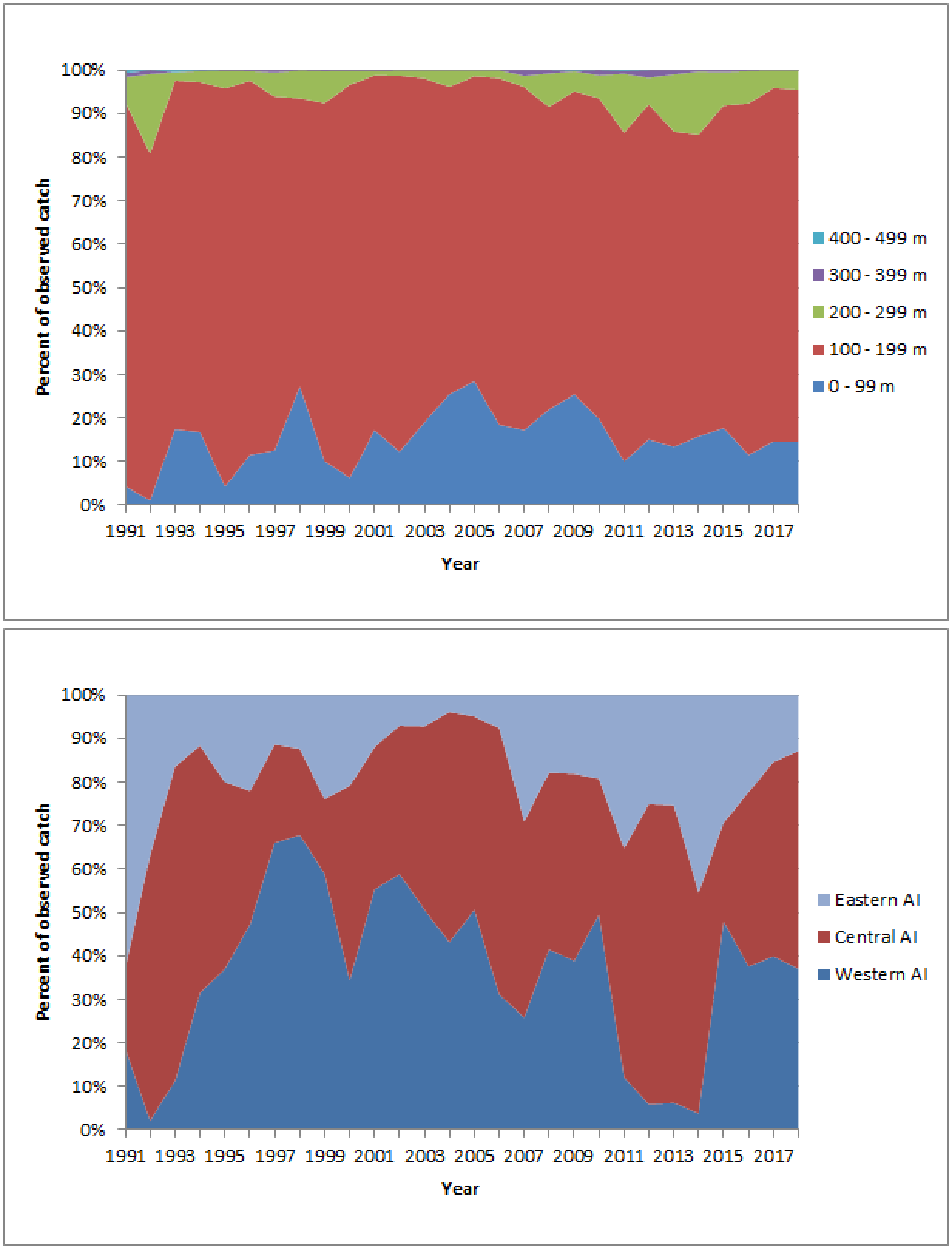


Figure 4. Distribution of observed Aleutian Islands northern rockfish catch (from North Pacific Groundfish Observer Program) by depth zone (top panel) and AI subarea (bottom panel) from 1991 to 2018.

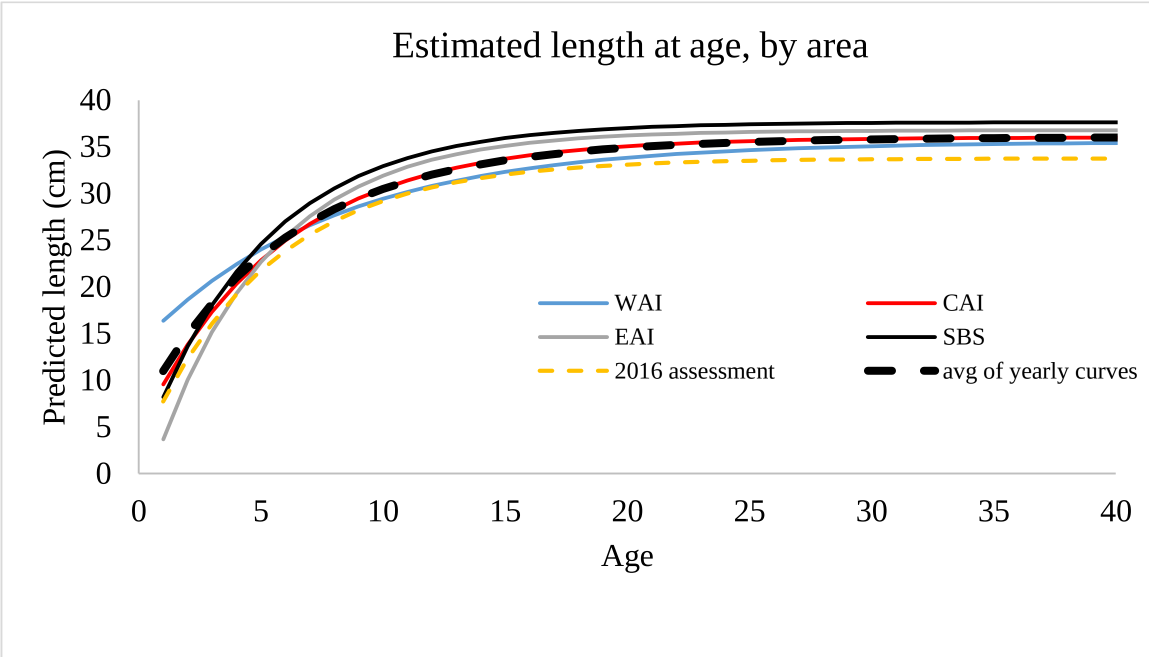
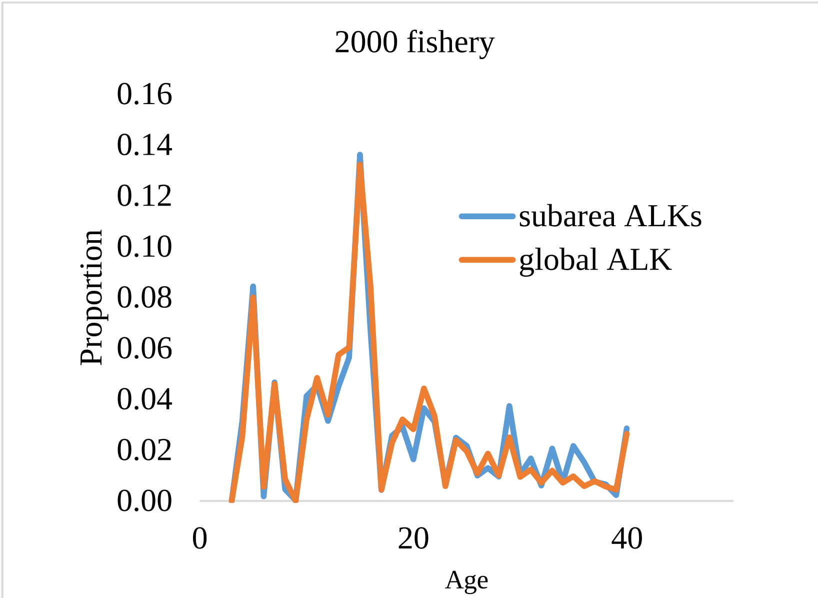


Figure 5. Estimated fishery size at age across the AI subareas from fitted von Bertalannfy curves; for comparison, the size at age from the 2016 assessment (from survey data, with a global age-length) is also shown



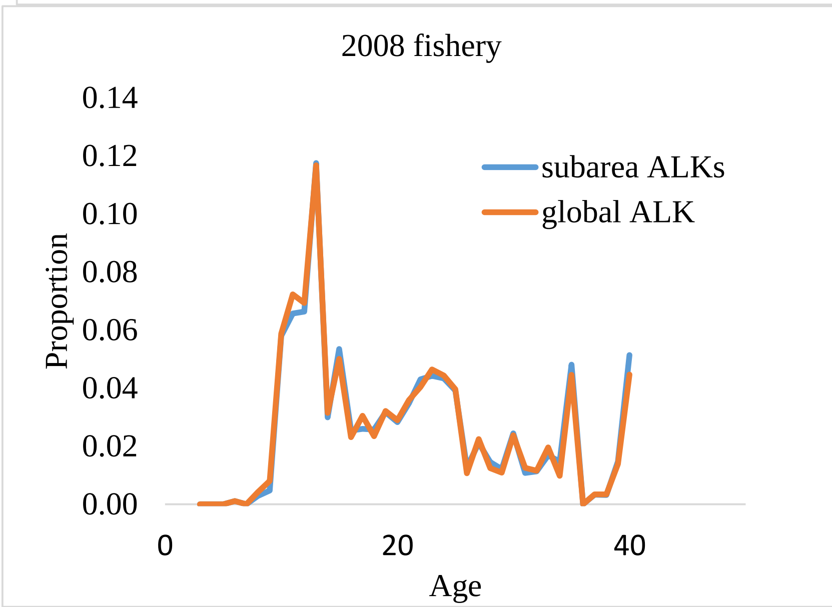


Figure 6. Example fishery age comps for application of the subarea age length keys (with the subarea age compositions weighted by fishery catch) and the global age length key.

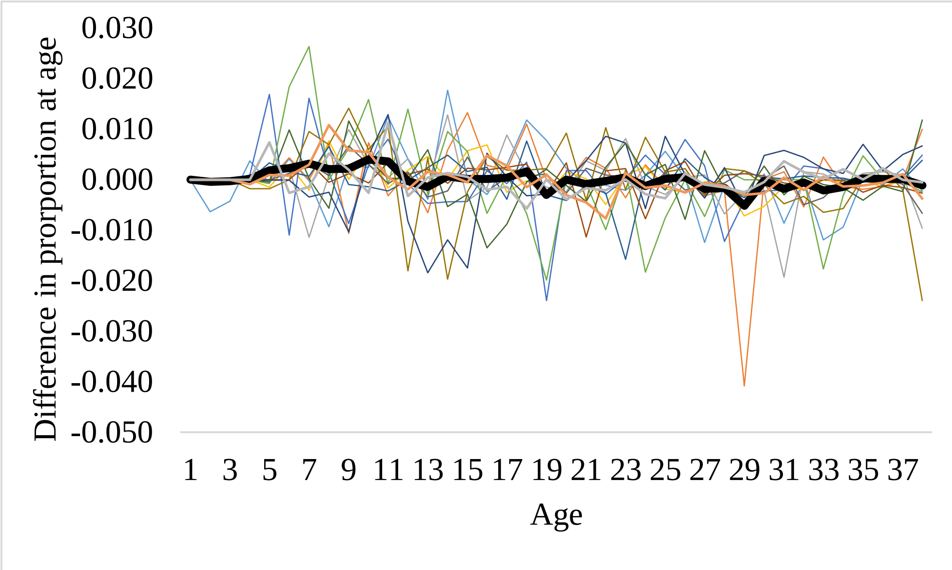


Figure 7. Values of the age compositions from the global age length key minus the age composition from the weighted subarea age length keys, by age. Individual fishery years are shown in the colored light lines, and the average across all fishery years is shown in the bold line.

