18. Assessment of the skate stock complex in the Bering Sea and Aleutian Islands

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Executive Summary

The Bering Sea and Aleutian Islands (BSAI) skate stock complex is managed in aggregate, with a single set of harvest specifications applied to the entire complex. However, to generate the harvest recommendations the stock is divided into two units. Harvest recommendations for Alaska skate *Bathyraja parmifera*, the most abundant skate species in the BSAI, are made using the results of an age-structured model and are managed under Tier 3. The remaining species (Other skates) are managed under Tier 5 due to a lack of data. The Tier 3 and Tier 5 recommendations are combined to generate recommendations for the complex as a whole.

BSAI skates are assessed on a biennial stock assessment schedule. An operational assessment is conducted in even years, and in odd years a harvest projection is produced.

Summary of Changes in Assessment Inputs

Changes in the input data:

1) Catch data have been updated through October 1, 2023. Total catch for 2023 was estimated by the mean proportion of catch occurring after October 1 over the last 5 years.
2) The time series of eastern Bering Sea (EBS) shelf bottom trawl survey biomass estimates from 2000 – 2019 were updated to reflect updates to the design-based estimator.
3) 2022 Aleutian Islands (AI) and 2021 – 2023 EBS bottom trawl survey data were included.
4) Survey length compositions from the 2021-2023 EBS shelf bottom trawl survey were included.

Changes in assessment methodology:

There were no changes to the assessment methodology. However, the Tier 3 Alaska skate model, Model 14.2, was migrated from SS3 v3.23 to SS3 v3.30.21 and some changes to historical data were incorporated. This was done in a series of bridging steps and the updated model, Model 14.2d was sufficiently consistent with Model 14.2 that it is not considered a model change. The updated model, Model 14.2d, was re-run with updated data.

For the Tier 5 Other Skate species, the total biomass was estimated using the *rema* framework (Sullivan et al., 2022), updating it from the previous random effects code. This is not considered a methodology change. The previous Tier 5 assessment did not have a model designation, thus we are now designating it as Model 23.0.

Summary of Results

The principal results of the present assessment, based on the author-recommended models, Model 14.2d for Alaska skate and Model 23.0 for the Other skates, are listed in the table below (biomass and catch figures are in units of t) and compared with the corresponding quantities as specified last year by the SSC:

Alaska skate harvest recommendations				
	As estimated or specified *last* year for:		As estimated or recommended *this* year for:	
Quantity	2023	2024	2024*	2025*
M (natural mortality rate)	0.13	0.13	0.13	0.13
Tier	3a	3a	3a	3a
Projected total (age 0+) biomass (t)	473,527	450,679	455,367	439,806
Projected Female spawning biomass (t)	114,804	105,595	107,197	99,482
$B_{100\%}$	178,425	178,425	172,881	172,881
$B_{40\%}$	71,370	71,370	69,152	69,152
$B_{35\%}$	62,449	62,449	60,508	60,508
F_{OFL}	0.092	0.092	0.093	0.093
$maxF_{ABC}$	0.079	0.079	0.080	0.080
F_{ABC}	0.079	0.079	0.080	0.080
OFL (t)	35,503	33,451	32,608	31,217
maxABC (t)	30,567	28,799	28,104	26,904
ABC (t)	30,567	28,799	28,104	26,904
	As determined *last* year for:		As determined *this* year for:	
Status	2021	2022	2022	2023
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 17,427 t for 2023 and 18,959 t (5 yr mean total catch) used in place of maximum permissible ABC for 2024 and 2025.

Other skate harvest recommendations				
	As estimated or specified *last* year for:		As estimated or recommended *this* year for:	
Quantity	2023	2024	2024	2025
M (natural mortality rate)	0.10	0.10	0.10	0.10
Tier	5	5	5	5
Biomass (t)	107,174	107,174	131,446	131,446
F_{OFL}	0.10	0.10	0.10	0.10
$maxF_{ABC}$	0.075	0.075	0.075	0.075
F_{ABC}	0.075	0.075	0.075	0.075
OFL (t)	10,717	10,717	13,145	13,145
maxABC (t)	8,038	8,038	9,858	9,858
ABC (t)	8,038	8,308	9,858	9,858
	As determined *last* year for:		As determined *this* year for:	
Status	2021	2022	2022	2023
Overfishing	No	n/a	No	n/a

aggregate harvest recommendations for the BSAI skate complex				
	As estimated or specified *last* year for:		As estimated or recommended this year for:	
Quantity	2023	2024	2024	2025
OFL (t)	46,220	44,168	**45,753**	44,632
maxABC (t)	38,605	36,837	37,962	36,762
ABC (t)	38,605	36,837	**37,962**	36,762

Summaries for Plan Team

Area	Year	Age 0+ Biomass	OFL	ABC	TAC	Catch
BSAI	2022	597,042	47,790	39,958	30,000	28,110
	2023	580,701	46,220	38,605	27,441	19,633
	2024	586,813	45,753	37,962	n/a	n/a
	2025	571,252	44,632	36,762	n/a	n/a

For 2022, NMFS increased the TAC to 31,100 t with a reallocation of 1,100 from the non-specified reserves. A TAC allocation is expected to occur for 2023, however, it has not been specified at the time of writing.

Responses to SSC and Plan Team Comments on Assessments in General

Comments relevant to this assessment are recorded here and will be responded to at the next full assessment.

"The SSC supports the JGPT's recommendation that stock assessment authors transition from the ADMB RE variants to the rema framework, which implements the same model variants in a single framework with several improvements."(SSC, Oct 2022)

We have transitioned to using the *rema* framework for the Tier 5 portion of the BSAI skate stock complex.

SSC and Plan Team Comments Specific to this Assessment

There were no recommendations from the BSAI Groundfish Plan Team.

"*..... the declining trend of leopard skate is notable, from a high of 11,825 t in 2010 to 2,634 t in 2018. The SSC registers some concern with the decline of this endemic species, and asks if there are any additional data that could be brought forward to attempt to discern if there is a conservation issue associated with this decline."* (SSC December 2020)

The leopard skate biomass in the Aleutian Islands continues to decline (Appendix Figure 18B.1). Discussions with RACE GAP staff have highlighted that survey gear and habitat rugosity may contribute to low reliability of the Aleutian Islands trawl survey for skate species in general. We will prioritize further evaluations and collaborate with RACE staff. This species is not identified by observers, therefore it is not possible to track fishery catch of the species.

"The SSC requests that the methods used for catch projections be detailed in future assessments." (SSC December 2021)

We reached out to members of the SSC to clarify this request. There are a number of concerns or clarifications that are beyond the scope of this specific assessment, and which are worthy of refinement and or further discussion. One concern, specific to this assessment, was how the total catch for the current year (2023 in this case) was calculated. We use the 5 year mean proportion of catch occurring after the data pull date, October 1 for this year's assessment, to expand total year catch for the terminal year. Also, for scenario 2, we use the estimated total catch for 2023 in place of the ABC for the years 2024 and 2025 because catch is generally well below the ABC. A more detailed description of the methods are presented in the Harvest Recommendations section.

"*The SSC suggests that it may be appropriate to update the stock structure template during the next full assessment, with a focus on Alaska skate, as was requested by the SSC in 2018.*" (SSC December 2020)

"The SSC continues to support prior SSC and GPT recommendations for the next full assessment, including transitioning the model from ADMB to the rema framework and considering whether updating the stock structure template for Alaska skate is warranted." (SSC December 2022)

We have transitioned to using the *rema* framework for the Tier 5 portion of the BSAI skate stock complex.

Staffing limitations precluded us from considering updating the stock structure template for the Alaska skate for this year, but we agree with the SSC that this issue should be revisited in future assessments.

Introduction

This report presents an operational update assessment for the Bering Sea/Aleutian Islands (BSAI) skate stock complex. The last operational full assessment occurred in 2020 (Ormseth 2020, available at https://www.npfmc.org/library/safe-reports/). Please refer to the 2020 operational full assessment for detailed information on the distribution, biology, and life history of species in the skate stock complex.

To generate harvest recommendations, the BSAI skate stock complex assessment is split into two units: the Alaska skate (*Bathyraja parmifera*) and the Other skates complex. This is due to differences in spatial distribution, relative abundance, and information available for the various skate species in the BSAI Fishery Management Plan (FMP) area. The Alaska skate is the dominant species of skate in the BSAI FMP area, accounting for over 90% of the skate biomass on the eastern Bering Sea (EBS) continental shelf (most commonly at depths of 50-200 m). This species is also found in the Aleutian Islands (AI) and EBS slope habitat areas, but is far less abundant.

The Other skates complex in the BSAI FMP consists of the following species: big skate (formerly known as *Raja binoculata*, now *Beringraja binoculata*; Ishihara et al. 2012), longnose skate (formerly *Raja rhina* and *Beringraja rhina*, now putatively *Caliraja rhina*; Ebert 2022), Aleutian skate (*Bathyraja aleutica*), Bering skate (*Bathyraja interrupta*), Commander skate (*Bathyraja lindbergi*), whiteblotched skate (*Bathyraja maculata*), butterfly skate (*Bathyraja mariposa*), whitebrow skate (*Bathyraja minispinosa*), mud skate (*Bathyraja taranetzi*), roughtail skate (*Bathyrara trachura*), Okhotsk skate (*Bathyraja violacea*), roughshoulder skate (*Amblyraja badia*), deepsea skate (*Bathyraja abyssicola*), and leopard skate (*Bathyraja panthera*). Additionally, the rare deepwater Pacific white skate (*Bathyraja spinosissima*) was recently identified for the first time in the Bering Sea (Stevenson et al. 2019). The species compositions in the Aleutian Islands (AI) and the eastern Bering Sea (EBS) slope differ from each other and from the EBS shelf. More details on species-specific abundance and spatial distributions are available in the previous operational full assessment (Ormseth, 2020).

Fishery

There is no directed fishing for skates in the BSAI, though some of the skate bycatch is retained. A detailed account of the fishery history of the skate stock complex, including the additional steps to estimate species-specific catch of unidentified skates, can be found in the last full operational stock assessment (Ormseth, 2020).

The BSAI skate stock complex species are caught primarily in the EBS, with a low level of relatively constant catch in the AI (Figure 18.1). Most of the catch occurs in longline fisheries targeting Pacific cod, with catch in the yellowfin sole trawl fishery being next most common (Figure 18.1).

Due to challenges with skate species identification, much of the complex catch is accounted for as “unidentified skates”. The unidentified skate catch is portioned to species by a process accepted in 2018 (Ormseth 2018), which we continue to use. Alaska skate is the predominant species caught in the BSAI skate stock complex (Figure 18.1).

There has been a northward shift in the spatial distribution of catch of skates in some years, both of Alaska skates and Other skates based on observer sampling (Figure 18.2). Over the last 5 years, on average 75% of the skate catch in the EBS has occurred in fisheries targeting Pacific cod (Figure 18.1), and the northward shift or expansion in catch is likely reflective of shift in the directed Pacific cod fishery.

Updated catch, acceptable biological catch (ABC), overfishing limit (OFL), total allowable catch (TAC) and associated management measures are reported in Table 18.1. Estimates of species-specific catch are not updated for this operational update assessment, except for Alaska skate, as shown in Table 18.2. Species-specific catch of Other skates can be found in the last operational full stock assessment. Estimated discards for the BSAI skate stock complex by gear and FMP sub area are reported in Table 18.3.

Data

The BSAI Alaska skate Tier 3 assessment model uses the following data (Figure 18.3):

Source	Data	Years
NMFS EBS shelf bottom trawl	Survey biomass	1982-2023 (no survey in 2020)
NMFS EBS shelf bottom trawl	Length composition	2000-2023 (no survey in 2020)
NMFS EBS shelf bottom trawl	Length-at-age	2003, 2007-2009, 2015
Catch Reconstruction	Fishery Catch	1954 – 1996
AKRO Blend Catch Estimation	Fishery Catch	1997 – 2002
AKRO Catch Accounting System	Fishery Catch	2003 – 2023
North Pacific Groundfish Observer Program	Length composition	2009 – 2023

Due to challenges with species identification, there are three time frames of species specific catch estimation: 1954 - 1996, 1997 - 2006 and 2007- present. Details are available in the last operational full assessment (Ormseth, 2020).

The BSAI Other skates complex Tier 5 assessment is based on the following NMFS groundfish bottom trawl survey biomass data:

Source	Data	Years
NMFS EBS shelf bottom trawl	Survey biomass	1982-2023 (no survey in 2020)
NMFS EBS slope bottom trawl	Survey biomass	2000, 2002, 2008, 2010, 2012, 2016
NMFS AI bottom trawl	Survey biomass	2000, 2002, 2004, 2006, 2010, 2012, 2014, 2016, 2018, 2022

Fishery

Fishery data for Alaska skate are grouped by gear type: longline and trawl. Estimated catch of Alaska skate in pot gear is minimal and therefore combined with trawl catch estimates. Alaska skate catch by fishery for Model 14.2 are reported in Table 18.2. Fishery length compositions by year with input sample sizes are provided in Table 18.4. Fishery length composition input data are available at: https://github.com/afsc-assessments/AFSC_BSAI_SKATE_Assessment/blob/main/2023/Tier3/Output/M14_2lengthcomps_summary.csv.

Fishery data are not included in the Tier 5 Model 23.0.

Survey

Table 18.5 and Figure 18.4 report the survey biomass estimates, with uncertainty, which are used in this operational update assessment. Model 14.2 includes the biomass estimates for Alaska skates from the EBS shelf survey. The northern Bering Sea survey is not included in Model 14.2; however, we have included those survey biomass estimates in Appendix B for reference.

Model 23.0 includes the combined Other skates biomass for each of the three surveys (Table 18.5). Species-specific survey biomass estimates for the dominant species for each survey, as well as the "minor" group, are provided in Appendix B. The leopard skate, which is endemic to the Aleutian Islands, was not formally identified as a separate species from the Alaska skate until 2010. Survey biomass estimates of Alaska skate prior to 2010 are portioned between the two species by the mean proportion of leopard skate from 2010 onwards (Ormseth, 2020).

There are no new survey age data to report since the last full assessment. Survey length sample sizes by year with input sample sizes are reported in Table 18.4. Survey length composition input data are available at: https://github.com/afsc-assessments/AFSC_BSAI_SKATE_Assessment/blob/main/2023/Tier3/Output/M14_2lengthcomps_summary.csv.

Other time series data used in the assessment

None

Analytic Approach

General Model Structure

Here we present harvest recommendations for the BSAI skate stock complex using the accepted base models. Details are available in the previous operational full assessment (Ormseth, 2020).

Harvest recommendations are generated separately for Alaska skates (Tier 3) and the Other skates complex (Tier 5) and then combined to present recommendations for the BSAI skate stock complex as a whole. Below we describe the base models for both units of the BSAI skate stock complex.

Description of Base Model (Alaska skate)

The age- and size-structured population dynamics model for BSAI Alaska skate, Model 14.2, is run using the Stock Synthesis platform (SS3, technical details given in Methot and Wetzel 2013, Methot et al. 2020 and in the Stock Synthesis Virtual Lab). No major changes to the assessment approach have occurred since 2014.

The current update assessment run of Model 14.2 retains the same assumptions as the original model. The entire BSAI is treated as one homogenous area. Because growth and maturity patterns are similar for males and females, only one sex is specified. Spawning is assumed to occur at the midpoint of the year. No informative priors were used. It was assumed that parameters did not vary with season or year and were not influenced by environmental conditions. All parameters are listed in Table 18.6 and described in more detail below.

The bridging exercise undertaken to develop Model 14.2 (2023) was as follows: (Figure 18.5):

1) Model 14.2 in SS3 v3.23 (base model from 2020 operational full assessment)
2) Model 14.2a same as Model 14.2 updating to SS3 v3.30.21
3) Model 14.2b same as Model 14.2a with updated historical data including changes to EBS shelf survey biomass (2000 – 2019) and minor changes to catch time series.
4) Model 14.2c same as Model 14.2a with three years of new data, but historical data unchanged.
5) Model 14.2d both updating historical data and adding three years of new data

Model 14.2d is the recommended model for the 2023 harvest specifications.

Description of Base Model (Other skates)

The BSAI Other skates complex is managed under Tier 5, where OFL is equal to estimated biomass multiplied by an estimate of natural mortality (*M*). The current species groupings (i.e., dominant species and combined minor species for each survey) were established in 2020, however, the harvest recommendation model is run on the combined biomasses of the Other skates for each survey area. The reason for this is that all of the Other Skates species are assigned the same *M* value (*M* = 0.1), which makes running the model separately equivalent to running them together. Since 2014, survey biomass has been estimated using a random effects model. This year, following recommendations by the Plan Team and SSC, we transitioned to using the *rema* framework to estimate biomass for Other skates. Based on guidance provided by the Plan Teams and SSC, the *rema* framework is not considered a substantive model change from the previous assessment and does not warrant an operational full assessment. There has not been a model number for the BSAI Other Skates analysis, therefore, we are naming the Tier 5 model Model 23.0.

The *rema* model was run for all skates combined (omitting Alaska skates on the EBS shelf survey) for each of the three bottom trawl surveys spanning the following time periods: EBS shelf (1999-2023), EBS slope (2002-2023), and AI (2000-2023). The model runs begin in 1999 due to concerns over accuracy of species identifications prior to then. Surveys on the EBS shelf have occurred with higher frequency (annually) than in the AI (10 observations) and EBS slope (6 observations). There were no surveys conducted in 2020.

Parameters Estimated Outside the Assessment Model (Alaska skate)

Natural mortality (*M*)

In the 2007 Alaska skate model, an *M* value of 0.13 was selected from a range of values estimated indirectly from other species-specific life history parameters (Alverson and Carney 1975, Rikhter and Efanov 1976, Pauly 1980, Hoenig 1983, Roff 1984, Charnov 1993, Jensen 1996, Gunderson 2003). The previous assessment author demonstrated that this value of *M* has consistently provided the best model fit, so we continue to fix *M* at 0.13.

Length at maturity

SS3 incorporates female maturity parameters into the model using the following equation:

$$proportion\ mature = \frac{1}{1 + e^{b(L - L_{50})}}$$

where L_{50} is the length at 50% maturity and b is a slope parameter. Maturity parameters were obtained from Matta (2006), where b = -0.548 and L_{50} = 93.28 cm TL. Maturity was estimated directly from paired length and maturity stage data as described in Matta and Gunderson (2007); maturity stage was assessed through macroscopic examination of the reproductive organs.

Ageing error

A fixed ageing error matrix based on paired independent readings of skate vertebrae (Matta and Gunderson 2007) was included in the model. For each age, the standard deviation of the estimated age was calculated from the at least two reads of each vertebra and incorporated into the model to account for variability in age determination.

Survey catchability

Survey catchability was fixed at 1 as in previous Alaska skate assessment models. The EBS shelf survey appears to sample Alaska skates very reliably, with CVs of approximately 0.05 (Table 18.5).

Weight at length

Parameters from the allometric length-weight relationship (W = aTL^b, where W is weight in kg and TL is total length in cm) were estimated from data obtained during an Alaska skate tagging project conducted aboard EBS shelf surveys 2008-2010 (O. Ormseth, unpublished data). Parameters were not significantly different between sexes, so data were combined. For sexes combined, a was estimated as 9.0 X 10^{-6} and b was estimated as 2.9617 (r^2 = 0.93, n = 1,515).

Stock-recruit parameters

The standard Tier 3 approach was followed in which no relationship was assumed between the stock and recruitment. Steepness was therefore fixed at 1.0 to create a mean level of recruitment. The σ_R value was fixed to a value of 0.4.

