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. In previous years, 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 assessment. The 2015 model was updated with new data from the previously-used data sources only and OFLs and ABCs were calculated using a Tier 5 management approach and these results are reported in Appendix 6A for comparison with the 2017 model.

Summary of Changes in Assessment Inputs

The following substantive changes were made to assessment inputs:

(1) All data were input into the assessment by region where they were collected (Eastern GOA or Western-Central GOA)
(2) Fishery age composition data from hauls and ports were added to the model for 1990, 1995, 1999, 2003, 2005, 2007, 2009, 2010, 2012, 2014-2016
(3) GOA trawl survey data for age-at-length were used as assessment inputs instead of age composition data; 2015 age-at-length data were added to the assessment

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

(4) 2016-2017 catch biomass was added to the model
(5) 2015 catch biomass was updated to reflect October-December 2015 catches
(6) 2016-2017 fishery length composition data were added to the model and 2015 fishery length composition data were updated to reflect October – December 2015 catches
(7) 2017 GOA trawl survey biomass estimates was added to the model
(8) 2017 GOA trawl survey length composition data was added to the model

Summary of Changes in Assessment Methodology

(1) A likelihood component was added to fit the model to fishery age composition data
(2) Growth was estimated within the assessment model using a conditional age-at-length approach
(3) The model was split into two areas with growth estimated within each area to account for differences in length-at-age between the Eastern GOA and the Western-Central GOA. A recruitment allocation parameter (non-time-varying) was estimated to distribute recruitment between the Eastern GOA and Western-Central GOA and otherwise no movement between areas was modeled. Growth was estimated internally within each of the two areas. Fishery selectivity was estimated only for the Western-Central region where the fishery occurs.

Summary of Results

The key results of the assessment, based on the author's preferred (base case) model, are compared to the key results of the accepted 2016 update assessment in the table below. A Tier 3a approach was used to calculate recommended quantities for the 2017 assessment, while previously a Tier 5 approach was used. Three tables are presented. The first shows quantities for the entire GOA, showing quantities as specified in the 2016 assessment based on a Tier 5 approach and quantities recommended for the 2017 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:		As estimated or *recommended this* year for:	
	2017	2018	2018	2019
M (natural mortality rate)	0.17	0.17	0.17	0.17
Tier	5	5	3a	3a
Projected total (3+) biomass (t)			97,982	97,967
Female spawning biomass (t)	47,008	49,317	45,750	43,575
$B_{100\%}$	56,845	56,845	See area-specific tables below	
$B_{40\%}$	22,738	22,738		
$B_{35\%}$	19,896	19,896		
F_{OFL}	0.170	0.170		
$maxF_{ABC}$	0.128	0.128		
F_{ABC}	0.128	0.128		
OFL (t)	10,860	11,004	18,706	17,692
maxABC (t)	8,311	8,421	15,373	14,529
ABC (t)	8,311	8,421	15,373	14,529
Status	As determined in 2016 for:		As determined in 2017 for:	
	2015	2016	2016	2017
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: 2017	2018	As estimated or *recommended this* year for: 2018	2019
M (natural mortality rate)	0.17	0.17	0.17	0.17
Tier	5	5	3a	3a
Projected total (3+) biomass (t)	Not calculated		76,644	76,631
Female spawning biomass (t)			36,374	34,569
$B_{100\%}$			48,138	48,138
$B_{40\%}$			19,255	19,255
$B_{35\%}$			16,848	16,848
F_{OFL}			0.29	0.29
$maxF_{ABC}$			0.23	0.23
F_{ABC}			0.23	0.23
OFL (t)			14,375	13,558
maxABC (t)			11,825	11,145
ABC (t)			11,825	11,145
Status	As determined in 2016 for: 2015	2016	As determined in 2017 for: 2016	2017
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 1,550t and 2,508 t that was used in place of maximum permissible ABC for 2017 and 2018-2019, respectively. The 2017 projected catch was calculated as the current catch of GOA rex sole as of October 8, 2017 added to the average October 8 – December 31 GOA rex sole catches over the 5 previous years. The 2018-2019 projected catch was calculated as the average catch from 2013-2017.

Quantity: (Eastern GOA)	As estimated or *specified this* year for:		As estimated or *recommended this* year for:	
	2017	2018	2018	2019
M (natural mortality rate)	0.17	0.17	0.17	0.17
Tier	5	5	3a	3a
Projected total (3+) biomass (t)	Not calculated		21,338	21,336
Female spawning biomass (t)			9,376	9,006
$B_{100\%}$			9,597	9,597
$B_{40\%}$			3,839	3,839
$B_{35\%}$			3,359	3,359
F_{OFL}			0.31	0.31
$maxF_{ABC}$			0.25	0.25
F_{ABC}			0.25	0.25
OFL (t)			4,331	4,134
maxABC (t)			3,548	3,384
ABC (t)			3,548	3,384
Status	As determined in 2016 for:		As determined in 2017 for:	
	2015	2016	2016	2017
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 2017 projected catch was calculated as the current catch of Eastern GOA rex sole as of October 8, 2017 added to the average October 8 – December 31 Eastern GOA rex sole catches over the 5 previous years. The 2018-2019 projected catch was calculated as the Eastern GOA average catch from 2013-2017. Catches from the Eastern GOA are small and many are confidential.

The table below shows apportionment of the 2018 and 2019 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 2018-2019. 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	26.10%	73.90%	100.00%	48.96%	51.04%	100.00%
2018 ABC (t)	3,086	8,739	11,825	1,737	1,811	3,548
2019 ABC (t)	2,909	8,236	11,145	1,657	1,727	3,384

Responses to SSC and Plan Team Comments on Assessments in General

Dec 2016, SSC: Any new model that diverges substantial from the currently accepted model will be marked with the two-digit year and a "0" version designation (e.g., 16.0 for a model from 2016). Variants that incorporate major changes are then distinguished by incremental increases in the version integer (e.g., 16.1 then 16.2), and minor changes are identified by the addition of a letter designation (e.g., 16.1a). The SSC recommends this method of model naming and notes that it should reduce confusion and simplify issues associated with tracking model development over time.

All models presented in this assessment are numbered using the recommended naming conventions.

Responses to SSC and Plan Team Comments Specific to this Assessment

December 2015, GPT and SSC: The Team/SSC recommends examining rex sole age, growth, and maturity information and updating the growth data used in the model as it currently only includes data up to 1996.

An examination of survey and fishery age and length-at-age data was conducted for this assessment and growth was re-estimated within the model using data up to 2015. The analysis of length-at-age showed differences in the growth curve in Eastern region of the GOA as compared to the Western-Central regions and poor model fits to fishery length and age composition data. A consistent pattern occurred over time for models with updated growth estimates whereby the model predicted that the fishery caught more small fish than were observed and fewer young fish than were observed. An assessment modeling approach was used that accounted for differences in growth among the two regions and led to substantially better fits to fishery length and age composition data.

December 2015, SSC: The SSC concurs with the PT and author recommendation that more information should be collected on fishery size and age compositions to inform selectivity parameters and potentially improve estimates of harvest rates.

Historical fishery otoliths were aged over the past three years in a collaboration between the authors and the AFSC age and growth lab. The historical fishery age data were added to the assessment for the first time and substantially reduced uncertainty in estimates of fishery selectivity-at-age and reference points related to fishing mortality, and showed that fishery selectivity occurs at a similar age as for maturity, resulting in improved estimation of harvest rates. Based on these improved estimates of harvest rates, this year, GOA rex sole OFLs and ABCs were calculated using a Tier 3 approach using the biomass and fishing mortality estimates from the assessment.

December 2015, SSC: The SSC concurs that further research on genetics and growth should be conducted to explore these two growth patterns seen on the otoliths.

A future research collaboration with staff from the ageing program could be conducted to explore whether genetic differences exist between rex sole with different growth curves (in particular, rex sole in the Eastern GOA as compared to rex sole in the Western and Central GOA). The analysis of survey and fishery length-at-age data in this assessment corroborates the differences found in otolith patterns by the age and growth lab. It is not known whether differences are related to genetics or environmental conditions, or a combination.

September 2017, GPT: The Team recommended to include the new age data going forward based on the age-length keys specific to year, gear season.

Fishery age-length keys specific to year and season were used in this assessment. GOA rex sole are only caught by non-pelagic trawl. Additionally, note that using fishery age-length keys that were not specific to gear and season produced nearly identical results.

September 2017, GPT: The Team also recommended to re-evaluate how growth affects model results.

See response to December 2015 SSC and November 2015 GPT comments.

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.

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. Fishing seasons are driven by seasonal halibut PSC apportionments, with approximately 7 months of fishing occurring between January and November and the greatest proportion of catches 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.

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. Historically, catches of rex sole have exhibited decadal-scale trends. 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 1,748 t in 2015. The current catch in 2017 (as of October 8, 2017) was 1,315 t.

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 1995-2017 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 2015-2017 the fishery catches ranged from 18-21% 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); 2001-2017 (biennial)
	Ages Conditioned on Length	1984, 1987, 1993, 1999; 2001-2015 (biennial)
	Age Composition*	1984, 1987, 1993, 1999; 2001-2015 (biennial)
	Length Composition	1984-1999 (triennial); 2001-2017 (biennial)
U.S. Trawl Fisheries	Catch	1982- October 8, 2017
	Length Composition	1982-1984, 1990-2017
	Age Composition	1992,1995,1999,2003,2005,2007,2009,2010,2012 2014-2016

*Developmental models only

Fishery Data

This assessment used (1) fishery catches from 1982 through October 8, 2017 (Table 1, Figure 1), (2) the proportion of individuals caught by length group and sex for the years specified in the table above (through October 8, 2017); http://www.afsc.noaa.gov/REFM/Docs/2017/FTP_GOA_Rex_Composition_Data_And_SampleSize_2017.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. Table 3 and Table 4 show that the proportion of length samples from each quarter and NMFS area are similar to the proportion of catches from each quarter and NMFS area, respectively, indicating that use of raw length data (rather than length data standardized by size of each fishery haul) was reasonable. 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. Figure 2-Figure 5 show 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 (http://www.afsc.noaa.gov/REFM/Docs/2017/FTP_GOA_Rex_Composition_Data_And_SampleSize_2017.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 (2001-2017) 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. 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 most recent period from 2011 – 2017, the survey biomass was slightly lower, between 87,313 t and 101,000 t. The survey biomass for 2017 was 97,720 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, as were estimates of the distribution of ages in each year (http://www.afsc.noaa.gov/REFM/Docs/2017/FTP_GOA_Rex_Composition_Data_And_SampleSize_2017.xlsx). Survey age data were available for all survey years except for 2017 (1984, 1987, 1990, 1993, 1996, 1999, 2001, 2003, 2005, 2007, 2009, 2011, 2013, and 2015). 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.

In the preferred model, raw age data by length was entered directly into the assessment (a conditional age-at-length approach). In other developmental model runs, age compositions were calculated from age-length data using the corresponding size compositions; in these models, size compositions were de-weighted in the model likelihood for years where age composition data was available to avoid double-use of data. In these developmental models, survey size composition data was fully weighted in the model likelihood only for years when age compositions were unavailable (1990 and 2011). Effective sample sizes used in the model are listed with length and age composition data at http://www.afsc.noaa.gov/REFM/Docs/2017/FTP_GOA_Rex_Composition_Data_And_SampleSize_2017.xlsx. Number of hauls for which length samples exist was used as effective sample size for length composition data where age compositions were used. 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 in the preferred base case model and were aggregated over all areas in the GOA in developmental models.

Figure 6-Figure 10 show survey length-at-age data by cohort and by year, area, and depth. 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 9-Figure 10).

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.

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.

Three developmental models (Model 15.0, 17.0, and 17.1) and one base case model (Model 17.2) are presented in this assessment. Model 15.0 was the most recently accepted model with 2016 and 2017 data added to the same data sources that were used in 2015 (McGilliard et al. 2015).

Model 17.0 was the same as model 15.0, but with the addition of newly available historical fishery age data for the years described in the table of data inputs above. These age data were added because previous models estimated unusual age-based fishery selectivity curves based only fishery length composition data; these estimated selectivity curves led to unusually high estimates of F_{OFL} and F_{ABC} that were thought to be unreliable (e.g. McGilliard et al. 2015, Stockhausen et al. 2011, and earlier assessments).

Model 17.1 was the same model as for 17.0, except that it implemented a conditional age-at-length approach to estimate growth by entering raw age data by associated length bin and fitting to these data using a multinomial likelihood component for age data within each length bin. Estimating growth within the assessment model using this approach allows for uncertainty in growth estimates to propagate through the model such that it is taken into account in uncertainty estimates of key model outputs and derived quantities. In addition, it resolves a key issue with external estimation of growth where it is not possible to account for the effects of size-based selectivity on length-at-age data when estimating growth curves (Stewart 2007). Growth estimates for GOA rex sole had not been updated since 1996 and growth estimates using more recent data were needed and requested by the GOA Plan Team and SSC (see "Results" section for more details).

Model 17.2 differs from Model 17.1 in that it 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 the newly available fishery age data as for Models 17.0 and 17.1 and a conditional age-at-length approach as for Model 17.1, but 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 models that incorporated the newly available historical fishery age data; 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 8). 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 "Results" section for more details).

Other approaches were considered 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 for Model 17.2 (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). Models 15.0, 17.0, and 17.1 use sex-specific survey and fishery selectivity. In Model 17.2 (the growth morph model), 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 in Model 17.2 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 the Eastern GOA.

Recruitment Deviations

Recruitment deviations were estimated for an early period from 1965-1981 and a current period from 1982-2015 with a $\sigma_R = 0.6$ and were set to mean recruitment for 2016-2017 (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), as for the 2015 model (McGilliard et al. 2015). For Model 17.2 (the growth morph model), Eastern GOA and Western-Central GOA length composition data shared a variance adjustment (1.5) according to the McAllister-Ianelli method. Likewise, the conditional age-at-length data shared a variance adjustment according to the McAllister-Ianelli method (0.5); 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. The variance adjustment for fishery length composition data was 0.2 and the variance adjustment for fishery age composition data was 0.6. A data weighting approach following Francis (2013) was implemented as a sensitivity analysis.

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).

Growth

Growth was estimated within the assessment model for the base case model (17.2) and for Model 17.1 and are described in the section “Parameters Estimated Inside the Assessment Model.”

For Models 15.0 and 17.0:

Length-at-age was estimated externally using data from the GOA groundfish survey from 1984-1996 (Turnock et al. 2005) and assumed to follow the von-Bertalanffy growth curve as described in Methot and Wetzel Appendix A (2013):

The estimated values are as follows, where age at minimum size was 2 and age at maximum size was 20:

	L_{amin}	L_{amax}	k
Females	14.99	44.787	0.315
Males	14.56	39.473	0.379

Fixed sex-specific age-length conversion matrices were calculated within SS (Methot and Wetzel 2013) based on the parameters of the von-Bertalanffy growth curve and specified coefficients of variation (CVs) for length-at-age for the youngest and oldest age classes of 0.13 and 0.08, respectively, for both males and females.

Weight-at-Age Relationship

The weight-at-age relationship was that used in the previous assessment (McGilliard et al. 2015) 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 all models. In Model 17.2 (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, and selectivity parameters for the fishery and survey. The selectivity parameters are described in greater detail in Table 9.

In the growth morph model (Model 17.2), 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 Model 17.2 were estimated by sex and for the Western-Central GOA only.

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 Models 17.1 and 17.2. For Model 17.2, 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).

Results

Model Evaluation

Summary of the development of the base case model and comparison of models

In previous years, the biomass estimates from the rex sole assessment were used to calculate management quantities using a Tier 5 approach; a Tier 5 approach was chosen because the fishing mortality rates and corresponding F_{OFL} and F_{ABC} values estimated by the model were thought to be unrealistically high (F_{OFL} = 1.42 and F_{ABC} = 0.99 for the 2015 model based on a Tier 3a management approach). These high fishing mortality rates are driven by a fishery selectivity curve estimated by the model that suggests that only fish older than the age-at-maturity are caught by the fishery. This model (Model 15.0) was implemented with new data added and exhibited similar model fits and parameter estimates to those found in 2015 (Figure 11, top left panel).

At the September 2017 GOA Plan Team meeting, an alternative model was presented where historical fishery age data that were newly aged were added as a data source to the assessment and the model was fit to these ages in place of fishery lengths in the years where ages existed (Model 17.0). The addition of fishery age composition data to the assessment led to estimates of fishery selectivity occurring at approximately the age at maturity (Figure 11, top right panel). This new selectivity curve led to lower estimates of fishing mortality rates (Figure 22) and F-related reference points (F_{OFL} = 0.35 and F_{ABC} = 0.28). However, fits to fishery length composition data showed a mismatch between model estimates and the data (Figure 12, top right panel). Specifically, the model estimated that more small fish and fewer large fish (both male and female) were caught in the fishery than were observed. In addition, the opposite trend occurred in fits to the fishery age composition data, where more young fish were observed than were predicted (Figure 13, top right panel). Fits to survey length and age composition data for Model 17.0 did not show the patterns exhibited by the fishery composition data and were fairly reasonable (Figure 12 and Figure 13, top right panels).The author and GOA Plan Team agreed that although the addition of fishery age data to the model was an improvement, new growth curves were needed to explore and (hopefully) resolve the poor fits to fishery length and age composition data. Figure 14 shows fits to length-at-age from the growth curves that were estimated outside of the assessment model (based on data up to 1996) and corresponding 95% confidence intervals overlaid on raw age-length data. Confidence bounds do not appear to encompass 95% of the observations. In addition, it appears as though the growth curve for females may underestimate lengths at older ages.

Model 17.1 addressed concerns about outdated growth estimates by using a conditional age-at-length approach to estimate growth within the assessment model based on survey age-at-length data (Figure 15). Estimating growth within the assessment model allows for uncertainty in growth estimates to propagate through the model such that it is taken into account in uncertainty estimates of key model outputs and derived quantities. In addition, this approach resolves a key issue with estimating growth outside of the assessment model, which is that it is not possible to account for the effects of survey selectivity on age-length data when estimating the growth curves outside the model. CVs in length at ages 2 and 20 are higher in Model 17.1 than in Model 17.0 for both males and females (Table 11, Figure 14, and Figure 15). However, Model 17.1 showed a similar mismatch in model fits to fishery length and age composition data as for Model 17.0 in that both models estimated that more small fish and fewer large fish were caught in the fishery than were observed (Figure 12, bottom left panel) and more young fish were observed by the fishery than predicted (Figure 13, bottom left panel).

An examination of survey age-length data by year, area, and depth (Figure 6-Figure 10) showed differences in growth in the Eastern GOA (Figure 6-Figure 8). Specifically, fish in the Western and Central GOA grow larger than fish in the Eastern GOA. A direct comparison of the eastern GOA to the combined Western-Central GOA is shown in Figure 8. The fishery does not operate in the Eastern GOA; it operates only in the Western and Central GOA, and fishery age-length data are similar to those in the Western and Central GOA (compare Figure 4 to the Western-Central GOA in Figure 8). Growth curves estimated using both Eastern GOA and Western-Central GOA age-length data, therefore, could underestimate length-at-age in the Western-Central region and could lead to the patterns in model fits to fishery age- and length-composition data that were observed in Models 17.0 and 17.1 in Figure 12 and Figure 13 (upper right and lower left panels).

Model 17.2 was developed to account for differences in growth in the Eastern and Western-Central regions. The model is a two-area model with growth and survey selectivity parameters estimated separately for each region (see section entitled “Model Structure”). Fits to fishery age and length composition data and fits to survey length composition data are much improved in Model 17.2 (Figure 12 and Figure 13, lower right panel). Figure 16 shows fits of the area- and sex-specific growth curves to the survey age-length data for Model 17.2. Accounting for differences in growth in the Eastern GOA leads to lower estimates of variability in growth in both regions as compared to Model 17.1, where area-specific differences in growth are not taken into account (Table 11). Length at age 20 is 9.75 cm smaller for females and 6.3 cm smaller for males in the Eastern GOA as compared to females and males in the Western-Central region, respectively.

Figure 17 shows observed and predicted survey biomass for the one-area models: Models 15.0, 17.0, and 17.1, and Figure 18 shows observed and predicted survey biomass for Model 17.2 for the Western-Central area and the Eastern area. Predicted survey biomass is similar among the three one-area models and for the Western-Central area in Model 17.2. The predicted survey biomass for the Eastern area in Model 17.2 exhibits a similar trend to the predicted survey biomass in the Western-Central area. There were no samples taken in the Eastern GOA in 2001 and estimates of survey biomass in the Eastern GOA in 1999 and 2003 do not follow the observations closely. This may be related to uncertainty due to the missing observation in 2001. Overall, predicted survey biomass follows observations reasonably well in most years for the two areas, as compared to Model 17.1 (Figure 17 and Figure 18).

Figure 19-Figure 22 show a comparison of spawning biomass, recruitment, recruitment deviations, and fishing mortality among models. Figure 19 shows that accounting for differences in growth among areas leads to slightly higher estimates of spawning biomass than for the three one-area models (15.0, 17.0, and 17.1). Estimates of recruitment and recruitment deviations are similar among models with some differences in early recruitment deviations and variation in the estimate of the most recent recruitment deviation (for which uncertainty is always higher than for recruitment deviations in the middle of the time series). In addition, the estimates of the log of unfished recruitment is similar among models (Table 13). Yearly estimates of fishing mortality are substantially higher in model 15.0 than for the three models where newly available historical fishery age data were incorporated (Figure 22). High fishing mortality rates in Model 15.0 are a result of the estimated fishery selectivity-at-age occurring at a much older age than for the other three models (and a much older age than the age at maturity, as discussed earlier; Figure 11). Figure 23 and Table 12 show survey and fishery selectivity for each of the four models. Survey selectivity is very similar among models (and for the Western-Central and Eastern GOA in Model 17.2). Fishery selectivity is estimated to occur at a much younger age in all models where fishery age data are incorporated and is very similar in these models (Models 17.0-17.2; Table 12 and Figure 23). In the model without fishery age data (Model 15.0), the model had considerable flexibility when estimating fishery selectivity-at-age due to variability in length-at-age (the CV in length-at-age 2 and 20 were 0.08 and 0.13, respectively (Table 11).

Model 17.2 was chosen as the base case model because it (a) substantially reduces uncertainty about fishing mortality rates and F-related reference points by fitting to fishery age composition data, (b) incorporates all years of survey age-length data to estimate growth parameters, (c) estimates growth within the assessment model using a conditional age-at-length approach, which allows for more thorough inclusion of uncertainty in the model and accounts for size selectivity when estimating growth, (d) explicitly accounts for substantial differences in growth that occur in the Eastern GOA relative to growth in the Western-Central GOA, which allows for more precise estimation of growth parameters and smaller estimates of variability in growth, while requiring only 6 additional growth parameters, and (e) visibly reduces the mismatches between observed and predicted fishery length and age composition data, while exhibiting reasonable fits to survey length composition and age-length data. Fits to survey biomass for the Western-Central GOA are similar to fits to the total survey biomass in the GOA shown in the one-area models (to the extent that they can be compared).

The base case model (Model 17.2)

Figure 24 shows spawning biomass and recruits by area. The model estimate of the recruitment allocation parameter (a single, non-time-varying parameter specifying the proportion of recruitment that occurs in the Eastern GOA) was estimated to be 0.2975, and therefore the proportion of recruitment occurring in the Western-Central GOA was 0.7025. An average over time of approximately 25-35% of the survey biomass occurs in the Eastern GOA, similar to the proportion of recruits estimated to occur in the Eastern GOA. The model shows that spawning biomass has been fairly constant in the Eastern GOA over time and that in the Western-Central GOA a dip in spawning biomass occurred in the early 2000's where spawning biomass declined from 45,452 t in 1992 to 24,434 t in 2001 (Table 23). The spawning biomass in the Western-Central GOA then increased to a peak of almost 47,271 t in 2012 and has been decreasing since 2012; peak catches occurred between 1992 and 1998, just before the decline in spawning biomass in the early 2000's. The model shows two large peaks in age-0 recruitment occurring in 2003-2005 and more recently in 2014-2015 (Table 23).

Model fits to yearly fishery length composition data are poor for 1982-1984, and observations of the distribution of lengths caught show some year-to-year variation. A small mismatch whereby the model tends to predict slightly more small fish than observed still exists (this was a dominant pattern in Models 17.0 and 17.1), but overall fits to fishery length composition are reasonable in most years (Figure 25-Figure 26, Figure 35). The fishery age data show variability from year to year in the distribution of ages caught (Figure 27-Figure 28). In several years there is a peak in females between the ages of 5 and 10 that is not predicted by the model (1992, 1995, 2005, and 2007). This peak is evident in the fit to fishery age data aggregated over time shown in Figure 13, lower right panel for Model 17.2.

Model fits to yearly survey length composition data are poor in the initial few years of the model (1984-1990 for the Western-Central GOA and 1984-1993 for the Eastern GOA; Figure 29, Figure 30, Figure 35). Model fits to survey length composition data are much improved in subsequent years. Differences in survey methodology occurred in 1984 and 1987 relative to other survey years and this may contribute to poor fits in these two years. However, the differences in length frequencies caught by the survey extend beyond 1987 and suggest that there may have been a shift in population dynamics, behavior, or survey selectivity after 1990. Overall, fits to survey length composition data aggregated over time are very reasonable (Figure 13, lower right panel for Model 17.2).