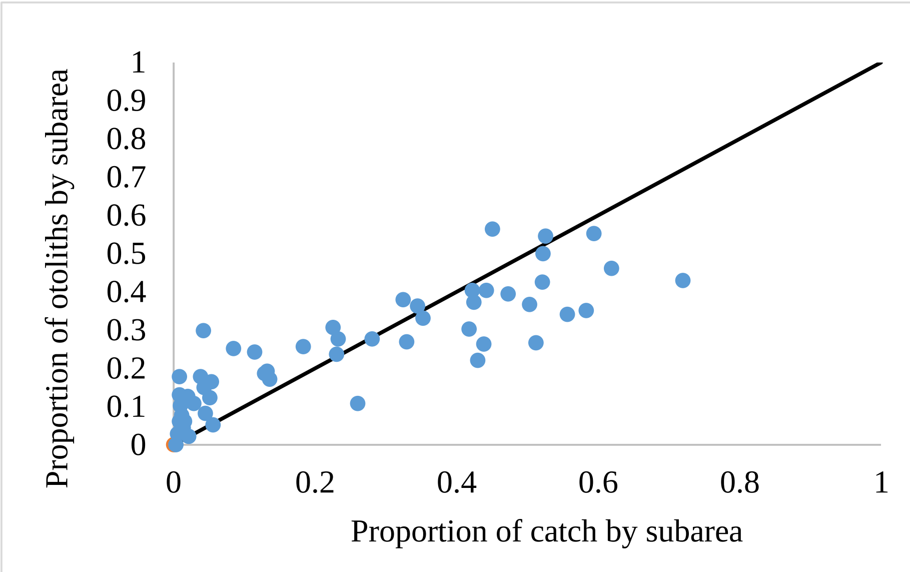


Figure 8.. The proportion of the extrapolated fishery catch numbers in AI subarea (i.e., WAI, CAI, EAI, and BS, from North Pacific Groundfish Observer Program) and the proportion of the read otoliths by subarea. Random sampling of otoliths from the fishery catch would be expected to generate data near the 1:1 line (in black).

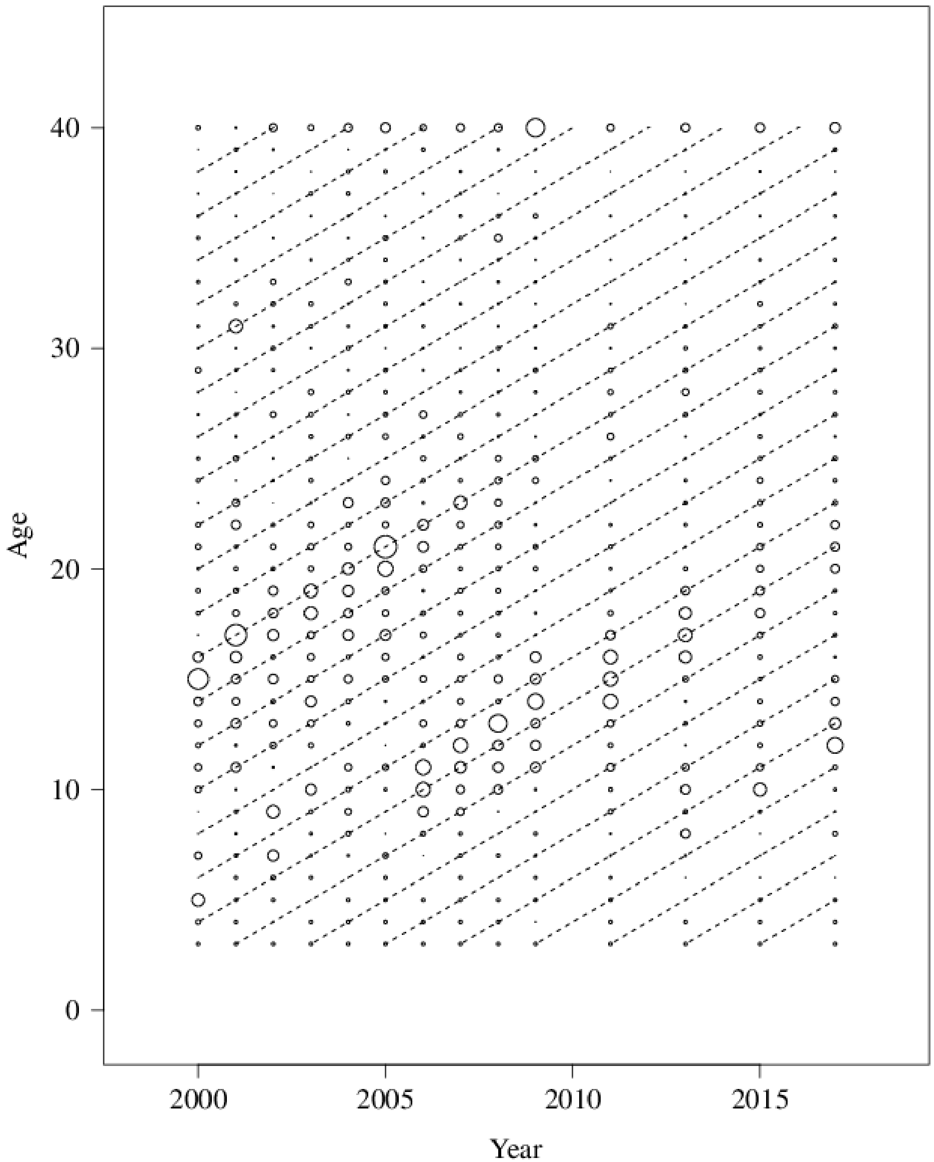


Figure 9. Fishery age composition data for the Aleutian Islands; bubbles are scaled within each year of samples; and dashed lines denote cohorts.

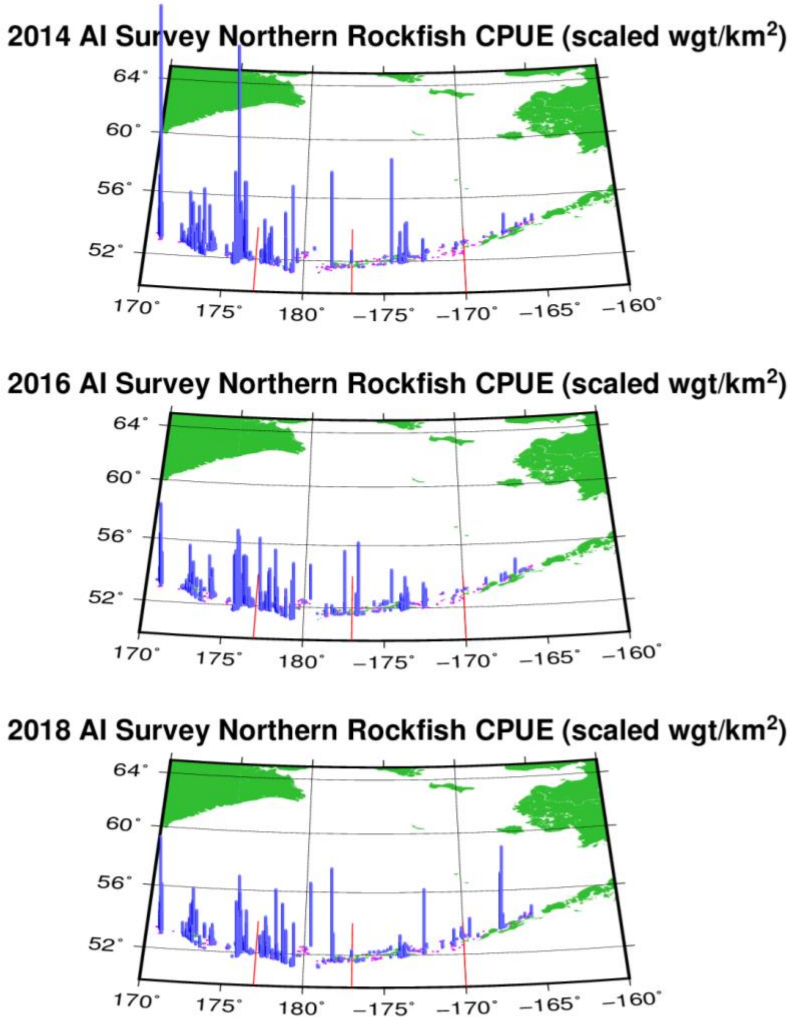


Figure 10. Scaled AI survey northern rockfish CPUE from (square root of kg/km$_2$) from 2014-2018; the red lines indicate boundaries between the WAI, CAI, EAI, and EBS areas.

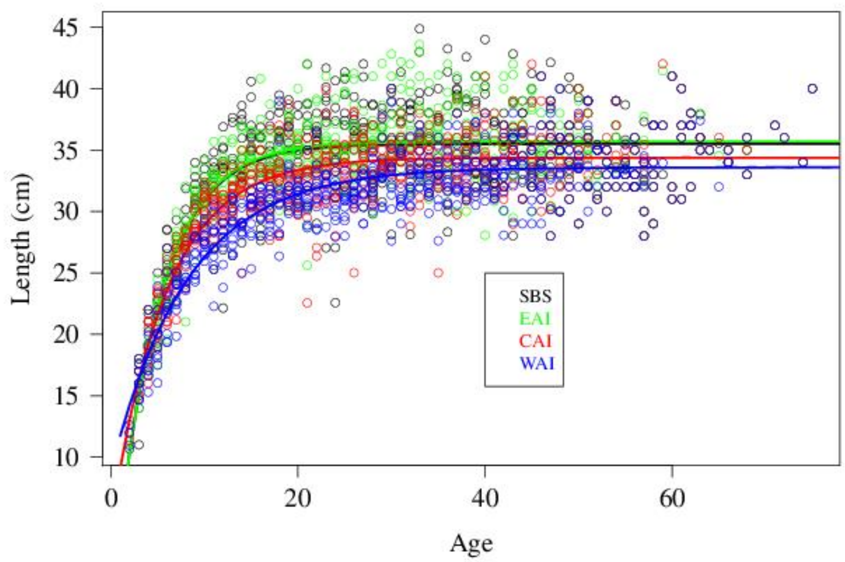


Figure 11. Estimated survey size at age across the AI subareas from fitted von Bertalannfy curves.