Parameter Estimates (Other skates)

The only parameter used to make harvest recommendations for the other skates complex is M. Estimates of M for skates are highly uncertain and may vary among species. We applied the accepted conservative, complex-wide value of M = 0.10 that has been used in previous assessments of the BSAI Other skates complex.

Parameters Estimated Inside the Assessment Model (Alaska skate)

Growth parameters

Alaska skate length-at-age (LAA) observations are best fitted by the Gompertz growth model (Matta and Gunderson 2007). In line with previous assessments, the Schnute 4-parameter growth model (Schnute 1981) was used to approximate the Gompertz growth function in SS3. The Schnute model is formulated as

$$Y(t) = \left\{ y_1^\gamma + \left(y_2^\gamma - y_1^\gamma\right) \frac{1 - exp[-\kappa(t-\tau_1)]}{1 - exp[-\kappa(\tau_2 - \tau_1)]} \right\}^{1/\gamma}$$

where $Y(t)$ is length at age t, y_1 and y_2 are the length at ages τ_1 and τ_2, respectively, and κ and γ are parameters that control the shape of the growth curve. In SS3, κ is referred to as the von Bertalanffy k parameter and γ is referred to as the Richards coefficient. All growth parameters were estimated within the model based on paired length and age data from the eastern Bering Sea bottom trawl surveys in 2003, 2007-2009, and 2015, as were the two uncertainty parameters (CV of length-at-age at ages τ_1 and τ_2).

Length selectivity

Selectivity at length was estimated separately for each fishery (trawl and longline) and the EBS shelf bottom trawl survey using a double-normal function with defined initial and final selectivity levels (Methot et al. 2020) where all parameters were estimated inside the model. The six parameters of the double-normal function are: p1 (the peak or ascending inflection size), p2 (the width of the plateau), p3 (the ascending width), p4 (the descending width), p5 (the selectivity at the first length bin, and p6 (the selectivity at the last length bin). The bounds were set to the default values listed in the SS3 documentation (Methot et al. 2020).

Stock-recruit parameters

The natural log of unfished recruitment (R_0) value was estimated inside the Alaska skate model. Recruitment deviations were also estimated for 1950-2023. In SS3, each deviation is considered a separate parameter.

Initial fishing mortality

Initial fishing mortality in the longline and trawl fisheries was set to zero.

Results

Model Evaluation (Alaska skate)

Model evaluation criteria

A summary of model fit statistics, with 2020 results for comparison, are located in Table 18.7. The model was evaluated based on overall quality of fit, the retrospective pattern, and comparison of results to previous runs, using the below criteria.

1) Standard deviations of the parameter estimates were converted to CV; a lower CV indicated a better fit.
2) Model fit to the survey data was conducted by comparing root mean squared error (RMSE), the average standardized residual, the correlation between observed and predicted values and the proportion of survey biomass estimates where the model estimate was within the 95% confidence interval (CI) of the observed value. For RMSE and the average residual, lower values indicated a better fit. For the correlation and the proportion of model estimates within the CIs, higher values indicated a better fit.
3) Comparison of effective sample sizes (N_{eff}) for length compositions and LAA datasets, with higher N_{eff} indicating better fit to the data.
4) Visual inspection of model fits to length compositions and LAA data.
5) Reasonable estimates of fishery length selectivity parameters.
6) Analysis of 12-year retrospective patterns of biomass.

Evaluation of model criteria

Overall the model fit the data reasonably well (Table 18.7), with similar results to the 2020 model run for biomass (Table 18.8) and recruitment (Table 18.9). The one exception is that the estimated total biomass is only within the range of the survey biomass confidence intervals 57.5% of the time, which is down from 75.7% in the previous assessment. Model 14.2d tended to underestimate LAA for the oldest age classes in the early years, 2003 and 2007 (Figure 18.6). The fits to the survey length composition data often overestimate smaller sizes and underestimate the largest sizes (Figure 18.7), which is opposite of the model fit to the longline (Figure 18.8) and trawl (Figure 18.9) fishery length composition data. The Pearson residuals also suggest some length groups with poor fit (Figure 18.10). Model 14.2d estimates dome shaped selectivity for all three inputs, with some notable changes from the previous full assessment: longline fishery selectivity was previously asymptotic and the descending limb of the dome is greatly reduced for the survey (Figure 18.11). The model did estimate terminal year survey biomass well; however, biomass was overestimated from 2008- 2015 (Figure 18.12).

The retrospective pattern for spawning biomass and relative difference (Figure 18.13), as well as the associated statistics (see table below) suggest that the model has substantial retrospective bias. With each peel, the model estimate of SSB increases, suggesting that the model is overestimating SSB. Following the guidance of the Retrospective Working Group (Hanselman et al. 2013), the retrospective pattern for Model 14.2d would be classified as Occasional Overage Potential Stock (OOPS). The implications of which are that if the recommended ABCs were fully harvested, the realized fishing mortality could have actually been higher than the maximum permissible fishing mortality. Mohn’s rho was 0.154. The relatively high Woods Hole rho (1.411) could be indicative of limited contrast in the reconstructed catch history and/or a low average fishing mortality rate. While there is a systematic increase in the SSB with each respective peel, there is a relatively large increase between 2016 and 2015. This coincides with when the model switches from overestimating to underestimating of total biomass (Figure 18.12) and when recruitment estimates begin to decline (Figure 18.16).

Model Evaluation (Other skate)

The last assessment was conducted in 2020, and since then, there has been one survey in the AI and three in the EBS shelf. The combined Tier 5 AI biomass is slightly down since the 2020 assessment (Figure 18.14) and the model fit the survey biomass well. The EBS shelf survey has been trending up since 2020 and the model underestimated the high 2023 value (Figure 18.14). There has not been an updated data point for the EBS slope survey since 2016; the predicted biomass is stable since then (Figure 18.14).

Time Series Results (Alaska skate)

Definitions

Biomass is shown as total (age 0+) biomass (metric tons; t) of all Alaska skates in the population, and as spawning biomass (for both sexes; t). Recruitment is reported as the number (in thousands) of Alaska skates at age 0. The CV is included for spawning biomass and age-0 recruits.

Biomass time series

Time series of total biomass and spawning biomass estimates from 1950-2023 are reported in Table 18.8. Spawning biomass is also shown in Figure 18.15. The model suggests that the Alaska skate population declined beginning in the 1950s, with the steepest decline during the 1970s. The population then rebounded dramatically during the 1980s, increasing until ~1995. It then declined slightly and began to increase in 2007. The 2023 model run suggests that total biomass has decreased since 2015 and spawning biomass has decreased since 2020.

Recruitment

Time series of age-0 recruitment are reported in Table 18.9 and Figure 18.16. The model suggests that a period of increased recruitment occurred between the years 1980-1984, with the highest level of recruitment in 1982. The model also estimates that recruitment increased during the 2000s, peaking in 2006, and declining until 2015. The model estimated a relatively large increase in recruitment between 2019 and 2020 and variable estimates since then.

Exploitation rate

A time series of exploitation (catch/total biomass) is given in Table 18.10 and Figure 18.17. These rates suggest that skates experienced the greatest fishing pressure in the 1970s. Exploitation rates have been fairly stable (~0.04-0.05) since the 1990s.

Numbers at age

Model 14.2d indicates that the large year classes that occurred in the 1980s are essentially gone from the population and that the moderately-sized year classes of the 2000s are beginning to show up in the older population (Figure 18.18). There appears to be an incoming cohort of young animals. Table results of numbers at age are available at: https://github.com/afsc-assessments/AFSC_BSAI_SKATE_Assessment/blob/main/2023/Tier3/Output/M14_2NAA_summary.csv

Phase-plane plot

The trajectory of relative spawning biomass vs. relative fishing mortality (Figure 18.19) reflects the high F and decrease in biomass during the 1970s, as well the subsequent increase in biomass. In recent years the relationship between the two variables has been consistent, with spawning biomass well above $B_{35\%}$ (Figure 18.15) and F well below $F_{35\%}$ (Figure 18.17).

Time Series Results (Other skates)

Model 23.0 Other skate biomass time series are presented in Table 18.11 and Figure 18.14. The declining trend in the Aleutian Islands continued through the 2022 survey; this is largely driven by declines in leopard and Aleutian skate survey biomass estimates (Appendix 18B). Butterfly skates are considered a minor species, they had also been declining, but increased in 2022 (Appendix 18B). The 2023 EBS shelf survey biomass estimate for Other Skates was the greatest of the time series, and as a result, the estimated biomass also increased. There has been no EBS slope survey since 2016, thus the estimated biomass from that region is unchanged.

Harvest Recommendations

Amendment 56 Reference Points

This assessment using Model 14.2d provides reliable estimates of B_0, $B_{40\%}$, and the fishing mortality rates corresponding to $F_{40\%}$ and $F_{35\%}$. Therefore, management recommendations are made under Tier 3 of the BSAI Groundfish Fishery Management Plan. Using Tier 3, ABC and OFL are set according to the following criteria:

3a) Stock status: $B/B_{40\%} > 1$
$F_{OFL} = F_{35\%}$
$F_{ABC} \leq F_{40\%}$
3b) Stock status: $0.05 < B/B_{40\%} < 1$
$F_{OFL} = F_{35\%}$ x $(B/B_{40\%} - 0.05) \times 1/0.95$
$F_{ABC} < F_{40\%}$ x $(B/B_{40\%} - 0.05) \times 1/0.95$
3c) Stock status: $B/B40\% < 0.05$
$F_{OFL} = 0$
$F_{ABC} = 0$

The BSAI Other Skates are Tier 5, thus the OFL is the only reference point.

Specification of OFL and Maximum Permissible ABC (Alaska skate)

The 2024 estimate of female spawning biomass for BSAI Alaska skates is 107,197 t. The estimate of $B_{40\%}$ is 69,152 t, so $B/B_{40\%}$ is 1.55 and 2024-2025 Alaska skate harvest levels can be assigned according to subtier 3a. Therefore, $F_{OFL}= F_{35\%} = 0.093$ and maximum $F_{ABC}= F_{40\%} = 0.080$. The corresponding 2024 OFL is 32,608 t and maximum allowable ABC is 28,104 t. For 2025, OFL is projected to be 31,217 t and maximum allowable ABC will be 26,904 t.

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). Results of the projection exercise are in Table 18.12.

For each scenario, the projections begin with the vector of 2023 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2024 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2023. 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 are sometimes used in Environmental Assessments. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2024, are as follows ("max F_{ABC}" = maximum permissible F_{ABC} under Amendment 56) and results are shown in Table 18.12 and Figure 18.20:

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

Scenario 2: In all future years, F is set equal to a constant fraction of max F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2024 recommended in the assessment to the max F_{ABC} for 2024. (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 Alaska skates the recommended F_{ABC} is typically the max F_{ABC}, however the total catch is usually well below ABC (Table 18.1). Therefore, for Scenario 2 the catch in 2024 and 2025 is set equal to the estimate of 2023 total catch used in the model.

Scenario 3: In all future years, F is set equal to the 2019-2023 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 4: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 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 its MSY level in 2024 and above its MSY level in 2034 under this scenario, then the stock is not overfished.)

Scenario 7: In 2024 and 2025, 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 2035 under this scenario, then the stock is not approaching an overfished condition.)

Specification of OFL and Maximum Permissible ABC (Other skates)

Model	F_{OFL}	F_{ABC}	Combined B_{rema}	OFL	ABC
23.0	0.1	0.075	131,446	13,145	9,858

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: No Concern	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: 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 3: 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.

<u>Assessment considerations</u>
The model for Alaska skate appears to have strong retrospective bias and with each successive year added the estimated SSB decreases, suggesting the model has been overestimating the population. There are many potential areas for improvement in the model. For the Alaska skate model we rate Assessment Considerations at Level 2.

The Other Skate group is managed under Tier 5, so it is by definition data-limited. There are no assessment concerns for that group. A continuing concern is the lack of EBS slope data, but that is unlikely to be resolved soon and does not affect the risk assessment. The Other skate group is rated Level 1.

<u>Population dynamics considerations</u>
The biomass of Alaska skates has been declining, however, there appears to be a strong cohort developing and projections suggest that the population is not at risk of becoming overfished, therefore there is not increased concern. The Alaska skate is rated Level 1.

The biomass of Other skate overall is increased, but decreasing within the AI. In particular leopard (an endemic species) and Aleutian skate have been decreasing in recent years and are below the long term average. There is a greater level of uncertainty in the AI survey estimates for skates due to higher rugosity of the seafloor, untrawable habitat, and footrope design. The leopard skate was also only recently treated as a separate species from the Alaska skate; therefore the time series may be too short to draw any definitive conclusions about biomass trends. Given the considerations regarding the reliability of the AI bottom trawl survey for estimating biomass of skate species, we are not elevating the level of concern for leopard skates at this time. Overall, the Other skates are a Level 1, but we continue to monitor the species-specific trends in the Aleutian Islands.

<u>Environmental/Ecosystem considerations (contributed by Ebett Siddon and Ivonne Ortiz)</u>
The BSAI skates complex contains multiple stocks, with each subarea comprising a different species composition. The Alaska skate dominates the continental shelf of the EBS, but skate species diversity is higher over the slope, where Aleutian skates, Bering skates, Commander skates, and whiteblotched skates are found in significant numbers (Ormseth 2020). Species composition in the AI also varies by depth, but whiteblotched skates are found most commonly (Ormseth 2020). Two species of skate are endemic to the AI: leopard and butterfly skates. Skates are mobile, demersal animals that are fairly ubiquitous and are generalists in terms of prey. Limited knowledge of these species is available to identify stock-specific indicators, but some general life history information is available for Alaska skate. Outside of this information and for the rest of the complex, indicators of ecosystem status are considered with respect to benthic productivity more generally.

Environmental processes: Annual mean sea surface temperature in the North Pacific Ocean had a regime shift to warmer temperatures in 2013-2014; this includes all Alaskan waters - the EBS, Gulf of Alaska and the AI (Xioa and Ren 2023). In 2023, broad-scale climate patterns, like the North Pacific Index, reflected a transition from La Niña conditions to developing El Niño conditions in the tropical Pacific. In the EBS, regional sea surface temperature (SST) trends were at or near the long-term average in 2023. Exceptions to near-normal sea surface temperature conditions include a relatively warm winter across the shelf. Above-average SSTs lasted through spring over the outer (100-200 m isobaths) and middle (50-100 m isobaths) domains. Bottom temperatures derived from the ROMS model showed consistently cooler than average bottom temperatures over the outer domain (100-200 m) from September 2022 through August 2023. Sea ice metrics, such as early ice extent (Oct.-Dec.), annual ice extent, and sea ice thickness were all near the respective time series averages. The 2023 cold pool extent was also near its historical average (Hennon et al., 2023). Data from the 2023 EBS bottom trawl survey as well as the slope longline survey show bottom temperatures below 6°C (O'Leary 2022, Siwicke 2023). Likewise, bottom temperatures in the AI from 1994-2022 show mean bottom temperatures across the chain below 6°C (O'Leary 2022). Temperatures from the longline survey show temperature between 100 and 300 m was also below 6°C in the eastern Aleutians (Siwicke 2023). Embryo development time may be highly sensitive to ocean temperature, with time to hatching decreasing sharply between 4-10°C (Hoff 2007). Slowly increasing temperatures in the AI may shorten hatching time. For the EBS, there seems to be some northward shift in distribution, and both Aleutian skate and big skate may be potentially increasing in biomass due to warmer temperatures since 2013-2014. However, it is unclear whether this would be a result of movement from the GOA, or a true increase in abundance. Bycatch distribution of skates in the longline fisheries now includes the northern Bering Sea as the longline fishery has extended into this area (Figure 18.2). A more detailed analysis is needed to evaluate the effect of temperature in the distribution, abundance, and phenology of skates. In general, Spencer et al. (2019) considered Alaska skates to have moderate vulnerability to climate changes.

Prey: Prey resources for skates include benthic infauna as well as epifauna and fish. Direct measurements of infaunal biomass are not available; trends in epifauna reflect infaunal prey availability while also indicating a direct prey resource to flatfish. Trends in the abundance of motile epifauna declined in 2023 from 2022 but remain above the long term mean (Siddon, 2023). This indicates sufficient benthic prey availability for skates over the southern Bering Sea shelf. No information on benthic prey is available for the AI.

Predators: Skates are most vulnerable to predation during the embryonic (egg case) and early juvenile stages. Gastropod snails are predators of skate egg cases, and Pacific cod and Pacific halibut consume newly hatched skates, with consumption peaking during winter and early summer (Hoff 2007). Gastropod snails are included in the motile epifauna guild; trends in the abundance of this guild declined in 2023 from 2022 but remain above the long term mean (Siddon 2023). Pacific cod had a modest increase in biomass from 2022 to 2023. In the AI, total biomass of Pacific cod has been decreasing, with biomass in 2022 at ~25% of its peak biomass in 1989 (Spies et al. 2022). The Pacific halibut stock decreased from a peak in the early 2000s and remains low in 2023, therefore representing no increase in predation pressure (Stewart and Hicks 2022).

Competitors: Potential competitors to this stock complex include flatfish stocks and stock complexes that comprise the benthic foragers guild and the apex predators guild. The trend in biomass of the benthic foragers guild has been declining since approximately 2010 in the EBS, decreased from 2022 to 2023, and remains below the long term mean of the time series (Siddon 2023), suggesting a reduction in prey competition from this guild. The biomass within the apex predator guild was nearly equal to the long term mean in 2023 (Siddon 2023). In the AI, the overall abundance of groundfish apex predators also decreased in 2022 compared to 2018 (Ortiz and Zador 2022).

Summary for Environmental/Ecosystem considerations:

- Summer bottom temperatures over the southeastern and northern Bering Sea during the NOAA bottom trawl survey were near the time series average for 2022 and 2023; the southeastern shelf had above-average bottom temperatures in 2021 while the northern shelf had average bottom temperatures. The spatial extent of the cold pool was below the time series average in 2021 and average in 2022 and 2023, indicating cooler thermal conditions relative to the recent extended warm phase (~2014-2021) for skates. Skate egg case incubation times appear to be influenced by temperature, and there is evidence to suggest that skate hatch times may be very sensitive to thermal fluctuations (Hoff 2007). In the AI, sustained increasing bottom temperatures in the past 10 years may be shortening hatching times.

- Indirect measures of prey abundance declined in 2023 from 2022, but remain above the long term mean, indicating sufficient benthic prey availability for skates over the southern Bering Sea shelf.
- Biomass of potential competitors decreased or remained average from 2022 to 2023, suggesting a reduction in prey competition.
- Trends in predator biomass were mixed in 2023 for the EBS, with a decrease in predation pressure on egg cases and a modest increase in predation pressure from Pacific cod, an a continued decrease in predation pressure by Pacific halibut. In the AI, there has been a decrease in predation pressure by Pacific cod and Pacific halibut. Together, there is no increased concern in predation pressure on the BSAI skate complex.

Proper evaluation of ecosystem risk is difficult for a data-limited stock. However, the available data suggest there are no apparent ecosystem concerns for either Alaska skate or the Other Skates--level 1.

Fishery performance
Skates are a bycatch species and the amount of harvest depends on skate abundance and the behavior of target fisheries. Level 1.