Figure 31-Figure 34 show observed and predicted yearly mean age-at-length and corresponding observed and predicted standard deviations in mean age-at-length. As is expected, observed standard deviations can be very low for ages and length bins with low sample sizes (a sample size of 1 will have a standard deviation of 0), but model predicted standard deviation in mean age-at-length will increase at low sample sizes. Therefore, it is not expected that the column of panels on the right showing standard deviations in mean age-at-length would show direct correspondence between observations and predictions. Mean age-at-length values show some variation over time, suggesting that growth may have varied over time for GOA rex sole in both the Western-Central and Eastern regions, but overall, the model estimated growth curves that are a reasonable fit to the data and CV's of young and old fish that encapsulate the range of observations (Figure 16).

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 38. Little, if any, retrospective pattern is evident for 1-3 year peels for spawning biomass. A small positive retrospective bias appears in 7-8 year peels and a smaller positive retrospective bias occurs for the 10 year peel. Yearly estimates of fishing mortality are nearly identical for each peel and estimates of historical recruitment are very similar as well. Larger differences in estimates of recruitment occur in the last few years of each model run, as is expected given that only a small amount of information exists to inform recruitment in the last years of any stock assessment model for a fish that is first observed typically around age 3. Mohn's ρ for spawning biomass, recruitment, and fishing mortality are as follows:

Spawning Biomass	Recruitment	Fishing Mortality
0.0512	-0.0498	-0.0476

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.

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 http://www.afsc.noaa.gov/REFM/Docs/2017/FTP_GOA_Rex_TimeSeries_of_NumbersAtAge_2017.xlsx . Figure 36 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 37.

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 1982-2015 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 2017 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 $\leq F_{40\%}$, and F_{OFL} is defined to be $F_{35\%}$. The values of these quantities are:

	Western-Central GOA	Eastern GOA
SSB 2018	36,374	9,376
B40	19,255	3,839
F40	0.23	0.25
$maxF_{ABC}$	0.23	0.25
B_{35}	16,848	3,359
F_{35}	0.29	0.31
F_{OFL}	0.29	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 2017 numbers-at-age estimated in the assessment. This vector is then projected forward to the beginning of 2018 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2017. 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 2018 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 2018 recommended in the assessment to the *max*F_{ABC} for 2018. (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 2013-2017 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 $B_{35\%}$):

Scenario 6: In all future years, *F* is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above its MSY level in 2018, then the stock is not overfished.)

Scenario 7: In 2018 and 2019, *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 2018 of scenario 6 is 36,374, more than 2 times $B_{35\%}$ (16,848 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 2030 of scenario 7 (17,986 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 2018 of scenario 6 is 9,376 t, more than 2 times *B35%* (3,359 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 2030 of scenario 7 (3,582 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 2018 and 2019 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 2018-2019. 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	26.10%	73.90%	100.00%	48.96%	51.04%	100.00%
2018 ABC (t)	3,086	8,739	11,825	1,737	1,811	3,548
2019 ABC (t)	2,909	8,236	11,145	1,657	1,727	3,384

Ecosystem Considerations

Ecosystem effects on the stock

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 39). Polychaetes, euphausiids, and miscellaneous worms were the most important prey for rex sole in the Gulf of Alaska (Figure 40). 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 41). 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 and Table 27 show the contribution of the GOA rex sole fishery to bycatch of non-target and prohibited species. No birds were recorded as bycatch in the GOA rex sole fishery. Halibut PSC and halibut mortality has decreased every year since 2013. The 2017 PSC data are all confidential as of October 8, 2017.

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 and catchability for GOA rex sole could be conducted.

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 2017 is through October 8, 2017.

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	3633	134	3498	2
2011	2877	131	2745	1
2012	2443	215	2228	Confidential
2013	3707	104	3603	0
2014	3577	126	3450	1
2015	1957	76	1881	Confidential
2016	1748	172	1574	3
2017	1315	45	1269	Confidential

Table 2. Proportion of catch by gear 1994 to 2017.

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

Table 3. Proportion of catch by quarter and fishery length samples by quarter for 1994-September 29, 2017 with conditional formatting showing a scale from no catches (white) to the highest proportion of catches (dark green) within each data source.

	Fishery Catches				**Fishery Length Samples**			
Year	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1994	0.14	0.38	0.35	0.12	0.22	0.23	0.4	0.14
1995	0.24	0.47	0.19	0.1	0.03	0.59	0.31	0.06
1996	0.33	0.33	0.22	0.12	0.3	0.43	0.26	0.01
1997	0.44	0.25	0.1	0.21	0.28	0.37	0.09	0.26
1998	0.31	0.48	0.17	0.04	0.24	0.67	0.07	0.02
1999	0.25	0.48	0.18	0.08	0.2	0.67	0.06	0.07
2000	0.2	0.58	0.15	0.07	0.17	0.65	0.08	0.1
2001	0.19	0.62	0.13	0.05	0.05	0.92	0.02	0.01
2002	0.14	0.67	0.16	0.04	0.06	0.9	0.03	0.01
2003	0.13	0.59	0.22	0.07	0.09	0.78	0.12	0.02
2004	0.17	0.51	0.31	0.01	0.02	0.93	0.05	0
2005	0.34	0.4	0.25	0.01	0.19	0.59	0.22	0
2006	0.24	0.29	0.37	0.09	0.14	0.49	0.25	0.11
2007	0.31	0.38	0.25	0.07	0.2	0.64	0.09	0.07
2008	0.23	0.43	0.27	0.07	0.18	0.54	0.25	0.04
2009	0.22	0.37	0.3	0.11	0.08	0.37	0.46	0.09
2010	0.17	0.53	0.13	0.17	0.19	0.63	0.09	0.09
2011	0.2	0.49	0.22	0.1	0.15	0.48	0.31	0.05
2012	0.2	0.45	0.2	0.15	0.05	0.48	0.43	0.04
2013	0.23	0.61	0.07	0.1	0.1	0.76	0.09	0.05
2014	0.2	0.66	0.1	0.04	0.06	0.91	0.03	0
2015	0.1	0.58	0.11	0.21	0	0.76	0.06	0.17
2016	0.22	0.48	0.14	0.15	0.01	0.79	0.11	0.09
2017	0.22	0.6	0.18	0	0.19	0.81	0	0

Table 4. Proportion of catch by NMFS area and fishery length samples by NMFS area for 1994-September 29, 2017 with conditional formatting showing a scale from no catches (white) to the highest proportion of catches (dark green) within each data source.

	Fishery Catches					Fishery Length Samples				
Year	610	620	630	640	650	610	620	630	640	650
1994	0.01	0.37	0.6	0.02	0	0	0.39	0.52	0.05	0.02
1995	0.05	0.34	0.56	0.04	0	0	0.26	0.67	0.07	0
1996	0.09	0.52	0.35	0.03	0	0.09	0.38	0.5	0.03	0
1997	0.21	0.52	0.22	0.04	0.01	0.17	0.49	0.08	0.08	0.18
1998	0.16	0.3	0.52	0.01	0	0.12	0.36	0.51	0.02	0
1999	0.2	0.45	0.33	0.01	0.01	0.15	0.66	0.19	0	0
2000	0.25	0.33	0.42	0	0	0.37	0.4	0.24	0	0
2001	0.15	0.37	0.49	0	0	0.1	0.58	0.33	0	0
2002	0.13	0.49	0.38	0	0	0.14	0.75	0.12	0	0
2003	0.22	0.49	0.29	0	0	0.16	0.66	0.18	0	0
2004	0.36	0.17	0.47	0	0	0.63	0.25	0.12	0	0
2005	0.26	0.37	0.36	0	0	0.21	0.69	0.1	0	0
2006	0.11	0.45	0.44	0	0	0.38	0.1	0.52	0	0
2007	0.14	0.27	0.59	0	0	0.29	0.43	0.29	0	0
2008	0.07	0.26	0.67	0	0	0.14	0.51	0.35	0	0
2009	0.07	0.5	0.43	0	0	0.19	0.67	0.14	0	0
2010	0.04	0.42	0.54	0	0	0.02	0.66	0.32	0	0
2011	0.05	0.39	0.56	0	0	0.12	0.61	0.27	0.01	0
2012	0.09	0.36	0.55	0	0	0.16	0.66	0.18	0	0
2013	0.03	0.35	0.62	0	0	0.07	0.59	0.35	0	0
2014	0.04	0.28	0.69	0	0	0.08	0.57	0.35	0	0
2015	0.04	0.44	0.52	0	0	0.07	0.67	0.27	0	0
2016	0.1	0.32	0.58	0	0	0.17	0.45	0.36	0.02	0
2017	0.04	0.6	0.36	0	0	0.11	0.83	0.06	0	0

Table 5. Historical catch specifications, percent of the catch retained, and percent of the TAC and ABC caught from 1995-2017. Total catch in 2017 is the catch up to October 8, 2017.

Year	**OFL (t)**	**ABC (t)**	**TAC (t)**	**Total Catch**	**% Retained**	**% of TAC caught**	**% of ABC Caught**
1995	13,091	11,210	9,690	4,021	90%	41%	36%
1996	13,091	11,210	9,690	5,874	95%	61%	52%
1997	11,920	9,150	9,150	3,294	92%	36%	36%
1998	11,920	9,150	9,150	2,669	97%	29%	29%
1999	11,920	9,150	9,150	3,060	96%	33%	33%
2000	12,300	9,440	9,440	3,591	97%	38%	38%
2001	12,300	9,440	9,440	2,940	95%	31%	31%
2002	12,320	9,470	9,470	2,941	95%	31%	31%
2003	12,320	9,470	9,470	3,485	95%	37%	37%
2004	16,480	12,650	12,650	1,464	92%	12%	12%
2005	16,480	12,650	12,650	2,176	91%	17%	17%
2006	12,000	9,200	9,200	3,294	95%	36%	36%
2007	11,900	9,100	9,100	2,852	98%	31%	31%
2008	11,933	9,132	9,132	2,703	97%	30%	30%
2009	11,756	8,996	8,996	4,753	99%	53%	53%
2010	12,714	9,729	9,729	3,636	98%	37%	37%
2011	12,499	9,565	9,565	2,594	97%	27%	27%
2012	12,561	9,612	9,612	2,425	96%	25%	25%
2013	12,492	9,560	9,560	3,707	98%	39%	39%
2014	12,207	9,341	9,341	3,577	99%	38%	38%
2015	11,957	9,150	9,150	1,957	98%	21%	21%
2016	9,791	7,493	7,493	1,748	96%	23%	23%
2017	10,860	8,311	8,311	1,315	97%	16%	16%

Table 6. GOA rex sole fishery closures by sub-area in (a) 2017 and (b) 2016
(a)

Sub-Area	Program	Status	Reason	Effective Date
GOA - Central 620/630	All	Bycatch	Regulations	1-Jan-17
GOA - Western 610	All	Bycatch	Regulations	1-Jan-17
West Yakutat - 640	All	Bycatch	Regulations	1-Jan-17
GOA - Central 620/630	All	Open	Regulations	20-Jan-17
GOA - Western 610	All	Open	Regulations	20-Jan-17
West Yakutat - 640	All	Open	Regulations	20-Jan-17
GOA - Central 620/630	All	Open	Regulations	1-Apr-17
GOA - Western 610	All	Open	Regulations	1-Apr-17
West Yakutat - 640	All	Open	Regulations	1-Apr-17
GOA - Central 620/630	All	Open	Regulations	1-Jul-17
GOA - Western 610	All	Open	Regulations	1-Jul-17
West Yakutat - 640	All	Open	Regulations	1-Jul-17
GOA - Central 620/630	All	Open	Regulations	1-Sep-17
GOA - Western 610	All	Open	Regulations	1-Sep-17
West Yakutat - 640	All	Open	Regulations	1-Sep-17
GOA - Central 620/630	All	Open	Regulations	1-Oct-17
GOA - Western 610	All	Open	Regulations	1-Oct-17
West Yakutat - 640	All	Open	Regulations	1-Oct-17

b.

Sub-Area	Program	Status	Reason	Effective Date
GOA - Central 620/630	All	Bycatch	Regulations	1-Jan-16
GOA - Western 610	All	Bycatch	Regulations	1-Jan-16
West Yakutat - 640	All	Bycatch	Regulations	1-Jan-16
GOA - Central 620/630	All	Open	Regulations	20-Jan-16
GOA - Western 610	All	Open	Regulations	20-Jan-16
West Yakutat - 640	All	Open	Regulations	20-Jan-16
GOA - Central 620/630	All	Bycatch	Halibut	16-Mar-16
GOA - Western 610	All	Bycatch	Halibut	16-Mar-16
West Yakutat - 640	All	Bycatch	Halibut	16-Mar-16
GOA - Central 620/630	All	Open	Regulations	1-Apr-16
GOA - Western 610	All	Open	Regulations	1-Apr-16
West Yakutat - 640	All	Open	Regulations	1-Apr-16
GOA - Central 620/630	All	Bycatch	Halibut	30-Apr-16
GOA - Western 610	All	Bycatch	Halibut	30-Apr-16
West Yakutat - 640	All	Bycatch	Halibut	30-Apr-16
GOA - Central 620/630	All	Open	Halibut	15-May-16
West Yakutat - 640	All	Open	Halibut	15-May-16

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

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

		Regulatory Area			
		Central	**Eastern**	**Western**	**Total**
1984		**40,688**	**13,311**	**6,672**	**60,670**
	1	1,423	2,235	329	3,987
	101	26,777	7,519	2,744	37,040
	201	8,557	2,041	2,485	13,083
	301	2,900	1,223	1,038	5,161
	501	689	292	76	1,057
	701	342	0	0	342
1987		**39,722**	**15,304**	**8,801**	**63,826**
	1	2,504	2,246	941	5,691
	101	24,515	9,351	6,379	40,244
	201	11,537	2,031	940	14,508
	301	711	767	335	1,812
	501	426	909	207	1,542
	701	30		0	30
1990		**75,147**	**16,313**	**6,765**	**98,225**
	1	8,717	5,472	1,272	15,460
	101	48,066	8,049	3,718	59,833
	201	17,970	2,097	1,724	21,791
	301	394	696	51	1,140
1993		**55,310**	**20,901**	**10,760**	**86,911**
	1	4,980	3,143	3,170	11,233
	101	36,890	11,115	6,059	54,064
	201	11,665	4,754	577	16,995
	301	1,775	1,889	954	4,619
1996		**43,778**	**19,560**	**9,419**	**72,757**
	1	4,421	2,460	3,522	10,403
	101	29,214	10,784	3,421	43,419
	201	9,049	4,036	1,844	14,929
	301	1,094	2,280	632	4,006
1999		**42,750**	**19,464**	**12,755**	**74,969**
	1	2,677	4,365	7,640	14,682
	101	30,570	7,271	2,399	40,239
	201	8,231	6,142	1,393	15,766
	301	1,001	1,523	1,317	3,841
	501	271	163	6	440
	701	0	0	0	0
2001		**41,687**		**9,571**	**51,258**
	1	6,458		1,284	7,742
	101	24,792		4,414	29,206
	201	8,964		2,081	11,045
	301	1,473		1,793	3,265
2003		**57,973**	**28,659**	**13,265**	**99,897**
	1	6,220	7,411	3,898	17,529
	101	37,610	14,832	6,345	58,787
	201	13,078	3,668	2,348	19,094
	301	985	2,368	664	4,017
	501	81	380	9	470
2005		**60,600**	**27,795**	**12,766**	**101,161**
	1	8,142	4,061	2,580	14,783

	101	40,766	15,392	8,902	65,060
	201	10,457	5,241	939	16,637
	301	1,136	3,063	335	4,535
	501	98	29	9	136
	701	0	10	0	10
2007		**76,514**	**15,672**	**11,614**	**103,800**
	1	4,505	2,022	2,577	9,105
	101	55,711	9,466	6,338	71,514
	201	13,371	3,050	1,947	18,368
	301	2,803	948	752	4,504
	501	124	186	0	309
	701	0	0	0	0
2009		**82,091**	**22,873**	**19,780**	**124,744**
	1	8,533	3,419	4,065	16,017
	101	52,749	13,539	13,375	79,662
	201	19,267	3,801	1,964	25,032
	301	1,332	1,272	376	2,980
	501	211	843	0	1,054
	701	0	0	0	0
2011		**63,490**	**18,681**	**12,964**	**95,134**
	1	4,614	3,421	3,934	11,969
	101	39,259	7,942	5,998	53,199
	201	18,749	3,980	2,442	25,171
	301	726	3,027	590	4,342
	501	143	311	0	454
2013		**64,188**	**22,913**	**13,877**	**100,978**
	1	4,784	7,110	837	12,731
	101	47,669	10,460	10,307	68,435
	201	10,686	2,998	1,899	15,583
	301	782	1,659	835	3,276
	501	267	686	0	952
2015		**48,903**	**22,474**	**15,936**	**87,286**
	1	5,116	7,437	2,839	15,365
	101	33,365	9,593	9,733	52,691
	201	9,431	2,890	3,096	15,416
	301	906	1,919	269	3,093
	501	85	636	0	721
	701	0	0	0	0
2017		**57,176**	**20,352**	**20,192**	**97,720**
	1	3,837	1,291	7,916	13,044
	101	30,580	10,837	10,132	51,550
	201	21,392	4,288	1,498	27,179
	301	1,276	3,813	646	5,736
	501	90	123	0	213

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 survey likelihood component can be compared for models 15.0, 17.0, and 17.1, but not 17.2. The length composition likelihood component can be compared for models 15.0 and 17.0. The age composition likelihood component and the total likelihood cannot be compared between any of the models.

Likelihood Component	2015 Model, New Data 15.0	Added Fishery Ages 17.0	Estimates growth and adds fishery ages 17.1	Estimates growth by region and adds fishery ages 17.2
TOTAL	258	502	2,995	2,543
Survey	-14.91	-12.15	-1.99	-12.10
Length_comp	200	273	599	488
Age_comp	77	243	2,402	2,067
Recruitment	-4.812	-2.592	-4.772	-1.522

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

	Models 15.0 & 17.0		**Model 17.1**		**Model 17.2: West-Central**		**Model 17.2: Eastern**	
Parameter	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
Length at age 2 (f)	14.99	NA	14.15	0.46	13.77	0.54	13.52	0.88
Length at age 20 (f)	44.78	NA	45.51	0.19	46.50	0.20	36.76	0.28
von Bertalanffy k (f)	0.32	NA	0.26	0.01	0.28	0.01	0.30	0.02
CV in length at age 2 (f)	0.13	NA	0.18	0.01	0.17	0.01	0.17	0.02
CV in length at age 20 (f)	0.08	NA	0.11	0.00	0.09	0.00	0.10	0.00
Length at age 2 (m)	14.56	NA	14.72	0.55	14.16	0.60	14.41	1.02
Length at age 20 (m)	39.47	NA	39.93	0.16	40.86	0.16	34.55	0.25
von Bertalanffy k (m)	0.38	NA	0.32	0.01	0.33	0.01	0.31	0.02
CV in length at age 2 (m)	0.13	NA	0.19	0.01	0.19	0.01	0.19	0.02
CV in length at age 20 (m)	0.08	NA	0.10	0.00	0.08	0.00	0.08	0.00

Table 12. Estimates of selectivity parameters for all models.

		Model 15.0		Model 17.0		Model 17.1		Model 17.2: Western-Central		Model 17.2: Eastern	
		Est	StDev	Est	StDev	Est	StDev	Est	StDev	Est	StDev
Fishery	Peak: beginning size for the plateau (f)	12.592	0.920	8.036	0.196	8.310	0.185	7.764	0.221	NA	NA
	Ascending width (f; ln)	2.762	0.254	1.506	0.133	1.482	0.122	1.361	0.160	NA	NA
	Male peak offset	0.112	0.755	-0.942	0.291	-0.599	0.253	-0.969	0.285	NA	NA
	Male ascending width offset (ln)	0.101	0.257	-0.194	0.217	0.044	0.173	-0.239	0.229	NA	NA
Survey	Peak: beginning size for the plateau (f)	5.817	0.375	5.625	0.350	5.491	0.139	6.151	0.143	5.355	0.226
	Ascending width (f; ln)	1.771	0.221	1.639	0.220	1.434	0.096	1.702	0.078	1.337	0.158
	Male peak offset	-0.398	0.461	-0.351	0.435	-0.605	0.175	NA	NA	NA	NA
	Male ascending width offset (ln)	-0.293	0.301	-0.280	0.299	-0.388	0.141	NA	NA	NA	NA

Table 13. Log of unfished number of recruits estimated for each model (Est) and corresponding standard deviations (Std. Dev.)

	Model 15.0		Model 17.0		Model 17.1		Model 17.2*	
Parameter	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**	**Est**	**Std. Dev.**
$\ln(R_0)$	11.5683	0.0367	11.5432	0.0348	11.4535	0.0315	11.6351	0.0306

*A non-time-varying recruitment allocation parameter determines the proportion of total recruitment that settles in each area of the model: the model estimates that 0.2975 is the proportion of recruits each year that settle in the Eastern GOA and 0.7025 settle in the Western-Central area.

Table 14. Estimated yearly recruitment deviations for the current base case model. Recruitment deviations are fixed at 0 for years 2016 onward, as no information exists to inform recruitment deviations in these years yet.