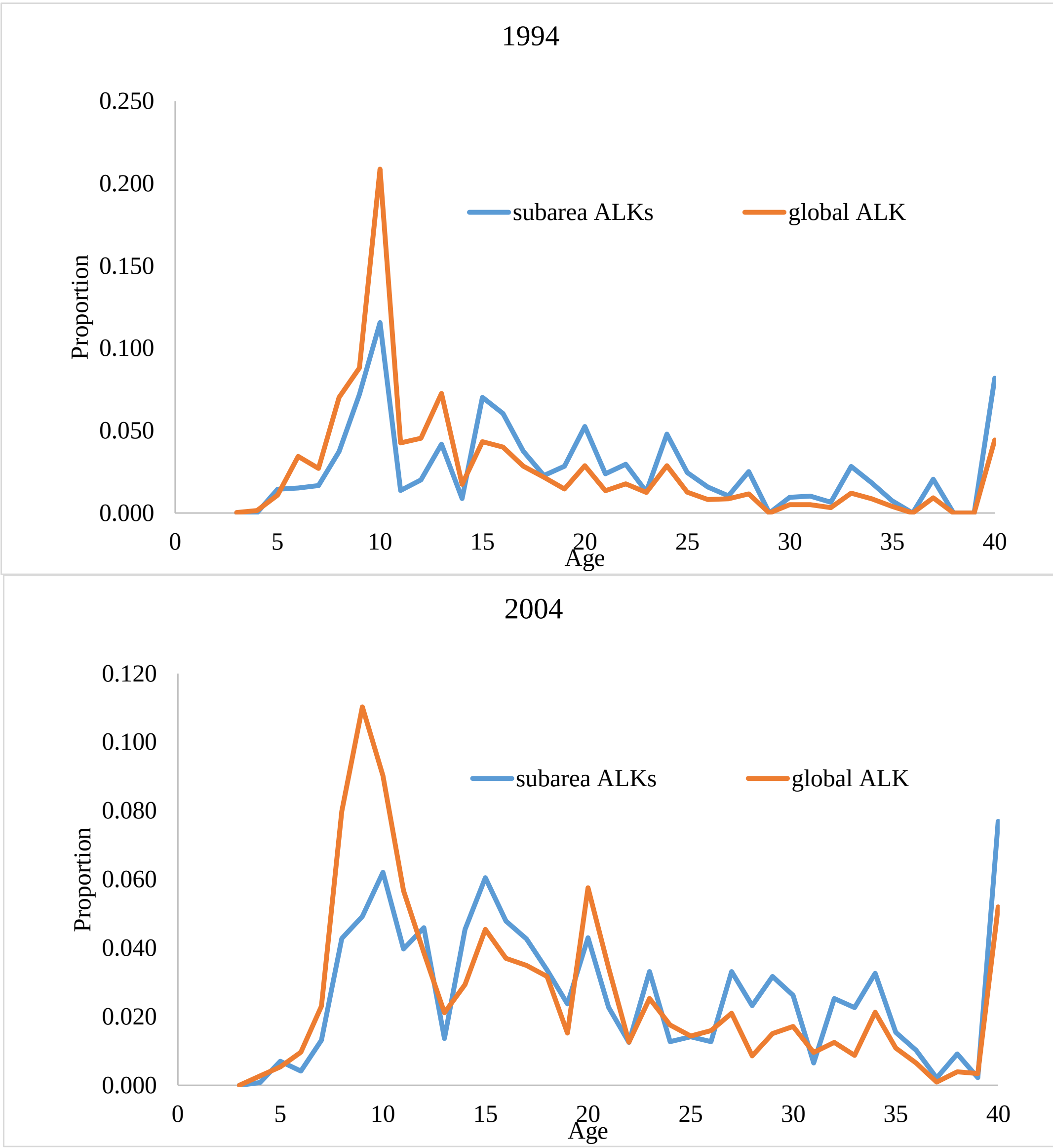


Figure 12. Example survey age comps for application of the subarea age length keys (with the subarea age compositions weighted by fishery catch) and the global age length key.

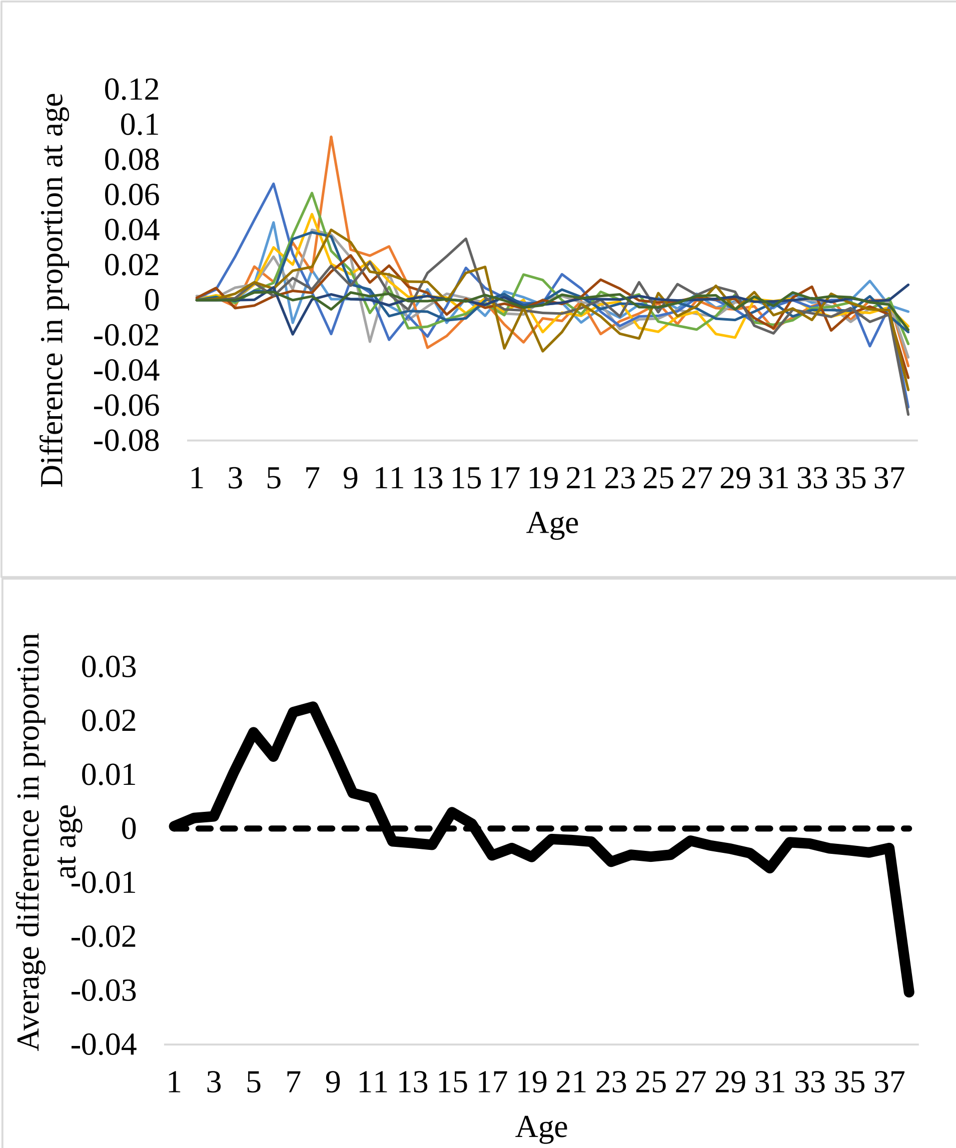


Figure 13. Values of the AI survey age compositions from the global age length key minus the age composition from the weighted subarea age length keys, by age. Individual survey years are shown in the colored light lines, and the average across all fishery years is shown in the bold line (lower panel).

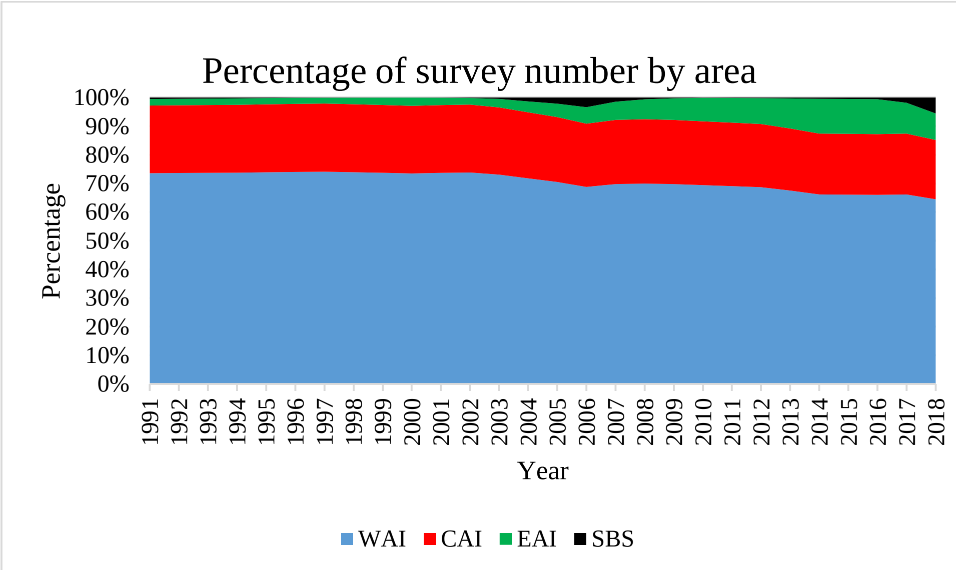


Figure 14. Proportion of northern rockfish survey abundance by area, from a smoother applied to survey estimates form 1991-2018.

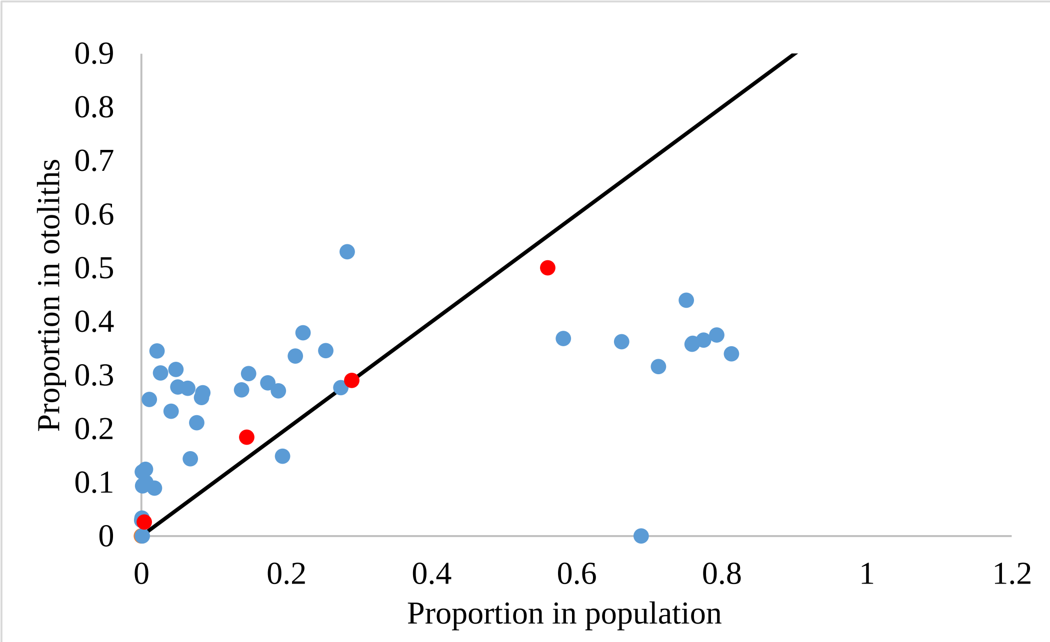


Figure 15. The proportion of the survey population abundance by AI subarea (i.e., WAI, CAI, EAI, and BS) and the proportion of the read otoliths by subarea. Random sampling of otoliths occurred in the 2016 survey (shown in red), which would be expected to generate data near the 1:1 line (in black).