Summary and ABC recommendation

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ ecosystem considerations*	*Fishery Performance considerations*
Level 2 for Alaska skates Level 1 for Other skates	Level 1: no increased concerns	Level 1: no increased concerns	Level 1: no increased concerns

While there are increased concerns in the assessment considerations for Alaska skate, we feel that these are not sufficient to warrant a reduction in ABC at this time. Similarly, there are not sufficient concerns to warrant a reduction in the ABC for Other skates. Therefore, no reductions from maximum permissible ABC are recommended for the BSAI skate stock complex.

Status Determination
The 2022 total BSAI skate stock complex catch was 28,110 t (Table 18.1) and the OFL was 47,790 t, therefore the BSAI skate stock complex was not subject to overfishing.

While the status determination is at the stock complex level, we provide the relative measures for the Alaska skate component of the BSAI skate stock complex. The 2022 Alaska skate total catch estimate was 24,999 t, which is less than the 2022 OFL of 36,665 t and overfishing was not occurring. The projected 2024 female spawning stock biomass (107,197 t) is greater than $B_{35\%}$ (60,508 t); therefore the Alaska skate is not overfished. The projections for Scenarios 6 & 7 indicate that the Alaska skate stock will be above $B_{35\%}$ (60,508 t) in 2036, so Alaska skates are not currently in an overfished condition and are not approaching an overfished condition. The F rate that would have produced a catch equal to the 2022 OFL being taken was 0.13, which compares to the estimated F2022 of 0.06 (0.06-0.07, 95% confidence interval).

For the Tier 5 Other skates, the 2022 OFL was 10,717 t and catch was 3,111 t, therefore overfishing did not occur. It is not possible to determine if Tier 5 stocks are approaching or are overfished.

Ecosystem Considerations

Ecosystem considerations are described in detail in the previous full operational assessment of the BSAI skate stock complex (Ormseth, 2020).

Data Gaps and Research Priorities

The previous full operational assessment of the BSAI skate stock complex (2020) identified data gaps and several areas of potential research:

- Continue the AI and resume the EBS slope bottom trawl surveys to monitor changes in abundance and species composition in these areas, particularly the EBS slope survey which is among the only sources of biological information for deepwater species.
- Evaluate tagging data for the Alaska skate (collected on the EBS shelf since 2008) and investigate skate movements.
- Improve estimates of fecundity.
- Improve estimates of mortality during early life history (eggcase and early juvenile stages).

We further recommend the following for consideration in future operational assessments:

- Add updated age and growth information (the last age data included in the Alaska skate model were collected in 2015).
- Encourage age validation/verification research for the Alaska skate using independent methods (e.g., tagging, microchemical analysis, etc.)
- Refine estimates of *M* for the other skates complex.
- Explore inclusion of northern Bering Sea survey in the Model 14.2d.

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Auxiliary Files

All code and output files are available as listed below

Tier 3 Model 14.2 through Model 14.2d SS3 runs: https://github.com/afsc-assessments/AFSC_BSAI_SKATE_Assessment/tree/main/2023/Tier3/Model_Runs

Tier 3 summary output, tables and figures: https://github.com/afsc-assessments/AFSC_BSAI_SKATE_Assessment/tree/main/2023/Tier3/Output

Tier 5 Model 23.0 rema: https://github.com/afsc-assessments/AFSC_BSAI_SKATE_Assessment/tree/main/2023/Tier5

Tier 5 summary output, tables and figures: https://github.com/afsc-assessments/AFSC_BSAI_SKATE_Assessment/tree/main/2023/Tier5/Output

Tables

Table 18.1 Estimated catch (t) of the skate stock complex in the Bering Sea and Aleutian Islands (BSAI). The total BSAI skate catch is provided by the NMFS Alaska Regional Office in the Catch Accounting System, queried October 1, 2023. Catch data were incomplete for 2023, so the catch as of October 1, 2023 was expanded by a correction factor based on seasonal catch patterns from the last 5 years.

Year	Management Method	OFL	ABC	TAC	total BSAI skate catch
1992	Other Species	27,200	27,200	20,000	16,962
1993	Other Species	26,600	26,600	26,600	12,226
1994	Other Species	141,000	27,500	26,390	14,223
1995	Other Species	136,000	27,600	20,000	14,892
1996	Other Species	137,000	27,600	20,125	12,643
1997	Other Species	138,000	25,800	25,800	17,747
1998	Other Species	134,000	25,800	25,800	19,318
1999	Other Species	129,000	32,860	32,860	14,080
2000	Other Species	71,500	31,360	31,360	18,877
2001	Other Species	69,000	33,600	26,500	20,570
2002	Other Species	78,900	39,100	30,825	21,279
2003	Other Species	81,100	43,300	32,309	20,270
2004	Other Species	81,150	46,810	27,205	20,673
2005	Other Species	87,920	53,860	29,000	21,539
2006	Other Species	89,404	58,882	29,000	19,094
2007	Other Species	91,700	68,800	37,355	17,691
2008	Other Species	104,000	78,100	50,000	20,168
2009	Other Species	80,800	63,700	50,000	19,008
2010	Other Species	88,200	61,100	50,000	17,066
2011	Skate Complex	37,800	31,500	16,500	22,897
2012	Skate Complex	39,100	32,600	24,700	23,603
2013	Skate Complex	45,800	38,800	24,000	25,852
2014	Skate Complex	41,849	35,383	26,000	26,190
2015	Skate Complex	49,575	41,658	25,700	26,989
2016	Skate Complex	50,215	42,134	26,000	27,654
2017	Skate Complex	49,063	41,144	26,000	30,401
2018	Skate Complex	46,668	39,082	27,000	29,634
2019	Skate Complex	51,152	42,714	26,000	19,197
2020	Skate Complex	49,792	41,543	16,313	18,239
2021	Skate Complex	49,297	41,257	18,000	19,332
2022	Skate Complex	47,790	39,958	30,000	28,110
2023	Skate Complex	46,220	38,605	27,441	*19,633*

Table 18.2. Reconstructed catch data used in the Alaska skate model, by year and gear type. Catch estimates from 2007-2023 are estimated by the method defined in previous stock assessments (Ormseth, 2018). Data are provided by NMFS AKRO Catch Accounting System and the North Pacific Observer Program, queried through AKFIN on October 1, 2023. Catch data were incomplete for 2023, so the catch as of October 1, 2023 was expanded by a correction factor based on seasonal catch patterns from the last 5 years.

Year	Longline	Trawl	Year	Longline	Trawl	Year	Longline	Trawl
1954	0	0	1981	4,503	12,553	2008	9,423	5,432
1955	0	0	1982	2,349	6,437	2009	8,403	7,046
1956	0	0	1983	1,971	5,456	2010	7,509	5,682
1957	0	0	1984	1,072	2,995	2011	12,579	5,523
1958	8	61	1985	1,443	4,045	2012	13,416	5,322
1959	21	156	1986	1,301	3,675	2013	15,648	5,622
1960	0	0	1987	1,062	3,006	2014	16,480	3,903
1961	0	0	1988	1,443	4,287	2015	18,020	2,497
1962	0	0	1989	588	1,752	2016	19,725	2,326
1963	0	0	1990	688	2,009	2017	20,598	3,108
1964	43	304	1991	6,246	1,372	2018	19,256	4,313
1965	150	928	1992	12,586	2,815	2019	9,524	5,606
1966	130	924	1993	9,072	2,029	2020	10,541	4,238
1967	537	1,967	1994	10,554	2,361	2021	10,751	5,566
1968	1,539	9,252	1995	11,050	2,472	2022	20,181	4,818
1969	690	4,365	1996	9,381	2,098	2023	*14,467*	*2,960*
1970	1,220	6,502	1997	13,059	2,932			
1971	856	5,613	1998	14,100	3,178			
1972	1,377	4,916	1999	10,288	2,318			
1973	3,264	23,062	2000	13,362	3,055			
1974	3,700	24,994	2001	14,244	3,291			
1975	3,348	22,736	2002	15,943	3,571			
1976	1,702	10,897	2003	15,580	3,693			
1977	2,559	15,090	2004	16,308	3,892			
1978	3,864	25,571	2005	17,661	3,405			
1979	2,609	16,207	2006	14,907	3,347			
1980	4,578	12,310	2007	8,325	6,654			

Table 18.3. Estimated discard rates of skates in the eastern Bering Sea and Aleutian Islands. Data are provided by NMFS AKRO Catch Accounting System, queried through AKFIN on October 1, 2023.

	Aleutian Islands		Eastern Bering Sea	
Year	**Longline**	**Trawl**	**Longline**	**Trawl**
2003	2%	4%	52%	52%
2004	3%	4%	70%	58%
2005	2%	5%	64%	60%
2006	4%	3%	68%	62%
2007	3%	4%	67%	64%
2008	6%	3%	63%	54%
2009	4%	3%	69%	56%
2010	6%	4%	64%	53%
2011	4%	5%	76%	55%
2012	2%	6%	71%	59%
2013	1%	6%	71%	58%
2014	2%	9%	69%	53%
2015	2%	9%	71%	52%
2016	1%	10%	79%	45%
2017	2%	9%	70%	50%
2018	2%	9%	61%	40%
2019	3%	5%	49%	46%
2020	4%	9%	48%	49%
2021	4%	6%	50%	53%
2022	1%	9%	52%	63%
2023	0%	11%	48%	63%

Table 18.4. Alaska skate survey and fishery hauls sampled, number of lengths and vertebrae collected, number of vertebrae aged, and input sample sizes for Model 14.2d. Input sample size is fixed at 200 for survey and the square root of the number of hauls for fishery. Survey length data are available from 2000 to present, and ages in 2003, 2007-2009 and 2015. There was no survey in 2020. Fishery length data are available since 2009, and there are no fishery ages.

	EBS Shelf Survey					Longline			Trawl		
Year	**Hauls**	**Vert coll**	**Aged**	**Lengths**	**Input N**	**Hauls**	**Lengths**	**Input N**	**Hauls**	**Lengths**	**Input N**
2000	319			2,135	200						
2001	339			3,188	200						
2002	335			2,669	200						
2003	335	306	182	2,818	200						
2004	348			4,180	200						
2005	344			4,491	200						
2006	339			4,759	200						
2007	363	252	244	4,997	200						
2008	347	181	175	4,131	200						
2009	334	350	337	4,584	200	4,496	18,934	67.1	3,082	8,476	55.5
2010	348			3,610	200	4,255	16,972	65.2	3,752	9,633	61.3
2011	343			4,522	200	5,156	22,166	71.8	3,181	6,601	56.4
2012	337			3,704	200	5,934	26,462	77	2,495	5,338	49.9
2013	356			3,797	200	7,252	31,269	85.2	3,705	7,721	60.9
2014	349			3,576	200	7,594	32,481	87.1	2,925	6,025	54.1
2015	353	323	313	3,906	200	7,536	31,189	86.8	2,043	3,910	45.2
2016	353			4,246	200	6,448	27,892	80.3	2,040	4,134	45.2
2017	360			4,243	200	6,198	26,250	78.7	3,096	6,375	55.6
2018	363			4,593	200	4,445	20,254	66.7	5,152	11,758	71.8
2019	348			3,651	200	3,034	12,847	55.1	6,246	16,057	79
2020						2,374	10,627	48.7	4,333	10,646	65.8
2021	356			3,855	200	2,363	11,209	48.6	4,156	10,994	64.5
2022	365			3,783	200	2,729	12,895	52.2	3,749	8,757	61.2
2023	351			3,688	200	1,363	6,508	36.9	1,726	4,771	41.5

Table 18.5. Survey biomass estimates time series as used in Model 14.2d (eastern Bering Sea, EBS, shelf Alaska skates) and Model 23.0 (all Other skates), from the NMFS EBS shelf, EBS slope and Aleutian Islands (AI) bottom trawl surveys. CV = coefficient of variation. No bottom trawl surveys were conducted in 2020 due to the coronavirus pandemic.

	EBS Shelf AK skate		**EBS Shelf Other skates**		**EBS Slope all species**		**AI Survey all species**	
Year	**Biomass**	**CV**	**Biomass**	**CV**	**Biomass**	**CV**	**Biomass**	**CV**
1987	127,212	0.12	45,536	0.23				
1988	106,714	0.21	13,176	0.38				
1989	771	1.00	0	0				
1990	0	0	0	0				
1991	0	0	0	0			15,009	0.17
1992	18,651	0.22	16	1.00				
1993	0	0	0	0				
1994	0	0	0	0			24,991	0.10
1995	0	0	0	0				
1996	351,731	0.06	65,270	0.20				
1997	333,399	0.07	71,897	0.23			29,001	0.14
1998	356,732	0.05	4,192	0.42				
1999	321,732	0.17	15,867	0.43				
2000	311,652	0.06	24,598	0.21			29,219	0.09
2001	413,816	0.06	17,256	0.15				
2002	363,236	0.07	18,538	0.14	69,232	0.50	34,465	0.11
2003	372,100	0.05	32,081	0.24				
2004	424,508	0.05	14,553	0.13	33,156	0.08	53,225	0.16
2005	487,010	0.05	20,615	0.25				
2006	437,468	0.05	18,392	0.15			54,213	0.12
2007	479,235	0.07	17,108	0.21				
2008	361,585	0.06	19,495	0.22	36,384	0.08	51,941	0.11
2009	350,384	0.06	20,032	0.17				
2010	366,930	0.06	18,782	0.16	35,177	0.12	35,405	0.12
2011	410,961	0.05	17,691	0.25				
2012	370,249	0.06	16,525	0.15	59,687	0.10		
2013	387,225	0.06	26,690	0.23				
2014	405,036	0.05	24,291	0.18			42,905	0.11
2015	448,213	0.06	39,162	0.23				
2016	550,912	0.04	36,652	0.19	49,152	0.11	27,767	0.14
2017	545,059	0.07	65,644	0.33				
2018	546,263	0.05	63,921	0.22			29,489	0.14
2019	490,420	0.05	37,539	0.16				
2021	468,113	0.05	43,812	0.17				
2022	463,017	0.06	45,363	0.17			23,011	0.23
2023	418,484	0.08	80,944	0.27				

Table 18.6. Input parameter values for model 14.2d. Minimum and maximum bounds are shown for parameters estimated freely within the model.

Parameter type	Parameter	Value	Min	Max	Fix?
growth and natural mortality	natural mortality (*M*)	0.13			X
	length at A1 (L1)	20	-10	30	
	length at A2 (L2)	110	70	150	
	von Bertalanffy coefficient (κ)	0.15	0.05	0.50	
	Richards coefficient (γ)	0.1	-1	2	
	CV of LAA @ L1	0.1	0.05	0.35	
	CV of LAA @ L2	0.1	0.05	0.25	
length-weight relationship	coefficient (a)	9.00×10^{-6}			X
	exponent (b)	2.962			X
length at maturity	length at 50% maturity (a)	93.28			X
	slope (b)	-0.548			X
stock-recruit function	ln virgin recruitment level (R_0)	10.00	5	15	
	Steepness	1			X
	σ_R	0.4			X
EBS shelf survey catchability	ln catchability (q)	0			X
longline length selectivity	peak (p1)	111	7.6	126	
	top (p2)	-0.1	-6	4	
	ascending width (p3)	4.9	-1	9	
	descending width (p4)	4.7	-1	9	
	selectivity at first size bin (p5)	-2.2	-5	9	
	selectivity at last size bin (p6)	9	-5	9	
trawl length selectivity	peak (p1)	49	7.6	126	
	top (p2)	-5	-6	4	
	ascending width (p3)	4.8	-1	9	
	descending width (p4)	4.4	-1	9	
	selectivity at first size bin (p5)	-0.7	-5	9	
	selectivity at last size bin (p6)	9	-5	9	
survey length selectivity	peak (p1)	49	7.6	126	
	top (p2)	-5	-6	4	
	ascending width (p3)	4.8	-1	9	
	descending width (p4)	4.4	-1	9	
	selectivity at first size bin (p5)	-0.7	-5	9	
	selectivity at last size bin (p6)	9	-5	9	
initial fishing mortality	longline fishery F	0			X
	trawl fishery F	0			X

Table 18.7. Selected parameter estimates and model fit statistics for model 14.2 (2020 run) and 14.2d (2023 run). CV= coefficient of variation.

Model number **Description**	**14.2** **2020 run**	**14.2d** **2023 run**
likelihood components		
Survey	-5.59	-13.48
length comps	132.11	175.19
LAA	161.00	167.53
Recruitment	-40.96	-43.83
Total	246.58	287.01
# of parameters estimated	94	104
L_amin	13.98	14.98
SD	0.419	0.892
L_amax	101.96	102.10
SD	0.230	0.388
K	0.38	0.37
SD	.017	.011
CV young	0.35	0.32
SD	0.00008	0.034
CV old	0.05	0.05
SD	0.00031	0.0000034
ln (Rzero)	10.12	10.09
SD	0.036	0.037
unfished spawning biomass (t)	334,279	319,912
CV	0.038	0.038
unfished recruitment (1000s)	24,879	24,131
SD	0.036	0.037
RMSE_survey	0.146	0.143
% within survey CI	75.7%	57.5%
correlation obs-pred	0.782	0.792
mean longline input N	78.1	67.1
mean longline eff N	738.9	662.3
mean longline effN/N	9.46	9.9
mean trawl input N	53.3	57.9
mean trawl eff N	851.9	667.5
mean trawl effN/N	16.0	11.5
mean survey input N	200.0	200.0
mean survey eff N	841.0	718
mean survey effN/N	4.2	3.4

Table 18.8. Time series of total (age 0+) biomass (t) and spawning biomass (t) predicted by Model 14.2d. CV = coefficient of variation. Estimates from the 2020 Model 14.2 run are included for comparison.

Year	Age 0+ Biomass	SSB	CV	14.2 spawning biomass	Year	Age 0+ Biomass	SSB	CV	14.2 spawning biomass
Unfished	545,394	319,912	0.038	334,279	1988	330,198	112,192	0.087	121,445
1950	545,274	319,912	0.038	334,279	1989	356,860	122,795	0.082	132,377
1951	545,016	319,912	0.038	334,279	1990	383,341	140,619	0.080	151,182
1952	544,498	319,912	0.038	334,279	1991	404,732	164,286	0.074	178,115
1953	543,545	319,912	0.038	334,279	1992	416,175	186,131	0.071	202,830
1954	541,940	319,912	0.038	334,279	1993	415,390	201,069	0.070	219,892
1955	539,479	319,912	0.038	334,279	1994	415,445	213,259	0.070	233,371
1956	536,029	319,912	0.038	334,279	1995	411,639	219,206	0.070	239,748
1957	531,578	319,912	0.038	334,279	1996	406,107	220,361	0.069	240,680
1958	526,226	319,912	0.038	334,279	1997	402,594	219,672	0.068	239,419
1959	520,083	318,662	0.040	332,767	1998	395,592	214,547	0.067	233,635
1960	513,307	316,481	0.044	330,242	1999	389,183	208,080	0.066	226,706
1961	506,357	313,571	0.050	326,945	2000	389,911	204,334	0.065	222,786
1962	499,181	310,012	0.057	322,997	2001	389,563	197,812	0.065	216,133
1963	491,865	306,043	0.064	318,667	2002	390,798	190,830	0.066	209,091
1964	484,459	301,853	0.070	314,161	2003	392,695	184,700	0.066	203,143
1965	476,645	297,343	0.074	309,383	2004	397,075	181,807	0.066	200,774
1966	468,073	292,329	0.078	304,150	2005	402,251	179,577	0.066	198,833
1967	459,525	287,318	0.081	298,961	2006	408,211	179,070	0.066	198,418
1968	449,573	281,371	0.084	292,875	2007	418,059	181,590	0.066	201,316
1969	431,561	270,178	0.087	281,594	2008	432,544	187,234	0.066	207,403
1970	419,649	262,672	0.088	273,994	2009	448,640	194,839	0.066	215,349
1971	405,451	253,512	0.090	264,754	2010	465,367	201,781	0.065	221,991
1972	392,972	245,251	0.091	256,407	2011	484,957	208,996	0.064	229,038
1973	381,184	237,213	0.091	248,276	2012	499,703	214,769	0.064	234,248
1974	350,213	216,801	0.096	227,828	2013	512,530	222,360	0.064	241,820
1975	318,222	195,323	0.101	206,289	2014	520,477	229,607	0.064	249,105
1976	290,355	176,025	0.107	186,881	2015	525,829	239,464	0.063	259,031
1977	277,417	165,646	0.109	176,326	2016	526,909	247,150	0.063	266,532
1978	260,962	152,800	0.112	163,273	2017	521,868	254,639	0.062	274,746
1979	234,678	133,733	0.120	143,977	2018	510,397	259,898	0.062	279,688
1980	221,256	121,837	0.123	131,840	2019	494,871	262,592	0.062	281,272
1981	212,679	111,833	0.126	121,598	2020	484,658	266,812	0.061	284,268
1982	207,504	102,775	0.128	112,313	2021	472,589	268,549	0.060	
1983	214,432	99,223	0.125	108,578	2022	458,825	265,673	0.060	
1984	227,305	97,487	0.120	106,692	2023	437,954	253,708	0.061	
1985	248,390	98,619	0.111	107,739					
1986	272,616	100,659	0.104	109,749					
1987	300,462	104,903	0.095	114,029					

Table 18.9. Time series of age-0 recruits (1000s) predicted by Model 14.2d. CV = coefficient of variation. Estimates from the 2020 Model 14.2 run are included for comparison.