Year	Recruitment Deviations	Std. Dev.	Year	Recruitment Deviations	Std. Dev.
1965	-0.512	0.419	1995	-0.316	0.091
1966	-0.434	0.393	1996	-0.013	0.081
1967	-0.373	0.368	1997	0.468	0.067
1968	0.045	0.299	1998	0.564	0.064
1969	-0.202	0.310	1999	0.588	0.062
1970	-0.556	0.334	2000	0.356	0.068
1971	-0.320	0.292	2001	0.114	0.076
1972	-0.406	0.289	2002	0.092	0.082
1973	-0.493	0.276	2003	0.649	0.069
1974	-0.310	0.248	2004	0.517	0.080
1975	-0.220	0.235	2005	0.835	0.069
1976	-0.072	0.210	2006	0.143	0.097
1977	0.080	0.190	2007	0.045	0.101
1978	0.078	0.180	2008	-0.637	0.138
1979	0.004	0.172	2009	-0.695	0.156
1980	-0.015	0.157	2010	-0.020	0.140
1981	-0.419	0.193	2011	-0.054	0.172
1982	0.049	0.150	2012	-0.887	0.300
1983	0.369	0.132	2013	-1.254	0.401
1984	0.339	0.122	2014	0.576	0.249
1985	0.449	0.103	2015	0.926	0.337
1986	0.279	0.101			
1987	0.306	0.094			
1988	-0.206	0.108			
1989	-0.481	0.116			
1990	-0.435	0.110			
1991	-0.846	0.128			
1992	-0.616	0.113			
1993	-0.670	0.116			
1994	-0.532	0.104			

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

Year	Estimate	StdDev	Year	Estimate	StdDev
1982	0.016	0.001	**2001**	0.016	0.001
1983	0.010	0.001	**2002**	0.010	0.001
1984	0.006	0.000	**2003**	0.006	0.000
1985	0.002	0.000	**2004**	0.002	0.000
1986	0.001	0.000	**2005**	0.001	0.000
1987	0.018	0.001	**2006**	0.018	0.001
1988	0.018	0.001	**2007**	0.018	0.001
1989	0.009	0.000	**2008**	0.009	0.000
1990	0.018	0.001	**2009**	0.018	0.001
1991	0.064	0.002	**2010**	0.064	0.002
1992	0.042	0.001	**2011**	0.042	0.001
1993	0.042	0.001	**2012**	0.042	0.001
1994	0.053	0.002	**2013**	0.053	0.002
1995	0.063	0.002	**2014**	0.063	0.002
1996	0.104	0.003	**2015**	0.104	0.003
1997	0.065	0.002	**2016**	0.065	0.002
1998	0.058	0.002	**2017**	0.058	0.002
1999	0.073	0.003			
2000	0.093	0.003			

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
2017	38,069	38,069	38,069	38,069	38,069	38,069	38,069
2018	36,374	36,374	36,374	36,374	36,374	36,374	36,374
2019	34,569	34,569	34,569	34,569	34,569	28,007	29,412
2020	34,032	34,032	34,032	34,032	34,032	23,612	25,661
2021	29,935	29,935	34,816	34,386	35,796	21,631	23,021
2022	26,973	26,973	35,698	34,871	37,627	20,274	21,200
2023	24,737	24,737	36,429	35,242	39,256	19,321	19,876
2024	23,111	23,111	37,004	35,506	40,648	18,739	19,053
2025	21,950	21,950	37,449	35,684	41,824	18,378	18,548
2026	21,165	21,165	37,797	35,807	42,818	18,168	18,257
2027	20,666	20,666	38,087	35,909	43,672	18,064	18,108
2028	20,364	20,364	38,335	36,001	44,411	18,026	18,048
2029	20,182	20,182	38,544	36,080	45,045	18,016	18,026
2030	20,041	20,041	38,689	36,117	45,559	17,982	17,986

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
2017	0.03	0.03	0.03	0.03	0.03	0.03	0.03
2018	0.04	0.04	0.04	0.04	0.04	0.29	0.23
2019	0.05	0.05	0.05	0.05	0.05	0.29	0.23
2020	0.23	0.23	0.04	0.05	0.00	0.29	0.29
2021	0.23	0.23	0.04	0.05	0.00	0.29	0.29
2022	0.23	0.23	0.04	0.05	0.00	0.28	0.28
2023	0.23	0.23	0.04	0.05	0.00	0.27	0.27
2024	0.23	0.23	0.04	0.05	0.00	0.26	0.27
2025	0.23	0.23	0.04	0.05	0.00	0.26	0.26
2026	0.22	0.22	0.04	0.05	0.00	0.26	0.26
2027	0.22	0.22	0.04	0.05	0.00	0.26	0.26
2028	0.22	0.22	0.04	0.05	0.00	0.26	0.26
2029	0.22	0.22	0.04	0.05	0.00	0.26	0.26
2030	0.22	0.22	0.04	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
2017	1,550	1,550	1,550	1,550	1,550	1,550	1,550
2018	2,508	2,508	2,508	2,508	2,508	14,375	11,825
2019	2,508	2,508	2,508	2,508	2,508	10,956	9,462
2020	11,181	11,181	1,863	2,681	0	9,467	10,284
2021	10,018	10,018	1,952	2,773	0	8,869	9,424
2022	9,029	9,029	2,010	2,822	0	8,145	8,608
2023	8,264	8,264	2,047	2,847	0	7,537	7,836
2024	7,695	7,695	2,076	2,865	0	7,183	7,354
2025	7,247	7,247	2,098	2,876	0	6,970	7,062
2026	6,933	6,933	2,116	2,883	0	6,851	6,898
2027	6,733	6,733	2,131	2,890	0	6,791	6,815
2028	6,614	6,614	2,144	2,897	0	6,771	6,782
2029	6,545	6,545	2,156	2,904	0	6,772	6,777
2030	6,489	6,489	2,163	2,906	0	6,755	6,757

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
2017	9,871	9,871	9,871	9,871	9,871	9,871	9,871
2018	9,376	9,376	9,376	9,376	9,376	9,376	9,376
2019	9,006	9,006	9,006	9,006	9,006	6,844	7,234
2020	8,908	8,908	8,908	8,908	8,908	5,478	6,022
2021	7,374	7,374	8,995	8,612	8,995	4,790	5,145
2022	6,293	6,293	9,112	8,391	9,112	4,329	4,557
2023	5,520	5,520	9,211	8,195	9,211	4,007	4,148
2024	4,982	4,982	9,287	8,023	9,287	3,813	3,892
2025	4,610	4,610	9,345	7,874	9,345	3,699	3,741
2026	4,362	4,362	9,391	7,749	9,391	3,637	3,658
2027	4,205	4,205	9,432	7,649	9,432	3,606	3,617
2028	4,110	4,110	9,468	7,571	9,468	3,595	3,600
2029	4,052	4,052	9,500	7,508	9,500	3,591	3,593
2030	4,010	4,010	9,520	7,451	9,520	3,581	3,582

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
2017	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2018	0.00	0.00	0.00	0.00	0.00	0.31	0.25
2019	0.00	0.00	0.00	0.00	0.00	0.31	0.25
2020	0.25	0.25	0.00	0.05	0.00	0.31	0.31
2021	0.25	0.25	0.00	0.05	0.00	0.31	0.31
2022	0.25	0.25	0.00	0.05	0.00	0.31	0.31
2023	0.25	0.25	0.00	0.05	0.00	0.30	0.30
2024	0.25	0.25	0.00	0.05	0.00	0.29	0.29
2025	0.25	0.25	0.00	0.05	0.00	0.28	0.29
2026	0.24	0.24	0.00	0.05	0.00	0.28	0.28
2027	0.24	0.24	0.00	0.05	0.00	0.28	0.28
2028	0.24	0.24	0.00	0.05	0.00	0.28	0.28
2029	0.24	0.24	0.00	0.05	0.00	0.28	0.28
2030	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
2017	2	2	2	2	2	2	2
2018	1	1	1	1	1	4,331	3,548
2019	1	1	1	1	1	3,128	2,708
2020	3,398	3,398	0	800	0	2,551	2,806
2021	2,844	2,844	0	787	0	2,261	2,428
2022	2,419	2,419	0	768	0	2,023	2,137
2023	2,114	2,114	0	748	0	1,815	1,900
2024	1,904	1,904	0	732	0	1,685	1,735
2025	1,751	1,751	0	718	0	1,609	1,636
2026	1,642	1,642	0	706	0	1,569	1,582
2027	1,570	1,570	0	697	0	1,549	1,555
2028	1,527	1,527	0	690	0	1,542	1,545
2029	1,500	1,500	0	684	0	1,540	1,542
2030	1,481	1,481	0	679	0	1,535	1,536

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

	2015 Assessment			*2017 Assessment*		
Year	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. dev**	**Recruits (Age 3)**	**Recruits (Age 0)**	**Std. dev**
1981						
1982	41,482	109,895	39,073	61,316	105,098	15,858
1983	42,848	134,359	42,463	59,823	144,103	18,860
1984	53,239	115,260	33,387	39,743	139,053	16,593
1985	65,992	120,360	27,370	63,111	154,457	15,463
1986	80,682	81,861	18,470	86,533	129,565	12,731
1987	69,213	106,408	17,368	83,501	132,510	12,005
1988	72,275	69,799	17,618	92,750	78,978	8,446
1989	49,157	66,105	15,992	77,803	59,804	6,944
1990	63,897	67,566	15,105	79,571	62,661	6,819
1991	41,914	53,026	13,098	47,426	41,529	5,361
1992	39,696	56,642	13,125	35,911	52,278	5,893
1993	40,573	47,958	11,772	37,628	49,521	5,725
1994	31,842	60,975	13,314	24,938	56,856	5,897
1995	34,013	78,470	14,742	31,392	70,568	6,447
1996	28,799	102,590	17,303	29,737	95,589	7,727
1997	36,615	158,494	22,816	34,141	154,501	10,195
1998	47,121	140,311	22,102	42,375	170,189	10,789
1999	61,605	136,120	23,678	57,400	174,341	10,798
2000	95,175	132,195	22,752	92,775	138,178	9,423
2001	84,256	110,284	21,640	102,195	108,519	8,450
2002	81,739	90,007	19,115	104,689	106,159	8,997
2003	79,383	134,241	23,925	82,973	185,134	13,233
2004	66,225	124,948	21,982	65,164	162,319	13,389
2005	54,049	132,228	22,336	63,747	223,018	16,180
2006	80,611	59,067	14,231	111,171	111,620	11,303
2007	75,031	63,013	15,471	97,471	101,201	10,780
2008	79,402	26,933	9,624	133,920	51,179	7,395
2009	35,470	32,716	13,889	67,027	48,299	7,860
2010	37,839	233,793	41,012	60,770	94,900	13,867
2011	16,173	122,091	37,674	30,732	91,658	16,145
2012	19,646	163,140	32,474	29,003	39,850	12,262
2013	140,392	105,746	3,973	56,986	28,270	11,645
2014	73,315	105,746	3,973	55,040	180,497	45,371
2015	97,965	105,746		23,929	262,142	91107
2016				16,976	112,996	3454
2017				108,387	112,996	
Average	59,342	101,415		63,557	111,959	

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	43,077	73,836	18,239	31,262
1983	42,028	101,238	17,795	42,864
1984	27,921	97,691	11,822	41,362
1985	44,338	108,512	18,773	45,944
1986	60,793	91,025	25,740	38,540
1987	58,663	93,094	24,838	39,416
1988	65,161	55,486	27,589	23,493
1989	54,660	42,015	23,143	17,789
1990	55,902	44,022	23,669	18,639
1991	33,319	29,176	14,107	12,353
1992	25,229	36,727	10,682	15,550
1993	26,435	34,791	11,193	14,730
1994	17,520	39,944	7,418	16,912
1995	22,054	49,577	9,338	20,991
1996	20,891	67,155	8,846	28,434
1997	23,985	108,544	10,156	45,957
1998	29,770	119,565	12,605	50,624
1999	40,326	122,482	17,074	51,859
2000	65,178	97,076	27,597	41,102
2001	71,796	76,240	30,399	32,280
2002	73,548	74,581	31,141	31,578
2003	58,292	130,065	24,681	55,069
2004	45,780	114,036	19,384	48,283
2005	44,785	156,680	18,962	66,338
2006	78,102	78,418	33,069	33,202
2007	68,477	71,098	28,994	30,103
2008	94,084	35,955	39,836	15,223
2009	47,089	33,932	19,938	14,367
2010	42,693	66,672	18,077	28,229
2011	21,590	64,394	9,142	27,264
2012	20,376	27,997	8,627	11,854
2013	40,035	19,861	16,951	8,409
2014	38,668	126,807	16,372	53,690
2015	16,811	184,166	7,118	77,976
2016	11,926	79,385	5,050	33,611
2017	76,146	79,385	32,241	33,611
Average	44,651	78,656	18,906	33,303

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 2018 and 2019 are from projections using Scenario 1.

	2015 Assessment			*2017 Assessment*		
Year	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**	**Total Biomass (age 3+)**	**Spawning Biomass**	**Stdev_SPB**
1982	128,146	40,287	3,342	127,143	46,408	2,507
1983	83,452	38,780	3,037	99,299	46,648	2,381
1984	81,587	37,781	2,724	100,125	47,417	2,271
1985	81,428	37,361	2,435	100,169	48,245	2,168
1986	83,327	37,672	2,196	100,752	48,874	2,066
1987	87,719	38,892	2,029	103,035	49,321	1,959
1988	92,967	40,523	1,932	106,439	49,579	1,845
1989	97,696	42,811	1,916	110,173	50,734	1,746
1990	100,960	45,444	1,971	113,942	52,974	1,675
1991	104,380	47,126	2,036	118,207	55,080	1,621
1992	105,170	46,247	2,049	119,635	55,043	1,571
1993	101,180	45,789	1,974	115,398	55,074	1,514
1994	98,051	44,586	1,850	111,157	53,839	1,447
1995	93,862	42,488	1,729	105,083	50,996	1,367
1996	88,646	39,874	1,637	97,703	47,149	1,278
1997	82,727	36,036	1,574	89,760	41,919	1,188
1998	75,557	33,813	1,522	80,540	38,356	1,102
1999	72,500	32,147	1,476	75,234	35,546	1,026
2000	72,131	30,893	1,449	72,466	33,210	966
2001	75,230	30,514	1,463	72,909	31,704	931
2002	80,016	32,193	1,527	76,201	32,188	931
2003	86,671	35,247	1,642	82,765	34,481	980
2004	93,426	38,519	1,761	89,609	37,918	1,077
2005	98,501	42,724	1,869	94,713	42,708	1,196
2006	103,483	45,726	1,966	100,236	46,419	1,307
2007	107,540	47,084	2,027	106,135	48,480	1,396
2008	110,056	48,232	2,022	110,995	50,409	1,473
2009	113,154	49,560	1,994	118,540	52,952	1,570
2010	113,501	49,667	1,997	123,956	55,080	1,703
2011	109,702	49,603	2,038	125,073	57,713	1,858
2012	104,087	48,466	2,080	123,488	59,350	1,996
2013	97,408	46,191	2,099	119,548	59,091	2,080
2014	98,124	42,728	2,119	115,384	56,301	2,109
2015	99,119	41,418	2,304	109,839	52,735	2,109
2016	108,340	43,808	0	103,157	50,180	2,120
2017				96,924	47,939	2,153
2018				97,982	45,750	
2019				97,967	43,575	

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	103,884	23,259	38,698	7,710
1983	81,047	18,252	38,795	7,853
1984	81,552	18,574	39,381	8,036
1985	81,563	18,606	40,051	8,194
1986	82,000	18,752	40,582	8,292
1987	83,795	19,240	40,964	8,357
1988	86,532	19,908	41,082	8,498
1989	89,348	20,825	41,944	8,789
1990	92,269	21,673	43,776	9,198
1991	95,733	22,474	45,452	9,628
1992	96,867	22,768	45,069	9,974
1993	92,830	22,569	44,930	10,144
1994	89,118	22,039	43,770	10,069
1995	83,955	21,127	41,232	9,764
1996	77,608	20,095	37,841	9,308
1997	70,760	19,000	33,139	8,779
1998	62,561	17,980	30,106	8,249
1999	58,068	17,166	27,767	7,779
2000	55,739	16,726	25,782	7,429
2001	55,885	17,024	24,434	7,270
2002	58,276	17,925	24,802	7,386
2003	63,505	19,260	26,672	7,809
2004	69,058	20,551	29,467	8,452
2005	73,187	21,526	33,575	9,133
2006	78,035	22,201	36,731	9,687
2007	82,900	23,235	38,411	10,069
2008	86,739	24,256	40,005	10,404
2009	92,771	25,769	42,118	10,834
2010	97,301	26,655	43,714	11,366
2011	98,000	27,073	45,858	11,854
2012	96,790	26,698	47,271	12,079
2013	93,773	25,776	47,155	11,936
2014	90,521	24,863	44,806	11,495
2015	85,878	23,961	41,812	10,923
2016	80,413	22,744	39,807	10,374
2017	75,618	21,306	38,068	9,870
2018	76,644	21,338	36,374	9,376
2019	76,631	21,336	34,569	9,006

Table 26. Non-target catch in the directed GOA rex sole fishery in metric tons for the past 10 years. Conditional highlighting from white (lowest numbers) to green (highest numbers) is applied. Birds (recorded in numbers) have not been recorded as bycatch in the GOA rex sole fishery.

Species	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008
Benthic urochordata			0.05							
Bivalves							C		0.46	0.60
Brittle star unidentified	C		0.01		0.01		0.00	C	0.21	0.33
Capelin			0.01		0.00				0.02	0.00
Corals Bryozoans - Corals Bryozoans Unidentified			0.00		0.06	0.03	0.00	C	0.07	
Corals Bryozoans - Red Tree Coral					0.33					
Eelpouts	C		0.00				C	C	0.00	
Eulachon	C		0.00	0.00	0.04	0.13		0.17	0.19	0.00
Giant Grenadier	C				3.80	1.90	144.35	130.65	101.68	88.64
Greenlings				0.05				C	0.50	
Grenadier - Ratail Grenadier Unidentified										0.52
Grenadier - Rattail Grenadier Unidentified				5.03			83.75			
Gunnels										0.03
Hermit crab unidentified	C			0.00	0.01	0.01	0.01	C	0.07	0.00
Invertebrate unidentified			0.05					0.31	0.02	0.33
Large Sculpins - Bigmouth Sculpin						8.88			24.95	2.27
Large Sculpins - Great Sculpin									4.51	0.30
Large Sculpins - Hemilepidotus Unidentified									0.49	
Large Sculpins - Yellow Irish Lord						6.39			0.68	C
Misc crabs	C				0.00		C	0.07	1.06	0.98
Misc crustaceans	C		0.00			0.27	0.01			
Misc fish	C	0.07	1.75	1.03	3.94	1.70	2.98	7.01	16.61	7.94
Misc inverts (worms etc)							0.02	C		
Other Sculpins						0.07			0.89	0.98
Other osmerids		0.00	0.01	0.02			0.03	C	0.56	0.02
Pandalid shrimp	C	0.01	0.08	0.05	0.28	0.02	0.03	0.15	0.18	0.06
Polychaete unidentified			0.00		0.00			C	0.02	
Scypho jellies		0.13		0.17	0.27	C	0.00	0.80	0.34	
Sea anemone unidentified	C		0.04	0.03	0.02	0.07	0.04	0.21	2.67	C
Sea pens whips	C				0.00					
Sea star	C	0.18	0.40	0.18	1.45	0.24	1.26	4.18	2.87	1.84
Snails	C	0.01		0.02	0.14	0.02	0.06	0.13	0.34	0.94
Sponge unidentified	C	0.00	0.11	0.18	0.69		0.22	0.02	0.66	
State-managed Rockfish				1.37						
Stichaeidae	C		0.03		0.01			C	0.03	0.02
Urchins dollars cucumbers	C	0.02	0.21	0.05	0.27	0.32	0.11	0.74	1.14	0.02

Table 27. Prohibited species catch in the GOA rex sole directed fishery as a proportion of all prohibited species catch in the GOA for 2014-2017 in metric tons. PSC estimate reports halibut and herring, counts of fish for crab and salmon. "C" indicates confidential data.

	2017		2016		2015		2014		2013	
Species Group Name	PSC	Halibut Mort.	PSC	Halibut Mort.	PSC	Halibut Mort.	PSC	Halibut Mort.	PSC	Halibut Mort.
Bairdi Tanner Crab	C		0		81		233		750	
Blue King Crab	C		0		0		0		0	
Chinook Salmon	C		0		132		384		2,590	
Golden (Brown) King Crab	C		0		0		0		0	
Halibut	C	11	21	15	43	29	80	55	221	153
Herring	C		0		0		0		0	
Non-Chinook Salmon	C		0		0		116		251	
Opilio Tanner (Snow) Crab	C		0		0		0		0	
Red King Crab	C		0		0		0		0	
Grand Total	C	11	21	15	257	29	813	55	3,813	153

Figures

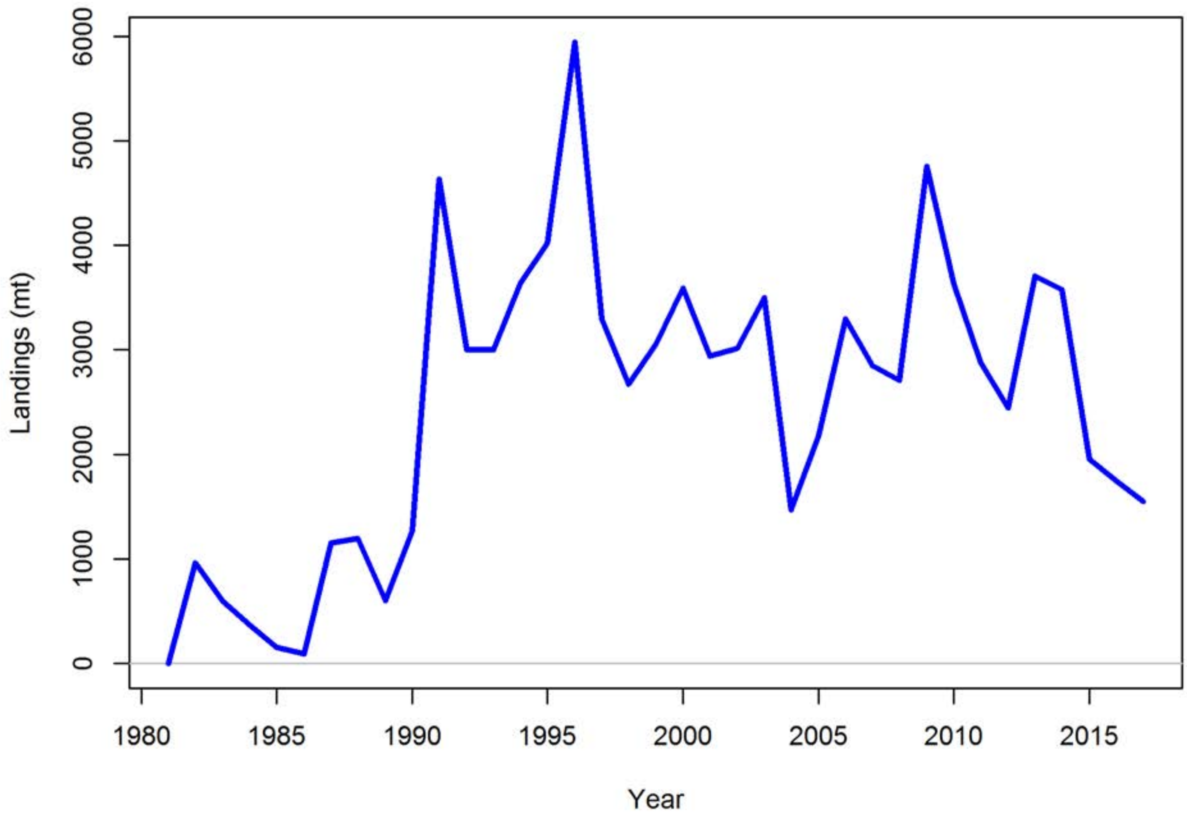


Figure 1. Fishery catches for GOA rex sole, 1982-2017. Catch for 2015 is through October 8, 2017.

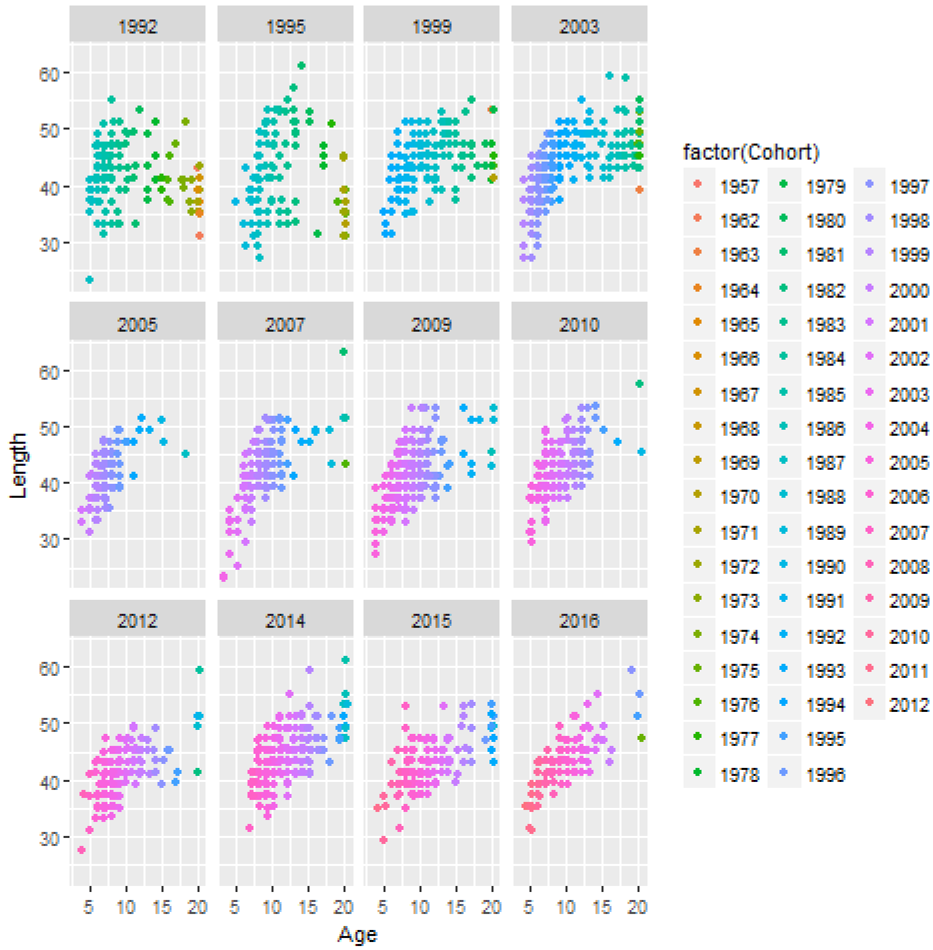


Figure 2a. Fishery age-length data by cohort and year for females.

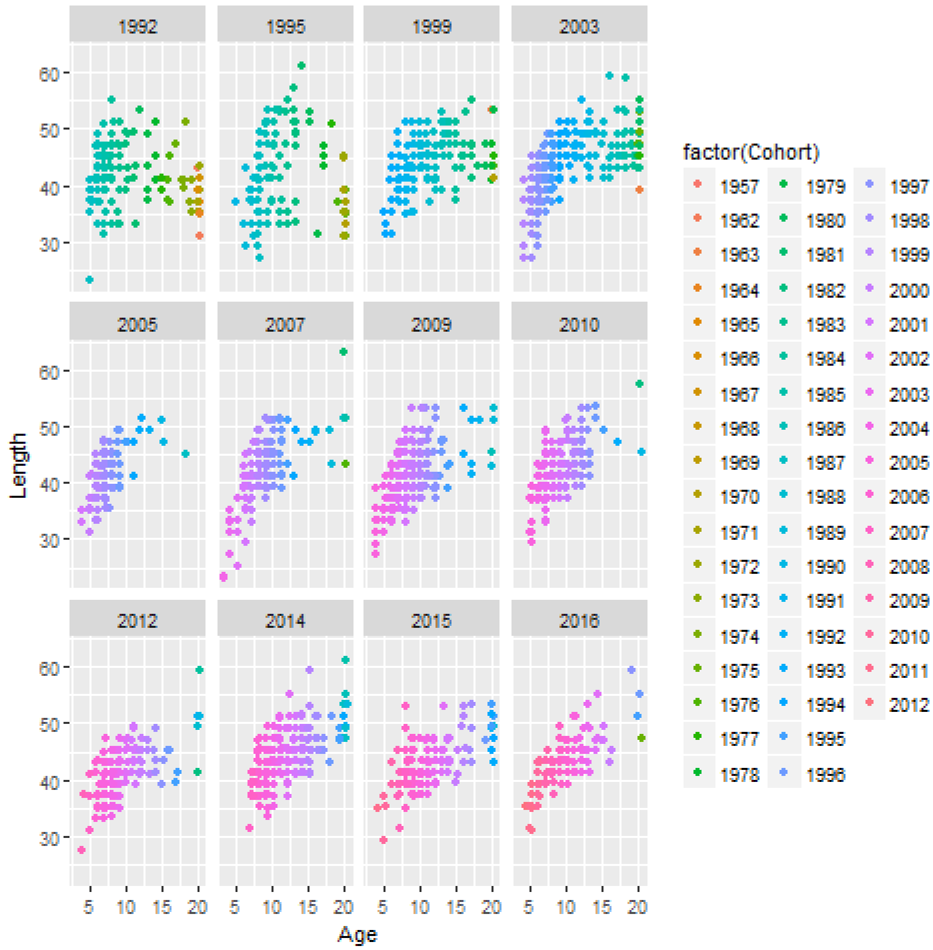


Figure 2b. Fishery age-length data by cohort and year for males.

