6. Assessment of the rex sole stock in the Gulf of Alaska

By

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Executive Summary

A full, age-structured assessment is presented for GOA rex sole. Prior to 2017, the biomass estimates of the assessment were used to calculate OFLs and ABCs using a Tier 5 management approach because F_{OFL} and F_{ABC} reference points estimated from the assessment were thought to be unreliable. In September 2017, newly available historical fishery age data were added to the assessment that substantially improved reliability of estimates of F_{OFL} and F_{ABC}. Therefore, all estimates from the assessment were used to calculate OFLs and ABCs using a Tier 3a management approach for the 2017 subsequent assessments, including the 2021 assessment.

Summary of Changes in Assessment Inputs

The following data sources were updated with newest years of data:

(1) 2018-2021 catch biomass was added to the model
(2) 2017 catch biomass was updated to reflect final (rather than projected) 2017 catches
(3) 2018-2021 fishery length composition data were added to the model and 2017 fishery length composition data were updated to reflect October – December 2017 catches
(4) 2017-2020 fishery age composition data were added to the model
(5) 2019 and 2021 GOA trawl survey biomass estimates were added to the model
(6) 2019 and 2021 GOA trawl survey length composition data were added to the model
(7) 2019 GOA trawl survey age-at-length data were added to the model
(8) Iterative data weighting (Francis 2011) was conducted and updated after the addition of new data.

Summary of Changes in Assessment Methodology

(1) Iterative data weighting was conducted using methodology described in Francis 2011.
(2) Survey data from 1984 and 1987 were excluded
(3) Catchability was estimated using a normal prior with a mean of 1.2 and a standard deviation of 0.175. The model assumes that the survey catchability is the same in the Western-Central GOA as for the Eastern GOA.

Summary of Results

The key results of the assessment, based on the author's preferred (base case) model, are compared to the key specifications from 2020 in the table below. A Tier 3a approach was used to calculate recommended quantities for the 2021 assessment. Three tables are presented. The first shows quantities for the entire GOA, showing quantities as specified in 2020 assessment and quantities recommended for the 2021 assessment using a Tier 3a approach. The second table describes the Western-Central GOA where length-at-age is larger than for the Eastern GOA, based on a Tier 3a approach. The third table shows quantities for the Eastern GOA, also based on a Tier 3a approach.

Quantity	As estimated or *specified this* year for: 2021	2022	As estimated or *recommended this* year for: 2022*	2023*
M (natural mortality rate)	0.17	0.17	0.17	0.17
Tier	3a	3a	3a	3a
Projected total (3+) biomass (t)	101,244	101,244	124,543	126,939
Female spawning biomass (t)	44,500	44,500	51,713	56,777
$B_{100\%}$	See area-specific tables below		See area-specific tables below	
$B_{40\%}$				
$B_{35\%}$				
F_{OFL}				
$maxF_{ABC}$				
F_{ABC}				
OFL (t)	18,779	18,779	23,302	25,049
maxABC (t)	15,416	15,416	19,141	20,594
ABC (t)	15,416	15,416	19,141	20,594
Status	As determined *last* year for: 2019	2020	As determined *this* year for: 2020	2021
Overfishing	no	n/a	no	n/a
Overfished	n/a	no	n/a	no
Approaching overfished	n/a	no	n/a	no

Quantity: (Western-Central GOA)	As estimated or *specified this* year for:		As estimated or *recommended this* year for:	
	2021	2022	2022*	2023*
M (natural mortality rate)	0.17	0.17	0.17	0.17
Tier	3a	3a	3a	3a
Projected total (3+) biomass (t)	79,666	79,666	99,428	101,606
Female spawning biomass (t)	35,506	35,506	41,906	46,224
$B_{100\%}$	48,138	48,138	46,850	46,850
$B_{40\%}$	19,255	19,255	18,740	18,740
$B_{35\%}$	16,848	16,848	16,398	16,398
F_{OFL}	0.29	0.29	0.28	0.28
$maxF_{ABC}$	0.23	0.23	0.23	0.23
F_{ABC}	0.23	0.23	0.23	0.23
OFL (t)	14,512	14,512	18,314	19,779
maxABC (t)	11,925	11,925	15,057	16,276
ABC (t)	11,925	11,925	15,057	16,276
Status	As determined *last* year for:		As determined *this* year for:	
	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 392 t and 1,567 t that was used in place of maximum permissible ABC for 2021 and 2022-2023, respectively. The 2021 projected catch was calculated as the current catch of GOA rex sole as of September 26, 2021 added to the average September 27 – December 31 GOA rex sole catches over the 5 previous years. The 2022-2023 projected catch was calculated as the average catch from 2016-2020.

Quantity: (Eastern GOA)	As estimated or *specified this* year for:		As estimated or *recommended this* year for:	
	2021	2022	2022*	2023*
M (natural mortality rate)	0.17	0.17	0.17	0.17
Tier	3a	3a	3a	3a
Projected total (3+) biomass (t)	21,578	21,578	25,115	25,333
Female spawning biomass (t)	8,994	8,994	9,807	10,553
$B_{100\%}$	9,597	9,597	8,998	8,998
$B_{40\%}$	3,839	3,839	3,599	3,599
$B_{35\%}$	3,359	3,359	3,149	3,149
F_{OFL}	0.31	0.31	0.31	0.31
$maxF_{ABC}$	0.25	0.25	0.25	0.25
F_{ABC}	0.25	0.25	0.25	0.25
OFL (t)	4,267	4,267	4,988	5,270
maxABC (t)	3,491	3,491	4,084	4,318
ABC (t)	3,491	3,491	4,084	4,318
Status	As determined *last* year for:		As determined *this* year for:	
	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; the 2021-2023 projected catch was calculated as the average catch from 2016-2020. Catches from the Eastern GOA are small and many are confidential.

The table below shows apportionment of the 2022 and 2023 ABCs among areas. The ABCs calculated for the Western-Central area (based on model estimates) are apportioned based on random effects model predictions of the proportion of Western-Central survey biomass in the Western and Central areas, respectively, in 2022-2023. Likewise, the ABC calculated for the Eastern area (based on model estimates) are apportioned based on random effects model predictions of the proportion Eastern survey biomass in the West Yakutat and Southeast areas, respectively.

Quantity	Western	Central	Total Western-Central	West Yakutat	Southeast	Total Eastern
Area Apportionment	19.80%	80.20%	100.00%	33.34%	66.66%	100.00%
2022 ABC (t)	2,981	12,076	15,057	1,361	2,723	4,084
2023 ABC (t)	3,222	13,054	16,276	1,439	2,879	4,318

Responses to SSC and Plan Team Comments on Assessments in General

Dec 2017, SSC: It should be noted that GOA flatfish stock assessment authors have already benefitted from the staggered cycle for their assessments. The reduced number of assessments for 2017 allowed the authors of the rex sole assessment to more carefully examine the underlying model structure and assumptions leading to the approval of a change in the management category from Tier 5 to Tier 3a.

The underlying model structure adopted in 2017 was again used in 2021 and small improvements continue to be made. In this assessment, we were able to include additional model runs dropping 1984 and 1987 survey data to address concerns about differences in survey timing in those years, adopting Francis data weighting (to account for more trust in the survey index than in a recent recruitment pulse that shows up in the data), and estimating catchability to better account for uncertainty within the assessment.

Responses to SSC and Plan Team Comments Specific to this Assessment

December 2017, The SSC recommends that the author prioritize the inclusion of an aging error matrix in the model for next year, which might further improve the fit to the age composition data.

The authors agree that including an ageing error matrix could improve the fit to the age composition data and plan to do an ageing error analysis and include an ageing error matrix in the next rex sole assessment.

Introduction

Rex sole (*Glyptocephalus zachirus*) is a right-eyed flatfish occurring from southern California to the Bering Sea and ranging from shallow water (<100m) to about 800 meters depth (Mecklenburg et al., 2002). They are most abundant at depths between 100 and 200m and are found throughout the Gulf of Alaska (GOA), with the highest biomass found in the Central GOA.

Rex sole appear to exhibit latitudinal changes in growth rates and size at sexual maturity. Abookire (2006) found marked differences in growth rates and female size at maturity between stocks in the GOA and off the coast of Oregon. Size at sexual maturity was greater for fish in the GOA than in Oregon, as was size-at-age. However, these trends offset each other such that age-at-maturity was similar between the two regions. McGilliard and Palsson (2017) found that rex sole in the Western and Central GOA tend to grow to larger maximum sizes than those in the Eastern GOA.

Rex sole are batch spawners with a protracted spawning season in the GOA (Abookire, 2006). The spawning season for rex sole spans at least 8 months, from October to May. Eggs are fertilized near the sea bed, become pelagic, and probably require a few weeks to hatch (Hosie et al. 1977). Hatched eggs produce pelagic larvae that are about 6 mm in length and are thought to spend up to 9 months in a pelagic stage in the northern GOA before settling out to the bottom as 5 cm juveniles (Abookire and Bailey 2006). Rex sole are found offshore in the GOA during the spawning season and larvae are broadly distributed over the slope and shelf. Rex sole are one of several GOA flatfish species with larvae that exhibit cross-shelf transport, moving to several nearshore nursery areas where they remain as juveniles (Bailey et al. 2008, Abookire and Bailey 2006). Several flatfish species in the Gulf of Alaska, including rex sole, Dover sole, Pacific halibut, and arrowtooth flounder have shown synchrony in recruitment patterns over time that have been linked to an environmental indicator related to sea surface height (Stachura et al. 2014).

Rex sole are benthic feeders, preying primarily on amphipods, polychaetes, and some shrimp.

Management units and stock structure

In 1993 rex sole was split out of the deep-water management category because of concerns regarding the Pacific ocean perch bycatch in the rex sole target fishery. The stock within the GOA is managed as a unit stock but with area-specific ABC and TAC apportionments to avoid the potential for localized depletion. Little is known on the stock structure of this species. However, otoliths exhibit two distinct growth patterns (pers. Comm. D. Anderl 2015) and data shown in this assessment show that length older ages in the Eastern GOA is smaller than those for the Western and Central areas.

Fishery

Rex sole in the Gulf of Alaska are caught in a directed fishery using bottom trawl gear. Typically, approximately 7 months of fishing occur between January and November and the greatest proportion of catches typically occur in the second quarter of the year (Table 1-Table 3). Catches of rex sole occur primarily in the Western and Central management area in the Gulf (statistical areas 610 and 620 + 630, respectively), with the greatest proportion of catch in the Central region (Table 1 & Table 4). Recruitment to the fishery begins at about age 5.

In 2021, the GOA groundfish trawl catcher vessel (CV) fishery was closed to directed fishing of non-pollock species from March 25-August 24. This occurred because the Chinook salmon PSC limit was reached in the Western GOA trawl CV Pacific cod fishery. This closure, along with other market pressures (potentially some due to COVID) led to very low catches of GOA rex sole this year (207 t as of September 26, 2021) as compared to other years (Table 1). The 5-year average year-end catch from 2016-2020 was 1,567 t and the 5-year average catch between Sept 27-Dec 31 from 2016-2020 was 185 t.

Catch is currently reported for rex sole by management area (Table 1). Catches for rex sole were estimated from 1982 to 1994 by multiplying the deepwater flatfish catch by the fraction of rex sole in the observed catch. Catches increased from a low of 93 t in 1986 to a high of 5,874 t in 1996, then declined to 1,464 t in 2004. The 2009 catch (4,753 t) was the largest since 1996. Catches declined after 1996, but increased to 3,707 t in 2013. Catch declined from 3,577 t in 2014 to 1,484 t in 2017.

The catch of rex sole is widely distributed along the outer margin of the continental shelf in the central and western portions of the Gulf (Table 1) and few, if any, catches occur in the Eastern Gulf.

Historical specifications from 1995-2021 are shown in Table 5. The ABC for rex sole has been specified as the TAC in each year since 1997. The fishery catches from 2010-2014 ranged from 25-39% of the TAC and ABC. From 2016-2020 the fishery catches ranged from 8-21% of the TAC.

Estimates of retained and discarded catch (t) in the rex sole fishery since 1995 were calculated from discard rates observed from at-sea sampling and industry reported retained catch (Table 5). Retention of rex sole is high and has generally been over 95%.

Data

The following data were included in the assessment model:

Source	Data	Years
NMFS Groundfish Survey	Survey Biomass	1984-1999 (triennial); 2001-2021 (biennial)
	Ages Conditioned on Length	1984, 1987, 1993, 1999; 2001-2019 (biennial)
	Age Composition*	1984, 1987, 1993, 1999; 2001-2019 (biennial)
	Length Composition	1984-1999 (triennial); 2001-2021 (biennial)
U.S. Trawl Fisheries	Catch	1982-2021 (Sept 26, 2021-Dec 31, 2021 projected)
	Length Composition+	1982-1984, 1990-2021
	Age Composition	1992,1995,1999,2003,2005,2007,2009,2010,2012 2014-2020

*Not included in the objective function; +Not included in the objective function in years when fishery age compositions are available

Fishery Data

This assessment used (1) fishery catches from 1982 through September 26, 2021 (Table 1, Figure 1), (2) the proportion of individuals caught by length group and sex for the years specified in the table above (through September 26, 2021; https://apps-afsc.fisheries.noaa.gov/Plan_Team/2021/FTP_GOA_Rex_Composition_Data_And_SampleSize_2021.xlsx) and (3) estimates of the proportion of individuals caught by age group and sex for the years specified in the table above. Unsexed individuals were excluded from the fishery length- and age-data.

An age-length key specific to year and season was used to calculate age compositions using raw length frequency data collected at the time of the haul and at ports for years in which age data was available. Size of haul was not available for samples collected at a port; therefore, use of raw length data allowed for samples from ports and hauls to be included in the analysis together. The 2017 assessment (McGilliard and Palsson 2017) showed figures of fishery length-at-age data by cohort by year, management area, season, and type of sample (port vs haul). Some older cohorts appear to be smaller than older fish in newer cohorts. These older cohorts appear to be sampled at the port. No obvious area-specific differences in length-at-age can be seen from these plots. However, the fishery does not operate in the Eastern GOA. There is some variation in length-at-age by season and this is why age-length keys specific to both year and season were used to calculate fishery age compositions.

Sample sizes for the length and age compositions were set to the number of fishery hauls for which length or age data were collected, respectively, excluding unsexed individuals (https://apps-afsc.fisheries.noaa.gov/Plan_Team/2021/FTP_GOA_Rex_Composition_Data_And_SampleSize_2021.xlsx). In cases where length or age samples were collected at a port and the number of hauls from which the age data originated was missing for that port sample, the mean number of hauls per port sample (9 hauls) was used.

Survey Data

This assessment used estimates of total biomass for rex sole in the Gulf of Alaska from triennial (1984-1999) and biennial (2001-2021) groundfish surveys conducted by the AFSC's Resource Assessment and Conservation Engineering (RACE) division to provide an index of population abundance (Table 7 and Table 8). The preferred model separated estimates of biomass for eastern GOA from biomass estimates from the western and central regions (Table 7). Although survey depth coverage has been inconsistent for depth strata > 500 m (Table 8), the fraction of the rex sole stock occurring in these depth strata is typically small, so the survey estimates of total biomass were not corrected for missing depth strata (Figure 2 and Table 8). Survey biomass has fluctuated on decadal time scales. From an initial low of ~60,000 t in 1984, estimated biomass increased to a high of almost 100,000 t in 1990, then declined during the 1990s to slightly above 70,000 t. Subsequently, survey biomass increased once again and was above 100,000 t in the 2005-2009 period. In the period from 2011 – 2017, the survey biomass was slightly lower, between 87,313 t and 101,000 t. The survey biomass for 2021 was 112,333 t. Consistently over time, survey biomass has been greatest in the Central GOA and smallest in the Western GOA, but occurs in all three regions (Central, Eastern, and Western GOA).

Estimates of the total number of individuals by length group (length compositions) from each RACE GOA groundfish survey were included in the assessment. Estimates of the distribution of ages in each year were plotted, but were not included in the objective function of any model runs, as raw age data by length were included in the model rather than age compositions (a conditional age-at-length approach):

https://apps-afsc.fisheries.noaa.gov/Plan_Team/2021/FTP_GOA_Rex_Composition_Data_And_SampleSize_2021.xlsx). Survey age data were available for all survey years except for 2021. The age data for 1990 were excluded from the model because the underlying ages may be biased due to the age reading technique (surface age reading) used to process the otoliths.

Number of hauls for which length samples exist was used as effective sample size for length composition data. Number of otoliths aged was used as effective sample size for conditional age-at-length data. Samples collected in the Eastern GOA were entered separately from data in the Western-Central GOA.

Figure 3-Figure 7 show survey length-at-age data by cohort and by year, area, and depth and Figure 8 shows a map of residuals from single-area sex-specific von-Bertalanffy growth curves. These figures indicate that older fish in the Eastern GOA are smaller than those in the Western and Central GOA for both males and females. Fewer very large fish (and fewer fish in general) occur at depths of 500m and deeper. Additionally, there is a small amount of variation in length-at-age over time (Figure 6-Figure 7).

Analytic Approach

Model Structure

The assessment was a split sex, age-structured statistical catch-at-age model implemented in Stock Synthesis version 3.3 (SS) using a maximum likelihood approach. SS equations can be found in Methot and Wetzel (2013) and further technical documentation is outlined in Methot (2009). Age classes included in the model run from age 0 to 20. The oldest age class in the model, age 20, serves as a plus group. Age at recruitment was set at 3 for the purpose of projections and calculation of management quantities, as few rex sole are observed before age 3. Survey catchability was fixed at 1.0 in previous models and was estimated with a prior based on herding experiments in the current assessment.

Age-based double-normal functions without a descending limb (instead of a logistic function) were used to model fishery and survey selectivity for all model runs. The double-normal formulation was used because the SS modeling framework does not currently include the option of estimating sex-specific, age-based logistic selectivity where both male and female selectivity maintain a logistic shape.

The most recent accepted model was Model 17.2 (McGilliard and Palsson 2017), which is presented this year with the addition of new data, along with Model 21.0, which makes three small changes to Model 17.2: (1) data weighting was conducted using methodology from Francis (2011), (2) 1984 and 1987 survey data were removed from the objective function, and (3) catchability was estimated using a normal prior with a mean of 1.2 and a standard deviation of 0.175 in normal-space.

Model 17.2 was a 2-area model (Eastern GOA and Western-Central GOA) with separate growth curves estimated based on survey data from each area. This model used newly available fishery age and a conditional age-at-length approach and split the survey data by region: the Eastern GOA and Western-Central GOA. Survey biomass estimates, length composition data, and conditional age-at-length data were input separately for these two regions. Survey catchability was fixed at 1 for both regions. A non-time-varying parameter was estimated to specify the proportion of recruits that settle in the Eastern GOA. Therefore, Model 17.2 assumes that the Eastern and Western-Central GOA have a similar recruitment pattern among years. All fishery data are input to the model and associated with only the Western-Central GOA. Survey selectivity parameters and growth parameters (von-Bertalanffy k, L_{max}, and L_{min}, and the CV of the youngest and oldest fish) were estimated for each of the two regions separately. Male survey selectivity was nearly identical to female survey selectivity in preliminary model runs and therefore male and female survey selectivity was set to be equal in Model 17.2. This model was implemented because fits to fishery length and age composition data were particularly poor in all one-area models that incorporated the newly available historical fishery age data (which were presented in 2017); an examination of survey and fishery length-age data showed that fish in the Eastern GOA do not grow as large as fish in the Western-Central GOA (Figure 5). The fishery only operates in the Western-Central GOA and we hypothesized that model fits showing an expectation of more small fish and fewer large fish in the fishery than were observed could be caused by a lack of accounting for differences in growth in the Eastern GOA as compared to the Western and Central GOA (see McGilliard and Palsson 2017 for more details).

Model 21.0 makes three updates to Model 17.2: (1) a change to data weighting using methodology outlined in Francis (2011), (2) omitting 1984 and 1987 survey data, where it is known that survey timing and sampling methodology were different than in other years, and (3) estimating survey catchability with a normal prior based on the results of herding experiments. Two additional bridging models are presented making these three updates one at a time, as well as the 2017 accepted model without the addition of new data.

Other approaches were considered in 2017 to account for the difference in growth between the Western-Central GOA and the Eastern GOA, as follows, including (1) conducting an assessment for the Western-Central GOA and using data for this region only; this method was not used because ABCs and OFLs are specified for the entire GOA and not just the Western-Central region; (2) conducting the model with survey biomass observations for the entire GOA and survey length and age data for only the Western-Central region; this method was not used because it is a mis-specification or a “hack” that could lead to biased estimates; (3) conducting separate models for the Western-Central GOA and the Eastern GOA and summing model results; this method was not used because it would require the estimation of many more parameters (including yearly recruitment deviations and yearly fishing mortality for two separate regions) and important information shared by the two areas could not be used to inform the models. In addition, distribution of recruits among areas could not be taken into account, which could lead to bias in situations where fishing intensity varies among areas (Cope and Punt 2011); (4) conducting a model with two areas and a separate growth curve in each area (as for 17.2), but estimating yearly deviations in the proportion of recruits that settle in the Eastern GOA. Model runs using this method (assuming a standard deviation of 0.5 for the distribution of deviations in proportion of fish settling in the Eastern GOA) did not improve fits to the data despite allowing the model to estimate many more parameters. Therefore, it was concluded that estimating a single, non-time-varying parameter to describe the proportion of recruits settling in the Eastern GOA (an assumption that the recruitment signal among areas is related) is reasonable.

Fishery and Survey Selectivity

The fishery and survey selectivity curves were estimated using age-based double-normal functions without a descending limb (instead of a logistic function). The SS modeling framework does not currently include the option of estimating sex-specific, age-based logistic selectivity where both male and female selectivity maintain a logistic shape (as was used in the previous assessment models prior to moving the model to SS). The 2015 assessment (McGilliard et al. 2015) discusses the logistic and double normal selectivity curves in detail in the context of converting the model to Stock Synthesis. Survey selectivity was made the same for males and females after preliminary model runs showed that male and female survey selectivity were estimated to be nearly identical. Fishery selectivity was sex-specific and the fishery occurred only in the Western-Central GOA. Very little data exist to inform fishery selectivity curves for the Eastern GOA because trawling is not permitted in most of the Eastern GOA. Yearly catches in the Eastern GOA are typically 3 t or less (Table 1).

Recruitment Deviations

Recruitment deviations were estimated for an early period from 1965-1981 and a current period from 1982-2019 with a σ_R = 0.6 and were set to mean recruitment for 2020-2021 (little information exists on 0-1 year old GOA rex sole and recruitment cannot be estimated reliably for these years).

Data Weighting

Effective sample sizes for all length and age composition data were set to the number of hauls for which lengths were measured for length compositions and number of hauls for which ages were measured for age compositions (Pennington and Volstad 1994). Effective sample size for conditional age-at-length data was set at the number of individuals. Data sources were weighted relative to one another using the McAllister-Ianelli method (McAllister and Ianelli 2007) in Model 17.2 and using the Francis (2011) method for Model 21.0.

The Eastern GOA and Western-Central GOA length composition data shared a variance adjustment in all models. Likewise, the conditional age-at-length data shared a variance adjustment; the number of hauls for which length samples existed in each region provided a weighting for data from each region relative to the other region.

Parameters Estimated Outside the Assessment Model

Natural mortality

Male and female natural mortality were fixed and equal to 0.17, as for previous assessments (McGilliard et al. 2015, McGilliard and Palsson 2017).

Weight-at-Age Relationship

The weight-at-age relationship was that used in the previous assessments (e.g. McGilliard and Palsson 2017) and is based on the weight-length relationship $w_L = \alpha L^{\beta}$ and the parameters of the von-Bertalanffy growth curve. The parameters of the weight-length relationship are as follows:

	α	β
Females	1.35E-06	3.44963
Males	2.18E-06	3.30571

Maturity

Abookire (2006) modeled female rex sole size-at-maturity using a logistic model, obtaining a value for size at 50% maturity of 351.7 mm with a slope of 0.0392 mm^{-1}. About half of the maturity samples were obtained from fishery catches and half from research trawls during 2000-2001. Using the mean length-at-age relationship estimated from the 1984-1996 survey data, the age at 50%-maturity was estimated at 5.7 years and the slope was equal to -1.113. Estimates of mean size-at-age for the maturity samples were similar to those for mean size-at-age estimated from the survey data (Turnock et al., 2005).

Survey catchability

Survey catchability was fixed at 1 in Model 17.2 and in the bridging models presented (the growth morph model), survey catchability was equal to 1 for all areas/growth morphs.

Parameters Estimated Inside the Assessment Model

Parameters estimated within all models were the log of unfished recruitment (R_0), log-scale recruitment deviations, yearly fishing mortality, sex- and area-specific parameters of the von-Bertalanffy growth curve, the CV in length-at-age of age 2 and age 20 fish, and selectivity parameters for the fishery and survey. The selectivity parameters are described in greater detail in Table 9. Survey selectivity parameters were not sex-specific and two survey selectivity curves were estimated; one for the Eastern GOA and one for the Western-Central GOA. Fishery selectivity parameters for were estimated by sex and for the Western-Central GOA only. Catchability was estimated within Model 21.0.

Growth

Sex-specific growth parameters ($L_{amax=20+}$, $L_{amin=2}$, k, CV of length-at-age at age 2, CV of length-at-age at age 20+) were estimated inside the assessment model for all models, these growth parameters were estimated separately for the Eastern GOA and for the Western-Central GOA for a total of 4 sets of estimated growth parameters (female Eastern GOA, male Eastern GOA, female Western-Central GOA, male Western-Central GOA).