Year	Age 0 recruits	CV	14.2 recruits	Year	Age 0 recruits	CV	14.2 recruits
Unfished	24,131	0.037	24,879	1988	20,460	0.359	20,859
1950	20,790	0.388	21,248	1989	20,844	0.359	21,485
1951	20,587	0.386	21,060	1990	21,693	0.356	22,728
1952	20,363	0.384	20,853	1991	21,528	0.348	22,880
1953	20,118	0.382	20,625	1992	18,765	0.340	20,012
1954	19,852	0.380	20,377	1993	19,266	0.336	20,306
1955	19,564	0.377	20,106	1994	24,585	0.340	25,614
1956	19,256	0.374	19,815	1995	29,938	0.318	31,237
1957	18,929	0.371	19,506	1996	25,903	0.339	26,825
1958	18,587	0.368	19,180	1997	29,326	0.321	29,491
1959	18,234	0.364	18,841	1998	30,442	0.326	31,779
1960	17,874	0.361	18,493	1999	31,002	0.306	33,494
1961	17,511	0.358	18,141	2000	34,806	0.262	35,791
1962	17,148	0.354	17,788	2001	29,528	0.264	30,204
1963	16,791	0.351	17,439	2002	27,651	0.280	27,631
1964	16,443	0.347	17,096	2003	33,946	0.281	34,329
1965	16,113	0.344	16,766	2004	40,145	0.287	42,135
1966	15,810	0.341	16,460	2005	38,739	0.318	40,215
1967	15,535	0.338	16,186	2006	43,871	0.289	44,607
1968	15,276	0.335	15,939	2007	33,910	0.356	35,121
1969	15,037	0.333	15,709	2008	40,737	0.306	44,573
1970	14,803	0.331	15,475	2009	38,444	0.313	38,130
1971	14,594	0.329	15,246	2010	33,611	0.328	33,168
1972	14,440	0.327	15,063	2011	28,816	0.326	28,536
1973	14,356	0.326	14,965	2012	28,478	0.297	26,366
1974	14,421	0.326	15,003	2013	23,564	0.302	19,980
1975	14,717	0.328	15,240	2014	20,385	0.283	16,850
1976	15,390	0.333	15,804	2015	16,767	0.287	15,346
1977	16,621	0.342	16,903	2016	18,716	0.279	19,526
1978	18,757	0.357	18,894	2017	20,531	0.267	26,107
1979	22,403	0.383	22,391	2018	17,972	0.289	22,687
1980	28,519	0.429	28,476	2019	24,113	0.310	24,879
1981	38,343	0.502	39,189	2020	40,607	0.262	24,879
1982	43,744	0.531	49,743	2021	28,582	0.351	
1983	33,787	0.479	36,851	2022	34,565	0.368	
1984	26,717	0.419	28,292	2023	23,812	0.402	
1985	22,885	0.387	23,813				
1986	21,028	0.370	21,609				
1987	20,437	0.362	20,828				

Table 18.10. Time series of exploitation rates (catch/total biomass) estimated by model 14.2d.

Year	Longline	Trawl	Total *F*	Year	Longline	Trawl	Total *F*
1950	0	0	0	1988	0.005	0.014	0.018
1951	0	0	0	1989	0.002	0.005	0.007
1952	0	0	0	1990	0.002	0.006	0.007
1953	0	0	0	1991	0.018	0.004	0.021
1954	0	0	0	1992	0.035	0.007	0.041
1955	0	0	0	1993	0.025	0.005	0.030
1956	0	0	0	1994	0.030	0.006	0.035
1957	0	0	0	1995	0.031	0.007	0.037
1958	<0.001	<0.001	<0.001	1996	0.027	0.006	0.032
1959	<0.001	<0.001	<0.001	1997	0.039	0.008	0.045
1960	0	0	0	1998	0.043	0.009	0.050
1961	0	0	0	1999	0.032	0.007	0.037
1962	0	0	0	2000	0.042	0.009	0.049
1963	0	0	0	2001	0.045	0.010	0.053
1964	0	0.001	0.001	2002	0.050	0.010	0.058
1965	0	0.002	0.002	2003	0.049	0.011	0.057
1966	0	0.002	0.002	2004	0.050	0.011	0.059
1967	0.001	0.005	0.006	2005	0.054	0.010	0.061
1968	0.004	0.024	0.026	2006	0.045	0.009	0.052
1969	0.002	0.012	0.013	2007	0.024	0.018	0.040
1970	0.003	0.018	0.020	2008	0.027	0.014	0.039
1971	0.002	0.016	0.017	2009	0.023	0.018	0.039
1972	0.004	0.015	0.018	2010	0.020	0.014	0.032
1973	0.010	0.072	0.078	2011	0.031	0.013	0.042
1974	0.013	0.086	0.093	2012	0.032	0.012	0.043
1975	0.013	0.086	0.093	2013	0.037	0.012	0.047
1976	0.007	0.044	0.048	2014	0.038	0.008	0.044
1977	0.011	0.065	0.071	2015	0.040	0.005	0.044
1978	0.018	0.119	0.130	2016	0.044	0.005	0.047
1979	0.014	0.083	0.091	2017	0.046	0.007	0.051
1980	0.026	0.066	0.087	2018	0.044	0.001	0.052
1981	0.027	0.070	0.092	2019	0.022	0.013	0.034
1982	0.014	0.036	0.048	2020	0.025	0.010	0.034
1983	0.012	0.030	0.039	2021	0.027	0.014	0.039
1984	0.006	0.015	0.020	2022	0.052	0.012	0.062
1985	0.007	0.018	0.024	2023	0.040	0.008	0.046
1986	0.006	0.015	0.020				
1987	0.004	0.011	0.014				

Table 18.11. Aggregated biomass estimates for Other skates from *rema* (Model 23.0) and exploitation rates. Alaska skates are not included in the eastern Bering Sea (EBS) Shelf *rema* model, but are included in the Aleutian Islands and EBS slope *rema* models. The 2023 total Other skate biomass estimate was used for harvest recommendations. No survey was conducted in 2020. Species specific *rema* model results are available for the dominant species in Appendix B. Detailed *rema* outputs with confidence intervals are available at: https://github.com/afsc-assessments/AFSC_BSAI_SKATE_Assessment/tree/main/2023/Tier5/Output

Year	Aleutian Islands	EBS Shelf	EBS Slope	Total BSAI Other Skate Biomass	Exploitation Rate
1999		19,632			
2000	30,159	20,333			
2001	32,771	18,696			
2002	35,610	19,005	38,230	92,844	
2003	41,092	19,976	36,035	97,103	0.029
2004	47,419	16,739	33,966	98,123	0.042
2005	49,724	18,000	34,583	102,307	0.039
2006	52,140	18,211	35,212	105,563	0.029
2007	51,312	18,204	35,852	105,368	0.026
2008	50,497	18,906	36,503	105,906	0.050
2009	49,695	19,280	37,557	106,532	0.033
2010	48,906	18,947	38,641	106,494	0.036
2011	43,381	18,792	45,881	108,055	0.044
2012	38,481	19,175	54,478	112,134	0.043
2013	38,930	23,461	53,265	115,656	0.040
2014	39,384	26,818	52,079	118,280	0.049
2015	34,600	33,442	50,919	118,961	0.054
2016	30,397	38,221	49,785	118,403	0.047
2017	29,748	45,076	49,785	124,610	0.054
2018	29,113	47,983	49,785	126,882	0.048
2019	28,057	42,903	49,785	120,745	0.034
2020	27,039	44,245	49,785	121,069	0.029
2021	26,058	45,629	49,785	121,472	0.025
2022	25,112	48,990	49,785	123,888	0.025
2023	25,112	56,548	49,785	131,446	0.032

Table 18.12. Standard harvest scenarios projected through 2036 with resultant female spawning biomass, full selection fishing mortality (*F*) and catch (t).

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
Female Spawning Biomass							
2023	112,692	112,692	112,692	112,692	112,692	112,692	112,692
2024	107,197	107,197	91,065	108,782	110,570	106,644	107,197
2025	99,482	99,482	57,157	104,571	110,530	97,750	99,482
2026	92,096	92,096	35,896	100,252	110,165	89,384	91,622
2027	85,579	85,579	22,823	96,416	110,077	82,061	84,094
2028	80,441	80,441	14,963	93,681	110,977	76,242	78,085
2029	76,963	76,963	10,310	92,471	113,435	72,152	73,821
2030	75,019	75,019	7,544	92,771	117,559	69,625	71,129
2031	74,072	74,078	5,848	94,056	122,822	68,156	69,462
2032	73,514	73,514	4,773	95,629	128,393	67,207	68,264
2033	72,969	72,966	4,093	97,007	133,604	66,412	67,233
2034	72,335	72,335	3,674	98,040	138,176	65,676	66,289
2035	71,688	71,688	3,429	98,791	142,124	65,043	65,481
2036	71,111	71,111	3,295	99,371	145,561	64,565	64,860
Fully-Selected *F*							
2023	0.047	0.047	0.047	0.047	0.047	0.047	0.047
2024	0.08	0.08	0.5	0.042	0	0.093	0.08
2025	0.08	0.08	0.5	0.042	0	0.093	0.08
2026	0.08	0.08	0.5	0.042	0	0.093	0.093
2027	0.08	0.08	0.5	0.042	0	0.093	0.093
2028	0.08	0.08	0.5	0.042	0	0.093	0.093
2029	0.08	0.08	0.5	0.042	0	0.093	0.093
2030	0.08	0.08	0.5	0.042	0	0.093	0.093
2031	0.08	0.08	0.5	0.042	0	0.092	0.093
2032	0.08	0.08	0.5	0.042	0	0.09	0.092
2033	0.08	0.08	0.5	0.042	0	0.089	0.09
2034	0.08	0.08	0.5	0.042	0	0.088	0.089
2035	0.08	0.08	0.5	0.042	0	0.087	0.088
2036	0.079	0.079	0.5	0.042	0	0.087	0.087
Catch (t)							
2023	17,427	17,427	17,427	17,427	17,427	17,427	17,427
2024	28,104	28,104	148,231	15,031	0	32,608	28,104
2025	26,904	26,904	100,996	14,846	0	30,874	26,904
2026	26,185	26,185	73,203	14,869	0	29,750	30,385
2027	25,800	25,800	56,474	15,035	0	29,050	29,616
2028	25,575	25,575	46,008	15,257	0	28,566	29,064
2029	25,388	25,388	39,321	15,470	0	28,154	28,586
2030	25,192	25,192	35,147	15,643	0	27,762	28,131
2031	24,991	24,991	32,667	15,774	0	26,994	27,703
2032	24,803	24,803	31,287	15,875	0	26,330	26,974
2033	24,651	24,651	30,601	15,963	0	25,823	26,294
2034	24,542	24,542	30,315	16,045	0	25,428	25,758
2035	24,457	24,457	30,214	16,126	0	25,145	25,362
2036	24,330	24,330	30,165	16,203	0	24,965	25,096

Figures

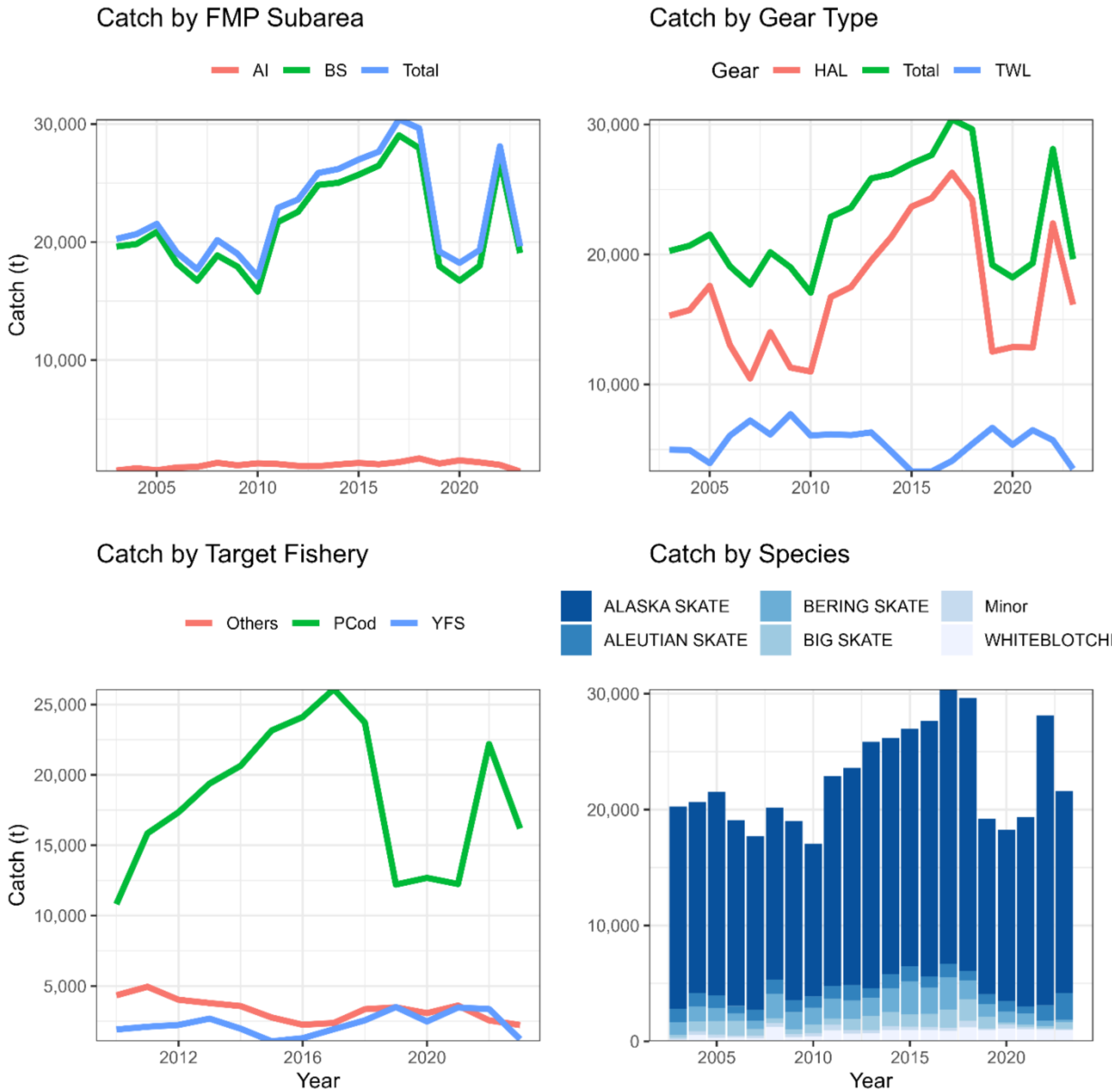

Figure 18.1. Total catch estimates of the Bering Sea/Aleutian Islands skate stock complex. Top left: total catch by Fishery Management Plan sub-areas: Bering Sea (BS) and Aleutian Islands (AI). Top right: total catch by longline (HAL) and trawl (TWL) gear types. Bottom left: Catch of skates in the Pacific cod (PCod) and yellowfin sole (YFS) fisheries, all other target fisheries that catch skates are combined. Bottom right: species-specific catch, as estimated following Ormseth (2018), where unidentified skates are portioned by observed species compositions. Data are provided by NMFS AKRO Catch Accounting System and the North Pacific Observer Program, queried through AKFIN on October 1, 2023.

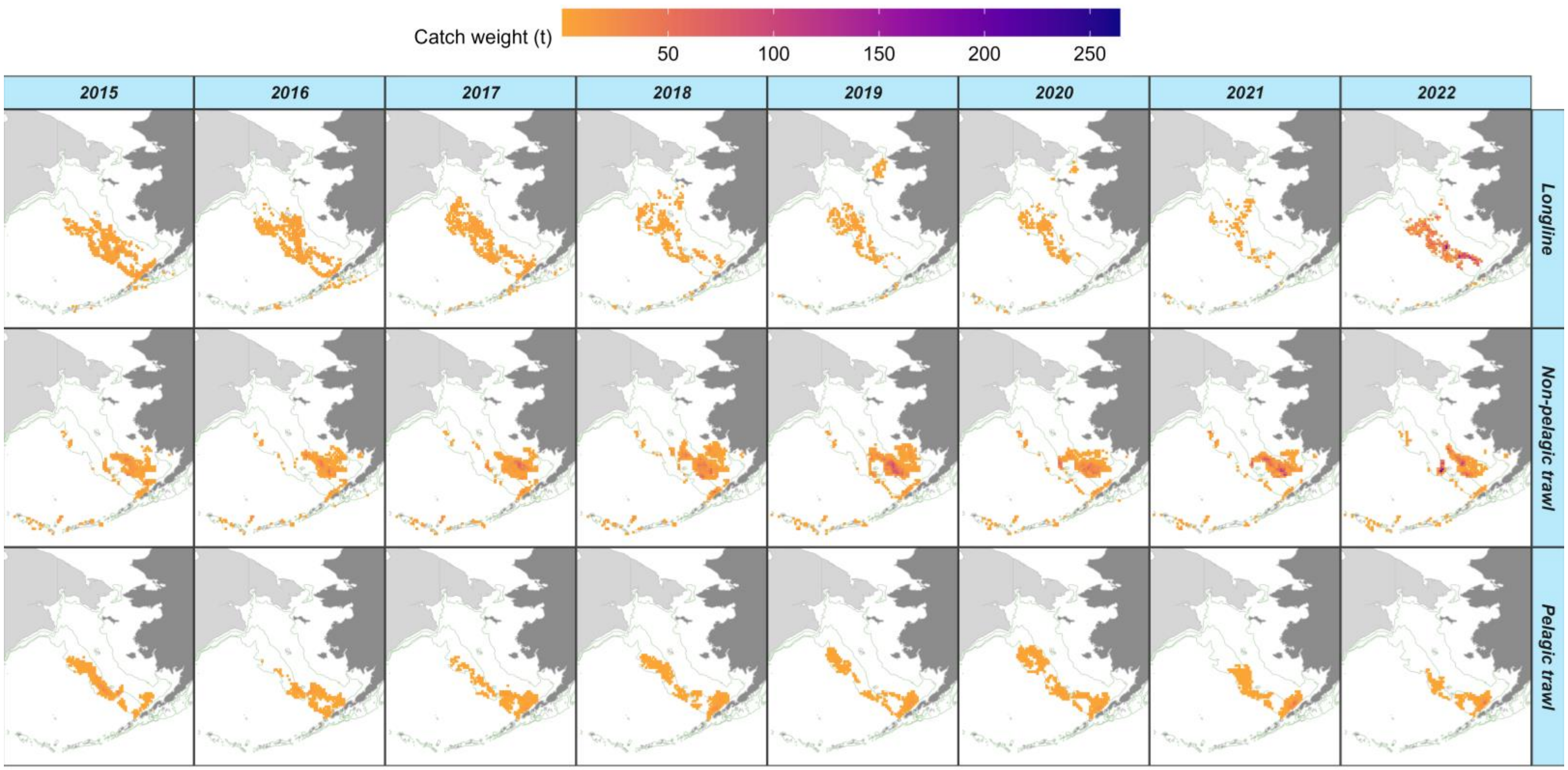

Figure 18.2. Alaska skate catch since 2015 using longline, pelagic trawl, and non-pelagic trawl gears in the BSAI. Data available from the North Pacific Groundfish Observer Program website (https://www.fisheries.noaa.gov/resource/map/spatial-data-collected-groundfish-observers-alaska), queried on October 12, 2023.