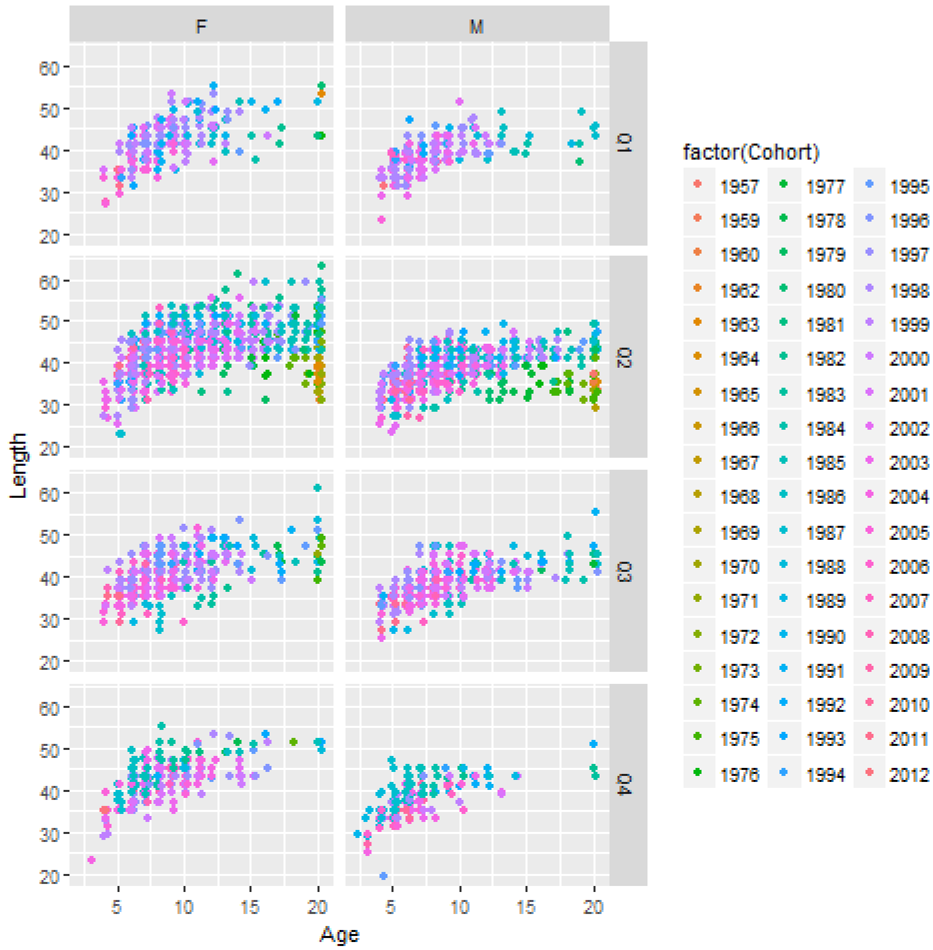


Figure 3. Fishery age-length data by season (quarter 1-4; rows), sex and cohort. "F" indicates females and "M" indicates males (columns).

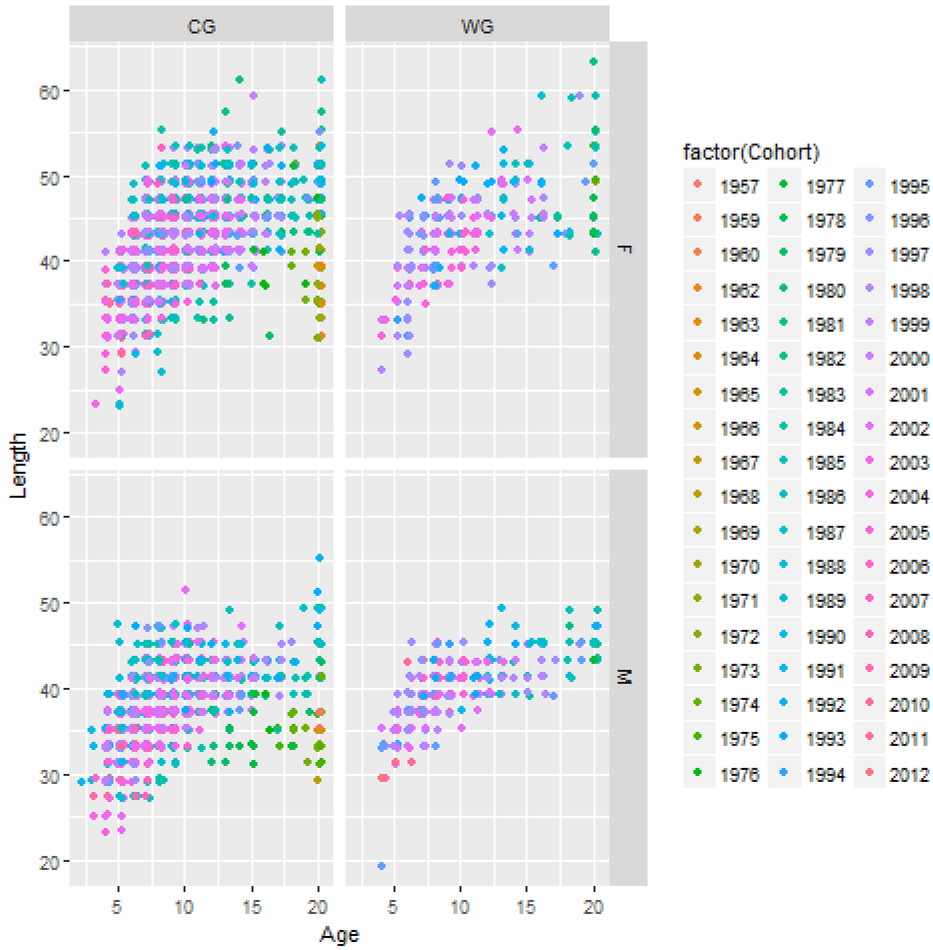


Figure 4. Fishery age-length data by management area (WG = Western GOA, CG = Central GOA). "F" indicates females and "M" indicates males. The fishery does not occur in the Eastern GOA.

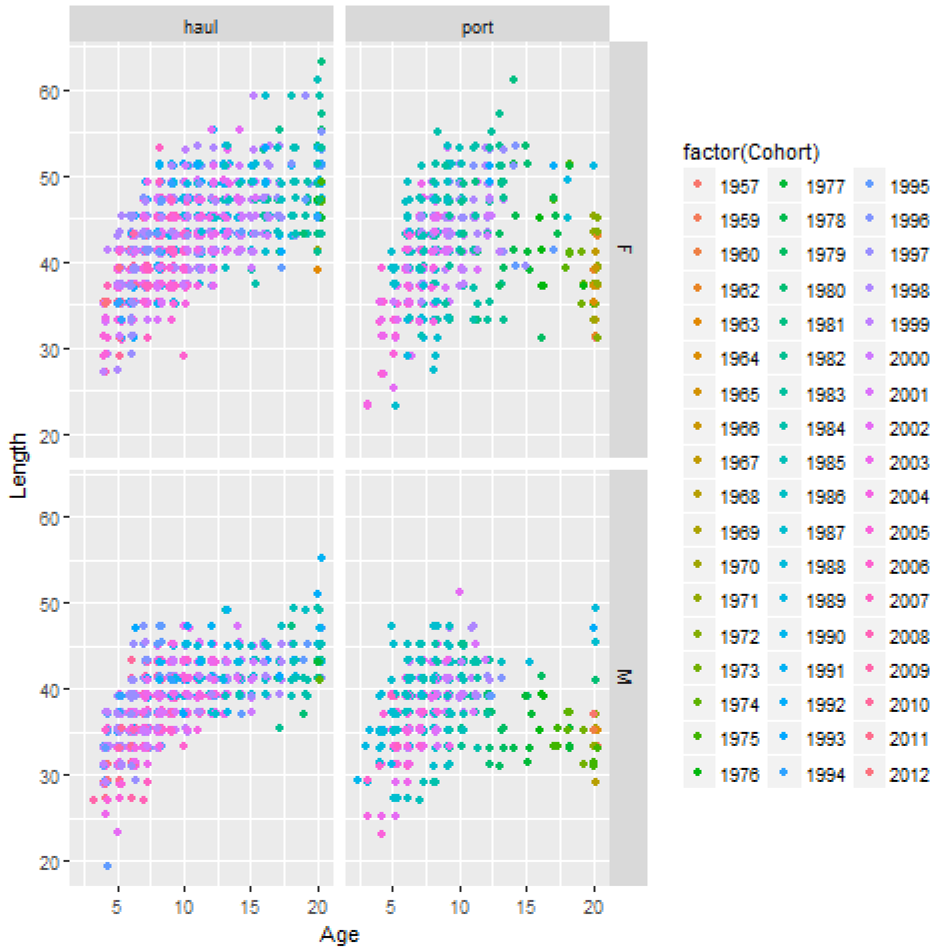


Figure 5. Fishery age-length data by cohort and for port data and haul data. "F" indicates females and "M" indicates males.

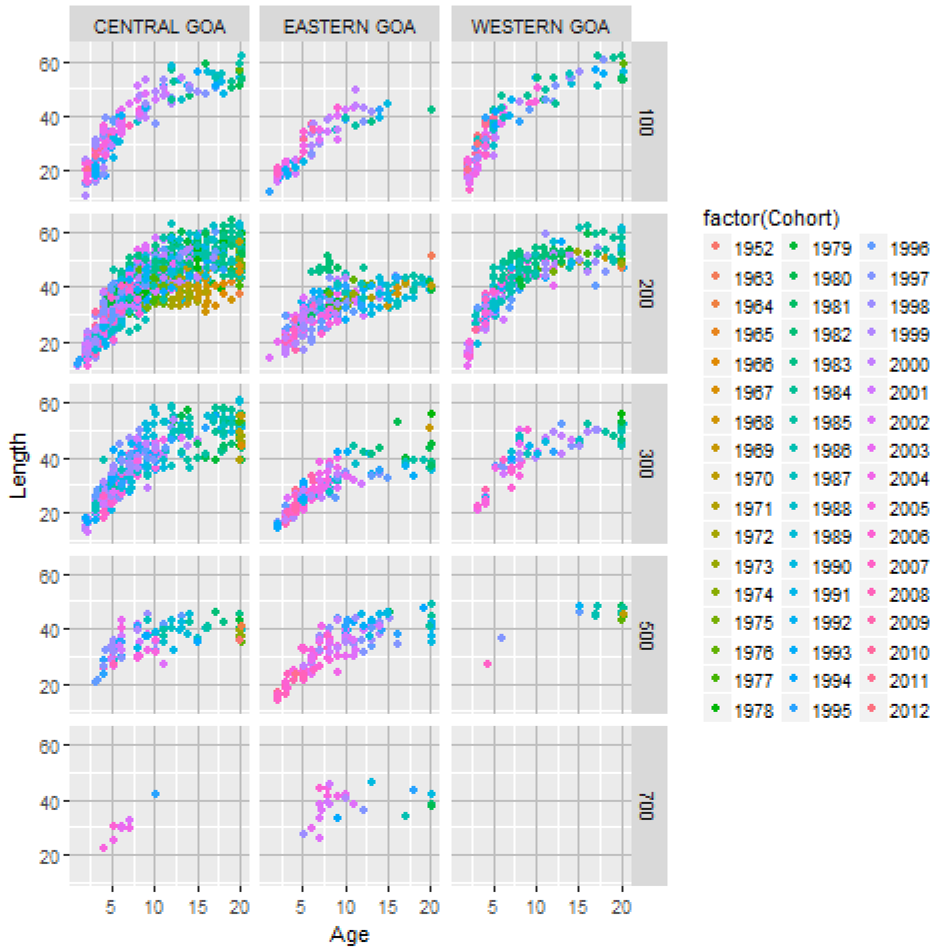


Figure 6. Female age-length data from the GOA trawl survey by cohort, management area (columns), and depth (rows).

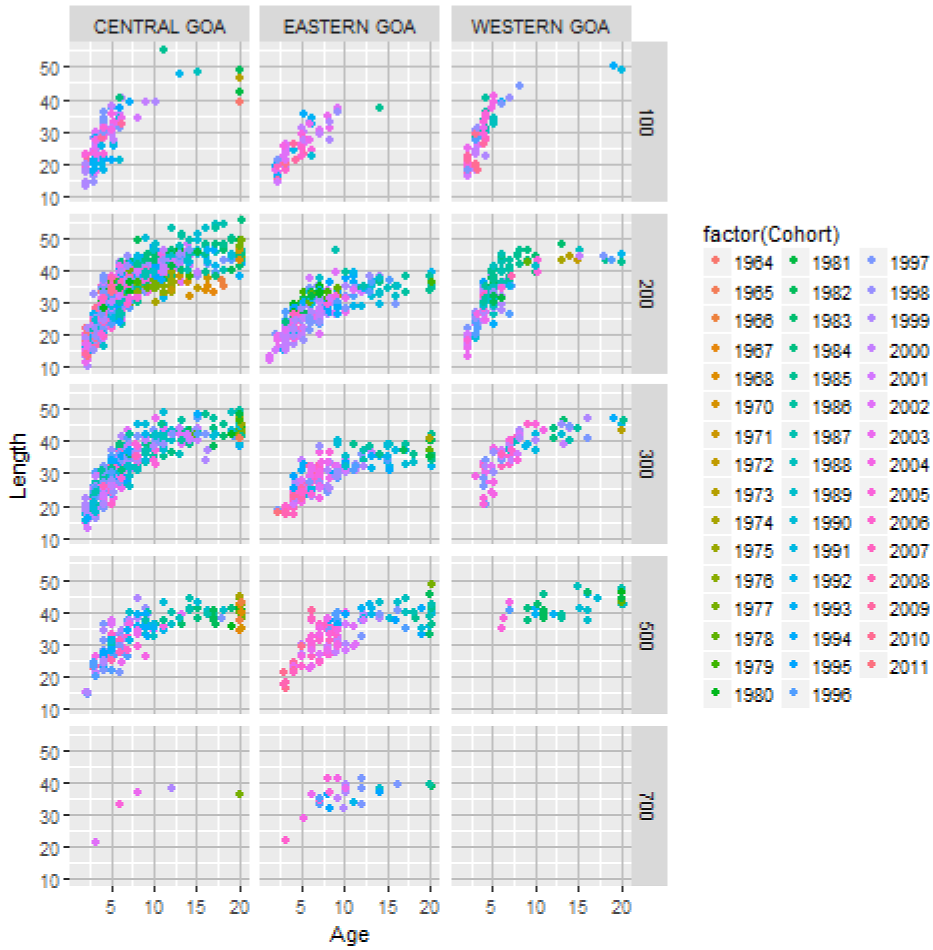


Figure 7. Male age-length data from the GOA trawl survey by cohort, management area (columns), and depth (rows).

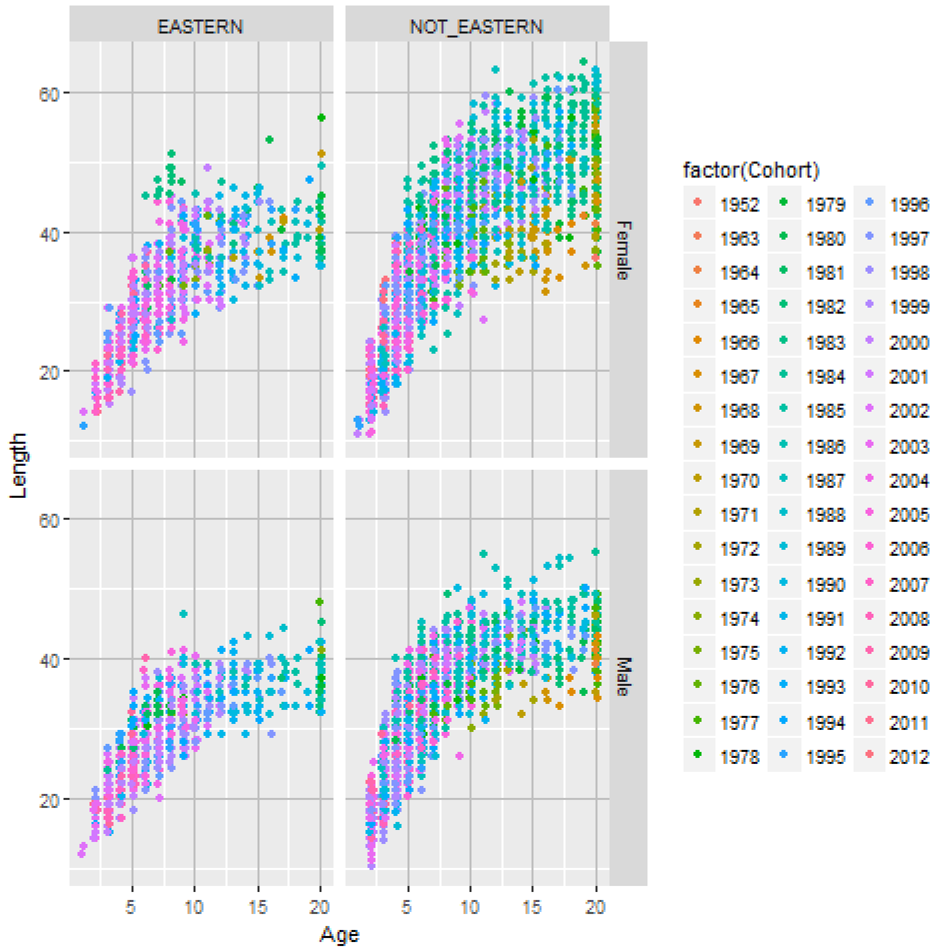


Figure 8. GOA trawl survey age-length data by cohort for the eastern GOA and for the Western-Central GOA (NOT_EASTERN) for females and males.

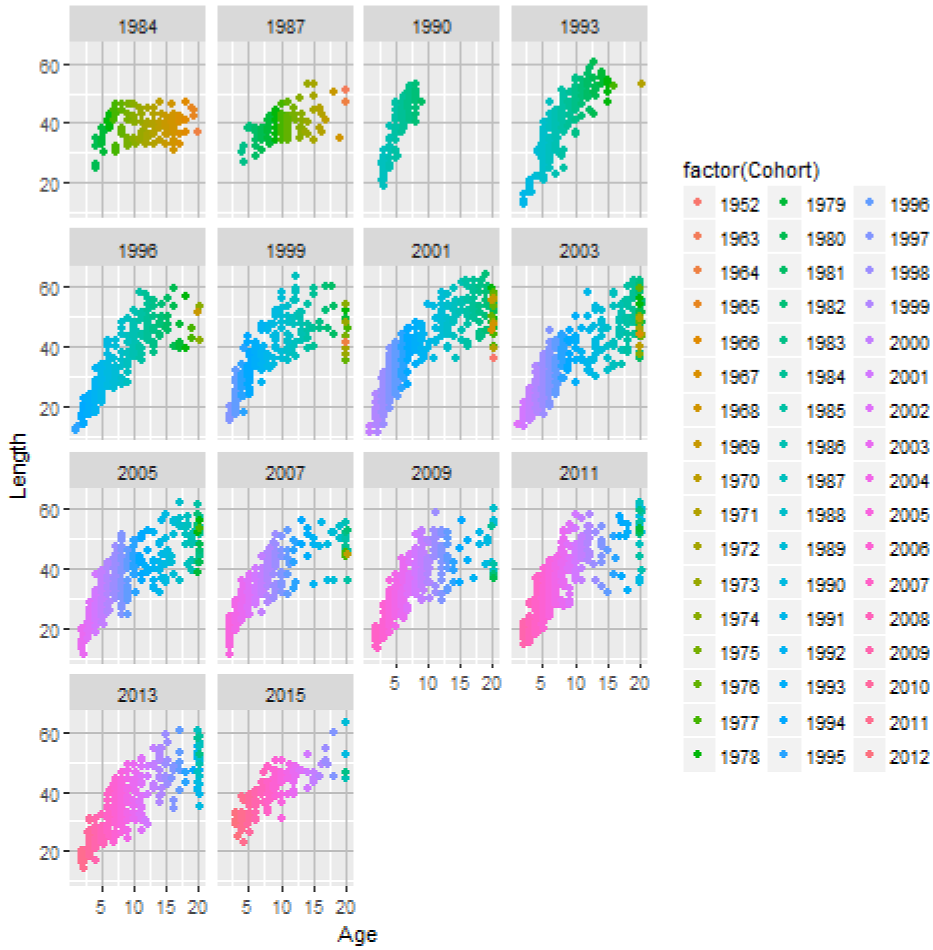


Figure 9. Female age-length data by cohort and year from the GOA trawl survey. A different ageing technique was used in 1990 (surface ageing), resulting in potentially biased results and 1990 age-length data were not used in the model.

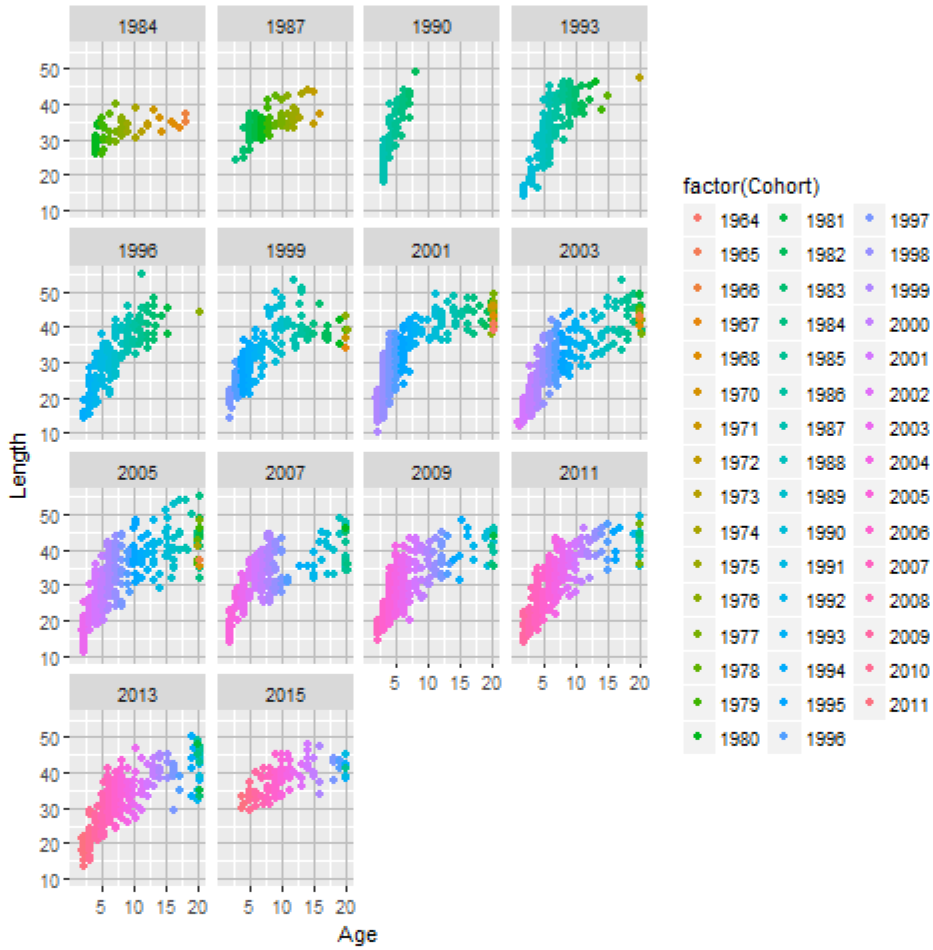


Figure 10. Male age-length data by cohort and year from the GOA trawl survey. A different ageing technique was used in 1990 (surface ageing), resulting in potentially biased results and 1990 age-length data were not used in the model.