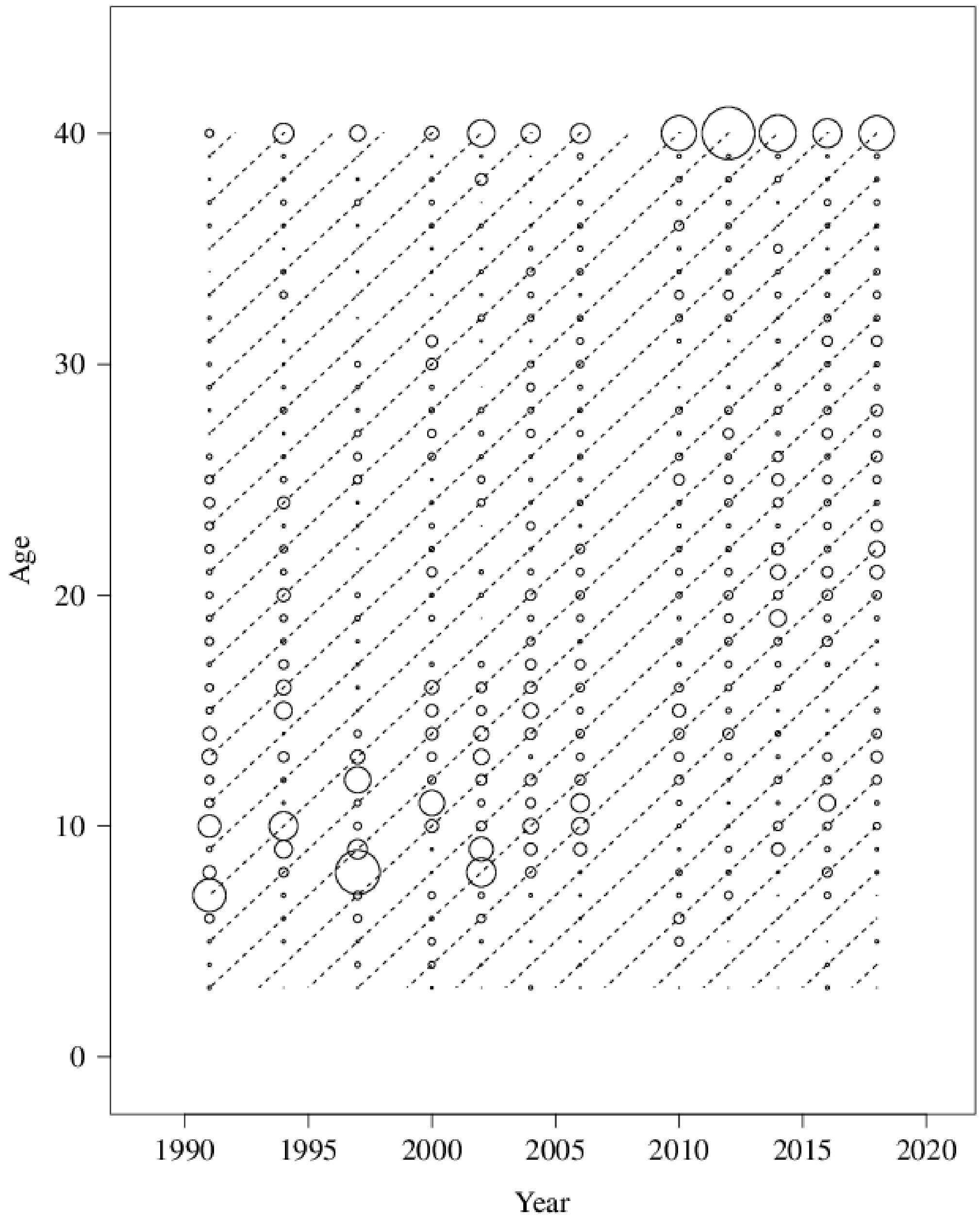


Figure 16. Age composition data from the Aleutian Islands trawl survey; bubbles are scaled within each year of samples; and dashed lines denote cohorts.

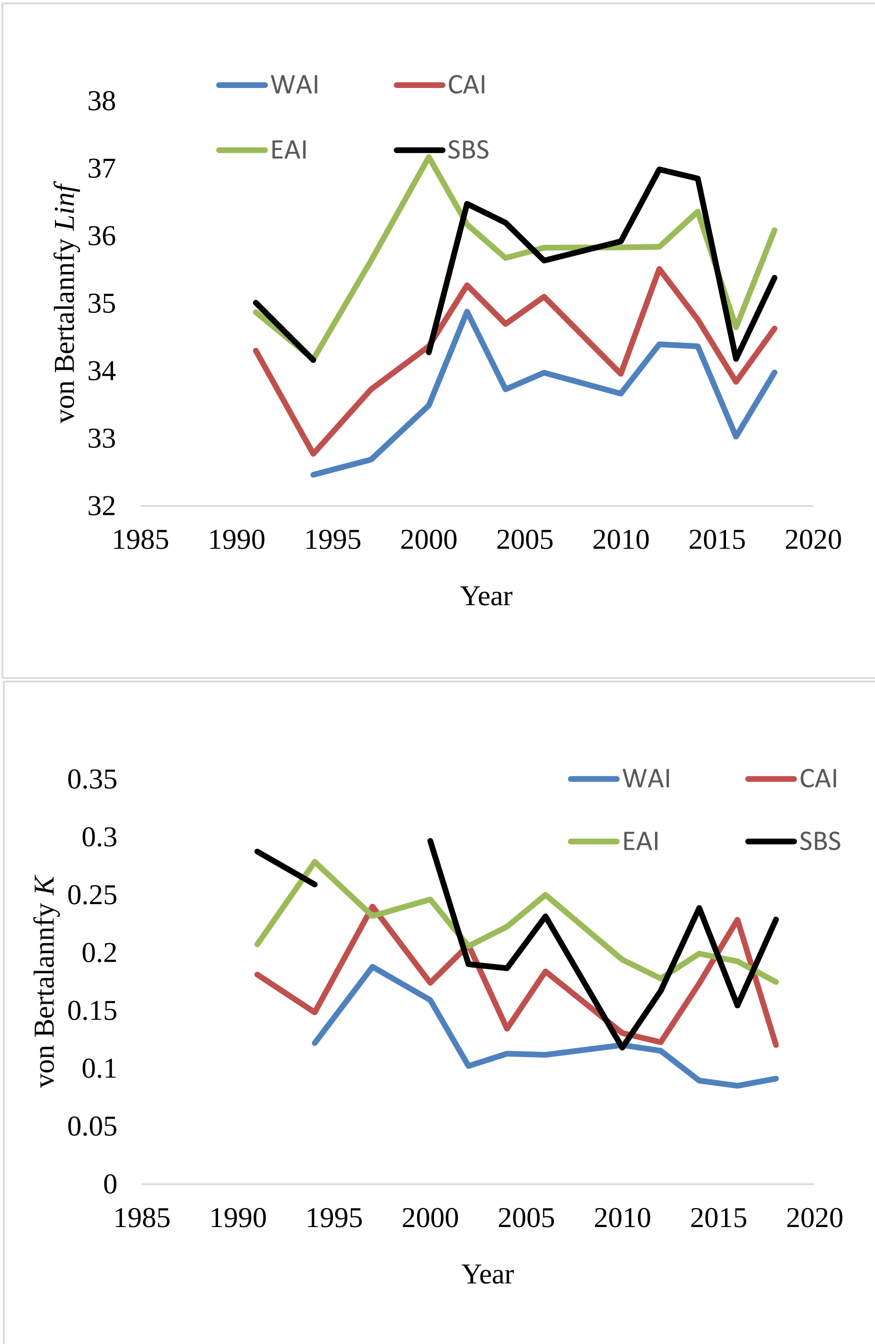
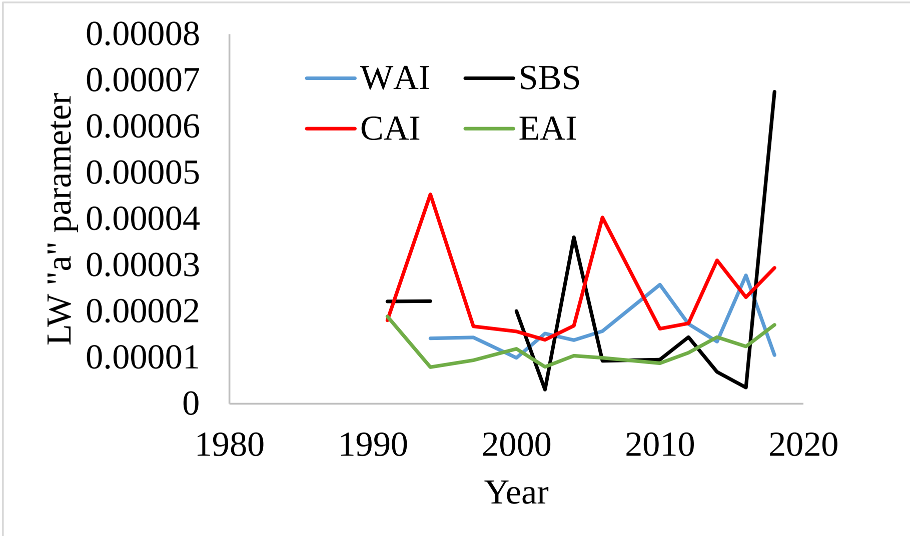


Figure 17. Estimates of von Bertalanffy parameters Linf and K by area and year for the AI trawl survey.