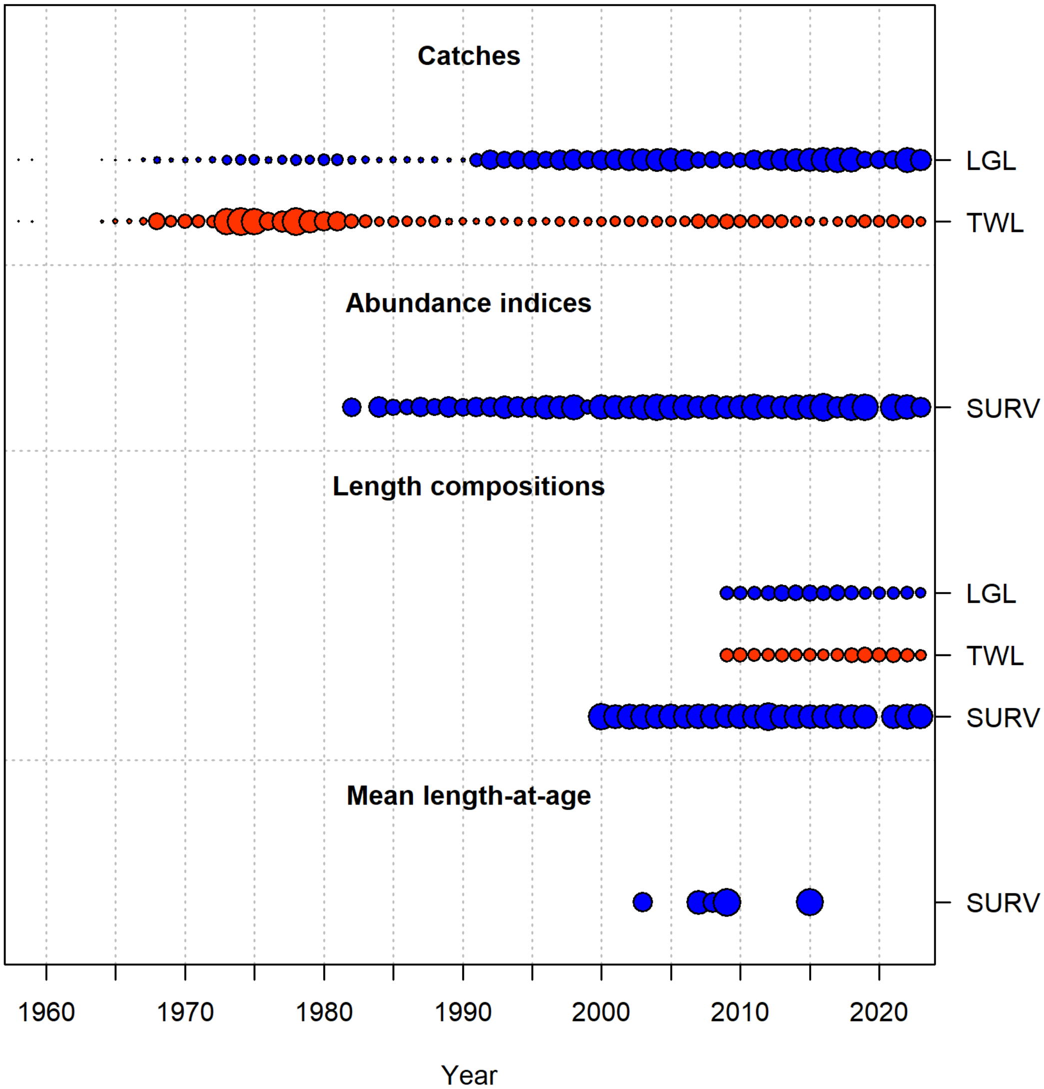

Figure 18.3. Data inputs for Model 14.2d. Dots indicate years in which data are available and the size of the dot is relative sample size or volume within that data category.

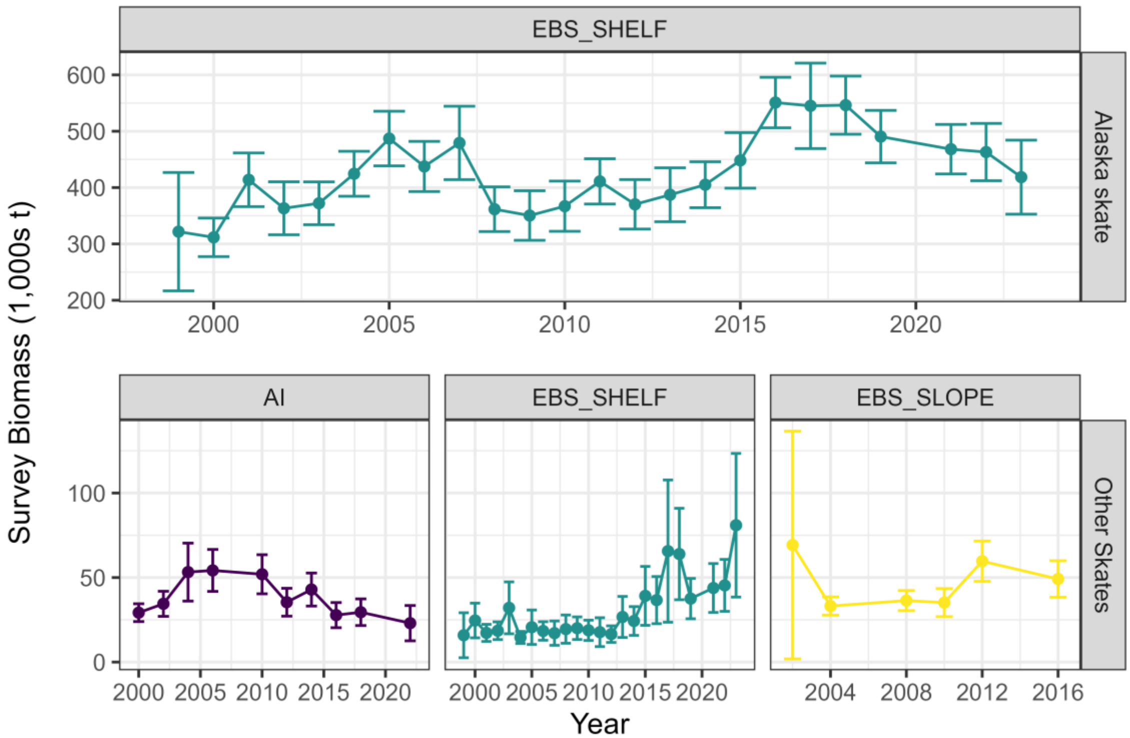

Figure 18.4. Alaska Fisheries Science Center Aleutian Island (AI), eastern Bering Sea shelf (EBS_SHELF) and EBS slope (EBS_SLOPE) surveys design-based biomass estimates with 95% error bars.

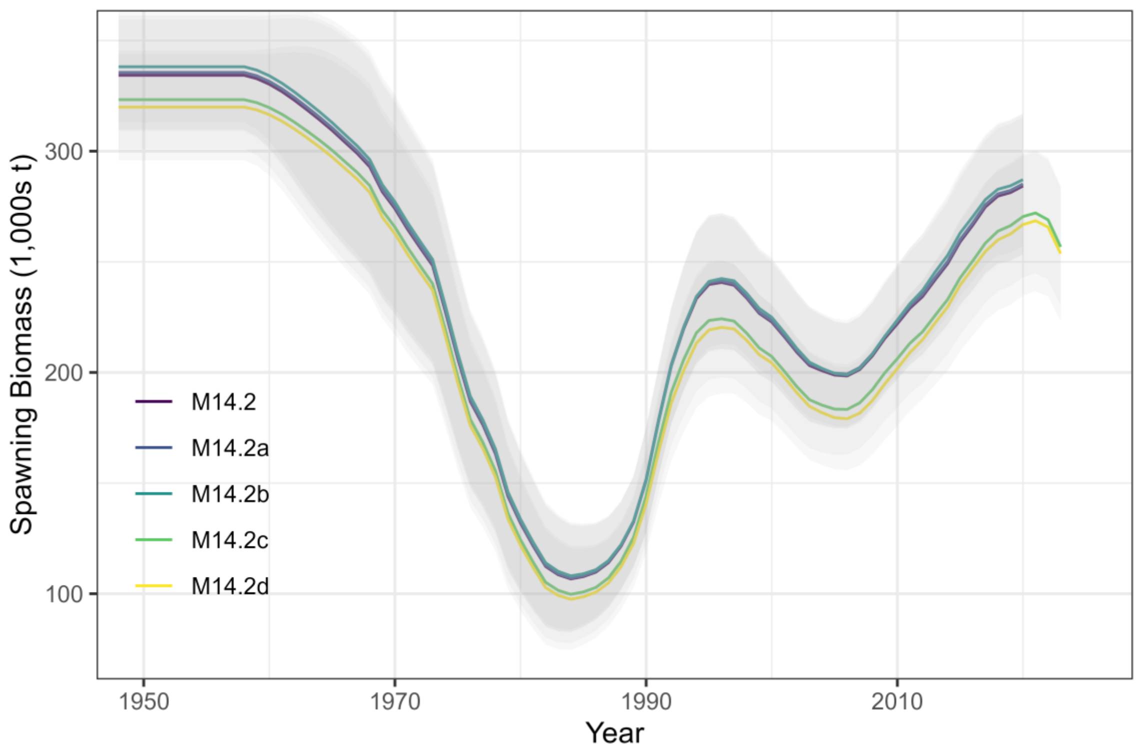

Figure 18.5. Results of bridging the 2020 Model 14.2 to the 2023 Model 14.2d.

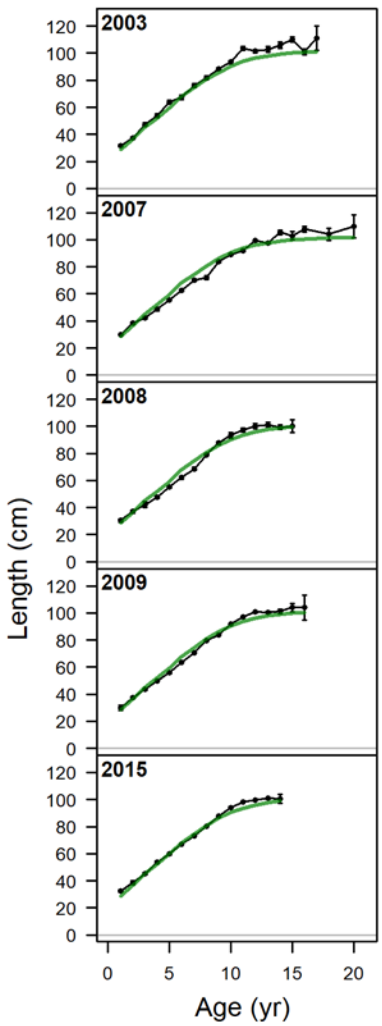

Figure 18.6. Mean length at age for Alaska skate with Model 14.2d model fits.

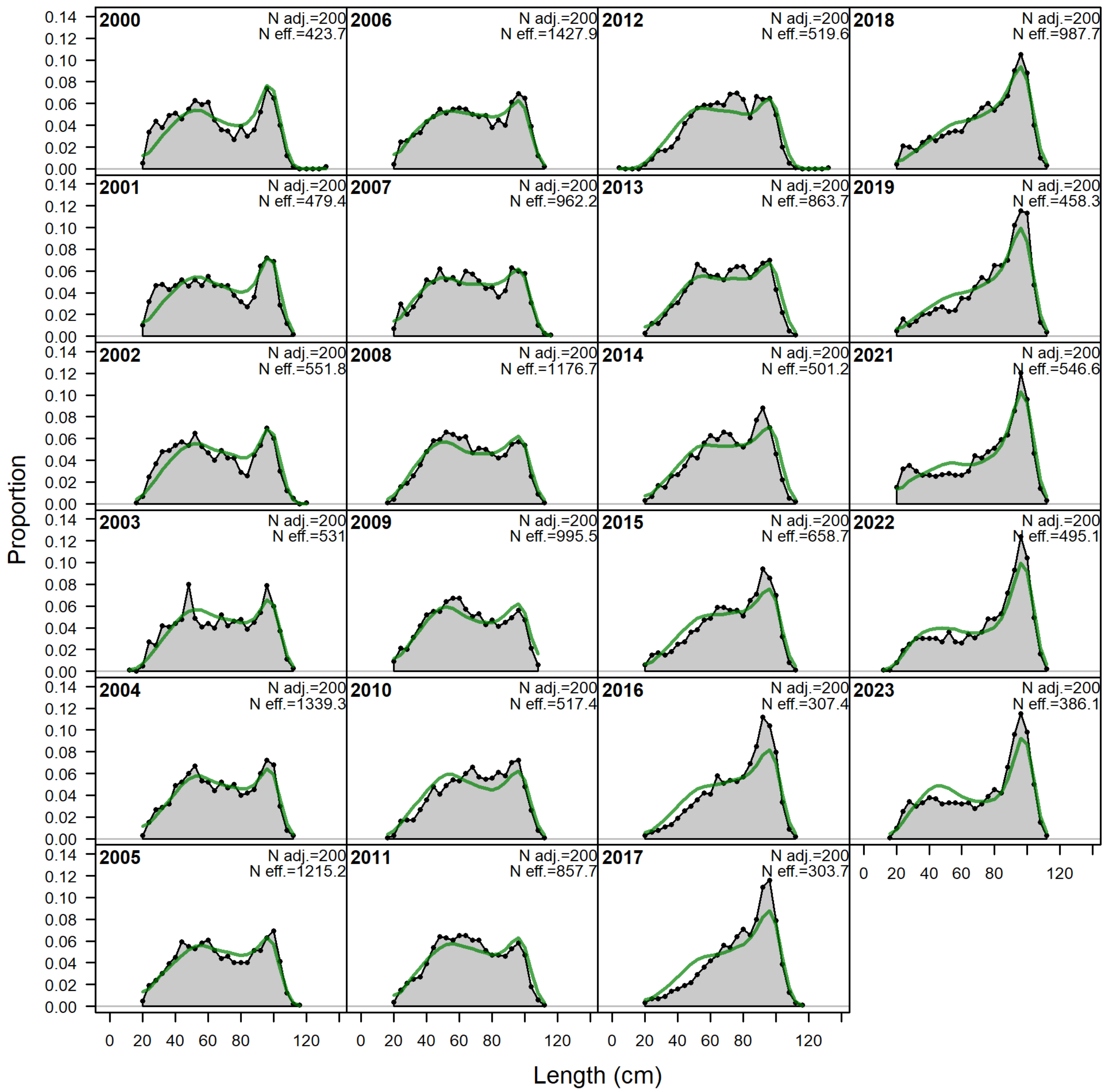

Figure 18.7. Alaska skate length compositions from the eastern Bering Sea bottom trawl survey with the Model 14.2d fits. The input sample size (N adj.) and effective sample sizes (N eff.) are provided in each panel.

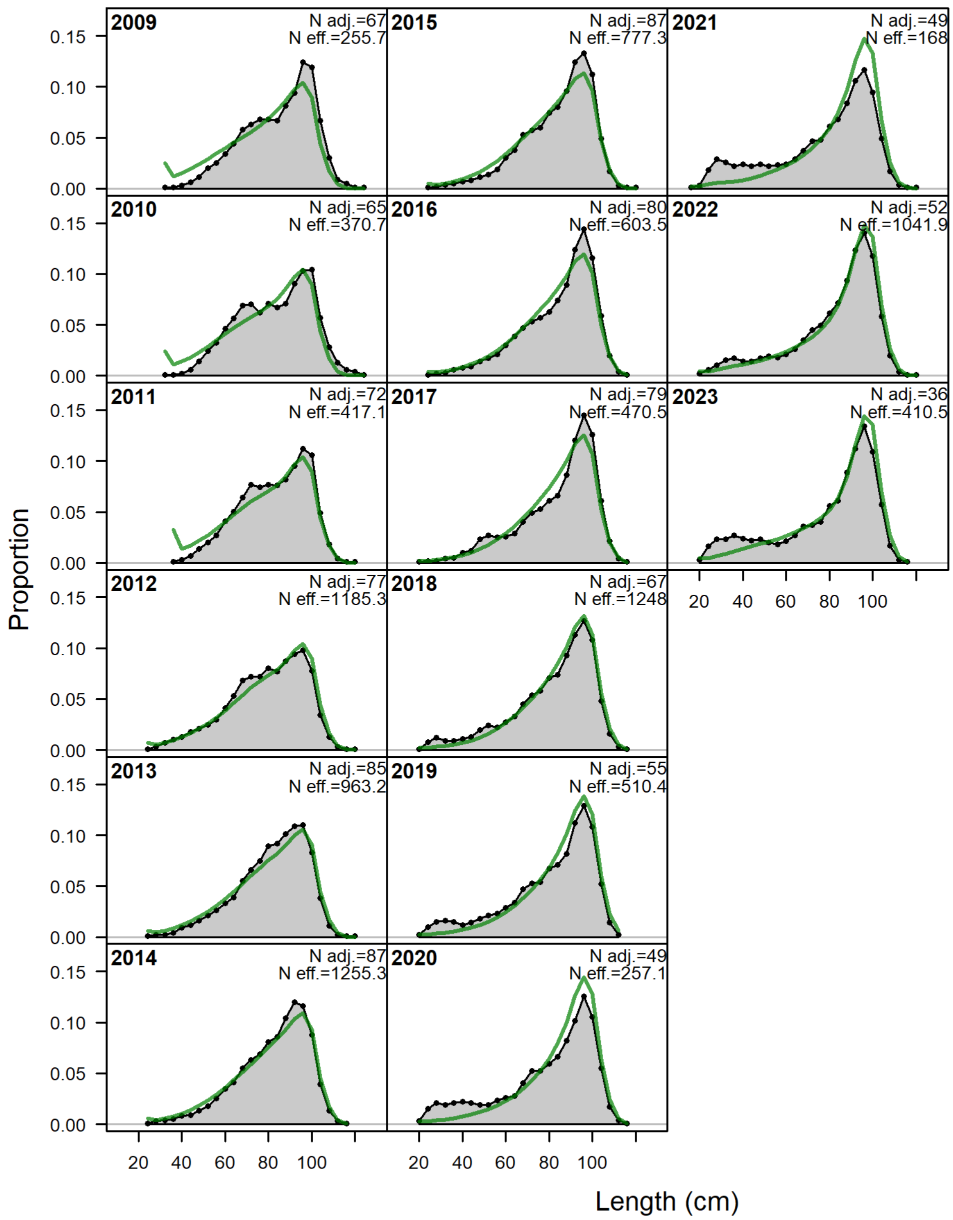

Figure 18.8. Alaska skate length compositions from longline fisheries data with the Model 14.2d fits. The input sample size (N adj.) and effective sample sizes (N eff.) are provided in each panel.

