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 2019. The following changes were made to northern rockfish assessment relative to the November 2019 SAFE:

Summary of Changes in Assessment Inputs

Changes in the input data:

1) Catch data was updated through 2020, and total catch for 2021 was projected.
2) The 2019 and 2020 fishery age composition data were included in the assessment.

Changes in the Assessment Methodology

1) The recommended model places a constraint on the asymptotic survey selectivity curve to ensure that the selectivity at age 30 was close to 1 (the constraint had been at age 15 in the 2019 assessment)

Summary of Results

BSAI northern rockfish are not overfished or approaching an overfished condition. The recommended 2022 ABC and OFL are 19,217 t and 23,440 t, which are 28% and 29% increases from the values specified last year for 2022 of 14,984 t and 18,221 t. The reason for the increase in the harvest level is a modeled 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 1: Normal	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.

The concerns identified above are not addressed in the assessment and Tier status for this stock. Issues such as the retrospective pattern and the use of strong prior distributions affect the results of the assessment, but are not mitigated or otherwise addressed within the assessment. These factors are also not addressed by our current Tier system. Additionally, the mismatch between the genetic spatial structure and the spatial management of the stock is also not addressed within the assessment or the Tier system, as this issues extends beyond the assessment itself.

Overall, the stock abundance is high and the 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:

	As estimated or specified last year for:		As estimated or recommended this year for:	
Quantity	2021	2022	2022*	2023*
M (natural mortality rate)	0.048	0.048	0.054	0.054
Tier	3a	3a	3a	3a
Projected total (age 3+) biomass (t)	244,600	240,022	279,584	275,210
Female spawning biomass (t)				
Projected	107,003	103,467	121,126	117,333
$B_{100\%}$	159,850	159,850	171,768	171,768
$B_{40\%}$	63,940	63,940	68,707	68,707
$B_{35\%}$	55,947	55,947	60,119	60,119
F_{OFL}	0.075	0.075	0.085	0.085
$maxF_{ABC}$	0.061	0.061	0.069	0.069
F_{ABC}	0.061	0.061	0.069	0.069
OFL (t)	18,917	18,221	23,420	22,594
maxABC (t)	15,557	14,984	19,217	18,538
ABC (t)	15,557	14,984	19,217	18,538
	As determined last year for: for:		As determined this year	
Status	2019	2020	2020	2021
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 8,213 t and 7,922 t used in place of maximum permissible ABC for 2022 and 2023.

Summaries for the Plan Team

The following table gives the recent biomass estimates, catch, and harvest specifications, and projected biomass, OFL and ABC for 2020-2021.

Year	Biomass[1]	OFL	ABC	TAC	Catch[2]
2020	256,262	19,751	16,243	10,000	8,443
2021	244,600	18,917	15,557	13,000	5,721
2022	279,584	23,420	19,217		
2023	275,210	22,594	18,538		

[1] Total biomass from age-structured projection model.
[2] Catch as of September 25, 2021.

Responses to SSC and Plan Team Comments on Assessments in General

(SSC, October 2021) The SSC developed guidance for the use of risk tables, with 14 comments/recommendations shown below. This guidance was used when updating the risk table in this assessment.

1. *The SSC concluded that the risk table framework is working well. The tables have expanded communication among assessment authors and between assessment authors and ecosystem/process researchers. The framework is intended to provide a clear and transparent basis for communicating assessment-related and stock condition concerns that are not directly captured in model-based uncertainty, the tier system, or harvest control rules.*
2. *The SSC recommended no changes to the language in the Risk Table template.*
3. *The SSC recognizes that within the context of the risk tables, "risk" is the risk of the ABC exceeding the true (but unknown) OFL. The risk tables are intended to inform the process of adjusting the ABC from the maximum permissible when needed. Recommendations of an ABC reduction from the maximum permissible requires justification. The risk tables provide an avenue for articulating that justification.*
4. *The SSC recommends that consideration for reductions from maxABC be based on current year information unless relevant risk factors for a stock continue to be present from previous years.*
5. *The SSC recommends that for stocks managed in Tiers 1-3, that risk tables are produced for all full assessments of groundfish (and perhaps crab) stocks and stock complexes in the fishery. Risk tables can be produced in other years at the discretion of the lead author if there have been notable changes to previous conditions.*
6. *The SSC recommends that Risk Tables should not be mandatory for other Tiers; however, stock assessments must include compelling rationale for why a Risk Table would not be informative.*
7. *For stock complexes, the SSC recommends that the decision concerning which species (or multiple species) to focus on be up to the author.*
8. *The SSC recommended maintaining the status quo, where authors are encouraged (but not required) to provide a recommendation on a reduction from maxABC, if warranted, and the Plan Teams and SSC would then evaluate and modify the reductions (if needed) based on the information available for the stock.*
9. *Risk scores should be specific to a given stock or stock complex. While comparison across species (e.g., within a tier, with similar life histories) or stocks is useful for consistency, the SSC does not support trying to prescribe a common reduction from the maximum permissible ABC for a given risk score across species or stocks because the processes underlying the score may differ among species and stocks. The SSC recommends that considerations of reductions in ABCs below the maximum permissible continue to be made on a case-by-case basis with justification based on risk scoring. The risk table rankings include qualitative information that requires a certain amount of subjective but well-informed interpretation of the available data by the author(s), the Plan Teams and the SSC, and as such, the SSC feels that blanket comparisons across species or stocks for the purpose of explicitly defining reductions in ABC below the maximum permissible are not prudent.*

10. *The SSC encourages the inclusion of LK/TK/S as a source of knowledge about the condition of the stock, a shift in the spatial or temporal distribution of the resource, or changes in the size or condition of species in the fishery.*
11. *The SSC recommends that the fishery/community performance column should focus on information that would inform the biological status of the resource (e.g., an unexplained drop in CPUE that could indicate un-modelled stock decline, or a spatial shift indicating changes in species' range), and not the effects of proposed ABCs on the fishery or communities or bycatch-related considerations. The SSC recognizes that the community impact information is critical for Council decision making and supports efforts to effectively communicate where this information can be accessed.*
12. *The SSC appreciates the discussion of avoiding double-counting information, in the assessment/Tier system and risk table, or among columns of the risk table. The SSC agrees that authors should avoid inclusion of stock trends/processes that are incorporated in the assessment or reflected in the Tier when scoring the risk tables. For cases where a process external to the assessment is relevant to two or more risk categories, the SSC recommends that the narrative reflect the interconnected relationships that exist between rankings among risk categories.*
13. *The SSC suggests a revision to the category levels: from the existing four to three categories (normal, increased, extreme). The SSC recommends postponing this change until 2022 as many authors have already begun working on risk tables for 2021.*
14. *The SSC reiterates that reductions in ABC below the maximum permissible should be applied sparingly and that the tier system should be regarded as the primary basis for establishing the ABC. If they begin to become commonplace, that should warrant further review of the assessment and/or the Tier system.*

Responses to SSC and Plan Team Comments Specific to this Assessment

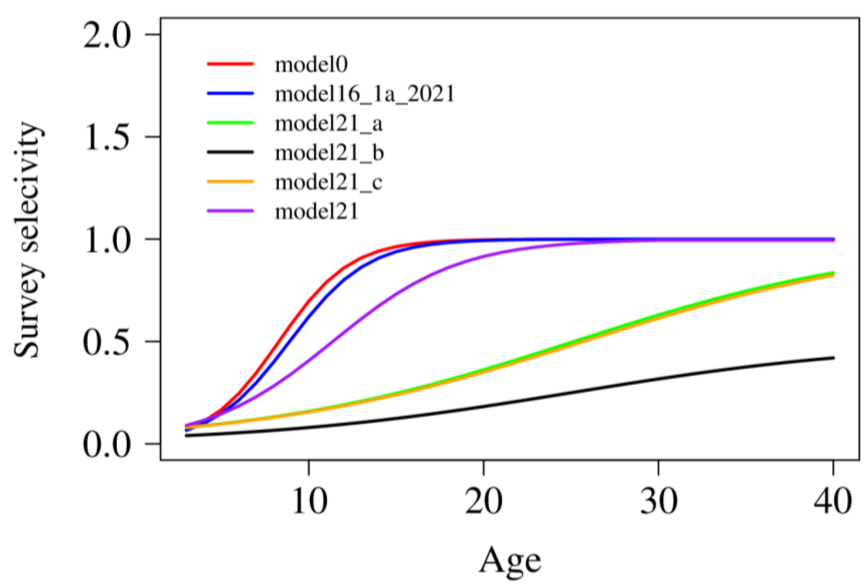
(BSAI Plan Team, November 2019) *The Team recommended addressing the issues concerning the restrictive priors on key parameters in the model and exploring alternatives for estimating survey selectivity.*

In the 2019 assessment, a penalty was placed on the estimated selectivity at age 15 in order to force it to be relatively close to 1. Model runs without this penalty indicated survey selectivity substantially below 1 for all ages, with larger estimated biomass than seen in previous assessments. These results in the 2019 assessment reflect computation of the survey age composition to reflect that a large proportion of the population and survey abundance occurs in the western Aleutian Islands, where size at age is smaller than in other regions. Thus, fish of a given size in the western Aleutian Islands are older than in other regions, which affected the survey age composition data and the estimated survey selectivity curve.

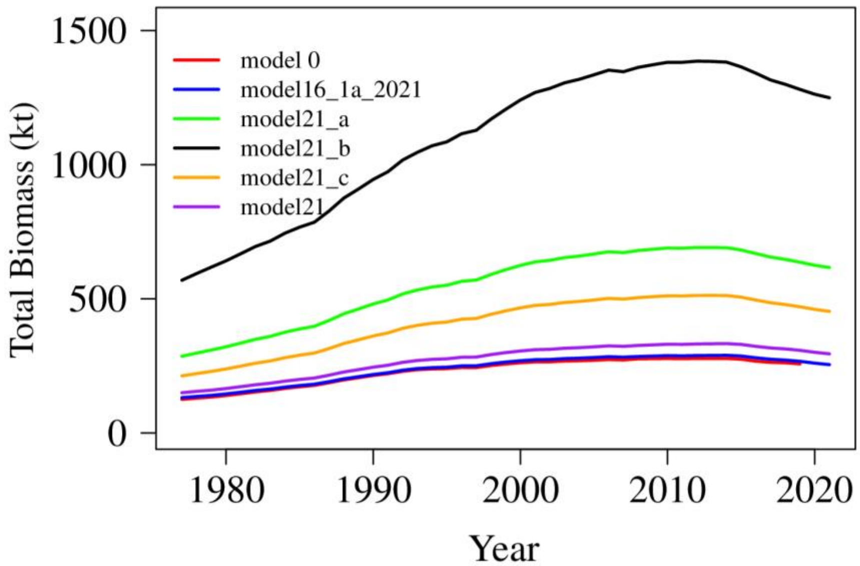
Some exploratory runs were conducted to investigate the alternate approaches for estimating survey selectivity. These exploratory model runs are described below. Unless otherwise noted, a strong prior is placed on survey catchability parameter to essentially fix it at 1; modifying this assumption is explored in Model 21c. Each of these runs use the data weights from the 2019 assessment.

Model	Description
Model 0	The 2019 model and results
Model 16_1a(2021)	The 2019 model, with data updated through 2021
Model 21a	Data updated through 2021, logistic survey selectivity with no constraint
Model 21b	Data updated through 2021, double logistic survey selectivity with no constraint
Model 21c	Data updated through 2021, logistic survey selectivity with no constraint, and a prior place on the average of survey catchability * selectivity over ages 30 to 40.
Model 21	Data updated through 2021, logistic survey selectivity estimated to age 30 and fixed for ages > 30. A prior is placed on selectivity at age 30 to ensure that it is close to 1.

Model 16.1a(2021) produces a similar selectivity curve in the 2019 assessment, indicating that the updated data has relatively little effect on estimated survey selectivity. As in the 2019 assessment, model runs without any constraint on selectivity produce much lower estimated selectivity that are below 1 for all ages, especially when fitting double logistic selectivity (Model 21b). Model 21b does not suggest any dome-shaped pattern to survey selectivity.

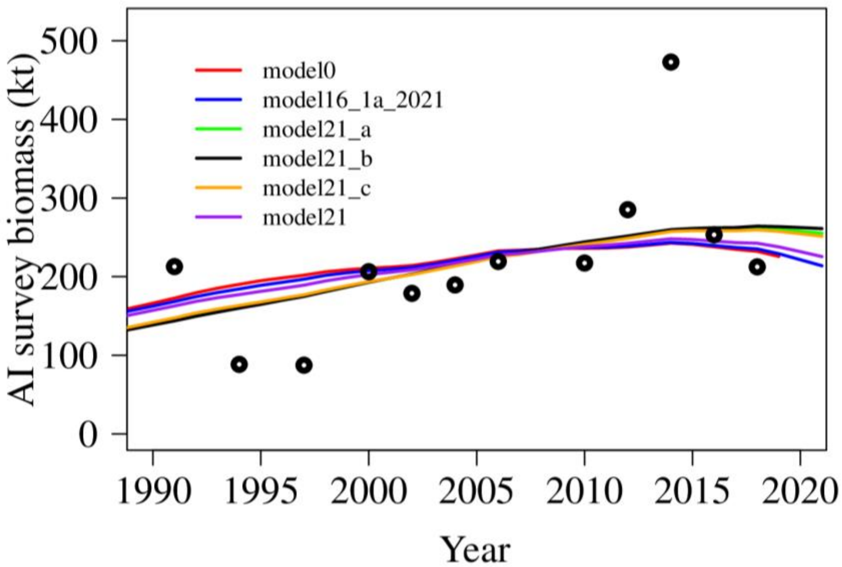


The reductions in survey selectivity imply higher total biomass (because survey q is fixed at 1), particularly for model 21b (double logistic with no constraint), which had the lowest selectivity. The survey catchability is typically interpreted as corresponding to fully selected ages (i.e., ages with survey selectivity of 1), in which case placing a strong prior on survey catchability would have the intended effect of keeping the scale of estimated biomass from the assessment consistent with the input survey biomass estimates. However, estimates of survey selectivity substantially below 1 essentially prevent the prior on survey catchability from scaling the biomass, as seen in the graph below.



Model 21c accounts for the unconstrained logistic survey selectivity in Model 21a being below 1 by placing the prior of 1 not on survey *q* by itself, but rather the average of the product of survey *q* *selectivity over a range of ages (30 – 40) expected to be fully selected. This reduces the estimated biomass relative to Model 21a, but the biomass is still higher that estimated in the 2019 assessment because of the relatively low selectivity for most ages.

The fits to the AI survey biomass are relatively similar among these exploratory models, but with the models that place a constraint on the logistic curve producing a slight downward trend in abundance in recent years, consistent with empirical survey biomass estimates.



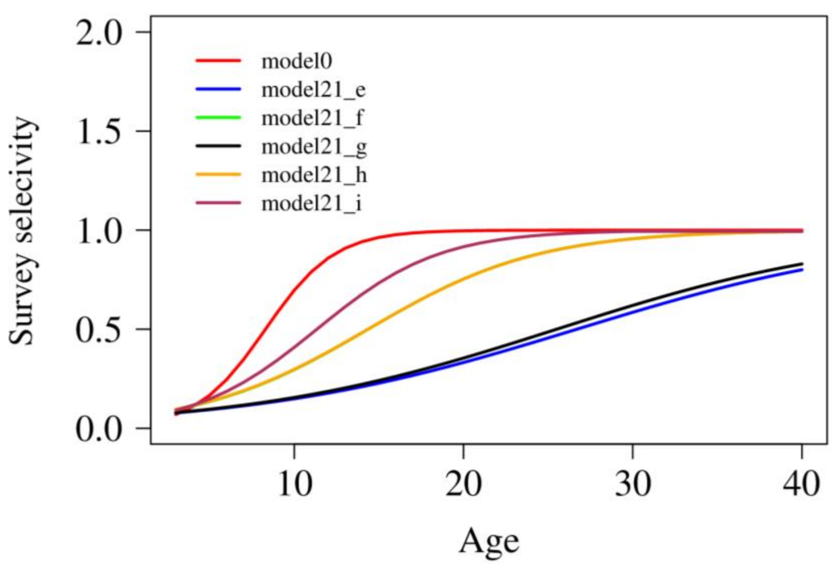
Model 21 is reasonable alternative that allows for more flexibility in fitting reduced selectivity, and is recommended in this assessment (after updating the data weights). This model is discussed more in the Model Evaluation section, but some arguments in its favor are:

1) It preserves that shape of a logistic selectivity pattern, as rockfish are commonly thought to be "fully selected" after some relatively old age (and there is little evidence here of a dome-shaped selectivity pattern).
2) The age at which selectivity is constrained to be close to 1 is age 30, which is relatively close to the plus group age for other Alaska rockfish assessments.

Some additional exploratory runs were conducted to examine the general issue of "restrictive priors on key parameters". A table describing these exploratory runs is shown below, with some results:

		Constraints			Estimated values			
Model	**Max age of estimated selectivity**	**survey *q***	**Survey Selectivity**	***M***	**Maximum survey selectivity**	***q***	***M***	**2021 biomass (kt)**
Model 21_e	40	No	No	Yes	0.8	2.77	0.057	224
Model 21_f	40	No	Yes	Yes	0.99	0.36	0.062	1010
Model 21_g	40	Yes	No	No	0.83	1	0.065	616
Model 21_h	40	Yes	Yes	No	0.99	1	0.057	353
Model21_i	30	Yes	Yes	No	0.99	1	0.53	297

A plot of the survey selectivity curves from these exploratory models is shown below; model 0 is the result from the 2019 assessment, and the selectivities for models 21_h and 21_f overlap each other.



Models 21_e and 21_f retain the prior on M (CV=0.15), but remove the prior on survey catchability. Conversely, Models 21_g and 21_h retain the prior on survey catchability, but remove the prior on M.

Within each of these sets, separate model runs are made that either include or remove the constraint that survey selectivity be near 1 at a specified age (set to 40 for these 4 runs).

Models that remove the constraint on survey selectivity result in survey selectivity curves shifted to the right such that selectivity is below 1 for all ages (models 21_e and 21_g). When the prior on survey catchability is also removed, the estimated 2021 biomass is reduced to 224 kt (model 21_e); conversely, when the prior for survey catchability is retained, the estimated 2021 total biomass increases to 616 kt (model 21_g). Models that retain the constraint on survey selectivity (21_f and 21_h) have different estimates of the 2021 total biomass depending on whether the prior for catchability is removed (model 21_f; estimated 2021 total biomass = 1010 kt) or retained (model 21_h; estimated 2021 total biomass = 353 t). Model 21_i is most similar to the recommended assessment model, with the substantial difference being the removal of the prior on M, and may be worth further exploring in future assessments.

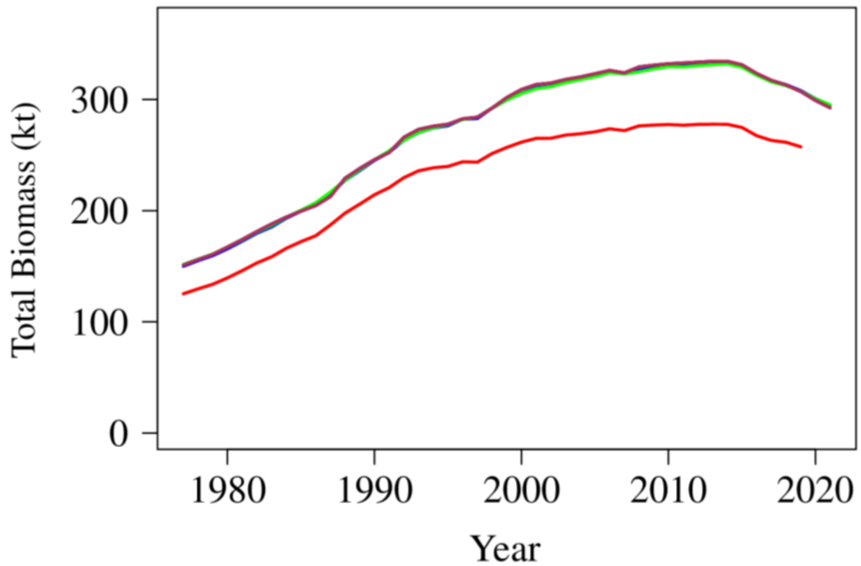
The wide range of estimates for survey catchability, selectivity, and terminal biomass from these exploratory runs illustrate the degree to which uncertainty is understated by adopting any particular set of parameter constraints, which is a consideration in evaluating assessment-related concerns as a level 2 in the risk table (substantially increased concern).

(BSAI Plan Team, November 2019) *The Team recommended exploring global age-length keys that weight by population size between areas.*

In the presentation of the 2019 assessment to the Plan Team, we suggested that computing a single age-length key, in which the contribution of the length-specific age composition in each subarea is weighted by its subarea survey estimate of population length (as opposed to the otolith sample size), could be an alternative method. Upon further review, this method is mathematically equivalent to the current method of computing subarea age-length keys and age compositions, and averaging the subarea age compositions (weighted by the estimated subarea survey abundance) (Appendix A).

SSC (December, 2019). *The SSC also notes that the aging error matrix is currently based on GOA northern rockfish information and requests that it be updated using BSAI information, if possible.*

We were not able to complete a full evaluation of updated aging error matrices this assessment cycle. However, we did complete a sensitivity analysis of the effect of the aging error matrix on model results. The sensitivity runs included: 1) removing the aging error matrix; 2) dividing the currently-used standard deviation of read ages for each true age by 2; and 3) multiplying the currently-used standard deviation of read ages for each true age by 2. The estimated total biomass for these sensitivity runs are shown below (with the data weighting from the 2019 assessment), and for comparison the 2019 model results are also shown (red line). There is little difference in estimated total biomass between the three aging error sensitivity runs. A more complete evaluation will be conducted for the 2023 full assessment.



(SSC, December 2019) *The SSC concurs that a reduction from maxABC is not warranted and requests that going forward further clarification be included regarding the extent to which the concerns listed in the Risk Table are addressed in the assessment and Tier status for this stock.*

The concerns identified in the risk table (i.e., retrospective pattern, the use of strong prior distributions, and cancelation of the 2020 survey) affect the results of the assessment, but are not mitigated or otherwise addressed within the assessment or the Tier system. A statement to this effect is included in the description of the scores for the risk table.

Introduction

Northern rockfish (*Sebastes polyspinus*) inhabit the outer continental shelf and upper slope regions of the North Pacific Ocean and Bering Sea. Northern rockfish 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 (*S. zacentrus*) 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 (*Pleurogrammus monopterygius*) 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 54%. 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 having rockfish be the 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 7,197 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 288 in 2019, and declined to 226 in 2020. 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 and 2020, 49% and 44%, respectively, 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 4,536 t in 2016 to 9,092 t in 2019, which is the largest on record. In 2021, reductions have occurred in the total catch, the number of hauls targeting northern rockfish, and the proportion of catch obtained on targeted hauls (as of Sept 25), which may reflect the influence of Covid-19.

The distribution of the percent northern rockfish in the total catch by haul, for vessels identified as targeting northern rockfish, has ranged between 18% and 99% (Figure 2) from 2018 to 2021. The percent of these target hauls for which the northern rockfish catch exceeded 70% of the total catch ranged between 18% in 2018 to 31% in 2021.

The observer records of catch of northern rockfish in tows targeting northern rockfish was 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 3a), and years with high catches also had high CPUE values (Figure 3b). CPUE values have declined in 2021 (through September 25).

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 2021. 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 2021 recommended 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, and decreased from 2020 to 2021 (Figure 4).

Temporal variability has occurred in AI subareas in which northern rockfish are captured, and to a lesser extent in the depth of capture (Figure 5). 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. The 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 – 2020.

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. Discard rates in the EBS have been more variable since 2018, ranging between 17% (2019) to 66% (2018).

Catch by species from BSAI trips targeting rockfish from 2016 to 2021 indicate that the largest non-rockfish species caught are Atka mackerel, walleye pollock (*Gadus chalcogrammus*), Pacific cod (*G. microcephalus*), Kamchatka flounder (*Atheresthes evermanni*), and arrowtooth flounder (*A. stomas*) (Table 6). Northern rockfish are primarily caught in rockfish trips targeting rockfish and Atka mackerel (Table 7). Catch of prohibited species is low in trips targeting rockfish, with the catch of most prohibited species groups averaging less than 5 t or 5000 individuals from 2016-2021 (Table 8). Catch of non-FMP species by in BSAI trips targeting rockfish are largest for giant grenadier (*Albatrossia pectoralis*), miscellaneous fish, and unidentified sponge (Table 9).

Non-commercial catch data are shown in Appendix B.

Data

Fishery Data

The fishery data is characterized by inconsistent sampling of lengths and ages (Table 10). 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 (Table 11). 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, 2017, and 2019-2020 were used to estimate the age-frequency of the fishery catch (Table 12).