Catchability

Catchability was estimated within Model 21.0 with a normal prior: ~N(1.2, 0.175), based on herding studies for rex sole (Somerton and Munro 2001).

Results

Model Evaluation

Comparison of models

Model 17.2, where a McAllister-Ianelli data weighting approach is used, led to higher estimates of survey biomass than was observed, outside of the range of the 95% asymptotic uncertainty interval estimated for the most recent (2021) data point for both the Western-Central GOA and the Eastern GOA (Figure 11). This was likely driven by a large pulse of age 4 males and females that appeared in the survey data in 2019 (Figure 9) and a pulse of age-4 and age-5 males in the fishery age composition data in 2019 and 2020, respectively (Figure 22). The McAllister-Ianelli methodology for data-weighting tends to put more emphasis on the composition data than the Francis (2011) methodology. The Francis (2011) methodology down-weights composition data and put more emphasis on the survey biomass data, particularly when there is a lot of variation in fits to mean lengths and ages over time. As the (now) age 6 individuals have been observed few times, the Francis (2011) methodology is more appropriate for this year's model. The models in the bridging analysis, including Model 21.0, used the Francis (2011) methodology in place of the McAllister-Ianelli method, leading to a better fit to recent survey biomass observations within the range of the 95% asymptotic uncertainty intervals for the data points for all models using the Francis methodology. Model fits to the survey biomass indices were very similar among models using the Francis (2011) methodology and survey biomass has increased since 2019. Aggregated fits to length composition data were nearly identical for Models 17.2 and 21.0 (Figure 18) and fits to composition data and conditional age-at-length data in general were nearly identical Models 17.2 and 21.0, indicating that there was not a major change in the ability of the model to fit to length and age data using the Francis (2011) methodology (Figure 19-Figure 30). Dropping 1984 and 1987 survey data had almost no impact on the model, aside from slightly higher estimates of survey biomass in those years than for the 2017 model with Francis (2011) data weighting. Model 21.0, which estimated survey catchability, was also very similar to the other models, but led to lower estimates of spawning biomass (Figure 12), as the estimate of survey catchability was 1.17, just above the fixed value in the other models of 1. Estimating catchability led to slightly better objective function values than for the same model with catchability fixed at 1 for all relevant likelihood components (Table 10); this is not a big surprise, as the model has the flexibility of estimating one additional parameter. Parameter values for Models 17.2 and 21.0 are very similar (Table 11-Table 15, Figure 16). While estimates of catchability and natural mortality can be highly correlated, this year's analysis did not include any models or exploration of estimating natural mortality, which may be useful in future analyses. Nevertheless, given that the estimate of catchability in Model 21.0 is close to the fixed value in previous models, the benefit of choosing a model with catchability estimated is that it acknowledges more uncertainty than does Model 17.2. Therefore, we chose Model 21.0 as the base case model for 2021.

The base case model (Model 21.0)

This year's model and data indicate an increase in survey biomass since 2019, as well as a large year class of (now) age 6 fish (Figure 22 and Figure 38). Figure 18 shows that the model estimates a larger proportion of ~20-30cm fish in the fishery than what were observed over time, while fits to survey length composition data aggregated over time matched observed proportions-at-length well. Figure 19 shows that the model estimated fewer fish at age 10 and more fish at older ages than were observed for both males and females. However, aggregated fits to both fishery and age composition data were similar to those in 2017 and in 2017 these fits were vastly improved by implementing a 2-area model. It is possible that the shift in size-at-age between the Central and Eastern GOA does not occur right on the line between these FMP management areas and that the fishery catches some fish that are smaller at age that would typically be found in the Eastern GOA. However, estimated area- and sex-specific growth curves fit the age-length data well, aggregated over time (Figure 20).

Fishery length and age composition in 2021 is composed of less data than in most years due to the small size of the fishery. Fishery age compositions in 2020 and 2021 show a large proportion of males that are now age 6 (2015 year class). The model fits to these proportions fairly well in 2021, but not in 2020, which may be caused by low male fishery selectivity at age 4 (Figure 16); fishery selectivity is not time-varying in the model.

Yearly fits to survey length data are very good in most years (Figure 21-Figure 24) and expected fishery ages in the Western-Central GOA match very well with the whole GOA age composition data (which are not fit in the model; Figure 38).

As mentioned above, estimated area- and sex-specific growth curves fit the age-length data well, aggregated over time (Figure 20). Yearly fits to survey age-length data vary over time and in the most recent years, the model estimates that fish are older at length than observed, especially in the Eastern GOA (Figure 26-Figure 30). This may occur because there are simply not many observations at these older ages, or it could occur if there is a time-varying growth pattern that is not taken into account within the assessment.

Time Series Results

Time series results are shown in Table 22-Table 25. Age 3 recruitment, age 0 recruitment, and standard deviations of age 0 recruitment are presented in Table 22-Table 23. Total biomass for ages 3+, spawning stock biomass, and standard deviations of spawning stock biomass estimates for the previous and current assessments are presented in Table 24-Table 25. Female and male estimates of numbers-at-age for the current assessment are shown in https://apps-afsc.fisheries.noaa.gov/Plan_Team/2021/FTP_GOA_Rex_TimeSeries_of_NumbersAtAge_2021.xlsx

Figure 31 shows spawning stock biomass estimates and corresponding asymptotic 95% confidence intervals. A plot of biomass relative to $B_{35\%}$ and F relative to $F_{35\%}$ for each year in the time series, along with the OFL and ABC control rules is shown in Figure 32.

Retrospective analysis

Spawning stock biomass, recruitment, recruitment deviations, and fishing mortality estimates, along with corresponding 95% asymptotic confidence intervals from a retrospective analysis extending back 10 years are shown in Figure 33. A relatively small retrospective pattern exists for spawning biomass, driven by changes in selectivity parameter estimates between peels. Mohn's ρ for spawning biomass, recruitment, and fishing mortality are as follows:

Spawning Biomass	Recruitment	Fishing Mortality
0.057	-0.073	-0.055

Hurtado-Ferro et al. (2015) developed some rules of thumb for ranges of Mohn's ρ values that may arise without the influence of model mis-specification. They found that values between -0.15 and 0.20 for longer lived species and values between -0.22 and 0.30 for shorter-lived species could arise without the influence of model mis-specification based on a simulation-estimation study. The values for Mohn's ρ for this year's GOA rex sole assessment are well within these bounds.

Harvest Recommendations

A Tier 3a management approach was used for rex sole harvest recommendations. The reference fishing mortality rate for rex sole is determined by the amount of reliable population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Gulf of Alaska). Estimates of $F_{40\%}$, $F_{35\%}$, and $SPR_{40\%}$ were obtained from a spawner-per recruit analysis separately for the Western-Central GOA and the Eastern GOA. Assuming that the average recruitment from the 1982-2019 year classes in each area estimated in this assessment represents a reliable estimate of equilibrium recruitment, then an estimate of $B_{40\%}$ is calculated as the product of $SPR_{40\%}$ times the equilibrium number of recruits. Since reliable estimates of the spawning biomass (B), $B_{40\%}$, $F_{40\%}$, and $F_{35\%}$ exist and B>$B_{40\%}$, the rex sole reference fishing mortality is defined in Tier 3a. For this tier, F_{ABC} is constrained to be ≤ $F_{40\%}$, and F_{OFL} is defined to be $F_{35\%}$. The values of these quantities are:

	Western-Central GOA	Eastern GOA
SSB_2022	41,906	9,807
B40	18,740	3,599
F40	0.23	0.25
maxFabc	0.23	0.25
B35	16,398	3,149
F35	0.28	0.31
Fofl	0.28	0.31

Because the rex sole stock has not been overfished in recent years and the stock biomass is relatively high, it is not recommended to adjust F_{ABC} downward from its upper bound.

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}, where this fraction is equal to the ratio of the F_{ABC} value for 2022 recommended in the assessment to the *max*F_{ABC} for 2022. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

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

Scenario 4: In all future years, F is set equal to the 2017-2021 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.) The recommended F_{ABC} and the maximum F_{ABC} are equivalent in this assessment, so scenarios 1 and 2 yield identical results.

The 12-year projections of the mean spawning stock biomass, fishing mortality, and catches for the five scenarios are shown in Table 16-Table 18 for the Western-Central GOA subpopulation and Table 19-Table 21 for the Eastern GOA subpopulation. Management quantities and determinations are not specific to area for the GOA rex sole stock, but projections are run separately because F_{OFL} and F_{ABC} are area-specific.

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether the rex sole stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follows (for Tier 3 stocks, the MSY level is defined as *B35%*):

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 2022, 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 2030 under this scenario, then the stock is not approaching an overfished condition.)

Scenario 6 and 7 results for the Western-Central GOA area

The results of these two scenarios indicate that the Western-GOA subpopulation is not overfished and is not approaching an overfished condition. With regard to assessing the current subpopulation biomass level, the expected subpopulation size in the year 2022 of scenario 6 is 41,906, more than 2 times $B_{35\%}$ (16,398 t). Thus the subpopulation is not currently overfished. With regard to whether the subpopulation is approaching an overfished condition, the expected spawning subpopulation size in the year 2034 of scenario 7 (17,495 t) is greater than $B_{35\%}$; thus, the subpopulation is not approaching an overfished condition.

Scenario 6 and 7 results for the Eastern GOA area

The results of these two scenarios indicate that the subpopulation is not overfished and is not approaching an overfished condition. With regard to assessing the current subpopulation biomass level, the expected subpopulation size in the year 2022 of scenario 6 is 9,807 t, more than 2 times *B35%* (3,149 t). Thus the subpopulation is not currently overfished. With regard to whether the subpopulation is approaching an overfished condition, the expected spawning subpopulation size in the year 2034 of scenario 7 (3,360 t) is greater than $B_{35\%}$; thus, the subpopulation is not approaching an overfished condition.

Status determination of the GOA rex sole stock

The results for Scenarios 6 and 7 for the Western-Central and Eastern GOA subpopulations show that neither subpopulation is overfished or approaching an overfished condition. Therefore, the GOA rex sole stock is not overfished or approaching an overfished condition.

Area allocation of harvests

The table below shows apportionment of the ABCs among areas for the next two years. The ABCs calculated for the Western-Central area (based on model estimates) are apportioned based on random effects model predictions of the proportion of Western-Central survey biomass in the Western and Central areas, respectively, in the next two years. Likewise, the ABC calculated for the Eastern area (based on model estimates) are apportioned based on random effects model predictions of the proportion Eastern survey biomass in the West Yakutat and Southeast areas, respectively.

Quantity	**Western**	**Central**	**Total Western-Central**	**West Yakutat**	**Southeast**	**Total Eastern**
Area Apportionment	19.80%	80.20%	100.00%	33.34%	66.66%	100.00%
2022 ABC (t)	2,981	12,076	15,057	1,361	2,723	4,084
2023 ABC (t)	3,222	13,054	16,276	1,439	2,879	4,318

Risk Table

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 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

The GOA rex sole assessment data inputs of survey biomass, survey length composition, survey conditional age-at-length, and fishery age and length composition, are generally adequate. One concern is that the fishery selectivity curve and maturity curve are estimated to be similar. Therefore, a small shift in either curve could have a substantial impact on reference points. Another concern is that the model estimates a very large 2015 year class, which has only been observed partially 2 times in the fishery data and once in the survey data. However, the current survey biomass estimated by the model is well within the uncertainty bounds of the asymptotic 95% confidence interval about the most recent survey data point and the concern is addressed within the model by way of using the Francis (2011) methodology for data weighting, which down-weights length and age composition data. A third concern is that the quality of fits to some conditional age-at-length data fluctuate over time, indicating that there may be a time-varying pattern in growth that is not currently modeled. Future analysis could continue to improve accounting for uncertainty within the model by exploring estimation of natural mortality within the model, as is the case for many stock assessments. The fact that maturity-at-age is similar to fishery selectivity-at-age is less typical and potentially impactful. Therefore, the assessment considerations column of the risk table is assigned a 2 for “substantially increased assessment uncertainty/ unresolved issues.”

Population dynamics considerations

Recruitment estimates for the age 4 and 5 year class are higher than have been seen historically and spawning stock biomass estimates are slightly high, but within range of historical population dynamics for this stock. Therefore, we assign a risk table value of 2 for population dynamics considerations, or “Stock trends are unusual; abundance increasing or decreasing faster than has been seen recently, or recruitment pattern is atypical.”

Environmental/Ecosystem considerations

We scored this category as Level 1 (normal concern) given moderate environmental conditions, limited and mixed information on the abundance of prey, predators, and competitors, and a lack of a mechanistic understanding for the direct and indirect effects of environmental change on the survival and productivity of rex sole.

Gulf of Alaska (GOA) rex sole adults are demersal ranging from offshore, slope to shallow shelf habitats. Spawning occurs during winter months of October through March in the GOA (Abookire 2006). Eggs are fertilized near the benthos then float to the surface. Larvae are transported nearshore by eddies and coastal currents from April to September where they settle to the benthos as juveniles during autumn (Abookire and Bailey 2007).

Physical and biological mechanisms regulating the feeding, growth, and survival of rex sole are poorly understood. Transport of eggs and larvae from offshore to nearshore nursery areas can improve with relaxed downwelling, increased flow from offshore to nearshore via winds or surface currents, and eddy activity that retain larvae nearshore (Atwood et al. 2010, Bailey et al. 2008). However, the 2021 OSCURS models time series of spring transport in days, distance, and bearing from the central Gulf of Alaska to nearshore showed no significant correlation with age-0 rex sole abundance estimates, 1982-2017 (https://oceanview.pfeg.noaa.gov/oscurs/).Winter and spring of 2021 transport conditions may have been favorable for rex sole eggs and larvae due to westerly winds in the late winter, spring and summer, creating upwelling favorable conditions (Bond 2021) and reducing the initial northward transport (southerly winds) that started the winter (Stockhausen 2021). The winter also had above average eddy kinetic energy, with persistent eddies along the shelf edge off Kodiak and Seward (Cheng, 2021). However, conditions were potentially less favorable for rex sole recruitment success, based on a positive correlation between spring Pacific Decadal Oscillation index (negative in 2021) and sea surface temperatures in the GOA since 2002. During the larval stages, the recruitment success of rex sole was positively correlated with the spring Pacific Decadal Oscillation index and sea surface temperatures in the GOA since 2002, the beginning of multiyear periods of warm and cool conditions ($R2 > 0.50$) (Figure 34). GOA summer temperatures ~ 200 m were 5.2-5.4 °C (either at or slightly above survey-specific long-term averages; AFSC Bottom Trawl Survey, Laman 2021; Seward Line Survey, Danielson 2021). Off California, survey abundances of rex sole increased with bottom temperatures in the 6-10.5 °C range (Howard et al. 2020). Spring sea temperatures in the GOA and nearshore during 2021 were cooler than average (Danielson and Hopcroft 2021) indicating less favorable conditions for rex sole recruitment during the age-0 stage.

Prey of rex sole include primarily shrimp, amphipods, and worms. During the AFSC bottom trawl survey, CPUE of shrimp was relatively moderate around the Kodiak, and Yakutat areas, and high around Chirikof, 80 miles southwest of Kodiak (Palsson 2021). During the AFSC spring larval survey, the low relative abundance of larval fish and low zooplankton densities (Deary et al. 2021) around Kodiak indicated below average feeding and growing conditions for larval fish, such as rex sole, during 2021.

Predators of rex sole include primarily sharks, skates, rays, lingcod, arrowtooth flounder, and some species of rockfish (Kemper et al. 2017). Population trends for arrowtooth flounder in the GOA have declined in abundance by approximately 25% since the early 2000s (Shotwell et al. 2020). AFSC bottom trawl survey CPUE anomalies were below average for arrowtooth flounder and above and below average for skates in recent years 2010-2021 (Worton 2021). Little is known about the impacts of these predators and competitors on rex sole population levels, but these predator population levels remain low.

Fishery performance

The non-pollock trawl CV sector was closed for an extended period due to Chinook salmon bycatch in the Pacific cod trawl fishery. Catches of GOA rex sole were extremely low relative to recent history for both catcher vessels and catcher processors. However, this does not present a concern about the ABC for the species, and may have been a one-time event. Therefore, the fishery performance column of the risk table is assigned a 1 for “No apparent fishery/resource-use performance and/or behavior concerns.”

Summary and ABC recommendation

Assessment-related considerations	*Population dynamics considerations*	*Environmental/ ecosystem considerations*	*Fishery Performance considerations*
Level 2: substantially increased concerns	Level 2: substantially increased concerns	Level 1: no increased concerns	Level 1: no increased concerns

Based on these scores, the authors do not recommend a reduction in ABC for 2022.

Ecosystem Considerations

Ecosystem effects on the stock

Also see the "Environmental/Ecosystem Considerations" description for the Risk Table above.

Prey availability/abundance trends

Based on results from an ecosystem model for the Gulf of Alaska (Aydin et al., 2007), rex sole in the Gulf of Alaska occupy an intermediate trophic level (Figure 35). Polychaetes, euphausiids, and miscellaneous worms were the most important prey for rex sole in the Gulf of Alaska (Figure 36). Other major prey items included benthic amphipods, polychaetes, and shrimp (Livingston and Goiney, 1983; Yang, 1993; Yang and Nelson, 2000). Little to no information is available to assess trends in abundance for the major benthic prey species of rex sole.

Predator population trends

Important predators on rex sole include longnosed skate and arrowtooth flounder (Figure 37). The flatfish-directed fishery constitutes the second-largest known source of mortality on rex sole. However, unexplained mortality is the second largest component of mortality.

Fishery Effects on the Ecosystem

Table 26-Table 28 show the contribution of the GOA rex sole fishery to bycatch of FMP, non-target, ecosystem, and prohibited species. No birds were recorded as bycatch in the GOA rex sole fishery. The 2021 data are current up to October 17, 2021.

Data gaps and research priorities

Updated information on maturity-at-age for GOA rex sole would reduce uncertainty in the maturity curve relative to the fishery selectivity curve, as this is important for the determination of F_{OFL} and F_{ABC} for this stock. The ADF&G small mesh survey could be included as well, and an ageing error matrix could be developed. Further exploration of natural mortality rates for GOA rex sole could be conducted. Estimating natural mortality within the assessment would better account for uncertainty.

This assessment showed that growth curves in the Eastern GOA differ from those in the Western and Central GOA. The age and growth laboratory previously noted that GOA rex sole otoliths appear to show two different patterns for the same age and year of fish, corroborating the results of this assessment. Further research could be conducted to determine whether the two growth patterns represent two genetic sub-stocks or one genetic sub-stock where environmental conditions or other ecosystem dynamics contribute to different growth rates in the two regions modeled in this assessment.

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Tables

Table 1. Fishery catches for GOA rex sole by management area. Catch for 2021 is through Sep 26, 2021.

Year	Total Catch	Western Gulf	Central Gulf	Eastern Gulf
1982	959			
1983	595			
1984	365			
1985	154			
1986	93			
1987	1151			
1988	1192			
1989	599			
1990	1269			
1991	4636			
1992	3000			
1993	3000			
1994	3642	49	3508	85
1995	4021	220	3628	174
1996	5945	552	5202	191
1997	3296	681	2438	177
1998	2671	440	2195	36
1999	3059	603	2393	63
2000	3592	883	2702	Confidential
2001	2943	435	2507	Confidential
2002	3017	398	2619	Confidential
2003	3499	772	2726	2
2004	1467	527	940	0
2005	2180	576	1603	Confidential
2006	3295	350	2944	0
2007	2851	411	2438	1
2008	2707	185	2522	Confidential
2009	4753	342	4410	1
2010	3669	134	3534	2
2011	2878	131	2746	1
2012	2443	215	2228	Confidential
2013	3700	104	3596	0
2014	3577	126	3450	1
2015	1957	76	1882	Confidential
2016	1749	172	1575	3
2017	1484	48	1434	2
2018	1750	83	1665	2
2019	1612	74	1536	2
2020	1238	36	1201	1
2021	207	11	194	2

Table 2. Proportion of catch by gear 1994 to 2021.

Year	Non-pelagic trawl	Pelagic trawl
1994	0	0
1995	0	0
1996	1	0
1997	0.99	0.01
1998	1	0
1999	1	0
2000	1	0
2001	0.98	0.02
2002	0.99	0.01
2003	1	0
2004	0.98	0.02
2005	0.99	0.01
2006	0.98	0.02
2007	0.99	0.01
2008	0.99	0.01
2009	1	0
2010	0.99	0.01
2011	1	0
2012	0.99	0.01
2013	1	0
2014	0.99	0.01
2015	0.99	0.01
2016	0.99	0.01
2017	1	0
2018	0.99	0.01
2019	0.99	0.01
2020	1	0
2021	0.95	0.05

Table 3. Proportion of catch by quarter 1994-September 26, 2021 with conditional formatting showing a scale from no catches (white) to the highest proportion of catches (dark green).

	Fishery Catches			
Year	Q1	Q2	Q3	Q4
1994	0.14	0.38	0.35	0.12
1995	0.24	0.47	0.19	0.1
1996	0.33	0.33	0.22	0.12
1997	0.44	0.25	0.1	0.21
1998	0.31	0.48	0.17	0.04
1999	0.25	0.48	0.18	0.08
2000	0.2	0.58	0.15	0.07
2001	0.19	0.62	0.13	0.05
2002	0.14	0.67	0.16	0.04
2003	0.13	0.59	0.22	0.07
2004	0.17	0.51	0.31	0.01
2005	0.34	0.4	0.25	0.01
2006	0.24	0.29	0.37	0.09
2007	0.31	0.38	0.25	0.07
2008	0.23	0.43	0.27	0.07
2009	0.22	0.37	0.3	0.11
2010	0.17	0.52	0.14	0.17
2011	0.2	0.49	0.22	0.1
2012	0.2	0.45	0.2	0.15
2013	0.23	0.61	0.06	0.1
2014	0.2	0.66	0.1	0.04
2015	0.1	0.58	0.11	0.21
2016	0.22	0.48	0.14	0.15
2017	0.17	0.47	0.24	0.12
2018	0.14	0.57	0.11	0.18
2019	0.19	0.58	0.11	0.12
2020	0.12	0.73	0.09	0.05
2021	0.02	0.28	0.47	0.24

Table 4. Proportion of catch by NMFS area for 1994-September 26, 2021 with conditional formatting showing a scale from no catches (white) to the highest proportion of catches (dark green).

	Fishery Catches				
Year	610	620	630	640	650
1994	0.01	0.37	0.6	0.02	0
1995	0.05	0.34	0.56	0.04	0
1996	0.09	0.52	0.35	0.03	0
1997	0.21	0.52	0.22	0.04	0.01
1998	0.16	0.3	0.52	0.01	0
1999	0.2	0.45	0.33	0.01	0.01
2000	0.25	0.33	0.42	0	0
2001	0.15	0.37	0.49	0	0
2002	0.13	0.49	0.38	0	0
2003	0.22	0.49	0.29	0	0
2004	0.36	0.17	0.47	0	0
2005	0.26	0.37	0.36	0	0
2006	0.11	0.45	0.44	0	0
2007	0.14	0.27	0.59	0	0
2008	0.07	0.26	0.67	0	0
2009	0.07	0.5	0.43	0	0
2010	0.04	0.42	0.54	0	0
2011	0.05	0.39	0.56	0	0
2012	0.09	0.36	0.55	0	0
2013	0.03	0.35	0.62	0	0
2014	0.04	0.28	0.69	0	0
2015	0.04	0.44	0.52	0	0
2016	0.1	0.32	0.58	0	0
2017	0.03	0.62	0.35	0	0
2018	0.05	0.3	0.65	0	0
2019	0.05	0.25	0.71	0	0
2020	0.03	0.39	0.58	0	0
2021	0.05	0.56	0.38	0.01	0

Table 5. Historical catch specifications, percent of the catch retained, and percent of the TAC and ABC caught from 1995-2021. Total catch in 2021 is the catch up to September 26, 2021.

Year	OFL (t)	ABC (t)	TAC (t)	Total Catch	% Retained	% of TAC caught	% of ABC Caught
1995	13,091	11,210	9,690	3,628	90%	37%	32%
1996	13,091	11,210	9,690	5,202	95%	54%	46%
1997	11,920	9,150	9,150	2,438	92%	27%	27%
1998	11,920	9,150	9,150	2,195	97%	24%	24%
1999	11,920	9,150	9,150	2,393	96%	26%	26%
2000	12,300	9,440	9,440	2,702	97%	29%	29%
2001	12,300	9,440	9,440	2,507	95%	27%	27%
2002	12,320	9,470	9,470	2,619	95%	28%	28%
2003	12,320	9,470	9,470	2,726	95%	29%	29%
2004	16,480	12,650	12,650	940	92%	7%	7%
2005	16,480	12,650	12,650	1,603	91%	13%	13%
2006	12,000	9,200	9,200	2,944	95%	32%	32%
2007	11,900	9,100	9,100	2,438	98%	27%	27%
2008	11,933	9,132	9,132	2,522	97%	28%	28%
2009	11,756	8,996	8,996	4,410	99%	49%	49%
2010	12,714	9,729	9,729	3,534	97%	36%	36%
2011	12,499	9,565	9,565	2,746	97%	29%	29%
2012	12,561	9,612	9,612	2,228	98%	23%	23%
2013	12,492	9,560	9,560	3,596	99%	38%	38%
2014	12,207	9,341	9,341	3,450	99%	37%	37%
2015	11,957	9,150	9,150	1,882	98%	21%	21%
2016	9,791	7,493	7,493	1,575	96%	21%	21%
2017	10,860	8,311	8,311	1,434	96%	17%	17%
2018	18,706	15,373	15,373	1,665	96%	11%	11%
2019	17,889	14,692	14,692	1,536	95%	10%	10%
2020	18,127	14,878	14,878	1,201	95%	8%	8%
2021	18,779	15,416	15,416	194	86%	1%	1%

Table 6. GOA catcher vessel (CV) closures for rex sole by sub-area for 2017-2021. Note: there were no closures 2017-2020 and no closures for CPs during this time.