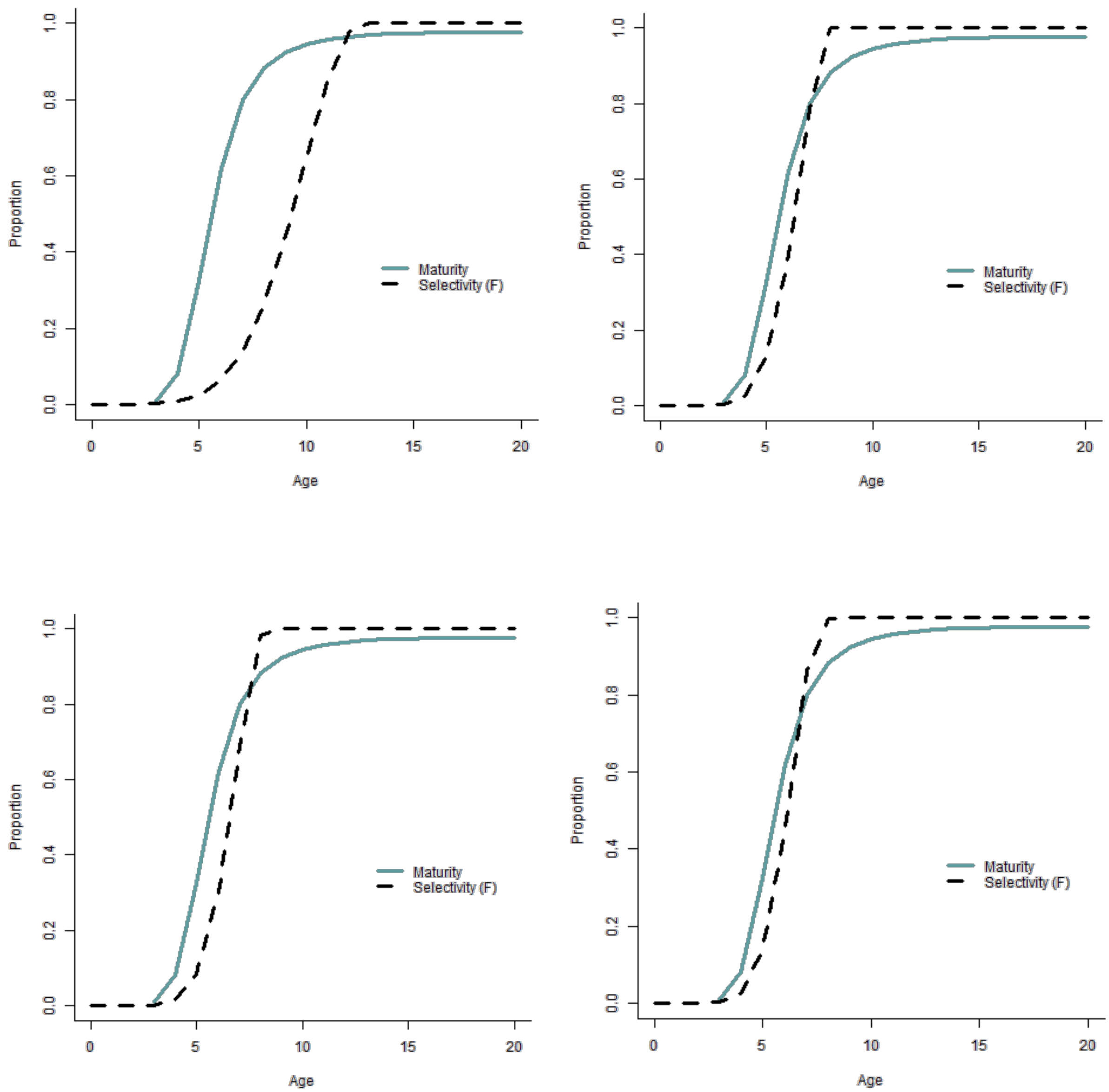


Figure 11. Maturity-at-age and female fishery selectivity-at-age for the 2015 model with new data (Model 15.0; top left), the 2015 model with newly aged fishery age data (Model 17.0; top right), the model with fishery age data and internal estimation of growth (Model 17.1; bottom left), and the base case growth morph model (Model 17.2; bottom right).

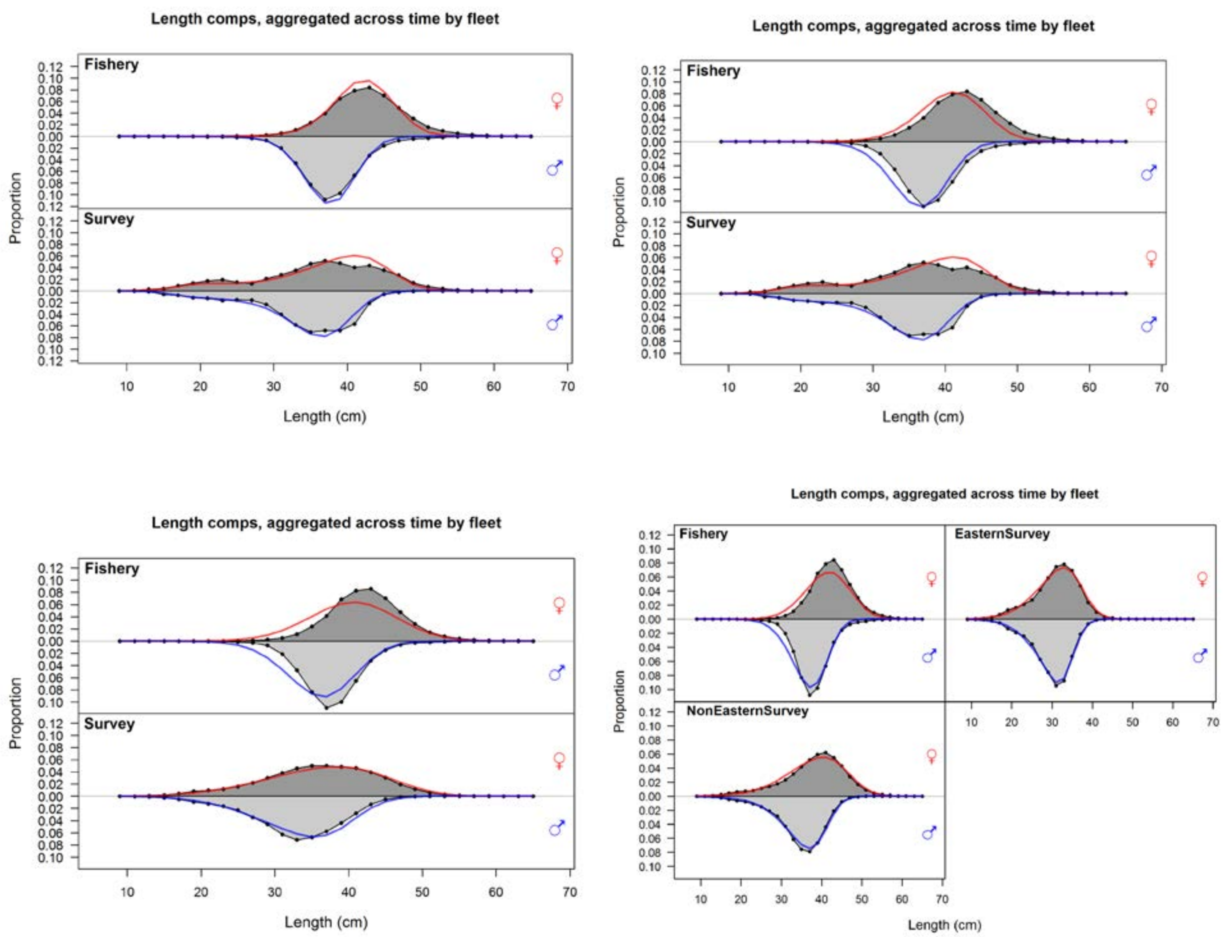


Figure 12. Predicted (red and blue lines) and observed length compositions (grey filled areas), aggregated over time for the 2015 model with new data (Model 15.0; top left), the 2015 model with newly aged fishery age data (Model 17.0; top right), the model with fishery age data and internal estimation of growth (Model 17.1; bottom left), and the base case growth morph model (Model 17.2; bottom right).

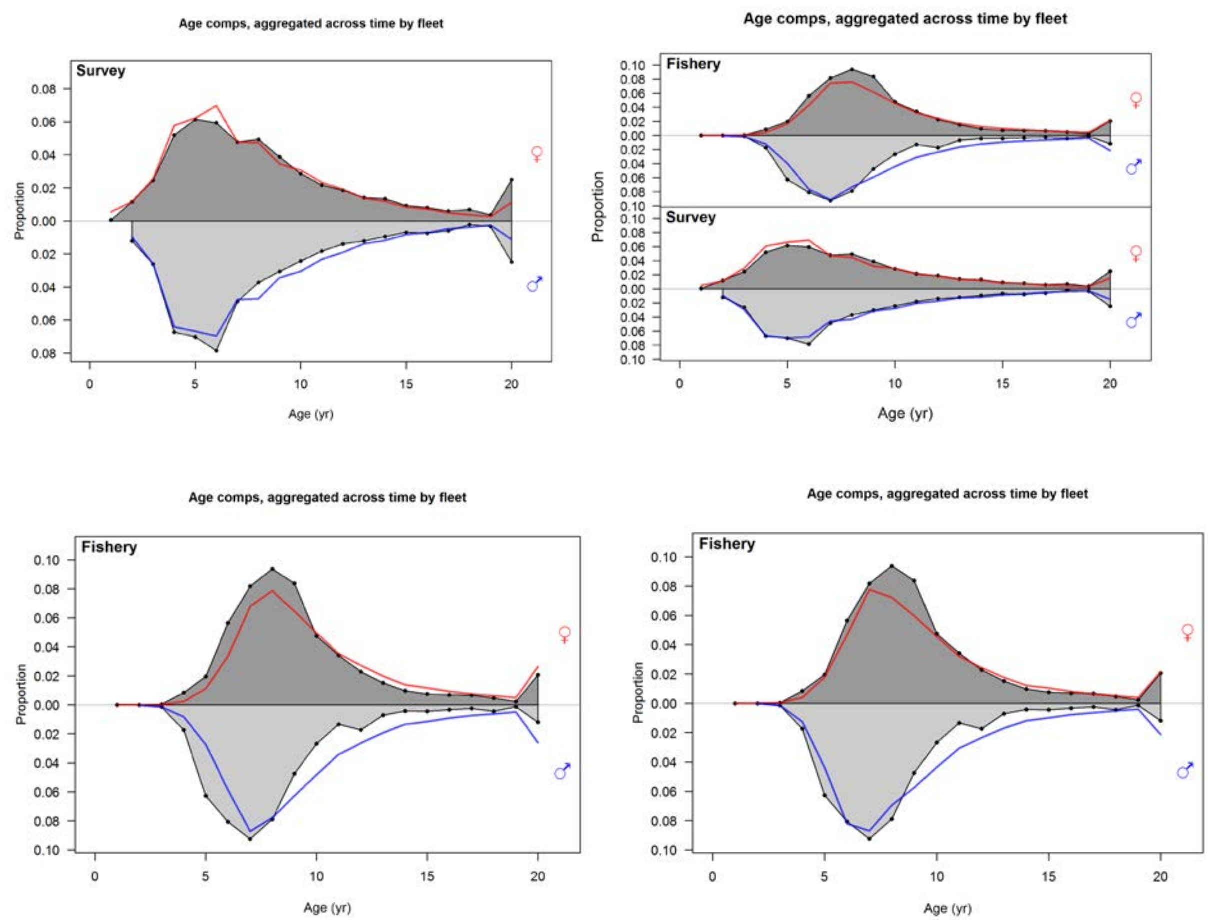


Figure 13. Predicted (red and blue lines) and observed age compositions (grey filled areas), aggregated over time for the 2015 model with new data (Model 15.0; top left; no fishery age composition data was used), the 2015 model with newly aged fishery age data (Model 17.0; top right), the model with fishery age data and internal estimation of growth (Model 17.1; bottom left), and the base case growth morph model with internal estimation of growth (Model 17.2; bottom right). Conditional age-at-length data were used in place of age composition data for the survey for models 17.1 and 17.2, so only fits to fishery age composition data are shown for those models.

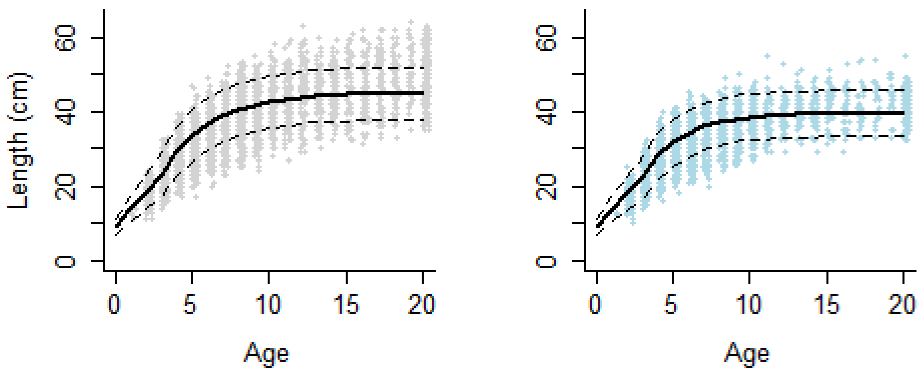


Figure 14. Observed (dots) and predicted (black lines) length-at-age for models 15.0 and 17.0, where a single growth curve was estimated for each sex outside of the assessment model and based on data only up to 1996. Females are shown on the left panel, grey dots, and males are shown on the right panel; blue dots. Dotted lines show 95% confidence intervals based on CVs of 2 year old and 20 year old fish.

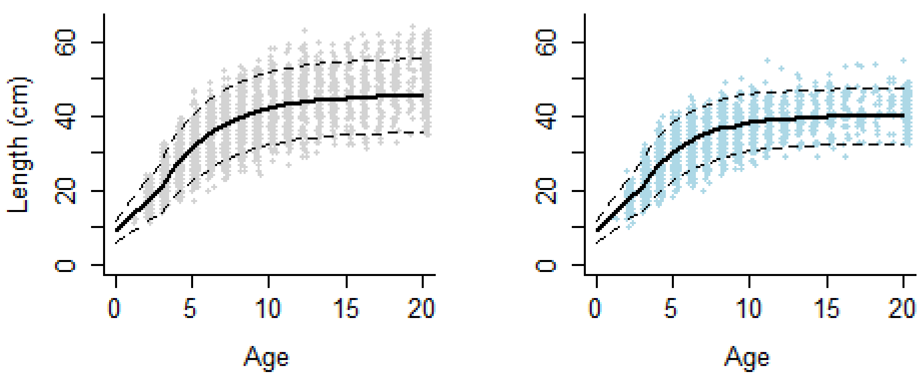


Figure 15. Observed (dots) and predicted (black lines) length-at-age for model 17.1, where a single growth curve was estimated for each sex within the assessment model. Females are shown on the left panel, grey dots, and males are shown on the right panel; blue dots. Dotted lines show 95% confidence intervals based on CVs of 2 year old and 20 year old fish.

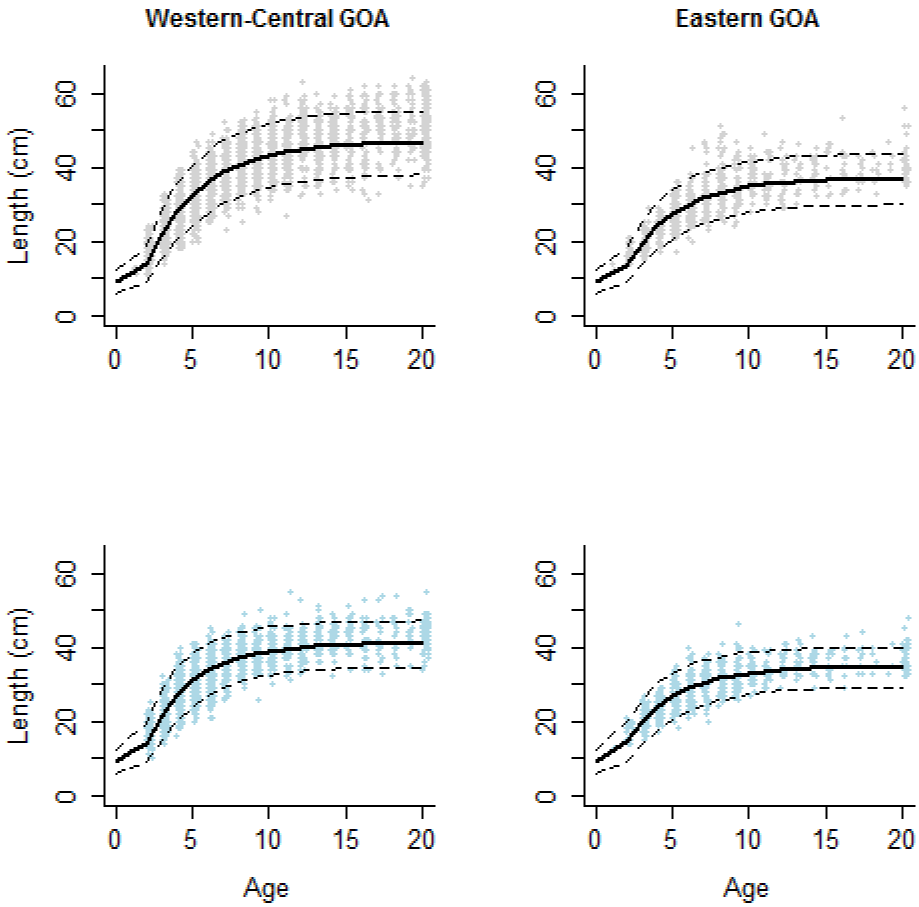


Figure 16. Observed (dots) and predicted (black lines) length-at-age for model 17.2, where separate growth curves were estimated within the assessment model by sex and by area for the Western-Central GOA and for the Eastern GOA. Females are shown on the upper panels (grey dots), and males are shown on the lower panels (blue dots). Dotted lines show 95% confidence intervals based on CVs of 2 year old and 20 year old fish.

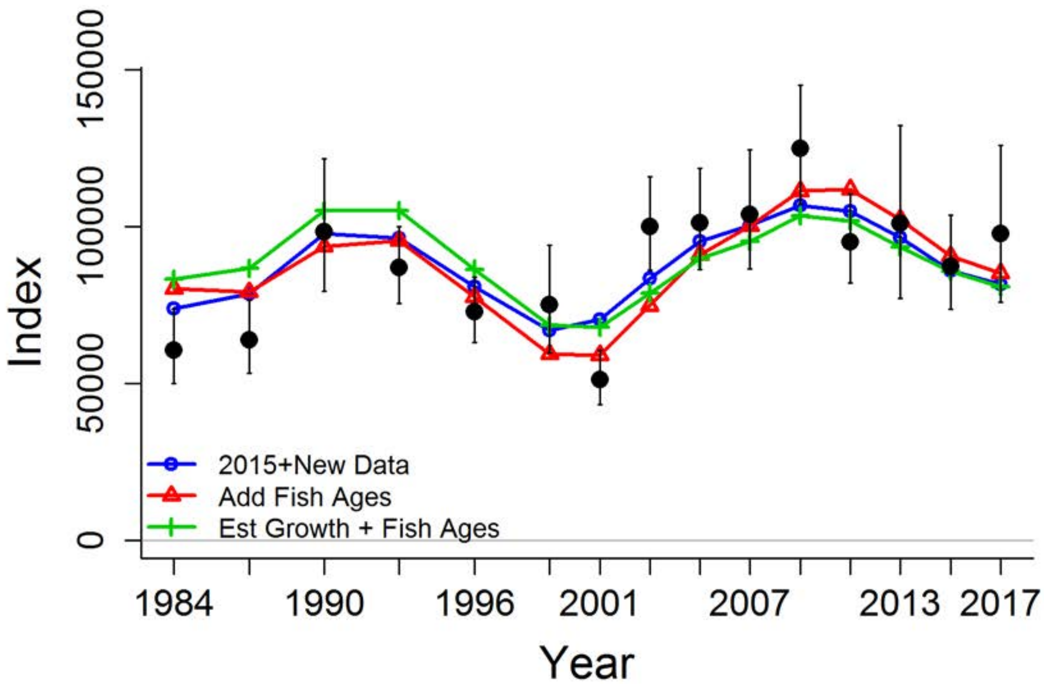
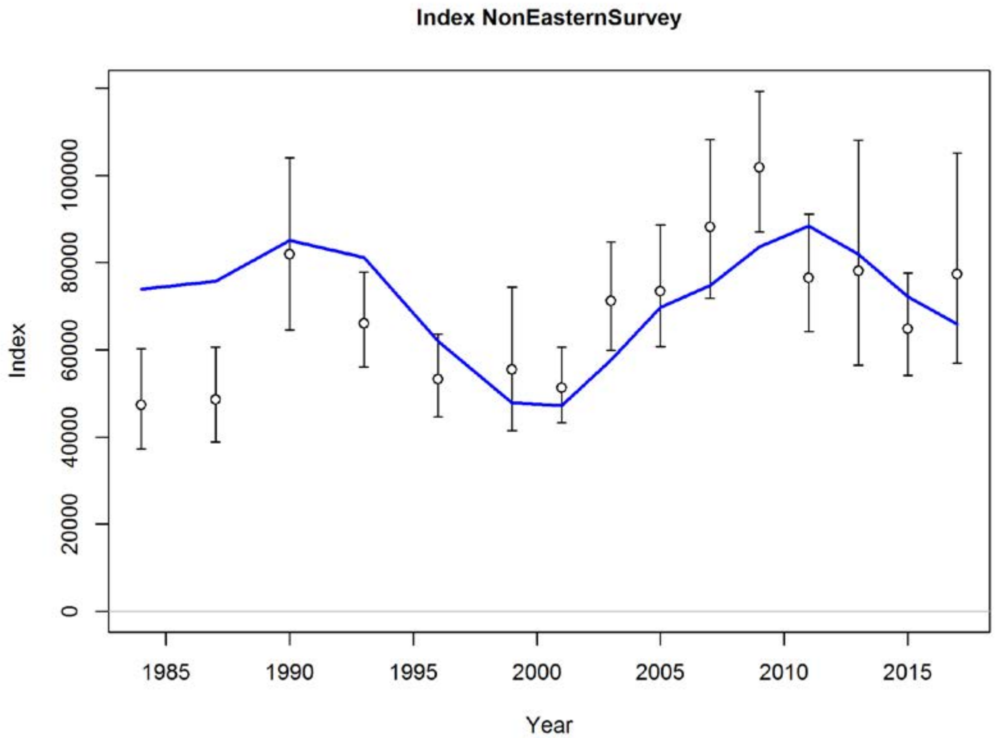


Figure 17. Observed (black dots) and predicted index of survey biomass for the 2015 model with new data (model 15.0; blue), the model with fishery ages added (model 17.0; red), and the model with fishery ages and internal estimation of growth (model 17.1; green). Vertical black lines show 95% confidence intervals about the observations.



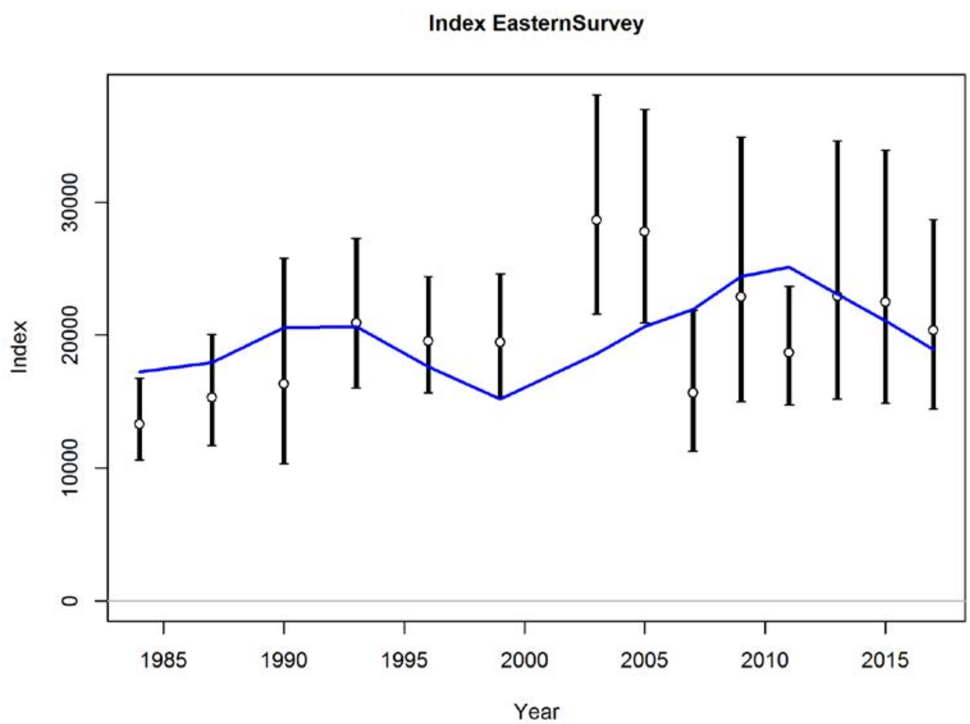


Figure 18. Observed (black dots) and predicted (blue lines) Observed (black dots) index of survey biomass from Model 17.2. The Western-Central ("NonEastern") area is shown in the upper panel and the Eastern area is shown in the lower panel.