The estimated lengths at age by subarea, across all years, is shown in Figure 6, and indicate a cline from small fish in WAI to larger fish in the EAI and SBS areas. In the 2016 and prior 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 the 2019 and subsequent assessments 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 (Spencer and Ianelli 2016), which results from randomized sampling of fishery otoliths in which the distribution of read otoliths being relatively similar to the distribution of fishery catch (Figure 7).

The fishery age composition data indicates the relatively strong cohorts in 1984-1985, 1995. The 2005 year class initially appeared strong through the 2017 sampling year, but in the 2019 and 2020 samples the 2006 year class appears stronger than the 2005 year class (Figure 8, Table 12).

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 13), as indicated by a plot of the survey CPUE values by tow (Figure 9). 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 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 in 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 10), and assessments in and prior to 2016 a global age-length key, per year, was used that did not account for this pattern. In the 2019 and subsequent assessments, 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 (Spencer and Ianelli 2016), and this pattern is generally consistent across all survey years. The survey abundance is concentrated in the WAI (Figure 11) 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 subarea 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 12). Application of the global age-length key (i.e., weighing the spatial areas by the otolith sample size rather than abundance) gives 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 indicates a relatively strong 2005 year class (Figure 13, Table 14).

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 read and lengths measured are shown in Table 15, along with the number of hauls producing these data. The number of otoliths read by area is shown in Table 16. 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 10). Variability occurs between years but without any apparent direction trend, and indicated by the L_{inf} and K parameters (Figure 14). 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 15). The estimated survey weight at age curves by AI subarea are shown in Figure 16. A similar pattern across areas is seen in the subareas weights at age in the fishery; additionally, the fishery weights at age are generally larger than those from the AI survey.

In assessments in and prior to 2016, "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 the 2019 and subsequent assessments, 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 16 (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 to present were set to the 2018 values. A similar procedure was used for the fishery weights at age from 1990 - 2020, 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 2021 were set to the 2020 values. An average of the 2014-2018 survey weight at age, and an average of the 2016-2020 fishery weight at age, is shown in Table 17.

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 1990-2020 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 1998-2021), 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 0.11 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	1977-2021
Fishery age composition	2000-2009, 2011, 2013, 2015, 2017, 2019-2020
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

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

where *Z* is the sum of the instantaneous fishing mortality rate ($F_{t,a}$) and the natural mortality rate (*M*), *A* is the maximum number of age groups modeled in the population, and *T* is the terminal year of the analysis (defined as 2021).

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-dependent deviations from average recruitment allows estimation of year class strength.

The total numbers of age 3 fish from 1977 to 2018 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 2019-2021 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.

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 the 2019 assessment, application of Model 16.1 estimated survey selectivity as being substantially lower than in assessments prior to 2016, resulting in substantial biomass increases. In order to estimate selectivity curves more typical to previous assessments, and other Alaska rockfish assessments, a penalty was used to constrain the survey selectivity at age 15 to be close to 1. This modeling assumption was based on the expectation that northern rockfish would be nearly fully selected by the trawl survey near age 15.

Exploratory model runs with alternative method for modeling survey selectivity are described in the Executive Summary of this assessment. Based on these runs, we more fully consider the alternative of increasing the age at which the constraint on survey selectivity is placed. The status quo model and alternative model considered in this assessment are described below.

Model	Description
Model 16_1a(2021)	The 2019 model, with data and data weights updated. Ages 3-40 are used to model logistic selectivity, but a penalty (with CV=0.03) is used to ensure selectivity at age 15 is close to 1.
Model 21	Data and data weights are updated, and age 3-30 is used to model logistic survey selectivity, with selectivity for ages > 30 fixed to the value estimated for age 30. A penalty (CV=0.003) is placed on selectivity at age 30 to ensure that it is close to 1.

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 2021 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 binomial 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

$$
\begin{aligned}
&\lambda_1\left[\sum_{t=1}^{n}\frac{\left(\nu_t+\sigma_r^{\,2}/2\right)^2}{2\sigma_r^{\,2}}+n\ln(\sigma_r)\right]+\\
&\lambda_1\left[\sum_{a=4}^{A}\frac{\left(\gamma_a+\sigma_r^{\,2}/2\right)^2}{2\sigma_r^{\,2}}+(A-3)\ln(\sigma_r)\right]+\\
&\lambda_2\sum_t\left(\ln(obs\_biom_t)-\ln(pred\_biom_t)\right)^2/2cv_t^2+\\
&-n_{f,t,l}\sum_{s,t,l}(p_{f,t,l}\ln(\hat{p}_{f,t,l})+p_{f,t,l}\ln(p_{f,t,l}))+\\
&-n_{f,t,a}\sum_{s,t,l}(p_{f,t,a}\ln(\hat{p}_{f,t,a})+p_{f,t,a}\ln(p_{f,t,a}))+\\
&-n_{surv,t,a}\sum_{s,t,a}(p_{surv,t,a}\ln(\hat{p}_{surv,t,a})+p_{surv,t,a}\ln(p_{surv,t,a}))+\\
&-n_{surv,t,l}\sum_{s,t,a}(p_{surv,t,l}\ln(\hat{p}_{surv,t,l})+p_{surv,t,l}\ln(p_{surv,t,l}))+\\
&\lambda_3\sum_t\left(\ln(obs\_cat_t)-\ln(pred\_cat_t)\right)^2
\end{aligned}
$$

For the model run in this analysis, λ_1, λ_2, and λ_3 were assigned weights of 1,1, and 200, reflecting the strong emphasis on fitting the catch data.

The 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	45
3) recruitment mean	1
4) recruitment deviations	42
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	135

Results

Model Evaluation

Because each of the two models reweights the input samples for the age and length composition data, quantitative model selection criteria are generally not applicable due to differences in the input data. For example, the overall likelihood is lower in Model 16.1a(2021), and is due to a reduction in likelihood for the fishery age compositions (Table 18). However, this reduction stems from a reduction in the weight for this data component being lower in Model 16.1a(2021) than Model 21 (0.72 and 0.79, respectively; Figure 17). A more useful metric for model evaluation is the RMSE values, are nearly identical between the model for each of the age and length composition data components. This is also illustrated in the plot of the fits of the two models to the survey age compositions, which are nearly identical to each other (Figure 18). Model 21 does produce a slightly improved fit to the AI survey biomass index, which results primarily in the fit to the estimates from 1994 to 2016 (Figure 19). However, in general the differences in the fits of the two models are very slight.

The information available for BSAI northern rockfish is not strongly informative regarding the shape and scale of the selectivity curve. Additionally, because selectivity influences the scale of population size (via the product of selectivity and catchability), there is also little information in the data regarding the scale of population abundance. A reasonable assumption for Alaska rockfish is a logistic selectivity pattern for the trawl survey with older ages being fully selected (i.e., selectivity of 1). This pattern is modeled for 5 of the other age-structured Alaska rockfish assessments (the exception being GOA rougheye/blackspotted rockfish, which has dome-shaped survey selectivity). Additionally, with the exception of the blackspotted/rougheye rockfish (which have lower natural mortality rates), the age at which survey selectivity is estimated to reach 1 is less than 17 years old in other Alaska rockfish stocks with age-structured population models. Additionally, for some Alaska rockfish stocks the age-plus groups is lower than 30 years (i.e., 25 years for GOA POP and dusky rockfish), and the logistic selectivity would be expected to reach 1 at or before the age-plus group.

Increasing the age at which selectivity is penalized from being different from 1, from 15 to 30, adds additional flexibility to the model. The model would not be prevented from fitting logistic survey selectivity that reaches 1 at a lower age, if there was information in the data suggesting that this would improve the model fit; however, it is not constrained to do so. For many models we are familiar with, the estimates of logistic selectivity reach 1 at older ages without the need for any constraint, and cases where they do not reach 1 have sometimes been addressed by dividing the estimated selectivity by its maximum value. This approach is not used here because the *max* function is not differentiable.

The underlying reason for the reduced selectivity, particularly for lower- and middle-aged fish, is the area-weighted estimates of age compositions, which is an appropriate treatment of the data given the reduced size at age in the western Aleutian Islands and the concentration of population biomass in this area. The model is interpreting the reduced proportion of younger fish (relative to the global age-length key used in assessments prior to 2019) as resulting from reduced selectivity. Alternatively, the reduced proportions of younger aged fish could result from reduced recruitment, but the ability for the model to change the scale of recruitment estimates is diminished by the use of a strong prior on survey catchability (and models without a prior for survey catchability produce implausible estimates of this parameter). This uncertainty will not be resolved from the currently available information. However, relaxing the age at which survey selectivity is constrained to be close to 1 from 15 years to 30 years adds additional flexibility, and is the recommended assessment model. The results and harvest recommendations below refer to Model 21. A list of parameter estimates and their standard deviations is shown in Table 19.

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 20, and the estimated numbers at age are shown in Table 21.

Biomass trends

The estimated survey biomass shows an increasing trend, starting at 94,822 t in 1977 and increasing to a peak of 246,478 t in 2014, and declining to 222,251 in 2021 (Figure 20). The estimated total biomass shows a similar trend, increasing to a peak value of 325,040 t in 2014, and the estimated spawner biomass increases from 57,227 in 1977 to its highest value of 143,590 in 2015 (Table 20, Figure 21).

Age/size compositions

The model fits to the fishery age and size compositions are shown in Figures 22-23, and the model fit to the survey age composition data is shown in Figure 24. 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 years (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) are 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 11.1, whereas this parameter was 8.3 in the 2019 assessment, and the selectivity slope was reduced to 0.28 relative to the value of 0.49 in the 2019 assessment. These estimated parameter values resulted in a decrease in survey selectivity for ages between 6 and 23 (Figure 25) and accounts for the change in the scale observed in total biomass between the 2021 and 2019 assessments. The fishery selectivity had an age of 50% selection of 9.1, similar to the value of 8.8 obtained in the 2019 assessment (Figure 26).

Fishing mortality

The estimates of instantaneous fishing mortality rate are shown in Figure 27. 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 declined from the late 1990s to 2014. Fishing mortality rates have increased since 2014, and the 2021 estimate is 0.030. 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 28).

Recruitment

Recruitment strengths by year class are shown in Figure 29. Relatively strong year classes are observed in 1978-1979, 1981, 1984-1985, 1989, 1993, 1995-1998, and 2005, reflecting several of the strong year classes observed in the age composition input data (Figures 22 and 24). The model estimate of the 2006 and 2007 year classes (56.9 million and 49.1 million, respectively) are substantially larger than their estimates from the 2019 assessment (14.5 million and 18.0 million). The scatterplot of recruitment against spawning stock biomass is shown in Figure 30, 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 “peels” were conducted in which the end year of the model was varied from 2021 to 2011, 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 31. The retrospective estimates show three distinct groups that reflect years when survey data are included in the assessment. For example, all the retrospective runs ending in 2018 and later are very similar to each other, as all include the full time series of survey biomass estimates. The 2018 and 2014 survey biomass estimates are influential, and exclusion of these data result in an intermediate group of retrospective SSB estimates for the 2014-2017 peels, and a third group of lower estimates of SSB for the 2011 – 2013 peels. 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 -0.18, a increase (in absolute value) from the value of -0.14 in the 2019 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 1977-2015 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 68,707 t. The year 2022 spawning stock biomass is estimated as 121,126 t.

Specification of OFL and maximum permissible ABC

Since reliable estimates of the 2022 spawning biomass (B), $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and B>$B_{0.40}$ (121,126 t > 68,707 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 0.069 and 0.085, respectively.

The ABC associated with the $F_{0.40}$ level of 0.061 is 19,217 t.

The estimated catch level for year 2022 associated with the overfishing level of F = 0.085 is 23,420 t. A summary of these values is below.

2022 SSB estimate (B)	**=**	**121,126 t**
$B_{0.40}$	=	68,707 t
$F_{ABC} = F_{0.40}$	=	0.069
$F_{OFL} = F_{0.35}$	=	0.085
MaxPermABC	=	19,217 t
OFL	=	23,420 t

Projections

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

For each scenario, the projections begin with the vector of 2021 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2022 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2021. 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 2022, 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 2016-2020 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 2021 or 2) above ½ of its MSY level in 2021 and above its MSY level in 2031 under this scenario, then the stock is not overfished.)

Scenario 7: In 2022 and 2023, *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 2033 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 22.

Risk Table and ABC recommendation

Overview

The following template is used to complete the risk table:

	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. Survey catchability and selectivity are highly constrained by prior distributions, which underestimates the level of uncertainty in the assessment and impedes our ability to estimate the scale of abundance. 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, and differences in the estimated survey selectivity as additional age composition data are included. The Mohn's rho of -0.18 is larger (in absolute terms) than the Mohn's rho in the 2019 assessment (-0.14). 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. Finally, the 2020 survey was cancelled due to Covid-19, and skipped surveys were identified as one criteria in evaluating assessment considerations for the risk table. Simulations conducted by Meaghan Bryan (AFSC) for the September Plan indicated that dropping the most recent survey may have the largest effect for stocks with a consistent retrospective pattern. 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 Aleutian Islands Ecosystem Status Report was updated in 2021, so the indicators noted here largely reflect conditions in 2021 and earlier. However, the most recent bottom trawl survey was conducted in 2018, so indicators based on those data have not been updated since that time. Northern rockfish showed a declining trend in condition (defined as mean weight-length residuals) from 2010 to 2018, indicating that insufficient prey was available to promote optimal growth. In fact, fish sampled 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 were widespread throughout the large marine ecosystem.

Sea surface temperatures and mid-depth temperatures above those observed prior to 2013 have continued through 2021. These increased temperatures would presumably increase bioenergetics needs and may potentially be one of the factors affecting the poor fish condition observed in the most recent surveys.

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 2021, kittiwakes, auklets and Leach’s storm petrels (which consume a mix of zooplankton and invertebrates) showed average to above average reproductive success, indicating that sufficient zooplankton prey were available to support reproduction in the western AI. Piscivorous murres and piscivorous/cephalopod-eating tufted puffins had mostly above average reproductive success, indicating that forage fish to support chick-rearing was available this year. Seabird success suggests broad availability of prey (both in terms of zooplankton, forage fish and squid) which overlaps with prey of northern rockfish larger than 20 cm.

Springer and van Vliet 2014 found pink salmon abundance affected the availability of copepods and euphausiids in least auklet diets, with copepods, hyperiids and pteropods generally more frequent in odd years, and euphausiids generally more frequent in even years. There is no apparent biennial pattern in the time series of age-3 northern rockfish that would indicate that the even-odd abundance pattern of pink salmon impacts them through competition for prey. Also, despite the steep increase in abundance of both even and odd year pink salmon since 2014 and their high abundance this year, the reproductive success of seabirds suggests little or no decreased availability of prey.

The last two surveys (2016, 2018) showed the distribution of Northern rockfish had shifted somewhat towards the central Aleutians (area 542), with almost half of the fish still in the western Aleutians (area 543). Although zooplankton indicators indicate sufficient prey may be available for northern rockfish, we are not able to assess this with condition factors due to the lack of recent surveys. Based on the availability of prey, and despite recent temperature trends and lack of recent fish condition data, we consider the concern level to be 1. (*No apparent environmental/ecosystem concerns*).

Fishery performance

The growth of the northern rockfish stock since the mid-2000s 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. Although the CPUE and the number of hauls in which northern rockfish are identified as the target species (based on species composition) have declined in 2021, the proportion of the harvest obtained in these northern rockfish targeted tows remains generally high, and the catch as a percentage of the ABC has increased since 2014. This indicates that the fishing fleet fishing fleet has not encountered reduced performance in their ability to target this stock. Inferring conditions of the stock based on fishery indicators is difficult due to the evident change in targeting behavior over time. We rank the fishery performance as a 1 (*No apparent fishery/resource-use performance and/or behavior concerns*).

Summary and ABC recommendation

The assessment–related concerns relate to the retrospective pattern in the assessment, the use of strong priors for some key model parameters that cannot be reliably estimated (in effect understating the level of uncertainty in the assessment), and cancelation of the 2020 survey. 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 catches in 2021 appear reduced from their levels in 2021.

The concerns identified above are not addressed in the assessment and Tier status for this stock. Issues such as the retrospective pattern and the use of strong prior distributions affect the results of the assessment, but are not mitigated or otherwise addressed within the assessment. These factors are also not addressed by our current Tier system. Additionally, the mismatch between the genetic spatial structure and the spatial management of the stock is also not addressed within the assessment or the Tier system, as this issues extends beyond the assessment itself.

Overall, the stock abundance is high and the exploitation rates are low. Given the current stock status, we recommend the maximum permissible ABC 19,217 t for 2022.

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 2022, it does not provide the best estimate of OFL for 2023, because the mean 2022 catch under Scenario 6 is predicated on the 2022 catch being equal to the 2022 OFL, whereas the actual 2022 catch will likely be less than the 2022 OFL. Catches for 2022 and 2022 were obtained by setting the F rate for these years to the average of the estimated F rates for 2020 and 2021.

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 (2020) is 8,443 t. This is less than the 2020 BSAI OFL of 19,751 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 2021:

a. If spawning biomass for 2021 is estimated to be below ½ $B_{35\%}$, the stock is below its MSST.
b. If spawning biomass for 2021 is estimated to be above $B_{35\%}$ the stock is above its MSST.

c. If spawning biomass for 2021 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 22). If the mean spawning biomass for 2031 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 2023 is below 1/2 $B_{35\%}$, the stock is approaching an overfished condition.

b. If the mean spawning biomass for 2023 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c. If the mean spawning biomass for 2023 is above 1/2 $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2033. If the mean spawning biomass for 2033 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 2021 stock size is 2.1 times its $B_{35\%.}$ value of 60,119 t. With regard to whether BSAI northern rockfish is likely to be overfished in the future, the expected stock size in 2023 of Scenario 7 is 1.9 times the $B_{35\%}$ value.

Based on the recommended model, the *F* that would have produced a catch for 2020 equal to the 2020 OFL is 0.055.

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				
Year	Management Group	OFL (t)	ABC (t)	TAC (t)	Catch (t)	Management 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 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	8190	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	2763
2012	Northern rockfish	10500	8610	4700	2487
2013	Northern rockfish	12200	9850	3000	2037
2014	Northern rockfish	12077	9761	2594	2342
2015	Northern rockfish	15337	12488	3250	7197
2016	Northern rockfish	14689	11960	4500	4536
2017	Northern rockfish	16242	13264	5000	4697
2018	Northern rockfish	15888	12975	6100	5765
2019	Northern rockfish	15507	12664	6500	9092
2020	Northern rockfish	19751	16243	10000	8443
2021*	Northern rockfish	18917	15557	13000	5721

*Catch data through September 25, 2021, 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			3,064	3,111
2010			299			4,032	4,332
2011			197			2,566	2,763
2012			91			2,395	2,487
2013			137			1,900	2,037
2014			147			2,195	2,342
2015			199			6,998	7,197
2016			203			4,333	4,536
2017			225			4,472	4,697
2018			186			5,579	5,765
2019			492			8,601	9,092
2020			307			8,136	8,443
2021*			104			5,617	5,721

*Catch data through September 25, 2021, from NMFS Alaska Regional Office.

Table 4. Area-specific catches of northern rockfish (t) in the BSAI area, obtained from the NMFS Alaska Regional Office.

Year	WAI	CAI	EAI	EBS	Total
1994	1,572	2,534	560	61	4,727
1995	1,421	1,641	796	266	4,124
1996	3,146	1,978	1,514	87	6,724
1997	1,287	490	219	164	2,161
1998	2,392	916	438	45	3,791
1999	3,185	1,104	1,203	157	5,650
2000	1,516	2,347	1,202	97	5,162
2001	3,725	1,840	743	180	6,488
2002	2,328	1,318	298	114	4,057
2003	2,506	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	1,344	608	22	3,287
2009	1,191	1,315	558	48	3,111
2010	1,988	1,266	778	299	4,332
2011	311	1,351	905	197	2,763
2012	140	1,651	605	91	2,487
2013	115	1,308	478	137	2,037
2014	83	1,111	1,002	147	2,342
2015	3,346	1,600	2,052	199	7,197
2016	1,624	1,728	981	203	4,536
2017	1,776	2,013	683	225	4,697
2018	2,072	2,790	716	186	5,765
2019	5,106	1,763	1,732	492	9,092
2020	4,780	2,614	742	307	8,443
2021*	3,417	1,850	350	104	5,721

* Estimated removals through September 25, 2021.

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	51	67	75.22%
2004	Northerns	686	3881	4567	84.97%	Northerns	35	82	116	70.23%
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	46	70	66.46%
2008	Northerns	1523	1742	3265	53.34%	Northerns	8	14	22	64.25%
2009	Northerns	1941	1122	3064	36.63%	Northerns	40	8	48	15.90%
2010	Northerns	3075	957	4032	23.74%	Northerns	284	15	299	4.97%
2011	Northerns	2442	124	2566	4.85%	Northerns	167	30	197	15.17%
2012	Northerns	2015	380	2395	15.88%	Northerns	45	46	91	50.19%
2013	Northerns	1720	181	1900	9.52%	Northerns	104	33	137	24.36%
2014	Northerns	2115	80	2195	3.66%	Northerns	88	59	147	40.20%
2015	Northerns	6619	379	6998	5.41%	Northerns	127	72	199	36.39%
2016	Northerns	4112	222	4333	5.12%	Northerns	134	69	203	33.83%
2017	Northerns	4191	281	4472	6.28%	Northerns	181	44	225	19.58%
2018	Northerns	5181	397	5579	7.12%	Northerns	63	123	186	66.17%
2019	Northerns	8196	405	8601	4.71%	Northerns	407	84	492	17.13%
2020	Northerns	7099	1037	8136	12.74%	Northerns	232	75	307	24.29%
2021*	Northerns	5213	404	5617	7.20%	Northerns	41	63	104	60.49%

* Estimated removals through September 25, 2021.

Table 6. Catch (t) of FMP groundfish species caught in BSAI trips targeting rockfish. "Conf" indicates confidential records with less than three vessels or processors. Source: Alaska Regional Office, via AKFIN 10/29/2021.

Species Group Name	2016	2017	2018	2019	2020	2021	Average
Pacific Ocean Perch	19,589	20,422	21,091	27,651	25,802	20,193	22,458
Atka Mackerel	5,255	5,365	5,513	8,734	8,527	6,569	6,661
Northern Rockfish	1,338	1,476	1,768	4,527	3,512	2,035	2,443
Pollock	875	1,424	1,524	2,254	1,997	1,576	1,608
Pacific Cod	625	813	637	1,217	972	708	829
BSAI Kamchatka Flounder	462	427	322	518	714	525	495
Arrowtooth Flounder	363	359	257	465	579	441	411
Other Rockfish	129	163	198	342	405	218	243
Sablefish	14	143	147	286	370	361	220
BSAI Skate	139	144	165	294	282	171	199
BSAI Rougheye Rockfish	70	65	116	246	288	176	160
Sculpin	88	135	106	199	188		143
BSAI Shortraker Rockfish	37	36	116	121	146	158	102
BSAI Other Flatfish	16	52	88	157	141	98	92
Greenland Turbot	28	37	53	119	165	114	86
Flathead Sole	41	53	67	119	89	97	78
Rock Sole	15	32	36	67	61	36	41
Squid	26	31	50				35
Shark	2	Conf.	2	2	4	3	3
Octopus	1	3	3	4	2	2	2
Yellowfin Sole	1	0	4	1	1	5	2
BSAI Alaska Plaice	Conf.		1		0	1	1

Table 7. Catch (t) of BSAI northern rockfish by trip target fishery. “Conf” indicates confidential records with less than three vessels or processors. Source: Alaska Regional Office, via AKFIN 10/29/2021.

Target	2016	2017	2018	2019	2020	2021	Average
Atka Mackerel	2941	3071	3865	4361	4681	3689	3768
Rockfish	1338	1476	1768	4527	3512	2035	2442
Pollock - midwater	109	48	70	78	107	72	81
Pacific Cod	83	67	48	66	63	48	63
Pollock - bottom	45	14	8	37	51	1	26
Kamchatka Flounder - BSAI	1	20		15	16	3	11
Flathead Sole				8			8
Arrowtooth Flounder	18				3	1	7
Halibut	0		1	0	0		0
Other Flatfish - BSAI		0					0

Table 8. Bycatch (t) of non-FMP species by BSAI trip targeting rockfish. "Conf" indicates confidential records with less than three vessels or processors. Source: Alaska Regional Office, via AKFIN 10/29/2021.