Effective Date	Gear	Sub Area	Program	Status	Reason
8/24/2021	Trawl Gear	GOA - Central 620/630	Catcher Vessel	Open	Chinook Salmon
8/24/2021	Trawl Gear	GOA - Western 610	Catcher Vessel	Open	Chinook Salmon
3/26/2021	Trawl Gear	GOA - Western 610	Catcher Vessel	Bycatch	Chinook Salmon
3/26/2021	Trawl Gear	GOA - Central 620/630	Catcher Vessel	Bycatch	Chinook Salmon

Table 7. GOA rex sole survey biomass for the Western-Central GOA and for the Eastern GOA. No samples were taken in the Eastern GOA in 2001.

	Western & Central GOA		Eastern GOA	
Year	Biomass	Standard Error	Biomass	Standard Error
1984	47,359	0.12	13,311	0.12
1987	48,522	0.11	15,304	0.14
1990	81,912	0.12	16,313	0.23
1993	66,071	0.08	20,901	0.14
1996	53,197	0.09	19,560	0.11
1999	55,504	0.15	19,464	0.12
2001	51,258	0.09		
2003	71,238	0.09	28,659	0.14
2005	73,365	0.10	27,795	0.15
2007	88,128	0.10	15,672	0.17
2009	101,872	0.08	22,873	0.22
2011	76,453	0.09	18,681	0.12
2013	78,065	0.17	22,913	0.21
2015	64,839	0.09	22,474	0.21
2017	77,368	0.16	20,352	0.18
2019	66,171	0.12	24,243	0.17
2021	86,209	0.09	26,124	0.14

Table 8. Survey biomass by year and depth in metric tons

	Depth						
Year	1-100m	101-200m	201-300m	301-400m	501-700m	701-1000m	Total
1984	3,987	37,040	13,083	5,161	1,057	342	60,670
1987	5,691	40,244	14,508	1,812	1,542	30	63,826
1990	15,460	59,833	21,791	1,140			98,225
1993	11,294	54,064	16,995	4,619			86,972
1996	10,403	43,419	14,929	4,006			72,757
1999	14,682	40,239	15,766	3,841	440	-	74,969
2001	7,742	29,206	11,045	3,265			51,258
2003	17,529	58,787	19,094	4,017	470		99,897
2005	14,783	65,060	16,637	4,535	136	10	101,161
2007	9,105	71,514	18,368	4,504	309	-	103,800
2009	16,017	79,662	25,032	2,980	1,054	-	124,744
2011	11,969	53,199	25,171	4,342	454		95,134
2013	12,731	68,435	15,583	3,276	952		100,978
2015	15,391	52,691	15,416	3,093	721	-	87,313
2017	13,044	51,550	27,179	5,736	213		97,720
2019	15,653	53,128	17,461	3,674	498		90,414
2021	22,302	69,251	17,000	2,581	1,199		112,333

Table 9. Configuration of fishery and survey age-based, sex-specific double-normal selectivity curves used in the assessment. A numeric value indicates the fixed value of a parameter.

Double-normal selectivity parameters	**Fishery**	**Survey**
Peak: beginning size for the plateau	Estimated	Estimated
Width: width of plateau	30	30
Ascending width (log space)	Estimated	Estimated
Descending width (log space)	8	8
Initial: selectivity at smallest length or age bin	0	0
Final: selectivity at largest length or age bin	999	999
Male Peak Offset	Estimated	Estimated
Male ascending width offset (log space)	Estimated	Estimated
Male descending width offset (log space)	0	0
Male "Final" offset (transformation required)	0	0
Male apical selectivity	1	1

Table 10. Likelihood components for each model. The likelihood components and total likelihood cannot be directly compared among models. The likelihood components for Model 21.0 can be compared to those for the same model without estimation of survey catchability. The survey likelihood component can be compared between Model 17.2 and the same model using Francis data weighting.

Likelihood Component	Old Model 17.2	Model 17.2 (Old 17.2 + new data)	17.2 but Francis weighting	17.2 but Francis weighting and leave out 80s survey data	Model 21.0, Francis weighting, leave out 80s survey data, estimate q
TOTAL	2,543	2,848	654	583	547
Survey	-12.10	-13.22	-34.80	-33.02	-34.79
Length_comp	488	583	159	171	144
Age_comp	2,067	2,279	531	447	442
Recruitment	-1.522	-1.695	-1.551	-0.838	-4.024

Table 11. Estimates of growth parameters for Models 17.2 and 21.0. Length at ages 2 and 20 are in cm. Parameter estimates are denoted "Est" and standard deviations of parameter estimates are denoted "Std. Dev."

	Model 17.2: West-Central		**Model 17.2: Eastern**		**Model 21.0: West-Central**		**Model 21.0: Eastern**	
Parameter	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Length at age 2 (f)	14.60	0.43	14.11	0.64	14.76	0.82	14.28	1.54
Length at age 20 (f)	46.72	0.20	36.67	0.23	46.83	0.36	36.73	0.59
von Bertalanffy k (f)	0.27	0.01	0.31	0.01	0.28	0.01	0.30	0.04
CV in length at age 2 (f)	0.17	0.01	0.18	0.01	0.18	0.01	0.17	0.03
CV in length at age 20 (f)	0.09	0.00	0.10	0.00	0.09	0.00	0.10	0.01
Length at age 2 (m)	14.70	0.52	14.78	0.71	15.05	0.93	15.02	1.76
Length at age 20 (m)	41.04	0.17	34.52	0.19	41.02	0.27	34.64	0.49
von Bertalanffy k (m)	0.32	0.01	0.32	0.02	0.32	0.02	0.31	0.04
CV in length at age 2 (m)	0.19	0.01	0.19	0.01	0.19	0.02	0.19	0.03
CV in length at age 20 (m)	0.08	0.00	0.08	0.00	0.07	0.00	0.08	0.01

Table 12. Estimates of selectivity parameters for models 17.2 and 21.0.

		Model 17.2: Western-Central		Model 17.2: Eastern		Model 21.0: Western-Central		Model 21.0: Eastern	
		Est	StDev	Est	StDev	Est	StDev	Est	StDev
Fishery	Peak: beginning size for the plateau (f)	7.894	0.230	NA	NA	7.707	0.340	NA	NA
	Ascending width (f; ln)	1.399	0.161	NA	NA	1.374	0.245	NA	NA
	Male peak offset	-1.351	0.285	NA	NA	-1.469	0.433	NA	NA
	Male ascending width offset (ln)	-0.400	0.230	NA	NA	-0.530	0.379	NA	NA
Survey	Peak: beginning size for the plateau (f)	6.046	0.130	5.158	0.165	5.968	0.238	5.085	0.373
	Ascending width (f; ln)	1.657	0.071	1.279	0.116	1.680	0.124	1.278	0.271
	Male peak offset	NA	NA	NA	NA	NA	NA	NA	NA
	Male ascending width offset (ln)	NA	NA	NA	NA	NA	NA	NA	NA

Table 13. Model estimates (Est) and corresponding standard deviations (Std. Dev.) for the log of unfished recruitment (mean recruitment in this model), recruitment allocation between the Western-Central GOA and the Eastern GOA, and the catchability parameter (q) in logspace.

	Model 17.2		**Model 21.0**	
Parameter	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
$\ln(R_0)$	11.568	0.037	11.543	0.035
Recruitment Allocation*	-0.856	0.044	-0.875	0.060
ln(q)	0 (fixed)		0.155	0.100

*A non-time-varying recruitment allocation parameter determines the proportion of total recruitment that settles in each area of the model, which is parameterized as *exp(Est)/(exp(Est)+1)*. Therefore, both models estimate that 0.3 is the proportion of recruits each year that settle in the Eastern GOA and 0.7 is the proportion of recruits that settle in the Western-Central area each year.

Table 14. Estimated yearly recruitment deviations for the current base case model. Recruitment deviations are fixed at 0 for years 2020 onward, as no information exists to inform recruitment deviations in these years yet.

Year	Recruitment Deviations	Std. Dev.	Year	Recruitment Deviations	Std. Dev.
1965	-0.140	0.560	1995	-0.376	0.164
1966	-0.160	0.554	1996	-0.113	0.145
1967	-0.183	0.548	1997	0.416	0.111
1968	-0.209	0.541	1998	0.622	0.098
1969	-0.236	0.534	1999	0.614	0.095
1970	-0.265	0.526	2000	0.293	0.107
1971	-0.292	0.519	2001	0.008	0.122
1972	-0.318	0.511	2002	-0.054	0.133
1973	-0.345	0.471	2003	0.537	0.107
1974	-0.235	0.448	2004	0.342	0.129
1975	-0.441	0.462	2005	0.731	0.106
1976	-0.310	0.414	2006	0.058	0.149
1977	-0.421	0.413	2007	-0.040	0.151
1978	-0.222	0.375	2008	-0.503	0.185
1979	-0.421	0.394	2009	-0.547	0.193
1980	-0.207	0.366	2010	-0.262	0.178
1981	-0.232	0.374	2011	-0.229	0.179
1982	0.086	0.294	2012	-0.610	0.215
1983	0.266	0.254	2013	-0.828	0.254
1984	0.327	0.209	2014	-0.164	0.236
1985	0.372	0.176	2015	1.291	0.141
1986	0.189	0.173	2016	0.875	0.251
1987	0.288	0.160	2017	0.454	0.380
1988	-0.299	0.198	2018	0.011	0.494
1989	-0.603	0.216	2019	-0.065	0.517
1990	-0.558	0.208			
1991	-0.775	0.224			
1992	-0.632	0.206			
1993	-0.566	0.201			
1994	-0.556	0.189			

Table 15. Estimated fishing mortality for the current base case model.

Year	Estimate	StdDev	Year	Estimate	StdDev
1982	0.016	0.002	**2001**	0.016	0.002
1983	0.011	0.001	**2002**	0.011	0.001
1984	0.007	0.001	**2003**	0.007	0.001
1985	0.003	0.000	**2004**	0.003	0.000
1986	0.002	0.000	**2005**	0.002	0.000
1987	0.021	0.002	**2006**	0.021	0.002
1988	0.022	0.002	**2007**	0.022	0.002
1989	0.010	0.001	**2008**	0.010	0.001
1990	0.021	0.002	**2009**	0.021	0.002
1991	0.074	0.007	**2010**	0.074	0.007
1992	0.048	0.005	**2011**	0.048	0.005
1993	0.048	0.004	**2012**	0.048	0.004
1994	0.062	0.006	**2013**	0.062	0.006
1995	0.074	0.007	**2014**	0.074	0.007
1996	0.125	0.012	**2015**	0.125	0.012
1997	0.079	0.008	**2016**	0.079	0.008
1998	0.070	0.007	**2017**	0.070	0.007
1999	0.087	0.009	**2018**	0.087	0.009
2000	0.111	0.013	**2019**	0.111	0.013
			2020	0.094	0.011
			2021	0.092	0.011

Table 16. Projected spawning biomass for the Western-Central GOA for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2021	35,797	35,797	35,797	35,797	35,797	35,797	35,797
2022	41,906	41,906	41,906	41,906	41,906	41,906	41,906
2023	46,224	46,224	46,224	46,224	46,224	37,849	39,476
2024	48,502	48,502	48,502	48,502	48,502	32,830	35,582
2025	41,109	41,109	48,878	47,889	50,054	28,144	30,094
2026	34,956	34,956	48,429	46,575	50,686	24,497	25,829
2027	30,272	30,272	47,637	45,071	50,833	21,894	22,783
2028	26,832	26,832	46,718	43,585	50,707	20,094	20,669
2029	24,350	24,350	45,780	42,205	50,424	18,931	19,274
2030	22,597	22,597	44,894	40,983	50,072	18,232	18,426
2031	21,401	21,401	44,104	39,942	49,710	17,843	17,948
2032	20,618	20,618	43,423	39,079	49,371	17,648	17,703
2033	20,115	20,115	42,843	38,368	49,061	17,556	17,583
2034	19,770	19,770	42,329	37,760	48,761	17,482	17,495

Table 17. Projected fishing mortality for the Western-Central GOA for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2021	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2022	0.02	0.02	0.02	0.02	0.02	0.28	0.23
2023	0.02	0.02	0.02	0.02	0.02	0.28	0.23
2024	0.23	0.23	0.03	0.05	0.00	0.28	0.28
2025	0.23	0.23	0.03	0.05	0.00	0.28	0.28
2026	0.23	0.23	0.03	0.05	0.00	0.28	0.28
2027	0.23	0.23	0.03	0.05	0.00	0.28	0.28
2028	0.23	0.23	0.03	0.05	0.00	0.28	0.28
2029	0.23	0.23	0.03	0.05	0.00	0.27	0.27
2030	0.23	0.23	0.03	0.05	0.00	0.26	0.26
2031	0.22	0.22	0.03	0.05	0.00	0.26	0.26
2032	0.22	0.22	0.03	0.05	0.00	0.26	0.26
2033	0.22	0.22	0.03	0.05	0.00	0.26	0.26
2034	0.22	0.22	0.03	0.05	0.00	0.26	0.26

Table 18. Projected catch for the Western-Central GOA for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2021	392	392	392	392	392	392	392
2022	1,567	1,567	1,567	1,567	1,567	18,314	15,058
2023	1,567	1,567	1,567	1,567	1,567	15,997	13,763
2024	16,619	16,619	2,178	4,012	0	13,435	14,617
2025	13,780	13,780	2,155	3,887	0	11,322	12,134
2026	11,602	11,602	2,116	3,745	0	9,812	10,355
2027	10,020	10,020	2,073	3,610	0	8,762	9,137
2028	8,882	8,882	2,029	3,485	0	7,910	8,197
2029	8,068	8,068	1,986	3,373	0	7,308	7,493
2030	7,474	7,474	1,948	3,276	0	6,943	7,048
2031	7,046	7,046	1,915	3,196	0	6,738	6,796
2032	6,758	6,758	1,887	3,131	0	6,639	6,669
2033	6,564	6,564	1,864	3,078	0	6,599	6,614
2034	6,425	6,425	1,843	3,032	0	6,560	6,567

Table 19. Projected spawning biomass for the Eastern GOA subpopulation for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2021	8,797	8,797	8,797	8,797	8,797	8,797	8,797
2022	9,807	9,807	9,807	9,807	9,807	9,807	9,807
2023	10,553	10,553	10,553	10,553	10,553	8,308	8,715
2024	10,900	10,900	10,900	10,900	10,900	6,863	7,513
2025	8,854	8,854	10,954	10,456	10,954	5,674	6,115
2026	7,274	7,274	10,859	9,934	10,859	4,819	5,108
2027	6,131	6,131	10,703	9,430	10,703	4,242	4,428
2028	5,327	5,327	10,524	8,976	10,524	3,861	3,977
2029	4,767	4,767	10,340	8,580	10,340	3,626	3,693
2030	4,385	4,385	10,166	8,244	10,166	3,491	3,527
2031	4,131	4,131	10,008	7,965	10,008	3,420	3,439
2032	3,969	3,969	9,870	7,738	9,870	3,387	3,396
2033	3,867	3,867	9,750	7,553	9,750	3,371	3,376
2034	3,799	3,799	9,641	7,398	9,641	3,358	3,360

Table 20. Projected fishing mortality for the Eastern GOA subpopulation for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2021	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2022	0.00	0.00	0.00	0.00	0.00	0.31	0.25
2023	0.00	0.00	0.00	0.00	0.00	0.31	0.25
2024	0.25	0.25	0.00	0.05	0.00	0.31	0.31
2025	0.25	0.25	0.00	0.05	0.00	0.31	0.31
2026	0.25	0.25	0.00	0.05	0.00	0.31	0.31
2027	0.25	0.25	0.00	0.05	0.00	0.31	0.31
2028	0.25	0.25	0.00	0.05	0.00	0.30	0.30
2029	0.25	0.25	0.00	0.05	0.00	0.29	0.29
2030	0.24	0.24	0.00	0.05	0.00	0.28	0.29
2031	0.24	0.24	0.00	0.05	0.00	0.28	0.28
2032	0.24	0.24	0.00	0.05	0.00	0.28	0.28
2033	0.24	0.24	0.00	0.05	0.00	0.28	0.28
2034	0.24	0.24	0.00	0.05	0.00	0.28	0.28

Table 21. Projected catch for the Eastern GOA subpopulation for the seven harvest scenarios listed in the "Harvest Recommendations" section.

Year	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
2021	2	2	2	2	2	2	2
2022	2	2	2	2	2	4,988	4,084
2023	2	2	2	2	2	4,083	3,520
2024	4,358	4,358	0	1,032	0	3,268	3,597
2025	3,470	3,470	0	975	0	2,659	2,877
2026	2,823	2,823	0	919	0	2,249	2,389
2027	2,371	2,371	0	870	0	1,976	2,070
2028	2,057	2,057	0	827	0	1,764	1,833
2029	1,839	1,839	0	790	0	1,621	1,664
2030	1,686	1,686	0	759	0	1,538	1,562
2031	1,578	1,578	0	734	0	1,494	1,506
2032	1,507	1,507	0	714	0	1,474	1,480
2033	1,460	1,460	0	698	0	1,466	1,469
2034	1,427	1,427	0	684	0	1,458	1,459

Table 22. Time series of recruitment at ages 3 and 0 and standard deviation of age 0 recruits for the previous and current assessments.

	2017 Assessment			*2021 Assessment*		
Year	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. dev**	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. dev**
1982	61,316	105,098	15,858	36,555	99,500	30,702
1983	59,823	144,103	18,860	45,057	118,585	31,644
1984	39,743	139,053	16,593	43,716	125,315	27,803
1985	63,111	154,457	15,463	59,749	130,443	24,500
1986	86,533	129,565	12,731	71,210	108,074	19,904
1987	83,501	132,510	12,005	75,251	118,684	20,098
1988	92,750	78,978	8,446	78,330	65,628	13,599
1989	77,803	59,804	6,944	64,897	48,337	10,848
1990	79,571	62,661	6,819	71,268	50,551	10,922
1991	47,426	41,529	5,361	39,410	40,675	9,501
1992	35,911	52,278	5,893	29,026	46,939	10,119
1993	37,628	49,521	5,725	30,355	50,140	10,605
1994	24,938	56,856	5,897	24,425	50,660	10,295
1995	31,392	70,568	6,447	28,186	60,607	11,005
1996	29,737	95,589	7,727	30,108	78,852	13,038
1997	34,141	154,501	10,195	30,420	133,868	18,427
1998	42,375	170,189	10,789	36,393	164,493	21,121
1999	57,400	174,341	10,798	47,349	163,131	20,858
2000	92,775	138,178	9,423	80,385	118,422	16,145
2001	102,195	108,519	8,450	98,775	88,968	13,238
2002	104,689	106,159	8,997	97,957	83,691	13,200
2003	82,973	185,134	13,233	71,110	151,127	20,581
2004	65,164	162,319	13,389	53,424	124,309	19,192
2005	63,747	223,018	16,180	50,255	183,425	24,700
2006	111,171	111,620	11,303	90,750	93,541	16,162
2007	97,471	101,201	10,780	74,646	84,870	14,806
2008	133,920	51,179	7,395	110,144	53,419	11,048
2009	67,027	48,299	7,860	56,170	51,098	10,952
2010	60,770	94,900	13,867	50,963	67,972	13,647
2011	30,732	91,658	16,145	32,077	70,248	14,244
2012	29,003	39,850	12,262	30,684	47,978	11,365
2013	56,986	28,270	11,645	40,817	38,586	10,623
2014	55,040	180,497	45,371	42,183	74,952	19,267
2015	23,929	262,142	91,107	28,810	320,967	54036
2016	16,976	112,996	3,454	23,170	211,759	57034
2017	108,387	112,996		45,007	147,545	57830
2018				192,738	100,522	51115
2019				127,159	96,598	51777
2020				88,599	103,085	8896
2021				60,363	103,085	
Average	63,557	111,959		59,697	101,766	

Table 23. Time series of recruitment at ages 3 and 0 by area.

	Western-Central GOA		*Eastern GOA*	
Year	**Recruits (Age 3)**	**Recruits (Age 0)**	**Recruits (Age 3)**	**Recruits (Age 0)**
1982	25,796	70,216	10,759	29,284
1983	31,796	83,684	13,261	34,901
1984	30,850	88,433	12,866	36,882
1985	42,164	92,052	17,585	38,391
1986	50,252	76,267	20,958	31,808
1987	53,104	83,753	22,147	34,930
1988	55,276	46,313	23,054	19,315
1989	45,797	34,111	19,100	14,226
1990	50,293	35,673	20,975	14,878
1991	27,811	28,704	11,599	11,971
1992	20,483	33,124	8,543	13,815
1993	21,421	35,383	8,934	14,757
1994	17,236	35,750	7,189	14,910
1995	19,890	42,770	8,296	17,838
1996	21,247	55,644	8,861	23,207
1997	21,467	94,468	8,953	39,399
1998	25,682	116,081	10,711	48,413
1999	33,413	115,119	13,936	48,012
2000	56,726	83,569	23,659	34,853
2001	69,703	62,784	29,072	26,185
2002	69,126	59,060	28,831	24,631
2003	50,181	106,648	20,929	44,479
2004	37,700	87,723	15,724	36,586
2005	35,464	129,440	14,791	53,984
2006	64,041	66,011	26,709	27,530
2007	52,676	59,891	21,970	24,978
2008	77,727	37,697	32,417	15,722
2009	39,638	36,059	16,532	15,039
2010	35,964	47,967	14,999	20,005
2011	22,636	49,573	9,441	20,675
2012	21,653	33,858	9,031	14,121
2013	28,804	27,229	12,013	11,356
2014	29,768	52,892	12,415	22,059
2015	20,331	226,502	8,479	94,465
2016	16,351	149,435	6,819	62,324
2017	31,761	104,120	13,246	43,424
2018	136,012	70,937	56,726	29,585
2019	89,734	68,168	37,425	28,430
2020	62,523	72,746	26,076	30,339
2021	42,597	72,746	17,766	30,339
Average	42,127	71,815	17,570	29,951

Table 24. Time series of total and spawning biomass and standard deviation of spawning biomass (Std_Dev) for the previous and current assessments. Values for 2022 and 2023 are from projections using Scenario 1.

	2017 Assessment			*2021 Assessment*		
Year	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**
1982	127,143	46,408	2,507	90,005	43,946	5,216
1983	99,299	46,648	2,381	87,858	42,480	4,944
1984	100,125	47,417	2,271	86,486	41,430	4,680
1985	100,169	48,245	2,168	86,915	40,728	4,441
1986	100,752	48,874	2,066	89,356	40,462	4,245
1987	103,035	49,321	1,959	93,298	40,759	4,115
1988	106,439	49,579	1,845	97,327	41,275	4,060
1989	110,173	50,734	1,746	100,943	42,664	4,075
1990	113,942	52,974	1,675	105,283	44,987	4,135
1991	118,207	55,080	1,621	106,275	47,068	4,198
1992	119,635	55,043	1,571	101,560	46,990	4,220
1993	115,398	55,074	1,514	97,134	47,025	4,176
1994	111,157	53,839	1,447	91,360	45,892	4,051
1995	105,083	50,996	1,367	84,650	43,238	3,851
1996	97,703	47,149	1,278	77,830	39,709	3,611
1997	89,760	41,919	1,188	69,731	34,962	3,366
1998	80,540	38,356	1,102	65,497	32,008	3,141
1999	75,234	35,546	1,026	63,552	29,825	2,954
2000	72,466	33,210	966	64,894	28,004	2,823
2001	72,909	31,704	931	69,433	26,800	2,775
2002	76,201	32,188	931	76,964	27,377	2,850
2003	82,765	34,481	980	83,720	29,691	3,081
2004	89,609	37,918	1,077	87,984	33,198	3,447
2005	94,713	42,708	1,196	92,355	37,971	3,848
2006	100,236	46,419	1,307	97,373	41,476	4,174
2007	106,135	48,480	1,396	100,540	43,086	4,383
2008	110,995	50,409	1,473	106,661	44,339	4,528
2009	118,540	52,952	1,570	110,043	45,991	4,689
2010	123,956	55,080	1,703	109,469	47,089	4,889
2011	125,073	57,713	1,858	107,045	48,762	5,086
2012	123,488	59,350	1,996	103,354	49,830	5,197
2013	119,548	59,091	2,080	99,490	49,511	5,172
2014	115,384	56,301	2,109	94,215	47,120	5,034
2015	109,839	52,735	2,109	88,332	44,116	4,837
2016	103,157	50,180	2,120	83,471	41,982	4,636
2017	96,924	47,939	2,153	80,181	40,045	4,450
2018	97,982	45,750		89,283	38,424	4,288
2019	97,967	43,575		100,243	37,515	4,209
2020				110,746	39,239	4,381
2021				118,571	44,594	4,931
2022				99,428	41,906	--
2023				101,606	46,224	--

Table 25. Total (age 3+) biomass and spawning biomass for the Western-Central GOA and Eastern GOA.