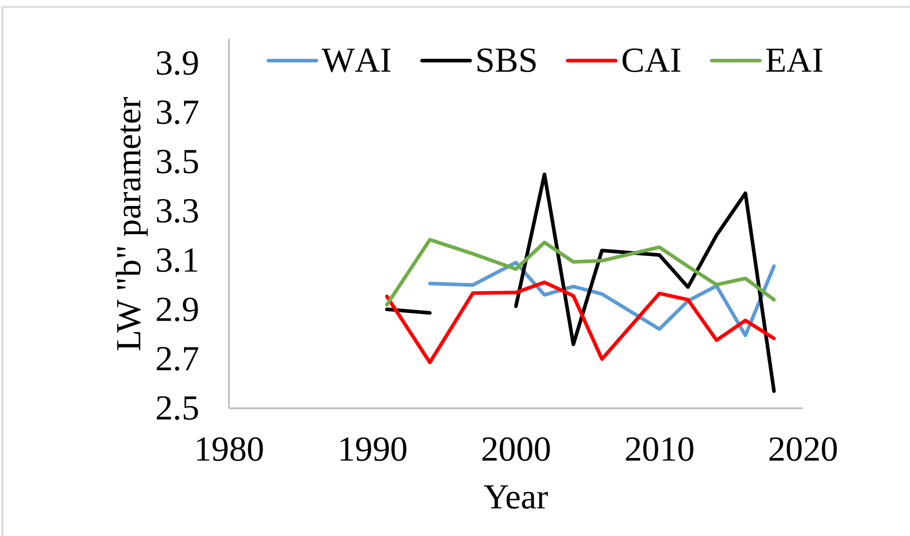


Figure 18. Estimates of the *a* and *b* parameters for the weight-length relationship ($W = aL^b$) by year and area for the AI trawl survey.

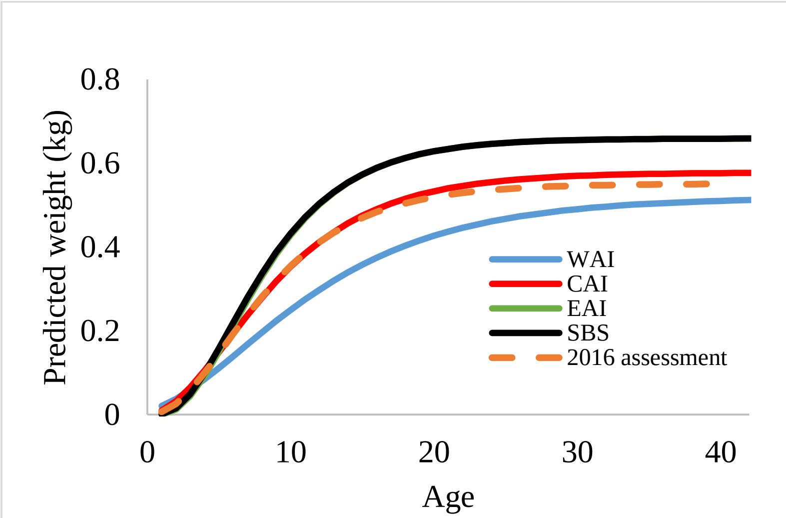


Figure 19. Estimated weights at age by area from the AI trawl survey, combining data across years within each area. For comparison, the weight at age used in the 2016 assessment is also shown.

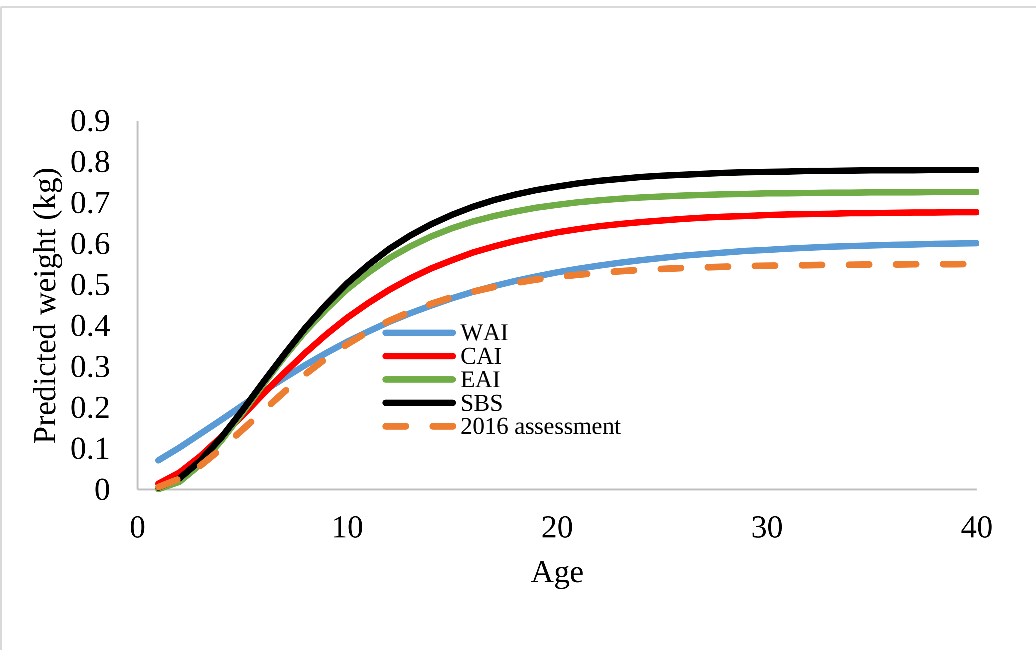


Figure 20. Estimated weights at age by area from the fishery, combining data across years within each area. For comparison, the weight at age used in the 2016 assessment (based on survey data) is also shown.

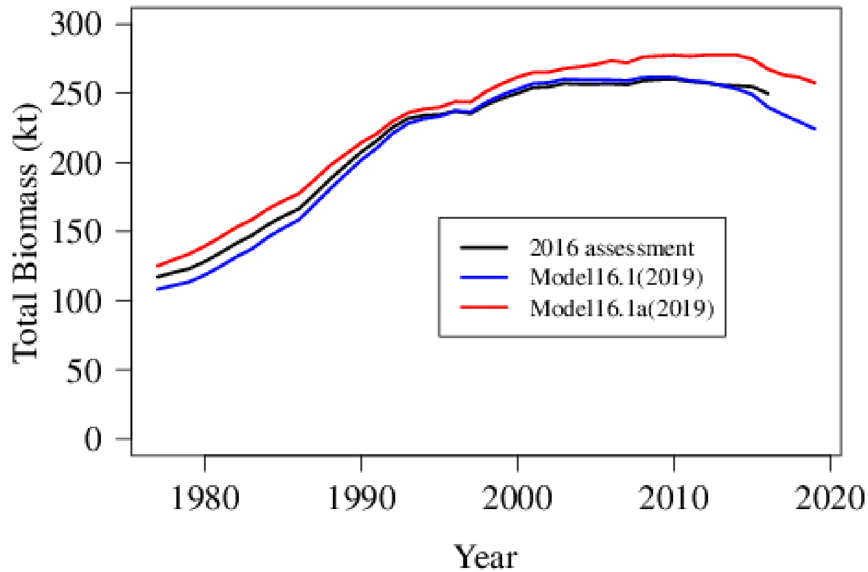


Figure 21. Estimated time series of total stock biomass for Model 16.1a, compared to the results from the 2016 assessment, and the resulted obtained from applying the Model 16.1 to data updated with the same data processing procedures used in 2016 (i.e., Model 16.1(2019)).

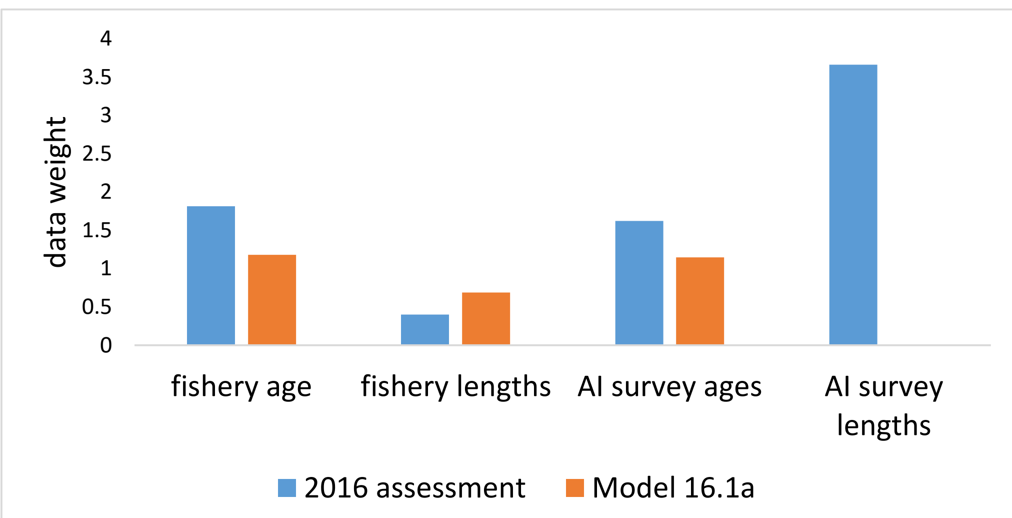


Figure 22. Data weights for the age and length composition data for the 2016 and 2019 assessments.

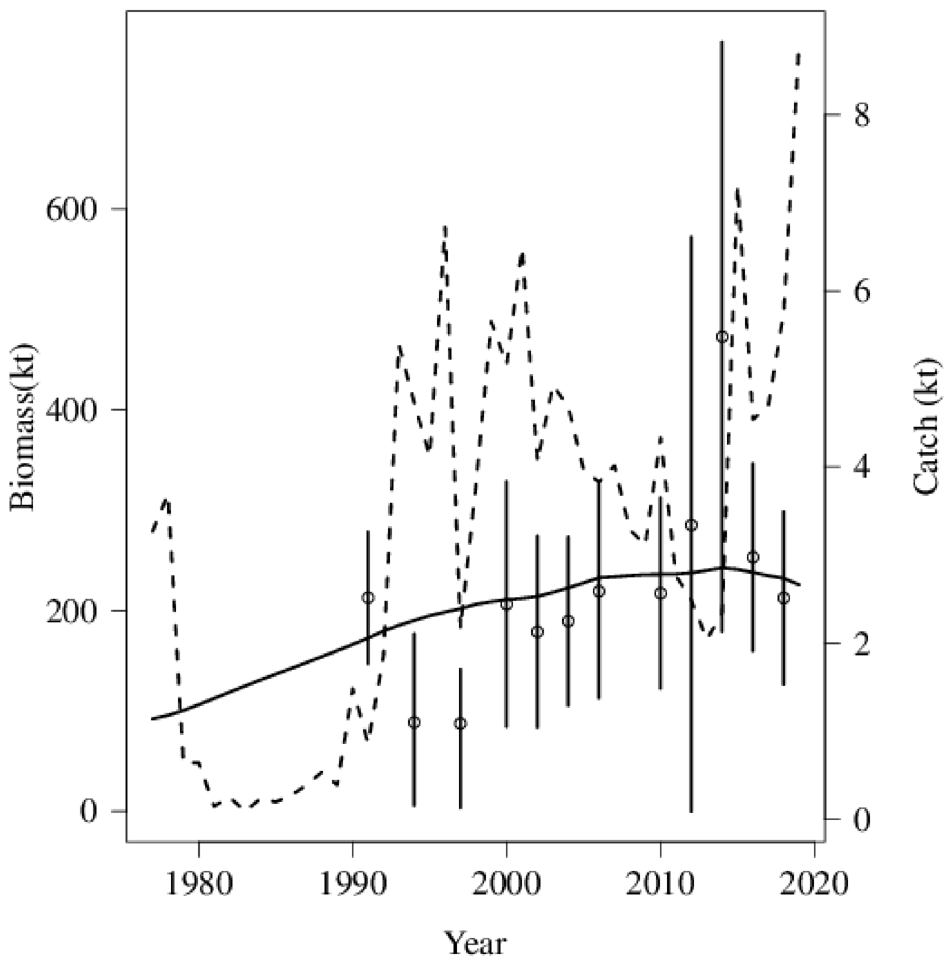


Figure 23. Observed Aleutian Islands survey biomass (data points, ± 2 standard deviations), predicted survey biomass (solid line) and BSAI harvest (dashed line).