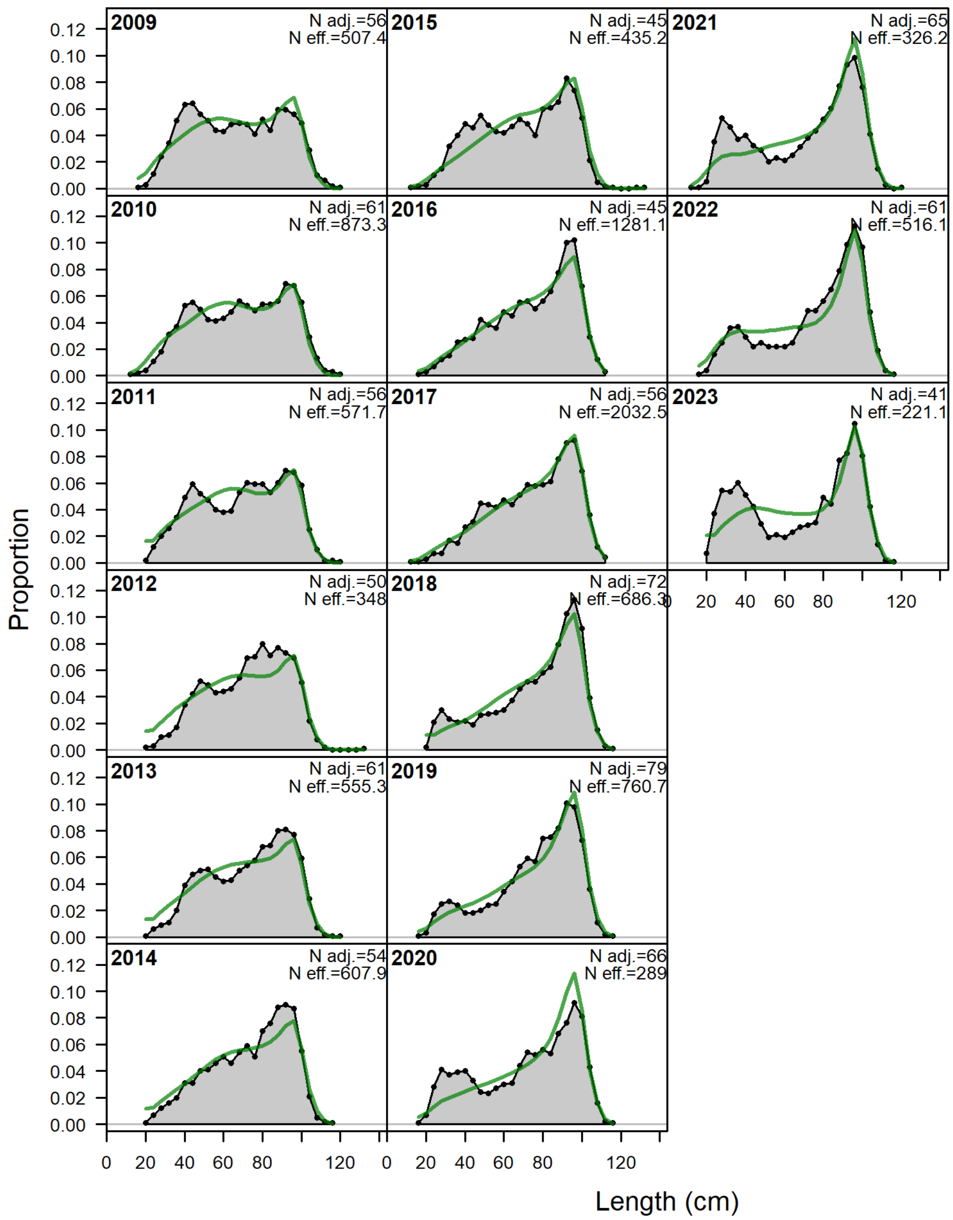

Figure 18.9. Alaska skate length compositions from the trawl fisheries data with the Model 14.2d fits. The input sample size (N adj.) and effective sample sizes (N eff.) are provided in each panel.

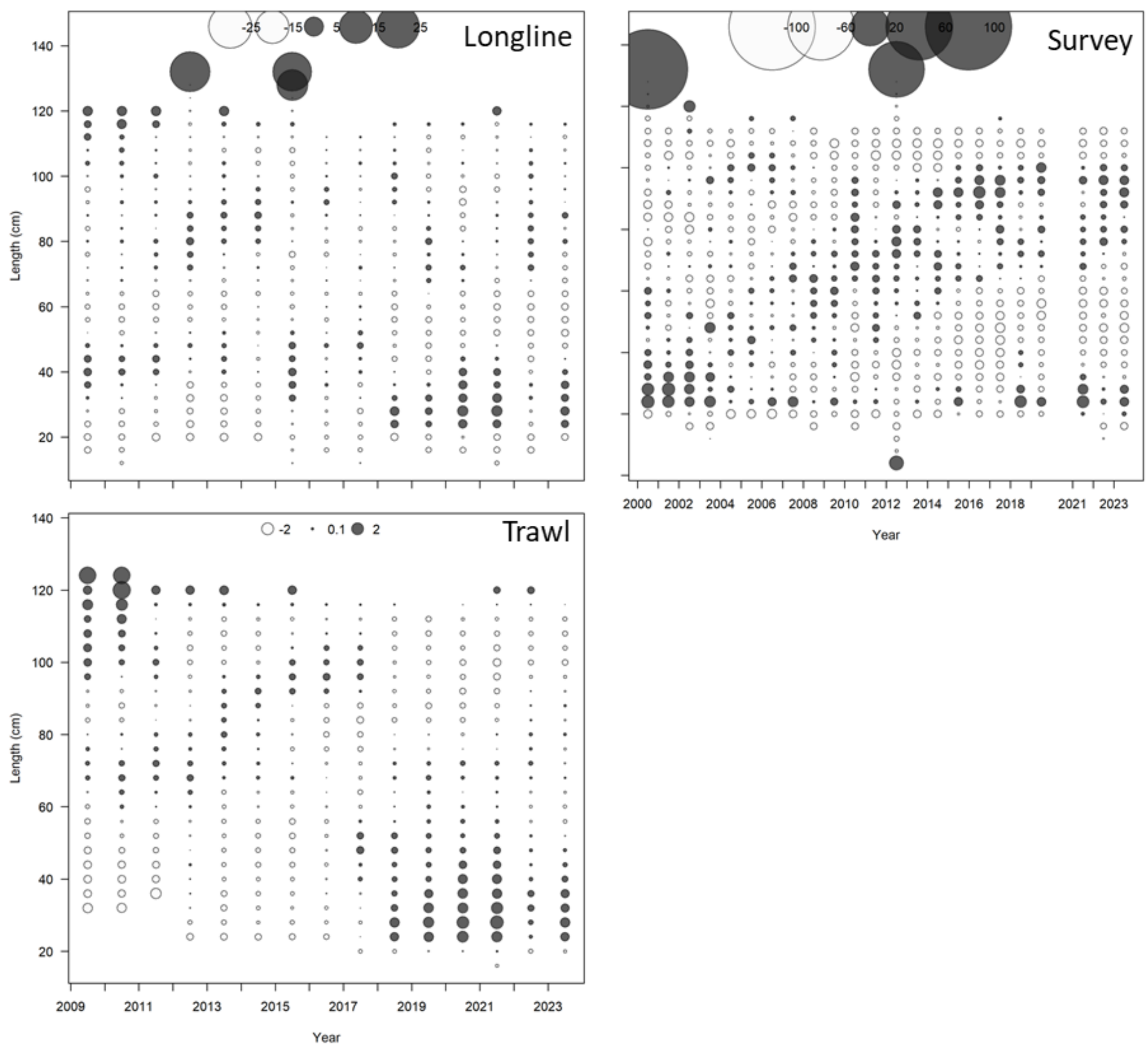

Figure 18.10. Pearson residuals for the eastern Bering Sea bottom trawl survey, longline and trawl fisheries length compositions.

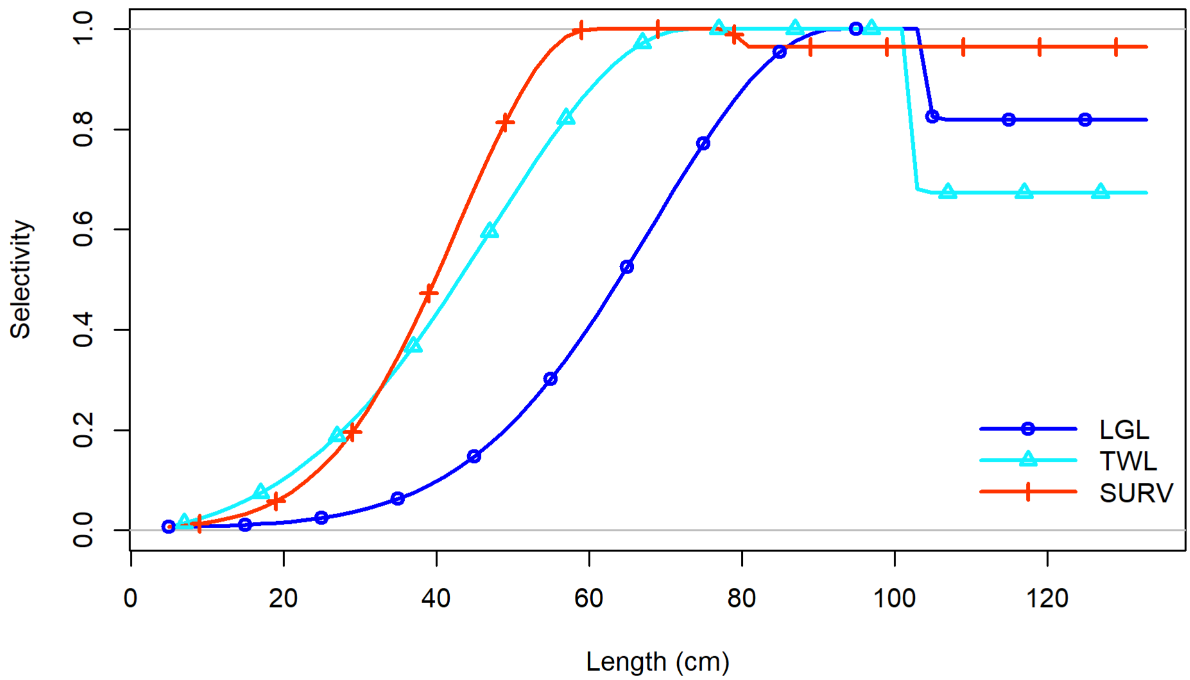

Figure 18.11. Selectivity curves estimated from Model 14.2d for the eastern Bering Sea bottom trawl survey (SURV), longline (LGL) and trawl (TWL) fisheries.

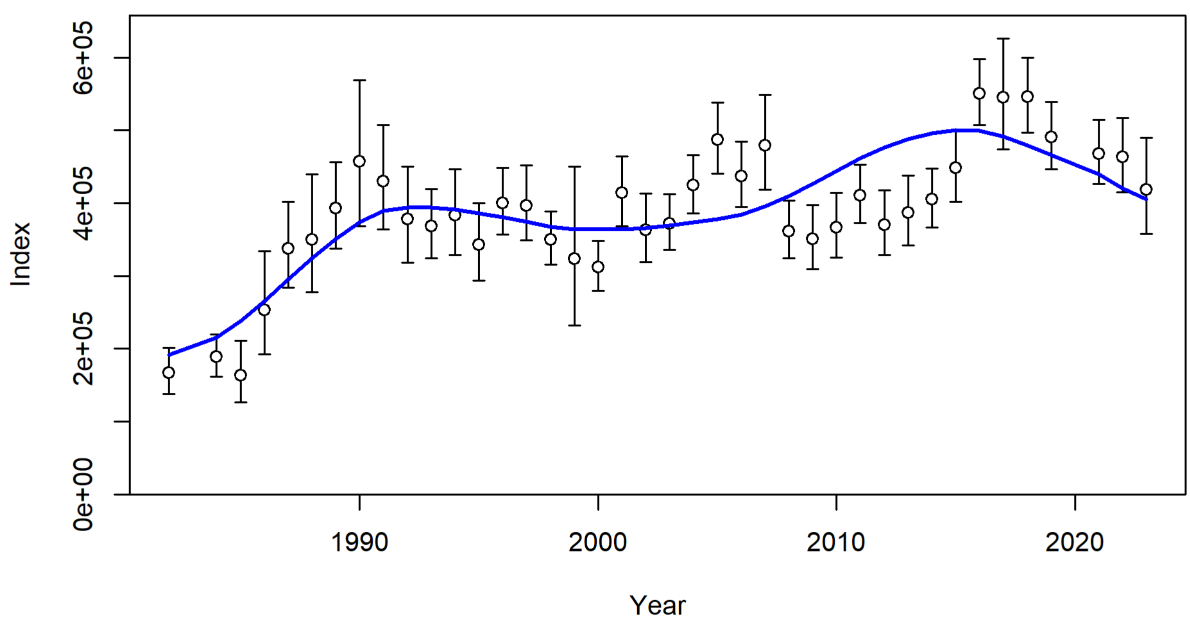

Figure 18.12. Model 14.2d fit to the eastern Bering Sea bottom trawl survey design based biomass estimates.

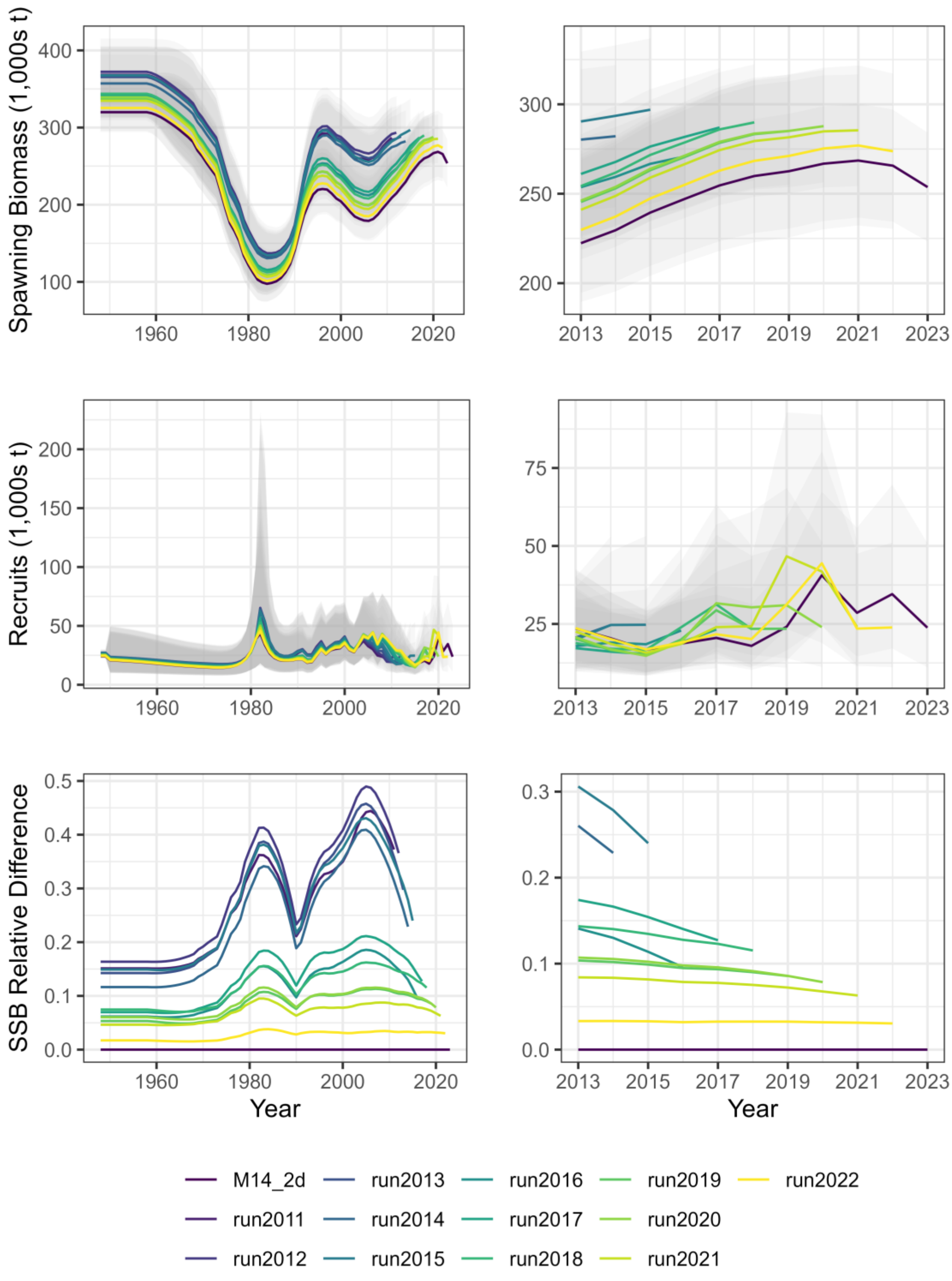

Figure 18.13. Retrospective peels of Model 14.2d for female spawning stock biomass (SSB, top), recruits, and the relative difference (bottom). Left panels are the full time series, right are the recent 10 years.