	2016	2017	2018	2019	2020	2021
Benthic urochordata	0.18	0.32	2.88	12.16	6.08	0.28
Birds - Auklets			Conf.			
Birds - Laysan Albatross			Conf.			
Birds - Northern Fulmar			Conf.			
Birds - Shearwaters		Conf.	Conf.			Conf.
Birds - Storm Petrels			Conf.			
Bivalves	0.05	0.02	0.05	0.15	0.03	0.16
Brittle star unidentified	0.12	0.14	5.02	3.21	6.08	3.43
Corals Bryozoans - Corals Bryozoans Unidentified	11.15	26.61	5.89	23.56	9.25	5.89
Eelpouts	1.33	4.56	1.75	2.46	3.57	3.27
Giant Grenadier	108.59	29.33	121.74	95.36	181.68	305.57
Greenlings		Conf.	Conf.	0.67	0.79	0.10
Grenadier - Rattail Grenadier Unidentified			Conf.	23.44		Conf.
Hermit crab unidentified	0.02	0.01	0.04	0.10	0.04	0.07
Invertebrate unidentified	1.86	0.13	0.16	4.86	1.69	2.30
Lanternfishes (myctophidae)	Conf.	Conf.	0.03	0.11	Conf.	0.13
Misc crabs	0.40	0.24	0.28	1.00	0.30	0.26
Misc crustaceans	0.11	0.38	0.22	0.18	0.18	0.14
Misc deep fish	Conf.		Conf.	Conf.	Conf.	0.01
Misc fish	58.93	107.35	74.95	104.32	78.92	47.23
Misc inverts (worms etc)	Conf.		Conf.	0.00	0.03	0.01
Other osmerids			Conf.	Conf.	Conf.	0.01
Pacific Sand lance					Conf.	
Pandalid shrimp	0.15	0.10	0.32	0.14	0.16	0.33
Polychaete unidentified	Conf.		0.02	0.03	Conf.	0.00
Saffron Cod			Conf.			
Sculpin						66.79
Scypho jellies	0.52	0.39	1.23	11.50	3.43	3.58
Sea anemone unidentified	0.19	0.25	0.49	1.22	0.36	4.31
Sea pens whips	0.06	Conf.	0.46	0.14	0.20	0.15
Sea star	3.29	4.27	45.25	32.69	16.01	10.47
Snails	0.13	0.31	0.81	0.80	0.79	0.68
Sponge unidentified	48.31	71.48	77.81	96.75	92.48	68.04
Squid				23.41	56.42	72.04
State-managed Rockfish	0.62	Conf.	0.36	0.34	1.13	0.46
Stichaeidae	Conf.		Conf.		Conf.	
urchins dollars cucumbers	0.37	1.14	2.10	2.64	0.69	1.01

Table 9. Bycatch (t) of PSC species by BSAI trip targeting rockfish, in tons for halibut and herring and 1000s of individuals for crab and salmon. “Source: Alaska Regional Office, via AKFIN 10/29/2021.

Species Group Name	2016	2017	2018	2019	2020	2021	Average
Bairdi Tanner Crab	0.07	0.10	0.84	0.62	0.25	7.66	1.59
Blue King Crab	0	0	0	0	0	0	0
Chinook Salmon	0.21	0.58	0.27	1.04	0.17	0.05	0.39
Golden (Brown) King Crab	5.29	3.02	4.95	6.30	3.66	3.32	4.42
Halibut	24.97	51.18	44.16	86.00	59.64	40.00	50.99
Herring	0	0	0	1	0	0	0
Non-Chinook Salmon	0.19	0.12	0.76	1.28	0.41	0.77	0.59
Opilio Tanner (Snow) Crab	0.02	0.07	14.54	0.71	0.10	2.31	2.96
Red King Crab	0.06	0.63	0.48	0.33	0.06	0.21	0.29

Table 10. Samples sizes of otoliths and lengths from fishery sampling, with the number of hauls from which these data were collected, from 1977-2021. Years where either age or length compositions were used in the assessment are shown in bold.

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	7998	761	1620	**553**	804
2020	6989	688	1474	**434**	591
2021	2278	267	466		

Table 11. Estimated BSAI northern rockfish fishery length compositions.

	Year									
Length (cm)	1977	1978	1996	1998	1999	2010	2012	2014	2016	2018
15	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
17	0.001	0.000	0.000	0.000	0.002	0.000	0.000	0.001	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
19	0.001	0.000	0.001	0.000	0.000	0.000	0.001	0.001	0.001	0.001
20	0.000	0.000	0.000	0.000	0.002	0.000	0.001	0.001	0.000	0.001
21	0.005	0.000	0.000	0.000	0.002	0.000	0.003	0.002	0.002	0.001
22	0.034	0.048	0.000	0.000	0.000	0.002	0.005	0.002	0.002	0.001
23	0.040	0.024	0.002	0.000	0.004	0.000	0.012	0.004	0.001	0.001
24	0.070	0.109	0.006	0.000	0.001	0.002	0.021	0.005	0.002	0.003
25	0.095	0.089	0.017	0.000	0.006	0.002	0.021	0.010	0.003	0.005
26	0.143	0.115	0.046	0.000	0.000	0.005	0.041	0.018	0.006	0.006
27	0.121	0.108	0.046	0.000	0.018	0.006	0.041	0.039	0.014	0.009
28	0.125	0.119	0.027	0.012	0.013	0.017	0.055	0.036	0.019	0.020
29	0.118	0.095	0.068	0.028	0.034	0.041	0.066	0.054	0.047	0.035
30	0.090	0.071	0.046	0.071	0.052	0.062	0.061	0.054	0.068	0.069
31	0.060	0.091	0.103	0.083	0.099	0.093	0.087	0.076	0.092	0.108
32	0.055	0.080	0.107	0.113	0.122	0.132	0.096	0.083	0.113	0.139
33	0.026	0.025	0.061	0.154	0.134	0.149	0.096	0.071	0.128	0.147
34	0.010	0.017	0.121	0.142	0.133	0.134	0.083	0.109	0.139	0.125
35	0.003	0.007	0.151	0.096	0.136	0.115	0.069	0.091	0.109	0.094
36	0.001	0.002	0.088	0.098	0.098	0.078	0.059	0.086	0.075	0.076
37	0.000	0.000	0.027	0.058	0.074	0.044	0.043	0.058	0.066	0.054
38+	0.001	0.000	0.084	0.145	0.069	0.117	0.138	0.198	0.115	0.105

Table 12. Estimated BSAI northern rockfish fishery age compositions.

	Year															
Age	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2011	2013	2015	2017	2019	2020
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.031	0.000	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.000
5	0.084	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.001	0.004
6	0.002	0.000	0.031	0.000	0.003	0.000	0.002	0.000	0.001	0.021	0.018	0.004	0.007	0.003	0.004	0.004
7	0.047	0.000	0.073	0.016	0.014	0.035	0.001	0.000	0.000	0.014	0.010	0.012	0.007	0.003	0.004	0.011
8	0.004	0.015	0.005	0.019	0.032	0.004	0.032	0.000	0.003	0.000	0.011	0.059	0.005	0.031	0.014	0.008
9	0.000	0.000	0.086	0.025	0.043	0.003	0.068	0.049	0.005	0.006	0.031	0.028	0.020	0.008	0.016	0.013
10	0.041	0.011	0.004	0.069	0.031	0.019	0.093	0.053	0.058	0.016	0.025	0.060	0.085	0.018	0.031	0.022
11	0.045	0.064	0.014	0.008	0.047	0.041	0.101	0.076	0.066	0.067	0.051	0.048	0.046	0.030	0.022	0.034
12	0.032	0.017	0.042	0.032	0.005	0.003	0.027	0.096	0.066	0.065	0.031	0.009	0.031	0.105	0.059	0.035
13	0.045	0.064	0.049	0.045	0.024	0.011	0.045	0.052	0.117	0.060	0.046	0.025	0.037	0.075	0.078	0.062
14	0.056	0.049	0.029	0.072	0.031	0.014	0.018	0.039	0.030	0.103	0.097	0.014	0.031	0.054	0.042	0.086
15	0.136	0.060	0.064	0.043	0.054	0.040	0.043	0.039	0.054	0.069	0.095	0.038	0.022	0.045	0.034	0.038
16	0.068	0.075	0.028	0.046	0.025	0.046	0.016	0.038	0.025	0.071	0.093	0.079	0.028	0.015	0.049	0.043
17	0.004	0.143	0.073	0.046	0.069	0.070	0.039	0.022	0.026	0.008	0.062	0.089	0.039	0.023	0.030	0.022
18	0.025	0.043	0.062	0.087	0.058	0.042	0.030	0.028	0.026	0.015	0.034	0.077	0.061	0.022	0.028	0.034
19	0.028	0.034	0.060	0.087	0.071	0.048	0.017	0.032	0.032	0.007	0.020	0.055	0.058	0.023	0.016	0.042
20	0.016	0.027	0.025	0.035	0.077	0.102	0.047	0.024	0.028	0.028	0.017	0.026	0.046	0.057	0.044	0.038
21	0.036	0.000	0.036	0.041	0.045	0.150	0.069	0.030	0.035	0.031	0.025	0.009	0.043	0.058	0.037	0.051
22	0.032	0.060	0.022	0.038	0.030	0.042	0.070	0.045	0.043	0.016	0.018	0.021	0.032	0.056	0.049	0.027
23	0.007	0.047	0.001	0.013	0.064	0.058	0.015	0.085	0.044	0.009	0.007	0.024	0.032	0.031	0.048	0.021
24	0.025	0.006	0.014	0.026	0.010	0.054	0.024	0.025	0.043	0.040	0.009	0.019	0.038	0.024	0.028	0.054
25	0.021	0.036	0.011	0.020	0.003	0.006	0.034	0.016	0.039	0.038	0.021	0.011	0.026	0.029	0.035	0.031
26	0.010	0.013	0.009	0.025	0.029	0.035	0.019	0.035	0.013	0.010	0.044	0.008	0.025	0.012	0.033	0.034
27	0.014	0.021	0.038	0.029	0.008	0.029	0.048	0.025	0.021	0.006	0.025	0.028	0.017	0.026	0.034	0.020
28	0.009	0.003	0.003	0.035	0.025	0.000	0.005	0.016	0.015	0.018	0.035	0.044	0.026	0.022	0.033	0.024
29	0.037	0.018	0.020	0.005	0.011	0.026	0.012	0.016	0.012	0.029	0.028	0.029	0.025	0.017	0.016	0.033
30	0.010	0.010	0.026	0.010	0.026	0.006	0.012	0.007	0.024	0.013	0.011	0.024	0.020	0.016	0.037	0.019
31	0.017	0.089	0.016	0.023	0.016	0.000	0.018	0.010	0.011	0.014	0.033	0.021	0.021	0.030	0.018	0.016
32	0.006	0.024	0.028	0.028	0.011	0.000	0.014	0.015	0.011	0.008	0.009	0.004	0.030	0.019	0.009	0.037
33	0.021	0.006	0.036	0.005	0.038	0.000	0.010	0.005	0.017	0.015	0.005	0.017	0.016	0.012	0.022	0.023
34	0.007	0.016	0.004	0.013	0.017	0.000	0.004	0.010	0.015	0.008	0.007	0.005	0.016	0.020	0.013	0.008
35	0.022	0.006	0.011	0.005	0.011	0.032	0.008	0.000	0.048	0.017	0.007	0.013	0.009	0.009	0.013	0.023
36	0.015	0.009	0.004	0.009	0.012	0.009	0.004	0.018	0.000	0.028	0.011	0.014	0.012	0.016	0.008	0.012
37	0.008	0.010	0.001	0.000	0.000	0.001	0.009	0.015	0.003	0.006	0.009	0.012	0.011	0.015	0.015	0.015
38	0.007	0.012	0.004	0.004	0.000	0.000	0.003	0.016	0.003	0.009	0.002	0.005	0.013	0.007	0.009	0.003
39	0.002	0.000	0.012	0.000	0.004	0.010	0.000	0.008	0.015	0.008	0.005	0.009	0.008	0.000	0.006	0.002
40+	0.028	0.011	0.052	0.039	0.054	0.064	0.042	0.052	0.051	0.122	0.048	0.056	0.061	0.068	0.066	0.045

Table 13. 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 14. Estimated age compositions from the Aleutian Islands trawl survey.

	Year											
Age	1991	1994	1997	2000	2002	2004	2006	2010	2012	2014	2016	2018
3	0.000	0.000	0.004	0.009	0.000	0.000	0.004	0.002	0.001	0.000	0.000	0.001
4	0.000	0.000	0.022	0.027	0.009	0.001	0.010	0.006	0.003	0.000	0.000	0.002
5	0.015	0.014	0.012	0.029	0.014	0.007	0.006	0.035	0.001	0.004	0.003	0.000
6	0.037	0.015	0.033	0.016	0.034	0.004	0.010	0.042	0.009	0.004	0.002	0.001
7	0.133	0.017	0.033	0.028	0.024	0.013	0.009	0.018	0.031	0.003	0.026	0.001
8	0.053	0.037	0.179	0.007	0.117	0.043	0.012	0.025	0.020	0.011	0.039	0.000
9	0.021	0.072	0.079	0.010	0.096	0.049	0.052	0.010	0.024	0.051	0.020	0.013
10	0.091	0.116	0.031	0.052	0.040	0.062	0.068	0.014	0.011	0.037	0.032	0.029
11	0.036	0.014	0.027	0.102	0.029	0.040	0.074	0.020	0.010	0.014	0.067	0.017
12	0.034	0.020	0.106	0.033	0.043	0.046	0.041	0.036	0.012	0.029	0.032	0.036
13	0.061	0.042	0.057	0.037	0.064	0.014	0.030	0.036	0.027	0.014	0.034	0.046
14	0.053	0.009	0.029	0.050	0.058	0.045	0.034	0.043	0.044	0.021	0.008	0.037
15	0.027	0.070	0.010	0.049	0.038	0.060	0.025	0.053	0.021	0.009	0.009	0.020
16	0.032	0.060	0.012	0.055	0.041	0.048	0.035	0.035	0.026	0.020	0.007	0.009
17	0.016	0.038	0.011	0.016	0.023	0.043	0.039	0.016	0.026	0.022	0.017	0.007
18	0.033	0.023	0.013	0.002	0.004	0.034	0.016	0.022	0.031	0.031	0.040	0.011
19	0.024	0.028	0.020	0.023	0.000	0.024	0.027	0.015	0.034	0.067	0.028	0.019
20	0.027	0.053	0.019	0.016	0.016	0.043	0.034	0.024	0.035	0.034	0.042	0.036
21	0.022	0.024	0.004	0.039	0.016	0.023	0.030	0.027	0.028	0.059	0.044	0.055
22	0.034	0.030	0.004	0.021	0.003	0.012	0.037	0.021	0.021	0.048	0.026	0.064
23	0.033	0.013	0.010	0.019	0.001	0.033	0.010	0.015	0.016	0.015	0.029	0.044
24	0.042	0.048	0.010	0.014	0.030	0.013	0.022	0.018	0.031	0.038	0.027	0.020
25	0.033	0.024	0.034	0.009	0.029	0.014	0.015	0.043	0.032	0.047	0.033	0.031
26	0.022	0.016	0.032	0.030	0.015	0.013	0.020	0.029	0.024	0.041	0.021	0.043
27	0.005	0.010	0.026	0.034	0.019	0.033	0.024	0.015	0.041	0.015	0.041	0.028
28	0.010	0.025	0.014	0.021	0.021	0.023	0.018	0.027	0.030	0.028	0.031	0.046
29	0.017	0.000	0.015	0.018	0.000	0.032	0.018	0.005	0.011	0.023	0.024	0.021
30	0.016	0.009	0.023	0.046	0.000	0.026	0.029	0.004	0.005	0.012	0.021	0.020
31	0.013	0.010	0.007	0.046	0.008	0.006	0.027	0.015	0.006	0.016	0.040	0.042
32	0.000	0.007	0.004	0.003	0.025	0.025	0.023	0.027	0.025	0.010	0.028	0.023
33	0.010	0.028	0.004	0.006	0.010	0.023	0.011	0.035	0.036	0.024	0.019	0.028
34	0.000	0.018	0.007	0.008	0.000	0.033	0.025	0.015	0.020	0.016	0.018	0.024
35	0.004	0.007	0.002	0.011	0.008	0.015	0.021	0.014	0.017	0.034	0.010	0.013
36	0.000	0.000	0.009	0.017	0.000	0.010	0.020	0.040	0.022	0.006	0.018	0.015
37	0.000	0.021	0.023	0.018	0.000	0.002	0.018	0.019	0.018	0.007	0.025	0.021
38	0.008	0.000	0.011	0.016	0.048	0.009	0.006	0.022	0.022	0.023	0.012	0.016
39	0.008	0.000	0.002	0.007	0.010	0.002	0.023	0.016	0.015	0.017	0.012	0.019
40+	0.033	0.082	0.064	0.056	0.109	0.077	0.079	0.141	0.213	0.148	0.117	0.141

Table 15. 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 16. 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 17. Average of predicted weight (from 2014 – 2018 from AI trawl survey data, and from 2016-2020 from the fishery), and proportion mature at age for BSAI northern rockfish.

	Predicted weight (g)		Proportion
Age	AI Survey (2014-2018)	Fishery (2016-2020)	mature
3	59	120	0.026
4	90	164	0.050
5	125	209	0.096
6	161	253	0.176
7	197	296	0.301
8	232	336	0.464
9	265	372	0.636
10	295	406	0.779
11	323	436	0.876
12	349	462	0.934
13	372	486	0.966
14	392	507	0.983
15	411	525	0.991
16	427	541	0.996
17	442	555	0.998
18	455	568	0.999
19	466	578	0.999
20	476	587	1
21	485	595	1
22	493	602	1
23	499	608	1
24	505	614	1
25	511	618	1
26	515	622	1
27	520	626	1
28	523	629	1
29	526	631	1
30	529	633	1
31	532	635	1
32	534	637	1
33	536	638	1
34	537	640	1
35	539	641	1
36	540	642	1
37	541	643	1
38	542	643	1
39	543	644	1
40	547	646	1

Table 18. Negative log likelihood of model components, root mean squared errors, and estimates and standard deviations of key quantities.

	Model 16.1a(2021)	Model 21
Negative log-likelihood		
Data components		
AI survey biomass	8.74	8.43
Catch biomass	0.00	0.00
Fishery age comp	225.25	237.93
Fishery length comp	74.19	75.33
AI survey age comp	172.99	172.67
Maturity	7.21	7.21
Priors and penalties		
Recruitment	-5.41	-5.72
Prior on survey q	0.00	0.00
Prior on M	0.60	0.23
penalty on survey sel	1.46	1.61
Fishing mortality penalty	5.83	5.73
Total negative log-likelihood	490.85	503.42
Parameters	135	135
Root mean square error		
AI survey biomass	0.392	0.375
Recruitment	0.571	0.571
Fishery age comp	0.015	0.015
Fishery length comp	0.030	0.030
AI survey age comp	0.017	0.017
Estimated key quantities		
M	0.050	0.054
standard deviation	0.005	0.005
CV	0.090	0.088
2021 total biomass	245,690	285,730
standard deviation	25,927	30,895
CV	0.11	0.10

Table 19. Estimated parameter values and standard deviations.

Parameter	Estimate	Standard Deviation	parameter	estimate	Standard Deviation	parameter	estimate	Standard Deviation
sel_aslope_forfish	0.7845	0.0695	fmort_dev	0.5729	0.0910	rec_dev	-0.5526	0.4235
sel_a50_forfish	9.0530	0.2545	fmort_dev	0.6281	0.0954	rec_dev	-0.4976	0.5122
sel_aslope_srv	0.2763	0.0178	fmort_dev	0.8492	0.1001	rec_dev	-0.4355	0.5449
sel_a50_srv	11.1040	0.5639	fmort_dev	1.3525	0.1055	mean_log_r	3.8698	0.1015
M	0.0536	0.0047	fmort_dev	1.3290	0.1112	log_rinit	3.1373	0.2318
log_avg_fmort	-4.9103	0.0780	fmort_dev	1.4044	0.1170	fydev	0.3458	0.7375
fmort_dev	1.0197	0.1164	rec_dev	0.2521	0.4649	fydev	0.4418	0.6821
fmort_dev	1.1017	0.1125	rec_dev	-0.0408	0.5496	fydev	0.2936	0.8079
fmort_dev	-0.6934	0.1079	rec_dev	-0.1397	0.5184	fydev	1.7898	0.3591
fmort_dev	-0.7716	0.1029	rec_dev	-0.1433	0.5226	fydev	0.3301	0.8141
fmort_dev	-2.3094	0.0982	rec_dev	0.1588	0.4557	fydev	0.1890	0.7062
fmort_dev	-1.8215	0.0938	rec_dev	0.1095	0.4313	fydev	0.2254	0.6650
fmort_dev	-2.8886	0.0895	rec_dev	-0.3892	0.5441	fydev	0.0383	0.6756
fmort_dev	-1.9833	0.0852	rec_dev	0.3690	0.3214	fydev	0.0770	0.7011
fmort_dev	-2.1799	0.0811	rec_dev	-0.2148	0.4739	fydev	0.4677	0.7363
fmort_dev	-1.8879	0.0773	rec_dev	-0.3862	0.5187	fydev	0.4142	0.7785
fmort_dev	-1.5648	0.0737	rec_dev	0.9109	0.2414	fydev	0.1560	0.7350
fmort_dev	-1.2677	0.0704	rec_dev	0.9039	0.2577	fydev	0.1396	0.7130
fmort_dev	-1.6262	0.0674	rec_dev	0.0188	0.4605	fydev	0.0798	0.6959
fmort_dev	-0.2726	0.0646	rec_dev	0.1889	0.3375	fydev	-0.1232	0.6698
fmort_dev	-0.9329	0.0622	rec_dev	-0.0581	0.3940	fydev	-0.2434	0.6494
fmort_dev	-0.1136	0.0599	rec_dev	0.8648	0.1815	fydev	-0.2768	0.6434
fmort_dev	0.9355	0.0582	rec_dev	-0.0847	0.3637	fydev	-0.2966	0.6435
fmort_dev	0.8450	0.0568	rec_dev	0.0218	0.2997	fydev	-0.3021	0.6452
fmort_dev	0.6606	0.0555	rec_dev	-0.3893	0.4119	fydev	-0.2742	0.6516
fmort_dev	1.1610	0.0543	rec_dev	0.6748	0.1776	fydev	-0.2382	0.6586
fmort_dev	0.0374	0.0534	rec_dev	-0.0783	0.3447	fydev	-0.2212	0.6634
fmort_dev	0.5757	0.0527	rec_dev	0.9095	0.1700	fydev	-0.2200	0.6659
fmort_dev	0.9402	0.0524	rec_dev	0.7099	0.2080	fydev	-0.2196	0.6670
fmort_dev	0.8144	0.0524	rec_dev	0.4977	0.2320	fydev	-0.2147	0.6685
fmort_dev	1.0707	0.0526	rec_dev	0.2689	0.2418	fydev	-0.2078	0.6706
fmort_dev	0.6066	0.0533	rec_dev	-0.4553	0.3626	fydev	-0.1996	0.6731
fmort_dev	0.7717	0.0543	rec_dev	-0.2339	0.2671	fydev	-0.1915	0.6755
fmort_dev	0.6925	0.0556	rec_dev	-0.7989	0.3886	fydev	-0.1840	0.6778
fmort_dev	0.5110	0.0572	rec_dev	0.0680	0.2241	fydev	-0.1765	0.6801
fmort_dev	0.4232	0.0591	rec_dev	0.0966	0.2382	fydev	-0.1691	0.6823
fmort_dev	0.4281	0.0612	rec_dev	-0.0073	0.2794	fydev	-0.1621	0.6845
fmort_dev	0.2609	0.0636	rec_dev	0.8407	0.1569	fydev	-0.1551	0.6867
fmort_dev	0.2038	0.0663	rec_dev	0.1540	0.2556	fydev	-0.1485	0.6888
fmort_dev	0.5456	0.0693	rec_dev	0.0248	0.2540	fydev	-0.1422	0.69073
fmort_dev	0.0330	0.0725	rec_dev	-0.4117	0.3184	fydev	-0.1363	0.6926
fmort_dev	-0.0659	0.0758	rec_dev	-0.0331	0.2320	fydev	-0.4852	0.6026
fmort_dev	-0.2734	0.0792	rec_dev	-0.9811	0.3982	q_srv3	1.0000	0.0010
fmort_dev	-0.1636	0.0827	rec_dev	-0.7231	0.3459	mat_beta1	-5.7428	0.6954
fmort_dev	1.0418	0.0867	rec_dev	-0.9887	0.4437	mat_beta2	0.7000	0.0094