	Total Biomass		*Spawning Biomass*	
Year	**Western-Central**	**Eastern**	**Western-Central**	**Eastern**
1982	73,960	16,045	36,896	7,050
1983	72,006	15,851	35,578	6,902
1984	70,777	15,709	34,649	6,781
1985	71,029	15,886	34,036	6,692
1986	72,949	16,407	33,805	6,657
1987	76,120	17,179	34,047	6,712
1988	79,195	18,132	34,374	6,900
1989	82,012	18,931	35,439	7,224
1990	85,542	19,740	37,352	7,635
1991	86,323	19,952	39,021	8,047
1992	81,876	19,684	38,617	8,374
1993	77,996	19,138	38,484	8,540
1994	73,042	18,318	37,404	8,487
1995	67,212	17,439	35,012	8,227
1996	61,248	16,582	31,868	7,842
1997	53,944	15,787	27,550	7,412
1998	50,325	15,172	25,008	7,000
1999	48,681	14,871	23,180	6,645
2000	49,578	15,316	21,618	6,385
2001	52,984	16,449	20,524	6,276
2002	59,018	17,946	20,977	6,400
2003	64,535	19,185	22,881	6,810
2004	68,004	19,980	25,759	7,439
2005	71,941	20,414	29,874	8,097
2006	76,121	21,253	32,878	8,598
2007	78,618	21,922	34,194	8,892
2008	83,523	23,138	35,236	9,103
2009	86,396	23,647	36,620	9,371
2010	85,691	23,778	37,373	9,716
2011	83,736	23,310	38,724	10,038
2012	80,868	22,486	39,660	10,171
2013	77,866	21,623	39,477	10,034
2014	73,448	20,767	37,440	9,680
2015	68,590	19,741	34,895	9,221
2016	64,866	18,605	33,225	8,757
2017	62,361	17,820	31,727	8,318
2018	69,576	19,707	30,491	7,933
2019	78,506	21,738	29,786	7,728
2020	87,280	23,466	31,259	7,980
2021	94,048	24,523	35,797	8,797
2022	99,428	25,115	41,906	9,807
2023	101,606	25,333	46,224	10,553

Table 26. Non-target catch in the directed GOA rex sole fishery in metric tons for 2017-2020. Birds (recorded in numbers) have not been recorded as bycatch in the GOA rex sole fishery.

Species Group Name	2020	2019	2018	2017
Benthic urochordata			C	
Brittle star unidentified			C	C
Eelpouts				C
Eulachon				C
Giant Grenadier				C
Hermit crab unidentified			C	C
Misc crabs		C		C
Misc crustaceans				C
Misc fish	C	C	0.275	C
Misc inverts (worms etc)			C	
Pandalid shrimp	C		0.014	C
Scypho jellies	C	C		
Sea anemone unidentified	C			C
Sea pens whips	C			C
Sea star	C	C	0.089	C
Snails	C		C	C
Sponge unidentified			C	C
Squid	C			
Stichaeidae			C	C
urchins dollars cucumbers	C		0.059	C

Table 27. FMP other species bycatch in the GOA rex sole fishery in metric tons for 2017-2020.

Species Common Name	Retained/Discarded	2017	2018	2019	2020
octopus, North Pacific	Discarded		C	C	C
shark, spiny dogfish	Discarded	C	C	C	C
shark, spiny dogfish	Retained			C	
skate, Aleutian	Retained	C			
skate, big	Discarded	C	C	C	
skate, big	Retained	C	3.038		
skate, longnose	Discarded	C	C	C	
skate, longnose	Retained	C	1.995	C	
skate, other	Discarded	C	C	C	C
squid, majestic	Discarded	C	C		
squid, majestic	Retained		C		

Table 28. Prohibited species catch in the GOA rex sole directed fishery as a proportion of all prohibited species catch in the GOA for 2017-2021 in metric tons. PSC estimate reports halibut and herring, counts of fish for crab and salmon. "C" indicates confidential data.

	2020		**2019**		**2018**		**2017**	
Species Group Name	PSCNQ Estimate (*)	Halibut Mortality (mt)	PSCNQ Estimate (*)	Halibut Mortality (mt)	PSCNQ Estimate (*)	Halibut Mortality (mt)	PSCNQ Estimate (*)	Halibut Mortality (mt)
Bairdi Tanner Crab	C		C		252.721		C	
Blue King Crab	C		C		0.000		C	
Chinook Salmon	C		C		6.200		C	
Golden (Brown) King Crab	C		C		0.188		C	
Halibut	C	C	C	C	6.245	5.051	C	C
Herring	C		C		0.016		C	
Non-Chinook Salmon	C		C		5.407		C	
Opilio Tanner (Snow) Crab	C		C		0.000		C	
Red King Crab	C		C		0.000		C	

Figures

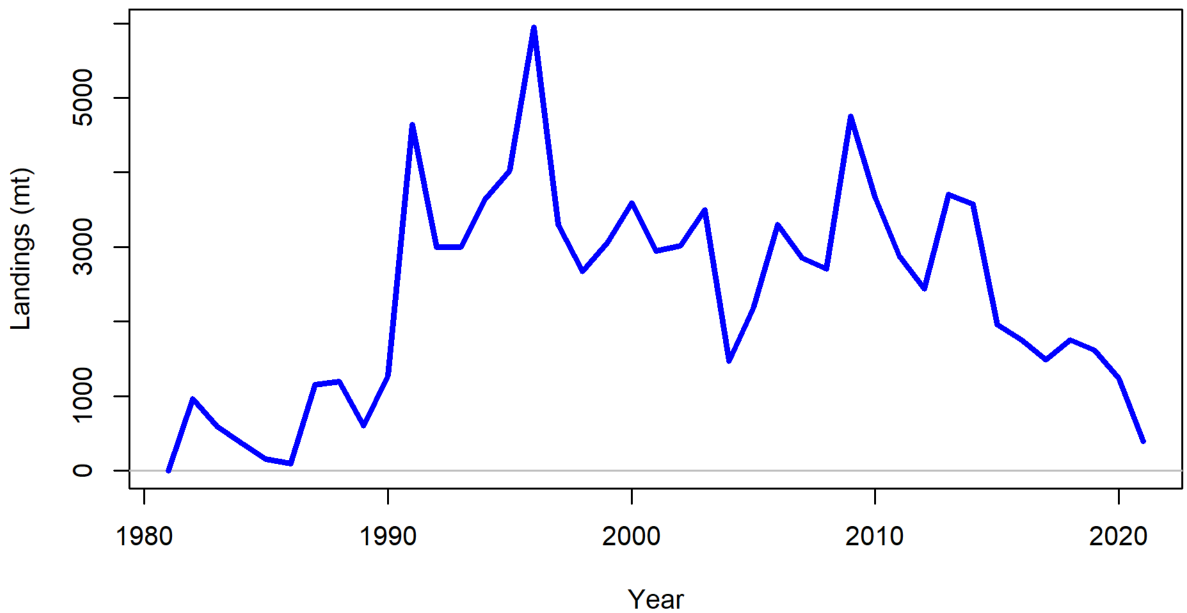

Figure 1. Fishery catches for GOA rex sole, 1982-2017. Catch for 2015 is through Sept 26, 2021.

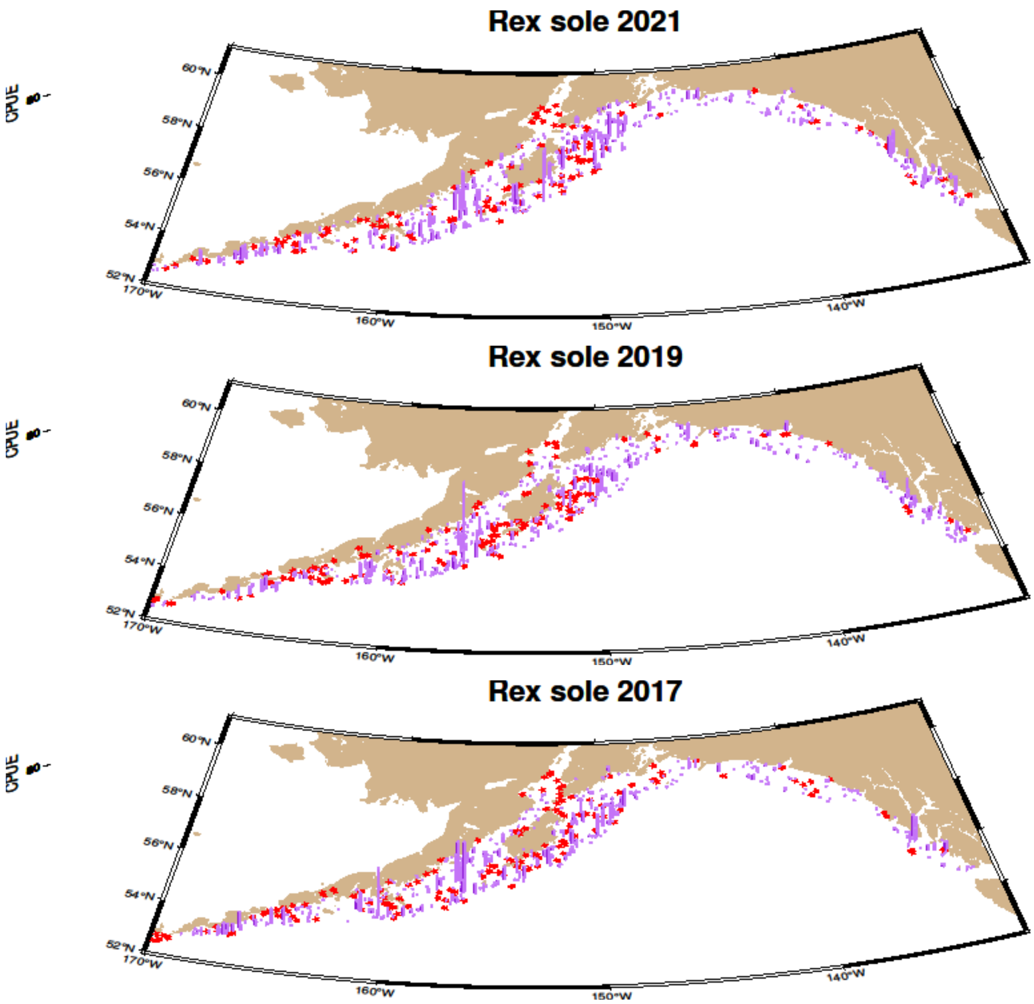

Figure 2. Survey CPUE by area for GOA rex sole in 2017, 2019, and 2021.

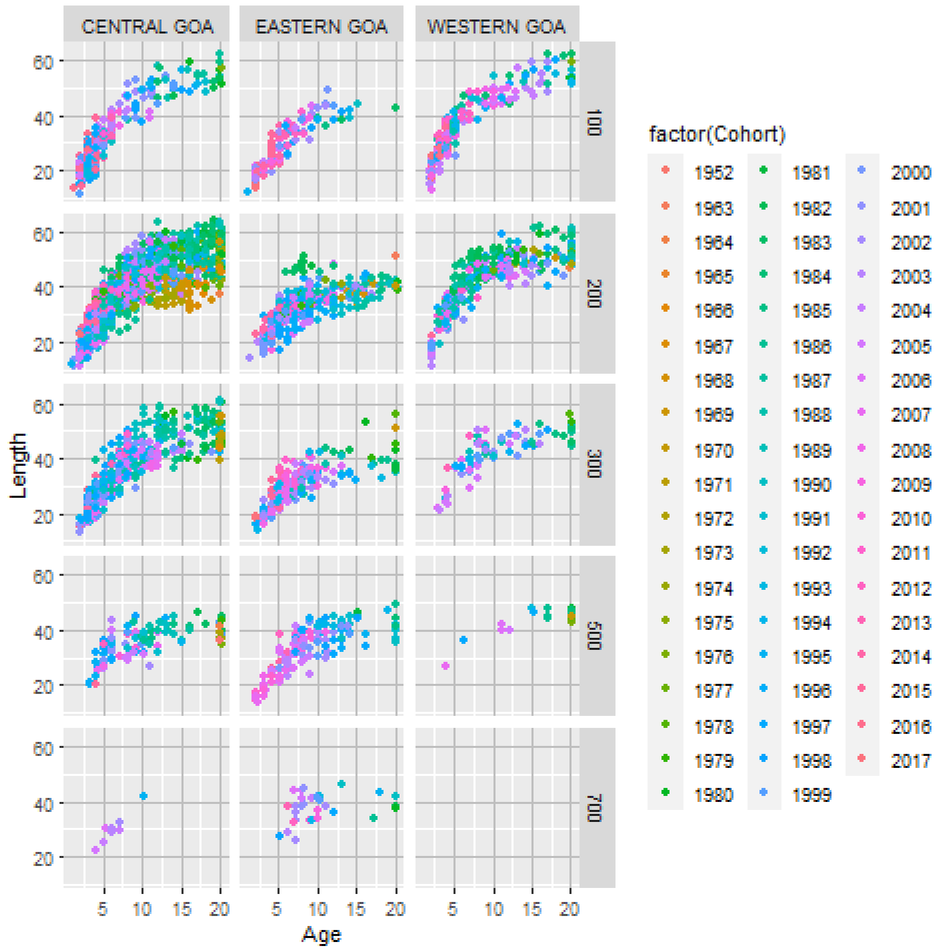

Figure 3. Female age-length data from the GOA trawl survey by cohort, management area (columns), and depth (rows).

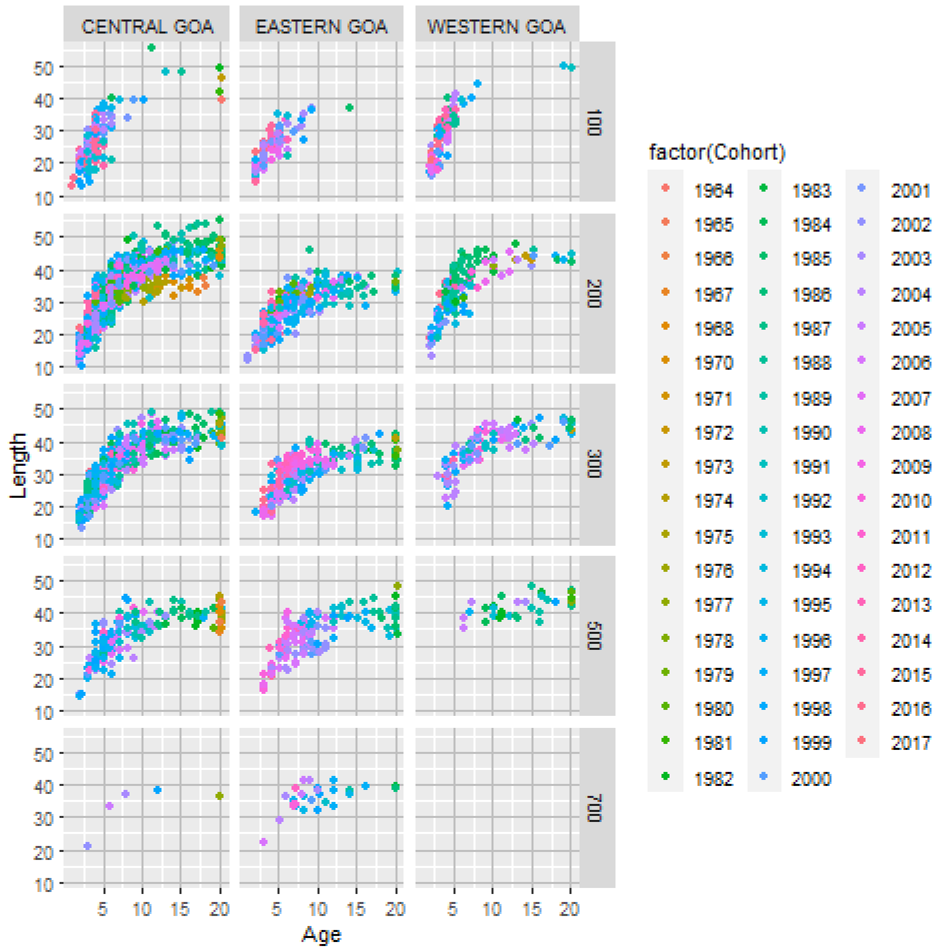

Figure 4. Male age-length data from the GOA trawl survey by cohort, management area (columns), and depth (rows).

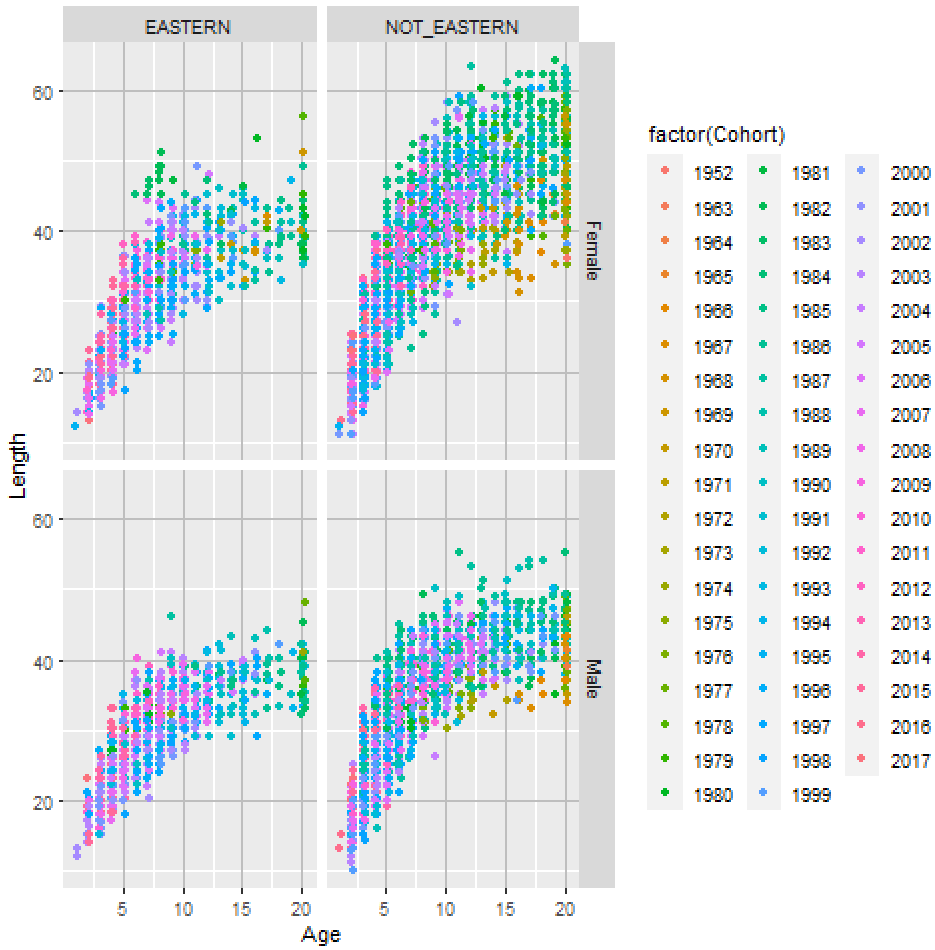

Figure 5. GOA trawl survey age-length data by cohort for the eastern GOA and for the Western-Central GOA (NOT_EASTERN) for females and males.

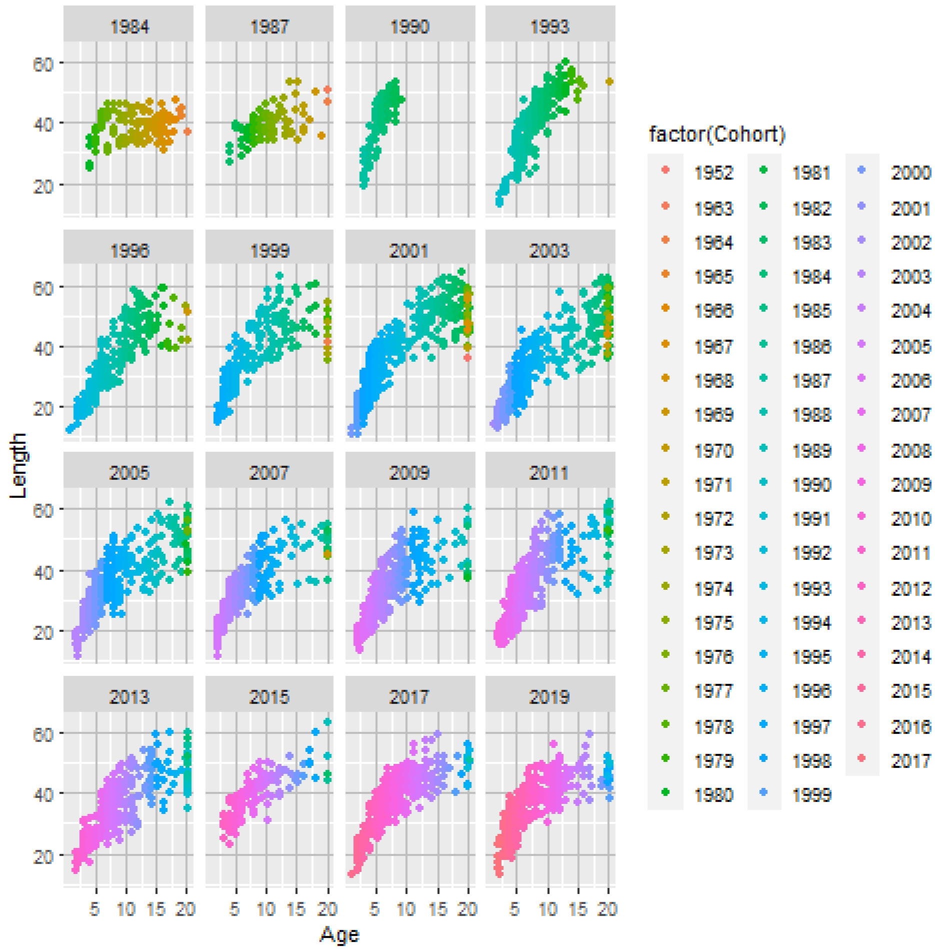

Figure 6. Female age-length data by cohort and year from the GOA trawl survey. A different ageing technique was used in 1990 (surface ageing), resulting in potentially biased results and 1990 age-length data were not used in the model.

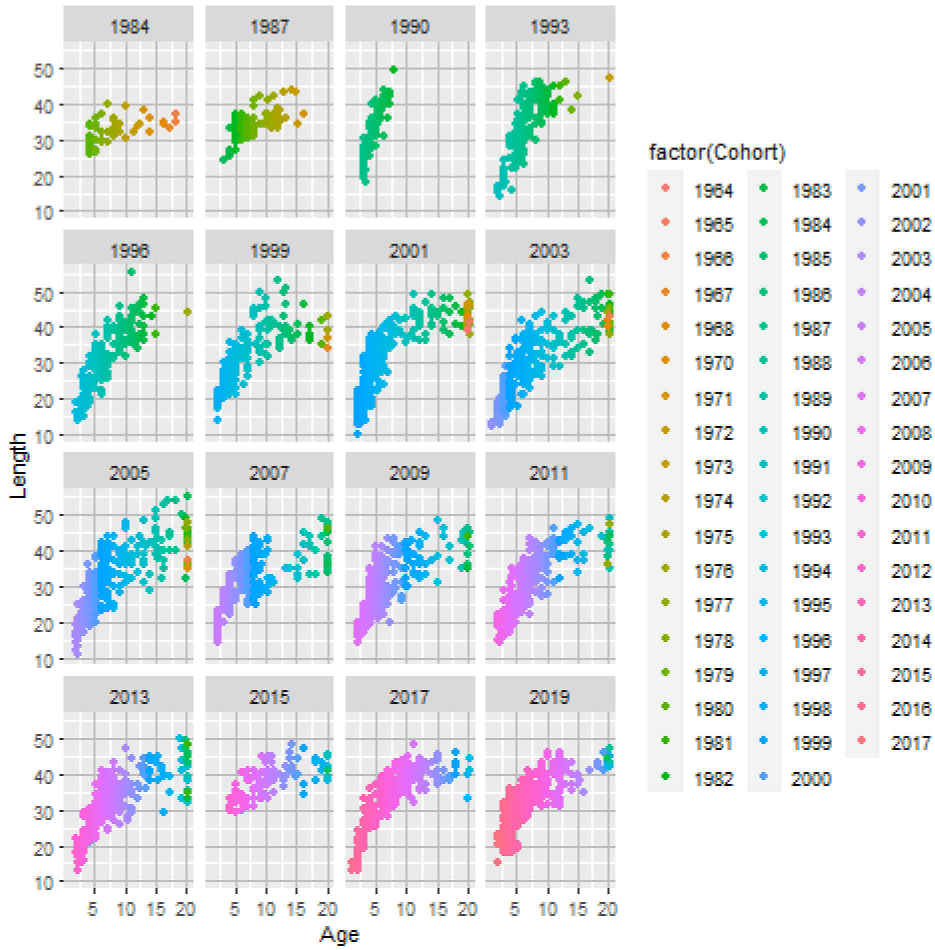

Figure 7. Male age-length data by cohort and year from the GOA trawl survey. A different ageing technique was used in 1990 (surface ageing), resulting in potentially biased results and 1990 age-length data were not used in the model.