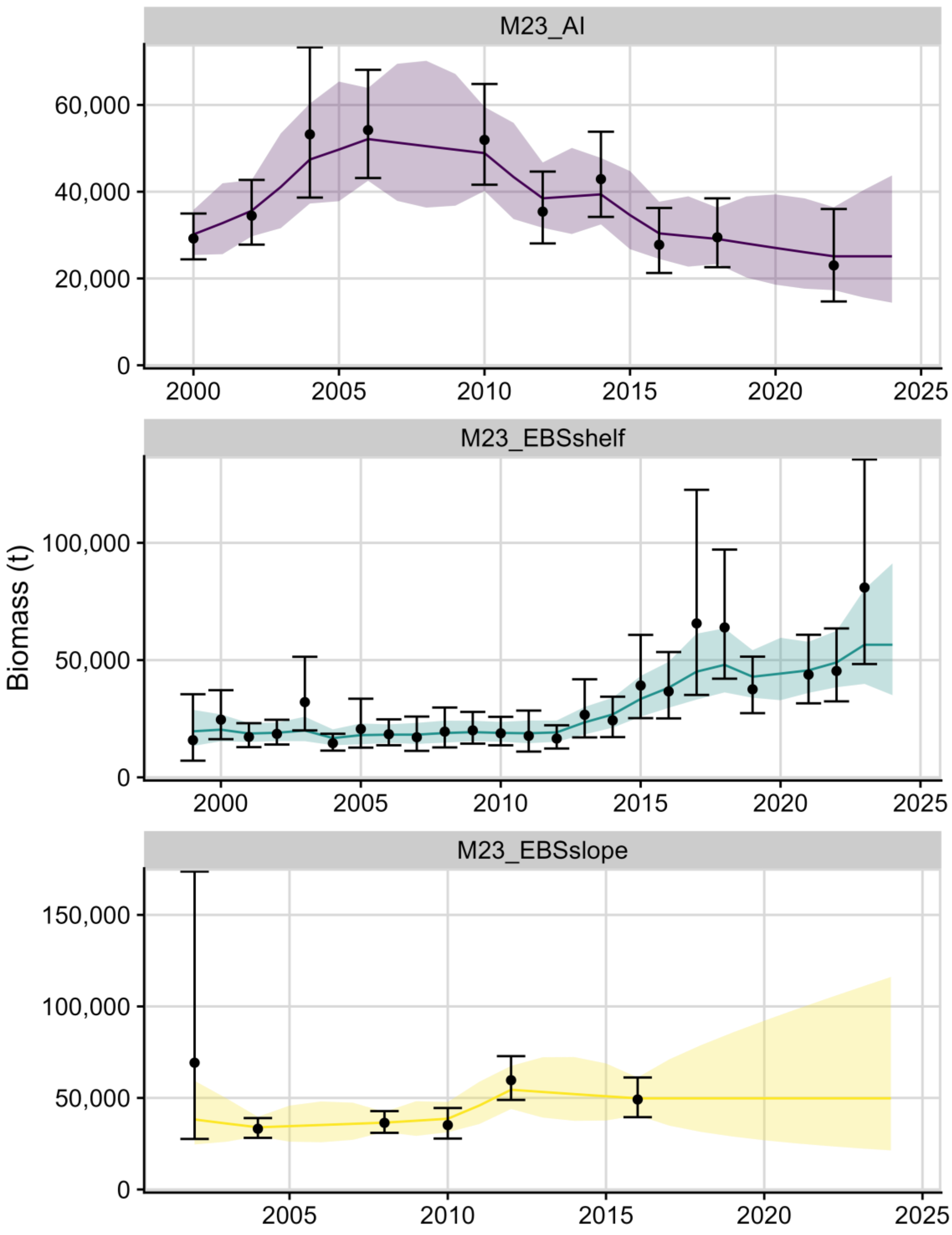

Figure 18.14. Model 23.0 *rema* biomass estimates for the Aleutian Islands (AI), eastern Bering Sea shelf (EBSshelf) and EBS slope (EBSslope) surveys with the design based biomass estimates and 95% confidence intervals. The EBS shelf estimates do not include Alaska skate, but that species is included in the AI and EBS slope.

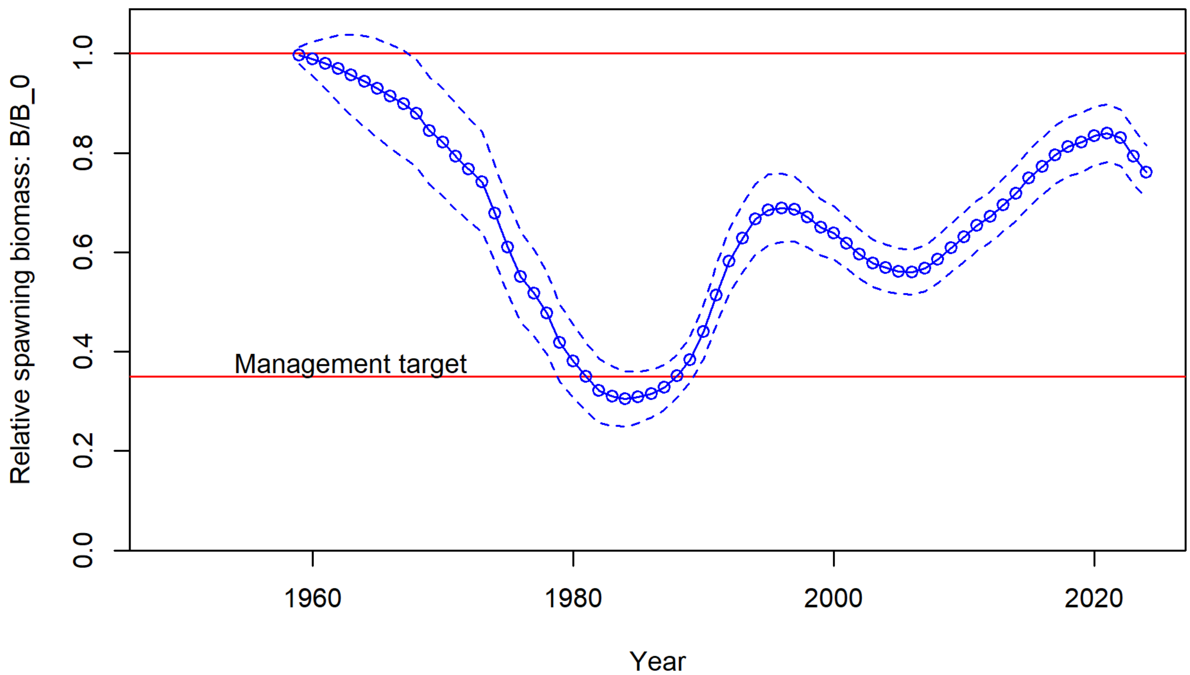

Figure 18.15. Model 14.2d estimated female spawning stock biomass relative to unfished, with 95% asymptotic intervals. The management target is $B_{35\%}$.

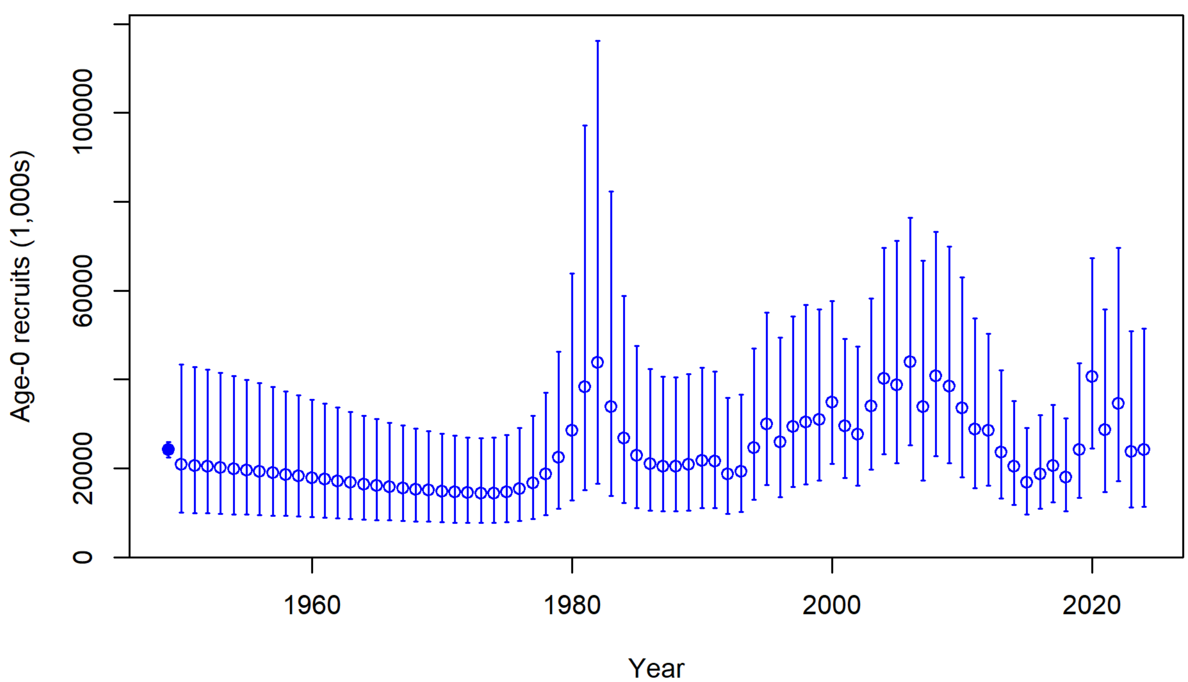

Figure 18.16. Model 14.2d estimates of recruitment with 95% confidence intervals.

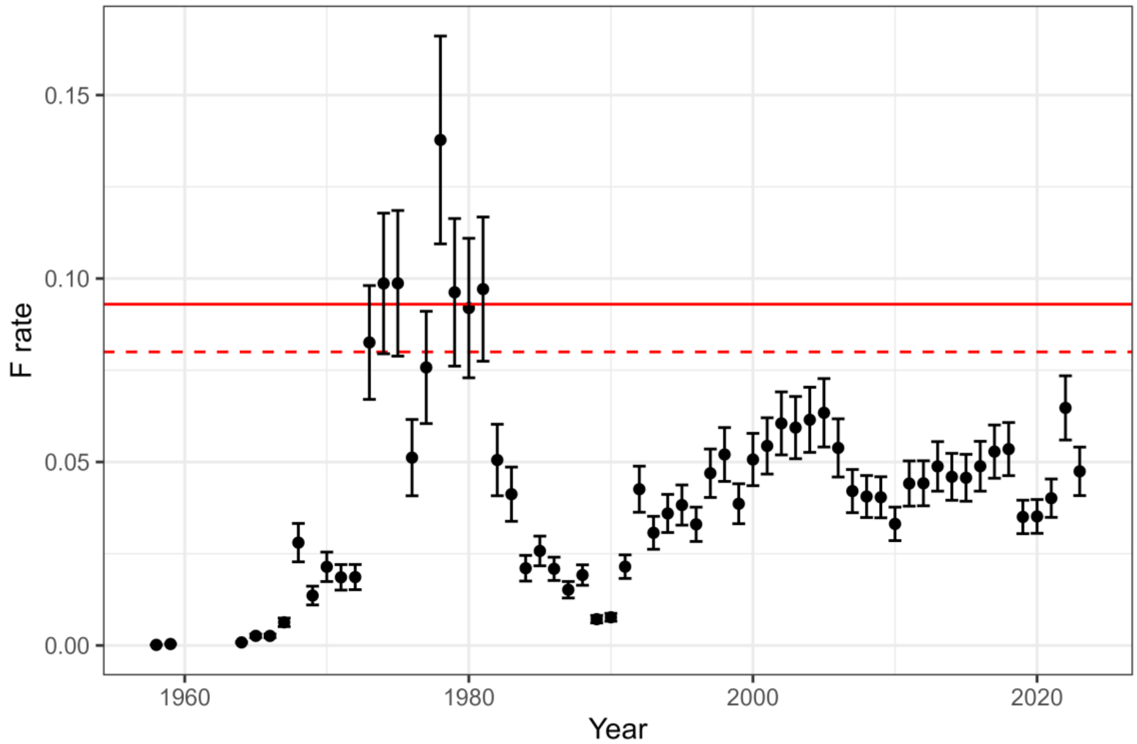

Figure 18.17. Model 14.2d estimates of exploitation rate. Solid red line is the $F_{OFL} = F_{35\%}$ and the dashed red line is the $F_{ABC} = F_{40\%}$.

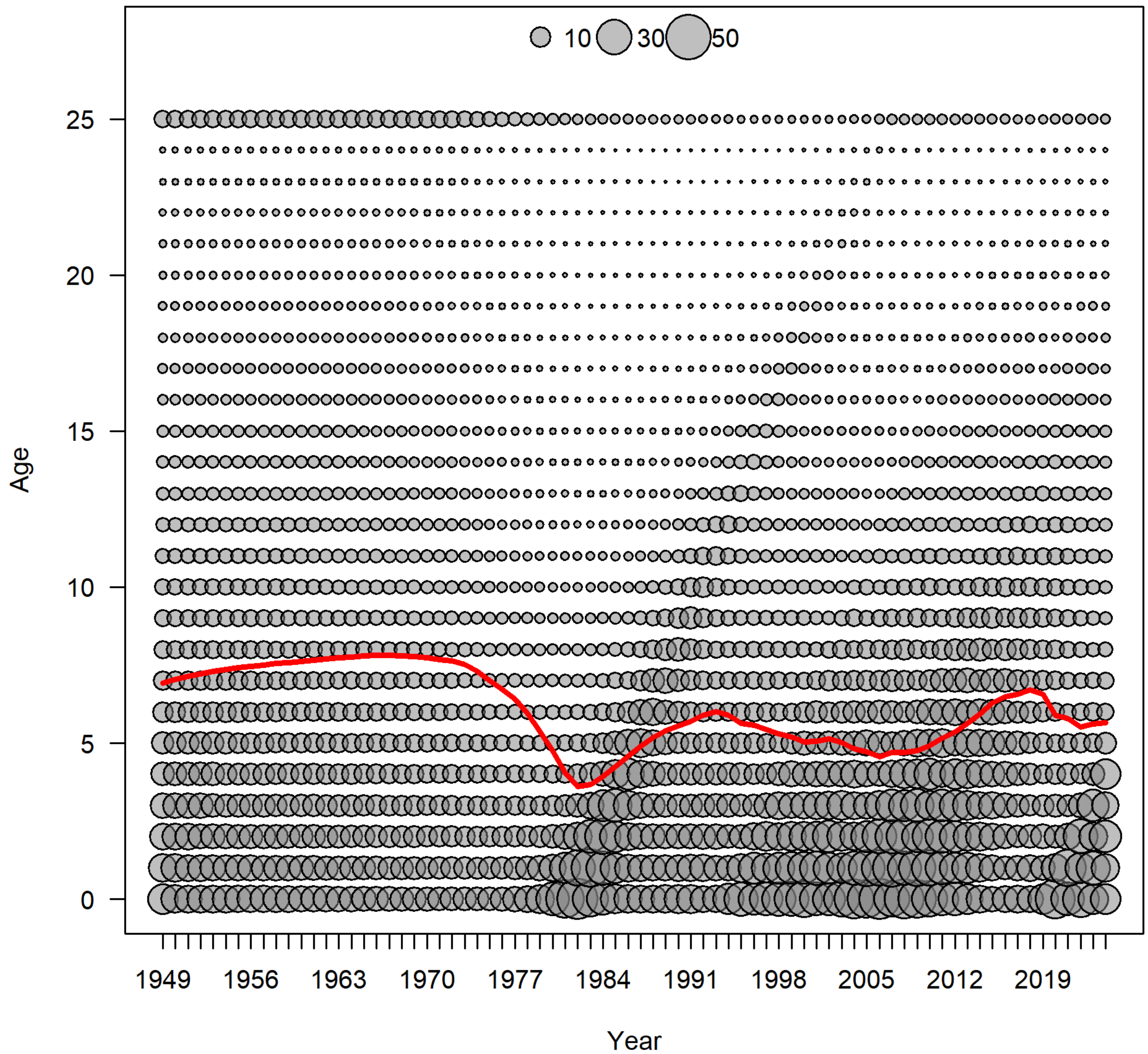

Figure 18.18. Model 14.2d estimated numbers at age. The red line is the average age of the population each year.

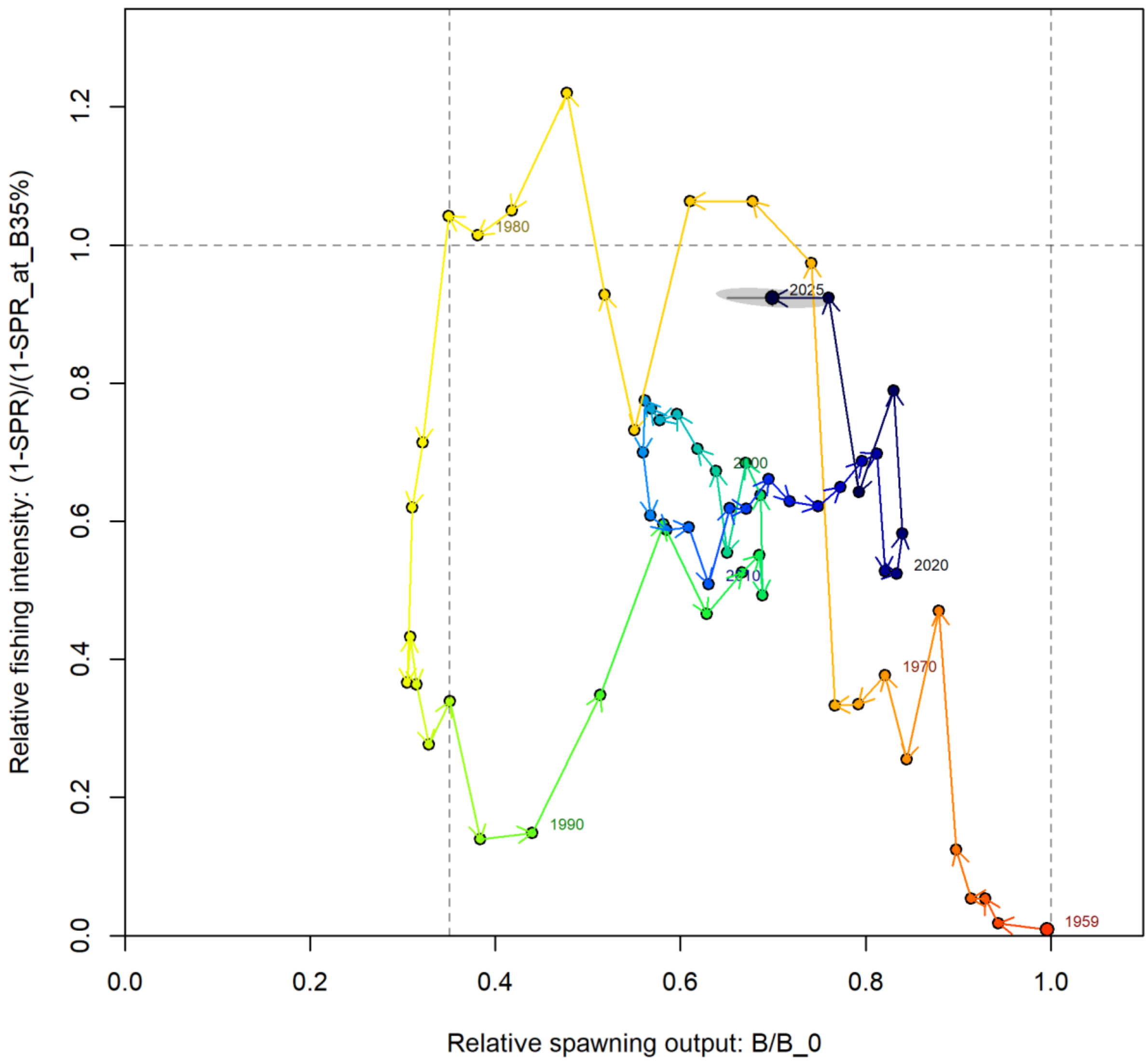

Figure 18.19. Model 14.2d phase plane plot with two years of forward projections included.