Table 20. 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			
	2021		2019		2021		2019		2021		2019	
Year	Est.	CV	Est.	CV	Est.	CV	Est.	CV	Est.	CV	Est.	CV
1977	151,640	0.145	125,250	0.137	57,227	0.161	47,111	0.154	61,674	0.480	50,404	0.511
1978	156,490	0.143	129,720	0.135	59,577	0.161	49,176	0.155	46,013	0.562	40,597	0.583
1979	160,760	0.140	133,820	0.133	62,431	0.157	51,732	0.152	41,684	0.531	37,765	0.532
1980	166,870	0.136	139,590	0.129	65,979	0.151	55,019	0.145	41,530	0.536	32,055	0.570
1981	173,620	0.132	146,040	0.125	69,346	0.144	58,193	0.139	56,180	0.467	47,348	0.467
1982	180,600	0.127	152,960	0.121	72,615	0.139	61,338	0.133	53,475	0.443	47,925	0.426
1983	186,240	0.123	158,560	0.117	75,727	0.134	64,390	0.128	32,477	0.561	25,477	0.587
1984	193,660	0.119	166,140	0.113	78,770	0.129	67,427	0.124	69,321	0.332	64,591	0.304
1985	199,470	0.115	172,160	0.109	81,680	0.124	70,370	0.119	38,668	0.487	32,897	0.489
1986	204,510	0.111	177,450	0.105	84,520	0.119	73,271	0.115	32,575	0.533	25,889	0.553
1987	214,150	0.107	187,180	0.101	87,332	0.115	76,175	0.111	119,190	0.257	109,310	0.232
1988	225,180	0.103	197,820	0.098	90,111	0.112	79,079	0.107	118,350	0.274	100,550	0.259
1989	233,410	0.100	205,910	0.094	92,903	0.108	82,029	0.104	48,840	0.474	38,480	0.475
1990	242,000	0.096	214,330	0.091	95,823	0.106	85,114	0.102	57,894	0.347	47,558	0.321
1991	248,810	0.093	220,780	0.088	98,895	0.104	88,317	0.100	45,227	0.411	32,045	0.409
1992	259,530	0.090	229,730	0.085	102,610	0.103	92,075	0.099	113,820	0.199	78,684	0.199
1993	266,290	0.088	235,880	0.083	106,270	0.102	95,693	0.097	44,039	0.380	37,667	0.328
1994	270,150	0.086	238,610	0.081	109,250	0.100	98,513	0.095	48,987	0.310	32,381	0.302
1995	272,470	0.084	239,820	0.079	112,100	0.096	101,080	0.091	32,476	0.429	17,652	0.448
1996	278,040	0.083	244,000	0.078	114,590	0.093	103,140	0.087	94,115	0.194	75,787	0.167
1997	279,010	0.082	243,700	0.077	116,460	0.091	104,430	0.085	44,321	0.362	29,545	0.381
1998	287,720	0.080	251,430	0.075	119,310	0.089	106,590	0.082	119,010	0.188	110,620	0.160
1999	295,010	0.079	256,930	0.074	121,240	0.087	107,800	0.081	97,476	0.226	72,123	0.229
2000	300,500	0.078	261,690	0.074	122,550	0.086	108,410	0.080	78,842	0.248	74,782	0.205
2001	305,020	0.077	265,090	0.073	123,690	0.086	108,910	0.081	62,717	0.254	45,145	0.239
2002	306,180	0.077	265,200	0.073	125,010	0.087	109,650	0.083	30,402	0.377	14,323	0.420
2003	309,920	0.076	268,010	0.072	127,970	0.088	112,000	0.084	37,934	0.277	27,278	0.238
2004	311,940	0.076	269,190	0.072	131,400	0.088	114,850	0.085	21,560	0.403	12,312	0.420
2005	314,540	0.076	270,950	0.073	134,880	0.087	117,810	0.083	51,306	0.236	39,400	0.225
2006	317,910	0.076	273,670	0.073	138,320	0.085	120,760	0.081	52,793	0.251	44,848	0.240
2007	316,250	0.077	272,070	0.073	138,950	0.083	121,210	0.079	47,582	0.293	37,186	0.314
2008	319,230	0.077	276,320	0.074	139,290	0.082	121,350	0.078	111,100	0.171	122,650	0.147
2009	321,230	0.078	277,010	0.075	139,380	0.082	121,270	0.078	55,913	0.269	14,516	0.462
2010	323,200	0.079	277,530	0.076	139,250	0.083	121,040	0.080	49,133	0.264	17,982	0.368
2011	322,850	0.081	276,890	0.078	139,010	0.085	120,790	0.082	31,756	0.332	28,663	0.342
2012	324,060	0.082	277,630	0.080	139,660	0.088	121,480	0.085	46,372	0.245	36,779	0.304
2013	324,630	0.084	277,760	0.081	141,310	0.090	123,040	0.087	17,969	0.413	10,371	0.499
2014	325,040	0.086	277,710	0.083	143,310	0.092	124,780	0.088	23,259	0.360	13,817	0.481
2015	321,960	0.088	274,890	0.085	143,590	0.093	124,750	0.089	17,834	0.460	13,419	0.540
2016	314,450	0.091	267,440	0.089	142,090	0.095	122,870	0.092	27,581	0.438	16,048	0.574
2017	308,400	0.095	263,270	0.091	140,510	0.097	121,070	0.094	29,141	0.529		
2018	304,580	0.098	261,560	0.094	139,270	0.100	119,610	0.098	31,010	0.563		
2019	299,120	0.101	257,480	0.097	135,660	0.104	115,667	0.101				
2020	291,690	0.105	250,235		130,750	0.109	111,476					
2021	285,730	0.108			125,930	0.114						
2022	279,584				121,126							
Mean recruitment of post-1976 year classes									54,671		44,003	

Table 21. 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	61.67	30.86	32.20	26.31	111.34	24.51	20.18	19.83	15.59	15.36	21.51	19.33	14.15	13.19	11.78	9.11	7.66	7.02
1978	46.01	58.44	29.24	30.49	24.89	105.16	23.09	18.93	18.54	14.53	14.29	19.99	17.95	13.14	12.25	10.94	8.46	7.11
1979	41.68	43.60	55.37	27.68	28.84	23.51	99.00	21.65	17.68	17.25	13.49	13.26	18.54	16.65	12.18	11.36	10.14	7.84
1980	41.53	39.51	41.32	52.47	26.23	27.32	22.25	93.66	20.47	16.70	16.30	12.74	12.52	17.51	15.72	11.51	10.73	9.57
1981	56.18	39.36	37.44	39.16	49.72	24.85	25.87	21.06	88.57	19.34	15.78	15.39	12.04	11.83	16.54	14.85	10.87	10.13
1982	53.48	53.25	37.30	35.48	37.11	47.11	23.54	24.51	19.95	83.89	18.32	14.95	14.58	11.40	11.20	15.67	14.06	10.29
1983	32.48	50.68	50.46	35.36	33.63	35.17	44.64	22.30	23.21	18.89	79.42	17.34	14.15	13.80	10.79	10.60	14.83	13.31
1984	69.32	30.78	48.04	47.83	33.51	31.87	33.33	42.30	21.13	21.99	17.89	75.25	16.43	13.41	13.08	10.23	10.04	14.05
1985	38.67	65.70	29.17	45.53	45.33	31.75	30.20	31.57	40.06	20.01	20.82	16.94	71.25	15.56	12.69	12.38	9.68	9.51
1986	32.58	36.65	62.27	27.65	43.14	42.95	30.09	28.61	29.91	37.94	18.95	19.72	16.05	67.47	14.73	12.02	11.72	9.17
1987	119.19	30.87	34.73	59.02	26.20	40.88	40.70	28.50	27.09	28.32	35.93	17.94	18.67	15.19	63.88	13.95	11.38	11.10
1988	118.35	112.96	29.26	32.92	55.93	24.83	38.73	38.54	26.98	25.65	26.80	34.00	16.98	17.67	14.38	60.45	13.20	10.77
1989	48.84	112.17	107.06	27.73	31.19	52.99	23.52	36.67	36.48	25.53	24.26	25.35	32.16	16.06	16.71	13.60	57.17	12.48
1990	57.89	46.29	106.31	101.46	26.28	29.56	50.20	22.27	34.72	34.53	24.17	22.96	23.99	30.44	15.20	15.81	12.87	54.11
1991	45.23	54.87	43.87	100.73	96.12	24.88	27.97	47.45	21.03	32.76	32.56	22.78	21.64	22.61	28.69	14.33	14.90	12.13
1992	113.82	42.86	52.00	41.57	95.45	91.06	23.56	26.47	44.88	19.88	30.97	30.78	21.53	20.46	21.37	27.11	13.54	14.09
1993	44.04	107.87	40.62	49.27	39.38	90.37	86.13	22.26	24.97	42.31	18.73	29.16	28.98	20.27	19.26	20.12	25.53	12.75
1994	48.99	41.73	102.20	38.47	46.63	37.21	85.16	80.88	20.83	23.31	39.42	17.44	27.14	26.96	18.86	17.92	18.72	23.74
1995	32.48	46.42	39.54	96.80	36.41	44.07	35.08	80.04	75.77	19.47	21.75	36.75	16.25	25.29	25.12	17.57	16.69	17.44
1996	94.12	30.78	43.99	37.45	91.63	34.43	41.58	33.02	75.13	70.98	18.21	20.33	34.35	15.19	23.63	23.47	16.42	15.60
1997	44.32	89.18	29.16	41.65	35.43	86.51	32.40	38.96	30.80	69.84	65.85	16.88	18.83	31.81	14.06	21.87	21.73	15.20
1998	119.01	42.00	84.51	27.63	39.45	33.54	81.80	30.59	36.73	29.01	65.74	61.95	15.88	17.71	29.92	13.23	20.57	20.44
1999	97.48	112.79	39.80	80.06	26.15	37.31	31.66	77.03	28.74	34.44	27.17	61.53	57.97	14.85	16.57	27.99	12.37	19.25
2000	78.84	92.37	106.86	37.69	75.76	24.71	35.16	29.73	72.08	26.82	32.09	25.29	57.25	53.93	13.82	15.41	26.03	11.51
2001	62.72	74.71	87.52	101.21	35.68	71.60	23.30	33.05	27.86	67.39	25.03	29.93	23.58	53.37	50.27	12.88	14.37	24.26
2002	30.40	59.43	70.78	82.88	95.75	33.69	67.42	21.85	30.87	25.94	62.63	23.24	27.78	21.88	49.51	46.63	11.95	13.33
2003	37.93	28.81	56.31	67.05	78.46	90.55	31.80	63.48	20.52	28.94	24.29	58.60	21.74	25.98	20.46	46.30	43.61	11.17
2004	21.56	35.95	27.30	53.34	63.47	74.17	85.41	29.91	59.52	19.20	27.03	22.67	54.68	20.28	24.23	19.08	43.19	40.67
2005	51.31	20.43	34.06	25.86	50.49	60.00	69.98	80.36	28.06	55.73	17.95	25.26	21.18	51.07	18.94	22.63	17.82	40.33
2006	52.79	48.62	19.36	32.27	24.48	47.76	56.66	65.93	75.54	26.33	52.23	16.82	23.66	19.83	47.82	17.73	21.19	16.68
2007	47.58	50.03	46.07	18.34	30.55	23.16	45.11	53.41	62.01	70.93	24.70	48.98	15.76	22.17	18.59	44.81	16.62	19.86
2008	111.10	45.09	47.41	43.65	17.37	28.90	21.88	42.52	50.23	58.23	66.54	23.16	45.91	14.78	20.78	17.42	42.00	15.58
2009	55.91	105.29	42.73	44.92	41.33	16.43	27.31	20.64	40.04	47.23	54.71	62.49	21.75	43.10	13.87	19.51	16.35	39.43
2010	49.13	52.99	99.77	40.48	42.54	39.12	15.53	25.77	19.44	37.66	44.40	51.41	58.71	20.43	40.48	13.03	18.32	15.36
2011	31.76	46.56	50.21	94.52	38.33	40.23	36.93	14.63	24.22	18.23	35.29	41.57	48.12	54.94	19.12	37.89	12.19	17.15
2012	46.37	30.10	44.12	47.57	89.52	36.28	38.04	34.87	13.79	22.81	17.16	33.20	39.11	45.26	51.68	17.98	35.63	11.47
2013	17.97	43.95	28.52	41.81	45.06	84.75	34.32	35.93	32.90	13.00	21.48	16.16	31.26	36.81	42.61	48.65	16.92	33.54
2014	23.26	17.03	41.65	27.03	39.61	42.67	80.19	32.43	33.93	31.04	12.26	20.25	15.23	29.46	34.70	40.16	45.85	15.95
2015	17.83	22.04	16.14	39.46	25.60	37.50	40.37	75.77	30.61	31.99	29.25	11.55	19.08	14.35	27.75	32.68	37.82	43.18
2016	27.58	16.90	20.88	15.28	37.34	24.18	35.32	37.87	70.80	28.52	29.75	27.17	10.72	17.71	13.32	25.76	30.34	35.11
2017	29.14	26.14	16.01	19.78	14.47	35.31	22.83	33.26	35.57	66.39	26.71	27.85	25.43	10.03	16.57	12.46	24.09	28.38
2018	31.01	27.62	24.77	15.17	18.73	13.68	33.33	21.49	31.23	33.34	62.14	24.98	26.04	23.77	9.38	15.49	11.65	22.52
2019	63.50	29.39	26.17	23.46	14.36	17.70	12.90	31.32	20.13	29.18	31.10	57.93	23.28	24.26	22.15	8.74	14.43	10.85
2020	63.50	60.17	27.84	24.77	22.18	13.54	16.63	12.06	29.12	18.64	26.95	28.69	53.39	21.45	22.35	20.40	8.05	13.29
2021	63.50	60.17	57.00	26.35	23.42	20.92	12.73	15.55	11.21	26.97	17.22	24.87	26.46	49.23	19.78	20.60	18.81	7.42

Table 21 (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	6.52	6.15	5.99	5.89	5.68	5.39	5.11	4.86	4.64	4.44	4.24	4.05	3.86	3.69	3.52	3.36	3.21	3.06	2.92	10.27
1978	6.52	6.06	5.71	5.56	5.47	5.27	5.00	4.74	4.52	4.31	4.12	3.94	3.76	3.59	3.43	3.27	3.12	2.98	2.84	12.25
1979	6.59	6.04	5.61	5.29	5.16	5.07	4.89	4.64	4.40	4.19	4.00	3.82	3.65	3.48	3.33	3.18	3.03	2.89	2.76	13.99
1980	7.41	6.23	5.71	5.30	5.00	4.87	4.79	4.61	4.38	4.15	3.95	3.77	3.61	3.44	3.29	3.14	3.00	2.86	2.73	15.81
1981	9.04	7.00	5.88	5.39	5.01	4.72	4.60	4.52	4.36	4.14	3.92	3.73	3.56	3.41	3.25	3.11	2.97	2.83	2.70	17.52
1982	9.59	8.56	6.63	5.57	5.10	4.74	4.47	4.36	4.28	4.13	3.92	3.71	3.54	3.38	3.23	3.08	2.94	2.81	2.68	19.15
1983	9.74	9.08	8.11	6.27	5.27	4.83	4.49	4.23	4.12	4.05	3.91	3.71	3.52	3.35	3.20	3.05	2.92	2.79	2.66	20.67
1984	12.61	9.23	8.60	7.68	5.94	4.99	4.58	4.25	4.01	3.91	3.84	3.70	3.51	3.33	3.17	3.03	2.89	2.76	2.64	22.10
1985	13.30	11.94	8.74	8.15	7.27	5.63	4.73	4.33	4.03	3.80	3.70	3.64	3.50	3.33	3.15	3.00	2.87	2.74	2.62	23.43
1986	9.01	12.60	11.31	8.28	7.72	6.89	5.33	4.48	4.10	3.81	3.60	3.50	3.44	3.32	3.15	2.99	2.84	2.71	2.59	24.66
1987	8.68	8.53	11.93	10.71	7.84	7.30	6.52	5.04	4.24	3.89	3.61	3.40	3.32	3.26	3.14	2.98	2.83	2.69	2.57	25.81
1988	10.50	8.21	8.07	11.29	10.13	7.42	6.91	6.17	4.77	4.01	3.68	3.42	3.22	3.14	3.08	2.97	2.82	2.68	2.55	26.85
1989	10.18	9.94	7.77	7.63	10.67	9.58	7.01	6.54	5.84	4.52	3.79	3.48	3.23	3.05	2.97	2.92	2.81	2.67	2.53	27.81
1990	11.82	9.64	9.40	7.35	7.22	10.10	9.07	6.64	6.19	5.52	4.27	3.59	3.29	3.06	2.88	2.81	2.76	2.66	2.53	28.71
1991	51.00	11.14	9.08	8.86	6.93	6.81	9.52	8.55	6.26	5.83	5.21	4.03	3.38	3.10	2.88	2.72	2.65	2.60	2.51	29.44
1992	11.46	48.19	10.52	8.59	8.37	6.55	6.43	9.00	8.08	5.91	5.51	4.92	3.81	3.20	2.93	2.72	2.57	2.50	2.46	30.19
1993	13.26	10.79	45.38	9.91	8.08	7.89	6.17	6.06	8.47	7.61	5.57	5.19	4.63	3.58	3.01	2.76	2.57	2.42	2.36	30.74
1994	11.86	12.34	10.04	42.21	9.22	7.52	7.33	5.74	5.63	7.88	7.07	5.18	4.83	4.31	3.33	2.80	2.57	2.39	2.25	30.79
1995	22.12	11.05	11.49	9.35	39.32	8.59	7.01	6.83	5.34	5.25	7.34	6.59	4.82	4.50	4.01	3.11	2.61	2.39	2.22	30.78
1996	16.29	20.67	10.32	10.74	8.74	36.74	8.02	6.55	6.38	4.99	4.90	6.86	6.16	4.51	4.20	3.75	2.90	2.44	2.24	30.84
1997	14.44	15.08	19.13	9.56	9.94	8.09	34.01	7.43	6.06	5.91	4.62	4.54	6.35	5.70	4.17	3.89	3.47	2.69	2.26	30.61
1998	14.30	13.58	14.19	18.00	8.99	9.35	7.61	31.99	6.99	5.70	5.56	4.35	4.27	5.97	5.36	3.92	3.66	3.27	2.53	30.92
1999	19.12	13.37	12.70	13.27	16.83	8.41	8.75	7.12	29.93	6.53	5.33	5.20	4.07	3.99	5.59	5.02	3.67	3.42	3.05	31.29
2000	17.90	17.78	12.44	11.81	12.34	15.66	7.82	8.13	6.62	27.83	6.08	4.96	4.84	3.78	3.72	5.20	4.67	3.41	3.18	31.94
2001	10.73	16.69	16.58	11.59	11.01	11.51	14.59	7.29	7.58	6.17	25.94	5.67	4.62	4.51	3.53	3.46	4.84	4.35	3.18	32.74
2002	22.51	9.95	15.48	15.38	10.75	10.22	10.67	13.54	6.76	7.03	5.72	24.07	5.26	4.29	4.18	3.27	3.21	4.49	4.03	33.32
2003	12.46	21.04	9.30	14.47	14.38	10.06	9.55	9.98	12.66	6.32	6.58	5.35	22.50	4.91	4.01	3.91	3.06	3.00	4.20	34.93
2004	10.42	11.62	19.63	8.68	13.50	13.41	9.38	8.91	9.31	11.81	5.90	6.14	4.99	20.99	4.58	3.74	3.65	2.85	2.80	36.50
2005	37.99	9.73	10.86	18.33	8.10	12.61	12.52	8.76	8.32	8.69	11.03	5.51	5.73	4.66	19.60	4.28	3.49	3.41	2.66	36.70
2006	37.76	35.56	9.11	10.16	17.16	7.59	11.80	11.73	8.20	7.79	8.14	10.32	5.16	5.36	4.36	18.35	4.01	3.27	3.19	36.86
2007	15.64	35.39	33.33	8.54	9.53	16.09	7.11	11.06	10.99	7.69	7.30	7.63	9.68	4.83	5.03	4.09	17.20	3.76	3.06	37.53
2008	18.61	14.65	33.16	31.23	8.00	8.93	15.07	6.66	10.37	10.30	7.20	6.84	7.15	9.07	4.53	4.71	3.83	16.12	3.52	38.04
2009	14.62	17.47	13.76	31.13	29.32	7.51	8.38	14.15	6.26	9.73	9.67	6.76	6.42	6.71	8.51	4.25	4.42	3.60	15.13	39.02
2010	37.03	13.73	16.41	12.92	29.24	27.54	7.06	7.87	13.29	5.88	9.14	9.08	6.35	6.03	6.30	7.99	3.99	4.15	3.38	50.86
2011	14.37	34.65	12.85	15.36	12.09	27.36	25.77	6.60	7.37	12.44	5.50	8.55	8.50	5.94	5.65	5.90	7.48	3.74	3.89	50.76
2012	16.13	13.52	32.59	12.09	14.44	11.37	25.74	24.24	6.21	6.93	11.70	5.17	8.05	7.99	5.59	5.31	5.55	7.04	3.51	51.40
2013	10.79	15.18	12.72	30.68	11.38	13.59	10.70	24.23	22.82	5.85	6.52	11.01	4.87	7.57	7.52	5.26	5.00	5.22	6.62	51.69
2014	31.61	10.17	14.31	11.99	28.92	10.72	12.81	10.09	22.83	21.50	5.51	6.15	10.38	4.59	7.14	7.09	4.96	4.71	4.92	54.96
2015	15.02	29.77	9.58	13.47	11.30	27.23	10.10	12.07	9.50	21.50	20.25	5.19	5.79	9.78	4.32	6.72	6.68	4.67	4.44	56.40
2016	40.08	13.95	27.64	8.89	12.51	10.48	25.28	9.38	11.20	8.82	19.96	18.80	4.82	5.37	9.07	4.01	6.24	6.20	4.34	56.47
2017	32.84	37.50	13.05	25.85	8.32	11.70	9.81	23.65	8.77	10.48	8.25	18.67	17.59	4.51	5.03	8.49	3.75	5.84	5.80	56.88
2018	26.53	30.70	35.05	12.19	24.17	7.78	10.94	9.17	22.11	8.20	9.80	7.71	17.45	16.44	4.21	4.70	7.93	3.51	5.46	58.59
2019	20.98	24.71	28.60	32.65	11.36	22.51	7.25	10.19	8.54	20.59	7.64	9.13	7.19	16.26	15.32	3.92	4.38	7.39	3.27	59.66
2020	9.99	19.33	22.76	26.34	30.08	10.46	20.74	6.67	9.39	7.87	18.97	7.04	8.41	6.62	14.98	14.11	3.61	4.03	6.81	57.97
2021	12.25	9.21	17.82	20.98	24.28	27.72	9.65	19.12	6.15	8.65	7.25	17.49	6.48	7.75	6.10	13.81	13.00	3.33	3.72	59.71

Table 22. 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 68,707 t and 60,119 t, respectively.

Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2021	8,882	8,882	8,882	8,882	8,882	8,882	8,882
2022	19,217	19,217	4,566	5,722	0	23,420	19,217
2023	17,847	17,847	4,458	5,566	0	21,431	17,847
2024	16,717	16,717	4,380	5,449	0	19,793	20,376
2025	15,833	15,833	4,338	5,377	0	18,505	19,025
2026	15,167	15,167	4,328	5,348	0	17,521	17,983
2027	14,658	14,658	4,341	5,348	0	16,757	17,166
2028	14,242	14,242	4,365	5,362	0	16,131	16,492
2029	13,882	13,882	4,391	5,380	0	15,591	15,909
2030	13,560	13,560	4,417	5,398	0	15,115	15,394
2031	13,272	13,272	4,441	5,416	0	14,690	14,939
2032	13,017	13,017	4,465	5,433	0	14,279	14,518
2033	12,789	12,789	4,487	5,449	0	13,871	14,100
2034	12,580	12,580	4,508	5,464	0	13,490	13,703
Sp. Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2021	125,696	125,696	125,696	125,696	125,696	125,696	125,696
2022	119,965	119,965	121,503	121,384	121,971	119,512	119,965
2023	111,932	111,932	119,135	118,563	121,401	109,884	111,932
2024	105,323	105,323	117,512	116,521	121,474	101,972	104,935
2025	100,075	100,075	116,663	115,283	122,232	95,663	98,305
2026	95,942	95,942	116,447	114,703	123,549	90,662	93,011
2027	92,607	92,607	116,639	114,553	125,218	86,609	88,692
2028	89,798	89,798	117,036	114,623	127,044	83,204	85,045
2029	87,361	87,361	117,522	114,798	128,918	80,269	81,893
2030	85,212	85,212	118,036	115,016	130,776	77,709	79,138
2031	83,316	83,316	118,565	115,264	132,607	75,477	76,732
2032	81,637	81,637	119,092	115,525	134,391	73,531	74,629
2033	80,147	80,147	119,612	115,791	136,126	71,848	72,798
2034	78,822	78,822	120,111	116,051	137,796	70,407	71,221
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2021	0.030	0.030	0.030	0.030	0.030	0.030	0.030
2022	0.069	0.069	0.016	0.020	0.000	0.085	0.069
2023	0.069	0.069	0.016	0.020	0.000	0.085	0.069
2024	0.069	0.069	0.016	0.020	0.000	0.085	0.085
2025	0.069	0.069	0.016	0.020	0.000	0.085	0.085
2026	0.069	0.069	0.016	0.020	0.000	0.085	0.085
2027	0.069	0.069	0.016	0.020	0.000	0.085	0.085
2028	0.069	0.069	0.016	0.020	0.000	0.085	0.085
2029	0.069	0.069	0.016	0.020	0.000	0.085	0.085
2030	0.069	0.069	0.016	0.020	0.000	0.085	0.085
2031	0.069	0.069	0.016	0.020	0.000	0.085	0.085
2032	0.069	0.069	0.016	0.020	0.000	0.084	0.085
2033	0.069	0.069	0.016	0.020	0.000	0.084	0.084
2034	0.069	0.069	0.016	0.020	0.000	0.083	0.083

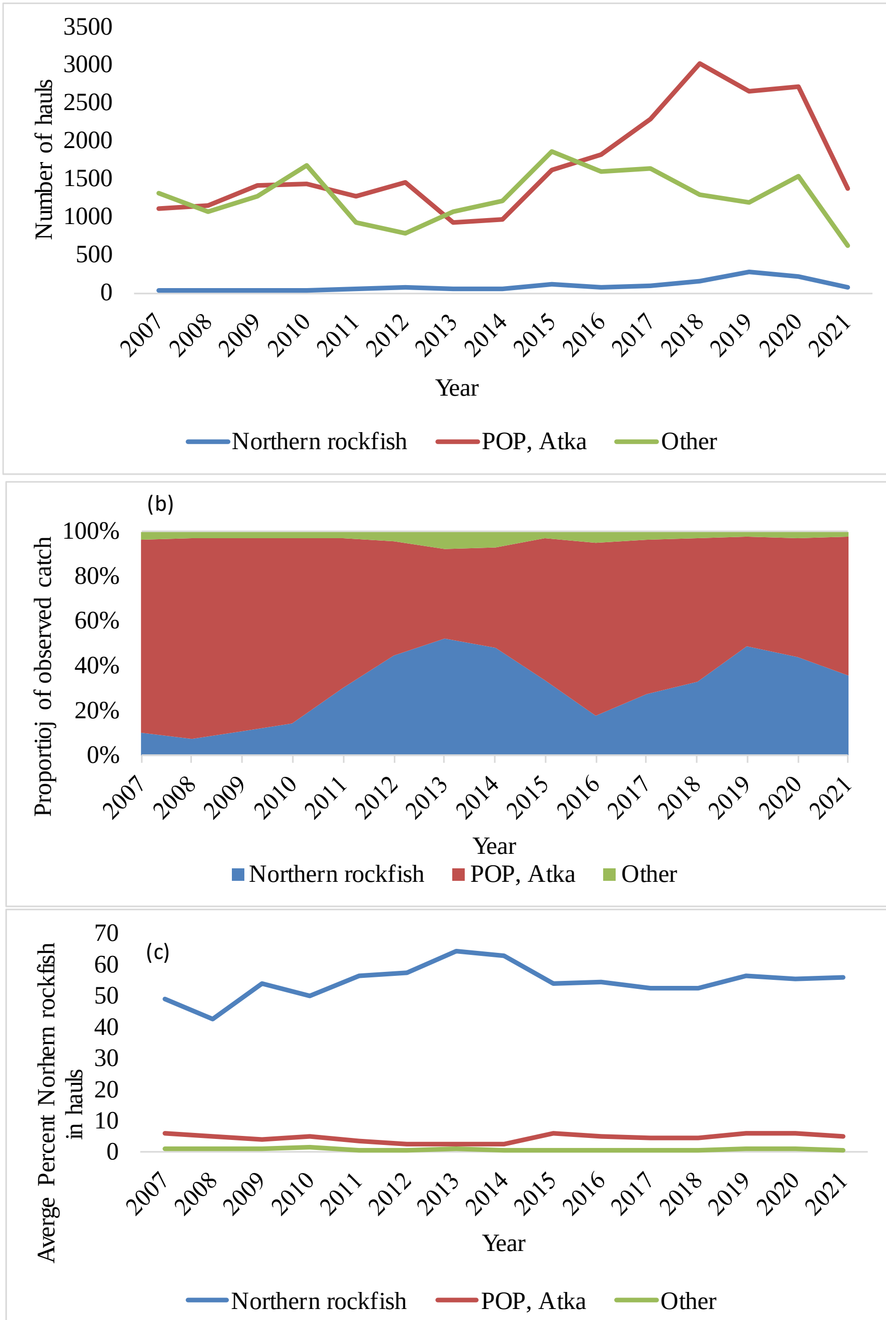

Figure 1. Number of tows, (a), percentage of observed catch (b), and average percent northern rockfish across in across hauls (c) from 2007 to 2021 (through September 10) by target fishery. Data are from the North Pacific Groundfish Observer Program.

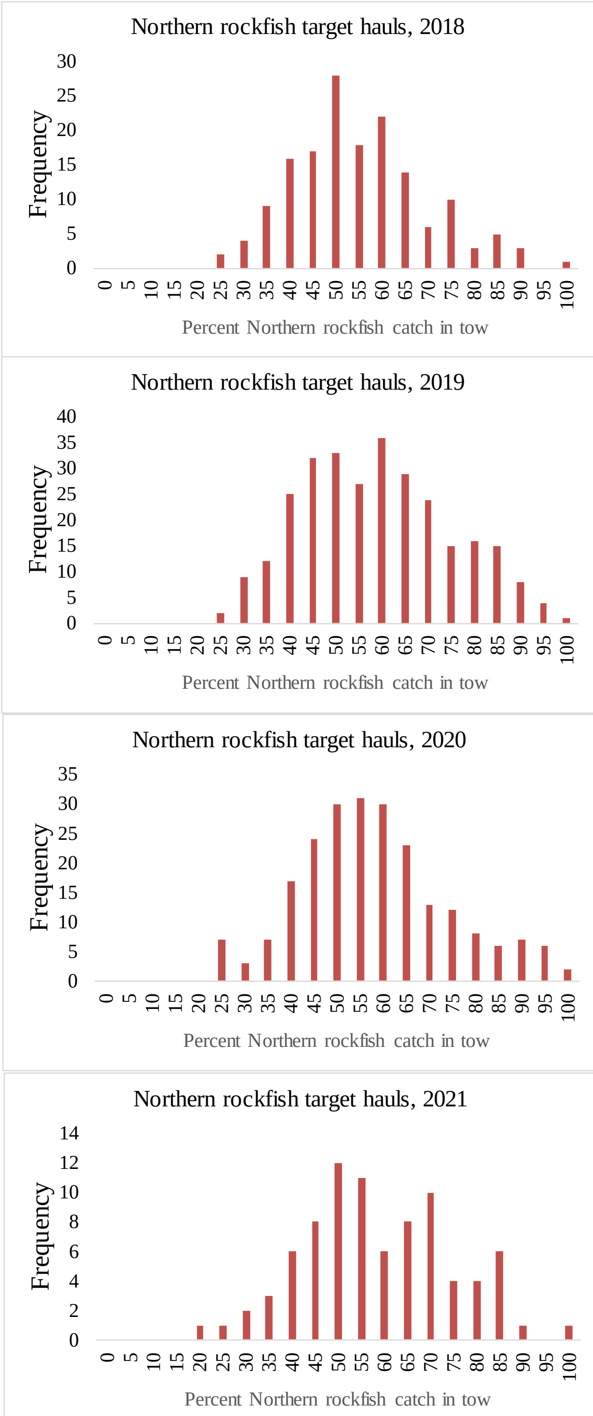

Figure 2. Distribution of the percent northern rockfish in the catch in hauls identified as targeting northern rockfish (based on species composition), from 2018 to 2021 (through September 10). Data are from the North Pacific Groundfish Observer Program.

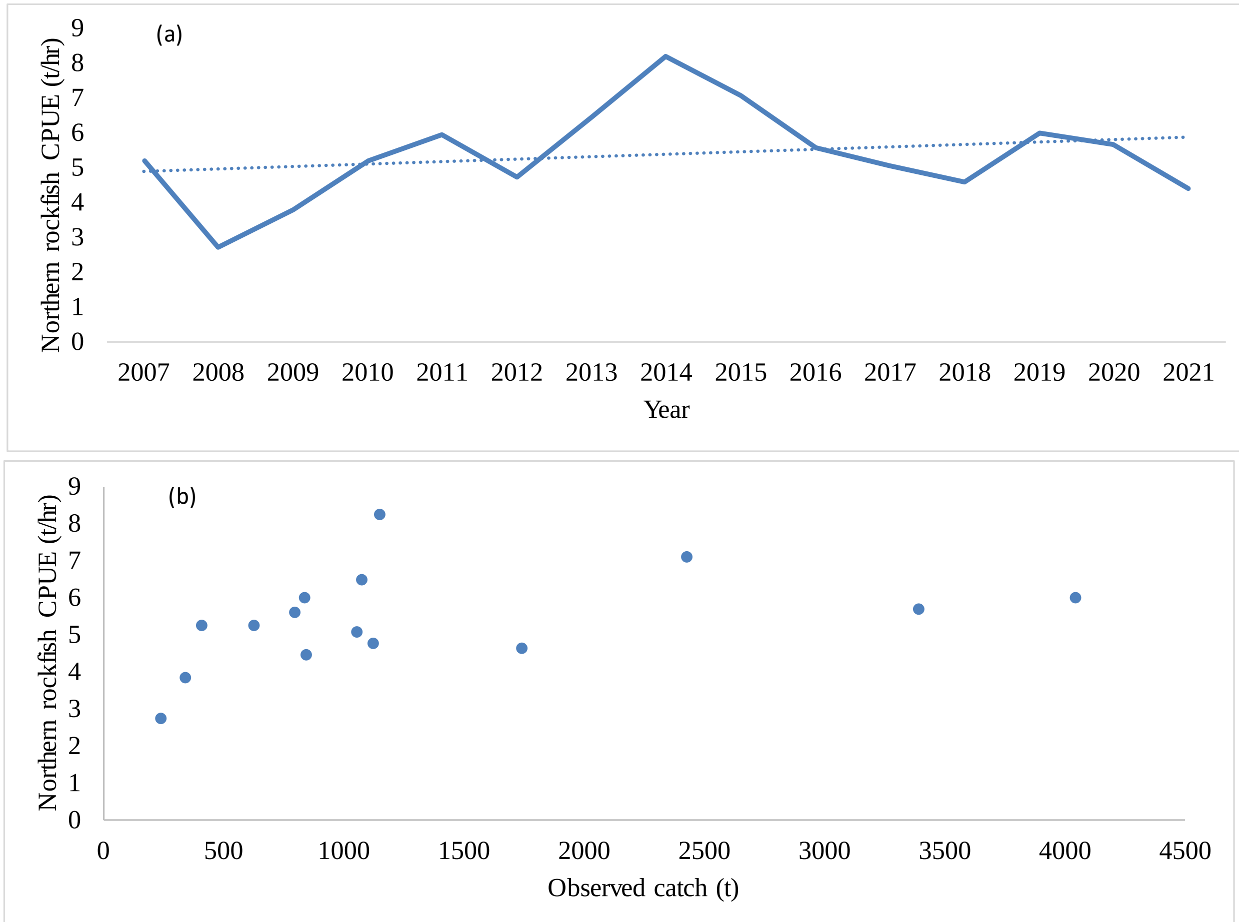

Figure 3. Catch per unit effort of northern rockfish in tows targeting northern rockfish from 2007 to 2021 (through September 25) (a), and plotted against observed catch (b). Data are from the North Pacific Groundfish Observer Program.

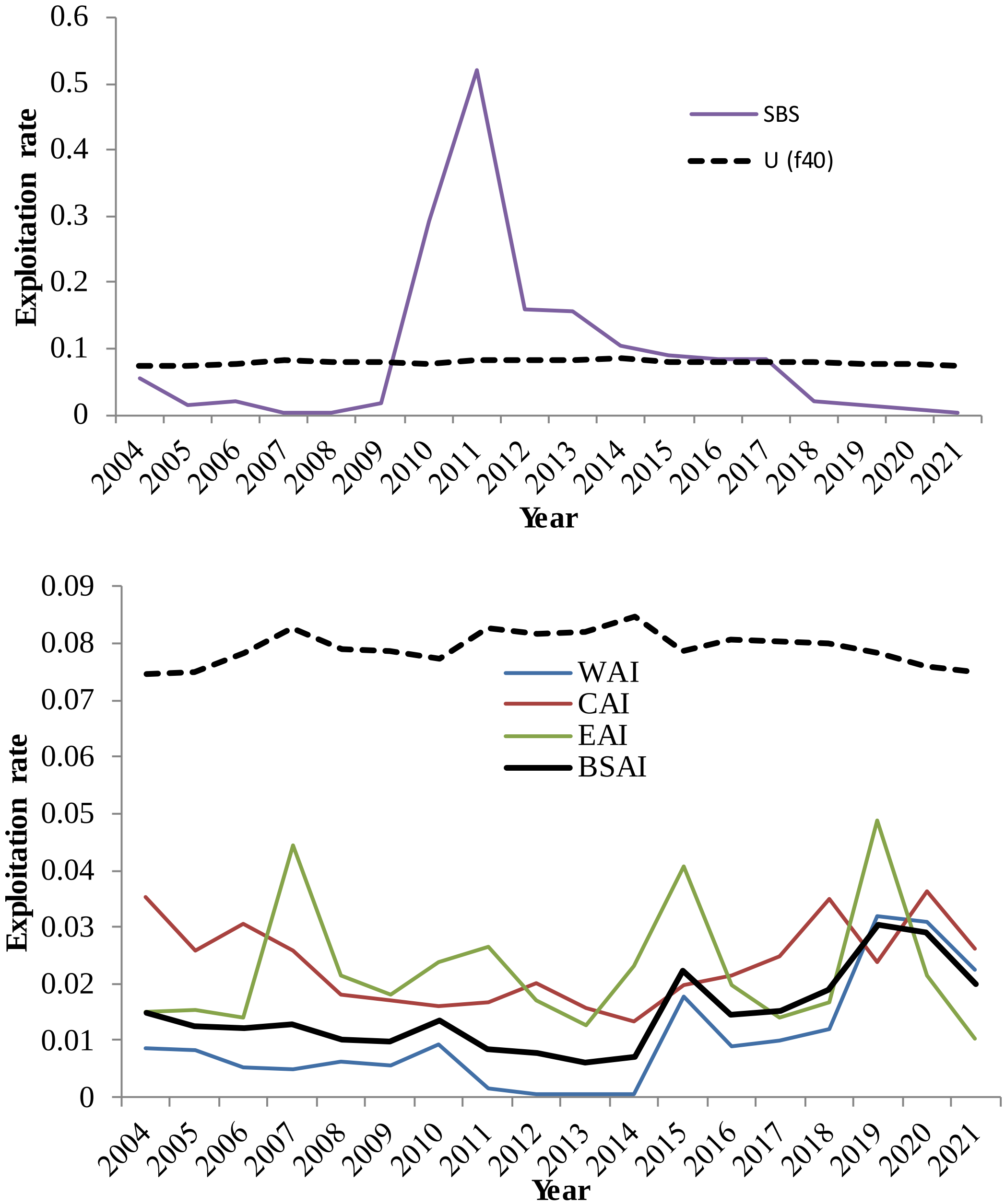

Figure 4. Exploitation rates for northern rockfish. The $U_{F40\%}$ is the exploitation rate for each year that would occur from fishing at $F_{40\%}$, and is a function of the beginning year numbers at age, size at age, and fishing selectivity. The high exploitation rates in the southern Bering Sea (SBS) area result from high variable survey biomass estimates for this area. Exploitation rates for 2021 are preliminary and based on catch through September 25, 2021.

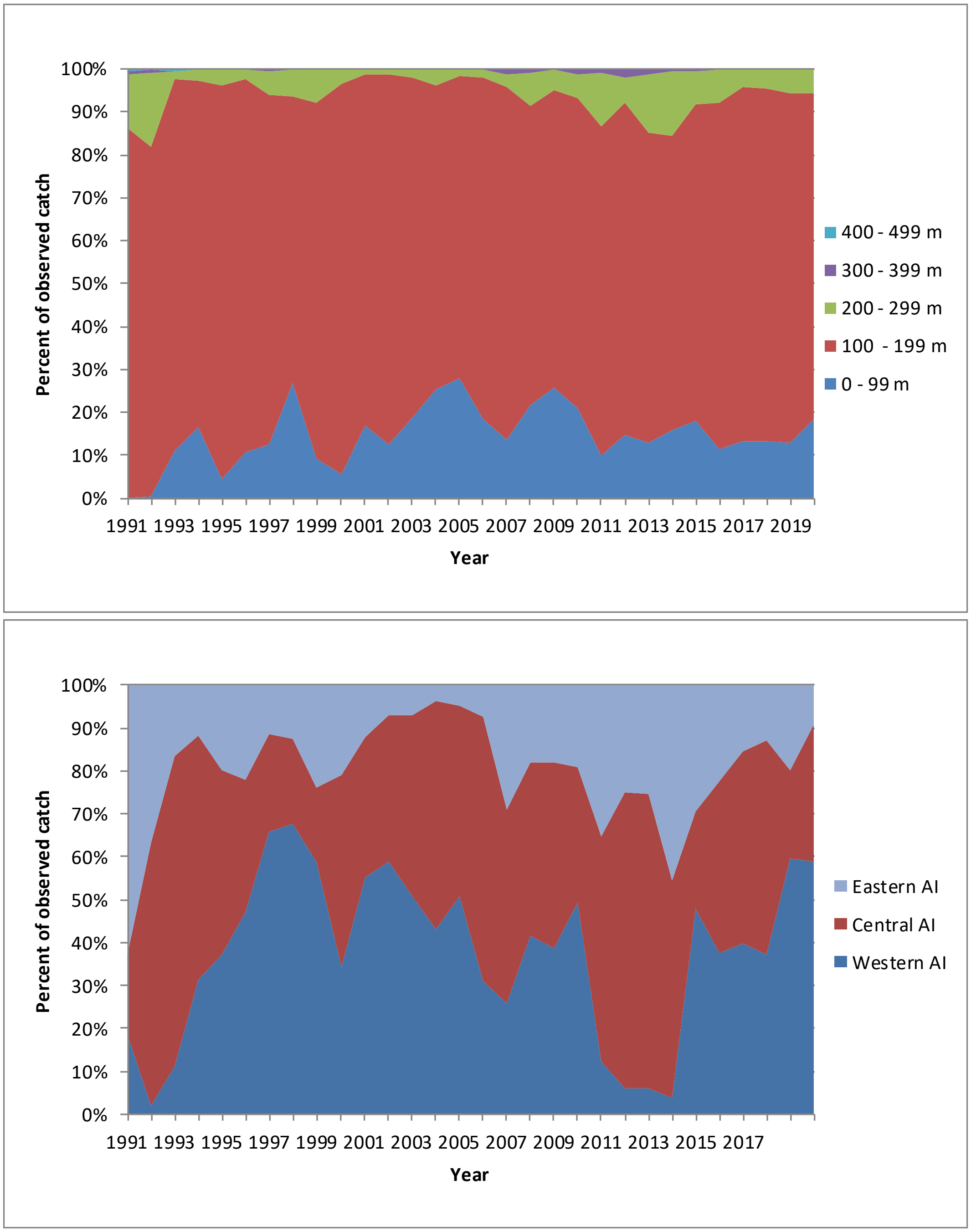

Figure 5. Distribution of observed Aleutian Islands northern rockfish catch (from North Pacific Groundfish Observer Program) by depth zone (top panel) and AI subarea (bottom panel) from 1991 to 2020.

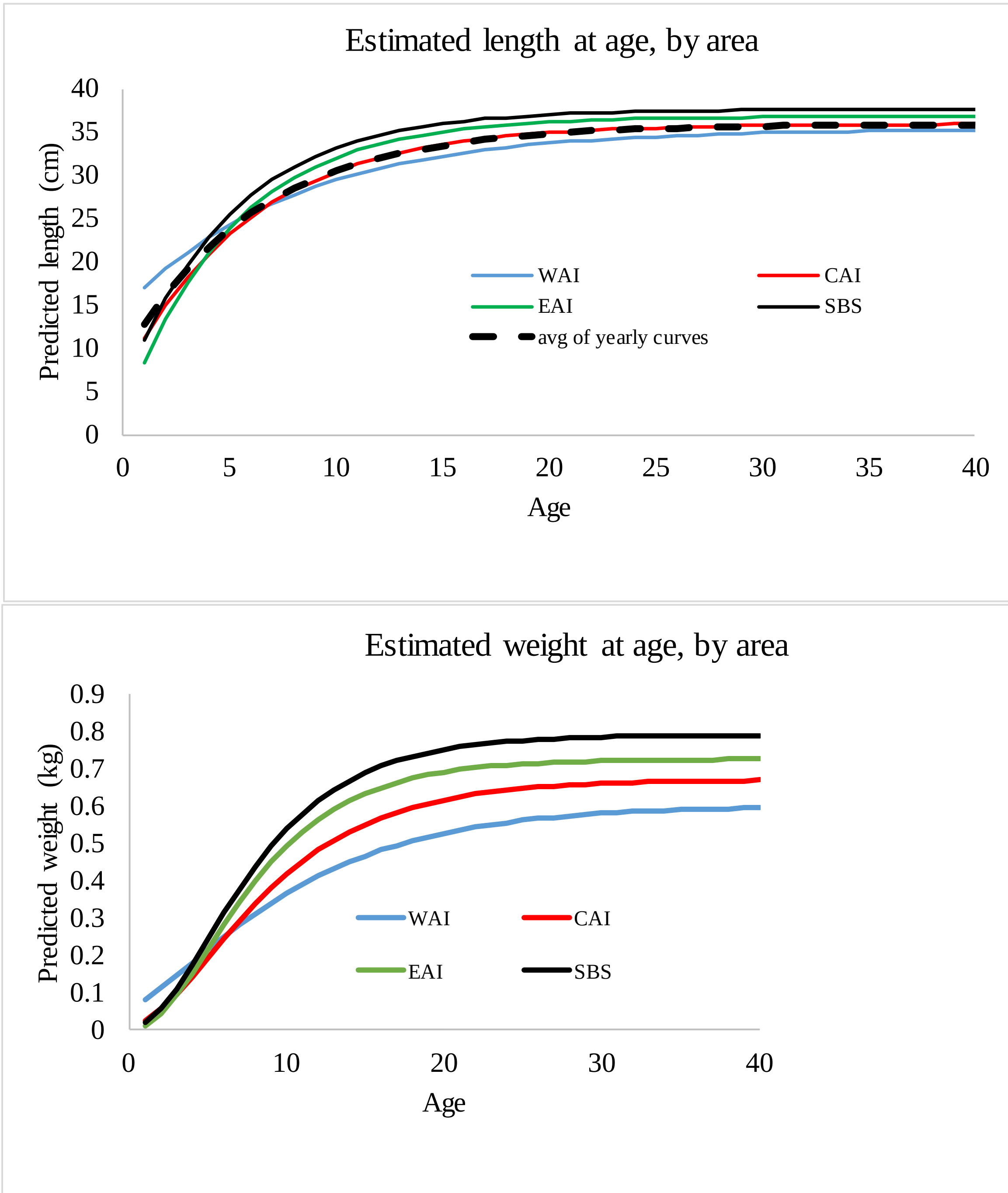

Figure 6. Estimated fishery length and size at age across the AI subareas, from fitted von Bertalanffy curves and length-weight relationships.

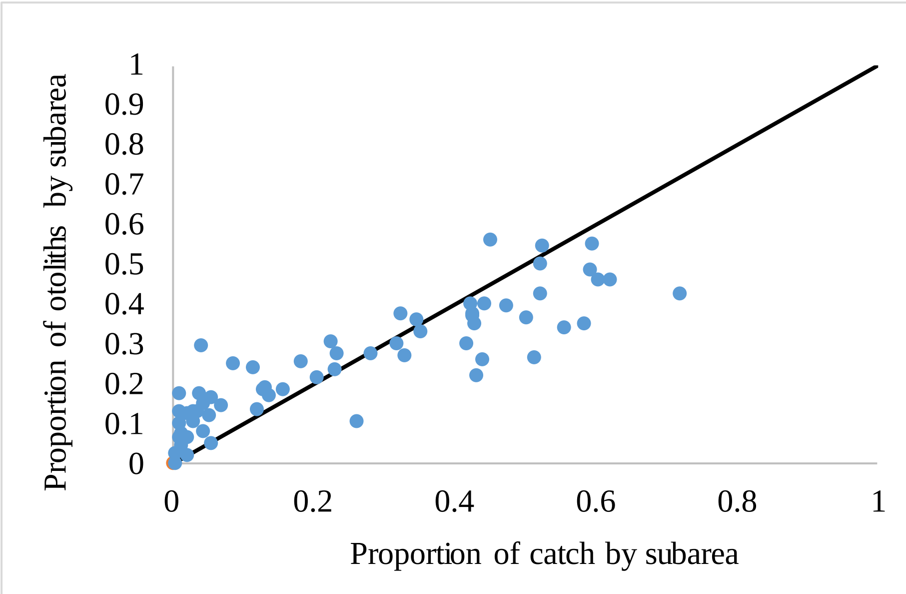

Figure 7. The proportion of the extrapolated fishery catch numbers in AI subarea (i.e., WAI, CAI, EAI, and BS, from North Pacific Groundfish Observer Program) and the proportion of the read otoliths by subarea. Random sampling of otoliths from the fishery catch would be expected to generate data near the 1:1 line (in black).