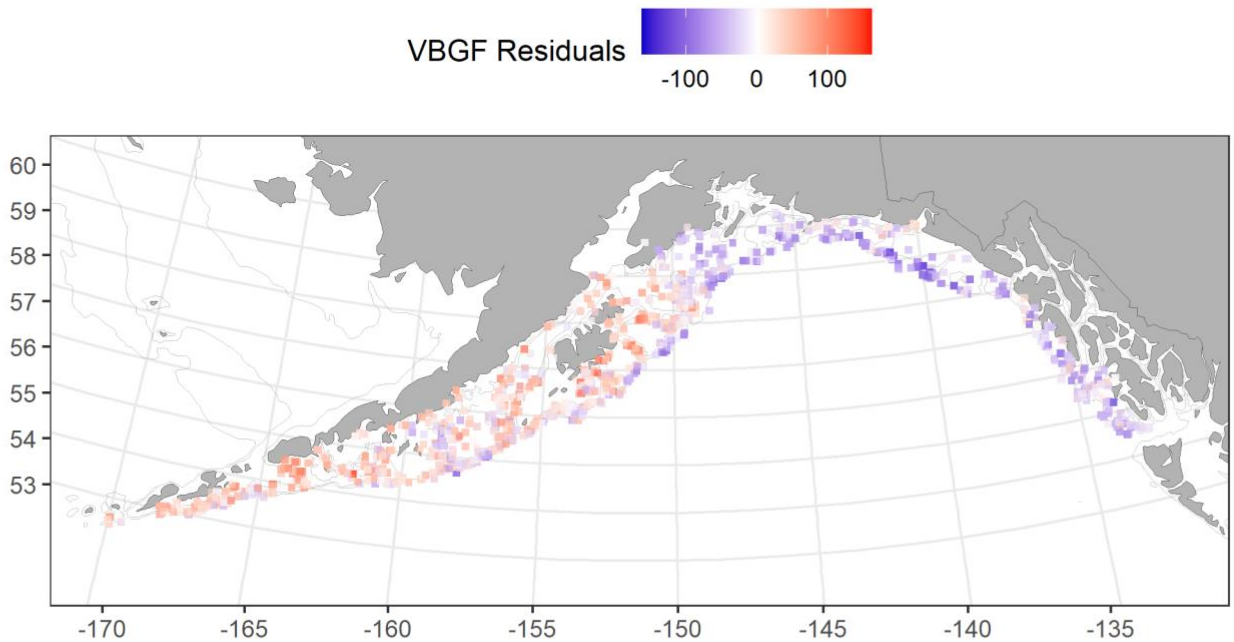

Figure 8. Residuals from single-area von-Bertalanffy growth curves fit to survey age-length data plotted by location for males and females combined. Positive residuals are plotted in red indicating data points where length-at-age was larger than the mean and negative residuals are plotted in blue and indicate data points that are smaller than the mean. The points are shaded to indicate the size of the residuals (residuals are not standardized).

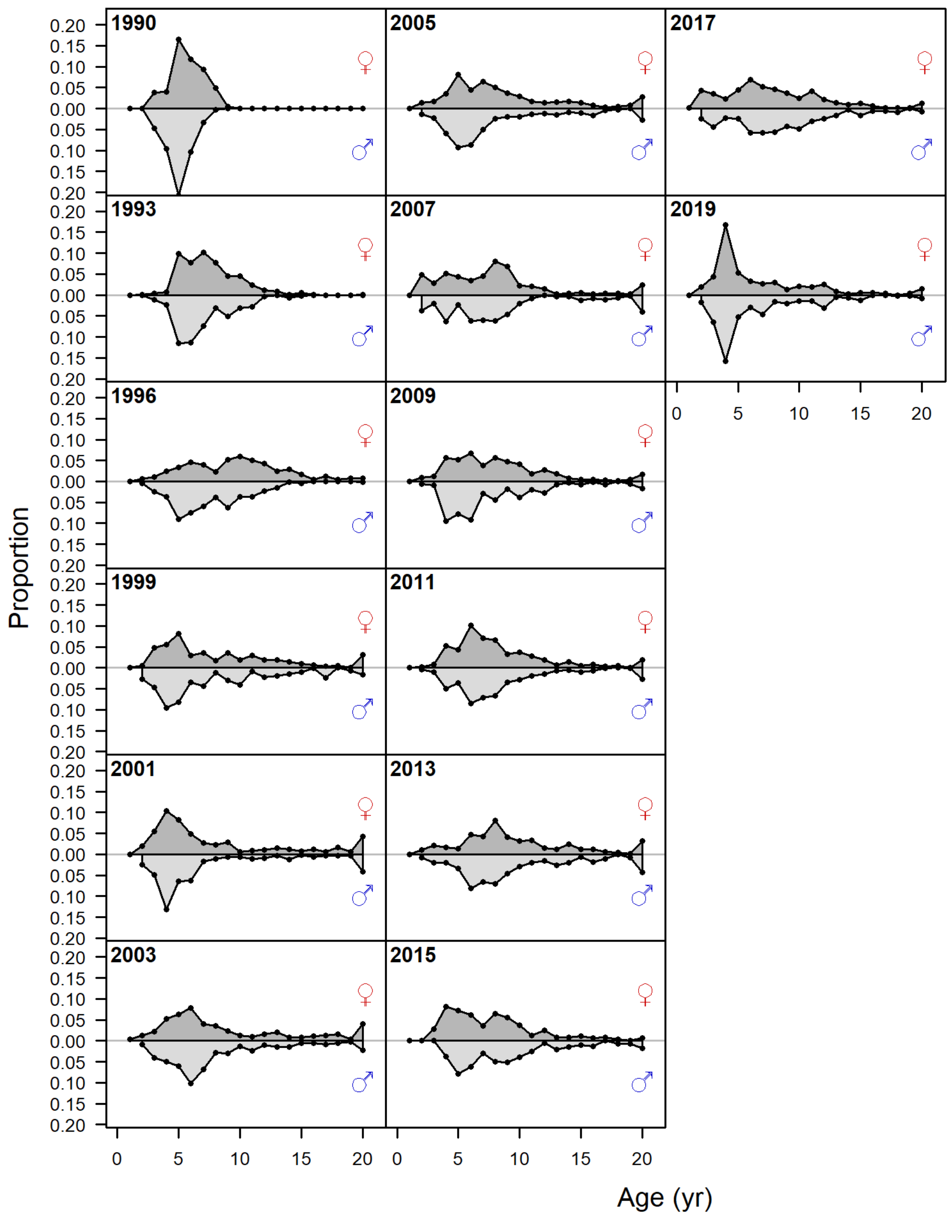

Figure 9. Observed ghosted survey age compositions for the whole GOA for all years of survey data. The term "ghosted" indicates that these data are excluded from the objective function. Males (below the x-axis) and females (above the x-axis).

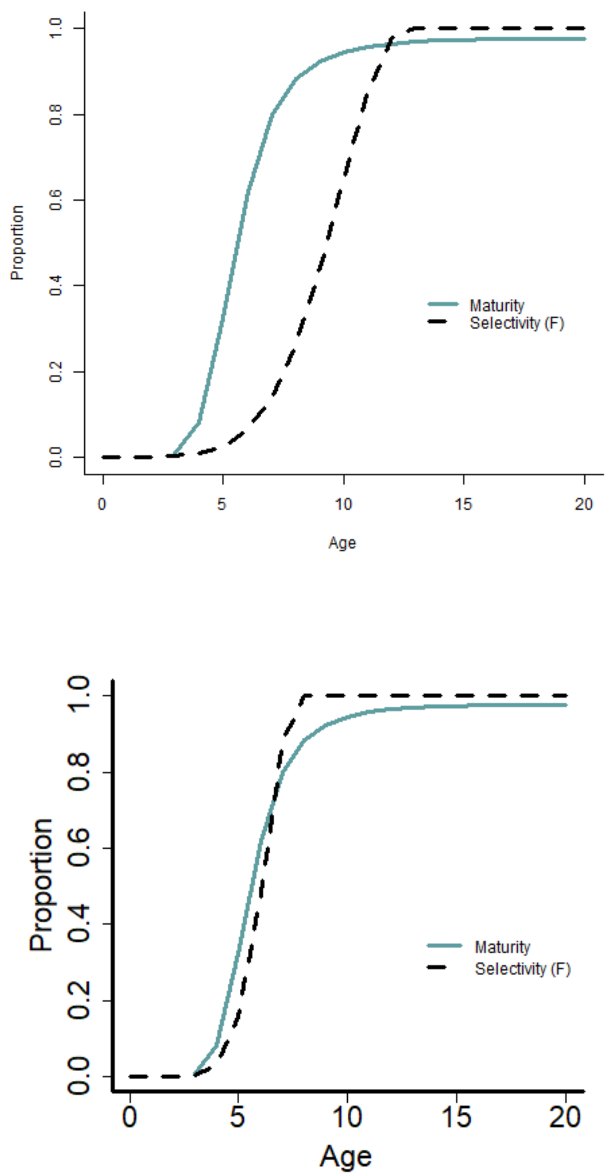

Figure 10. Maturity-at-age and female fishery selectivity-at-age from a one-area model without fishery age data presented in 2017 (top panel; McGilliard and Palsson 2017), and Model 21.0 (bottom panel).

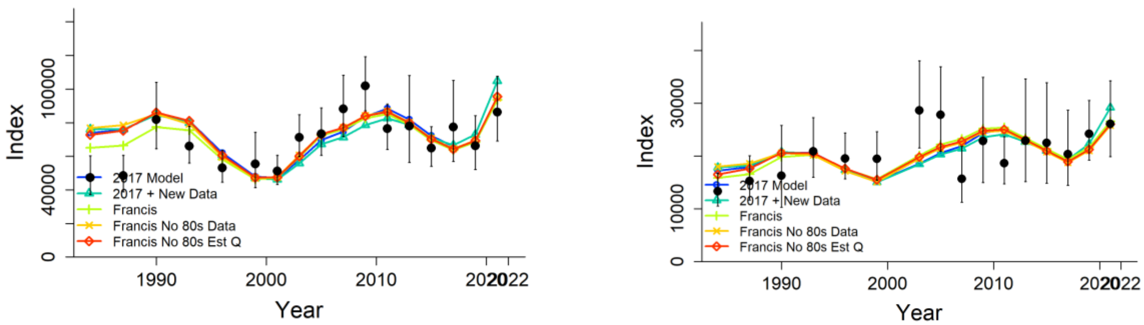

Figure 11. Observed (black dots) and predicted index of survey biomass for the Western-Central GOA index of biomass (left) and for the Eastern GOA index of biomass (right). Vertical black lines show 95% confidence intervals about the observations. All models in the bridging analysis are shown, including the 2017 model with new data (Model 17.2; turquoise) and the 2021 model with Francis data weighting, 1984 and 1987 survey data omitted, and survey catchability estimated (Model 21.0; red).

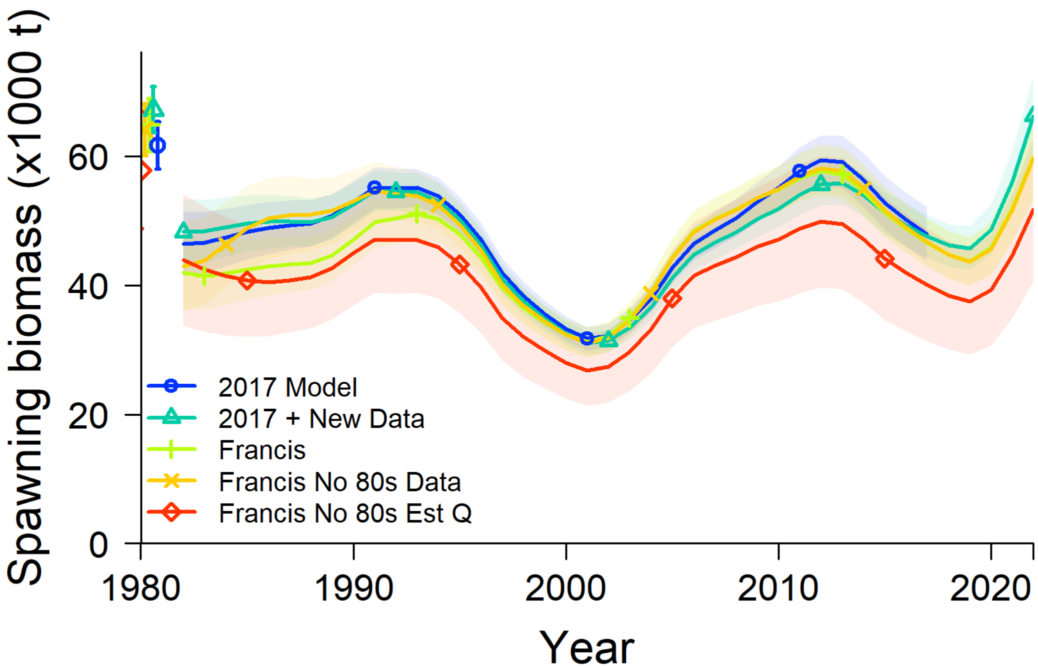

Figure 12. A comparison of spawning biomass across models in the bridging analysis. All models in the bridging analysis are shown, including the 2017 model with new data (Model 17.2; turquoise) and the 2021 model with Francis data weighting, 1984 and 1987 survey data omitted, and survey catchability estimated (Model 21.0; red). Shaded regions indicate 95% asymptotic uncertainty intervals.

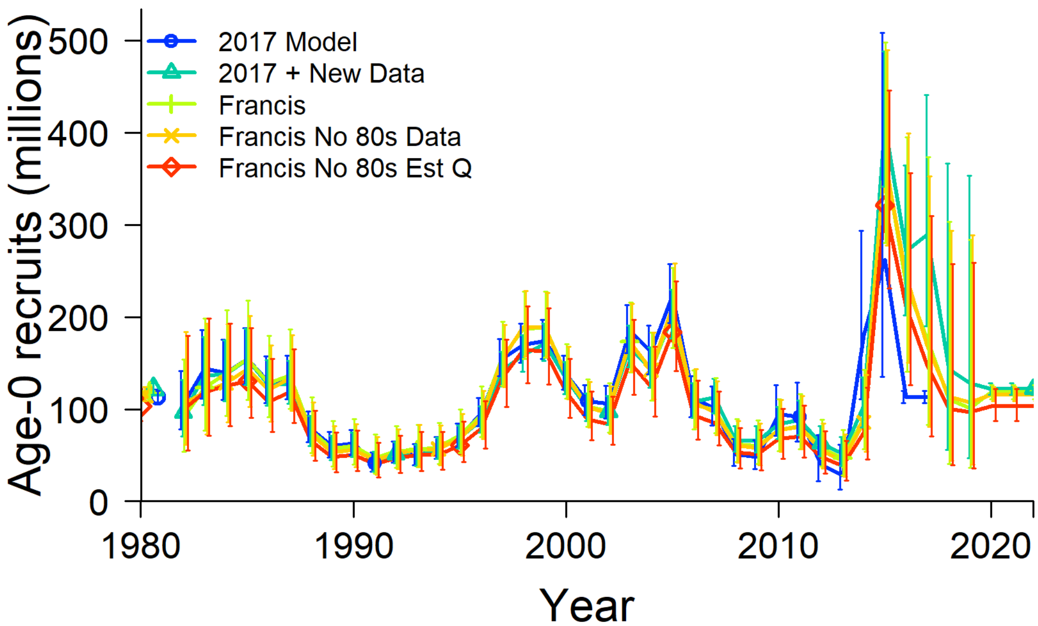

Figure 13. Estimates of age 0 recruitments with associated 95% asymptotic confidence intervals for all models in the bridging analysis, including the 2017 model with new data (Model 17.2; turquoise) and the 2021 model with Francis data weighting, 1984 and 1987 survey data omitted, and survey catchability estimated (Model 21.0; red).

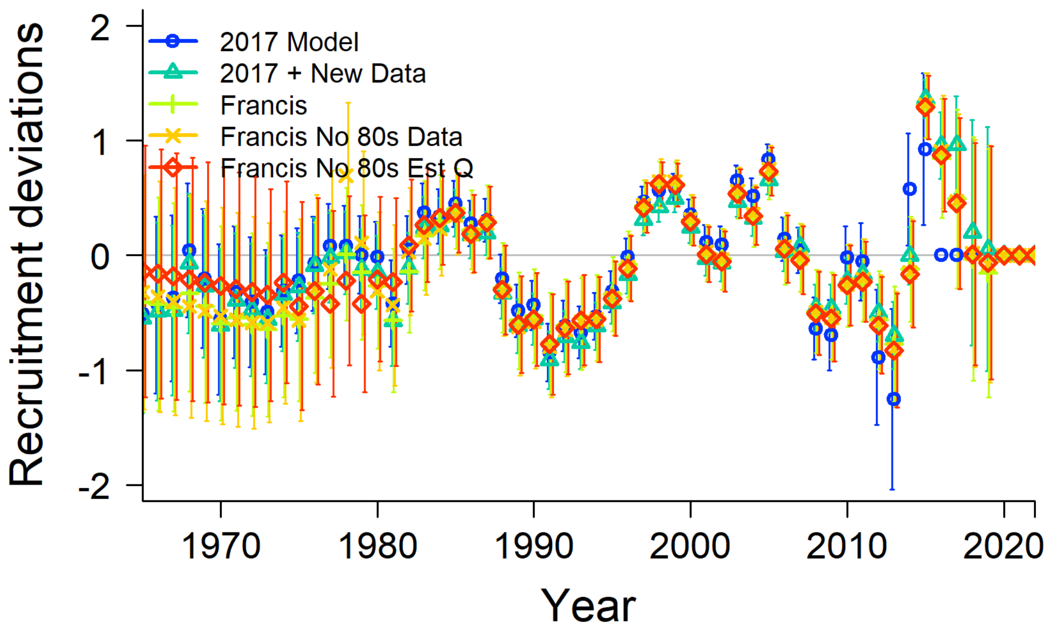

Figure 14. Estimates of recruitment deviations and corresponding 95% asymptotic confidence intervals for all models in the bridging analysis, including the 2017 model with new data (Model 17.2; turquoise) and the 2021 model with Francis data weighting, 1984 and 1987 survey data omitted, and survey catchability estimated (Model 21.0; red).

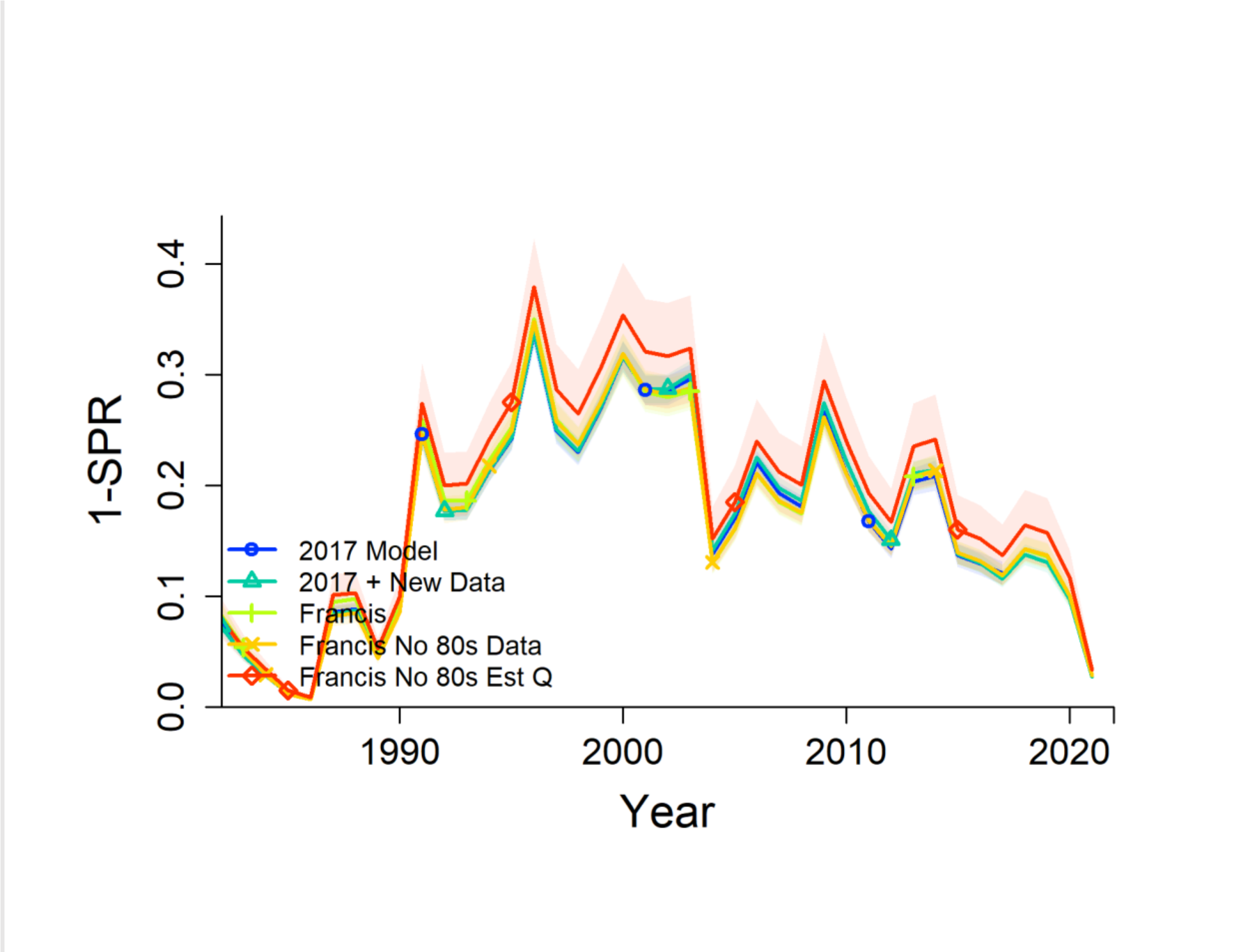

Figure 15. Estimates of a measure of fishing intensity (1-spawning potential ratio) and corresponding 95% asymptotic confidence intervals for all models in the bridging analysis, including the 2017 model with new data (Model 17.2; turquoise) and the 2021 model with Francis data weighting, 1984 and 1987 survey data omitted, and survey catchability estimated (Model 21.0; red).

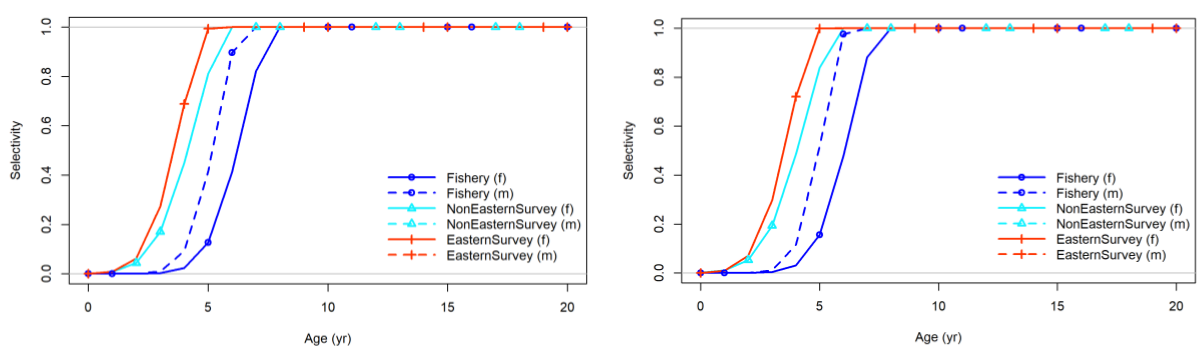

Figure 16. Fishery and survey selectivity at age for the 2017 model with new data (Model 17.2; left panel) and the 2021 model with Francis data weighting, no 1984 and 1987 survey data, and estimated survey catchability (Model 21.0; right panel). Survey selectivity all models presented was not sex-specific after preliminary model runs confirmed that male and female survey selectivity were nearly identical.

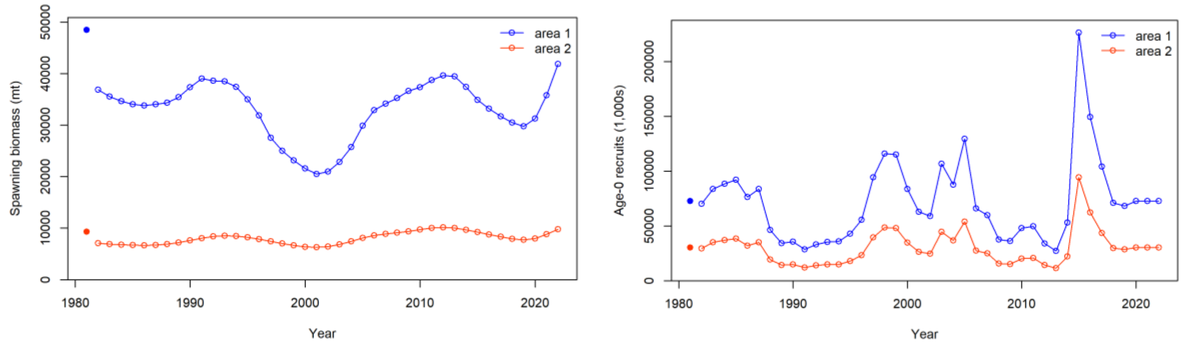

Figure 17. Spawning biomass (left panel) and age-0 recruits (right panel) by area for the base case model (Model 21.0). Blue lines indicate the Western-Central GOA and red lines indicate the Eastern GOA.