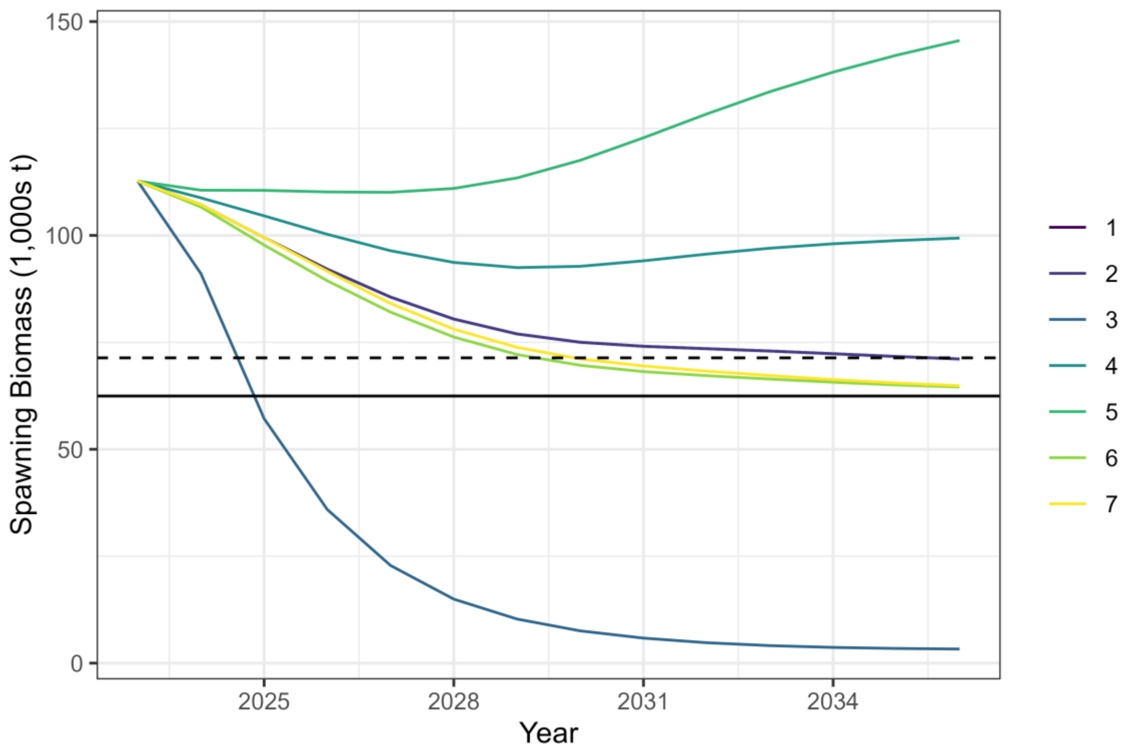

Figure 18.20. Harvest projection scenarios for Model 14.2d. Note that Scenario 1 and 2 are overlapping.

Appendix 18A. Non-commercial catch table

Table 18A.1. Table of reported removals from non-commercial fisheries through 2022. Weight is in kilograms. Not all data sources provide both numbers and weight. The large catch of skates by trawl surveys in 2012 was due to an exempted fishing permit occurring that year.

	ADFG		IPHC	NMFS Longline Survey		Trawl Surveys Combined	
Year	**Number**	**Weight**	**Weight**	**Number**	**Weight**	**Number**	**Weight**
2010	277	799	41,976	2,796	6,093	15,182	53,289
2011	28	217	25,617	3,167	5,393	12,776	55,802
2012	26	162	27,786	2,386	7,459	14,341	1,132,760
2013	18	138	42,782	3,585	7,980	8,387	29,136
2014	19	119	55,220	3,395	11,698	8,920	35,562
2015	20	117	42,530	3,250	5,836	8,319	33,217
2016	57	209	51,004	2,623	7,760	8,562	33,630
2017	99	278	42,615	3,682	8,573	5,256	24,407
2018	24	124	30,238	2,709	9,897	6,090	28,205
2019	24	146	33,479	2,564	3,253	4,660	21,615
2020	-	-	787	2,784	8,859	-	-
2021	33	278	9,564	2,624	12,044	4,774	20,955
2022	46	256	15,628	2,039	9,987	5,114	24,170

Appendix 18B. Species-specific *rema* output

There are many species within the BSAI skate stock complex, and the dominant species varies for each survey. Here we present the species-specific *rema* model output for the dominant species and combined minor species in each of the three surveys included in the Tier 5 BSAI skate stock complex harvest recommendations. The dominant groupings for each survey are as follows:

Aleutian Islands (Figure 18B.1)

Dominant	Minor
Bering	Butterfly
Big	Commander
Alaska	Longnose
Aleutian	Mud
Whiteblotched	Roughtail
Leopard	Whitebrow
	Skate unidentified

Eastern Bering Sea shelf (Figure 18B.2)

Dominant	Minor
Bering	Longnose
Big	Mud
Aleutian	Okhotsk

Eastern Bering Sea slope (Figure 18B.3)

Dominant	Minor
Bering	Commander
mud	Deepsea
roughtail	Longnose
Aleutian	Mud
commander	Okhotsk
whiteblotched	Roughtail
Whitebrow	Whitebrow
Alaska	Skate unidentified

Table of survey biomass, uncertainty and *rema* model outputs are available here: https://github.com/afsc-assessments/AFSC_BSAI_SKATE_Assessment/blob/main/2023/Tier5/Output/Appendix_SpeciesSpecific_rema_output.csv

The northern Bering Sea has only encountered Alaska skates and we include that here for information (Figure 18B.4). The northern Bering Sea tables of survey biomass, uncertainty and *rema* model outputs are available here: https://github.com/afsc-assessments/AFSC_BSAI_SKATE_Assessment/blob/main/2023/Tier5/Output/Appendix_NBS_AKskate_rema_output.csv.

Figures

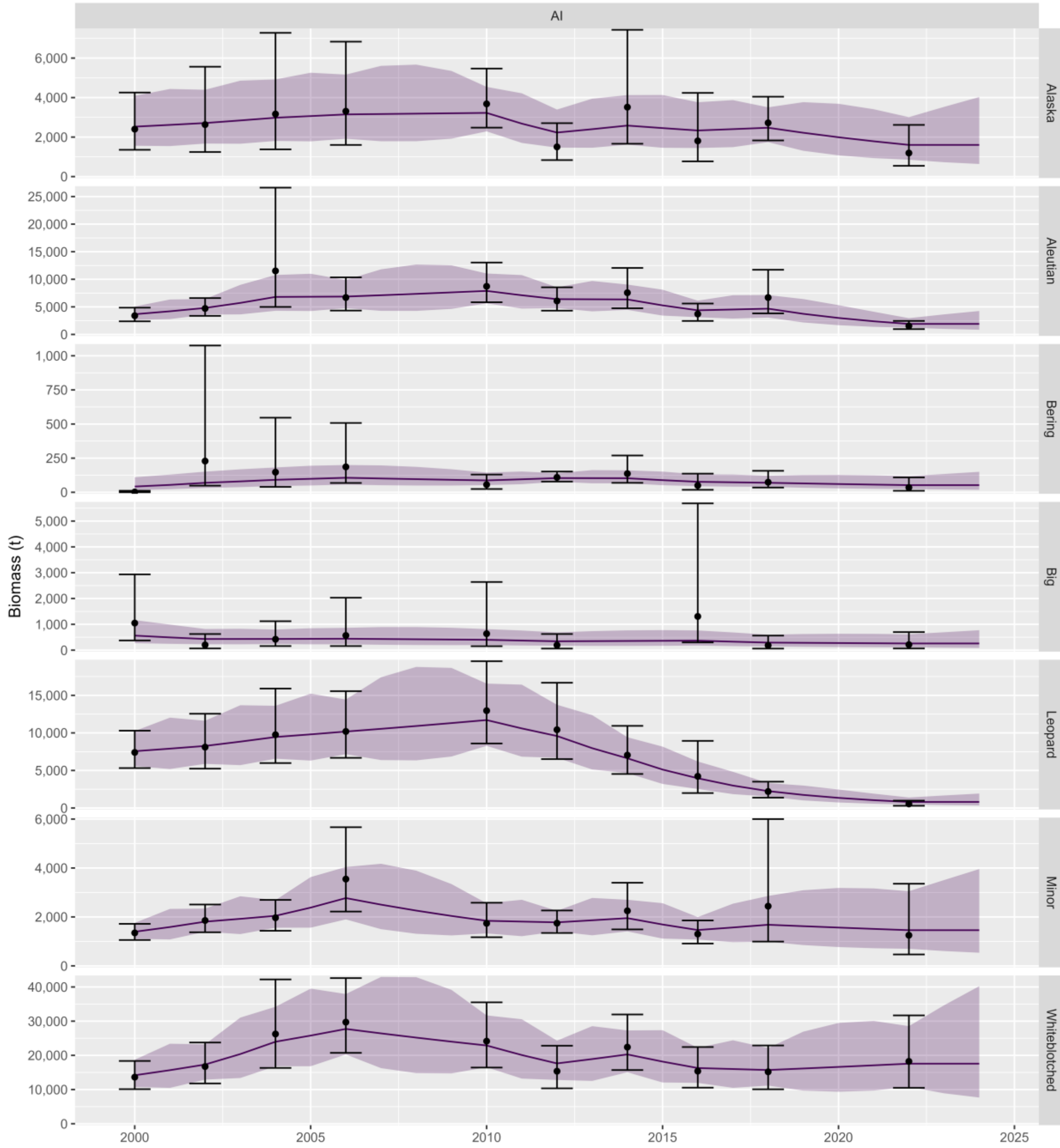

Figure 18B.1. Aleutian Islands species-specific survey estimates and *rema* model outputs.

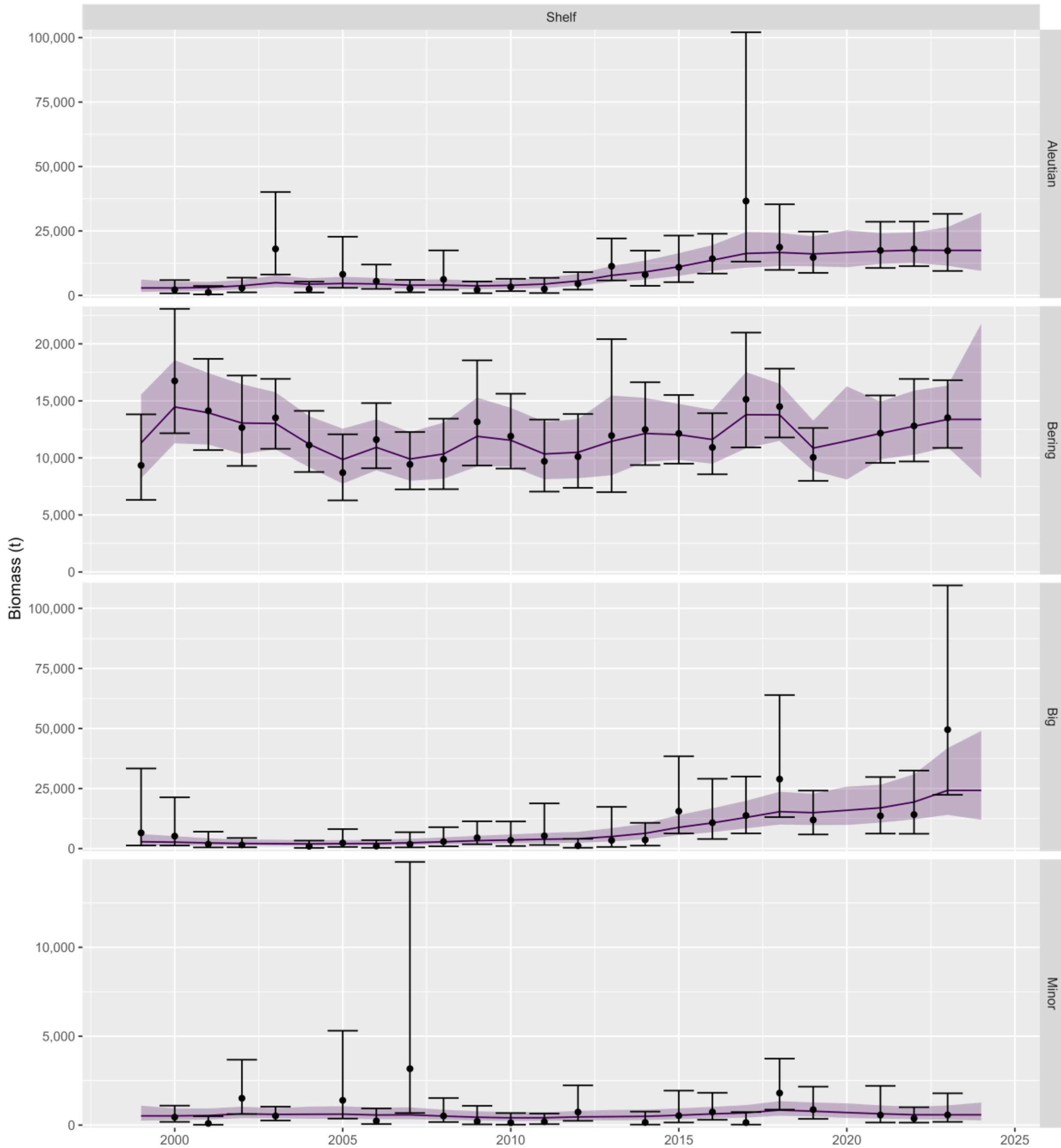

Figure 18B.2. EBS Shelf survey species-specific survey estimates and *rema* model outputs.

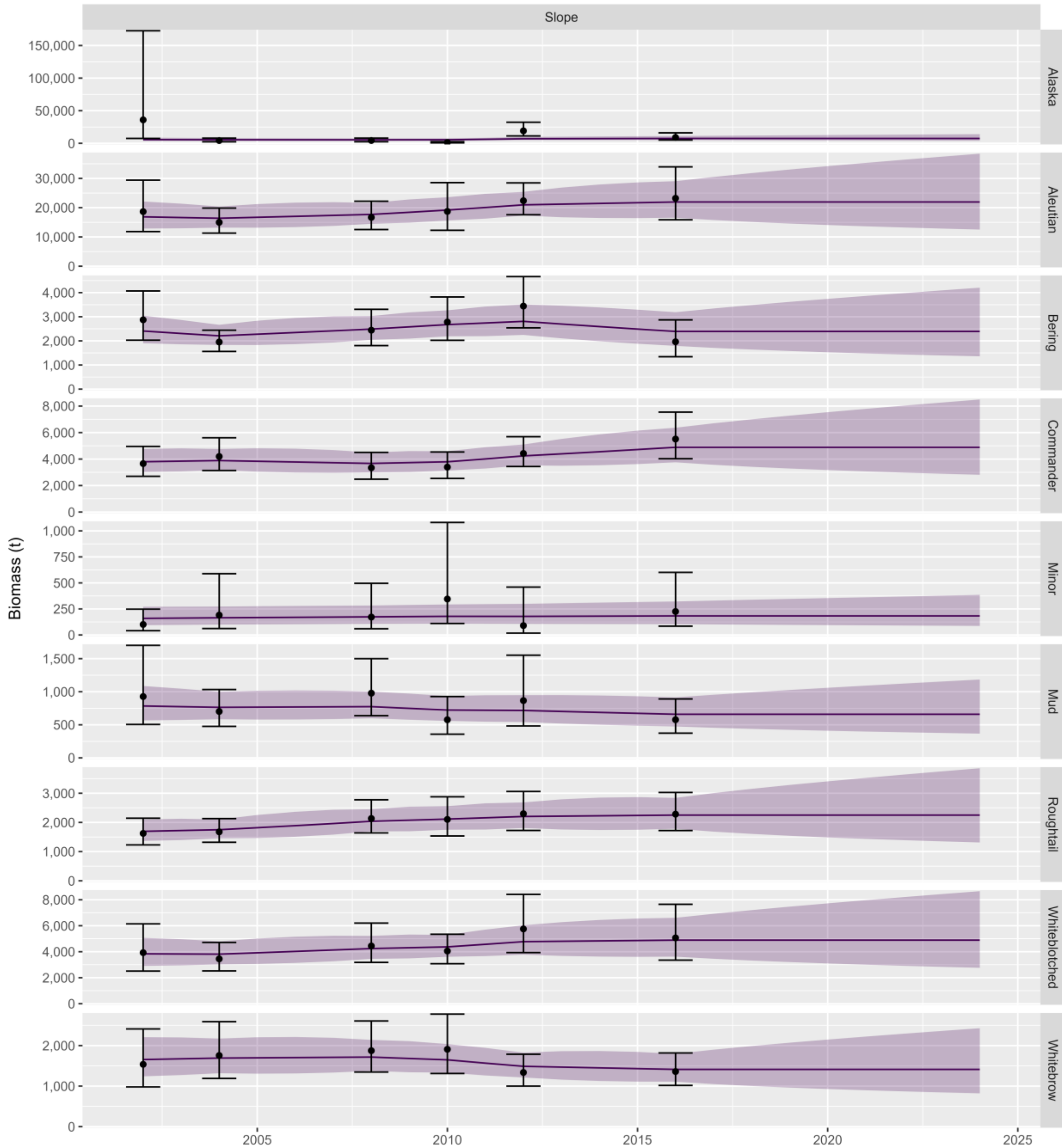

Figure 18B.3. EBS slope survey species-specific survey estimates and *rema* model outputs.

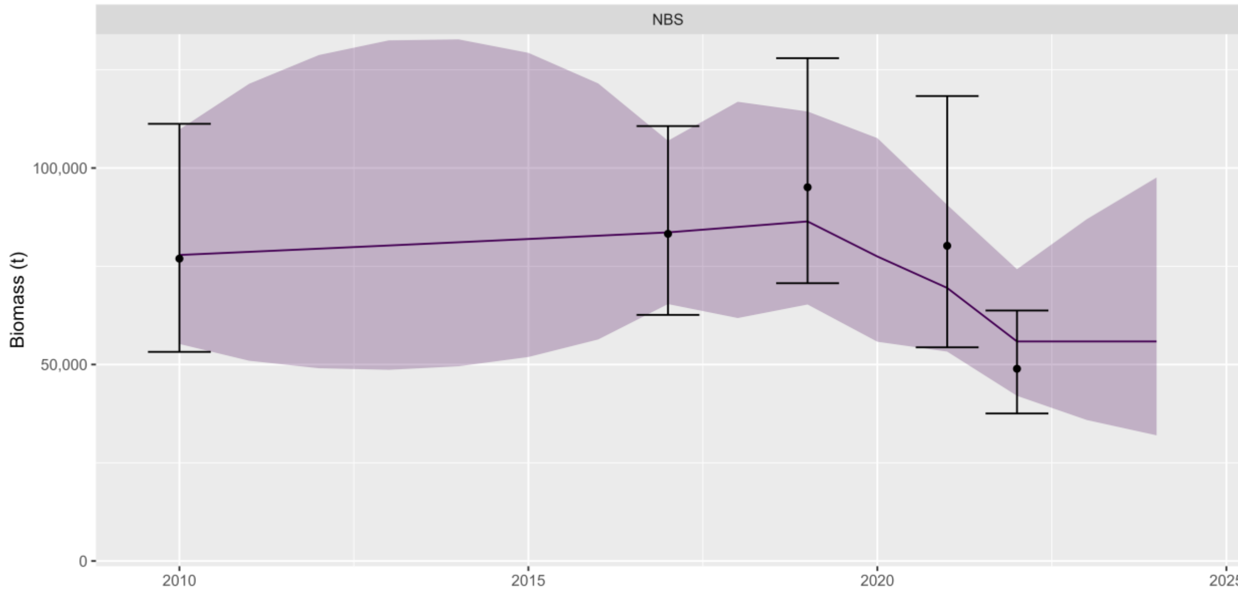

Figure 18B.4. Northern Bering Sea (NBS) Shelf survey Alaska skate biomass estimates and rema model outputs.