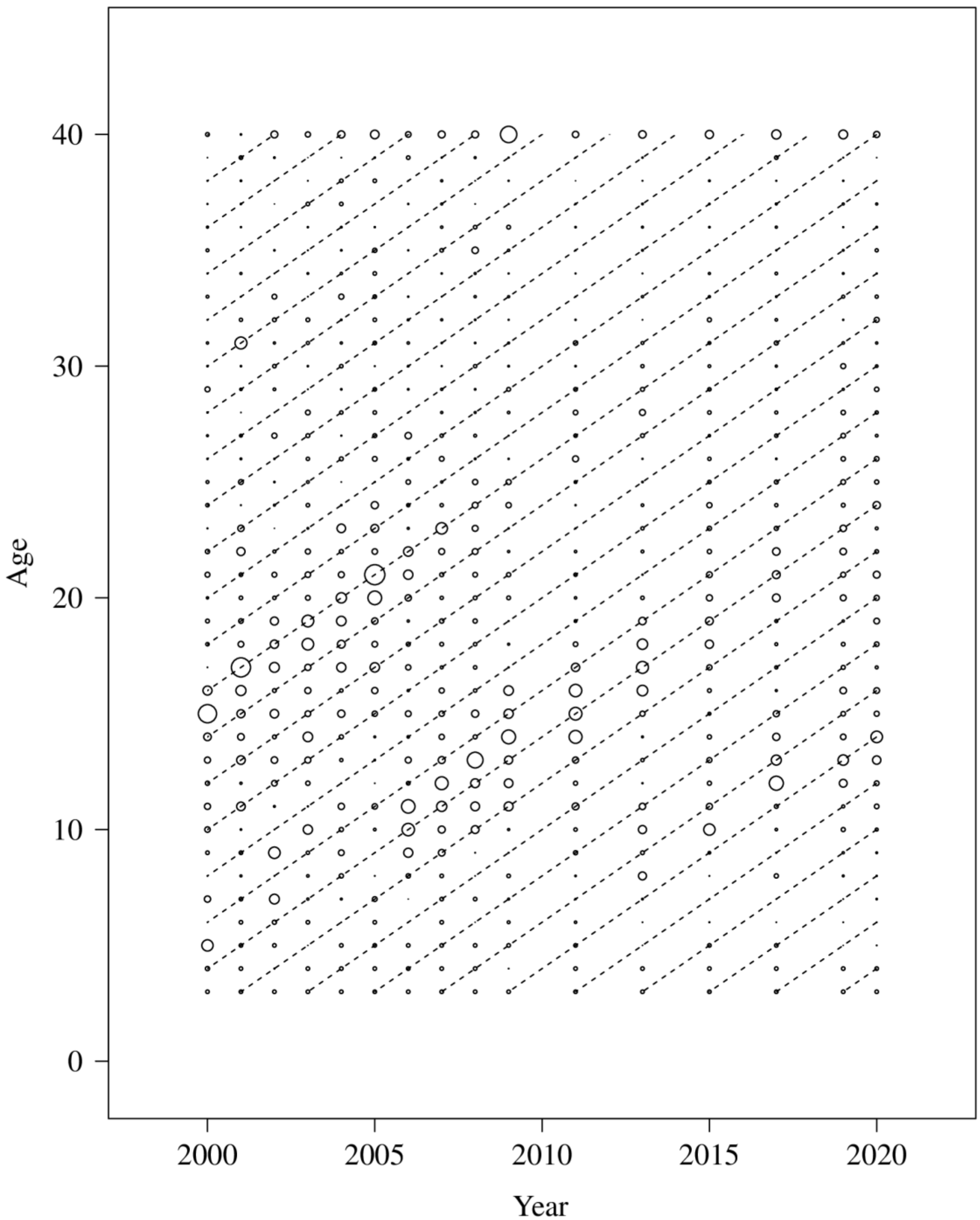

Figure 8. Fishery age composition data for the Aleutian Islands; bubbles are scaled within each year of samples; and dashed lines denote cohorts (beginning at age 3).

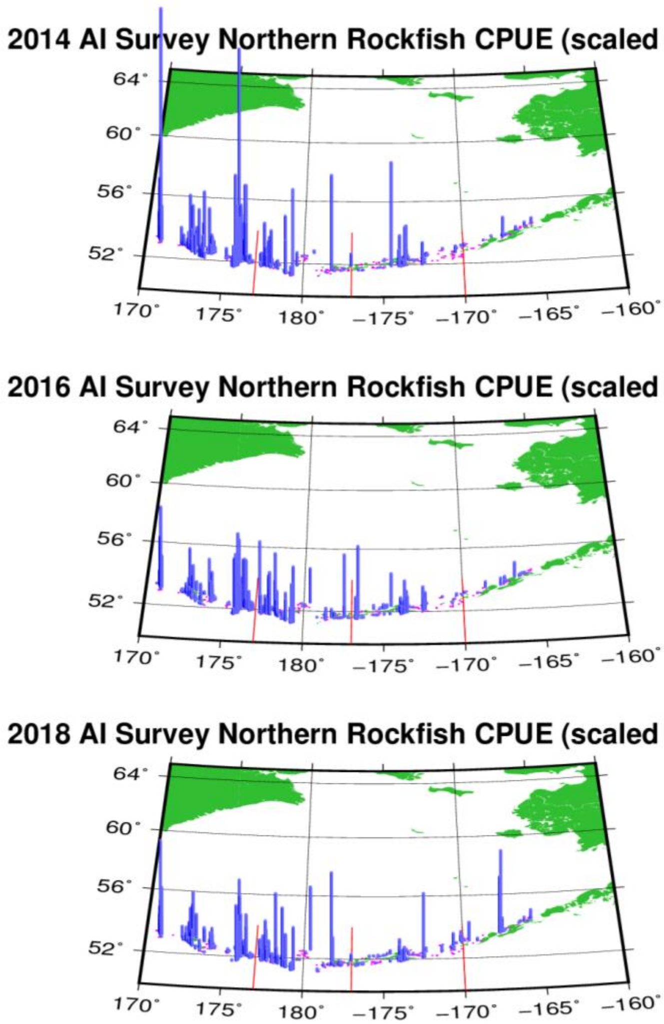

Figure 9. Scaled AI survey northern rockfish CPUE from (square root of kg/km^2) from 2014-2018; the red lines indicate boundaries between the WAI, CAI, EAI, and EBS areas.

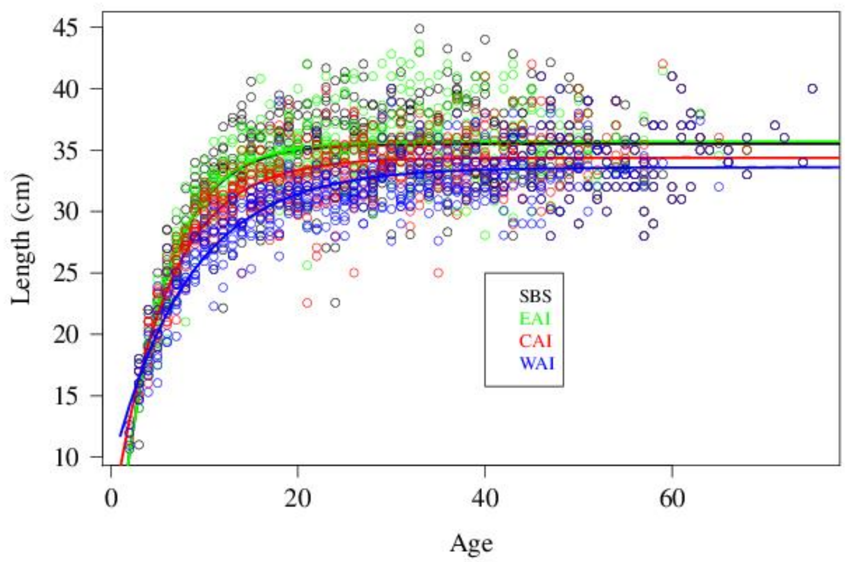

Figure 10. Estimated survey size at age across the AI subareas from fitted von Bertalannfy curves.

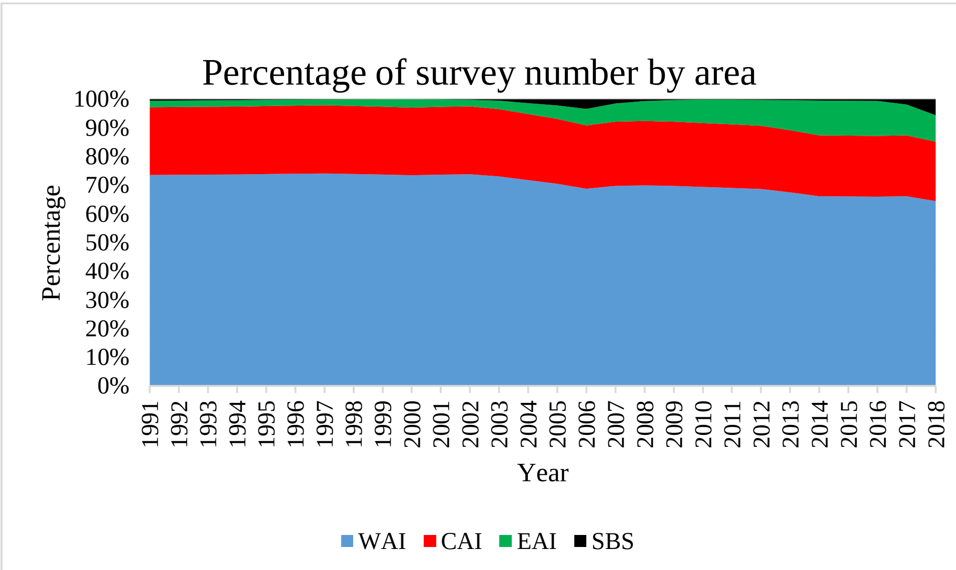

Figure 11. Proportion of northern rockfish survey abundance by area, from a smoother applied to survey estimates form 1991-2018.

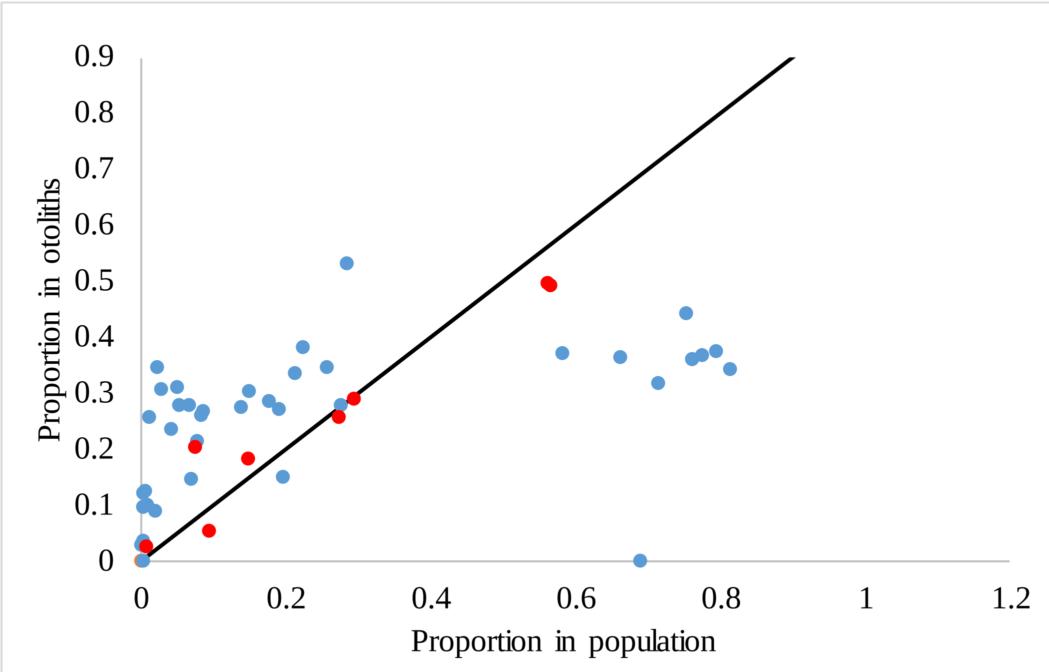

Figure 12. The proportion of the survey population abundance by AI subarea (i.e., WAI, CAI, EAI, and BS) and the proportion of the read otoliths by subarea. Random sampling of otoliths occurred in the 2016 and 2018 surveys (shown in red), which would be expected to generate data near the 1:1 line (in black).

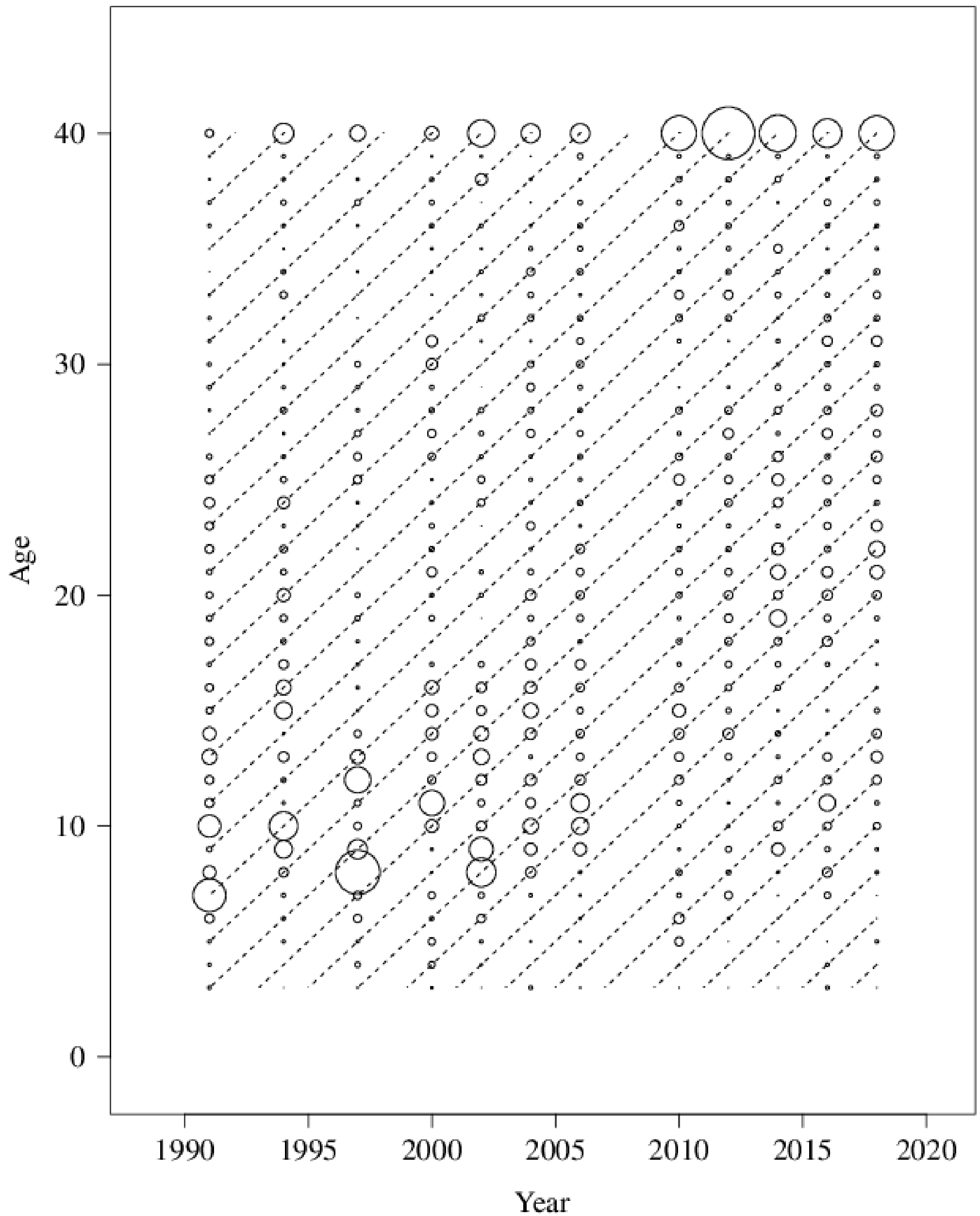

Figure 13. Age composition data from the Aleutian Islands trawl survey; bubbles are scaled within each year of samples; and dashed lines denote cohorts.

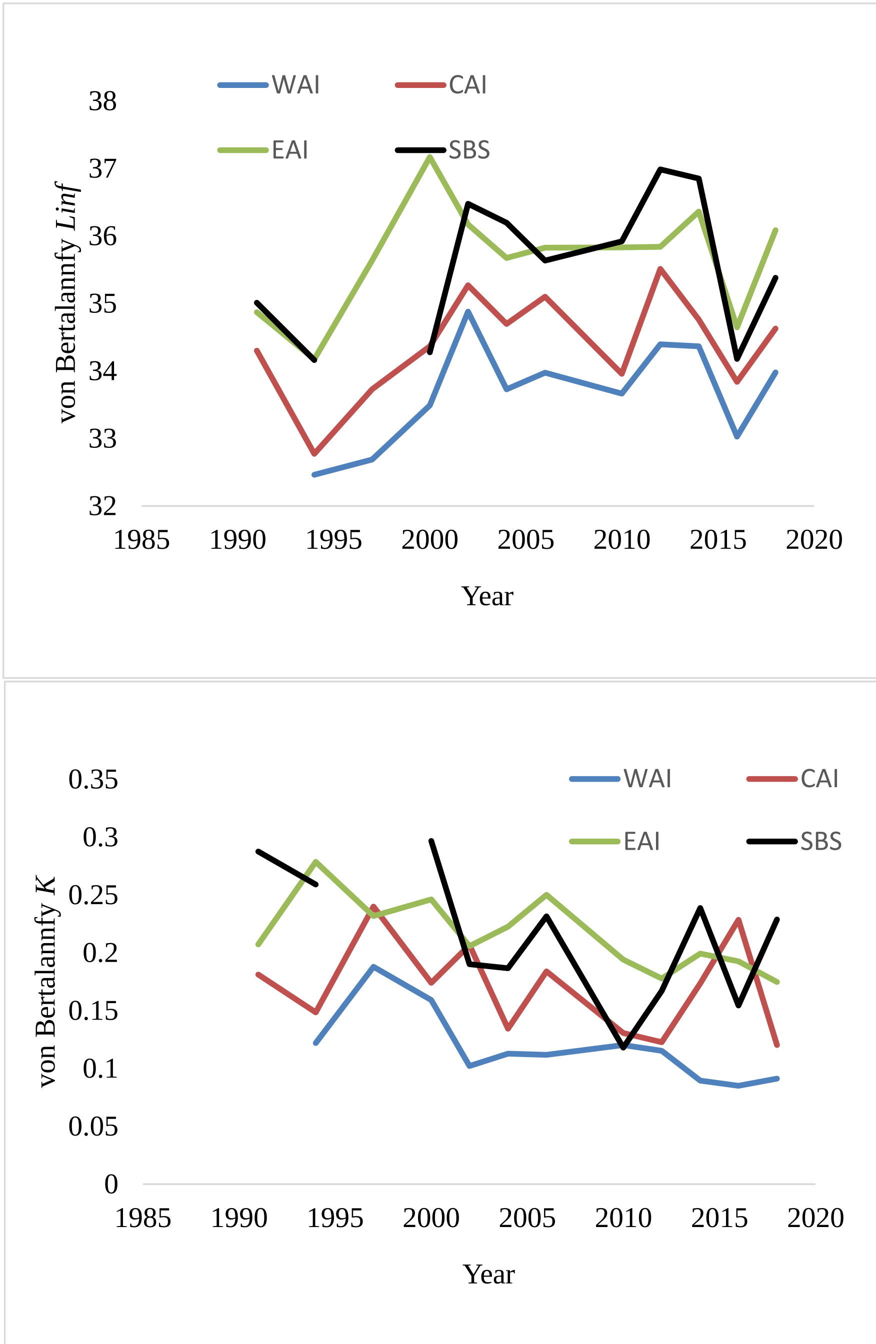

Figure 14. Estimates of von Bertalanffy parameters Linf and K by area and year for the AI trawl survey.

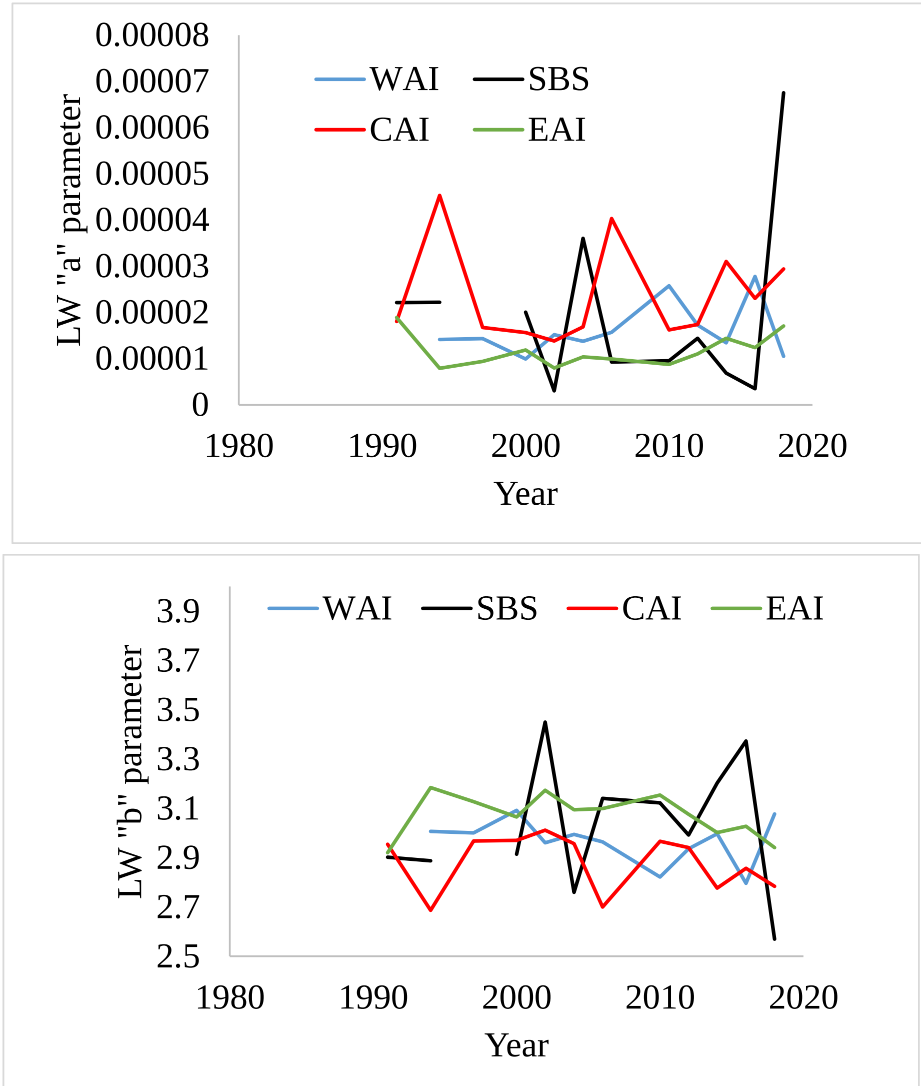

Figure 15. Estimates of the *a* and *b* parameters for the weight-length relationship ($W = aL^b$) by year and area for the AI trawl survey.

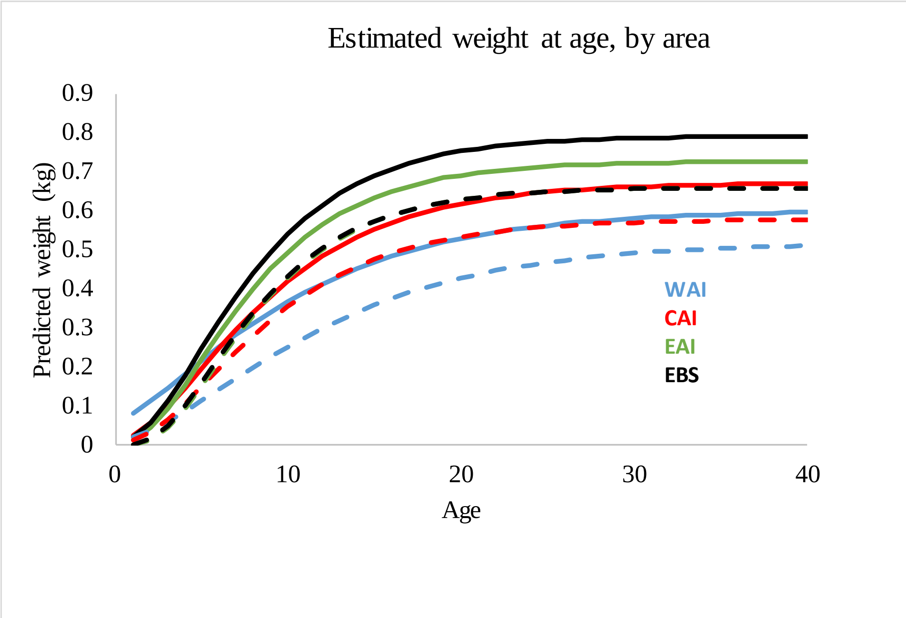

Figure 16. Estimated weights at age by area from the AI trawl survey (dashed lines), combining data across years within each area. The survey size at age for the EAI and EBS are very similar and overlay each other. For comparison, the weight at age in the fishery (solid lines) are also shown.