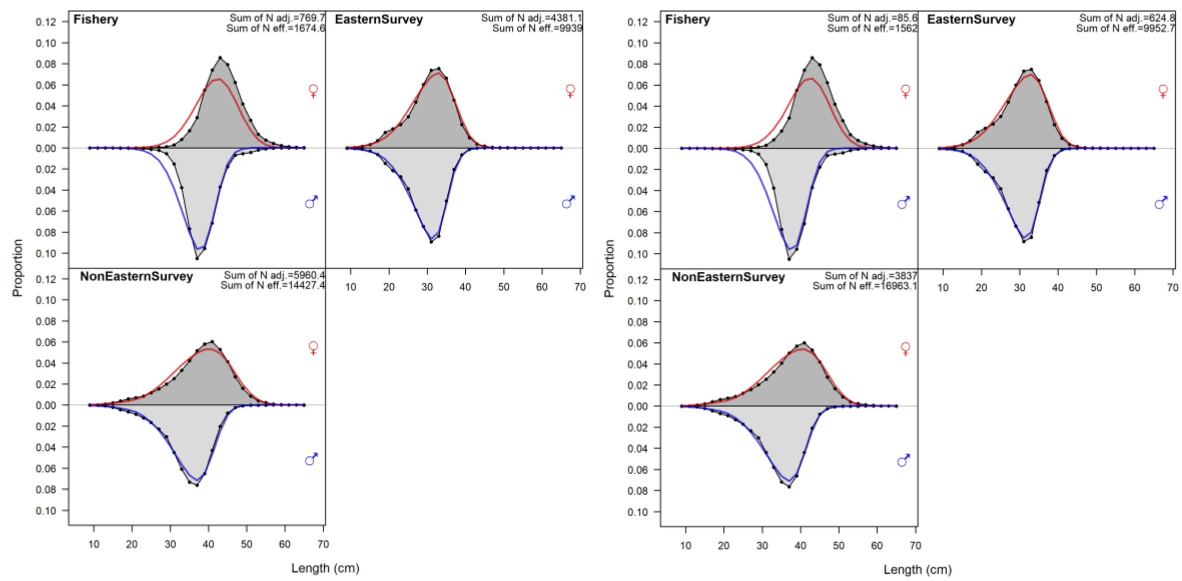

Figure 18. Predicted (red and blue lines) and observed length compositions (grey filled areas), aggregated over time for the 2017 model with new data (Model 17.2; left) and the 2021 model with Francis data weighing, 1984 and 1987 data omitted and survey catchability estimated within the model (21.0). The labels in the upper right corner of each plot indicate the input sample size after data-weighting occurs (N adj). N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

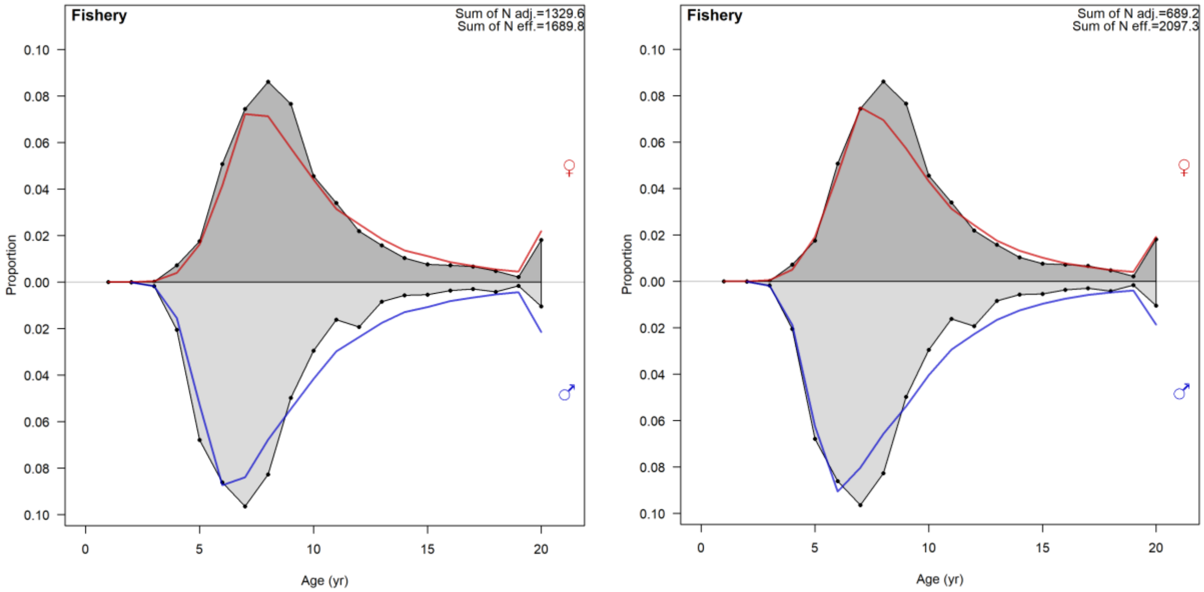

Figure 19. Predicted (red and blue lines) and observed fishery age compositions (grey filled areas), aggregated over time for the 2017 model with new data (Model 17.2; left) and the 2021 model (Model 17.2; right). The labels in the upper right corner of each plot indicate the input sample size after data-weighting occurs (N adj). N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

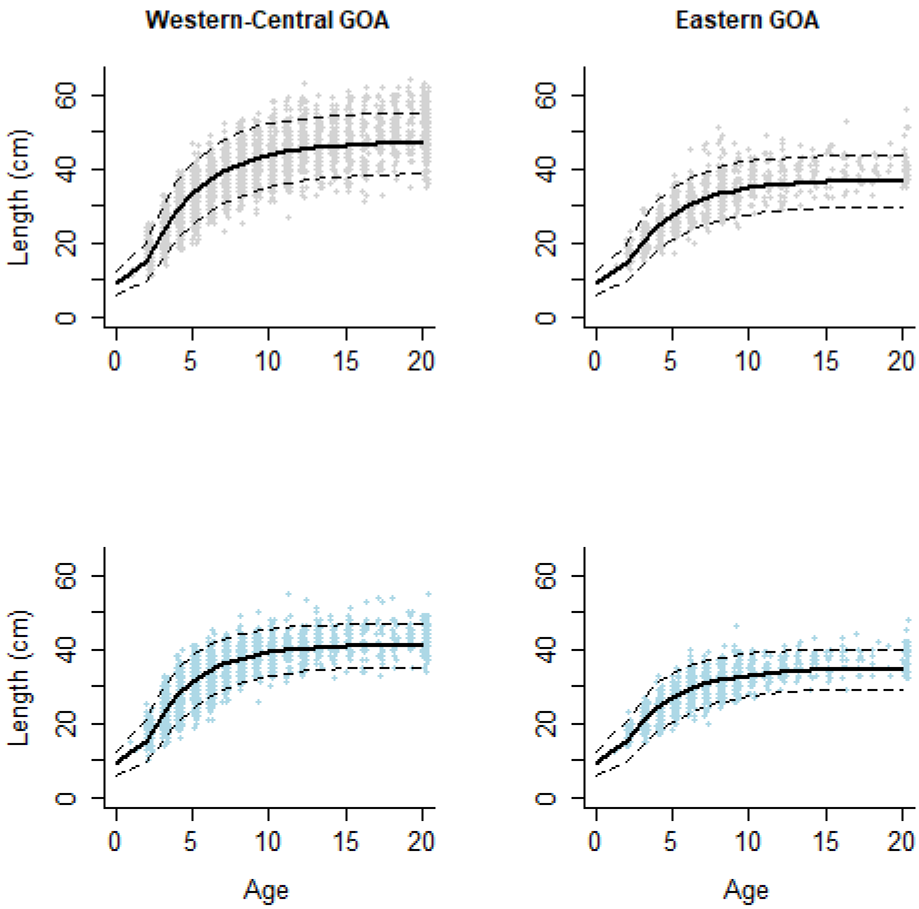

Figure 20. Observed (dots) and predicted (black lines) length-at-age for Model 21.0. Separate growth curves were estimated within the assessment model by sex and by area for the Western-Central GOA and for the Eastern GOA. Females are shown on the upper panels (grey dots), and males are shown on the lower panels (blue dots). Dotted lines show 95% confidence intervals based on CVs of 2 year old and 20 year old fish.

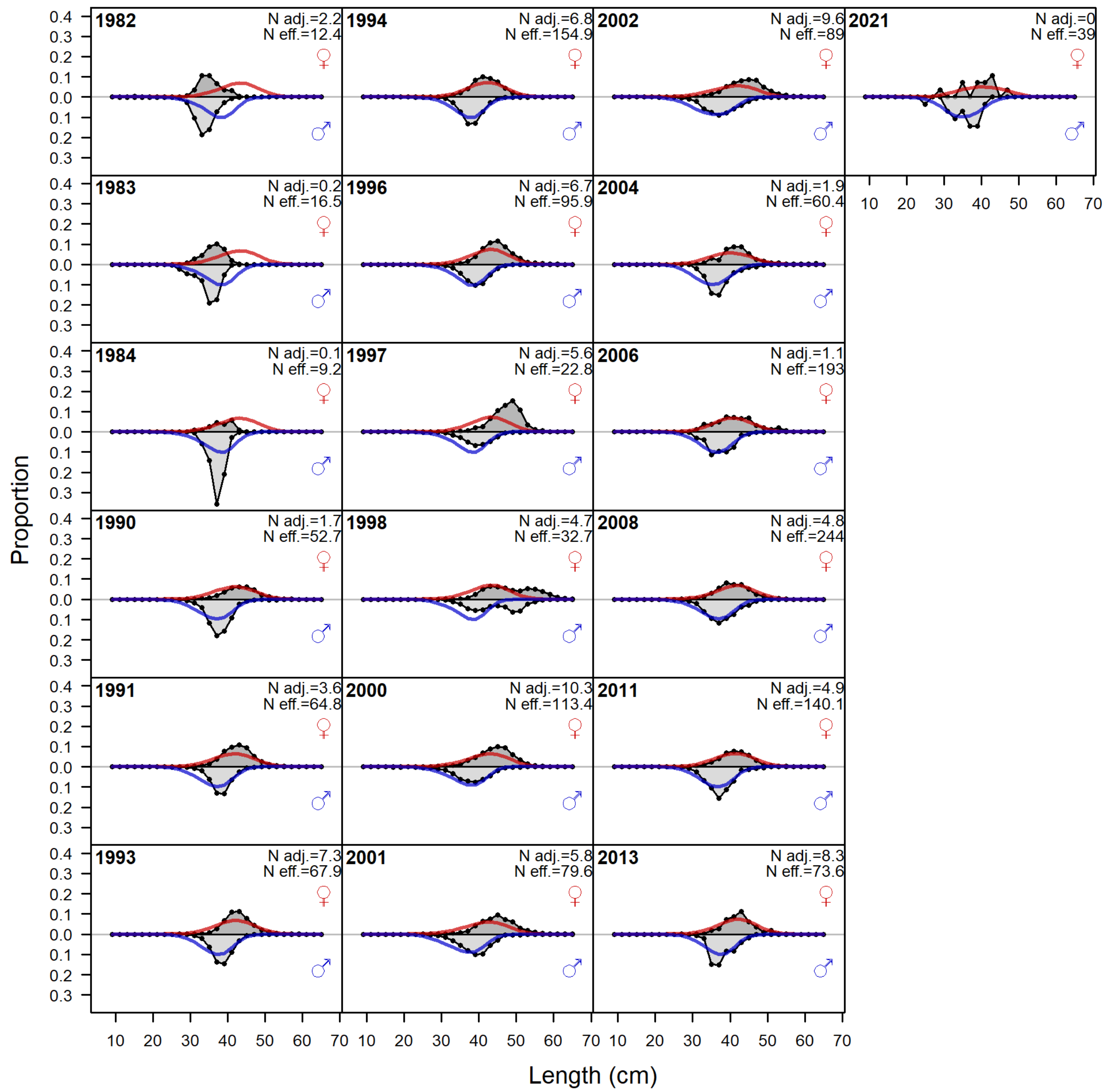

Figure 21. Observed (grey filled area and black line) and expected (red and blue lines) fishery length compositions for years 1982-2021 for males (blue lines) and females (red lines) for the 2021 model (Model 21.0). The labels in the upper right corner of each plot indicate the input sample size after data-weighting occurs (N adj). N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

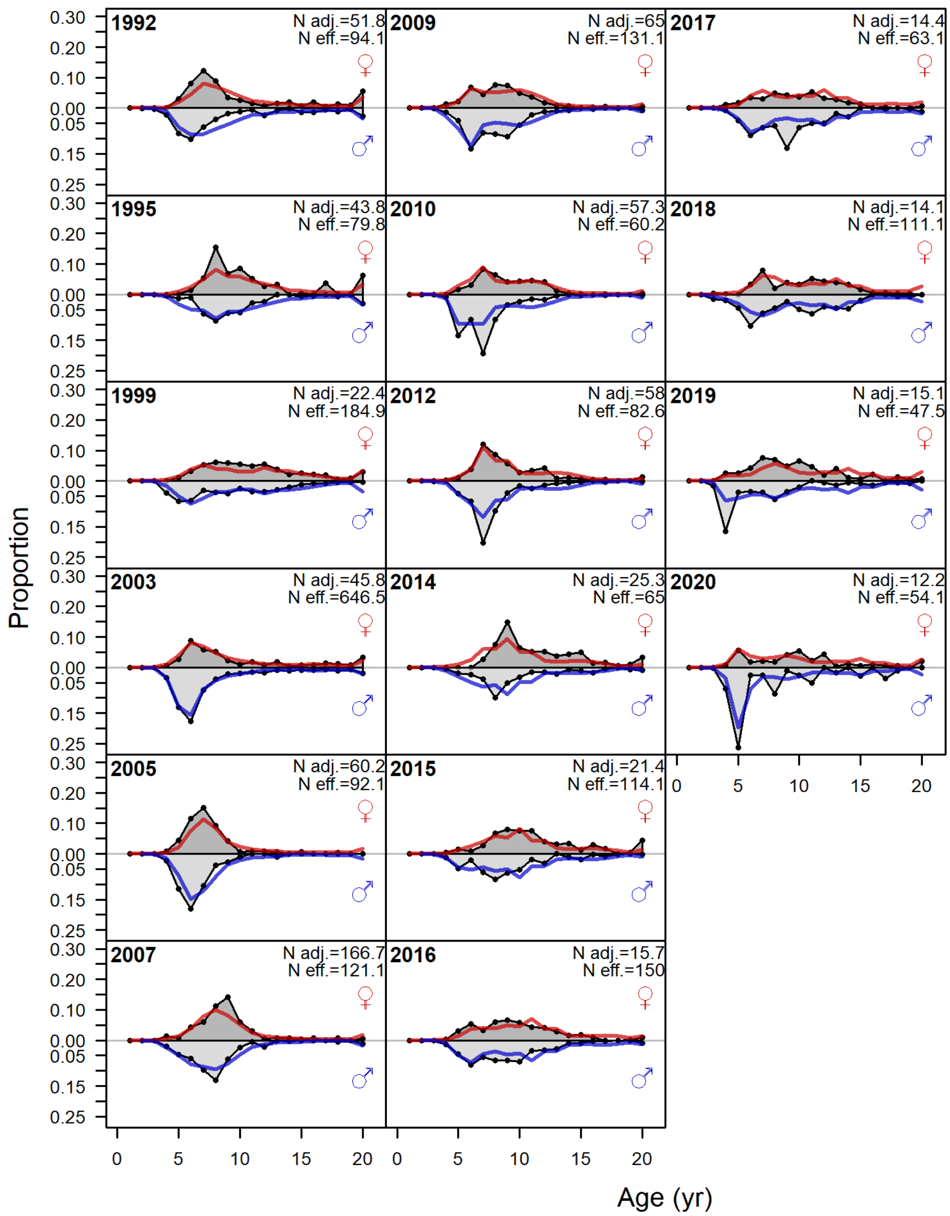

Figure 22. Observed (grey filled area and black line) and expected (red and blue lines) fishery age compositions for all available years of data for males (blue lines) and females (red lines) for Model 21.0. The labels in the upper right corner of each plot indicate the input sample size after data-weighting occurs (N adj). N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

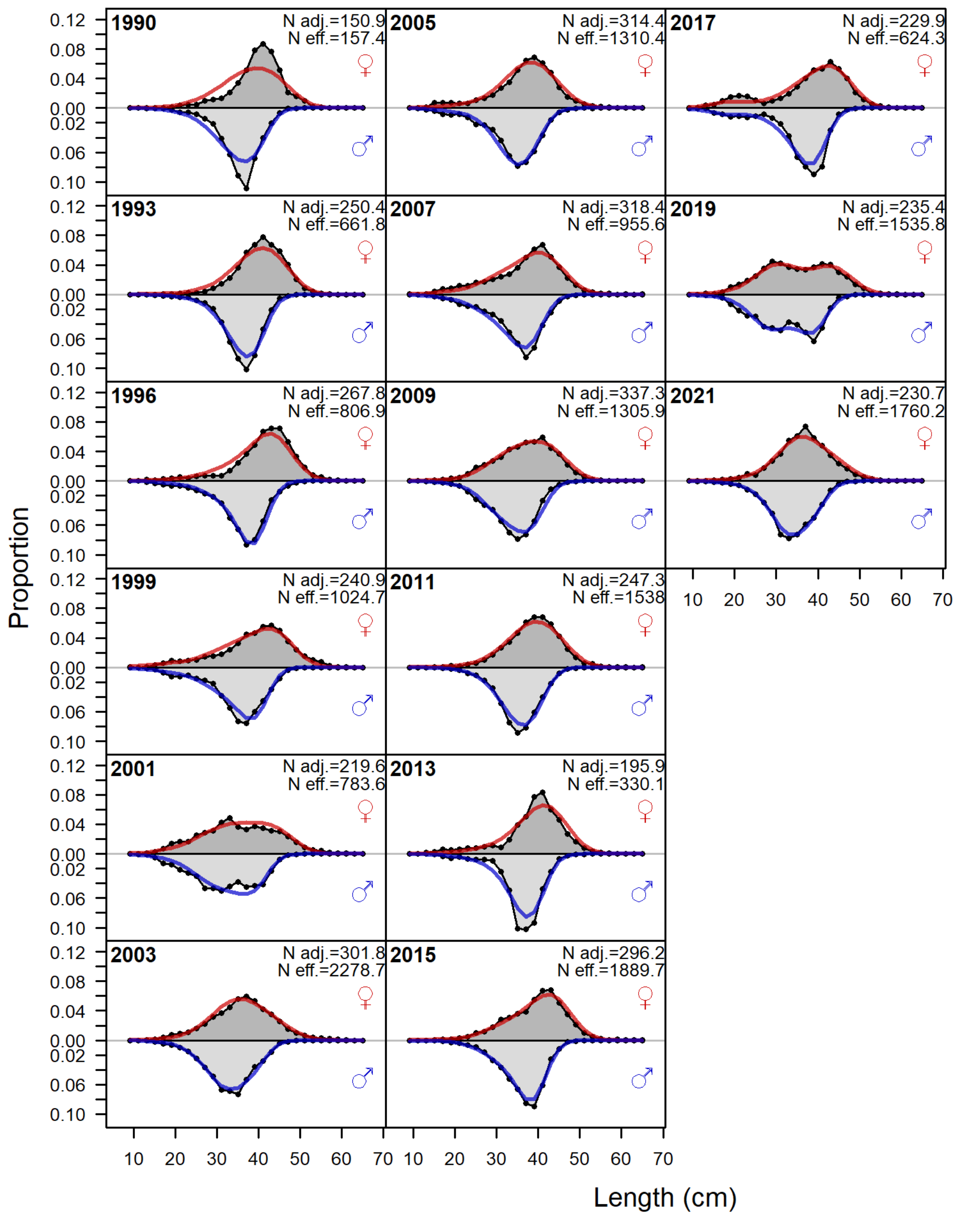

Figure 23. Observed (grey filled area and black line) and expected (red and blue lines) survey length compositions for the Western-Central (non-Eastern) GOA for all years of survey data for males (blue lines) and females (red lines) for the 2021 model (Model 21.0). The labels in the upper right corner of each plot indicate the input sample size after data-weighting occurs (N adj). N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

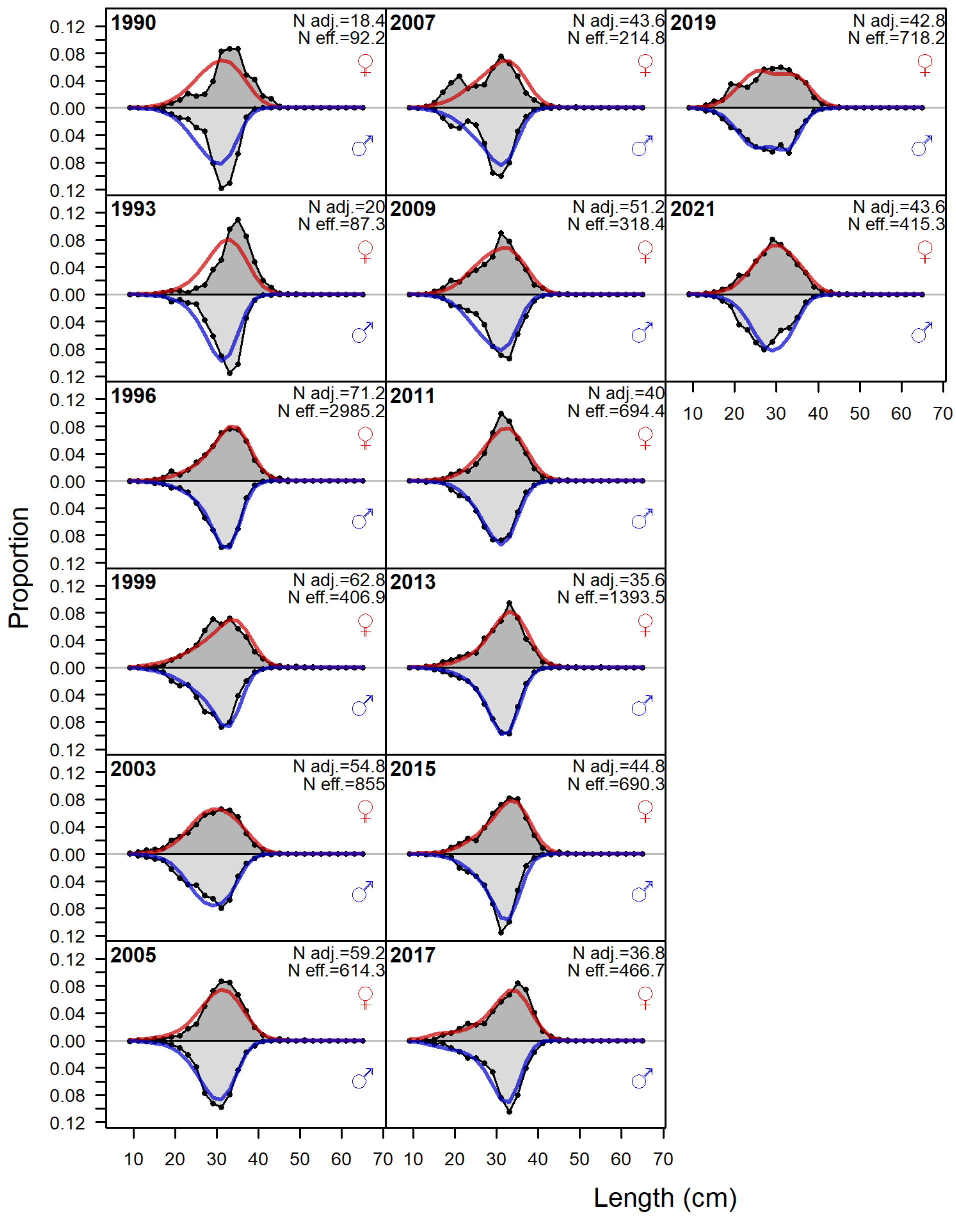

Figure 24. Observed (grey filled area and black line) and expected (red and blue lines) survey length compositions for the Eastern GOA for all years of survey data for males (blue lines) and females (red lines) for the 2021 model (Model 21.0). The labels in the upper right corner of each plot indicate the input sample size after data-weighting occurs (N adj). N eff. is the calculated effective sample size used in the McAllister-Ianelli tuning method.

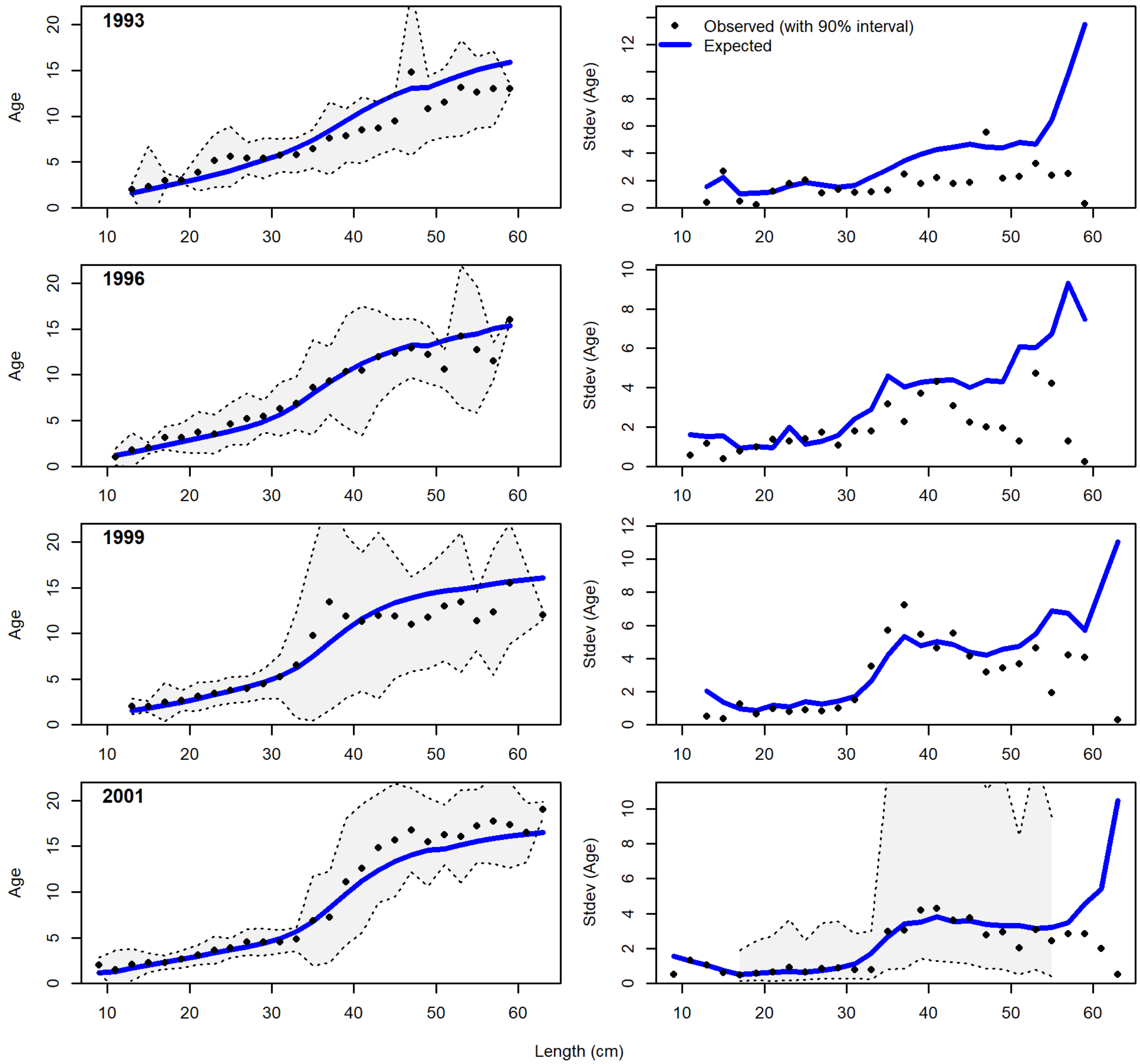

Figure 25. Observed and expected mean age-at-length for both females and males in the Western-Central (Non-Eastern) GOA with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the base case model (Model 21.0) for years 1993-2001.