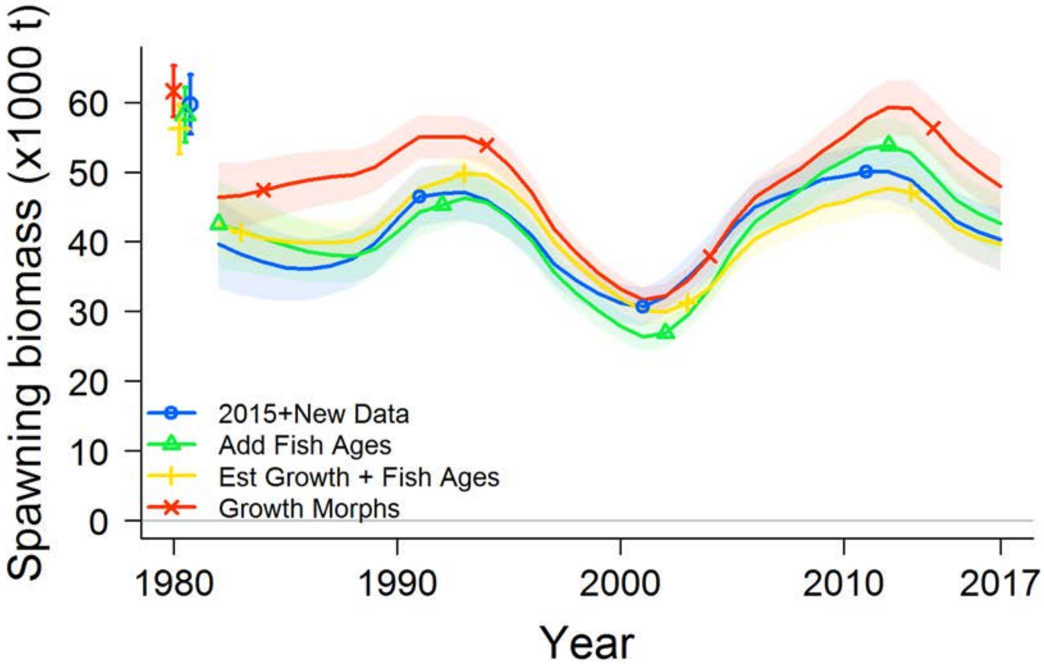


Figure 19. Spawning biomass for the 2015 model with new data (model 15.0; blue), the model with fishery ages added (model 17.0; green), the model with fishery ages and internal estimation of growth (model 17.1; yellow), and the base case model with two areas, each with its own growth morph (model 17.2; red).

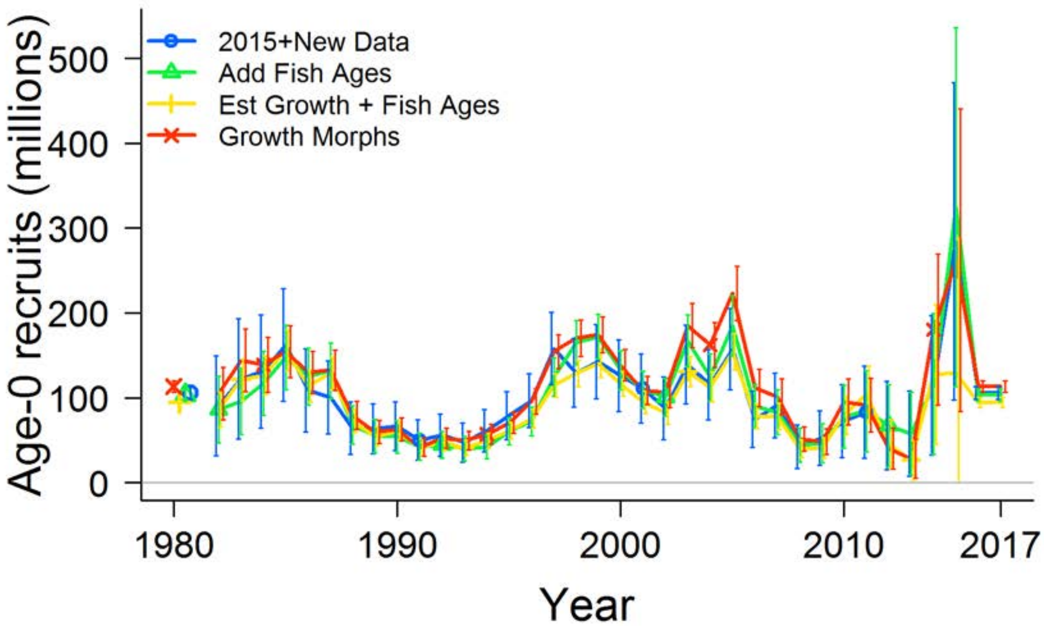


Figure 20. Estimates of age 0 recruitments with associated 95% asymptotic confidence intervals for the 2015 model with new data (model 15.0; blue), the model with fishery ages added (model 17.0; green), the model with fishery ages and internal estimation of growth (model 17.1; yellow), and the base case model with two areas, each with its own growth morph (model 17.2; red).

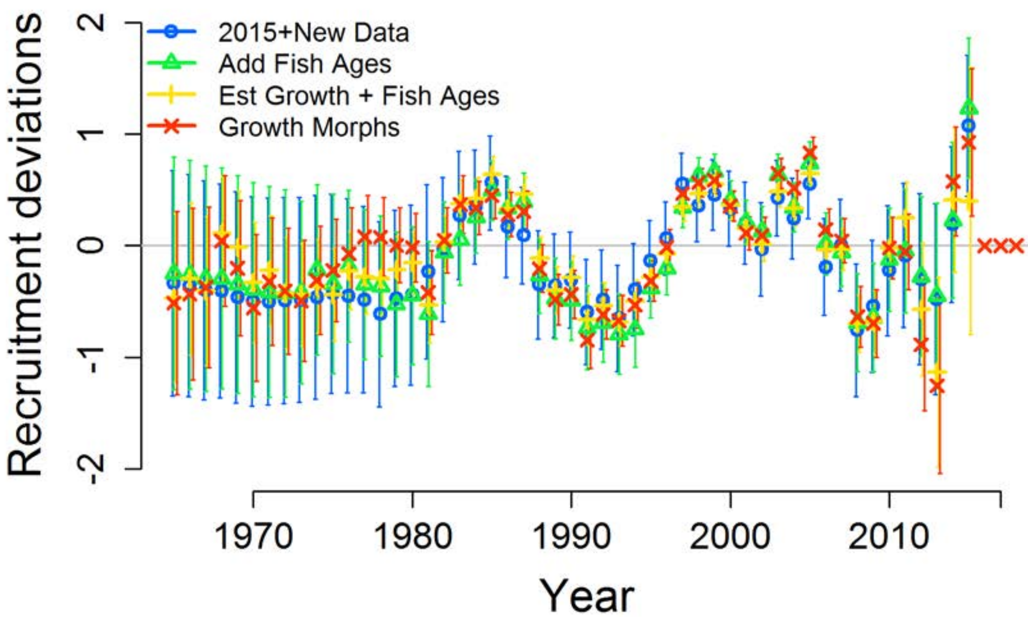


Figure 21. Estimates of recruitment deviations and corresponding 95% asymptotic confidence intervals for the 2015 model with new data (model 15.0; blue), the model with fishery ages added (model 17.0; green), the model with fishery ages and internal estimation of growth (model 17.1; yellow), and the base case model with two areas, each with its own growth morph (model 17.2; red).

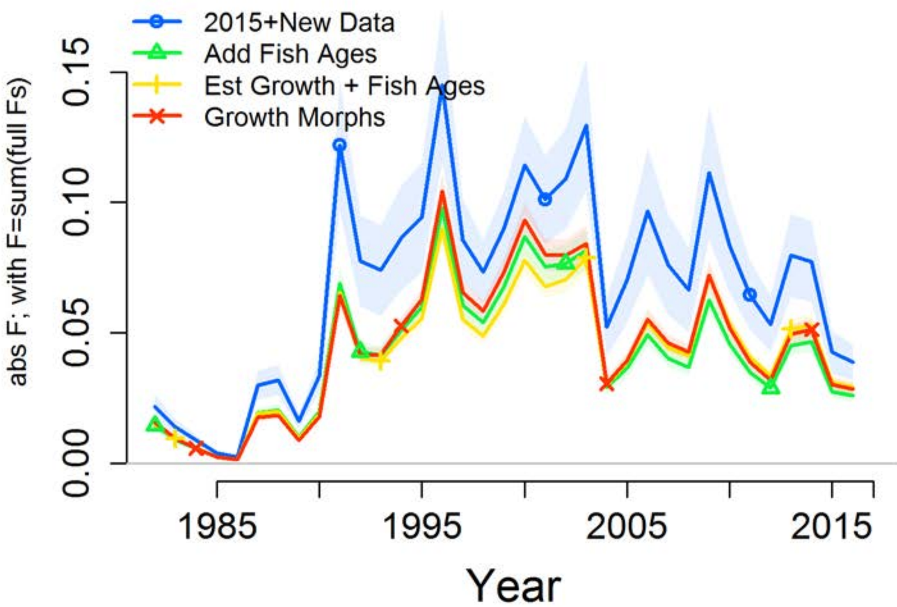


Figure 22. Estimates of fishing mortality for the 2015 model with new data (model 15.0; blue), the model with fishery ages added (model 17.0; green), the model with fishery ages and internal estimation of growth (model 17.1; yellow), and the base case model with two areas, each with its own growth morph (model 17.2; red).

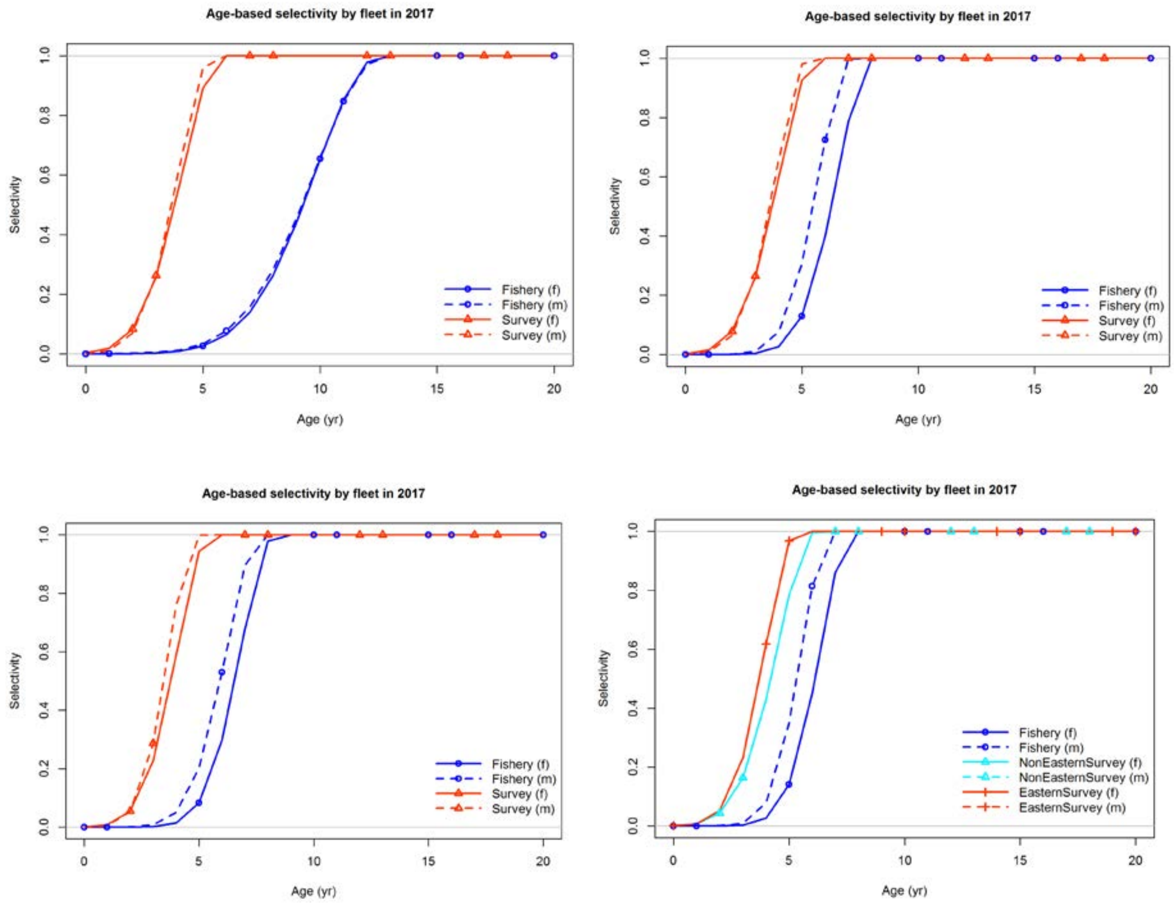


Figure 23. Fishery and survey selectivity at age for the 2015 model with new data (Model 15.0; top left, no fishery age data was used), the 2015 model with newly aged fishery age data (Model 17.0; top right), the model with fishery age data and internal estimation of growth (Model 17.1; bottom left), and the base case growth morph model with internal estimation of growth (Model 17.2; bottom right). Survey selectivity in Model 17.2 was not sex-specific after preliminary model runs confirmed that male and female survey selectivity were nearly identical.

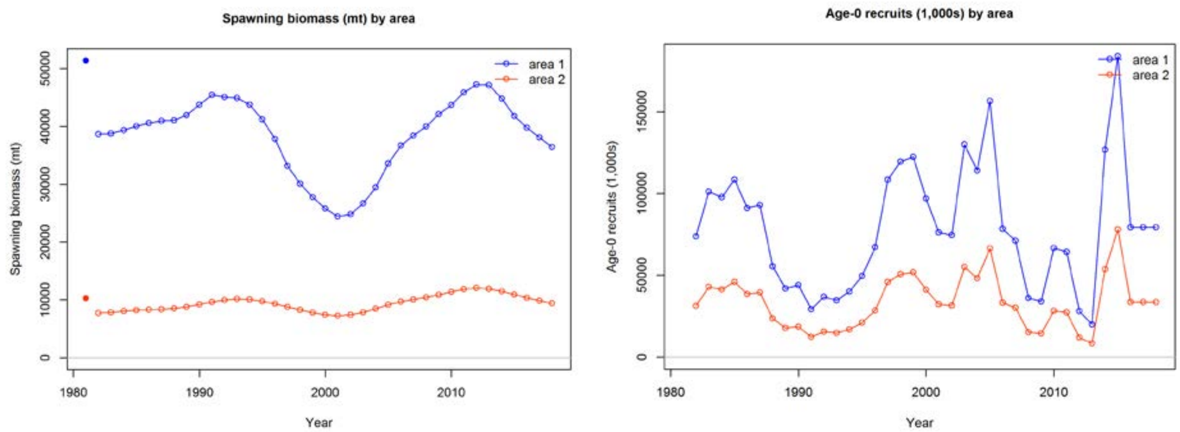


Figure 24. Spawning biomass (left panel) and age-0 recruits (right panel) by area for the base case model (Model 17.2). Blue lines indicate the Western-Central GOA and red lines indicate the Eastern GOA.

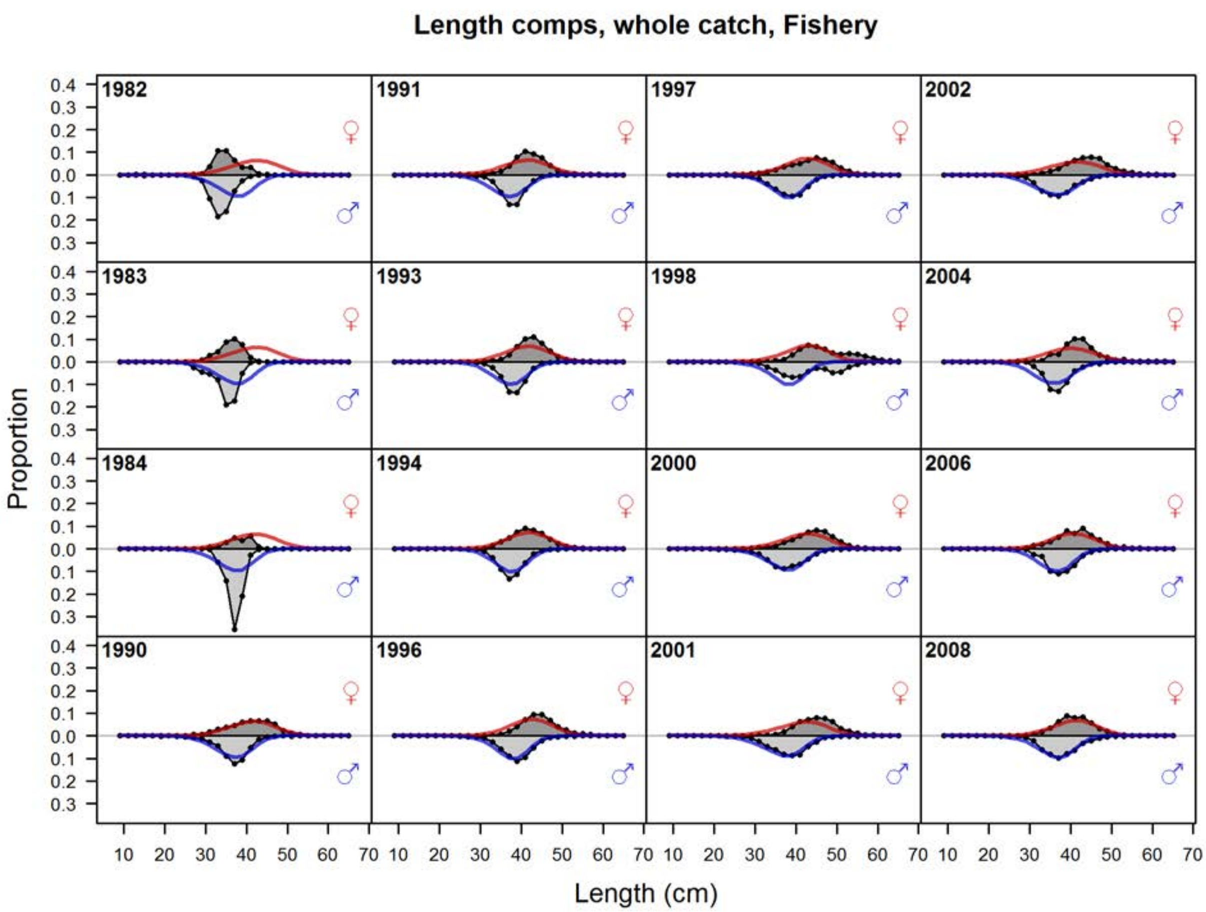


Figure 25. Observed (grey filled area and black line) and expected (red and blue lines) fishery length compositions for years 1982-2008 for males (blue lines) and females (red lines).

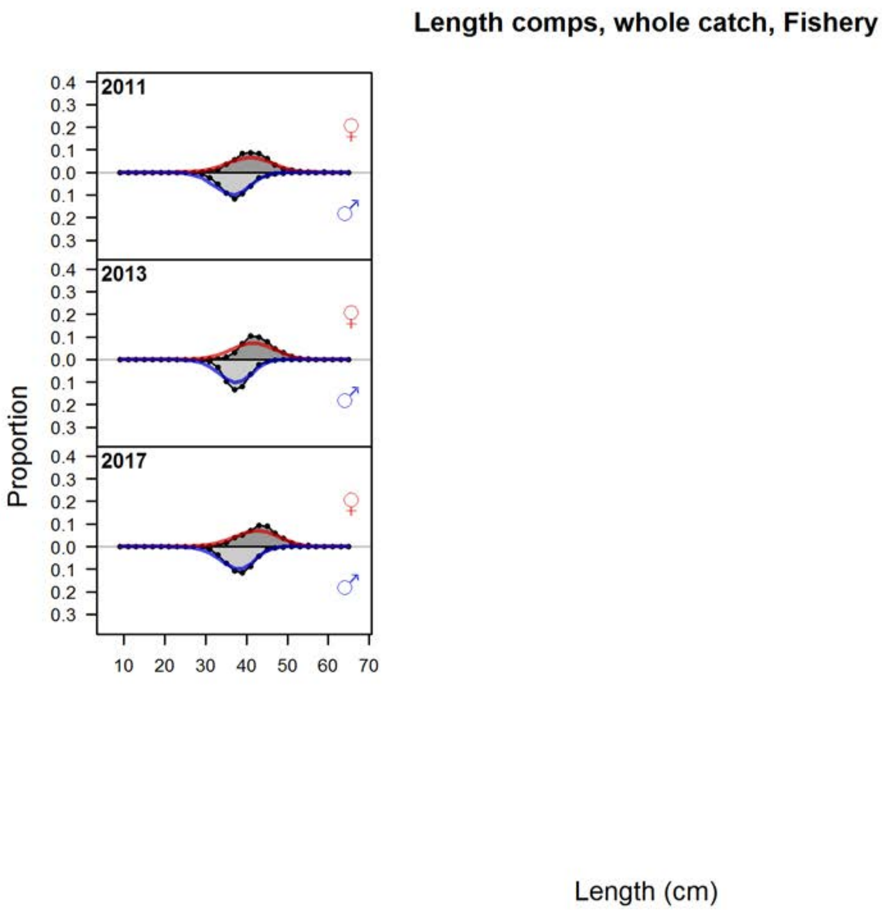


Figure 26. As for Figure 25, but for years 2011-2017.

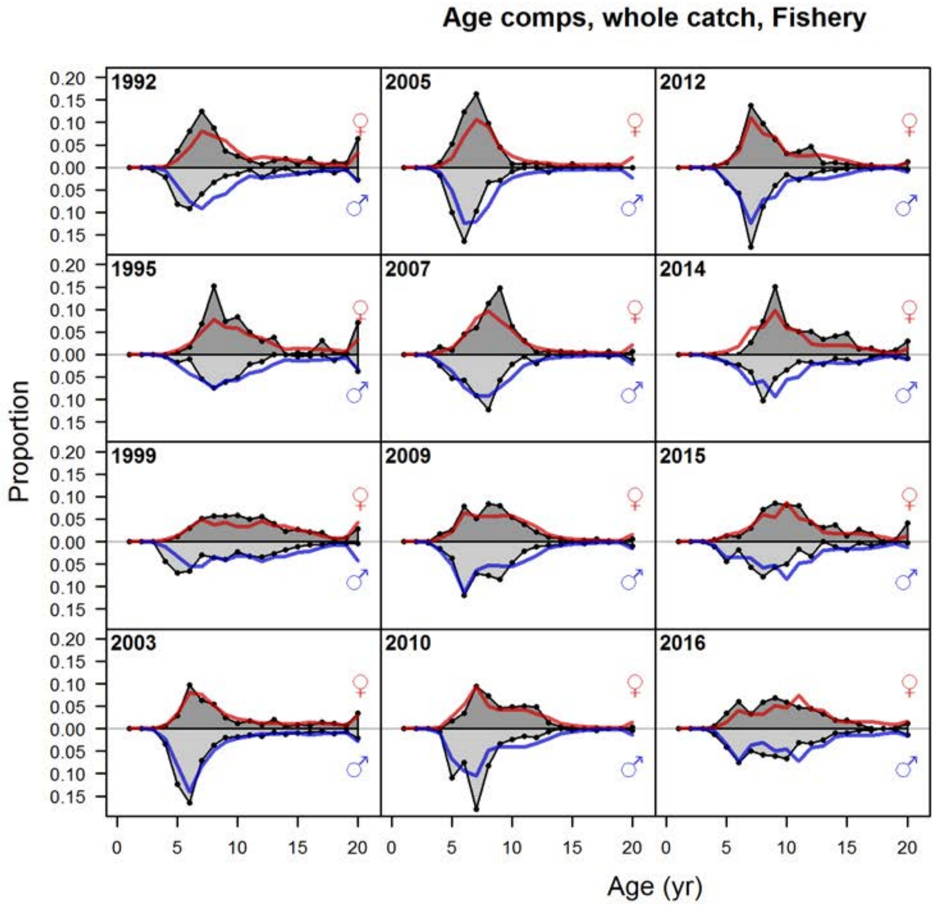


Figure 27. Observed (grey filled area and black line) and expected (red and blue lines) fishery age compositions for all available years of data for males (blue lines) and females (red lines).