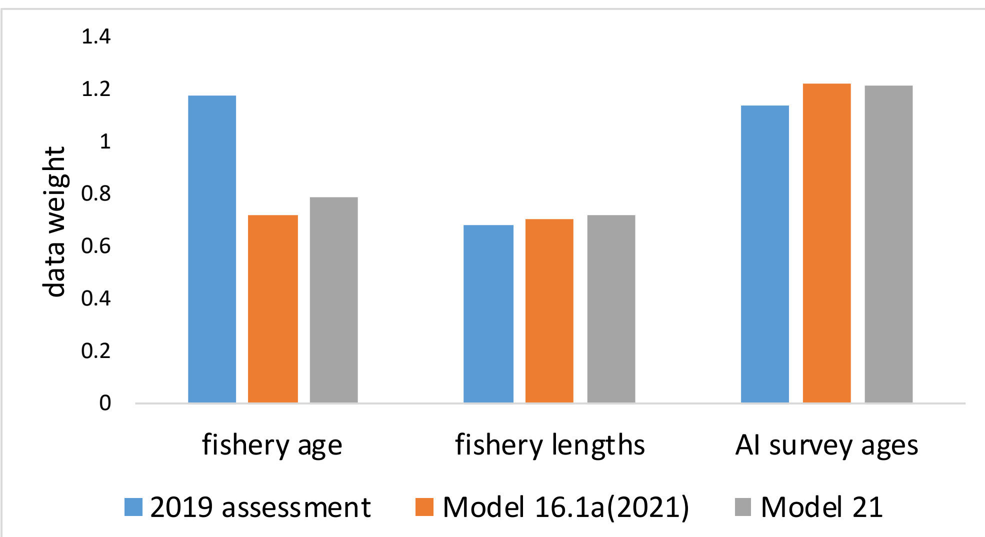

Figure 17. Data weights for the age and length composition data for the 2019 and 2021 assessments.

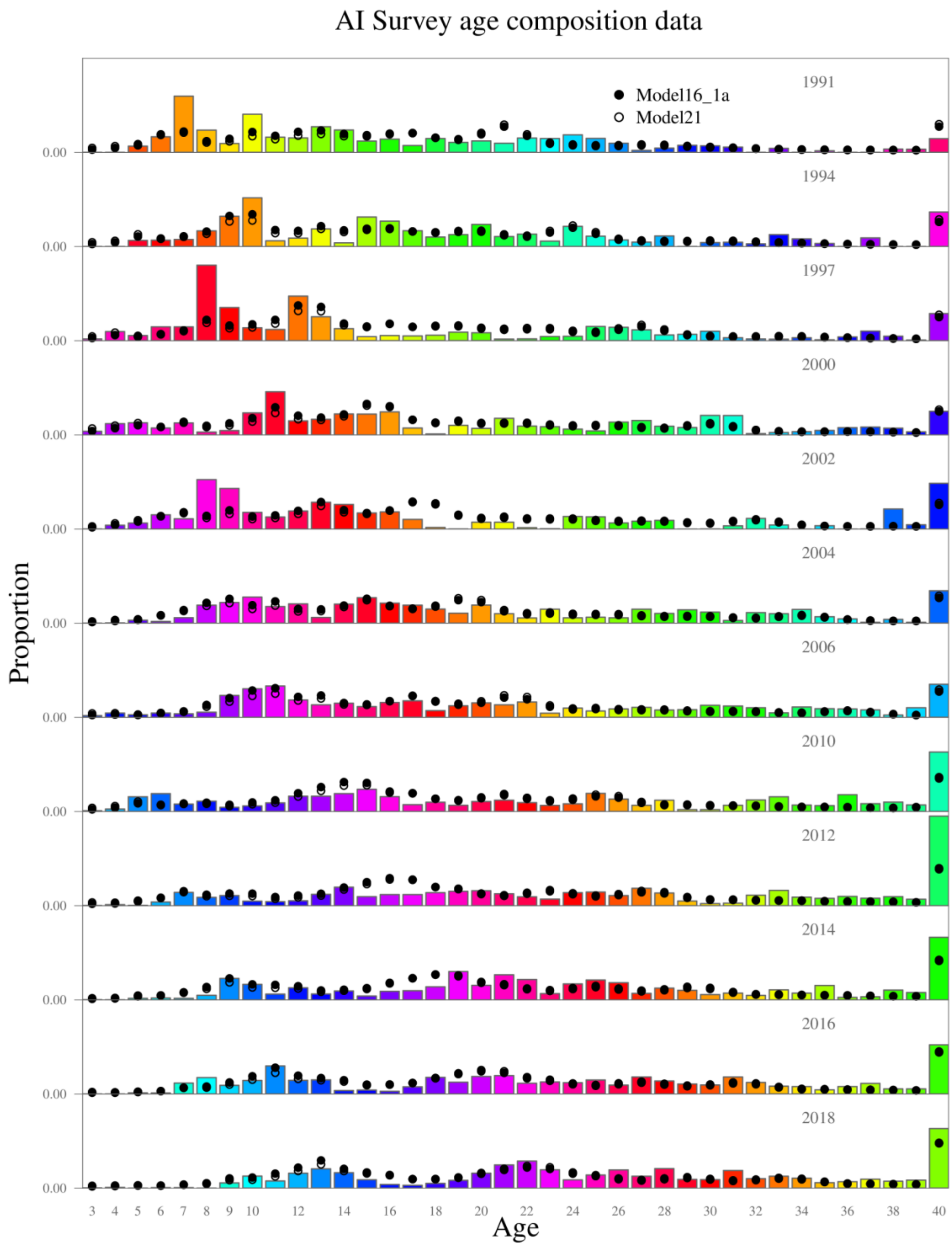

Figure 18. Fits of Model 16.1a(2021) and Model 21 to the survey age composition data.

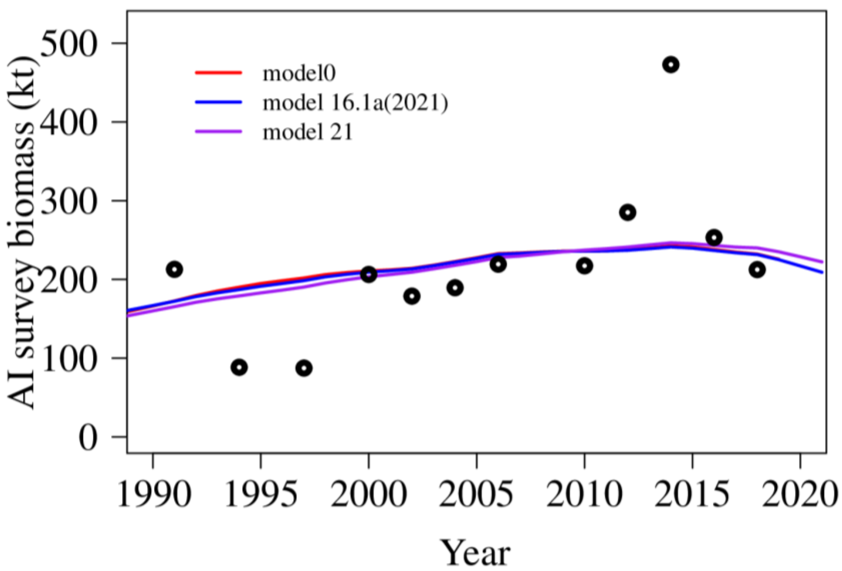

Figure 19. Fits of Model 16.1a(2021) and Model 21 to the survey biomass index; for comparison, the results from the 2019 assessment are also shown and are very similar to Model 16.1a(2021).

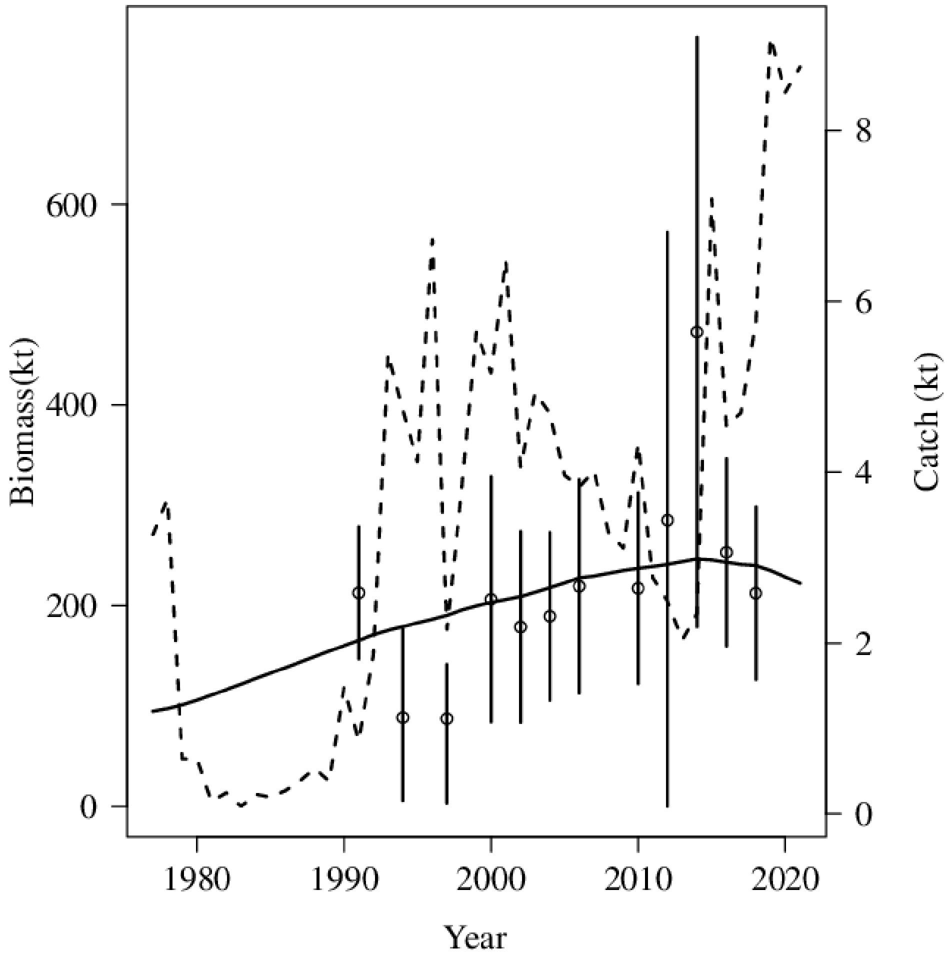

Figure 20. Observed Aleutian Islands survey biomass (data points, ± 2 standard deviations), predicted survey biomass (solid line) and BSAI harvest (dashed line).

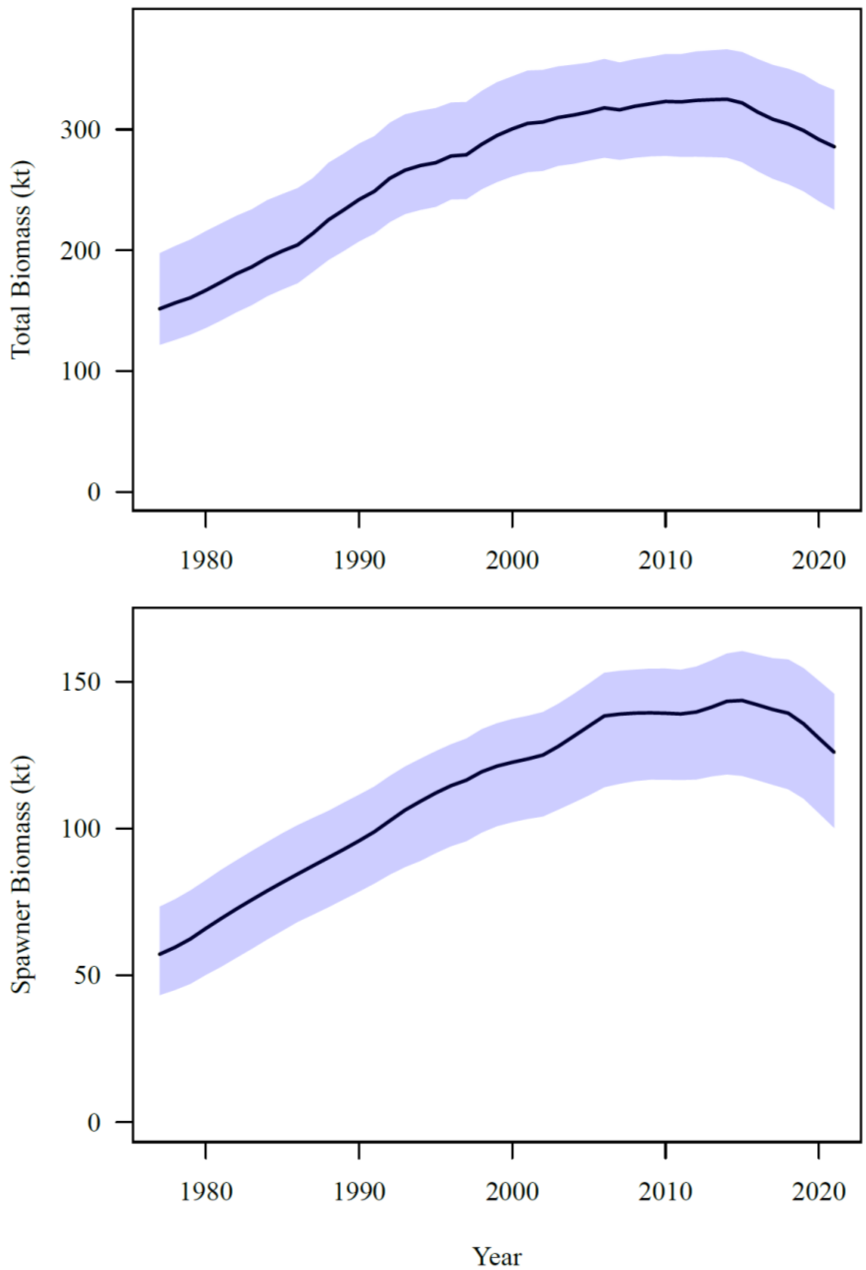

Figure 21. Total and spawner biomass for BSAI northern rockfish with 95% credible intervals from MCMC integration.

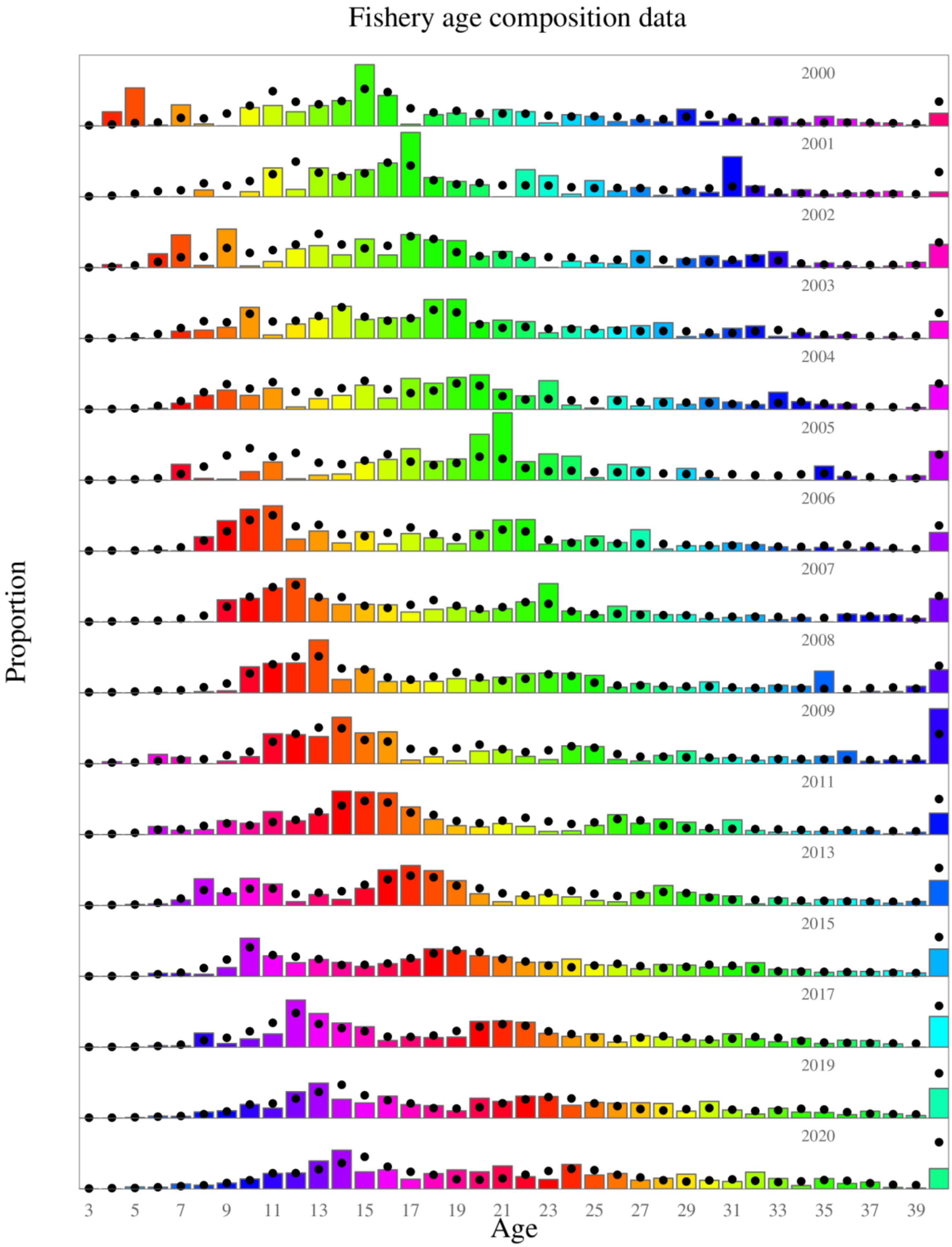

Figure 22. Model fits (dots) to the fishery age composition data (columns) for BSAI northern rockfish. Colors of the bars correspond to cohorts (except for the 40+ group).

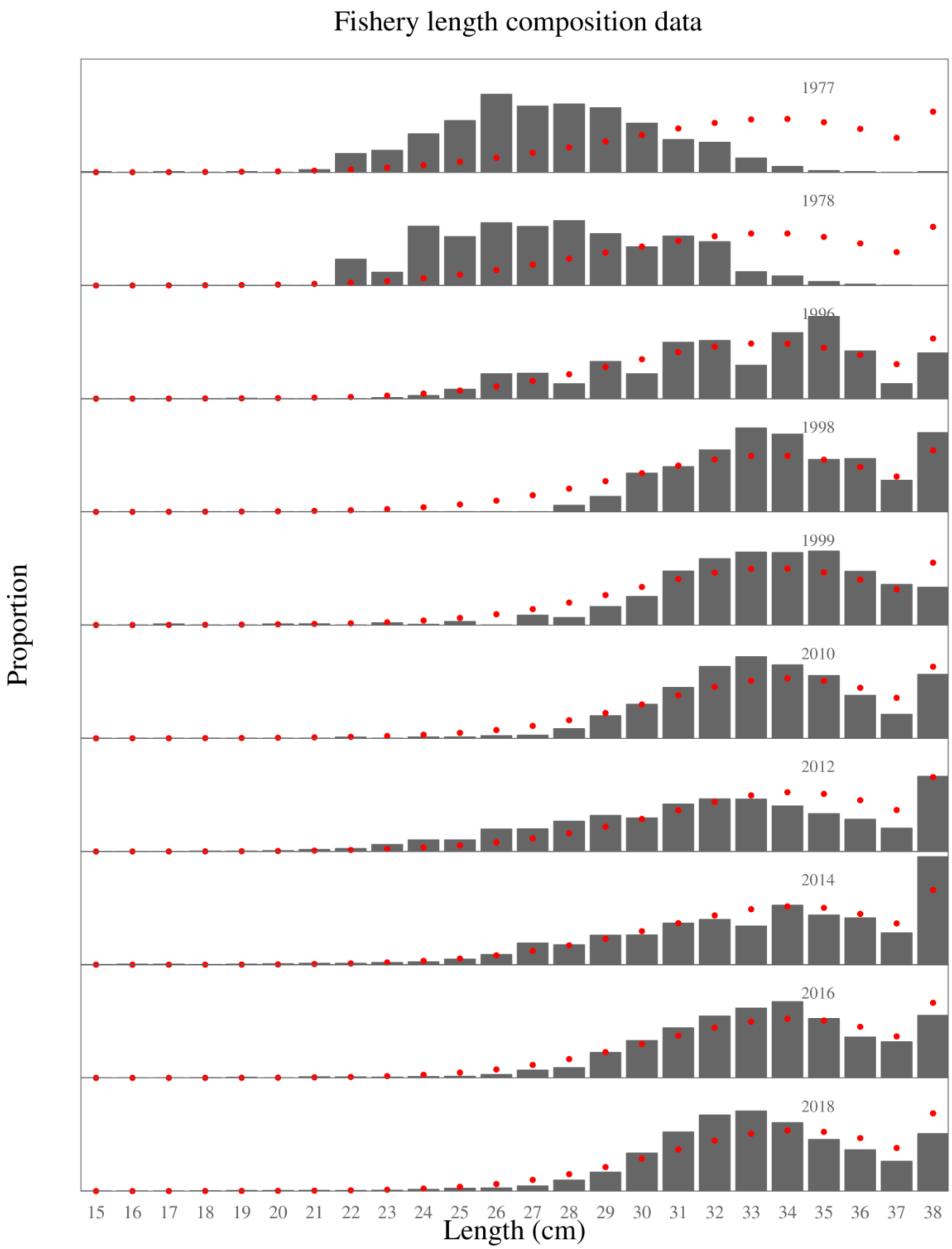

Figure 23. Model fits (dots) to the fishery length composition data (columns) for BSAI northern rockfish.

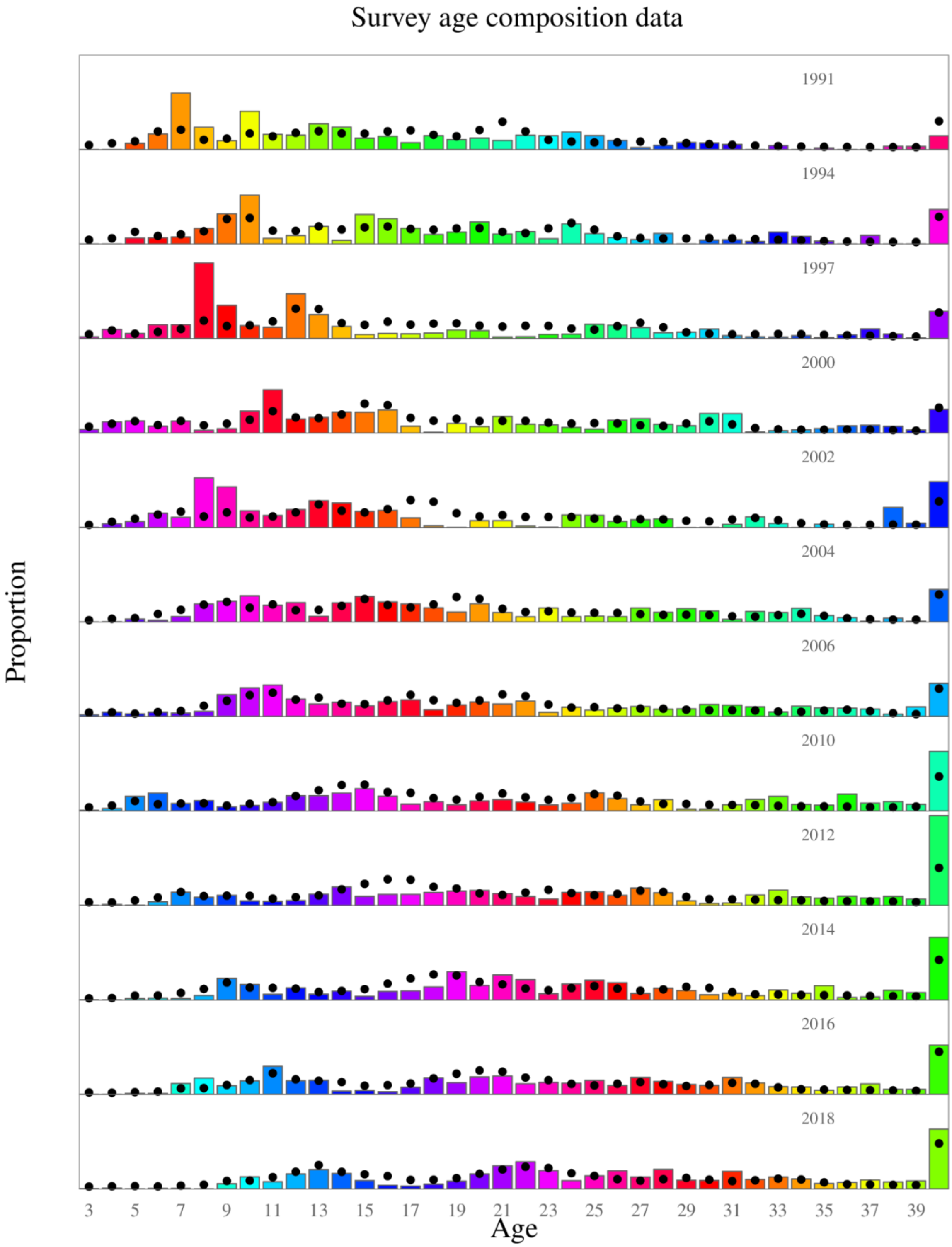

Figure 24. Model fits (dots) to the survey age composition data (columns) for BSAI northern rockfish. Colors of the bars correspond to cohorts (except for the 40+ group).