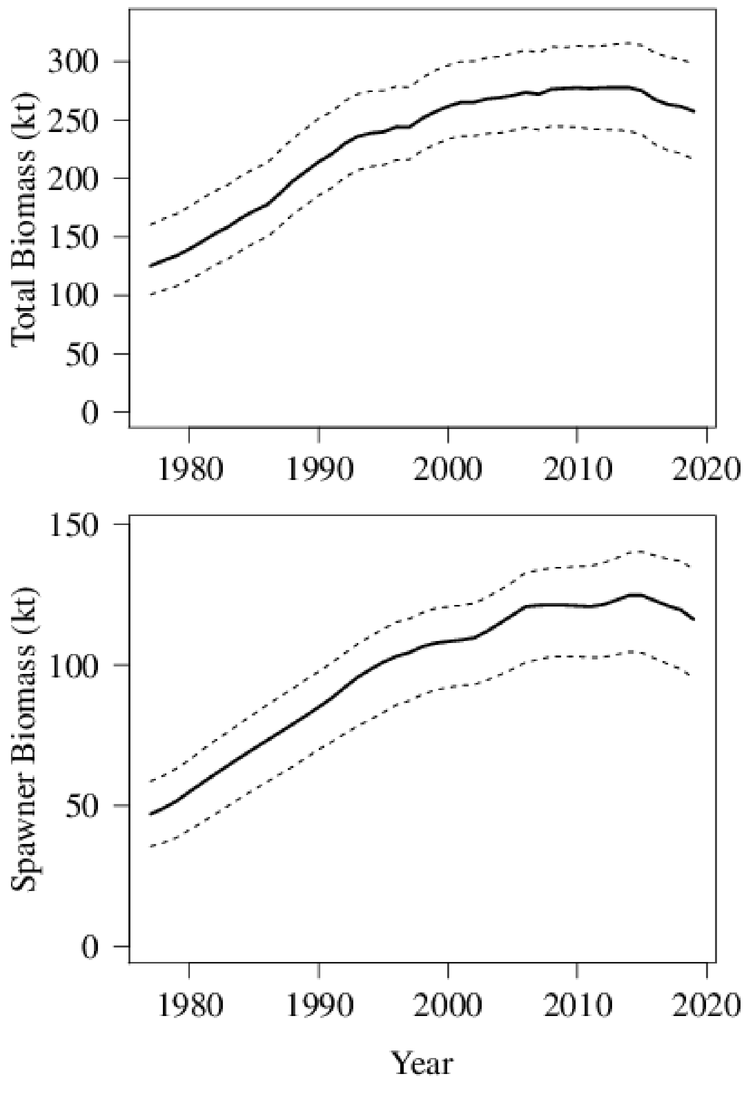


Figure 24. Total and spawner biomass for BSAI northern rockfish with 95% confidence intervals from MCMC integration.

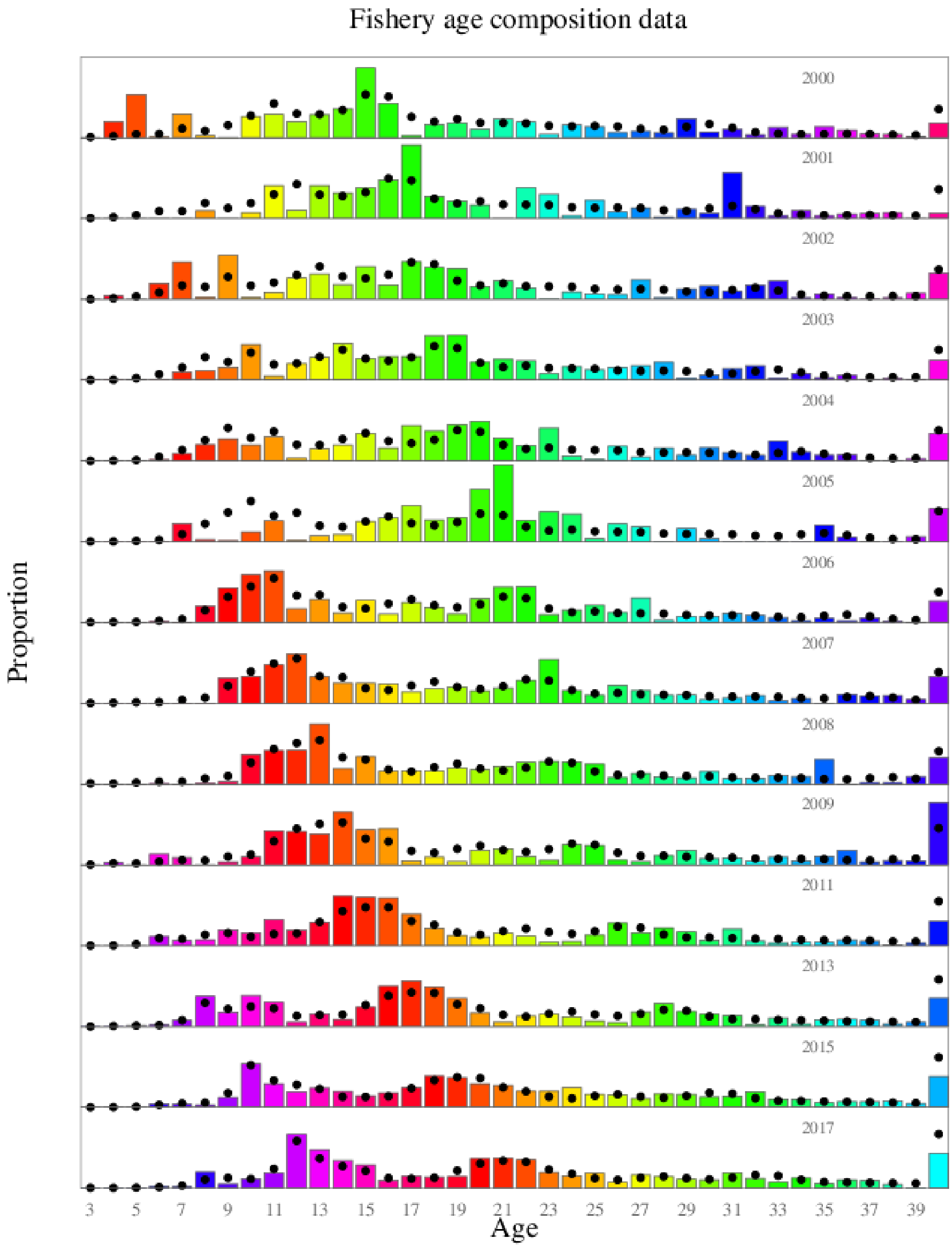


Figure 25. Model fits (dots) to the fishery age composition data (columns) for BSAI northern rockfish. Colors of the bars correspond to cohorts (except for the 40+ group).

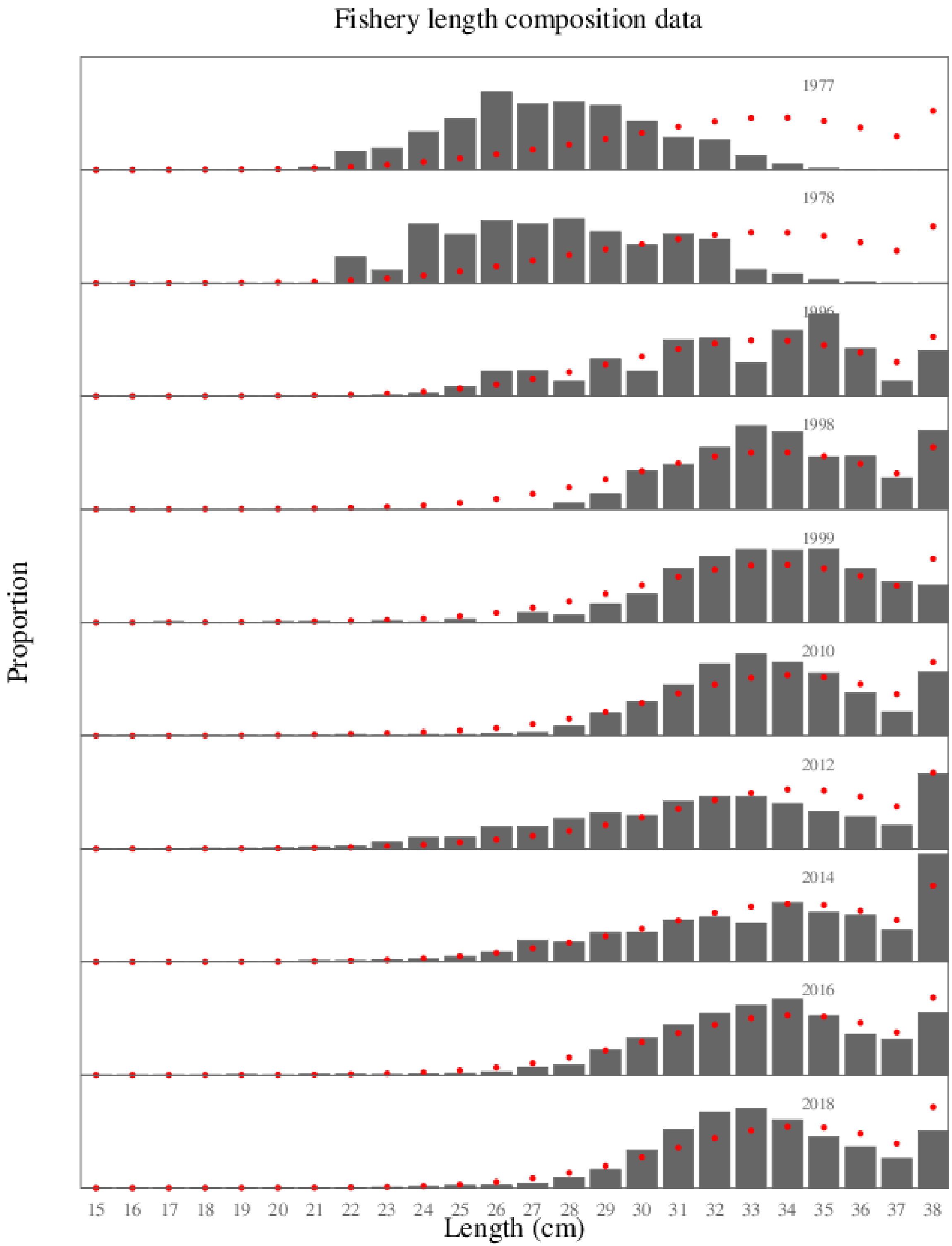


Figure 26. Model fits (dots) to the fishery length composition data (columns) for BSAI northern rockfish.