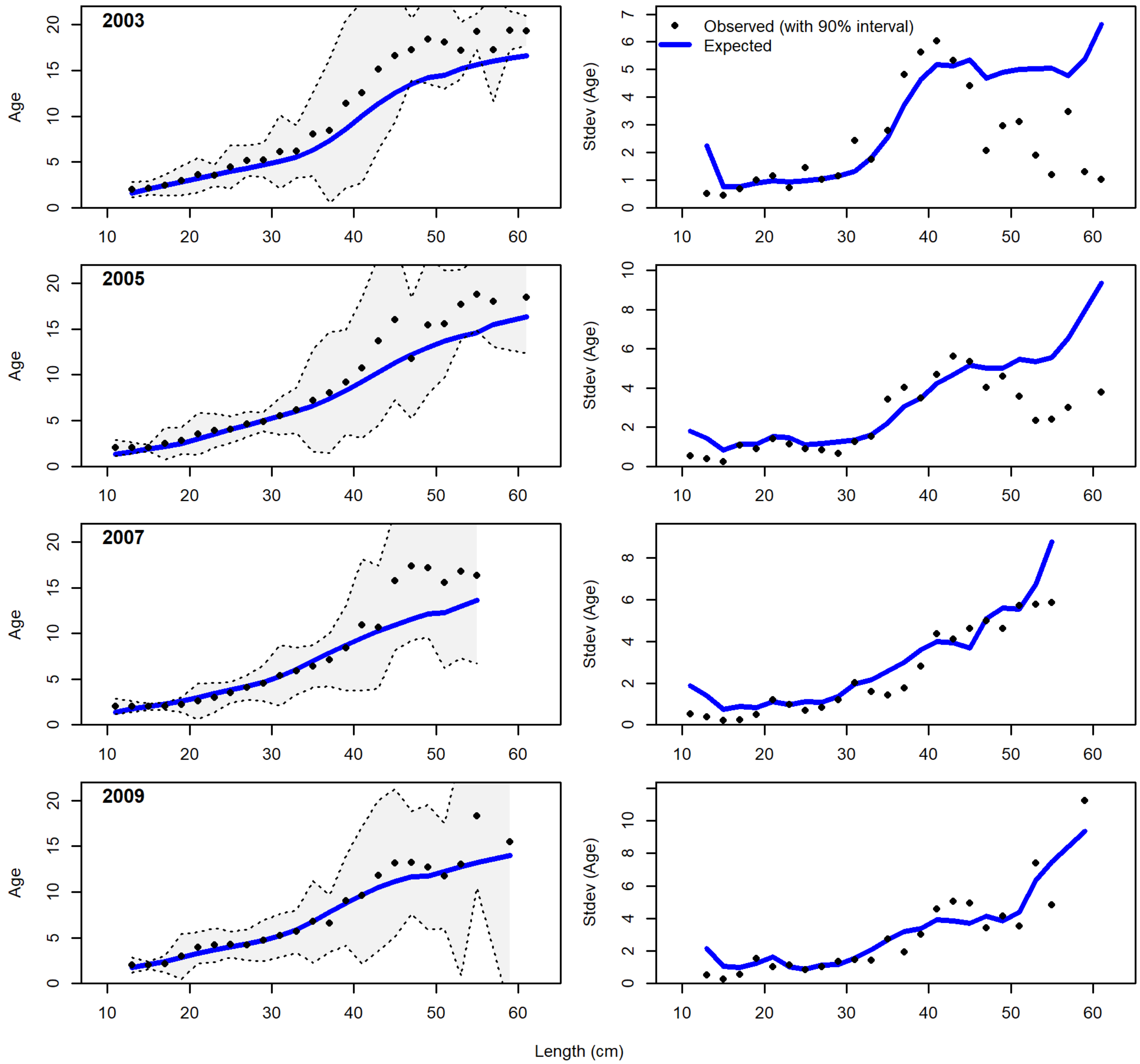

Figure 26. As for Figure 25 (Western-Central conditional age-at-length observations and fits for Model 21.0), but for years 2003-2009.

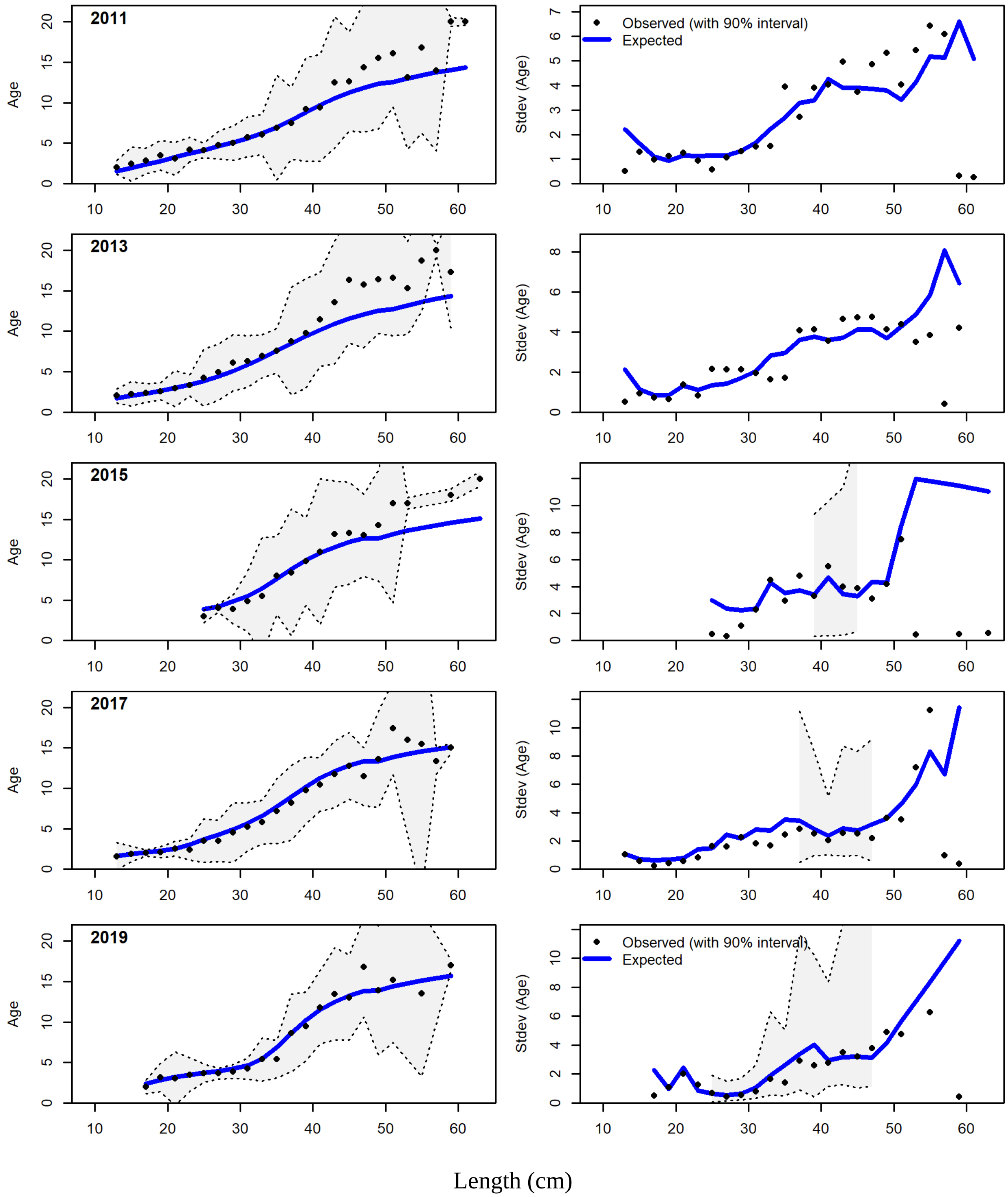

Figure 27. As for Figure 25 (Western-Central conditional age-at-length observations and fits for Model 21.0), but for years 2011-2019.

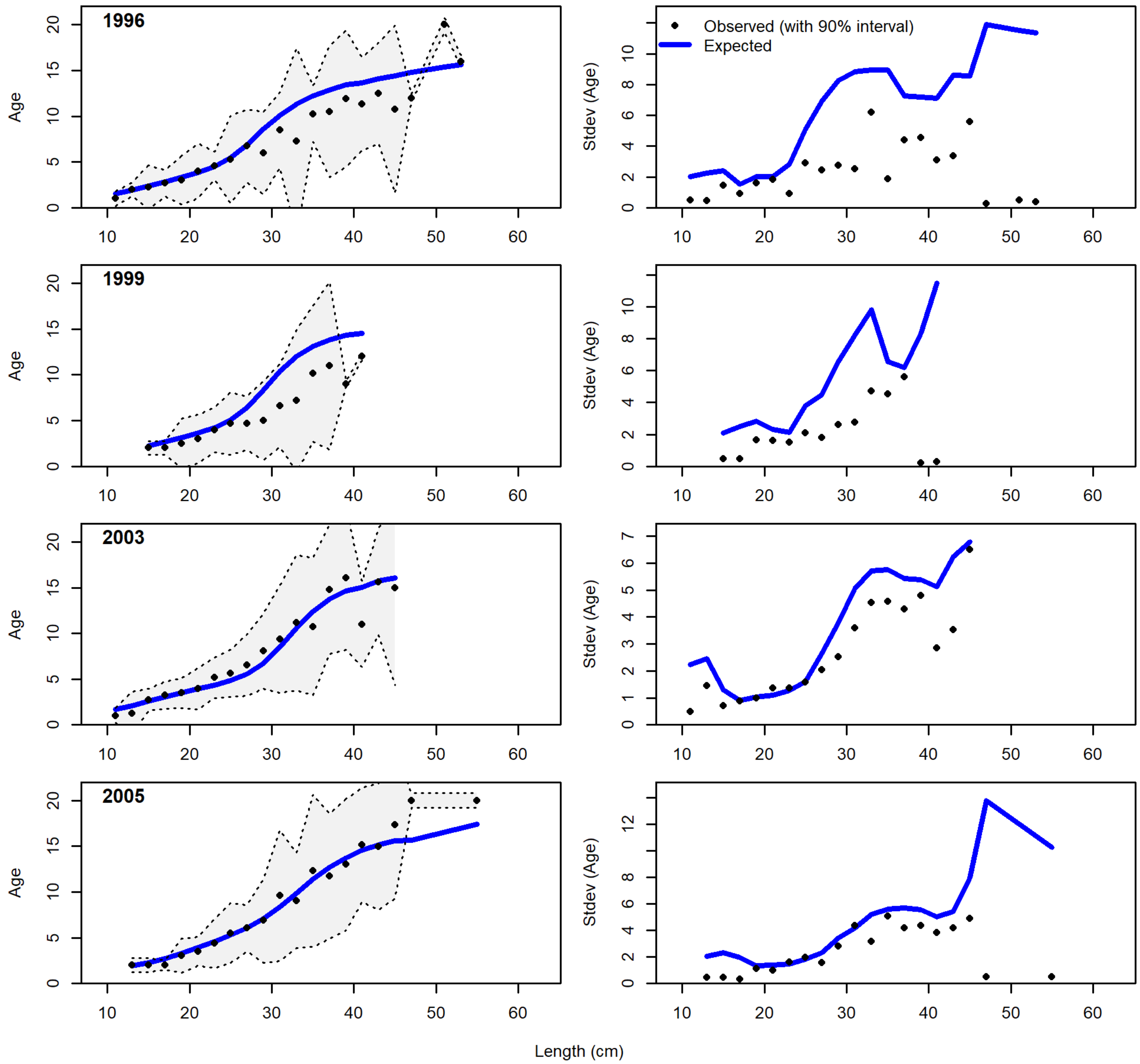

Figure 28. Observed and expected mean age-at-length for both females and males in the Eastern (Non-Eastern) GOA with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the base case model (Model 21.0) for years 1996-2005.

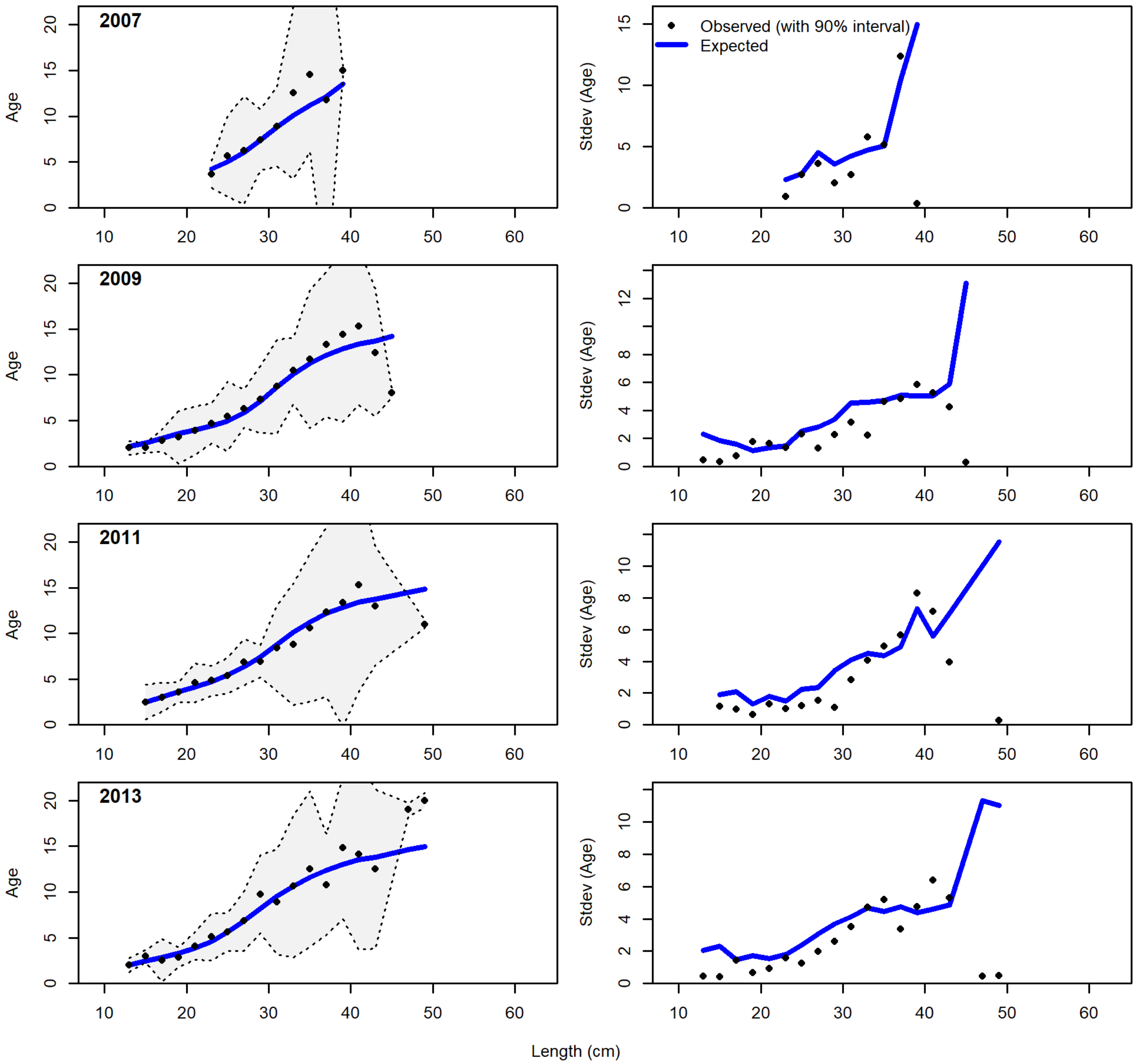

Figure 29. As for Figure 28 (Eastern GOA conditional age-at-length observations and fits for Model 21.0), but for years 2007-2013.

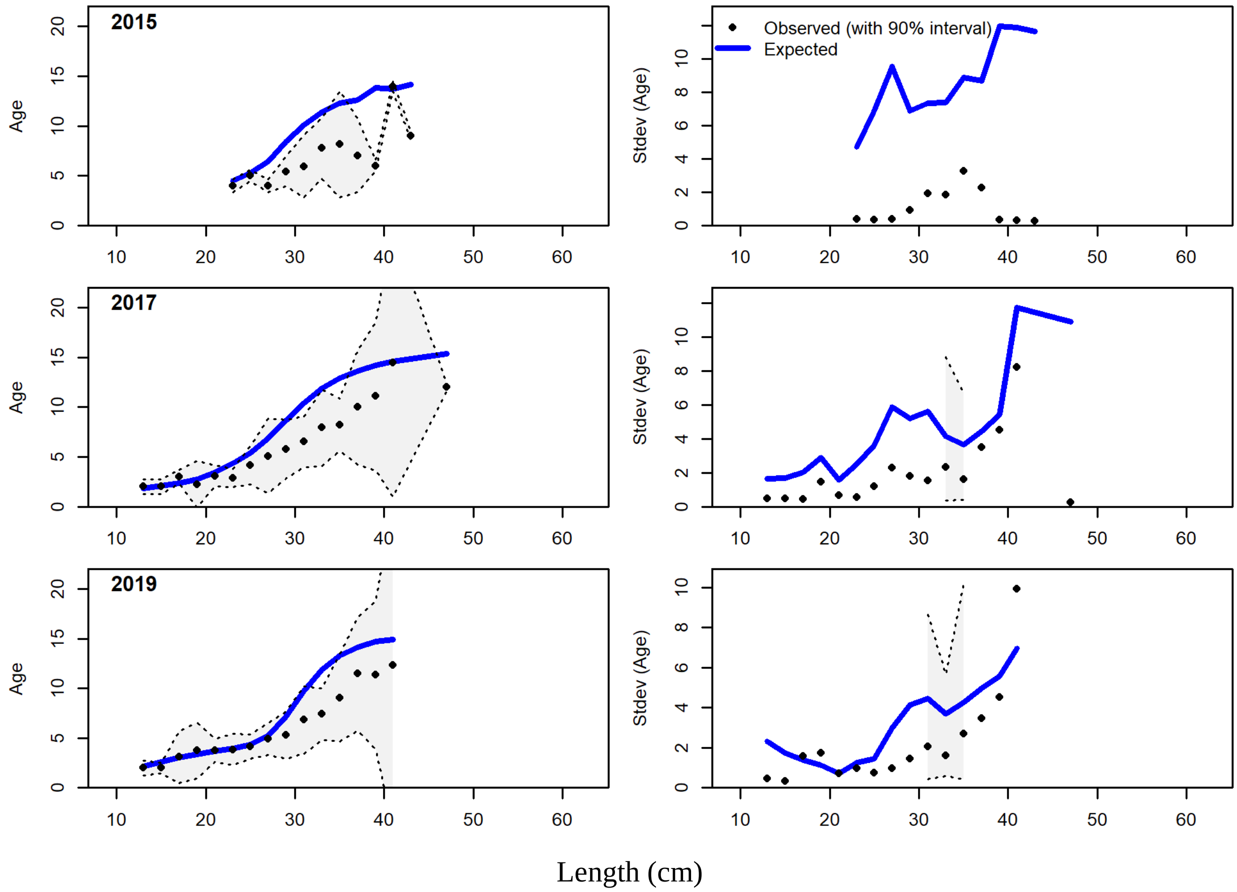

Figure 30. As for Figure 28 (Eastern GOA conditional age-at-length observations and fits for Model 21.0), but for years 2015-2019.

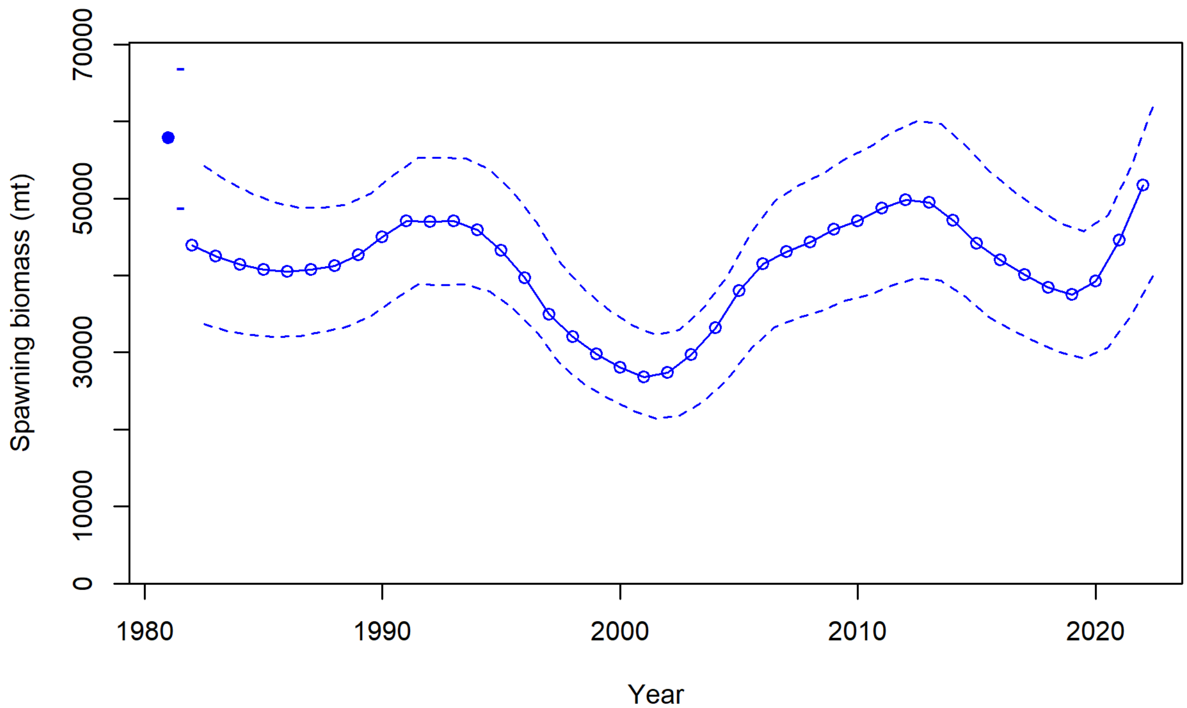

Figure 31. Spawning stock biomass (solid blue line with dots) and 95% asymptotic confidence intervals (dotted blue lines) for the base case assessment model (Model 21.0).