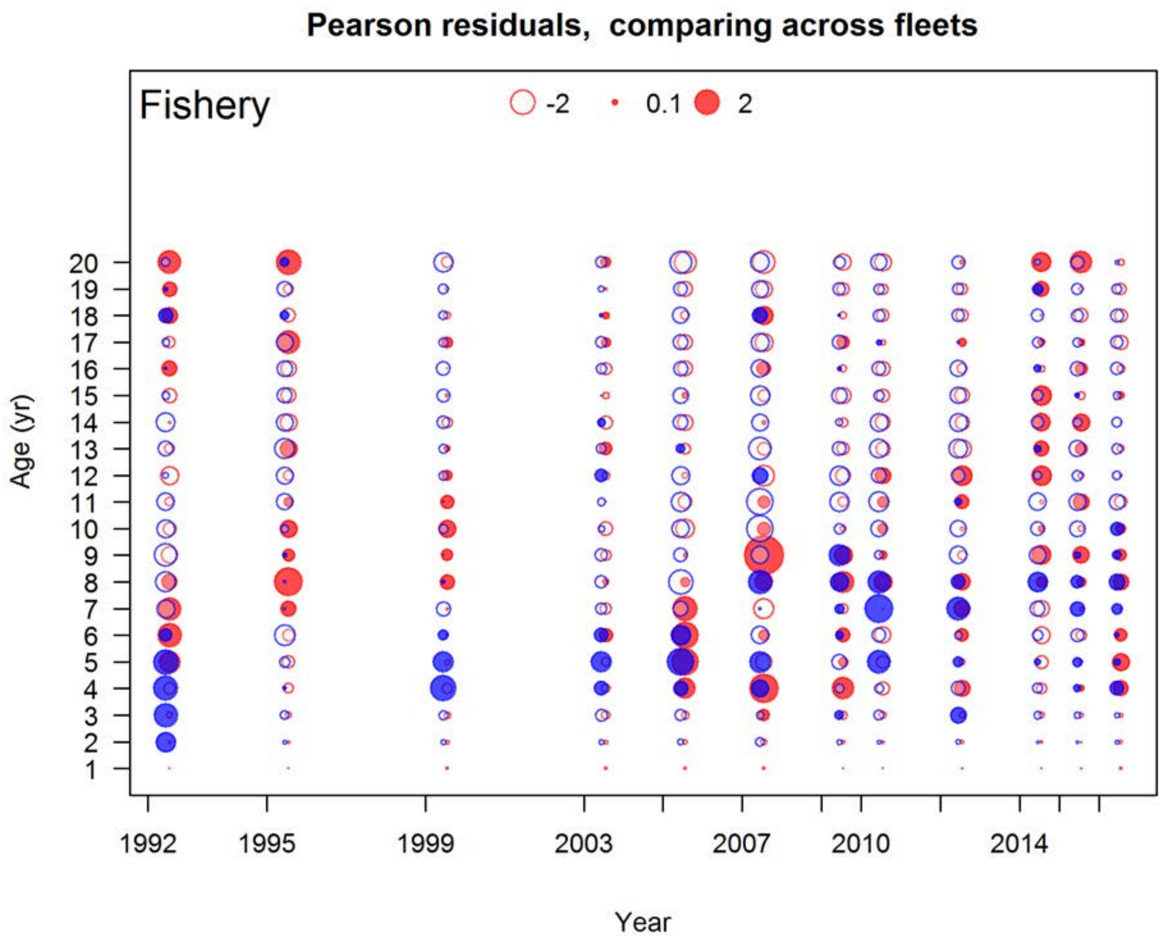


Figure 28. Pearson residuals for the fishery age composition data. Females are shown in red and males in blue. Filled dots indicate positive residuals where observed values were greater than predicted values. Open dots indicate negative residuals.

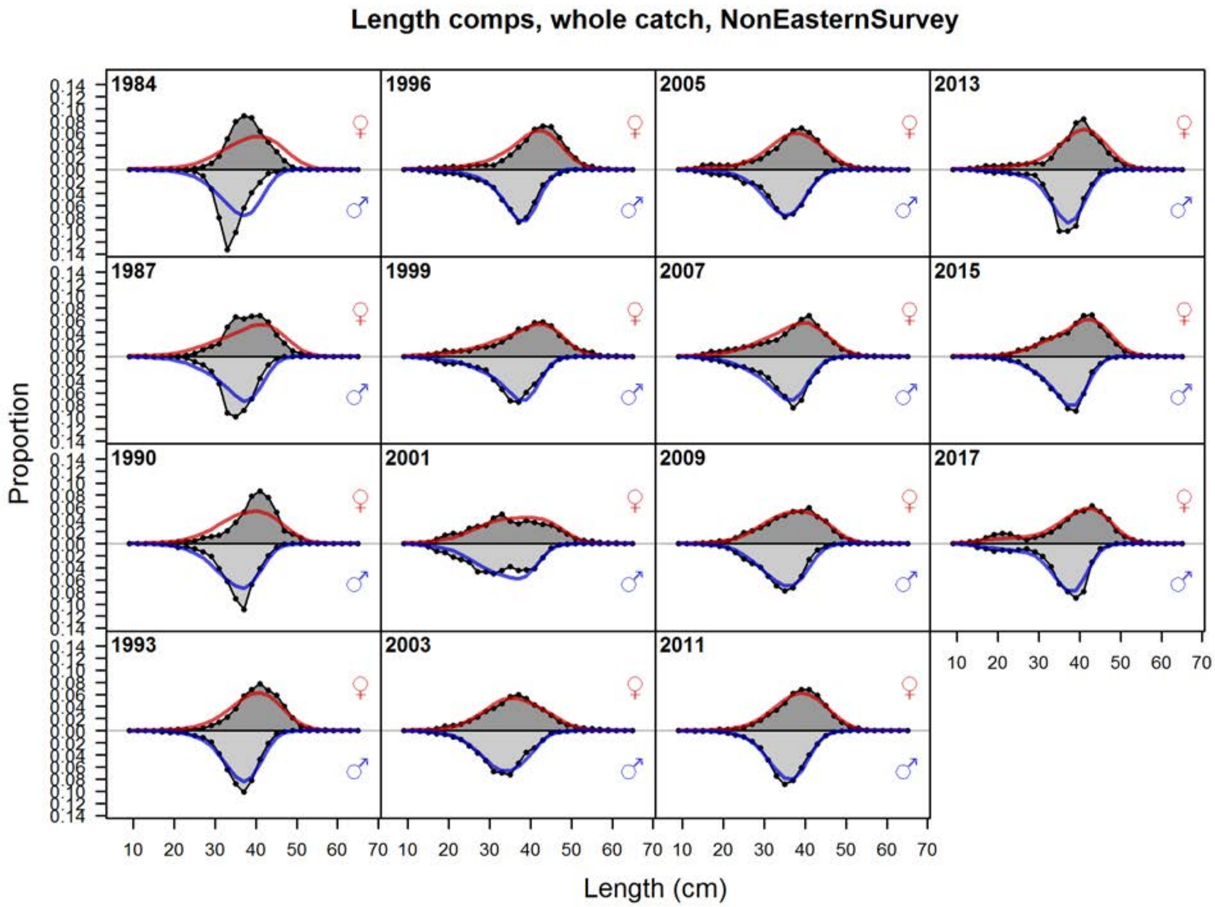


Figure 29. Observed (grey filled area and black line) and expected (red and blue lines) survey length compositions for the Western-Central (non-Eastern) GOA for all years of survey data for males (blue lines) and females (red lines).

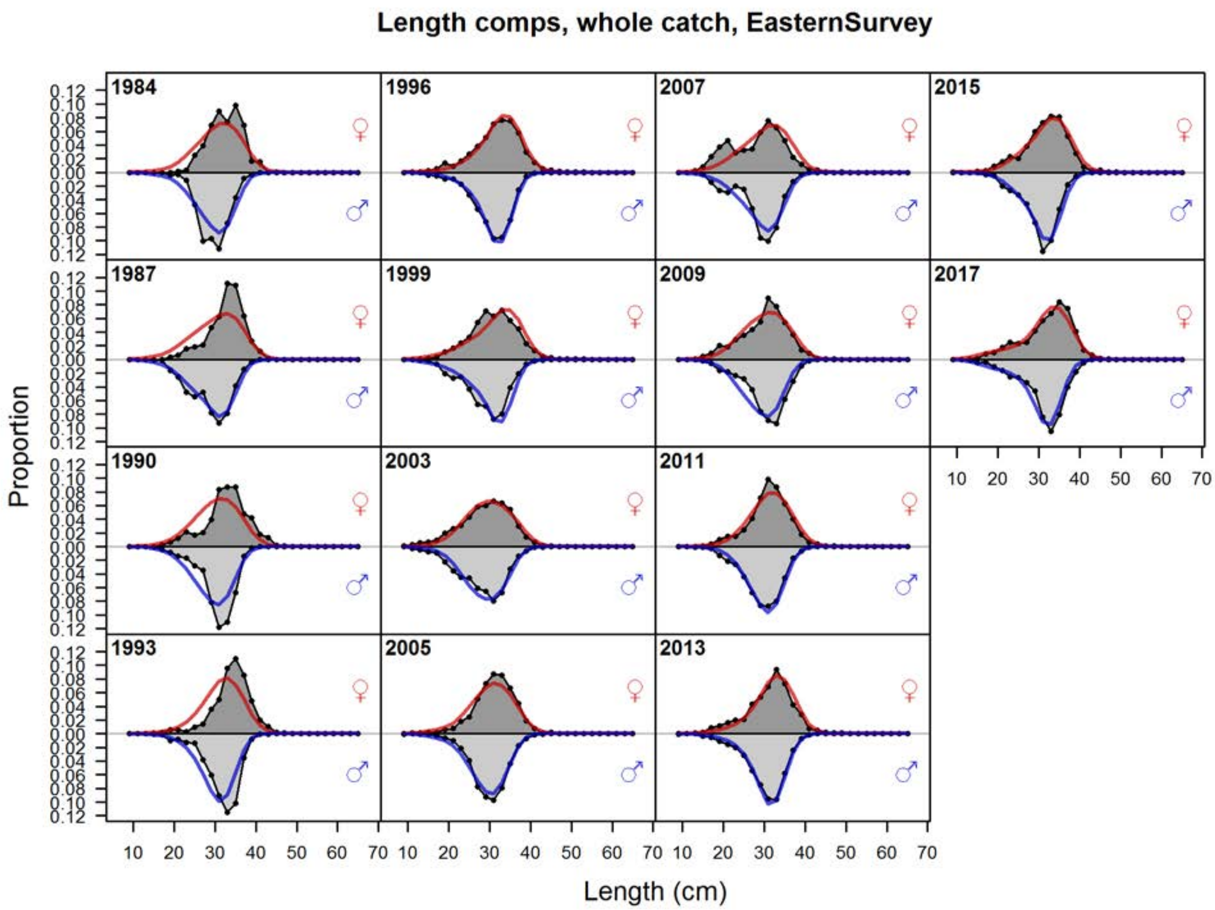


Figure 30. Observed (grey filled area and black line) and expected (red and blue lines) survey age compositions for the Eastern GOA for all years of survey data for males (blue lines) and females (red lines).

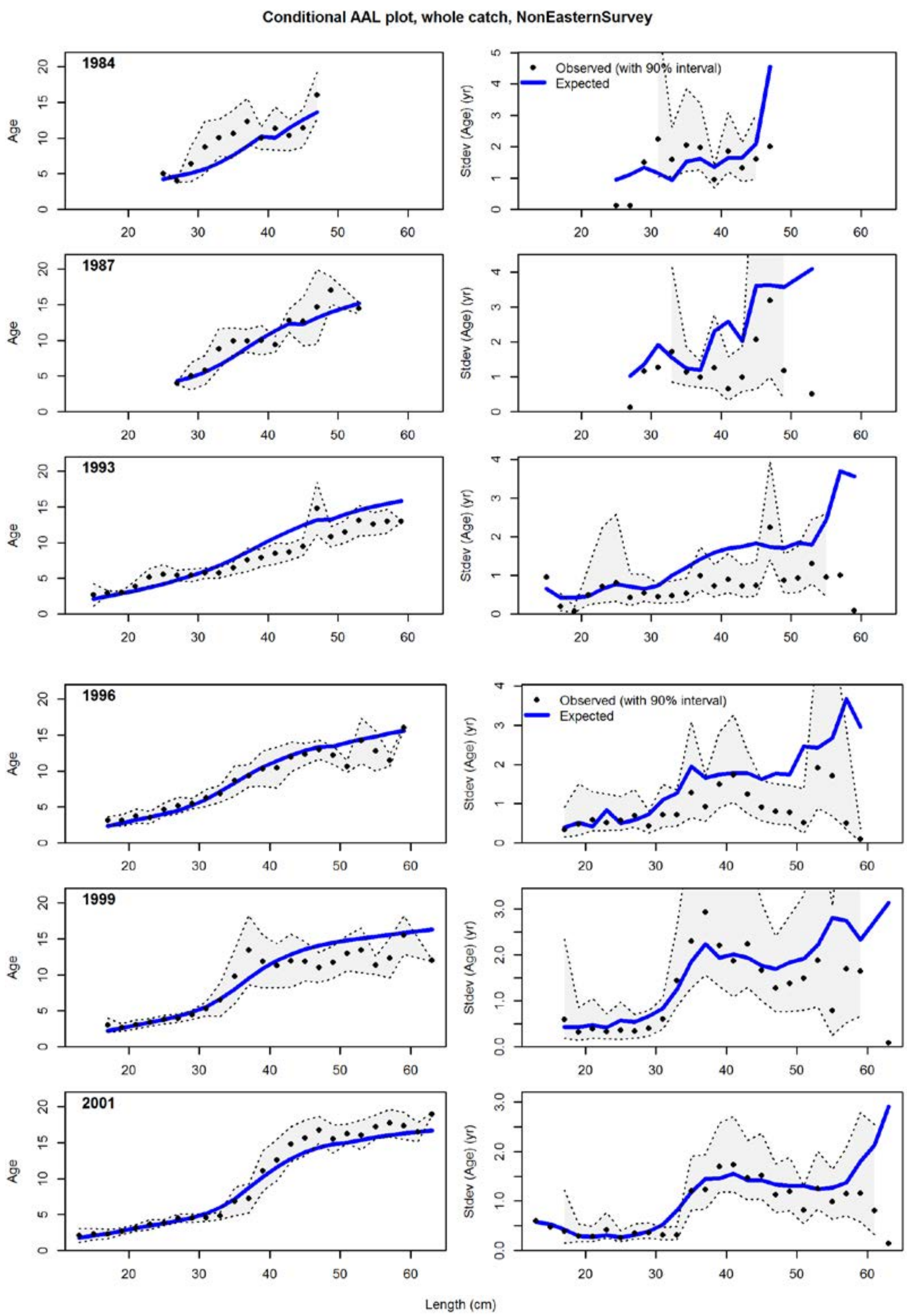


Figure 31. Observed and expected mean age-at-length for both females and males in the Western-Central (Non-Eastern) GOA with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the base case model (Model 17.2) for years 1984-2001.

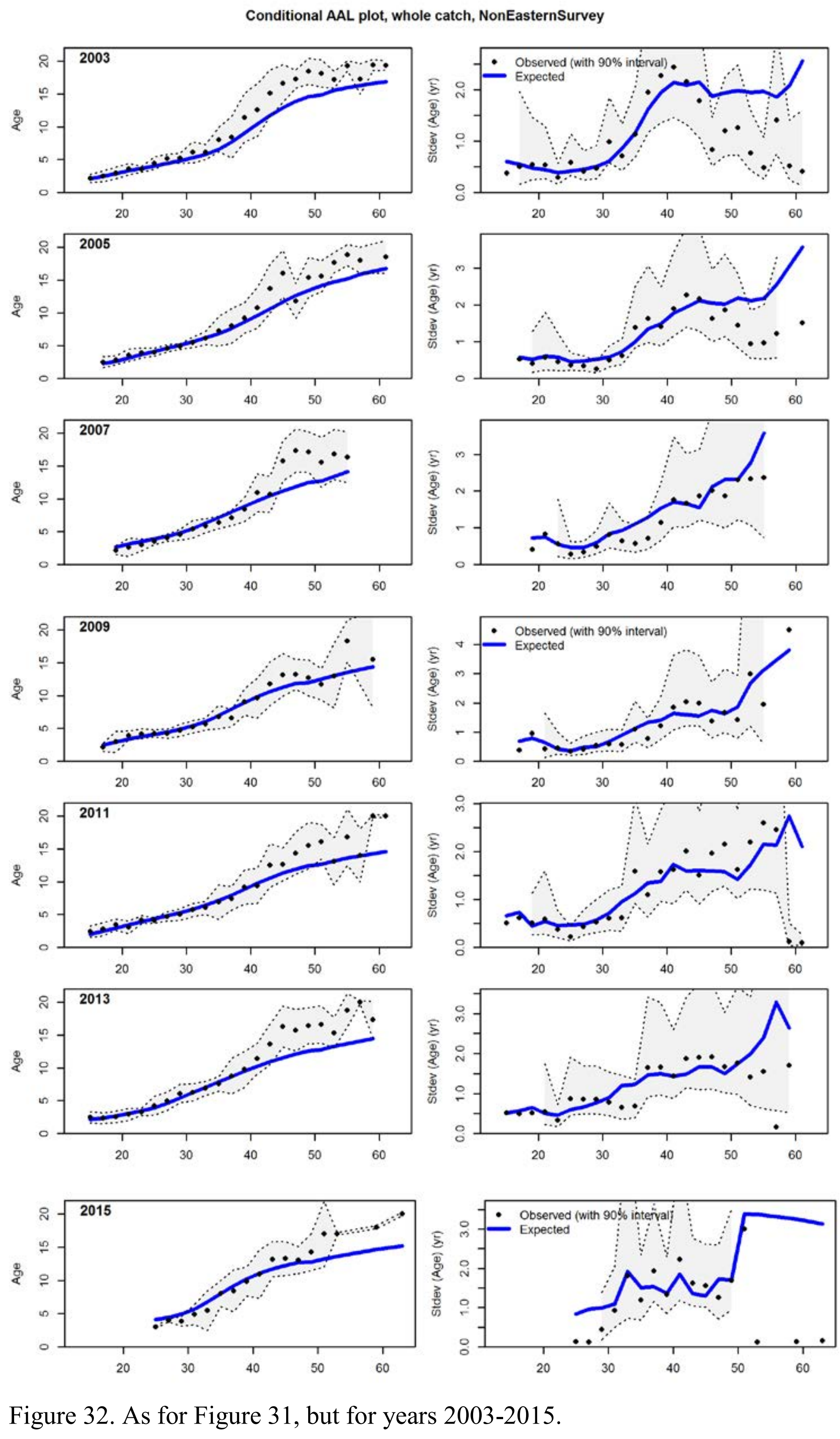


Figure 32. As for Figure 31, but for years 2003-2015.

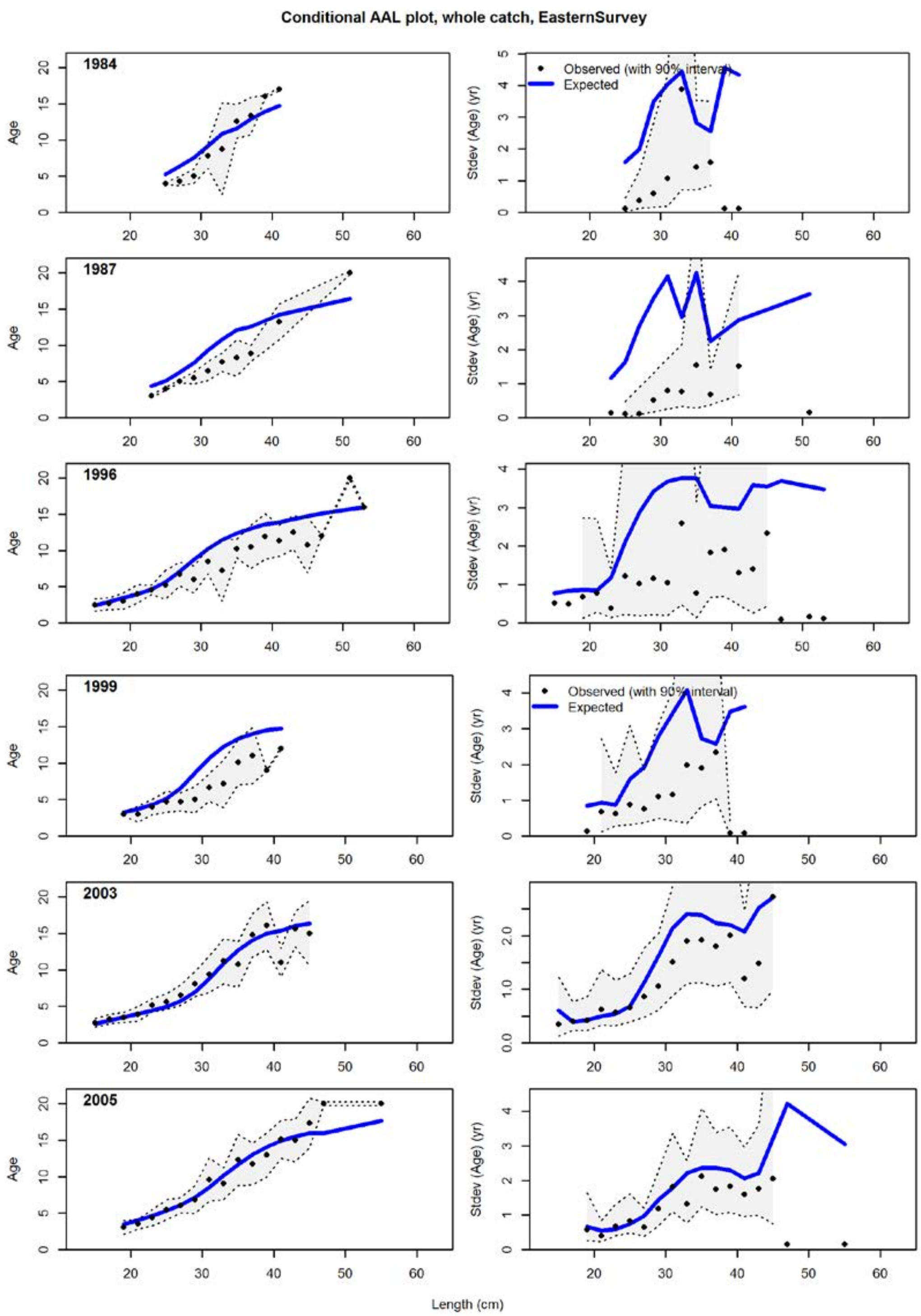


Figure 33. Observed and expected mean age-at-length for both females and males in the Eastern (Non-Eastern) GOA with 90% intervals about observed age-at-length (left panels) and observed and expected standard deviation in age-at-length (right panels) for the base case model (Model 17.2) for years 1984-2005.

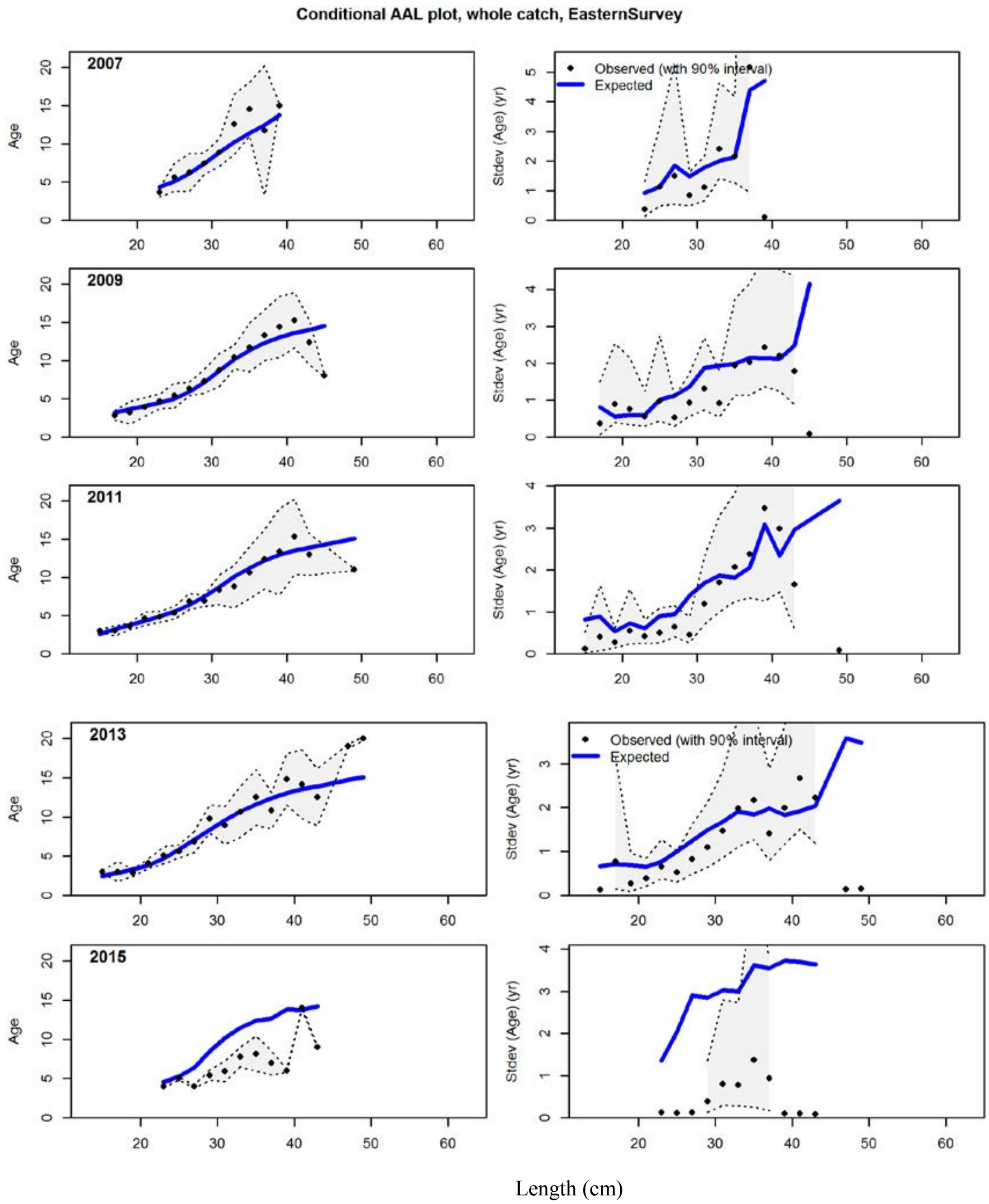


Figure 34. As for Figure 33, but for years 2007-2015.