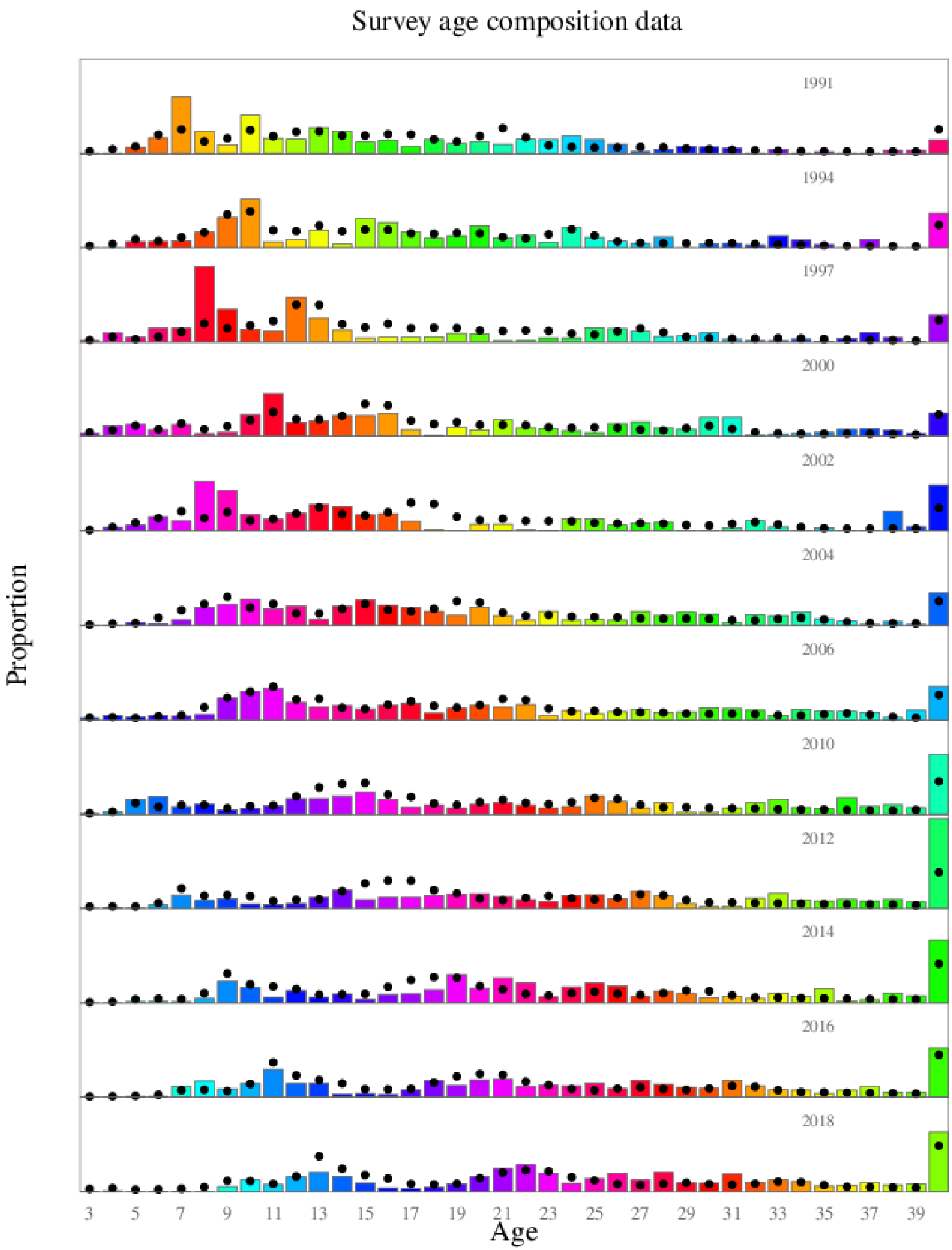


Figure 27. Model fits (dots) to the survey age composition data (columns) for BSAI northern rockfish. Colors of the bars correspond to cohorts (except for the 40+ group).

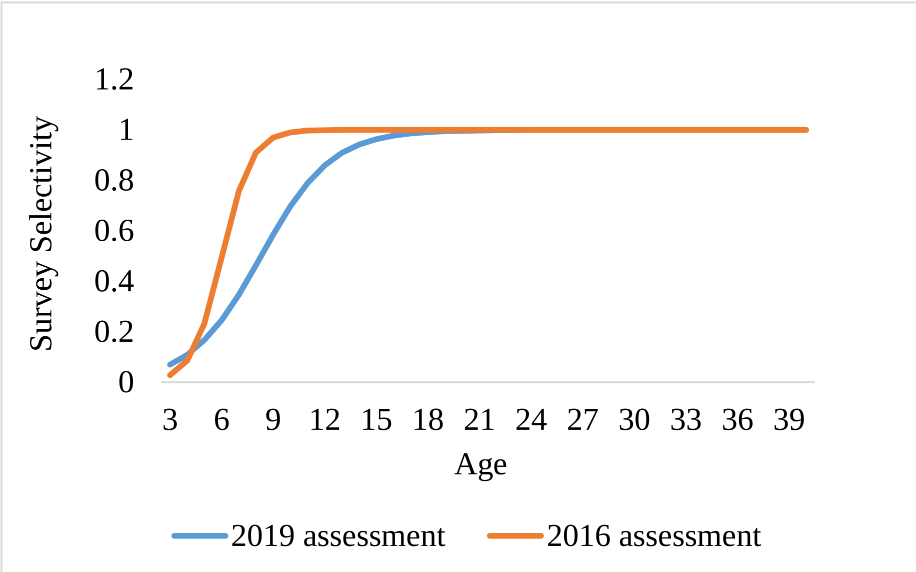


Figure 28. Survey selectivity curves for the 2016 and 2019 assessments.

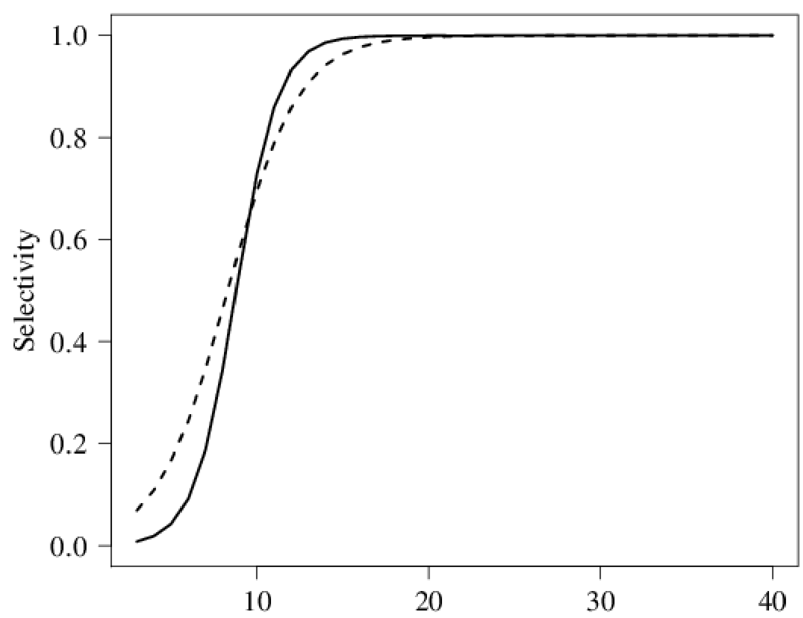


Figure 29. Estimated fishery (solid line) and survey (dashed line) selectivity at age for BSAI northern rockfish.

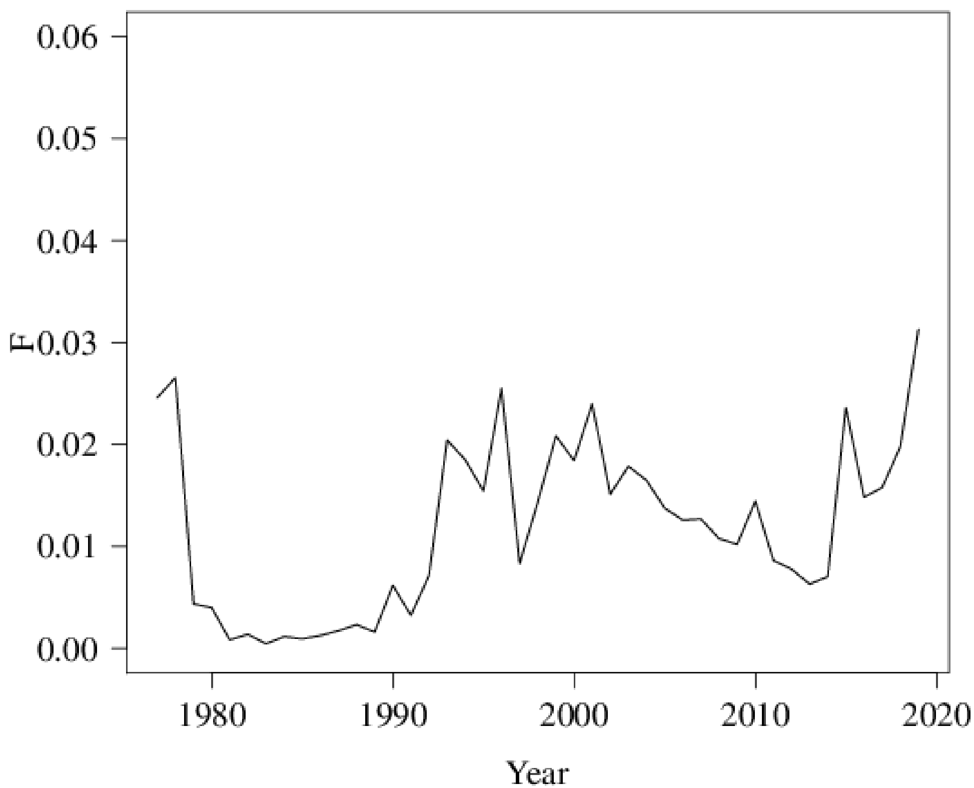


Figure 30. Estimated fully-selected fishing mortality rate for BSAI northern rockfish.