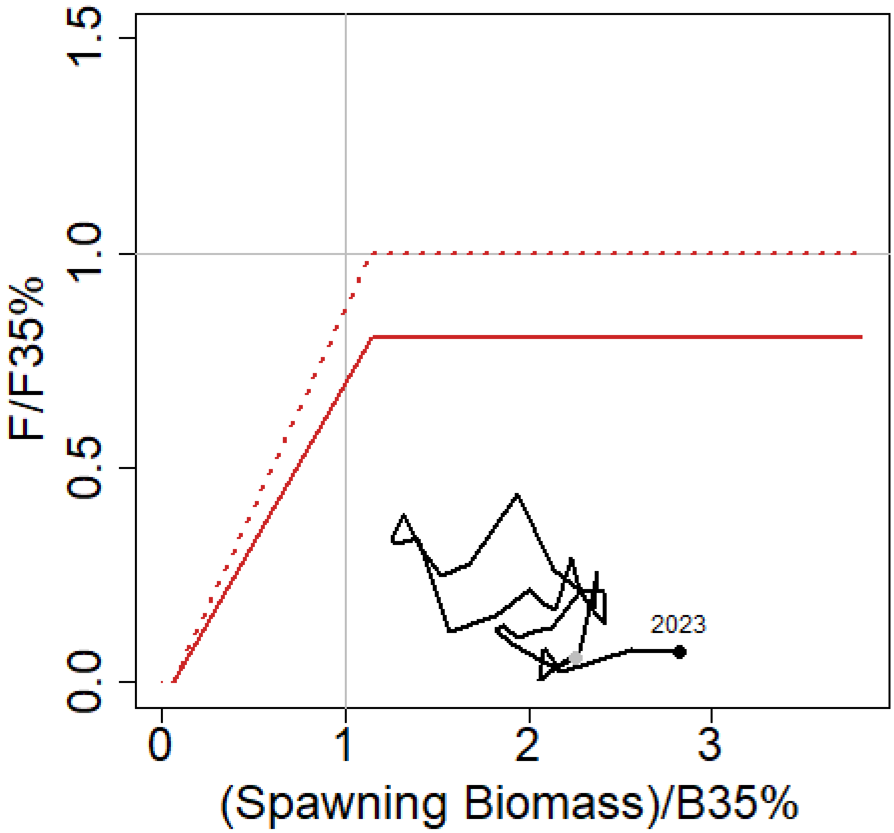

Figure 32. Spawning stock biomass relative to B35% and fishing mortality (F) relative to F35% from 1982-2023 (solid black line), the OFL control rule (dotted red line), the maxABC control rule (solid red line), B35% (vertical grey line), and F35% (horizontal grey line). The grey dot represents values for 1982, the beginning of the time series. The 2033 and 2023 spawning biomass and fishing mortality rates are as predicted by Alternative 1 in the harvest projections. The plot shows the Western-Central GOA, where fishing occurs.

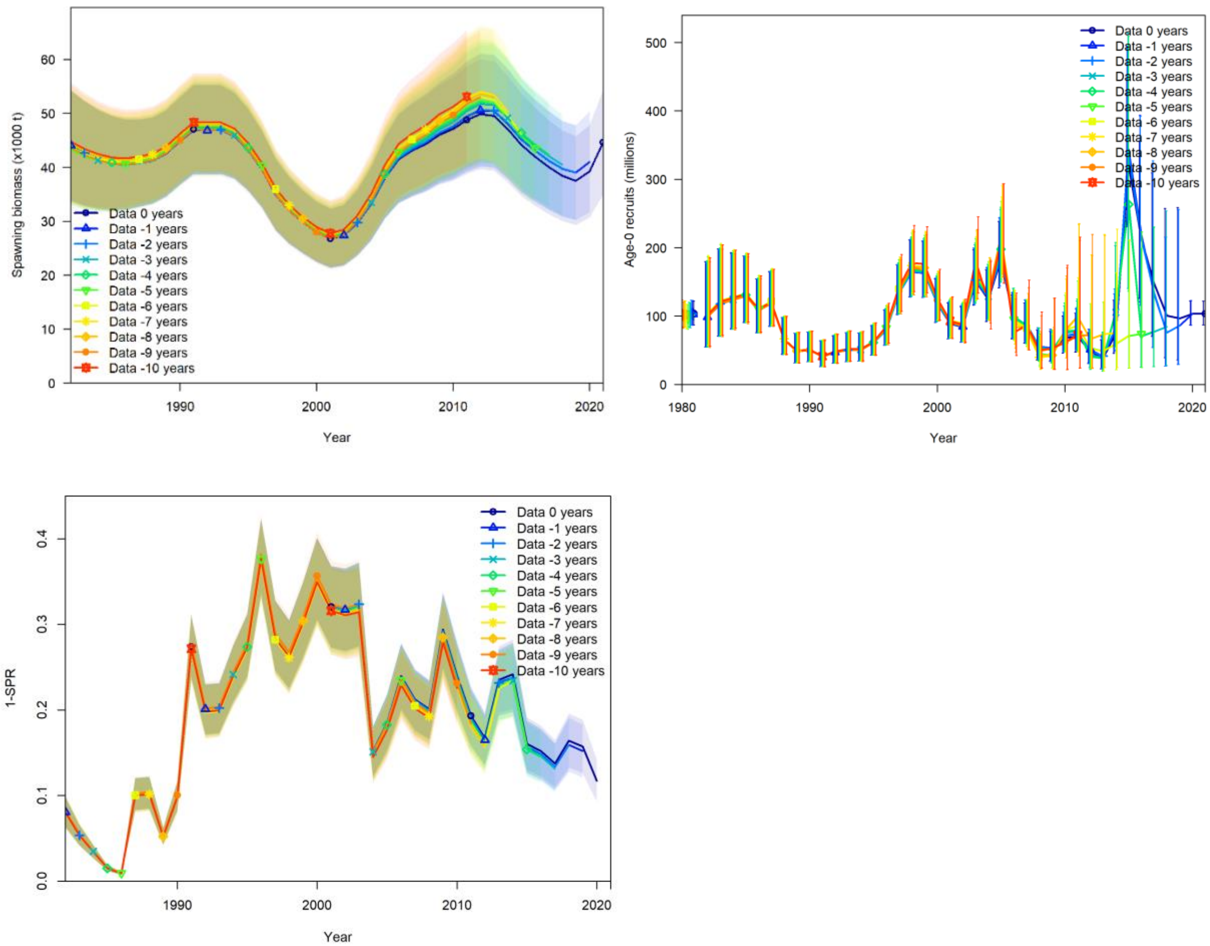

Figure 33. Spawning stock biomass (top left), recruitment (top right), and a measure of fishing intensity (1-spawning potential ratio; bottom left) for retrospective model runs leaving out 0 to 10 years of the most recent data for Model 21.0. Vertical lines show corresponding 95% asymptotic confidence intervals.

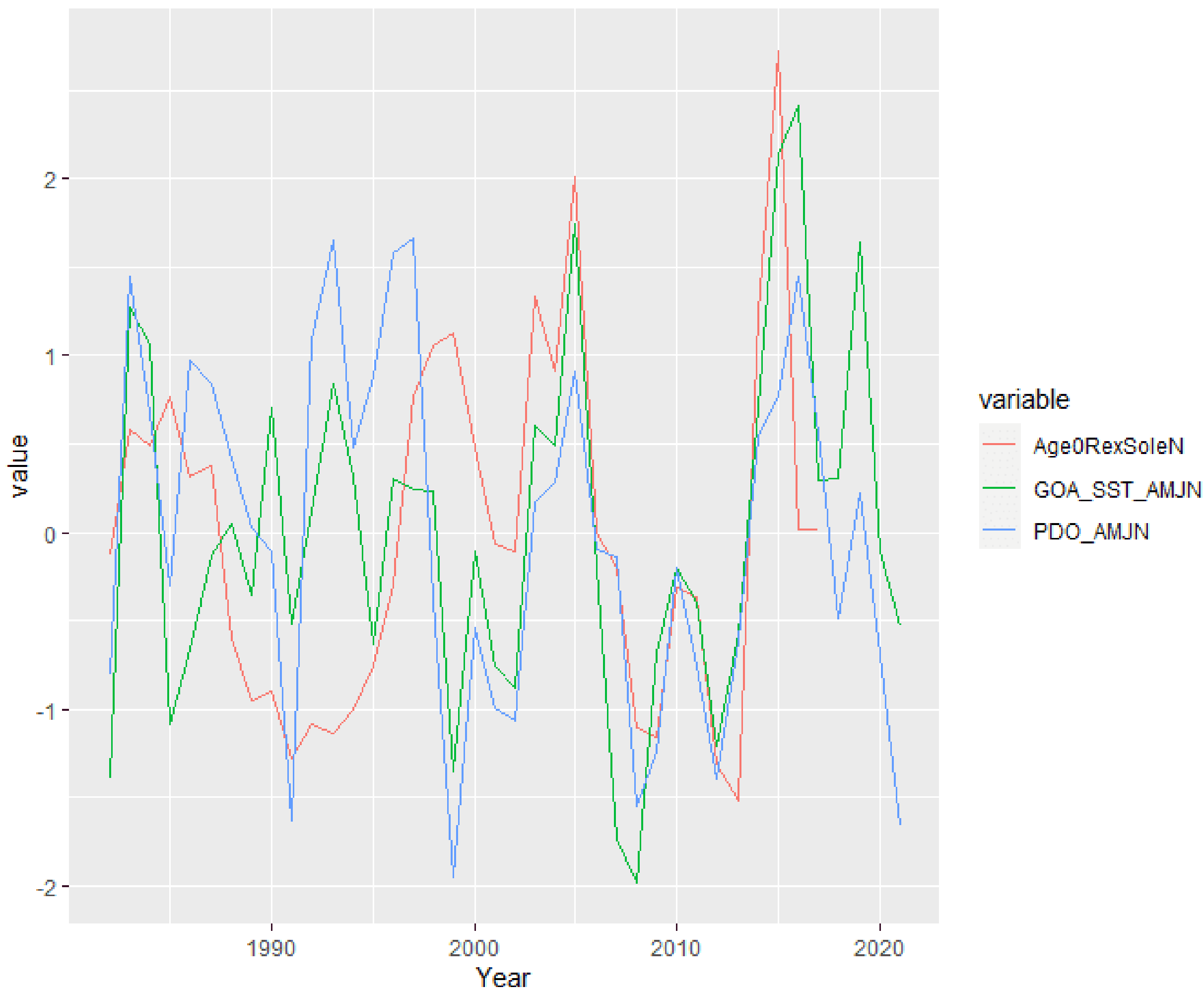

Figure 34. Normalized values for estimates of age-0 rex sole abundance, April-June sea surface temperatures in the Gulf of Alaska, and mean April-June Pacific Decadal Oscillation index, 1982-2021.

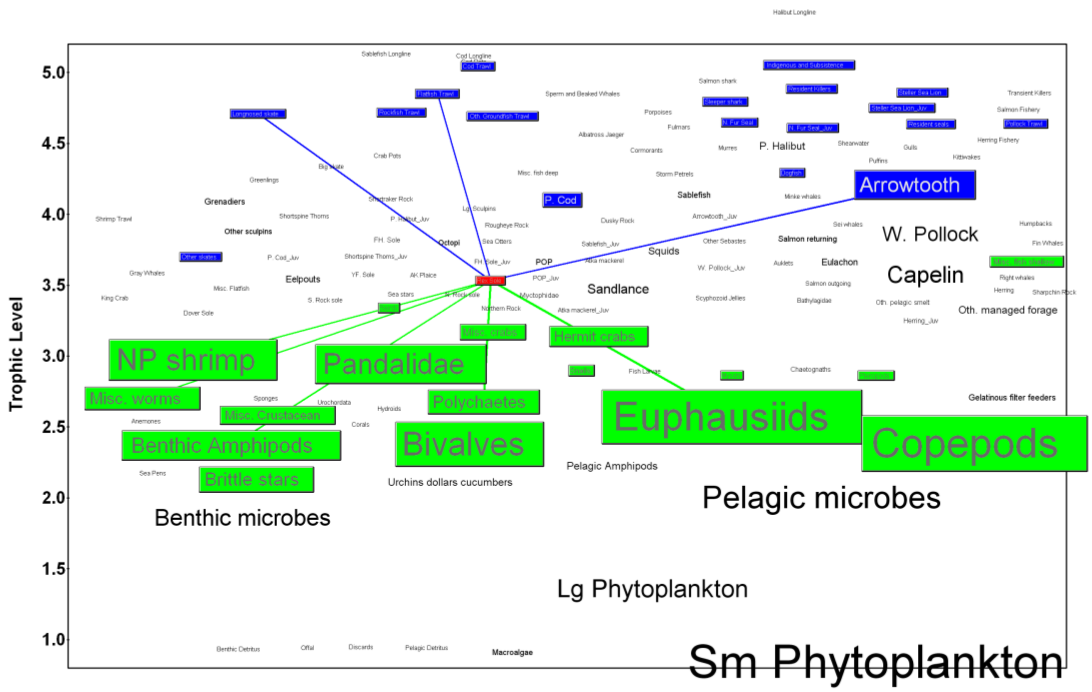

Figure 35. Gulf of Alaska food web from the GOA ecosystem model (Aydin et al., 2007) highlighting rex sole links to predators (blue boxes and lines) and prey (green boxes and lines). Box size reflects relative standing stock biomass.

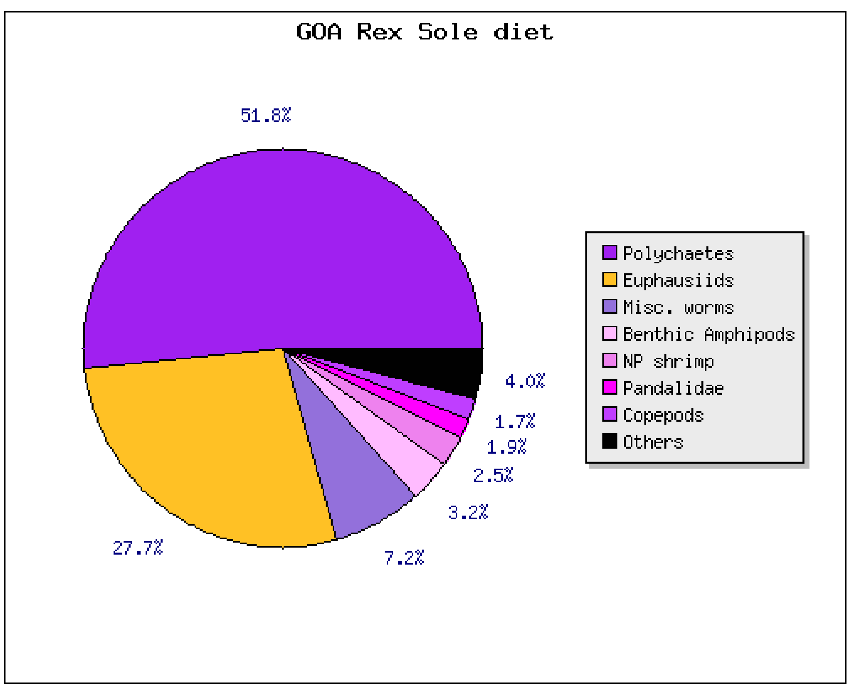

Figure 36. Diet composition for Gulf of Alaska rex sole from the GOA ecosystem model (Aydin et al., 2007).

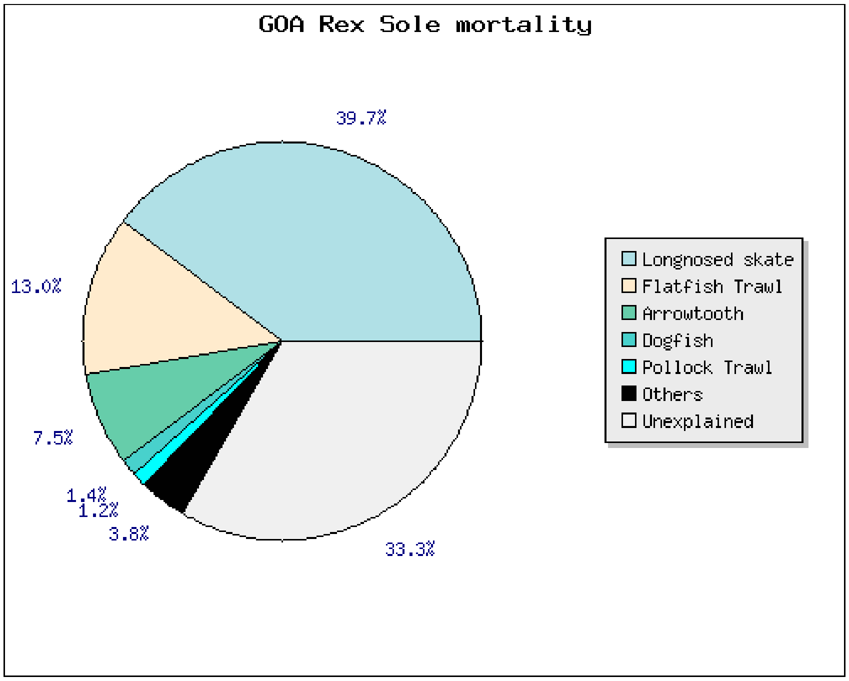

Figure 37. Decomposition of natural mortality for Gulf of Alaska rex sole from the GOA ecosystem model (Aydin et al., 2007).

Appendix 6A: Specifications for the Model 17.2 model run in SS

Quantity	As estimated or *specified this* year for: 2021	2022	As estimated or *recommended this* year for: 2022*	2023*
M (natural mortality rate)	0.17	0.17	0.17	0.17
Tier	3a	3a	3a	3a
Projected total (3+) biomass (t)	101,244	101,244	166,815	171,020
Female spawning biomass (t)	44,500	44,500	66,209	74,651
$B_{100\%}$	See area-specific tables below		See area-specific tables below	
$B_{40\%}$				
$B_{35\%}$				
F_{OFL}				
$maxF_{ABC}$				
F_{ABC}				
OFL (t)	18,779	18,779	30,359	34,169
maxABC (t)	15,416	15,416	24,818	27,963
ABC (t)	15,416	15,416	24,818	27,963
Status	As determined *last* year for: 2019	2020	As determined *this* year for: 2020	2021
Overfishing	no	n/a	no	n/a
Overfished	n/a	no	n/a	no
Approaching overfished	n/a	no	n/a	no

Quantity: (Western-Central GOA)	As estimated or *specified this* year for:		As estimated or *recommended this* year for:	
	2021	2022	2022*	2023*
M (natural mortality rate)	0.17	0.17	0.17	0.17
Tier	3a	3a	3a	3a
Projected total (3+) biomass (t)	79,666	79,666	132,915	136,700
Female spawning biomass (t)	35,506	35,506	53,546	60,642
$B_{100\%}$	48,138	48,138	54,627	54,627
$B_{40\%}$	19,255	19,255	21,851	21,851
$B_{35\%}$	16,848	16,848	19,119	19,119
F_{OFL}	0.29	0.29	0.3	0.3
$maxF_{ABC}$	0.23	0.23	0.24	0.24
F_{ABC}	0.23	0.23	0.24	0.24
OFL (t)	14,512	14,512	23,726	26,838
maxABC (t)	11,925	11,925	19,420	21,991
ABC (t)	11,925	11,925	19,420	21,991
Status	As determined *last* year for:		As determined *this* year for:	
	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 392 t and 1,567 t that was used in place of maximum permissible ABC for 2021 and 2022-2023, respectively. The 2021 projected catch was calculated as the current catch of GOA rex sole as of September 26, 2021 added to the average September 27 – December 31 GOA rex sole catches over the 5 previous years. The 2022-2023 projected catch was calculated as the average catch from 2016-2020.

Quantity: (Eastern GOA)	As estimated or *specified this* year for: 2021	2022	As estimated or *recommended this* year for: 2022*	2023*
M (natural mortality rate)	0.17	0.17	0.17	0.17
Tier	3a	3a	3a	3a
Projected total (3+) biomass (t)	21,578	21,578	33,900	34,320
Female spawning biomass (t)	8,994	8,994	12,663	14,009
$B_{100\%}$	9,597	9,597	10,894	10,894
$B_{40\%}$	3,839	3,839	4,357	4,357
$B_{35\%}$	3,359	3,359	3,813	3,813
F_{OFL}	0.31	0.31	0.33	0.33
$maxF_{ABC}$	0.25	0.25	0.26	0.26
F_{ABC}	0.25	0.25	0.26	0.26
OFL (t)	4,267	4,267	6,633	7,331
maxABC (t)	3,491	3,491	5,398	5,972
ABC (t)	3,491	3,491	5,398	5,972
Status	As determined *last* year for: 2019	2020	As determined *this* year for: 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; the 2021-2023 projected catch was calculated as the average catch from 2016-2020. Catches from the Eastern GOA are small and many are confidential.

Appendix 6B: Non-Commercial Catches of GOA Rex Sole

Table 29. ADF&G Sources of non-commercial catch of GOA rex sole.

Year	Kachemak Bay Large Mesh Trawl Survey	Kodiak Scallop Dredge	Large-Mesh Trawl Survey	Prince William Sound Large Mesh Trawl Survey	Prince William Sound Sablefish Tagging	Scallop Dredge Survey	Small-Mesh Trawl Survey	Subsistence Fishery	Yakutat Scallop Dredge
1991								393	
1998			283			2			
1999			843						
2000			380			0	106		
2001			1,294						
2002			506			2			
2003			1,964				285		
2004			625			0	128		
2005			1,468			3	267		
2006			307			12	265		
2007			771			1	100		
2008			229						
2009			1,075			1			
2010			5,453			0	342		
2011			4,368				147		
2012			3,829			0	63		
2013			3,924				78		
2014			1,810				137		
2015			1,894		1		111		
2016			1,328			3	44		
2017	686	77	1,398	409			67		52
2018			3,974				39		
2019			5,437			0	61		
2020			4,135			19	257		

Table 30. Other NMFS Sources of non-commercial catch of GOA rex sole.

Year	AFSC Annual Longline Survey	GOA Shelf and Slope Walleye Pollock Acoustic-Trawl Survey	Gulf of Alaska Bottom Trawl Survey	Salmon EFP 13-01	Shelikof Acoustic Survey	Shumigans Acoustic Survey	Winter Acoustic-Trawl Survey of Walleye Pollock in Shelikof Strait and Vicinity
1989	1.83						
1992	0.915						
1994	5.489						
1995	0.915						
2010					8.928	36.258	
2011			5751.324				
2012	0.915						
2013	1.83		5022.4	130			
2014				184			
2015			7679.445				
2017		4.91	4949.725				
2019			4481.736				3.85
2020	3.66						

Appendix 6C: Fits to ghosted age compositions for Model 21.0

The following figure appears in an appendix because the model fits to conditional age-at-length data by area rather than to whole-GOA age composition data. In addition, the data shown in the figure is for the whole GOA (Western-Central and Eastern GOA combined), while expected values shown are either for just the Western-Central GOA or the Eastern GOA. Therefore, it is a figure of interest, but not used to formally evaluate the model. The large year class of age-4's in 2019 is captured well by the model.

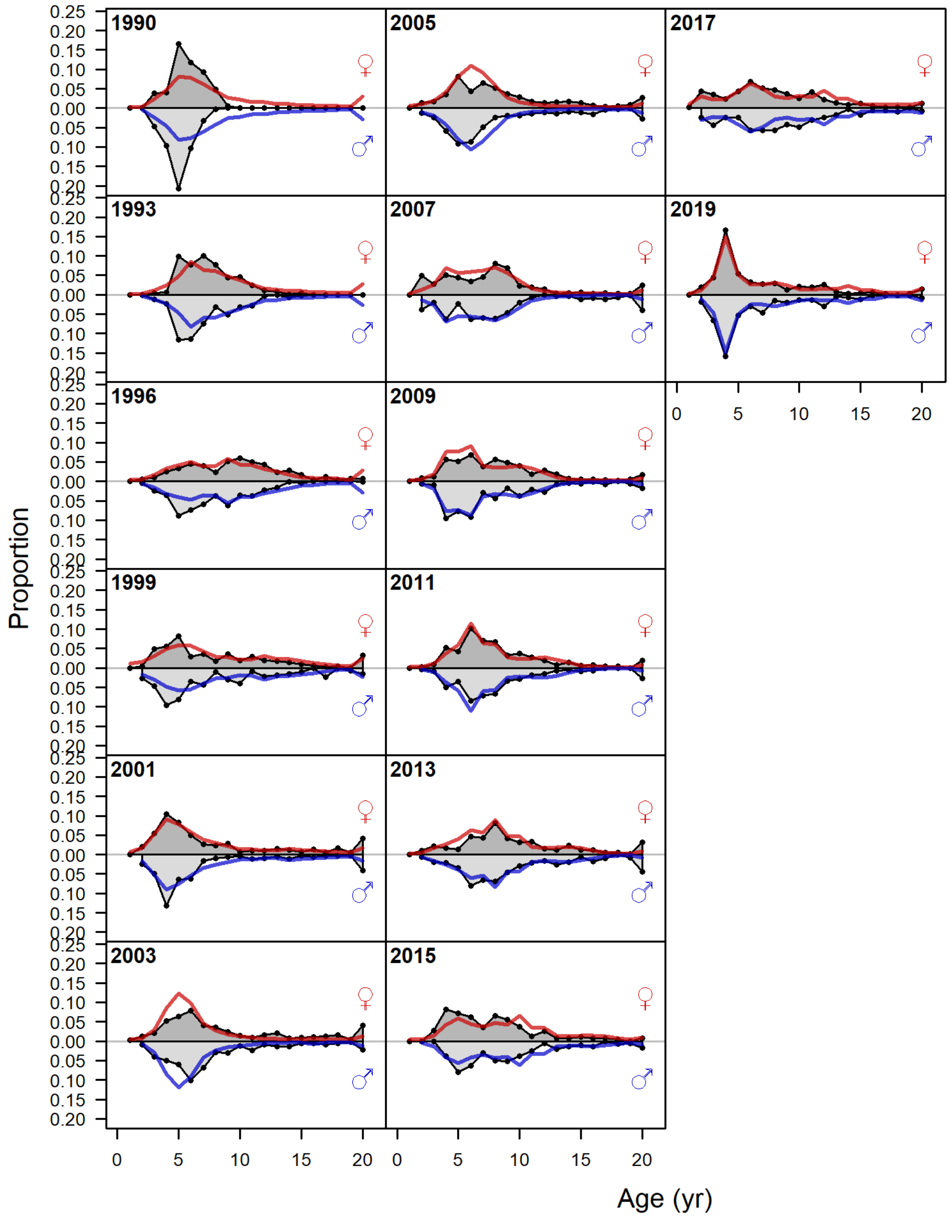

Figure 38. Observed **ghosted** survey age compositions for the **whole GOA** (grey filled area and black line) and expected (red and blue lines) survey age compositions for the **Western-Central GOA** for males (blue lines) and females (red lines) for Model 21.0.