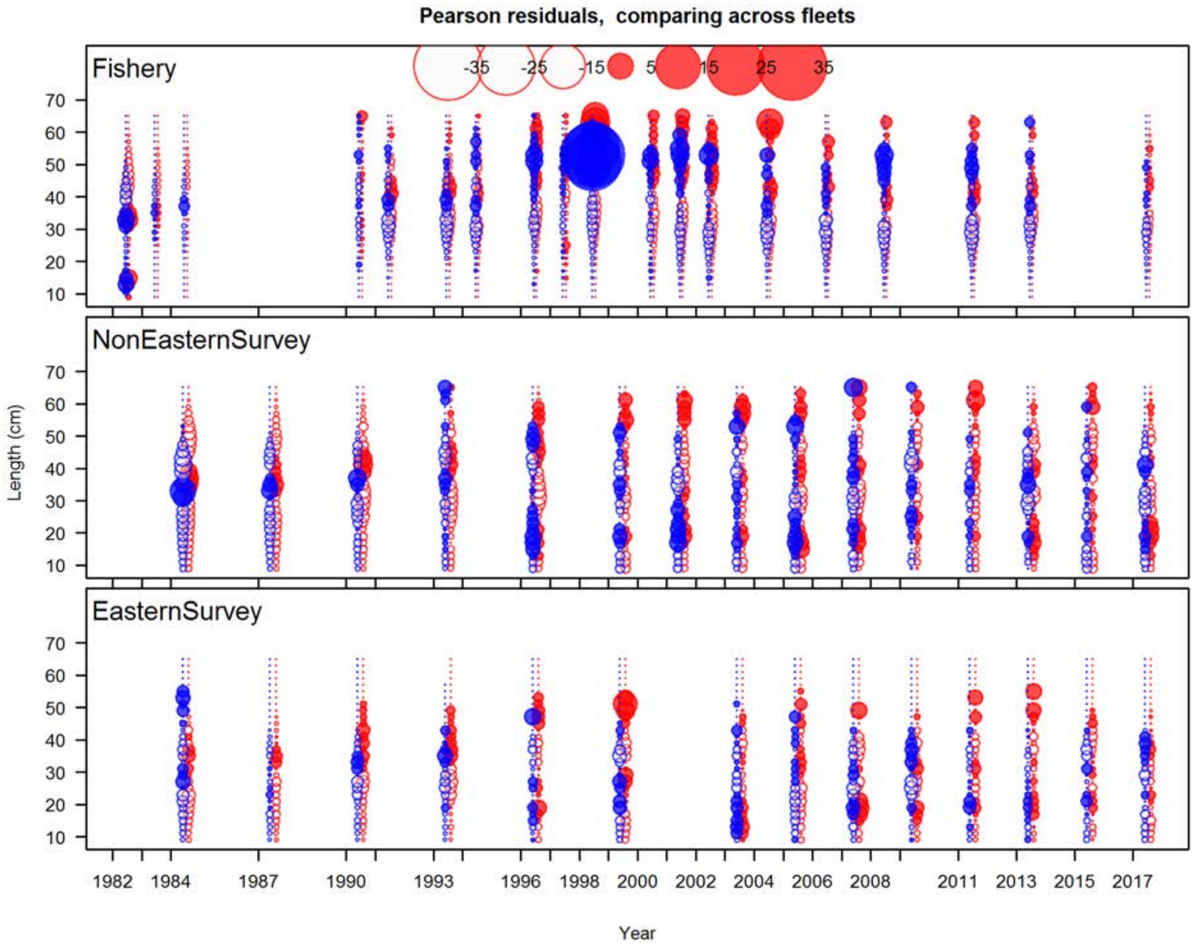


Figure 35. Pearson residuals for the length composition data for the fishery and the two survey areas. Females are shown in red and males in blue. Filled dots indicate positive residuals where observed values were greater than predicted values. Open dots indicate negative residuals.

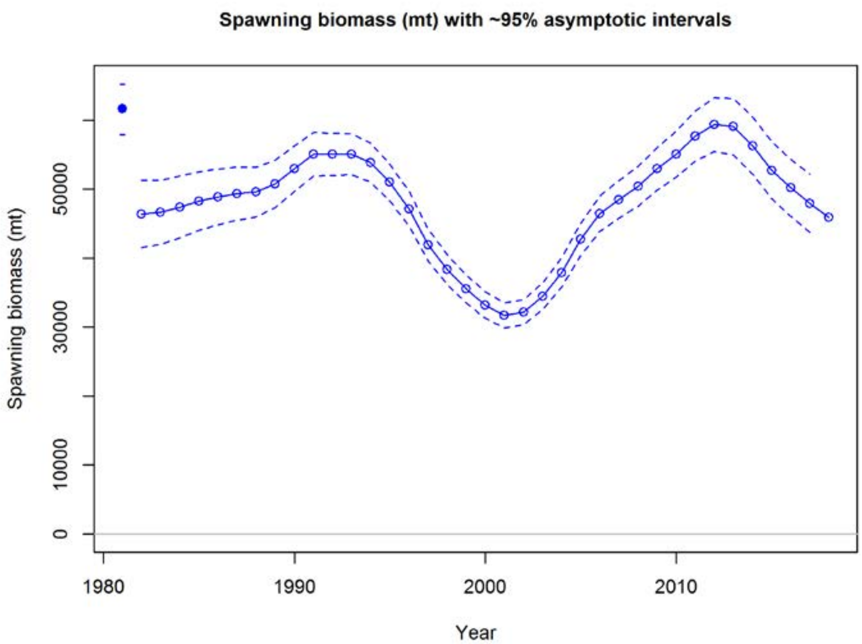


Figure 36. Spawning stock biomass (solid blue line with dots) and 95% asymptotic confidence intervals (dotted blue lines) for the base case assessment model (Model 17.2).

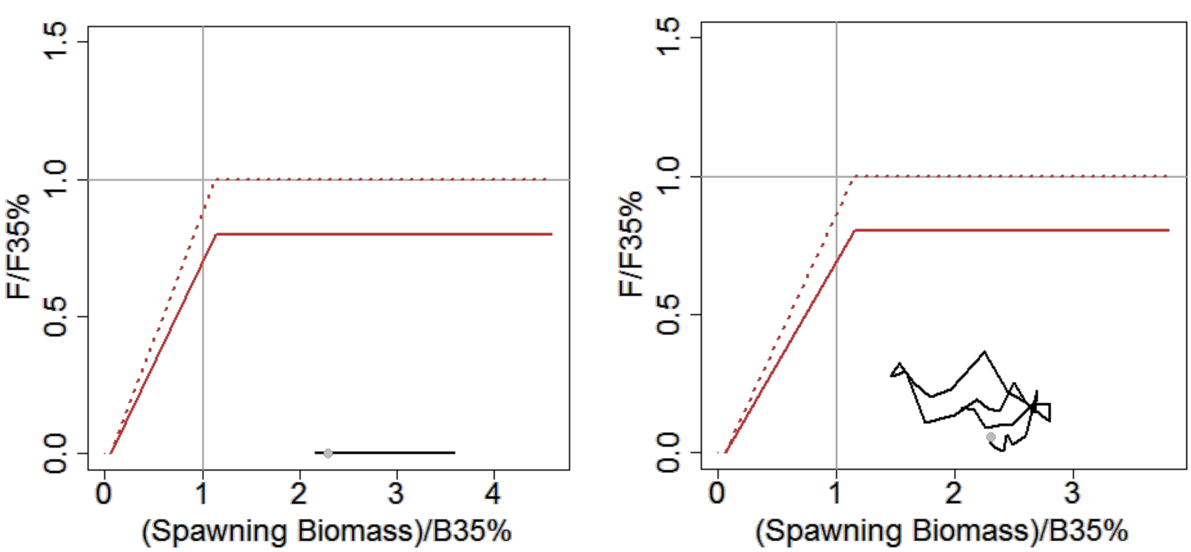


Figure 37. Spawning stock biomass relative to $B_{35\%}$ and fishing mortality (F) relative to $F_{35\%}$ from 1982-2019 (solid black line), the OFL control rule (dotted red line), the maxABC control rule (solid red line), $B_{35\%}$ (vertical grey line), and $F_{35\%}$ (horizontal grey line). The grey dot represents values for 1982, the beginning of the time series. The 2018 and 2019 spawning biomass and fishing mortality rates are as predicted by Alternative 1 in the harvest projections. Eastern GOA (left panel), Western-Central GOA (right panel).

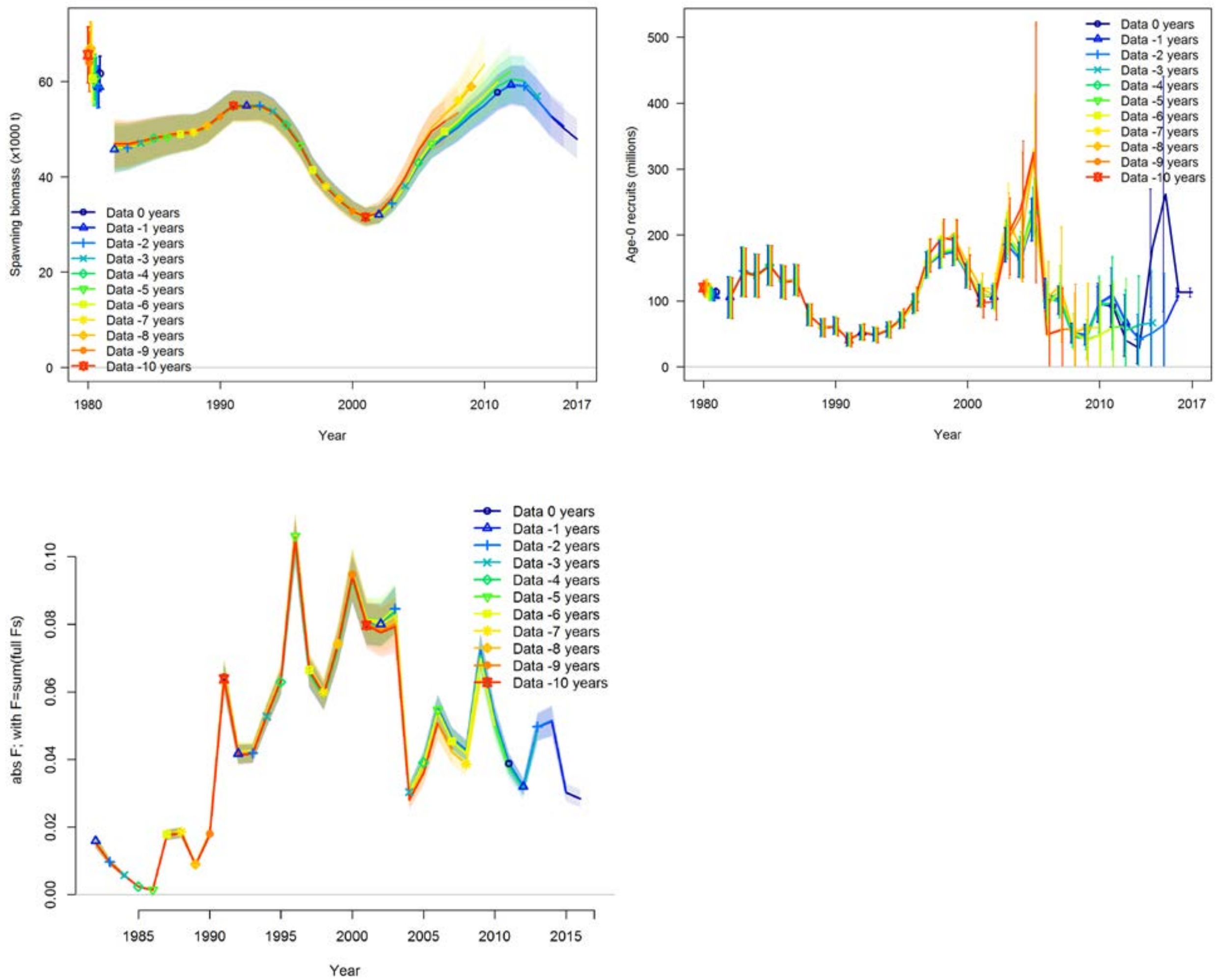


Figure 38. Spawning stock biomass (top left), recruitment (top right), and fishing mortality (bottom left) for retrospective model runs leaving out 0 to 10 years of the most recent data for Model 17.2. Vertical lines show corresponding 95% asymptotic confidence intervals.

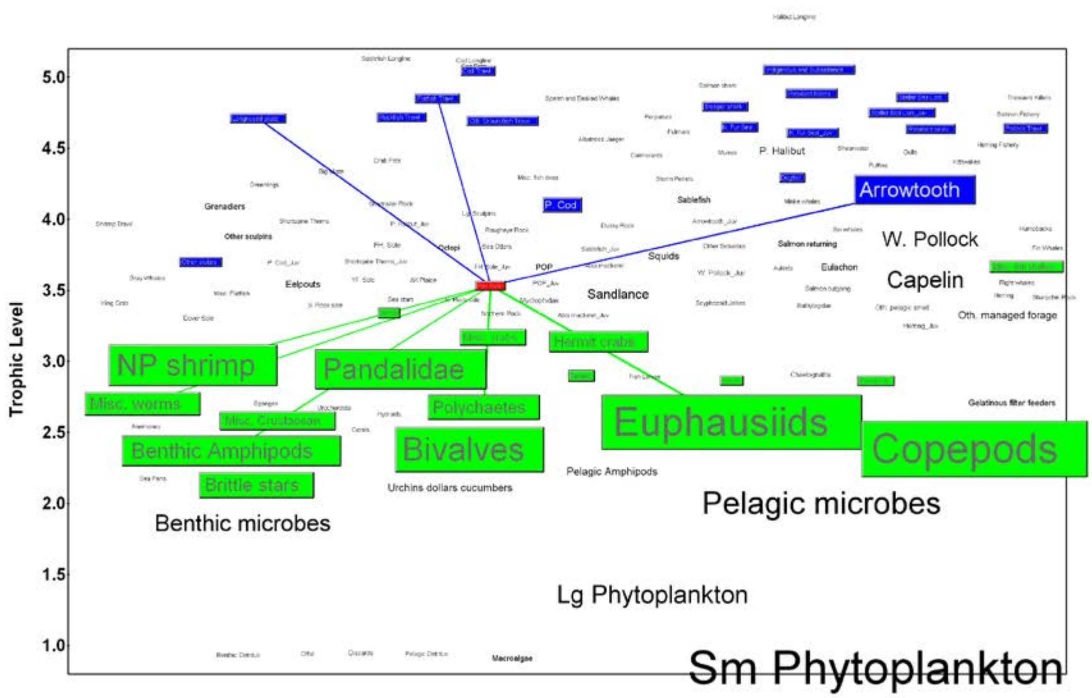


Figure 39. Gulf of Alaska food web from the GOA ecosystem model (Aydin et al., 2007) highlighting rex sole links to predators (blue boxes and lines) and prey (green boxes and lines). Box size reflects relative standing stock biomass.

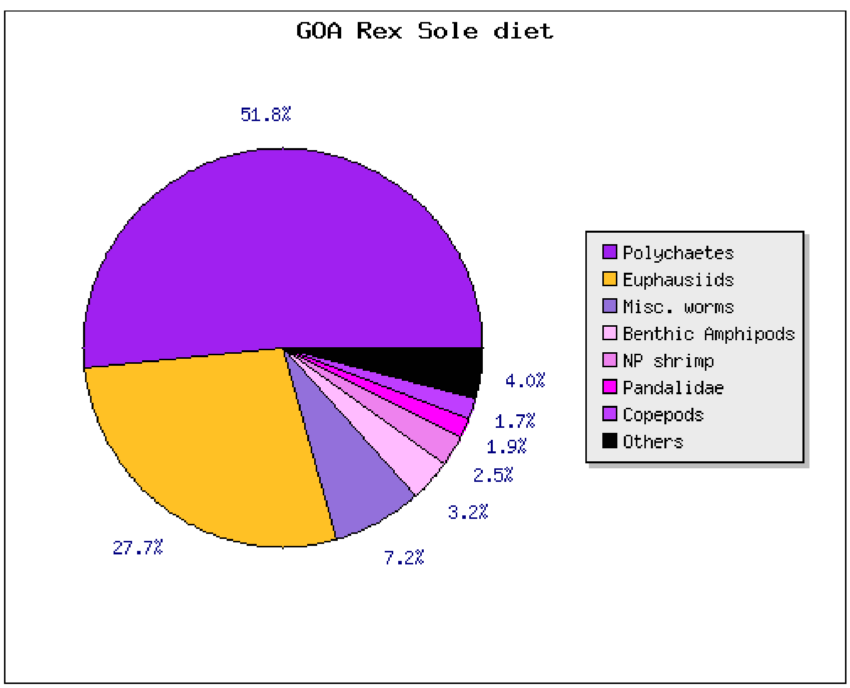


Figure 40. Diet composition for Gulf of Alaska rex sole from the GOA ecosystem model (Aydin et al., 2007).

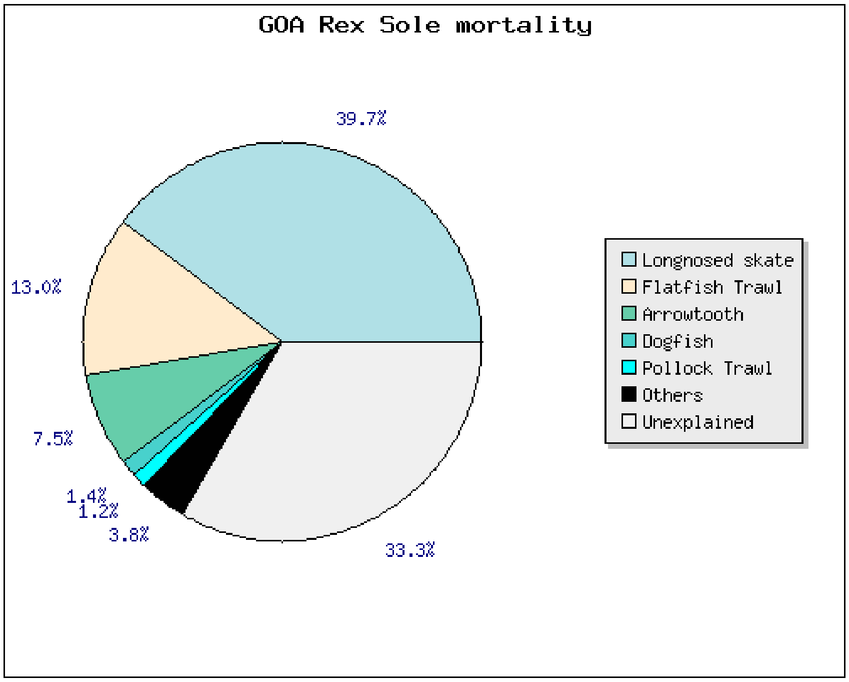


Figure 41. Decomposition of natural mortality for Gulf of Alaska rex sole from the GOA ecosystem model (Aydin et al., 2007).

Appendix 6A: Specifications for the Model 15.0 model run in SS

Reference fishing mortality rates

Because $F_{35\%}$ and $F_{40\%}$ were highly uncertain in previous assessments, Tier 3 considerations were not used to set reference fishing mortality rates and make harvest specifications for the GOA rex sole stock. In 2009, the GOA Plan Team decided that reference rates and harvest specifications for rex sole should be set using Tier 5 considerations. For Tier 5 stocks, reference fishing mortality rates are given by F_{OFL} = M (the rate of natural mortality) and max F_{ABC} = 0.75·M. Consequently, values for the reference fishing mortality rates for GOA rex sole a Tier 5 approach are F_{OFL} = 0.17 yr^{-1} and F_{ABC} = 0.128 yr^{-1}.

Acceptable Biological Catch and Overfishing Level

For Tier 5 stocks, harvest specifications are given by $OFL = F_{OFL} \cdot \bar{B}$ and $ABC = F_{ABC} \cdot \bar{B}$, where $\bar{B}$ is an estimate of stock biomass. For most Tier 5 stocks, the estimate of survey biomass for the stock from the most recent groundfish survey is used as $\bar{B}$. For rex sole, however, the GOA Plan Team determined that estimates of "adult" biomass (i.e., total biomass-at-age weighted by the fraction mature-at-age) from the assessment model provided more appropriate estimates of stock biomass than the groundfish survey and should be used for setting harvest specifications. Estimating adult biomass in the assessment model for 2018 and 2019 requires predictions of the total catch taken in 2015 and 2016. Because the 2017 fishery is not yet complete, we estimated the total catch taken in 2017 as the current catch of GOA rex sole as of October 8, 2017 added to the average October 8 – December 31 GOA rex sole catches over the 5 previous years. Total catch in 2018 and 2019 was the average catch over the last five years (2013-2017). Using these values and the estimated numbers-at-age at the start of 2017 from the assessment model, we projected the stock ahead and calculated adult biomass (B_A) at the start of 2016 and 2017 using the Baranov catch equation

$$\bar{B} = \frac{(1 - e^{-Z})}{Z} \cdot B_A$$

where Z=M+F and F was F_{ABC} or F_{OFL}.

Quantity	As estimated or *recommended last* year for:		As estimated or *recommended this* year for:	
	2016	2017	2017	2018
M (natural mortality rate)	0.17	0.17	0.17	0.17
Tier	5	5	5	5
Projected total (3+) biomass (t)	75,359	76,356	67,547	67,704
Female spawning biomass (t)	47,008	49,317	39,378	38,461
$B_{100\%}$	56,845	56,845	52,043	52,043
$B_{40\%}$	22,738	22,738	20,817	20,817
$B_{35\%}$	19,896	19,896	18,215	18,215
$F_{OFL}=M$	0.170	0.170	0.17	0.17
$maxF_{ABC}=0.75*M$	0.128	0.128	0.128	0.128
F_{ABC}	0.128	0.128	0.128	0.128
OFL (t)	10,860	11,004	9,735	9,757
maxABC (t)	8,311	8,421	7,449	7,467
ABC (t)	8,311	8,421	7,449	7,467
Status	As determined in 2016 for:		As determined in 2017 for:	
	2015	2016	2016	2017
Overfishing	no	n/a	no	n/a
Overfished	n/a	no	n/a	no

* Projections are based on estimated catches of 1,550t and 2,508 t that was used in place of maximum permissible ABC for 2017 and 2018-2019, respectively. The 2017 projected catch was calculated as the current catch of GOA rex sole as of October 8, 2017 added to the average October 8 – December 31 GOA rex sole catches over the 5 previous years. The 2018-2019 projected catch was calculated as the average catch from 2013-2017.

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

	ADF&G Sources				
Year	Large-Mesh Trawl Survey	Prince William Sound Sablefish Tagging	Scallop Dredge Survey	Small-Mesh Trawl Survey	Subsistence Fishery
1991					392.648
1998	282.75		2.21		
1999	842.63				
2000	380.37		0.3	105.63	
2001	1294.13				
2002	505.56		1.58		
2003	1964.35			284.59	
2004	625.35		0.21	128.37	
2005	1468.14		2.85	266.52	
2006	307.47		11.55	264.94	
2007	770.91		0.5	99.58	
2008	229.35				
2009	1075.48		0.55		
2010	5452.668		0.48	342.18	
2011	4367.688			146.95	
2012	3828.64		0.44	62.58	
2013	3923.75			78.051	
2014	1810.35			137.188	
2015	1893.994	1.18		110.67	
2016	1327.919		3.174	44.08	

	NMFS Sources				
Year	Annual Longline Survey	Gulf of Alaska Bottom Trawl Survey	Salmon EFP 13-01	Shelikof Acoustic Survey	Shumigans Acoustic Survey
1992	0.92				
1994	5.49				
1995	0.92				
2010				8.93	36.26
2011		5,751.32			
2012	0.91				
2013	1.83	5,022.40	130.00		
2014			184.00		
2015		7,679.45			