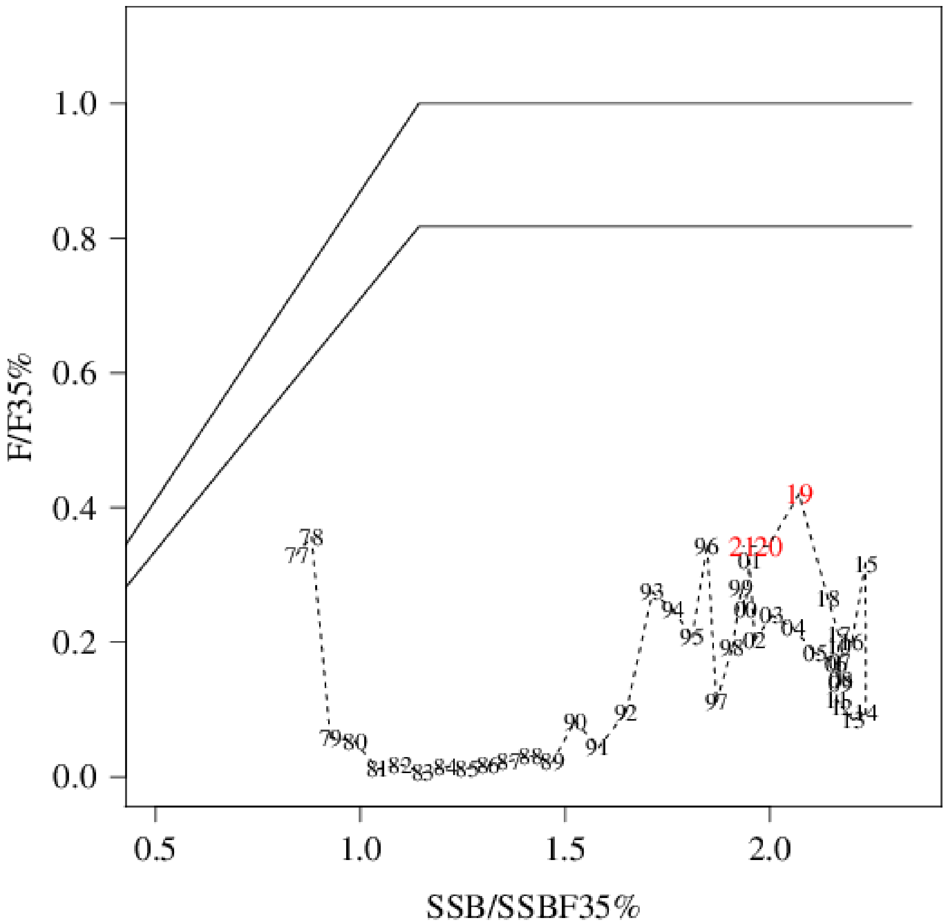


Figure 31. Estimated fishing mortality and SSB from 1977-2021 in reference to OFL (upper line) and ABC (lower line) harvest control rules (values for 2020 and 2021 are based on projections).

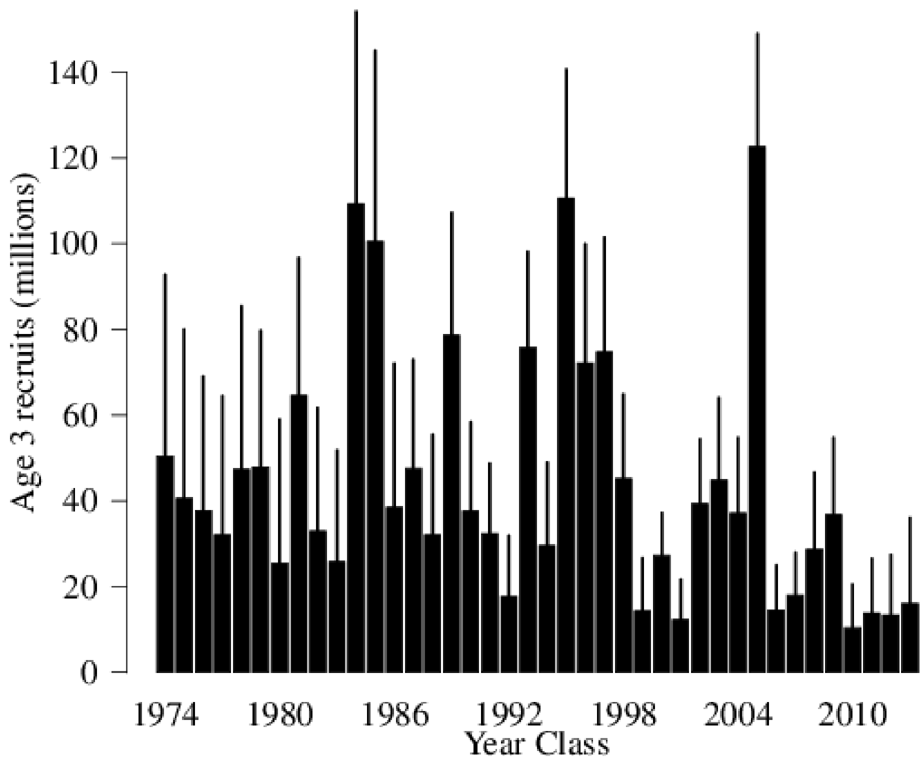


Figure 32. Estimated recruitment (age 3) of BSAI northern rockfish, with 95% CI limits obtained from MCMC integration.

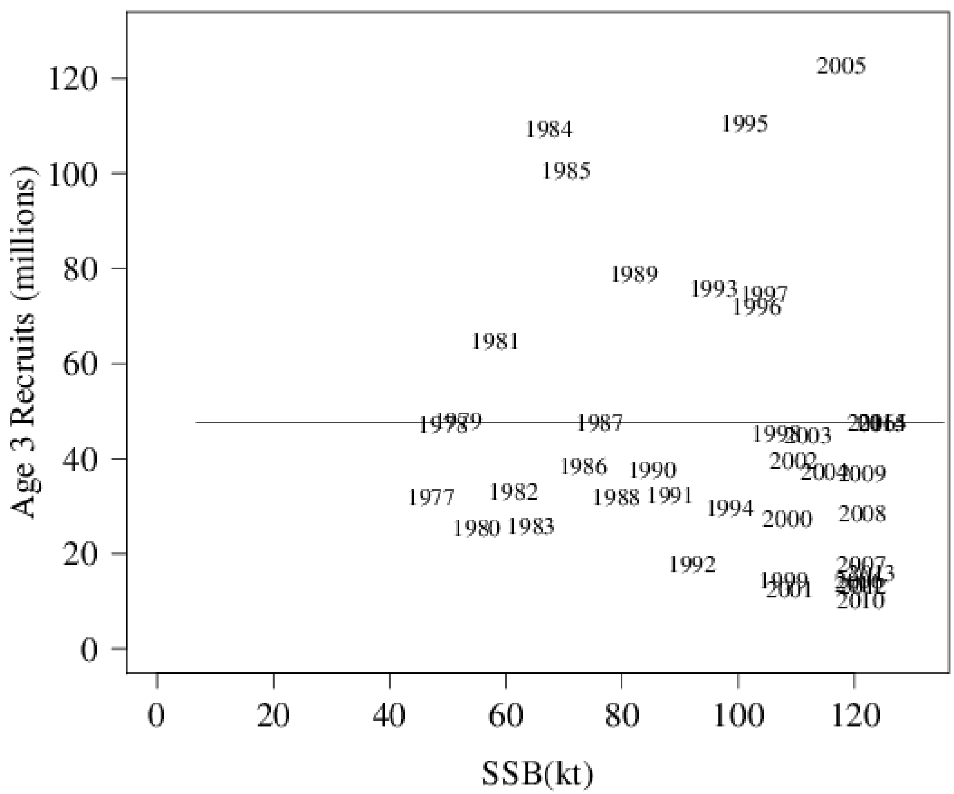


Figure 33. Scatterplot of BSAI northern rockfish spawner-recruit data; label is year class.

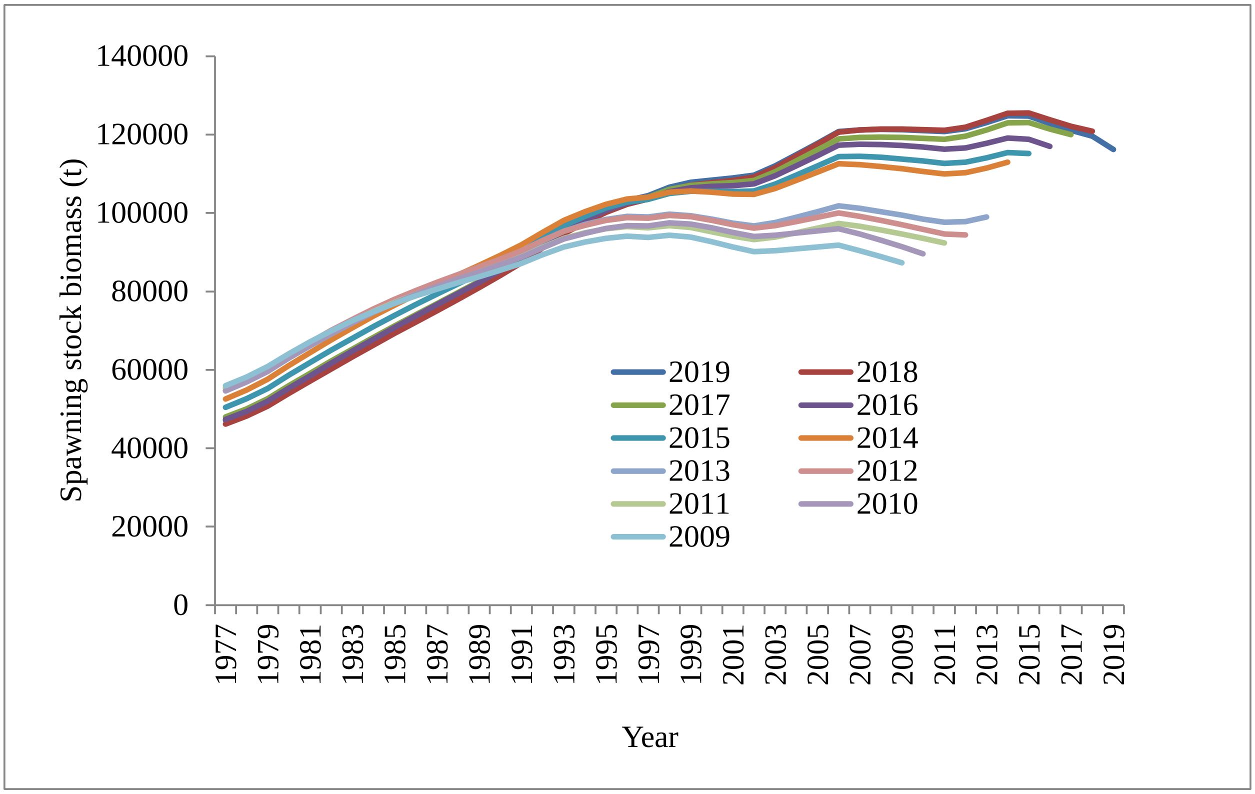


Figure 34. Retrospective estimates of spawning stock biomass for model runs with end years of 2009 to 2019.

Appendix A. Supplemental Catch Data.

In order to comply with the Annual Catch Limit (ACL) requirements, non-commercial removals that do not occur during directed groundfish fishing activities are reported (Table A1). 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 has not exceeded 0.07 t. Total removals ranged between 0.01 t and 140 t between 2010 and 2018, which did not exceed 1.6% of the ABC in these years.

Appendix Table A1. Removals of BSAI northern rockfish from activities other than groundfish fishing from 1977-2018. Trawl and longline include research survey and occasional short-term projects. "Other" is recreational, personal use, and subsistence harvest.

Year	Source	Trawl	Longline
1977			
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	NMFS-AFSC survey databases	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		50.354	0.025
2011		140.163	0.022
2012		89.765	0.021
2013		0.014	0.039
2014	AKFIN database	69.154	0.032
2015		0.010	0.000
2016		52.211	0.069
2017		0.043	0.004
2018		49.451	0.000