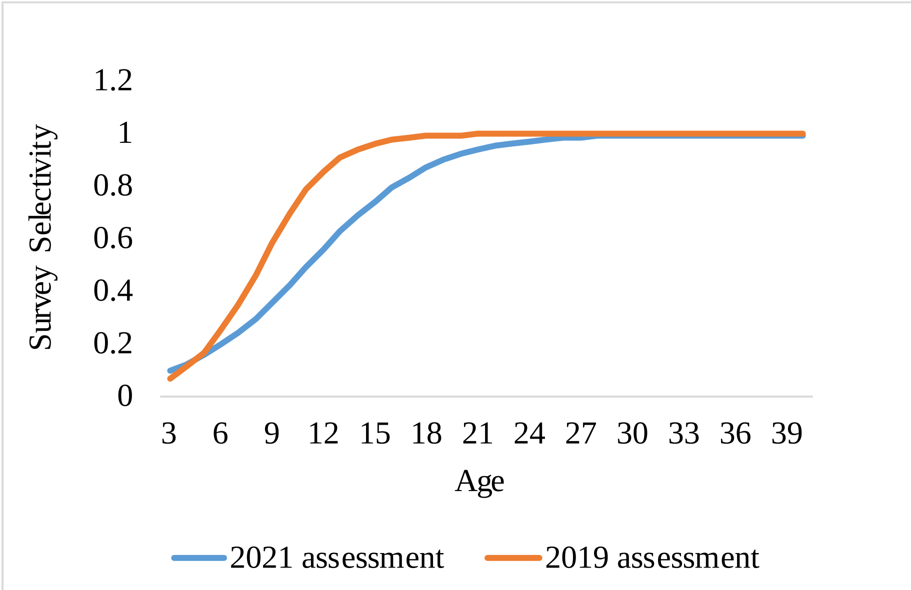

Figure 25. Survey selectivity curves for the 2019 and 2021 assessments.

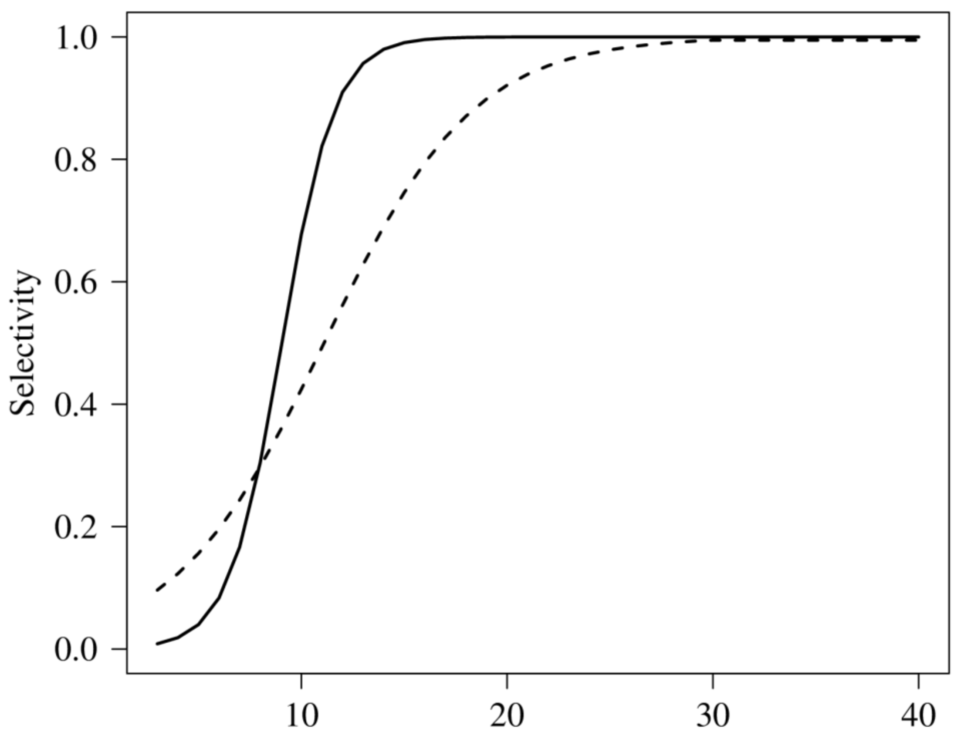

Figure 26. Estimated fishery (solid line) and survey (dashed line) selectivity at age for BSAI northern rockfish.

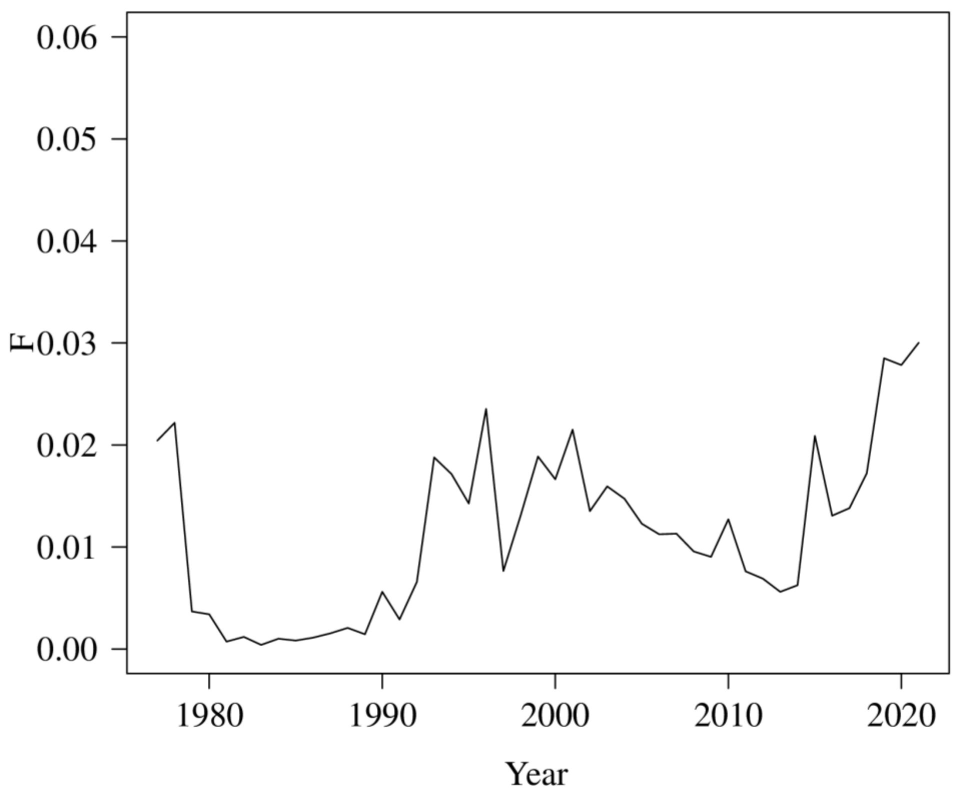

Figure 27. Estimated fully-selected fishing mortality rate for BSAI northern rockfish.

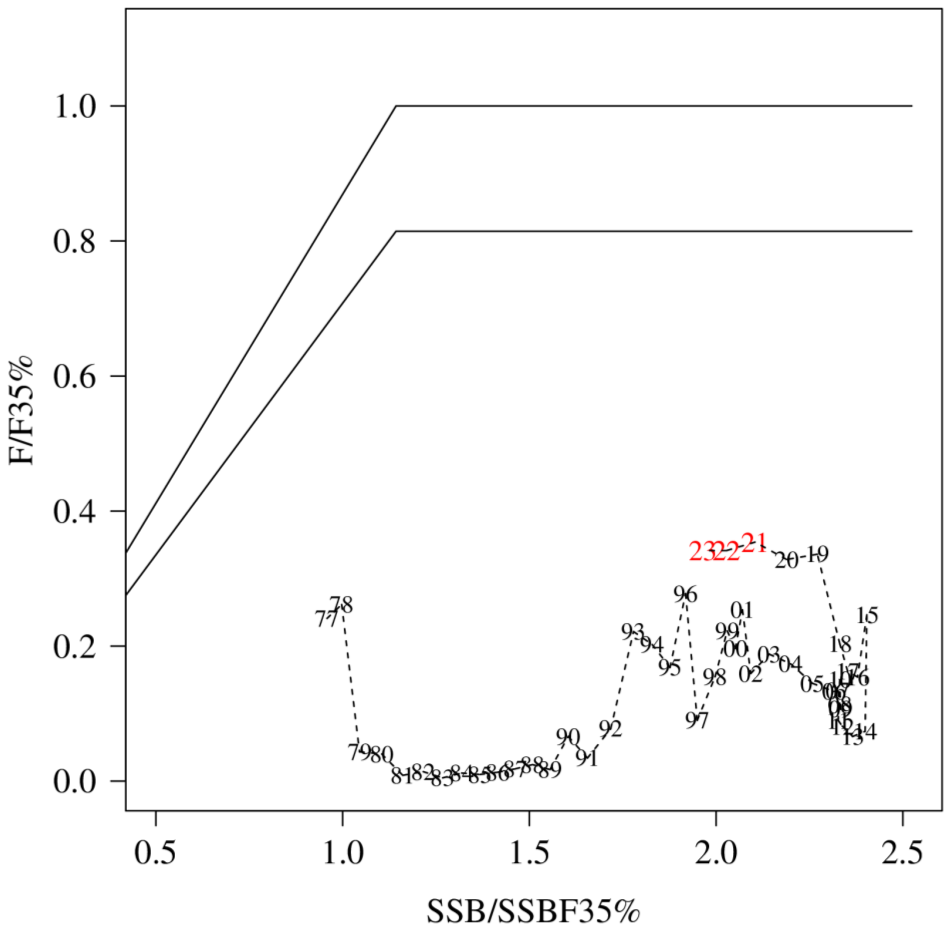

Figure 28. Estimated fishing mortality and SSB from 1977-2023 in reference to OFL (upper line) and ABC (lower line) harvest control rules (values for 2022 and 2023 are based on projections).

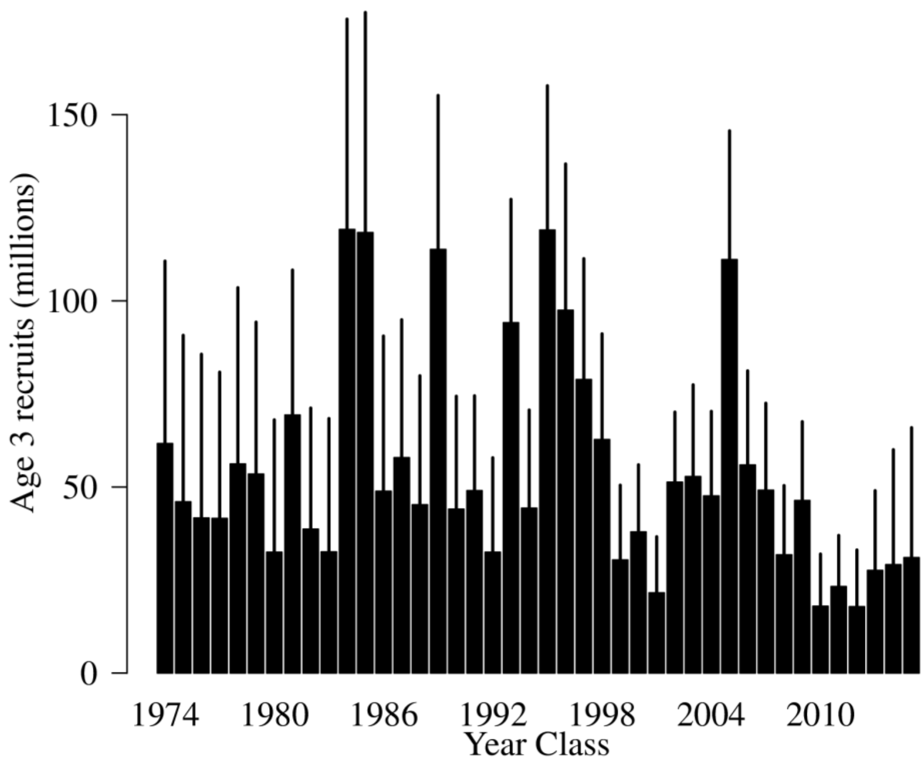

Figure 29. Estimated recruitment (age 3) of BSAI northern rockfish, with 95% CI limits obtained from MCMC integration.

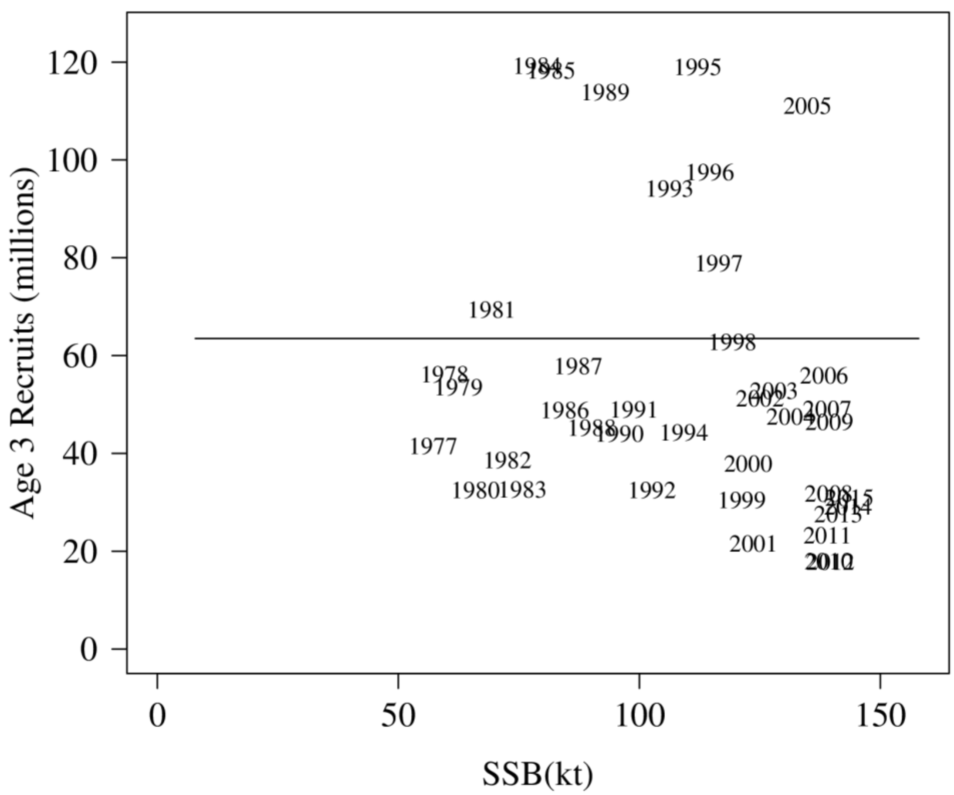

Figure 30. Scatterplot of BSAI northern rockfish spawner-recruit data; label is year class.

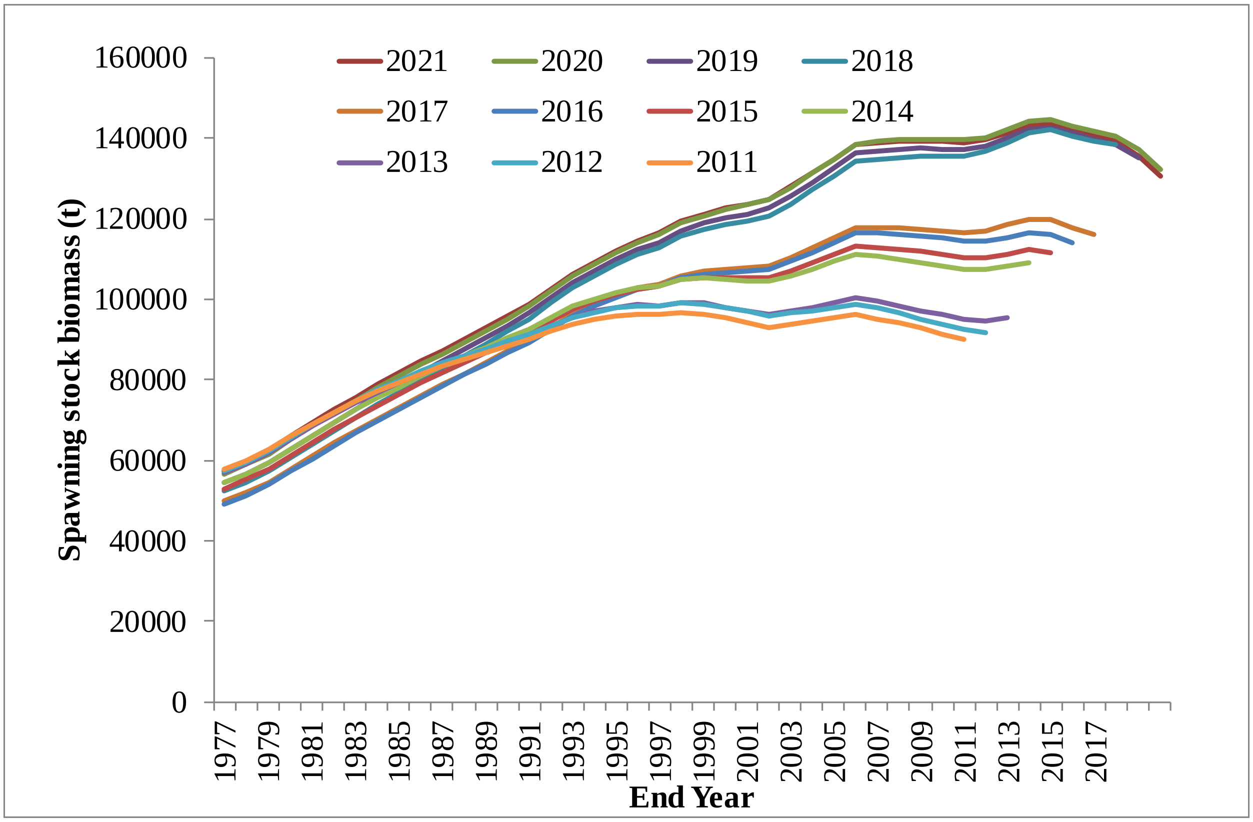

Figure 31. Retrospective estimates of spawning stock biomass for model runs with end years of 2011 to 2021.

Appendix A. Calculation of weighted age compositions.

Beginning in the 2019 BSAI northern rockfish assessment, the age compositions (both survey and fishery) have been calculated by first computing subarea age compositions (i.e., from subarea age-length keys and length compositions), and then taking an average of the subarea age compositions, weighted by either estimated subarea abundance or catch. During the presentation of the 2019 assessment to the Plan Team, we hypothesized that computing a single age-length key, but with the information on the distribution of age for each length weighted by the population abundance (rather than otolith sample size) would be an alternative approach of integrating across subareas. The purpose of this assessment is to show that these two approaches are mathematically equivalent. This appendix is pertains to the survey compositions, but replacing "abundance" with "catch" below would produce an identical result for the fishery age composition.

First, define the following:

N_s = estimated total abundance in subarea *s*.
N_{sj} = estimated total abundance in subarea *s* within length category *j*.
$l_{sj} = N_{sj} / N_s$ = the estimated proportion of the abundance in subarea *s* with length category *j*.
n_{sj}^*= number of fish in subarea *s* in length category *j* that are aged.
m_{sij}= number of the n_{sj}^* fish of age *i*.
$q_{sij}' = m_{sij} / n_{sj}^*$

q_{sij}' is the estimated proportion of fish in subarea *s* of length category *j* that are age *i*, or the entries in the age-length key.

The estimated proportion of the population of age *i* is

$$p_{si} = \sum_{j=1}^{n_l} l_{sj} q_{sij}' \qquad \text{Eq. 1}$$

where n_l is the number of length categories. Equation 1 is the standard application of the age-length key applied to a particular subarea, with the exception of using the estimated total abundance by size category (obtained from survey estimates of abundance and size composition, weighting tows by their CPUE, and scaling up to the area surveyed) rather than a random sample of lengths from the population.

Computing p_i for each subarea *s* and taking an average weighted by the subarea population sizes is calculated as

$$p_i = \sum_s \frac{N_s}{N} \sum_{j=1}^{n_l} l_{sj} q_{sij}' \qquad \text{Eq. 2}$$

where *N* is the estimated total abundance across the subareas.

Alternatively, we could produce single age-length key (q_{ij}'') that reflects the differences in population size across the subareas:

$$q_{ij}'' = \sum_s \frac{N_{sj}}{N_j} q_{sij}'$$

where N_j is the estimated total abundance in length category j across the subareas. Application of the age-length key then yields

$$p_i = \sum_{j=1}^{n_l} l_j q''_{ij} = \sum_{j=1}^{n_l} \frac{N_j}{N} q''_{ij} = \sum_{j=1}^{n_l} \frac{N_j}{N} \sum_s \frac{N_{sj}}{N_j} q'_{sij} \qquad \text{Eq. 3}$$

where $l_j = N_j/N$ and is the estimated proportion of the population across all subareas in length category j.

Simplifying and re-expressing Eq. 3:

$$p_i = \sum_{j=1}^{n_l} \frac{N_j}{N} \sum_s \frac{N_{sj}}{N_j} q'_{sij}$$

$$p_i = \sum_{j=1}^{n_l} \frac{1}{N} \sum_s N_{sj}\, q'_{sij}$$

$$p_i = \frac{1}{N} \sum_{j=1}^{n_l} \sum_s N_{sj}\, q'_{sij}$$

$$p_i = \frac{1}{N} \sum_s \sum_{j=1}^{n_l} N_{sj} q'_{sij}$$

$$p_i = \sum_s \frac{1}{N} \sum_{j=1}^{n_l} N_{sj} q'_{sij}$$

$$p_i = \sum_s \frac{N_s}{N} \sum_{j=1}^{n_l} \frac{N_{sj}}{N_s} q'_{sij}$$

$$p_i = \sum_s \frac{N_s}{N} \sum_{j=1}^{n_l} l_{sj} q'_{sij}$$

which is equivalent to Eq. 2.

Appendix B. 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 t and 140 t between 2010 and 2020, 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.

Year	Source	Trawl	Longline
1977	NMFS-AFSC survey databases		
1978		0.000	
1979		0.012	
1980		3.576	
1981		0.059	
1982		0.898	
1983		29.285	
1984		0.095	
1985		0.021	
1986		56.895	
1987		0.168	
1988		0.130	
1989		0.062	
1990		0.740	
1991		15.470	
1992		0.077	
1993		0.001	
1994		13.155	
1995		0.015	
1996		0.001	0.034
1997		17.728	
1998		0.252	0.004
1999		0.089	
2000		39.883	0.002
2001		0.038	0.006
2002		36.657	0.011
2003		0.124	0.002
2004		56.763	0.005
2005		0.002	0.002
2006		41.112	0.059
2007		0.172	0.008
2008		0.026	0.008
2009		0.005	0.023
2010	AKFIN database	50.354	0.000
2011		140.163	0.014
2012		89.765	0.010
2013		0.014	0.000
2014		69.154	0.000
2015		0.010	0.000
2016		52.211	0.069
2017		0.043	0.004
2018		49.451	0.000
2019		0.021	0.000
2020		0.000	0.000